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Feasibility Assessment Report CDRL A002

Rupert Fairfield

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INSTITUTE FOR SIMULATION AND TRAINING

PREPARED UNDER CONTRACT NUMBER N61339-90-C-0125
for
NAVAL TRAINING SYSTEMS CENTER
and
NAVAL AIR TEST CENTER

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM

Feasibility Assessment Report CDRL A002

APRIL 12, 1991

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Orlando, Florida 32816

University of Central Florida
Division of Sponsored Research

IST

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FEASIBILITY ASSESSMENT REPORT

CDRL A002

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and
Naval Air Test Center**

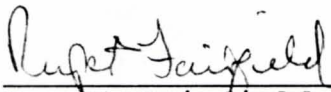
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TACTICAL ELECTRONICS SIMULATION TEST SYSTEM FEASIBILITY ASSESSMENT REPORT

EXECUTIVE SUMMARY

This report addresses the preliminary findings of the Tactical Electronics Simulation Test System (TESTS) Phase I effort: Requirements Analysis and Feasibility Assessment. This first phase involved: (1) a determination of the requirements for an advanced IFF simulation environment; (2) determination of existing facilities and resources which are applicable and available to subsequent project phases; (3) assessment of technical issues and concerns to minimize risk; (4) and development of a technical approach and conceptual design for an advanced IFF system and environment simulation leading to TESTS.

Emerging IFF systems incorporate a number of operational modes and must function in a wide variety of tactical and environmental conditions. The MK XV IFF requirements specify almost a dozen functional modes, embedded MK XII modes 1 - 4 and C, multiple MK XV time dependent formats and subformats, Mode S and Radar Mode; a large number of environmental conditions, including ECM (benign, jamming), spoofing, weather/atmospheric, ground (over water, over land, near land), density, and platform variations; and a variety of operational conditions, including altitude configurations (High IR - High XP, Low IR - High XP, High IR - Low XP). Combination of these factors means that potentially, there are several hundred test cases to be considered. Simulation provides a cost effective and efficient way to subject the system to a large set of test conditions with accurately measured results. In addition to cost and efficiency considerations, some tactical conditions requisite to testing the system without simulation can be unsafe, impractical or impact security considerations.

A seven month extensive survey was conducted as part of the TESTS feasibility assessment to gather the data required to determine the feasibility of the TESTS concept, determine areas of research required to support the development and develop an initial design concept for TESTS. The survey included site visits to various government facilities, briefings on various IFF issues and review of an extensive collection of literature. The data collected and analysis of that data is reflected in the findings of this feasibility assessment report.

An analysis of the MK XV Test and Evaluation Master Plan (TEMP) was conducted to identify the performance requirements of TESTS. The analysis was based upon a review of the MK XV TEMP, the Navy inputs to the TEMP and briefing presented in September 1990 by NAVAIRTESTCEN personnel on IFF testing. The DRAFT U.S. Navy Input to the MK XV Identification Friend or Foe Combined Test Force Test Plan document, August 28, 1990, provided detailed insight on how TESTS might be applied during developmental test and evaluation. It provided details on the projected setup of test scenarios and conditions, and the interaction between

various TEMP objectives. The focus of this analysis was five primary simulation TEMP objectives; Probability of Correct ID, Anti-Jam, Interrogation Volume/System Capacity, Code Validation and Split Targets.

It appears technically feasible for TESTS to meet all five primary simulation TEMP objectives. System capacity and interrogation volume drive the TESTS design because of the number of platforms required. The TESTS recommended conceptual design provides a feasible approach to achieve these requirements in an effective manner. While it is not possible to achieve 100% fidelity, i.e., absolute emulation of the real world, in the TESTS design, it appears that all primary simulation TEMP objectives for TESTS can be achieved with high levels of fidelity. In addition, TESTS should be able to augment test and evaluation of a broad range of additional TEMP objectives.

Four basic approaches to implementing TESTS were examined. Based on this examination, an approach utilizing the Message Level Interface coupled with the modular channel effects hardware devices is the recommended TESTS approach. This approach provides an effective mixture of hardware and software implementation. Most importantly, the software computational requirements for MK XV data generation for large numbers of targets can be accommodated by generating data at a message level rather than the pulse level. This approach is described in more detail in Section 4.0 of the full Feasibility Assessment Report. The TESTS software is used to generate multiple transponder or interrogator signals via time division multiplexing, under control of the TESTS host computer. A number of separate signal generators may be easily added to increase the Reply rate or Interrogation rate capacity of the TESTS system. Programmable gain, phase, time delay and frequency distortion hardware devices will be used in a modular fashion to introduce channel effects in the generated signals. This separates the hardware functions, and allows for easier specification, design, testing and calibration of the equipment. It also provides for a more cost effective growth path to achieve the final TESTS capacity requirements, and it allows for greater flexibility in utilization of TESTS equipment.

In order to provide a low risk, high confidence, and cost effective approach to the design, purchase, fabrication, and integration of the hardware and software components of the TESTS system, an evolving Prototype Build Plan will be adopted. The plan utilizes a number of incremental builds which provide increasing capability and diversity in the number of platforms and signals to be generated, and simultaneously, increasing fidelity in the environmental and channel propagation effects to be simulated by TESTS. This evolutionary approach will allow early closed loop testing and validation of the TESTS system with existing IFF systems such as the MK XII, and provide a low risk transition to more advanced IFF systems utilizing spread spectrum signals.

The Navy's active support and cooperation ensured that the feasibility assessment was both comprehensive and thorough. The TESTS project team was permitted to study all relevant documentation and visit all pertinent facilities. Seemingly insurmountable technical obstacles diminished in difficulty as the team's knowledge increased. The conceptual design approach optimizes the TESTS to achieve identified TEMP objectives for an advanced IFF systems utilizing a spread spectrum format. TESTS represents a significant, yet practical, advancement in the state-of-the-art simulation environment. A systematic research and development effort to determine parameter values for the channel effects and platform factors, e.g., antenna patterns, is required to realize the potential of the TESTS conceptual design. The essential conclusion is that TESTS will enable the Navy to address the five primary TEMP objectives identified for simulation and achieve accurate test results with high levels of confidence. In addition, TESTS should greatly improve the statistical confidence and accomplishment of a number of additional TEMP objectives.

TACTICAL ELECTRONICS SIMULATION TEST SYSTEM FEASIBILITY ASSESSMENT REPORT

1.0 INTRODUCTION

This report addresses the preliminary findings of the Phase I effort: Requirements Analysis and Feasibility Assessment. The Tactical Electronics Simulation Test System (TESTS) project was envisioned from the outset to be a multi-phased effort wherein both technical and cost risk would be diminished during each successive phase. The first phase involved:

1. a determination of the requirements for an advanced IFF simulation environment,
2. a determination of existing facilities and resources which are applicable and available to subsequent project phases,
3. an assessment of technical issues and concerns to minimize risk, and
4. the development of a technical approach and conceptual design for advanced IFF system and environment simulation leading to TESTS.

The contract awarded to the University of Central Florida, Institute for Simulation and Training (IST) by the Naval Training Systems Center, Orlando, Florida was initiated on August 14, 1990 with this report cited as a deliverable in February, 1991 and a final report due in May 1991. By general agreement of key personnel at both the Naval Air Test Center (NAVAIRTESTCEN) and the Naval Training Systems Center (NAVTRASYSCEN) it is intended that, if necessary, the final report of Phase I could be used to modify the feasibility assessment report. However, the Institute for Simulation and Training together with the Electrical Engineering Department are sufficiently confident in the feasibility of the required simulation and in the ultimate value to the U.S. Navy of acquiring such a simulation test tool that the discussion contained in this report will go beyond discussing technical feasibility issues and will also address a recommended technical approach which will lead to the cost effective development of the Tactical Electronics Simulation Test System (TESTS).

IST, a research organization dedicated to the advancement of simulation science and technology, has long been aware of the great value that simulation holds in the test and evaluation of emerging systems. The Department of Defense has been particularly interested in the expanding role of simulation for T & E purposes. Major weapons systems, and their associated tactical electronics subsystems, have advanced technologically to the point where if simulation science is not used, full and accurate test and evaluation cannot be conducted. Without full

and accurate T & E activities in both the developmental and operational test phases, little confidence can be held in the predicted performance of either the major weapons system itself or its installed electronic subsystems.

This introductory section seeks to provide both a contractual and programmatic overview of TESTS prior to the technical discussion based on survey findings, requirements analysis, and feasibility assessment. The objectives of the initial phase of the project as documented in the finding of this report were:

- 1) to determine existing baseline capabilities at NAVTRASYSCEN and NAVAIRTESTCEN applicable to the development of a tactical electronics simulation/stimulation model;
- 2) to determine the requirements and constraints for the development of a tactical electronics simulation/stimulation model;
- 3) to assess simulation technical risk issues;
- 4) to develop a conceptual design for a prototype model applicable to the IFF;
- 5) to conduct a feasibility assessment to ascertain that a MK XV IFF TESTS can be developed, that it can achieve test objectives, and that it represents a cost-effective solution and;
- 6) to develop a research plan for development of a prototype model.

1.1 PROBLEM

Emerging IFF systems incorporate a number of operational modes and must function in a wide variety of tactical and environmental conditions. The MK XV IFF requirements specify almost a dozen functional modes, embedded MK XII modes 1 - 4 and C, multiple MK XV time dependent formats and subformats, Mode S and Radar Mode Front End; a large number of environmental conditions, including ECM (benign, jamming), spoofing, weather/atmospheric, ground (over water, over land, near land), density, and platform variations; and a variety of operational conditions, including altitude configurations (High IR - High XP, Low IR - High XP, High IR -Low XP). Combination of these factors means that potentially, there are several hundred test cases to be considered. Simulation provides a cost effective and efficient way to subject the system to a large set of test conditions with accurately measured results. In addition to cost and efficiency considerations, some tactical conditions requisite to testing the system without simulation can be unsafe or impractical because of degree of difficulty or security considerations.

When IST became aware of the MK XV IFF program, it became evident that it might represent an ideal candidate system for application of simulation technology in the T & E phases. Initial discussions with NAVAIRTESTCEN revealed that the U.S. Navy held similar opinions, but were concerned that such a simulation may not be feasible or once developed, lack credibility for the testing purposes required. IST requested a copy of the MK XV IFF Test and Evaluation Master Plan (TEMP). Of the 32 identified test objectives in the plan, it was evident that five critical objectives could not be achieved except through testing with simulation and that a large number of others could be tested with more confidence if a simulation test tool were developed. The practical goal of the T & E simulation thus defined, NAVAIRTESTCEN solicited comment from various key agencies to determine what technical obstacles and issues could hinder or prevent the cost effective development of the simulation test tool, now called TESTS. Comments by these key agencies were then consolidated into a listing of technical issues and concerns. These became the basis for the Phase I TESTS effort as reflected in both the contract and workplan.

One final important observation must be made. From the initiation of the TESTS project, an appreciation of three critical factors have been interwoven into every aspect of the approach used by the TESTS project team:

Affordability - TESTS had to be cost-effective. A design-to-cost approach has been the project team's objective from the outset.

Versatility - TESTS must serve the Navy's needs regardless of whether the final prime system were a MK XV or a MK XII enhanced IFF or any variation which might occur downstream. It must also make best possible use of existing facilities, simulation tools, and equipments.

Risk Reduction - Each successive project phase must reduce both technical and programmatic risk. An answer which solved one small piece of the problem without advancing the overall solution was never acceptable. No element of this project could be characterized as more than moderate risk and most of the technical issues have been reduced to low risk elements.

The following sections address the selected study approach use in Phase I, and include discussions of the TEMP analysis, survey, and assessment of technical issues.

2.0 STUDY APPROACH

2.1 SURVEY

A seven month extensive survey was conducted as part of the TESTS feasibility assessment to gather the data required to determine the feasibility of the TESTS concept, determine areas of research required to support the development and develop an initial design concept for TESTS. The survey included site visits to various government facilities, briefings on various IFF issues and review of an extensive collection of literature. The data collected and analysis of that data is reflected in the findings of this feasibility assessment report.

A total of ten site visits were conducted by various IST and EE technical personnel. The primary focus of the site visits focused on the facilities at NAVAIRTESTCEN. Four site visits were made to NAVAIRTESTCEN. During these visits initial and follow up discussions were conducted at each of the ACETEF laboratories, the IFF data center, and the Chesapeake Range Facility, among others. These visits provided the information required to assess current hardware and software capabilities at NAVAIRTESTCEN related to TESTS, future plans and resources, current practices and procedures, and points of contact that will be needed throughout the project. In addition to the visits to NAVAIRTESTCEN, additional site visits were made to NAVTRASYSCEN, NESEA, NRL, Kirtland AFB, and Bendix. These additional visits were conducted to gather information, clarify various technical issues and determine existing capabilities and resources which might be applicable to the accomplishment of the TESTS project objectives.

In addition to the information accumulated during the visits to various government and contractor facilities, six to eight additional briefings related to TESTS were conducted at IST by government representatives. In conjunction with the government briefings and site visits, over 90 technical documents totalling almost 3000 pages were reviewed regarding the MK XV, MK XII, Simulated Warfare Environment generator (SWEG), Air Combat Test and Evaluation Facility (ACETEF) laboratories, etc. Based on the data gathered from these various sources, the UCF TESTS team was able to develop a thorough understanding of the operation of IFF systems, the requirements for TESTS, and potential approaches for the development and implementation of TESTS.

During the Phase I study, various supporting tools and/or implementation equipments were discovered that can be used to significantly reduce the time and money expenditure to produce a simulation tool. Among these items are:

- 1) Software configuration management system.
- 2) Various software packages for use in analysis of channel effects.

- 3) Bendix MK XV modified ADM test equipment (residual of AF MK XV Program).
- 4) Object oriented ADA packages.
- 5) RF signal generation equipment, multichannel, for threat simulation (CAL CORP.)

2.1.1 NAVTRASYSNEN Capabilities

The survey of NAVTRASYSNEN capabilities initially indicated that there are several IFF training systems available. Examination of these systems revealed that detailed design information and software source code were not available. Hence, other than lessons learned information, existing IFF training systems could not aid in the development of TESTS. NAVTRASYSNEN can provide a number of resources which will be utilized during TESTS development. These resources include:

- 1) A software configuration management system that may be applicable to TESTS.
- 2) Secured laboratories which are accessible to the project when TESTS reaches the signal generation development and transmission phases.
- 3) Guidance on the development of Ada based simulation devices.
- 4) Access to the NAVTRASYSNEN Electronic Warfare Database which provides a valuable source of emitter data. This data base incorporates the Naval Emitter Reference File (NERF) and the Naval Warfare Tactical Database.

During discussions with NAVTRASYSNEN software development personnel, it was recommended that several CASE tools from Mark V Systems, Inc. be procured to support the software development activities in TESTS. These CASE tools provide a common software development environment which supports MIL-STD-2167A software development activities and has available language extensions for both Ada and C. The language modules support autocode generation and documentation activities.

2.1.2 NAVAIRTESTNEN ACETEF Capabilities

The ACETEF and its existing computer resources, emitters, antennas, and hardware interfaces were examined. A determination was made as to the required hardware environment for the simulation model. Specifically, the CNIL (Communications, Navigation, and Identification Laboratory), the EWISTL (Electronic Warfare Integrated Systems Tests Laboratory), EMEGS (Electromagnetic Environment Evaluation Facility, and the ACETEF OCC (Operations and Control Center) were surveyed. Also, data capture and current RF emitter capabilities relevant to the MK XV

IFF were examined. The followings subsections summarize those resources which might be utilized for TESTS.

2.1.2.1 EWISTL. EWISTL will provide the initial baseline threat simulation/stimulation for TESTS when it is operating within ACETEF. It provides RF threat simulation/stimulation of EW systems. EWISTL capabilities are centered around the ETEWES (Enhanced Tactical Electronic Warfare Environment Simulator) hardware. In conjunction with other hardware this facility has the capability to generate friendly Radar Warning Receiver signals and generate red signals. A current limitation of EWISTL is that it can not generate spread spectrum EW signals suitable for TESTS.

2.1.2.2 EMEGS. The EMEGS laboratory recently acquired the MINI TASS (Tactical Signal Simulator). The MINI TASS is a highly compact, multipurpose, electronic combat environment simulator, designed for electronic warfare applications from receiver systems testing to on-board operator training. It accurately generates threats ranging from simple search radars to highly complex, multi-mode radars on platforms in motion. The simulator generates realistic EW scenarios comprised of up to 16 simultaneous complex emitters in the 0.5 to 18 GHz band and simulates three-dimensional platform motion in real-time. System features include: low cost, modular, state-of-the-art, off-the-shelf, expandable, stand alone, multi-emitters, multiple octave RF source, external interface to other rf source (i.e. HP 8791 synthesizers), interactive software, portable MS DOS software and direction of arrival (DOA). Available options: wide band rf source, calibration, graphic display, high powered amplifier trigger, antennas, laptop PC version, digital or video interface, ruggedized MILSPEC version, pre-programmed emitter and scenario data on removable memory module. This system could support TESTS in the stand alone configuration to provide an ECM environment.

2.1.2.3 CNIL. The CNIL will provide the primary interface for TESTS when it is configured within ACETEF. As such, the various software protocols and architectures of CNIL must be accommodated in TESTS. The details of this laboratories design are still TBD, but preliminary design concepts are compatible with the recommended TESTS design concept. Planned procurements for the CNIL include various RF generation and analysis systems. Evaluation of the preliminary list indicates that this signal processing equipment could be used to calibrate TESTS thereby reducing hardware procurement costs.

2.1.2.4 OCC. The OCC provides the simulation control for TESTS via SWEG when TESTS is operating in the fully integrated ACETEF environment. It should be noted that when CNIL is running independent of the full ACETEF, it will provide the host environment for SWEG. In the stand alone configuration SWEG will reside within TESTS in the TESTS Database.

2.1.3 Other NAVAIRTESTCEN Laboratory Capabilities

In addition to visiting laboratories within the NAVAIRTESTCEN ACETEF complex, several other laboratories at NAVAIRTESTCEN were surveyed. These additional laboratories included the IFF Data Center, ATLAS (Advanced Test Laboratory for Antenna Systems), NIFFTE (Navy IFF Test and Evaluation) laboratory, and the Chesapeake Test Range (CTR). The capabilities of these facilities relevant to TESTS are summarized below.

2.1.3.1 IFF Data Center. The IFF Data Center will determine the data capture formats and protocols for TESTS, since this facility will provide the data analysis capabilities for TESTS. Human computer interface guidelines developed for the data center will be used as guidance for the user interface in TESTS to minimize relearning by TESTS operators.

2.1.3.2 ATLAS. ATLAS provides the capability to develop antenna pattern data from aircraft in flight which can be utilized in TESTS validation and verification (V&V). This includes three dimensional empirical antenna pattern data on a variety of platforms. In addition, ATLAS has a smooth surface over water multipath model to extract antenna gain patterns from raw experimental data. This model might be useful as a reference baseline during TESTS development

2.1.3.3 NIFFTE. The NIFFTE laboratory is currently oriented to MK XII interrogator and transponder testing. The MK XII IFF hardware in this facility can be used to evaluate and demonstrate the early versions of TESTS.

2.1.3.4 CTR. The CTR could provide a valuable source of flight test data for parts of TESTS V&V. Flight test scenarios from CTR could be replicated in TESTS and the actual flight test data compared to TESTS derived data.

2.1.4 Bendix Capabilities

Discussions with Bendix indicate that they have basic signal generation capabilities which might be tailored to TESTS requirements. These capabilities will continue to be explored because they may reduce requirements for custom hardware development. If this is feasible, it will reduce technical risk, cost and schedule, while potentially improving overall fidelity of the TESTS system.

Under the Air Force MK XV contract, Bendix was to build 10 sets of subsystem elements of test equipment for use in MK XV test and calibration. These subsystems were based on modified ADM equipment designs. One set of the test equipment was completed before contract termination. The subsystems for the transponder and/or interrogator test sets were designed to mount on mobile carts. The ensemble of test set subsystems included a digital interface drawer, density signal generator drawer (2 channels),

D-band RF drawer, radar mode RF drawer, COMSEC drawer and power supply.

IST's evaluation of this Bendix test set found

- 1) Standard IFF modes/formats implemented with provisions for outside additional waveforms
- 2) Hardware modularized within each drawer, with easy access to interconnections for hardware modifications or additions, such as inputs for channel effects
- 3) Flexibility to accommodate external computer control of critical elements and/or time synchronization
- 4) Receiver demodulation and decode already implemented

It is possible that selected subsystems could be effectively used for part of the hardware implementation under the recommended design approach described in Section 4.1. Applicable components include the digital interface drawer to provide all modes/formats of waveform generator and receiver, the density signal generator (multiple elements to accommodate simultaneous modulated RF signals) and the power supply. Additional evaluation is necessary to determine the differences associated with operation as an interrogator tool or transponder tool within TESTS.

2.1.5 Other Relevant Resources

During the course of the survey several computer programs from other government organizations were identified as potentially beneficial to the development of TESTS. These computer programs support the directed research activities required for TESTS. The ECAC-TTP, Release 3, EMC Program has been obtained from the Electromagnetic Compatibility Analysis Center. This program contains a "Terrain Integrated Rough Earth Model" which will be useful in investigating various aspects of multipath effects. GEMACS has been obtained from Rome Development Center through a technology transfer agreement with the Air Force. This government developed program is designed to investigate antenna pattern and near field effects. UCF/IST has also obtained the INAC-3 and STRIPES programs to aid in the analysis of antenna effects. The BOSS (Block Oriented Simulation System) program has also been obtained and will be used to develop a research tool to support the TESTS project. This ensemble of software programs, mostly developed under government support, provide a comprehensive set of research tools for the TESTS project.

Based on discussions with NAVTRASYSCEN software development personnel, several CASE tools from Mark V Systems, Inc. are being procured to support the software development activities in TESTS. These CASE tools provide a common software development environment which supports MIL-STD-2167A software development activities and has available language extensions for both Ada and

C. The language modules support autocode generation and documentation activities. The core program "Object Maker" is designed to support a total top-down design approach. It supports the use of object-oriented analysis models, development and maintenance of software data flow diagrams, development of documentation and general configuration management. These CASE tools will reduce software development time while increasing overall quality.

2.1.6 Current Software Procedures at NAVAIRTESTCEN

The current software capabilities within NAVAIRTESTCEN were examined to determine whether portions of existing simulation models could be utilized to minimize cost and development time. The software and interface requirements of the EWISTL and EMEGS facilities, as well as the Simulated Warfare Environment Generator (SWE) software were examined. Essentially, the software protocols are straight forward and do not impose any design problems.

Mixed procedures are currently in place. Several software languages are currently in use and compliance with MIL-STD-2167A is selective. Older laboratories, such as EWISTL, use FORTRAN though they have recently procured a C compiler to upgrade the system. SWE is also Fortran based and can not be cost effectively recoded. Newer facilities, i.e., CNIL and the IFF Data Center, have adopted the DoD ADA standard. The IFF Data Center and CNIL do not have the demanding software computational requirements of the other laboratories, so ADA is an acceptable alternative. In CNIL applications, approximately half of the systems are controlling real black boxes and thus computationally intensive functions are implemented in hardware.

TESTS will use ADA in as many applications as possible, but the use of ADA will depend on the computational requirements of the code required. When these requirements cannot be met with ADA, C or C++ will be used. These languages are becoming the commonly accepted standard for most applications and can facilitate integration with off-the-shelf software packages. A tailored approach to MIL-STD-2167A will be proposed which is compatible with the proposed TESTS evolving prototype approach. The draft of the tailored MIL-STD-2167A Software Development Plan is provided in Annex B. A summary discussion of the Software Development Plan is also provide in Section 4.4.

2.1.7 Summary of Major Survey Findings

Existing capabilities within ACETEF and other laboratories at NAVAIRTESTCEN reduce the development requirements for TESTS. While simple models will need to be developed or procured to support TESTS validation and testing of the design, TESTS will be designed to make use of existing resources to the maximum extent possible. ACETEF provides initial capabilities for required ECM environments, scenario control, data capture and other facets as described above. Some capabilities, such as ECM do not currently

include the necessary advanced jamming capabilities, however, these capabilities are planned and will be available by the completion of the TESTS implementation.

The computer and network hardware environments are predominantly VAX and SUN based and use industry standard interfaces/bus architectures. These computer environments provide a relatively standard and open architecture. This will simplify the integration of TESTS into ACETEF and should not impose any significant cost burden to the program. The use of SUN computers offers the opportunity to implement TESTS using a distributed or federated approach. High-speed, low cost coprocessors are available for this environment which permit a very cost effective computer environment for TESTS. This environment is easily expandable to accommodate increased or unexpected processing requirements and future growth. Hence, we do not perceive that the implementation of TESTS within NAVAIRTESTCEN facilities imposes any technical risk.

One area which TESTS must address is signal generation capabilities for spread spectrum type signals. Current facilities at NAVAIRTESTCEN can not adequately support this requirement. Several viable methods for developing this capability within TESTS are being studied. Cost and schedule will probably be the criteria used to determine the most effective approach. Jammer capabilities within EWISTL and EMEGS can be easily interfaced to TESTS.

The area of greatest concern is SWEG. This is the required interface for TESTS and the primary source of simulation control. The Navy version of SWEG is still in development and the final level of capability is still undetermined. SWEG is derived from a battlefield simulation called SUPPRESSOR which is approximately ten years old. The ability to upgrade or modify any software package that old represents a degree of technical risk. Short cuts also tend to be adopted in updating software which might compromise performance if not fully tested. For example, SUPPRESSOR utilized metric conventions for all units, i.e., meters rather than feet. Selected parts of SWEG have been modified to use english units, i.e., feet. This is necessary since most of the Navy's measurements are in feet. However, an examination of the SWEG source code indicates that not all units have been changed, only those directly related to certain input parameters. Hence, there is a mixture of measurement units in the current version of SWEG. Conversion between units within SWEG could introduce an unknown degree of error simply because of round off errors. There will also be a need to supplement SWEG with a TESTS specific data base. SWEG appears to have the basic capability to support TESTS and provides as much fidelity as any available scenario simulation package. However, until SWEG is fully upgraded and validated within ACETEF it represents a potential impact on TESTS.

Signal generation capabilities available from Bendix resulting from the original MK XV contact must continue to be evaluated.

Several components may directly support the recommended TESTS design approach described in Section 4.1. This could significantly reduce development risk.

2.2 ANALYSIS OF TEMP OBJECTIVES

Analysis of the MK XV Test and Evaluation Master Plan (TEMP) objectives was conducted to identify the performance requirements of TESTS. The analysis was based upon a review of the MK XV TEMP, Navy inputs to the MK XV Combined Test Force, and a briefing on IFF test procedures by NAVAIRTESTCEN presented in September 1990. The DRAFT U.S. Navy Input to the MK XV Identification Friend or Foe Combined Test Force Test Plan document, August 28, 1990, provided detailed insight on the manner in which TESTS might be applied during developmental test and evaluation.

The focus of this analysis was five primary simulation TEMP objectives identified for TESTS by the Navy. These primary TEMP objectives for TESTS include:

- Probability of Correct ID
- Anti-Jam
- System Capacity/Interrogation Volume
- Code Validation
- Split Targets

The goal of TESTS is to maximize the ability to meet these five objectives. These five objectives were identified as requiring simulation to adequately test due to cost, the high number of simultaneous aircraft required, repeatability concerns, safety, and OPSEC.

Not all of the thirty-two MK XV TEMP objectives are relevant to the TESTS project, e.g. Logistics Supportability and Safety. However, while not a specific requirement, TESTS should also provide the capability to assist in the evaluation of a number of other TEMP objectives, hereafter called secondary TEMP objectives. This may provide secondary cost benefits through reduction of flight test hours, or provide additional data to enhance the test and evaluation findings. Flight tests can only sample a small subset of data points from the possible combinations of all parameters. A simulation/stimulation test tool can supplement flight test data by providing a high density environment for all objectives as necessary, large data samples and a much richer combination of test conditions covering altitude configurations, modes and formats, physical environments, ECM conditions, PRF's and scan rates and Reply/Interrogator densities. Secondary TEMP objectives which might benefit from TESTS include:

- Maximum Range
- Minimum Range
- Range Resolution
- Range Accuracy

Azimuth Resolution
 Azimuth Accuracy
 FRUIT Rate
 Diversity Performance
 Multipath Performance
 Anti-Spoof
 Crypto
 Interoperability & Compatibility
 EMC

The following sections provide brief discussions of the requirements of these various TEMP objectives. A definition is provided for each objective, followed by the key issues of that objective, a short discussion and an estimated of the fidelity level of TESTS for that objective. Table 2-1 provides a summary of the scale used to make the fidelity assessments.

TABLE 2-1
 ASSESSMENT OF TESTS FIDELITY

<u>% RATING</u>	<u>DEFINITION</u>
100	Perfect emulation of the real world
90	Sufficient to fully meet specification requirements
70-80	One or two minor deficiencies which may reduce the total scope of test capability, but still meet other aspects at a high level of fidelity.
60-70	General overall reduction in capability, but sufficient to conduct selected tests
40-50	Some capability in selected areas, but major weaknesses
0	No capability

2.2.1 Probability of Correct ID

Definitions: The system single scan and multiple scan probability of Friend Identification and Probability of Enemy Acceptance.

Issues:

- Normally requires a dense environment.
- Must be conducted for embedded MK XII modes and MK XV formats both individually and in interlaced presentations.

- c) Effects of split targets, multipath, and false detection

Discussion: The probability of correct ID is affected by the target data processors algorithm used to predict the target location. Any algorithm will have to tradeoff location accuracy, azimuth resolution and probability of friend declaration and enemy acceptance. Probability of correct ID then becomes a part or subset of the system capacity evaluation. This will be determined by either single or multiple interrogations and multiple replies. Implementation of the capability to accomplishment of this TEMP objective within TESTS does not present any design difficulties.

Estimated Fidelity: It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.2 Anti-Jam Capabilities

Definition: The amount of performance degradation under various Electronic Counter Measures (ECM) environments.

- Issues:
- a) Threat systems include: airborne jammers (Big Crow/Little Crow jammer aircraft), heliborne jammers, ground based jammers.
 - b) Interacts with all other performance parameters.

Discussion: There is a need to investigate the immunity of the receiver from hostile ECM signals. This will be a function of the processing gain, the ECM signals, other multiple channels, system dynamic range, and the receiver sensitivity. There do not appear to be any technical barriers in meeting this objective. However, the ability to meet this objective will be determined by cost and TESTS configuration. There is a requirement for TESTS to operate in a stand alone configuration or integrated with ACETEF. In the ACETEF configuration, threat signals would be provided by capabilities resident in ACETEF. In the stand alone configuration, ability to meet this objective is driven by cost. Only very simple threat models will be developed to exercise TESTS during its development. In the stand alone configuration the most cost effective implementation is for TESTS to utilize a benign environment which does not accommodate this TEMP objective. However, provisions for adding/integrating a jamming "module" will be

included in TESTS. An off-the-shelf commercial threat stimulation system could be easily added to TESTS to provide a hostile threat environment. NAVAIRTESTCEN currently has a system with this capability in the EMEGS laboratory called Mini-TASS developed by CAL. Configurations of this system can provide a wide range of jamming capability as required by TESTS.

Estimated
Fidelity:

Test fidelity for this objective is dependent upon TESTS configuration. In the stand alone benign configuration the test fidelity is 0 %. In the stand alone configuration with external jamming subsystem, fidelity will range from 70 - 90 % depending upon the capabilities of the selected jamming system. When integrated with ACETEF, current jamming capabilities will provide approximately 70 % fidelity because new jammers, spread spectrum, are not available. When new capabilities identified for ACETEF are implemented this should increase to 90 %.

2.2.3 System Capacity/Interrogation Volume

Definition: The ability to identify friendly targets and adequately locate them in range/azimuth to correlate/associate with the primary sensor in an environment of increasing interrogation rates.

Issues:

- a) The severity of signal overlapping to degrade system
- b) The number of overlapping signals to degrade the system
- c) System performance with overlapped waveforms
- d) In-beam: effects of overlapped waveforms, including FRUIT rate.
- e) Number of platforms required in real time simulation.

Discussion: This is going to be the most difficult item to fully simulate since it is a function of all parameters and a function of how the parameters interact. This is one of the TEMP objectives in which number of platforms is critical. Simulation of large numbers of platforms in high fidelity and real time appears to be the major technical driver and cost for TESTS. The proposed approach minimizes, though it does not eliminate, the technical risk and cost to accomplish this objective.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. When tested in support of other objectives, the fidelity will be determined by the objective with the lowest fidelity level.

2.2.4 Code Validation

Definition: Percentage of proper code validations per interrogation, a ratio of times the interrogator correctly decodes the reply over the number of interrogations during the dwell on a target transponder.

Issues:

Interrogator Tests -

- a) Probability of friend rejection
- b) Probability of enemy acceptance
- c) Effects of split targets, multipath, and false detection

Transponder Tests -

- d) Garbling and synchronization of received signals
- e) Code information reliability

Discussion:

The probability of correct ID is affected by the target data processors algorithm used to predict the target location. Any algorithm will have to tradeoff location accuracy, azimuth resolution and probability of friend declaration and enemy acceptance. Code validation then becomes a part or subset of the system capacity evaluation. This is going to be a function of the number of signals, fading, multipath, etc. Ultimately, it will depend upon the simulation accuracy in software and/or hardware of the code generation. It appears that this objective can be accomplished within the TESTS concept.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.5 Split Targets

Definition: Percentage of targets declared as multiple targets per scan.

Issues:

- a) The conditions creating target splits.

- b) Effects of split targets during detection on code validation and probability of correct ID.
- c) Effects of multipath and false detections.
- d) Probability of friend rejection.
- e) Probability of enemy acceptance.

Discussion: This is the percentage of transponder responses per interrogation interval which appear to originate from two or more azimuths. The primary measurement is in a benign environment. It must be assessed in conjunction with other position characteristics including target correlation, range accuracy and resolution, azimuth accuracy and resolution, and beam sharpening. While SWEG positional resolution is a concern, it will not be a major impact on this parameter. There may be a small reduction in fidelity, but it appears that the capability required to accomplish this objective can be implemented in TESTS.

Estimated Fidelity: It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.6 Diversity Performance

Definition: The capability of the transponder algorithms to determine through which antenna the reply should be sent. The reply is sent through the antenna receiving the strongest and/or first interrogation pulse.

- Issues:
- a) The performance of the MK XV must be evaluated in various interrogator - transponder geometries.
 - b) Must be evaluated in conjunction with tests for maximum range, range resolution, minimum range, multipath and azimuth resolution.

Discussion: The transponder diversity decision is compared to the calculated decision based on aircraft pitch, roll, heading and platform location. Hence, the limiting factor on this objective is the platform position resolution in SWEG, which is a function of update rates and the resolution of measurement units in SWEG. A TESTS design factor that must be resolved is whether the TESTS transponder simulator/stimulator will represent a generic platform or a specific platform(s) due to the varying antenna locations across platforms or

within models of the same platform and the resulting potential impact on diversity performance. Roll and pitch characteristics for specific platforms also vary widely.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. It is possible that SWEG limitations or platform specificity may reduce fidelity to 70-80 %, but this can not be determined at this time.

2.2.7 Maximum Range

Definition: The maximum range in nautical miles at which consistent ID is lost.

Issues:

- a) The maximum range for each combination of variables without a potential false max range created by hitting the line-of-sight limit, where the line-of-sight or theoretical maximum range is defined as 80% of the radio horizon.
- b) Maximum range must be equal to or greater than the platform's primary sensor capabilities.

Discussion: This will be a function of environmental conditions, ECM, processing gain, sensitivity, multiple channels, and jamming. Antenna gain, pattern and channels need to be considered. TESTS is projected to incorporate the factors required to test this objective. While flight test provides a solid data base for assessment of this objective, TESTS can be used to extend the number of variable combinations evaluated.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.8 Range Resolution

Definition: The minimum range separation of two targets where they are still distinguishable.

Issues:

- a) Range separation is measured in feet.
- b) Baseline established in a benign environment.

Discussion: This objective will be a function of the environment, processing gain, and sensitivity. Antenna resolution and timing accuracy are very important. A limiting factor on this objective is

the positional resolution in SWEG, which is a function of update rates and the measurement unit resolution in SWEG.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. It is possible that SWEG limitations may reduce fidelity to 70-80 %, but this can not be determined at this time.

2.2.9 Minimum Range

Definition: The minimum range at which consistent ID is lost.

Issues: a) The minimum range for each combination of variables in a benign or jamming environment.

Discussion: This objective will be a function of the environment, ECM, processing gain, sensitivity, system dynamic range, and jammers. This objective will push the TESTS signal delay/time to reply specification. TESTS should be able to reply to an interrogation as fast or faster than in the real world. While flight test provides a solid data base for assessment of this objective, TESTS can be used to extend the number of variable combinations evaluated, e.g., wider variety of environmental conditions.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.10 Range Accuracy

Definition: Accuracy of target range over entire range of system.

Issues: a) Target range measured in feet.

Discussion: This is the magnitude of error in the interrogator's estimation of the transponder's slant range. This should be a function of the processing gain and processing/transmission delays. Timing accuracy within TESTS will be very important for this objective. Must be assessed in conjunction with other position characteristics including target correlation, range resolution, azimuth accuracy and resolution, and beam sharpening. A limiting factor on this objective is the positional resolution in SWEG, which is a function of update rates and measurement unit resolution in SWEG.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. It is possible that SWEG limitations may reduce fidelity to 70-80 %, but this can not be determined at this time.

2.2.11 Azimuth Resolution

Definition: The minimum azimuth separation of two distinguishable targets.

Issues:

- a) Measured in feet and expressed as a percentage of the host systems antenna beam width.
- b) Determine the azimuth resolution in a benign environment.
- c) Due to the potential impact of propagation effects, the most critical test case is a near land scenario.

Discussion: Must be assessed in conjunction with other position characteristics including target correlation, range accuracy and resolution, azimuth accuracy and beam sharpening. This is primarily driven by the geometry of the relationship between the Interrogator and the Transponder platforms and the fidelity selected in the subsystems (i.e., resolutions of antenna pattern, propagation effects, etc.) of the simulator. The limiting factor on this objective is the positional resolution in SWEG, which is a function of update rates and the measurement unit resolution in SWEG.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. It is possible that SWEG limitations may reduce fidelity to 70-80 %, but this can not be determined at this time.

2.2.12 Azimuth Accuracy

Definition: Evaluate accuracy of IFF reported target azimuth over the entire system range.

Issues:

- a) Target azimuthal position measured in feet. Flight test assessment is limited by truth data accuracy at short range, whereas simulation testing can extend this assessment over the entire range of the system.

Discussion: Must be assessed in conjunction with other position characteristics including target

correlation, range accuracy and resolution, azimuth resolution and beam sharpening. The limiting factor on this objective is the positional resolution in SWEG. The total positional resolution accuracy in SWEG may be affected by database update rates.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. It is possible that SWEG limitations may reduce fidelity to 70-80 %, but this can not be determined at this time.

2.2.13 Multipath

Definition: Evaluate the impacts to system performance as a result of multipath effects.

Issues:

- a) Altitude combinations for Interrogators and Transponders
- b) Over land, over water and combined effects.
- c) Atmospheric reflections
- d) Comparison of system performance in non-multipath conditions with multipath conditions.

Discussions: This is going to be a function of any type of multipath and fading problems. The recommended approach described in Section 4.1 provides a readily implementable hardware solution to multipath effects. The multipath looks very much like another channel; therefore, it can be handled via superposition. The inclusion of multipath and other propagation effects will be one of the major contributions of TESTS and the primary feature which distinguishes it from a black box test set. It is required to provide sufficient fidelity to conduct other objectives. Hence, TESTS will be directly applicable to this secondary TESTS TEMP objective.

Estimated
Fidelity:

It is estimated that the fidelity of testing this TEMP objective will be 90 %. Multipath fidelity is a selectable tradeoff with system capacity within the recommended design approach. With lower system capacity, the fidelity of multipath can be improved although the minimum level of fidelity should meet system specifications.

2.2.14 FRUIT Rate

Definition: Replies received by an interrogator which were intended for another interrogator.

Issues: a) System performance degradation in a dense, non-ECM environment.
b) Effects of FRUIT on other parameters

Discussion: FRUIT is the result of the omnidirectional characteristics of the transponder which leads to the reception of replies meant for other interrogators. This objective is directed toward the embedded MK XII within the MK XV. The large number of simulated valid replies required for this objective is a primary design issue for TESTS. The recommended design described in Section 4.1 provides an effective method to address this issue. Hence, TESTS should have the basic capability to aid in the evaluation of this objective.

Estimated Fidelity: It is estimated that the fidelity of testing this TEMP objective will be 90 %.

2.2.15 Anti-Spoof

Definition: Resistance to exploitation of spoofing.

Issues: The resistance to spoofing by calculating probability of enemy acceptance in the presence of a spoofer.

Discussion: This TEMP objective is similar to anti-jam. The configuration of TESTS will provide the capability to accommodate spoofing. The development of spoofing capability is a government responsibility and TESTS will be designed to accommodate that capability as available. TESTS itself could be used to simulate a spoofer which could be used to exercise this feature.

Estimated Fidelity: Dependent upon government capability. Current assets for anti-spoof limit fidelity of this test to 70 - 80 %. However, new planned anti-spoof capabilities mentioned during site visits at NAVAIRTESTCEN suggest that this fidelity level could approach 90 % when the new capability becomes available.

2.2.16 Crypto (included because of impact on other objectives)

Definition: The adequacy of the crypto components for maintaining system integrity and crypto stability and accuracy.

Issues: a) TOD synchronization
b) Cryptographic processing capacity and timing compatibility

Discussion: While the impact of the crypto unit on other TEMP objectives must be considered, the specific assessment of the crypto objective is a "black box" test that can not be addressed by TESTS. However, the simulation of the crypto and its timing features is a challenging design feature. Several methods for incorporating the crypto function are being evaluated. Discussions with NSA will be required during the detail design process to select the most effective approach.

Estimated Fidelity: Not applicable to testing with TESTS

2.2.17 Interoperability and Compatibility

Definition: The ability of the MK XV IFF system to operate within the civil ATC, current military IFF systems, and the NIS.

Issues: a) Embedded MK XII IFF vs. current US and NATO, civil ATC and military IFF systems
b) Integral Mode S vs. emerging civil ATC Mode S system, MK XV IFF (both radar Mode and TDF) vs. NIS as developed by participating countries.

Discussion: TESTS could be used directly to assess compatibility and interoperability with other related systems. In essence, this would be accomplished by using the system in questions, e.g., a NATO ID system, as the system under test (SUT). TESTS could aid in assessing this TEMP objective, but should not be the primary test method for this objective.

Estimated Fidelity: It is estimated that the fidelity of testing this TEMP objective will be 90 %. This could be reduced dependent upon the interface characteristics of other systems but the impact should be minor.

2.2.18 Electromagnetic Compatibility

Definition: The ability to operate simultaneously with other systems within the platform without degradation due to Electromagnetic Interference (EMI).

Issues:

- a) Compatibility - Verify the compatibility of the MK XV IFF as installed and operated within the host platform without presenting an unacceptable interference to or receiving and unacceptable interference from any system within the environment.
- b) Determine the ability of the MK XV system to operate at the inter element, inter platform and intra platform levels
- c) Aircraft carrier suitability - evaluate the suitability of MK XV IFF to the environments encountered by aircraft carrier-based platforms.

Discussion: This is a problem due to the fact that the MK XV will not be in an isolated environment but rather running in an environment where there are other communications systems with many signals and signal levels in the immediate vicinity of the receiver. TESTS could be used to exercise the system under test. TESTS should not be the primary test method, but could augment the test procedure.

Estimated Fidelity: Not directly applicable (see discussion), but should be at least 60 - 70 %.

2.2.19 Summary of TEMP Objective Analysis

An analysis of the applicability of TESTS to the relevant subset of TEMP objectives was conducted. Of the five primary TEMP objectives that TESTS was formulated to address, it appears that all can be technically met. System capacity/interrogation volume drive the TESTS design because of the number of platforms required. The TESTS conceptual design addressed in later sections provides a feasible approach to achieve these requirements in an effective manner. The ability to meet the anti-jam objective will require additional capability in a stand alone configuration, however, off-the-shelf systems are available which provide that capability. The accomplishment of the anti-jam objective in a stand alone configuration is therefore a cost decision. While it is not possible to achieve 100% fidelity, i.e., perfect emulation of the real world and all its variations, in the TESTS design, it appears that all primary TEMP objectives for TESTS can be achieved with high levels of fidelity. The scheme for introducing propagation effects proposed for TESTS

will require a systematic direct research to determine appropriate parameters and levels of fidelity, however, it appears technically feasible and within cost boundaries.

The key is selective levels of fidelity. Selective fidelity emphasizes choosing the lowest level of fidelity which provides realistic test conditions and appropriate system performance impact. Different levels of fidelity may be selected for every factor in the design, i.e., high levels of fidelity are chosen for critical factors and lower levels of fidelity are chosen for those factors which impose little impact on system performance. For example, consider the number of multipaths. In the real world there may be N multipaths, but it may not be necessary to simulate all possible multipaths to have a realistic system. The objective is to include the minimum number of multipaths which subject the system to a realistic degrading impact of multipath. For the MK XV the maximum number of multipaths that could impact the system is bounded by the COMSEC and TRANSEC characteristics and the db cutoffs of the system. Only when the multipath signal falls within the correct interval or is of sufficient intensity will it be accepted. Other multipath signals are irrelevant to the simulation. However, within the pool of acceptable multipath signals, not all have the same degree of impact. From a simplified view, the potential impact of each successive multipath becomes less because of reductions in gain, etc. If the system can reject the first few strong multipath signals, it should be able to reject all subsequent multipath signals. Hence, to test the resistance to multipath effects, it is only necessary to subject the system under test to those which have the greatest probability of impacting system performance. As a result, a simulation approach to multipath requires a minimum of one multipath to provide the basic impact of the variable. This provides the largest increment of the potential impact on system performance. The maximum number of additional multipath signals required is determined by examining the asymptotic trends of the signal characteristics. The recommended TESTS approach, described in Section 4.1, splits the generated signal/message into a primary signal and multipath signal(s) which are modified by channel effects. The operation of the hardware/software channel for both types of signal is the same. This common configuration permits the number of multipath signals to trade off with the number of platforms, i.e., as the number of platforms increases the available number of multipaths per platform decreases. The minimum acceptable configuration provides for one multipath signal per platform at the maximum number of platforms in the systems specification. One of the supporting research tasks for TESTS is to determine whether more than one multipath signal per platform must be included in the baseline configuration. The recommended design permits this baseline capability to be easily expanded, though the cost of expansion increases exponentially.

In addition to the primary TEMP objectives associated with TESTS, TESTS should be able to augment test and evaluation of a broad range of secondary TEMP objectives. The basic capability

required for these secondary objectives are a subset of the parameters which must be included in TESTS to achieve acceptable levels of fidelity on the primary TESTS TEMP objectives.

2.3 ASSESSMENT OF TECHNICAL ISSUES

Based on the information gathered during the TESTS survey, the IST/EE team conducted an in depth assessment of the technical requirements for TESTS. During this assessment, extensive interchanges were conducted with NAVAIRTESTCEN technical representatives in order to maximize the outcomes of the activity. The EE Department took the lead in examining technical risk issues regarding signal processing requirements for TESTS and the potential for modeling various propagation effects. These analyses are required to maximize the fidelity of TESTS and enhance the eventual validation and verification of the models incorporated in TESTS. IST took the lead in the development of the TESTS conceptual design and the procedures that will be followed during TESTS development and implementation. A joint effort between the two groups was pursued in the analysis of signal simulations approaches and the development of signal generation concepts. The findings and discussions of the TESTS technical feasibility issues is provided in the following sections of this report.

Ten specific technical risk issues were identified for the feasibility assessment. Each of these issues is addressed below. References to supporting discussions in other sections of the report are indicated in each response as appropriate.

2.3.1 MK XV Time Dependent Formats

2.3.1.1 Problem Definition. A communication system consists of a transmitter and receiver. The use of time dependent modulation formats in a communications system can be thought of as using modulation systems whose parameters vary with time. One means of mechanization of time dependent formats (TDF) in a cooperating communication system requires that the transmitter and receiver parameters will vary in time and be synchronized.

2.3.1.2 Method of Investigation. During the initial phase of this investigation analysis tools were applied to various modulation schemes for spread spectrum applications.

2.3.1.3 Findings. Typical transmitter and receiver models were formulated using a time dependent PN sequence as a method to modulate a signal wave form (see Figures 5-4 and 5-5 in Section 5.1.2.2). The modulation generates signals in time as a function of both the time varying message data and the time dependent modulation control signal. The time dependent control signal is generated through the interpretation of time dependent code sequences which are, in turn generated from a time dependent code generator. The implementation of the spreading process (Section 5.1.1.1) requires a PN sequence to selectively identify the coefficients of the primitive polynomial that is used to uniquely

spread the input. These fixed field, random (but known) PN sequences or formats are made time dependent. Synchronization depends on the fact that the time dependent code generator of each (transmitter and receiver) is using code generation algorithms, time and initialization conventions that are known to the cooperating communication systems.

2.3.1.4 Conclusions. The simulator computer can synthesize a fixed field of PN sequences and transmit it to the SUT, as well as other friendly emitters, while synchronizing all sequences to the simulator time reference. The spreading or despreading process is therefore controlled by masking (in real-time) the coefficients of the primitive polynomial with the PN sequence to yield the appropriate modulation for the process as a function of time. This method of simulator implementation would provide early testing of SUT's without the necessity of using the KI-15 equipment.

2.3.2 Rapidly Changing Masking Functions

2.3.2.1 Problem Definition. Masking functions are used in the signal processing scenario of the Mark XV IFF System. It is usually implemented by merging two binary fields (using basic instruction set commands); it minimizes computer computation time requirements.

2.3.2.2 Method of Investigation. The technique of using masking functions that can be time varying is common to digital logic instruction for undergraduate Computer or Electrical Engineering courses here at UCF. These methods were surveyed to select appropriate techniques to apply to the signal process scenario of the simulator waveform generation subsystem.

2.3.2.3 Findings. An example of a time dependent masking function application is covered in Section 2.3.1. In this case the spreading sequence is particularized by taking the complement of an "EXCLUSIVE OR" command, bit by bit across the field of PN control sequences and the field of coefficients of the primitive polynomials for each change in time. Other applications of this function will be used in the simulator tool. This masking operation is fast enough to implement changing masking functions every millisecond if necessary.

2.3.2.4 Conclusions. Time dependent masking will be implemented in the simulator tool and specifically in the waveform generation subsystem. Its use and synchronization is compatible to the mechanization described for the TDF discussion (Section 2.3.1). The use of the Bendix waveform generation equipment (see Section 2.1.1.3) for the implementation of the simulator tool also would use masking techniques (already implemented) for conditioning the waveform through all of the IFF MODES of operation.

It would be very cost effective to implement Bendix test equipment as it is already designed and tested. However, if the Bendix equipment is not available, other alternative hardware to

accomplish the same function can be purchased (Hewlet-Packard) and modified to satisfy this requirement.

2.3.3 COMSEC Validity Interval

2.3.3.1 Problem Definition. The COMSEC validity interval changes at a rapid rate in the MK XV/K-15 system. MK XV system performance is totally dependent upon the validity of the COMSEC interval. If the COMSEC validity interval is not synchronized between TESTS and the SUT, then it will be virtually impossible to generate valid system data. System errors would be a function of the timing desynchronization, not MK XV capability. During the testing of the ADM it was necessary to develop a portable time calibration device to achieve acceptable synchronization between test systems.

2.3.3.2 Method of Investigation. This issue was addressed by examination of specification documents, briefings and discussion with personnel from the Naval Research Laboratory (NRL) and NAVAIRTESTCEN, and directed questions to NSA personnel presented through NAVAIRTESTCEN. This was followed by an analysis of the data within the context of the TESTS design and the platform interfacing capabilities resident at NAVAIRTESTCEN.

2.3.3.3 Findings. The NSA has indicated that they would make available the interface (pin-out) information for the K-15 as they have for the KIT/KIR. The impetus for this problem came from the difficulty in synchronizing the ADM with the PUT during flight testing of the ADM, where a custom portable time synch unit had to be developed. This has potential application to solve this problem in TESTS. However, TESTS has an advantage over the ADM testing in that the TESTS tool and the PUT will be in close physical vicinity. TESTS and the PUT will already have a certain degree of hard wire interfacing to support data collection. With the information available from NSA the simplest solution is to interface both TESTS and the K-15 of the SUT to a common external clock source. Driving both TESTS and the SUT from the same time source will ensure proper synchronization. An alternative would be to extract the clock synchronization from the SUT and port this signal into TESTS. In the external clock source solution the critical aspect is to develop a clock source which has the accuracy and stability required. It is possible that either the portable time unit developed for ADM testing or hardware developed by Bendix provide the most direct, and "effectively off-the-shelf" options.

2.3.3.4 Conclusions. The synchronization requirements for the COMSEC interval in TESTS can best be achieved by linking both TESTS and the K-15 of the SUT to a common source. Information obtained during the survey indicates that the required technical data will be made available as needed. This will require close coordination with the NSA to select the most acceptable and technically feasible approach.

2.3.4 MK XV IFF Radar Mode

2.3.4.1 Problem Definition. The simulation tool will be required to stimulate radar mode transponders only, therefore, the Interrogator Simulator Tool (IST) portion of the simulation tool needs to be synthesized. The differences in the MK XV IFF RMFE waveform processing must be analyzed and related to the requirements for the IST.

2.3.4.2 Method of Investigation. The particulars of the IFF RMFE specifications are analyzed with respect to differences in waveform format, generation, and modulation; simulation implementations of these differences are identified.

2.3.4.3 Findings. The modulation/carrier frequency for the IFF RMFE are at X and S-Band vs L-Band for the other IFF modes. The waveform format and processing functions for the RMFE is also quite different than the format used in the L-Band modulation protocols. These differences suggest that a separate processing channel be used to satisfy the RMFE Interrogator Simulator Tool (IST) requirement.

2.3.4.4 Conclusions. The implementation of the IFF-RMFE into the IST is accomplished by systematically modeling the RMFE channel to satisfy the processing protocol and to provide for carrier frequency modulation at X-Band and S-Band. The potential use of the Bendix Test equipment RMFE waveform and modulation equipment would dramatically shorten this task.

2.3.5 RF Generation of Spread Spectrum Signals

2.3.5.1 Problem Definition. The MK XV IFF system utilizes spread spectrum signals to enhance communication performance and security. The sort of chip rates associated with spread spectrum signals severely limits the waveform manipulation and summation that can be performed in the TESTS host computer due to the enormous processing requirements associated with performing convolutions and correlations on large data sets in real time.

2.3.5.2 Method of Investigation. During the Phase I period, various techniques employed to generate spread spectrum waveforms were investigated, and their mathematical properties defined. The two major techniques investigated were Direct Sequence (DS) and Frequency Hopping (FH). In addition, the impact of utilizing Time Dependent Formats in a spread spectrum communication system was studied for both DS and FH systems. Specific characteristics of the spreading and modulation techniques employed in the Mark XV system specification were also analyzed. These studies provide the mathematical basis for understanding and modeling spread spectrum communication signals, for either the current MK XV specification, or any other MK XII replacement using spread spectrum techniques.

2.3.5.3 Findings. Section 5.1 presents the technical findings regarding RF generation of spread spectrum signals. Spreading

information in the frequency domain inherently requires shrinking of pulse widths, called chips, in the time domain. The high chip rates associated with spread spectrum signals of interest would require enormous processing speeds in order to perform convolutions and correlations on these signals in a simulation environment in real time. Computer simulation of real time spread spectrum systems will typically require giga-flop processing speeds, while hardware implementations require less than 100 MHz clock rates on the fastest components.

2.3.5.4 Conclusions. The high chip rates required for RF generation of spread spectrum signals severely limits the waveform manipulation and summation that could be performed in the TESTS host computer. Therefore the recommended implementation of a TESTS system requires the use of hardware components to perform the actual spreading and despreading operations, and to let the superposition of overlapping signals occur in the hardware channel at RF carrier frequencies. The TESTS host computer will manipulate IFF messages at baseband information levels, and communicate such information to the TESTS hardware signal generation devices.

2.3.6 RF Generation of Multiple Spread Spectrum Signals

2.3.6.1 Problem Definition. MK XV TEMP Objectives require the testing of the IFF system in realistic scenarios where many additional transponders and interrogators will be operating simultaneously. This leads to high interrogation rates if the System Under Test (SUT) is a transponder, or high total reply rates if the SUT is an interrogator. Interrogation rates on the order of several thousand per second, and reply rates on the order of 30 thousand per second are possible in these test scenarios. These rates stress the computational capacity of the TESTS host computer, and require that multiple RF signal generators be incorporated in order to realistically simulate a high density signal environment at the receiver of the SUT.

2.3.6.2 Method of Investigation. It is assumed that programmable signal generators can be used that will allow time division multiplexing of IFF messages that do not overlap in time. Messages which overlap in time will be transmitted over multiple independent emitters. Therefore, a computer analysis was performed to determine the probability of message overlap, assuming that each IFF message is the same length, and treating each response as an independent stochastic source. The methods and mathematical fundamentals used in this analysis are presented in Annex C.

2.3.6.3 Findings. The program was written to search on the number of overlapping messages, as an independent variable in order to determine the message rate (which could be either reply rate or interrogation rate) required to achieve a fixed cumulative probability (99.9 %). The results were then generated and presented parametrically as a function of message length, as shown in Figure 3-4. Additional discussion of these

findings can be found in Section 3.1.3, and examples shown in Table 3-2.

2.3.6.4 Conclusions. Further analysis and refinement of these results will be performed, using a more realistic mix of message lengths, and simulating a more realistic distribution of interrogators and transponders. The overriding consideration for this analysis is that if spread spectrum waveforms are mixed, the content of each message can not be extracted unless one of the messages is known. This requires separate signal generators to preclude overlapping signals. These results do indicate, however, that a finite and feasible number of RF signal generators (approximately 2 to 10) can be used in the recommended TESTS approach to achieve the signal density environments required by the proposed test scenarios.

2.3.7 Simulation of Multipath Propagation Effects

2.3.7.1 Problem Definition. Multipath propagation effects are caused by the interference of a reflected electromagnetic waveform with the primary, direct path waveform at the receiver. The reflections are often caused by the surface of the earth, although man-made objects and sometimes tropospheric reflections may contribute to multipath effects. The interference at the receiver may be either constructive, or destructive, and depends upon the gain, phase, frequency shift, and time delay of the reflected signals relative to the direct signal. Multipath effects are a part of the real world RF communications problem, and depend upon many parameters such as the geometry of the transmitting and receiving platforms, the electromagnetic properties of the reflecting surface, and the type and complexity of the intervening terrain.

2.3.7.2 Method of Investigation. The technical findings of the Phase I investigation regarding multipath effects are presented in Section 5.3. The investigation followed two major divisions: Sea Surface Reflections, and Near Land and Irregular Terrain Reflections. Mathematical equations and computer models were readily found to describe many of the effects in question. In addition, a quick look computer analysis was performed to determine the multipath propagation delay times associated with an ideal reflected path relative to the direct path. The analysis, based on these computations using a four-thirds radius round earth model, is discussed in Section 3.1.2.

2.3.7.3 Findings. Mathematical and analytical models describing multipath propagation effects on various levels of fidelity are presently available, and much experimental data has been published in the literature for comparison purposes. Two important considerations have been identified for the simulation of multipath effects by TESTS:

- 1) the requirement to solve the equations describing the multipath effects in real time for multiple platforms,

- 2) the requirement to superimpose the reflected signals with the direct signals at the RF receiver of the Platform Under Test (PUT).

The first consideration is both a computer resource and simulation modeling problem. However, the geometry and terrain features which affect the multipath calculations, change much slower than the transmission rates of the IFF signals in question. Therefore, it is felt that by selection of a sufficiently powerful floating point processor to host TESTS, and by efficient algorithm preparation, and proper task segmentation, very high fidelity simulation of multipath effects can be performed by TESTS, in real time. The second consideration was addressed by the quick look computer analysis of multipath delay times discussed in Section 3.1.2. From this study, it is apparent that the difference in propagation delays may vary from less than a pulse width, to something greater than several pulse widths, or even an entire message, using the MK XII formats as a reference.

2.3.7.4 Conclusions. The conclusions of the phase I investigations of multipath effect, are directly represented in the recommended TESTS concept presented in Section 4.1. In order to alleviate TESTS host computer processing loads, and to provide accurate, credible superpositioning of direct and reflected path signals, the recommended TESTS concept uses separate, parallel hardware channels (split from a common signal/message input) within the RF Signal Conditioner to represent the direct and multipath signals, as shown in Figure 4-1. A separate set of programmable time delay, gain and phase distorters will be provided in hardware to represent the indirect signal, which is summed in the hardware channel with the direct path signal and presented at the RF receiver of the PUT. Based upon conditions of the test scenario, TESTS software components will compute the equations and algorithms for the multipath effects to determine the appropriate gain, phase, and time delays to transmit to the hardware distortion devices. This approach appears both feasible and cost effective.

2.3.8 Reception and Processing of Time Dependent Formats

2.3.8.1 Problem Definition. A description of the reception and processing of TDFs is sought. Identification of the processes and timing considerations are needed to relate the TDF issues.

2.3.8.2 Method of Investigation. The receiver processes are analyzed to relate the sensitivities of the TDF's to fidelity of the data capture. The BOSS software package will be used to test these sensitivities.

2.3.8.3 Findings. The reciprocal process of demodulation, decode and identification follows inversely the waveform generation, the TDF and masking discussions above. It was found that the PN sequence mask must be synchronized to the received waveform in order to despread the spread spectrum signal and

recover the data correctly. Timing was found to be extremely sensitive to correct data capture.

2.3.8.4 Conclusions. The implementation of the Bendix Test equipment, namely, the receiver subsystem, has already mechanized the demodulation and decode processes. If Bendix equipment is not available, other hardware can be purchased and modified to implement this process. Using this subsystem along with the synchronized PN sequences (TDF) that are centrally generated by the simulator computer, the implementation of the simulator tool can be made much easier.

2.3.9 Near Field Effects

2.3.9.1 Problem Definition. The near field effects of an antenna relate to the modification of the radiation pattern by the close proximity of various objects or other antenna to the transmitter (Section 5.2).

2.3.9.2 Method of Investigation. Various models are used, namely, "New-Air", INAC-3, GEMACS, and STRIPES, to analyze the near field effects of interrogator geometries, antennae placements (diversity systems), and to give antenna pattern functional relationships for a range of IFF platforms.

2.3.9.3 Findings. We have determined that particular state-of-the-art models can be used to quantify the following near-field effects:

- (a) "New-Air" Code can be used to find near field patterns of antenna mounted on aircraft or missiles. This program which is a high frequency model will be used primarily to predict near field effects. This code has been developed at Ohio State University.
- (b) GEMACS is a hybrid method. It combines both the Geometrical Optics (GO) approach and the method of moments.
- (c) STRIPES is based on the transmission line method and is not intrinsically limited in frequency. The only requirement is that the physical space of the platform is modelled by a mesh with resolution no coarser than 10 cells per wave length. STRIPES is only limited in frequency in terms of computer capacity. We are analyzing this with a Sun-Sparc II computer, therefore, this limitation is minimized.

2.3.9.4 Conclusion. All the above listed programs have been used to access their value. The ranges and functionality have been determined to be appropriate to the needed fidelity and to model the near field antenna patterns required.

2.3.10 Modeling of Antenna Pattern Effects

2.3.10.1 Definition. Computer Models are necessary to relate the parameter of "antenna gain" to all aspects (azimuth and pitch angle) of the various platforms under study.

2.3.10.2 Method of Investigation. The models described in Section 2.3.9 will be used to generate 3-D antenna pattern (antenna gain) by computer simulation.

2.3.10.3 Findings. In order to have any kind of relation with real world performance, the antenna characteristics have to be incorporated on the stimulation signal. The near field and far field patterns can be incorporated in terms of power, gain, directivity, phase and polarization. The stimulated signal will depend on the efficiency and gain of the transmitting and receiving antenna. The models identified (Section 2.3.9), have been used to access the fidelity of the needed antenna patterns. The angular resolution needed to accurately model the antenna gain is one degree (1°) in both azimuth and pitch. Since the computation time of this parameter must be kept minimal, a table look-up file will be used to implement the antenna gain factor into the real-time computer algorithm.

2.3.10.4 Conclusion. The generation of the computer models for antenna gain have been analyzed to the extent that a method of real-time implementation is formulated. The need and unique ability of simulation modeling to easily generate three dimensional antenna patterns is critical to TESTS. The collection of real antenna pattern data in three dimensions requires difficult to impossible maneuvers for an aircraft to only partially measure the vertical components of antenna gain. A case for "simulation"!

3.0 TESTS CONCEPTS AND DESIGN TRADEOFFS

This section provides a hierarchical discussion of the evaluation of potential TESTS design concepts. The first subsection addresses a number of critical design issues that were considered during the design evaluation. The remaining subsections provide progressively more detailed description of TESTS design concepts. Each level of evaluation had a different objective so the aspects of the TESTS design evaluated and described herein vary appropriately. First level of discussion is a high level (top level) discussion of the functional flow concept for TESTS. As such it does not provide discussion of detailed design concepts. Instead it defines basic design concepts. The second level describes the preliminary overall concept architectures of TESTS interrogator and transponder simulators. These discussions provide an intermediate level of detail and include interfaces to external TESTS elements such as SWEG and data collection. The third level focuses on an evaluation of four conceptual designs which vary in the degree of software/hardware allocation and the method for implementing signal generation and channel effects.

3.1 TESTS CRITICAL REQUIREMENTS ISSUES

Analysis of the MK XV TEMP Objectives, and the initial survey of technical feasibility issues regarding signal synthesis and channel effects, has resulted in identification of several critical requirements issues that drive the preliminary design concepts for a feasible TESTS system. An overview of these issues is presented in the following paragraphs.

3.1.1 Simulation Real-Time Response for IFF Communication Signals

Figure 3-1 presents a quick look analysis of the pulse sequences required to stimulate or respond to actual IFF equipment in real-time for either MK XII or MK XV. In the real world, IFF communications are initiated by a query, which is transmitted by an interrogator. After a propagation delay, the query is received by a transponder. After a processing delay, the transponder transmits its reply, and after another propagation delay, the reply is received back at the interrogator. This process is repeated every Pulse Repetition Interval (PRI) determined by the interrogator. Figure 3-1, further illustrates how this pulse pattern could be simulated by TESTS, where the SUT may be either an interrogator or a transponder.

If the SUT is an interrogator, the required response time depends upon the round trip propagation delays, the message lengths and the transponder processing delay. For a worst case condition at zero range, the TESTS simulator response time would have to be equal to or better than that of an actual transponder. If the simulator cannot meet this time requirement, the result is an increase in the minimum range at which the TESTS simulator can be effective. Worst case (zero range) processing delay times are shown in Table 3-1 for different transponder/modes:

Figure 3-1 Pulse Sequence Analysis

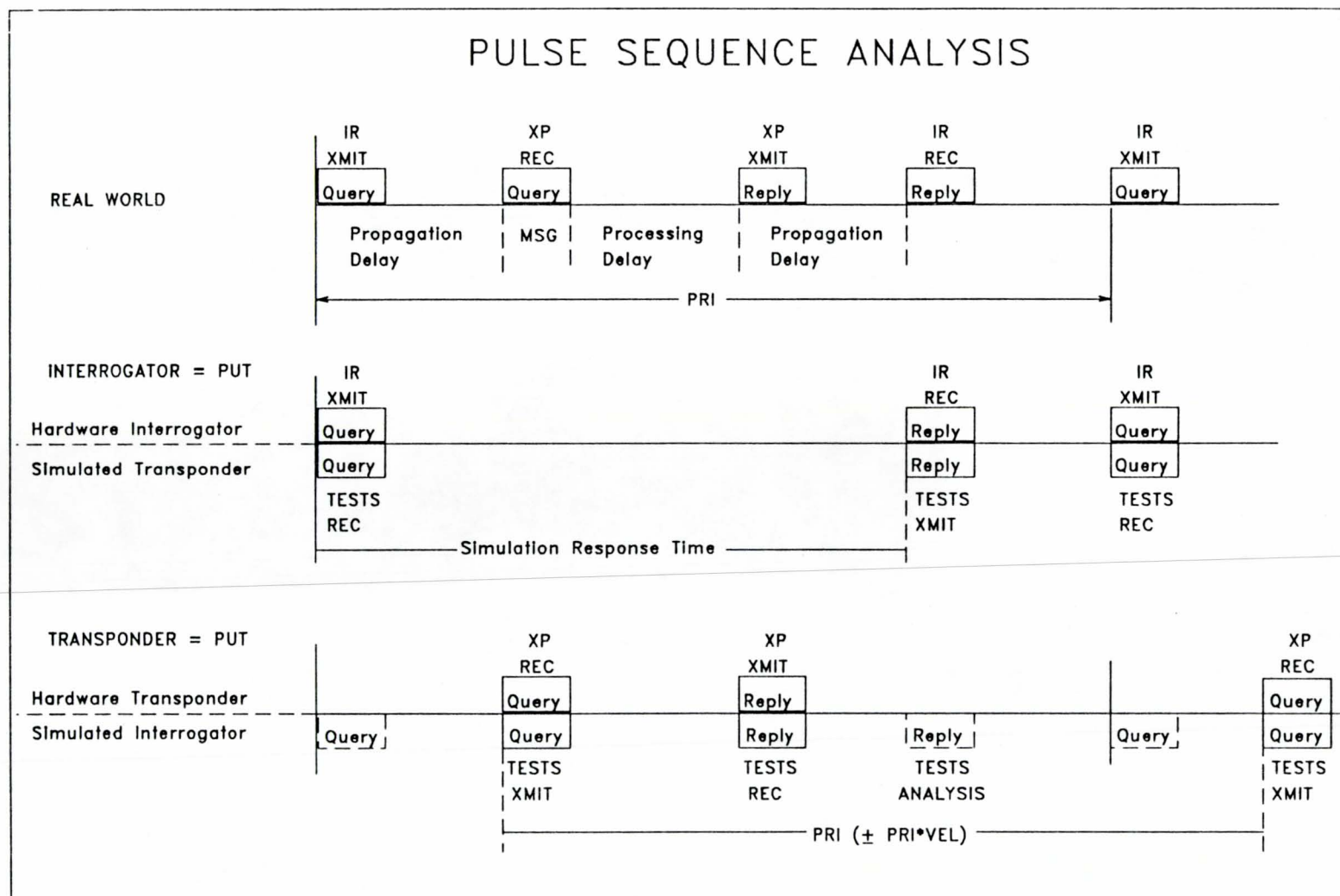


TABLE 3-1

PROCESSING DELAY TIMES FOR DIFFERENT TRANSPONDERS/MODES

		<u>Processing Delay</u>
MK XII	SIF Modes	3 microseconds
MK XII	Mode 4	(classified)
MK XV	(All)	(classified)

[SEE CLASSIFIED ADDENDUM FOR COMPLETE TABLE]

Round trip propagation delays add another 12 microseconds per nautical mile of range. Timing accuracy is also an issue since 100 nanoseconds of timing error will translate into 50 feet of range error.

If the SUT is a transponder, the PRI of the simulated interrogator is the critical factor, and for a moderately high Interrogation Rate of 500 / sec, the PRI yields a much less stringent response time requirement on the order of 2000 microseconds. Note that pulse to pulse changes in the response time due to target velocity (platform motion) have a small negligible effect (on the order of .0001 %).

3.1.2 Simulation of Multipath Channel Effects

A quick look computer analysis was performed to determine the multipath propagation delay times associated with an ideal reflected path relative to the direct path, using a four-thirds radius round earth. Annex C provides a description of the computations used in this analysis. Figures 3-2 a, b, and c, present the results of this analysis as a function of platform separation distance for several combinations of platform separation altitudes. The MK XII pulse widths are .45 +/- .1 microseconds for the transponder reply, and .8 +/- .1 microseconds for the interrogation query. Non-encrypted MK XII interrogation messages range from 3 to 21 microseconds, and transponder reply messages range from 20.3 to 24.65 microseconds. From this study, it is apparent that the difference in propagation delays may vary from less than a pulse width, to something greater than several pulse widths, or even an entire message, using the MK XII data formats as a reference.

Therefore, accurate simulation of multipath channel effects will require that in many instances, the reflected path signal will need to be transmitted separately from the direct path signal by the TESTS RF transmitter, with the same information and signal content, but with different channel effect parameters. This also requires an accurate adjustment of delay time, phase, attenuation/gain and frequency shift for the reflected signal, in order to simulate the interference phenomenon that would occur in the real world at the RF receiver.

$H_1 = 5,000$ feet

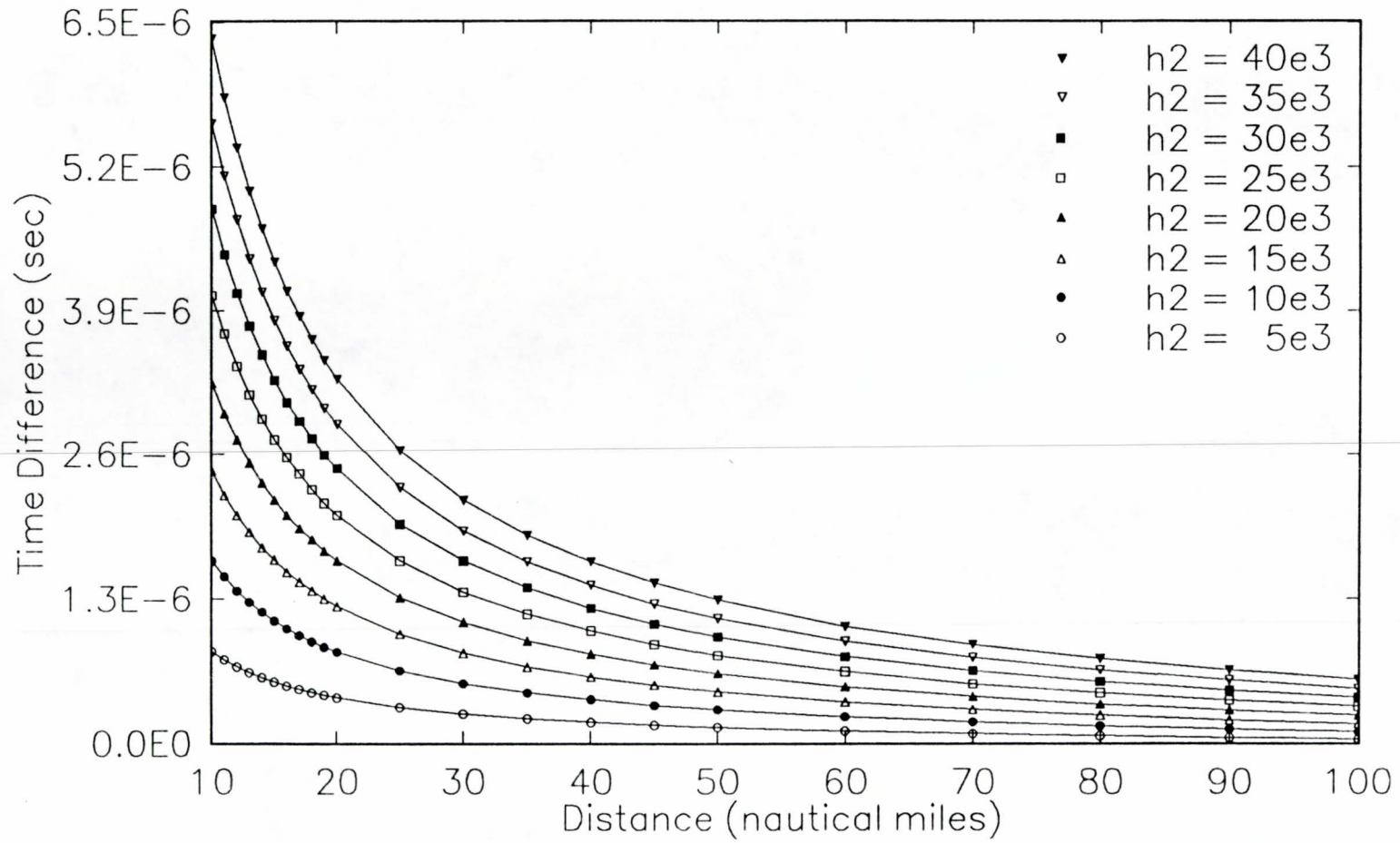


Figure 3-2a Multipath Delay Times, $H_1 = 5000$ ft.

$H_1 = 20,000$ feet

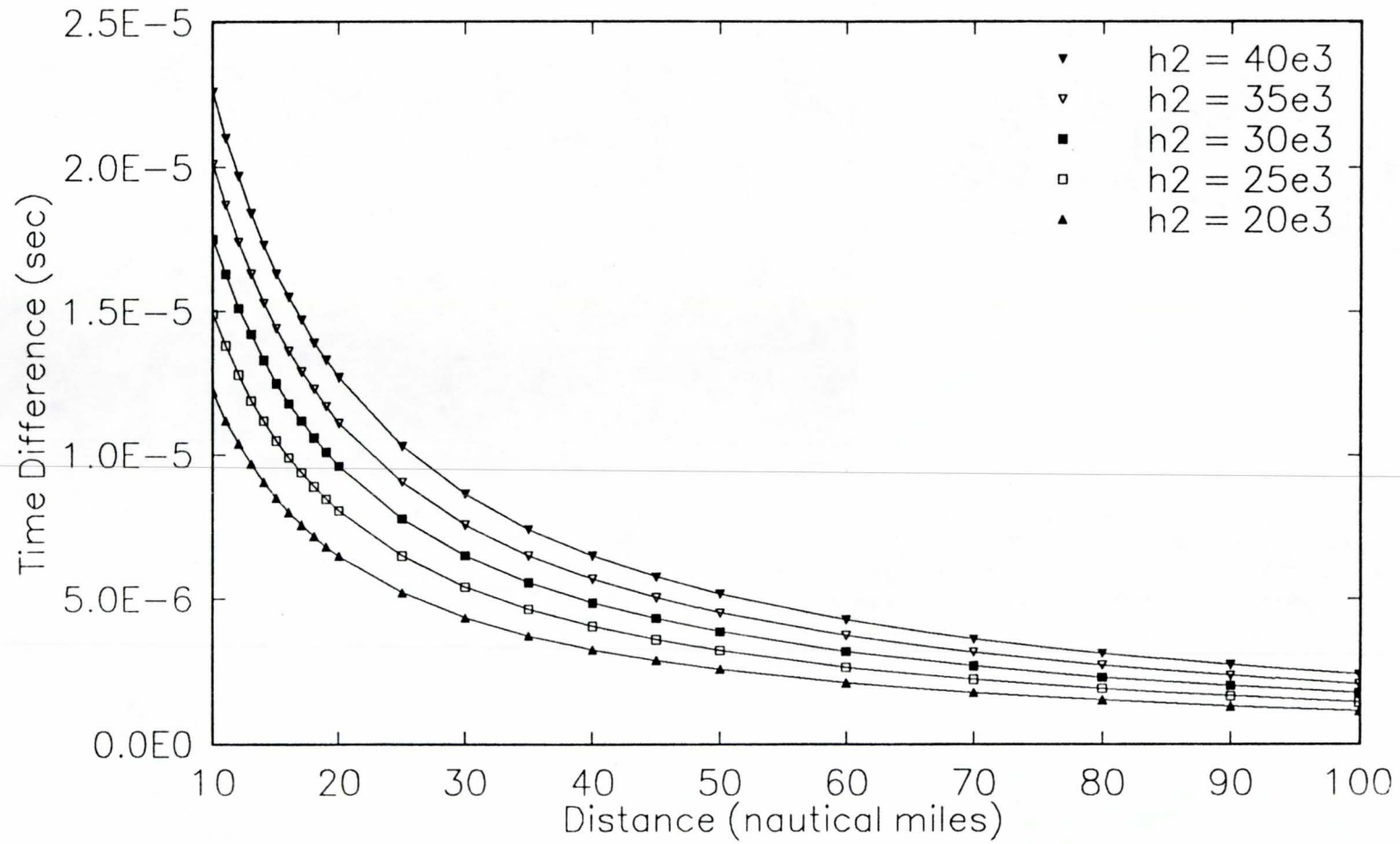


Figure 3-2b Multipath Delay Times, $H_1 = 20,000$ ft.

$H_1 = 40,000$ feet

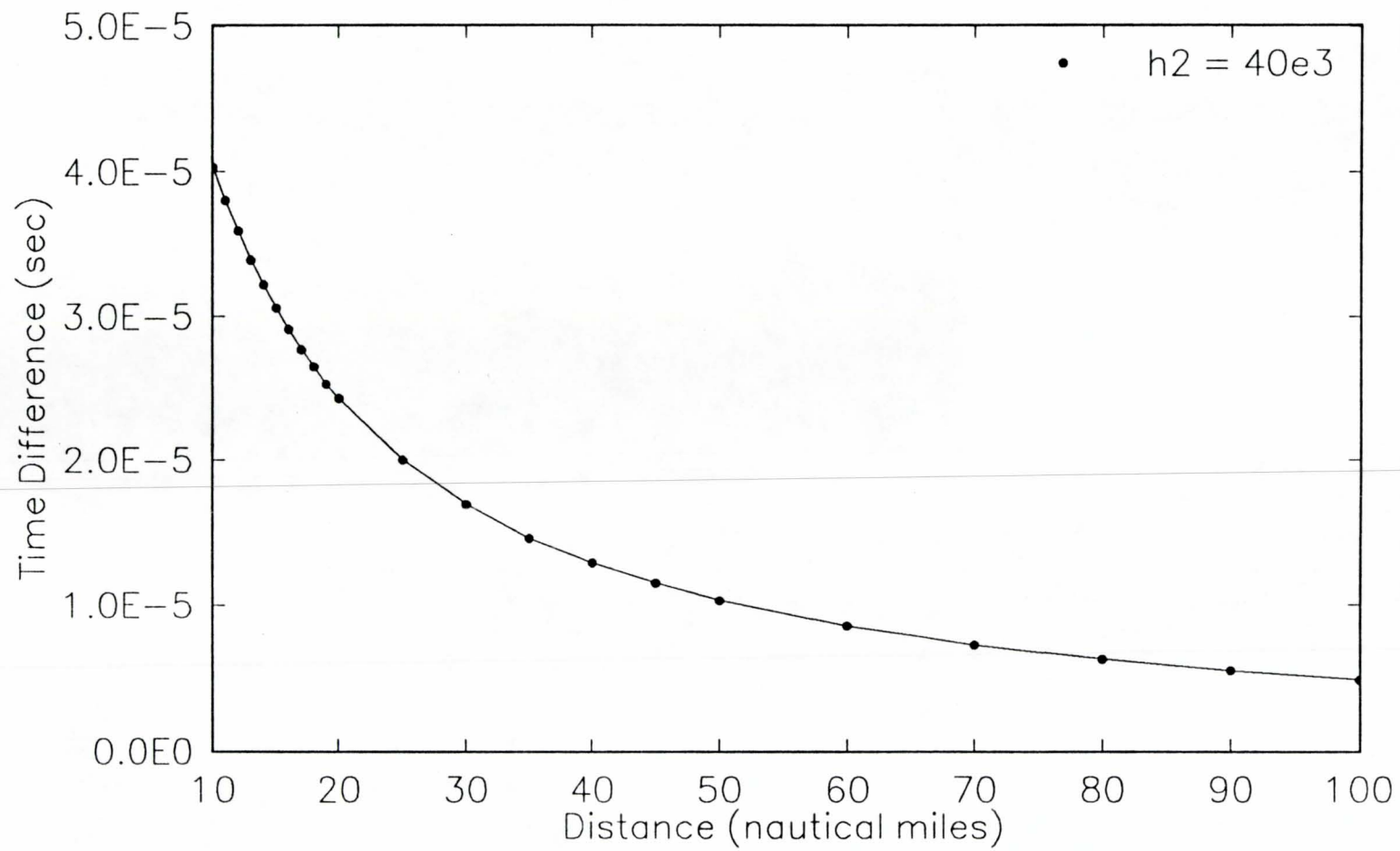


Figure 3-2c Multipath Delay Times, $H_1 = 40,000$ ft.

3.1.3 Simulation of Multiple Transponders and Interrogators

MK XV TEMP Objectives require the testing of the System Under Test in realistic scenarios where many additional transponders and interrogators will be operating simultaneously. This leads to high interrogation rates if the SUT is a transponder, or high total reply rates if the SUT is an interrogator, which includes solicited replies plus Friendly Replies Unsynchronized in Time (FRUIT), as applicable. Interrogation rates on the order of five thousand per second, and reply rates on the order of thirty thousand per second are possible in these test scenarios.

As the number of IFF messages is increased (reply rate, or interrogation rate), the probability of message overlap at the receiver of the SUT likewise increases. It is considered important to be able to simulate this effect with high fidelity, in order to test important features of the IFF receiver and processor which are designed to deal with message garble, prioritization, synchronization, inter symbol interference and the like. Therefore, the TESTS RF Transmitter must be able to generate multiple signals, and their associated multipath components, simultaneously.

Assuming that each IFF message is the same length and treating each response as an independent stochastic source, a parametric analysis was performed to determine the maximum number of message overlaps that occur within a cumulative probability of 99.9%. As used in this context, cumulative probability refers to the sum of the individual probabilities for 0, 1, 2, ... n message overlaps, where the individual probabilities are given by the first n successive terms of the binomial distribution function. Annex C provides a description of the computations and a listing of the computer program used for this analysis.

From a feasibility standpoint, TESTS must be able to provide at least the same number of independent emitters (n) as the number of simultaneous overlapping signals that we wish to simulate. Figure 3-3 summarizes the results of this study by plotting the number of emitters required (same as the number of overlapping signals) as a function of message rate for different values of message length. Thus, this figure provides a good indication of the number of independent TESTS RF emitters required to achieve a 99.9% level of fidelity over a range of parametric conditions. Note that in order to achieve a 100% level of fidelity (cumulative probability under the binomial distribution curve) the number of emitters would have to equal the total message rate for all cases. This is a good example of the law of diminishing returns at work.

Further analysis and refinement of these results will be performed, however it appears that somewhere between 2 and 10 independent RF signal emitters will be sufficient to achieve the signal density environments required by the proposed test scenarios. Table 3-2 gives some examples relating to specific MK XII and MK XV message lengths.

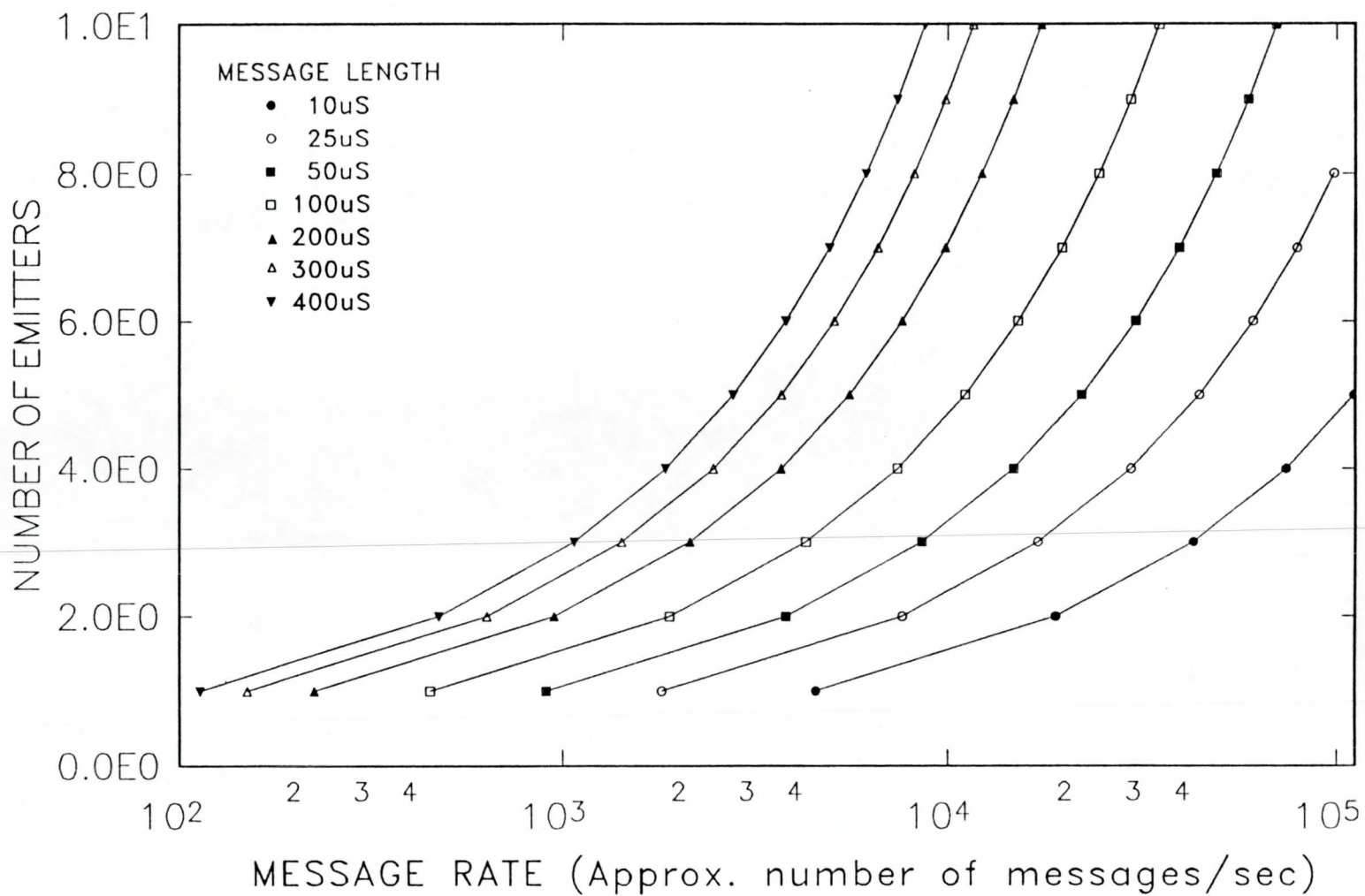


Figure 3-3 Number of Independent RF Transmitters Required for a 99.9% Confidence

TABLE 3-2
 EXAMPLES OF THE NUMBER OF TESTS EMITTERS
 REQUIRED FOR MK XII AND MK XV MESSAGES

<u>MESSAGE TYPE</u>	<u>APPROXIMATE MESSAGE LENGTH</u>	<u>MESSAGE RATE</u>	<u># OF EMITTERS REQUIRED</u>
(U) MK XII MODE 3A INTERROGATION	10 u sec	5000/sec	1
(U) MK XII MODE C INTERROGATION	25 u sec	5000/sec	2
(U) MK XII MODE 4 INTERROGATION	75 u sec	5000/sec	2
(S) MK XV INTERROGATION	(classified)	5000/sec	
(U) MK XII MODE 3A REPLY	25 u sec	30000/sec	4
(U) MK XII MODE C REPLY	25 u sec	30000/sec	4
(U) MK XII MODE 4 REPLY	5 u sec	30000/sec	2
(S) MK XV REPLY	(classified)	30000/sec	

Another fallout of generating high signal densities, is the inherent impact on processing speed of the TESTS host computer, and the associated data transfer rate between the TESTS host computer and the TESTS RF Signal Generator. Both of these critical requirements are greatly influenced by the choice of interface format between the TESTS host computer and the RF Signal Generator, i.e., the allocation of tasks between hardware and software components. Section 3.5 presents several possible approaches to this division, and examines the consequences and feasibility of each.

3.1.4 Generation of RF Spread Spectrum Signals

The MK XV IFF system utilizes spread spectrum signals to enhance communication performance and security. The sort of chip rates associated with spread spectrum signals, severely limits the waveform manipulation and summation that can be performed in the TESTS host computer, due to the enormous processing requirements associated with performing convolutions and correlations on large data sets in real time. Thus, the requirement to generate multiple spread spectrum signals, reinforces the impetus to use multiple independent RF transmitters, and let the superposition of overlapping signals occur in the hardware channel via hardware summing devices at RF carrier frequencies. Additional discussion of the generation of spread spectrum signals is provided in Section 5.1 and as part of the discussion of technical issues in Section 2.3

3.1.5 Encoding and Decoding of Secure Transmission Modes

MK XII Mode 4 utilizes the security codes generated by KIT/KIR equipment to provide secure and encrypted IFF transmissions. Likewise, embedded MK XII Mode 4, and all MK XV transmission modes utilize the COMSEC / TRANSEC codes generated by the KI-15 equipment to provide secure and encrypted IFF transmissions. While it is possible to bypass the KIT/KIR equipment in the Mark XII, the KI-15, or an equivalent emulation box, has to be presented in the Mark XV. The NSA has indicated that they would make the interface (pin-out) information for the K-15 as they have for the KIT/KIR. The availability of this information provides the options to use either real equipment or in conjunction with guidance for NSA to develop an equivalent simulation based emulator for TESTS, which is the preferred approach.

In order to test encrypted modes when interfacing with an actual transponder or interrogator as the SUT, the TESTS tool will have to perform the complementary encryption / decryption functions. This will require an interface from the KIT/KIR and/or KI-15 equipment in order for TESTS to receive the COMSEC / TRANSEC codes, or some suitable alternative. Utilization of the COMSEC / TRANSEC codes by TESTS has a significant impact on the total processing requirements, and hence will also influence the division of signal processing tasks between hardware and software. An ancillary consideration will be the impact of

security classification and access restrictions imposed upon the TESTS hardware and software components. Section 2.3.3 outlined approaches to addressing the KI issue based on currently available information.

3.1.6 Data Recording and Analysis

An important and essential element of any testing tool is its ability and capacity to record data pertinent to the testing objectives. While there is an existing or planned capacity within ACETEF to record and reduce data, TESTS should nevertheless provide access ports to data in a format that is relevant to IFF testing objectives, and provide some capacity to record and display that data. Due to the extremely high data rates at RF frequencies, access to all data transmitted and received by TESTS should be made available at a baseband format. This consideration may also influence the selection of the TESTS hardware/software interface. Data parameters and data capture rates will be specified by the NAVAIRTESTCEN IFF Data Center.

3.1.7 Hardware/Software Allocation

Perhaps the most critical design decision of the TESTS concept, is the division between hardware and software functions in the generation of real time IFF signals, and the associated interface format. As mentioned previously, this choice greatly impacts the requirements for TESTS host computer processing speeds, and the data transfer rate between the TESTS processor and the TESTS hardware signal generators.

Figure 3-4 illustrates the uncoupled functional flow from an interrogator to a transponder related to TESTS, where the Mark XV interpretation block represents the SUT. An equivalent flow diagram can be easily defined for the transponder to interrogator link. This flow diagram indicates the basic functions/factors involved in TESTS. Based on the mode selected and inputs from SWEG, an IFF message is generated. This message is encrypted or not depending upon the mode or format of the system involved. This message is modified by various characteristics of the transmitter environment landmass factors and jammers before reaching the destination platform. At the receiving platform the signal must also be modified by various characteristics of the platform to determine the final signal which actually reaches the MK XV for decryption and interpretation.

In developing TESTS a determination must be made as to which functions are accomplished in software and which functions are accomplished in hardware. Theoretically, the interface or transition boundary between software and hardware can occur anywhere along this continuum, from essentially a total software implementation to a total hardware implementation. The task is to determine the optimum tradeoff in terms of cost and performance. Overriding these factors is technical feasibility and risk.

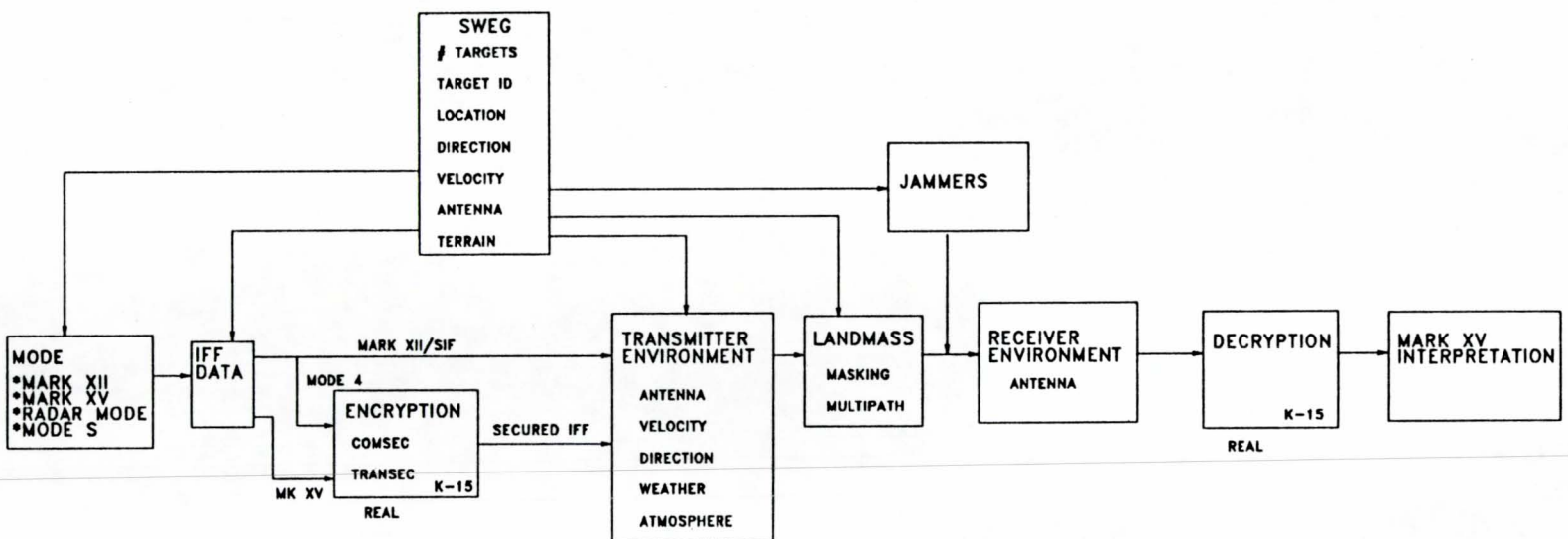


Figure 3-4 Hardware/Software Allocation Flow Diagram

The following section discusses four generic design concepts examined as part of the feasibility assessment effort. These alternatives span the spectrum of potential hardware/software divisions within TESTS. The analysis of these alternatives lead to the recommended design approach described in Section 4.1.

3.2 TESTS FUNCTIONAL FLOW OVERVIEW

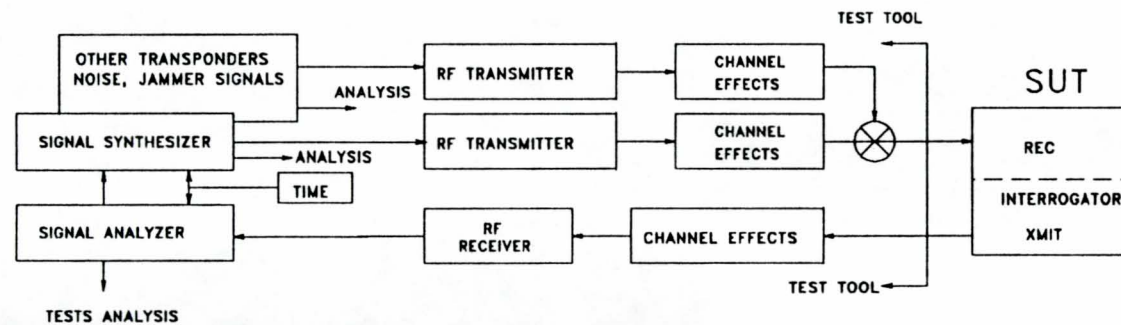
The TESTS functional flow shown in Figure 3-5, presents the real-time communications loop between the TESTS Simulator / Stimulator tool and the System Under Test (SUT) . The SUT may be either an actual interrogator or transponder mounted on its aircraft platform inside the shielded hangar or anechoic chamber. The TESTS tool will interface to the SUT via shielded cable connected to the RF transmit and receive ports of the SUT. The TESTS tool will then provide a realistic simulation of the external environment as seen at this interface via combination of hardware and software components as required.

The high level functional blocks of the TESTS communications loop consist of :

- Signal Synthesis - Determination of the scenario appropriate baseband IFF challenge or reply in order to stimulate or respond to the SUT. This block must be expandable to include additional interrogators, and transponders, as well as possible jammers of various types.
- RF Transmitter - The TESTS RF Transmitter must be able to create and modulate the uplink and downlink RF carrier frequencies to the desired waveforms of the MK XII signals, MK XV spread spectrum signals, and Mode S signals, and transmit them to the SUT. It must also be able to generate MK XV Radar Mode interrogations.
- Channel Effects - Channel effects will be calculated in software by the TESTS tool based on time and scenario dependent conditions which affect the electromagnetic transmission, propagation, and reception of the IFF signal waveforms. Channel effects include, but are not limited to:
 - a) antenna pattern gains at the transmitter and receiver,
 - b) aircraft and platform masking,
 - c) electromagnetic propagation time delays,
 - d) multipath propagation effects,

FUNCTIONAL FLOW

TRANSPONDER SIMULATOR: (TST)



INTERROGATOR SIMULATOR: (IST)

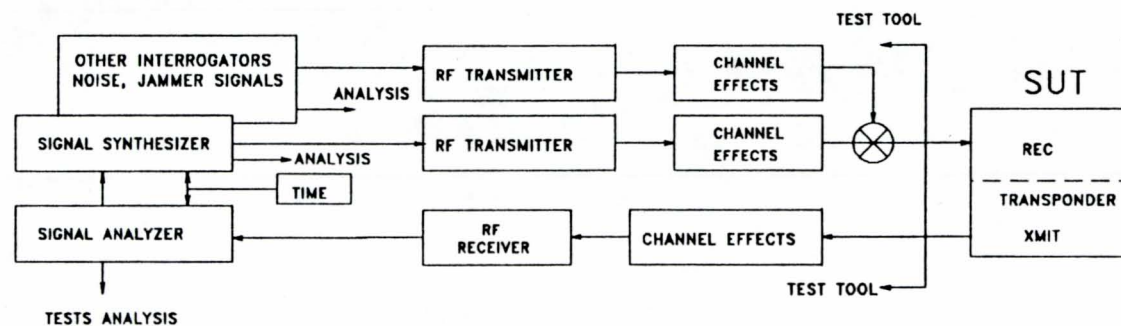


Figure 3-5 TESTS Functional Flow

- e) atmospheric absorption, refraction, diffraction, etc.
- f) relative polarization phenomenon,
- g) frequency dispersion and doppler shift.

Research efforts will define the complexity and fidelity of algorithms required to model these effects, resulting in the computation and application of distortions in the amplitude, phase, and frequency of the transmitted signal. Processing time delays and tolerances of the simulated IFF components must also be considered in conjunction with electromagnetic propagation delays, in simulating the closed loop time delay of the communication system. The total time delay, plus amplitude, phase, and frequency distortions will be applied to the RF signal(s) synthesized and transmitted by the TESTS tool, in order to simulate a high fidelity representation of the external world to the SUT. Channel effects applied to signals received from the SUT will be limited to propagation delay and antenna pattern effects.

RF Receiver - The TESTS RF Receiver must be able to receive and demodulate the MK XII and MK XV IFF signals, transmitted by the SUT at RF carrier frequencies, to an appropriate baseband format. It must also be able to receive Mode S signals.

Signal Analyzer - The TESTS Signal Analyzer will extract message mode and information data from IFF signals received from the SUT, and will analyze the signals for desired performance characteristics. The Signal Analyzer will then provide feedback to the Signal Synthesis function, and output data to collection devices as required for post test data analysis. The Signal Analyzer will also time tag and output signals generated by TESTS to data collection devices.

3.3 GENERIC TESTS CONCEPTS

Addressing some of the critical requirements issues discussed in paragraphs 3.1.1 through 3.1.7, Figures 3-6, and 3-7, present a preliminary concept for the TESTS configuration, interfacing with either a transponder or interrogator as the SUT, respectively. These figures show the divisions between components of the TESTS hardware and TESTS software, as well as the interfaces between TESTS and the SUT, and TESTS and SWEG. SWEG will provide the active test scenario data base, from which TESTS software components will extract necessary platform information such as

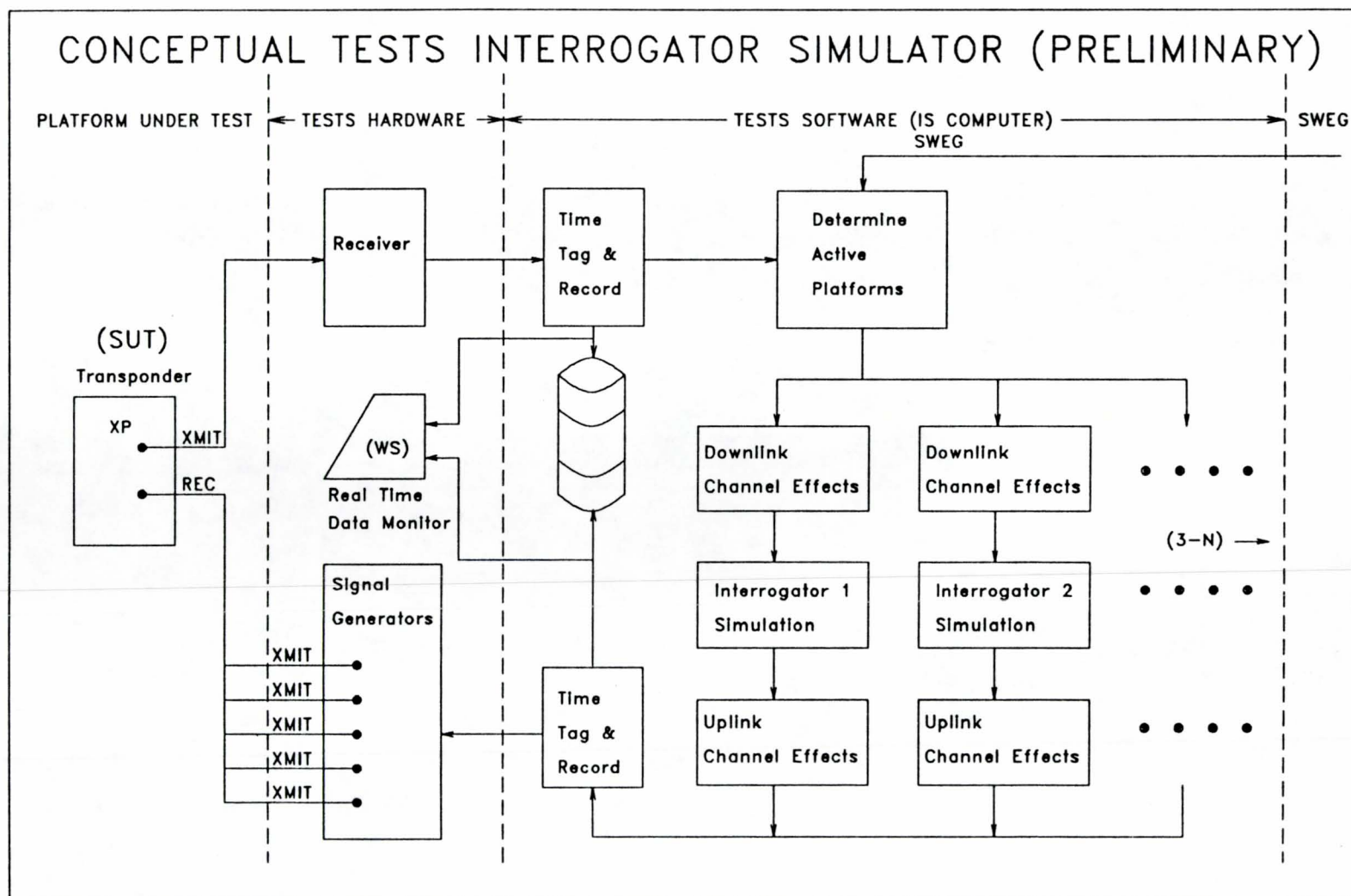


Figure 3-6 Conceptual TESTS Interrogator Simulator

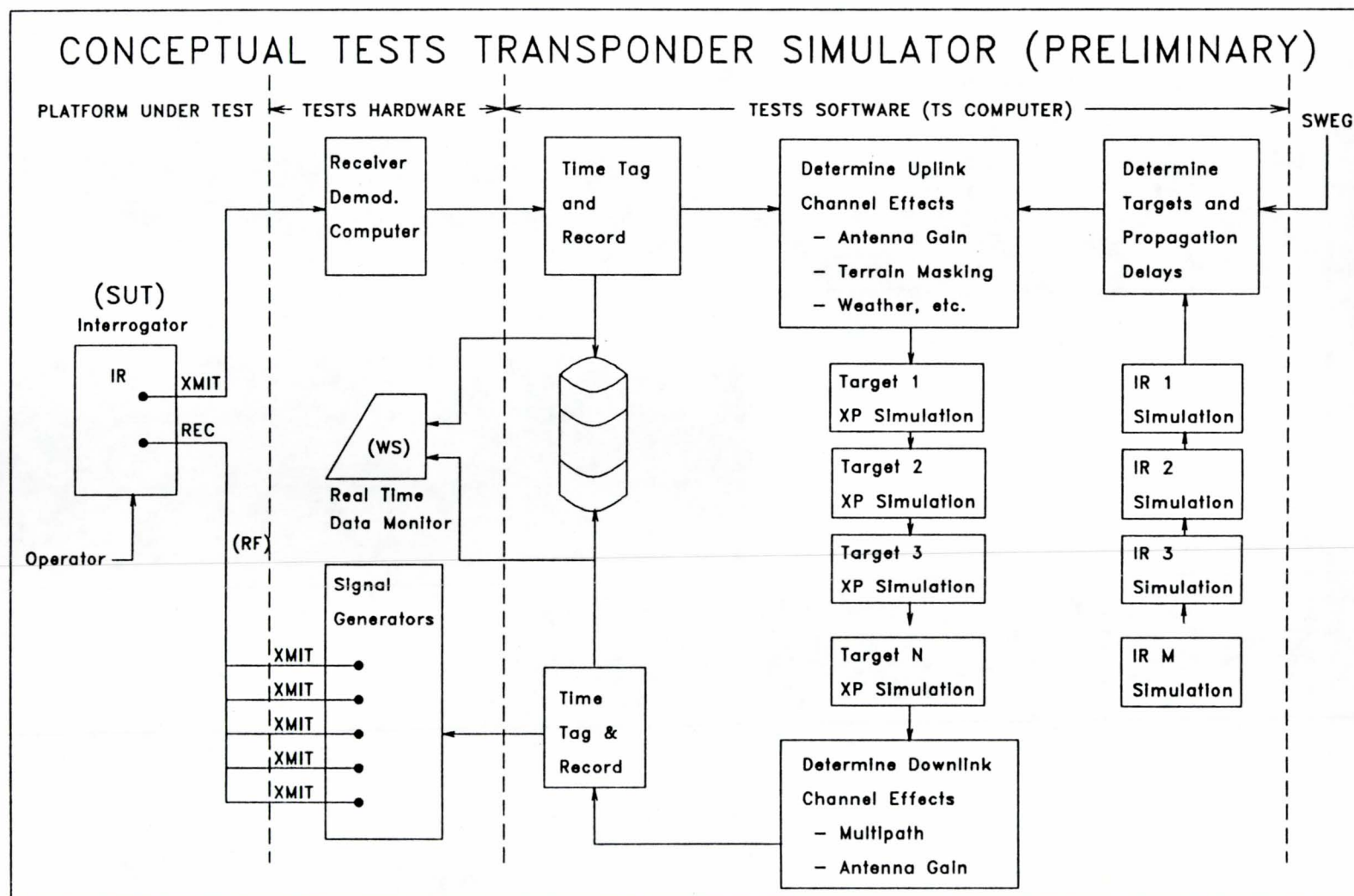


Figure 3-7 Conceptual TESTS Transponder Simulator

positions, velocities, attitudes, stored antenna patterns, radar pointing angles, and so forth. The Platform Under Test will be defined as one of the "players" in SWEG. TESTS software components will determine which active platforms are within the main lobe and first sidelobe of each interrogator, and will time queue IFF message traffic at the appropriate transponder simulations on the uplink, and at the appropriate interrogator simulations on the downlink. Queued IFF messages may be received from another interrogator / transponder simulation, or from the actual SUT via the TESTS receiver interface. In the case shown in Figure 3-7, where the SUT is an interrogator, it is essential for TESTS to respond to the actual queries issued by the SUT. In the case shown in Figure 3-6, where the SUT is a transponder, the received replies may simply be decoded and recorded for later analysis. The Crypto box is not shown in these diagrams for simplicity.

3.3.1 Generic Simulator Block Descriptions

3.3.1.1 Generic Interrogator Simulator

For this Interrogator Simulator (IS) configuration, (see Figure 3-6) a description of each element/block of the TESTS IS will be covered with focus given to the functional and data flow significance of each element.

Interrogator Simulator Computer - Starting with the SWEG initialization (upper right Figure 3-6), platforms/emitters are identified by their respective position, velocity, attitude and emitter description; these are downloaded to the IS Computer. The positions, velocities and attitudes of these emitters with respect to the SUT (main and sidelobe interface) will, in turn, identify the interrogators and modes necessary to stimulate the SUT. These blocks are shown as Interrogator 1,...,n with their respective uplink and down link channel effects.

Uplink and Downlink Channel Effects - These channel effects are computed or table driven by the IS to condition the transponder reply (attenuation, phase shift, time delay, frequency shift) to environmental conditions between the SUT and each respective interrogator for the uplink channel effects. The downlink channel effects control attenuation phase shift, time delay, and frequency change of the interrogator RF signal transmitted to the SUT.

Interrogator Simulators - The interrogators are identified in the computer and generate the proper waveform message for the given mode with the proper ID to identify its platform (collect for analysis).

Signal Generators - These interrogator signals/waveforms are sent to the signal generators (time tagged and recorded for analysis) where they are modulated at the carrier frequency, while at the same time conditioned for

environmental effects due to Uplink Communication Effects. The form and sophistication of the signal generator hardware depends on the form of representation used for the message (i.e. sampled data, pulse waveforms or message level, going from high bit rate to low bit rate, respectively)

System Under Test (SUT) - The SUT receives the RF output of the signal generator hardware (multiple signal generator to accommodate overlapping or multipath signals) of the identified interrogators stimulating the SUT. The SUT transponder receiver demodulates, decodes and replies to validated interrogator signals.

Tests Receiver - This reply is received by the TESTS receiver (hardware) where it is demodulated, decoded, time tagged, recorded and matched up to the interrogator platforms/emitters to complete the loop.

Real Time Data Monitor - A real time monitor (WS) is shown to monitor and control the simulation. "Quick Look" simulation tracking and simplified on-line analysis is contemplated for the simulator operator at this station. Simulator control will also be implemented at this station.

3.3.1.2 Generic Transponder Simulator

The Transponder Simulator (TS) configuration is shown in Figure 3-7; a functional description and signal flow analysis will be sequentially covered block by block.

Transponder Simulator Computer - The target set of transponders are identified by the scenerio set up using SWEG for the test and downloaded to the TS computer. This is similar to the method employed by the interrogator simulator.

Propagation and Channel Effects - The TS computer will use the computed relative positions and velocities of the targets with respect to the position of the SUT (main and sidelobe interrogation) to generate the propagation delays and environmental modification parameters for the Uplink communication RF signal. Also available is the downlink channel effects for use in conditioning the transponder transmitter RF signal.

Transponder Simulator - The transponder transmitter(XP) for the target set takes the transponder waveform reply formats (properly coded) conditioned by the downlink channel effects to control the signal generators RF transmissions back to the SUT.

Signal Generators - These interrogator signals/waveforms are sent to the signal generators (time tagged and recorded for analysis) where they are modulated at the carrier frequency, while at the same time conditioned for

environmental effects due to Uplink Communication Effects. The form and sophistication of the signal generator hardware depends on the form of representation used for the message (i.e. sampled data, pulse waveforms or message level, going from high bit rate to low bit rate, respectively)

System Under Test (SUT) - The operator initiates the interrogator of the SUT through the operator workstation, and sends the interrogator RF signal to the simulator receiver.

Transponder Simulator Receiver - The TS receiver (hardware) demodulates and decodes, and discriminates desired targets; this target set (time tag of received input) is sent to each target transponder simulation corrected for uplink channel effects (already calculated) to complete the data processing loop.

The timing of the response to the SUT interrogators is critical in the TS Configuration. The response time must conform to the timing threshold/specification of the SUT.

Real Time Data Monitor - The real time data monitor provides the quick look analysis visibility and controls the simulation progress.

TESTS software components will compute the channel effects that are associated with each uplink and downlink message, to the fidelity required. It is expected that highly accurate channel effects will be determined for message traffic that will be transmitted to the SUT, while simple approximations will be performed for message traffic received from the SUT, or for messages passed between purely simulated IFF components.

3.4 TESTS Simulator Environment

It is anticipated that a modular multitasking approach to the design of software components will facilitate the expandability of TESTS to simulate multiple interrogator, multiple transponder scenarios. This modular approach will also provide easy transition to a parallel processing architecture, where several software components of the real-time communications loop may execute concurrently in different processors, all of which access the SWEG data base and TESTS signal generators as illustrated in Figure 3-8. Efficient software design, coupled with recent advances in vectorizing accelerator boards, and high capacity data channels now available for desktop workstations, make such a distributed processing approach both feasible and cost effective.

3.5 Design Concepts

The following subsections provide descriptions and discussions of the four conceptual design approaches evaluated for TESTS. For each concept a description of the design approach is provided. In addition, a block by block description of the approach is

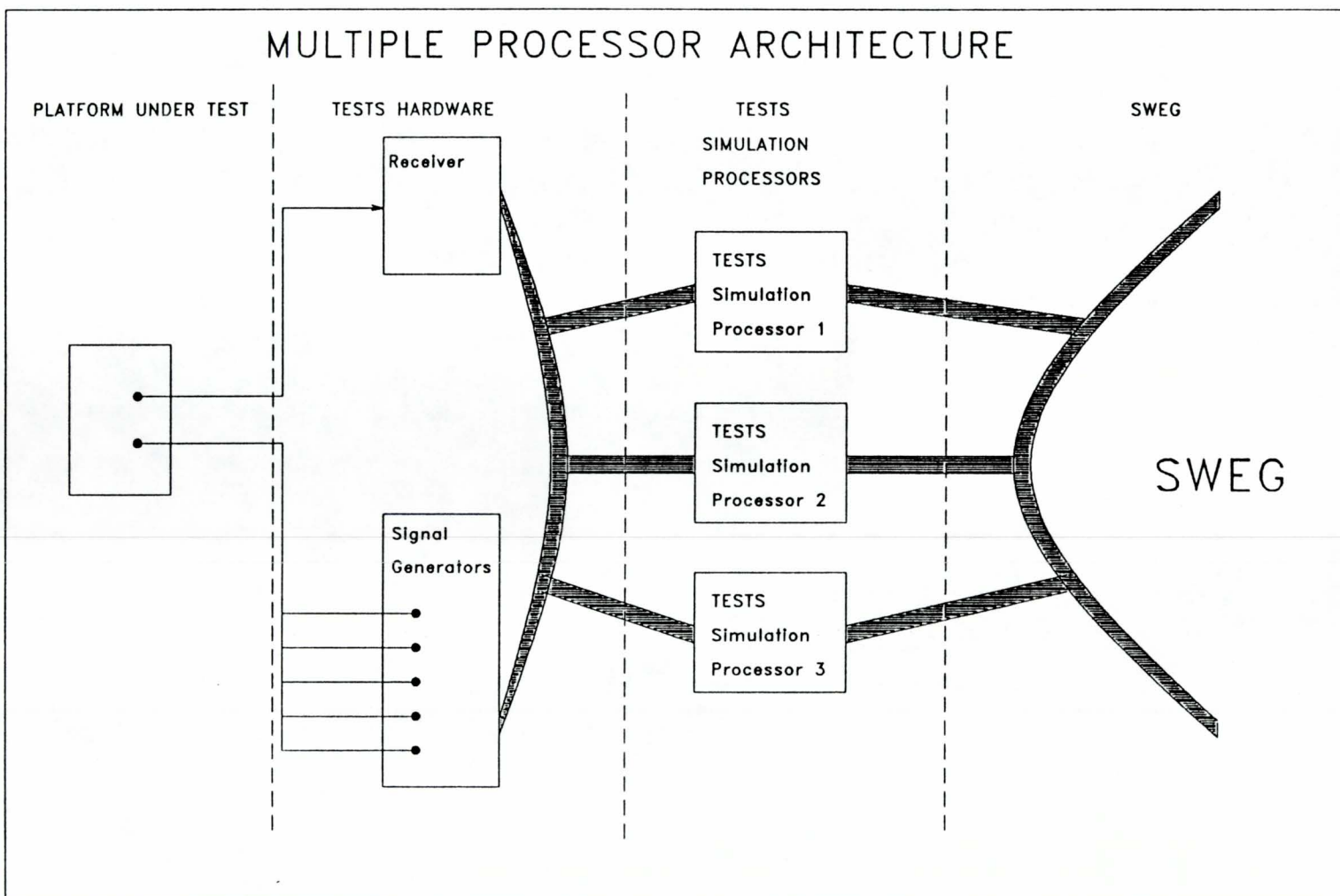


Figure 3-8 Multiple Processor Architecture

included supplemented by additional detail in a supporting discussion.

3.5.1 Concept A - Sampled Data Interface

The most direct approach to TESTS signal generation and detection is the Sampled Data Interface concept. This approach consists of sampling or slicing a signal in time so as to represent a signal numerically by a sequence of numbers. This approach is a software intensive implementation of TESTS with hardware generation of the final RF signal.

This approach has one primary advantage which is the ability to conveniently apply digital techniques to required signal processing operations. This would allow for versatile signal processing capabilities and system programmability. This is more than offset by the disadvantages which include the high degree of computational capability required to pursue the advantage and the inability to support black box-to-black box testing.

Figure 3-9 illustrates a Sampled Data Interface approach to TESTS signal generation and detection. The Sampled Data Interface approach may be applied to testing of interrogator or transponder platforms. The interrogator platform in this example merely serves to illustrate the Sampled Data Interface concept and could be replaced by a transponder under test in a different example to illustrate the same concept. TESTS hardware is used as an interface between RF signals and sampled data signals. The Sampled Data Interface approach focuses on software in order to capitalize on the advantages of this approach in terms of versatility and direct signal programmability. As a consequence the manipulation of RF signals represented by time sampled data streams would be a software operation.

3.5.1.1 Block Descriptions

The functionality of this design concept is described below.

PLATFORM UNDER TEST:

INTERROGATOR

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

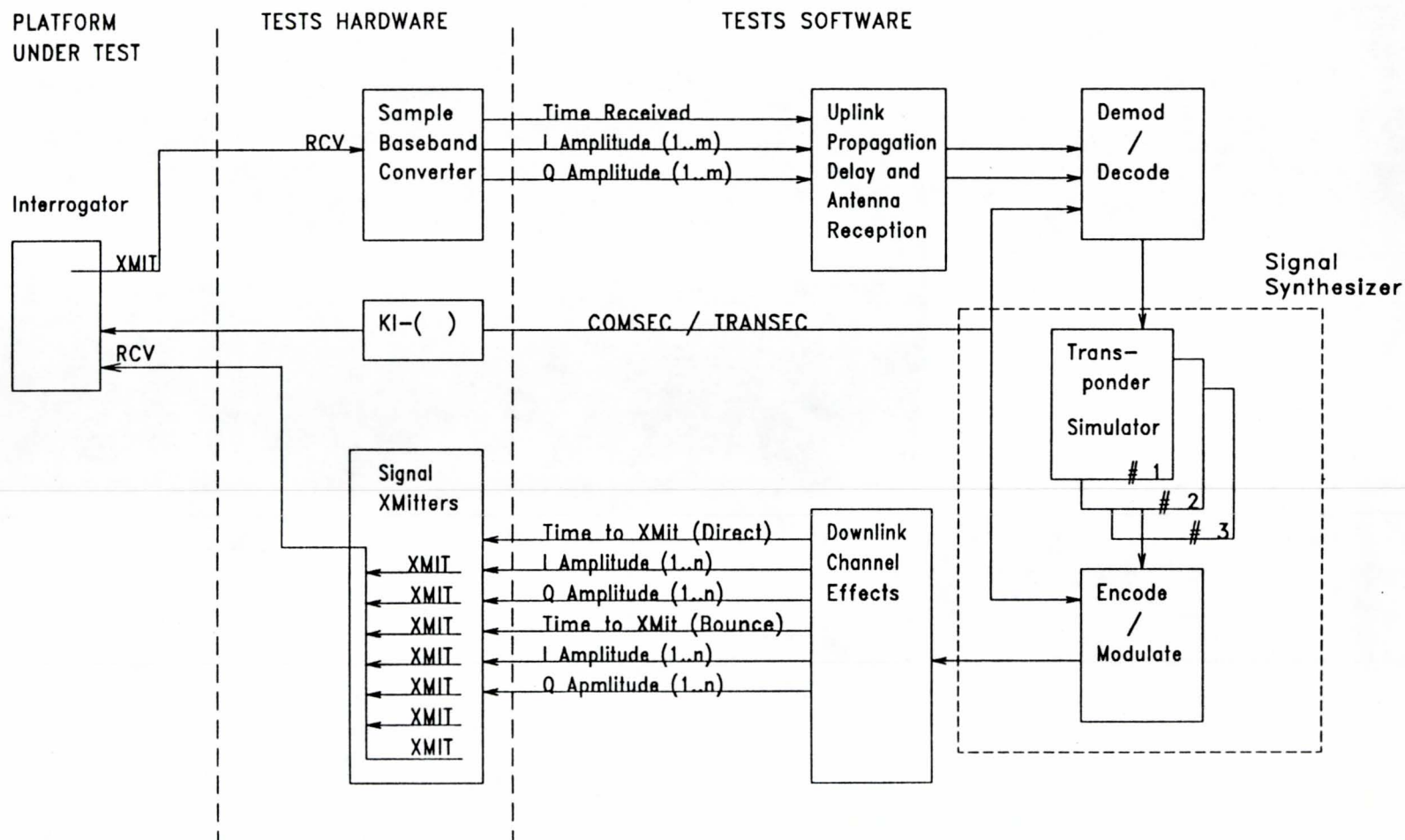
Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:

RF interrogation waveforms.

CONCEPT A - Sampled Data Interface

Figure 3-9 Concept A - Sampled Data Interface



Internal Operations:

Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests. Uses COMSEC/TRANSEC coding information to interpret RF reply waveforms.

TRANSPONDER

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

RF Interrogation WAVEFORMS, KI-()
COMSEC and TRANSEC coding information.

Block Outputs:

RF reply waveforms.

Internal Operations:

Uses COMSEC/TRANSEC coding information to interpret interrogation waveforms and generate, when appropriate, reply waveforms.

TESTS HARDWARE:

SAMPLE BASEBAND CONVERTER

Functional Description:

Detects RF IFF signals from SUT, converting them to an I/Q protocol time sampled data format.

Block Inputs:

SUT IFF system output waveforms.

Block Outputs:

Time sampled I/Q protocol data RF signal description.

Internal Operations:

Quadrature demodulation followed by dual low pass filtering and high speed A/D conversion.

SIGNAL TRANSMITTER

Functional Description:

Converts software generated I/Q protocol time sampled data signals into RF SUT stimulus signals.

Block Inputs:

Time sampled I/Q protocol data RF signal descriptions.

Block Outputs:

RF SUT stimulus signals.

Internal Operations:

Dual high speed D/A conversion followed by quadrature modulation to RF carrier. Combines signals into a single complex waveform.

KI-()

Functional Description:

Crypto unit which interacts with MK XV or Navy Advanced IFF Subsystem to provide COMSEC/TRANSEC information to IFF Subsystem and TESTS host processor.

Block Inputs:

Time of day information and key codes.

Block Outputs:

COMSEC/TRANSEC information via shielded cable.

Internal Operations:

Actual internal operation is classified and may be replaced in some test cases with an unclassified substitute.

TESTS SOFTWARE:

UPLINK PROPAGATION DELAY AND ANTENNA RECEPTION

Functional Description:

Applies propagation delay to I/Q sampled data format SUT RF signal descriptions, and passes or rejects signal based on whether the signal was in the antenna receiving lobe.

Block Inputs:

I/Q sampled data format descriptions of SUT RF signals.

Block Outputs:

I/Q sampled data format signal descriptions adjusted for propagation delay.

Internal Operations:

Computational application of channel effects via I/Q model protocols detailed in Annex A. After adding propagation delay, the signal is passed if it was in the antenna's reception lobe or rejected if it was not validly received.

DEMOD / DECODE

Functional Description:

Demodulation, despreading and/or decryption of I/Q sampled data format signals into IFF message

types, modes and contents.

Block Inputs:

I/Q sampled data format signal descriptions
adjusted for channel effects; COMSEC/TRANSEC
information.

Block Outputs:

IFF message types, modes and content.

Internal Operations:

Applies appropriate demodulation, despread-
ing and/or decryption processes through I/Q model
protocols as described in Annex A.

TRANSPONDER SIMULATOR

Functional Description:

Invokes TESTS interrogations or replies
appropriate to the test function and time
dependent scenario conditions.

Block Inputs:

IFF message types, modes and content.

Block Outputs:

New IFF message types, modes and content.

Internal Operations:

Follows test scenario to simulate individual IFF
platforms.

ENCODE / MODULATE

Functional Description:

Modulation, spreading and/or encryption of
new IFF message types, modes and content into
I/Q sampled data format signals.

Block Inputs:

New IFF message types, modes and content;
COMSEC/TRANSEC information.

Block Outputs:

I/Q sampled data format signal descriptions.

Internal Operations:

Applies appropriate modulation, spreading
and/or encryption processes through I/Q model
protocols as described in Annex A.

DOWNLINK CHANNEL EFFECTS

Functional Description:

Applies channel effects to I/Q sampled data format

SUT RF signal descriptions.

Block Inputs:

I/Q sampled data format signal descriptions.

Block Outputs:

I/Q sampled data format signal descriptions
adjusted for channel effects.

Internal Operations:

Computational application of channel effects via
I/Q model protocols detailed in Annex A.

3.5.1.2 Supporting Discussion

Figure 3-9 refers to an "I/Q" (In-phase/Quadrature) protocol for the transfer of time sampled RF waveforms at the junction between "hardware" and "software." The I/Q protocol represents an attempt to alleviate the high computational requirements associated with the Sampled Data Interface approach. Computational speed requirements for processing time sampled signals grow in direct proportion to the rate at which signals are sampled. Direct data sampling of radio frequency (RF) signals requires sampling or time slicing rates in excess of twice the carrier frequency. A carrier frequency of a thousand megahertz would require such an RF protocol sampling rate in excess of two thousand megahertz. If the signal were instead down converted to an intermediate frequency (IF) of two hundred megahertz the resulting "IF protocol" sampling rate would be a mere four hundred megahertz. In contrast, I/Q protocol time sampling requires a sampling rate equal to the RF bandwidth and not twice the RF or IF carrier frequency. A signal with a 50 megahertz signal bandwidth requires a 50 megahertz sampling rate for each channel, "I" and "Q." I/Q protocol signal processing speed requirements are consequently relaxed, in this example, by a ratio of 2000 to 50 or forty to one over RF protocol sampling or by a ratio of 400 to 50 or eight to one over IF protocol sampling. Although digital processing computations are treated differently when employing I/Q protocol sampling than when employing RF or IF protocol sampling, I/Q protocol sampling is clearly and by far the most feasible protocol for data sampling in the Sampled Data Interface approach. I/Q protocol modeling, time sampling and signal processing are treated in detail and with examples in Annex A.

The Sampled Data Interface concept may be described in more detail by specifying the function of the various components shown in Figure 3-9. The interrogator is the system under test installed in an aircraft in an anechoic chamber or shielded hangar. It responds to interrogation requests from its platform with RF waveforms encoded according to KI-() dependent protocols. The interrogator receives RF replies generated, in this scenario, by TESTS. The interrogator decodes and decrypts TESTS' replies into identification information regarding platforms simulated by TESTS.

TESTS hardware shown also in Figure 3-9 includes a sample baseband converter, which serves as the receiver for this concept, which functions as an interface between the RF waveform output from the interrogator to the I/Q protocol sampled data stream to be processed by the TESTS software. The sample baseband converter operates internally as a quadrature demodulator and a high speed analog to digital (A/D) converter. The other piece of TESTS hardware is a signal transmitter which converts TESTS generated I/Q protocol sampled data streams directly into RF waveforms. The internal operation is that of two high speed digital to analog (D/A) converters followed by a quadrature amplitude modulator.

TESTS software in the Sampled Data Interface concept accepts an I/Q protocol sampled data stream from the TESTS receiver and returns I/Q protocol sampled data streams to the signal transmitter. The interface data shown in Figure 3-9, assumes that $1 \dots m$ samples of I/Q data are required to represent each signal received by tests, and that $1 \dots n$ samples are required to represent each signal transmitted by tests. Channel effects for each message to be transmitted by TESTS, can be included in the I/Q representations of each signal, with a separate I/Q signal generated to represent the indirect or bounce path for multipath effects.

Figure 3-9 indicates various functions which would be carried out by TESTS software which would depend on the test scenario driving the simulation. Software would be programmed to interpret any messages contained in the I/Q protocol sampled data stream. The "Uplink Propagation Delay and Antenna Reception" function represents a software evaluation of the effectiveness of each transponder in the test scenario to receive and react to each interrogation. The uplink channel effects modify the signal for propagation delay and pass the signal only if it was received in the antenna's reception lobe. The "Signal Synthesizer" responds to these evaluations with appropriate replies. "Downlink Channel Effects" applies scenario dependent propagation and environmental effects as needed within the framework of the I/Q protocol Sampled Data Interface concept.

Ideally, the I/Q protocol standard Sampled Data Interface concept represents a versatile adaptable solution to the TESTS RF signal detection, simulation and generation requirements. In practice, this solution is difficult to realize due to computational and data transfer considerations. An example is given which shows the data rates and computational complexities which may be required when implementing the I/Q protocol Sampled Data Interface concept. This example calculates the amount of data, in bits, which must be considered when applying the I/Q protocol Sampled Data Interface concept to a MK XII Mode 3A reply. This example assumes 8 bits or 48 dB of resolution per sample, a 50 megahertz signal bandwidth and a 25.1 microsecond signal duration.

Example - Concept A - MK XII Mode 3A Reply requires :

50 MHz Sampling Frequency (due to bandpass filter)

longest message length = 25.1 usec

number of samples = (50 MHz) (25.1 usec) = 1255 samples /
message

Tests Transmit Message Format :

Time to XMIT (Direct)	=	32 bits	
I Amplitude (Direct)	=	10,040 bits	(1255 samples x 8 bits)
Q Amplitude (Direct)	=	10,040 bits	
Time to XMIT (Bounce)	=	32 bits	
I Amplitude (Bounce)	=	10,040 bits	(1255 samples x 8 bits)
Q Amplitude (Bounce)	=	10,040 bits	

total	=	40,224 bits	/ message

The result is that over forty thousand bits of information must be processed in order to simulate and deliver a single twenty-five microsecond MK XII Mode 3A reply within the framework of the I/Q Sampled Data Interface concept. This data must be processed by the signal transmitter at a rate of 50 megabytes per second in order to successfully reproduce the appropriate reply for a single signal. Hence, a single signal pushes the state-of-the-art in computers. The total number of bits per message required to transmit or receive can likewise be computed for other MK XII queries and replies. The same format can also handle encrypted MK XII messages (Mode 4), as well as MK XV spread spectrum messages, but in general the number of bits per message required will be greatly increased. Note that this approach also requires that the decode / encode, and despread / spread functions for encrypted and spread spectrum signals be performed in the software components of TESTS. Using the sampled data approach, multipath effects could be simulated entirely in software by direct summation of the I and Q components of the delayed reflected signal with those of the direct signal, taking time delay into account. However, because the time delay may reach or exceed an entire message length (refer to Section 3.1.2) allowance was made in the data rate analysis for sending both direct and reflected signals across the TESTS hardware/software interface.

This approach allows for simple TESTS transmit and receive hardware to be used. However, it requires enormous real time digital signal processing and data transfer rates to be performed by TESTS software components executing in the host computer. When compounded by more complicated formats and multiple transponders, the high computational and data transfer requirements grow enormously. At the most complicated scenarios,

in terms of number of targets, multipath effects, etc., the computational requirements effectively exceed the capability of a supercomputer. The cost associated with maintaining such a massive computational and data transfer capability is an incentive to pursue other design concepts.

3.5.2 Concept B - Pulse Level Interface

One manner in which computational and data transfer requirements may be alleviated within a TESTS RF simulation and stimulation tool is to apply pulse level decomposition to RF signals. The "Pulse Level Interface" concept, illustrated in Figure 3-10, approaches signal reception, processing and generation by applying pulse level decomposition and modeling to RF signals. This design approach shifts a moderate portion of the processing requirements to hardware in order to reduce the data rate requirements across the software/hardware interface.

The Pulse Level Interface concept is similar to the Sampled Data Interface concept in the sense that its heavy software orientation lends itself to a high degree of programmability and versatility. Concept A is most versatile for the same reason that it is least practical. Arbitrarily fast time sampling and digital signal processing allow absolute freedom in modeling RF signals within the bandwidth determined by the sampling rate at the expense of being prohibitively impractical to implement in terms of cost and available technology. Concept B gains computational advantage over Concept A by modeling RF signals through predetermined characteristic pulses or predetermined modulated data symbol shapes as defined in MK XII or MK XV specifications. The TESTS Hardware for Concept B, shown in Figure 3-10, is used to interface between RF signals and their pulse level model representations. Manipulation of RF signals, modeled in terms of their pulse decomposition representations, again takes place in TESTS software.

3.5.2.1 Block Descriptions

The functionality of Figure 3-10 is described below.

PLATFORM UNDER TEST:

INTERROGATOR

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:

RF interrogation waveforms.

CONCEPT B - Pulse Level Interface

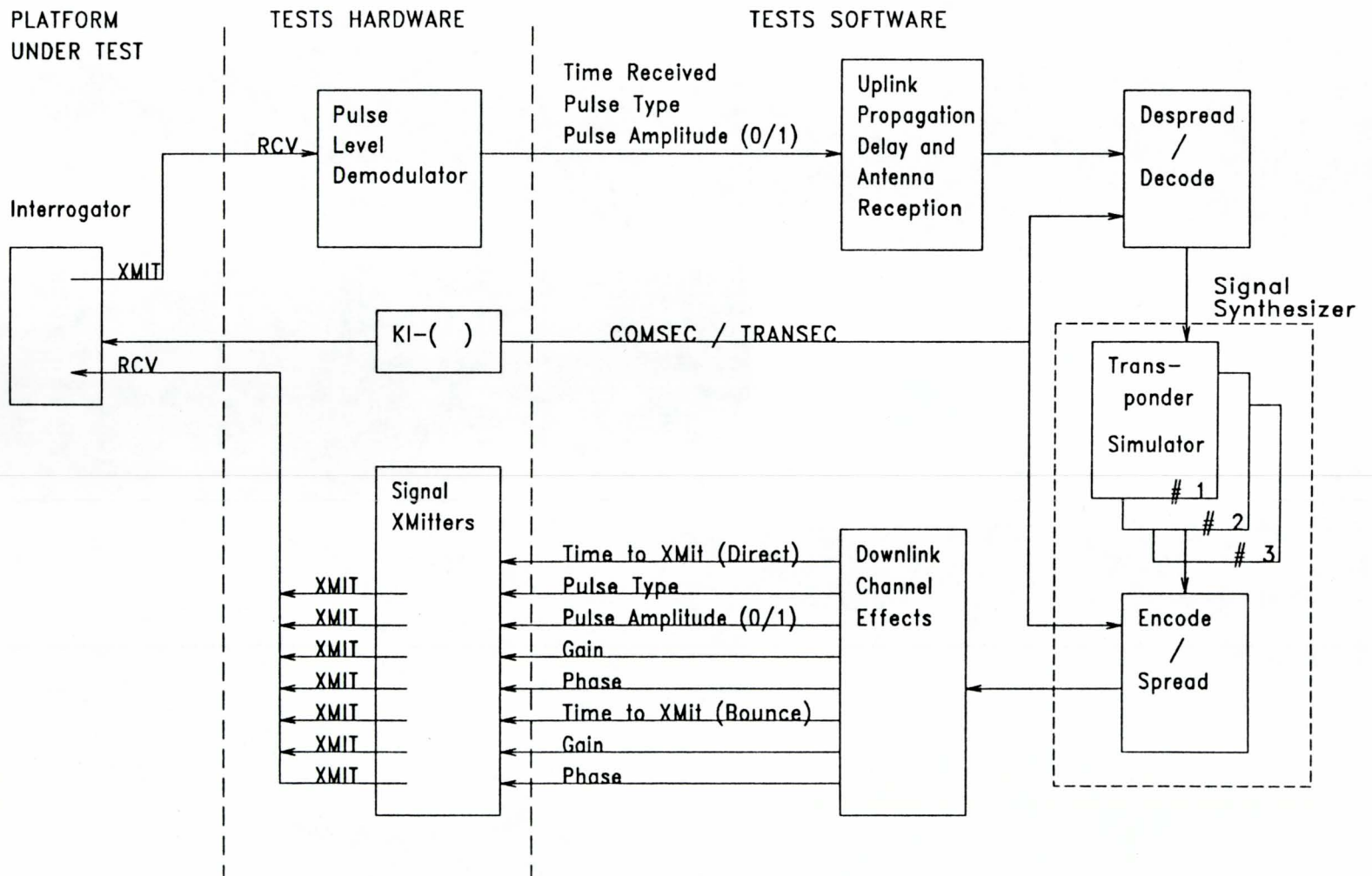


Figure 3-10 Concept B - Pulse Level Interface

Internal Operations:

Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests. Uses COMSEC/TRANSEC coding information to interpret RF reply waveforms.

TRANSPONDER

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

RF Interrogation WAVEFORMS, KI-()
COMSEC and TRANSEC coding information.

Block Outputs:

RF reply waveforms.

Internal Operations:

Uses COMSEC/TRANSEC coding information to interpret interrogation waveforms and generate, when appropriate, reply waveforms.

TESTS HARDWARE:

PULSE LEVEL DEMODULATOR

Functional Description:

Detects RF IFF signals from SUT, converting them to a pulse level data format.

Block Inputs:

SUT IFF system output RF waveforms.

Block Outputs:

Pulse level data format RF signal description, i.e., stream of pulses (chips) formatted by time received, type of pulse as characterized by Mode or Format specifications, and amplitude.

Internal Operations:

Data symbol shape recognition according to various IFF modes and formats and demodulation to the pulse or chip level as appropriate to the MK XII or MK XV.

SIGNAL TRANSMITTER

Functional Description:

Converts software generated pulse level data format signals into RF SUT stimulus signals.

Block Inputs:

Pulse level data format RF signal descriptions.

Block Outputs:
RF SUT stimulus signals.

Internal Operations:
Data symbol level modulation from pulses (chips)
to RF carrier.

KI-()

Functional Description:
Crypto unit which interacts with MK XV or Navy
Advanced IFF Subsystem to provide COMSEC/TRANSEC
information to IFF Subsystem and TESTS host
processor.

Block Inputs:
Time of day information and key codes.

Block Outputs:
COMSEC/TRANSEC information via shielded cable.

Internal Operations:
Actual internal operation is classified and may
be replaced in some test cases with an
unclassified substitute.

TESTS SOFTWARE:

UPLINK PROPAGATION DELAY AND ANTENNA RECEPTION

Functional Description:
Applies propagation delay to pulse level data
format SUT RF signal descriptions. Passes pulse
level data when received in antenna reception
lobe, rejects otherwise.

Block Inputs:
Pulse level data format descriptions of SUT RF
signals.

Block Outputs:
Pulse level data format signal descriptions
adjusted for channel effects.

Internal Operations:
Computational application of propagation delay via
pulse level data format descriptions and decides
whether to pass the data based on whether the
signal was located in the antenna's reception
lobe.

DESPREAD / DECODE

Functional Description:

Demodulation, despreading and/or decryption of pulse level data format signals into IFF message types, modes and contents.

Block Inputs:

Pulse level data format signal descriptions adjusted for channel effects; COMSEC/TRANSEC information.

Block Outputs:

IFF message types, modes and content.

Internal Operations:

Applies appropriate (remaining) demodulation, despreading and/or decryption processes through pulse level data format model.

TRANSPONDER SIMULATOR

Functional Description:

Invokes TESTS interrogations or replies appropriate to the test function and time dependent scenario conditions.

Block Inputs:

IFF message types, modes and content.

Block Outputs:

New IFF message types, modes and content.

Internal Operations:

Follows test scenario to simulate individual IFF platforms.

ENCODE / SPREAD

Functional Description:

Modulation, spreading and/or encryption of new IFF message types, modes and content into pulse level data format signals.

Block Inputs:

New IFF message types, modes and content; COMSEC/TRANSEC information.

Block Outputs:

Pulse level data format signal descriptions.

Internal Operations:

Applies appropriate modulation to pulse level, spreading and/or encryption processes through pulse level data model.

DOWNLINK CHANNEL EFFECTS

Functional Description:

Applies channel effects to pulse level data format SUT RF signal descriptions.

Block Inputs:

Pulse level data format signal descriptions.

Block Outputs:

Pulse level data format signal descriptions adjusted for channel effects.

Internal Operations:

Computational application of channel effects via pulse level data model.

3.5.2.2 Supporting Discussion

The Pulse Level Interface concept may be described in more detail by comparing the functions of various Concept B components shown in Figure 3-10 to their corresponding Concept A components shown in Figure 3-9. The interrogator under test performs the same function in both concepts. Differences begin in TESTS hardware.

The Concept B TESTS pulse level demodulator, the receiver for this concept, detects RF interrogations from the SUT. Concept B hardware is designed to expect waveforms with predetermined modulation data formats such as MK XII and MK XV interrogation formats. When interrogations are detected at the TESTS pulse level demodulator, they are decomposed into pulse sequence descriptions, not despread to baseband, corresponding to the various MK XII, MK XV, Radar Mode and Mode S data formats. A pulse sequence description consists of a starting time, a pulse type (i.e., MK XII Reply, MK XII Query, MK XII Mode 4 Reply, etc.) and a pulse amplitude (0/1 or f-mark / f-space). Pulse sequence descriptions are passed on to TESTS software by the TESTS pulse level demodulator as fully characterized interrogations received where appropriate responses are formulated. TESTS software in turn sends pulse sequence descriptions to the TESTS hardware signal transmitters, queued to be transmitted at specific times. Environmental effects modeling requires that pulse sequence descriptions of replies include gain and phase properties on a pulse by pulse basis for full RF reply signal fidelity. The pulse type, amplitude (0/1), gain, phase, and possibly frequency, information must be sent for each pulse of the direct path message. Also, a corresponding delay time, gain, and phase must be sent for the indirect bounce path to simulate multipath effects. The Concept B signal transmitters illustrated in Figure 3-10 would be equipped to accept such full fidelity pulse sequence descriptions from TESTS software and convert them into equal fidelity RF replies. Channel effects are thus computed in software, but applied in

hardware via the programmable gain, phase, frequency and time delay settings associated with each pulse.

As in Concept A, this approach requires that the decode / encode, and despread / spread functions for encrypted and spread spectrum signals be performed in the software components of TESTS. The difference is that Concept B software is geared to the processing of RF pulse sequence signal descriptions which save enormously on computational and data transfer requirements over the Sampled Data Interface concept. The example given in section 3.2.1 illustrates this savings when it is repeated for the Pulse Level Interface concept. This example again treats the MK XII Mode 3A reply.

Example - Concept B - MK XII Mode 3A Reply requires :

longest message length = 15 pulses

Tests Transmit Message Format :

Time to XMII	(Direct)	=	32 bits
Pulse Type	(Direct)	=	15 bits
Pulse Amplitude	(Direct)	=	1 bits
Pulse Gain	(Direct)	=	8 bits
Pulse Phase	(Direct)	=	8 bits
Time to XMII	(Bounce)	=	32 bits
Pulse Gain	(Bounce)	=	8 bits
Pulse Phase	(Bounce)	=	8 bits

112 bits / pulse
x 15

total = 1680 bits / message

The result is that a modeling requirement of over forty thousand bits of information in Concept A is reduced to less than two thousand bits of information in Concept B. Hence, for MK XII signals, Concept B yields a significant computational and data transfer advantage over Concept A. Concept B, however, still requires computation and data transfer rates that become difficult to implement as the pulse shapes used to characterize signals become small. However, it must be cautioned that this order of reduction can not be achieved for spread spectrum signals of the type used by MK XV. Spread spectrum signals with high chipping rates would again become prohibitively cumbersome to implement in terms of a pulse level signal component software model. Therefore, while MK XII signals are compatible with state-of-the-art computing resources, Mark XV signals under this design concept still exceed the capability of a supercomputer. As with Concept A, the cost associated with the development and maintenance of such a system motivates newer alternatives.

An additional disadvantage of this concept is that it does not

work for spread spectrum signals in a hostile, i.e., jamming, or noisy environment. This concept can work for conventional systems, such as MK XII, where there is an adequate signal-to-noise ratio. For spread spectrum signals this concept will only operate in a benign environment where THE Power Spectral Density of the noise is significantly lower than that of the spread spectrum signal.

3.5.3 Concept C - Message Level Interface

A highly feasible and practical alternative to the Pulse Level Interface is the Message Level Interface illustrated in Figure 3-11. The Message Level Interface represents a logical step in the evolution of the TESTS concepts which alleviates the data transfer and computational requirements of the TESTS software by at least an order of magnitude over the Pulse Level Interface concept. It reallocates a larger portion of the processing to hardware. Under this design approach software assumes a "command and control" function whereby it generates messages and calculates environmental effects which are implemented through hardware.

Detailed analysis of those concepts studied reveals that Concept C most closely approximates the recommended TESTS concept, as described in Section 4.1. Like Concepts A and B, Concept C allows for versatility in terms of signal modeling to accommodate environmental effects and signal superposition. Unlike Concepts A and B, Concept C does not break up RF signals into any types of components in the detection or generation process. Concept C instead employs TESTS hardware for complete message RF signal demodulation and generation. The recommended TESTS concept is in fact a Concept C approach modified through components borrowed from Concept D for an increased hardware emphasis but equal versatility.

3.5.3.1 Block Descriptions

The functionality of this design concept is described below.

PLATFORM UNDER TEST:

INTERROGATOR

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

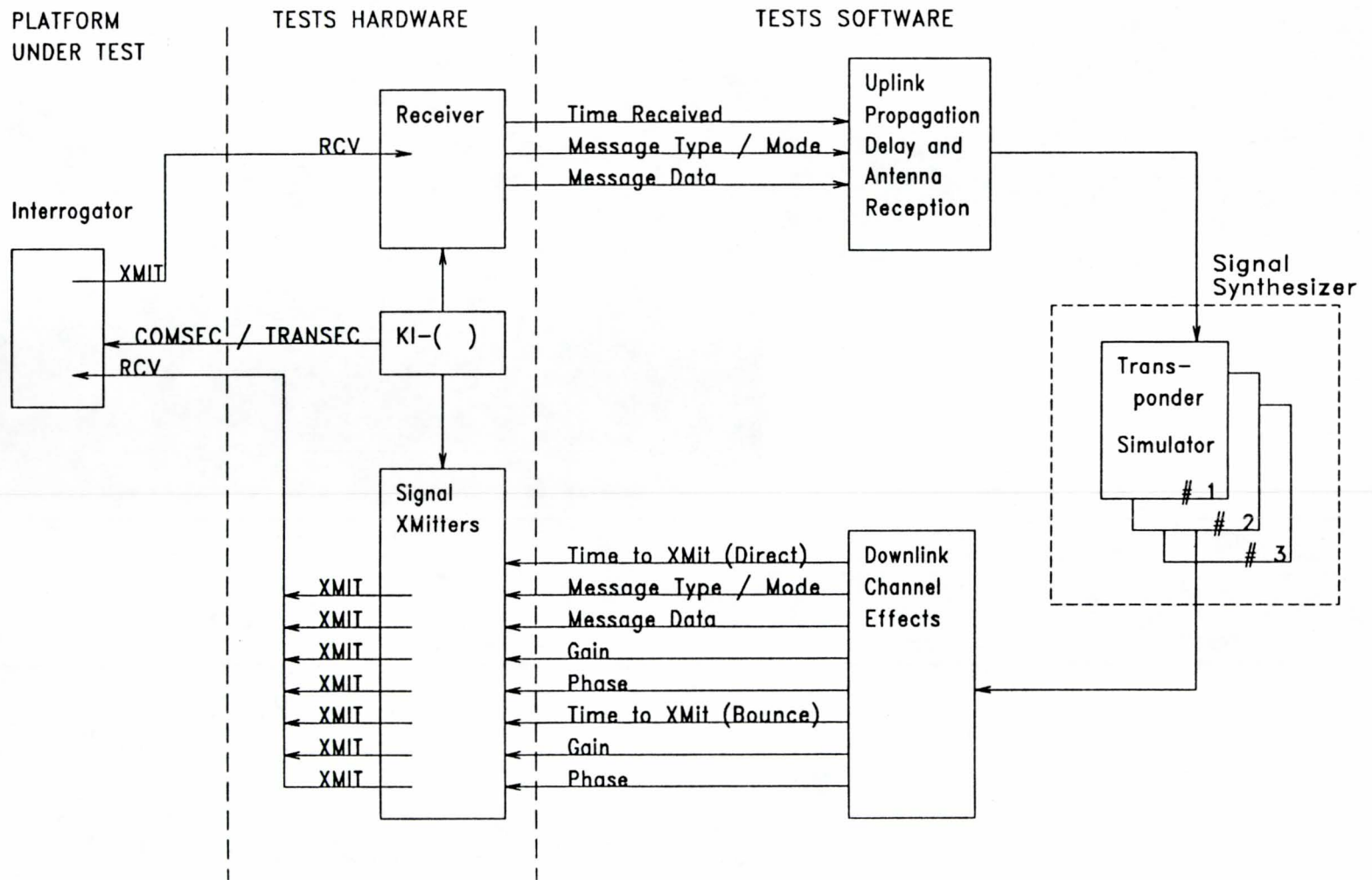
Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:

RF interrogation waveforms, threat ID information.

CONCEPT C – Message Level Interface

Figure 3-11 Concept C – Message Level Interface



Internal Operations:

Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests. Uses COMSEC/TRANSEC coding information to interpret RF reply waveforms.

TRANSPONDER

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

RF Interrogation WAVEFORMS, KI-()
COMSEC and TRANSEC information.

Block Outputs:

RF reply waveforms.

Internal Operations:

Uses COMSEC/TRANSEC coding information to interpret interrogation waveforms and generate, when appropriate, reply waveforms.

TESTS HARDWARE:

SIGNAL RECEIVER

Functional Description:

Detects RF IFF signals from SUT, converting them to a message level data format.

Block Inputs:

SUT IFF system output waveforms; COMSEC/TRANSEC information.

Block Outputs:

Message level data format RF signal description.

Internal Operations:

Demodulation including despreading, decoding and/or decryption and Message level signal recognition.

SIGNAL TRANSMITTER

Functional Description:

Converts software generated message level data format signals into RF SUT stimulus signals.

Block Inputs:

Message level data format RF signal descriptions; COMSEC/TRANSEC information.

Block Outputs:
RF SUT stimulus signals.

Internal Operations:
Message level modulation including spreading, encoding and/or encryption, and modification for channel effects by adjusting gain, phase, delay and frequency shift of generated signal.

KI-()

Functional Description:
Crypto unit which interacts with MK XV or Navy Advanced IFF Subsystem to provide COMSEC/TRANSEC information to IFF Subsystem and TESTS host processor.

Block Inputs:
Time of day information and key codes.

Block Outputs:
COMSEC/TRANSEC codes via shielded cable.

Internal Operations:
Actual internal operation is classified and may be replaced in some test cases with an unclassified substitute.

TESTS SOFTWARE:

UPLINK PROPAGATION DELAY AND ANTENNA RECEPTION

Functional Description:
Computes propagation delay to message level data SUT RF signal descriptions. Passes data if it was received in the antenna's reception lobe.

Block Inputs:
Message level data format descriptions of SUT RF signals.

Block Outputs:
Message level data format signal descriptions modified for propagation delay.

Internal Operations:
Addition of propagation delay via message level data format descriptions computed for direct and reflected signals. Rejects data if it was not received in the antenna's reception lobe.

TRANSPONDER SIMULATOR

Functional Description:
Invokes TESTS interrogations or replies

appropriate to the test function and time dependent scenario conditions.

Block Inputs:

IFF message types, modes and content.

Block Outputs:

New IFF message types, modes and content.

Internal Operations:

Follows test scenario to simulate individual IFF platforms.

DOWNLINK CHANNEL EFFECTS

Functional Description:

Computes channel effects to message level data format.

Block Inputs:

Message level data format signal descriptions.

Block Outputs:

Message level data format signal descriptions adjusted for channel effects.

Internal Operations:

Addition of channel effects via message level data model.

3.5.3.2 Supporting Discussion

Figure 3-11 illustrates the Message Level Interface concept. In this approach the entire IFF messages is represented in digital data format. The TESTS Hardware consists of a receiver and a bank of signal transmitters. The Concept C receiver is designed to detect, demodulate, decode and despread interrogations from the SUT. The message contained in the interrogation is then passed on to TESTS software along with the time received and the type of interrogation employed. TESTS signal synthesizer software components can then work directly with digital baseband data, in order to formulate appropriate responses. The signal transmitters in TESTS hardware may be invoked by TESTS software to send given replies to the SUT under given modulation types or modes. Meaningful stimulation fidelity levels are achieved by requiring TESTS software to specify transmitted signal absolute amplitude (gain) and propagation phase as well as bounce path characteristics and transmit time. Thus, the message type and mode, along with the gain, phase, and frequency distortions due to channel effects, are sent for each direct path message; and a corresponding delay time, gain, and phase is sent for the indirect bounce path to simulate multipath effects. These characteristics are incorporated into the stimulus signals through the signal transmitter hardware which construct

the set of desired MK XII or MK XV messages at RF carrier frequencies.

Computation and data transfer software requirements are greatly alleviated through the use of message level signal descriptions. TESTS software functions include evaluating the impact of uplink propagation delay on simulated transponder operation. Another TESTS software function is the synthesis of transponder replies through message level transmission descriptions based on scenario information in the simulation. A third TESTS software function is to specify downlink channel effects for the Concept C signal transmitter consistent with simulation scenario information. Hence, channel effects are thus computed in software, but applied in hardware via the programmable gain, phase, frequency and time delay settings associated with each message. In contrast to the sampled data and pulse level concepts, this approach allows signal encoding, spreading and modulation functions for encrypted and spread spectrum signals to be performed in the hardware components of TESTS.

Significant data transfer and computational gains of the Message Level Interface concept over the Pulse Level Interface and Data Level Interface concepts may be illustrated again with a MK XII Mode 3A reply example. The data required for describing a MK XII Mode 3A reply under the Message Level Interface concept are as follows:

Example - Concept C - MK XII Mode 3A Reply requires :

.....
longest message length = 15 bits of data

Tests Transmit Message Format :

Time to XMIT	(Direct)	=	32 bits
Message Type/Mode	(Direct)	=	16 bits
Message Data	(Direct)	=	16 bits
Message Gain	(Direct)	=	8 bits
Message Phase	(Direct)	=	8 bits
Time to XMIT	(Bounce)	=	32 bits
Message Gain	(Bounce)	=	8 bits
Message Phase	(Bounce)	=	8 bits

total		=	128 bits / message

Thus the message level format significantly alleviates computational and data transfer requirements for TESTS software to the point where computing technologies required for real time operation are both feasible and affordable. Furthermore, this reduction can be achieved for both encrypted and spread spectrum signals, since all modulation is performed in the TESTS hardware functions. This is a direct result of emphasizing TESTS hardware with respect to TESTS software in the conditioning of RF stimulus signals.

3.5.4 Concept D - Hardware Intensive Design Concept

Figure 3-12 illustrates the last design concept, the Hardware Intensive Design Concept. Each TESTS concept described is a step in the evolution of the TESTS approach from Concept A - a very software intensive design - to concepts which employed successively more hardware processing and less software processing. Concept D represents the extreme in the evolution of the TESTS approach which employs a minimal amount of software signal processing. This approach assumes actual and complementary IFF equipment will be used to stimulate the SUT. Hence, the vast majority of the signal manipulation work in Concept D is done in TESTS hardware.

3.5.4.1 Block Description

The functionality of the Hardware Intensive Design Concept is described below.

PLATFORM UNDER TEST:

INTERROGATOR

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:

RF interrogation waveforms, threat ID information.

Internal Operations:

Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests.

TRANSPONDER

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

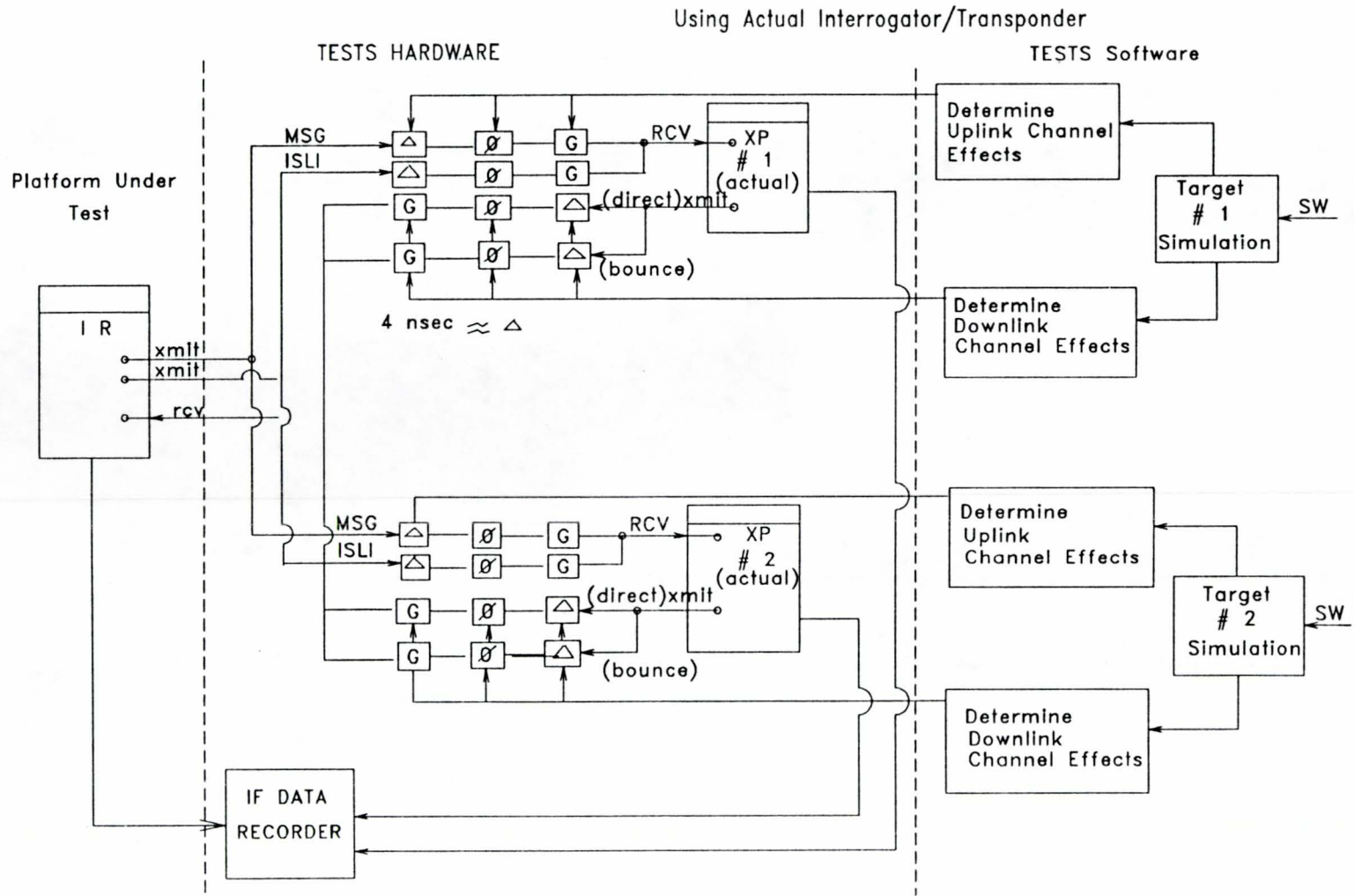
RF interrogation waveforms; KI-() COMSEC and TRANSEC coding information.

Block Outputs:

RF reply waveforms.

CONCEPT D - Hardware Intensive Design

Figure 3-12 Concept D - Hardware Intensive Design



Internal Operations:

Uses COMSEC/TRANSEC coding information to interpret interrogation and generate reply waveforms when appropriate.

TESTS HARDWARE:

TRANSPONDERS

Functional Description:

Authentic IFF transponder to reply to SUT interrogator.

Block Inputs:

IFF interrogation waveforms perturbed by RF environmental simulation hardware; COMSEC/TRANSEC information.

Block Outputs:

IFF reply waveforms.

Internal Operations:

Interprets and replies to interrogations.

INTERROGATORS

Functional Description:

Authentic IFF interrogators to query SUT transponder for the case of transponder PUT.

Block Inputs:

Interrogation requests; COMSEC/TRANSEC information; reply waveforms perturbed by RF environmental simulation hardware.

Block Outputs:

IFF interrogation waveforms; threat ID information.

Internal Operations:

Generates interrogation waveforms upon request and interprets replies.

IF DATA RECORDER

Functional Description:

Records IF signal exchange between SUT and TESTS hardware. Records the transmitted IF from the interrogator and transponder.

Block Inputs:

SUT IF waveforms; TESTS hardware IF waveforms.

Block Outputs:

Record of IF signal exchange for future analysis.

Internal Operations:

Convenient demodulation and data recording functions are implemented.

PROGRAMMABLE TIME DELAY, PHASE, GAIN AND FREQUENCY BLOCKS

Functional Descriptions:

Implementation of channel effects on RF signals.

Block Inputs:

Control signals originating in software.

Block Outputs:

Perturbations on RF signals.

Internal Operations:

Programmable time delay would respond to predetermined control signals with predetermined amounts of uniform group delay. Programmable phase and gain blocks would similarly apply variable levels of carrier phase and signal attenuation.

TESTS SOFTWARE:

CHANNEL EFFECTS

Functional Description:

Applies channel effects control signals to programmable time delay, phase and gain blocks.

Block Inputs:

Simulation scenario environment information.

Block Outputs:

Control signals for programmable time delay, phase and gain blocks.

Internal Operations:

Addition of channel effects via message level data format descriptions.

TARGET SIMULATION

Functional Description:

Keeps track of scenario environment information so as to update channel effects control blocks.

Block Inputs:

Time dependent simulation information.

Block Outputs:

Simulation scenario environment information.

Internal Operations:

Follows test scenario to update individual IFF channel effects control boxes.

3.5.4.2 Supporting Discussion

Figure 3-12 illustrates the Hardware Intensive Design concept in the case where the SUT is again a interrogator system. TESTS hardware includes authentic transponders. No message information is communicated between software and hardware. Authentic transponders which reside completely in hardware are used to stimulate the platform under test.

Concept D TESTS software components in Figure 3-12 accomplish scenario simulations by tracking platform positions and computing uplink and downlink channel effects. These effects are interfaced into TESTS hardware in the form of control over programmable TESTS hardware gain blocks, phase blocks, frequency changers and time delay lines. The configuration shown in Figure 3-12 provides for two sets of programmable time delay lines. This allows for interrogator sidelobe suppression pulses to be simulated on the uplink and multiple path propagation to be simulated for the downlink. Interrogator Side Lobe Suppression (ISLS) pulses are transmitted separately from the mode identifying pulses either through an omnidirectional antenna (sum and omni) or through the difference pattern of the same antenna (sum and difference).

An advantage of this approach is that IFF signal generation is achieved through authentic IFF equipment. This approach would demonstrate the compatibility and interoperability of IFF systems employed. This approach has the fewest software to hardware interface requirements of all approaches investigated. Channel effects change slowly with respect to interrogation rates. The update rates on programmable time delays and gain and phase blocks may be significantly less than the message update rates.

This concept has several disadvantages. First and foremost, it is difficult to expand this configuration to simulate test scenarios which require more than a few interrogators and transponders. Secondly, Concept D requires a great deal of hardware equipment including the availability of authentic interrogators and transponders for each platform in the test scenario. Finally, the Hardware Intensive concept requires that test data recording and analysis be performed at RF frequencies, both 1030 and 1090 MHz, because there is no direct simulation access to modulated IFF signal information.

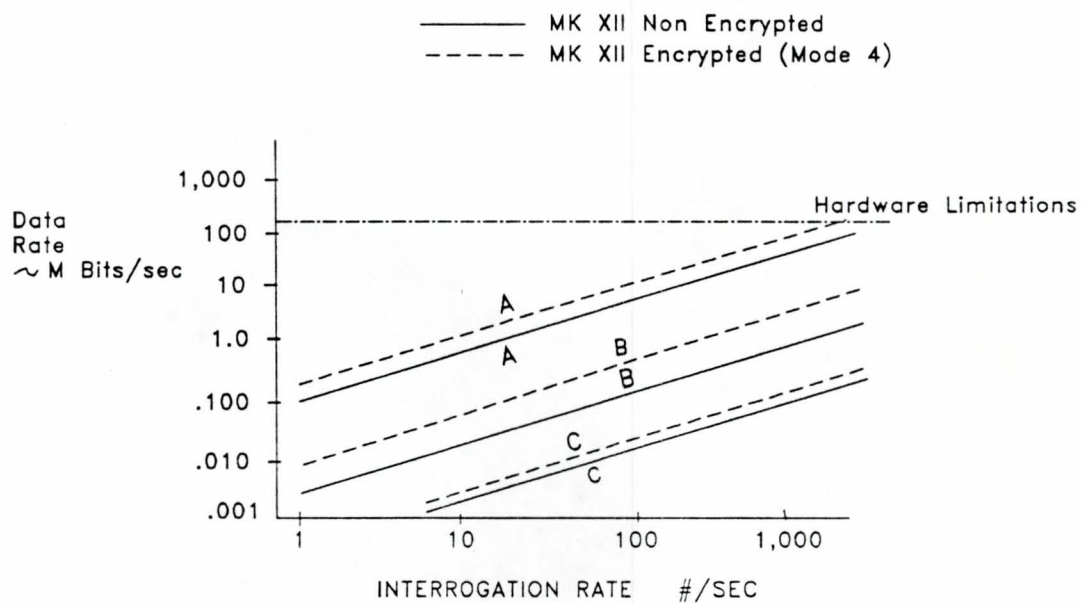
3.5.5 Summary Analysis of Generic TESTS Conceptual Design Approaches

Figure 3-13 presents a summary of the data rate requirements for the generic TESTS concepts A, B, and C, as functions of interrogation rate and reply rate where the total reply rate includes FRUIT. These plots were generated based on MK XII IFF

signals, treating non-encrypted modes separately from encrypted signals (Mode 4). The interrogation rate analysis assumes that one reply (plus bounce path) is generated for each interrogation. The reply rate analysis assumes that a constant interrogation rate of 100 queries per second is generated by the SUT. As these results demonstrate, Concepts A and B rapidly approach or exceed hardware limitations for channel capacity (around 150 MBits / sec) of commercially available communications busses. Figure 3-14 (classified SECRET and transmitted under a separate cover) presents a similar analysis using MK XV spread spectrum signals. It is evident from these analyses that Concept C provides the only viable hardware/software allocation approach at high interrogation rates or high reply rates because of the extremely high data rates. The data rate requirements for concept A or B cannot be achieved with conventional computer technology.

Given that C represents the best hardware/allocation, an approach for implementing the hardware elements of TESTS must be selected. The hardware elements must accomplish the actual signal generation and provide the capability to modify signals for channel effects. As describe in Section 4.1, the signal and channel effects hardware approach described in Concept D has been selected as the recommended hardware implementation. This hybrid combination of Concepts C and D provides a flexible and effective design approach for TESTS.

DATA RATE REQUIREMENTS vs INTERROGATION RATE



DATA RATE REQUIREMENTS vs TOTAL REPLY RATE (Constant Interrogation Rate of 100/sec)

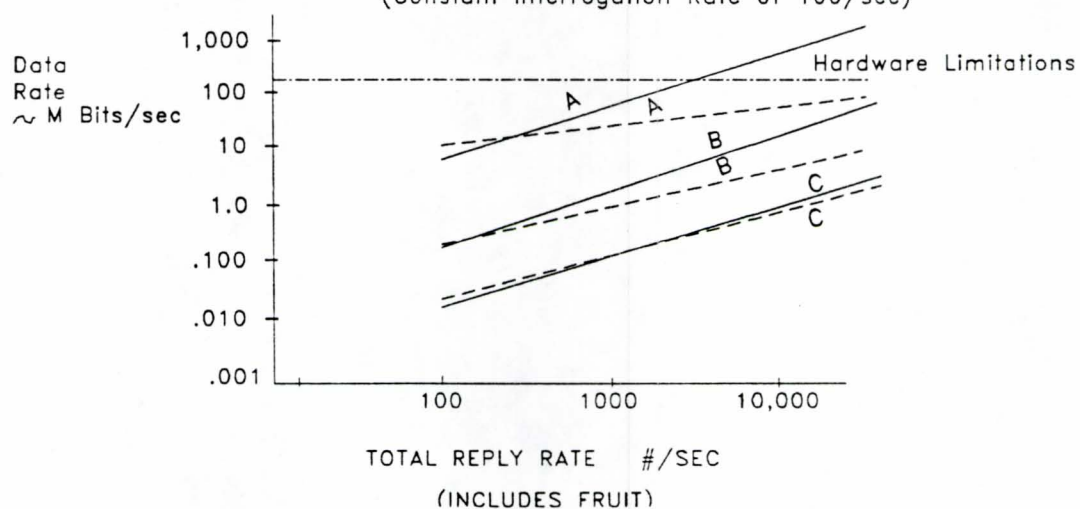


Figure 3-13 Plot of Data Rate Requirements vs. Interrogation / Total Reply Rates for MK XII

Classified Figure - Included in Classified Addendum

Figure 3-14 Plot of MK XV Data Rate Requirements vs.
Interrogation / Total Reply rates

4.1 RECOMMENDED TESTS CONCEPT

Based upon the analyses of generic TESTS concepts presented in Section 3.0, an approach utilizing the Message Level Interface of Design Concept C, coupled with the modular channel effects hardware devices shown in Design Concept D is presented in Figure 4-1 as the Recommended Approach.

Important aspects of the recommended approach to the TESTS hardware/software interface that are represented in Figure 4-1 are:

TESTS Receiver - Able to recognize each of the possible IFF signal types and modes, and to demodulate, decode, and despread the signal to determine message data content.

KI-() - Real or simulated encryption device that provides the COMSEC / TRANSEC sequences to the TESTS Receiver, TESTS Signal Generators, and Platform Under Test.

TESTS Signal Generators (XMIT) - Receives a complete message in binary (baseband) format from the TESTS host computer, and constructs the desired IFF message modulated at RF frequency for transmission over hardware channels to the Platform Under Test. The signal/message is split and distributed to separate primary and multipath channels for modification by the RF Signal Conditioner.

RF Signal Conditioner (G-P-D-F) - Special purpose hardware devices that can be used to dynamically introduce channel effects in the generated IFF signals. They contain programmable Gain (G), Phase (P), Time Delay (D), and Frequency Shift (F) devices that can be directly controlled from the TESTS host computer. Separately programmable paths will be provided to allow for at least one direct and one indirect signal path to simulate multipath effects at the receiver of the Platform Under Test.

Platform Under Test (PUT) - This represents the RF transmit and receive hardware lines of the actual IFF equipment on the Platform Under Test.

4.1.1 Block Descriptions

PLATFORM UNDER TEST:INTERROGATOR

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

RECOMMENDED APPROACH - Modular Hardware / Message Level Interface

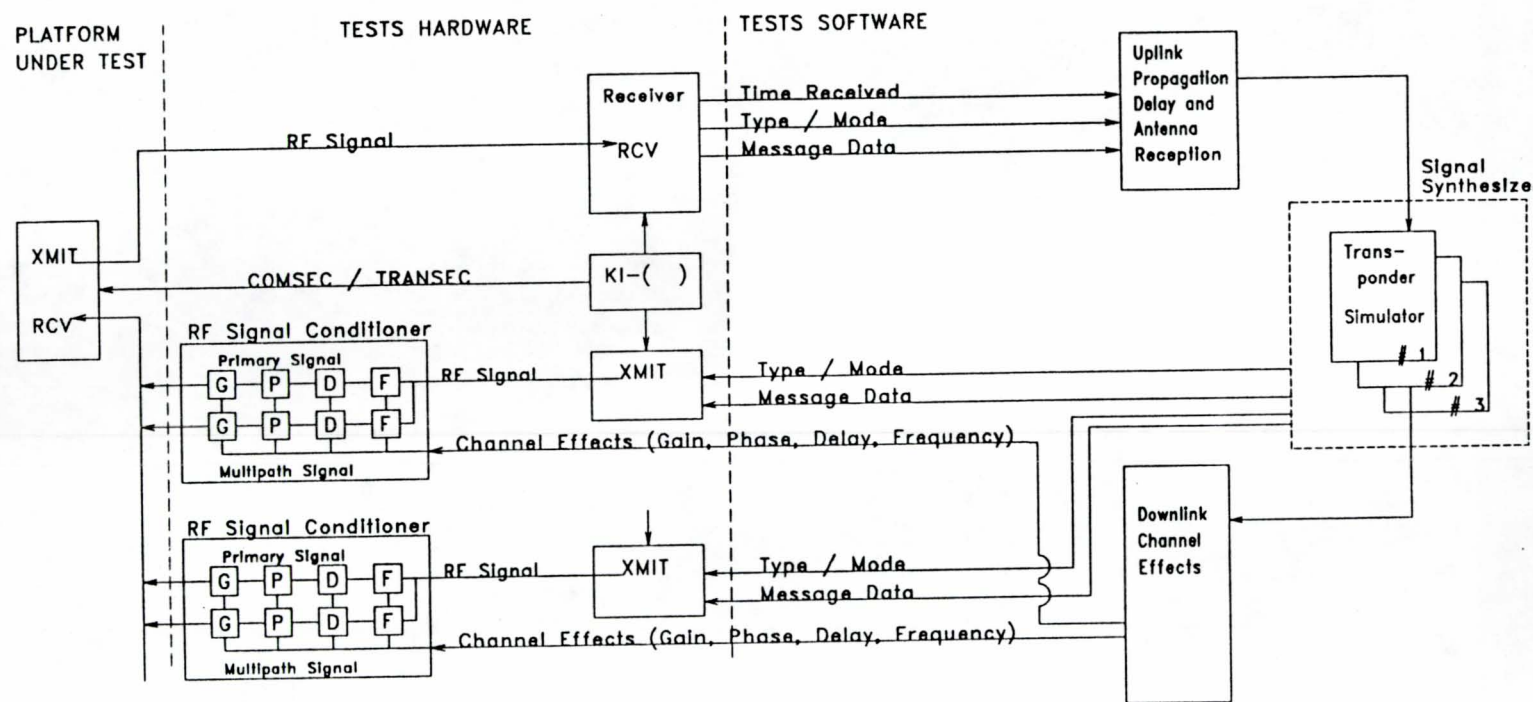


Figure 4-1 Recommended Approach - Modular Hardware / Message Level Interface

Block Inputs:

Interrogation requests from platform, KI-() COMSEC and TRANSEC coding information, RF reply waveforms.

Block Outputs:

RF interrogation waveforms, threat ID information.

Internal Operations:

Uses COMSEC/TRANSEC coding information to generate interrogation waveforms in response to platform interrogation requests. Uses COMSEC/TRANSEC coding information to interpret RF reply waveforms.

TRANSPONDER

Functional Description:

System under test (SUT) installed in an aircraft in an anechoic chamber or shielded hangar.

Block Inputs:

RF Interrogation WAVEFORMS, KI-()
COMSEC and TRANSEC information.

Block Outputs:

RF reply waveforms.

Internal Operations:

Uses COMSEC/TRANSEC coding information to interpret interrogation waveforms and generate, when appropriate, reply waveforms.

TESTS HARDWARE:

SIGNAL RECEIVER

Functional Description:

Detects RF IFF signals from SUT, converting them to a message level data format.

Block Inputs:

SUT IFF system output waveforms; COMSEC/TRANSEC information.

Block Outputs:

Message level data format RF signal description.

Internal Operations:

Message level signal recognition and demodulation including despreading, decoding and/or decryption.

SIGNAL TRANSMITTER

Functional Description:

Converts software generated message level data format signals into RF SUT stimulus signals.

Block Inputs:
Message level data format RF signal descriptions;
COMSEC/TRANSEC information.

Block Outputs:
RF SUT stimulus signals.

Internal Operations:
Message level modulation including spreading,
encoding and/or encryption.

KI-()

Functional Description:
Crypto unit which interacts with MK XV or Navy
Advanced IFF Subsystem to provide COMSEC/TRANSEC
information to IFF Subsystem and TESTS host
processor.

Block Inputs:
Time of day information and key codes.

Block Outputs:
COMSEC/TRANSEC codes via shielded cable.

Internal Operations:
Actual internal operation is classified and may
be replaced in some test cases with an
unclassified substitute.

RF SIGNAL CONDITIONER

Functional Descriptions:
Implementation of channel effects on RF signals.

Block Inputs:
Control signals originating in software.

Block Outputs:
Perturbations on RF signals.

Internal Operations:
Programmable time delay would respond to
predetermined control signals with predetermined
amounts of uniform group delay. Programmable
phase and gain blocks would similarly apply
variable levels of carrier phase and signal
attenuation.

UPLINK PROPAGATION DELAY AND ANTENNA RECEPTION

Functional Description:

Computes propagation delay to message level data format SUT RF signal descriptions and passes data if it was received in the antenna's reception lobe.

Block Inputs:

Message level data format descriptions of SUT RF signals.

Block Outputs:

Message level data format signal descriptions modified for propagation delay.

Internal Operations:

Addition of propagation delay via message level data format descriptions computed for direct and reflected signals. Rejects data if it was not received in the antenna's reception lobe.

TRANSPONDER SIMULATOR

Functional Description:

Invokes TESTS interrogations or replies appropriate to the test function and time dependent scenario conditions.

Block Inputs:

IFF message types, modes and content.

Block Outputs:

New IFF message types, modes and content.

Internal Operations:

Follows test scenario to simulate individual IFF platforms.

DOWNLINK CHANNEL EFFECTS

Functional Description:

Computes channel effects to message level data format.

Block Inputs:

Simulation scenario environment information.

Block Outputs:

Control signals for programmable time delay, phase and gain blocks.

Internal Operations:

Addition of channel effects via message level data format descriptions.

4.1.2 Supporting Discussion

In the Message Level Interface approach the entire IFF messages is represented in digital data format. The TESTS Hardware consists of a receiver and a bank of signal transmitters. The Recommended Concept receiver is designed to detect, demodulate, decode and despread interrogations from the SUT. The message contained in the interrogation is then passed on to TESTS software along with the time received and the type of interrogation employed. TESTS signal synthesizer software components can then work directly with digital baseband data, in order to formulate appropriate responses. The signal transmitters in TESTS hardware may be invoked by TESTS software to send given replies to the SUT under given modulation types or modes. The Recommended Concept TESTS software components accomplish scenario simulations by tracking platform positions and computing uplink and downlink channel effects. These effects are introduced via a software driven hardware interface subsystem which has been labeled an "RF Signal conditioner". This TESTS hardware subsystem is comprised of programmable TESTS hardware gain blocks, phase blocks, frequency changers and time delay lines. Section 5.1.4 provides additional discussion of the operation of these devices.

This configuration differs from that of Design Concept D in that the signal generator devices (XMIT) are driven from the TESTS software components and each may be used to generate multiple transponder or interrogator signals via time division multiplexing, under control of the TESTS host computer. A number of separate signal generators may be easily added to increase the reply rate or Interrogation rate capacity of the TESTS system. The programmable gain, phase, time delay, and frequency distortion devices are special purpose hardware devices that can be built separately, and used in a modular fashion to introduce channel effects in the generated signals. This separates the hardware functions, and allows for easier specification, design, testing and calibration of the equipment. It also provides for a more low cost growth path to achieve the final TESTS capacity requirements, and it allows for greater flexibility in utilization of TESTS equipment. For example, the channel effects boxes of this approach could also be used to connect an actual IFF transponder and interrogator pair, to approximate the configuration shown in Design Concept D. As shown in Figure 4-1, each channel effects box would contain at least two sets of separately programmable signal distortion devices, in order to simulate at least one indirect bounce path for multipath effects. If more than one bounce path is required for certain multipath conditions, multiple boxes could be used in parallel with the same RF Signal input to achieve this effect. The results of future research programs, as described in Section 5.5, will be needed to determine if and under what conditions the simulation of multiple bounce paths becomes necessary.

Section 5.1.4 provides additional technical details of one approach for implementation of the recommended design concept. This discussion assumes the development of a custom signal generation system implementation base on quadrature modulation hardware, direct sequence PN or frequency hopping generators for spreading, the proper encryption hardware, filter, mixing and other signal manipulation. Other approaches, such as use of Bendix MK XV test set signal generation hardware will also continue to be evaluated.

This hybrid combination of Concepts C and D provides a flexible and effective design approach for TESTS. Furthermore, while requiring a systematic design and research effort, this approach is the opinion of the IST/UCF team that it is both cost-effective and technologically achievable.

4.2 TESTS PROTOTYPE BUILD PLAN

In order to provide a low risk, high confidence, and low cost approach to the design, purchase, fabrication, and integration of the hardware and software components of the TESTS system, an evolving Prototype Build Plan will be adopted as shown in Figure 4-2. This plan shows a number of incremental builds which provide increasing capability and diversity in the number of platforms and signals to be generated, and simultaneously, increasing fidelity in the environmental and channel propagation effects to be simulated by TESTS. This evolutionary approach will allow early closed loop testing and validation of the TESTS system with existing IFF systems such as the MK XII, and provide a low risk transition to more advanced IFF systems utilizing spread spectrum signals. It will also provide scheduling milestones for the completion and integration of faculty research projects regarding the various channel effects, with the corresponding design requirements for TESTS software components and signal generation hardware.

Figure 4-2 was derived while the TESTS was responding to the MK XV program. As the new Navy unique advanced IFF program progresses, the prototype build plan will need to be updated. It is expected that other Navy aircraft platforms, e.g., F-14 will replace the Air Force F-15 in the matrix. The order of platforms in the build matrix may also change as the Navy formulates its test plan. Other aspects of the build plan may initially remain unchanged with updates incorporated as the Navy unique objectives unfold. It is likely that both the missile and ship models will remain in the build plan to accommodate aircraft testing in all operational settings, e.g., a complete test of an airborne transponder includes its ability to receive and correctly reply to a missile interrogation such as the Hawk's. The original build plan incorporates the worst case TESTS development scenario, hence this initial plan will be retained until further definition of the Navy unique IFF test plan become available.

TESTS – Prototype Build Plan – page 1

Prototype	PLATFORM										SIGNALS		Dynamics	
	F-18 (XP)	F-15 (IR)	F-15 (XP)	Hawk (IR)	Ship (IR)	Radar Mode (X-IR)	Radar Mode (S-IR)	Mk XII (Clear)	Mk XII (Mode 4)	Mk XV	Mode S	Stationary	Moving	SWEG
1.0	X						X				X			
1.1	X	X					X				X	X		
1.2	X	X					X	X			X	X		
2.0	X						X	X	X		X	X		
2.1	X	X					X	X	X		X	X		
2.2	X	X	X				X	X	X		X	X	X	
3.0	X	X	X	X	X		X	X	X		X	X	X	
3.1	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 4-2 TESTS Prototype Build Plan (1 of 2)

TESTS – Prototype Build Plan – page 2

Prototype			Emitters		Terrain Data		Multipath		Antenna		Propagation			
	Single	Multiple	4/3 Rad Earth	DMA Topography	Roughness	Single Reflection	Stochastic	Free Space	Platform Masking	Coupling	Standard Atmos.	Weather	Dust / Clouds	Ducting
1.0	X		X			X	X			X				
1.1	X		X			X	X			X				
1.2	X	X	X			X	X			X	X			
2.0	X	X	X			X	X	X		X	X			
2.1	X	X	X			X	X	X		X	X	X		
2.2	X	X	X	X		X	X	X		X	X	X		
3.0	X	X	X	X	X	X	X	X	X	X	X	X		
3.1	X	X	X	X	X	X	X	X	X	X	X	X	X	

Figure 4-2 TESTS Prototype Build Plan (2 of 2)

The Air Combat Environment Test and Evaluation Facility (ACETEF) provides a controlled environment for integrated testing of aircraft avionics systems at the Naval Air Test Center (NAVAIRTESTCEN). ACETEF provides a suite of laboratories and facilities that can interact to provide a variety of electromagnetic test environments and stimulations for actual avionics systems mounted on an aircraft and radiated in an anechoic chamber. An adjacent shielded hangar provides additional space for hard wired testing of several aircraft. Presently there are several operational elements of ACETEF, such as the Aircrew Systems Evaluation Facility (ASEF), the Electronic Warfare Integrated Systems Test Laboratory, (EWISTL) the Electromagnetic Environmental Generation System (EMEGS), and the Tactical Avionics and Software Test and Evaluation Facility (TASTEF). Other planned facilities include the Communications, Navigation, and Identification Laboratory (CNIL), the Offensive Sensors Laboratory (OSL), the Electromagnetics Environment Effects Test Laboratory (E3TL), and others. TESTS will integrate into the expanding capabilities of ACETEF, initially to provide Development Testing of the MK XII / MK XV IFF system, and eventually to provide full Operational Testing of IFF systems as part of the CNIL. It is anticipated that TESTS will be employed in at least four different configurations:

- 1) as a stand alone benign test tool to provide IFF testing on aircraft in the shielded hangar,
- 2) as a stand alone test tool integrated with additional equipment such as the Tactical Agile Signal Simulator (TASS), used to provide an ECM/jamming environment,
- 3) integrated in CNIL with CNIL operating independently of ACETEF, or
- 4) in a fully integrated ACETEF testing environment utilizing several assets at once to test aircraft systems in the anechoic chamber.

4.3.1 SWEG Interface

The primary interface of TESTS to the other components of ACETEF required during testing will be provided by the Simulated Warfare Environment Generator (SWEG). An outgrowth of the SUPPRESSOR simulation program, SWEG has been updated to control and coordinate tactical engagement simulations in ACETEF, and provides a rich library of platform and emitter models. SWEG provides a standard format for the shared memory interface between the various components of ACETEF, and defines the protocol for interactions between components. The software components of TESTS will interface to the SWEG shared memory for required scenario simulation data, such as platform positions, attitudes, velocities, terrain elevation data, antenna pattern directional attenuations, antenna scan rates, etc. TESTS will

utilize or upgrade existing ACETEF simulation models whenever possible, and will conform to the ACETEF established conventions for scenario preparation, initialization, execution, shutdown, and post processing phases of operation. Note that TESTS will utilize some subset of SWEG capabilities to provide scenario preparation and execution, even when operating in a stand alone configuration in the shielded hangar. It is anticipated that all interactions between TESTS software components, and other components of ACETEF, will take place via the SWEG shared memory interface.

While TESTS can operate in a stand alone configuration or integrated through CNIL to ACETEF, SWEG will always be required. In the stand alone configuration SWEG will need to be hosted at a workstation level, such as a VAXstation. When integrated with CNIL/ACETEF, TESTS will receive SWEG inputs through the appropriate level of shared memory. In the CNIL/ACETEF integrated configuration TESTS may require two interfaces to the shared memory. In order to meet real time processing requirements for multipath calculations, a second direct access interface to the SWEG terrain data base will be required. The need for this second access to shared memory will depend upon the final architecture for the CNIL. This requirement will be reassessed as the CNIL design solidifies.

The SWEG terrain data base utilizes standard DMA data. The resolution of the data base is determined by available memory. The SWEG terrain data base can accept the finest resolution of DMA data available. While DMA data is not of infinite resolution, it is sufficient to achieve a moderately high level of fidelity. It should be noted that almost any level of terrain resolution is representative of actual terrain somewhere. Given the resolution of terrain data available to SWEG, the capability exists to provide an environment representative of most terrain. Hence, it does not appear that the SWEG terrain data base resolution will impose any severe limitation on the development or utility of TESTS.

The most critical technical terrain data base issue is the real time calculation of platform inter-visibility. This is critical for low altitude platforms, especially when a large number of platforms are present and terrain elevations are changing rapidly. Under these conditions, terrain masking can be changing very rapidly. This is an area of the simulation that will require careful study. A number of efforts are ongoing to deal with this problem in other projects, some underway at IST. These current efforts are examining a variety of approaches to resolving the problem. Some approaches involve brute force computing power, others use innovative techniques such as precomputed inter-visibility surfaces and position predictive algorithms. We are examining various approaches to determine the most effective to TESTS. While this is a difficult problem, solutions exist. Additionally, it should be recognized that the percentage of the total scenarios in which this is a factor is

relatively low. Hence, the potential impact on the overall utility of TESTS may not be large.

4.3.2 Scenario Update Rates

Simulation assets of SWEG may either be event driven or updated periodically. The update period for certain platform parameters such as positions (latitude, longitude, altitude) and attitudes (pitch, roll, yaw), is critical to the fidelity requirements of TESTS. Although further study may be required of this issue as TESTS research programs progress, a preliminary analysis indicates that approximately 1.0 degrees of angular motion, and 50.0 feet of relative translational motion can be tolerated per simulation update cycle. Assuming average aircraft angular rates of 30.0 degrees per second, or less, and average closing velocities of 1500 feet per second or less, a simulation update rate of 30 times per second should be adequate for TESTS. Discussions with NAVAIRTESTCEN personnel indicate that SWEG platform position and attitude data is commonly updated at 60 to 120 times per second during scenario execution.

4.4 SOFTWARE DEVELOPMENT APPROACH

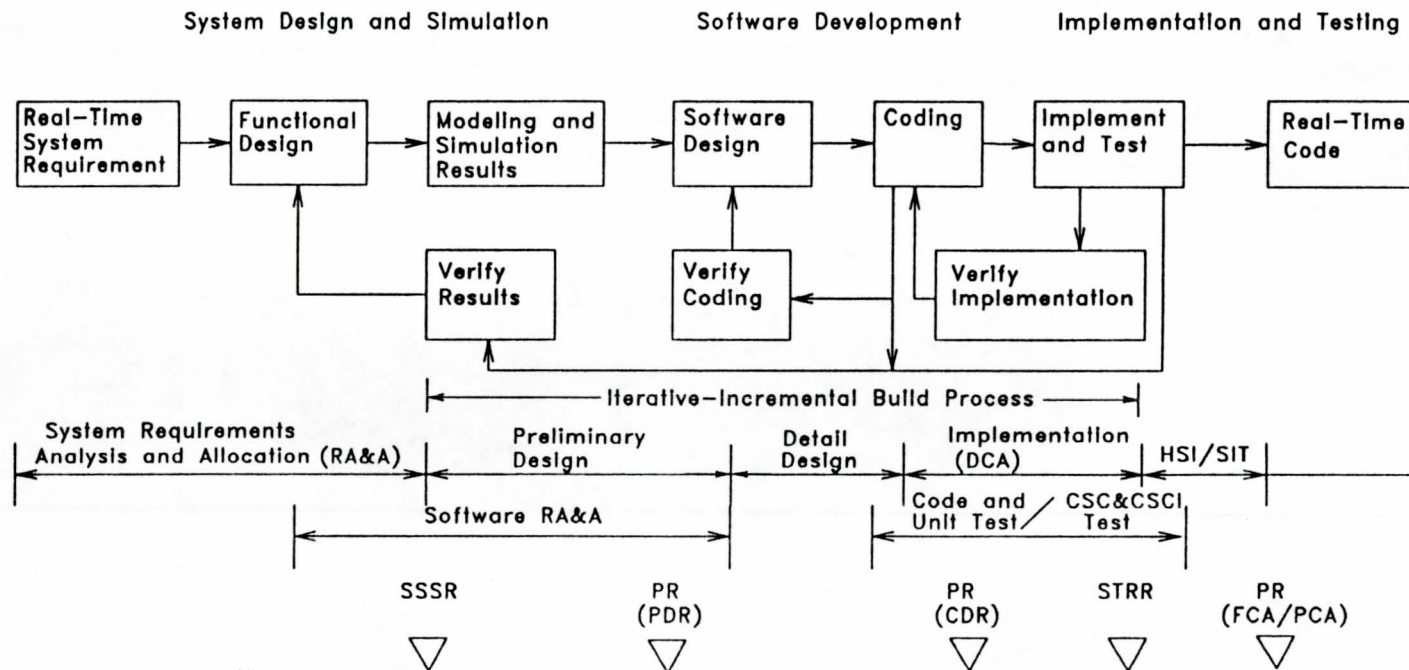
The TESTS project will utilize a tailored MIL-STD-2167A software development approach. A tailored approach to DoD software development standards is proposed to accommodate the prototyping approach to the TESTS development, accommodate the research aspects of TESTS and maintain the cost effectiveness of the TESTS concept. Figure 4-3 provides an overview of the real time system development process which will be implemented in TESTS. It depicts major design, development and test activities, major project milestones. The draft of the TESTS Software Development Plan (SDP) is provided in Annex B of this document. This draft SDP provides a description of all activities in the TESTS development, including documentation. This plan was developed in accordance with DoD data item descriptions.

The term prototype as used herein refers to an instance of a software version that does not exhibit all properties of the final system as defined in DoD-HDBK-287. It is an intermediate stage to the development of the final product. TESTS will be developed following an evolving prototype approach. This approach has the advantage of providing continual feedback on the progress and operation of TESTS. This approach has been successfully used in a number of major DoD programs. While not the standard MIL-STD-2167A approach to system development, the evolving prototype approach is compatible with and can be implemented in compliance with the requirements of MIL-STD-2167A. Figure 4-4 depicts the flow of an evolving prototyping approach within MIL-STD-2167A.

While the TESTS tailored MIL-STD-2167A approach will greatly reduce the project documentation requirements, the UCF TESTS project team recognizes the need for comprehensive and properly developed documentation. The SDP provides for documentation

Figure 4-3 Overview of Real Time System Development Process

REAL-TIME SYSTEM DEVELOPMENT PROCESS



Notes on Tailoring:

- 2167A and 1521B call out 9 major reviews as minimum plus potentially separate HW-SW PDRs/CDRs: Schedule above shows 5 reviews but assumes the PDR, CDR, & FCA/PCA could be replaced by a Progress Review (PR)
- 2167A calls out 17 Data Items and 490A implies A, B and C specs. A potential plan for SW Development would be to combine the SSS (Aspec) and the PIDS/CIDS (B/C) and the SSDD into the Functional Description (FD), DI-E-30104B, with a contractor defined RTM.

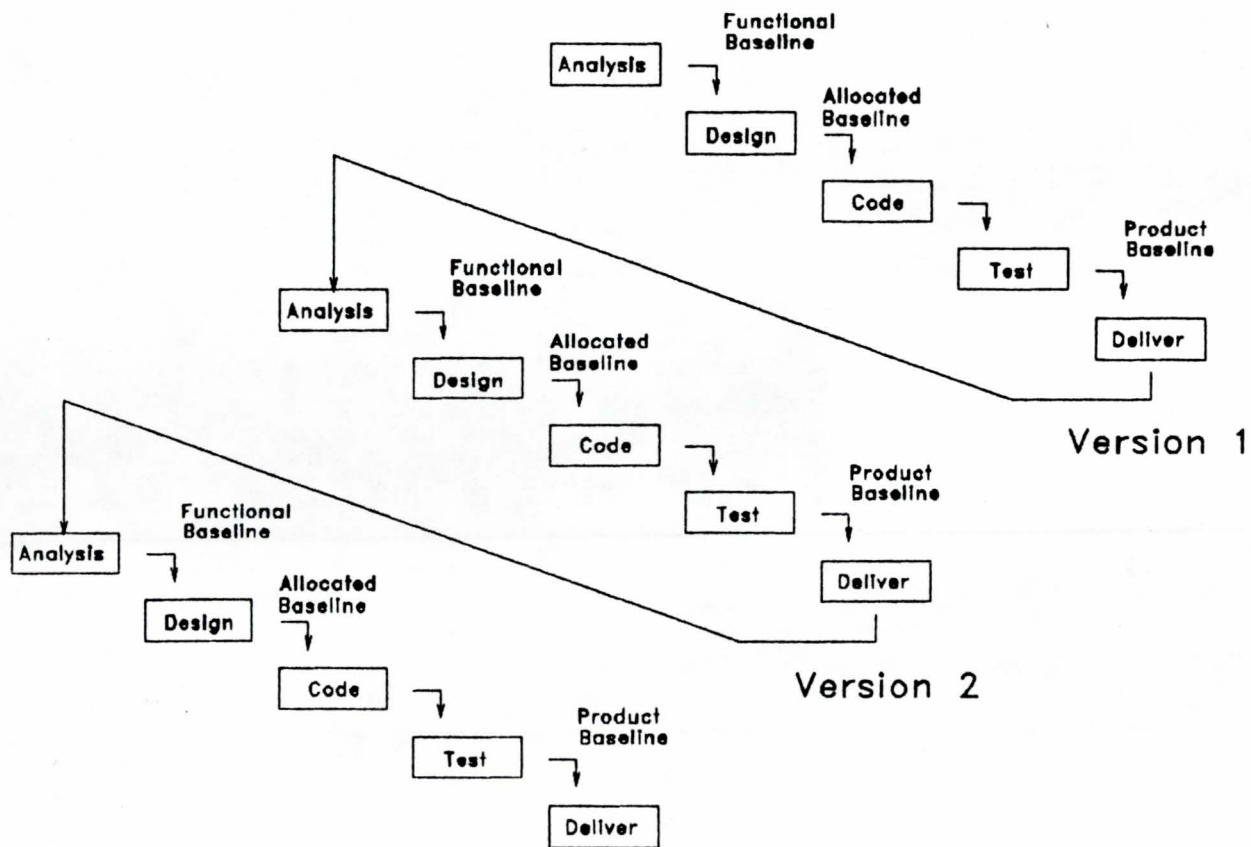


Figure 4-4 Prototyping in a MIL-STD-2167 Development Environment

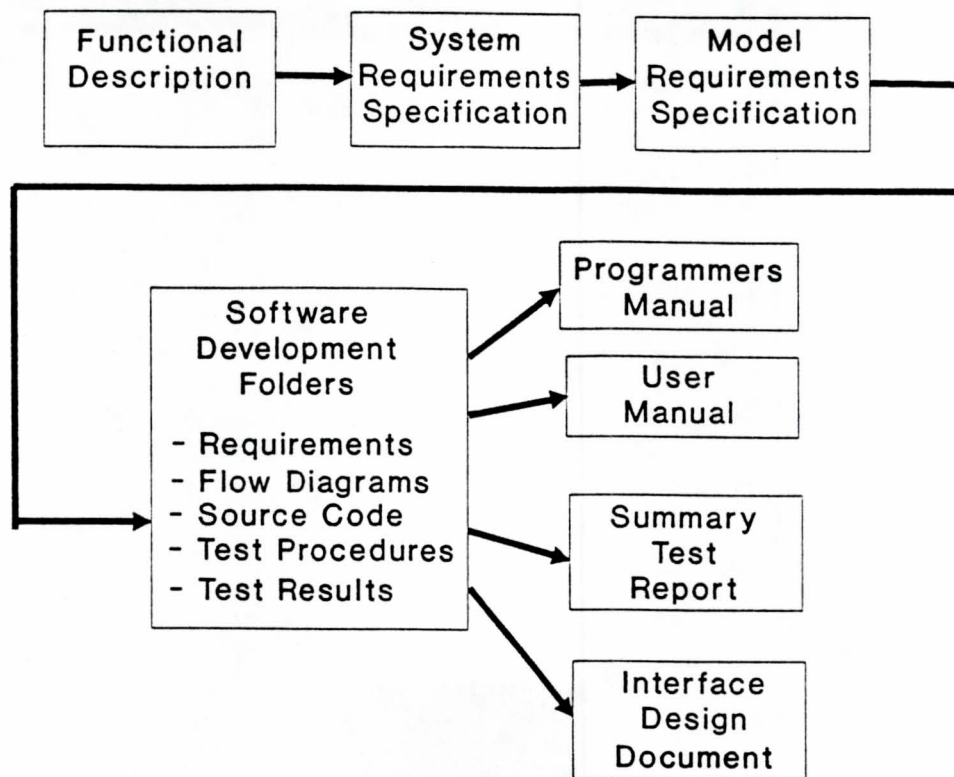


Figure 4-5 Simplified Evolution of Software Documentation

which meets the intent of MIL-STD-2167A. The documentation will provide complete design details, audit trails, manuals, test reports, etc. The goal is to ensure that the documentation will support design reviews, TESTS operation and TESTS software maintenance. Figure 4-5 shows a simplified flow of the documentation development for TESTS. The reader should refer to Annex B, TESTS: Software Development Plan - Preliminary, Section 7.2.2 for a complete list of the documents recommended for TESTS.

4.5 TESTS - CONCLUSION

There are four major functional blocks within the overall TESTS architecture as shown in Figure 4-6 . These major functional blocks within TESTS, which include supporting interface structures, consist of the TESTS simulator component, the TESTS stimulation component, the scenario control component and the environmental component. The first two components comprise the core functionality of TESTS. The later two components are external capabilities required for TESTS to be fully functional.

Simulator Component

In the signal generation operation, the TESTS simulator component generates IFF messages, calculates propagation effects, etc., in software and formats the simulation commands to the stimulation component. In the receiving

operation, the simulator component decodes the received signal and passes it to the data capture facility.

Stimulation Component

The stimulation component is the hardware RF generator portion of TESTS. It includes both the signal generation hardware and the signal distortion, i.e., channel effects, hardware. This component translates the message level simulation command into the appropriate signal signature(s), both data and characteristics, required to stimulate the SUT. On the receiving side, it demodulates the SUT signal and transforms the received signal into a format interpretable by the simulator module.

Scenario control Component

The primary scenario control component for TESTS is SWEG. SWEG provides all of the operational information concerning platforms, and environmental data and terrain data required for multipath and other propagation effects determinations. This component also initializes the appropriate test conditions and provides the interface to other facilities, e.g., CNIL, ACETEF. SWEG will be augmented by a TESTS specific scenario control subcomponent if it is determined that all parameters required for TESTS can not be obtained from SWEG.

Environmental Component

The environmental component provides the jammer/ECM environment for TESTS. This component will be provided by external resources. TESTS will provide the appropriate interface to integrate this capability. Depending upon the TESTS configuration, this capability may be provided by ACETEF through EWISTL or other off-the-shelf hardware.

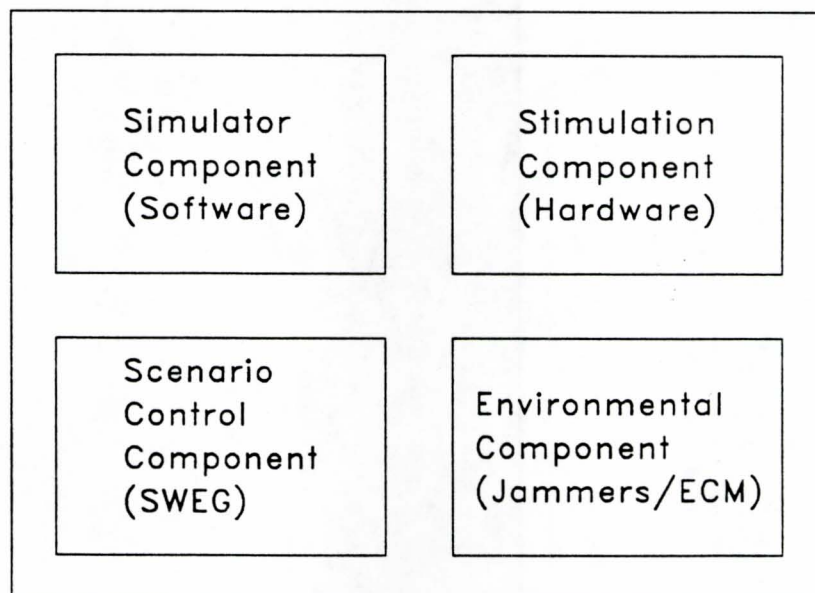


Figure 4-6 TESTS: System Simulator Tool

4.5.1 TESTS Operation

The "system simulator tool" implementation first goes through a set up period for initialization by compiling TESTS software and generating executable code, data map files, interface addresses, scenario inputs and generally structuring the simulator real time program. Initializing starting parameters and selecting emitter/suite from SWEG files is the next step. Calibration of input/output parameters is next to be accomplished. Finally, operation is initiated where stimulation is begun and data analysis/collection is accomplished. A post run analysis of data collection is then completed resulting in the formal output report of the test.

The human interface planned for the operational phase will be made "user friendly" and support easy diagnostic recovery in every respect.

5.0 SUPPORTING ASSESSMENT OF TECHNICAL FINDINGS

The analysis of the defined simulation tool subsystems described in Section 3.0, identifies the technical implementation issues for the feasibility assessment as:

- a) The optimal hardware vs. software implementation/demarkation within the simulation tool.
- b) The technique/method of dynamically introducing channel effects to the generated RF signal.
- c) The determination of multipath signals, how many and how to implement.
- d) Timing analysis to give real-time response (equipment in simulation loop), as well as, supply appropriate fidelity of subsystems to evaluate IFF system against "test objectives."
- e) The generation of "spread spectrum" RF signals using time dependent, waveform spreading changes.

These issues have been surveyed and findings found to answer the feasibility question for this real-time simulator.

The Phase I study period has given the "team" a much deeper understanding of the major technical issues involved with the fabrication of a real-time simulation tool. Each of the issues were examined and one or more implementation techniques for each, was identified. For the most part, this simulator test tool is feasible; its implementation can be accomplished with enough functional flexibility to accommodate additional test objectives, as well as, other associated flight communication and/or avionics equipment. In this respect, the design of the "recommended concept" is open for further evolution.

5.1 SIGNAL GENERATION

This section provides general and specific discussions which support other sections of this report. Some discussions are designed to demonstrate conceptual understanding, while other subsections, i.e., 5.1.4, directly support the recommended TESTS design approach.

5.1.1 Generation of Spread Spectrum Signals (Single or Multiple)

The Spread Spectrum process is the spreading of information energy over a frequency band much larger than the required information bandwidth. This spreading operation makes the transmitted RF signal somewhat transparent in the channel. This feature is very desirable in hostile environments and crowded channels. It reduces the probability of intercept by friendly or unfriendly unwanted receivers, as well as increasing the anti-

jamming capability of the system. Spread spectrum also permits the use of Code Division Multiple Access which allows the use of multiple spread spectrum signaling over the same channel. The two major spread spectrum techniques are Direct Sequence (DS), and Frequency Hopping (FH). Timing and range finding are also operations that can be performed by a DS Spread Spectrum System. DS systems are very well suited for low probability of intercept, while FH systems are better suited for anti-jamming scenarios.

5.1.1.1 Direct Sequence Spread Spectrum System. A transmitted DS spread spectrum signal used in conjunction with a BPSK modulator is modeled by :

$$x(t) = Ad(t)g(t)\cos\{\omega_c t + \theta\}$$

where A is a constant, d(t) is the message signal, g(t) is the spreading waveform, ω_c is the carrier frequency, and θ is the carrier phase. d(t) and g(t) are modeled by:

$$d(t) = \sum_{k=-\infty}^{\infty} d_k p(t - kT_b)$$

$$g(t) = \sum_{j=-\infty}^{\infty} g_j p(t - jT_c)$$

d_k and g_j are the data bits and the spreading bits referred to as chips. T_b is the inverse data rate, and T_c is the inverse chip rate. $p(t)$ is generally a rectangular pulse unless pulse shaping is used.

The received DS spread spectrum signal is modeled by:

$$y(t) = n(t) + \alpha x(t - \tau)$$

$$x(t - \tau) = Ad(t - \tau)g(t - \tau)\cos(\omega_c t + \theta - \omega_c \tau)$$

$n(t)$ is Additive White Gaussian Noise (AWGN), α is the channel attenuation, and τ is the channel delay. The above model does not include doppler shift which can easily be added, nor dispersion.

5.1.1.1.1 Spreading Operation. $g(t)$ is the spreading waveform, it is usually the output of a maximal length sequence (MLS) generator. This MLS is a sequence of bits that repeats every $2^n - 1$ bits, thus forming a pseudo-random sequence. MLS sequences are easily implemented with n shift registers with preset initial conditions, exclusive-OR gates, and strategically chosen feedback paths. The feedback paths are governed by primitive polynomials of order n given by:

$$p(x) = c_n X^n + c_{n-1} X^{n-1} + c_{n-2} X^{n-2} + \dots + c_2 X^2 + c_1 X + C_0$$

These primitive polynomials exhibit some nice correlation properties which makes receiver synchronization possible.

5.1.1.1.2 Despreading Operation. Despreading is possible if the primitive polynomial is known apriori at the receiver, the chip rate needs to be also known before synchronization can take place. A correlator receiver is used to line up the phases of the PN generators of the transceiver. The despreading operation is generally split into two parts. The Code Acquisition or coarse acquisition, and Code Tracking or fine acquisition. Coarse acquisition techniques such as the Rapid Acquisition by Sequential Estimation (RASE), and the Sliding Correlator (SC), synchronize the receiver local PN generator to within one chip. Code Tracking loop such as the Tau Dither Loop, and the Delayed Locked Loop synchronize the transceiver PN generators inside one chip interval.

These synchronization techniques can measure the delay between the PN generator at the transmitter and the PN generator at the receiver.

5.1.1.2 Frequency Hopping Spread Spectrum.

5.1.1.2.1 Spreading Operation. In a FH spread spectrum transmitter, data information is first Frequency Shift Keying (FSK) modulated. A PN sequence generator is used to drive a frequency synthesizer. The output frequency of this synthesizer, which changes over a discrete number of preset frequencies controlled by the PN generator, is used to modulate, via simple mixing, the output of the FSK modulator. The synthesizer output frequency rate of change is called the hopping rate. The output of the FSK modulator is given by:

$$x(t) = A \cos \left\{ 2\pi \left(f_c + d(t) \frac{\Delta}{2} \right) t + \theta(t) \right\}$$

f_c is the carrier frequency, $d(t) = +/- 1$, Δ is the spacing between the two FSK tones, and θ is the phase introduced by the FSK modulator.

The FH transmitted signal can then be modeled as:

$$x_j(t) = A \cos \left\{ 2\pi \left(f_c + d(t) \frac{\Delta}{2} + f_j \right) t + \phi \right\}$$

$f_c + f_j$ is the j th frequency in the discrete hopping band, ϕ is the transmitted carrier phase.

5.1.1.2.2 Despreading Operation. As with DS systems, the primitive polynomial, as well as the chip rate has to be known or generated at the receiver of a FH spread spectrum transceiver. The acquisition process consists also of a two part system. First Code Acquisition or coarse acquisition is performed, CAMP and WAIT is a popular technique. This technique is very similar to the classical Frequency Demodulator Using Feedback.

Once coarse acquisition is achieved, Tracking Loops for fine

acquisition are used. The EARLY-LATE GATE TRACKING SYSTEM is a very popular fine tracking system. The heart of both the camp and wait, and the early-late gate tracking loops is the VCO that drives the receiver local PN generator. The synchronization can be sustained even in the presence of large disturbances, such as jammers, as long as the phase delay between the PN generators of the transceiver is less than $T_H = 1 / f_H$, where f_H is the hopping frequency.

5.1.2 Spread Spectrum Signals with Time Dependent Modulation Formats

5.1.2.1 Time Domain Formats. A PN sequence generated for spread spectrum communication is composed of various schemes for providing secure communications, low probability of intercept and anti-jam capabilities. This is accomplished by modifying a message to be transmitted by spreading it in time, using pseudo-random, but known, series of pulses, and then having the known code at the receiver for the matched filter, or de-spreading, sequence. The spreading in time reduces the power at any one frequency, thereby appearing to be a noise source while the matched filter at the receiver requires knowing the code for the matched filter, yielding security and processing gain.

As an example, let's assume the smallest pulse ever transmitted is 10nsec wide and is of a quadrature phase shift key (QPSK) format. The spectral energy in the frequency domain is a sampling function having a null bandwidth of 200MHZ and a first sidelobe -13dB referenced to the peak response. This is illustrated in Figure 5-1.

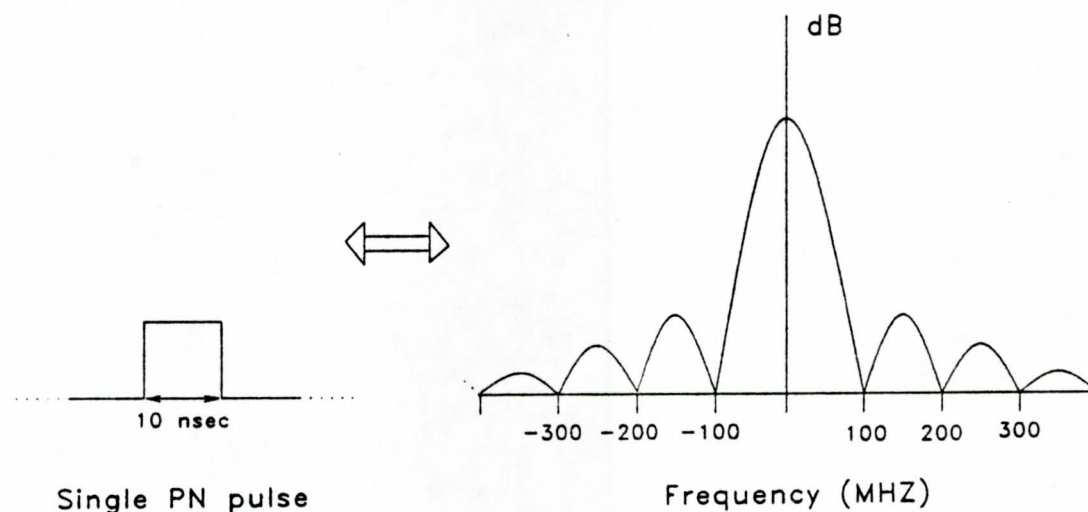


Figure 5-1 Spectral Energy in the Frequency Domain

The bandwidth and sidelobe roll off are set by the pulse shape (rectangular) and pulse width (10nsec). Narrowing the pulse width increases the frequency information bandwidth while smoothing the pulse shape (i.e., gaussian as an example), reduces the sidelobe level and out-of-band spurious generation.

A message is obtained by serial strings of pulses generated in a prescribed manner. Given a linear system, the time response can be modeled as the sum of multiple time responses with their respective frequency responses. Figure 5-2 illustrates this concept of superposition.

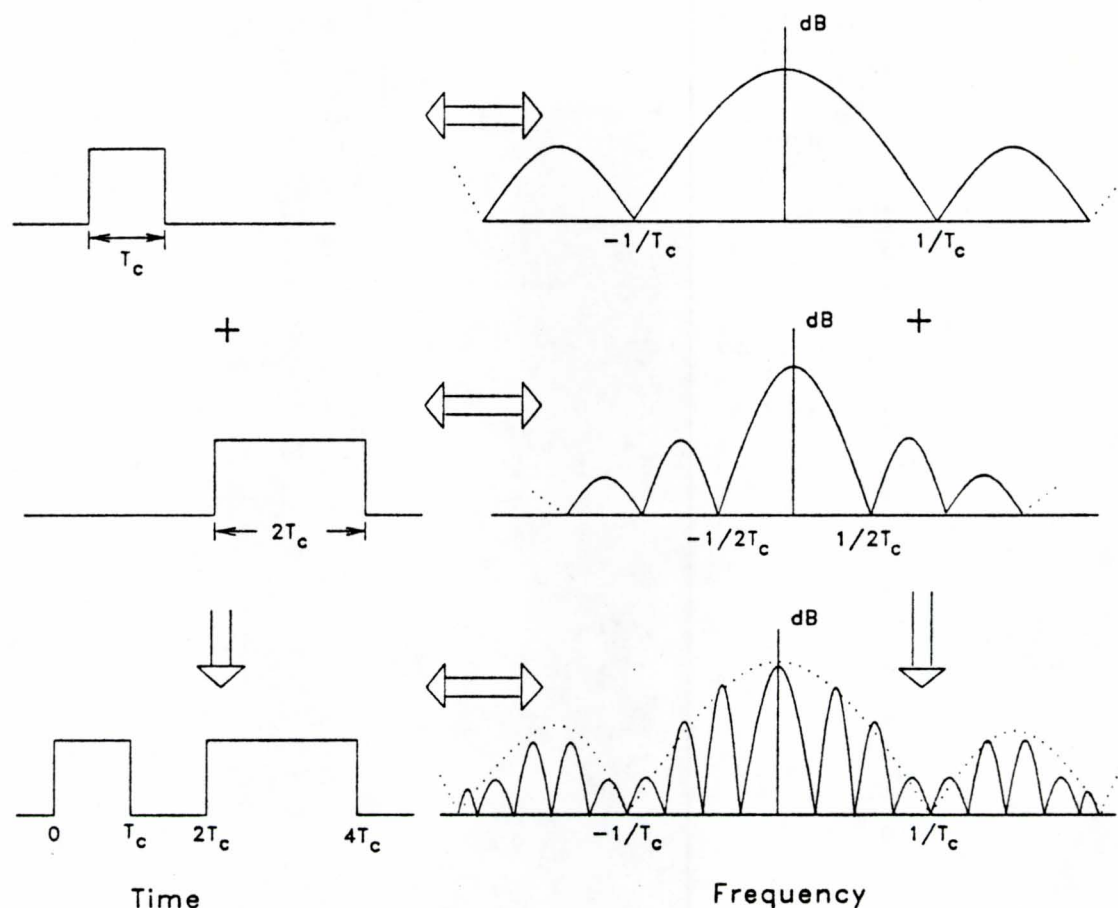


Figure 5-2 Concept of Superposition

The combined filter effect in the frequency domain of Figure 5-2 is dependent on the delay between pulses. However, the envelope of the spectrum of the magnitude of the frequency is fixed by the narrowest pulse. This can be expanded to an infinite sum of pulses.

As an example, choose a train of equal pulse width pulses having equal amplitude, and constant delta time, and arbitrary phase. In time, this can be written as

$$h(t) = a_0 \text{rect}\left(\frac{t}{\tau_c}\right) + a_1 \text{rect}\left(\frac{(t - \Delta t)}{\tau_c}\right) + a_2 \text{rect}\left(\frac{(t - 2\Delta t)}{\tau_c}\right) + a_3 \text{rect}\left(\frac{(t - 3\Delta t)}{\tau_c}\right) + \dots$$

where $a_n = \pm 1$ and are pseudo-random.

Then

$$H(f) = \tau_c Sa\left(\frac{\omega \tau_c}{2}\right) [a_0 + a_1 e^{-j\omega \Delta t} + a_2 e^{-j\omega 2\Delta t} + \dots]$$

The sampling function, (Sa), defines the envelope of the signal which is independent of the bracketed argument. Therefore, $H(f)$ or the bandwidth of information transmitted is only a function of τ_c , which is a function of the pulse width. The coding is embedded in the a_n terms. As a_n changes, a unique time and frequency function are simultaneously defined.

If pulses of varying width are used or if there is a delay between pulse sequences, the method of superposition, as shown above, can be applied. Again, the information bandwidth is determined by the smallest pulse width. Therefore, any delays or staggered intervals are normally greater than a pulse width within the message.

As an example, in typical systems which are sending information, messages or bits of information may be staggered by integer values of τ_c , as shown in Figure 5-3.

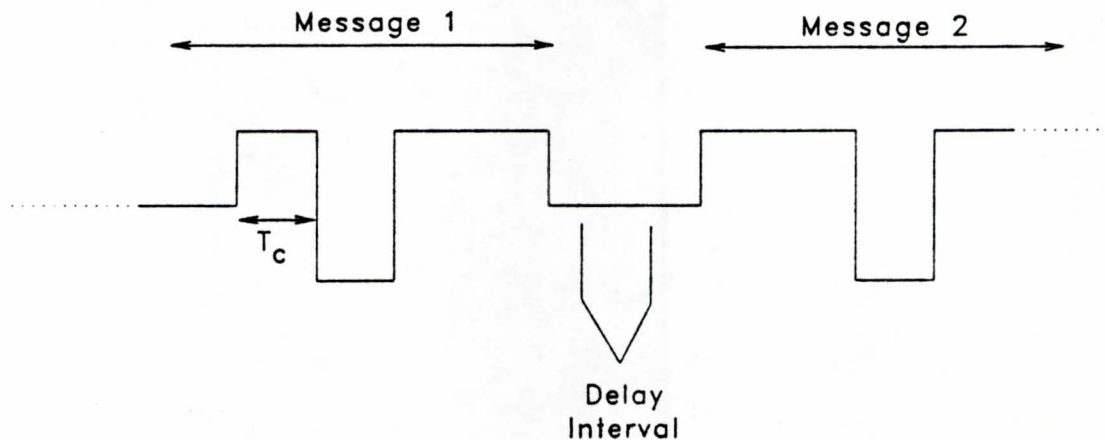


Figure 5-3 Illustration of Information Stagger

The delay interval in Figure 5-3 is 3τ . The effect of the delay interval is to produce spectral energy within the information bandwidth.

5.1.2.2 Operational Use of Time Dependent Formats. A point to point communication system consists of a transmitter and a receiver. Time dependent modulation formats may be thought of as modulation systems whose parameters vary with time. This means that the operation of both the transmitter and the receiver changes with time. This concept is best explained through the use of illustrations.

A block diagram of a generalized time dependent modulation transmitter is shown in Figure 5-4. The modulator generates signals in time as a function of both the time varying message data and the time dependent modulation control signal. The time dependent control signal is generated through the interpretation of time dependent code sequences which are in turn generated from a time dependent code generator. Communications security depends on the fact that the time dependent code generator uses code generation algorithms and time and initialization conventions which are unknown to those who are foreign to the specific communication process.

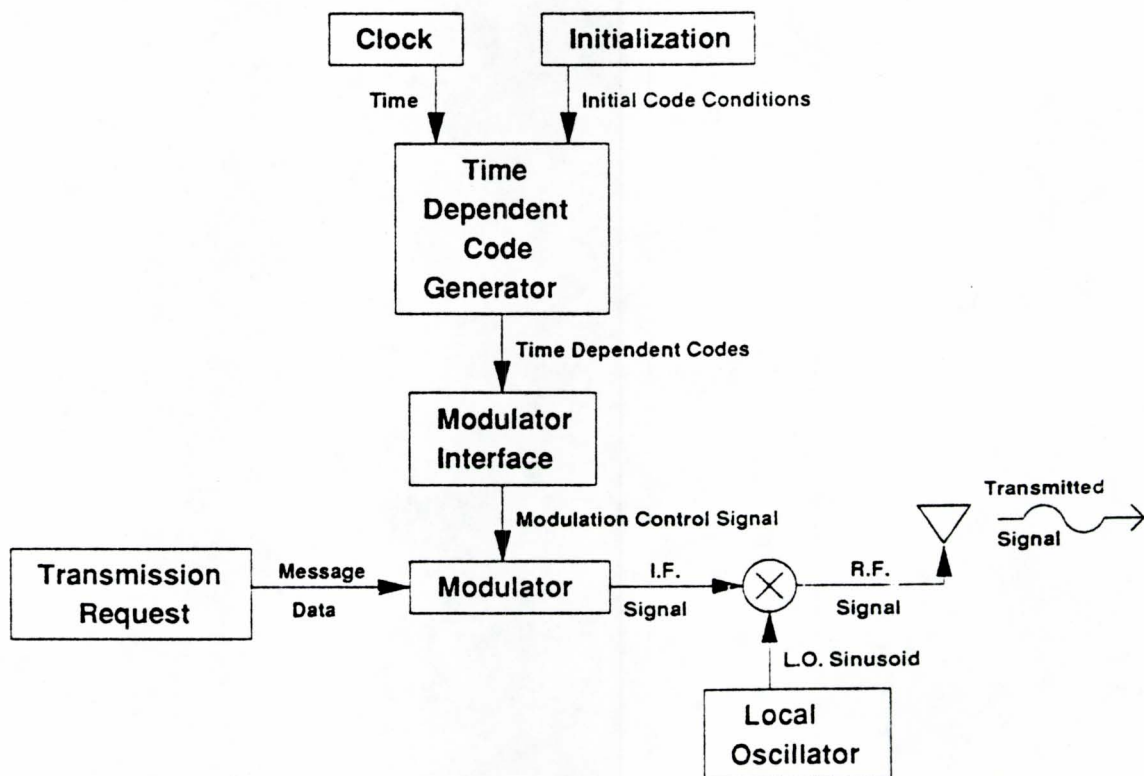


Figure 5-4 Block Diagram of Transmitter for a Communication System Employing Time Dependent Modulation Formats.

For clarity it should be stated that the "Modulator" block in Figure 5-4 includes any error correction encoding or preliminary processing done on the message data. It is also shown that modulation takes place at a convenient "I.F. " or "Intermediate Frequency" which is convenient to the system designer. An "L.O." or "Local Oscillator" is used to raise the signal to the desired transmission frequency. These details are common to most communication systems.

A time dependent modulation receiver is pictured in Figure 5-5. Again, a time reference, an initial condition reference and a code generation algorithm are required. This time they are used in demodulation or interpreting the received signal. Successful demodulation requires that the time reference, initialization reference and code generation algorithm be common to both the demodulator and the modulator.

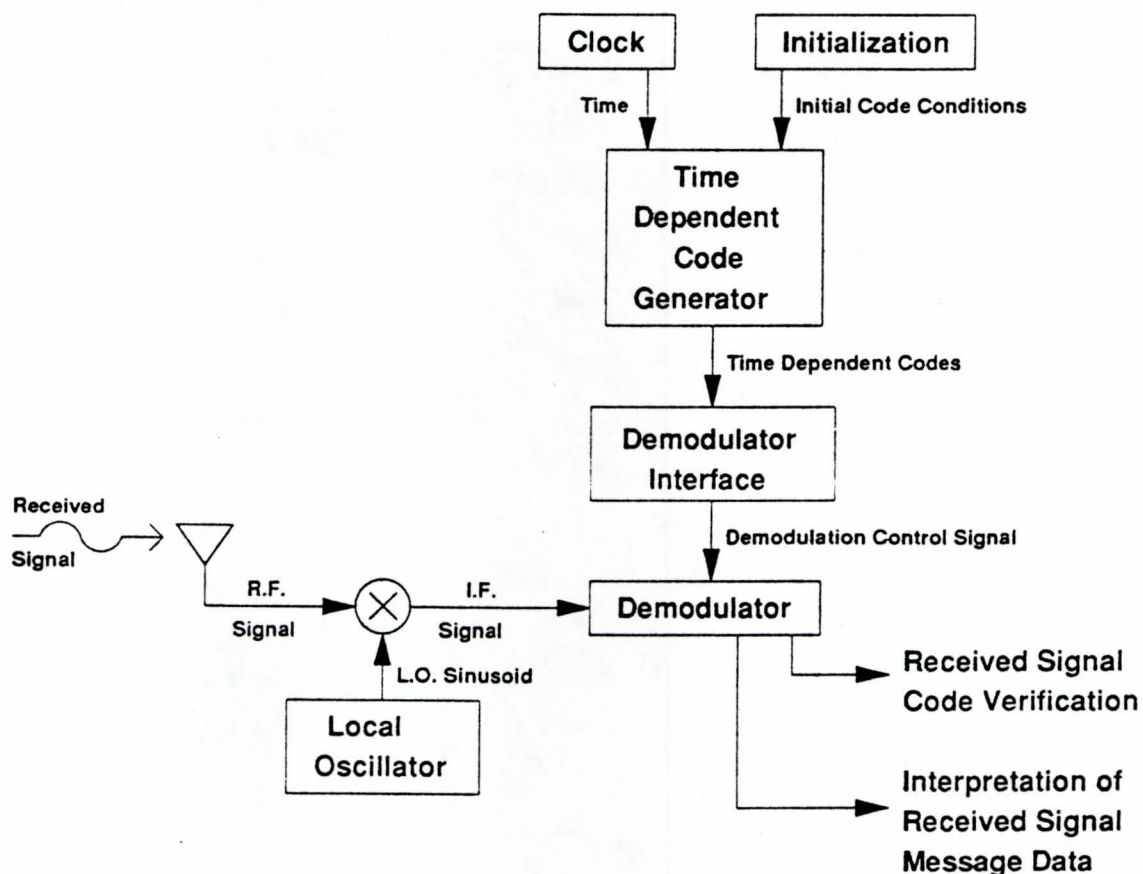


Figure 5-5 Block Diagram of a Receiver for a Communication System Employing Time Dependent Modulation Formats.

An interface step is used to convert the time dependent codes to the demodulator control. The demodulator uses various comparison techniques to determine whether the received signal or signals were modulated using the same time dependent coding format. If code verification is accomplished then demodulation, or interpretation of the received message data, is possible.

Again, processing is done at the most convenient I.F. frequency. The demodulator takes care of error correction and data post processing.

5.1.2.2.1 Examples of Communication Systems With Time Dependent Modulation Formats. Examples of systems where time dependent coding is used in modulation are helpful in understanding the function of time dependent modulation formatting. Four illustrated examples follow. Illustrations decouple preliminary data encoding from the modulation process in order to emphasize the parts of the modulation processes which are time dependent by nature.

Direct Sequence Spread Spectrum

When applied to direct sequence spread spectrum communications, time dependent formatting and deformatting is represented by time dependent PN sequence spreading and despreading. An illustration of a time dependent code PN modulator is shown in Figure 5-6.

The PN sequence generator pictured applies an algorithm to the time dependent codes to produce a PN sequence. The direct sequence modulator multiplies the time varying PN sequence with the encoded data and then multiplies it by an I.F. carrier. The resulting direct sequence I.F. signal is converted to an R.F. signal and transmitted.

An illustration of a time dependent code direct sequence demodulator is given in Figure 5-7. The only way a received signal may be demodulated is for the direct sequence demodulator to have access to the same PN sequence as the modulator. When this is the case the received signal code will have been verified. It would then be possible for the receiver to interpret the information content of the modulated signal.

For the PN sequence to be present and the signal to be demodulated the system requires that the demodulator have the same time dependent code generation algorithm, the same time and the same initialization as the modulator. Time dependent modulation formats offer communications security but require time synchronization.

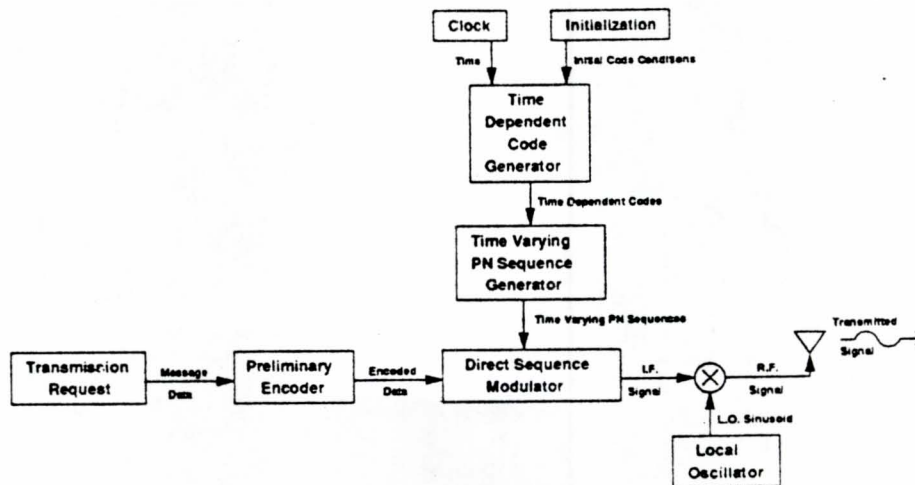


Figure 5-6 Block Diagram of a Transmitter for a Direct Sequence Spread Spectrum Communication System Employing Time Dependent PN Spreading Sequences.

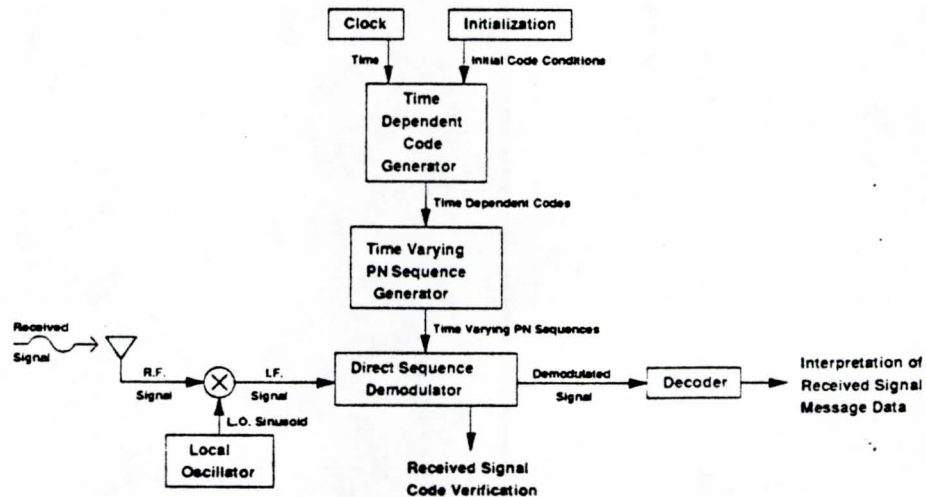


Figure 5-7 Block Diagram of a Receiver for a Direct Sequence Spread Spectrum Communication System Employing Time Dependent PN Spreading Sequences.

Frequency Hopping Spread Spectrum

A frequency hopping spread spectrum modulation system which employs time dependent formatting is shown in Figure 5-8. Time dependent frequency hop systems derive their ever changing hop patterns from the secure time dependent code generator. Frequency sequences serve the same purpose in frequency hop systems as PN sequences in direct sequence systems.

A time dependent frequency hop format demodulator is shown in Figure 5-9. As for direct sequence demodulation and PN sequences, frequency hop demodulation systems require that the frequency sequence be known before demodulation may take place. This means, in time dependent format systems, that the means for generating time dependent modulation codes must be available to the demodulator for communication to be successful.

Pulse Width Modulation

The use of time dependent coding for modulating a pulse width modulation process is illustrated in Figure 5-10. The demodulation system is given in Figure 5-11. Again, time coordination and shared coding initial conditions and algorithms make communication possible.

Pulse Position Modulation

Another modulation technique which may utilize time dependent formatting is pulse position modulation. The transmitter and receiver associated with this system is illustrated in Figures 5-12 and 5-13. Time dependent codes/formats are used to vary, in time, the manner in which encoded data is pulse position modulated.

Cascading Time Dependent Modulation

It should be noted that these and possibly other time dependent format implementations may be cascaded to achieve multiple levels of communication security. In the cascaded time dependent format implementation one time dependent modulation format would serve as the "encoding" or "preprocessing" step for the time dependent modulation formats which follow it.

5.1.2.2.2 Impact of Time Dependent Formats on R.F. System Simulation and Stimulation. R.F. communication system simulation and stimulation require modulation and demodulation capability. This capability, for a given time dependent modulation format, requires a test tool with the same time dependent code generator, time reference and initial condition as the hardware it is testing.

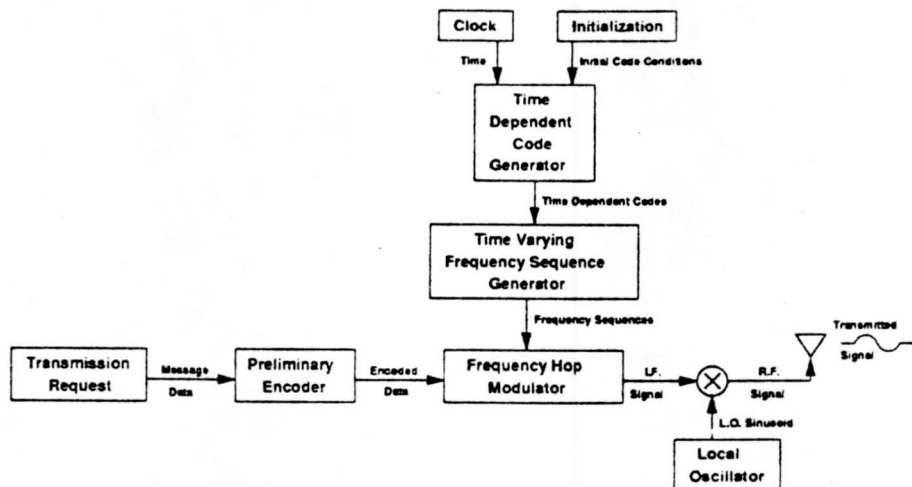


Figure 5-8 Block Diagram of a Transmitter for a Frequency Hopping Spread Spectrum Communication System Employing Time Dependent Frequency Sequences.

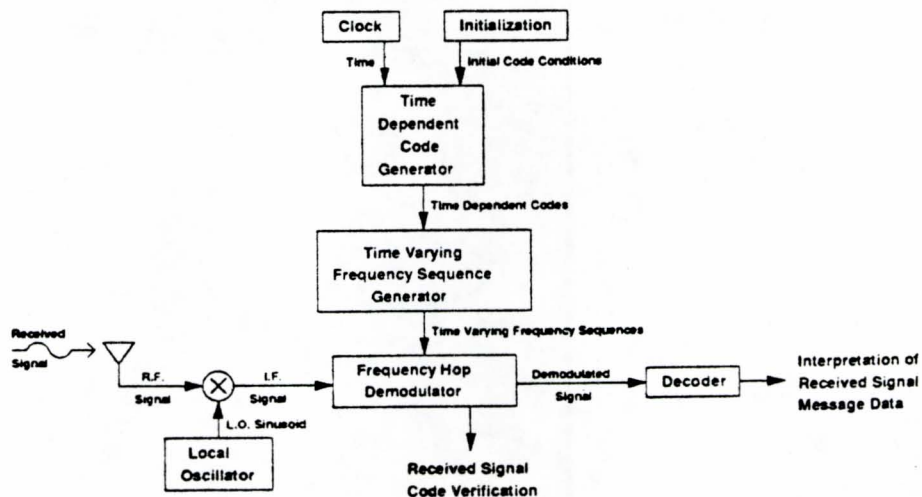


Figure 5-9 Block Diagram of a Receiver for a Frequency Hopping Spread Spectrum Communication System Employing Time Dependent Frequency Sequences.

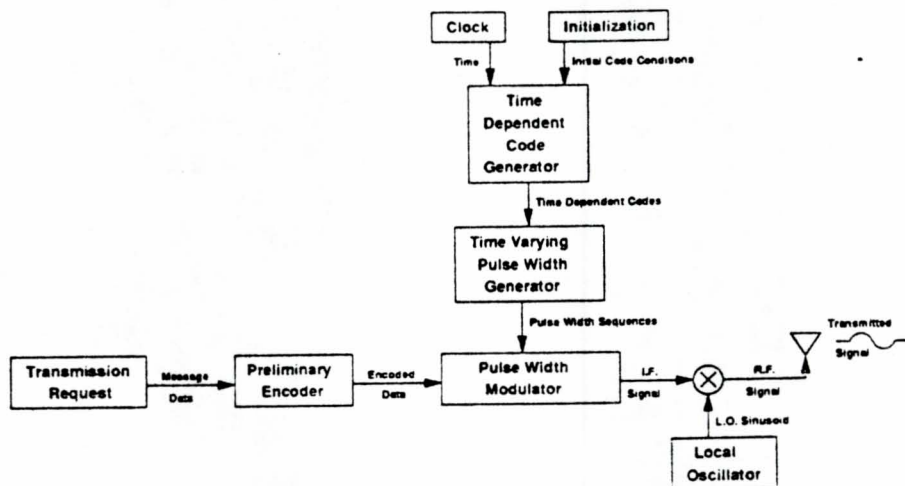


Figure 5-10 Block Diagram of a Transmitter for a Pulse Width Modulation Communication System Employing Time Dependent Pulse Width Sequences.

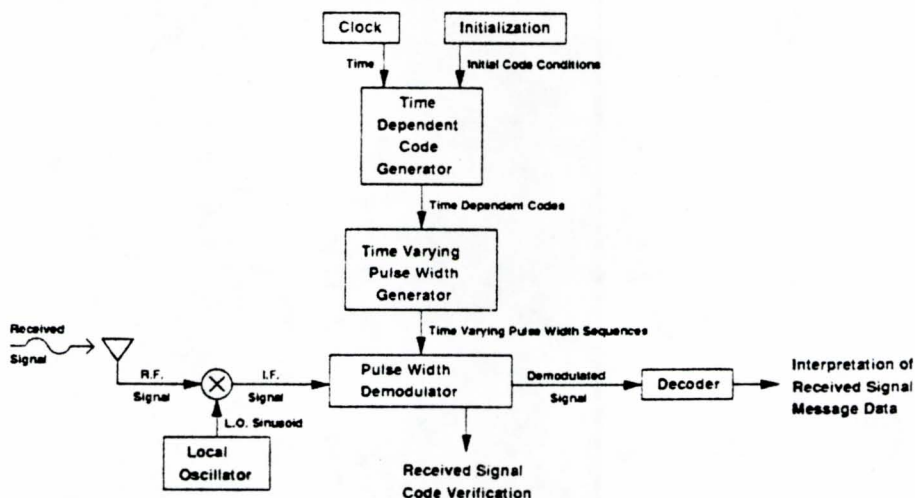


Figure 5-11 Block Diagram of a Receiver for a Pulse Width Modulation Communication System Employing Time Dependent Pulse Width Sequences.

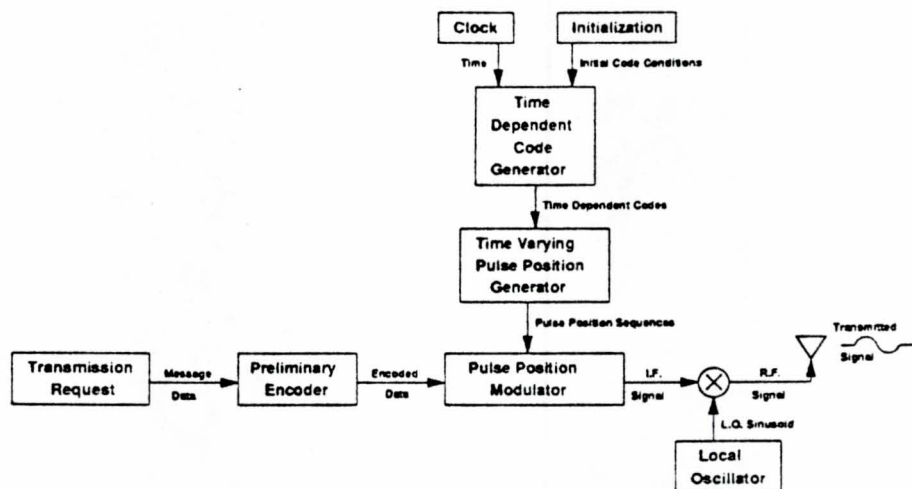


Figure 5-12 Block Diagram of a Transmitter for a Pulse Position Modulation Communication System Employing Time Dependent Pulse Position Sequences.

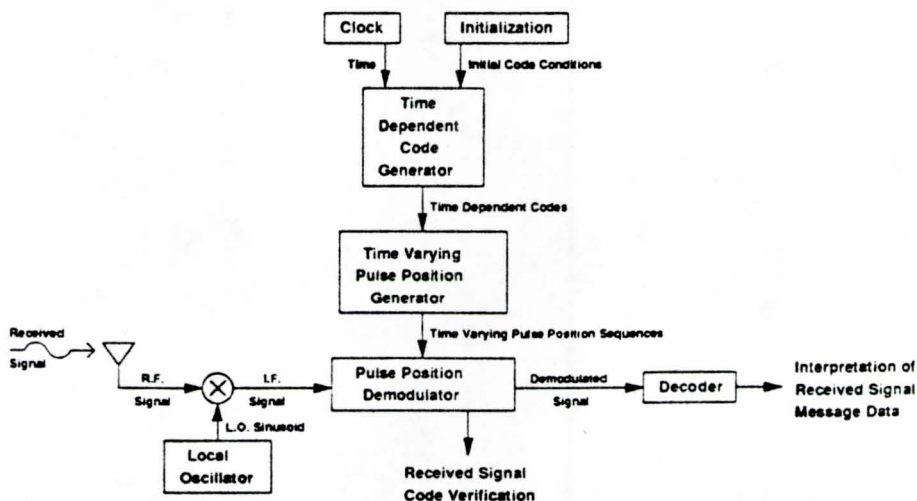


Figure 5-13 Block Diagram of a Receiver for a Pulse Position Modulation Communication System Employing Time Dependent Pulse Position Sequences.

5.1.2.3 Summary. Time dependent modulation formatting may be applied to any modulation technique. Time dependent formatting provides communications security but adds complexity to the modulation and demodulation systems. Successful communication through systems employing time dependent formatting requires time synchronization, common code generation algorithms and shared initialization conditions. Successful testing of systems which employ time dependent modulation formatting requires that these parameters be included in the testing tools.

5.1.3 Mathematical Fundamentals of an I/Q RF Signal Generation Model

The communication system test tool under development requires the modeling and synthesis of RF signals. A set of RF signal model conventions are presented. A set of signal model conventions such as this will provide the basis for modeling RF signals under the influence of attenuation, time delay, dispersion and superposition. A model such as this will provide the foundation for computer simulations of RF signals. Hence, this model was also treated as part of design Concept A in Section 3.5.1

The given model is based on a center frequency for simulation and represents an RF signal in terms of its time dependent in-phase and quadrature (I and Q) components, or its cosine and sine envelopes. This is shown to be equivalent to modeling an RF signal on the basis of its instantaneous amplitude and phase. Time sampling and quantization may be applied to this model in order to make it suitable for computer simulation. A consistent frequency domain model is shown to be compatible with conventional fast Fourier transform techniques. It is shown how the modeling conventions introduced may be used to apply attenuation, time delay, frequency shift, dispersion and superposition to RF signals modeled by their I/Q components. The mathematical development is shown in Annex A.

5.1.4 Implementation for Simulation Tool

The major element identified to successfully implement this real-time simulation tool, as recommended in Section 4.1, is a software driven hardware interface subsystem called an "RF Signal Conditioner." Its function is to dynamically modify the RF signal amplitude, phase, frequency and to be able to insert time delays into the signal process.

The rationale for the proposed implementation is to use the computer to generate data and perform calculations necessary to drive the required hardware. This may, in itself, tax the speeds of the fastest computer. The hardware performs special tasks, in a serial manner, in either the digital or analog domain. The key feature is to use the optimum hardware configuration for the best/required processing gain. Computer simulations of real time spread spectrum systems will typically require giga-flops speeds while hardware implementation will require less than 100 MHz clock rates on the fastest components.

5.1.4.1 Signal Generation.

Computer Software Driver - The proposed approach for signal generation of the MK XV spread spectrum system is shown in Figure 5-14. It is composed of a computer which provides software generation of the message and provides hardware driver information on lines D-1-D₄. It is proposed that the message be developed to the necessary complexity as required by the MK XV and compatible with real-time operation. The effective data rates associated with spread spectrum modulation will limit the role which software plays in signal generation.

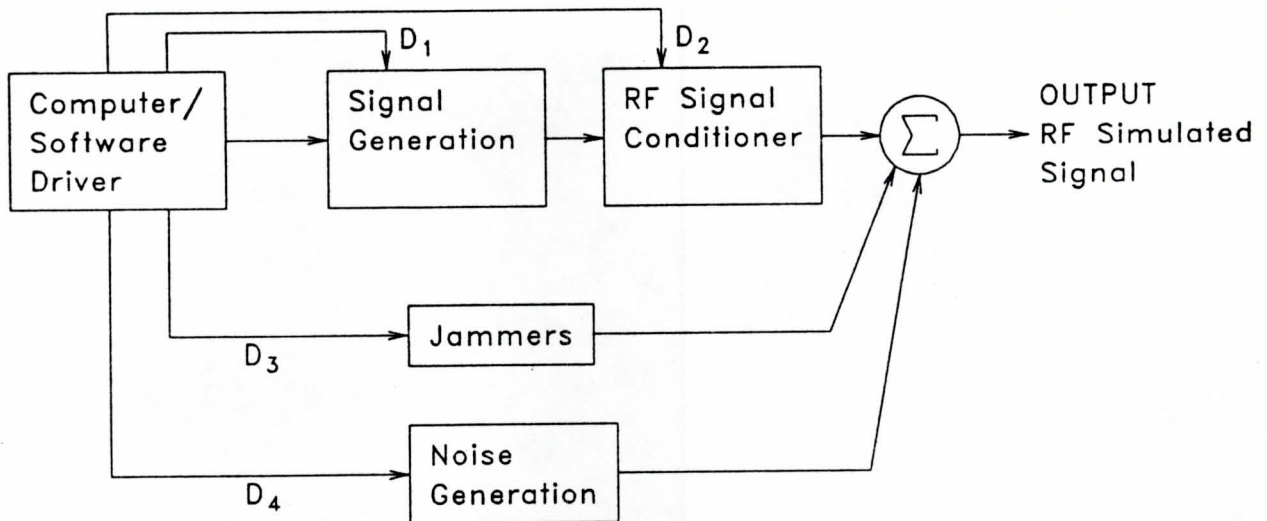


Figure 5-14 Signal Generation System Overview

Signal Generation - The signal generator under computer control will format the signal per the MK XV specifications. This will be accomplished using quadrature modulation hardware, PN direct sequence or frequency hopping generators for spreading, the proper encryption hardware, filter, mixing and other signal manipulation. The output from the signal generator should be a properly formatted, near ideal signal with the waveform characteristics and data content requested by the controlling computer. The signal generator will be agile, i.e., can output arbitrary waveforms, within its own limitations and the driver inputs.

RF Signal Conditioner - The RF Signal Conditioner will take the ideal signal and condition it via known inputs. There are a finite number of signal parameters which will model all environmental and second order effects, namely:

- a. amplitude
- b. phase

- c. delay
- d. frequency offset

Dispersion is a second order effect that can be modeled by implementing a combination of changes to the amplitudes and phase of the signal.

Figure 5-15 illustrates an implementation of a RF Signal Conditioner which sets the programmable amplitude, D_{21} ; delay, D_{22} ; phase, D_{23} ; and frequency offset, D_{24} .

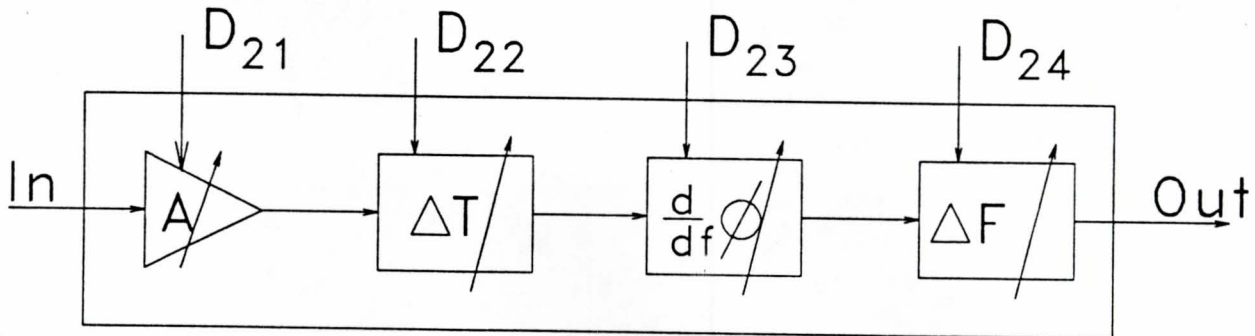


Figure 5-15 RF Signal Conditioner

Jammers - The jammer should be a signal generator capable of generating pulsed signals, frequency hopped or direct sequence spread spectrum signals, or continuous wave jamming signals. TESTS will provide the appropriate interface to integrate and control the jamming capability. Depending upon the TESTS configuration, this capability may be provided by ACETEF through EWISTL, or other off-the-shelf hardware.

Noise Generation - The noise processor will be computer controlled and capable of generating white noise and possibly other types of signals to be determined in the future by the Navy.

Signal Summation - The summation of the conditioned RF signal with noise and jamming signal components is preformed via hardware summing devices and provided as the output simulated signal.

5.1.4.2 Detector-Demodulation Tools. The detector-demodulation implementation will undergo a reverse process, as shown in Figure 5-16.

The RF signal received from the SUT will be converted, de-encrypted and de-spread, base band converted and analog-digital converted for sampling. The computer will take the data and analyze the response for probability of error, message integrity and other parameters of interest.

The detector-demodulator will verify the signal simulation tools or can be used in a closed loop system, simulating communications of a MK XV transceiver system.

RECEIVED RF SIGNAL

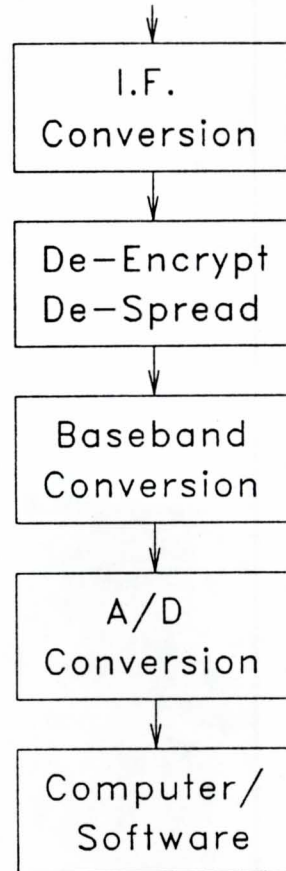


Figure 5-16 Detector-demodulation Tools

5.2 NEAR-FIELD EFFECTS AND MODELING OF ANTENNA PATTERN EFFECTS

This problem can be divided into the following parts (tasks):

Antenna Effects

These are the effects of antenna height above any ground plane. The presence of a ground plane changes the radiation patterns of the antenna and its gain by introducing vertical lobing. That means that the signal transmitted by the system will have some nulls in some directions. These directions must be determined.

Platform Effects

The radiation patterns of an antenna is dependent on the geometry of the platform (ship, plane, ground surveillance system, etc.) and the location of the antenna on a specific platform. The proximity of the antenna to various objects on a platform changes the near field pattern as well as the far-field patterns. Any nulls or depolarization changes

introduced by the specific platform should be accurately predicted and accounted for in any communication link.

3-Dimensional Patterns

Complete azimuthal and elevation plane patterns are critical since received and transmitted signals propagate in any direction. The ability to predict the radiation patterns in any plane cut will determine the gain, power and sensitivity needs of the receiver and transmitter.

These effects are near field effects and are due to the proximity of two or more antennas to each other. In a diversity system more than one antennas will be used. The effects of interaction between the two or more antennas should be known. Both maximum and minimum power transmitted from the antennas are related to their degree of coupling. The amount of coupling and its effects on input impedance of the antennas are important for the correct calibration of the system.

5.2.1 State-of-the Art Available Models

The state-of-the art models that we propose to use are summarized as follows:

a. NEC-Basic Scattering Code

High Frequency

Based on the Uniform Theory of Diffraction

It can handle various platform Geometries

b. New Air

High Frequency

Based on the Geometrical Theory of Diffraction

It can handle aircraft platforms (If antenna is placed on fuselage)

c. INAC-3

Low Frequencies

Based on the method of moments

It can handle ship and aircraft geometries

d. GEMACS

Most Frequencies of Interest

Hybrid method (GTD and Method of Moments)

Good for aircraft platforms and ship configurations

e. STRIPES

Most Frequencies of Interest

Transmission Line Method -It requires a mesh generation (could be a frequency limitation)

It can be applied to various platform geometries.

The above models can achieve about 70% of our objectives.

5.2.2 Technical Approach

5.2.2.1 Antenna and Platform Effects. In order to have any kind of relation with real world performance, the antenna characteristics have to be incorporated on the stimulation signal. The near field and far field patterns can be incorporated in terms of power, gain, directivity, phase, and polarization. The stimulated signal will depend on the efficiency and gain of the transmitting and receiving antennas. Currently, there are various models and methods that tackle the desired tasks. Basically, all of them can be categorized in three groups as follows:

- a) High Frequency > 100 MHz
In this category, the Geometrical Optics (GO) [1-3] and the Geometrical Theory of Diffraction (GTD) [4-5] are used to find the reflected and diffracted fields from any platform. Some existing models such as, "New Air" are limited to the specific placement of the antenna on an aircraft, for example, the fuselage. Others, are limited to the type of platform that they can handle (i.e., aircraft, ships, etc.) and some can predict only far-field patterns and some only near-field patterns.
- b) Low Frequency < 100 MHz
In this category, the method of moments [6-7] is primarily employed to solve for the induced currents and then evaluate the scattered field. Again, this approach is limited to low frequency applications and small structures in terms of wavelengths.
- c) High-Low Frequency
In this case, hybrid techniques are used. Combinations such as the method of moments and GTD [8] are utilized to cover a larger frequency range. An example of that is "GEMACS." Still, they do not cover all geometries. Another example is "STRIPES" that makes use of the Transmission line method.

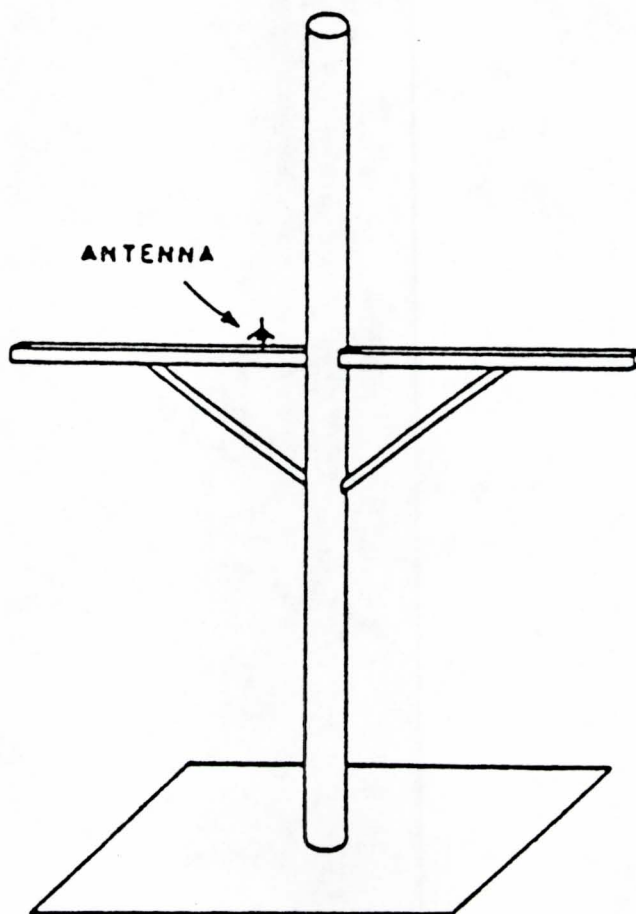
We propose to use a combination of all three approaches (Hybrid model) that will cover the entire frequency of interest for the IFF problem and for a wide variety of platforms.

The state-of-the art models that will enable us achieve this goal are:

- 1) NEC-Basic Scattering Code which can be used to predict far-field patterns of various antennas placed on different platforms, such as ships, aircraft, missiles etc. We cannot use this particular program to study

near field effects or coupling between two antennas.

- 2) New-Air Code which can be used to find both near and far-field patterns of antennas mounted on aircraft or missiles. This program which is also a high frequency model will be used primarily to predict near field effects. Figures 5-17 and 5-18 show examples what of structures that these two codes cover. Both codes have been developed at Ohio State University.
- 3) INAC-3 is a good model that can be used for lower frequencies since it is based on the method of moments. In this code, arbitrary complex two or three dimensional objects are modeled by linear segmented wire frame structures as shown in Figure 5-19. It can be used to find a) the far-field components of all field components, b) the near field distribution for all field components, and c) the current and charge distributions.

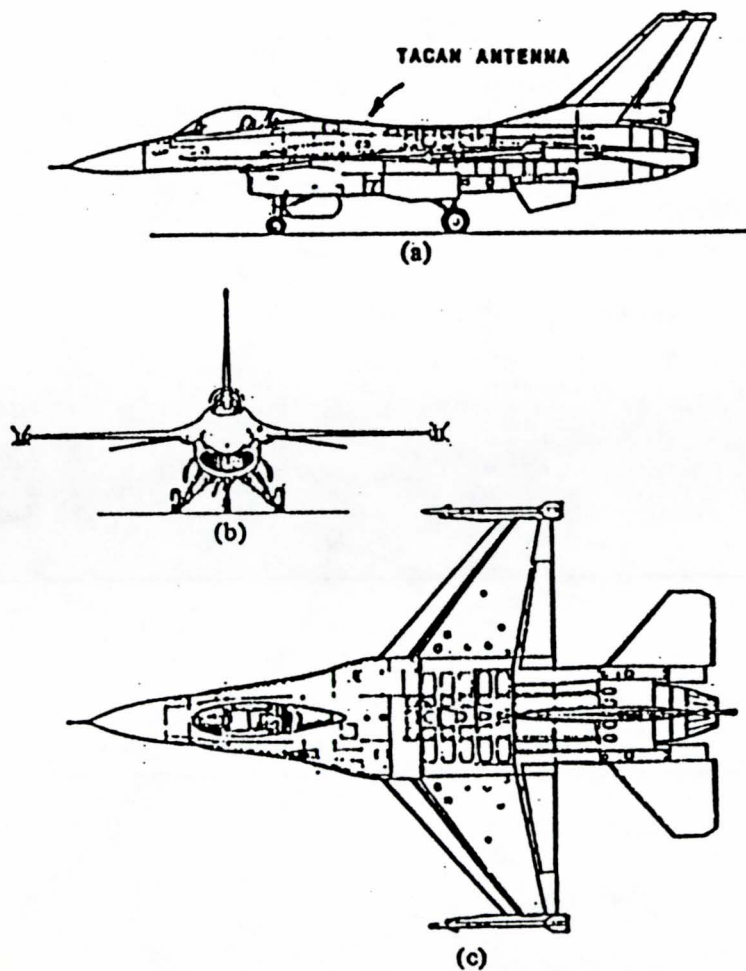


Example of an antenna in a typical shipboard environment.

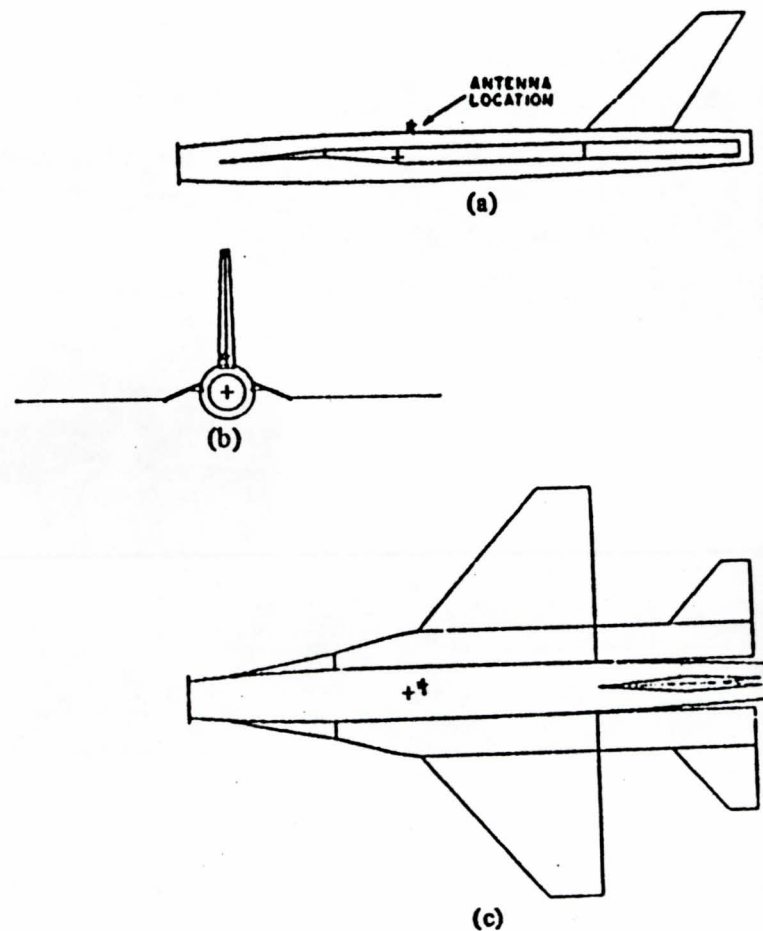
Figure 5-17 A "New-Air" Application Example A

Figure 5-18 A "New-Air" Application Example B

5-22



F-16 fighter aircraft. (a) Side view. (b) Front view. (c) Top view.



Computer simulated model of an F-16 fighter aircraft. (a) Side view. (b) Front view. (c) Top view.

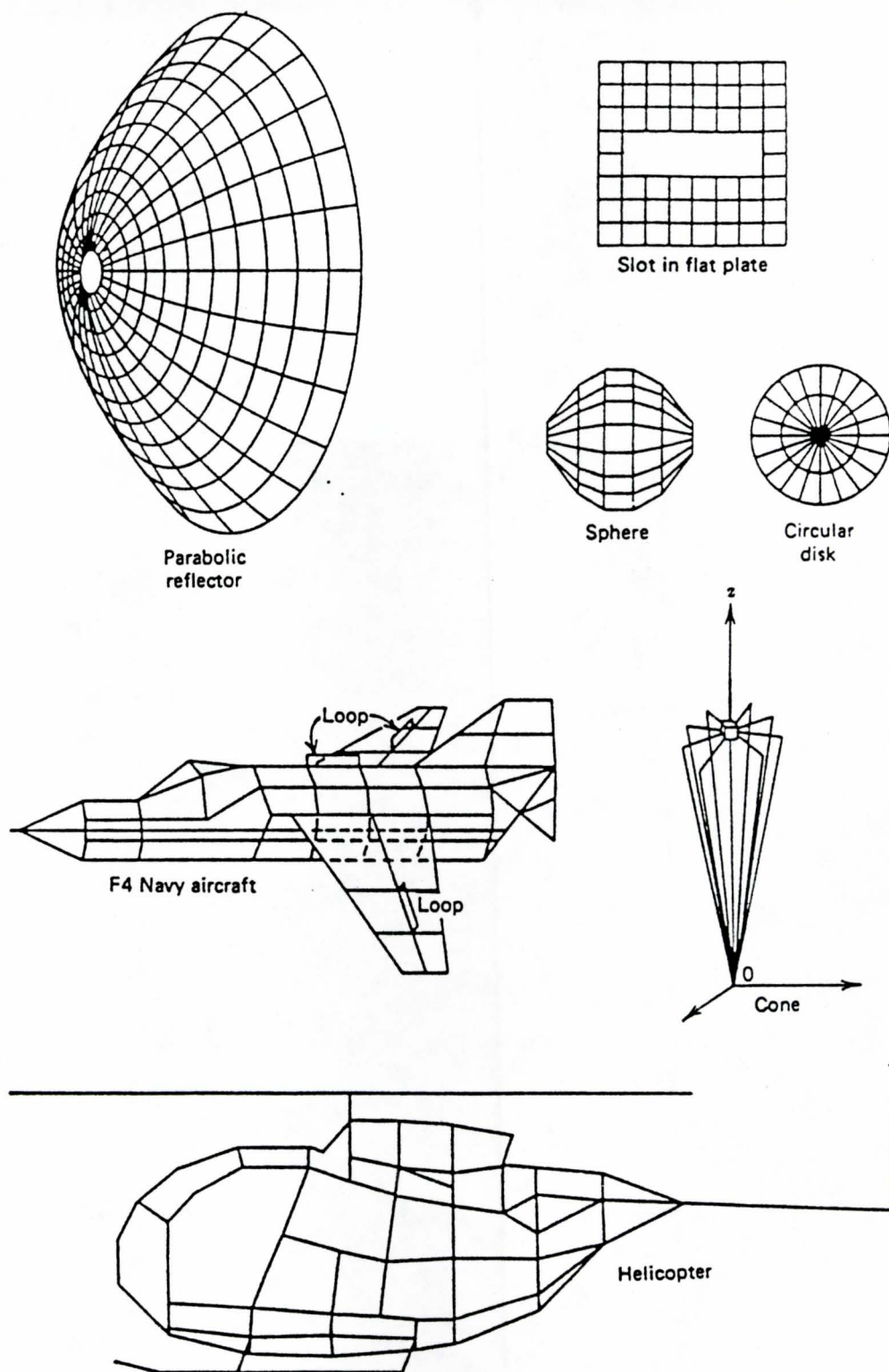


Figure 5-19 Wire-frame Structures for the Method of Moments

- 4) GEMACS is a hybrid method. It combines both the Geometrical Optics approach and the method of moments. This seems to be the most appropriate model for the TESTS project.
- 5) STRIPES is based on the transmission line method and is not intrinsically limited in frequency. The only requirement is that the physical space of the platform is modelled by a mesh with resolution no coarser than 10 cells per wavelength (Figure 5-20). Therefore, STRIPES is only limited in frequency in terms that computer capacity may be exhausted.

We intend to study these models, extensively, modify them and combine them to generate a hybrid model that will yield far and near field patterns for all frequencies of interest, as well as, most platforms pertinent to IFF scenarios.

5.2.2.2 Three-Dimensional Patterns. Currently, flight measurements at NAVAIRTESTCEN and other facilities can yield complete azimuthal plane patterns and partial elevation patterns. The limitation on the elevation pattern is due to flight dynamics as shown in Figure 5-21. This limitation can be very critical in a real life situation since interrogations and responses can be transmitted or received in any direction and angle. The capability of having a three-dimensional radiation pattern will greatly enhance the confidence and reliability level of a communication link between two vehicles. Also, having a model that can predict, accurately, three dimensional patterns will save a lot of time and money by reducing the number of flight measurements required.

The models described in the previous section will also lead in the generation of three dimensional patterns.

5.2.2.3 Coupling Among Antennas. The degree of coupling between two or more antenna depends on the type of antenna under test, their location on the platform, their proximity to various conducting objects, their frequency of operation and the polarization of the transmitted and received waves. This problem could be quite complex and it will require further research once the information on the antennas and their arrangement are known.

We intend to include this option into the model that will be developed to handle the 3-D radiation patterns and platform effects, since a change in the coupling changes the patterns as well. Coupling is important because it can change the gain of the transmitting and receiving antennas. Without this information the system cannot accurately be calibrated.

Coupling is directly related to the near field effects of the antennas. An accurate near field pattern without allowing for any coupling could first be obtained using standard antenna theory. This could also be obtained experimentally, or depending on the complexity of the pattern, it could be extracted from a

TLM model of an F111 aircraft illuminated by an E-field plane wave along the fuselage to predict axial current densities J_A

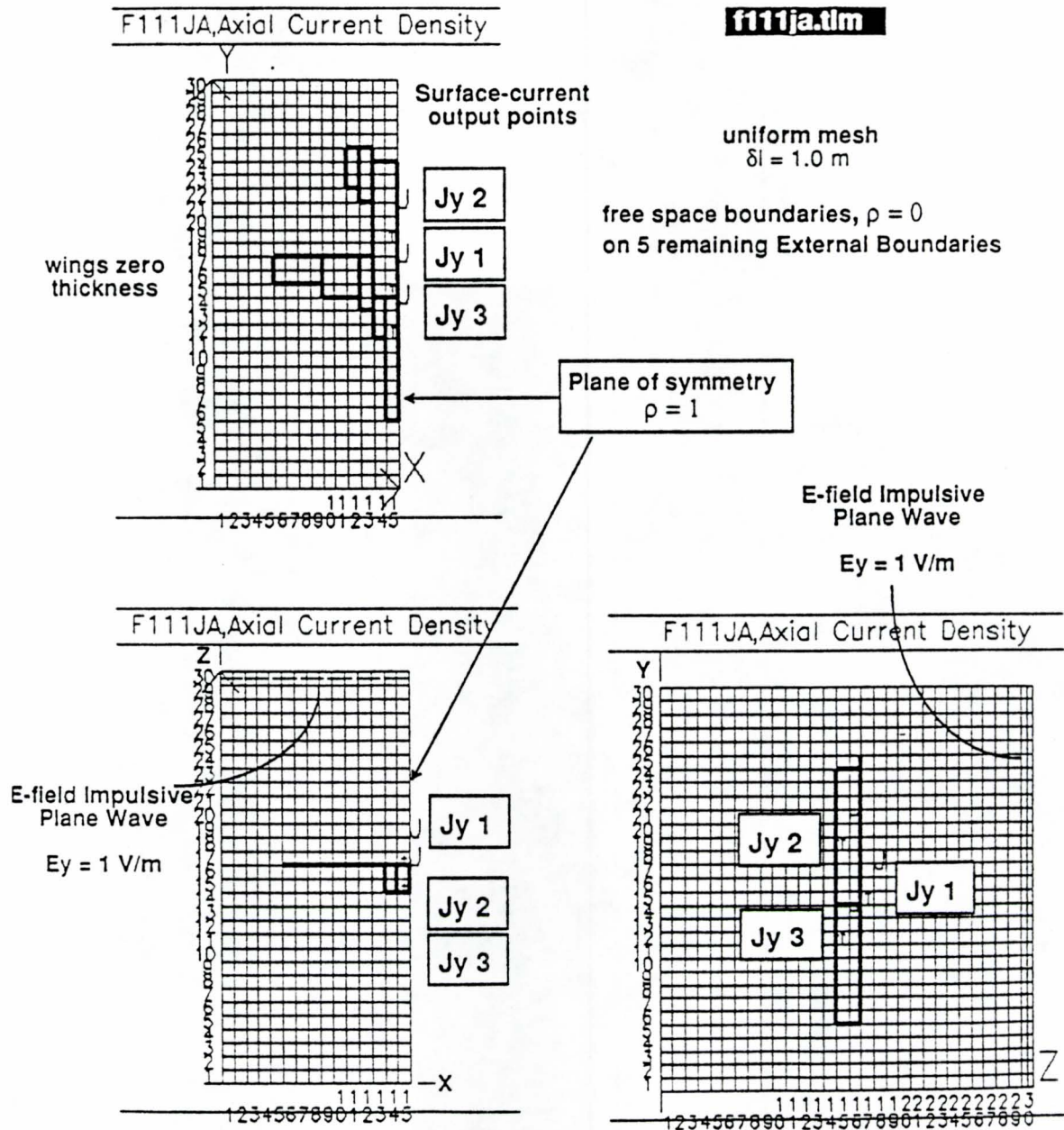
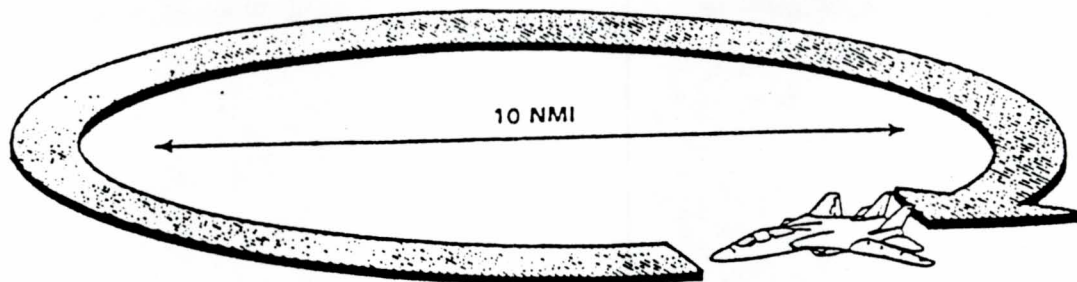
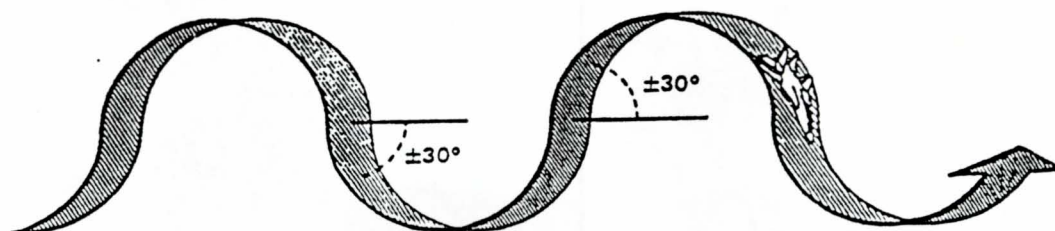


Figure 5-20 A "STRIPES" Application Example



Orbit Turn



Porpoise

Figure 5-21 Flight Profiles at NAVAIRTSTCEN

knowledge of far field characteristics. The coupling would be introduced as a second step and its effects on the antenna near field characteristics would be studied.

5.2.3 Testing and Verification

1. Far-field and near field patterns.

Will be verified by comparing our data against published theoretical and experimental data, as well as, data provided by NAVAIRTESTCEN.

2. 3-D plots

Can be verified by comparing our results with available in flight measurements from NAVAIRTESTCEN. Some additional in-flight measurements may be required for further verification of this part.

3. Coupling

It can be verified, partially, by using experimental techniques, such as, lab measurements and in-flight measurements. Prior to the verification of this part the platform effects and 3-D patterns should be verified.

All the above mentioned effects should be incorporated on the stimulation signal to produce a real life IFF scenario.

5.2.4 References

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- [10] INAC-3 (Interactive Antenna Software Package), Applied Electromagnetics Engineering, Volder Halden II D-777, Salem 1, Germany.
- [11] GEMACS- Rome Air Development Center.
- [12] Stripes, Kimberly Communication Consultants Ltd., Unit 104, Plessey Business Park, Technology Drive, Beeston Nottingham, NG9 2nd.

This problem can be divided into the following parts (tasks):

Sea Surface Reflection

Predict the effects of multipath propagation and their probability of occurrence due to sea reflection on the received signals. These effects will introduce signal fading, phase delay and depolarization. The point of reflection between a transmitter and a receiver should also be determined given the distance of the transmitter and receiver and their height above the sea. Reflection from random sea surfaces (other than calm state) should also be determined.

Near Land Effects

Predict the multipath effects due to the proximity of land to a sea body. In this case, not only reflections but paths emanating from diffraction phenomena due to the surrounding terrain near a sea body should also be included. The amount of energy and diffracted depends on the geometry of the land near the sea body and its electrical properties.

Complex-Irregular Terrain

Find the multipath effects (and the probability of their occurrence) on the transmitted signal due to various land terrains. Land terrains are characterized by irregular distributions of obstacles, such as, hills, buildings, trees, etc. A model based on statistical methods, should be developed to predict the probability of occurrence, the signal attenuation and phase delay of a transmitted pulsed and/or spectrum signal.

5.3.1 Technical Approach and State-of-the Art Available Models

The presence of the earth (hills, buildings, sea, lakes, etc.) near a radiating antenna affects the radiation mechanism by introducing the following phenomena [1].

- a) Reflection or Scattering of energy directed towards the earth (hills, sea, etc.). The amount of energy reflected and its direction depends on the geometry and electromagnetic properties of the ground, sea, etc.
- b) Diffraction Phenomena due to the introduction of finite size objects in the path of the incident field.
- c) Refraction Effects due to atmospheric inhomogeneities which lead to ducting, ray bending, etc.

In this analysis, we categorize the terrain into two main categories:

Sea Reflection
Near Land and Irregular Terrain.

5.3.1.1 Sea Surface Reflection. For this problem we intend to use Balanis' model [2], which covers:

1. Receiver and transmitter antenna heights.
2. Path length and divergence.
3. Receiver and transmitter antenna beamwidths and polarization states.
4. Frequency.
5. Ground-to-air cases.
6. Air-to-ground cases.
7. Air-to-air cases.

This formulation is well documented and valid provided the sea surface is smooth. It does not consider any other sea states due to various wind conditions. To summarize Balanis' approach consider two paths, a direct and a reflected one, as shown in Figure 5-22, emanated from a vertical dipole. The total E_θ component for example can be written as [3]:

$$E_\theta = \frac{j\eta k I_o e^{-jkr}}{4\pi r} \sin\theta \left[e^{-jkh\cos\theta} + DR_v e^{-jkh\cos\theta} \right]$$

where D , is the divergence factor that takes into account the spreading (weakening) of energy from a curved surface given by [4]:

$$D \approx \left[1 + 2 \frac{h'_1 h'_2}{a d \tan^3 \psi} \right]^{-1/2}$$

and:

h'_1 = height of source point above the earth

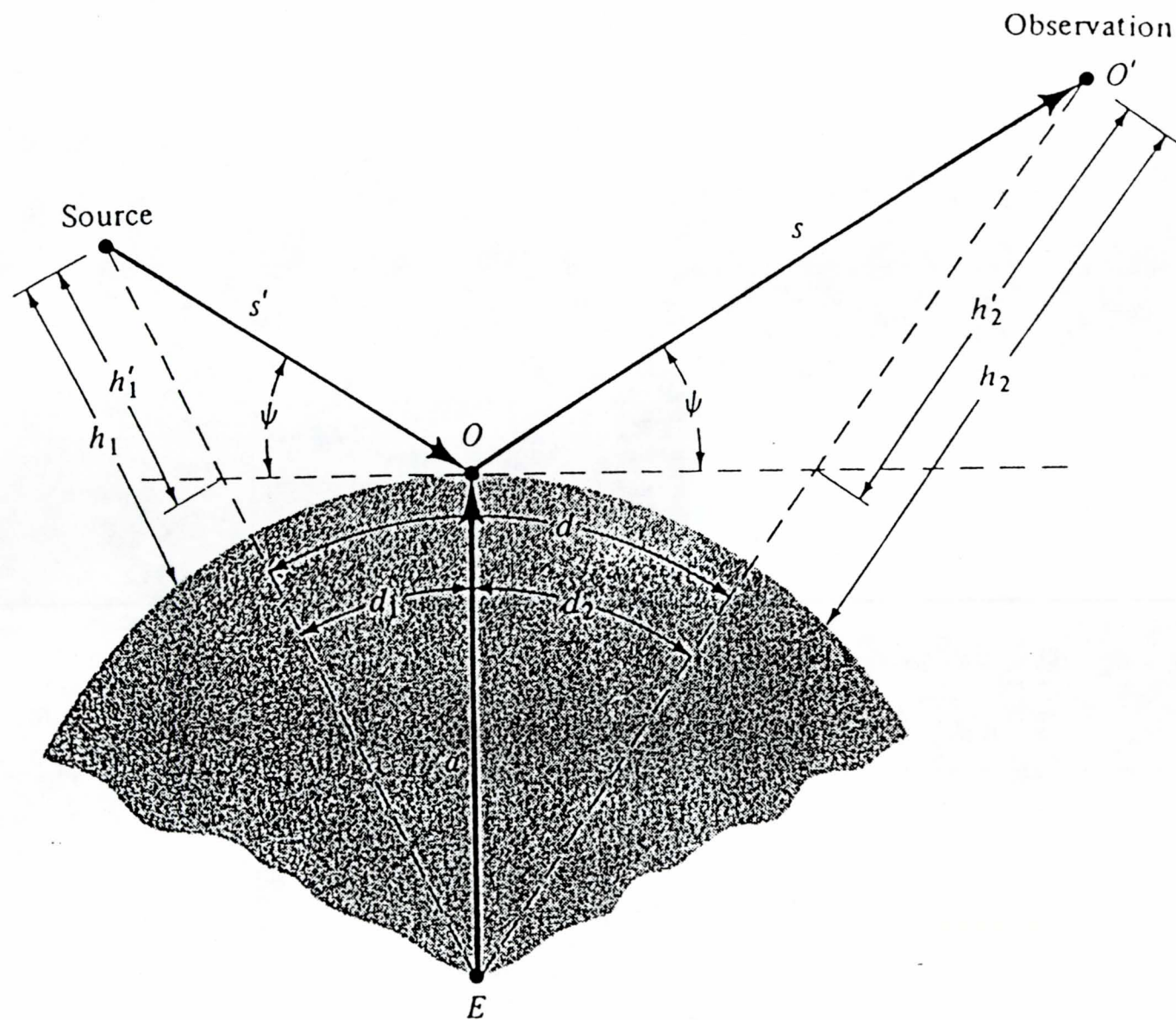
h'_2 = height of observation point above the earth

d = range between the source and the observation point

a = radius of the earth (4/3 radius of earth is used)

ψ = reflection angle with respect to the tangent at the point of reflection

R_v = reflection coefficient for vertical polarization



Geometry for reflections from a spherical surface.

Figure 5-22 Geometry for Reflections from a Spherical Surface

Also:

$$s' \approx \frac{h'_1}{\sin\psi}$$

and

$$s \approx \frac{h'_2}{\sin\psi}$$

In a real life situation, one will have to replace the pattern of the vertical dipole by the pattern of the antenna placed on a specific platform. This is important since the shape of the receiving or transmitting antenna patterns, as well as, their height above sea surface will determine the actual reflection point from which the reflected wave emanates from. For an incident plane wave there will be only one reflected path.

The above mentioned model does not consider any other sea states or wind conditions. However, this formulation can still be used for other rough surfaces provided the geometry satisfies the Rayleigh criterion [5]:

$$h = \frac{\lambda}{8\sin\psi}$$

where:

h = maximum height of waves

λ = wavelength

ψ = grazing angle.

If this condition is not satisfied then a statistical analysis will be required since the reflecting surfaces become random surfaces. This complicates the formulation because depending on the height of the waves there may be more than one reflected paths directed towards the receiving antenna. The problem here is to determinate an average reflection coefficient and the probability that a ray of significant magnitude will be reflected towards the receiver.

5.3.1.2 Near Land and Irregular Terrain. Normally, irregular multipath propagation exist in hilly terrain, but it can also be found in any populated areas where obstacles, such as, buildings, trees, etc. are present. System degradation due to multipath effects depends on the particular system used. In this project, we are interested, primarily, in pulse communication systems. In particular, the delays of the reflected or

diffracted pulses pose a potential problem, depending on the pulse width and the amplitude of the reflected (diffracted) pulses and the distance of separation between the receiver and transmitter.

Usually, the amplitude of the reflected pulse has to fall within a certain range above and below the amplitude of the direct-path signal before system degradation occurs. If the reflected signal is substantially smaller than the direct-path signal it is suppressed. On the other hand, if the reflected signal is larger then it is locked onto instead of the direct-path signal. For this project, it is important that we develop a model that predicts the frequency of occurrence of multipath propagation and determine the delay and change in amplitude.

Over the years, various models have been developed for different terrains, heights above these terrains, frequency of operation, range, and pulse width of transmitted signals. The two models that we are proposing to start with are explained herein:

5.3.1.2.1 **Model 1-Multipath for Pulse Signals.** In this model [6], the probability of occurrence of multipath propagation of pulse signals over irregular terrain at VHF and UHF are determined. In free space the available power received by an antenna is given by:

$$P_{r,o} = P_t(G_t/4\pi R^2)A_e$$

where:

$$A_e = G_r\lambda^2/4\pi$$

$$G_t = \eta D$$

Under the assumption of a smooth plane earth and at near grazing propagation [7] the power received is:

$$P_{r,p} = P_t G_t G_r (h_t h_r / R^2)^2$$

where:

P_t = transmitted power

G_t = gain of transmitting antenna

G_r = gain of receiving antenna

D = directive gain of antenna

R = transmitter-receiver distance of separation

A_e = effective aperture of antenna

η = antenna efficiency

h_t = height of transmitting antenna

h_r = height of receiving antenna

In practical situations, the assumption of a smooth earth is not valid and additional losses occur that must be accounted for. For "Irregular" terrain, Egli [8] gives a statistically derived expression for the median received power at frequencies above 40 MHz as:

$$P_{r,50} = P_t G_t G_r (h_t h_r / R^2)^2 (40/f)^2$$

for a $h_r > 9$ meters. $P_{r,50}$ is the median (exceeded in 50 of the locations) small-sector received power as shown in Figure 5-23. Frequency is denoted by f . This equation gives a measure of the power that will be received from a direct ray. For a reflected path such as the one shown in Figure 5-24, R is replaced by $(R_1 + R_2)$. Also, Figure 5-24 depicts the locus of points for which the total path length $R_1 + R_2$ traveled by a reflected wave is constant. A reflected pulse of certain delay is generated by all terrain features that exist sufficiently close to the perimeter of the ellipse.

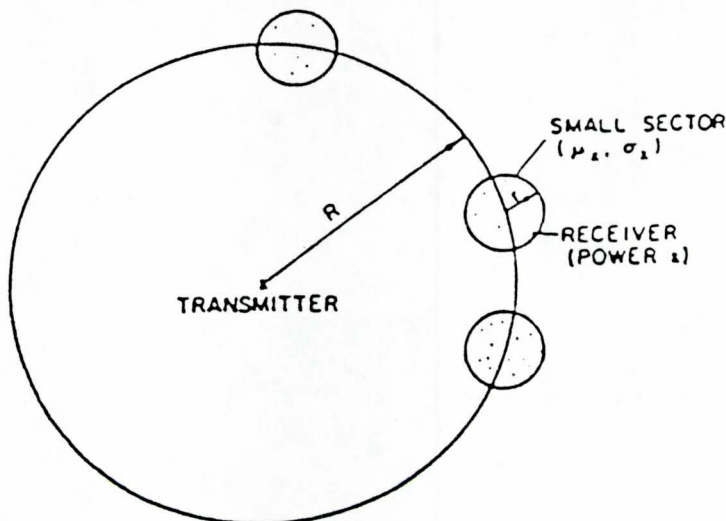


Figure 5-23 Transmitter and Receiver Locations

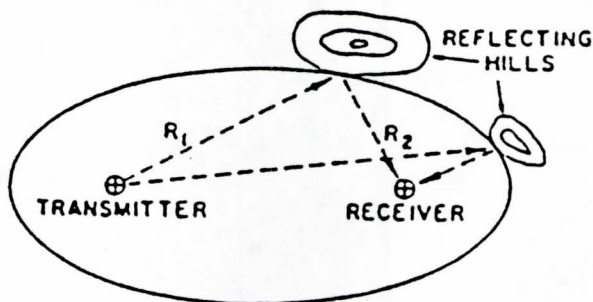


Figure 5-24 Multipath Propagation of Constant Delay

5.3.1.2.2 ECAC Model. This model was developed by the Electromagnetic Compatibility Analysis Center in Annapolis [9] and it can handle the line-of-sight, diffraction, and tropospheric modes of propagation over an irregular terrain as shown in Figure 5-25. Basically, we propose to use the Integrated Terrain Rough Earth Model (ITREM). This code covers:

1. Most multipath effects between 20 MHz and 20 GHz.
2. Distance and elevation profiles.
3. Geographic coordinates (Latitude and Longitude) of the transmitter and receiver.
4. Environmental parameters of the terrain (permeativity, conductivity, etc.).
5. Antenna heights, their frequency, and polarization.
6. Antenna gains and transmitter power.
7. Topographic profiles between the transmitter and the receiver. Terrain topography can be obtained from the Defense Mapping Agency DMA for many locations or the user can input any terrain profile of his own.
8. Degree of reliability of the propagation between a transmitter and a receiver.

This model, however, does not consider pulse signals and their dispersion through the atmosphere (see Figure 5-26) It is also restricted to a number of specific types of antennas. That means that an antenna radiation pattern that include all platform effects should be entered in this code to simulate real life signals.

The above mentioned models can achieve about 60% of the desired objectives.

5.3.2 Testing and Verification

Basically, our analysis can be validated through:

1. In flight measurements at NAVAIRTESTCEN or elsewhere.
2. Comparison with available published experimental data.
3. Laboratory experiments for some simple cases.

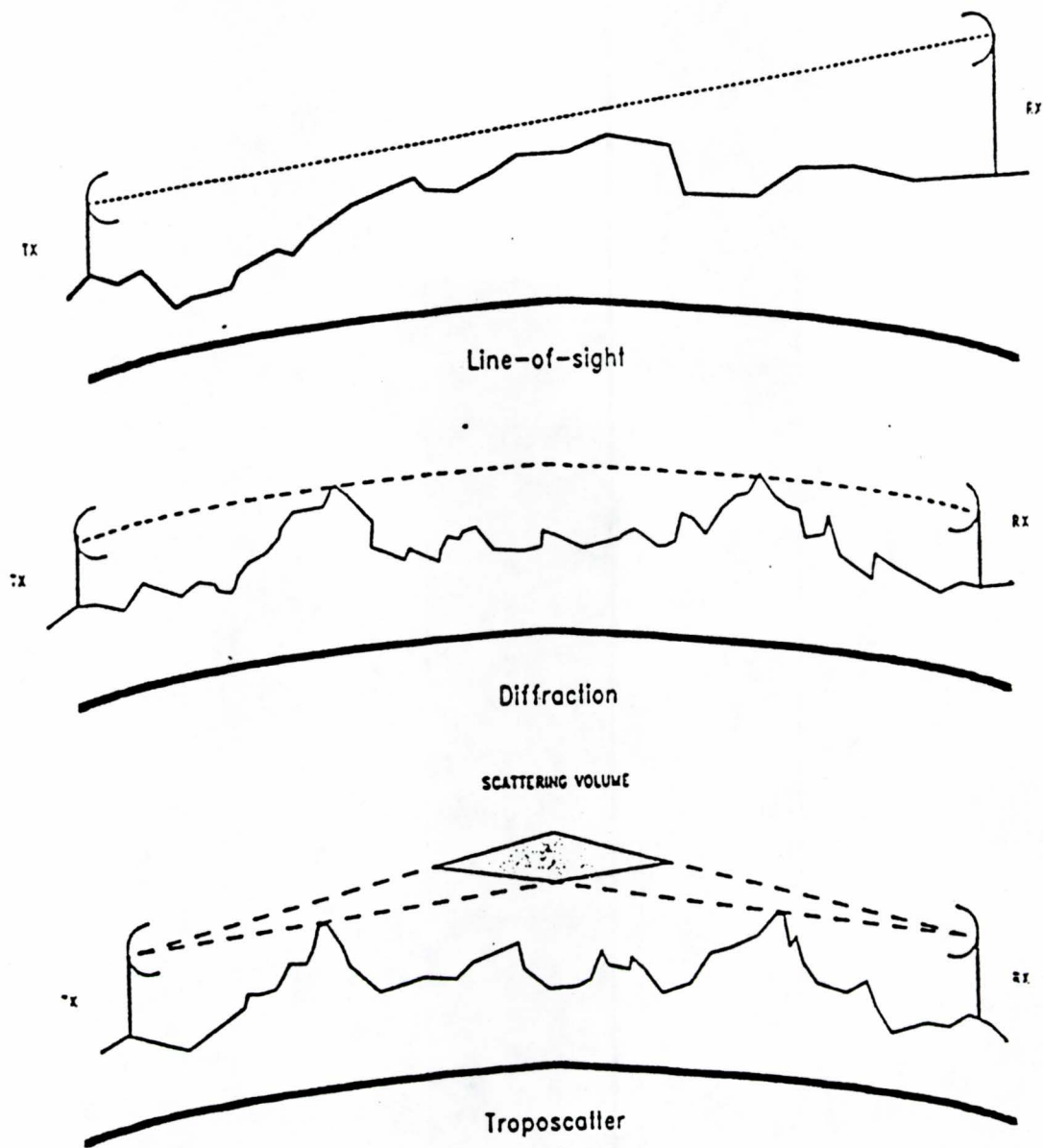
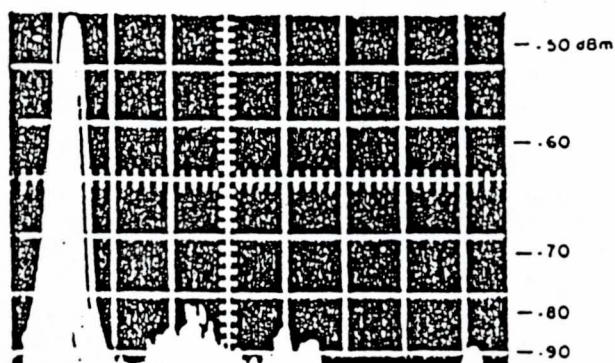
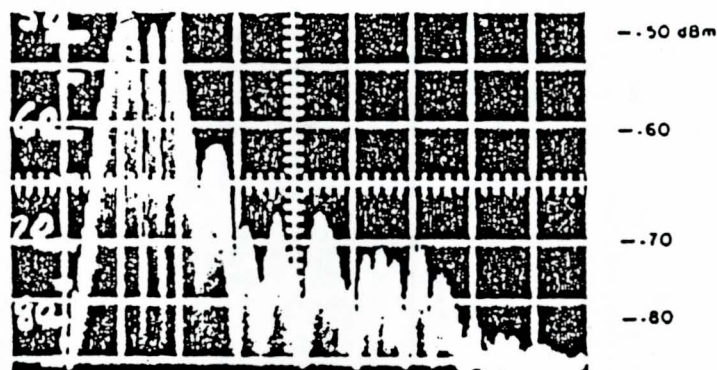


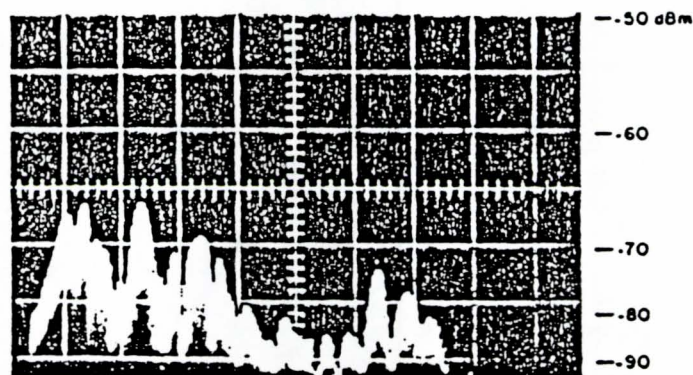
Figure 5-25 Propagation Modes Assumed for Different Paths



(a)



(b)



(c)

Figure 5-26 Typical Oscilloscope Displays of a Pulse Received Over a Line-of-Sight Path and Over Paths in Hilly Terrain; Pulse Width: 5 us, Horizontal: 10 us/div. (a) Line-of-Sight Reception at 40 km. (b) Non-Line-of-Sight Reception at 10 km. (c) Non-Line-of-Sight Reception at 20 km.

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5.4 Propagation Effects

Propagation phenomena such as absorption, scattering, scintillation and fading multipath affect the characteristics of an electromagnetic wave. Many of these phenomena can be present on the transmission path at the same time and it is usually extremely difficult to identify the mechanism or phenomena which produce a change in the characteristics of the transmitted signal. This situation is illustrated in Figure 5-27, which indicates how the various propagation mechanisms affect the measurable parameters of a signal. The parameters that can be observed or measured are amplitude, phase, polarization, frequency. bandwidth and angle of arrival. Each of the propagation mechanisms, if present in the path, will affect one or more of the wave parameters, as shown in Figure 5-27. For example, a reduction of amplitude caused by rain is the result of absorption and scattering.

OBSERVABLE PARAMETER

PROPAGATION MECHANISM

AMPLITUDE

Absorption

PHASE

Scattering

Refraction

POLARIZATION

Diffraction

FREQUENCY

Multipath

Scintillation

BANDWIDTH

Fading

ANGLE OF ARRIVAL

Dispersion

Figure 5-27 Affects of Propagation Mechanisms on Signal

The major propagation factors that can affect the behavior of the electromagnetic wave are:

Atmospheric Absorption
Tropospheric/Ionospheric Scintillation
Ducting

5.4.1 Atmospheric Attenuation/Absorption

The presence of rain, fog, cloud, hail, ice or snow in the propagation path can modify the transmitted signal and cause major impairments to the communication system as a whole. Rain drops absorb and scatter the electromagnetic wave, resulting in signal attenuation. Hail, ice and snow play a minor role in producing attenuation of the signal as compared to rain, clouds and fog.

The attenuation of a wave propagating in a volume of rain of extent L in the direction of propagation is expressed as

$$A = \int_0^L \alpha \, dx \quad (1)$$

For a plane wave of transmitted power P_t incident on a volume of uniformly distributed spherical water drops, of radius r , extending over a length L , the received power P_r is

$$P_r = e^{-kL}$$

where k is the attenuation coefficient for the rain volume in units of reciprocal length.

The attenuation of the wave, is given by

$$A = 10 \log_{10} \frac{P_t}{P_r} \quad db$$

using (1),

$$A = 4.343 kL \quad db$$

The attenuation coefficient is expressed as

$$k = \rho Q_t$$

where ρ is the drop density, i.e., the number of drops per unit volume and Q_t is the attenuation cross section. Q_t is a function of the drop radius, r , the wavelength λ , of the wave and the complex refractive index of the water drop, m . That is

$$Q_i(r, \lambda, m) = Q_s + Q_a$$

Q_s is the scattering cross section and Q_a is the absorption cross section. In general the attenuation coefficient can be expressed as

$$k = \int Q_i(r, \lambda, m) n(r) dr$$

where $n(r)$ is the drop size distribution. The specific attenuation is db/km is

$$\alpha = 4.343 \int Q_i(r, \lambda, m) n(r) dr$$

The above result demonstrates the dependance of rain attenuation on drop size, drop size distribution, rain rate and attenuation cross section. The first three parameters are characteristics of the rain structure only. It is through the attenuation cross section that the frequency and temperature dependance of rain attenuation is determined. All of the parameters exhibit time and spatial variations which are random in nature and hence predictions of rain attenuations must depend on statistical methods of analysis.

The distribution of rain drop size as a function of the rain rate and type of storm activity can be represented by an exponential of the form

$$n(r) = N_0 e^{-br} = N_0 e^{-cR^{-d}} dr$$

where R is the rain rate in mm/hr and r is the drop radius. N_0, b, c and d are empirical constants determined from measured distributions.

The specific attenuation can now be expressed as

$$\alpha = 4.343 N_0 \int Q_i(r, \lambda, m) e^{-br} dr \text{ db/km}$$

The total rain attenuation over a given path L is then given by

$$A = 4.343 \int_0^L \left[N_0 \int Q_i e^{-br} dr \right] dx \text{ db}$$

The specific attenuation produced on the wave path can be approximated by

$$\alpha = aR^b \text{ db/km}$$

where a and b are frequency and temperature dependent constants.

5.4.1.1 Models for Rain Attenuation Prediction. Almost all prediction models use surface measured rain rate as the statistical variable and assume the aR^b relationship to determine the rain attenuation. The prediction models can be expressed in the form

$$A(db) = aR^b L(R)$$

where $L(r)$ is an effective path length parameter.

Rice-Holmberg Model

This model constructs a rain rate distribution by assuming that the rain structure can be divided into two types - thunderstorm rain and all other rain. The sum of these two modes produces the total distribution.

Dutton-Dougherty Model

This model is based on meteorological considerations of the propagation path. It provides atmospheric attenuation, i.e., gaseous, cloud and rain attenuation. The model has been updated to provide a more flexible procedure for general use.

CCIR Rain Attenuation Model

This model determines an annual attenuation distribution at a specified location from an average year rain rate distribution. It employs three separate methods for maritime climates, continental climates, and tropical climates.

5.4.2 Tropospheric /Ionospheric Scintillation

Scintillation is the rapid fluctuation of the signal parameters caused by time-dependent irregularities in the path of the wave. The amplitude, phase, polarization and angle of arrival of the wave are affected by scintillations. Scintillation effects are produced in the troposphere and in the ionosphere, however, the mechanisms and characteristics for each differ.

Ionospheric scintillations, produced by electron density fluctuations approximately 200-400 km in altitude, are prevalent in the equatorial regions and high latitude locations. A detailed analytical procedure to predict the ionospheric scintillations is difficult to attain. Approximate solutions of the wave propagation model for a volume of random refractive index irregularities for specialized conditions are available.

Tropospheric scintillation is produced by refractive index fluctuations in the first few kilometers of altitude and is caused by high humidity gradients. The effects are dependent on

the seasons and vary with the local climate. The tropospheric scintillations can, as a first approximation, be considered as being horizontally stratified with the refractive index of the thin layers changing with altitude.

5.4.2.1 Available Models.

Ionospheric Scintillation

Born Approximation	Weak scintillation produced by a thin region or a single dominant irregularity
Rytov Approximation	Weak scintillation and a thick irregularity region
Single thin phase screen	Strong scintillation and a thin layer
Markov Approximation	Strong scintillation and a thick layer

Tropospheric Scintillation

ECAC Software Package

Naval Ocean Laboratories Software Package

CCIR Tropospheric Scintillation Model

5.4.3 Atmospheric Ducting

The propagation of electromagnetic waves is affected by the earth's surface and its atmosphere. Electromagnetic waves traveling within the earth's atmosphere do not travel in straight lines, but are bent or refracted. The effect of this refraction is to increase the distance to the horizon or to increase the radar range, as shown in Figure 5-28, and to introduce errors in the measurement of the elevation angle. The downward bending of the waves is caused by the decrease in the index of refraction with altitude which causes an increase in the velocity of propagation of the wave. This phenomena, shown in Figure 5-29, is referred to as superrefraction, ducting or trapping. A duct which lies close to the ground is called a ground or surface duct, while a duct that lies above the surface is called an elevated duct. To propagate energy within an elevated duct, the angle the wave makes with the duct direction, defined by the levels of constant index of refraction, should be less than one degree. Atmospheric ducts are generally of the order of 10 or 20 meters in height, and never more than 150 to 200 meters.

Ducting, Figure 5-29, can occur under various circumstances. For the index of refraction to decrease with height, the temperature must increase or the humidity must decrease with height. This is referred to as a temperature inversion and occurs when the temperature of the sea or land surface is appreciably less than

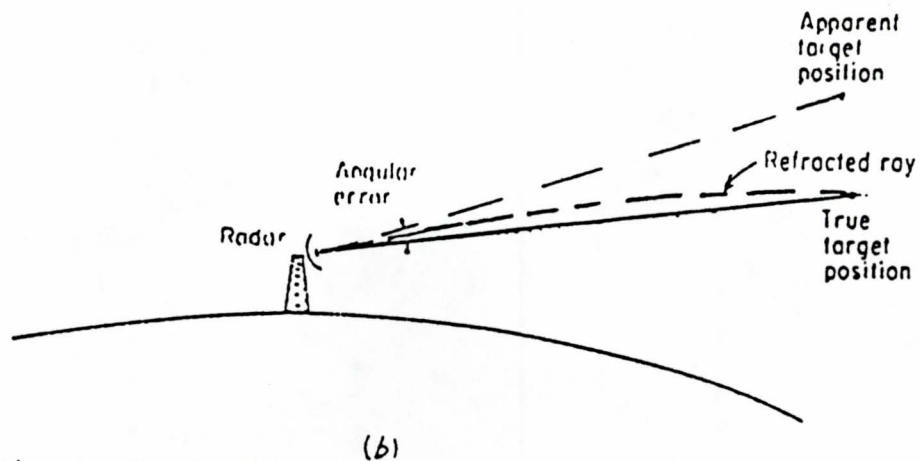
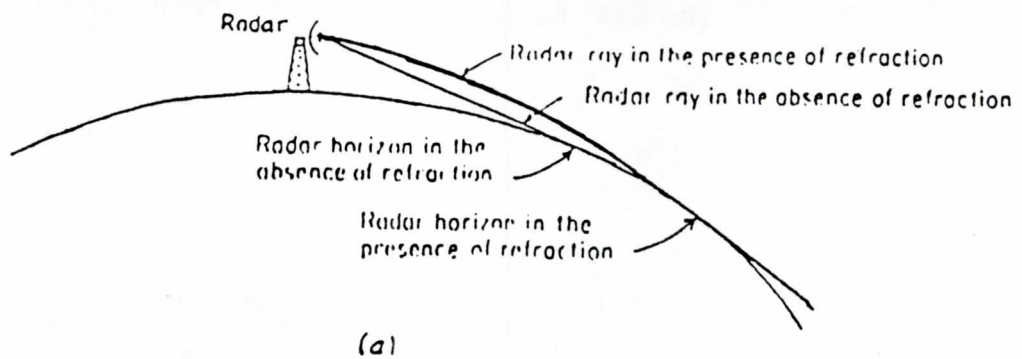


Figure 5-28 Effect of Refraction on Radar Range

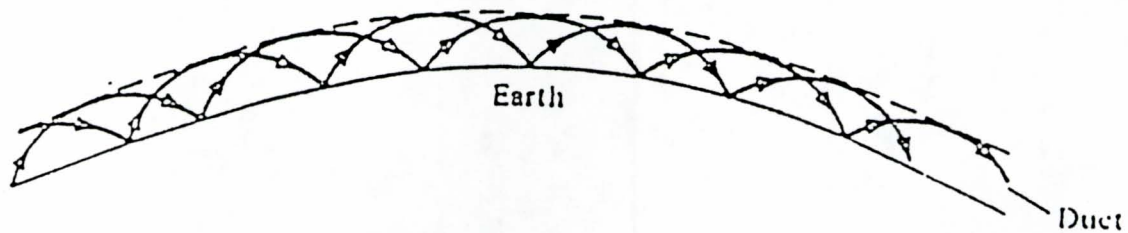


Figure 5-29 Illustration of Ducting

that of the air. Ducting also occurs when the upper air is exceptionally warm and dry in comparison with the air at the surface, or due to the movement of warm dry air from land over cooler bodies of water.

When propagating within the duct, the extension of the radar range results in a reduction of coverage in other directions. The regions with reduced coverage are called radar holes. Due to the presence of a surface duct, targets just above the duct that would normally be detected would be missed, as shown in Figure 5-28. On the other hand, an evaporation duct (over the sea or an ocean), when used with a properly sited antenna, can provide considerably extended coverage against surface targets or low flying targets. These targets normally may not be detected in the absence of the duct. Distances up to approximately 3200 km are possible through ducting. However, the presence of the extended range cannot always be predicted in advance. Generally, the consequence of the presence of the duct is more negative than positive.

The variation of refraction with height can be modeled in a linear or exponential form. At microwave frequencies, the linear model is used.

$$N = (n - 1) 10^6 = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2}$$

where P = barometric pressure, mbar (1mm = 1.3332 mbar)

e = partial pressure of water vapor, mbar

T = absolute temperature, K

N = the refractivity, the "scale up" index of refraction.

The index of refraction of the earth's surface is 1.0003 and in a standard atmosphere the index decrease at the rate of about $4 \times 10^{-6} \text{ m}^{-1}$ of height.

For purposes of computation, the atmospheric refraction is accounted for by a factor k . This factor k , when multiplied by the actual radius r_a of the earth, will yield the effective radius r_e ($r_e = k r_a$). Then the actual atmosphere is replaced by a homogeneous atmosphere where the waves will travel in straight lines rather than curved lines, as shown in Figure 5-31. The value for k can then be written as

$$k = \frac{1}{1 + r_a \left(\frac{dn}{dh} \right)}$$

$\frac{dn}{dh}$ = rate of change of the earth's atmospheric refractive index n with altitude h above the earth's surface. Usually $\frac{dn}{dh}$ is less than 0 where r_a is the actual radius of the earth.

This standard refraction is used when the index of refraction decreases uniformly with altitude so that $k = 3/4$.

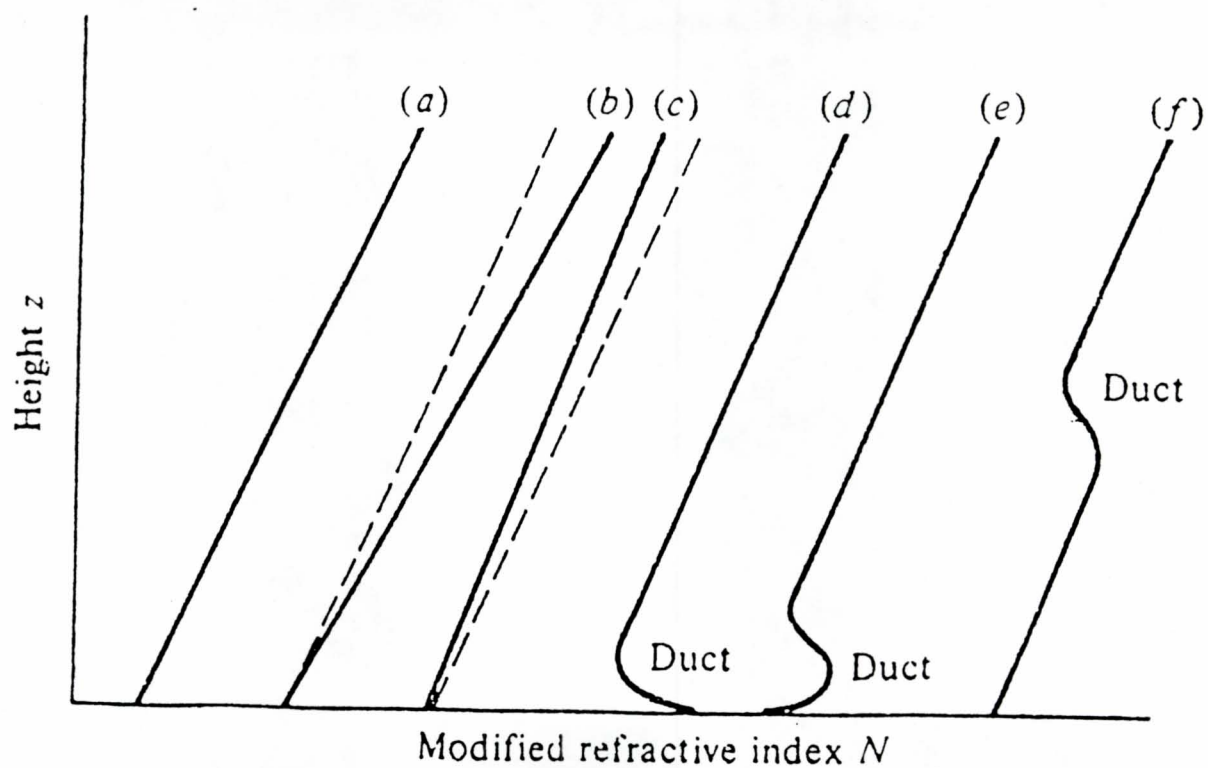


Figure 5-30 Effect of Ducting on Radar Detection

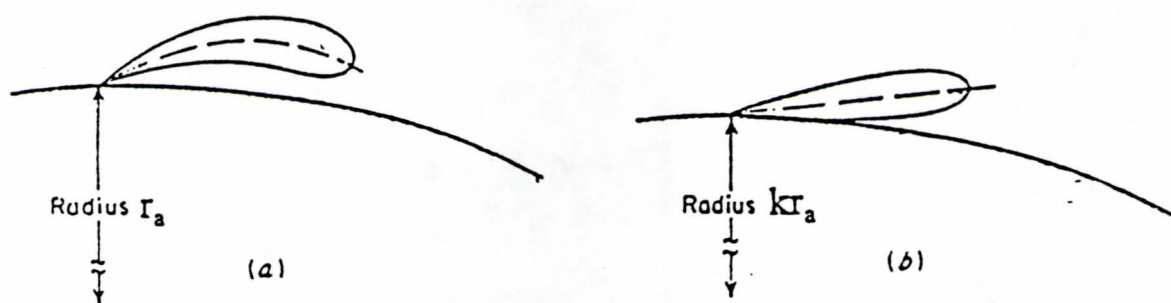


Figure 5-31 Calculation of Atmospheric Refraction

The horizontal distance from the radar at a height h is calculated as

$$d = \sqrt{2kr_e h}$$

for $k = 3/4$

$$d = \sqrt{2h(ft)} \quad \text{statuemiles}$$

$$d = 1.23\sqrt{h(ft)} \quad \text{nauticalmiles}$$

$$d = 130\sqrt{h(km)} \quad \text{km}$$

The use of r_e in the linear model implies that n decreases linearly with height. However, for heights above 1 km, the experimental results are in disagreement with the linear model. A more accurate model is one in which the refractivity varies exponentially with height

$$N = N_s \exp(-C_e(h_t - h_r))$$

where N_s = refractivity at the surface of the earth

h_t = altitude of the target

h_r = altitude of the radar

$C_e = \ln(N_s/N_1)$ = constant depending on N_s and N_1 , the refractivity at an altitude of 1 km.

A simplified model of propagation in the atmospheric ducts gives the maximum wavelength that can be propagated in a surface duct as

$$\lambda_{\max} = 2.5 \left(- \frac{\Delta n}{\Delta h} \right)^{\frac{1}{2}} d^{\frac{3}{2}}$$

where d = depth of the surface duct

Δh = altitude above the ground

λ_{\max} , d , Δh have the same units.

For $\frac{\Delta n}{\Delta h} = -1.57E-7 \text{ m}^{-1}$ at the X band, $\lambda = 3 \text{ cm}$ and d must be greater than 10m. In the S band, $\lambda = 10 \text{ cm}$ and d must be greater than 22m.

5.4.4 References

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5.5 SUMMARY OF TESTS SUPPORTING RESEARCH ACTIVITIES

During the Phase I investigation, several technical issues surfaced that should be resolved to reduce the technical risk of developing an IFF Simulator Test Tool. This section formulates these research efforts and outlines the anticipated use of a communications oriented analysis tool, BOSS.

The Block Oriented Software Simulator (BOSS) that can be used to model communication systems. The package includes an extensive library that contains many common digital signal processing and communication modules. These modules can be placed into almost any arrangement to give maximum flexibility in user design. In cases where the library is inadequate, custom programs (C programs) can be written and added to the library. To simplify this task, software templates are used to standardize the input/output formats. A source code option of the library modules is available from the manufacturer (Comdisco). BOSS will be used to develop a simulation model that can be used as a research tool to support directed research activities for TESTS. It will be used in conjunction with other programs, such as

GEMACS, to provide a flexible set of research tools. It will be used to determine various propagation effect parameters for TESTS and other issues such as antenna models, etc.

5.5.1 Signal Prediction and Distortion from Multipath Effects

Two areas of investigation are recommended to resolve issues concerning multipath effects as related to the real-time simulation.

5.5.1.1 Effects of Pulse Widths.

Changes due to diffraction or reflection from sea or irregular terrain, such as hills, buildings, random sea surfaces etc. should be analyzed.

Dispersion effects on the pulse width are of paramount importance since they will determine the degree of overlapping (at the receiver) of the same pulse train through various paths. Research should be carried out to determine how these pulses add up (constructive or destructive interference) at the receiver as a function of antenna heights and antenna coupling in a space diversity system. Since these pulses can be transmitted at various frequencies and through different atmospheric conditions, their dispersion will vary widely, and the spreading of the pulses will cause problems.

Any model should be able to predict the degree of overlap as a function of pulse width for the transmitted signal. This model can be validated through experimental results and existing in-flight measurements.

5.5.1.2 Probability of Occurrence.

Under what conditions can all or some multipath effects be neglected? When do multipath effects become insignificant?

A model is needed to predict the probability of occurrence of multipath signals as a function of:

- Frequency and polarization of transmitted signal
- Geographical location of transmitting and receiving antennas and the statistical nature of the terrain.
- Environmental conditions (rain, fog, dust, ducting, etc.)
- Pulse width of transmitted signals
- Height of antennas and coupling among antennas in a diversity system

In order to evaluate the probability of occurrence of multipath we should develop appropriate models for the multipath effects in

the environment under investigation. Based on these models we will be able to evaluate the probability of occurrence of multipath. Then, the validity of the utilized models will be verified through existing experimental results or through-appropriate measurements pertaining to the environment under consideration.

5.5.2 Signal Generation Hardware

The purpose of this research is to support TESTS hardware development of the spread spectrum signal generation simulation tools, environmental simulation tools, jammer processor tools, and detector and demodulation tools. Tools refers to a combination of hardware, software, and software-driven hardware interface.

5.5.2.1 Approach.

The rationale for the proposed implementation is to use the computer to generate the signal and perform calculations necessary to drive the required hardware. This may, in itself tax the speeds of the fastest computer. The hardware performs special tasks, in a serial manner, in either the digital or analog domain. The key feature is to use the optimum hardware configuration for the best/required processing gain. Computer simulations of real time spread spectrum systems will typically require giga-flop speeds which hardware implementation will require less than 100MHz clock rates on the fastest components.

The proposed approach for signal generation of the MK XV spread spectrum system is shown in Figure 5-32. It is composed of a computer which provides software generation of the message and provides hardware driver information on lines D₁-D₄. It is proposed that the message be developed to the necessary complexity as required by the MK XV and compatible with real-time operation. The effective data rates associated with spread spectrum modulation will limit the role which software plays in signal generation.

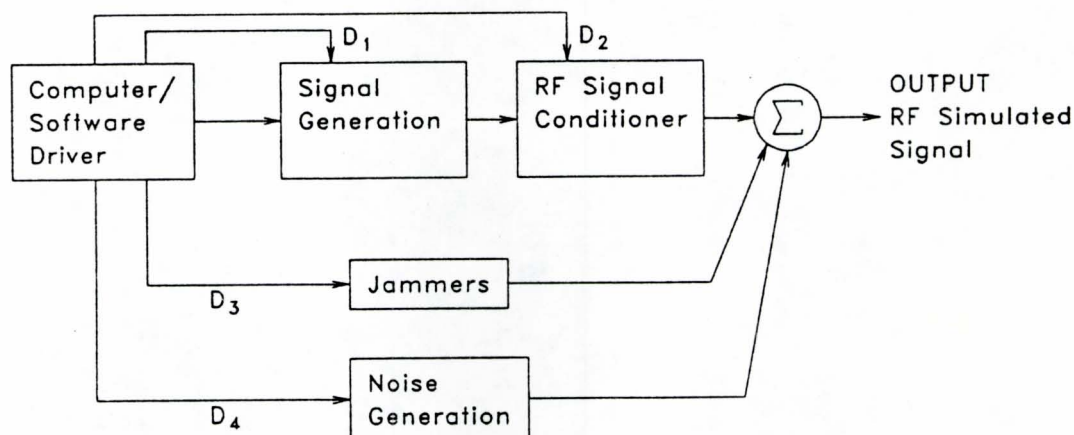


Figure 5-32 Signal Generation System Overview

The signal generator will format the signal per the MK XV specifications. This will be accomplished using quadrature modulation hardware, PN direct sequence or frequency hopping generators for spreading, the proper encryption hardware, filter, mixing and other signal manipulation. The output from the signal generator should be a properly formatted, near ideal signal with waveform characteristics and data content requested by the controlling computer. The signal generator will be agile, i.e., can output arbitrary waveforms, within its own limitations and the driver inputs.

The RF signal conditioner will take the ideal signal and condition/change it via known inputs. There are a finite number of signal parameters which will model all environmental and second order effects, namely: (a) amplitude, (b) phase, (c) delay, and (d) frequency offset. Dispersion is a second order effect that can be modeled by implementing a combination of changes to the signal amplitude and phase.

The jammer should be a signal generator capable of generating pulsed signals, frequency hopped or direct sequence spread spectrum signals, or continuous wave jamming signals. The computer will drive the jammer.

The noise processor will be capable of generating white noise and possibly other types of signals to be determined in the future by the Navy.

The full simulated signal is provided as the output of the signal simulation software.

5.5.2.2 Research.

It is believed that the highest risk is involved in the environmental simulation hardware tools. The ability to have arbitrary gain and phase dispersion, and offset delay has not yet been demonstrated. If a module could be developed inexpensively (<\$5000), it would be possible to use multiple units to simulate multiple transmitters, fading, and multipath interference. It is proposed that this research be conducted to determine an optimal way to achieve these goals.

The work will involve specification of the required components, component integration, component design (if necessary), and testing of the environmental simulation module.

It is proposed to use variable gain amplifiers or attenuators for adjustable gain. Variable offset delay will be obtained by using one or more programmable SAW delay lines. Dispersion will be added using a programmable Acoustic Charge Transport (ACT) device of SAW. Frequency offset will be achieved using a mixer and frequency synthesizer. The integrated module will be tested for bandwidth, dynamic range, signal accuracy, and many other performance parameters of interest.

5.5.3 Transceiver Fidelity Analysis

A sensitivity analysis of each stage/element of the waveform generation (i.e., encryption, D/A conversion, baseband modulation, etc.) is needed in order to determine the fidelity (input to output) of each stage, as well as, the total input/output transfer function of TESTS. This supporting analysis is required to determine the design parameters for TESTS and to obtain calibration data to adjust the signal levels of TESTS to that of the SUT. These sensitivity factors are obtained by perturbing each input and measuring the output response yielding a pulse response transfer function for each stage. This leads to a set of fidelity factors, (sensitivity coefficients) and to a set of input signal levels that can be used to calibrate signal levels of TESTS to the signal threshold levels of the SUT.

The research effort will utilize a generic transceiver simulation as a research tool for conducting various analyses. The transceiver model can be as simple as a MK XII or as complex as MK XV. The system represents a one directional flow of information starting from a source and ending with a sink. The blocks in between represent the rest of the system. Additional blocks could be added to provide directional data flow and multiple branches for systems with multiple transmitters and/or receivers.

5.5.3.1 System Fidelity.

Since the simulator has an open-ended architecture that allows construction of a communication system, signal values can be traced throughout the entire process. This is, at any block location and on any level, sink files can be placed to retrieve incoming and outgoing information. These sink files can then be used to calculate system performance and parameter sensitivity. Examples of calculations that can be made include: Signal to Noise Ratios, Probability of Error, System Capacity, Parameter Sensitivity, etc.

Signal to Noise Ratio: Since the signal and noise ratio fields are available, calculations of power can be obtained to determine the signal to noise ratios.

Probability of Error: Error probability is measured by comparing the original data file (source file) to the final data file (sink file) and counting the number of errors for a given SNR. The number of errors divided by the number of symbols sent is the probability of error, provided that enough samples are taken. This error rate can then be compared to theoretical values to assess system design and model accuracies.

System Capacity: System capacity can be defined in many ways. One type of capacity is limit in the number of signals that a system can receive at one time and still process effectively. This can be measured by setting up a simulation model to meet a

specified design and then to introduce an incremental number of signals until the system no longer functions within a defined tolerance. Close monitoring of the input and output files would indicate the threshold that could be considered the system capacity.

Parameter Sensitivity: Communication systems can be broken down into individual blocks that have N inputs and M outputs. Focusing in on one such block would allow the designer the flexibility to change any input or block parameter (transfer function) and monitor the resulting change in the output(s). This would indicate the sensitivity. On a larger scale, a change can be made anywhere in the system and the final output file (sink file) can be monitored to determine the overall system sensitivity to a change in a parameter.

6.0 TESTS MANAGEMENT

6.1 SCHEDULE

The UCF TESTS team, in collaboration with NAVAIRTESTCEN and NAVTRASYSCEN, has a significant degree of flexibility in managing the development of the TESTS and can adjust to both IFF program changes as well as to TESTS funding changes. Present efforts should concentrate on developing a high fidelity simulation of the current IFF equipment, the MK XII, but in such a manner that as prime IFF equipment enhancements occur, the simulation could be expanded to replicate the emerging, advanced IFF. For example, a modular software and hardware design approach would be utilized such that whether or not a spread spectrum system is ultimately selected, no effort is wasted in the development of the TESTS. Similarly, all research efforts undertaken by the EE component of the UCF TESTS team would use a versatile approach able to respond to the emerging advanced IFF system changes.

During Phase I the EE component of the project team acquired the necessary software and hardware tools to begin assessing the various environmental and channel effects models available worldwide and, more importantly began addressing ways to improve them for TESTS. The IST component will acquire its requisite tools, both software and hardware, to begin structuring the TESTS simulation architecture and writing the simulation code. As mentioned in the previous paragraph, some degree of flexibility in terms of schedule and resources required exists. A team to achieve the first development milestone, an improved MK XII simulation test tool, is on hand at UCF. All involved personnel have appropriate clearances; hardware and software tools to achieve the desired first stage prototype TESTS have been acquired, and technical risk has been significantly reduced. A simulation test tool would greatly increase the test and evaluation capability of NAVAIRTESTCEN on IFF systems as well as all other emerging systems which may utilize a spread spectrum signal format.

In addition to expanding NAVAIRTESTCEN capabilities by offering a better simulation test tool and performing research into spread spectrum signal formats which may suggest improvements to other future systems, the TESTS first stage prototype could be used as a means of conducting tests and tradeoff analyses for the emerging Advanced IFF system. The flexibility of TESTS will provide a vehicle to analyze vulnerability questions down to the subsystem level or to analytically evaluate performance requirements to aid in the development of achievable system specifications. Sensitivity data, coming from this analysis, will identify potential subsystem design enhancements and will be able to quantify potential gains. TESTS could also provide a generic test tool for advanced IFF systems that could be utilized to conduct basic system tests, i.e., "black box tests." Since TESTS will have capabilities not usually found in black box test tools, it will enhance system development testing and identify

potential performance limits and design tradeoffs early in the design phase i.e., Advance Development Model (ADM). The earlier tradeoffs are identified, the easier and more cost effective it is to implement those changes.

Concurrent with development of the simulation, the TESTS project team would continue to advise and assist the Navy in identifying hardware improvements required at NAVAIRTESTCEN to properly carry the simulated signals and effects and stimulate installed tactical electronic subsystems. A considerable amount of effort has gone into assessing stimulation hardware to date. This ensures that the TESTS can be fully utilized when development is complete.

6.2 ORGANIZATION

The two major UCF organizations which make up the UCF TESTS project team are: The Institute for Simulation and Training, (IST) under an Executive Director who reports directly to the Vice-President of Sponsored Research, and the Department of Electrical Engineering (EE), chaired by Dr. Nick Tzannes. Dr. Tzannes reports directly to the Dean, College of Engineering and is also directly involved in managing the EE component to ensure that research tasks requisite to the success of the project are accomplished. IST is the responsible organization for the design and development of the TESTS to include all software, hardware, and integration aspects of the prototype test tool, including the signal generation implementation. Dr. Michael Companion is the IST Principal Investigator and technical lead directly responsible for this effort. Dr. Roger Johnson will serve as the Lead Simulation Engineer responsible for structuring and creating the simulation code and modules which will form the software basis of TESTS. EE, as a subcontract entity to IST, is responsible for research on all technical issues, environmental and channel effects model improvements, and such other related research tasks to ensure the successful development of TESTS. Dr. Wasfy Mikhael is the EE Principal Investigator and research lead and will work closely with IST key personnel to ensure that appropriate research results are accurately incorporated into the TESTS development effort. He leads a team of five EE professors with the multi-disciplinary qualifications and technical expertise to accomplish the requisite research efforts.

The TESTS Project Manager, Mr. Rupert Fairfield handles all business aspects of the program, prepares periodic reports, coordinates programmatic and contractual activities, and functions as primary liaison between the UCF component organizations, NAVAIRTESTCEN, and NAVTRASYSSEN. He reports directly to the Executive Director, IST, Dr. Lou Medin.

6.3 MANAGEMENT PLAN

The TESTS project has the full support and commitment of all key managers at IST, the College of Engineering, and at the

Presidential and Vice-Presidential level of administration at the university. Although the project team has resources considered adequate to the task of developing the TESTS, unanticipated requirements can be readily addressed by involving other internal IST personnel, faculty on campus, or if necessary, any other talent with appropriate clearances throughout industry or the state university system. Since TESTS has been established as a collaborative program involving both NAVTRASYSCEN and NAVAIRTESTCEN, all technical reviews and program discussions have been open and all concerned parties are thoroughly knowledgeable of exact project status, technical issues being undertaken, and perceived difficulties. Project financial status is reported to NAVAIRTESTCEN weekly. Technical status and milestones are reported formally monthly. All managers are also charged with technical tasks and responsibilities in a formal workplan submitted at each successive phase of the project. These program controls, reports, and dedication to milestone achievement will be characteristic of the next phase of TESTS, development of the simulation test tool.

The TESTS Project Manager will serve as the single focal point for all programmatic issues between the university, NAVAIRTESTCEN and NAVTRASYSCEN. All project changes desired by either the sponsoring or contracting agencies should be channeled through him in order that he can work through the appropriate offices at the university to accomplish the change. If a program issue involves a change in scope or direction of research under the EE Department, he will coordinate that change with the Department Chairman, Dr. Nick Tzannes.

Dialogue between the members of the two technical components of the team, IST and EE, will be informal and continuous. Dr. Wasfy Mikhael, EE, will lead a group of five researchers and approximately three graduate students in continuing the resolution of technical issues and concerns and those results will be reported to IST as they occur. Dr. Michael Companion, IST, will lead a team of ten to fifteen personnel, depending on available funding, to design, develop and produce the TESTS. As the design of the TESTS firms up, and the Navy selects presented design options, the EE component will respond by focusing only on those research efforts which will contribute to the TESTS. Dr. Roger Johnson will function as daily technical liaison between the two groups to ensure that all technical effort is properly directed and focused.

6.4 SECURITY

TESTS project team members, in order to simulate the IFF waveform and message, must review classified literature and documents. All such classified material shall be stored and handled in accordance with the Industrial Security Manual for Safeguarding Classified Information (ISM) DoD 5220.22-M. Development of the classified portions of the simulation test tool shall be conducted in protected areas of IST and/or TEMPEST approved areas at NAVTRASYSCEN as required by the design activity. NAVTRASYSCEN

TEMPEST facilities will be utilized when the TESTS development and validation requires the radiation of data signals. Arrangements for utilization of NAVTRASYSCEN facilities as necessary to achieve project security requirements are presently underway. All TESTS project key personnel, Drs. Michael Companion, Wasfy Mikhael, Roger Johnson and Mr. Rupert Fairfield have worked on similar DoD projects and are thoroughly familiar with security rules and procedures. The UCF Security Officer is located at IST. She, together with local representatives of the Defense Intelligence office have reviewed project requirements and procedures, and have monitored activities to ensure strict compliance.

The University of Central Florida has a Facility Clearance at the level of SECRET (CAGE: 9H673), issued by DIS in 1979, with safeguarding capabilities at the level of SECRET. The classified mailing address is:

University of Central Florida
Institute for Simulation and Training
12424 Research Parkway
Suite 300
Orlando, FL 32826

All technical personnel assigned to this contract will be cleared at the level of SECRET. Protection of classified information will be in accordance with the Industrial Security Manual (ISM). Public releases will be subject to the review/approval of the COTR.

7.0 CONCLUSIONS

The Navy's active support and cooperation ensured that the feasibility assessment was both comprehensive and thorough. The TESTS project team was permitted to study all relevant documentation and visit all pertinent facilities. Seemingly unsurmountable technical obstacles diminished in difficulty as the team's knowledge increased. The essential conclusion is that TESTS will enable the Navy to address the five primary simulation TEMP objectives identified for simulation and achieve accurate test results with high levels of confidence. Additionally, the project team is confident that TESTS can greatly improve the statistical confidence and accomplishment of a number of secondary TEMP objectives. The recommended conceptual design presented in this document optimizes the TESTS to achieve identified TEMP objectives for an advance IFF system utilizing a spread spectrum format, as well as the current MK XII system. Moreover, the simulation test tool should provide extremely important insight for all future avionics and electronic subsystems using a spread spectrum format.

The concepts proposed herein for the TESTS represent a significant, yet practical, advancement in the state-of-the-art simulation environment for DT&E and OT&E testing of both current and proposed IFF systems. A systematic research and development effort is required to realize the potential of the TESTS conceptual design. These efforts are characterized by the discussion of research activities in Section 5.5 and the sections pertaining to the software development plan. The planned research activities to support TESTS development should lead to advances in the state-of-the-art which will be accomplished in several key areas. The IST/UCF TESTS project team will follow accepted systems engineering practices to guide TESTS development and control technical risk.

ANNEX A

MATHEMATICAL FUNDAMENTALS OF THE

"I/Q" RF SIGNAL MODEL

1 INTRODUCTION

The communication system test tool under development requires the modeling and synthesis of RF signals. A set of RF signal model conventions are presented. A set of signal model conventions such as this will provide the basis for modeling RF signals under the influence of attenuation, time delay, dispersion and superposition. A model such as this will provide the foundation for computer simulations of RF signals.

2 SIGNAL MODEL

The given model is based on a center frequency for simulation and represents an RF signal in terms of its time dependent in phase and quadrature (I and Q) components, or its cosine and sine envelopes. This is shown to be equivalent to modeling an RF signal on the basis of its instantaneous amplitude and phase. Time sampling and quantization may be applied to this model in order to make it suitable for computer simulation. A consistent frequency domain model is shown to be compatible with conventional fast Fourier transform techniques. It is shown how the modeling conventions introduced may be used to apply attenuation, time delay, frequency shift, dispersion and superposition to RF signals modeled by their I/Q components.

2.1 Cosine and Sine Envelopes

Purpose: Complete characterization of an RF signal by two video signals - I/Q Model.

An RF signal $g(t)$ of known bandwidth about a given center frequency f_c may be modeled completely in terms of two sinusoids, $\cos(2\pi f_c t)$ and $\sin(2\pi f_c t)$ with time varying amplitudes $E_I(t)$ and $E_Q(t)$ using

$$g(t) = E_I(t) \cos(2\pi f_c t) + E_Q(t) \sin(2\pi f_c t) \quad (1)$$

Knowledge of the cosine envelope $E_I(t)$ and the sine envelope $E_Q(t)$ allows for reconstruction of the RF signal $g(t)$ as shown in Figure 1.

The example used in Figure 1 corresponds to a Mark XII Mode 1 interrogation at an RF frequency of 10 MHz. The example assumes a carrier shift of 30 degrees between P_1 and P_3 and an ISLS pulse with an independent phase reference. The carrier frequency of 10 MHz was chosen for this example because higher carrier frequencies are more difficult to illustrate.

2.2 Amplitude and Phase Representation

Purpose: Complete characterization of an RF signal by two video signals - amplitude/phase model.

An equivalent RF signal modeling format involves representing the RF signal $g(t)$ by a single sinusoid of frequency f_c with a time dependent amplitude $A(t)$ and a time dependent relative phase $\Phi(t)$ using

$$g(t) = A(t) \cos(2\pi f_c t - \Phi(t)) \quad (2)$$

The polar RF amplitude representation, $A(t)$, and phase representation, $\Phi(t)$ are related to the rectangular RF signal envelopes $E_I(t)$ and $E_Q(t)$ through the rectangular to polar conversion equations

$$A(t) = \sqrt{E_I^2(t) + E_Q^2(t)} \quad (3)$$

and

$$\Phi(t) = \tan^{-1} \left(\frac{E_I(t)}{E_Q(t)} \right) \quad (4)$$

where the inverse tangent function represents all four quadrants. Knowledge of the envelope $A(t)$ and the phase $\Phi(t)$ allows for reconstruction of the RF signal $g(t)$ as shown in Figure 2. The example illustrated in Figure 2 employs the same RF signal illustrated in Figure 1.

2.3 Time Sampling

Purpose: To maintain RF signal model accuracy while applying time sampling to its I/Q model components.

Time sampling refers to the mapping of a signal from a continuous time domain to a discrete time domain. Time sampling may be applied to the I/Q model components $E_I(t)$ and $E_Q(t)$ using

$$E_{Is}(t) = \sum_{n=-\infty}^{\infty} E_I(nT_s) \delta(t - nT_s) \quad (5)$$

and

$$E_{Qs}(t) = \sum_{n=-\infty}^{\infty} E_Q(nT_s) \delta(t - nT_s) \quad (6)$$

where $\delta(t)$ is the Dirac delta distribution and T_s is the sampling period. $E_{Is}(t)$ and $E_{Qs}(t)$ are therefore time sampled representations of $E_I(t)$ and $E_Q(t)$. The sampling frequency f_s is the inverse of the sampling period T_s , or

$$f_s = \frac{1}{T_s} \quad (7)$$

The Nyquist sampling theorem gives the criterion which determines the accuracy of a sampling operation. The Nyquist theorem states that the sampling frequency must be at least twice the total signal bandwidth of a signal in order for the signal to be reconstructed from its sampled form.

The "total signal bandwidth" is the total space occupied by the signal in the frequency domain. This "total signal bandwidth" should not be confused with the 3 dB bandwidth. The total signal bandwidth is sometimes approximated as the bandwidth where spectral features (sidelobes) have been attenuated to an arbitrarily insignificant fraction of the main spectral components (main lobe). This fraction is nominally between 50 and 100 dB.

In the case of the I/Q model, sampling both $E_I(t)$ and $E_Q(t)$ at a rate equal to or greater than the total bandwidth of the RF signal $g(t)$ satisfies the Nyquist criterion because sampling two orthogonal signal components effectively doubles the sampling rate on the composite signal.

It is a common practice to sample higher than the Nyquist rate. It is common for systems to employ sampling at double the Nyquist rate or higher. In the case of sampling I/Q components, sampling at twice the Nyquist rate means sampling both $E_I(t)$ and $E_Q(t)$ at a frequency equal to twice the RF signal bandwidth.

The strength of the I/Q model is the fact that the sampling rate is determined by the RF signal bandwidth and not by the center frequency of the carrier. This provides for accurate signal modeling at sampling rates lower than those needed to otherwise reproduce the RF signal.

As an example, suppose an RF signal to be modeled has a center frequency of 10 GHz and a 90 dB bandwidth of 100 MHz. Suppose also that the I/Q format was used to model this signal. If the simulation sampling took place at twice the Nyquist rate the sampling frequency would be 200 MHz and the sampling interval would be 5 nanoseconds.

2.4 Quantization

Purpose: To maintain RF signal amplitude dynamic range while digitizing its time sampled I/Q model components.

Signal modeling is subject to errors when a sequence of signal samples are digitized. The resolution of the digitizing process determines the amplitude dynamic range of the signal model.

Each bit of signal quantization accuracy corresponds to about 6 dB of amplitude dynamic range. Each decimal point of signal quantization accuracy represents 20 dB of amplitude dynamic range.

As an example, suppose that 70 dB of dynamic range were required in a digital simulation. This would require a quantization accuracy of 12 bits (6 dB per bit times 12 bits yields 72 dB resolution) or 4 decimal places (20 dB per decimal place times 4 places yields 80 dB resolution).

2.5 Frequency Domain Model

Purpose: To establish conventions for the application of a frequency domain model to the quantized time sampled I/Q component model.

A digitized time sampled I/Q model of a finite time signal lends itself directly to frequency domain study through computer fast Fourier transform (FFT) methods.

Application of the FFT to a digitized time sampled I/Q model is best illustrated through an example. The example is again a Mark XII Mode 1 interrogation, whose I/Q model is illustrated in Figure 3. The center frequency for this example is 1000 MHz. The sampling period T_s is 0.01 microseconds. 1000 samples are considered for a total time duration of 10 microseconds. The time corresponding to the first sample is 0 (zero) microseconds and the time corresponding to the 1000'th sample is 9.99 microseconds. The 1000 term sequence to be transformed is the set of complex numbers $E_I(nT_s) + jE_Q(nT_s)$ where j is the imaginary operator and n corresponds to a member of the set of 1000 integers from 0 to 999.

The result of the FFT is illustrated in Figure 4. The result is the frequency domain model which is also a 1000 term sequence of complex numbers. The bandwidth BW of the frequency domain model is equal to the inverse of the time sampling period T_s , or

$$BW = \frac{1}{T_s} \quad (8)$$

The first point of the frequency domain data corresponds to the center frequency of the simulation, which was 1000 MHz. Points which follow are separated from each other by the spacing Δf which is calculated using

$$\Delta f_s = \frac{1}{NT_s} \quad (9)$$

where N is the number of points in the simulation. Since N equals 1000 and T_s is 0.01 microseconds, the frequency spacing Δf equals 0.1 megahertz.

The frequencies corresponding to each point continue to rise from the simulation center frequency to the simulation high frequency, which is half way through the frequency domain data. This point corresponds to the frequency $f_c + \frac{1}{2}BW$. That data point also represents the lowest frequency modeled, which is $f_c - \frac{1}{2}BW$. The frequencies resume their rise until the last point, which corresponds to the frequency $f_c - \Delta f$. In the example, the frequency domain data begins at 1000 MHz and continues to 1050 MHz. It then jumps down to 950.1 MHz and resumes rising to 999.9 MHz.

2.6 Attenuation or Gain

Purpose: To model the effects of antenna gain, propagation loss, polarization loss or reflection loss on the amplitudes of RF signals modeled through the I/Q component approach.

Consider a linear attenuation k_{at} applied to a signal $g(t)$ with I/Q envelopes $E_I(t)$ and $E_Q(t)$. The resulting signal would be modeled

$$k_{at}g(t) = k_{at}E_I(t) \cos(2\pi f_c t) + k_{at}E_Q(t) \sin(2\pi f_c t) \quad (10)$$

The new I and Q envelopes would be $k_{at}E_I(t)$ and $k_{at}E_Q(t)$.

Figure 5 illustrates the I/Q model for the signal which results when an attenuation of 0.5 is applied to the signal illustrated in Figure 3.

2.7 Carrier Phase Shift

Purpose: To model the effects of a carrier phase shifts on RF signals modeled through the I/Q component approach.

Consider an RF signal $g(t)$ subject to a carrier phase shift of Θ . The resulting RF signal $g_\Theta(t)$ would be modeled

$$\begin{aligned} g_\Theta(t) &= E_I(t) \cos(2\pi f_c t + \Theta) + E_Q(t) \sin(2\pi f_c t + \Theta) \\ &= E_I(t) [\cos(2\pi f_c t) \cos \Theta - \sin(2\pi f_c t) \sin \Theta] \\ &\quad + E_Q(t) [\sin(2\pi f_c t) \cos \Theta + \cos(2\pi f_c t) \sin \Theta] \\ &= [E_I(t) \cos \Theta + E_Q(t) \sin \Theta] \cos(2\pi f_c t) \\ &\quad + [E_Q(t) \cos \Theta - E_I(t) \sin \Theta] \sin(2\pi f_c t) \end{aligned} \quad (11)$$

The new I and Q envelopes would be $E_I(t) \cos \Theta + E_Q(t) \sin \Theta$ and $E_Q(t) \cos \Theta - E_I(t) \sin \Theta$.

2.8 Time Delay

Purpose: To model the effects of propagation or response time delay on RF signals modeled through the I/Q component approach.

Consider a time delay of ΔT applied to an RF signal $g(t)$. The resulting signal would be modeled through the I/Q approach using

$$g(t - \Delta T) = E_I(t - \Delta T) \cos(2\pi f_c(t - \Delta T)) + E_Q(t - \Delta T) \sin(2\pi f_c(t - \Delta T)) \quad (12)$$

$$\begin{aligned} &= E_I(t - \Delta T) \cos(2\pi f_c t - 2\pi f_c \Delta T) + E_Q(t - \Delta T) \sin(2\pi f_c t - 2\pi f_c \Delta T) \\ &= [E_I(t - \Delta T) \cos(2\pi f_c \Delta T) - E_Q(t - \Delta T) \sin(2\pi f_c \Delta T)] \cos(2\pi f_c t) \\ &\quad + [E_I(t - \Delta T) \sin(2\pi f_c \Delta T) + E_Q(t - \Delta T) \cos(2\pi f_c \Delta T)] \sin(2\pi f_c t) \end{aligned}$$

This is equivalent to a time shift in the I and Q envelopes and a phase shift in the carrier. The resulting I and Q envelopes would be $E_I(t - \Delta T) \cos(2\pi f_c \Delta T) - E_Q(t - \Delta T) \sin(2\pi f_c \Delta T)$ and $E_I(t - \Delta T) \sin(2\pi f_c \Delta T) + E_Q(t - \Delta T) \cos(2\pi f_c \Delta T)$.

Figure 7 illustrates the I/Q model of the signal illustrated in Figure 3 after being subject to 3.0005 microseconds of time delay.

2.9 Frequency Shift

Purpose: To model the effects of frequency shift from sources such as signal agility and Doppler on RF signals modeled through the I/Q component approach.

Consider a frequency shift of Δf applied to an RF signal $g(t)$. The resulting RF signal $g_{\Delta f}(t)$ is modeled using

$$\begin{aligned} g_{\Delta f}(t) &= E_I(t) \cos(2\pi(f_c + \Delta f)t) + E_Q(t) \sin(2\pi(f_c + \Delta f)t) \quad (13) \\ &= E_I(t) [\cos(2\pi f_c t) \cos(2\pi \Delta f t) - \sin(2\pi f_c t) \sin(2\pi \Delta f t)] \\ &\quad + E_Q(t) [\sin(2\pi f_c t) \cos(2\pi \Delta f t) + \cos(2\pi f_c t) \sin(2\pi \Delta f t)] \\ &= [E_I(t) \cos(2\pi \Delta f t) + E_Q(t) \sin(2\pi \Delta f t)] \cos(2\pi f_c t) \\ &\quad + [E_Q(t) \cos(2\pi \Delta f t) - E_I(t) \sin(2\pi \Delta f t)] \sin(2\pi f_c t) \end{aligned}$$

The resulting I and Q envelopes would be $E_I(t) \cos(2\pi \Delta f t) + E_Q(t) \sin(2\pi \Delta f t)$ and $E_Q(t) \cos(2\pi \Delta f t) - E_I(t) \sin(2\pi \Delta f t)$.

Figure 8 illustrates the I/Q model of the signal illustrated in Figure 3 after being subject to 0.4 megahertz of positive frequency shift.

2.10 Dispersion

Purpose: To model effects such as diffuse path propagation dispersion and other filter type effects on RF signals modeled through the I/Q component approach.

The effects of a linear transfer function $H(f)$ on a signal $g_1(t)$ may be modeled in the frequency domain using

$$G_2(f) = H(f)G_1(f) \quad (14)$$

where the resulting signal is $g_2(t)$ with Fourier transform $G_2(f)$ and $G_1(f)$ is the Fourier transform of $g_1(t)$. $g_2(t)$ may be modeled directly in the time domain using convolution. If $h(t)$ is the Fourier transform of $H(f)$, then

$$g_2(t) = h(t) \otimes g_1(t) = \int_{-\infty}^{\infty} h(\tau)g_1(t - \tau)d\tau \quad (15)$$

Convolution may be applied to I/Q signal models. Suppose $g_1(t)$ is sampled with a sampling period T_s . In the case where $h(t)$ is causal and limited in time to $0 \leq t \leq NT_s$, $g_2(nT_s)$ is modeled using

$$E_{2I}(nT_s) = \frac{1}{2}T_s \sum_{k=0}^N h_I(kT_s)E_{1I}((n-k)T_s) - h_Q(kT_s)E_{1Q}((n-k)T_s) \quad (16)$$

and

$$E_{2Q}(nT_s) = \frac{1}{2}T_s \sum_{k=0}^N h_I(kT_s)E_{1Q}((n-k)T_s) + h_Q(kT_s)E_{1I}((n-k)T_s) \quad (17)$$

where $h_I(t)$ and $h_Q(t)$ are the I/Q model components of $h(t)$, $E_{1I}(t)$ and $E_{1Q}(t)$ are the I/Q model components of $g_1(t)$ and $E_{2I}(t)$ and $E_{2Q}(t)$ are the I/Q model components of $g_2(t)$. In this example $g_2(t)$ is also sampled with a sampling period T_s .

As an example, consider the band pass filter response

$$h(t) = e^{-\frac{t}{\tau}} \cos(2\pi f_b t) \quad (18)$$

This represents a first order band pass filter with a center frequency f_b and a 3 dB bandwidth of $\frac{1}{\pi\tau}$. This filter response may be convolved with the signal modeled in Figure 3. Figure 9 illustrates the example where the band pass filter center frequency f_b equals 1001 MHz and time constant τ equals 0.075 microseconds for a 3 dB bandwidth of 4 megahertz. Figure 9 illustrates the I/Q models of the input signal, the filter response and the output signal.

2.11 Superposition of Signals

Purpose: To model how two signals modeled through the I/Q component approach may be added together within the framework of that approach.

Suppose three signals $g_1(t)$, $g_2(t)$ and $g_3(t)$ are time sampled with a sampling period T_s . Suppose also that $g_3(t)$ is the superposition, or sum, of $g_1(t)$ and $g_2(t)$. Applying the I/Q model to all three signals, $g_3(t)$ is modeled using

$$E_{3I}(nT_s) = E_{1I}(nT_s) + E_{2I}(nT_s) \quad (19)$$

and

$$E_{3Q}(nT_s) = E_{1Q}(nT_s) + E_{2Q}(nT_s) \quad (20)$$

As an example, let $g_1(t)$ be the input signal illustrated in Figure 9 and let $g_2(t)$ be the output signal illustrated in Figure 9 subject to a time delay of 0.25 microseconds and an attenuation of 0.3. The superposition of these two signals is illustrated in Figure 10.

3 RECOMMENDATIONS

The I/Q model should be understood by those people involved in RF signal simulation. The I/Q model should provide the basis for modeling RF signals under the influence of attenuation, time delay, dispersion and superposition. This model could provide the foundation for computer simulations of RF signals.

4 ILLUSTRATIONS

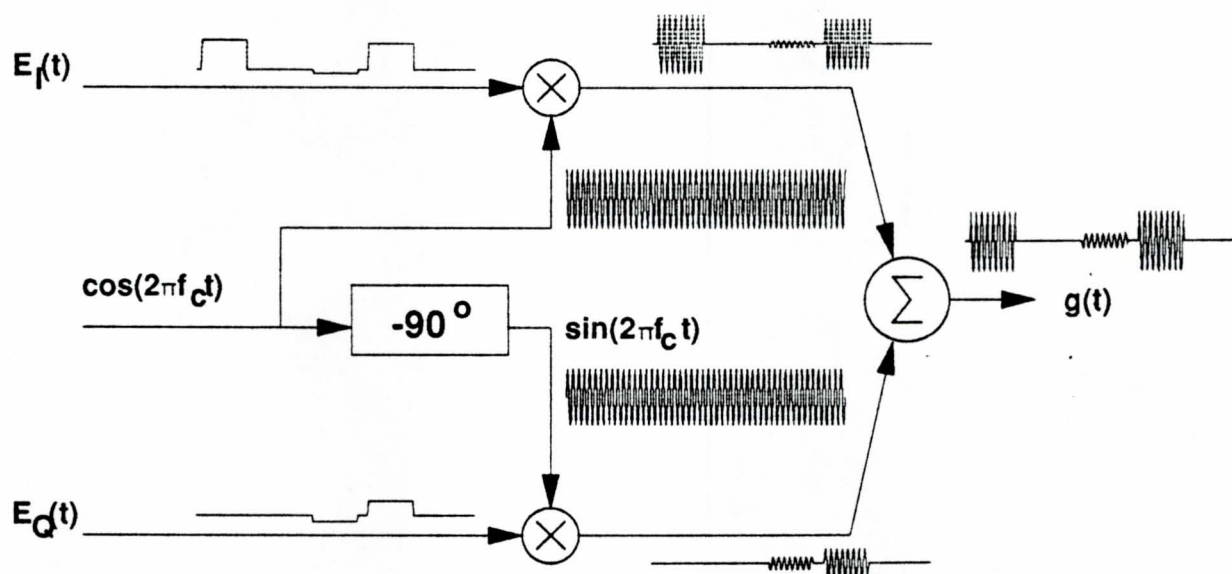


Figure 1. Reconstruction of an RF signal from its I/Q model.

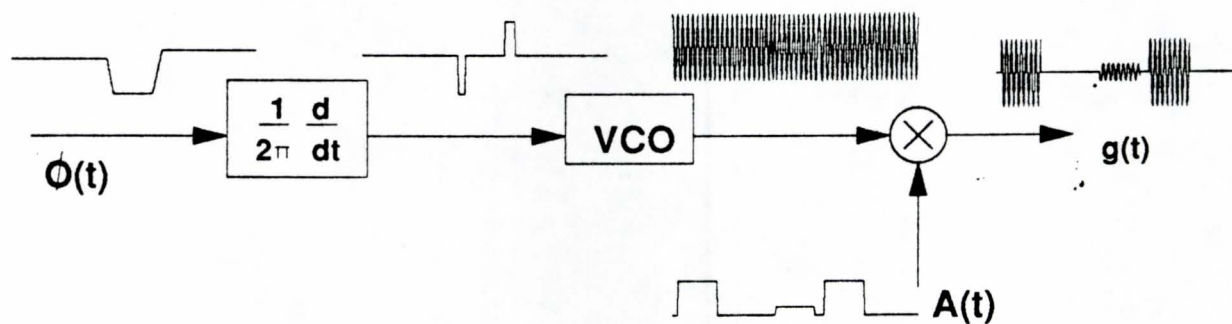


Figure 2. Reconstruction of an RF signal from its Amplitude/Phase model.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

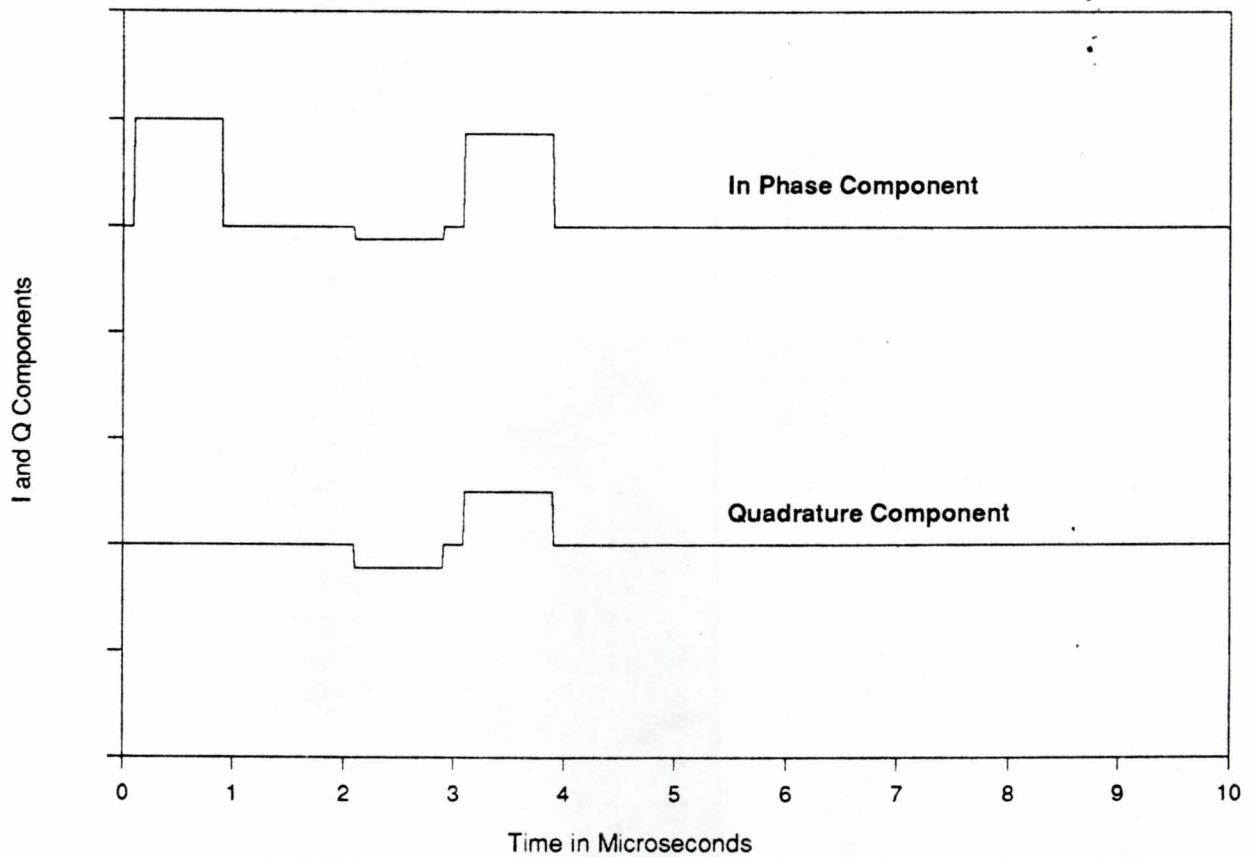


Figure 3. Time Domain I/Q Model of a Mark XII Mode 1 Interrogation.

I/Q MODEL - FREQUENCY DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

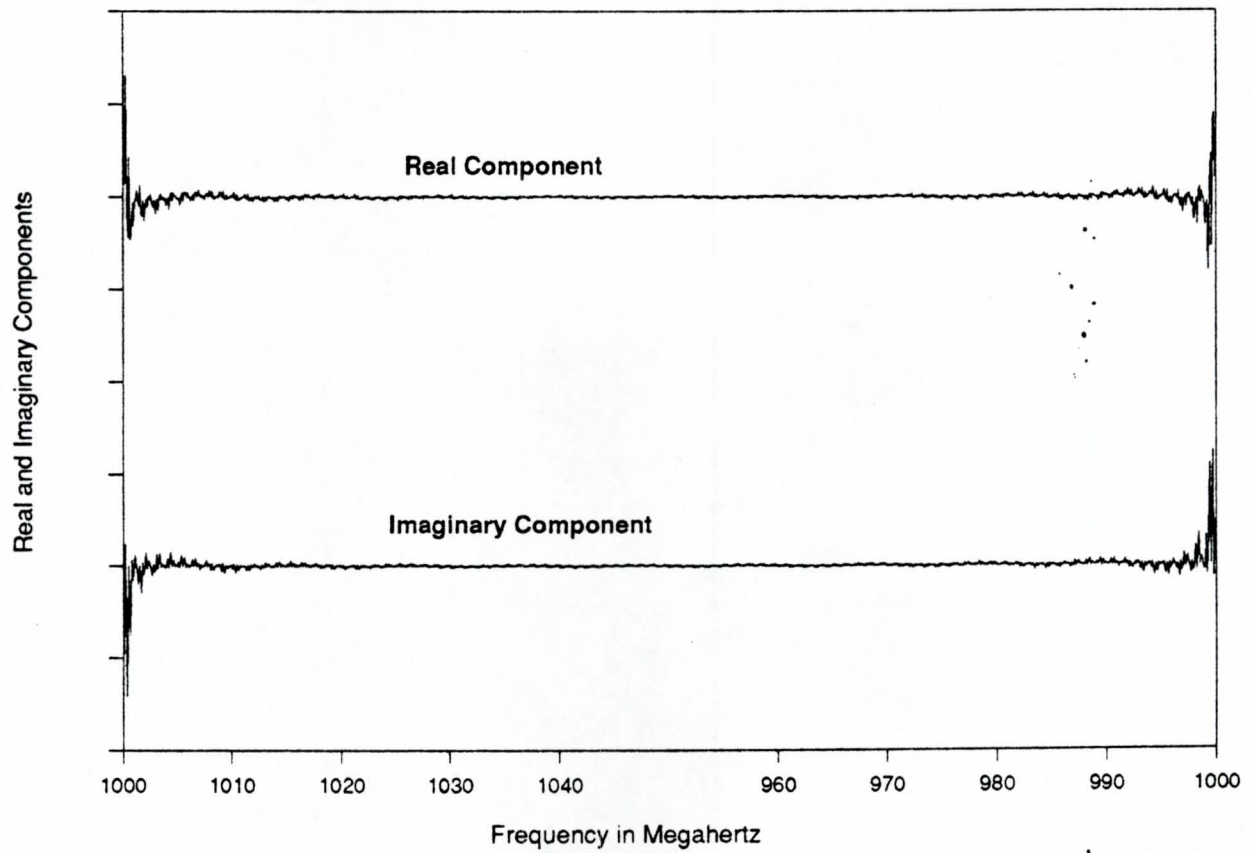


Figure 4. Frequency Domain Model of a Mark XII Mode 1 Interrogation.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

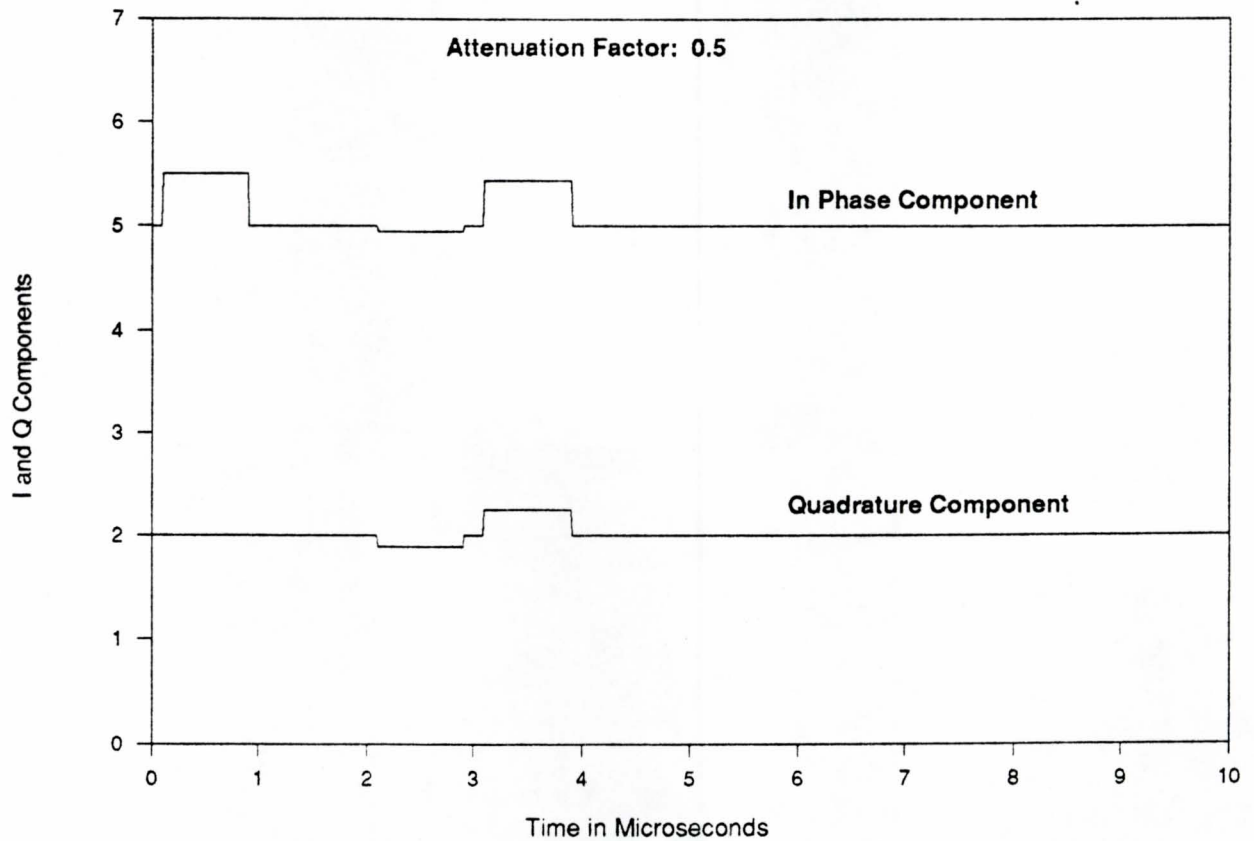


Figure 5. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing an Attenuation of 0.5.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

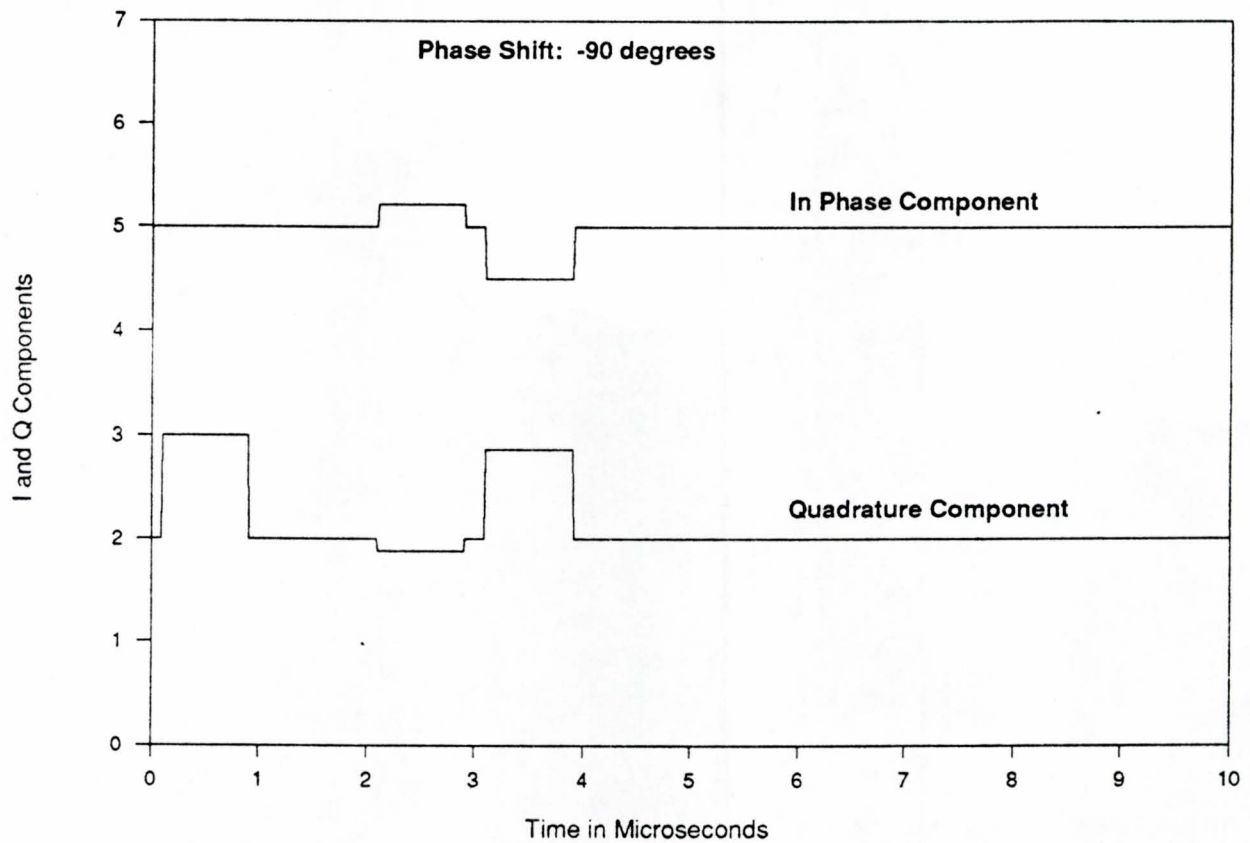


Figure 6. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing a Phase Shift of -90° .

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

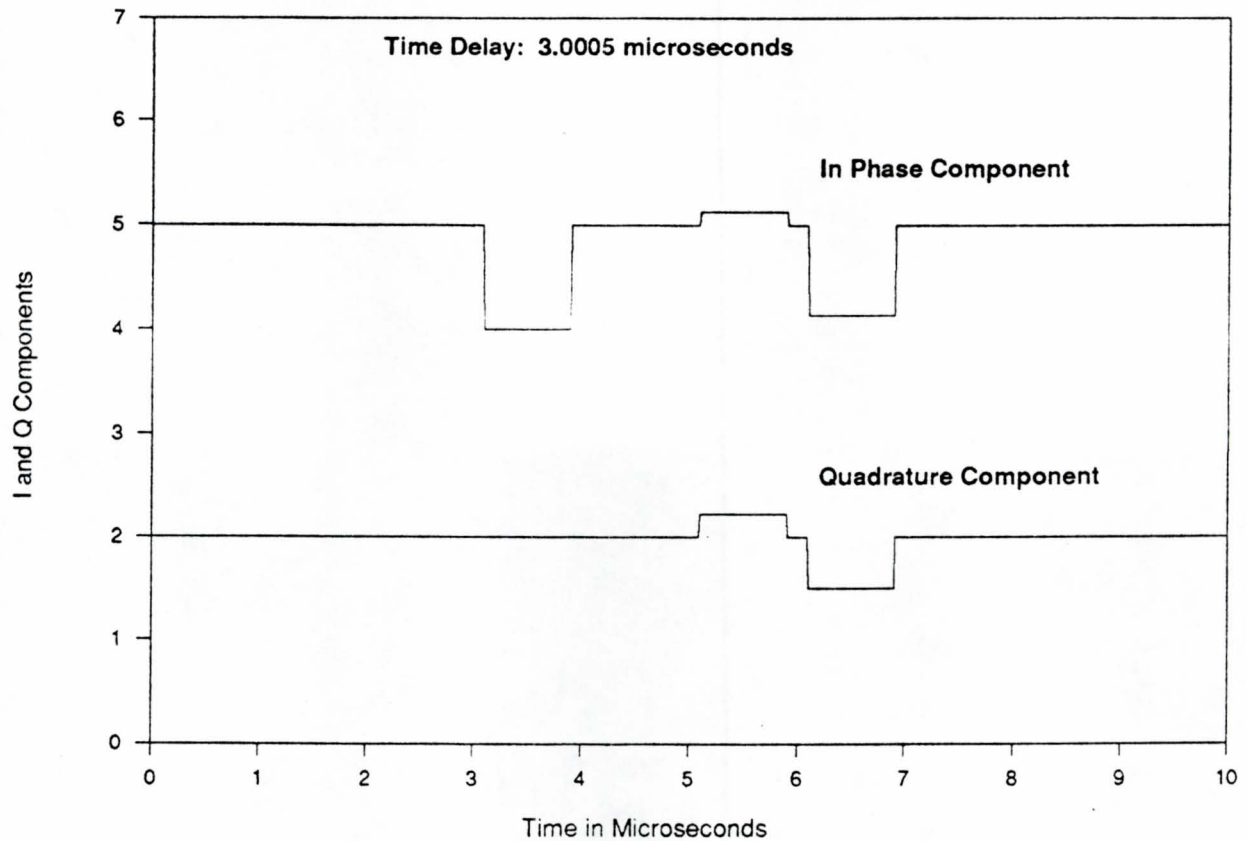


Figure 7. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing a Time Delay of 3.0005 Microseconds.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

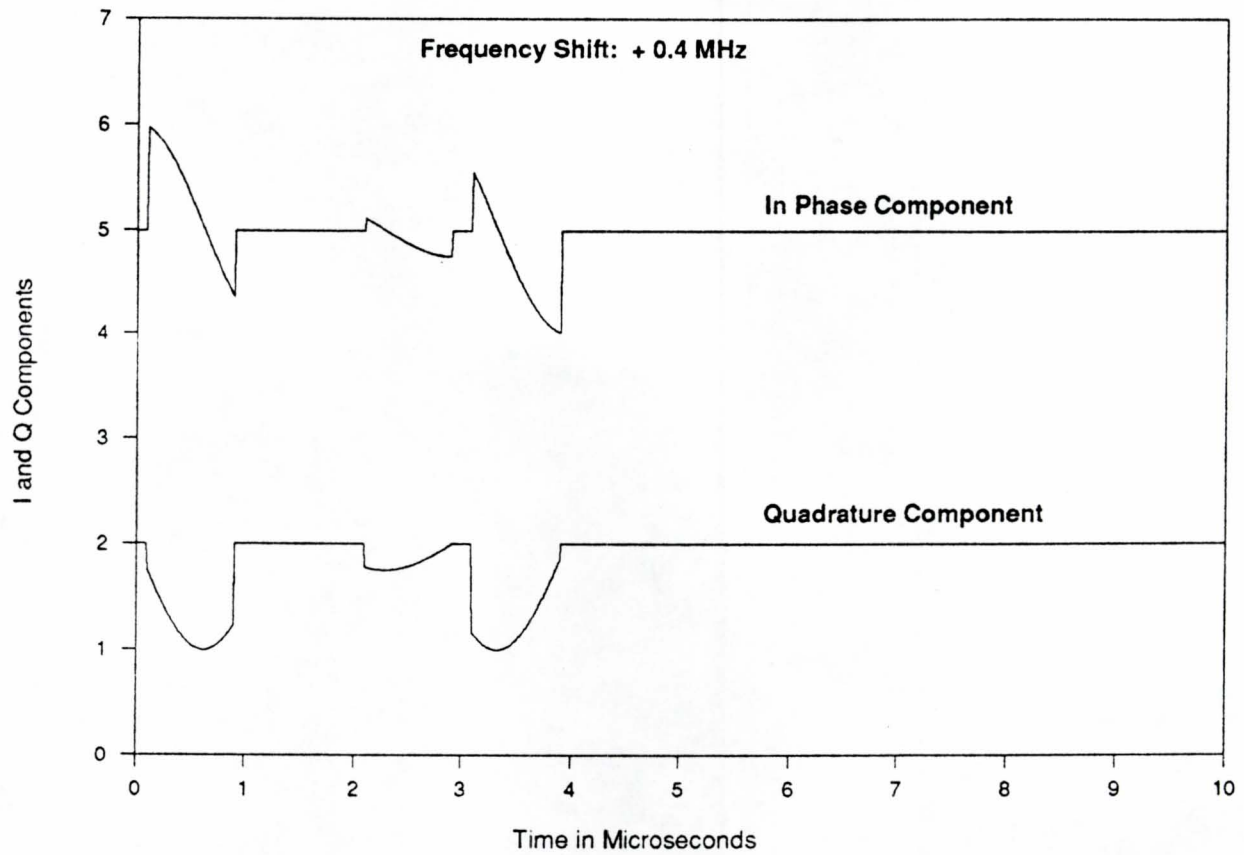


Figure 8. I/Q Model of the Mark XII Mode 1 Interrogation Example after Undergoing a Positive Frequency Shift of 0.4 Megahertz.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

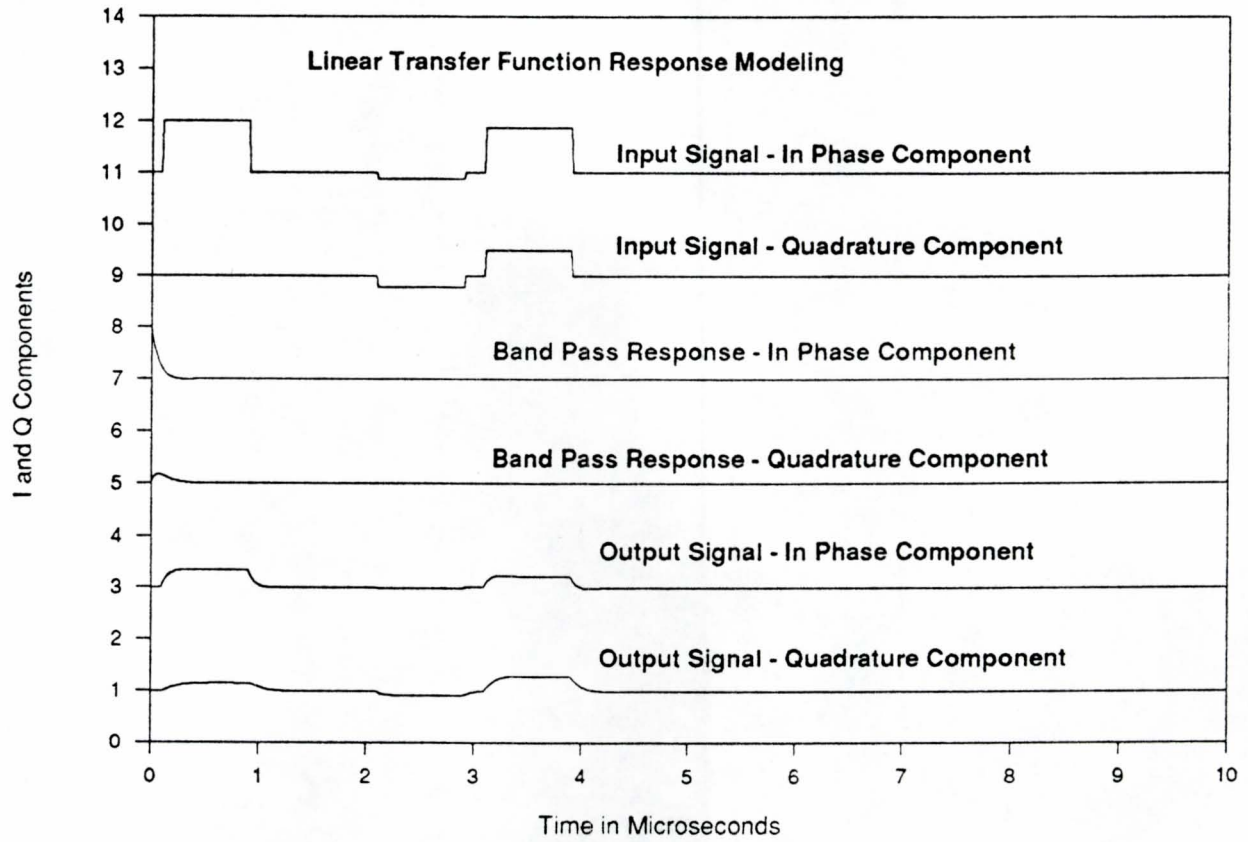


Figure 9. I/Q Model of the Mark XII Mode 1 Interrogation Example Undergoing Time Dispersion Through a Band Pass Filter.

I/Q MODEL - TIME DOMAIN

Mark XII Mode 1 Interrogation at 1 GHz

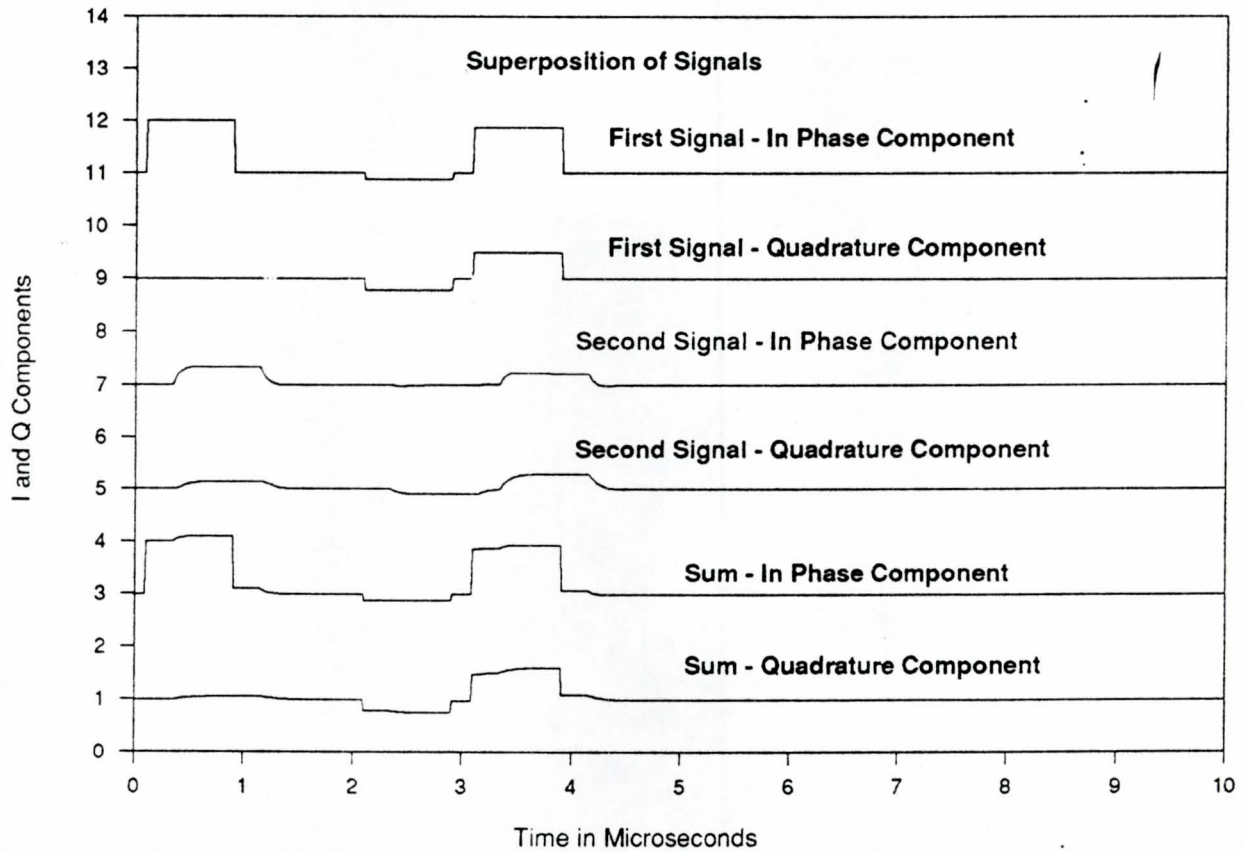


Figure 10. I/Q Model of the Mark XII Mode 1 Interrogation Example Undergoing Superposition.

ANNEX B

TESTS: SOFTWARE DEVELOPMENT PLAN

PRELIMINARY

LIST OF EFFECTIVE PAGES

NOTE:

This list of effective pages maintains a record of submittals against a specific Contract Data Requirements List (CDRL) Sequence Number. Original issues, revisions, and changes of data items are recorded in the following log.

In the event that this page accompanies a complete revision, destroy the superseded document and replace, in its entirety, with the latest revision.

Date of issue for original and change pages are:

Original . . . 04 Jan 91

Total number of pages in this publication is 71 consisting of the following:

Page No.	Change/Revision No.
Title	0
A	0
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1-1 to 1-3	0
2-1	0
3-1 to 3-9	0
4-1 to 4-8	0
5-1 to 5-2	0
6-1 to 6-3	0
7-1 to 7-6	0
8-1	0
9-1	0
A-1 to A-2	0
B-1 to B-4	0
C-1 to C-16	0
D-1 to D-2	0
E-1 to E-3	0

NOTE:

Zero in the "Change/Revision No." column indicates an original page.

FOREWORD

This Software Development Plan (SDP) is provided as a rough draft for the Tactical Electronics Simulation Test System (TESTS) Project, Phase I: Requirements Analysis and Feasibility Assessment, Contract No. N61339-90-C0125. The TESTS project is being developed by the University of Central Florida Institute for Simulation and Training and the Department of Electrical Engineering, hereafter called "the Contractor" in concert with NAVTRASYSCEN (NTSC) and NAVAIRTESTCEN (NATC). TESTS is to be delivered to and used by NATC.

This SDP has been prepared with the formats specified in Data Item Description (DID) DI-MCCR-80030A and DOD-STD-2167A as guidelines. Also the Military Handbook, MIL-HDBK-287, of 11 Aug 89, A Tailoring Guide for DOD-STD-2167A, Defense System Software Development, is being utilized substantially to streamline the software acquisition process for TESTS. This approach is justified since the TESTS project is early in the feasibility assessment stage of development. The tailoring approach is in accordance with policy directed in DODD 5000.43, Acquisition Streamlining, and MIL-HDBK-248, Guide for Application and Tailoring of Requirements for Defense Materiel Acquisitions. Also as stated in MIL-HDBK-287,

"The Software Development Plan (SDP) is the primary mechanism for describing the contractor-tailored development process in response to the tailored set of requirements."

Therefore, although this SDP follows the format of DI-MCCR-80030A, as paragraphs are encountered that are to be tailored, the phrase "tailored/deleted" or "tailored/replaced" will be indicated.

The SDP delivery has been divided into three submittals: Draft, Preliminary, and Final. The draft is being submitted as part of the early efforts of the feasibility study, the preliminary at the end of Phase I, and the final version at the end of Phase II. To identify any items that are not included in any submittal, i.e., to be determined, a TBD will be inserted, e.g. <<TBD>>. These TBDs will be addressed in later submittals and/or in project Progress Reviews (PRs).

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LIST OF ACRONYMS

ACETEF	Air Combat Environment Test and Evaluation Facility
APSE	Ada Programming Support Environment
CASE	Computer Aided Software Engineering
CDA	Critical Design Activity
CDR	Critical Design Review
CDRL	Contract Data Requirements List
CFAB	Composite Functional/Allocated Baseline
CIN	Configuration Identification Number
CM	Configuration Management
COTS	Commercial-Off-the-Shelf
CSC	Computer Software Component
CSCI	Computer Software Configuration Item
CSU	Computer Software Unit
DBMS	Data Base Management System
DCA	Development Configuration Activities
DEECS	Department of Electrical Engineering and Communications Sciences
DID	Data Item Description
DoD	Department of Defense
ECP	Engineering Change Proposal
FD	Functional Description
FQT	Formal Qualification Testing
GFE	Government Furnished Equipment
HWPDR	Hardware Preliminary Design Review
IBB	Incremental Build Baseline
IDD	Interface Design Document
IFF	Identification Friend or Foe
IRS	Interface Requirements Specification
IST	Institute for Simulation and Training
ITM	Integration and Test Manager
ITT	Interrogator Stimulators
IV&V	Independent Verification and Validation
LAN	Local Area Network
NA	Not Applicable
NATC	NAVAIRTESTCEN
NDS	Non-developmental Software
NTSC	NAVTRASYSCEN
OS	Operating System
PC	Physical Configuration Audit
PCR	Problem/Change Report
PDA	Preliminary Design Activity
PDR	Preliminary Design Review
PM	Program Manager
POM	Programmer's/Operator's Manual
PPB	Prototype Product Baseline
RCB	Risk Control Board
RFD	Request for Deviation
RTM	Requirements Traceability Matrix
RTSS	Real-Time Software System

LIST OF ACRONYMS - Continued

SCM	Software Configuration Management
SDC	Software Development Center
SDD	System Design Document
SDF	Software Development Folder/File
SDL	Software Development Library
SDP	Software Development Plan
SDR	System Design Review
SDS	Software Development System
SEI	Software Engineering Institute
SIT	Systems Integration Test
SPS	Software Product Specification
SQA	Software Quality Assurance
SRA	Software Requirements Analysis
SRR	Software Requirements Review
SRS	Software Requirements Specification
SSDD	System Segment Design Document
SS	System Specification
SSR	Software Specification Review
SSSR	System/Software Specification Review
STD	Software Test Description
STP	Software Test Plan
STPPRR	Simulator Test Plan/Procedures Results/Report
STR	Software Test Report
STRR	System Test Readiness Review
SWE	Software Engineer/Software Engineering
SWEG	Simulated Warfare Environment Generator
SWPDR	Software Preliminary Design Review
TESTS	Tactical Electronics Simulation Test System
TTT	Transponder Stimulators
UCF	University of Central Florida
VDD	Version Description Document

1.0 SCOPE

1.1 Identification

This Software Development Plan (SDP) establishes the software engineering effort to be used to develop all the Computer Software Configuration Items (CSCI's) for the Tactical Electronics Simulation Test System (TESTS). This SDP applies to the following CSCI's:

- a. The Software Development System (SDS) CSCI
- b. The Real-Time Software System (RTSS) CSCI.

1.2 System Overview

The TESTS shall be a computer-based system tool to simulate prototype models of advanced tactical electronic systems. The goal is to determine the feasibility of simulation to test and train Naval personnel on the operation of advanced tactical electronic systems. The simulation environment selected as a test case involves the Identification Friend or Foe (IFF) with emphasis on the Mark XII and Mark XV IFF systems. The TESTS project is a multi-phased effort with objectives as defined in the TESTS Work Plan Report, CDRL A001, 14 Sept 90.

It is proposed that the TESTS tool be designed to interface with various platforms under test (PUT) through simple, potentially off-the-shelf, connections. For the IFF test case, the TESTS tool would consist conceptually of three parts: interrogator stimulators (ITTs), transponder stimulators (TTTs), and a software development center (SDC). The ITTs and TTTs are the simulation prototype models containing the software and hardware to stimulate the respective PUT's interrogator or transponder receivers and transmitters. The SDC is the proposed environment to develop the TESTS software and may be ultimately used to support the delivered CSCIs in the field.

A summary of the preliminary computer hardware environment proposed for the TESTS includes the following Commercial-Off-the-Shelf (COTS) equipment and hardware:

- a. 3 SUN SPARC Workstations (networked),
- b. one SUN SPARC Server to control the network,
- c. 3-4 Skystation Sun compatible accelerator systems
- d. an Operator's Console, including <<TBD>>,
- e. <<TBD>> PUT Interfaces,
- f. <<TBD>> Signal Generators,
- g. <<TBD>> Receivers,
- h. Interface to the Simulated Warfare Environment Generator (SWEG),
- i. Interface to the other parts of the Air Combat Environment Test and Evaluation Facility (ACETEF).

The proposed TESTS software is a combination of COTS software, Simulator Operational software, and potentially SWEG, software that would be Government Furnished Equipment (GFE). There may also be Reusable Software as the prototypes evolve from simple to more complex IFF features and modes, and from the Mark XII to the Mark XV simulations.

The types of COTS software identified at this time include:

- a. The Operating System (OS) or Run-time Kernel for each computer system,
- b. The Ada Compiler and its Ada Programming Support Environment (APSE),
- c. The Local Area Network (LAN) software,
- d. The graphics software,
- e. The Data Base Management System (DBMS) software,
- f. The Configuration Management (CM) software,
- g. Other language compilers (C, C++ and/or assemblers),
- h. The Mark V Systems Objectmaker, Ada language module, and C language module Computer Aided Software Engineering (CASE) tools.

The Simulator Operational software identified at this time is the RTSS CSCI including:

- a. The software for the ITTs and the TTTs,
- b. The software for the Operator's Console,
- c. The software to interface to COTS,
- d. The software to interface with SWEG and/or ACETEF,
- e. The diagnostic software to ensure daily readiness of the system.

The need and usage of SWEG software, GFE or otherwise, is <<TBD>> at this time. It is expected that early in the development of TESTS will utilized only the data base structures of SWEG. Later in the development, TESTS will use the actual SWEG software augmented by TESTS specific data input routines.

Although the SDS CSCI consists primarily of the COTS software listed above, this CSCI also includes the following additional support software:

- a. Job control or command strings to build the operational software loads for the various processors,
- b. Test software drivers or stubs,
- c. Off-line software necessary to integrate COTS software development products (CM, CASE, APSE).

1.3 Document Overview

This SDP outlines the Contractor's plans to develop TESTS software utilizing DOD-STD-2167A as a guideline. The SDP also describes the organization and methods that will be utilized by the Contractor to perform software development. This SDP applies to all developed software as identified above in the Simulator

Operational category.

1.4 Relationship to Other Plans

This SDP is linked to the TESTS Work Plan Report, CDRL A001 for Phase I: Feasibility Assessment.

2.0 REFERENCED DOCUMENTS

The following documents are referenced within this SDP, the list does not necessarily represent all TESTS referenced documents.

ANSI/MIL-STD-1815A	Ada Language Standard
DOD-STD-2167A	Defense System Software Development
DOD-STD-2168	Defense System Software Quality Program
MIL-STD-483A	Configuration Management Practices for Systems, Equipment, Munitions and Computer Software
MIL-STD-490A	Specification Practices
MIL-STD-1521B	Technical Review and Audits for Systems, Equipment, and Computer Software
DOD-STD-480A	Configuration Control Engineering Changes, Deviations and Waivers
MIL-STD-1472C	Human Engineering Design Criteria for Military Systems, Equipment and Facilities

Contractor Generated Documents

CDRL A001	Work Plan Report, 14 Sept 90
-----------	------------------------------

3.0 SOFTWARE DEVELOPMENT MANAGEMENT

3.1 Project Organization & Resources

3.1.1 Contractor Facilities

The TESTS project development will be conducted at the University of Central Florida's (UCF) Institute for Simulation and Training (IST) and the Department of Electrical Engineering and Communication Sciences facilities in Orlando, Florida, including the TESTS program management, subcontract management (if needed), procurement, and the system, software, and hardware engineering activities. The initial facilities consist of two Sun Sparc 2 workstations plus one Sky Computers Skystation accelerator system. The software development environment at IST is located within a secure facility which is designed to meet DoD standards for classified data processing. The Contractor facility and equipment resources will support the requirements of the TESTS systems, software, and hardware engineering development activities.

3.1.2 Government Furnished Equipment, Software, and Services

There are <<TBD>> GFE, software or services identified at this time to accomplish the software engineering effort:

- a. SWEG and its support environment,
- b. Mark XII IFF equipment,
- c. Updated IFF equipment,
- d. <<TBD>>.

3.1.3 Organizational Structure

The overall TESTS project organizational chart is shown in Figure 3.1.3-1.

3.1.4 Personnel

Table 3.1.4-I provides the peak number or personnel required for the TESTS project team.

3.2 Schedules and Milestones

3.2.1 Activities ... "tailored/replaced"

The Program Master Milestone Schedule, which highlights the TESTS schedule is provided in Appendix A. The TESTS system/software development activities, including the following discussion, is summarized in Figure 3.2.1-1:

- a. System/Software Requirements Analysis Activity (SSRAA)

This activity includes requirements analysis and design activities, as documented in the Functional Description (FD),

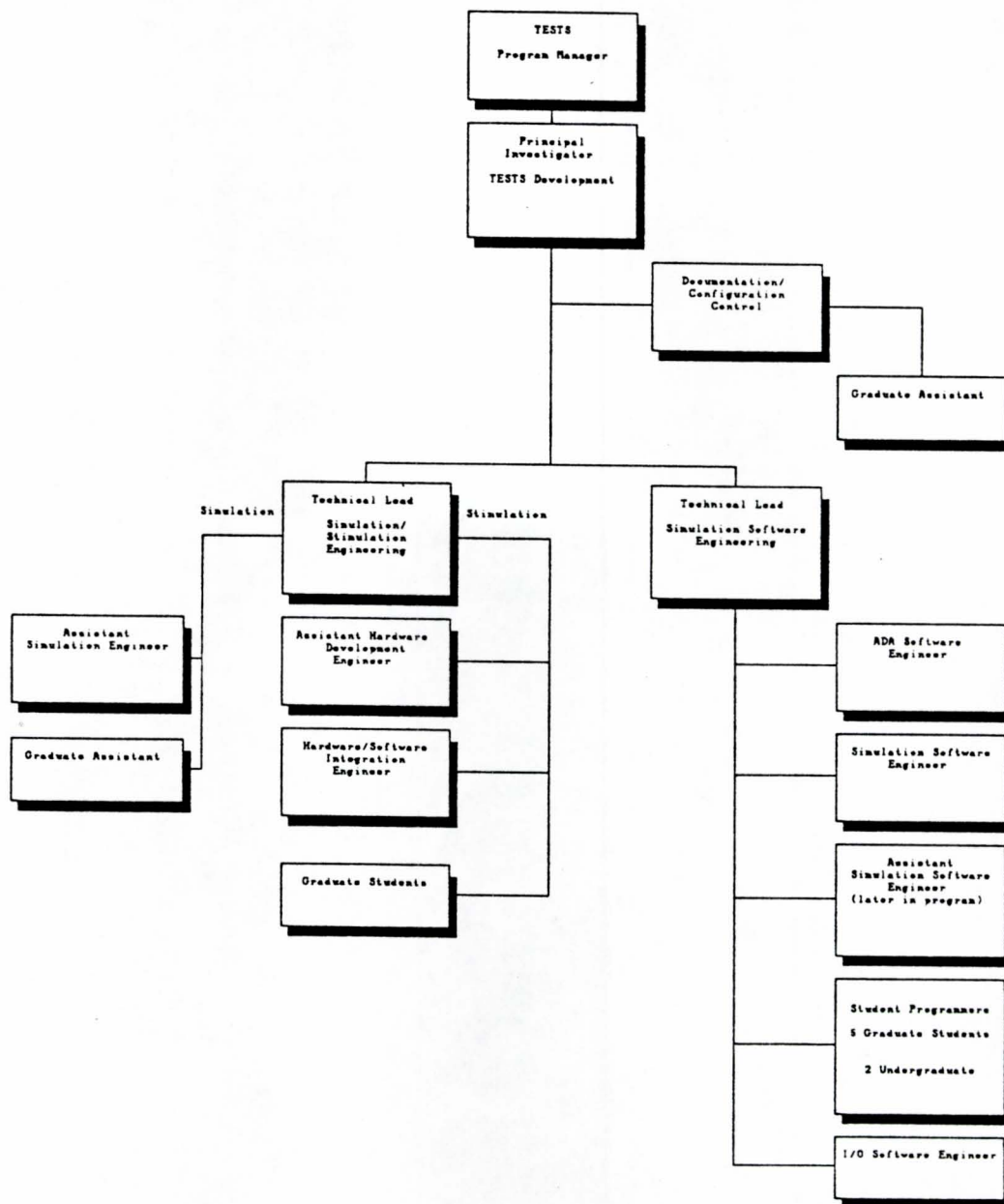
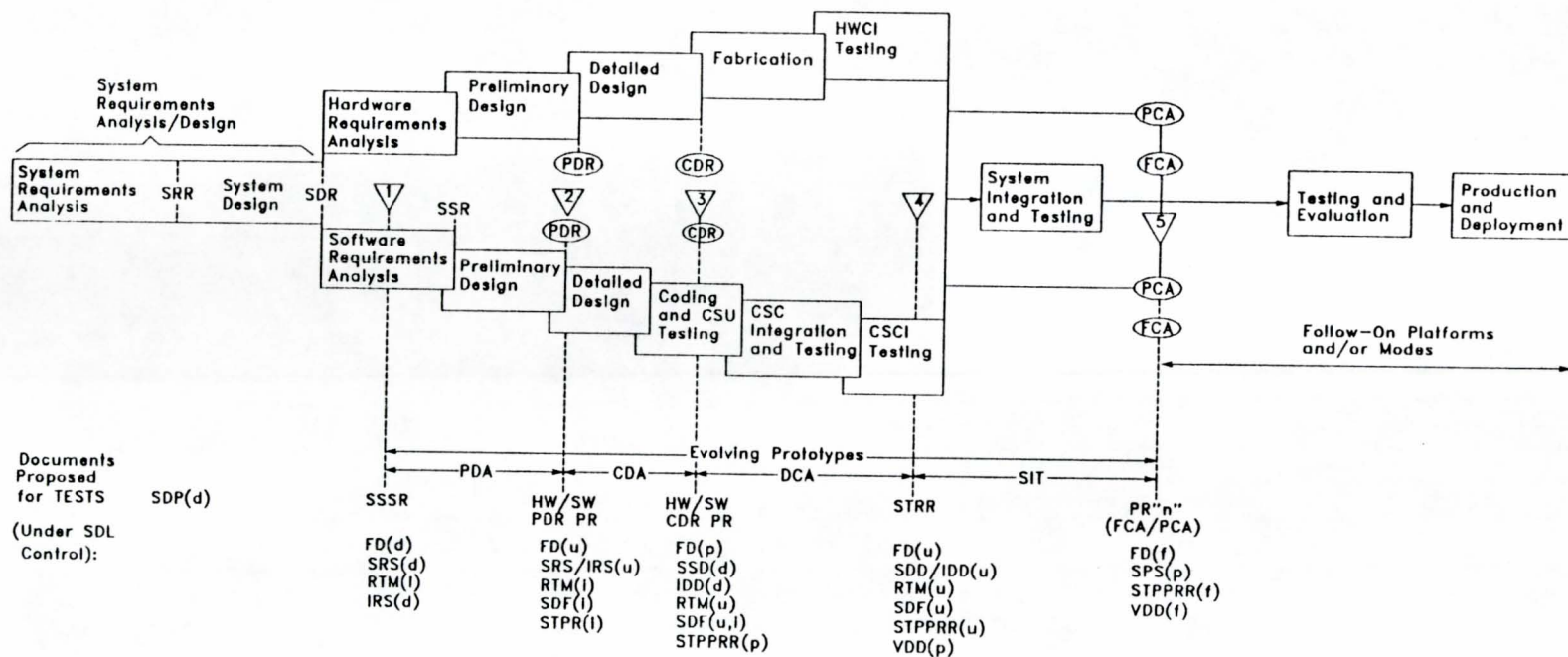


Figure 3.1.3-1. Preliminary TESTS Project Organization Chart

TABLE 3.1.4-I. Personnel Requirements

Category	Peak Number
Project Management	1
Principal Investigator	2
Principal Engineer	5
Senior Engineer	2
Simulation Engineer	2
Graduate Student	5
Undergraduate Student	2
Administrator	1

Figure 3.2.1-1. TESTS System/Software Development Activities



DI-E-30104B, which replaces the Systems/Segment Specification and the Systems/Segment Design Document (SSDD). Based on the allocation of systems requirements to the configuration items (HW and SW), software analyzes and derives engineering and interface requirements for the CSCIs. These requirements are documented at first in Software Development Folders/Files (SDFs) and then later in the Software Requirements Specification (SRS) and in the Interface Requirements Specification (IRS). Rough draft versions of the SRSs and IRS, along with supporting engineering analysis, the updated SDP, an internal version of the Requirements Traceability Matrix (RTM), and the a draft version of the FD are presented at the System/Software Specification Review (SSSR).

The SSSR combines essential elements of the MIL-STD-1521B System Requirements Review (SRR), the System Design Review (SDR), and the Software Specification Review (SSR). The system and software requirements will continue to be refined in later phases as different prototypes are evolved.

b. Preliminary Design Activity (PDA)

This activity begins with an establishment of the preliminary components of the software design. The engineering and interface requirements are allocated to these components. The preliminary software architecture for each of the processors is also established. The preliminary software architecture includes identification of interfaces to COTS software (Operating Systems, DBMSs, LANs, etc.), GFE (SWEG) and hardware (I/O systems, graphics boards, etc.) and identification of operational capabilities that are to be provided by each software element. This preliminary software design is updated in SRSs, the IRS, and the SDFs. The system/hardware design is updated in the FD.

During this activity, the Computer Software Components (CSCs) are defined and SDFs are created for each CSC. As features of the prototypes are implemented, further delineation of the CSCs into Computer Software Units (CSUs) will occur and SDFs will also be generated for CSUs. The process of defining CSCs and CSUs will continue throughout this activity and later activities as more prototyping is accomplished and as more information about the Mark XV becomes available.

The internal RTM is updated and is utilized to help generate a rough draft of a Simulator Test Plan/Procedures Results/Report (STPPRR) document. The STPPRR is similar to the MIL-STD-1644B Trainer Device Computer Program Test Procedures/Results document, DI-T-25852 (this DID will serve as a guideline), but tailored to the needs of TESTS during this activity. The STPPRR replaces the DOD-STD-2167A Software Test Plan (STP), the Software Test Description (STD), and the Software Test Report (STR). The STPPRR includes system level test plans, descriptions, procedures, and reports instead of just the software

counterparts. The activity culminates in PR "n" and the updated documents are included in the review. The status of the evolving prototypes (system, hardware, and software) is discussed and any demonstrations that may be ready are conducted. This PR replaces the MIL-STD-1815B HW and SW Preliminary Design Reviews (HWPDR and SWPDR).

c. Critical Design Activity (CDA)

The HWE and SWE efforts of the evolving prototypes begun in PDA are continued during this activity. As more and more features of the Mark XII are prototyped and as the Mark XV becomes available and its features and modes are prototyped, then these TESTS models become "builds". This implementation approach is also called an "incremental build" approach. As each prototype or feature gets implemented, it is tested in accordance with an incremental build plan for the project. A prototype may make up a build or prototypes may be grouped to form a build. The Contractor continues in the process commonly referred to "build a little, test a little" until the different features, modes, PUTs of each IFF for the project have been implemented and each build has been tested. Users manuals are generated for each of the prototype models or builds that will ultimately be a TESTS tool piece used at ACETEF. Presentations and/or demonstrations at various PRs of the builds are conducted and status is discussed.

Throughout this incremental build process, the development team is updating the SDFs, the FD, the RTM and the STPPRR. The SRSS and the IRS help the team develop detailed interfaces and software design and to continue to define CSCs and CSUs. These efforts are documented in the SDFs and draft versions of the Interface Design Document (IDD) and the Software Design Document (SDD).

At a mutually agreed upon PR (shown on the TESTS schedule), a collection of builds, their progression as documented in the SDFs, the RTM, the FD, the SDDs, the IDD, the STPPRR, the users manuals, related demonstrations and results are presented. This more extensive PR replaces the MIL-STD-1521B CDRs for HW and SW.

d. Code and CSU Test, CSC Integration and Testing and CSCI Testing Activities ... "tailored/replaced" by Development Configuration Activities (DCA)

Throughout the incremental build/evolving prototype process CSCs and CSUs are defined, coded, tested, and integrated with their respective builds. Results are compiled in the SDFs. This collection of activities involves system HW and SW integration (HSI), the placing of the CSCIs under a formal Software Configuration Management (SCM) system, and internal, confidence-level testing at a system level. The confidence-level tests are the tests that were specified in the STPPRR. At a <<TBD>> PR, a system level test readiness review (STRR) will occur. Some typical examples of system level tests might be:

1. Testing of the whole Mark XII, or
2. Testing the Mark XV for a particular platform, or

3. Testing all ITTs up to a certain mode, etc.

This level of testing groups large parts of the RTSS CSCI and the respective prototype models for demonstration. As previously done, users manuals for test groups or builds are written, as applicable.

Upon successful completion of CSCI and system level testing, the CSCI software version is documented in a Version Description Document (VDD). The SDDs and IDD are updated to reflect this testing also.

e. System Integration and Testing (SIT) Activity

The HSI and the confidence-level STPPRR testing efforts generally point out changes and tuning of the system that need to occur. Changes are incorporated and tracked by the SCM system and an updated VDD is generated. The updated SDDs and IDD with the magnetic media are compiled to generate the Software Product Specification (SPS). The users manuals for the prototypes and the SDC are compiled into the programmer's and operator's manual. This document replaces the DOD-STD 2167A Computer System Operator's Manual (CSOM), the Software User's Manual (SUM), the Software Programmer's Manual (SPM), and the Computer Resources Integrated Support Document (CRISD), but utilizes essential elements from those documents' DIDs as guidelines.

This activity is culminated by a PR to conduct the functional and physical configuration audits (FCA and PCA) with format specified by the Contractor.

3.2.2 Activity Network

The activity network depicting TESTS activities is provided in Appendix A, Schedules.

3.2.3 Source Identification

The software and hardware resources necessary for the software development effort are identified and described, including the need dates in Table A-4, Software Development Resources in Appendix A.

3.3 Risk Management ... "tailored/replaced"

Risk management for software will be accomplished as a function of the overall project risk management discussions at PRs as needed. A special functional group within the program organization, the Risk Control Board (RCB), is not needed and is deleted from this paragraph.

3.4 Security

The security requirements at this time require the ability to handle data and develop software at the secret level. The

Contractor has facilities to handle classified data at the secret level. A software development environment has been established at IST to comply with DoD requirements for classified software development. Any activities which can not be accommodated within IST facilities will be conducted at the Naval Training Systems Center.

3.5 Interface with Associate Contractors

No associate contractors have been identified at this time.

3.6 Interface with Software IV&V Agents

IV&V agents are not required at this time.

3.7 Subcontractor Management

There are no subcontracts anticipated at this time.

3.8 Formal Reviews

The reviews for the TESTS project are described in the text of section 3.2.1 above.

3.9 Software Development Library (SDL)

The SDL serves as a controlled repository for software products generated throughout the software development effort. The SDL will be maintained using commercially available or government furnished configuration management tools provided as part of the APSE. The products of and the procedures used to maintain the SDL are <<TBD>>.

3.10 Corrective Action Process

The corrective action process consists of a project implemented system based upon a Problem/Change Report (PCR) described in section 3.11 below. The PCR is utilized to effect change to CM controlled software (documentation and/or source code after the STRR is held), whether initiated by an ECP, test discrepancy, or a corrective action. Utilizing the PCR assures that the change is reviewed, coordinated and tracked.

3.11 Problem/Change Report

The project reporting system utilizes the PCR form, Figure D-9 provided in Appendix D, Forms. The PCR will be maintained using configuration management tools. The PCR is used in the following manner:

- a. To document software deficiencies in as much detail as possible using the PCR and submit to SCM.
- b. SCM assigns a control number and submits the PCR to the Lead Software Engineer for evaluation.

- c. The PCR and the proposed corrective action are submitted to the Principle Investigator for review and approval. If disapproved, the PCR is returned for re-evaluation. If approved, the change is implemented and the PCR is closed. If approved and the change impacts an established prototype, then approval for proposed corrective action requires review with the customer approval at the next PR.

Customer submitted deficiencies are also documented and tracked via the PCR form. The PCR remains open until the entire deficiency is addressed.

4.0 SOFTWARE ENGINEERING (SWE)

4.1 Organization and Resources - SWE

4.1.1 Organizational Structure - SWE

The overall software engineering organization and associated support organizations are discussed in 3.1.3 and the following. The TESTS software engineering organization is responsible for all developed software and the integration with non-developmental software (NDS) into TESTS.

The TESTS software engineering organization consists of a lead software engineer, 2-3 software engineers, including 5 graduate students and 2 undergraduate students, an engineering aide and a part-time software librarian. The position descriptions are given below.

Lead Software Engineer - <<TBD>> title/job description - The Lead Software Engineer is a member of the project's technical staff and leads the overall SWE technical and administrative (cost and schedule) activities of software requirements analysis, design, coding, and test.

Software Engineers - <<TBD>> title(s)/descriptions - A Software Engineer is responsible for designing, coding, documenting/updating SDFs, and testing of assigned component(s). Also, the software engineer is responsible for providing source data inputs to the data items. Graduate students may also perform many of these functions dependent on skill level.

Configuration Manager - <<TBD>> title/description - The Configuration Manager generates SCM schedule and status reports and performs procedures to maintain the software library and version control of the TESTS software. The Configuration Manager may be responsible for helping to coordinate source data generation for deliverable data items, reviewing SWE source data inputs for the deliverable data items and for the production and evaluation of deliverable data item. The Configuration Manager may also help compile and unit test CSUs. A graduate student could perform these functions.

4.1.2 Personnel ... "tailored/replaced" by 3.1.3 and 4.1.1

4.1.3 SWE Environment

The SWE Environment identifies the hardware and software elements proposed for the TESTS development. A description of each element is provided below.

4.1.3.1 Software Items

Table 4.1.3.1 - I, The TESTS APSE, CASE, and Software Tools,

Preliminary TESTS APSE, CASE and Software Tools

<u>Vendor</u>	<u>Product No.</u>	<u>Quantity</u>	<u>Description</u>
Mark V Systems Ltd.	OBJ-Sparc	1	Object Maker CASE tool
	CLM-Sparc	1	C and C++ Language Module Compilers
	MC-Sparc	1	Maintenance Extension
Meridian Software	Ada-Z	4	Ada Language Compiler & Professional Development System
Sun Microsystems	(Ada)	1	Ada Language Compiler
	(C)	1	C Language Compiler
Sky Computers	Sky Vec C	1	Sky Vectorizing and Optimizing C Compiler

TABLE 4.1.3.1-I. TESTS APSE, CASE, and Software Tools

describes the software items to be used to perform the software engineering activities. The table provides the vendor, product number, and a description of each item. This table will be updated as appropriate.

4.1.3.2 Hardware & Firmware Items

Table 4.1.3.2 - I, The TESTS APSE Hardware, describes the initial hardware and firmware items to be used in the software engineering environment. The table includes vendor, product number, and a description. This table will be updated at the end of Phase I and subsequent PRs. The initial configuration will consist of a single SUN workstation and Sky Computers Skystation accelerator. The complete development system will be implemented as the project progresses.

4.1.3.3 Proprietary Nature & Government Rights

Table 4.1.3.3-I, Software Item Government Rights, and Table 4.1.3.3-II, Hardware and Firmware Item Government Rights, describes the Government rights and restrictions associated with each item to the software engineering environment. This table will be updated at the end of Phase I and at the PR for the PCA/FCA.

4.1.3.4 Installation, Control, Maintenance

The APSE support group responsible for the installation, test and maintenance of the software engineering environment will be comprised of project engineering personnel. Each element of the support environment will be identified and logged into the project's configuration management data base.

The APSE support group will assemble and document the hardware, install/document the software, and run bench mark and checkout procedures to certify the fitness of the various products for use in the APSE. The APSE will then be made available for use by the project team.

Each item will be purchased with vendor support and update options. When updates are received, the changes will be logged in and evaluated before they are provided to the development team.

4.2 Software Standards and Procedures

The software standards and procedures are contained in a separate appendix of this document in order to facilitate its distribution to project personnel. Generally speaking, the topics for Software Standards and Procedures to be developed are as follows:

- Software Development Techniques and Methodologies
- Software Development Files
- Design Standards
- Coding Standards

Preliminary TESTS APSE Hardware

<u>Vendor</u>	<u>Model No.</u>	<u>Quantity</u>	<u>Description</u>
Sun Microsystems	4/75 GX-16-P40	2	SPARC station 2 Computer Workstation
	X 300 H	2	USA Keyboard
	SPRN-400	2	SPARC Printer
	S4SL2	2	SUN System Software
	SS2-07	2	SUN OS 4.1
	SX-09	2	SUN OS 4.1 Documentation
Sky	Series B110-P	1	Skystation Application Accelerator

TABLE 4.1.3.2-I. TESTS APSE Hardware

[GOVERNMENT SOFTWARE ITEM RIGHTS WILL
BE EXTRACTED FROM CONTRACT PROVISIONS]

TABLE 4.1.3.3-I. Software Item Government Rights

[GOVERNMENT HARDWARE AND FIRMWARE RIGHTS WILL
BE EXTRACTED FROM CONTRACT PROVISIONS]

TABLE 4.1.3.3-II. Hardware and Firmware Item Government Rights

4.3 Non-Developmental Software

Non-developmental software (NDS) consists of commercially available, Government furnished, and/or reusable software. In the interest of cost effectiveness, reliability and maintainability, the use of non-developmental software will be maximized. Use of NDS products will be as follows.

NDS shall be reviewed with respect to project software requirements. Selected NDS shall be documented within the appropriate CSCI's Software Design Document (SDD) as either a CSC or CSU and in their respective SDF. Where more than one CSCI utilizes the NDS, the appropriate CSCI is determined as that CSCI which utilizes the NDS most completely. Other CSCIs utilizing the same NDS in the same manner shall reference the documenting CSCI's SDD. If another CSCI utilizes the same NDS in a different manner then it is only necessary to document the unique usage and make the appropriate references.

The identification of the NDS as a CSC or CSU is determined by the level of requirement that the NDS satisfies. NDS that satisfies a high-level requirement should be considered as a CSC or sub-level CSC. NDS that satisfies a low-level requirement should be considered as a CSU.

Table 4.3-I, Non-Developmental Software, lists the non-developmental software which will be used on the TESTS. The table includes a title, NDS type, description and rationale for use for each item. This table will be updated at PRs that discuss prototype or the incremental build process and at the PR prior to the STRR. As with the developed SW, the users manuals will include NDS documentation.

[TO BE DETERMINED]

TABLE 4.3-I. Non-Developmental Software

5.1 Organization & Resources - FQT

5.1.1 Organizational Structure - FQT

The formal qualification and test (FQT) organization are members of the TESTS project organization and a representative from NTSC and NATC. The PM appoints a project team member to be the Integration and Test Manager (ITM). The ITM is also responsible for the oversight of the STPPRR preparation and to conduct the system level confidence tests and the SIT activity.

The TESTS FQT organization consists of the Integration and Test Manager and 2-3 number of project engineers.

5.1.2 Personnel - FQT ... "tailored/replaced"

Refer to section 4.1.1.

5.2 Test Approach/Philosophy - FQT - "tailored/replaced"

Philosophy: Formal testing will be accomplished by project personnel who have completed their respective software development responsibilities. In order to satisfy the independence requirement of 2167A the designated personnel will be assigned and report to the ITM for this effort. In addition, every attempt will be made to select engineers for testing software that was not developed by them. FQT will be accomplished during the SIT software development activity.

The development of the test cases and procedures will be a joint effort of the ITM and software/hardware engineering team members. The standards and criteria for the development of the cases and procedures will be established by the ITM. Final approval of all test products will rest with the ITM. However, the actual work will be performed by the development team.

Method: Preparation for testing will be initiated during the SSRAA. The PM, Principle Investigator, and Lead Software Engineer will review SRS and IRS requirements for completeness and testability. The PM will appoint the ITM to oversee the generation of the STPPRR. The software engineers will provide assistance to document the plans for FQT of each CSCI. The plan will be reviewed and approved at the PR that completes the CDA, refer to section 3.2.1 above.

The FQT will start with the STRR and CSCI/system level tests and will continue through HSI and SIT culminating with PCA/FCA. The ITM will be responsible for scheduling, testing, and recording all test activities for audit by the customer.

5.3 Test Planning Assumptions & Constraints - FQT

There are no assumptions or constraints identified at this time.

Further test planning is <<TBD>> at the end of Phase I and Phase II.

6.0 SOFTWARE PRODUCT EVALUATIONS (SPE) ... "tailored"

6.1 Organization and Resources - SPE

6.1.1 Organizational Structure - SPE

SPE for TESTS is designed to address quality issues through all software development activities. Controls are enforced by assigning specific responsibilities and authority to different members of the project team. Program Management is responsible for overall project management and development of system/software products and associated documentation. The PM assigns Configuration Management responsibility and monitors the effort. CM is responsible for maintaining a system of configuration identification, configuration control, configuration accounting, and configuration reviews for all deliverable elements of a system. The PM also assigns Software Quality Assurance responsibility and monitors that effort. SQA assures the performance of the software quality evaluation procedures throughout all software development activities.

The project team members that hold these responsibilities form the project SPE team. The specific responsibilities of each representative are <<TBD>>.

6.1.2 Personnel - SPE ... "tailored"

The number and skill level of all personnel requirements have been previously defined in sections 3.1.3 and 4.1.1.

6.2 SPE Procedures and Tools ... "tailored"

6.2.1 Procedures

The procedures for SPE fall into three categories: software engineering product evaluation procedures, software quality assurance product evaluation procedures, and deliverable product evaluation procedures. The procedures for each category are provided in the following paragraphs.

6.2.1.1 Software Engineering Product Evaluations

Specific procedures for engineering evaluations are provided in Appendix C, Software Standards and Procedures.

6.2.1.2 SQA Product Evaluations

SQA procedures for product evaluations are part of the <<TBD>> duties of the PM, the PI, the whole SWE team and specifically the PM's designee for SQA.

6.2.1.3 Deliverable Product Evaluations

Deliverable product evaluations will be accomplished in the following manner:

- a. A memo will be generated by the lead software engineer to identify the personnel responsible for the evaluation and specific review tasks.
- b. The memo, a copy of the product, a product evaluation checklist and a sign-off sheet will be routed to the assigned personnel for review and sign off.
- c. The product evaluation checklist, comments and deficiencies will be returned to the author for review and a written response generated for each critique of the product. The review is considered complete when all comments and deficiency dispositions have been agreed upon by the author and the reviewers, the software product has been updated and tested, and placed back under CM.
- d. Upon successful completion of the review process, the document is signed off, shipped, and the updated original of the document is stored in secured cabinets.

6.2.2 Tools

There are no evaluation tools identified for use by software engineering at this time.

6.3 Subcontractor Products

There are no current plans for UCF/IST to subcontract software development work on this program.

6.4 SPE Records ... "tailored"

6.4.1 SQAE Evaluation Records

Heavy usage will be made of checklists that will become part of the SDFs. The checklists are <<TBD>> but contain results of evaluations, and audits of engineering work. The SDFs are available for review and are discussed as needed at the PRs.

6.4.2 SWE Evaluation Records

SWE records will be maintained for all formal and informal reviews and audits performed by the software engineering staff. The evaluation records will be entered into the appropriate SDF as each review and test is accomplished. Informal CSC level review and test records will be maintained in the CSC level SDF while formal review and test records will be maintained in the CSCI level software development folder. The specific format and

form of the evaluation records and the procedures for using and maintaining the records is <<TBD>>.

6.5 Activity Dependent Product Evaluations ... "tailored"

Deliverable software and documentation will be evaluated by the assigned evaluation personnel to assure adherence to the specific checklists. Checklists will be generated and distributed to the development team. All checklists and records will be placed in the respective SDFs and are available for audit.

6.5.1 SPE - SSRAA ... "tailored"

The Software Development Plan (SDP), SRS, IRS, and FD will be inspected in accordance with the <<TBD>> checklist in Appendix E and results placed in the SDFs.

6.5.2 SPE - PDA ... "tailored"

The main effort during this activity is toward allocating SRS and IRS requirements to CSCs for each CSCI and for prototype cases that evolve during this activity, CSUs, developing test plans and procedures for the STPPRR, and performing preliminary design for the external interfaces and the CSCs of each CSCI.

6.5.3 SPE - CDA ... "tailored/replaced"

The primary effort during this activity is toward establishing the detailed level CSCI, CSC, and CSU design. The SDDs, IDD, and SDFs are evaluated to assure the software designs and test cases are being developed and placed in the SDFs as prototyping and the incremental build process proceeds. Checklists are completed and placed in the SDFs.

6.5.4 SPE - DCA ... "tailored/replaced"

The primary efforts during this activity are toward completing the "build a little, test a little" incremental build effort, performing HSI, placing SW under SCM, and conducting the system level confidence testing. The following product evaluations will be done in accordance with the checklists provided in Appendix E.

- a. The source code for each CSU as documented in the SDFs
- b. The test results for each CSU, CSC, & CSCI as documented in the SDFs
- c. The test procedures as documented in the SDFs
- d. The VDD is reviewed to verify that the SW is under CM

6.5.5 SPE - SIT ... "tailored/replaced"

All software and associated documentation will be updated and to reflect modifications made during SIT. The updated design documents and source code for each CSU will be inspected and evaluated according to the relevant criteria listed in sections 6.5.2, 6.5.3, and 6.5.4 to support any necessary retesting.

The specific tools, forms, procedures, and personnel responsibilities that will be used to accomplish SCM will not be completely defined until the APSE has been defined and/or at least not before the end of TESTS Phase I. However, there are certain broad statements that can be made at this time:

- a. Formal configuration control of the code (that is the formal filling out of forms and approvals) will not occur until just prior to the start of HSI. All CSUs, CSCs, and incremental builds have been successfully tested and evaluated prior to placing the SW under formal SCM.
- b. The <<TBD>> CM tool will be utilized to form audit trails and to enter and log the Problem/Change Report (PCR). All changes to documents and magnetic media will be initiated via the PCR and the CM tool.
- c. Changes for SW under formal CM will have to be evaluated by a review board including <<TBD>> members of the development and customer's team.
- d. The developmental configuration baselines described in DOD-STD-2167A have been tailored. Since the overall objective is to evaluate the feasibility of TESTS, the tested evolving prototypes may yield a product that could serve as a model system specification for future simulators. That is, the successful completion of SIT would normally yield a "Product Baseline" as defined in 2167A. TESTS, however, would yield working prototypes that could also serve as a blueprint for a "Functional Baseline" for future projects.

For TESTS, the baseline that will exist at the SSSR will be a composite of the 2167A Functional and Allocated Baselines. Since the Mark XV is still under development at this time, the Contractor has chosen an Incremental Build approach utilizing evolving prototypes. Since all requirements are not known at the time of Phase I (and perhaps during Phase II also), requirements are analyzed, allocated to HW and SW, made part of a "build", and implemented in a prototype. As new equipment is made available and/or as new requirements are defined, the added features are mapped into prototypes and the Contractor will update the RTM. An objective is to have the Mark XII and the Mark XV requirements for simulation defined, mapped into builds, and implemented into model prototypes by the end of CDA or by <<TBD>>, whichever comes first.

- e. CM would monitor the tracking of requirements in the RTM to the contents of the SDF during the PDA, CDA, and

DCA, informally but utilizing the <<TBD>> CM tool to the fullest extent possible. Once under formal CM, the VDD, the CM tool, and all SW documents and files will be monitored and be controlled.

7.1 Organization and Resources - SCM ... "tailored/replaced"

7.1.1 Organizational Structure - SCM ... "tailored/replaced"

The responsibility for TESTS CM will be assigned by the PM from the development team. The title and job description are <<TBD>>.

7.1.2 Personnel - SCM ... "tailored/replaced" by 7.1.1

7.2 Configuration Identification

7.2.1 Developmental Configuration Identification

The Contractor shall establish Developmental Configuration Identification or tailored 2167A baselines for major milestones or Phases of TESTS. A "Composite Functional/Allocated Baseline" (CFAB) based on <<TBD>> prototypes will be established at the end of the PDA. An "Incremental Build Baseline" (IBB) will be established at the end of the DCA, and the "Prototype Product Baseline" (PPB) will be established at the end of SIT. The methods to establish and the contents of the baselines are <<TBD>>.

7.2.2 Identification Methods

Software configuration control begins with the addition of CSCI(s), CSCs, CSUs, and documentation (or version) to the project's SDL and the establishment of the SDP and SDFs. These SWE products shall be named/identified in a <<TBD>> manner with respect to the CSCI they are a member. All versions of developed SWE products under this SDP are assigned version numbers of the form Version X.YZ, where:

- X - Indicates a major program version
- Y - Indicates a program update
- Z - Indicates a sub-version created for the purpose of testing or to support a peculiar requirement

A sample of a Configuration Identification Number (CIN) for document identification and version follows:

cccccx-xxx-a, where ...

cccc is the root SWE id no.,
xx is the CSCI identifier,
nnn is the document code,
a is the alpha revision level.

examples: I. 6133901-102-B may mean ...

61339 root SWE id for TESTS,
01 the Real-Time Software System CSCI
102 the SRS (for the RTSS CSCI)
B revision B

II. 6133902-108-A may mean ...

61339 root SWE id for TESTS,
02 the Software Development System CSCI
108 the SPS (for the SDS CSCI)
A revision A

A sample list of documents recommended for TESTS follows:

DOC/CODE	DESCRIPTION
100 FD	Functional Description
101 SDP	Software Development Plan
102 SRS	Software Requirements Specification
103 IRS	Interface Requirements Specification
104 SDD	Software Design Document
105 IDD	Interface Design Document
106 STPPRR	System Test Plan/Procedures Results Report
107 VDD	Version Description Document
108 SPS	Software Product Specification
109 POM	Programmer's/Operator's Manual.

7.3 Software Configuration Control ... "tailored/replaced"

As a minimum, changes to software baselines shall be documented in the source code in accordance with the design and coding standards described herein. Software changes will be initiated on PCRs and reviewed (reference 3.11). When the DCA and SIT testing are complete, a VDD and release is made, two copies of the new baseline software will be forwarded to the project/PM for review and release to the customer at a PR after PCA/FCA.

7.3.1 Flow of Configuration Control

Figure 7.3.1-1 illustrates the change process for source code and software documents under CM.

[TO BE DEVELOPED]

Figure 7.3.1-1. Configuration Control Flow

7.3.2 Reporting Documentation

The change reporting procedures describe the forms used and instructions for their use are <<TBD>>. The forms are included in Appendix D. Engineering Change Proposals (ECP) for modifications to accepted baselines, adjustments to contract funding and/or schedule shall be formally submitted. The ECP utilizes DOD-STD-480A as a guideline for its format and preparation.

7.3.3 Review Procedures ... "tailored/replaced"

As stated in the Activity section above, re 3.2.1, the TESTS project shall utilize PRs to brief the customer on status and to discuss changes and requirements that evolve out of prototyping. Internally, the project team would meet at <<TBD>> intervals (at least monthly) to discuss progress, refinements, and changes. These technical meetings shall serve as software and system review boards for the project. Minutes are kept and distributed, the RTM is updated and distributed, and SDFs are updated accordingly.

7.3.3.1 Review Board Procedures ... "tailored/deleted"

7.3.4 Storage, Handling, and Delivery of Project Media

Although the details are <<TBD>>, the storage and handling of the SW media is facilitated by the SDL and controlled by SCM. Storage of project media will be in DoD/GSA approved cabinets in accordance with industrial security requirements.

After the SDC is established, at least weekly backups to tape magnetic media will occur. Backups utilize three sets of media that are rotated so that data loss in the case of a system failure is kept to a minimum. During the testing activities, the backup procedure may occur more frequently than weekly.

Once selected, the SCM tool will help define procedures and capabilities. Delivery of released software would also be on the selected magnetic media per contract requirements.

7.3.5 Additional Controls

None identified at this time.

7.4 Configuration Status Accounting ... "tailored to Contractor format"

This is <<TBD>> at this time, but the reports will be used to assist in configuration audits.

7.5 Configuration Audits ... "tailored/replaced"

The PCA and FCA will use MIL-STD-1521B as a guideline but will conduct the audits to Contractor defined format and agendas.

7.6 Preparation for Specification Authentication

The successful conducting of the PCA after the successful completion of the SIT is the final authentication of the system. The following summarizes the efforts throughout the development to prepare for the authentication. SCM will perform walkthroughs with the development SWEs to verify that the SDFs, the RTM, the SRSSs, the IRS, the SDDs, the IDD, and the Incremental Build Plan track requirements and are in agreement. Walkthroughs will be held at least monthly during the CDA, biweekly during the DCA, and weekly during SIT. The PCR will be utilized to track and initiate changes. All updates will be reflected in the SPS; a VDD will be generated for the tested builds; all change documents will be compiled to prepare for the PCA.

7.7 SCM Major Milestones

Although the list is to be refined, the following are major milestones for TESTS and for SCM:

- Phase I completion,
- Completion of SSSR,
- Phase II completion,
- PRs to review Preliminary and Detailed Design,
- PRs to define the Incremental Builds,
- Phase "N" initiation and completion,
- Acquisition of Mark XV data and/or hardware,
- Completion of the STRR / placing of SW under formal CM,
- VDD completion and subsequent SW release,
- PCA/FCA completion.

8.0 Other SW Development Functions

None at this time.

APPENDIXES

APPENDIX A
Schedules

APPENDIX B
Software Development Library

APPENDIX C
Software Standards and Procedures

APPENDIX D
Forms

APPENDIX E
Software Product Evaluation
Checklists

APPENDIX A
TESTS MAJOR MILESTONE SCHEDULE

<<TBD>>

APPENDIX B
SDL DEVELOPMENT LIBRARY

11.0 SDL DEVELOPMENT LIBRARY

11.1 Introduction

The SDL serves as a controlled repository for the source programs, documentation and vendor support software products. The function of the SDL is to receive, document, identify, maintain, and control the configuration of the products. The SDL configuration is maintained by a member of the project team who performs the librarian duties and who ensures that the SDL products are only updated via change procedures. The SDL is the source of all code and data used for the test loads and baseline definitions.

11.2 Product Identification

Figure B-1 identifies the SDL products that will be generated during each design activity.

11.3 SDL Description

The SDL for the TESTS is the library scheme under which software associated specifications and data are developed, debugged, integrated, and tested. It may be manual or a <<TBD>> automated method and contains files and procedures for handling files. The SDL is under project control and monitored by the team member designated to do SCM duties.

The SDL ensures integrity of the software throughout the development of the project. The SDL will aid in:

- a. Uniquely identifying all software items
- b. The release process during and after the testing cycle
- c. The build process to support testing and the test load process
- d. Controlling the change process for all software items
- e. Giving visibility into the project development activities by SQA and CM team members.

The planned utilization of the <<TBD>> automated CMS streamlines a great deal of the SDL and CM activities. A summary of the CMS features follows:

- a. CMS manages the generation and documentation of changes. This provides management with control
- b. CMS provides status accounting and maintains an audit trail of changes.
- c. CMS stores and tracks all parts of an application through its development life
- d. CMS controls the evolution of the application from release to release, forming baselines from which further controlled development and maintenance occurs
- e. CMS automatically maintains different versions of information, allowing parallel development and maintenance on a single set of information.
- f. CMS generates reports to provide managers and software

engineers with control and visibility throughout the software life cycle.

[TO BE DEVELOPED]

Figure B-1. Software Development Library Products

APPENDIX C
SOFTWARE STANDARDS AND PROCEDURES

12.0 SOFTWARE STANDARDS AND PROCEDURES

12.1 Software Development Techniques and Methodologies

The following paragraphs define the software development standards and procedures which will be applied to the TESTS project software development using DOD-STD-2167A, Defense System Software Development, as a guideline.

The tasks are presented, to the extent possible, in a chronological order. However, there is not a requirement for the tasks to be completed in that order or that the tasks be completed once and for all. In most cases it will be necessary to iterate upon the tasks to complete them. For each of the tasks identified there is a one line summary of the task and a paragraph which describes the task. The one line task summaries are also included in a checklist for each activity. The checklists will be utilized to track the progress of the tasks' completion. The Software Development File/Folder (SDF) for each CSCI will contain the checklists associated with that particular CSCI.

a. System/Software Requirements Analysis Activity (SSRAA).

Tasks to be performed:

(1) Assign Software Engineers

The lead SWE and the PI shall assign a responsible SWE for each CSCI.

(2) Begin initial SSRAA tasks

The responsible SWEs shall perform the following for each CSCI:

(a) Establish SDF

The responsible SWE shall establish a SDF for the CSCI. The form of the SDF may be either electronic or paper. If suitable automated resources are available, all or part of the SDF maybe on electronic media. See the SDF table of contents/ checklists for required contents of the SDF.

(b) Obtain CIN

The responsible SWE shall obtain the CIN for the CSCI and enter it in the SDF.

(c) Initiate allocated requirements review

The responsible SWE shall extract all relevant information and allocated requirements from the FD, SRS (draft), and the IRS (draft) and place in SDF. The responsible SWE shall review allocated requirements for consistency and completeness. Identify any weaknesses (i.e. missing/implied requirements) and place in the SDF. If changes

are necessary to the FD, SRS, or IRS, submit a change request, placing a copy in the SDF.

(d) Establish "make/buy" decisions and reqs
If not predetermined in the FD, the SWE shall review allocated requirements for a "make/buy" decision and record any "buy" decisions in the SDF including derived requirements. Each derived requirement shall have a name, project unique identifier, purpose, performance in measurable terms, associated inputs and outputs and parent requirement.

(e) Review allocated and derived reqs. against FD
The SWE shall analyze the CSCI's set of allocated and derived requirements for completeness and document any identified inconsistencies in the SDF.

(f) Review CSCI's external interfaces
The SWE shall establish for each external I/F, a formal name, project identifier, short description and purpose, source, destination, and (if any) associated data elements and record in SDF.

(g) Identify necessary data elements
The SWE shall establish for each identified (and necessary) data element a formal name, project unique identifier and (as applicable) the following information and record in SDF:

1. communication protocol
2. priority level
3. concurrent or sequential
4. units of measure
5. limit/range
6. accuracy
7. precision/resolution
8. rate

(3) Internal review of initial SSRAA tasks
The LSE (or designee) shall conduct an internal review of the tasks completed thus far. The review should determine that the allocated and derived reqs and associated analysis specify the external interfaces of the CSCI.

(4) Begin remaining SSRAA tasks
Upon successful completion of internal review, the SWEs shall complete the remaining tasks:

(a) Identify necessary internal derived requirements.
The SWE shall identify the derived requirements that are necessary to bridge the external I/Fs from input to output. The SWE shall establish a

formal name, etc. as above for derived reqs. and record in SDF.

(b) Identify necessary internal data elements
The SWE shall identify data elements necessary to support the allocated or derived requirements. The SWE shall establish a formal name, etc. as above for data elements and record in SDF.

(c) Identify necessary internal interfaces
The SWE shall identify the necessary internal I/Fs between capabilities. The SWE shall establish a formal name, project identifier, description and a summary of information transmitted and record in SDF.

(d) Determine requirement testability and test method
The SWE shall review all allocated and derived reqs and determine the testability, the method and the level of testing to be performed for each req and record in SDF. If a requirement is not testable the requirement should either be reworded or deleted.

(e) Establish timing and sizing requirements
The SWE shall identify the timing and sizing reqs for memory and processing for the CSCI and record in SDF.

(f) Identify safety requirements
The SWE shall identify any necessary safety reqs and record in SDF.

(5) Internal review of SSRAA tasks
The LSE shall conduct an internal review of the completed tasks. The review should determine that the allocated and derived requirements and associated analysis present a complete, testable set of engineering and interface requirements for the CSCI.

(6) Generation of SRS and IRS portion
Upon successful completion of the internal review the SWE shall obtain from CM the CIN for the SRS and IRS and have them (relevant portion of the IRS) generated.

(7) Review of SRS and portion of IRS
Upon receipt of the SRS and portion of the IRS the SWE shall schedule with the PI a review of the SRS and IRS. Delegates from the engineers responsible for interfacing hardware shall be a part of the review. The customer shall be invited to attend the review but he may choose to review the results at the next PR.

(8) Software Specification Review preparation
Upon successful completion of the reviews of all the SRSs and the IRS, an evaluation shall be made of their completeness and technical value. The evaluation shall include any risks with an abatement plan and the individual status of each CSCI. Based on this evaluation, a decision shall be made whether the design effort can continue or whether rework is necessary. The evaluation, individual statuses and an overview of the CSCIs, including any support materials, will be presented at the System/Software Specification Review.

b. Preliminary Design Activity (PDA)

There are two separate efforts that take place during the PDA. The first effort involves the top-level design of each of the CSCIs and the interface of these CSCIs with each other and with other CIs (hardware). The first effort evolves from the CSCI-CSC structure to CSC and CSU structure and definition that defines the evolving TESTS prototypes. These prototypes are grouped into builds for the next step of implementation. Emphasis is placed on requirements definition and creating a SDF for the software elements. The second effort consists of outlining the overall system/software test plan and preliminary procedures for all the CSCIs and TESTS and concludes with the generation of the draft of the Simulator Test Plan/Procedures Results/Report (STPPRR) document.

Tasks to be performed:

(1) Establish a preliminary software architecture
Using the TESTS FD as the stimulator baseline document, the LSE, SWEs, and PI shall generate a system level diagram of the simulator/software architecture to depict the relationships between the CSCIs and the other CIs in the system based on the requirements in the SRS. Computer Software Components (CSCs) that were identified in the SRS should be noted, as applicable, in the architectural diagram.

A description of the organizational structure of the CSCIs, including the any internal structure represented, shall be generated by the SWE group to supplement the simulator/software architectural diagram. Together, the diagram and the description, shall provide the basis for the top-level design until further analysis or design identifies an inconsistency that was not evident in the systems level representation. Any design inconsistency shall be evaluated against the requirements to determine if the requirements were misunderstood or if the requirements were incomplete or incorrect. In the latter case, a problem/change report identifying the discrepancy shall be submitted and recorded in the CSCI SDF. If further work is at risk, because of the discrepancy, the LSWE shall redirect the tasks and report

the risk to the project and the risk will be discussed at a future PR.

(a) Evaluate requirements and identify the CSCs
The SWE group shall identify the CSCs and sub-level CSCs necessary to meet a requirement or set of reqs in the SRS and/or IRS such that all the requirements are allocated to CSCIs. The SWE group shall generate a summary of each CSC's purpose and record this in the CSCI SDF.

(b) Identify any non-developmental software CSCs
The SWE group shall determine any non-developmental software (NDS) that will be incorporated to meet the requirements of a CSC. Refer to paragraph 4.3, Non-developmental Software, in the Software Development Plan for the development requirements regarding incorporation of NDS.

(c) As TESTS prototypes are defined, the above steps are repeated for CSUs, SDFs are created for CSUs, and diagrams are refined to show sub-elements and functions.

(2) Assign Software Engineers
The LSWE shall assign the responsible software engineer(s) (SWEs) to the identified CSCs and CSUs as they evolve.

(3) Begin initial PDA tasks
The SWEs shall perform the following for each CSC:

(a) Establish SDF

The SWE shall establish a SDF for each currently identified CSC. The form of the SDF may be either electronic or paper. If suitable automated resources are available, all or part of the SDF maybe on electronic media. See the SDF table of contents/checklists for the required contents of the SDF.

(b) Identify parent specification(s)
The SWE shall identify the higher-level specification(s) containing the requirements from which the design of the CSCI was derived and record same in the CSC SDF.

(c) Establish the programming language of the CSC
Based on the allocated requirements the SWE shall determine the implementation programming language of the CSC and record this in the CSC's SDF. If Ada is not feasible, the design shall follow the same approach as presented for Ada noting any additional direction given for development "other than Ada". If a requirement or standard can not be met note this in the SDF and the LSWE will discuss the item at a future PR.

(d) Establish preliminary Object-based Architecture
The SWE shall review the Object Oriented Architecture

(OOA) identifying the components of the architecture necessary to implement the CSC.

1. Identify Objects
 - a) Identify Object's attributes/characteristics
 - b) Identify Object's behavior
2. Identify Managers
 - a) Identify control flow of Objects
 - b) Identify data flow of Objects
3. Identify Aggregate
4. Generate OOA diagram (depends on <<TBD>> CASE tool, methodology, and graphic representation to be used)

(e) The SWE shall review the components of the OOA and identify which components will be utilized in the development of the CSC. The use of a language other than Ada does not negate the advantages of an object-oriented approach. The language may not support the approach directly or may not have been implemented traditionally in an object-oriented manner. However, the structure and the relationships of the components of the OOA are applicable in other languages.

(4) Review CSC OOA approaches.

The LSWE shall perform an internal review of the CSC OOA approaches for consistency within and across the CSCs. The responsible SWE shall then generate the specific Ada packages in accordance with the <<TBD>> Design and Coding Standards

The following notes are possible guidelines for examination and as such are marked fore and aft by the line of asterisks.

The following summarizes <<TBD>> tasks that require further definition for each CSC and also depends on the final CASE tools. CSCs may have sub-level CSCs and, as the prototyping evolves, CSUs will emerge. The following description relates to CSCs and their lower elements as applicable.

- (a) Generate a CSCI top-level architecture to graphically illustrate the CSCs and their relationships.
- (b) Describe the relationships among the CSCs by identifying and stating the purpose of each CSC-to-CSC interface and the data transmitted via the interface.
- (c) Identify each system state and mode in which the CSCI operates and the CSCs that execute in each state and mode. A state/CSC table may be provided to illustrate the system states and modes that each CSC executes.
- (d) Describe the general flow of both execution control and data between CSCs while operating in the different states and modes. A flow diagram(s) may be used to illustrate the execution control and data flow in each

state and mode.

- (e) Allocate the memory and processing time to the CSCs. The allocation may be illustrated by a memory/processing time table.
- (f) For each CSC, sub-level CSC, and CSU generate the following information:
 - 1. Name
 - 2. Project unique identifier
 - 3. Description of its purpose.
 - 4. Identify the reqs allocated to the CSC from the applicable requirements specification(s). If the CSC is composed of sub-level CSCs, some or all of this information may be referenced and provided by the sub-level CSC or CSU description.
 - 5. Identify the preliminary design of the CSC in terms of execution control and data flow. If a CSC is composed of sub-level CSCs, this description shall identify the relationships among the sub-level CSCs. Repeat this process for CSUs.
 - 6. As applicable, identify each CSCI internal I/F documented in the Software Requirements Specification, that is to be addressed by the CSC and its sub-level CSCs. This information may be referenced rather than duplicated for each sub-level CSC. The process is repeated for CSUs.
 - 7. Identify the derived design requirements for the CSC and any given constraints imposed on or by the CSC. If the CSC is composed of sub-level CSCs, some or all of this information may be referenced and provided by the sub-level CSC description. The process is repeated for CSUs.
- (g) Provide traceability of the requirements allocated down to each CSC back to the requirements of the Software Requirements Specification and Interface Requirements Specification. Traceability is updated in the RTM.
- (h) Update the FD from CM for the refined CSCIs. Note that CSCs and CSUs are not included in the FD for they will be described in later activities in the SDD and IDD.
- (i) Identify and describe the role of the CSCI within the system.
- (j) Identify and state the purpose of each external I/F of the CSCI.
- (k) Include any general information that aids in understanding this document (e.g. background information, glossary, formula derivations).
- (l) Generate an alphabetical listing of all acronyms, abbreviations, and their meanings as used in this

document.

- (m) Utilize appendixes to provide information published separately for convenience in document maintenance (e.g. charts, classified data). As applicable, reference the applicable appendix in the main body of the document where the data would normally have been provided.

(5) Generation of the draft STPPRR
Obtain identification number, title, and abbreviation of the system to which this STPPRR applies. It shall also identify the CSCIs, CSCs, and the CSUs by title, abbreviation, and identifier. Briefly state the purpose of the system and the CSCIs, summarize the purpose and contents of this document, describe the relationship to related TESTS documents.

Identify and describe the plans for implementing and controlling the resources (software, firmware, and hardware) necessary to perform formal qualification testing (FQT). To reduce duplication, references may be made in the paragraphs below to the software engineering environment previously described in the SDP for those resources that are used in both environments.

- (a) Identify the software items (e.g., operating systems, compilers, code auditors, dynamic path analyzers, test drivers, preprocessors, test data generators, post-processors) necessary to perform the FQT activities. This paragraph shall describe the purpose of each item and shall identify any classified processing or security issues associated with the software items.
- (b) Identify the computer hardware, interfacing equipment, and firmware items that will be used in the software and system integration test environment. This paragraph shall describe the purpose of each item and shall identify any classified processing or security issues associated with the hardware or firmware items.
- (c) Identify the proprietary nature and Government rights associated with each item of the software test environment.
- (d) Identify the contractor's plans for installing and testing, controlling, and maintaining each item prior to its use.
- (e) Identify each FQT and to describe the FQT requirements for each CSCI, CSC, and CSU to which this STPPRR applies.

1. Identify a CSCI, CSC, or CSU by name and project-unique identifier and describe the scope of testing for the software element.
 2. Describe requirements that apply to the FQT or to a group of tests.
 3. Describe the types or classes of FQTs to be executed (e.g., stress tests, timing tests, erroneous input tests, maximum capacity tests).
 4. Describe the levels at which FQT will be performed
 5. Identify and describe each FQT to be conducted on the software element.
- (f) Provide the information specified below for the test. Some or all of this information may be provided graphically.
1. Test objective
 2. Any special requirements (e.g. 48 hours of continuous facility time, weapon simulation, SWEG, etc.)
 3. Test level
 4. Test type or class
 5. Qualification method
 6. Cross reference to the CSCI engineering requirements in the SRS addressed by this test
 7. Cross reference to the CSCI interface requirements in the IRS addressed by this test
 8. Type of data to be recorded
 9. Assumptions and constraints.
- (g) Describe the data reduction and analysis procedures to be used during and following the tests identified. Describe how information resulting from data reduction and analysis will be retained. The results of data recording, reduction, and analysis activities shall be documented in such a way that the resulting information will clearly show whether the test objectives have been met.

c. Critical Design Activity (CDA)

The tasks accomplished during this activity are a continuation of the PDA with iterations of the evolving prototype efforts. The incremental build definition and the process of "build a little, test a little" continues resulting in refinement of CSCs and completion of the CSU delineation. The main products of this activity are the SDD and the IDD, updates to the SDFs, STPPRR, and the FD and RTM, if needed. Tasks to be performed:

(1) Preliminary IDD

Obtain the identification number, title, and abbreviation of the system(s), CSCI(s), and interface(s) to which the IDD applies. Briefly state the purpose of the system and identify and describe the role of the interfaces, to which this IDD applies, within the system.

Specify for each CSCI to which this IDD applies, its relationship to the HWCIs, CSCIs, or critical items (CI) with which it interfaces. Generate one or more interface diagrams to depict the CI level interface relationships. For each interface state its purpose and describe the design of the interface including the data elements transmitted across the interface. For each data element provide the following information, as applicable:

- (a) A project unique identifier for the data element
- (b) A brief description of the data element
- (c) The CSCI, HWCI, or critical item that is the source
- (d) The CSCI(s), HWCI(s), or critical item(s) that are the users of the data element
- (e) The units of measure required for the data element, such as seconds, meters, kilohertz, etc.
- (f) The limit/range of values required for the data element (for constants provide the actual value)
- (g) The accuracy required for the data element
- (h) The precision or resolution required for the data element in terms of significant digits
- (i) The frequency at which the data element is calculated or refreshed, such as 10 KHz or 50 Msec
- (j) Legality checks performed on the data element
- (k) The data type, such as integer, ASCII, fixed, real, enumerated, etc.
 - 1. The data representation/format
 - 2. The priority of the data element

Identify the messages transmitted across the interface by name and project unique identifier, and describe the assignment of data elements to each message. Generate a cross-reference between messages and data elements in both directions. Specify the relative priority of the interface and of each message transmitted across the interface.

Identify and describe the commercial, military, or proprietary communications protocols associated with the interfaces addressing the following communications specification details, as applicable:

- (a) Fragmentation and reassembly of messages

- (b) Message formatting
- (c) Error control and recovery procedures, including fault tolerance features
- (d) Synchronization, including connection establishment, maintenance, termination, and timing
- (e) Flow control, including sequence numbering, window size, and buffer allocation
- (f) Data transfer rate, whether it is periodic or aperiodic, and minimum interval between transfers
- (g) Routing, addressing, and naming conventions
- (h) Transmission services, including priority and grade
- (i) Status, identification, notification, and any other reporting features
- (j) Security, including encryption, user authentication, compartmentalization, and auditing.

(2) Preliminary SDD

Obtain the identification number, title, and abbreviation of the system(s), CSCI(s), and interface(s) to which the SDD applies. Briefly state the purpose of the system and identify and describe the role of the interfaces and the hierarchical decomposition of CSCI requirements to CSCs and then to CSUs to which this SDD applies, within the system. Include the <<TBD>> graphical representation for the software architecture and lower level flow diagrams to show requirement flowdown from CSCI to CSC to CSU as applicable. Use the SWE methodology described in the SDP to perform further OOA analysis and describe the product. Make estimations of timing and sizing of the software elements. For each CSCI, CSC, or CSU update or provide the information, as applicable from the PDA, task "4-f". (Note that descriptions will not be repeated if described in detail at a lower CSU level, but may be referenced.)

Typically, the following lists items to be supplied that are more detailed than those mentioned in the PDA:

- (a) Hierarchical decompositions of the CSCs and sub-level CSCs and charts or flows to depict
- (b) Updates of states and modes for the elements
- (c) The listing of derived requirements and allocation to elements. The RTM is then updated.

- (d) The listing of I/O and interfaces is updated
- (e) Man-machine interface considerations are listed
- (f) System events, interrupts, error or exceptions are described
- (g) Processing and algorithms are described
- (h) Error handling is described
- (i) Conversions and restrictions of processing or data is included
- (j) Descriptions of the logic flow is included. This could be in the form of PDL and / or charts.
- (k) Data base and file information is included.
- (l) Preliminary test descriptions, procedures, and user considerations are written.

(3) Capture results in the SDFs
 Prototypes and incremental builds have been continuing during the CDA and data concerning these efforts are inserted in the SDFs:

- (a) All CSCI, CSC, and CSU descriptions, code, prototype test results are captured
- (b) Observations of potential risks and feasibility of the build and its effect on TESTS is included
- (c) Notes on usage of a software element or prototype are compiled for later inclusion in users manuals

d. Development Configuration Activities (DCA)

This activity includes the Code and Unit Test and SW Integration (SWI) efforts (CSC and CSCI testing) guidelines that are <<TBD>> until decisions on compilers, APSE, SCM are made.

A summary of the Coding Standards, however, will include Appendix B from DOD-STD-2167A as a guideline:

- (1) These standards apply to all source code developed under the contract.
- (2) The Presentation style for the source code shall include standards for:
 - (a) Indentation and spacing

- (b) Use of capitalization
 - (c) Uniform presentation of information in the source code, e. g., the grouping together of all data declarations
 - (d) Use of headers
 - (e) Layout of source code listings
 - (f) Conditions for comments and their format
 - (g) Size of code aggregates by average and a "not to exceed" statement shall be included
- (3) Naming conventions shall be described and the reserve words and keywords that are restricted shall be listed
 - (4) Restrictions on the implementation language due to project or machine-dependent characteristics shall be described
 - (5) The allowed use of language constructs and features shall be described for all intended implementation language/s
 - (6) The coding standards shall include controls and restrictions on the complexity of code aggregates.

In addition to these minimum code standards from 2167A, TESTS source code will have the following:

- (1) All source listings (CSUs and data file listings, as applicable) shall have a Preamble including:
 - (a) CSU name/identifier and linkages to parent software elements, like CSC, CSCI.
 - (b) Interfaces, external and internal, identifiers
 - (c) Usage restrictions
 - (d) Error handling, if applicable
 - (e) Version information of the software element
 - (f) Version information of the compiler/assembler
 - (g) Security related declarations
 - (h) RTM/requirements related to this element
 - (i) Calling and/or execution parameters

(j) Results parameter descriptions and elements called or invoked by this element

(k) <<TBD>>

(l) <<TBD>>

(2) a copy of the listing in the SDF

(3) The software element will be graphically shown on <<TBD>> CASE diagrams/flows/hierarchical/state representations. The software element shall be shown graphically with linkages to other CSUs, CSCs, and CSCI as applicable.

Other standards during the DCA that are <<TBD>> are:

(1) CSU testing

(2) String or "threaded string" testing per evolving prototypes of CSU to CSU and related CSC elements

(3) CSC to CSC and incremental build tests

(4) CSCI and large build tests

(5) Test data capture for all the above

(6) The contents of the SCM tool and placing elements under SCM

e. The System Integration and Testing (SIT) Activity

The standards for this activity are minimal since the previous activities primarily contain all developmental steps. The products of SIT are governed by the previously defined STPPRR, SCM procedures, and by the <<TBD>> format for the PCA and FCA.

12.2 Software Development Files/Folders (SDFs)

Software Development Files/Folders (SDFs) shall be established for all developed software on the project. SDFs are utilized to track the various software products (i.e., documents, reports, source code, schedule, test cases, test results, etc.) that are generated in the development of the software. The structure of the SDFs will follow the break-out of CSCIs, CSCs and CSUs. A SDF shall be established for each CSCI. The LSE) or LSE's designee shall be the custodian of the CSCI SDFs. The LSE shall maintain a composite list of all SDFs established and the associated custodians. Lower level SDFs will be established for CSCs and CSUs based on the work packages identified by the LSE and PM/PI. The lower level

SDFs shall be maintained by the assigned software engineer.

SDFs consist of a cover page which includes the title, abbreviation, and the CIN of the CSCI, CSC, or CSU(s) contained within. Also included on the cover page is the project name, the development location, the date the SDF was initiated, the completion dates of the internal and formal reviews, the names and CINs of the associated CDRLs and their completion dates, and the names of the LSE, assigned SWEs and other associated personnel (e.g., QA auditor, customer, etc). Individuals may utilize their initials when signing off on a particular entry. Additionally, if the SDF is for a CSC or CSU, the parent CSCI or CSC title and CIN are to be included as well. At the bottom of the page is a designated area for QA auditor initials and date.

For each level of SDF there is a checklist in the form of a table of contents which identifies what is required within the SDF. The table of contents shall immediately follow the cover page in the SDF. Following the line items in the table of contents are columns for sign-off and date of completion. The assigned engineer initials and dates the item when it is completed. Under each line item there is a line to designate the system name, directory path and file name for information that is stored on electronic media or the page number(s) within the SDF or the location, title and page numbers of the document containing the information when the information is in hard copy.

The SDF cover page and check lists are located in Appendix D, Forms and are <<TBD>>. However, the following is a summary of the types of information that will be captured in the SDF:

- (1) A statement of the software element's purpose and requirements, the RTM parts that relate to the element
- (2) The graphical representation (flow or structure chart or OOA) showing the element and its related CSUs, CSCs, and CSCI (For TESTS, this should also show the evolving prototype and/or incremental build that contains the element.)
- (3) The source code listing, as available
- (4) Test related items: plans, procedures, testware, results
- (5) Users notes, these may later get compiled to form users manuals
- (6) SCM items, version, time/date of rev, change reports
- (7) Meeting notes, agreements, minutes
- (8) <<TBD>>

APPENDIX D

FORMS

<<TBD>>

APPENDIX E

SOFTWARE PRODUCT EVALUATION CHECKLISTS

ROUGH DRAFTS

14.1 SPE Checklists

Although the details are <<TBD>> there will be SPE Checklists for the following:

- (1) The corrective action process
- (2) The program change process
- (3) The SDF and its contents
- (4) The SSRAA and its products:
 - (a) The RTM
 - (b) The SDP
 - (c) The FD
 - (d) The SRS
 - (e) The IRS
 - (f) The data element information
 - (g) The related Project Review/s (PR) agenda/s,
including a special agenda for the SSSR
 - (h) An informal walkthru agenda for internal reviews
- (5) The PDA and its products:
 - (a) The RTM
 - (b) The updated SDFs
 - (c) The updated SRSs and IRS
 - (d) The STPPRR and related test checklists
 - (e) The OOA diagrams and other graphical presentations
 - (f) The CSCI and CSC checklists
 - (g) The incremental build plan
 - (h) The updated FD including simulator HW descriptions
 - (i) The SDC and its environment
 - (j) The PR agendas
- (6) The CDA and its products:

- (a) Updates of RTM, SRS, IRS, FD, and STPPRR as needed
 - (b) The IDD checklist
 - (c) The SDD checklist
 - (d) The updated SDFs
 - (e) The incremental build/evolving prototype status
 - (f) The related PR agendas
 - (g) The CSC and CSU checklists
- (7) The DCA and its products:
- (a) The CSU checklists including the coding standards
 - (b) The updated SDDs and IDD
 - (c) The SCM checklist
 - (d) The users manuals
 - (e) STPPRR related items, e. g., test requirements, test cases, test descriptions, test procedures, test results
 - (f) The updated SDFs
 - (g) The incremental build status
 - (h) The related PR agendas
- (8) The SIT and its products:
- (a) Updated SDDs and IDD with media to generate the SPS
 - (b) The PCA and FCA checklists and related PRs
 - (c) The P/O Manual
 - (d) The VDD
 - (e) The test results and reports of the STPPRR
 - (g) The updated FD for follow on of other TESTS platforms

ANNEX C

DISCUSSION OF SUPPORTING ANALYSIS CALCULATIONS

1.0 CALCULATION OF THE NUMBER OF NEEDED EMITTERS FOR A GIVEN MESSAGE RATE

For a message rate of n signals per second and a signal length of p microseconds, the probability of exactly k signals (or $k - 1$ overlaps) present at any given time is given by the binomial distribution

$$p(k) = \frac{n!}{k!(n-k)!} p^k q^{n-k}$$

where $q = 1 - p$. The probability of k or fewer signals at a given time is the sum

$$\sum_{i=0}^k \frac{n!}{i!(n-i)!} p^i q^{n-i}$$

For a given value of k , the sum is a function of the message rate n . Determining the value of n that makes the sum equal to 0.999 thus indicates that k signal generators will create the necessary number of overlapping signals 99.9% of the time for that message rate. Since the sum is an increasing function of n , a binary search for the correct n may be used. The following program uses this method to find the value of n for several values of k for each of several message lengths.

1.1 Computer Program Listing

```
PROGRAM tempp4
c
dimension g(11), sum(8), tempn(8)
doubleprecision g, ktemp, ntemp, plrais, p2rais
doubleprecision sum, pl, p2
real a, b, c
p1 = .000050
10 p2 = 1 - p1
print *, 'p1=' , p1
print *, '
c The following do loop contains all calculations to
c determine the value (n) of the signal density at which
c the sum of the first k terms of the binomial series
c equals 0.999.
do 550 k = 1, 8
a = 0
b = 100000
n = 50000
100 g(1) = (p2)**n
ktemp = 1
ntemp = 1
c This loop calculates and saves, in array g, the terms of
c the series. ktemp = k! and ntemp = n(n-1)...(n-k+1).
```

```

do 300 l = 1, k
    ktemp = ktemp * l
    ntemp = ntemp * (n - l + 1)
    plrais = (p1)**l
    p2rais = (p2)**(n - l)
    g(l + 1) = real(ntemp) * plrais * p2rais / real(ktemp)
300 continue
sum(1) = g(1) + g(2)
c This loop along with the previous line, sum the first k
c terms which are then compared with the value of 0.999
do 350 i = 2, k
    sum(i) = sum(i - 1) + g(i + 1)
350 continue
c = b - a
if (c .eq. 1) goto 500
if (sum(k) .gt. 0.99900) then
    a = n
else
    b = n
endif
n = int((b + a)/2)
goto 100
500 print *, k, n
550 continue
c The signal densities are found for message lengths of 50 to
c 400 microseconds in increments of 50 microseconds.
if (p1 .gt. 0.000375) goto 880
p1 = p1 + 0.00005
goto 10
880 stop
end

```

2.0 CALCULATION OF MULTIPATH TIME DELAY

Each signal transmitted by a sender may travel by two paths - one signal traveling directly between the platforms and the other undergoing a reflection off the earth. The signal traveling directly between the platforms arrives first and the reflected signal arrives a short time later.

The time difference between the direct and reflected signals is shown in Figure C-1.

$$\frac{d - r_1 - r_2}{c}$$

where c is the speed of light and d is given by

$$d = \sqrt{(R_E + h_1)^2 + (R_E + h_2)^2 - 2(R_E + h_1)(R_E + h_2)\cos\theta}$$

d is known from radar and thus the above equation may be solved for θ . From the law of sines, r_1 and r_2 are given by

$$\frac{r_1}{\sin\theta_1} = \frac{R_E + h_1}{\sin(\alpha_1 + 90)}$$

and

$$\frac{r_2}{\sin\theta_2} = \frac{R_E + h_2}{\sin(\alpha_2 + 90)}$$

The angles, as shown in Figure C-2, are found by writing

$$\gamma = \tan^{-1}\left(\frac{b}{a}\right) = \tan^{-1}\left(\frac{R_E \sin\theta}{R_E(1 - \cos\theta) + h}\right)$$

which gives the expressions

$$\alpha_1 = 90 - \theta_1 - \tan^{-1}\left(\frac{R_E \sin\theta_1}{R_E(1 - \cos\theta_1) + h_1}\right)$$

and

$$\alpha_2 = 90 - \theta_2 - \tan^{-1}\left(\frac{R_E \sin\theta_2}{R_E(1 - \cos\theta_2) + h_2}\right)$$

For reflection, $a_1 = a_2$ and thus setting $\theta_2 = \theta - \theta_1$ gives

$$\theta_1 + \tan^{-1}\left(\frac{R_E \sin\theta_1}{R_E(1 - \cos\theta_1) + h_1}\right) = \theta - \theta_1 + \tan^{-1}\left(\frac{R_E \sin(\theta - \theta_1)}{R_E(1 - \cos(\theta - \theta_1)) + h_2}\right)$$

To find θ_1 , the value of θ_1 is incremented in small steps until the left and right hand sides of the last equation are equal to within a given tolerance. The other angles may then be determined and used to find r_1 and r_2 and hence the time difference. The following program does this calculation.

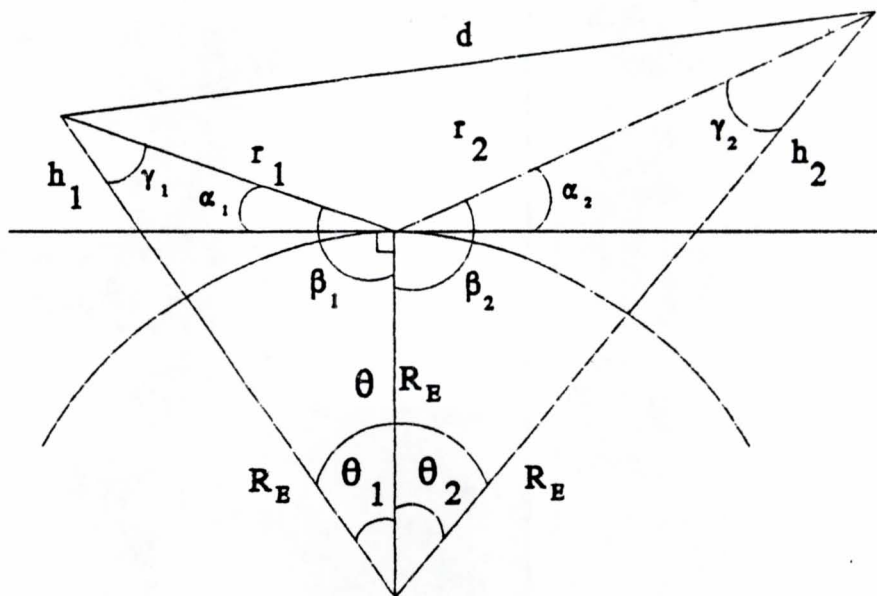
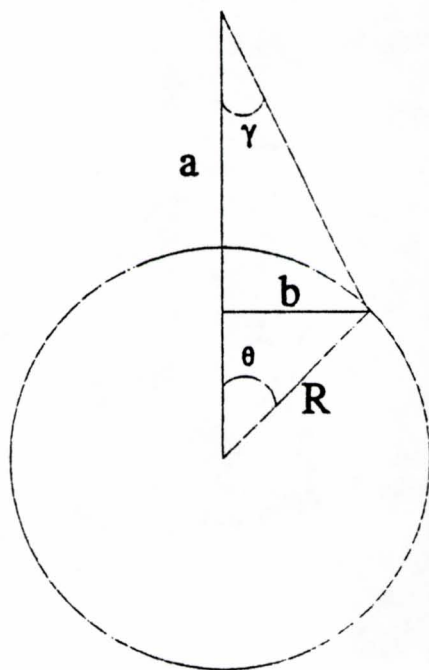


Figure C-1. Multipath Geometry for Reflections from a Spherical Surface



$$b = R \sin \theta$$

$$a = (R+h) - R \cos \theta$$

Figure C-2. Multipath Geometry - Gamma Components

2.1 Computer Program Listing

```
PROGRAM cur2

C
C This program calculates the multipath time delay for
C curved earth. All distances are measured in feet. Earth's
C radius is taken to be the equatorial radius of
C  $6.378 \times 10^6$  m = 20926218 ft (as given on p.A24 of Halliday
C and Resnick) times 4/3 so as to account for atmospheric
C refraction.
C
C     ainc = the value by which the distance d between the
C     platforms is incremented.
C     d = the distance between the two platforms.
C     dl = (4(earth's radius)/3) plus the height of platform one.
C     i.e. dl = r + h1
C
C Dimension g(8, 27, 9)
C double precision div
C parameter (r = 27901624)
C
C open (UNIT = 1, FILE = 'JOHN.DAT', STATUS = 'UNKNOWN')
C j = 0
C do 600 h1 = 5000, 40000, 5000
C     j = j + 1
C     l = 1
C     do 700 h2 = h1, 40000, 5000
C         l = l + 1
C         k = 0
C         d = 54684.9
C     This is d = 9 miles as an initial value.
C         ainc = 6076.1
C     This loop increases the distance between platforms from 10 to
C     20 nautical miles in increments of 1 mile; from 20 to 50
C     miles in increments of 5 miles and from 50 to 100 miles in
C     increments of 10 miles.
100     d = d + ainc
C         if (d .gt. 607611) then
C             goto 700
C         elseif (d .gt. 303804) then
C             ainc = 60761.0
C         elseif (d .gt. 121521) then
C             ainc = 30380.5
C         endif
C         k = k + 1
C         dl = r + h1
C         d2 = r + h2
C     The next two lines calculate the angle between the
C     platforms as measured from the center of the earth.
C         div = (dl * dl + d2 * d2 - d * d) / (2 * dl * d2)
C         a = acos(div)
C         btest = 6
C         altest = 0
C         a2test = 0
```

```

C      Angles are compared to this initial value of btest
C      to determine the smaller of the two. This loop finds
c      when incident and reflection angles are equal.
        a1 = 0
205      if (a1 .gt. a) goto 200
        a1 = a1 + 0.00001
        a2 = a - a1
        b1 = a1 + atan(r*sin(a1) / (r * (1 - cos(a1)) + h1))
        b2 = a2 + atan(r*sin(a2) / (r * (1 - cos(a2)) + h2))
        b12 = b1 - b2
        b12ab = abs(b12)
        if (b12ab .lt. btest) then
            btest = b12ab
            altest = a1
            a2test = a2
            bltest = b1
            b2test = b2
        endif
        goto 205
200      continue
        c1 = 3.14159 - bltest
        r1 = d1*sin(altest)/sin(c1)
        c2 = 3.14159 - b2test
        r2 = d2*sin(a2test)/sin(c2)
        dtcurv = (r1 + r2 - d)/ 9.843e+8
        g(j,k,1) = d / 6076.1
        g(j,k,1) = dtcurv
        goto 100
700      continue
600      continue
        do 50 j = 1, 8
            write(*,*) 'Currently storing data for j = (max j = 8)',j
            do 50 k = 1, 22
                write(1,111) (g(j,k,ii),ii=1,9)
                format (F5.0,8(E9.3))
111            continue
50          continue
        close (unit = 1)
        stop
        end

```


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