Range Commanders Council

RANGE SAFETY GROUP

SPECIAL REPORT
RS-38

ENHANCED FLIGHT TERMINATION SYSTEM STUDY

PHASE I – IV REPORTS

NOVEMBER 2002

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PREFACE

The Range Commanders Council (RCC) Range Safety Group (RSG) Flight Termination Standing Committee (FTSC) initiated task RS-38, Investigate More Robust Command Links for Flight Termination, in April 2000. The task consisted for four study phases, each designed to provide the RSG/FTSC with information on robust command link messages and modulation methods for flight termination systems (FTSs). This document incorporates into one Special Report the final reports and associated appendixes from the four phases of the study. In order that this Special Report receive the broadest distribution (Distribution A), several appendixes were withdrawn and placed in a Special Report Supplement (Distribution D). A listing of this material can be found in the Table of Contents.

This task, referred herein as RS-38 or EFTS study, was organized and managed by an alliance between NASA/Dryden Flight Research Center (DFRC), the Air Force Flight Test Center (AFFTC), and the FTSC with support from contractors from DFRC, AFFTC and Vandenberg AFB. Support from the RCC Telemetry Group, Telecommunications & Timing Group, and Frequency Management Group provided valuable data required for successful completion of this task. In the security area, the National Security Agency (NSA) diligently worked with the range safety community to come up with a mutually acceptable security solution. From academia, Brigham Young University provided digital engineering and modeling and simulation support to enhance and validate the team's approach to this new generation of flight termination systems. Industry representatives participated by providing input based on their expertise with flight termination system component design, testing, manufacturing, and cost estimations. The FTSC members provided the expertise and guidance required to enable a reasonable solution to the vulnerabilities of the current flight termination systems.

Because of the conscientious efforts and great teamwork of those who participated in this study, all phases of the task were successfully completed on time and documented with associated reports. The EFTS team would like to thank everyone who participated in this task and extend sincere appreciation for all of the time and effort that resulted in the successful completion of task RS-38.

The RSG/FTSC welcomes any comments, questions, corrections, additions, or deletions to this document. Any inquiries should be addressed to:

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ACRONYMS AND INITIALISMS

3-DES	triple data encryption standard
ac/AC	alternating current
ADAPS	Advanced Data Acquisition Processing System
AEPLRS	Airborne Enhanced Position Location Reporting System
AES	advanced encryption standard
AFDTC	Air Force Development Test Center
AFFTC	Air Force Flight Test Center
AFS	Air Force Station
AGC	automatic gain control
AGM	air-to-ground missile
AIU	airborne instrumentation unit
aka	also known as
AM	amplitude modulation
ARTM	advanced range telemetry
AWGN	additive white gaussian noise
Az	azimuth
BAE	British Aerospace Engineering
BER	bit error rate
BPF	bandpass filter
BPSK	binary phase shift keying
C2	command and control
CBD	Commerce Business Daily
CCAS	Cape Canaveral Air Station
CCF	Central Control Facility
CCRS	Central Command Remoting System
CCT	command control transmitter
CCTMS	command control transmitter mobile system
CDMA	code division multiple access
CDS	Command Destruct System
CER	character error rate
CM	countermeasure
CMC	command monitor computer
CMCS	COMSEC Material Control System
CMEV	command message encoder verifier
COMSEC	communications security
CONOPS	concept of operations
COTS	commercial-off-the-shelf
CPFSK	continuous phase frequency shift keying
CPS	command panel system
CRC	cyclic redundancy check
CRT	cathode ray tube

CRU	command remoting unit
CSCC	command system controller console
CTS	command transmit site
CTS	Command Transmitter System
CW	continuous wave
dc	direct current
DCS	Digital Control System
DDS	direct digital synthesis
DES	data encryption standard
DFT	discrete Fourier transform
DFRC	Dryden Flight Research Center
DID	data item description
DoD	Department of Defense
DPG	Dugway Proving Ground
DRS	digital range safety
DSP	digital signal processing
DTD	data transfer device
EEV	English Electric Valve
EFTR	enhanced flight termination receiver
EFTS	Enhanced Flight Termination System
EIRP	effective isotropic radiated power
el	elevation
ELV	expendable launch vehicles
EPLRS	Enhanced Position Location Reporting System
ETR	Eastern test Range
FCO	flight control officer
FCP	FTS control panel / flight control panel
FCS	Flight Control System
FDM	frequency division multiplexing
FEC	forward error correction
FEP	front end processor
FIT	flexible interoperable transceiver
FM	frequency modulation
FMG	Frequency Management Group
FMS	foreign military sale
FOV	field of view
FSO	flight safety officer
FSS	Flight Safety System
FST	full scale targets
FTP	flight termination panel
FTR	flight termination recorder
FTS	Flight Termination System
FTSC	Flight Termination Standing Committee

FTU	flight termination unit
GPS	Global Positioning System
GRDCUS	Gulf Range Drone Control Upgrade System
Grms	root mean square acceleration
GTR	Gulf Test Range
HA	high alphabet
HAE	high altitude endurance
HDD	high density data
HPA	high power amplifiers
Hz	hertz
I/O	input/output
IAMS	Interim Antenna Monitoring System
ICBM	intercontinental ballistic missile
IEEE	Institute of Electrical and Electronics Engineers
IF	interface panel
IGCE	independent government cost estimates
IIP	instantaneous impact predictions
IRIG	Inter-range Instrumentation Group
JDMTA	Jonathan Dickinson Missile Tracking Annex
JPC	joint spectrum center
KLC	Kodiak launch unit
kVA	kilovolt-ampere
LAN	local area network
LDC	LAN data controller
LED	light emitting diodes
LHC	left hand circular
LOS	line-of-sight
LSB	least significant bit
M&S	modeling and simulation
MCP	master command panel
MCS	Mobile Command System
MER	message error rate
MFCC	mission flight control center
MFTGS	Missile Flight Termination Ground System
MHA	modified high alphabet
MOA	military operation area
MRTFB	Major Range Test Facility Base
ms	milliseconds
msl	mean sea level

MSB	most significant bit
MSK	minimum shift keying
MSL	mean sea level
MSU	message storage unit
NASA	National Aeronautical and Space Administration
NAWC	Naval Air Warfare Center
NRZ	non-return-to-zero
NRZ-L	non-return-to-zero-level
NSA	National Security Agency
NTIA	National Telecommunications and Information Administration
NTISSP	National Telecommunications and Information Systems Security Policy
OT	operational trident
PAWS	Phased Array Warning System
PC	personal computer
PM	phase modulation
PMRF	Pacific Missile Range Facility
PN	pseudo-random number
RASCAD	range safety control and display
RCC	Range Commanders Council
RCP	remote command panel
RCSP	RF control signal processor
RF	radio frequency
RHCP	right hand circular polarization
RLV	reusable launch vehicles
RMCC	Ridley Mission Control Center
ROCC	range operations control center
RODS	Range Operations Display System
RPV	remotely piloted vehicles
RSA	Range Standardization And Automation Program
RSD	range safety display
RSDP	range safety data processor
RSG	Range Safety Group
RSO	range safety officer
RTS	Reagan Test Site
RX	receiver
SADL	situation awareness data link
SDC	serial data controller
SETTA	Southeast Test and Training Area
SFP	single failure point
SIR	signal-to-interference
SLAM	standoff land attack missile

S/N	signal-to-noise ratio
SNL	Sandia National Laboratory
SPC	System Planning Corporation
SRM	solid rocket motors
SSTO	signal strength telemetry output
STS	Secure Transmission System
T&E	test and evaluation
TDEA	triple data encryption algorithm
TDM	time division multiplexing / time domain multiplexing
TECCS	Test and Evaluation Command and Control System
TG	Telemetry Group
TMD	tactical missile defense
TTG	Telecommunications and Timing Group
TTL	transistor logic
TTR	Tonopah Test Range
TX	transmitter
UAV	unmanned aerial vehicle
UHF	ultra high frequency
UMS	un-manned secure
unk	unknown
UPS	uninterrupted power supply
USN	United States Navy
UTTR	Utah Test and Training Range
VAFB	Vandenberg Air Force Base
VCC	vehicle command count
VHS	vertical helix scan
VSWR	voltage standing wave ratio
WFF	Wallops Flight Facility
WRTTM	warhead replaceable tactical telemetry
WSEP	Weapon System Evaluation Program
WSMR	White Sands Missile Range

EXECUTIVE SUMMARY

The goal of the Enhanced Flight Termination System (EFTS) study was to investigate more robust command links for flight termination including message formats and modulation methods. This study was structured into four phases:

Phase I: Requirements Definition/Range Infrastructure: The goal of this phase was to research current flight termination systems (FTSs). System requirements were defined based on current RCC standards and these provided a guideline for the study. These requirements were defined through a process of gathering information from a representative sample of the different communities involved with FTSs, including testing ranges, vendors, and end-users. Range safety personnel provided information on current requirements that would apply to any new FTS technology. The Phase I report was completed in September 2000.

Phase II: Technology Assessment: This phase explored and analyzed current analog and digital modulation techniques available for FTS applications. Several manageable solutions were identified that would meet the guidelines and requirements established in Phase I. Based upon the best overall value, the modulation schemes that were determined to warrant additional analysis in Phase III were the continuous phase frequency shift keying (CPFSK) and modified high alphabet (MHA) schemes. The Phase II report was completed in March 2001.

Phase III: Technology Demonstration: Based upon the information gathered from Phase I and II of the study, further analysis was conducted during Phase III to determine the optimal modulation scheme and the layout of the digital message to be sent from the ground transmitting system to the flight termination receiver. The Phase III report was completed in January 2002.

This analysis resulted in the following recommendations to the Range Safety Group by the EFTS team:

1. EFTS should utilize continuous phase frequency shift keying (CPFSK) (aka pulse code modulation/frequency modulation) as the FTS modulation scheme based upon the following overall advantages:

- Supportable and upgradeable – CPFSK is easier to support (range and vendor) and upgrade based on the following factors:
  - CPFSK sensitivity
  - more technical documentation on CPFSK
  - test equipment availability
  - MHA difficult to increase number of bits or alter packet field
- Proven technology – There are currently more commercial users of CPFSK versus MHA.
- Range understanding – The ranges have an understanding of how to use CPFSK because of its prevalent use in the telemetry community.

2. The digital message should use the following proposed format:

Triple DES Encrypted

Authentication Check

Link Integrity Check

Frame Synch (? Bits)	Check Channel (1 Bit)	Range ID (16 Bits)	TX ID (4 Bits)	Vehicle ID (20 Bits)	Counter (12 Bits)	Command (6 Bits)	User Defined (5 Bits)	CRC/ FEC (? Bits)

This message format is subject to change. The EFTS design validation phase (to be completed) will provide feedback on the proposed number of bits and how they are utilized. With the tested units, the format will be updated accordingly.

Phase IV: RCC Standards Recommendations: The objectives of Phase IV were to wrap-up all tasks associated with RS-38 and to prepare and initiate the design validation phase. The tasks included generating the RCC tasks necessary to update the RCC standards affected by EFTS, addressing the TEMPEST requirements for security, implementing EFTS with different scenarios, developing new system performance specifications for validation and development, and estimating the costs for developing EFTS and upgrading the country's ground infrastructure.

The tasks for the design validation phase (Part Two of the EFTS project) will include writing the Request for Proposal package and generating cost estimates for the development of EFTS.

CHAPTER 1

INTRODUCTION

1.1 Enhanced Flight Termination System (EFTS) Study Objectives

This report documents the results of Phases I-IV of the EFTS study initiated April 2000. The objective of this study was to investigate more robust command links for flight termination including message formats and modulation methods. The study was designed to identify, analyze and evaluate various technology approaches, and then develop a recommendation for the optimal command destruct system for FTS use. This evaluation process included the following criteria:

- Security, including protection against unintended commands, and selectable termination for simultaneous multiple operations
- Use of the existing radio frequency spectrum and different frequency bands
- Impact on existing ground and airborne (including fail-safe) equipment
- Impact on transmission and processing time (latency)
- Maturity and reliability of new technologies and design solutions
- Immunity to interfering signals
- Cost

1.2 Background

Flight termination systems (FTSs) have been in place at various United States and foreign ranges for decades. These systems have characteristics that have proven reliable in extreme environments. The following paragraphs describe the existing policies regarding FTS and some of their common attributes.

1.3 Flight Termination Security Policy

The Range Commanders Council (RCC) FTS Commonality Standard 319-99[1] (RCC 319) traces security policy for space launch vehicle flight termination systems to two documents. The first is the National Telecommunications and Information Systems Security Policy (NTISSP) No. 1, titled *National Policy on Application of Communications Security to U.S. Civil and Commercial Space Systems*, dated 17 June 1985. The second is the National Security

[1] Range Commanders Council, Range Safety Group. *Flight Termination System Commonality Standard*, FOUO (Document 319-99), White Sands Missile Range, NM: Secretariat, 1999 (rcc@wsmr.army.mil).

Telecommunications and Information Systems Policy (NSTISSP) No. 100, titled *National Policy on Application of Communications Security to Command Destruct Systems*, dated 14 September 1999. To update these documents so that a clear and definitive understanding could be obtained as to the intent of these policies in light of current launch missions, a new document was drafted and approved. This superseding document is the NSTISSP No. 12, titled *National Information Assurance Policy for U.S. Space Systems*, dated January 2001. This policy and the associated RCC requirements are the basis for secure and non-secure Flight Termination Systems used today on member ranges.

The current generation of receivers and associated ground transmitting equipment share the following common attributes:

1.3.1 Command Link. The command link in current use is frequency modulated (FM) using a set of IRIG tones, message format, and message timing established in RCC 319. This scheme, when combined with attributes of the flight termination receiver (FTR) design implementation, provides a quantifiable level of security that serves as a basis for comparison to new designs and modulation techniques.

1.3.2 Capture Ratio. A primary advantage of the FM command link is the protection provided by capture ratio. Inherent qualities of FM receivers assure that the unit will stay locked on the strongest signal. This means that any interference must overcome the power imparted by the ground transmitting site in order to interfere with the command link. Accordingly, ranges typically employ high power (kilowatt range) transmitters — an approach that has historically provided high confidence in link integrity.

1.3.3 Sequence of Tones, Secure. The combination and sequence of tones (codes) for secure flight missions are assigned by the National Security Agency (NSA). During vehicle processing and pre-launch testing, this sequence is handled with special requirements. The tone sequence is loaded into the airborne FTR, ground flight control consoles, and ground transmitters using NSA-approved secure loading devices that inject the information directly into the respective devices. Pre-launch end-to-end tests use program-specific test codes; operational codes (e.g. ARM, DESTRUCT and OPTIONAL commands) are never transmitted via RF open-loop in the pre-launch period. End-to-end, open-loop testing is accomplished by use of a non-secure test command that has no impact on the mission or FTS reliability. This approach assures that the mission-assigned codes are fully protected and restricted to authorized use.

1.3.4 Sequence of Tones, Non-secure. The local range safety office normally assigns the combination and sequence of tones for non-secure flight missions. The tones are factory programmed into the airborne FTR and loaded into the ground flight control consoles or ground transmitters. Non-secure tones or tone sequences can be RF transmitted (open-loop) in the pre-launch period to verify receipt of signal and proper operation.

1.4 Task Structure

The RS-38 task was structured as a phased study. The phases were conducted serially, i.e., Phase I and Phase II were conducted prior to Phase III and Phase IV. The results of each of the phases were used in the succeeding phases and culminated in individual reports describing the salient facts and outcomes of the effort with appropriate recommendations. Participation and coordination with the Range Commanders Council (RCC) technical groups including the Range Safety Group (RSG), Frequency Management Group (FMG), Telecommunications and Timing Group (TTG), and Telemetry Group (TG) was imperative to the success of this study.

The study identifies various approaches for a new robust command link for flight termination. It also provides an estimation of cost and the provisions required that allow each range to continue to use their legacy system in conjunction with the new system. The FTSC-recommended approaches were used to perform modeling and simulation for the next generation of flight termination command links. At least two approaches were analyzed via modeling and simulation and detailed analysis. From the results of this study, a specifications document was drafted for a new proposed FTS.

1.4.1 Phase I: Requirements Definition/Range Infrastructure Study. FTS requirements were defined based on current RCC standards, and these requirements were used to provide a guideline for the study. The requirements analysis used data collected from on-site visits to a representative sample of the different communities involved with FTS, including ranges, vendors and end-users. FTS units are used in tactical vehicles, remotely piloted vehicles (RPVs), unmanned aerial vehicles (UAVs), full-scale and sub-scale targets, sounding rockets, and expendable (ELVs) and reusable launch vehicles (RLVs). Each of these uses has unique requirements that need to be considered when selecting a new technology for FTS. For example, UAVs generally will fly over large geographical areas requiring the support of several ranges with the flight termination systems all remotely controlled.

The requirements definition effort focused on researching the existing standards and directly interfacing with the range safety community to determine current requirements that had to be addressed in any proposed new FTS technology.

1.4.2 Phase II: Technology Assessment. In this Phase, an extensive assessment of current analog and digital modulation techniques was explored and analyzed. Vendors and EFTS team members developed seven approach descriptions (modulation schemes) that addressed the established design requirements from Phase I. The candidates were reduced to several manageable solutions that had the potential to be implemented. A tradeoff analysis was conducted on the final candidates to assist in the evaluation. The technology assessment phase was purely a paper study.

After evaluating the proposed seven approaches according to the advantages, disadvantages and risk of each, two modulation schemes were determined to warrant additional analysis in Phase III: continuous phase frequency shift keying (CPFSK) and modified high alphabet (MHA) schemes. These schemes were chosen because of their favorable ranking in various areas including the overall system, environmental considerations, performance and human factors.

The decision was made not to pursue binary phase shift keying (BPSK) or the spread spectrum methods because of the inherent problems associated with coherent schemes.

Currently, it is believed that the FTS radio frequency environment is characterized by significant Doppler shifts, high phase noise, and significant co-channel interference. None of these characteristics offer a friendly environment for coherent schemes. Thus, if a coherent scheme were to be used, sophisticated signal processing would be required to overcome these impairments. A further complication is the preference to reduce the cost of upgrading range infrastructure by retaining the existing non-linear power amplifiers. Use of non-linear amplifiers with non-constant envelope signals causes bandwidth problems because of "spectral regrowth" and may cause significant signal distortion.

To build the data format and determine the security technique for EFTS, all of the proposed approaches were examined during Phase III in order to identify the optimum solution.

1.4.3 Phase III: Technology Demonstration. The technology demonstration phase went a step beyond the traditional paper study methods to provide verifiable answers to complex questions. Further analysis was conducted on the candidate solutions provided in Phase II to determine the optimal solution to the EFTS requirements. Modeling and simulation of both the analog and digital solutions were conducted to determine their susceptibility to interference.

The candidate solutions were analyzed to determine interoperability with legacy systems. The analysis included simple tests that analyzed digital inputs to existing FTS systems, to more complex tests that explored the proposed modulation schemes and their viability in the FTS environment through examination of alternative transmitters and receivers. Mr. Eugene Law's (NAWCWD) RF test lab was used to evaluate the flight environments, such as multipath and RF interference, that could affect signal quality.

1.4.4 Phase IV: RCC Standards Recommendation. The final product of this study consists of a performance specification for ground-based transmitters and airborne receivers. A cost analysis was developed for the candidate solution (for sample ranges) to ensure that cost impacts are identified and provided to the range safety community. This effort also required extensive coordination with RCC technical groups. In addition, recommended updates to any affected RCC standards or documents were provided to the FTSC for review. It is anticipated that these recommendations will be the starting point of a new or supplemental RCC document.

The initiation of the Phase IV effort began shortly before the completion of Phase III. The draft performance specification was not completed until after the completion of the Phase III draft report. This provided the FTSC members with the relevant information from the study concurrent with the draft specification.

1.5 Carrier Frequency

The current frequency band for FTS use is 420 to 450 MHz. The Eastern and Western Ranges also use 416.5 MHz. All of the ranges have agreed to utilize a small subset of the frequencies for commonality purposes. For example, programs desiring to operate at more than one range are expected to use one of the assigned common frequencies.

At the beginning of this study, consideration was given to moving to a new frequency for FTS. There are two primary concerns with the current frequency spectrum for FTS. The first is that FTS is not the sole user of the 420-450 MHz band, thus posing interference issues. The second concern is the threat of being "forced" out of the band due to selling off of bandwidth to commercial users. In an attempt to quantify the risks of staying in the current region as well as to gain insight into the possibility of moving to another frequency sector, the Frequency Management Group (FMG) was consulted for direction.

The FMG offered suggestions to move to different band areas; however, the available bandwidth was extremely small and the task team considered this to be an unacceptable solution. In addition, the FMG could not quantify the timeframe in which being "forced" out of the current band might occur. Therefore, the task team concluded that the design criteria will include use of the current frequencies and encourage reduced use of bandwidth when applicable.

There are currently two tactical digital radio systems that provide automatic, real-time, precision location of combat forces on the battlefield and in the air being used by the military called the Enhanced Position Location Reporting System (EPLRS) and Airborne Enhanced Position Location Reporting System (AEPLRS). Due to the potential for interference with these systems, the FMG has asked the EFTS team to evaluate the possibility of moving FTS frequency usage to 375-400 MHz since this area of the spectrum is currently undergoing re-allocation and is "owned" by DoD. In addition, recent negotiations between the US and Mexico have caused concern over potential loss of particular, widely-used FTS frequencies. As part of EFTS, the team is working with the FMG to determine the feasibility of such a move, with consideration given to the fact that the Joint Spectrum Center (JSC) must approve any re-allocations. There will need to be a follow-up to EFTS, if this change is considered feasible.

1.6 Task FM-31

To support the idea of re-allocating the FTS frequency to dedicated areas of the spectrum and to evaluate the interference of other systems that share the FTS frequency band, a joint task between the RSG and FMG was initiated. The intent of this task is two-fold: identify areas of the spectrum that are available while still meeting the needs of the range safety community (i.e., acceptable bandwidth and low cost impacts to ground infrastructure) and, secondly, perform laboratory tests that measure the interference of other systems with FTS systems that use the 400-450 MHz band.

1.7 Security

Security is a key concern and requirement of the enhanced flight termination system. NSA has been an integral part of the team evaluating the requirements for the EFTS to ensure that security requirements are met. NSA evaluated the only available secure FTS at this time, the high alphabet system (briefly discussed in paragraph 1.3.3), to determine whether it met current encryption requirements. Their findings indicate that the current high alphabet system is adequate to protect command destruct flight termination operations into the near future, assuming that it is used only per published operational doctrine.

The standard system is adequate only to protect non "national security payloads" at the present time. The doctrine requirements appear to be procedurally cumbersome and unmanageable for practical use with both the secure and non-secure systems. It is NSA's recommendation that a new single system based on a more robust cryptographic backbone and less on operational doctrine, be developed, and that it begin to phase-out the old systems as soon as practical after a reasonable development, certification and production period.

1.8 Vendor Involvement

As a part of this study, we have attempted to keep our industry partners involved and informed. We have accomplished this by submitting Commerce Business Daily (CBD) synopses in June and October 2000 and November 2001. The initial synopsis was issued for the purpose of locating vendors interested in the EFTS study. The second was to invite industry representatives to a vendor day where information on EFTS could be briefed and questions answered. The third briefing was held to provide an update on the status of EFTS and the plans for development of test units.

CHAPTER 2

PHASE I: REQUIREMENT DEFINITIONS AND RANGE INFRASTRUCTURE

2.1 Airborne Flight Termination System

RCC Standard 319[2] provides a common set of design and testing requirements for programs launching from the major Department of Defense (DoD) test ranges and National Aeronautics and Space Administration (NASA) launch facilities. RCC 319 notes that a typical Flight Safety System (FSS) controls an airborne vehicle in a safe manner and that the FSS is made up of a Flight Termination System (FTS), a method to track the vehicle, and a means of receiving status data from the vehicle. In some cases the FSS is used to input commands into the vehicle flight control system (i.e., placing the vehicle into a recovery mode). Figure 2-1 is a diagram of a typical FSS/FTS.[3]

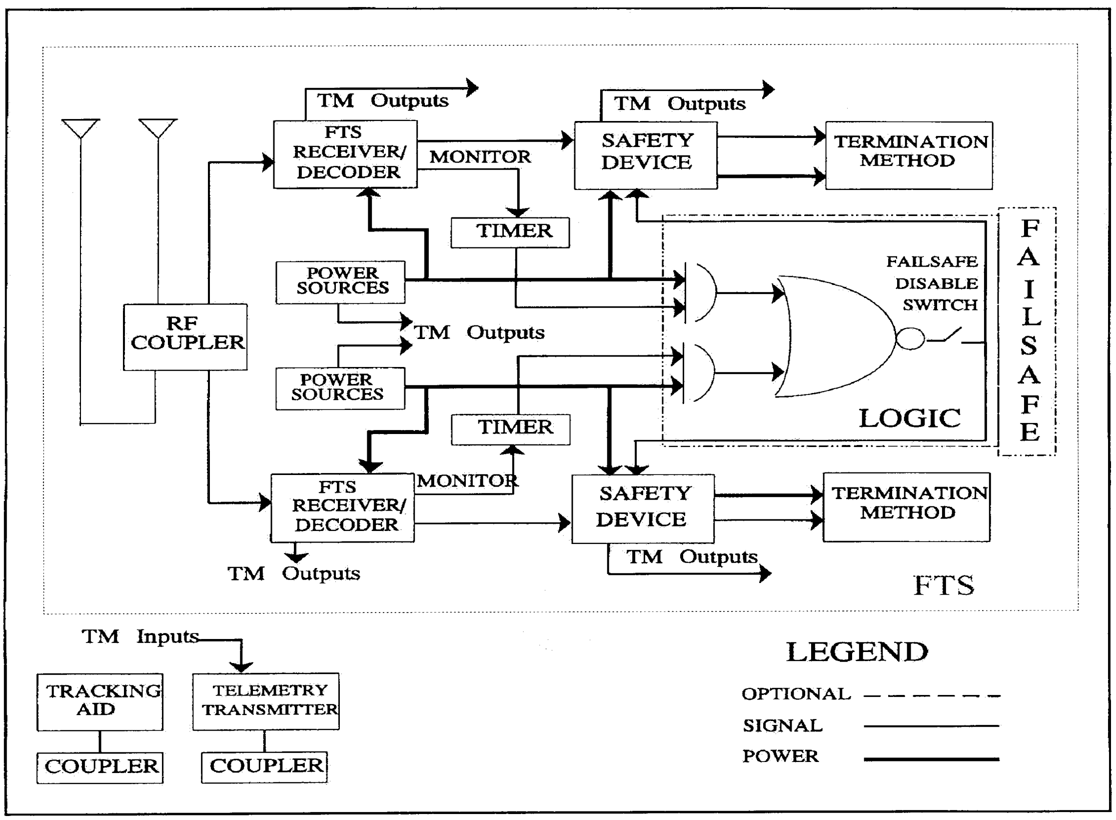

Figure 2-1. Typical flight safety system with FTS for tactical missiles, sounding rockets, and expendable launch vehicles/ballistic missiles.

[2] See page 1-1.
[3] From RCC Document 319-99, p.1-2.

The diagram shows two notional ultra-high frequency (UHF) antennas (small triangles at the upper left) providing signals to an RF coupler. The UHF signals are generated by a ground transmitting site described in detail in the ground survey section of this report. The RF coupler combines signals from antennas and forwards the resultant signal to the FTS receiver/decoder. This unit is the focus of the airborne portion of the study and will be referred to as the flight termination receiver (FTR) throughout this report.

The FTR translates commands from ground transmitters into outputs that initiate a flight termination action. The diagram shows one FTS output into a safety device (e.g., a safe and arm device) which, in turn, initiates the termination method (e.g., ordnance). Some ranges and missions use the FTR to initiate signals into the vehicle Flight Control System (FCS). For example, the FCS on a remotely-piloted vehicle can accept termination commands that direct the vehicle to initiate a pre-programmed landing sequence.

Note that the FTR provides telemetry outputs. Typical outputs could include indications of commands that have been received and detected (e.g., ARM and DESTRUCT) and indications of received signal strength (e.g., signal strength telemetry output). These telemetry outputs are used by range safety officers to monitor end-to-end command link closure and health and status of the FTS.

Fail-safe is an optional function of FTRs. Some ranges and missions use a fail-safe circuit within the FTR to initiate flight termination upon the absence of incoming signals. For example, a check channel can be used to demonstrate constant link closure between the ground transmitter and the airborne vehicle. The FTR detects this signal and provides a telemetry output to indicate link closure. If the link is broken, the FTR recognizes that the check channel is no longer being received and initiates the flight termination method.

The final element of the FSS is the method used to track the vehicle. The tracking system (not shown in the diagram) provides the range safety officer with real-time position/velocity information to monitor flight control. The tracking method may include radar tracking and use of Global Positioning System (GPS) receivers.

2.1.1 Phase I Airborne Activities. The members of the EFTS study team who represented airborne FTS applications recognized that a close working relationship with participating vendors was essential to task completion. Accordingly, a set of design guidelines was formulated based on: (a) objectives and parameters listed in the Introduction; (b) interviews and meetings with industry and academic experts; (c) operational experiences, especially from testing ranges such as White Sands Missile Range, Eglin AFB, Vandenberg AFB, and China Lake; (d) research into candidate technologies; and (e) range surveys.

The design guidelines are included in Appendix I-A and represent the culmination of the airborne portion of Phase I. Also, these guidelines paved the way for Phase II of the EFTS study task. Following an in-depth review by the Brigham Young University Technical Advisor, guidelines were provided to participating vendors (see Appendix I-E) for comment and discussion. Final guidelines were used by vendors to produce conceptual designs which were presented to the FTSC. Two stages of reporting were expected from the vendors. The first level

(Part One) provided conceptual designs that: (a) provide no less security that those imposed by secure FTS requirements from RCC 319; (b) work with existing ground equipment; and (c) work within current authorized bandwidth allocation. These restrictions are covered in the guidelines.

The second stage (Part Two) opened up the conceptual design process and allowed consideration of designs that employ wider bandwidth (to be determined). This part may impose more stringent security requirements in response to pending determinations from NSA on the applicable security levels imposed by RCC 319 regarding anticipated threats to future systems. During EFTS Phase II and III, a candidate list of conceptual designs was established and associated link budgets were constructed.

Appendix I-B is a summary of range survey results to date. This information will be periodically updated as additional ranges report, and these updates will be incorporated into the design guidelines. This process will be frozen when guidelines are supplied to vendors for development of conceptual designs. Care will be taken to ensure that all ranges have had an opportunity for input.

2.1.2 Airborne Summary. Existing flight termination systems typically employ high power command links using FM modulation. This combination has provided high confidence that link control is limited to authorized transmitters and that flight control is protected against potential interference. The EFTS study considered and evaluated enhancements offered by state-of-the-art techniques for modulation, security, as well as command structure and coding.

2.2 Ground Flight Termination Systems Survey

The goal of the ground FTS survey was to research current capabilities of test ranges and identify requirements that will be incorporated with the airborne segment to provide a "first cut" set of design guidelines. The ground survey information was generated by visiting a representative sample of ranges and conducting interviews with key operational and technical personnel. This included range safety officers and Command Transmitter System (CTS) engineers/technical leads. The personnel surveyed provided information on their local range safety mission along with a tour and explanation of range control center and CTS functions. Range overviews, procedures and applicable RCC documents were used as much as possible to augment interview notes. Requirement information gathered from the EFTS survey was also utilized to produce the final survey product. The following provides an overview of the individual ranges surveyed:

2.2.1 Cape Canaveral Air Force Station (AFS)

Cape Canaveral AFS is an extension of Patrick Air Force Base and a member of the Eastern Test Range (ETR). It is managed and operated by the 45th Space Wing Group. The primary mission is to conduct missile launches and assure access to space capability for DoD, NASA and commercial users. Types of missions supported include missile launches; high-altitude long-endurance UAVs; and space-based, ballistic, and space lift vehicles. Particular programs supported include STS, Atlas, Delta, Titan, Pegasus, Athena, and Trident.

2.2.1.1 Configuration. The Eastern Range Command Destruct System (CDS) consists of a network of UHF radio transmitters located at Cape Canaveral Air Station (CCAS), Jonathan Dickinson Missile Tracking Annex (JDMTA), Antigua, Argentia, Newfoundland and NASA Wallops Island, Virginia. These sites are linked to the Central Command Remoting System (CCRS) located in the CCAS range operations control center (ROCC). Flight control officers (FCOs) evaluate real-time data via the range safety display (RSD) to determine if the vehicle is within the mission's parameters or if it is necessary to transmit ARM and/or DESTRUCT commands to terminate the flight of an errant vehicle. Range user applications of the CDS also include the transmission of commands such as SAFE and ENGINE CUT-OFF, as well as the vehicle control messages.

For northerly launch azimuths, the NASA Wallops Island station and Argentia are used by range safety to provide extended range coverage or to mitigate plume attenuation. Wallops Island is also a support station for NASA manned launches as well as for DoD expendable launch vehicle (ELV) launches.

FCO-generated commands are sent through the CCRS to a remote transmitting station (CCAS, JDMTA, Antigua, Wallops Island, or Argentia) and then to the in-flight vehicle. The modulated commands are monitored at the transmitting antenna. They are then decoded, checked for accuracy, and relayed back to the FCO to confirm the transmission. Command transmissions are recorded for post-flight evaluation. The automatic gain control (AGC) from the vehicle command receiver is reported to the FCO via telemetry.

2.2.1.1.1 Central Command Remoting System (CCRS) Equipment. The CCRS consists of the following components:

- command message encoder verifier (CMEV)
- command system controller console (CSCC)
- range safety control and display (RASCAD)
- flight termination unit (FTU)
- communications modems
- message storage unit (MSU)

NOTE

All equipment is dual-redundant with automatic reconfiguration with the exception of the MSU.

2.2.1.1.2 CCRS Capabilities:

- Maintains overall control of the CDS
- Interfaces with the FCO

- Processes carrier and command requests from the FCO or CSC
- Determines operation mode and site equipment
- Monitors health and status of each transmitting station
- Specifies carrier and command message addressing priority and routing
- Formats the command message and checks for errors
- Determines automatically which station should have its transmitter activated (in auto carrier mode only)
- Transmits the message to the addressed site for action
- Receives confirmation of requested action.

The CCRS has external interfaces to the command stations at CCAS, JDMTA, Antigua, and Argentia, Newfoundland, and Wallops Island. The CMEVs are the control center of the entire CDS. There are two redundant DEC LSI-11/73-based CMEVs in the CCRS. Each CMEV is connected to four consoles: two operational consoles in the range safety area (RASCAD) and two checkout command system consoles (CSCs) in the CCRS. From these consoles, the FCO or the command controller may request the command carrier and/or range safety functions at any command station. These consoles may be configured to operate redundantly on a single mission or independently to support up to four missions simultaneously. During real-time launches the CSCs may be inhibited by means of a key-locked switch.

The RASCAD is the carrier and status interface to the FCO. The MSU provides ancillary, protected memory for the CMEVs and is capable of storing classified commands (i.e., ARM, DESTRUCT, etc.) for twelve missile pads simultaneously.

The FTUs are two sets of four switches located at the FCO console in the RSD room.

NOTE

The FTUs can only be programmed for a maximum of four command functions per the *Eastern Range Instrumentation Handbook,* (Chapter 6, section 6.2.5, column 2, paragraph 1).

The switching of command carrier from one site to another may be performed in one of three modes: single carrier with overlap, single carrier without overlap, or multiple carriers. *Eastern and Western Range Safety Policies* (EWR 127-1)[4] dictates single carrier with overlap mode. A console switch selects the desired mode. Carrier control may be either manual or automatic. The automatic carrier mode inhibits the selection of carrier by manual control.

[4] EWR 127-1, *Easter and Western Range Safety Policies and Processes*, Chapter 4, October 1997.

Automatic carrier selection to the best site is based on plus time, health status of sites, and look angles.

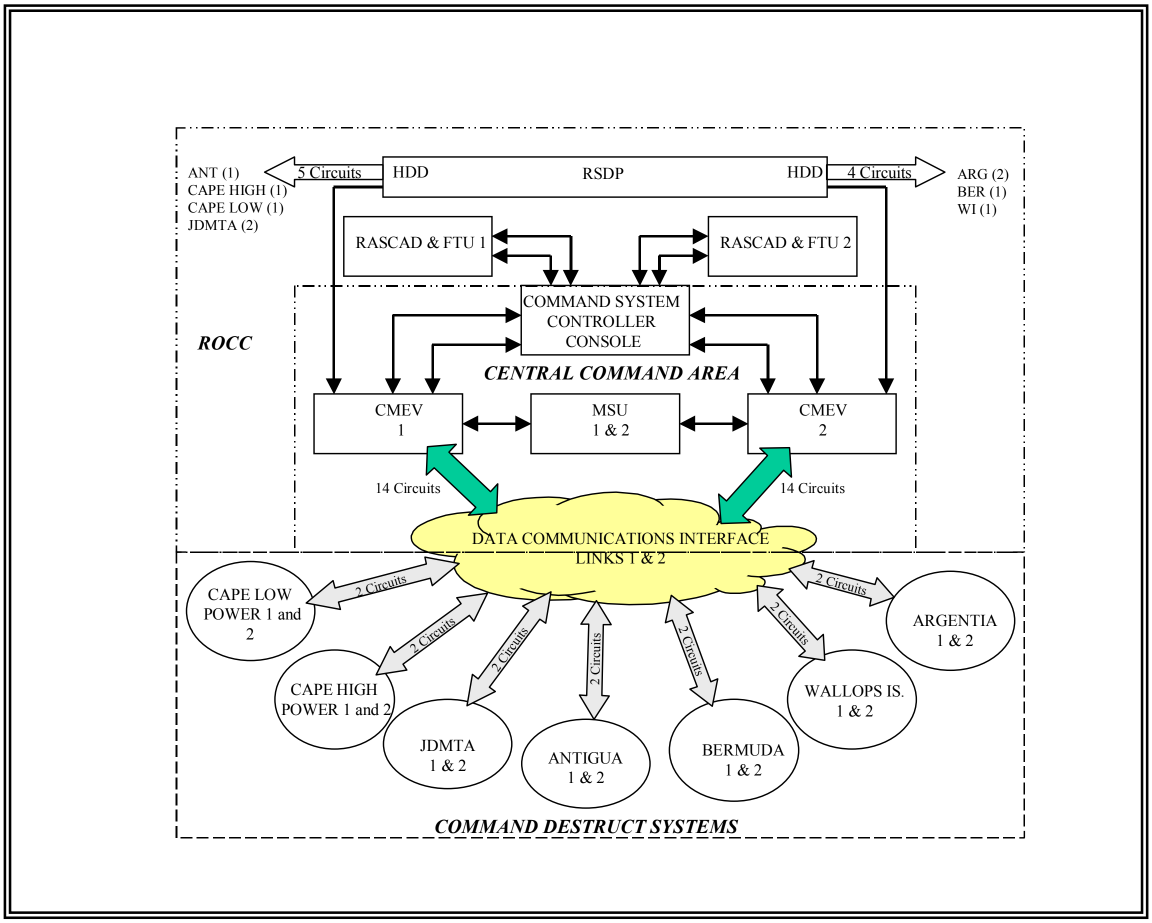

Figure 2-2. Central Command Remoting System (CCRS) configuration.

2.2.1.1.3 Secure/Non-Secure Concept. The CCRS can be operated in two basic modes: digital range safety (DRS) and Eastern Test Range (ETR) Inter-Range Instrumentation Group (IRIG). Within each of the two modes are two sub-modes. The DRS mode can be operated in either the manned secure STS mode to support the Shuttle program and unmanned secure (UMS) mode, which supports missiles with the secure Flight Termination System (FTS). Currently the Shuttle, Titan IV, Delta, and Atlas vehicles are the only programs using the secure FTS. The ETR mode can be operated in ETR normal or ETR operational Trident (OT). Currently the ETR normal mode supports Pegasus missions. The ETR-OT mode supports the C4 and D5 Trident missiles.

2.2.1.1.4 Command Transmitter System. Cape Canaveral utilizes three types of CTSs with the capability of switching between different antenna systems such as steerable and omni-directional. The CTS types include the Collins 240-D high power transmitter, AN/FRW-2 low power transmitter, and RS-10 high power (10-kW) transmitters.

2.2.1.1.5 JDMTA Command Site. The JDMTA command station is unique in design from any other command station. The RS-10 transmitter utilizes 4 cavity Klystron tubes manufactured by English Electric Valve (EEV), with an operating power of 8 kW and a maximum power rating of 10 kW. The station has two steerable antennas enclosed in radomes and two broad beam antennas used exclusively for U.S. Navy support. The site at the JDMTA command station is divided into three basic equipment groups: process/control, modulation/demodulation, and RF/transmitting. Each equipment group, with the exception of the Interim Antenna Monitoring System (IAMS) and Visicorder, is a stand-alone system.

2.2.1.1.5.1 Process/Control. The JDMTA command station process/control group is responsible for accepting carrier, command, and system control requests from the CCRS. This group acts on those requests, checks the message for errors, initiates the appropriate action, and then confirms to the CCRS the action taken. Types of requests are those such as arm/destruct and carrier on/off requests. Additionally, the group is responsible for reporting station status to the CCRS for display to the CSC and FCO and for recording all station events and status on permanent media.

2.2.1.1.5.2 Modulation/Demodulation. The JDMTA command station modulation/demodulation group is responsible for encoding the audio tones, forming the command message, and sending the message to the RF/transmitting group, which is responsible for analyzing samples of the composite audio signal and demodulating the message to identify the tone content of that signal. This confirms that the message that was modulated was the correct message. Modulating errors are also detected and reported to the command remoting unit (CRU).

2.2.1.1.5.3 RF/Transmitting. The JDMTA command station RF/transmitting group is responsible for the transmission of the modulated message via the exciter, power amplifier, and command antennas. This group is also responsible for receiving the high density data (HDD) from the range safety data processor (RSDP) front end processor (FEP) via the data switch, converting the data to site-specific coordinates and designating the steerable command antennas.

2.2.1.1.5.4 Operation Concept. The JDMTA command site operates in either local mode or remote mode. In local mode, the site retains control for the command carrier and functions. The local mode is used for checkout only and is never used for operations. When the station is ready to support the operation, the site is placed in remote mode. This mode allows the CCRS to remotely control the operation and function of the site carrier.

2.2.1.2 <u>Cape Canaveral CTS Parameter Summary Table</u>: Table 2-1 summarizes the CTS data per type and location:

TABLE 2-1. CAPE CANAVERAL CTS PARAMETERS

System Type	Location	Antenna	Gain (dBi)	Polar-ization	EIRP (Max) (dBm)	Freq. (MHz)	HPA (kW)	Latency (Link)	Mode
Collins 240D High Power	CCAS	Quad Helix and Omni	18 0	LHCP	85.37 82.94 67.88	416.5	8	15 ms	Standard and Secure
AN-FRW/2 Low Power	CCAS	Quad Helix and Omni	18 0	LHCP	74.75 74.94	416.5	.6	15 ms	Standard and Secure
RS-10	JDMTA	Datron Steerable Broad beam	21 15	LHCP	88.46	416.5	10	15 ms	Standard and Secure
Collins 240D Lucas Zeta	Antigua	ESCO Tri-Helix	15	LHCP	82.60 80.17	416.5	8 4.5	15 ms	Standard and Secure
Collins 240D Lucas Zeta	Antigua	TEMEC Dish	23	LHCP	89.31 86.88	416.5	8 4.5	15 ms	Standard and Secure
	Argentia	EMP	17.5	LHCP	79.89	416.5	2	15 ms	Standard and Secure
	Argentia	Antlab	20	LHCP	82.47	416.5	2	15 ms	Standard and Secure
Fixed CTS	Wallops Island	Orbit Steerable	20	LHCP	75.08	416.5	1	N/A	Secure

2.2.1.3 Cape Canaveral Requirements Survey Summary:

TABLE 2-2. CAPE CANAVERAL REQUIREMENTS SURVEY	
Latency (FTR)	Total FTR command process time (latency): Data assumes landline communication path. Include latency requirement from button activation to FTR response. Non-secure mode: 262 ms. Secure mode unmanned: 1060 ms. Secure mode manned: 2033 ms
Link distance (maximum)	ETR is normally to horizon but variables are: signal margin, vehicle sensitivity, transmitter power, and antenna gain.
Link margin (minimum)	9 to 12 dB
No. of targets (maximum)	4
Secondary non-FTS functions	Optional commands such as SAFE and ENGINE CUT-OFF, as well as the vehicle control messages
Update rate	--

2.2.2 Naval Air Warfare Center/Weapons Division (NAWCWD) (China Lake)

2.2.2.1 Overview. China Lake NAWCWD provides land range test support for airborne vehicles. Programs supported with flight termination include Tomahawk, HARM, JSOW, SLAM ER and Q-F4 drones, in addition to supporting various DoD unmanned air vehicle (UAV) projects such as Global Hawk. NAWCWD works in conjunction with Pt. Mugu, which acts as lead in support of range operations and development efforts.

2.2.2.2 Configuration. Two fixed and two mobile Command Transmitter Systems are utilized on the China Lake range. CTS-1 is located at Baker site and CTS-2 is located at Parrot Peak. Parrot Peak is an unmanned, remote-controlled site. Both fixed CTSs are remote controlled from the range operations center via the serial data controller (SDC) and communications system. The mobile CTSs are local control only. All CTSs are the Zeta 1376 type. In addition, P-3 aircraft with FTS relay capability are also utilized for over-the-horizon support. The following CTS characteristics pertain to the fixed and mobile 1-kW CTSs.

The CTS is a Zeta model 1376 with 1-kW capability. The system is fully redundant. A switchover unit continually monitors all system parameters through an IEEE-488 internal control bus. It will control and provide automatic or manual switching between the primary or backup RF transmission equipment. Automatic switching will occur when the RF levels drop below a predetermined amount, or when an equipment failure has been detected. The switchover unit will simultaneously route the command activation messages to both IRIG command encoders via the internal control bus.

The IRIG command encoders are manufactured by Emhiser Research. The command encoders receive the tone activation message and generate the required tones at the specified IRIG tone frequencies. The tones are then routed to the command exciter unit.

The command exciter is also made by Emhiser Research. This unit operates within the frequency range of 406 to 450 MHz.

The Power Systems Technology high power amplifiers (HPAs) amplify the signal from the command exciter to a maximum level of 1000 watts CW, between 406 to 450 MHz. The HPAs have a selectable output control that allows the amplifier to be adjusted from 100 to 1000 watts.

DC power is provided to the high power amplifier and the switchover unit by the TCR 3-phase power supply. Continuous power output is 30 Vdc to both units. The Zeta switchover unit monitors and controls all system functions to include the primary to backup RF transmission systems. The auto transfer switch front panel displays which system is on-line (primary or backup), as well as alarm and fault conditions. Finally, the primary RF signal is routed to the omni antenna system, while the backup RF signal is sent to a dummy load.

Remote control of the 1-kW CTS is accomplished with the serial data controller (SDC). The SDC acts as the control interface between the UHF CTS (at both central and remote sites) and the range digital communications network. Control/destruct functions at the central site are digitally encoded into a 72-bit serial message. This message is transmitted through the range digital link to the remote CTS. At the remote sites, the message is decoded and passed to the command transmitter. A redundant SDC with communications link is utilized to ensure reliability. System features include:

- site selectable
- carrier on/off
- cycling of command tones (ARM/TERMINATE)
- readback of tone activation
- minimal latency measured at 1.5 milliseconds

A new development is underway to replace the SDC with a rack-mounted PC-based system. This system uses "C" programming but is enhanced by a new Ethernet protocol and a V.35 interface implemented over a 56K communications link.

P-3 aircraft are used to provide over-the-horizon support for FTS functions. The P-3 incorporates an Emhiser 500-watt CTS to transmit the FTS commands and an Emhiser receiver/decoder unit to receive the FTS commands. An omni antenna along with a 45-degree beam width (10 dBi gain) helix antenna are used. Two modes of operation can be supported.

Mode 1: Range safety officer has capability to directly transmit FTS commands onboard the P-3.

Mode 2: In relay mode a receiver is tuned up to perform as a repeater. The FTS signal is received on one frequency and re-radiated on another frequency.

2.2.2.3 China Lake CTS Parameter Summary Table:

TABLE 2-3. CHINA LAKE CTS PARAMETERS									
System	**Location**	**Antenna**	**Gain** (dBi)	**Polar-ization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
CTS #1	Baker	Omni	--	LHCP	--	406-450	1	500	Stand.
CTS #2	Parrot Peak	Omni	--	LHCP	--	406-450	1	500	Stand.
Mobile #1		Omni	--	LHCP	--	406-450	1	500	Stand.
Mobile #2		Omni	--	LHCP	--	406-450	1	500	Stand.

2.2.2.4 China Lake Requirements Survey Summary:

TABLE 2-4. CHINA LAKE REQUIREMENTS SURVEY	
Latency (FTR)	Total FTR command process time (latency) < 100 ms
Link distance (maximum)	--
Link margin (minimum)	12 dB over 95% spherical antenna coverage
No. of targets (maximum)	3
Secondary non-FTS functions	None
Update rate	20 Hz (currently system is capable of 100 Hz)

2.2.3 Air Force Flight Test Center (AFFTC) and NASA/Dryden Flight Research Center (DFRC) (Edwards Air Force Base)

2.2.3.1 Overview. The AFFTC mission is to conduct and support research, development, test and evaluation of both manned and unmanned aerospace vehicles. The Dryden Flight Research Center (DFRC) is NASA's primary installation for flight research. DFRC conducts safe and timely flight research for discovery, technology development, and technology transfer for U.S. aeronautics and space programs. AFFTC and DFRC work under an alliance sharing range assets and staffing to maximize efficiency and reduce costs. The alliance has been extremely successful, especially in the area of range safety. Typical UAV high altitude endurance (HAE) missions supported at Edwards AFB include Global Hawk, Perseus, Theseus, Pathfinder, Centurion, Helios, Altus, Darkstar, Tornado, CID, Pegasus, Hi-Mat, and X-36. Some orbital and sub-orbital vehicles supported include X-33, X-34, X-38, X-37, X-40 and X-43.

2.2.3.2 Concerns. Unintended vehicle FTS receiver capture and or interference is a concern due to the close proximity of surrounding ranges such as China Lake NAWCWD, Tonopah Test Range and Nellis AFB Range. Risk of incident has increased with high power, line-of-sight transmitters and flight operation of high altitude/long endurance UAVs.

Plasma interference on sub-orbital UAVs such as the X-33 is also a concern. Analysis has indicated that problems would exist communicating with FTS at speeds above Mach 11. Alternate methods of FTS transmission, such as a higher frequency L-band, are being considered as a means to overcome the plasma interference for X-33.

2.2.3.3 Configuration. AFFTC and DFRC each maintain one operational CTS. The AFFTC has also procured a second CTS, which is scheduled for installation in October 2000. Combined FTS ground resources are comprised of the following systems:

2.2.3.3.1 AFFTC CTS. The CTS van is located next to building 5780, which is on the north side of the west gate entrance to the AFFTC. The CTS is the Zeta model 1376A. It is comprised of commercial-off-the-shelf (COTS) hardware. The CTS design incorporates system redundancy and reliability.

- The remote command panel (RCP) receives the command information via an RS-232 serial data stream from the master command panel (MCP) and decodes the message into a transistor logic (TTL) signal. The TTL is then sent to the Zeta switchover unit for system distribution.

- The switchover unit continually monitors all system parameters through an IEEE-488 internal control bus. It will control and provide automatic or manual switching between the primary or backup RF transmission equipment. The switchover unit will simultaneously route the command activation messages from the RCP to both IRIG command encoders via the internal control bus.

- The IRIG command encoders are Emhiser Research model #ECTE-5R20-02. The command encoders receive the tone activation message and will generate the required tones at the specified IRIG tone frequencies. The tones will then be routed to the command exciter unit.

- The command exciter is Emhiser Research model #ECEC-5R2B2A1R0-04. This unit will operate within the frequency range of 406 to 450 MHz.

- The Power Systems Technology model BHED48457-1000/5319 high power amplifiers (HPA) amplify the signal from the command exciter to a maximum level of 1000 watts CW, between 406 to 450 MHz. The HPAs have a selectable output control that will allow the amplifier to be adjusted from 100 to 1000 watts, in 100-watt intervals.

- DC power is provided to the HPA and the switchover unit by the TCR 3-phase power supply. Continuous power output is 30 Vdc to both units.

- The auto transfer switch front panel will display which system is on-line (primary or backup), as well as alarm and fault conditions.

- The primary RF signal will be routed to the omni antenna system, while the backup RF signal is sent to a dummy load.

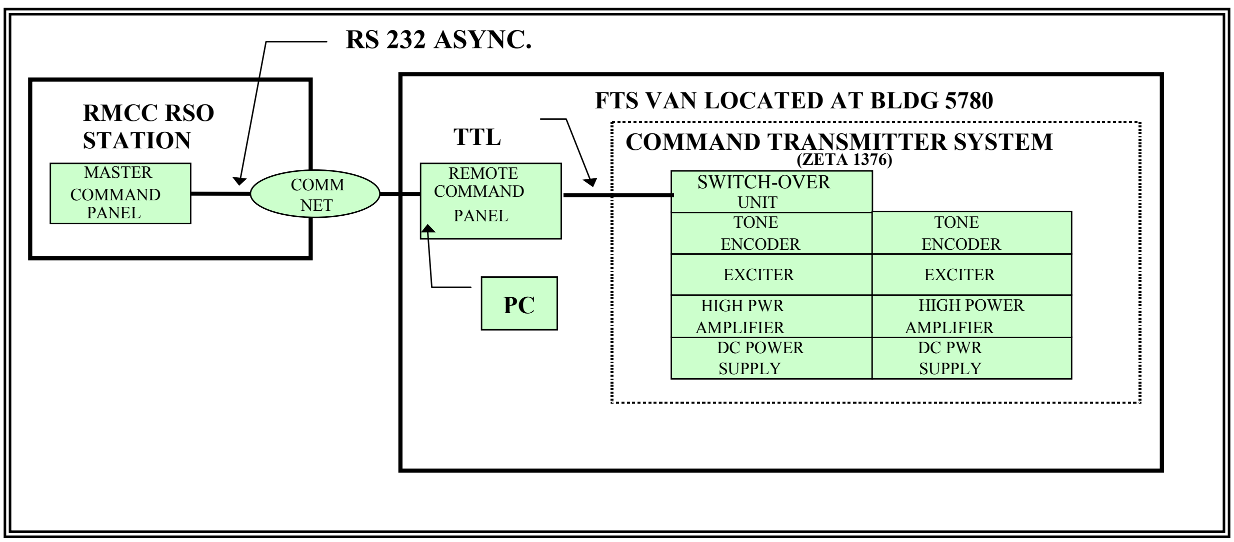

Figure 2-3. High level architecture of the AFFTC flight termination transmitter system.

2.2.3.3.2 Command Panel System (CPS). The CPS is comprised of the MCP and the RCP. The MCP and RCP are functionally similar; however, the MCP is designed to communicate with multiple RCPs, while the RCP will communicate with a single MCP and CTS. Two CPS modes of operation are available to select from – local and remote. The MCP is located at the range safety officer (RSO) station and will operate in the local mode. All RCPs will initially operate in the remote mode and will be located at their respective CTS sites. This configuration will allow the RSO the capability of issuing termination commands to all CTS sites. All CPS panels have ARM, DESTRUCT, CHECK and OPTIONAL channel switches on the front panel. The switches can be configured to activate any combination of IRIG tones 1-20, via a VT-100 dumb terminal, through a control port interface. The fronts of the control panels utilize light emitting diodes (LEDs) to visually display the individual communications link status, as well as any tone generation. The MCP and RCP incorporate sophisticated error-checking tools to validate the transmission of data between the panels.

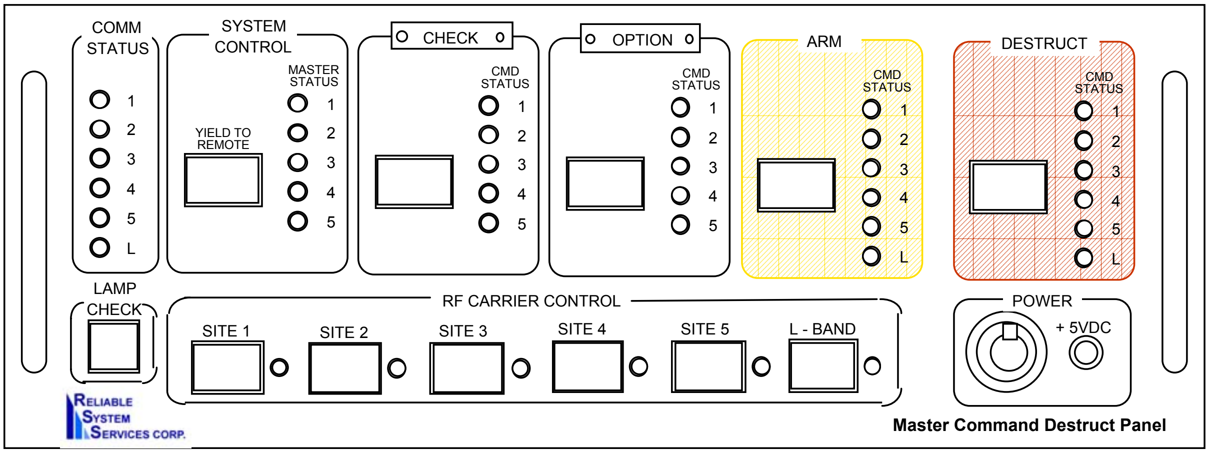

Figure 2-4. AFFTC master command panel.

2.2.3.3.3 Range Safety Officer (RSO) Station. The RSO station is located in the Ridley Mission Control Center (RMCC) range operations center. The station provides complete integrated mission command and control capabilities for the RSO. The MCP provides remote command activation to the FTS van. A radio frequency (RF) sniffer unit receives and demodulates the presence of any command tones radiated from the FTS antenna. Demodulated command tones are then displayed on a tone display panel. Command tones are recorded on a VHS recorder unit for archiving and future retrieval. Test and Evaluation Command and Control System (TECCS) and the Advanced Data Acquisition Processing System (ADAPS) provide vehicle tracking, command, control, and display of critical flight data.

2.2.3.4 AFFTC CTS Parameter Summary Table:

TABLE 2-5. AFFTC CTS PARAMETERS

System Type	**Location**	**Antenna**	**Gain** (dBi)	**Polarization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
Zeta 1376A (AFFTC)	Bldg. 5780	Omni	--	LHCP	56.0	Operating @ 421, 425, 428 Range is 406-450	1	500	Stand. Tone

2.2.3.5 DFRC Command Transmitter System (CTS) Information. The DFRC CTS consists of two redundant 1-kW transmitter systems. The DFRC FTS system can be controlled simultaneously from four locations: 3 independent DFRC mission control rooms and the AFFTC Ridley Mission Control Center. The two redundant systems can be operated independently or together. When operated as one system automatic switching between four transmitters is provided in the event of a loss of carrier power.

The ground transmitter was manufactured by System Planning Corporation (SPC). The system uses modified SPC command transmitters in conjunction with new SPC flight termination system control computers. The FTS transmitter command functions are controlled by flight termination panels (FTPs) connected by independent links to the three DFRC mission control rooms and the AFFTC Ridley Mission Control Center. The system operates within the 406–550 MHz range while generating up to six IRIG tones simultaneously. Redundancy is built into subsystems made up of control systems, tone generators/exciters and high power amplifiers. The subsystems feed automatic transfer systems, which bypass defective subsystems and route the modulated command signals to omni or directional antennae depending on mission requirements. The effective power output varies from 60 to 73 dBm as determined by the selected antenna. Table 2-6 summarizes the transmitter system performance specifications:

TABLE 2-6. TRANSMITTER SYSTEM PERFORMANCE SPECIFICATIONS					
Transmitter power	1 kW into 2:1 maximum VSWR				
System latency	Less than 200 milliseconds				
Link distance	Line of sight				
Polarization	Left hand circular (LHC)				
Frequency range	406 to 550 MHz				
Modulation type	Frequency deviation modulation of up to 6 simultaneous tones				
Frequency deviation	± 300 kHz				
Tones	20 standard IRIG tones 7.5 kHz. to 73.95 kHz.				
Antenna type	**Omni**	**Omni**	**Yagi Array**		
Antenna manufacturer	**Tecom**	**M2**	**M2**		
Antenna gain	**2 dBi**	**2 dBi**	**15 dBi**		
Polarization	**LHC**	**LHC**	**LHC**		
Antenna pattern (deg.)	**360 Az**	**360 Az**	**80 Az / 40 El**		
Max. EIRP (watts)	**1 kW**	**1 kW**	**20 kW**		
Max. EIRP (dBm)	**60 dBm**	**60 dBm**	**73 dBm**		

2.2.3.5.1 Figure 2-5 depicts a typical DFRC FTS transmitter functional block diagram and Figure 2-6 illustrates a flight termination panel.

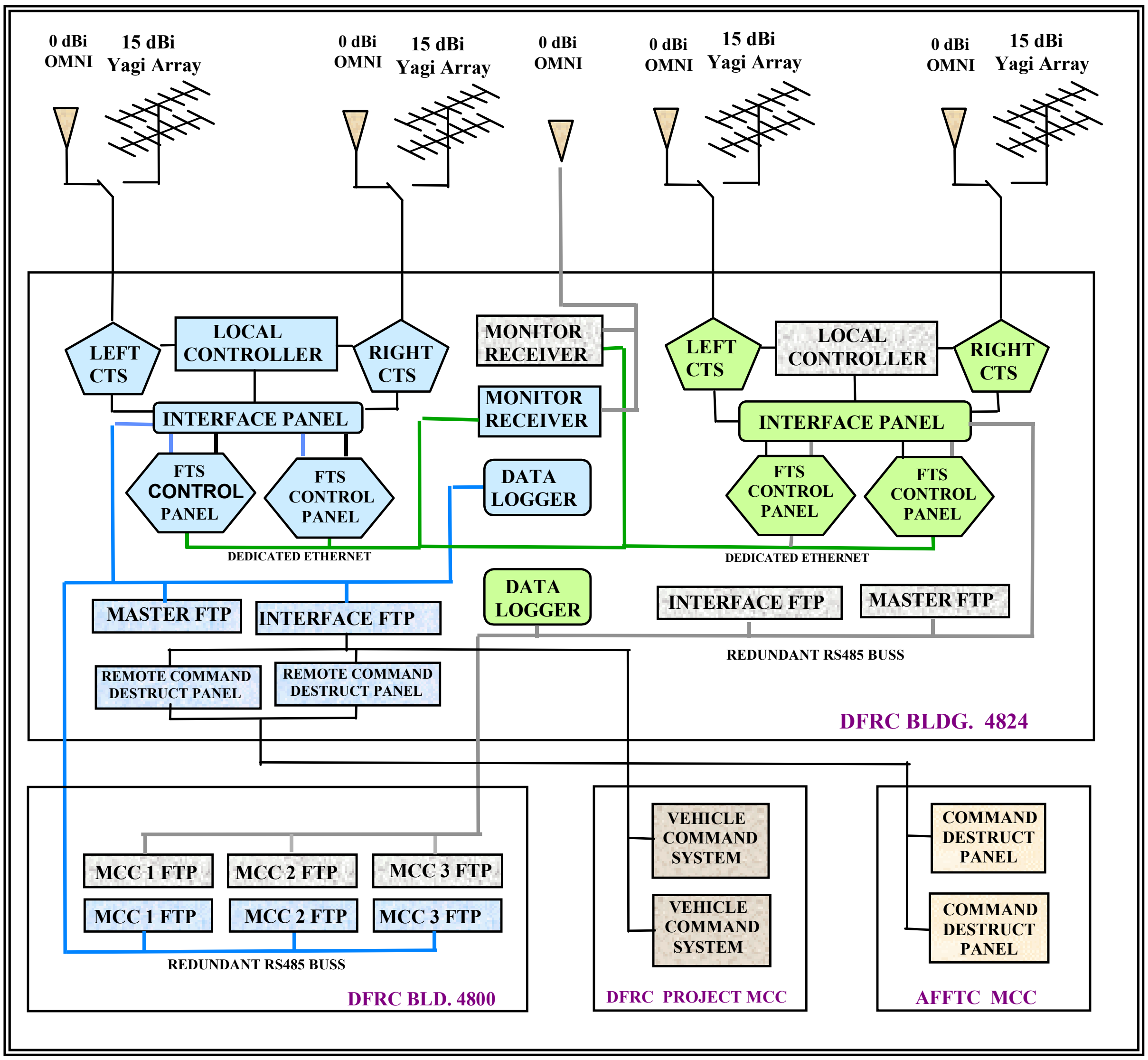

Figure 2-5. DFRC FTS transmitter functional block diagram.

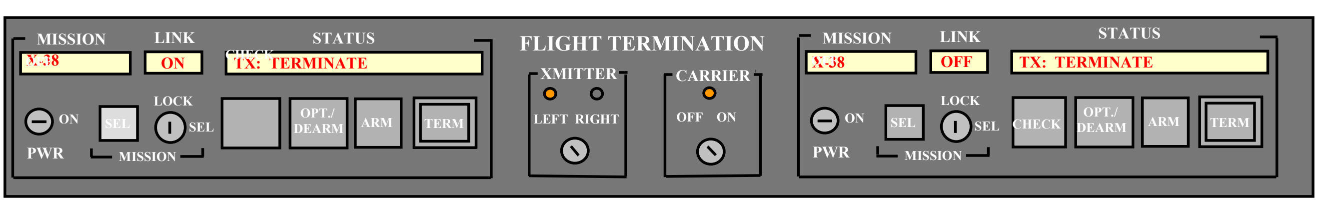

Figure 2-6. DFRC flight termination panel layout.

2.2.3.5.2 Transmitter Subsystem Components.

A. Flight Termination Panels (FTPs)

The FTPs are used by the range safety officers to remotely control the FTS transmitters. They are located in each of the three DFRC mission control rooms (MCCs) and the communications facility (building 4824). The communication facility FTP is interfaced with the AFFTC Ridley Mission Control Center to provide remote command capability. The FTPs are comprised of three systems within a single rack unit housing. These are made up of two commands and one transmitter control subsystem. The command section provides for mission selection, CHECK CHANNEL, OPTION, ARM AND TERMINATE commands. The transmitter control unit controls the carrier activation and transmitter select functions. The FTPs communicate with the FCP via a distributed RS-485 network. This system is utilized to allow the units to select individual missions at their respective locations. The network allows each FTP to be addressed and individually recognized by the FTS control computers. All activity on the RS-485 network is recorded on an event recorder.

B. Interface Panel

The interface panel (IF) provides for manual and automatic switching between the primary and secondary FCP computers. The switching can be done in real-time and is transparent with no interruption of FTS command sequencing or carrier output. The RS-485 bus and the FCP control interfaces are switched through an active parallel system designed to be resistant to single point failures.

C. FTS Control Computer

The FTS control computer panel provides for comprehensive control of the command transmitter system. The control capabilities include transmitter selection, transmitter power, carrier frequency, modulation deviation, mission tone profile, FTP access, transmitter tone command verification, forward/reflected power monitor, fault monitoring, status monitoring, and extensive system diagnostic programs. The uplink command latency is less than 150 ms.

D. Local Controller

The local controller provides for manual and automatic switching between the left and right transmitter systems. Time to switch the system is within 0.05 seconds or less. A switch from primary to backup will occur when the RF output power level drops over 3 dB at any time.

E. RF Exciter

The exciter is used to generate the 20 standard IRIG tones and modulate the carrier. A maximum of 6 tones can be transmitted simultaneously. The modulated carrier is amplified and used to drive the power amplifier. The exciter operates in the 406 to 550 MHz range and tunes in steps of 100 kHz. The selected frequency has an accuracy of 0.0005 percent. The exciter is capable of accepting external inputs, if needed, to meet mission requirements.

F. High Power Amplifier (HPA)

The HPA is capable of continuous output power at a maximum level of 1000 watts into a 50 ohm load between 406 and 550 MHz. The HPAs are constructed utilizing solid state electronics and operate with no degradation to the signal into a VSWR of up to 1.3 to 1. The HPAs are adjustable from 100 to 1000 watts as required for operational support. Each HPA is comprised of two 800-watt amplifiers combined together to form one system. In the event of a single amplifier failure, the remaining units can be operated individually to maintain carrier output at 75 percent power.

G. Data Logger

The data logger is used to monitor and record all traffic on the RS-485 bus. The bus ties the FTS control system with the flight termination panels used at all the range safety officer stations.

H. Command Monitor Computer (CMC) System

The CMC is SPC model 202395. It is used in conjunction with the receiver to independently monitor and record RF carrier and modulation characteristics. It also provides for command function verification by monitoring the intended commands and confirming that they are broadcast. In the event of command mis-compare, an alarm is triggered. The CMC also provides the capability to review past command events while still recording current missions in real-time.

2.2.3.6 Electrical Interfaces:

TABLE 2-7. ELECTRICAL INTERFACES							
Component	**Make**	**Model**	**Input Format**	**Input Level**	**Output Format**	**Output Level**	Power (Vac)
Flight Termination Panel	Systems Planning Corporation	FTP	RS-485	.5 to 4.5	RS-485	.5 to 4.5	120
Flight Termination System Control Panel	Systems Planning Corporation	FTSCP	RS-485 RS-422 TTL	.5 to 4.5	RS-485 RS-422 TTL	.5 to 4.5	120
Dual Transmitter System	Systems Planning Corporation	202264	RS-485 RS-422 TTL	.5 to 4.5	RS-485 RS-422 TTL	.5 to 4.5	208 WYE
Yagi Array	M2	425CP-16	RF	1 kW	RF	15 dBi	N/A
Omni Antenna	M2	430CP	RF	1 kW	RF	2 dBi gain	N/A

2.2.3.7 AFFTC/DFRC CTS Requirements Survey Summary:

TABLE 2-8. AFFTC/DFRC CTS REQUIREMENTS SURVEY	
Latency (total)	1 sec. from button push to destruct action (includes RSO reaction time)
Link distance (maximum)	235 nautical miles
Link margin (minimum)	12 dB over 95% spherical coverage
No. of targets (maximum)	5
Secondary non-FTS functions	Optional commands (e.g., inhibit for recovery system, weapons release, restart motors)
Update rate	--

2.2.4 Eglin and Tyndall Air Force Bases

2.2.4.1 Overview. The Eglin Gulf Test Range (GTR) encompasses 86 500 square miles of the Gulf of Mexico south of Eglin AFB, Florida. The GTR is an integral part of the Southeast Test and Training Area (SETTA) which encompasses Army ranges in Alabama, Navy ranges in Florida, and Army/Navy commands in Alabama, Florida, Georgia and Texas. Included are 19 miles of AF-owned beachfront property that provides a realistic littoral environment allowing over-water ingress from 100 miles out in the GTR into the Eglin land ranges with the reverse egress scenario also possible. Total available airspace of the SETTA is 133 927 square miles, which includes the GTR and adjoining over-land military operation areas (MOAs).

The GTR is used for long-range, all-altitude, air-to-air/drone target engagements, theater missile defense system T&E, long-range weapons T&E, surface-to-air, and anti-ship air-to-surface weapons T&E, sub-scale aerial targets, high altitude targets, cruise missiles, short-range remotely piloted vehicles (RPV), medium-range RPVs, long-range RPVs, and mobile ground targets. Flight duration can last from a few seconds to hours at altitudes of a few feet to 100 000 ft. Some missions might consist of up to four full-scale targets and four missiles in flight simultaneously.

The GTR has a large surface area for evaluation of large footprint weapons and associated debris impact patterns. These missions include all types of weapon systems, countermeasures (CMs) directed at seekers/sensors, delivery platforms, battlefield management systems, and command and control (C2) systems. Sites along the north shore of the GTR are designated for live firing of surface-to-air weapons such as guns, missiles, and rockets, and they are used for threat missile launches to evaluate CM techniques. Aerial drone targets are available in subsonic and supersonic speed regimes.

Multiple air-to-air tests over the range are supported through the Gulf Range Drone Control Upgrade System (GRDCUS), which is located at Tyndall AFB and linked to the central control facility (CCF) at Eglin. Command/destruct facilities provide range safety. Additionally, telemetry and airborne systems provide primary data or relay links with ground stations.

2.2.4.2 Configuration. The Air Force Development Test Center (AFDTC) command and control function is provided by a UHF command-guidance system, which provides the command link for remotely controlling unmanned airborne systems such as drones and missiles from transmitters. Primary AFDTC command-guidance capability employs CTS-100 UHF radio transmitters located at sites A-3 and D-3.

Two parallel UHF command-guidance chains extend from the CCF to sites A-3 and D-3. These chains can operate independently or one chain can be used as a backup. The UHF command-guidance system is primarily utilized as a destruct system for drones and missiles, and it has multiple destruct capability through tone encoding.

2.2.4.2.1 Remote Control. Remote control of CTS sites A3 and D3 is accomplished with a command panel which was built in-house by BAE Systems. Panel control is selectable between control rooms for support of multiple missions. A portable command panel is easily accessible for redundancy. The command panel operates via a ground closure, which activates an frequency shift keying (FSK) tone unit and is then modulated by the communications equipment. At the CTS site, the FSK tone is demodulated and converted back to a ground closure. The closure is then sent to the CTS encoder unit to activate the respective command tone. An LED panel provides a visual indication that the proper command was transmitted and received by the CTS. In addition, the RSO verifies the proper RF transmission with support from a frequency monitoring van. Additional command panel functions include:

- selectable time between tone transmission
- automatic tone sequencing
- antenna select
- transmitter site select (A3 or D3)
- carrier selects

2.2.4.2.2 Command Transmitter Systems. Two fully redundant Aleph 100 Systems are used at sites A3 and D3 for UHF transmission of the command destruct tones. The systems are nearing the end of their life cycle and are under evaluation for replacement. The Aleph exciter unit provides the tone modulation function. An HP 8640 signal generator is available as a backup for the Aleph exciter frequency and tone modulation function. Aleph high power amplifiers provide the signal amplification to a maximum of 1000 watts. The amplified signal is routed to either a directional or omni antenna system. The directional antenna is a Secor system with 25 to 45 degree beam width and 10 dB of gain. The omni-directional antenna is a Gabriel type with 5 dB of gain. The current primary operating frequencies are 421, 425 and 428 MHz.

2.2.4.3 Eglin CTS Parameter Summary Table:

TABLE 2-9. EGLIN AFB CTS PARAMETERS

System Type	Location	Antenna	Gain (dBi)	Polar-ization	EIRP (max) (dBm)	Freq. (MHz)	HPA (kW)	Latency (Link) (msec)	Mode
Aleph 100	A3	Directional Omni	10/5	LHCP	68/63	406-550	1	< 250	Stand. Tone
Aleph 100	D3	Directional Omni	10/5	LHCP	68/63	406-550	1	< 250	Stand. Tone

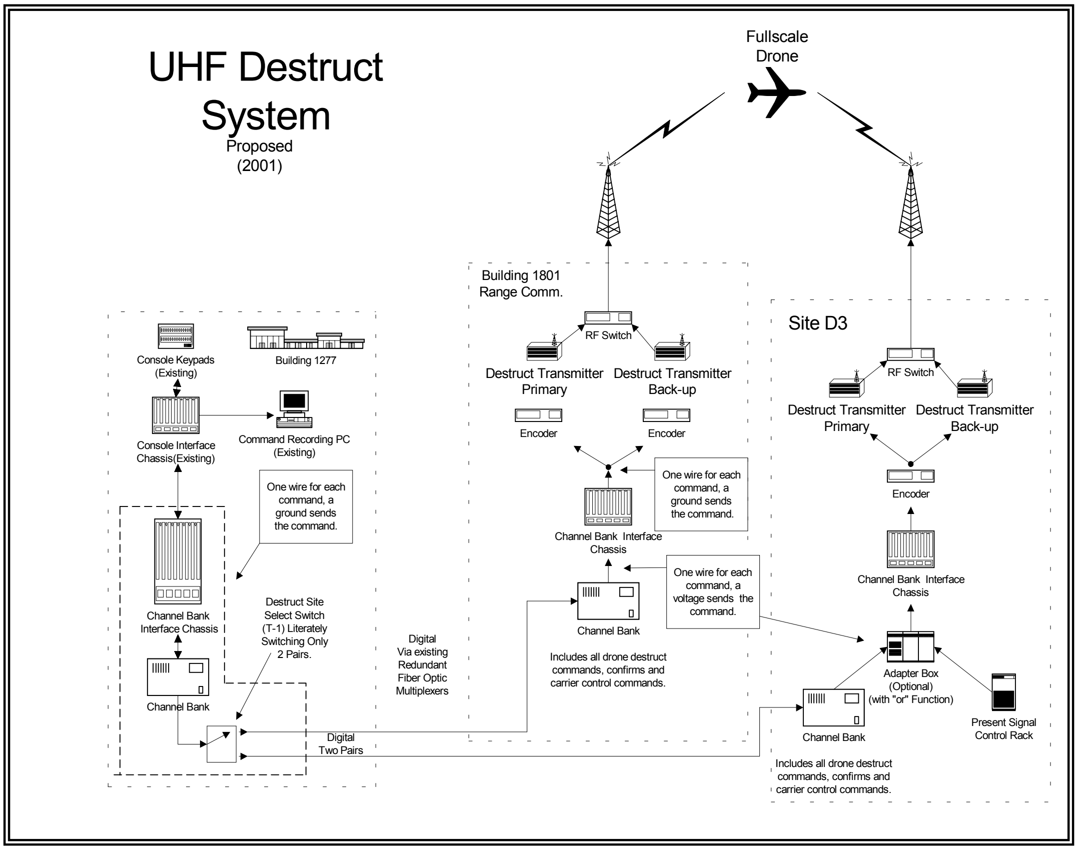

Figure 2-7. UHF destruct system (proposed 2001).

2.2.4.4 Eglin Requirements Survey Summary:

TABLE 2-10. EGLIN AFB REQUIREMENTS SURVEY	
Latency (FTR)	Total FTR command process time = 250 ms
Link distance (maximum)	120 nautical miles
Link margin (minimum)	12 dB
No. of targets (maximum)	Worst-case scenario is 4 missiles and 4 full-scale drones in the air simultaneously. There will also be 2 spare missiles and 2 spare drones. Need the capability of having different addresses for each along with multiple other addresses to ensure that the logistics does not become a problem.
Secondary non-FTS functions	On some systems, tone pairs are used to send up to 16 different commands to the override controller.
Update rate	Some systems have to be interrogated once every 250 ms, but normally it is 4-6 seconds.

2.2.5 Reagan Test Site (RTS)

2.2.5.1 Overview. The U.S. Army's Reagan Test Site offers strategic geographical location, unique instrumentation, and strong capability to support ballistic missile testing and space operations. RTS has provided research, development and T&E support for over 40 years Its current mission is to support operational and developmental tests of theatre and strategic ballistic missiles, theatre and strategic missile interceptors, NASA operations, and space experiments, etc.

The RTS range is located on eight islands throughout the Kwajalein atoll. Instrumentation includes precision metric and signature radars, optical sensors, telemetry receiving stations, and impact scoring assets. RTS provides mobile, fixed ground and flight safety instrumentation.

2.2.5.2 Configuration. RTS has two Command Transmitter Systems (CTSs) on Kwajalein Island and three on the USNS Worthy, a T-AGOS class ship, which has been commissioned to serve as a mobile instrumentation platform at RTS. The RTS Mobile Range Safety System is installed on the Worthy to support tactical missile defense (TMD)-related remote site launch activities. Each consists of custom manufactured controllers with Kalmus model LA2000UE 2-kW power amplifiers. The systems at each location use two 20-ft parabolic and two 6-ft omnidirectional antennas with 26 dB and 0 dB gain, respectively.

2.2.5.3 RTS CTS Parameter Summary Table:

TABLE 2-11. RTS CTS PARAMETERS

System Type	Location	Antenna	Gain (dBi)	Polarization	EIRP (max) (dBm)	Freq. (MHz)	HPA (kW)	Latency (Link) (msec)	Mode
CTS #1	Kwajalein Island	Omni & Directional	0 26	RHCP	88	400-500	2	500	Stand.
CTS #2	Kwajalein	Omni & Directional	0 26	RHCP	88	400-500	2	500	Stand.
CTS #3	Ship	Directional	26	RHCP	88	400-500	2	500	Stand.
CTS #4	Ship	Directional	26	RHCP	88	400-500	2	500	Stand.
CTS #5	Ship	Directional	26	RHCP	88	400-500	2	500	Stand.
CTS#1	Roi Namur Island	Omni & Directional	0 26	RHCP	88	400-500	2	500	Stand.
CTS #2	Roi Namur Island	Omni & Directional	0 26	RHCP	88	400-500	2	500	Stand.

2.2.5.4 RTS Requirements Survey Summary:

TABLE 2-12 RTS REQUIREMENTS SURVEY	
Latency (FTR)	500 ms
Link distance (maximum)	300 miles
Link margin (minimum)	12 dB over 95% spherical coverage
No. of targets (maximum)	8
Secondary non-FTS functions	In flight missile communication for guidance/targeting control
Update rate	10 Hz

2.2.6 Pacific Missile Range Facility (PMRF)

2.2.6.1 Overview. The PMRF is the world's largest multi-threat and multi-dimensional fleet training and testing range. This range supports a multi-level cadre of training and testing environments from instrumented deep oceans of 2500 fathoms to a shallow littoral range of 50 fathoms covering an area of 1100 square miles. It is overlapped by a wholly owned and controlled airspace of 42,000 square miles which is instrumented with state-of-the-art radar telemetry, communication, electronic warfare, optics, aircraft and surface craft. Range safety supports multiple mission scenarios to include:

- VANDALS
- HARPOONS
- AMRAAM
- STARS
- TERRIER
- SRALT
- LRALT

2.2.6.2 Configuration. PMRF is configured with four fixed CTS and two airborne FTSs that are utilized for FTS support at PMRF. The fixed CTS are Zeta 1376 1-kW transmitters upgraded to version 1376-MI in calendar year 1999-2000. PMRF also utilizes airborne FTS aboard the C-12/C-26 aircraft for relay of command destruct tones.

The 4 fixed CTS are Zeta model 1376-MI with 1-kW capability. Each system is fully redundant. A switchover unit continually monitors all system parameters through an IEEE-488 internal control bus. It will control and provide automatic or manual switching between the primary or backup RF transmission equipment. Automatic switching occurs when the RF levels drop below a predetermined point, or when an equipment failure has been detected. The switchover unit will simultaneously route the command activation messages to both IRIG command encoders via the internal control bus.

Emhiser Research manufactures the IRIG command encoders. The command encoders receive the tone activation message and generate the required tones at the specified IRIG tone frequencies. The tones are then routed to the Emhiser command exciter unit. This unit operates within the frequency range of 406-450 MHz. The CTS at PMRF operates between 420 and 450 MHz.

The Power System Technology high power amplifiers (HPA) amplify the signal from the command exciter to a maximum level of 1000 watts CW, between 406 and 450 MHz. The HPAs have a selectable output control that allows the amplifier to be adjusted from 100 to 1000 watts.

The TCR 3-phase power supply provides dc power to the HPA and the switchover unit. Continuous power output is 30 Vdc to both units. The Zeta switchover unit monitors and controls all system functions including the primary to backup RF transmission systems. The front panel of the auto transfer switch displays which system is on-line (primary or backup), as well as alarm and fault conditions. The primary RF signal is then routed to the antenna system, while the backup RF signal is sent to a dummy load. The primary RF signal can be routed to a 6-dB gain omni-directional or 12-dB gain, 60-degree beam width, directional antenna.

2.2.6.3 Remote Control. Remote control of the 1-kW CTS is accomplished with CTS LAN and CTS workstations or the LAN data controller (LDC). The LAN LDC is a full-duplex, redundant, network and computer-based system. The LDC is the control interface between the range operations control center (ROCC) at Barking Sands and the CTS, comprised of four transmitter systems, at Kokee Park. Two adjunct workstations developed in conjunction with the LDC allow pre-operational set up of the transmitter systems and tone monitoring and recording. A redundant CTS LAN is utilized to ensure reliability. Workstation features include:

- site selection
- carrier on/off
- antenna select (omni/directional)
- transmitter select (Tx 1/Tx 2) cycling of command tones (ARM/TERM)
- read back of tone activation
- minimal latency measured at 15 milliseconds

2.2.6.4 Extended Range. C-12/C-26 aircraft are used to provide over-the-horizon support for FTS functions. The C-12/C-26 incorporates an Emhiser 500-watt CTS to transmit the FTS commands and an Emhiser receiver/decoder unit to receive the FTS commands. An omni-directional antenna along with a 45-degree beam width (12 dB gain) helix antenna is used. Two modes of operation can be supported:

Mode 1: Range safety officer has the capability to directly transmit FTS commands onboard the C-12/C-26.

Mode 2: In relay mode, a receiver is tuned up to perform as a repeater. The FTS signal is received on one frequency and re-radiated on another frequency.

2.2.6.5 PMRF CTS Parameter Summary Table:

TABLE 2-13. PMRF CTS PARAMETERS

System Type	Location	Antenna	Gain (dBi)	Polar-ization	EIRP (max) (dBm)	Freq. (MHz)	HPA (kW)	Latency (Link) (msec)	Mode
CTS #1	Kokee Park	Omni & directional	6 12	LHCP		406-450	1		Standard & High Alpha.
CTS #2	Kokee Park	Omni & directional	6 12	LHCP		406-450	1		Standard & High Alpha.
CTS #3	Kokee Park	Omni & directional	6 12	LHCP		406-450	1		Standard & High Alpha.
CTS #4	Kokee Park	Omni & directional	6 12	RHCP		406-450	1		Standard & High Alpha.

2.2.6.6 PMRF Requirements Survey Summary:

TABLE 2-14 PMRF REQUIREMENTS SURVEY

Latency (FTR)	--
Link distance (maximum)	Have worked LOS to 2000 miles
Link margin (minimum)	--
No. of targets (maximum)	5 each per 5-target destruct panel
Secondary non-FTS functions	BQM-34 - SEPTAR
Update rate	--

2.2.7 Naval Air Warfare Center/Weapons Division (NAWCWD)(Pt. Mugu)

2.2.7.1 Overview. Point Mugu is an integral part of the NAWCWD. Range safety supports multiple mission scenarios to include:

- Tomahawk cruise missile — requiring complex test scenarios ranging over several states.
- Standoff land attack missile (SLAM) — whose hazard footprint requires very large test range space
- AMRAAM, Sidewinder and Sparrow air-to-air missiles — which require sharing aircraft, airspace resources, and aerial targets

2.2.7.2 Configuration. Two fixed Command Transmitter Systems (CTS) and two airborne CTS are utilized for FTS support at Pt. Mugu. CTS #1 is a Zeta 1376 1-kW transmitter of 1980s vintage. CTS #2 is a 10-kW system which is owned and controlled by Vandenberg AFB. Pt. Mugu also utilizes airborne CTS aboard P-3 aircraft for relay of command destruct tones.

CTS #1 is a Zeta model 1376 with 1-kW capability. The system is fully redundant. A switchover unit continually monitors all system parameters through an IEEE-488 internal control bus. It will control and provide automatic or manual switching between the primary or backup RF transmission equipment. Automatic switching will occur when the RF levels drop below a predetermined amount or when an equipment failure has been detected. The switchover unit will simultaneously route the command activation messages to both IRIG command encoders via the internal control bus.

The IRIG command encoders are manufactured by Emhiser. The command encoders receive the tone activation message and generate the required tones at the specified IRIG tone frequencies. The tones are then routed to the command exciter unit.

The command exciter is the Emhiser model. This unit operates within the frequency range of 406 to 450 MHz.

The Power Systems Technology high power amplifiers (HPA) amplify the signal from the command exciter to a maximum level of 1000 watts CW, between 406 and 450 MHz. The HPAs have a selectable output control, which allows the amplifier to be adjusted from 100 to 1000 watts.

DC power is provided to the high power amplifier and the switchover unit by the TCR 3 phase power supply. Continuous power output is 30 Vdc to both units. The Zeta switchover unit monitors and controls all system functions including the primary and backup RF transmission systems. The auto transfer switch front panel displays which system is on-line (primary or backup), as well as alarm and fault conditions. The primary RF signal is then routed to the antenna system, while the backup RF signal is sent to a dummy load. The primary RF signal can be routed to a 0-db gain omni or a 12-db gain, 60 degrees beam width directional antenna.

Remote control of the 1-kW CTS is accomplished with the serial data controller (SDC). The SDC acts as the control interface between the UHF CTS (at both central and remote sites) and the range digital communications network. Command/destruct functions at the central site are digitally encoded into a 72-bit serial message. This message is transmitted through the range's digital link to the remote CTS. At the remote sites the message is decoded and passed to the command transmitter. A redundant SDC with communications link is utilized to ensure reliability. SDC system features include:

- site selection
- carrier on/off
- cycling of command tones (ARM/TERMINATE)
- read-back of tone activation
- minimal latency measured at 1.5 milliseconds

A new development is underway to replace the SDC with a rack-mounted PC-based system. The new system also uses "C" programming; however, Ethernet protocol is utilized along with a V.35 interface to a 56K communications link.

P-3 aircraft are used to provide over-the-horizon support for FTS functions. The P-3 incorporates an Emhiser 500-watt CTS to transmit the FTS commands and an Emhiser receiver/decoder unit to receive the FTS commands. An omni antenna along with a 45-degree beam width (12 dB gain) helix antenna are used. Two modes of operation can be supported.

- Mode 1: Range safety officer has capability to directly transmit FTS commands onboard the P-3.

- Mode 2: In relay mode, a receiver is tuned up to perform as a repeater. The FTS signal is received on one frequency and re-radiated on another frequency.

The 10-kW CTS is located at Laguna Peak. The CTS is identical to the VAFB CCT-1 system. Laguna Peak CTS can be controlled either from VAFB or Pt. Mugu. The system operates with a 15-foot, 23-dB gain directional antenna.

NOTE	Pt. Mugu is the lead range for the Kodiak Launch Complex (KLC) and they are in the process of installing a 4-kW CTS at KLC.

2.2.7.3 Pt. Mugu CTS Parameter Summary Table:

TABLE 2-15. PT. MUGU CTS PARAMETERS									
System Type	**Location**	**Antenna**	**Gain** (dBi)	**Polarization**	**EIRP** (Max.) (dBm)	**Freq.** (MHz)	**HPA**	**Latency** (Link)	**Mode**
CTS #1	Laguna Peak	15 ft. directional	--	LHC	--	406-450	1 kW	--	Standard & High Alpha
CTS #2	Laguna Peak	Omni and directional	--	LHC	--	same	10 kW	--	Standard & High Alpha
CTS #3	San Nicholas	Directional	13	LHC	--	same	1 kW	--	Standard
CTS #4	P-3 Aircraft	Omni and directional	--	LHC	--	same	500 W	--	Standard

2.2.7.4 Pt. Mugu Requirements Survey Summary:

TABLE 2-16 PT. MUGU REQUIREMENTS SURVEY	
Latency (FTR)	(No current entries)
Link distance (maximum)	
Link margin (minimum)	
No. of targets (maximum)	
Secondary non-FTS functions	
Update rate	

2.2.8 NASA/Goddard Space Flight Center/Wallops Flight Facility

2.2.8.1 Overview. NASA/Goddard Space Flight Center/Wallops Flight Facility (WFF) is located at Wallops Island, Virginia. The WFF mission is primarily flight test support of sounding rocket testing over the Atlantic sea range. However, WFF also supports various DoD programs to include Navy projects from Patuxent River, NAWCAD and NASA space shuttle tracking support. WFF is also the NASA center for mobile tracking systems and is, therefore, actively involved in worldwide mobile systems deployments in support of various projects to include the X-33. Typical mobile systems utilized include telemetry, radar, and flight termination systems.

2.2.8.2 Configuration. Range safety operations are conducted from the range control center. Separate sections within the control center perform data analysis, airspace surveillance, data monitoring, and selection of best source tracking/telemetry data. The best source data is routed and displayed in the range safety room. Two separate stations provide trajectory displays with vehicle latitude, longitude, altitude, limit lines and instantaneous impact predictions (IIP). A remote command panel is also provided at each station for remote command activation of the fixed CTS located at Wallops Island. The stations are operated by a range safety officer (RSO) and a flight safety officer (FSO). The RSO has operational responsibility for the mission, while the FSO is responsible for judging the performance of the vehicle and issuing destruct commands. The RSO acts as a backup to the FSO for destruct action. The safety stations could also be used separately to provide multiple mission support, however remote panel redundancy would be sacrificed.

As previously mentioned, sounding rocket support is the primary mission at WFF. Sounding rockets do not require the use of an FTS. The rockets are launched from the coastline and flown over the water and allowed to drop harmlessly into the ocean. FTS is used by WFF to support DoD programs such as Vandal, Pegasus and VCL (Athena). RF penetration of vehicle plume has been a problem on certain missions including Pegasus. The problem is overcome by switching transmitter sites in order to transmit to the vehicle at different angles. Switching CTS sites must be accomplished within a 20-second window; therefore, a precise and coordinated countdown is utilized by the RSO to prevent coverage gaps.

Standard, as well as secure tone transmissions, are utilized by WFF. The 20 standard IRIG tones are used at a center frequency of 425 MHz for FTS operations. Additionally, the same 20 IRIG tones are also used for guidance control of certain vehicles such as Vandal. The control tones are transmitted from a separate CTS at a center frequency of 447 MHz.

2.2.8.2.1 Secure FTS. The secure (high alphabet) FTS is located on Wallops Island and is remotely operated by Patrick Air Force Base personnel to support missile launches such as Delta/Globalstar and Atlas. The system utilizes a computer and secure command encoder to receive and process the high alphabet (HA) message. The HA output is then routed to a standard Marconi signal generator and Zeta amplifier. WFF CTS operators perform preliminary system checks as well as manually (disconnecting and reconnecting a cable) transferring the output from the secure command encoders to the Marconi exciters. The RF from the Marconi exciter is then sent to the Zeta amplifiers for 2-kW amplification. The 2-kW RF is transmitted through a pair of redundant quad helix antennas. The antenna parameters are the same for both secure and standard transmissions. Two redundant and independent communications links are utilized between Patrick AFB and WFF to remotely command and control the secure system. The computer system verifies an FTS transmission by sniffing the RF and transmitting the decoded message back to Patrick AFB. The HA command set is sent via the command link real-time from Patrick AFB to the WFF site so there is no requirement for safe or key (code) loading equipment. The command is also mirrored back from the sites in real-time to ensure code integrity.

2.2.8.2.2 Standard FTS. The fixed site contains a Zeta 4-kW CTS and an Aleph 1-kW CTS. Two mobile CTSs are located on main base awaiting deployment with a third system undergoing acceptance testing. The 4-kW CTS incorporates an Aleph 20-tone IRIG generator, a Marconi 2018A signal generator and Zeta high power amplifiers to produce a maximum output of 4 kW. The HPAs are currently limited at a 2-kW output while antenna modifications are being made.

Transmission of the standard and secure RF is accomplished by utilizing a pair of redundant quad helix antennas that are located on the roof of the fixed site. The antennas operate with the following characteristics:

- 18-dB gain
- 20-degree beam width
- 400-450 MHz bandwidth
- 4-kW transmitter (currently limited to 2-kW transmission)

The Aleph 1-kW CTS has reached the end of its life cycle and is currently being replaced by a system that is identical to the models utilized for mobile FTS operations.

Two WFF Mobile Command Systems (MCS) are owned and operated by WFF to support worldwide deployments. They include a 33-ft van, and a 45-ft van with communications hub. The CTS equipment contained in each van is identical.

The MCS No. 1A is a 45-foot expandable trailer CTS containing redundant 1-kW standard tone command transmitters, quad helical directional antennas, antenna control system, uninterruptible power supplies, archiving system, auto fail-over system, communications system, and air conditioning equipment. Commercial-off-the-shelf (COTS) equipment was purchased and integrated by WFF engineers.

FTS IRIG tone control is accomplished by utilizing redundant Adkins 8/16-channel time division multiplexer decoders and encoders to receive the ARM and DESTRUCT commands from the WFF command destruct center via modem. Upon receiving the commands, the redundant Adkins 16-channel time division multiplexer encoders transmit the commands back to WFF to verify the receiving signal. The time division multiplexer decoders also send the commands to the tone sequencer. The tone sequencer sends the appropriate channel commands to the tone encoders. The tone encoders relay generated tones to the tone amplifiers, which send the tones to the RF signal generators. The signal generators use the tones to FM modulate the specified UHF RF signal at 30-kHz deviation per tone. The signal generators output a signal to the associated power amplifier. The backup signal generator is on but has its RF output turned off.

Amplification and radiation is provided by a solid-state 1000-watt amplifier that amplifies the tone-modulated RF output from the active system's signal generator. The amplified output is coupled through a Bird RF sniffer and a Bird RF coupler to the associated antenna for radiation.

Each antenna has a controller and a slaving computer to position it in azimuth and elevation. Modems receive antenna positioning information locally from telemetry and/or radar instrumentation and also remotely from Wallops. Antenna slewing is continuous and is active when position error is equal to or greater than one degree. A video camera is mounted on the antenna rotator to aid in tracking. A camera controller and monitor are rack-mounted in the van.

The auto-fail system provides continuous sampling of the transmitter's forward and reflected power with use of a Bird RF coupler and Bird power analyzer. The auto-fail computer monitors the output from the power analyzer and switches operation to the backup transmitter if an out-of-tolerance condition is detected. The switchover is automatic and does not require operator intervention. A manual switchover capability is also available.

Two redundant Pentium PCs perform the archiving function. The computers monitor and record IRIG-B tones selected for Check, Arm, and Destruct channels. Each computer has two National Instruments PCI-DIO-32HS data acquisition cards to monitor and record the encoder's and decoder's selected 20 tones. The operating program is a Lab-view program written at WFF.

Electrical power for the trailer consists of two parts: mission critical loads and non-mission critical loads. Two 15-kVA uninterruptible power systems supply the redundant mission critical loads. The external power source directly supplies the non-critical loads. The trailer electrical system connects to two (2) five-wire-208/120 V, 3-phase, 60-Hz posi-lock panels mounted in the sidewall of the trailer. The neutral and ground wires are independent and isolated throughout the entire internal electrical system. Commercial power or generators supply the external power source.

2.2.8.3 WFF CTS Parameter Summary Table:

TABLE 2-17. WFF CTS PARAMETERS									
System Type	**Location**	**Antenna**	**Gain** (dBi)	**Polar-ization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
Fixed	Wallops Island	Quad Helix	--	LHCP	80.0	Operating at 425 Range is 400-450	1	15	Standard & secure (Cape system)
MCS 1A	Mobile	Dual Helix	--	LHCP	73.0	same	1	N/A	Standard
MCS 2A	Mobile	Dual Helix	--	LHCP	73.0	same	1	N/A	Standard
MCS 3A	Mobile	Dual Helix	--	LHCP	73.0	same	1	N/A	Standard

2.2.8.4 WFF Requirements Survey Summary:

TABLE 2-18. WFF REQUIREMENTS SURVEY	
Latency (FTR)	(No current entries)
Link distance (maximum)	
Link margin (minimum)	
No. of targets (maximum)	
Secondary non-FTS functions	
Update rate	

2.2.9 Tonopah Test Range (TTR)

2.2.9.1 Overview. Sandia National Laboratories (SNL) operates TTR for the U.S. Department of Energy (DoE). The principal mission of the range is to provide research and development (R&D) test support for DoE-funded weapons projects. However, the range is available for use by other government agencies and their contractors. TTR provides UAV range safety support to the Air Force and NASA Dryden.

2.2.9.2 Configuration. TTR utilizes a fixed CTS site that is located within the operations control center. The CTS is a COTS based 1-kW system manufactured by Zeta (EPSCO) Corp. The CTS equipment is remotely activated by the RSO in the mission control area. The CTS hardware is similar to the AFFTC CTS (section 2.2.3.3.1) using the same Zeta model, but the TTR system uses an older model switchover unit.

2.2.9.3 TTR CTS Parameter Summary Table:

TABLE 2-19. TTR CTS PARAMETERS

System Type	Location	Antenna	Gain (dBi)	Polar-ization	EIRP (max) (dBm)	Freq. (MHz)	HPA (kW)	Latency (Link) (msec)	Mode
Zeta 1376	Ops. center	Omni/ helical	--	LHCP	Unk.	Range is 406-450	1	Unk.	Stand Tone

2.2.9.4 TTR CTS Requirements Survey Summary:

TABLE 2-20. CAPE CANAVERAL REQUIREMENTS SURVEY

Latency (FTR)	(No current entries)
Link distance (maximum)	
Link margin (minimum)	
No. of targets (maximum)	
Secondary non-FTS functions	
Update rate	

2.2.10 Utah Test and Training Range (UTTR)

2.2.10.1 Overview. The mission of UTTR is to test and evaluate new and diverse weapons systems and provide effective training areas for operational systems. The UTTR and Dugway Proving Ground (DPG) form a complex for testing of manned and unmanned air vehicles, munitions and missiles.

2.2.10.2 Configuration. UTTR utilizes a fixed CTS site at Cedar Mountain and Trout Creek. Both fixed CTS sites are located on the Dugway Proving Grounds (DPG) range. The CTS sites are remote controlled from the Hill Air Force Base via the serial data controller (SDC) and associated microwave/fiber-optic communications equipment.

2.2.10.2.1 Remote Command. Remote control of the CTS sites is accomplished with the SDC. The SDC acts as the control interface between the UHF CTS (at both central and remote sites) and the communications network. Control/destruct functions at the central site are digitally encoded into a 72-bit serial message. This message is transmitted through the ranges digital link to the remote CTS. At the remote sites the message is decoded and passed to the command transmitter. A redundant SDC with communications link is utilized to ensure reliability. SDC system features include:

- site selection
- carrier on/off
- cycling of command tones (ARM/TERM)
- read back of tone activation
- minimal latency measured at 1.5 milliseconds

2.2.10.2.2 Command Transmitter System. The CTS hardware at Cedar Mountain and Trout Creek are identical Zeta 1376 systems. Functionality of the CTS is similar to the AFFTC CTS (paragraph 2.2.3.3.1).

2.2.10.3 UTTR CTS Parameter Summary Table:

TABLE 2-21. UTTR CTS PARAMETERS									
System Type	**Location**	**Antenna**	**Gain** (dBi)	**Polar-ization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
Zeta 1376	Cedar Mtn.	Omni (high gain)	--	LHCP	62.5	Range is 406-450	1	Unk.	Stand. Tone
Zeta 1376	Trout Creek	Omni (high gain)	--	LHCP	62.5	Range is 406-450	1	Unk.	Stand. Tone

2.2.10.4 UTTR CTS Requirements Survey Summary:

TABLE2-22. UTTR CTS REQUIREMENTS SURVEY	
Latency (FTR)	--
Link distance (maximum)	--
Link margin (minimum)	12 dB
No. of targets (maximum)	--
Secondary non-FTS functions	--
Update rate	--

2.2.11 **Vandenberg Air Force Base (VAFB)**

2.2.11.1 Overview. VAFB test facilities encompass the Western Test Range and are under the operation of the 30th Space Wing. The Western Range consists of 37 miles of California coastline and extends west toward the Indian Ocean. The mission is to conduct flight testing of intercontinental ballistic missiles (ICBM) and launching of DoD and commercial satellite payloads into polar orbit. Range instrumentation used in support of the range is comprised primarily of tracking and surveillance radars, optical tracking systems, downlink telemetry systems, command transmitter systems (CTS), control centers and weather systems.

2.2.11.2 Configuration. The Missile Flight Termination Ground System (MFTGS) is utilized in support of in-flight missile flight control requirements. The mission of the MFTGS is to transmit selected RF non-command and command functions to missile systems to:

- maintain missile-borne receiver quieting where the command transmitter (carrier) captures the command receiver.
- provide signals for monitoring of missile-borne receiver/decoder operation.
- cause missile-borne receiver/decoder to activate the missile borne flight termination system.

2.2.11.3 CTS Systems. The CTS network consists of four sites that are remotely controlled from the range control center, Building 7000. CT-1 is comprised of a redundant 10-kW transmitter manufactured by Aydin Corporation. The CTS utilizes Magnetron tube technology in the high power amplifiers (HPAs). The CTS, along with range tracking systems, is scheduled for modernization within a five-year period.

- Operating frequency is 416.5 MHz; however; a plan is in the works to move frequency to 421 MHz
- Site (carrier) switching is required to overcome plasma attenuation problems.

The MFTGS is comprised of a Central Command System (CCS) located in the mission flight control center (MFCC), building 7000, and six remote command control transmitter (CCT) sites. CCT sites 1, 2 and 3 are located at VAFB. CCT site 4 is located at Pillar Point AFS, site 6 is located at USN NAWC, Laguna Peak, and a command control transmitter mobile system (CCTMS). All CCT sites are capable of being controlled from the CCS in the MFCC. CCT site 6 is capable of supporting USN remotely-piloted vehicle operations and can also be controlled from the NAWC Range Operations Display System (RODS).

Although the CCT sites are similar, CCT-1 site was the only fixed system visited by the survey team and discussed in detail. CCT-1 is located on North Vandenberg at building 21200. The site control system has been modernized and has been given the flexibility to be more easily modified to support future programs.

The CCT-1 system is a redundant, multiple microprocessor system designed to prevent inadvertent commands. The site units are also designed to preclude the site from not responding to operational commands due to a failure of one of the site subsystems. CCT-1 is an integral part of the MFTGS and is capable of supporting operations locally from the control console. It can also be remotely controlled from the CCPS located in the MFCC in building 7000. The system can also be configured to support either standard (non-secure) tone or high alphabet (secure) tone transmission. Recording system events is accomplished with a 5-1/4 inch high-density floppy disk drive and printer. Recording events are time tagged with timing derived from IRIG-B. The site is redundant and equipment strings are designated A and B.

The site utilizes two Aydin high power amplifiers (HPAs) capable of producing 10 kW. The HPAs are Varian type 4KM50000LA5 four-cavity velocity modulated beam klystrons. Frequency transmission is selectable between 400 - 450 MHz. The HPAs are driven by a synthesized signal source that feeds a low power amplifier to produce the drive power for the HPA Klystrons. The HPA output is a nominal 10-kW CW with a 60-dB bandwidth of ±180 kHz.

A Marconi 2019A synthesized signal generator provides the base frequency. The Marconi has a frequency range of 80 kHz up to 1040 MHz. The frequency synthesizer is controlled by the RF control signal processor (RCSP) subsystem in the control console. The RCSPs generate the modulation signals and monitor the output signals from the HPAs. The frequency selection is limited by firmware in the RCSP from 400 to 450 MHz in 0.5-MHz steps. The selected frequency is dependent on the antenna type. The omni antenna has a specified frequency band of 400 to 425 MHz. The directional antenna has a specified frequency band of 400 to 450 MHz.

The site console control system is capable of generating the following audio tones:

- IRIG (standard) tones 1 - 20 and high alphabet tones 1-7
- Standard mode
- Secure Transmission System (STS)
- Uplink mode

Three COMM processors are fully networked together so that system data is shared and the control subsystem is triple redundant. COMM processors A and B exercise overall control of the CCT-1 system and provide the interfaces for local and remote control. COMM processor C provides the CRT display and event recording and votes with the A and B processors on the site operations.

The control panel is manufactured by ITT Federal Systems and can be remotely activated by the mission flight control officers in building 7000 or locally by the system operators. Panel data format is comprised of a 40-bit HDLC message that is transmitted at 2400 bits per second. The transmission medium is a combination of fiber-optic and microwave transport systems. The latency requirement (EWR 127-1) for remote command activation is approximately 55 milliseconds. The actual measured time is 70 milliseconds from button push to leading edge of CTS transmission. A new development is in the works to provide a 56K data link.

The command panel can be selected to operate either in the secure (high alphabet) or standard tone transmission modes. Code loading is accomplished via KYK-13 load device. Codes are loaded at the range operations center and at the CCT site. Control panel features include the following:

- continuous or cycle tone modes
- selectable check (monitor) tones 4 or 5
- fail-over enable
- carrier control per site

The RF test panel routes the system RF between the control system and HPAs. It provides test points for the site operators.

There are two FM receivers (A&B). These Marconi 2305 modulation meters are the receive units for the control system of the RF sample and are controlled by the RCSPs. The deviation level is displayed on the front panel.

The site has a dual antenna system consisting of a 10-kW omni antenna and a 15-kW directional antenna. Both antennas are left-hand circular polarization (LHCP). The omni antenna has a 3-dB beam width of 190 degrees and 1-dB of gain. The directional antenna is a 15 foot parabolic dish with 3-dB beam width of 10 degrees and 23 dB of gain. Omni and directional antennas are interfaced to the HPA through the RF switching unit. This allows the RF antenna configuration to be controlled from the control console.

The RF switching system allows the HPAs to be terminated into a 15-kW dummy load or into the site antenna system. The switching system allows the A or B system HPA to be switched to the antenna system and allows selection of either the omni or directional antenna. RF switching is accomplished by using high power vacuum coaxial relays and vacuum coaxial isolators. These components allow the site to switch configurations with carrier blanked for less than 55 milliseconds and provide approximately 100 dB of dummy load isolation.

2.2.11.4 VAFB CTS Parameter Table:

TABLE 2-23. VAFB CTS PARAMETERS									
System Type	**Loc**	**Antenna**	**Gain** (dBi)	**Polar-ization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
CCT 1	--	Omni and directional	--	LHCP	--	Current is 416.5. Moving to 421 Range is 400-450	10	--	Standard & High Alpha.
CCT 2	--	Omni and directional	--	LHCP	--	Same	10	--	Standard & High Alpha.
CCT 3	--	Omni and directional	--	LHCP	--	Same	10	--	Standard & High Alpha.
CCT 4	--	Omni and directional	--	LHCP	--	Same	10	--	Standard & High Alpha.
CCT 5	--	Omni and directional	--	LHCP	--	Same	10	--	Standard & High Alpha.
CCT 6	--	Omni and directional	--	LHCP	--	Same	10	--	Standard & High Alpha.

2.2.11.4 VAFB Requirements Survey Summary:

TABLE 2-24. VAFB REQUIREMENTS SURVEY	
Latency (FTR)	Button push to Destruct = 250 ms. Overall delay with FCO reaction time = 2.5 sec.
Link distance (maximum)	Line-of-sight of transmitter
Link margin (minimum)	12 dB over 95% spherical antenna coverage
No. of targets (maximum)	2
Secondary non-FTS functions	ARM command is used to shutdown liquid rockets TEST command is sent to initiate a self-test of receivers with computer processors. DISABLE command is used to shutdown the receivers after the vehicle is beyond range safety responsibility (usually before going over the horizon). RESET command is used to remove commands that latch (used for ground processing/testing). OPTIONAL command is used for other functions such as placing the destruct system in safe mode (besides command receiver) and allowing selectively to shutdown certain liquid engines independently from the main ARM shutdown.
Update rate	N/A

2.2.12 White Sands Missile Range (WSMR)

2.2.12.1 Overview. WSMR is the nation's largest overland missile test facility. Spanning more than two million acres, this national range supports a variety of experimental test vehicles. Programs supported include interceptor missile development, test programs for universities, NASA, DoD and other government agencies, as well as for some foreign governments and private industry.

2.2.12.2 Configuration. Four fixed CTS sites are located on the WSMR range. The sites include C-Station, Salinas Peak, Clark and Red Butte. Systems Planning Corporation (SPC) manufactured the CTS equipment along with the Digital Control System (DCS). The ground FTS network utilizes state-of-the-art technology and is adaptable to changes in modulation techniques and frequencies due to the incorporation of digital signal processing (DSP) technology. The following characteristics pertain to all sites except where noted:

2.2.12.2.1 Command Transmitter Systems (CTS)

- Power output: 1000 watts
- Load impedance: 50 ohms
- VSWR: 2:1 max.
- Frequency range: 409 to 550 MHz
- Modulation type: frequency modulation
- Frequency deviation:: ± 300 kHz
- Tone frequencies: 20 standard IRIG tones, 7.5 kHz to 73.95 kHz both analog and digital waveforms through a 600-ohm port. To modulate the CTS with a digital waveform, a Manchester coded BI-phase format, or similar, must be used and a rate must not exceed 9.6 kbps.
- AC power: 208 Vac, 3-phase, 4-wire WYE plus ground, 60 Hz.
- Antenna system:
  - omni-directional with a peak gain of 3.0 dBi (all sites)
  - fixed, directional with a peak gain of 8 dBi (only fixed sites)
  - left-hand-circular-polarization.

2.2.12.2.2 Digital Control System (DCS). The DCS is a fully redundant, PC-based system that fully controls the CTS and the Patriot/special panels. Commands are routed from the DCS to the sites via 19.2-kbps data lines. The data lines are distributed over a combination of fiber-optic, copper and microwave circuits. The circuits are configured in a point-to-point network and are operated by WSMR personnel. The primary capabilities of the DCS are as follows:

- Full control of CTS and the Patriot/special panels
- Control of up to six sites simultaneously
- Twenty-five (25) control functions that can be designated as destruct or event with destruct having the highest priority. The control functions can be grouped together such that any action taken would only affect the control functions in that group (i.e. destruct A would only override event functions in group A). All control functions may consist of single tones, multiple tones, or multiple tone sequences.
- Logging of all actions to the hard drive. All logs are time-tagged with IRIG-B timing.
- The system is highly reliable with the probability of the system decoding an erroneous command of less than $1 \bullet 10^{-27}$ and a bit error rate (BER) of less than $1 \bullet 10^{-10}$.
- Remote command panels (RCPs) are located at multiple operations stations. The RCPs are simple switch closure devices, which interface to the DCS and provide the

operator with site select, carrier, and destruct functions. The DCS converts the RCP ground closure commands to an asynchronous bit stream that is routed to a modem for transport to the CTS sites. As previously mentioned, the data rate of the remote command links is 19.2 kbps. However, a plan to upgrade to 56-kbps data rate is being considered.

2.2.12.2.3 Command Monitoring and Recording System (CMRS). The CMRS is a PC-based system used to control off-air signal monitor receivers located at each site. The remote monitor receiver is capable of displaying CTS information such as tone activation, carrier frequency, signal strength and deviation. All logging is in a strip-chart format and can be played back or printed out as necessary. All logs are time-tagged with IRIG-B timing. The CMRS is also capable of logging the digital commands from the DCS to the CTS as well as the relay closures of the Patriot/Special panels.

2.2.12.2.4 Mobile Vans. There are three mobile vans that are configured to be virtually identical to the four fixed CTS sites.

- M1 and M2 are 16-ft length by 8.5 ft wide, self-propelled vans that contain SPC 1-kW CTS. The CTS utilizes an omni antenna. Back-up power capability is provided through an automatic transfer switch that switches commercial power to generator. Uninterrupted power supplies (UPSs) provide power during the transition time from commercial to generator.

- M3 is a 28-ft pull-type van that is utilized for long-term deployments. The van is similar to M1 and M2; however, it is completely self supported and incorporates two sections divided into an equipment area and an operations and maintenance area.

2.2.12.3 WSMR CTS Parameter Summary Table:

TABLE 2-25. WSMR CTS PARAMETERS									
System Type	**Location**	**Antenna**	**Gain** (dBi)	**Polar-ization**	**EIRP** (max) (dBm)	**Freq.** (MHz)	**HPA** (kW)	**Latency** (Link) (msec)	**Mode**
SPC	C-Station	Omni and directional	0-3/8	LHCP	68	Range is 409-450	1	10-15	Stand
SPC	Salinas Peak	Omni and directional	0-3/8	LHCP	68	Same	1	10-15	Stand
SPC	Clark	Omni and directional	0-3/8	LHCP	68	Same	1	10-15	Stand
SPC	Red Butte	Omni and directional	0-3/8	LHCP	68	Same	1	10-15	Stand
SPC	Mobile	Omni	0-3	LHCP	60-63	Same	1	10-15	Stand
SPC	Mobile	Omni	0-3	LHCP	60-63	Same	1	10-15	Stand
SPC	Mobile	Omni	0-3		60-63	Same	1	10-15	Stand

2.2.12.4 WSMR Requirements Survey Summary:

TABLE 2-26. WSMR REQUIREMENTS SURVEY	
Latency (FTR)	Link delay = 50 ms. Total delay ≤ 250 ms. Destruct sequence is repeated every 500 ms.
Link distance (maximum)	Maximum link distance for flight tests is approximately 200-250 km. Most flight tests are about 120 km.
Link margin (minimum)	12 dB over 95% spherical antenna coverage
No. of targets (maximum)	6
Secondary non-FTS functions	Cruise missiles use the FTS receiver for command control purposes. Chase planes have capability to fly the cruise missile (i.e., avoid other aircraft). Some targets also use the FTRs for inputting steering commands during flight. Some research vehicles use the FTR to activate payload experiments or command recovery chutes.
Update rate	Some FTS use fail-safe; this requires a continuous tone to be present at all times or else vehicle will automatically destruct. A reasonable time is allowed to account for RF drop-outs; this can range from 2-60 sec. depending on the vehicle.

2.3 Estimated Cost Projections

An estimate of the cost required to modernize the CTS assets is difficult to calculate given the large inventory of hardware and unknown technology to be implemented. However, a general estimate of cost to upgrade systems can be made. Upgrading to digital modulation schemes, which could be implemented by using the CTS external modulation capability or by replacing the system exciters, would involve the least cost. Upgrading to systems that require frequency hopping or frequency changes to bands outside of the operating ranges of the older systems would require the greatest cost. Such changes would require the replacement of the majority of the equipment at most of the ranges surveyed. The high cost of total system replacement could be mitigated, however, by utilizing systems not requiring high power or an extensive ground-based system of support sites. While a low-cost solution may not necessarily be the best, affordability will be a determining factor in the FTS community's ability to deploy a more robust flight termination system.

2.4 Summary

Ground CTS equipment capabilities vary from newly developed systems that can support either standard tone or high alphabet operations to older systems that have reached the end of their expected operational life and are in need of replacement. The CTS hardware also varies from COTS to locally-built equipment. Regardless of manufacturer, all of the systems surveyed were found to be compliant with RCC standards. Overall, the FTS community has adhered to standardization guidelines established by the RCC and "no surprises" or "show-stopping" requirements were identified. Range standardization and modernization efforts such as the Range Standardization and Automation (RSA) Program are also being implemented at the Eastern and Western Test Ranges, which will facilitate the development and use of a new FTS capability. The majority of the ranges do support the need for a more robust FTS that, as a minimum, will meet the current system's required level of reliability at an affordable cost.

References to Phase I

1. 30th Space Wing*,* *Range Instrumentation Handbook*, Section 5, "Missile Flight Termination Ground System," September 1999.

2. Range Commanders Council, Range Safety Group*.* *Current Range Safety Capabilities*, (Document 320-94), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1994.

3. Range Commanders Council, Range Safety Group. *Catalog of Existing and Proposed Command Systems* (Document 201-82), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1982.

4. Range Commanders Council, Range Safety Group, *Range Safety Transmitting Systems 406-549 MHZ Band* (Document 307-79), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1979.

5. Range Commanders Council, Telemetry Group. *IRIG Standards for UHF Command Systems* (Document 208-85), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1985.

6. *Eastern Range Instrumentation Handbook*, Section 6, "Command Destruct", January 1996.

7. EWR 127-1, *Eastern and Western Range Safety Policies and Processes*, Chapter 4, October 1997.

8. AFFTC/DFRC, *X-33 Range Safety Requirements*.

9. *PMTC Serial Data Controller System Manual*.

10. 30th Space Wing, WRR 127-9, *Western Range Integrated Missile Flight Control Ground Systems*, August 1993.

11. Range Commanders Council, Range Safety Group. *Flight Termination Systems Commonality Standard*, (Document 319-99), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1999.

12. *X-33 Range Interface Control Document*, IC604G9401, December 1998.

13. *Command Panel System Operations and Maintenance Manual*, August 1998.

14. ZETA (EPSCO) *Command Transmitter System Maintenance Manual for Model 1376*, April 1989.

CHAPTER 3

PHASE II: TECHNOLOGY ASSESSMENT

3.1 Objectives

The intent of the Phase II portion of the Enhanced Flight Termination System (EFTS) study was to perform a technology assessment of flight termination links, including modulation schemes and message formats. The objective was to investigate new methods of flight termination based upon the defined RS-38 study requirements and the design guidelines generated during Phase I and further refined during Phase II. Because of the desire to generate innovative ideas, many different sources were solicited. The approaches were then evaluated and those deemed most promising were selected for further evaluation. This section will provide details on the Phase II evaluation process and summarize the recommendations submitted to the Range Safety Group.

3.2 Phase II Process

3.2.1 Design Guidelines

With the completion of Phase I of the EFTS study, a preliminary version of the Design Guidelines[5] was generated. The purpose of the Design Guidelines was to provide the basic requirements for an enhanced flight termination receiver (EFTR) and the associated ground support equipment. Due to the nature of the study, the Design Guidelines are subject to change as new information and research is made available.

3.2.2 Technical Approaches

The method used to perform the technical assessment was based on solicitation of technical approaches from multiple and varied sources. The technical approaches were developed per guidelines and evaluation criteria provided by the EFTC (see paragraph 3.2.3). This method ensured that each proposed technical approach would address the same requirements and could be judged upon a standard measure.

3.2.3 Approach Description Guide and Evaluation Criteria

The "EFTS Phase II Approach Description Guide and Evaluation Criteria" (Appendix II-B) was a document generated to ensure that the requested technical approaches followed a consistent format and addressed each of the design guidelines. It also included the evaluation criteria by which the completed technical approaches would be judged. The initial draft of this document was submitted November 2000 and a final version was published January2001.

[5] Final version of Design Guidelines can be found in Appendix I-A.

3.2.4 Sources for Approaches

The EFTS team understood that there were many qualified sources for generating valid approaches for an EFTR and the associated ground equipment. The three sources were vendors, EFTS team members, and the MRTFB ranges.

3.2.4.1 Vendors. Soliciting vendors who currently manufacture flight termination receivers and vendors who manufacture the ground support equipment was imperative. Also solicited, through the Commerce Business Daily (CBD) were any other vendors who had an interest in the field of flight termination. A list of the vendors who responded is included in Appendix I-E. To explain the goals and purpose of the EFTS study, an Industry Day was held at NASA – Dryden Flight Research Center on November 8, 2000. Invitations were sent out to vendors who had expressed an interest in the CBD synopsis to ensure maximum participation. Following the Industry Day, vendors were contacted to determine their interest in developing a potential approach.

3.2.4.2 EFTS Team. The EFTS team consists of government and contractor engineering personnel supporting the present study. The method for generating ideas for technical approaches by the EFTS team was through a brainstorming session. At the conclusion of this session, four ideas were deemed feasible to pursue and expand into approaches. After further discussions with vendors, one of the four was dropped because it would be a duplicate effort.

3.2.4.3 Other Ranges. Solicitations were also sent to other RSG members associated with additional Major Range Test Base Facilities (MRTBFs). None of the ranges submitted an approach for evaluation.

3.2.5 Approach Descriptions

The approach developers were asked to submit descriptions of their approaches following the format established in the "Approach Description Guide." Table 3-1 shows the proposed EFTS approaches with their authors.

NOTE

The term continuous phase frequency shift keying (CPFSK) will be used interchangeably for pulse code modulation/frequency modulation (PCM/FM). PCM/FM is the term widely used in the telemetry community.

3.2.6 Approach Presentations and Method of Evaluation

All interested parties were invited to present their various approaches at a forum set up by the EFTS committee. Seven approaches were presented by vendors and EFTS team members. The forum provided the opportunity for discussion and questioning of presenters.

The original method of evaluation was designed to result in the choice of one best approach. After comments and discussion prior to and during the forum, it was decided that the evaluation team should evaluate each approach for its merits and demerits. It was felt that this method would allow the team the option of combining different elements of the approaches into a composite recommendation. This method differs slightly from the procedure outlined in the evaluation criteria document discussed in paragraph 3.2.3. Table 3-1 lists the seven proposed EFTS approaches presented at the forum.

TABLE 3-1. PROPOSED EFTS TECHNICAL APPROACHES

Approach	Author	Title of Approach or Technique
1	BAE/Cincinnati Electronics	Bi-phase frequency shift keying (FSK)
2	EFTS team	Bi-phase-level CPFSK
3	BAE/Cincinnati Electronics	Enhanced high alphabet (HA)
4	L-3 Communications – Conic Division	Enhanced secure flight termination system
5	System Planning Corporation	Non-coherent 3 of 13 tone messaging
6	EFTS team	Pseudorandom (PN) code
7	EFTS team	Scalable 3-DES encrypted BPSK modulated

3.2.7 Final Evaluation

The final step in the Phase II technical assessment was the evaluation of the technical approaches. Each evaluator's independent evaluations were consolidated and a meeting was held to arrive at a consensus recommendation on which of the technical approaches would undergo further analysis in Phase III of the study. The summary of this evaluation follows in paragraph 3.3.

3.2.8 Benchmark Testing

If the selected approach uses a modulation scheme other than the FM format currently used by all ranges, significant changes to existing ground transmit systems may be required. In order to accurately predict the impact to these systems, the EFTS team determined it was first necessary to identify their characteristics. The members selected which types of tests would best complete this objective with additional suggestions provided from the vendors. These were: phase noise (10 Hz to 1 MHz), bit error rate, two tone inter-modulation, linearity, gain balance, and group delay were chosen.

The EFTS team conducted these tests using Dryden Flight Research Center's 1 kW System Planning Corporation system and Vandenberg AFB's 10-kW Aydin system. Preliminary results show good linearity with the solid state (1-kW) system and poor linearity with the tube technology (10-kW) system. Tests will be continued and may extend to other ranges; however, it is presumed that selecting any coherent modulation format will impart almost complete upgrade requirements to the 10 kW systems. Further, a significant change to the FTS operating frequency range will greatly affect all systems.

3.3 Evaluation Summary

The following paragraphs summarize the findings of the evaluation team, and provide the basis for their final recommendations.

3.3.1 Evaluation Team

The following evaluators were selected because of their broad knowledge and expertise in their fields:

Maria Tobin, FTSC Chairman, NASA/KSC
Ron Cofer, FTSC member, Eglin AFB
Kevin Driscoll, FTSC member, WSMR
Mark Gotfraind, FTSC member, Vandenberg AFB
Jerry Witsken, FTSC member, NAVAIR CL
Eugene Law, Telemetry Group member, NAWCWD, Pt. Mugu
Darrin Lokin, Telecommunications & Timing Group member, WSMR
Greg Strombo, Frequency Management Group member,
Ron Kidwell, National Security Agency representative
Dr. Michael Rice, Brigham Young University, academic liaison
Robert Sakahara, Facilitator, NASA/DFRC, Edwards AFB

3.3.2 Evaluations

The following are the consensus evaluations of the advantages and disadvantages of each approach. Because of the commonality of approaches #1, #2, and #4 with their CPFSK modulation scheme, the common advantages and disadvantages were grouped together. A similar consolidation was done for approaches #3 and #5, which share modified high alphabet or analog modulation schemes. This information aided in the development of the consensus charts (Tables 3-3 and 3-4) that resulted in the final recommendations.

3.3.3 Approach #1: Bi-Phase Frequency Shift Keying (FSK) Approach

3.3.3.1 Approach #1 Advantages

3.3.3.1.1 Common to Approaches (#1, #2, #4)

a. Bi-phase frequency modulation (FM) is a simple modulation technique that is compatible with Flight Termination Systems (FTS) currently in use on many ranges. This scheme allows use of existing and proven technology and would present a low risk for both ground and airborne systems. There would be minimal impact to receiver designs and ground system hardware.

b. FSK uses non-coherent modulation that tends to be more robust in the presence of interference. Inherent FM advantages: "capture effect" can mitigate interference since the largest signal wins.

c. It should be robust against signal degradation during vehicle flight that causes received power level fluctuations, shock and vibration (comparable to current system).

d. Adapts easily to triple data encryption standard (3-DES) and advanced encryption standard (AES).

e. High-reliability parts should be available given the maturity of this technology.

f. Possibility exists for unique identifiers.

g. Approach is easy to prototype and/or simulate because of existing assets at ranges and at vendor facilities.

h. It has a shorter perceived implementation time due to technical similarities with existing ground and air assets.

i. It is tolerant of phase noise (comparable to current system).

3.3.3.1.2 Advantages Specific to Approach #1

a. The approach would allow the FTS to have the capability to output a separate command stream for vehicle override control.

b. It uses the spectrum more efficiently because of ± 8 kHz deviation.

c. Synchronization word is outside of encryption, making it simpler than having it inside encryption (less processing to determine block boundaries).

d. Multiple receivers can receive check channel simultaneously— only requires the synchronization word and a pilot bit for check channel.

3.3.3.2 Approach #1 Disadvantages

3.3.3.2.1 Disadvantages Common to CPFSK Approaches (#1, #2, #4)

a. The approach requires bit/frame synchronization.

b. This approach could be slightly more prone to interference and multipath than tone-based systems.

c. Ground stations must be time multiplexed (only one station can be active on the same frequency at the same time; comparable to current system).

d. Does not improve anti-jam capability (comparable to current system).

3.3.3.2.2 Disadvantages Specific to Approach #1

a. The 8 kb/s data rate (each bit is approximately 125 microseconds) could make it more susceptible to interference from radar pulses and multipath.

b. The peak deviation is only ± 8 kHz, probably lower than optimum for this application. A larger peak deviation would reduce the potential for incidental frequency modulation problems in severe environments.

c. 3-DES has a lot of overhead because of the requirement for 40 of the 64 bits/frame being used for authentication, as compared to AES (40 of 128).

d. The message format allows 11 additional commands and not the required 16 (4 bits for commands, 5 of possible 16 bit patterns are used for required commands).

e. Approach only has 8 bits for command counter per frame, which is insufficient.

f. One vehicle per DES packet is inefficient.

g. Use of (7, 4) Hamming code does not provide adequate error protection for this application with the expected error statistics.

3.3.4 Approach #2: Bi-Phase-level CPFSK Technique

3.3.4.1 Approach #2 Advantages

3.3.4.1.1 Advantages Common to CPFSK Approaches (#1, #2, #4)

a. Bi-phase frequency modulation (FM) is a simple modulation technique that is compatible to existing Flight Termination Systems (FTS) currently in use by many ranges. This allows use of existing and proven technology and would have a low risk for both ground and airborne systems. There would be a minimal impact to receiver designs and ground system hardware.

b. Uses non-coherent modulation that tends to be more robust in the presence of interference. Inherent FM advantages: “capture effect” can mitigate interference since the largest signal wins.

c. Should be robust against signal degradation caused during vehicle flight that causes received power level fluctuations, shock and vibration (comparable to current system).

d. Adapts easily to 3-DES and AES.

e. High-reliability parts should be available given the maturity of this technology.

f. Possibility exists for unique identifiers.

g. The approach is easy to prototype and/or simulate because of existing assets at ranges and at vendor facilities.

h. It has a shorter perceived implementation time due to technical similarities with existing ground and air assets.

i. Tolerant of phase noise.

3.3.4.1.2 Advantages Specific to Approach #2

a. The approach has a strong cyclic redundancy check (CRC).

b. The peak deviation is similar to that of two tones in the existing system. The fairly large peak deviation decreases the susceptibility to incidental FM. This equates to a large modulation index given the bandwidth of the data involved, improving the S/N ratio.

c. The use of advanced encryption standard (AES) instead of 3-DES allows a more efficient use of the bits.

d. Approach has the capability of addressing multiple vehicles in a single frame.

3.3.4.2 Approach #2 Disadvantages

3.3.4.2.1 Disadvantages Common to CPFSK Approaches (#1, #2, #4)

a. The approach requires bit/frame synchronization.

b. This approach could be slightly more prone to interference and multipath than tone-based systems.

c. Ground stations must be time multiplexed — only one station can be active on the same frequency at the same time (comparable to current system).

d. Does not improve anti-jam capability (comparable to current system).

3.3.4.2.2 Disadvantages Specific to Approach #2

a. The 2.88 kb/s data rate (each bit is approximately 347 microseconds) could make it more susceptible to interference from radar pulses and multipath.

b. This approach only uses 10 frames per second; therefore, the acquisition and response times are marginal compared to the requirements.

c. This approach has only one command counter for all vehicles; however, it is 16 bits long, which is equivalent to 12+ bits per vehicle with 12 vehicles.

d. The proposed 256-bit AES security method is not yet approved (risk).

e. Long frame length leads to potential problems in noisy RF environment; entire packet can be rejected by one bit error.

3.3.5 Approach #3: Enhanced High Alphabet (Hi Alpha) Approach

3.3.5.1 Approach #3 Advantages

3.3.5.1.1 Advantages Common to High-Alpha Approaches (#3, #5)

a. Uses a modulation technique that is compatible to existing FTS systems, both ground and airborne (range familiarity). Leverages proven technology (low risk).

b. The approach is relatively insensitive to short bursts of interference.

c. The approach is tolerant of phase noise problems with existing ground and airborne hardware.

d. Should be robust against signal degradation occurring during vehicle flight that causes received power level fluctuations, shock and vibration (comparable to current system).

e. The approach can adapt to 3-DES encryption method.

f. Approach should be relatively easy to implement at ranges supporting high alphabet systems.

g. High-reliability parts should be available given the maturity of this technology

h. Uses tones in the same frequency range as the existing tone-based systems. As a consequence, existing FM transmitters can be used.

3.3.5.1.2 Advantages Specific to Approach #3

a. May be able to use some existing high alphabet receivers with just some programming changes.

b. The check channel is sent as a broadcast tone allowing all receivers to respond.

c. The long tone character times of 2.5 ms makes it more tolerant to radar and other short duration pulse interference.

d. Approach has the capability of outputting a command stream.

3.3.5.2 Approach #3 Disadvantages

3.3.5.2.1 Disadvantages Common to High-Alpha Approaches (#3, #5)

a. Ground stations must be time multiplexed (only one station can be active on the same frequency at the same time; comparable to current system).

b. Does not improve anti-jam capability (comparable to current system).

c. Base-band analog approaches are not forward thinking.

d. Approach requires symbol/frame synchronization.

e. Incorporating AES is problematic — would have to send more combinations of tones, decreasing the update rate.

f. Approach only has 8 bits/frame for command counter, which is insufficient.

g. One vehicle per DES packet is inefficient use of the data formatting.

3.3.5.2 Disadvantages Specific to Approach #3

a. The approach message format allows 11 additional commands and not the required 16 (4 bits for commands, 5 of possible 16 bit patterns are used for required commands).

b. 3-DES has a lot of overhead because of the requirement for 40 of the 64 bits/frame being required for authentication. The system can only talk to one vehicle per frame (25 frames/second).

c. Use of (7, 4) Hamming code does not provide adequate error protection for this application with the expected error statistics.

d. There may be a possible loss of competitive marketing (Cincinnati Electronics has a manufacturing advantage).

3.3.6 Approach #4: Enhanced Secure Flight Termination System Technique

3.3.6.1 Approach #4 Advantages

3.3.6.2 Advantages Common to CPFSK Approaches (#1, #2, #4)

a. Bi-phase frequency modulation (FM) is a simple modulation technique that is compatible to existing Flight Termination Systems (FTS) currently in use on many range. This allows use of existing and proven technology and would have a low risk for both ground and airborne systems. There would be a small impact to receiver designs and ground system hardware.

b. Uses non-coherent modulation that tends to be more robust in the presence of interference. Inherent FM advantages: "capture effect" can mitigate interference since the largest signal wins.

c. Should be robust against signal degradation occurring during vehicle flight that causes received power level fluctuations, shock and vibration (comparable to current system).

d. Adapts easily to 3-DES and AES.

e. High-reliability parts should be available given the maturity of this technology.

f. Possibility exists for unique identifiers.

g. Easy to prototype and/or simulate because of existing assets at ranges and at vendor facilities.

h. Shorter perceived implementation time due to technical similarities with existing ground and air assets.

i. Tolerant of phase noise.

3.3.6.3 Advantages Specific to Approach #4

a. Monitors synchronization status in telemetry output.

b. The peak deviation is similar to that of two tones in the existing system. The fairly large peak deviation decreases the susceptibility to incidental FM. This equates to a large modulation index given the bandwidth of the data involved, improving the S/N ratio.

3.3.6.4 Approach #4 Disadvantages

3.3.6.4.1 Disadvantages Common to CPFSK Approaches (#1, #2, #4)

a. The approach requires bit/frame synchronization.

b. This approach could be slightly more prone to interference and multipath than tone-based systems.

c. Ground stations must be time multiplexed (only one station can be active on the same frequency at the same time; comparable to current system).

d. Does not improve anti-jam capability (comparable to current system).

3.3.6.4.2 Disadvantages Specific to Approach #4

a. Requires two correct synchronization words at proper location prior to decoding message. While this may provide a marginal improvement to the false lock, it increases the acquisition time.

b. Uses NRZ as opposed to Bi-phase. Randomized NRZ-L is not as good a code as Bi-Phase-L for ac-coupled, low bit rate applications.

c. 3-DES has a lot of overhead because of the requirement for 40 of the 64 bits/frame being used for authentication as compared to AES (40 of 128).

d. Did not state how using a monitor/check channel will ensure multiple missiles do not go into fail-safe since each missile will have to be addressed separately if you have 12 missiles.

e. AES requires a 128 bit frame (approach currently depicts use of 80 bits).

f. Evaluation team's interpretation of the approach is inefficient use of packet size, i.e., one vehicle per 80-bit packet.

g. Security proposal uses recommended counter field, but it is part of the authentication field.

3.3.7 Approach #5: Non-Coherent 3 of 13 Tone Messaging

3.3.7.1 Approach #5 Advantages

3.3.7.1.1 Advantages Common to High Alpha Approaches (#3, #5)

a. Uses a modulation technique which is compatible to existing FTS systems, both ground and airborne (range familiarity). Leverages proven technology (low risk).

b. The approach is relatively insensitive to short bursts of interference.

c. The approach is tolerant of phase noise problems with existing ground and airborne hardware.

d. Should be robust against signal degradation caused during vehicle flight that causes received power level fluctuations, shock and vibration (comparable to current system).

e. The approach can adapt to 3-DES encryption method.

f. Approach should be relatively easy to implement at ranges supporting high alphabet systems.

g. High-reliability parts should be available given the maturity of this technology.

h. Uses tones in the same frequency range as the existing tone based systems. As a consequence, existing FM transmitters can be used.

3.3.7.1.2 Advantages Specific to Approach #5

a. Ground system is addressed in-depth.

b. The 8.57 ms tone character time makes it more tolerant to radar and other short duration pulse interference.

3.3.7.2 Approach #5 Disadvantages

3.3.7.2.1 Disadvantages Common to High Alpha Approaches (#3, #5)

a. Ground stations must be time multiplexed — only one station can be active on the same frequency at the same time (comparable to current system).

b. Does not improve anti-jamming capability (comparable to current system).

c. Base-band analog approaches are not forward thinking.

d. Approach requires symbol/frame synchronization.
e. Incorporating AES is problematic — would have to send more combinations of tones, decreasing the update rate.

f. Approach only has 8 bits/frame for command counter, which is insufficient.

g. One vehicle per DES packet is inefficient use of the data formatting.

3.3.7.2.2 Disadvantages Specific to Approach #5

a. Airborne implementation is not well addressed. No analysis of receiver bit error rate (BER) performance or other receiver performance parameters was provided. Does not address how they will address multiple receivers to ensure they do not go into fail-safe.

b. 3-DES has a lot of overhead because of the requirement for 40 of the 64 bits/frame being required for authentication. The frame rate is only 10 frames/second and each frame only talks to one vehicle, therefore, the acquisition, response, and latency times are longer than they are for systems with more frames/second.

c. Use of tones requires more analysis to determine whether the approach is viable.

3.3.8 Approach #6: Pseudorandom (PN) Code Technique

3.3.8.1 Approach #6 Advantages

a. This approach has limited CW anti-jamming characteristics.

b. Uses multiple command transmitters that could provide higher link availability and better support for multiple range, long distance missions.

c. Can command eight vehicles simultaneously from a single transmitter.

d. Allows for simultaneous command transmitter operations — could result in reduction of 95 percent spherical coverage requirement and may increase link margin, if multiple simultaneous inputs can be used.

e. Coherent detection may result in increased link margin.

f. Should provide some long delay (in excess of one chip) multipath protection.

g. Leverages new technology for use in future, compatible with space-based schemes.

3.3.8.2 Approach #6 Disadvantages

a. Provides no multipath mitigation for short delay multipath (shorter than one chip time). Expected multipath is less than 5 microseconds.

b. Technology is unproven in this application and riskier to implement than other approaches.

c. The acquisition and re-acquisition characteristics are unknown and will likely be greater than the specified maximums.

d. Since the proposed system requires coherent detection, it is likely to be susceptible to phase noise that may be an issue during periods of large shock or vibration.

e. The limited processing gain of 19 dB may limit the ability to respond to both large and small signals simultaneously.

f. The 99 percent and –60 dBc bandwidths of the modulated signal are both very wide (~3.5 MHz and ~30 MHz) given that the spectral density is defined by sinx/x.

g. This approach only uses 10 frames per second; therefore, the acquisition and response times are marginal compared to the requirements.

h. Much of the existing infrastructure would have to be replaced and would require significant modification of ground transmitters. This increases cost of development and implementation.

i. As a new technology airborne receiver, this will require extensive development and testing. There may not be high reliability parts available for the receiver design. No current vendor involvement; increased development time and cost.

j. Simultaneous command transmitters may require transmitters closer to the vehicle to reduce power. May drive complex power control system; this would require analysis.

k. Unsure of how existing vehicle phase antenna patterns will degrade phase modulation.

l. The limit of 600-kHz bandwidth might be too small to adequately provide protection against radars and Airborne Enhanced Position Location Reporting System (AEPLRS). The approach will probably require greater bandwidth.

m. Approach does not use NSA-approved encryption format. The security approach is not well defined at this time. PY code operations and limitations unknown. No authentication bits are provided.

3.3.9 Approach #7: Scalable 3-DES Encrypted BPSK Modulated Technique

3.3.9.1 Approach #7 Advantages

a. Uses a well-known modulation scheme that builds on existing technology.

b. Frame format is versatile, efficient, innovative, and message rate is high.

c. Coherent detection may result in increased link margin.

d. Incorporates NSA-approved 3-DES security technique.

e. High-reliability parts should be available given the maturity of this technology.

f. Allows the addressing of up to 12 vehicles with one message.

g. Separate frame synchronization field not required.

h. Adaptable update rate allows ranges to support various numbers of vehicles.

3.3.9.2 Approach #7 Disadvantages

a. BPSK is more prone to co-channel (at the same frequency) interference than tone-based systems (in FM, stronger signal wins). No interfering signal rejection.

b. The 6.4 kb/s data rate (each bit is approximately 156 microseconds) could make it more susceptible to interference from radar pulses and multipath.

c. Since the proposed system requires coherent detection, it is likely to be susceptible to phase noise that may be an issue during periods of large shock or vibration.

d. Unsure on how existing vehicle phase antenna patterns will degrade phase modulation.

e. As a new technology airborne receiver, this will require development and testing. No current vendor involvement; increased development time and cost.

f. BPSK requires carrier phase synchronization. This, in addition to the bit synchronization, will increase acquisition time.

g. BPSK is unfamiliar to range personnel.

h. Excessive bandwidth — BPSK is spectrally inefficient with a non-linear amplifier. Proposed system claims to have a 247-kHz, 99%-bandwidth, and this is not spectrally efficient. The –60 dBc is not presented.

i. BPSK is not proven in the flight termination application.

j. 3-DES has a lot of overhead because of the requirement for 40 of the 64 bits/frame being required for authentication as compared to AES (40 of 128).

k. Doppler shift may also make coherent detection acquisition more challenging.

l. Much of the existing ground infrastructure would have to be replaced, increasing development time and cost.

m. Ground stations must be time multiplexed (only one station can be active on the same frequency at the same time; comparable to current system).

n. Coherent detection could have reliability problems during high vehicle dynamics.

3.3.10 Findings and Conclusions

3.3.10.1 Security Concerns

a. All presented approaches met the minimum security requirements as required by NSA, although some were more intrinsically preferred due to content and format of the base-band command "words." Approaches 1, 3, 4, and 7 are preferred for a traditional system. The PN code approach, however, had some advantages over the others from the security standpoint by having inherent anti-jamming properties. However, it is believed that this approach would be the most difficult and expensive to implement. The PN approach should include underlying 3-DES encryption, not proposed. The PN code itself should not be used exclusively to provide the security as generally the "codes" are determined by the hardware and may be difficult to change. This is not the case with keys for the 3-DES base-band approach covered with the PN chips. The PN code approach is the NSA choice for a unique, non-traditional, and anti-jam approach.

b. The aim is to make this new system cost effective yet secure. Only by designing a system that can operate in both secure and non-secure modes is it likely that cost effectiveness may be realized. Schemes that allow operation of both legacy and enhanced systems is required.

c. All proposed systems have better security and authentication capability than the existing tone-based systems.

d. Accommodating secure and non-secure modes was not adequately addressed by all approaches.

3.3.10.2 Implementation Concerns

a. NSA General: The PN Code technique is judged to be the most difficult to implement although it provides the most benefits. It would also require the most scrutiny by the government, in general, and NSA, in particular.

b. The impact on the ground infrastructure can make or break this effort. Modulation schemes compatible with existing ground systems pose a better solution in the near term. This does not mean the PN code approach should be ignored since it may be a better long-term remedy for missions requiring multiple transmitters.

c. Fail-safe requirements are not adequately addressed by the approaches.

d. There are no existing end-to-end systems today that meet requirement; it would require some modification of existing design and testing.

3.3.11 Approach Risk

The risks associated with the proposed approaches can be linked to the four modulation schemes.

TABLE 3-2. RISK ASSOCIATED WITH MODULATION SCHEMES

Pulse code modulation/frequency modulation (digital)	Low Risk
Modified high alphabet (analog)	Low Risk
Code division multiple access (CDMA) (digital)	High Risk – Due to need to perform detailed analysis to apply technology to FTS application.
Binary phase shift keying (digital)	High Risk – Due to need to perform detailed analysis to apply technology to FTS application.

3.3.12 Comparison Chart (Approaches versus Criteria)

Table 3-3 is a summary chart comparing all of the proposed approaches against the evaluation criteria. If the approach adequately addressed and met the criteria, it received a (✓).

TABLE 3-3. COMPARISON CHART (APPROACHES vs CRITERIA)

Technical Performance Criteria / Approach Number and Description	#1 BAE CPFSK	#2 EFTS CPFSK	#3 BAE HIGH ALPHA	#4 L3 CPFSK	#5 SPC HIGH ALPHA	#6 EFTS CDMA	#7 EFTS BPSK
SYSTEM IMPLEMENTATION CRITERIA							
Range unique identifiers	✓	✓	✓	✓	✓	✓	✓
Command update rate - 10 Hz/1 vehicle/8 vehicles	✓	✓				✓	✓
Vehicle command counter (security)	✓	✓	✓	✓	✓	✓*	✓
Multi-mode (encrypted and plain text)	✓		✓		✓		
AIRBORNE IMPLEMENTATION CRITERIA							
Check channel	✓		✓				
Fail-safe							
Telemetry output	✓	✓	✓	✓	✓	✓	✓
Additional commands		✓		✓	✓	✓	✓
Error detection/error correction with encryption	✓	✓	✓	✓	✓	✓	✓
SECURITY (ENCRYPTION) CRITERIA							
Encryption level - NSA approved (DES or AES)	✓		✓				✓
Open loop testing	✓	✓	✓	✓	✓	✓	✓
Non-standard NSA encryption used		✓				✓	
OTHER CRITERIA							
Ability to relay command from site to site	✓	✓	✓	✓	✓	✓	✓

*CDMA approach met the intent of using vehicle command count (VCC) because a different code would be used for each vehicle

3.3.13 Summary Consensus Chart (Modulation)

Table 3-4 is a chart comparing the four proposed modulation schemes against the requirements defined in task RS-38 (continued on next page).

TABLE 3-4. COMPARISON OF MODULATION TYPES

RS - 38 Requirements	CPFSK	HIGH ALPHA	CDMA	BPSK	Explanation
1) Use of the RF spectrum: can the allocated spectrum be used more effectively?	☺	☺	☹	☹	CDMA and BPSK may require more bandwidth
2) Use of different frequency bands (if FMG recommends NTIA authorization for 375-399.99 MHz)	☺	☺	☺	☺	All approaches can operate at the proposed center frequency
3) Existing command destruct system impacts: minimal impacts to the ground support systems	😐	😐	☹	😐	CDMA would require significant changes to the ground systems
4a) Airborne RF system impacts: minimal impacts	😐	😐	☹	☹	CDMA and BPSK would require significant changes to the airborne receiver
4b) Airborne RF system impacts: competition	☺	☹	☺	☺	One existing vendor has an advantage
5) Compatibility with existing fail-safe systems	😐	😐	😐	😐	
6) Selectable termination for simultaneous, multiple operations	☺	☺	☺	☺	
7) Protection against unintended commands: inadvertent activation of FTS	☺	☺	☺	☺	
8) Immunity to interfering signals (including multipath anomalies and inter-symbol/inter-modulation effects) – authentication	☺	☺	☺	☹	

☹ Impacts adversely 😐 Impacts requirement favorably ☺ Meets requirement

TABLE 3-4. COMPARISON OF MODULATION TYPES
(Cont'd)

RS - 38 Requirements	**CPFSK**	**ENH. HIGH ALPHA**	**CDMA**	**BPSK**	**Explanation**
9) Security: spoofing, end-to-end pre-flight testing, and authentication	☺	☺	☺	☺	
10) Maturity: technology exists with minor modification and testing	☺	☺	☹	😐	CDMA would require substantial testing
11) Reliability: comparable to current systems	☺	☺	😐	😐	Coherent systems require constant phase lock
12) Latency: comparable to current system	☺	☺	☺	☺	Does not include acquisition/reacquisition time
13) Cost: minimal impact	😐	😐	☹	☹	CDMA and BPSK would require significant analysis and testing
14) Size: comparable to current system	☺	☺	☺	☺	
15) Weight: comparable to current system	☺	☺	☺	☺	
16) Acquisition/reacquisition (layers are: 1. bit/symbol timing, 2. framing, 3. carrier phase synchronization, 4. code synchronization)	☺	☺	☹	☹	CDMA has 4 layers of synchronization, BPSK requires 3 layers of synchronization, others have 2 layers.
17) Operational impacts	😐	😐	😐	😐	Based upon affect to operations personnel
18.) **Totals**					
Total ☺ Meets requirement	**13**	**12**	**9**	**8**	
Total 😐 Impacts requirement favorably	**5**	**5**	**3**	**5**	
Total ☹ Impacts adversely	**0**	**1**	**6**	**5**	

3.3.14 Recommendations

3.3.14.1 Recommended Modulation Scheme. Based on the foregoing analysis, the EFTS recommends CPFSK and modified high alphabet modulation for use in FTS. If additional money is provided for research, it is recommended that the CDMA approach be analyzed further.

3.3.14.1.1 The following discriminators were primary factors in the selection of the above modulation schemes:

A. System Factors

1) System (ground and airborne) redesign: The selected modulation schemes would require the least amount of redesign to both airborne and ground systems.

2) Maturity of technology: The selected modulation schemes have been proven on test and launch ranges.

3) Overall cost: The selected modulation schemes have been estimated to have the least implementation cost impact to upgrade existing ranges and to redesign airborne receivers. It should be noted that the cost of the airborne component will be dependent on parts programs, testing requirements and quantities purchased, which is independent of the technology chosen.

4) Reliability, robustness: The selected modulation schemes have a proven track record that supports the high degree of link reliability and robustness required by command destruct systems.

B. Environmental Factors

A. High Doppler shift: The selected modulation schemes demonstrate the frequency tracking characteristics needed to adequately track vehicles during periods of high Doppler shift.

B. Low bit/symbol rate: The selected modulation schemes have a relatively small bit rate or symbol rate that leads to low bit error rate and high availability.

C. High phase noise: The selected modulation schemes overcome phase noise problems associated with existing infrastructure components, thus not mandating their replacement.

D. Interference: The selected modulation schemes have similar resistance to RF interference as do the existing command destruct systems; other approaches have much worse interference immunity.

C. Performance Factors

1) Uses current available bandwidth: The selected modulation schemes can meet the requirements of the design guidelines while not exceeding the existing amount of bandwidth allocated to the FTS application.

2) Acquisition/reacquisition/tracking: The selected approaches minimize the amount of time a receiver needs to acquire and reacquire the transmitted signal through the anticipated RF environment. Furthermore, the selected approaches have the ability to maintain synchronization (i.e. track) with the transmitted signal through the anticipated RF environment.

3) Bit error rate: The selected approaches will have a low bit error rate given the anticipated RF signal inputs at the receiver; these are based on current link margins.

4) Link availability: The selected approaches will have a link availability similar to or greater than that of existing systems. Given the same RF environment as the existing system, the implemented approaches would exhibit a similar probability that commands will be properly received and executed by the FTR.

D. Human Factors

1) Vendor familiarity with modulation technique: Existing range safety vendors have demonstrated a high degree of knowledge and interested in the approaches selected.

2) User familiarity with modulation technique: The range community is familiar with both CPFSK and tone-based FM modulation.

3) Flexibility for future upgrades: Vendors have demonstrated that these modulation techniques could be implemented such that software upgrades to ground and flight hardware would be possible in the future.

3.3.14.2 Recommended Security Method. Further analysis of both 3-DES (64 bits) and AES (128 bits) with proposed approaches is recommended.

3.3.14.3 Recommended Concept of Operations. Develop several options that address overall concept of operations including security, plain text modes, fail-safe, telemetry outputs, override control, and commands.

3.3.14.4 Recommended Data Format. Phase III analysis will look at all proposed approaches for best options. Considerations will be given to frame synchronization, range identification, transmitter identification, vehicle identification, mission identification, error detection, error correction, command counter, commands, check channel and authentication.

3.3.15 Multiple Access and Jamming/Anti-Jamming Provisions

BPSK, modified high alphabet, and CPFSK do not offer any improvements to the current system and, as such, are comparable to the current analog systems. CDMA offers the ability to provide multiple access and some anti-jam capability.

3.3.16 Summary

In summary, Phase II of the EFTS study was very successful. Approaches were proposed that included both analog and digital methods. Four modulation schemes were proposed allowing the evaluation team to consider the advantages and disadvantages of each. Many good ideas were included in the approaches that will be analyzed further in Phase III to determine the optimum solution for EFTS.

References to Phase II

1. Range Commanders Council, Range Safety Group. *Range Safety Transmitting Systems 406-549 MHZ Band,* (Document 307-79), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1979.

2. Range Commanders Council, Telemetry Group. *IRIG Standards for UHF Command Systems*, (Document 208-85). White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1985.

3. EWR 127-1, *Eastern and Western Range Safety Policies and Processes*, Chapter 4, October 1997.

4. Range Commanders Council, Range Safety Group. *Flight Termination Systems Commonality Standard*, (Document 319-99), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1999.

5. EFTS Team Document, *EFTS Phase II Approach Description Guide and Evaluation Criteria*, January 2001.

6. EFTS Team Document, *EFTS Recommended Security Approach Description*, February 2001

CHAPTER 4

PHASE III – TECHNOLOGY DEMONSTRATION

4.1 Objectives

The phase III objectives were very comprehensive. The goal was to use modeling and simulation, further analysis, and range surveys to provide more detailed information to the FTSC/EFTS team. From these results, the EFTS team could make a sound recommendation regarding the most favorable EFTS approach.

4.2 Process

The EFTS study has been a good example of the systems engineering process and concept exploration. Each phase of the study was designed to build on the information gathered in the previous phase(s). Initial plans were modified as the team became more knowledgeable and informed. The following analyses and reports were initiated during Phase III.

4.2.1 Modulation Selection. One of the major tasks during this phase was the selection of the modulation scheme from those chosen in Phase II. Several tasks were defined to provide adequate technical information to arrive at the optimal modulation format for the EFTS application. The modulations were subjected to modeling and simulation; plume impingement was addressed; and required bandwidth and key attributes to differentiate the schemes were identified.

4.2.1.1 Modulation Comparison. The modulation comparison report (Appendix III-G, Modulation Format Selection)[6] addresses the following information pertinent to making an informed decision on which modulation format to select.

(1) Description of the EFTS proposed modulation schemes.

(2) Description of known interference sources in the current flight termination system (FTS) band.

(3) Comparison of potential bandwidth plots.

(4) List of attributes prioritized by range personnel and their advantages.

4.2.1.2 Modeling and Simulation. The EFTS team enlisted the support of Brigham Young University through a grant to develop software models of the two proposed modulation schemes. These models were designed to introduce known interference from other RF sources. The modeling and simulation report (Appendix III-A, Modeling and Simulation of EFTS Phase III

[6] In Special Report Supplement, *EFTS Study Appendixes*, (Distribution D), Nov. 2002.

CPFSK and Modified High Alphabet Performance in the Presence of Interference) addresses how CPFSK and MHA are affected by an Enhanced Position Location Reporting System (EPLRS) source, chirped radar, CW pulsed radar, a standard IRIG tone-based FTS, and the high-alphabet FTS serving as interference sources. This information is presented graphically by plotting the signal-to-interference (SIR) ratio versus the frame error rate.

4.2.1.3 Plume Impingement Analysis. The effects of solid rocket motor plume attenuation during a launch is a concern of the Eastern and Western Ranges. The Plume Impingement Report (Appendix III-B) examined existing data related to plume to determine whether the modulation schemes analyzed in Phase III would be significantly affected by plume effects.

4.2.2 Message Format and Protocol. The other major task during Phase III was to define the message format and protocol of the digital message to be sent to the flight termination receiver. As noted in paragraphs 1.3.3 and 1.3.4 and, the current method of transmitting commands is via a combination of IRIG tones. With the potential EFTS requirement for a digital message, the format of that message had to be clearly defined.

4.2.2.1 Data Link Format Definition. The first activity associated with defining the message format was to take a look at the command link to ensure that all components are addressed. This Data Link Format Definition document (Appendix III-C, EFTS Data Link Format Definition) helped the EFTS team analyze the suggested message format with all of the required information available.

4.2.2.2 Operational Impact Analysis. The Message Format and Protocol Operational Impact Analysis (Appendix III-H)[7] provides a definition of EFTS study goals and features related to the message format based on the EFTS design guidelines developed in previous phases. Items in the document include:

a. Description of various potential format and protocol options based on the EFTS goals, with positive and negative technical and operational attributes.

b. Description of the level of configurations that different options and system capabilities may require.

c. Recommendation of several formats to meet the requirements of the EFTS.

d. Discussion of the formats from an operational standpoint.

4.2.3 Legacy Testing. The Phase I report provided a survey of the current systems being used to transmit the flight termination signals. The Legacy Systems Test Report (Appendix III-D) was produced to determine the limitations of the hardware and to ensure that the final recommendation from Phase III would cause minimal impact to legacy systems.

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[7] In Special Report Supplement, *EFTS Study Appendixes*, (Distribution D), Nov. 2002.

4.2.4 Range Surveys. Range surveys were utilized to solicit information from all of the test ranges. This EFTS Range Survey Report (Appendix III-F)[8] was used for development of the performance or design specification and for generation of the independent government cost estimates (IGCEs).

4.2.5 Other Issues

4.2.5.1 Spread Spectrum Study. One of the proposed modulation schemes from Phase II was a form of spread spectrum called code division multiple access (CDMA). The evaluation team did not choose to pursue further investigation into spread spectrum because of the potential cost and perceived technical obstacles. However, the team did recommend that, if funds became available, this solution should be researched because of the potential positive implications. NASA-DFRC was able to secure funds for this additional research and enlisted ITT Industries via Vandenberg AFB who contracted with two vendors experienced in this area. The Spread Spectrum Study Report (Appendix III-E) summarizes the research accomplished by these vendors.

4.2.5.2 Security. TEMPEST and encryption key management are two security related issues that were investigated in Phase III and will be documented in Phase IV. TEMPEST is a *generic* term used to describe systems or processes concerned with the improper emission of sensitive or classified information resulting in unauthorized use. The EFTS team is researching what the impacts will be due to TEMPEST. Key management is an area that the majority of ranges currently are not required to address because their command transmitter sites use the non-secure analog tones. With the capability to use encryption with EFTS, it may be necessary for ranges to secure and manage NSA-supplied encryption keys.

4.3 Phase III Conclusions

The following are the conclusions from the analyses and reports in Phase III.

4.3.1 Modulation Selection. The modulation comparison analysis resulted in the following findings:

- The bandwidth required for either modulation format was not a determining factor because both CPFSK and MHA fall within the EFTS goals of 360 kHz.

- , The most critical attributes examined in the comparison were sensitivity, re-acquisition time, multipath immunity, ground system implementation, and vibration. Based upon theoretical opinion, CPFSK modulation was favored in all attributes except vibration.

- The modeling and simulation results also did not prove any clear winner between the modulation schemes. For some interference types, CPFSK had the advantage and for

[8] Ibid.

other interference types, MHA had the advantage. In either case, an error correction method will provide a means to help overcome the interference effects.

- The plume impingement study provided no clear advantage or disadvantage for either modulation format.

Based upon the technical analysis conducted during Phase III, the comparison was basically equal. However, CPFSK had the advantage in the following areas:

- Supportable and upgradeable – CPFSK is easier to support (range and vendor) and upgrade due to:
  - CPFSK sensitivity
  - More technical documentation on CPFSK
  - Test equipment availability
  - MHA difficult to increase number of bits or alter packet field
- Proven technology – There are currently more commercial users of CPFSK compared to MHA.
- Range familiarity – The ranges have an understanding of how to use CPFSK because of its prevalent use in the telemetry community

4.3.2 Message Format and Protocol. The data link format definition and message format and protocol – operational impact analysis documents provide the necessary detailed information to make judgments on how the digital message sent to the flight termination receiver should be formatted. Frame synchronization and an error checking will be added to the 64-bit message encrypted using triple data encryption standard (3-DES). The proposed message format is depicted in Figure 4-1.

This message format is subject to change. The EFTS design validation phase will provide feedback on the proposed number of bits and how they are to be utilized. With the tested units, the format will be updated accordingly.

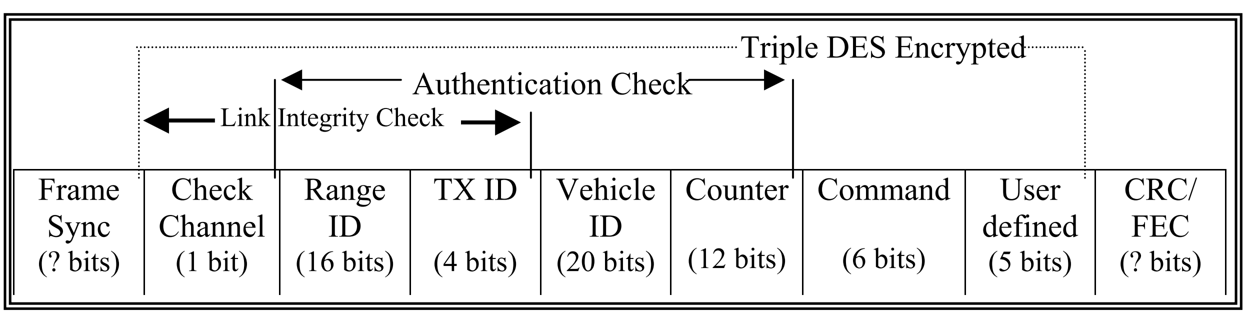

Figure 4-1. Proposed message format.

4.3.3 Legacy Testing. The legacy testing goals were addressed and met. It has been concluded that the impact to current command transmitter sites will be minimal with the implementation of either of the FM formats. Current hardware, such as mission control panels, interface cabling, high power amplifiers, RF cabling, and the antenna system will not require modification as a direct result of implementing either of these modulation formats. Upgrades or replacement of tone generators and monitoring equipment will require modification because of the advancement from tone-based commands to a digital format.

4.3.4 Range Surveys. Range surveys provided important data. The digital message format utilized information provided by the surveys. Range forecasts of future purchases assisted the team in developing cost estimates for the follow0on study. Finally, the specifications to be prepared in Phase IV that will be used for design validation and development will utilize all of this data to ensure that all of the Major Range Test Facility Base (MRTFB) requirements are addressed.

4.3.5 Other Issues. The additional research on spread spectrum modulation techniques provided helpful information. With this research, the same conclusion was arrived as in Phase II; however, some of the reasons were found to be incorrect. For example, one of the proposed methods would use significantly less bandwidth than the EFTS team had expected. Based on the results of this study, spread spectrum has certain advantages that make it attractive as an option for the future. However, it should be noted that cost impacts to both the ground and airborne systems would be drastically higher than the current EFTS recommendations. In addition, the extensive testing required would prevent the implementation of such a system well beyond current needs. As with all the information gathered in this study, some will be pertinent and applicable to some ranges and not to others.

4.4 Summary

Throughout this study, the emphasis was on providing sufficient detail to the EFTS team and other participants to enable informed decisions. It is hoped that information in these reports will assist in answering any future questions that may arise on issues related to the enhanced flight termination system study and the subsequent developmental phase.

Phase III of the EFTS study was very successful. Two of the major goals were achieved. Firstly, the EFTS team was able to conclude that the CPFSK modulation scheme would be proposed to the Range Safety Group for further validation in the follow-on development of flight testable units. Secondly, a draft data format was proposed and accepted that satisfies a majority of the EFTS goals and requirements. Both recommendations were presented and accepted at the April 2002 RSG meeting.

CHAPTER 5

PHASE IV: RCC STANDARDS RECOMMENDATIONS

5.1 Objectives

The Phase IV objectives were three-fold. The first objective was to finalize the EFTS study (RS-38) by completing tasks carried over from Phase III. Secondly, the team set out identify and make recommendations on the RCC standards affected by EFTS. The third objective was to prepare for Part Two of the EFTS program by developing the Request for Proposal (RFP) package for the design validation phase.

5.2 Carry-over Issues

5.2.2 Security Concerns

5.2.2.1 TEMPEST. TEMPEST and key management are two security issues that were investigated in Phase III. TEMPEST is a generic term used to describe systems or processes concerned with the improper emission of sensitive or classified information such that it can be obtained by an unauthorized entity. The EFTS team researched the impacts to EFTS due to TEMPEST. The EFTS TEMPEST requirements have been defined and coordinated with NSA and are documented in Appendix IV-D: TEMPEST Requirements for EFTS.

5.2.2.2 Encryption Key Process. Key management is an area that the majority of ranges are not currently required to address because their command transmitter sites use the non-secure analog tones. With the capability to use encryption with EFTS, it will be necessary for ranges to secure and manage NSA-provided encryption keys.

EFTS will adhere to the NSA key management process. This process begins with the development of a Key Specification and a Key Management Plan that defines the various attributes including key generation, key transferring, protective packaging, COMSEC Material Control System (CMCS), and courier service for the COMSEC account.

5.2.2.2.1 Key Specification. The Key Specification Document is used as a contract between NSA and a participating program for the form and functionality of the encryption key. A sample outline for the document is provided in Table 5-1.

TABLE 5-1. SAMPLE OUTLINE FOR KEY SPECIFICATION DOCUMENT	
1.0 Production specification architecture	4.2 Unique keys
1.1 Equipment description	4.3 Data format of keys
1.2 Environment and classification of traffic	4.4 Constraints
2.0 Key architecture	4.5 Parity generation
2.1 Key functions	4.6 Fill device compatibility
2.2 Previous requirements	4.7 Program static data
2.3 Supersession and crypto period	4.8 Key tags
2.4. Keys needed and relationship	4.9 Positive access control
3.0 General key requirements	5.0 Rules for encryption keys
3.1 Physical form	5.1 Algorithm specifications
3.2 Special handling requirements	5.2 Key handling requirements
3.3 Physical protective packaging	5.3 Known inputs and outputs
3.4 Other special requirements	5.4 Other data standards
4.0 Plaintext specification	5.5 Identify input to encryption algorithm
4.1 Data standards	

5.2.2.2.2 Key Management Plan. The Key Management Plan defines the use and distribution of the encryption key for a program and/or a specific range. This plan allows NSA and the program to define and document how keys are acquired, controlled, loaded into encryption devices and dispensed with. A sample outline for the Key Management Plan is provided in Table 5-2.

TABLE 5-2. SAMPLE OUTLINE FOR KEY MANAGEMENT PLAN	
1.0 General	5.1 Definition of key set
1.1 Applicable documents	5.2 Key structure and quantity
1.2 Reference documents	5.3 Key handling
2.0 Introductory information	5.4 Key operation
2.1 System overview (purpose)	5.5 Net structure
2.1.1 Encryption method and usage (Type 1 or 2)	6.0 Key access control
2.2 Roles and responsibilities	7.0 Key accounting
Controlling authority	8.0 Key distribution
Other	9.0 Key generation
NSTISSI 4009 - Glossary	10.0 Key recovery
3.0 Operation	11.0 Key storage and security
3.1 Use of keys	11.1 Key handling requirements
3.2 Key set locations	11.2 Seals
4.0 Communications architecture	12.0 Key usage
Voice/data	12.1 Key duplication
Min/max net sizes	12.2 Key destruction
5.0 Keying scheme	13.0 Acronyms

5.3 Operational Scenarios/Procedures

There will be significant differences between how range safety operates with the current analog-based flight termination systems and the digital-based EFTS. The EFTS team investigated and analyzed different range safety scenarios and applied them using the procedures drafted for the EFTS (see Appendix IV-G, Range Safety Operational Scenarios and Procedures as Applied to the EFTS).[9] The purpose of drafting these scenarios and procedures was to assist current range safety users in the transition to EFTS. This document will be updated with additional scenarios as they are presented.

5.4 Survey of Airborne FTS

The surveys conducted in Phases I and III, identified a need to address flight termination systems on airborne platforms. A new survey was devised and distributed to airborne FTS users. The results of the survey are found in Appendix IV-H, Airborne Flight Termination Systems Survey Report.[10] The key findings were that the four systems surveyed function independently or as relay sites from a ground transmitter and that the types of hardware used on the airborne

[9] In Special Report Supplement, *EFTS Study Appendixes,* (Distribution D).
[10] Ibid.

platforms do not differ from their ground counterparts. The report also identifies points of contact from each of the ranges surveyed.

5.5 Cost Estimates for Development

Throughout the EFTS study, one of the main concerns was the cost of development and implementation of any proposed system. The EFTS team addressed the cost issue by their inclusion of vendors during each phase of this study. The original estimate to develop EFTS was approximately $10 million over a period of three years. Due to funding issues, the EFTS development has been re-mapped as two phases over a period of 4 ½ years.

5.5.1 Design Validation Phase. The design validation phase will produce prototypes of flight termination receivers and ground encoders to be tested at the Edwards Flight Test Range. The goal is to have multiple vendors produce airborne prototypes, but this will be dependent upon available funding. These units will validate the proposed performance specifications developed during RS-38 (Appendix IV-E, EFTS Receiver Performance Specification and Appendix IV-F, EFTS Encoder Performance Specification) using documentation written during the study as reference material. The estimate for design validation is approximately $2.2 million over a period of 18 months. Currently, only $1.35 million has been secured. This estimate includes government labor, support contractor labor, development contractors, upgrade to range systems, other direct costs, government travel, and material costs.

5.5.2 Development Phase. The design validation phase will potentially result in design specifications for flight termination receivers for three different range applications: space, missile, and unmanned aerial vehicle. The design specification developed during the design validation phase will be used along with the environmental specifications for the different applications. At the conclusion of this phase, vendors will have the ability to produce EFTS-qualified units capable of supporting operations. The estimate for the development is approximately $8 million over a period of three years beginning in fiscal year 2004. A breakdown of estimated costs is available.

5.6 RCC Standards Recommendations

The development of new FTS technology will impact current RCC standards. In anticipation of this, a review was conducted to determine which standards would require updating and the following standards were identified. Associated Group tasks were designed and are included in the noted appendixes.

5.6.1 RCC Standard 208-85 (Telecommunications and Timing Group)

This standard is titled *IRIG Standards for UHF Command Systems*. This standard constitutes a guide for implementation and application of the UHF command transmitter systems (CTS) on the National Ranges. The objective of this task will be to include changes as a result of the Enhanced Flight Termination System (EFTS) program see Appendix IV-A, Telecommunications & Timing Group (TTG) Task TT-42 for the complete text of the task.

5.6.2 RCC Standard 307-79 (Range Safety Group)

This standard is titled *Range Safety Transmitting Systems 406-549 MHz Band*. This standard provides detailed descriptions of the range safety ground transmitter(s). It includes technical data regarding make-up of each Range's command termination transmitters as well as their geographical locations and any associated mobile systems. The objective of this task will be to reflect existing range hardware and where practical, include latest changes due to the Enhanced Flight Termination System (EFTS) program. See Appendix IV-B, Range Safety Group (RSG) task RS-XX for the complete text of the task.

5.6.3 RCC Standard 319-99 FOUO (Range Safety Group)

This standard is titled *Flight Termination Systems Commonality Standard (FOUO)*. The standard provides the design, test and operational requirements for range users and ranges planning to implement FTS. The objective of this task will be to modify the standard to reflect the study's new technology and requirements derived during the Enhanced Flight Termination System (EFTS) efforts (tasks RS-38 and RS-42). The EFTS requirements will address concerns associated with inadvertent termination caused by extraneous or interfering signals, as well as meeting NSA, NSTISSP 12, requirements for secure transmissions. The requirements developed in this task will support existing program requirements on all ranges and contain a flexible architecture for future program capabilities. See Appendix IV-C, Range Safety Group (RSG) task RS-XX for the complete text of the task.

5.6.4 RCC Standard 3XX-YY (Range Safety Group)

This will be a new standard based upon RCC 313-01 and will be titled *Test Standards for Enhanced Flight Termination Receivers/Decoders*. This standard will provide the methodology for testing enhanced flight termination receivers. It will outline the requirements for each test and establish the pass or fail criteria. This RSG task will not be initiated until the development phase of the EFTS program.

5.7 Phase IV Summary

Phase IV of the EFTS study accomplished several important objectives. The security aspects of EFTS were addressed along with the TEMPEST requirements. The initial effects of implementing EFTS with different scenarios were also investigated. A final survey was completed to identify all the airborne FTS platforms currently on RCC-member ranges. The documentation to initiate procurement of the design validation phase was written to verify the proposed performance specifications for the airborne and ground systems. Finally, the RCC standards affected by EFTS were identified and associated tasks were written.

References to Phase I

1. 30th Space Wing*, Range Instrumentation Handbook*, Section 5, "Missile Flight Termination Ground System," September 1999.

2. Range Commanders Council, Range Safety Group*.* *Current Range Safety Capabilities*, (Document 320-94), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1994.

3. Range Commanders Council, Range Safety Group. *Catalog of Existing and Proposed Command Systems* (Document 201-82), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1982.

4. Range Commanders Council, Range Safety Group, *Range Safety Transmitting Systems 406-549 MHZ Band* (Document 307-79), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1979.

5. Range Commanders Council, Telemetry Group. *IRIG Standards for UHF Command Systems* (Document 208-85), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1985.

6. *Eastern Range Instrumentation Handbook*, Section 6, "Command Destruct", January 1996.

7. EWR 127-1, *Eastern and Western Range Safety Policies and Processes*, Chapter 4, October 1997.

8. AFFTC/DFRC, *X-33 Range Safety Requirements*.

9. *PMTC Serial Data Controller System Manual*.

10. 30th Space Wing, WRR 127-9, *Western Range Integrated Missile Flight Control Ground Systems*, August 1993.

11. Range Commanders Council, Range Safety Group. *Flight Termination Systems Commonality Standard*, (Document 319-99), White Sands Missile Range, NM: Secretariat, Range Commanders Council, 1999.

12. *X-33 Range Interface Control Document*, IC604G9401, December 1998.

13. *Command Panel System Operations and Maintenance Manual*, August 1998.

14. ZETA (EPSCO) *Command Transmitter System Maintenance Manual for Model 1376*, April 1989.

APPENDIXES

PHASE I

APPENDIX I-A

EFTS DESIGN GUIDELINES

Prepared by: RCC Range Safety Group
Flight Termination Standing Committee
Updated 24 January 2001

1.0 INTRODUCTION

The FTSC determined to approach the conceptual design process in two parts. Part One would employ a set of baseline design parameters that were purposefully restricted to provide conceptual design solutions that would:

a) work with current ground equipment;

b) operate within currently authorized bandwidth and range of center frequencies;

c) deliver a level of security commensurate with requirements for secure units outlined in Range Commanders Council document (RCC) 319.

For Part Two, several key guidelines, such as bandwidth and ground transmitter capabilities, would be opened up to encourage new and innovative approaches.

2.0 PART ONE GUIDELINES

2.1 General Design Parameters:

2.1.1 Vehicles in the Air. The system must support simultaneous selective control of up to 8 vehicles (8 channels). Consider and comment on selective control of up to 12 vehicles. Comment on the level of signal processing isolation between channels during the conceptual design presentation as applicable. For example, if PN codes are used, cross-correlation protection should be presented.

2.1.2 Latency. The flight termination receiver (FTR) latency (response time) from receipt of signal to complete command output should be no greater than 50 milliseconds. Update rate should be no less than 10 Hz.

2.1.3 Fail-safe. Fail-safe must be available as a selectable option (i.e., purchased as an option).

2.1.4 Command and Telemetry Outputs. The FTR must accept and provide telemetry output confirmation for the following commands. Vendor is asked to comment on ability to provide up to 16 additional commands for ranges that use the command link for additional instructions to the vehicle.

a. CHECK. This function provides a command from the transmitter to the FTR to confirm link closure and the receiver's ability to completely demodulate and act upon commands issued by the transmitter.

b. ARM, OPTIONAL and FLIGHT TERMINATION

c. SIGNAL STRENGTH

d. DISABLE. Disables the receiver; typically used after orbital insertion.

2.1.5 Synchronization Status. The FTR must provide telemetry outputs that provide the most complete observation of synchronization status appropriate for the modulation scheme.

2.1.6 Range-unique Identifiers. Consider and comment on the ability to provide for selectable termination during simultaneous operations. This concept would employ unique identifiers for individual ranges and identifiers would be incorporated at the front of the command message. The range-unique identifier would ensure that commands would be accepted and processed only from the controlling range. This feature would support operations that do not require the full protection associated with encryption and still assure isolation from commands issued by other ranges. For example, for a routine operation that would not require security protection, the range could load special codes reserved for non-secure operations and rely on the unique identifier for protection against commands issued by other ranges or test agencies. This would be an optional feature. Finally, identifiers for individual flight programs within individual ranges should be provided.

2.1.7 Reference Environments:

a. Vibration**:** 50 Grms with maximum potential to 63.74 Grms. Typical test times vary from 3 through 18 minutes, with extreme cases of 45 minutes/axis.

b. Shock**:** Peak value at 5000 g's (with a breakpoint at 2 kHz). Frequency spectrum from 100 Hz to 10 kHz.

c. Operating Temperature: –54ºC to +90ºC.

d. Thermal Cycling**:** 18 acceptance cycles (–24ºC to +71ºC) and 24 qualification cycles from –54ºC to +90ºC with 1-hour thermal dwells.

e. Acceleration: 100 g's at 5 minutes minimum per axis.

> **NOTE**
>
> An estimate of worst-case power spectral density and shock response spectrum will be provided as available from range surveys.

2.1.8 Size and Weight. For preliminary planning purposes, the long-term goal for the volume of the unit should be 3 cubic inches. The short-term goal for the volume of the unit should be no more than 7 cubic inches and 8 ounces or less.

2.2 Baseband Formatting

2.2.1 Acquisition Time. For conceptual designs that employ digital implementations, acquisition time, reacquisition time and associated power levels should be presented at the conceptual design presentation if appropriate. Acquisition time and reacquisition times should be no more than 100 milliseconds from a power and signal reset.

2.2.2 Error Detection. If a digital encoding scheme is selected, error detection must be included and error correction should be considered. Telemetry outputs that indicate the status of error detection and correction must be included if applicable; examples are detected bit errors and corrected bit errors.

2.3 Format of Radio Frequency Signal

2.3.1 Radio Frequency Spectrum. Bandwidth for Part One conceptual design should not exceed requirements in RCC 319-99 (see note below). Center frequency should be factory selectable between 420 and 450 MHz; intent is to permit center frequency adjustment at the vendor facility without having to open the unit (externally selectable).

> **NOTE**
>
> "The receiver shall have an intermediate frequency (IF) bandwidth of 180 kHz minimum @ 3-dB point and 360 kHz maximum @ 60-dB point, centered within 0.005 percent of the assigned RF center frequency." [per 319-99, paragraph 4.5.9.2.2.1.7]

2.3.2 Dynamic Range. Assume that a dynamic range of +13 dBm to –116 dBm will be provided to the input port of the receiver. A digital system with authentication would have the same or better sensitivity.

2.3.3 Modulation. Assume that capabilities of existing transmitters will be maintained. These transmitters currently provide two types of technology for modulation. First, most stations on many of the ranges currently employ tube-driven high power amplifiers (HPAs); however several ranges currently employ solid-state HPAs. If a modulation scheme is selected that is sensitive to phase noise, comment on the maximum phase noise allowable for proper operation of the command link.

2.3.4 Bit Error Rate. Bit error rate, as a function of signal strength, should be presented at the conceptual design presentation if appropriate.

2.3.5 Lock. If a coherent modulation/demodulation scheme is proposed, comment on ability of the FTR to stay locked through the following dynamic conditions:

a. For conceptual design the following dynamic conditions should be considered: maximum baseline roll, pitch, and yaw rates of 200 deg/sec. Comment on the ability to maintain lock at a roll rate of up to 2000 deg/sec.

b. For conceptual design, consider phase effects of a typical half-wave, 90/180 degree, patch antenna system using a 90/180 degrees coupler.

c. The guideline for continuous lock is not intended to extend to unavoidable loss of ground signal associated with flight events such as staging, plume effects, or geographic masking.

2.3.6 Interference/Multipath. Comment on the impact that interference and multipath (including radar burst and continuous wave) will have on probability of receiving correct message.

2.3.7 Multiple Command Transmitters. Comment on the ability of the proposed FTR to simultaneously process signals from multiple command transmitters. Multiple (or parallel) processing would permit confirmation of link closure between a vehicle and multiple command transmitters.

2.4 Security

The flight termination receiver (FTR) must provide at least the same level of security provided by secure receiver requirements listed in RCC 319. The intent of this guideline is to provide a level of security, not to impose any other aspect of the security scheme listed in RCC 319. The Enhanced Flight Termination System (EFTS) should satisfy the following cryptographic requirements:

2.4.1 The authentication and the command should be cryptographically bound with strength of at least 3-key Triple DES (112 bits of cryptographic strength), and

2.4.2 The command should have at least 40 bits of integrity check, i.e., there should be less than a 10^{-12} chance of improperly authenticating a command.

3.0 PART TWO GUIDELINES: For Part Two, seek innovative conceptual designs that:

3.1 Close the link with reduced power. Example: use of digital technology may offer opportunities to close the link with reduced power. It is recognized that such solutions may demand more bandwidth (see item b).

3.2 Employ wider bandwidth. Consider solutions that employ bandwidths that extend beyond the 360 kHz restriction imposed in Part One. This part of the process should answer the question, "What could we do better if we could use more bandwidth?" Additional bandwidth should be considered and applied most judiciously. Present anti-jam capability for designs presented during the conceptual design review. Note that anti-jam is not a design requirement at this time, but incidental anti-jam protection would be of interest to the review team.

3.3 Employ new or modified ground systems. Advocate new or modified modulation techniques that could not be achieved using existing transmitters.

Part One guidelines, other than those covered in 3.1 through 3.3 above should be considered valid for Part Two.

Additional Notes: During the Phase II approach presentations, the presenter is asked to discuss operational methods of setting security modes into the individual receiver. Discussion items include 1) how security codes are loaded into each transmitter and receiver and 2) code implementation for pre-flight checkout.

APPENDIX I-B

RANGE OPERATIONAL/ENVIRONMENTAL LIMITS AS APPLIED TO FTS

(Continued next page)

Range	Latency	Max Link Distance	Link Margin	Max Targets	Acceleration	Shock
China Lake	<100 ms		-	3[2]	Per RCC 319	Per RCC 319
Eastern Range	Non secure 262 ms Secure unmanned 1060 ms Secure manned 2033 ms		9/12 dB	2	Vehicle dependent	Vehicle dependent
Edwards AFB/ Dryden Flight Research Center	1 second from button push to FTR activation	Vehicle flight profile dependent, limiting factor line-of-sight	12 dB	5	24 g's	1200 to 5000 g Some vehicles up to 10 000 g
Eglin AFB	≤250 ms	120 nm	12 dB[1]	12[3]	100 g's roll 2000 deg/sec pitch/yaw 200 deg/sec	Peaks at 1000 g at (2000-4000 Hz)
Western Range (VAFB)	<250 ms		12 dB	1[4]	24 g's	1200-5000 g Some vehicles up to 10 000 g
White Sands Missile Range	250 ms	Typical 120 km Max 200 km	12 dB	5[5]	120 g's	5000 g

Notes:

1. May be changed based on modulation method
2. One person can control 3 targets
3. 4 missiles, 4 drones, 4 spares
4. Typical = 1
   Trident = 2
5. Could be more

Appendix I-B (cont'd)

Range`	Temp	Vibe	EIRP	Update Rate	Antenna	Polar-ization	Secondary Commands	Altitude
China Lake	RCC 319	RCC 319	--	20 Hz current, capable of 100 Hz	0 dBm omni	LHC	None	0-60K ft
Eastern Range	Vehicle dependent	Vehicle dependent	67-88 dBm	2400 band control	18 dB quad helix	LHC	RF disable (orbit insertion)	To orbit
Edwards AFB/ Dryden Flight Research Center	–54 to +71°C	12 to 50 Grms typical, extreme at 75 Grms	AFFTC: 59 dBm DFRC: 60 to 73 dBm	20 Hz	AFFTC: 0 dB DFRC: 0 dB Omni & Hi gain Omni Yagi 15dB	LHC	Optional command used for (1) weapons release system inhibit, (2) recovery system inhibit, (3) restart motors	Surface to on-orbit
Eglin AFB	–54 to +90°C	63.74 Grms nonbuffet 45 min axis 18.24 Grms buffet, 18 min axis 19.82 Grms free flight 5 min axis	63 dBm fixed 55 dBm mobile	4-6 seconds typical, 250 ms for some systems		LHC	Up to 16 tone pairs to override controller	50-100K ft
Western Range (VAFB)	Tested from –34 to +71°C in qual.	12 to 50 Grms typical, extreme at 75 GRMS	92.7 dBm	No fail safe systems		LHC	ARM, TEST DISABLE, RESET, OPTIONAL	To orbit
White Sands Missile Range	–65 to +85°C	20 Grms free flight	60–63 dBm	Continuous tone, dropouts of 2–60 seconds allowed depending on vehicle		LHC		To 200 miles

APPENDIX I-C

LISTING OF GROUND SYSTEM MANUFACTURERS

Range	Manufacturer	System Integrator
AFFTC	ZETA Corp	Reliable Systems Services Corp.
NASA Dryden	Systems Planning Corp.	Systems Planning Corp.
WSMR	Systems Planning Corp.	Systems Planning Corp.
China Lake NAWCWD	ZETA	Pt. Mugu NAWCWD
Cape Canaveral AFS	Eastern Test Range	Eastern Test Range
Eglin AFB	Aleph	Eglin AFB
NASA Wallops Flight Facility	ZETA/RSS Corp.	NASA Wallops
Tyndall AFB	ZETA	Tyndall AFB
Pt. Mugu	ZETA	Pt. Mugu NAWCWD
VAFB	ZETA	VAFB

APPENDIX I-D

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Tim Wortham	Eglin AFB, FL	wortham@eglin.af.mil
Ron Kidwell	NAS /V41	rtkidwe@missi.ncsc.mil
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Ken Day	Vandenberg AFB, CA	Ken.day@fscnet.vafb.af.mil
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Kevin Driscoll	White Sands Missile Range, NM	driscolk@wsmr.army.mil
Darrin Loken	White Sands Missile Range, NM	lokend@wsmr.army.mil

APPENDIX I-E

LIST OF VENDORS

In June 2000, as part of the EFTS study, a Commerce Business Daily (CBD) synopsis was issued to determine which vendors might be interested in EFTS and the current study. The following vendors responded:

Company Name	POC	Phone #	Location
Aerospace Corp.	Manfred Peinemann	(310) 336-1798	P.O. Box 92957 Los Angeles, CA 90009-2957
ARINC	Daryl Melton	(801) 774-8256	1530N. Layton Hills Parkway Ste. 201, Layton, UT 84041
BAE Systems (Cincinnati Electronics)	William R. Lampe	(513) 573-6100	7500 Innovation Way Mason, Ohio 45040
General Dynamics	Peter Vedder	(301) 220-9900	7701 Greenbelt Rd. Ste. 500, Greenbelt, MD 20770
Herley Vega	Ralph Nowlan	(760) 931-1313	6965 El Camino Real Suite 105-553 Rancho La Costa, CA 92009
L-3	Avis Price	(858) 694-7561	9020 Balboa Ave. San Diego, CA 92123-3507
RSS Corp	Emilio J. Powers	(321) 255-6500	91 East Drive Melbourne, FL 32904
Space Systems Honeywell Inc.	Scott Lapham	(727) 539-4845	13350 U.S. Highway 19 North Clearwater, FL 33764-7290
System Planning Corp	Ron Easlely	(703) 351-8203	1429 N. Quincy St. Arlington, VA 2207
TRW	Jerry N. Mason	(909) 382-6234	P.O. Box 1310 San Bernardino, CA 92402-1310
TYBRIN Corp.	Peter Crump	(850) 337-2500	1030 Titan Court Fort Walton Beach, FL 32547
United Space Alliance	Stepheni Stephenson	(281) 212-6126	M/S USH-100D Houston, TX 77058

APPENDIXES

PHASE II

APPENDIX II-A

VENDOR CONTACT LIST

Name	Phone #	Fax #	Address	City, State Zip Code	E-mail
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IT&T					
Jason O'Neil	(703) 438-7988	(703) 438-8112	1761 Business Center Dr., Ste. 200	Reston, VA 20190	Jason.Oneil@itt.com
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Name	Phone #	Fax #	Address	City, State Zip Code	E-mail
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MICROPAC Industries, Inc.					
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Mission Research Corp.					
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Ohio State University					
Chris Bartone	(740) 593-9573		Ohio University 351 Stocker Center	Athens, OH 45701	bartone@ohio.edu
Reliable Systems Services					
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Science Applications International Corporation					
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Space Systems Honeywell Inc.					
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United Space Alliance					
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APPENDIX II-B

APPROACH DESCRIPTION GUIDE AND EVALUATION CRITERIA

1.0 INTRODUCTION

1.1 Purpose

The Enhanced Flight Termination System (EFTS) Study Team is currently in the process of developing technical approaches that will be evaluated as a next generation Flight Termination System.

The purpose of this document is to standardize the format that will be used to describe the developed approaches and to convey the criteria that will be employed when evaluating the approaches.

It should be noted that it is **not** the intent of this document to specify a preference for a specific approach or a family of approaches (e.g. analog versus digital modulation techniques). If any section of this document conveys a preference, it should be regarded as unintentional.

This document will be used for approaches developed from both Part 1 and Part 2 of the EFTS design guidelines. Part 1 of the EFTS study is concerned with near-term approaches that have a minimum impact to the existing range infrastructures and is the immediate focus of this evaluation. Part 2 is intended for "out of the box" approaches. These approaches should follow the guidelines set forth herein, where applicable.

1.2 Approach Description

An approach description of the suggested approach is requested in order to address the evaluation criteria. The format and content of the requested information are identified in section 2. Please follow the outline in section 2 to aid the evaluation team in finding the requested technical information quickly.

1.3 Evaluation Criteria

The Enhanced Flight Termination System (EFTS) Study Team will select the best overall approach, based upon an assessment of technical performance, approach risk, and cost to implement. This selection process is based upon evaluations of the given approach and it will be coordinated with the Range Commanders Council (RCC) Range Safety Group (RSG) Flight Termination Standing Committee (FTSC), RCC Frequency Management Group (FMG), the Telecommunications and Timing Group (TTG), and the Telemetry Group (TG). The EFTS team seeks to select the approach that will provide the Major Range Test Facility Bases (MRTFB) with the best approach that will meet or exceed the requirements and do so affordably. This may result in the selection of an approach with a higher cost estimate.

To arrive at a selection decision, the EFTS team will integrate the evaluation factors and sub-factors described belowWhile the EFTS evaluation team will strive for maximum objectivity, the selection process will rely heavily upon the professional judgment and experience of the team. Section 3 of this document provides a description of the criteria to be employed.

1.4 Rejection of Unrealistic Technical Approaches

The EFTS team may reject any technical approach that is evaluated to be unrealistic in terms of technical approach, including an unrealistically high risk to an EFTS solution.

1.5 Technical Summary

The following paragraphs contain general guidelines for use in describing an approach to be evaluated for the EFTS. It is suggested that each approach conform to the following paragraph structure if applicable, so that all approaches may be viewed in a uniform manner.

There are seven sections requested: General Approach Description, General Information, Security Concept of Operations, Format of Baseband Signal, Format of Modulated Signal, Analysis of Approach, and a Cost Estimate.

2.0 GENERAL APPROACH DESCRIPTION

In this section, describe the general approach taken. It is suggested that figures be used to illustrate the approach. The description should be specific enough to clearly identify what is meant by the approach, and it should identify any major discriminators.

2.1 General Information

The paragraphs in this section will be used to describe the information conveyed among ground stations and vehicles. The formatting of the information and the modulation techniques utilized are reserved for later paragraphs.

2.1.1 General Description of Commands Sent to and Processed by Each Vehicle. Enumerate the quantity and the types of commands sent to each vehicle. Identify the types of commands the FTR is capable of processing.

Describe to the greatest degree possible the logic a flight termination receiver (FTR) would need to incorporate in order to properly interpret the described commands, e.g., "The receiver would ignore properly decoded DESTRUCT commands without a preceding properly decoded ARM command."

2.1.2 Simultaneous Commands. Identify the number of commands that may be simultaneously sent to each vehicle. For example, the existing tone-based system allows the simultaneous sending of the Check command and the Arm/Destruct command.

2.1.3 Number of Vehicles Supported per Command Transmitter. Identify the maximum number of vehicles that are simultaneously supported by each command transmitter using the approach.

The description should also address whether identification of a specific receiver can be made, and the quantity and type of the identifiers that are used, e.g., an eight bit word is sent to accommodate up to 256 different vehicle IDs.

2.1.4 Support for Multiple Transmitters. Describe how multiple simultaneous transmitters may be accommodated by the approach. In many existing systems, only one transmitter is radiated at a time. For example, when a vehicle moves from one geographical area to the next, there may be a short duration when no transmitters are radiating.

This description should not address the use of redundant transmitters (e.g., one transmitter fails). It should only address multiple transmitters used for extended range purposes.

The description should also address whether identification of a specific transmitter can be made, and the quantity and type of the identifier that are used e.g., an eight bit word is sent to accommodate up to 256 different ground transmitter IDs.

2.1.5 Update Rate. Describe the update rate of the system. For example, how often is a command to be sent to each vehicle (e.g. 25 times per second).

2.1.6 Estimate of Receiver Size, Weight and Power. Estimate the size, weight and power of a flight termination receiver implemented using this approach.

2.1.7 Environments. Address the operating environment impacts of the approach. See design guidelines for goal.

2.2. Format of Baseband Signal

In this section, describe the format of the commands prior to modulation. It is suggested that the description of the baseband command structure be represented in a figure or table in order to better describe its contents. Include how each of the following would be represented in the data stream, if applicable, but not limited to:

- ✓ Representations of information
  - o Vehicle ID
  - o Station (Transmitter ID)
  - o Commands
- ✓ "Analog" Approach Information
  - o Analog Tones Used.

- ✓ Binary or "Digital" Approach Information
  - o Number and position of Bits
  - o Frames Size
  - o Frame Synchronization approach and number of frames required for authentication
- ✓ Command Durations
- ✓ Frequency of Command Updates
- ✓ Encryption/Authentication
- ✓ Error Detection
- ✓ Forward Error Correction
- ✓ Is Access to Multiple Vehicles Handled at the baseband level?

2.3 Format of Radio Frequency Signal

This section is used to describe the modulation technique presented in the approach.

2.3.1 Modulation Technique. Specifically describe how the baseband information would be modulated onto the carrier signal. Include the frequency band used and the 99% power bandwidth and the –60 dBc bandwidth.

2.3.2 Use of Multiple Transmitters. Pursuant to the general description given above on multiple transmitters (paragraph 2.1.4), describe in detail how multiple transmitters are accommodated by the modulation technique. If signal level separation is used, describe the capture ratio required to meet a BER of 10^{-6}.

2.3.3 Use of Existing Infrastructure. Describe whether it is intended that the existing ground infrastructure (i.e. tone generators, exciters, high power amplifiers (HPA), command panels, antennas, couplers, etc.) may be used, and which components may be preserved in using the infrastructure.

Describe the risks associated with reusing the existing legacy components.

2.3.4 Resistance to Interference and Multipath. Describe the impact that interference and multipath (including radar burst and continuous wave) will have on the probability of receiving a correct message, as well as the probability of detecting an incorrect message.

Does the approach have intrinsic interference or multipath immunity characteristics?

2.4 Security Concept of Operations

Describe the Security Concept of Operations (CONOPS). The following questions should be answered by the CONOPS, if encryption is used:

- ✓ What encryption algorithm is used?
- ✓ Does the approach allow for its optional use?

- ✓ How often must a key be loaded to use the approach? This may be expressed either in time, commands, or missions.
- ✓ Does each vehicle and transmitter use the same key?
- ✓ How many possible keys are there?
- ✓ Is pre-flight open loop testing permitted by the approach?

2.5 Analysis, Calculations and other Estimates

For each of the following paragraphs in this section, utilize the following parameters to perform an analysis:

- ✓ An input signal of –116 dBm at the input to a receiver.

- ✓ A thermal noise floor of –174 dBm/Hz (290°K or 68°F)

2.5.1 Estimated Receiver Effective Noise Temperature. Estimate the effective receiver noise temperature and noise figure given the thermal noise floor assumption given above in paragraph 2.5. It is understood that this is an estimate, and that values may differ greatly based on a specific implementation employed. Please include an estimated margin of error for this estimate (e.g. ±0.4 dB).

2.5.2 Bit Error Rate (BER). For approaches where it is applicable, estimate the BER using the given assumptions.

2.5.3 Link Margin at BER=10^{-6}. For approaches where it is applicable, estimate the link margin given an acceptable BER of 1 error in 10^{6} bits.

2.5.4 Receiver Message Synchronization Time. For approaches where it is applicable, estimate the maximum time required to synchronize and resynchronize the receiver due to loss of signal, such that commands can be interpreted. This should include any phase synchronization, bit synchronization, frame synchronization, code synchronization and any other synchronization required by the described technique. Describe the analysis taken.

It is understood that this is an estimate, and that values may differ greatly based on a specific implementation employed. Please include an estimated margin of error for this estimate (e.g. ±5%).

2.5.5 Receiver Maximum Message Processing Time. Assuming that synchronization has been established prior to receiving a message, estimate the receiver message processing time for the approach given. This is defined as the processing period from the moment the first part of the signal reaches the receiver, to the time the message has been properly decoded.

For approaches that can either be encrypted or not, include a sub-paragraph with an analysis of each. If time division multiplexing (TDM) is used, use the worst case to determine the maximum time that would be required. For example, use the longest duration in time possible (or the period between frames for the same vehicle) to calculate the worst-case start message processing time.

It is understood that this is an estimate, and that values may differ greatly based on a specific implementation employed. Please include an estimated margin of error for this estimate (e.g. ±5%).

2.5.6 Receiver Cold Start Message Processing Time (Acquisition Time). Given the assumptions set forth above in paragraph 2.5, determine the receiver cold start message processing time of the approach. This is the period from complete loss of signal to proper decoding of messages to include any synchronization required.

For approaches that can either be encrypted or not, include a sub-paragraph with an analysis of each.

If time domain multiplexing (TDM) is used, use the worst case to determine the maximum time that would be required. That is, use the longest duration in time possible (or the period between frames for the same vehicle) to calculate the worst-case cold start message processing time.

It is understood that this is an estimate, and that values may differ greatly based on a specific implementation employed. Please include an estimated margin of error for this estimate (e.g. ±5%).

2.5.7 Receiver Cold Start Message Error Probabilities. Given the assumptions set forth above in paragraph 2.5, determine the worst-case probability that a command will not be properly received and decoded in the following periods from a cold start:

1. 50 ms
2. 100 ms
3. 300 ms
4. 500 ms
5. 1 s

This estimate should utilize the bit error rate and error detection method, using the cold start message processing time and the number of messages that could be received in the period allotted.

For approaches that can either be encrypted or not, include a sub-paragraph with an analysis of each.

That is, the probability that a message gets through should be higher for 1 s than it is for 50 ms based on the possibility that multiple messages are received during that period.

2.5.8 Receiver Probability of Improper Authentication. Given the assumptions set forth above in paragraph 2.5, determine the probability that a command will be improperly received and authenticated during the following periods.

1. 5 minutes
2. 1 hour
3. 8 hours
4. 20 hours
5. 100 hours

Use the maximum number of possible messages sent during the period to determine the value. For approaches that can either be encrypted or not, include a sub-paragraph with an analysis of each.

2.6 Cost Estimates And Schedule

Please provide rough order of magnitude cost estimates for the development of the suggested approach based upon the approach description. Additionally, if possible, provide rough order of magnitude cost estimates of the per unit cost of the FTR and the cost impacts to the ground FTS due to new hardware requirements.

Provide a rough order of magnitude of the time to implement the approach as presented.

3.0 EVALUATION FACTORS AND SUB-FACTORS

The evaluation factors and sub-factors are described below. Factors 1 and 2 are of equal importance. Factor 3 will be evaluated based upon available information, but due to time constraints on developing approaches, it will not be a deciding factor. Within Factor 1 (Technical Performance), sub-factors A through D are of equal importance. Sub-factor E will be evaluated based upon the available information, but due to the time constraints on developing approaches, it will not be a deciding factor.

Factor 1: Technical Performance

Sub-factor A: System Implementation Criteria
Sub-factor B: Airborne Implementation Criteria
Sub-factor C: Ground Implementation Criteria
Sub-factor D: Security (Encryption) Criteria
Sub-factor E: Operations, Maintenance and Logistics Criteria

Factor 2: Approach Risk

Factor 3: Cost To Implement

A color rating will be assigned to each factor. Under the technical performance factor, the color rating depicts how well the technical approach meets the technical performance sub-factor requirements in accordance with the stated explanation. The following colors will be used: blue – exceeds criteria; green – meets criteria; yellow – does not meet the criteria but is capable of being made compliant with minor changes; red – fails to meet criteria.

The technical performance sub-factors are described in the paragraphs below. An approach risk rating will be assigned to the technical performance factor. Approach risk represents the risks identified with a technical approach as it relates to the technical performance sub-factor and to the any identified schedule. Performance confidence represents the Government's assessment of the probability of a technical approach successfully performing as proposed. Cost will be evaluated as described below. When the integrated assessment of all aspects of the evaluation is accomplished, the color ratings, approach risk ratings with performance confidence assessment, and evaluated cost will be considered.

3.1 Factor 1: Technical Performance

See below for a description of each technical performance sub-factor.

The criteria have been broken up into five mutually exclusive areas to preclude the redundant scoring of any criterion.

3.1.1 Sub-factor A: System Implementation Criteria. These are the implementation criteria that affect both ground and airborne systems.

3.1.1.1 Range Unique Identifiers. Does the approach employ some form of range-unique identifiers to overcome the potential unintentional destruction of a vehicle by an unauthorized range?

3.1.1.2 Multiple Vehicles. This is defined as the number of vehicles that a single transmitter can simultaneously support in the air at any one time and still meet the requirement for system throughput, processing and delay.

Does the approach have the capability to support simultaneous selective control of up to 12 vehicles? (optimum)

Does the approach have the capability to support simultaneous selective control of up to 8 vehicles? (acceptable)

Does the approach have the capability to support simultaneous selective control of more than 1 vehicle? (may be acceptable)

Does the approach allow the assignment of unique receiver identifiers for each FTR to be built? (optimum)

3.1.1.3 Multiple Command Transmitters. Is there a reasonable implementation of the approach that would allow an FTR to simultaneously process signals from multiple command transmitters? (May be acceptable if unable to satisfy requirement.)

If a PN code is used, does the approach implement adequate signal processing isolation and/or cross-correlation protection?

3.1.1.4 Command Update Rate. This is defined as the period from the start of a command to a vehicle to the next start of a command to the same vehicle. For example, a digital system with a 25 ms frame sent every 25 ms would have a rate of 40 times per second.

Is the command update rate greater than or equal to 10 times per second for each vehicle simultaneously being controlled?

3.1.1.5 Modulation Scheme. Does the approach present a modulation scheme **compatible with existing ground transmitters**? Compatibility covers transmitters that employ two types of high power amplifiers (HPA); tube type and solid state. Note that most range applications today use tube type HPAs, but that several ranges employ solid state units. (May be acceptable if unable to satisfy requirement.)

3.1.1.6 Interference and Multipath. This is defined as the ability of the system to overcome interference by any source (deliberate or unintentional). Does the approach have any intrinsic ability to overcome the impact that **interference and multipath** (including radar burst and continuous wave) will have on the probability of receiving the correct message?

3.1.1.7 Link Availability - Bit Error Rate. This is defined as the anticipated bit error rate of the system. Would the approach presented have an acceptable expected **bit error rate** as a function of signal strength level at –116 dBm?

3.1.1.8 Selectable Center Frequency. Could the approach be practically implemented with an FTR capable of having a factory re-settable center frequency from 420 to 450 MHz? If so, is it practical to assume that this can be implemented as a factory-settable function that can be performed without opening the FTR (externally selectable)?

3.1.1.9 Open Systems Approach. Does the approach adhere to known standards?

3.1.2 Sub-factor B: Airborne Implementation Criteria. This sub-factor addresses the airborne systems uniquely. For example the power and weight requirement of the airborne system differs from that of the ground system.

3.1.2.1 Fail-safe. Does the approach support implementations of FTRs with fail-safe capability? (May be acceptable if unable to satisfy requirement.)

3.1.2.2 Telemetry Output. Does the approach support FTRs that have **telemetry outputs** for CHECK, ARM, OPTIONAL, FLIGHT TERMINATION, and DISABLE commands and for signal strength?

Does the approach have the ability to provide up to 16 additional commands for ranges that use the command link to issue additional instructions to the flight vehicle?

Does the approach support the potential implementation of telemetry outputs that show the most complete observation of **synchronization status** appropriate for the proposed modulation scheme?

3.1.2.3 Error Detection/Error Correction. If the proposed approach uses a digital encoding scheme, was **error detection** included? Was error correction used? If so, does the approach allow the use of implementing telemetry outputs that indicate the status of error detection and correction?

3.1.2.4 Coherent Modulation Scheme. If the approach has a coherent modulation scheme proposed, was the capability of the FTR to **maintain lock** under the following dynamic conditions (maximum roll, pitch, yaw rates of 200 degrees/sec.) presented?

Does the approach address the ability to maintain lock at roll rates of up to 2000 degrees/second?

When presenting the capability to maintain lock, does the approach show the phase effects of a typical half-wave, 90/180 degree patch antenna using a 90/180 degree coupler?

3.1.2.5 IF Bandwidth. Can the approach be practically implemented such that its **IF bandwidth** is compliant with limitations listed in RCC 319-99, paragraph 4.5.9.2.2.1.7?

3.1.2.6 Dynamic Range. Does the approach allow the practical implementation of FTRs having a **dynamic range** between +13 to –116 dBm?

3.1.2.7 Sensitivity to Phase Noise. Is phase noise addressed? What is the sensitivity of the approach to phase noise?

3.1.2.8 Sensitivity to Non-Linear Amplifiers. What is the sensitivity of the approach to non-linear amplifiers?

3.1.2.9 Response Time. Is the receiver maximum message processing time as defined in paragraph 6.5 less than 50 ms?

3.1.2.10 Acquisition/Reacquisition Time. Is the receiver cold start message processing time (acquisition time) as defined in paragraph 2.5.6 less than 100 ms?

3.1.2.11 Size. The size of the current flight termination receivers impacts where the unit can be placed. The size of the unit must be addressed in the approach to ensure that impact can be evaluated. The design guidelines specify a specific maximum volume.
Was the **volume** of the unit restricted to 15.22 cubic inches or less?

3.1.2.12 Weight. The weight of the current flight termination receivers (FTR) impacts where the unit can be placed. The weight of the unit must be addressed in the approach to ensure that impact can be evaluated. The design guidelines specify a specific maximum weight.

Was the **weight** of the unit restricted to 18 ounces or less?

3.1.2.13 Power. Address the power requirements of the approach. The power type and consumption of the receivers based on the power requirements of existing FTR.

Are the power requirements of the approach within the 319-99 standards?

3.1.2.14 Environments. The environment the FTR is placed in is very extreme. The most extreme environments are those supported at the Eastern and Western Test Ranges.

Does the approach address the following **reference environments** for the proposed FTR?

a) Vibration – 50 grms with potential to 63.74 grms; typical test times from 3 to 18 minutes/axis, with extreme cases to 45 minutes/axis;
b) Shock – peak values to 5000 g's (with a breakpoint at 2 kHz), frequency spectrum from 100 Hz to 10 kHz;
c) Operating Temperature – from –54ºC to +90ºC;
d) Thermal Cycling – 18 acceptance cycles (–24ºC to +71ºC) and 24 qualification cycles from –54ºC to +90ºC, all with one hour thermal dwells;
e) Acceleration – 100 g's at 5 minutes per axis.

3.1.3 Sub-factor C: Ground Implementation Criteria. Implementation criteria that affects only ground based flight termination systems.

3.1.3.1 Size of Transmitters. Due to the current ground-based flight termination systems, significant changes to the size of the transmitters can affect rack space at the current FTS sites. Does the size of the ground transmitters fit within the space available at the current ground based sites?

3.1.3.2 Power. What is the estimated impact of the approach to the power type and consumption of the transmitters compared to the power of existing transmitters? Are the power requirements of the ground transmitters within the power capabilities of the current ground based sites?

3.1.3.3 Antenna. What is the estimated impact of the approach to the use of existing antenna systems? Does the approach have antenna requirements that can be met with current antenna systems?

3.1.3.4 Ground Station Impact/Downtime. Evaluate the ability to use the system and switch between the new system and existing systems. Does the approach have the capability to switch between the existing system and the enhanced system?

3.1.4 Sub-factor D: Security (Encryption) Criteria. The security (encryption) of the approach will be evaluated in this sub-factor.

3.1.4.1 Over the Air Keying. Is over the air keying an option (acceptable if unable to satisfy requirement)?

3.1.4.2 Encryption Level. Does the approach provide for an encryption system of at least the same level of **security** provided by secure receiver requirements listed in RCC 319?

3.1.4.3 Security Programming. The approach to download encryption to the receiver will be addressed. Is there a method of downloading encryption codes to the FTR and the ground system?

3.1.4.4 Non-Standard NSA Encryption Used. The design guidelines have included a suggested NSA encryption method of Triple DES. If a non-standard encryption method is proposed, does the approach address how this will be implemented and how it will be approved by NSA?

3.1.5 Sub-factor E: Operation, Maintenance and Logistics Criteria. If the proposed approach is a significant change to the current methods of operating and maintaining the flight termination system infrastructure, this sub-factor will be evaluated.

3.1.5.1 Impact to pre-Mission Testing. Is the impact to the system (time and complexity) for pre-mission testing versus the method for the existing system addressed?

3.1.5.2 Impact to Setup/Teardown. Is the impact to the system (time and complexity) for pre-mission setup versus the method for the existing standard and high-alpha system addressed?

3.1.5.3 Operator and Mission Support Technician Training. Is additional operational training required based upon the approach addressed?

3.1.5.4 Maintenance Training. Is the amount of maintenance training for a maintainer to support the approach addressed?

3.1.5.5 Specialized Test Equipment. It is desirable that commercial off-the-shelf (COTS) equipment be used to the greatest extent possible. Is the need for specialized test equipment by the approach addressed?

3.2 Factor 2: Approach Risk

Approach risk will be evaluated at the technical performance sub-factor level. The approach risk assessment focuses on the risks and weaknesses associated with a technical approach and includes an assessment of the potential for disruption of the proposed schedule and increased cost due to technical unknowns. For each identified risk, the assessment also addresses the approach for mitigating the risk and why that approach is or is not manageable.

3.3 Factor 3: Cost To Implement

The technical approach estimated costs will not be a dominant factor for selection purposes. The total cost proposed will be evaluated through a cost analysis by calculating a probable cost to develop and operate the technical approach, in order to determine if it is reasonable and realistic. This will include an evaluation of the extent to which proposed costs indicate a clear understanding of requirements and reflect a sound approach to satisfying those requirements.

The assessment will consider technical risks identified during the evaluation of the technical approach and associated costs. An additional cost will be added to the cost to implement associated with the risk and uncertainty of the proposed approach.

3.3.1 Cost to Develop Approach. The development cost of the approach will be evaluated. Is the development cost of the approach using a typical vendor within the budget established for development of the EFTS units?

3.3.2 Cost to Operate Approach. Operational costs will address the approach operating under typical conditions. Is the operational cost consistent with the cost to operate the current analog FTS? Is the cost to implement NSA doctrine an impact to ranges and programs?

APPENDIX II-C

RECOMMENDED SECURITY APPROACH DESCRIPTION

Prepared for: Flight Termination Standing Committee, Range Safety Group
By: Enhanced Flight Termination Committee
Date: 16 March 2001

1.0 PURPOSE AND SCOPE

The Enhanced Flight Termination System (EFTS) study is developing requirements and standards for an improved ground-based command destruct system for range safety applications.

This document has been prepared to provide a detailed explanation of the use of encryption and authentication for range safety EFTS applications. It defines the purpose for its use, a brief explanation of the basics of block encryption, authentication, use of a counter field, and provides insight into potential operational issues.

1.1 Why Use Encryption and Authentication?

EFTS will use encryption in order to mitigate the potential spoofing of flight termination commands from an unauthorized source. It accomplishes this in two ways:

1. By requiring that the receiver respond only to commands that are properly encrypted with an authenticated message. This prevents unauthorized transmission.

2. By requiring the use of a counter field to mitigate the chance of an unauthorized entity recording a message and replaying the message at an inopportune time. This allows pre-flight open loop testing of all actual commands.

In this situation, encryption is not used to protect the information sent between the ground and the vehicle, as this information is not sensitive, and it is often available from visual inspection and on unencrypted voice channels. It is also obvious information — an exploding missile is not a subtle event. Encryption will be used by EFTS to assure that the sender of the message is an authorized entity, thus only a message sent using the correct key would be properly authenticated by the receiver.

In addition, encryption will not aid in the mitigation of either intentional interference (jamming) or unintentional interference from competing RF signals.

Per policy, the use of encryption during a mission is up to the discretion of the program and is not a range safety requirement.

1.2 Continuous vs. On-Demand Messaging

There are two different proposed methods for sending messages to vehicles for the purpose of command destruct. In one method, messages are sent between the ground and the air only on demand. That is, a packet is only sent from the ground when needed. A single tone is sent as a check channel to maintain the integrity of the carrier. The existing analog-based systems can be thought of as this method.

In the other method, the status of the existing commands is continuously sent from the ground to the vehicle. This is required for most digital techniques (including CPFSK) in order to maintain bit synchronization.

Paragraphs 4.1 and 4.2 describe two different uses of the counter field. It was originally thought that a receiver should use a “>” algorithm when comparing the current value to the previously accepted value. Now it appears that a “≥” value may be more suitable in applications where a command is continuously sent.

2.0 BLOCK ENCRYPTION

The following paragraphs describe block encryption, the method of encryption recommended by NSA for range safety EFTS applications.

2.1 Basics

Encryption can be seen as a method of scrambling information in a known fashion such that it is difficult for an unauthorized entity to decode the information into its original form, but easy for an authorized entity with a known “key” to decrypt the information.

Codebook encryption is a type of encryption where there is a one-to-one mapping between an unencrypted message and an encrypted message. That is, for any specific code key, a specific message will always result in the same encrypted value.

A simple example of this would be the transposition of message characters to other characters in order to hide the information in transport. These have always been popular with kids as “secret decoder rings.” The actual encrypted value is set by which position (the key) the encrypter was in. This is a value that only the sender and the receiver are privy to. Examples are depicted in Figure 2-1A and 2-1B, two little Orphan Annie decoder devices that were found on *ebay.com*.

In the case of the Radio Orphan Annie Secret Society decoder badge, there are two circles, an inner and outer that both have the letters A-Z and the numbers 0-9 on them. The key to the code is the position of the inner circle relative to the outer circle. Example: An “A” on the inner circle lined up to a “B” on the outer circle. For every “A” in the message, a “B” will be used as the encrypted code. There are 36 possible keys here that correspond to the 36 positions (A-Z, 0-9) in which the inner circle can be laid upon the outer circle.

Figure 2-1A. 1937 Radio Orphan Annie (ROA) Secret Society decoder badge.

In the case of the Orphan Annie Slidomatic radio decoder, the letters A-Z are put on the grid several times. Encoding and decoding are accomplished by matching these letters to twenty-six numbers on a red sliding template. There are nine different keys or positions for the template to be put on. The code translates a letter on the white grid to a number on the red slide: e.g. an “A” on the grid lined up to a “10” on the red slide. For every “A” in the message, a “10” will be used as the encrypted code. There are nine possible keys here; one for each position in which the template can be placed.

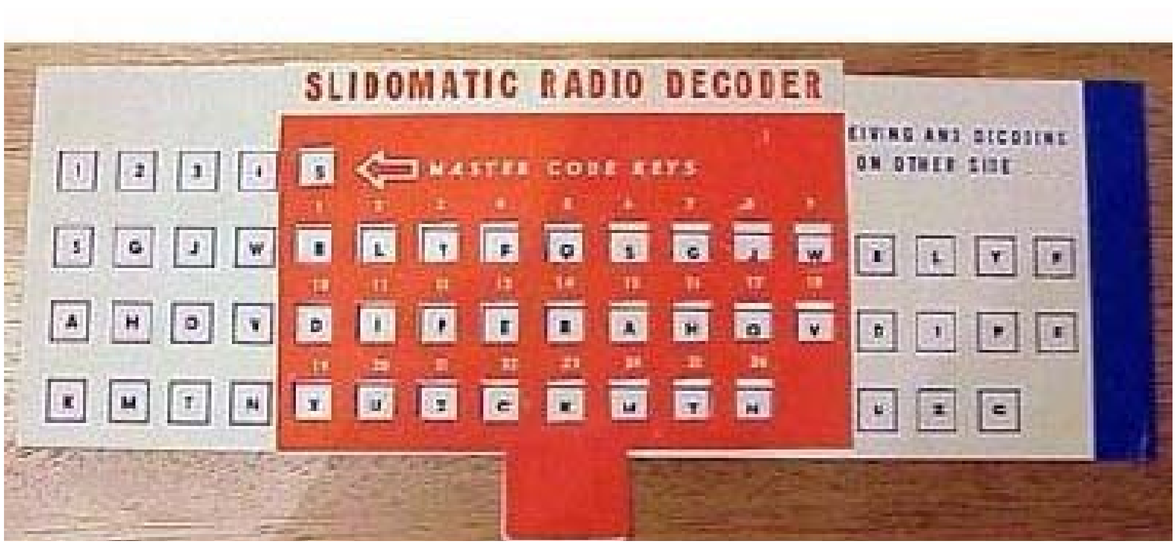


Figure 2-1B. 1941 Orphan Annie Slidomatic radio decoder.

2.2 Encryption Strength

The more possible combinations there are in a code, the more difficult it is to crack. In the cryptographic world this is known as encryption strength and it is measured in bits. The higher the number of bits, the more difficult it is to de-scramble by an unauthorized entity. For example, a code with 112 bits of encryption strength has 2^{112} unique ways of scrambling the bits.

2.3 Mapping

In the types of encryption recommended by NSA for this application, there is an equal mapping between the number of unencrypted values and the number of encrypted values. In fact, given a specific key, there is a one-to-one mapping between unencrypted data values and encrypted values. For example, for a 64 bit block of data, there is a one-to-one mapping between each of the 2^{64} unencrypted packets and the 2^{64} encrypted words.

The converse is also true. There is a one-to-one mapping between encrypted values and unencrypted values. This may seem obvious, but it is the main reason behind the need for authentication bits in our range safety system. Without authentication, a random set of bits sent by an unauthorized user would not be detected. Also, bit-errors encountered on the encrypted message would require an external error detection mechanism such as a cyclical redundancy check (CRC). This is further explained in section 3.0.

2.4 Entropy

Mandatory to any modern method of encryption is the need for a large degree of entropy, or the measure of the randomness of the encrypted data. That is, given any input to an encrypter, there should be an equal probability that any possible encrypted value will result. The actual "key" used determines the actual encrypted value of the information. However, if one does not know the key, it is assumed that any possible character could be generated. For example, a value of all 0s of unencrypted data could be *any* combination of 0s and 1s once it is encrypted: even all 0s. It is this nature of randomness that makes an encrypted data stream difficult to decipher.

Furthermore, there will be no apparent correlation between encrypted values and un-encrypted values. That is, 000..000 and 000..001 will most probably be many digits different from one another once encrypted. However, it is possible that they are one digit apart. They should truly have no relationship to one another once decrypted. This was not the case with the "Radio Orphan Annie Secret Society decoder badge" described above where knowing the value for "A" immediately tells one the value for the remaining 35 values. Also, message values next to one another such as "A" and "B" are always either 1 or 35 values apart in the encrypted code.

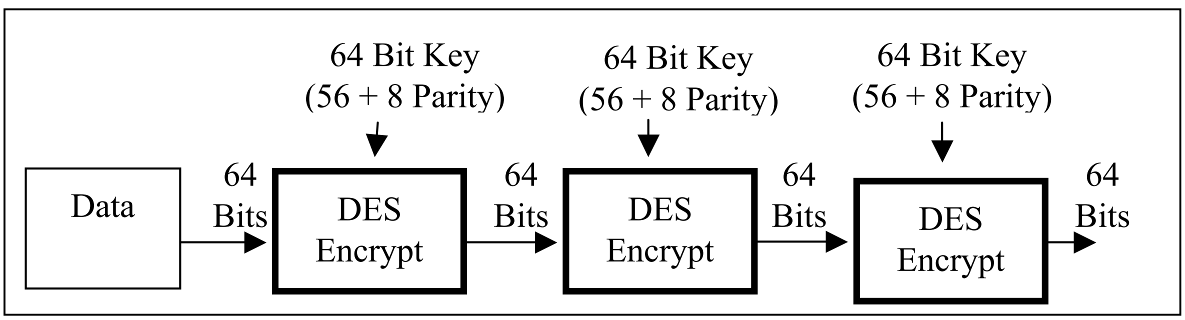
2.5 Triple DES

The data encryption standard (DES) is a public and open encryption scheme that converts between 64 bits of message data and 64 bits of encrypted data. It uses a 64-bit key that consists of 56 code bits and 8 parity bits. It is a block type of encryption.

Triple DES is a published algorithm that uses the DES three times. There are three different keys used. However, NSA will provide all three keys in one 192-bit key consisting of 168 bits and 24 bits of parity.

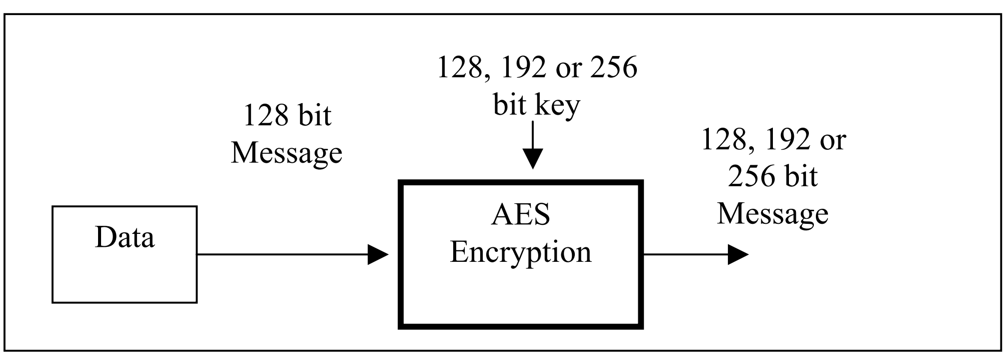
While it is widely known that the DES algorithm can be "broken" in several hours using modern computer technology, the use of the triple DES algorithm is a more secure method because it uses three DES keys and has 112 bits of encryption strength. The triple DES algorithm is currently used by many industries including the banking industry to make money transfers over the Internet. NSA supports the use of this algorithm for range safety applications for many years into the future.

A block diagram depicting the code is presented below.



2.6 Advanced Encryption Standard (AES)

The AES is a standard that is beginning to be accepted by Federal agencies. It is similar to triple-DES in that it is a block code, but it uses a different algorithm that is said to be easier to implement. NSA has defined AES for a message length of 128 bits, and key lengths of 128, 192 and 256 bits. The key length of AES is equivalent to its encryption strength. A block diagram of AES is shown below.



As AES is an emerging standard with a variety of formats and encryption, it is very well suited for EFTS. The official website for AES is: http://csrc.nist.gov/encryption/aes/.

3.0 AUTHENTICATION USING ENCRYPTION

Because of the nature of block codes, to decrypt any correctly sized block of information, it is necessary to include bits in known positions to verify that the proper message is sent. This approach reduces the probability that a bit error will result in an improperly decoded and authenticated message. Authentication is done after decryption.

Given a fixed block of information, any errors occurring between the encrypter and decrypter will result in the decryper outputting the wrong value. This is due to the one-to-one mapping of encrypted messages to decrypted messages as defined in 0 above. Many authentication bits are added to the message to reduce the probability that the decrypted message is accepted as valid. In the case of EFTS, NSA has recommended 40 bits of authentication. The 40 bits must be known expected values, but need not be fixed constants.

3.1 Probability of Improper Authentication

An example system uses triple-DES with 40 bits of authentication. Since triple DES uses 64 bit blocks, there are 2^{64} different combinations of blocks. If 1 to 64 bit-errors occur on the block between the encrypter and decrypter, the resultant decrypted packet will not be the message sent prior to encryption, but that is the only message that can be ruled out. That is, there are 264 – 1 different messages it could be.

The reason that it doesn't matter whether the number of errors is any number between 1 error per message and 64 errors per message or 64 is because of the entropy nature of modern encryption processes. There is no reason that an encrypted message with 1 error would result in a more "correct" decrypted message (i.e. a smaller *Hamming*[11] distance to the actual message) than that of an encrypted message with 64 bit errors. This is described in paragraph 2.4 above.

Because we are using 40 of the 64 bits for authentication, any combination of the other 24 bits with the correct 40 bits in place will be properly authenticated. Since one is the right value, that message is ruled out. That is, there are $2^{24} - 1$ messages that could be improperly authenticated.

To find the probability of improper authentication, we divide the possible number of improperly authenticating messages ($2^{24} - 1$) by the total number of possible messages ($2^{64} - 1$). Therefore the probability that 1 to 64 bit errors in the 64 bit encrypted packet will cause improper authentication is:

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[11] The *Hamming* distance is a measure of how similar two sets of bits are. It is defined as the number of places in which the two sets differ. E.g. Given A= 0001 and B=1000, there is a hamming distance of 2 between them; they differ in the first and last digits.

$(2^{24}-1)/(2^{64}-1) = \sim 1/2^{40}$ or $\sim 2^{-40}$ = one chance in $1.10 \cdot 10^{12}$ messages.

A similar analysis can be done for any block code of any length. For example, the calculation for AES using 128 bit packets and 40 bits of authentication is the following:
$(2^{88}-1)/(2128-1) = \sim 1/2^{40}$ or $\sim 2^{-40}$ = one chance in $1.10 \cdot 10^{12}$ messages.

3.2 Authentication Values

Authentication can be any known or expected value, but does not need to be a fixed constant. A CRC can be used for authentication within the encrypted frame. However, using Triple DES or another encryption method, there is no statistical advantage to using a CRC inside the encrypted packet. The counter value described in paragraph 4.1 cannot be used for authentication because of the "greater than" portion of the algorithm*[12]. Examples of range safety values that might be used for authentication:

- ✓ Range ID
- ✓ Transmitter ID
- ✓ Vehicle ID
- ✓ CRC
- ✓ Mission ID
- ✓ A fixed Constant.

3.2.1 Use of a CRC as an Encrypted Authentication Field

[This paragraph was added by Dr. Glenn Lilly of NSA.]

The CRC can be used within the authentication field when using encryption.

- It is a property of 3-key Triple DES encryption that any error in transmission will propagate to an apparent probability ½ errors in each of the 64 decrypted bits, i.e., the errors appear to be completely unpredictable and uncontrollable.

- Given this encryption environment, what does this mean for a 16-bit CRC computed on the other 48 bits of the 64 (some message, some authentication)?

There are four cases to consider, indexed by two properties: 1) either the 48 non-CRC bits are as transmitted or there's an error in them, and 2) the 16-bit CRC is what you expect from the other 48 bits received bits or it isn't.

1. There are $2^{16} = 65536$ possible 64-bit messages that have the 48 non-CRC bits without error. There is only one case where the 48 are correct and the 16 are also (and it won't happen since there was an error).

[12] In actuality, the entire counter field could be seen as 1 bit of authentication.

2. There are $2^{16} - 1 = 65535$ messages where the 48 non-CRC bits are correct, but the 16-bit CRC field doesn't match what you expect from those 48 bits.

3. There are $2^{64} - 2^{16} = 18446744073709486080$ messages where the 48 non-CRC bits have at least one error in them. Of those, $2^{48} - 1 = 281474976710655$ will have the 16-bit CRC match what you'd expect the CRC to be from those 48 bits.

4. The remainder of the messages, $2^{64} - 2^{48} - 2^{16} + 1 = 18446462598732775425$ will have an error in the 48 non-CRC bits, and the decrypted CRC won't match what you'd expect the CRC to be from those bits.

As it happens, if instead of a CRC, a fixed 16-bit field was used, the numbers in the four cases would come out exactly the same. A more complicated example can be created by also considering the 24 other authentication bits, but a simpler example is perhaps more enlightening.

Consider a 6-bit transmission (so the cases can be listed) with 4 bits of message followed by the two bit CRC driven by 1+x+x^2. Compare this with using a fixed field of 01 for the authentication. List the sixty-four possible decryptions and note which case we're in (message good/bad, authentication good/bad). For this example, say that the intended message was 1010.

TABLE 1. LIST OF 64 DECRYPTIONS

0000**00** *CRC*	010000	100000	110000
0000**01** *fixed field*	0100**01** *fixed field*	1000**01** *fixed field*	1100**01** *fixed field & CRC*
000010	0100**10** *CRC*	100010	110010
000011	010011	1000**11** *CRC*	110011
000100	010100	1001**00** *CRC*	110100
0001**01** *fixed field*	0101**01** *fixed field & CRC*	1001**01** *fixed field*	1101**01** *fixed field*
000110	010110	100110	1101**10** *CRC*
0001**11** *CRC*	010111	100111	110111
001000	011000	**1010**00 *message*	1110**00** *CRC*
0010**01** *fixed field & CRC*	0110**01** *fixed field*	**101001** *message & fixed field*	1110**01** *fixed field*
001010	011010	**101010** *message & CRC*	111010
001011	0110**11** *CRC*	**1010**11 *message*	111011
001100	0111**00** *CRC*	101100	111100
0011**01** *fixed field*	0111**01** *fixed field*	1011**01** *fixed field & CRC*	1111**01** *fixed field*
0011**10** *CRC*	011110	101110	111110
001111	011111	101111	1111**11** *CRC*

For the fixed field method, the cases are:

1. 1 entry with the message and the fixed field correct;
2. 2^2 – 1 = 3 entries with the message correct but the fixed field incorrect;
3. 2^4 – 1 = 15 entries with the message incorrect but the fixed field correct; and
4. 2^6 – 2^4 – 2^2 + 1 = 45 entries with neither correct.

For the CRC method, the cases are:

1. 1 entry with the message and the CRC correct;
2. 2^2 – 1 = 3 entries with the message correct but the CRC incorrect;
3. 2^4 – 1 = 15 entries with the message incorrect but the CRC correct; and
4. 2^6 – 2^4 – 2^2 + 1 = 45 entries with neither correct.

- This means that the CRC can be used (with encryption) as part of the 40 authentication bits. In fact, a longer CRC could be used if desired.

- Furthermore, the exact location of the CRC doesn't make a difference in the calculation above, so the CRC could be spread out over the 64-bit field if that was desirable for some other reason.

3.3 Redundancy in Authentication Bits

Range safety approaches that accept multiple values in a given field reduce the amount of authentication bits associated with that field. The reduction is the log base 2 of the number of acceptable values. For example: Assume 40 bits of authentication are used and the range ID is a field used for authentication. If the receiver can be programmed to accept any of 8 values in the range field because it is flying over 8 different ranges, the true number of bits used for authentication would be:

$$40 - \log_2(8) = 40 - 3 = 37 \text{ bits of authentication}$$

4.0 THE COUNTER FIELD

After the authentication of a message is complete, a counter field algorithm is used to determine if the message is an old message that has previously been processed. Without this feature any command could be recorded and played back to the receiver at an unauthorized time by an unauthorized entity.

The following two paragraphs define two different ways of determining whether a message is correctly used. In the first case messages are sent only upon need, and a separate method is used for traditional "Check" tone capability. In this case a greater than (">") algorithm is used to determine a valid message. In the case of continuously sent messages the greater than or equal to ("≥") algorithm is used to determine a valid message.

A major issue with this capability is the need to define the size of the counter field within an encrypted packet. This is truly driven by the operational requirements of the range safety mission. That is, how many different commands will be sent from the time the transmitter and receiver counters are set to 0.

4.1 The Counter Field, Non-Continuous Update

This paragraph defines the counter algorithm for approach types that do not continually send messages. An example approach would be an enhanced high alphabet approach. This approach uses the greater than (">") algorithm to determine a valid message. The rules for an algorithm are as such:

A transmitter begins each mission by placing a value of "0" in the transmitted counter field. When each new command is sent, the value entered into the transmitted counter field counter is incremented. The value in the transmitted counter field remains the same during the period when the command has not changed and are sent redundantly.

A receiver must maintain a variable that contains the value (receiver counter value) of the last command it accepted. It begins each mission with its received counter value set to "0". A receiver will only accept commands with a counter field set to **a value higher** than its received counter value. The following table shows an example of this algorithm:

TABLE 2. COUNTER (NON-CONTINUOUS UPDATE) ALGORITHM

Event No.	Action	TX Counter Field	RX Counter Value	Result at Receiver
1	Preflight mission starts: ARM command sent	1	0	$1>0$, so receiver accepts and acts on command. Receiver sets its value to 1.
2	Message is sent redundantly several times.	1	1	$1\leq1$, so receiver ignores acting on command.
3	Preflight OPTION is sent over the air.	2	1	$2>1$, so receiver accepts command. Receiver sets its value to 2.
4	Message is sent redundantly several times.	2	2	$2\leq2$, so receiver ignores acting on command.
5	Unauthorized entity has recorded previous ARM command and has greater signal then authorized carriers	1	2	$2\leq2$, so receiver ignores acting on command.
6	Receiver is "recaptured" by authorized transmitter ARM is sent	3	2	$3>2$, so receiver accepts and acts on command. Receiver sets its value to 3.
7	DESTRUCT is sent	4	3	$4>3$, so receiver accepts and acts on command. Receiver sets its value to 4 and executes command.

4.2 The Counter Field, Continuous Update

This paragraph defines the counter algorithm for approach types that do not continually send messages. An example approach would be an enhanced high alphabet approach. This approach uses the greater than or equal to ("≥") algorithm to determine a valid message. The rules for an algorithm are as such:

A transmitter begins each mission by placing a value of "1" in the transmitted counter field. When each new command is sent, the value entered into the transmitted counter field counter is incremented. The value in the transmitted counter field remains the same during the period when the command has not changed and these are sent redundantly.

A receiver must maintain a variable that contains the value (receiver counter value) of the last command it accepted. It begins each mission with its received counter value set to "0". A receiver will only accept commands with a counter field set to a **higher value or equivalent value** to its received counter value. The following table shows an example of this algorithm:

TABLE 3. COUNTER (CONTINUOUS UPDATE) ALGORITHM

Event No.	Action	TX Counter Field	RX Counter Value	Result at Receiver
1	Preflight mission starts: CHECK command sent	1	0	1≥0 so receiver accepts and acts on command. Receiver sets its value to 1.
2	Message is sent redundantly many times.	1	1	1≥1 so receiver accepts and acts on command. Receiver sets its value to 1.
3	Preflight ARM is sent over the air.	2	1	2≥1 so receiver accepts command. Receiver sets its value to 2.
4	Message is sent redundantly many times.	2	2	2≥2 so receive accepts and acts on command. Receiver sets its value to 2.
5	Preflight mission continues: CHECK command sent and ARM is off	3	2	3≥2 so receiver accepts and acts on command. Receiver sets its value to 3.
6	Mission begins, CHECK command continues	3	3	3≥3 receiver accepts and acts on command. Receiver sets its value to 3.
7	Unauthorized entity has recorded previous ARM command and has greater signal than authorized carriers	2	3	2<3 so receiver ignores acting on command.

TABLE 3. COUNTER (CONTINUOUS UPDATE) ALGORITHM				
Event No.	**Action**	**TX Counter Field**	**RX Counter Value**	**Result at Receiver**
8	Receiver is "recaptured" by authorized transmitter which is sending redundant CHECK commands	3	3	3≥3 so receiver accepts and acts on command. Receiver sets its value to 3
9	ARM is sent	4	3	4≥3 so receiver accepts and acts on command. Receiver sets its value to 4.
10	DESTRUCT is sent	5	4	5≥4 so receiver accepts and acts on command. Receiver sets its value to 5 and executes command.

5.0 OPERATIONAL ISSUES

5.1 Use of an Open Encryption Standard

NSA has recommended the use of an open encryption standard such as triple-DES or AES partially because of the storage requirements for such a device. Since the algorithm associated with the device is not classified, a device without the currently used key may be stored anywhere and does not require a secret storage facility. Similarly, keys are not classified and only need to be in a controlled environment similar to that in which the receivers are now held, e.g., within a controlled DoD or NASA facility.

In the event of a classified launch, the keys would be classified.

5.2 Use of Same Key for Multiple Missions

Use of a single key for multiple missions is deemed acceptable and is promoted by NSA for range safety applications. Receivers with the current keys installed need to be in a controlled environment during the duration that the key is in use. It may be possible to design receivers such that the key cannot be extracted, but NSA considers this to be a risk management issue.

APPENDIXES

PHASE III

APPENDIX III-A

MODELING AND SIMULATION OF EFTS CPFSK AND MODIFIED HIGH ALPHABET PERFORMANCE IN THE PRESENCE OF INTERFERENCE

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Prepared Through a Grant from NASA Dryden Flight Research Center

EXECUTIVE SUMMARY

The performance of the simulation models for the two candidate modulations, Modified High-Alphabet (MHA) and Continuous Phase Frequency Shift Keying (CPFSK) with non-coherent detection was measured in the presence of simulated interferers. Three burst sources (EPLRS, Chirped Pulse Radar, and CW Pulsed Radar) and the two legacy FTS sources (IRIG-tone FTS and High-Alphabet FTS) were used as interference signals. For the burst interference sources, both systems produce comparable frame error rates that exhibit a threshold effect: when the signal-to-interference ratio (SIR) is high enough, the frame error rate drops to zero. This threshold is about the same for two systems, although the MHA system has a slight advantage over the CPFSK system for CW pulsed radar interference. For the legacy FTS interferers, both systems display comparable frame error rates for comparable SIRs.

Most of the burst interference simulations resulted in a small number of character errors for the MHA system and many more bit errors in the CPFSK system. Clearly, this is due to the longer duration characters of the MHA system. While the MHA system has longer characters and therefore more interference averaging than the CPFSK system, this advantage is gained at the cost of sensitivity. The number of errors caused by the burst interferers is small enough to be corrected by a symbol-based error correcting code as long as the SIR is not too small. Error control coding is not recommended for the legacy interferers for SIRs less than 0 dB.

1.0 SYSTEM CONFIGURATION

The MHA system transmits 7-bit characters at a rate of 400 characters/sec (the corresponding character time is 2.5 ms/character). The equivalent bit rate is

$$R_{\text{bit}} = 400\,\frac{\text{characters}}{\text{sec}} \times 7\,\frac{\text{bits}}{\text{character}} = 2.8\,\frac{\text{kbits}}{\text{sec}}.$$

The MHA proposal envisions a frame consisting of 10 characters, or 70 bits. To make the comparison fair, the proposed CPFSK system was modified signal at the same bit rate (2.8 kbits/sec instead of 2.88 kbits/sec as originally proposed) and the frame length was fixed at 70 bits[13]. As a consequence, the frame length of 25 ms was used for both the MHA and CPFSK modulations. At the time of this writing, the frame length and required bit rate have not been determined, but the values used here should be representative of the values eventually adopted. The simulation study investigated the performance of the two candidate modulations in the presence of 5 types of interferers: 3 burst interferers (EPLRS, Chirped Radar, and CW Pulsed Radar) and 2 continuous interferers (the two legacy FTS systems). The results summarized in the next section simulated each interference threat individually. While multiple interference threats exist simultaneously in real systems, the threats were considered independently for the following reasons:

[13] We could have fixed the CPFSK system as originally proposed and altered the MHA system to provide the same equivalent bit rate and frame length. Since the tone spacing in the MHA system are tied to the character time, it was easier to alter the CPFSK system.

1. Individual assessment provides insight into the nature of the impact of each threat on the two candidate modulations.

2. A given operational scenario may only present one (or a few) of the interferers as a threat. Consequently, the individual assessment threat analysis holds.

For the burst interferers, a single burst per frame was simulated. This minimized the effect of frame length on the simulations. If multiple bursts occur during a frame, then the simulation results for frame error rate can simply be multiplied. The starting point for the burst (i.e. the position of the burst during a frame) was uniformly distributed over the entire length of the frame. In this way, all cases where the burst is wholly contained in a single character (or bit) or straddles multiple adjacent characters (or bits) is simulated. The frame error rates presented below are average frame error rates where the averaging is performed over the starting position. The simulation strategy did not include additive thermal noise, since it was assumed the interference-free signal to noise ratio was high enough to produce a very small frame error rate. The frame error rate curves presented below are a function of the signal-to-interference ratio or SIR. As expected, the frame error rate decreases with increasing SIR. The goal was to find the point where sufficiently high SIR reduced the frame error rate to zero. Details of the modeling and signal processing of the bursts are summarized in the Appendix that follows.

2.0 SIMULATION RESULTS

2.1 EPLRS-type Interference

The following simulation parameters were used to generate a Mode 3 EPLRS burst:

Chip Rate:	5 Mchips/sec (random 1's and 0's).
Pulse Shape:	Raised Cosine with 100% excess bandwidth
Modulation:	BPSK
RF Bandwidth:	10 MHz
Burst length:	1058 μsec (5290 chips)

The details of the data processing are explained in the appendix. The simulation results for the MHA and CPFSK systems are shown in Figure 1 below.

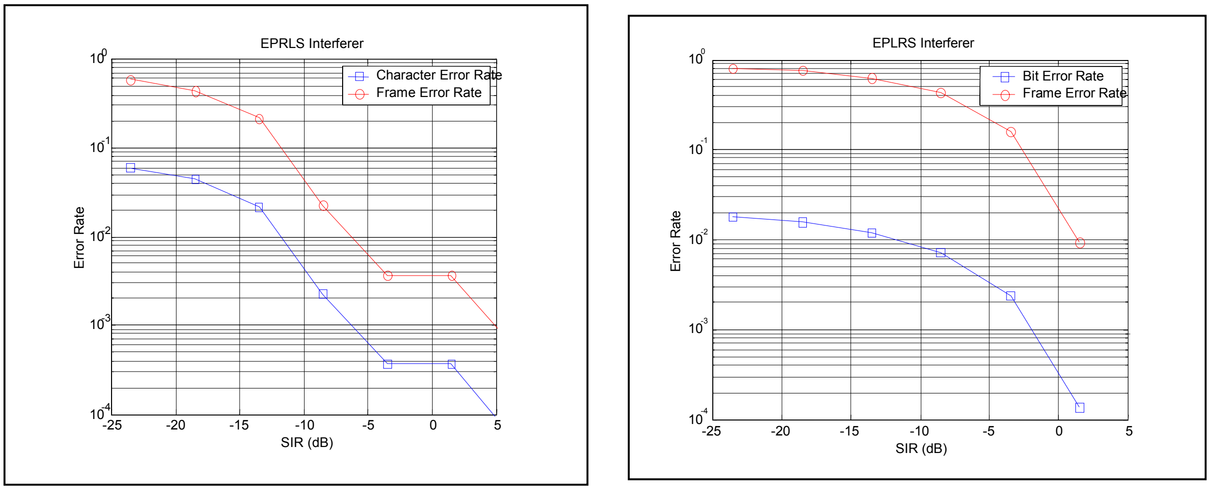

Figure 1. Frame error rate for MHA system (left) and CPFSK system (right) for EPLRS interference. The character/bit and frame error rates are zero for higher values of SIR.

In both plots, the abscissa is the Signal-to-Interference Ratio (SIR) that is defined as follows:

$$\mathrm{SIR} = \frac{\text{equivalent bit energy}}{\text{energy of interferer in the signal bandwidth}}.$$

This definition is convenient for the purposes of simulation, but not convenient for system planning. Translations to carrier power ratios are straightforward to compute and can be used for system level analyses. For both systems, EPLRS interference causes unacceptably high frame error rates when the SIR is too low. Once the SIR reaches a certain threshold (about 2 dB for both systems), the frame error rate drops to zero. The threshold is abrupt for the MHA system, but soft for the CPFSK system. This threshold appears to coincide with the FM capture threshold. If this is the case, then the interferers have negligible impact on system performance above the FM capture threshold.

For the MHA system, observe that the frame error rate is 10 times the character error rate. Since there are 10 characters per frame, this indicates that the frame errors were caused by single character errors. This is to be expected since the ratio of burst duration to character duration is 0.43. This means that an interference burst will occupy 43% of a character interval. It appears that when the interference burst is contained fully within a single character, the character error rate is 50%. But when the interference burst straddles two adjacent characters, there is rarely sufficient energy to cause a character error. Thus, single character errors were the dominant error source for this simulation.

For the CPFSK system, the frame error rate varies from 45 times the bit error rate at low SIR to 70 times the bit error rate at high SIR. This indicates that multiple bit errors caused frame errors at low SIR and single bit errors caused frame errors at high SIR. The ratio of burst duration to bit time is slightly under 3 so that at most 3 bit errors per interference burst are expected when the interference burst coincides with three bits and at most 4 bit errors per interference burst are expected when the interference burst straddles 4 adjacent bits. It appears that in the latter case, only 2 bit errors occurred on average and were the dominant error source for this simulation.

2.2 Chirped Pulse Radar Interference

Chirped pulse radar interference results when a radar burst is swept in frequency during the pulse. This type of pulsing is used in PAVE PAWS radars for example. The PAVE PAWS system features a variety of pulse durations and pulse repetition rates. For our simulations, we chose the longest duration pulse, since it had the potential to cause the greatest performance degradation. The following simulation parameters were used:

Pulse duration:	16 msec.
Pulse Shape:	NRZ
Modulation:	1 MHz linear frequency sweep
RF Bandwidth:	1.25 MHz

The details of the data processing are explained in the appendix. The simulation results for the MHA and CPFSK systems are shown in Figure 2 below.

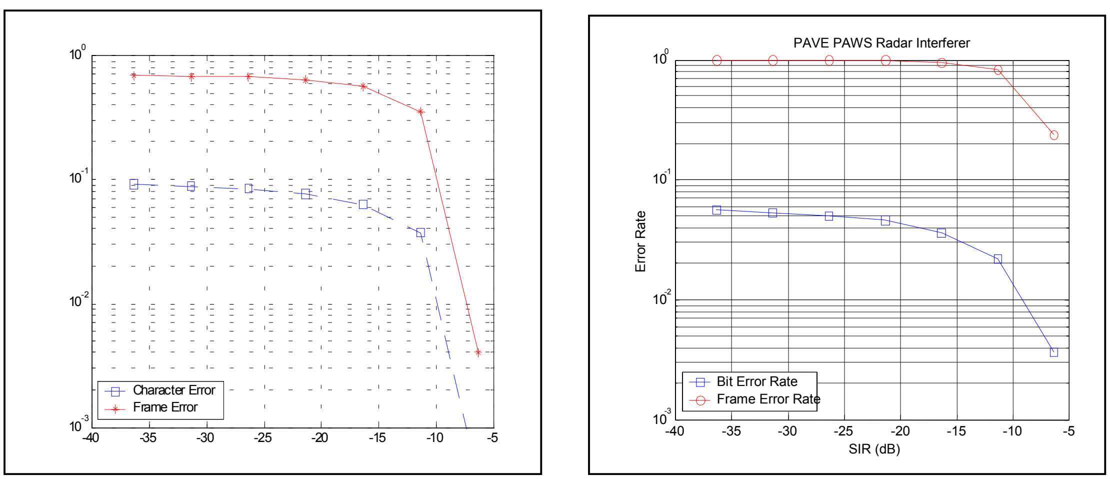

Figure 1. Frame error rate for MHA system (left) and CPFSK system (right) for chirped radar interference. The character/bit and frame error rates are zero for higher values of SIR.

In both plots, the abscissa is SIR that is defined as described in the previous section. For both systems, chirped pulse interference causes unacceptably high frame error rates when the SIR is too low. Once the SIR reaches a certain threshold (about -5 dB for the MHA and CPFSK systems), the frame error rate drops to zero. The threshold is more abrupt for the MHA system than the CPFSK system. (We speculate that the two system have approximately the same threshold point and that the apparent discrepancy in threshold points is due to the vagaries of the simulation process.)

For the MHA system, the frame error rate is 7.5 times the character error rate for low SIR and 10 times the character error rate for high SIR. Thus for low SIR, there were multiple character errors (1.3 on average) causing a frame error and for high SIR, frame errors were caused by single character errors. The ratio of burst duration to character duration is 6.4 so that at most 8 characters could be affected by the radar burst. However, an interesting phenomenon results from the band-pass filtering performed prior to the demodulator. Since the radar burst consists of a 1 MHz frequency sweep, only 18% of the radar burst energy is in the pass band of the filter. As a consequence, the time duration of the pulse at the bandpass filter output is only 18% of the total pulse duration (i.e. 2.88 msec or 1.2 characters). When averaged over the radar burst starting positions, the average number of character errors per frame is 1.3 for low SIR and 1 for high SIR.

For the CPFSK system, the frame error rate varies from 18 times the bit error rate at low SIR to 65 times the bit error rate at high SIR. This indicates that multiple bit errors caused frame errors at low SIR and single bit errors caused frame errors at high SIR. The ratio of burst duration to bit time is slightly under 45 so that at most 46 bit errors per interference burst are expected. Again due to the bandpass filtering of the chirp signal prior to demodulation, only 18% of the radar burst energy is in the pass band of the filter. As a consequence, the time duration of the pulse at the bandpass filter output is only 18% of the total pulse duration (i.e. 2.88 msec or 8 bits). When averaged over the radar burst starting positions, the average number of bit errors is 4 for low SIR and just over 1 for high SIR.

2.3 CW Pulsed Radar type Interference

A Continuous Wave (CW) pulsed radar emits an unmodulated carrier for a pulse and is one of the kinds of radar used for long-range air defense. The following simulation parameters were used:

Pulse duration:	12.5 μsec.
Pulse Shape:	NRZ
Modulation:	none
RF Bandwidth:	160 kHz

The details of the data processing are explained in the appendix. Simulation results for SIR > −30 dB produced no character or frame errors for the MHA system. The simulation results for the CPFSK systems are shown in Figure 3 below.

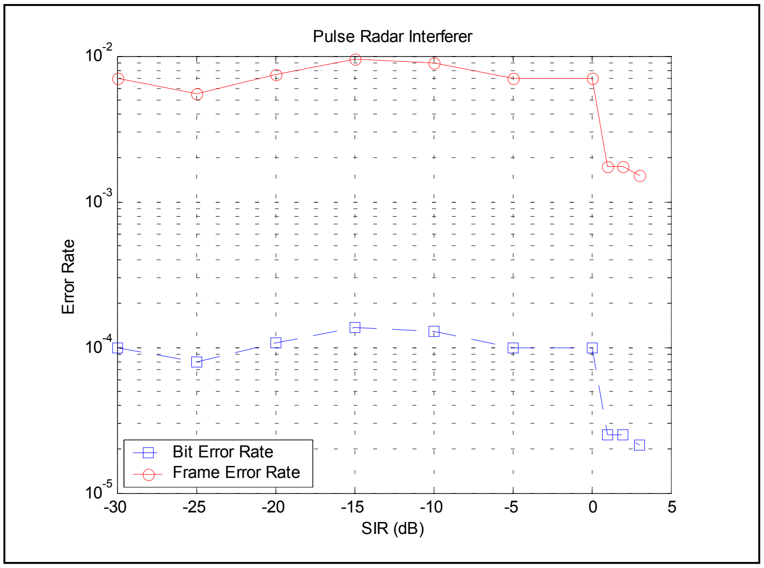

Figure 3. Frame error rate for CPFSK system for CW pulsed radar interference. The bit and frame error rates are zero for higher values of SIR.

The abscissa in Figure 3 is the Signal-to-Interference Ratio (or SIR) that is defined as described in the EPLRS-type interference section. The interference causes unacceptably high frame error rates when the SIR is too low. Once the SIR reaches a certain threshold (about 3 dB), the frame error rate drops to zero. Unlike the previous two cases, the threshold is abrupt for the CPFSK system. The frame error rate is 70 times the bit error rate. This indicates that single bit errors caused the frame errors. The ratio of burst duration to bit time is 0.035. As a consequence, a bit error occurs when the burst is wholly contained in a single bit interval and the interferer is strong enough to alter the sign of the demodulator output.

2.4 FTS (IRIG-tone) Interference

To evaluate the effects of simultaneous operation of legacy FTS systems and the proposed FTS systems, a simulated FTS signal (IRIG audio tones on an FM modulator) was also used as an interferer. Continuous transmission with a random selection of one or two valid tones was used as the interference source. The one or two tones were “on” for 5 msec, after which a new set of one or two tones was selected. The simulation results for the MHA and CPFSK systems are shown in Figure 4 below.

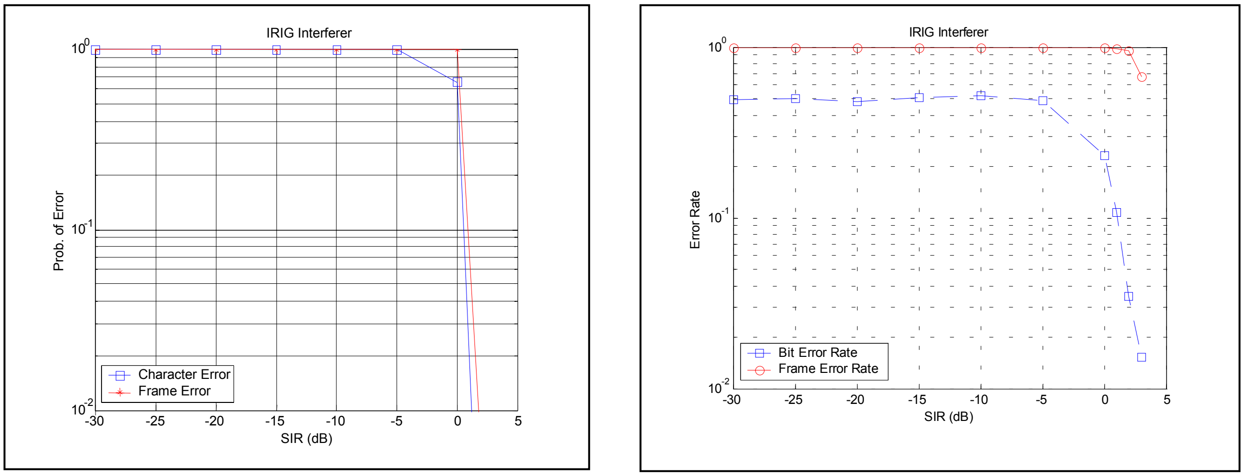

Figure 4. Frame error rate for MHA system (left) and CPFSK system (right) for FTS (IRIG-tone) interference. The bit and frame error rates are zero for higher values of SIR.

In both plots, the abscissa is Signal-to-Interference Ratio (or SIR) that is defined as described in the EPLRS-type Interference section. For both systems, the interference causes unacceptably high frame error rates when the SIR is too low. Once the SIR reaches a certain threshold (about 2 dB for the MHA system and about 3 dB for the CPFSK system), the frame error rate drops to zero. Again, the threshold is more abrupt for the MHA system than the CPFSK system as seen in the chirped radar response.

For the MHA system, the frame error rate is 1.5 times the character error rate for SIR = 0 dB and 10 times the character error rate for the higher SIRs. At SIR = 0 dB, frame errors were caused by 6 2/3 character errors on average, and single character errors caused the frame errors for higher SIRs. For the CPFSK system, the frame error rate varies from 2 times the bit error rate at low SIR to 44 times the bit error rate at high SIR. This indicates that multiple bit errors (approximately 35 bit errors) caused frame errors at low SIR and 2-bit error events caused frame errors at high SIR.

2.5 High-Alphabet FTS Interference

The second step in evaluating the effects of simultaneous operation of legacy FTS systems and the proposed FTS systems used a simulated High-Alphabet FTS signal as the interferer. Continuous transmission with a random selection of the tone sequence was simulated with the dead time between the characters.

The details of the data processing are explained in the appendix. The simulation results for the MHA and CPFSK systems are shown in Figure 5 below.

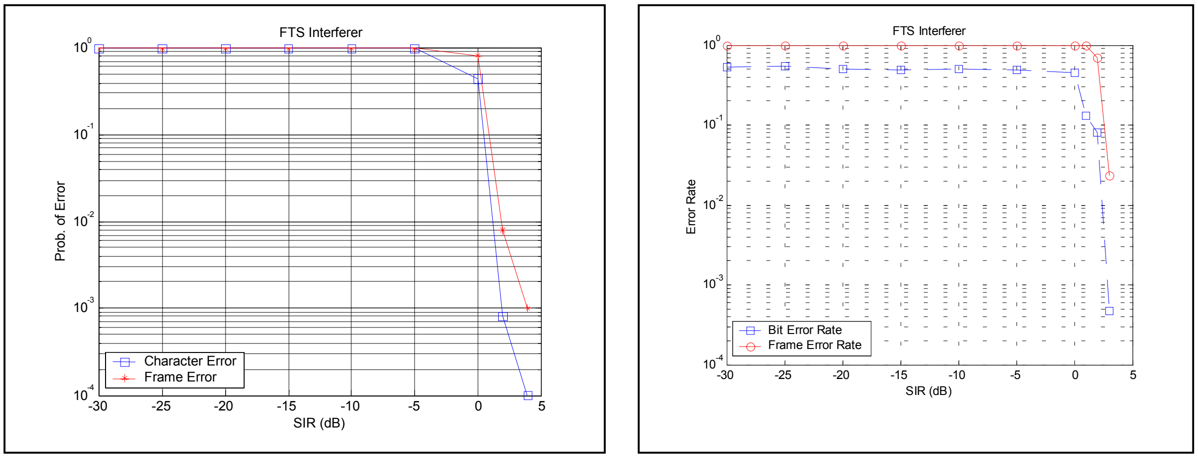

Figure 5. Frame error rate for MHA system (left) and CPFSK system (right) for high-alphabet FTS interference. The character/bit and frame error rates are zero for higher values of SIR.

In both plots, the abscissa is Signal-to-Interference Ratio (or SIR) that is defined as described in the EPLRS-type Interference section. For both systems, the interference causes unacceptably high frame error rates when the SIR is too low. Once the SIR reaches a certain threshold (about 4 dB for the MHA system and about 3 dB for the CPFSK system), the frame error rate drops to zero. The threshold is abrupt for both the MHA and CPFSK systems.

For the MHA system, the frame error rate is 2 times the character error rate for SIR = 0 dB and 10 times the character error rate for the higher SIRs. At SIR = 0 dB, frame errors were caused by 5 character errors on average and for higher SIRs, single character errors caused the frame errors. For the CPFSK system, the frame error rate varies from 2 times the bit error rate at low SIR to 50 times the bit error rate at high SIR. This indicates that multiple bit errors (approximately 35 bit errors) caused frame errors at low SIR and 2-bit error events caused frame errors at high SIR.

3.0 CONCLUSIONS

For the burst interference sources, both systems produce comparable frame error rates that exhibit a threshold effect: when the SIR is high enough, the frame error rate drops to zero. This threshold is about the same for the two systems, although the MHA system has an advantage over the CPFSK system for CW pulsed radar interference because it is a relatively short burst averaged over a much longer character time. For the legacy FTS interferers, both systems display comparable frame error rates for comparable SIRs.

Most of the burst interference simulations resulted in a small number of character errors for the MHA system and many more bit errors in the CPFSK system. Clearly, this is due to the longer duration characters of the MHA system. While the MHA system has longer characters and therefore more interference averaging than the CPFSK system, this advantage is gained at the cost of sensitivity. The number of errors caused by the burst interferers is small enough to be corrected by a symbol-based error correcting code as long as the SIR is not too small. Error control coding is not recommended for the legacy interferers for SIRs less than 0 dB.

4.0 APPENDIX: SIGNAL PROCESSING DETAILS

4.1 Modified High Alphabet System

The MHA signal is an FM signal of the form:

$$s(t) = \cos(\omega_0 t + \phi(t))$$

where $\phi(t)$ is the integral of the sum of three sinusoids selected by the "3 out of 11 rule" as specified in the MHA proposal. For the simulations, the signal was sampled at 800 ksamples/sec. This rate was chosen for the following reasons:

1. A summation (Reimann partition) approximation was used for the integrator. This approximation is valid as long as the baseband signal is at least 5 times oversampled. The bandwidth of the baseband signal was approximated by 11.6 kHz (the frequency of the highest possible audio tone) thus defining a sample rate of at least 58 kHz.

2. To accommodate the non-linear hard-limiter processing, a real valued bandpass signal was generated. Given that the signal bandwidth is approximately 360 kHz, the lowest practical carrier frequency is 200 kHz. (The band pass signal spectrum thus extends from 20 kHz to 380 kHz.) Thus the upper frequency is 380 kHz which was rounded up to 400 kHz.

The lowest sample rate that satisfies both criteria is 800 kHz. The power spectral density of an MHA signal is shown in Figure 6.

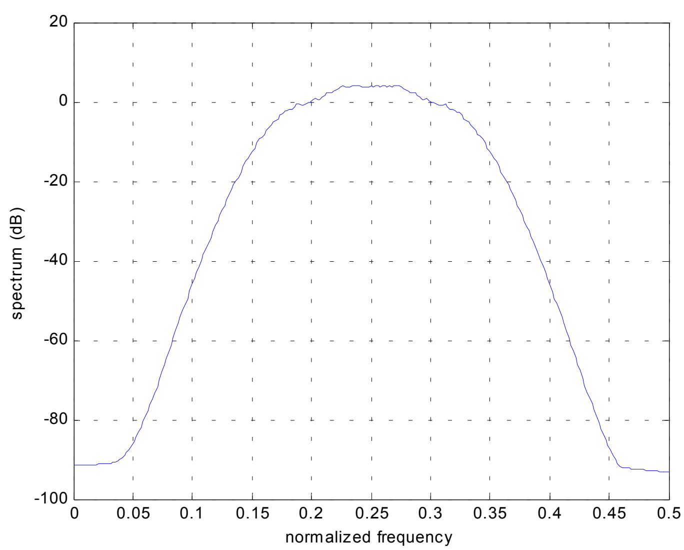

Figure 6. Power spectral density of an MHA signal sampled at 800 ksamples/sec centered at 200 kHz. The MHA signal consists of 250 randomly selected 3-tone characters. A 512-point FFT was used to compute the periodogram estimates.

The demodulation process is illustrated in the block diagram shown in Figure 7. In this process, samples of the received signal $r(n)$ are given by

$$r(n) = \cos(\Omega_0 n + \phi(n)) + w(n)$$

where $w(n)$ represents noise and interference. After the quadrature heterodyne and low-pass filtering, the in-phase and quadrature components are given by

$$I(n) = \cos(\phi(n)) + w_I(n)$$

$$Q(n) = \sin(\phi(n)) + w_Q(n)$$

from which the instantaneous phase is computed using

$$\phi(n) = \tan^{-1}\left\{\frac{Q(n)}{I(n)}\right\}.$$

The instantaneous frequency is given by the time derivative of the phase:

$$\dot{\phi}(n) = \frac{d}{dt}\tan^{-1}\left\{\frac{Q(n)}{I(n)}\right\}$$

$$= \frac{I(n)\dot{Q}(n) - \dot{I}(n)Q(n)}{I^2(n) + Q^2(n)}.$$

Thus, the quadrature heterodyne and low-pass filtering produce the baseband in-phase and quadrature components $I(n)$ and $Q(n)$. The discrete-time differentiators compute the derivatives of the in-phase and quadrature components which are then cross multiplied and subtracted to form the numerator of the desired expression. The numerator is scaled by the magnitude squared of the received signal to complete the computation of instantaneous frequency. Once the instantaneous frequency $\dot{\phi}(t)$ is computed, a DFT-based (discrete Fourier transform) detection scheme is used to determine the character. The simulations did not include the squelch feature—the three largest DFT bins in the valid frequency range were selected as the detector output.

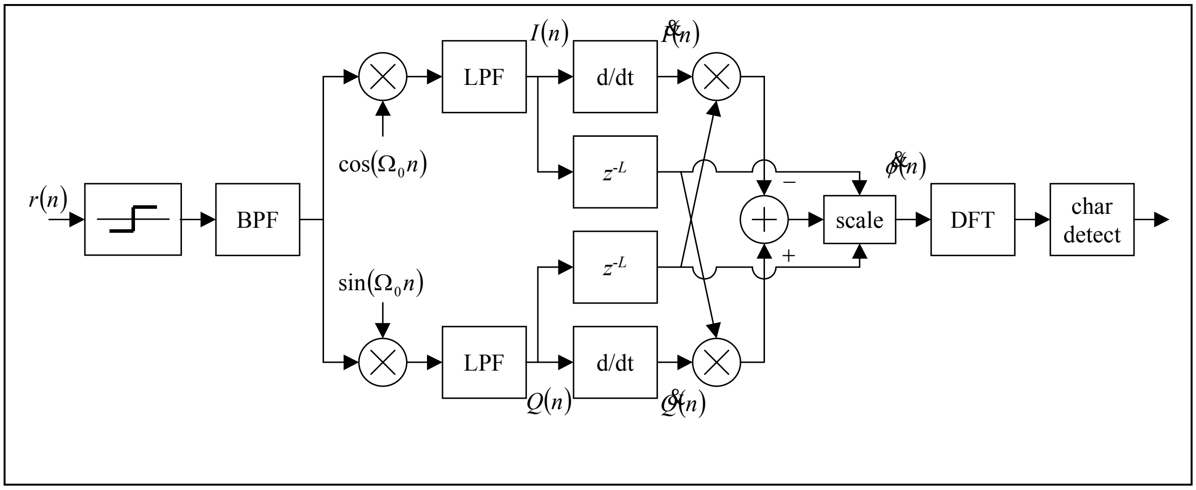

Figure 7. MHA demodulator and character detector used for the simulations.

The character error rate and frame error rate performance of this detector in additive thermal noise (AWGN) is illustrated in Figure 8.

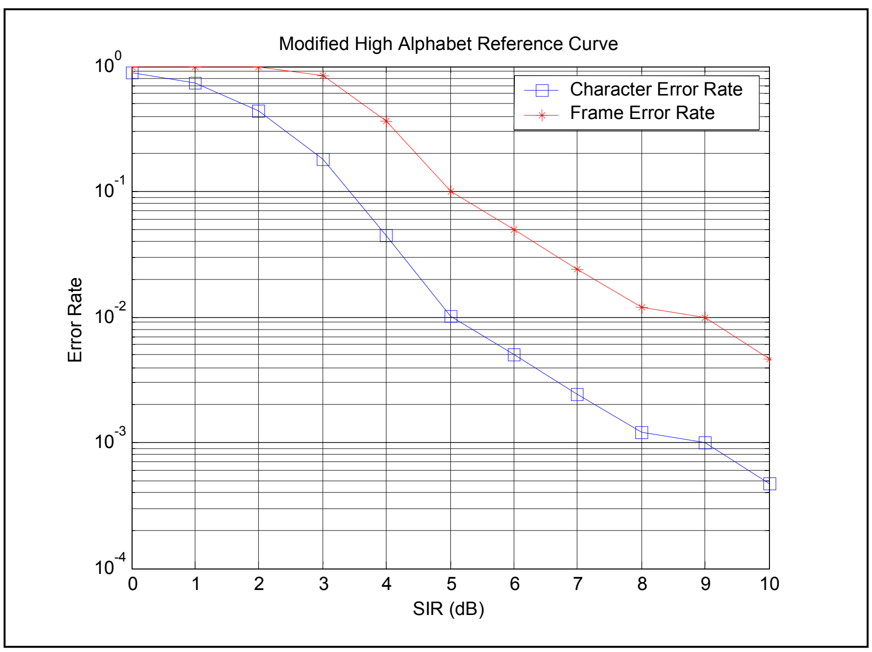

Figure 8. Character error rate and frame error rate performance for the MHA demodulator of Figure 7 with additive thermal noise (AWGN).

4.2 Continuous Phase Frequency Shift Keying

The CPFSK signal is also an FM signal of the form

$$s(t) = \cos(\omega_0 t + \phi(t))$$

where the instantaneous phase is a positive or negative ramp whose slope is determined by the frequency shift and the data bit. To be consistent with the MHA simulations, this signal was also centered at 200 kHz and sampled at 800 ksamples/second. The power spectral density of a simulated CPFSK signal with a peak frequency deviation of 60 kHz is shown in Figure 9.

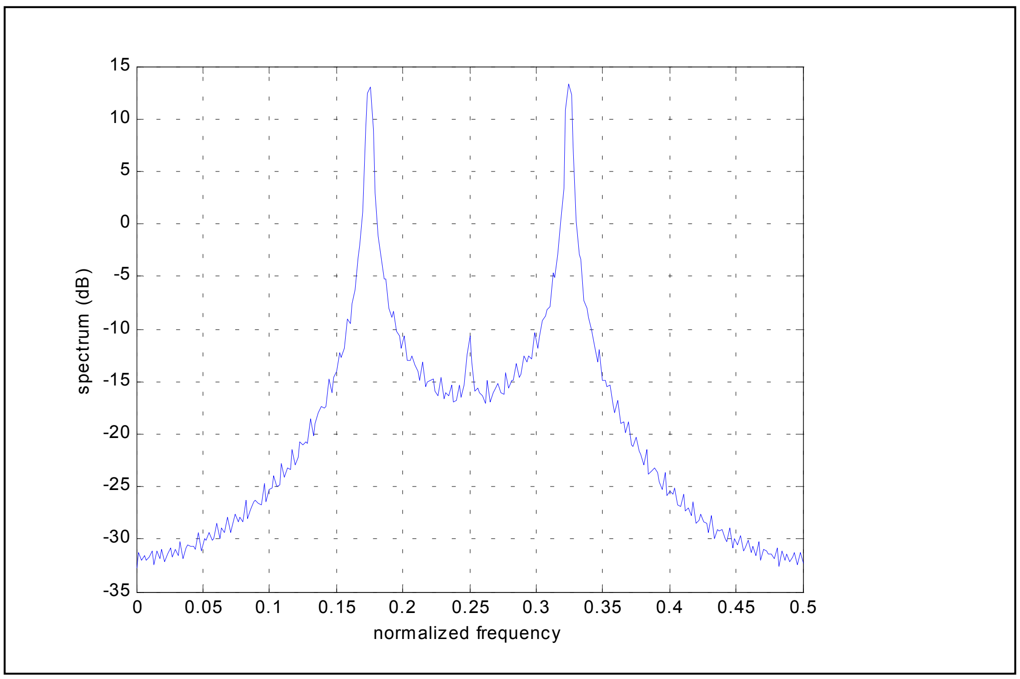

Figure 9. Power spectral density of a CPFSK signal sampled at 800 ksamples/sec centered at 200 kHz. The CPFSK signal consists of 1000 random bits. A 512-point FFT was used to compute the periodogram estimates.

Demodulation and detection is similar to what was done for the MHA system. The same structure is used to compute the instantaneous phase $\hat{\phi}(t)$. The instantaneous phase is then down sampled at the maximum eye opening and the sign of that sample is used to make the bit decision. A block diagram of the signal processing used is shown in Figure 10 and the corresponding bit error rate and frame error rate for the thermal noise (AWGN) environment is shown in Figure 11.

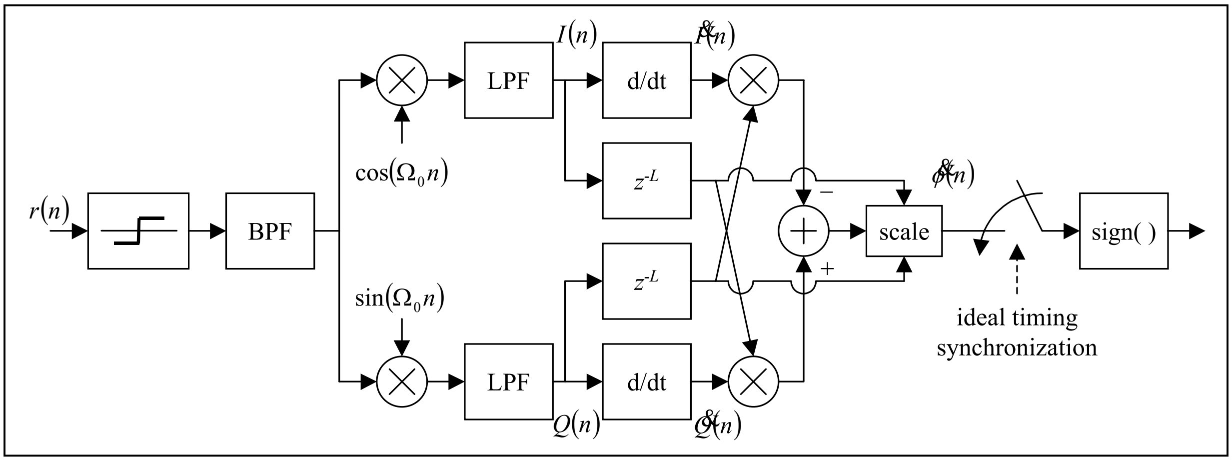

Figure 10. Demodulator and bit detector used for the CPFSK simulations.

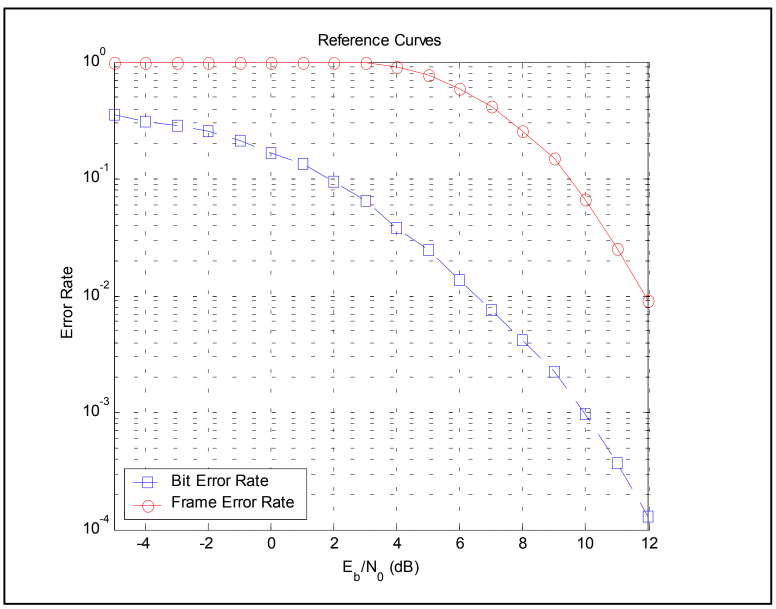

Figure 11. Bit error rate and frame error rate performance for the CPFSK demodulator of Figure 10 with additive thermal noise (AWGN).

4.3 EPLRS

The EPLRS interference signal is a spread-spectrum burst. The parameters selected for the simulations are the following:

Chip Rate:	5 Mchips/sec (Random 1's and 0's).
Pulse Shape:	Raised Cosine with 100% excess bandwidth
Modulation:	BPSK
RF Bandwidth:	10 MHz
Burst length:	1058 µsec (5290 chips)

The raised-cosine pulse shape was selected to bandlimit each chip to a baseband bandwidth of 5 MHz. The Nyquist sampling rate for each chip is thus 10 Msamples/sec (or 2 samples/chip). Each chip was weighted by either –1 or +1 to produce a baseband modulated chip stream 5290 chips long. In preparation for downsampling to the simulation sample rate of 800 ksamples/sec, the chip sequence was low-pass filtered by a length 2001 FIR filter with cut-off frequency at 18/1000 of the high sample rate and a stop band starting at 20/1000 of the high sample rate. The low-pass filtered signal was then downsampled by a factor 2/25 using a polyphase filterbank to produce a bandlimited baseband signal with a sample rate of 800 ksamples/sec. This signal was then heterodyned to the quarter sample frequency, scaled in amplitude, and added to the MHA and CPFSK signals for the simulation. An example of the time series for the EPLRS signal (at the low sample rate of 800 ksamples/sec) is illustrated in Figure 12 and the corresponding power spectral density in Figure 13.

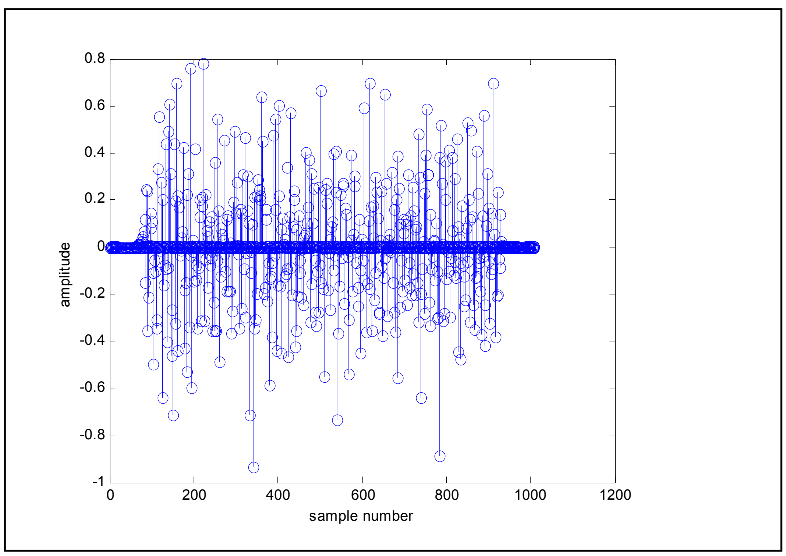

Figure 12. Example of a time series for a filtered EPLRS burst.

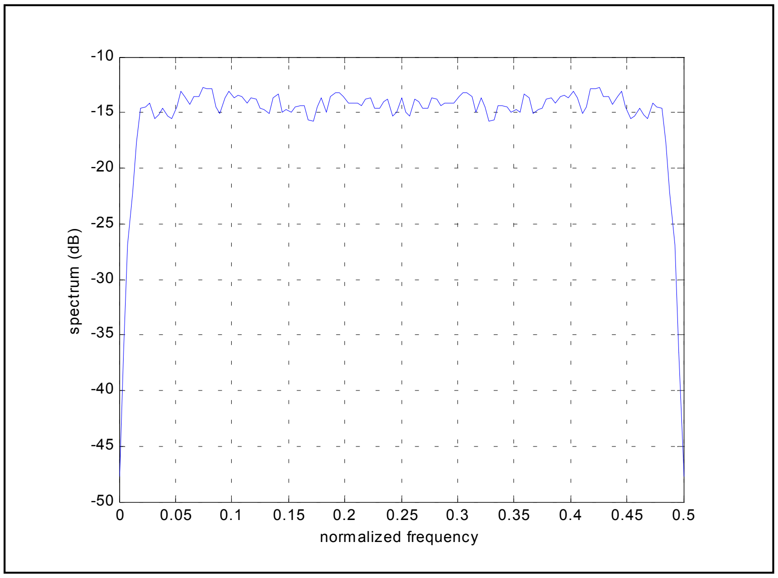

Figure 13. The power spectral density of the filtered EPLRS burst at the low sample rate (800 ksamples/sec). A 256-point FFT was used to compute the periodogram estimates.

4.4 Chirped Pulse Radar

A Chirped Pulse Radar uses a linear frequency sweep to modulate the RF carrier during the pulse time. A chirp signal is of the form

$$s(t) = \cos\left(\omega_0 t + \frac{\omega_s t^2}{2}\right).$$

The instantaneous frequency is given by the time derivative of the argument of the cosine and is $\omega_o + \omega_s t$. This means that the frequency increases with time at a rate of $\omega_s/2\pi$ Hz/sec. Chirp signals have the property that the power spectral density is a constant.

The PAVE PAWS radar system was used as the basis for formulating the simulated interferer. The following simulation parameters were used:

Pulse duration:	16 msec.
Pulse Shape:	NRZ
Modulation:	1 MHz linear frequency sweep
RF Bandwidth:	1.25 MHz

For this pulse, the frequency sweep is 1 MHz over 16 msec so that $\omega_s = 2\pi \times 62.5 \times 10^6$ rads/sec/sec.

As in the EPLRS case, a complex baseband version of the chirp pulse is generated at a high sample rate. The signal is then filtered, downsampled to the sample rate used in the simulations, and heterodyned to the quarter sample rate frequency to center the signal in the passband of the MHA or CPFSK signal. The complex baseband signal

$$s(t) = e^{j\frac{\omega_s t^2}{2}}$$

was sampled at 8 Msamples/sec to produce the time series shown in Figure 14. Also shown in Figure 15 shows a plot of the corresponding power spectral density.

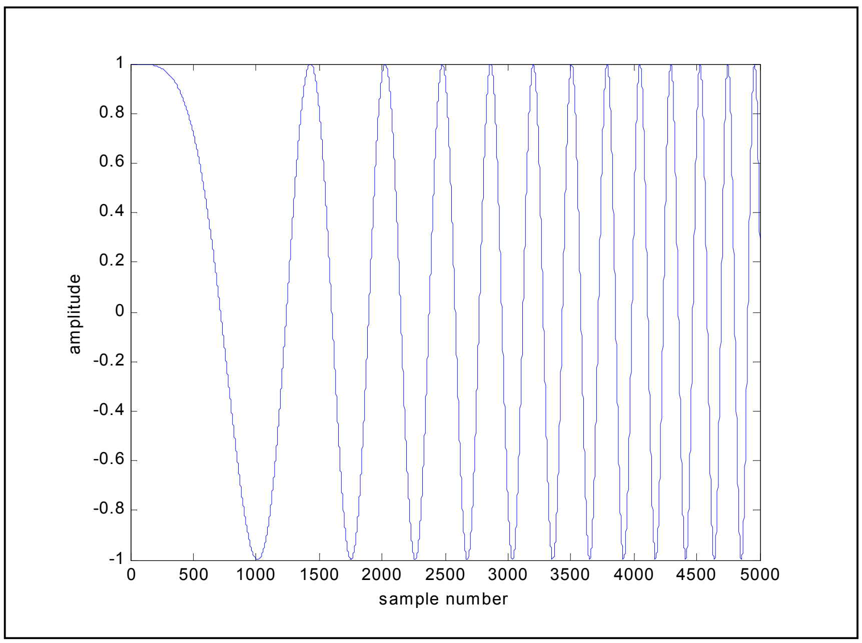

Figure 14. Time series of the real part of the complex baseband chirp pulse showing the first 5000 samples (first 625 μsec). The chirp pulse is sampled a 8 Msamples/sec and has a frequency sweep rate of 62.5 MHz/sec.

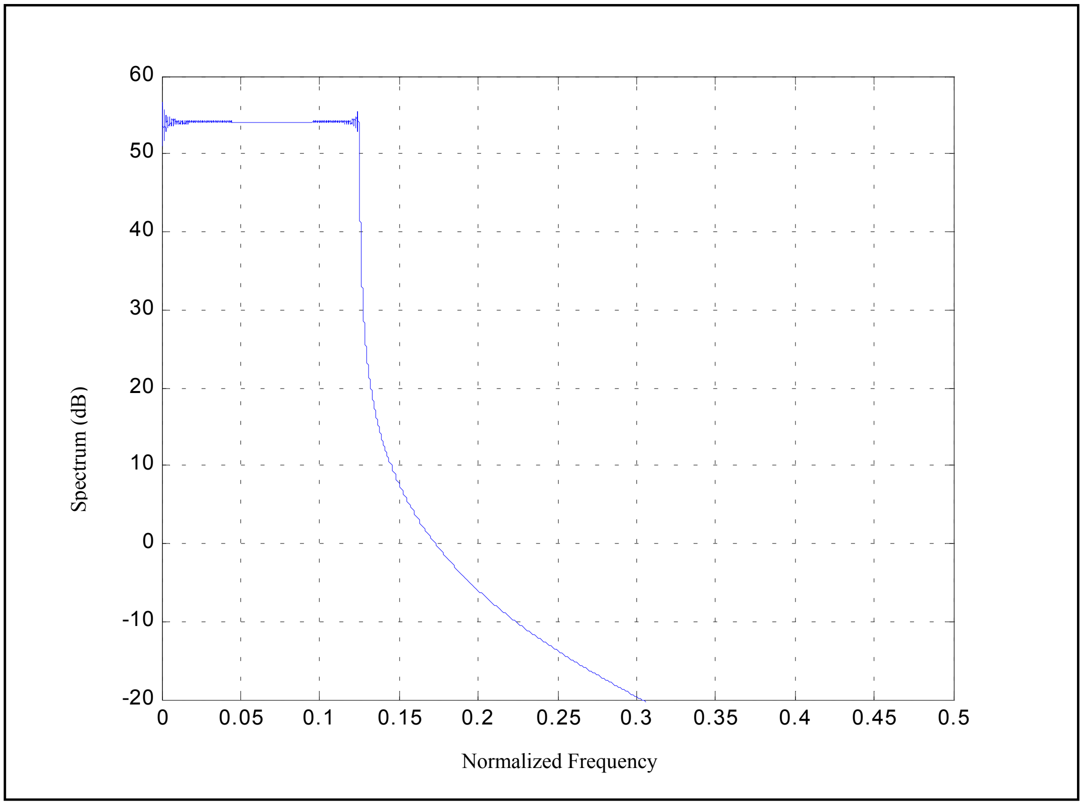

Figure 15. FFT of the entire chirp pulse illustrated in Figure 14. The sample rate is 8 Msamples/sec. Note the spectrum is flat from DC to 0.125 × the sample rate (or 1 MHz). 1 MHz corresponds to the instantaneous frequency at the end of the pulse.

The complex baseband signal was low-pass filtered by a length 2001 FIR filter with cut-off frequency at 18/800 of the high sample rate and a stop band starting at 20/800 of the high sample rate. The low-pass filtered signal was then downsampled by a factor 1/10 to produce a bandlimited baseband signal with a sample rate of 800 ksamples/sec. This signal was then heterodyned to the quarter sample frequency, scaled in amplitude, and added to the MHA and CPFSK signals for the simulation. An example of the time series for the filtered, downsampled, and heterodyned chirped pulse is illustrated in Figure 16 and the corresponding power spectral density is illustrated in Figure 17. Note that the time series drops to zero after about 2300 samples (or 2.9 msec). This is due to the lowpass filter with a 180 kHz cutoff frequency. The chirp has a frequency ramp of 62.5 MHz/sec so that after 2.9 μsec, the instantaneous frequency leaves the pass band of the low pass filter.

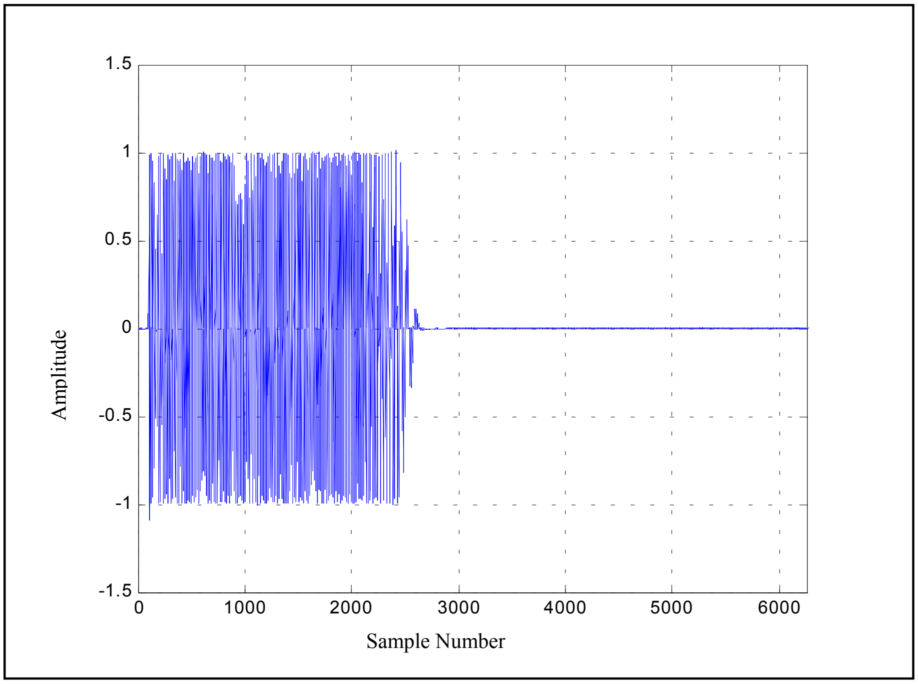

Figure 16. Time series corresponding to the filtered, downsampled, and heterodyned chirp pulse. The sample rate is 800 ksamples/sec. The signal amplitude drops to approximately zero for samples above about 2300. This corresponds to the time when the instantaneous frequency of the chirp exceeds the bandwidth of the MHA or CPFSK signals.

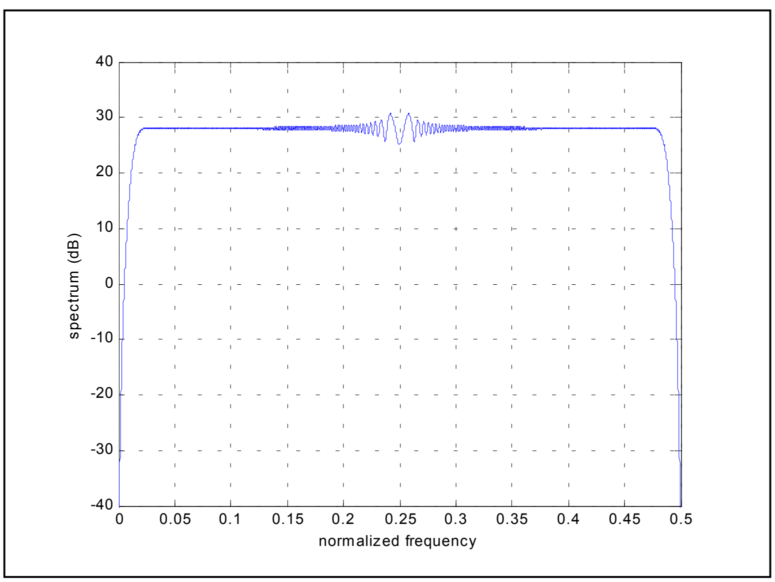

Figure 17. Power spectral density of the chirp pulse illustrated in Figure 16. The sample rate is 800 ksamples/sec.

4.5 Continuous Wave Pulsed Radar

A Continuous Wave (CW) pulsed radar emits an unmodulated carrier for a pulse. The following simulation parameters were used:

Pulse duration:	12.5 μsec.
Pulse Shape:	NRZ
Modulation:	none
RF Bandwidth:	160 kHz

Note that the RF bandwidth is less than that of the MHA or CPFSK signals and is adequately represented by a signal sampled at 800 ksamples/sec, centered at 200 kHz with a duration of 10 samples.

APPENDIX III-B

PLUME IMPINGEMENT REPORT

Prepared by:
Jonathan Brown
Spiral Technology, Inc.
26 December 2001

1.0 INTRODUCTION

This study was intended to collect and correlate data from previous studies and documents relating to RF plume impingement problems with the hope of finding substantive information relating to RF modulation schemes. Plume-induced RF impingement can take the form of attenuation or interference (absorption, diffraction, refraction, and to a much lesser degree, scattering), multipath, and noise (AM and PM). The interaction of electromagnetic radiation with a plume, and the resultant attenuation and interference, have been investigated in previous studies.

The existing studies have dealt with understanding the primary mechanisms which contribute to the attenuation and multipath of an RF signal, or analyzing real-time telemetry data with respect to signal strength and/or proper check channel decoding. The primary areas of interest have been RF attenuation relative to frequency, transmit power and receiver sensitivity, environmental effects, and transmitter-plume aspect angle.

The following documents were used in the collection of data relevant to the intended purpose of this study.

- *JANNAF Handbook on Rocket Exhaust Plume Technology*, CPIA Pub. 263 Chapter 4
- *UHF Command Destruct Link Analysis Report for the Eastern and Western Spacelift Ranges* Vol. 1, June 1995
- *Project SEETHRU, Flame Interference Measurements, Titan IIIC, Final Report,* April 1967
- Memo, updated 5 November, 1998, (Glory Trips 20, 21, 22, and 23)

There may exist the possibility for future RF attenuation investigations in conjunction with vehicle booster vendor testing, but presently there are no scheduled activities. It is hoped that a current or future program may afford additional opportunities to increase our knowledge base related to plume induced RF impingement.

Currently, there is a program at Kennedy Space Center (POC: Mr. Jeppie Compton, SRS Information Systems) utilizing an Unmanned Autonomous Vehicle (UAV) to collect atmospheric data in the dispersed plume cloud of launch vehicles. There may be a possibility for a collaborative effort with this program to collect RF attenuation data as well. However, given their current restrictions for take-off of T+120 seconds or after Solid Rocket Motors (SRM) separation in the case of the Shuttle, the relevant data acquired may be quite limited. Continued monitoring of this programs progress is warranted.

2.0 LIQUID MOTOR PLUME ATTENUATION

The use of liquid fuel motors greatly reduces the concern about of RF impingement. However, motors with extremely high thrust, even liquid fuel types, and transmitters with low aspect angles will experience attenuation and interference in VHF signals as noted in Figure 1 from the UHF Command Destruct Link Analysis Report derived from data collected during Operation SEETHRU. The VHF attenuation averaged about 8 dB while attenuation in the C-, S-, and X-bands progressively diminished to negligibility as the frequency increased.

3.0 SOLID ROCKET MOTOR PLUME ATTENUATION

Solid rocket motors (SRM) are the primary generators of plume characteristics that impinge upon RF data reception and transmission. Electron and ion concentrations in the plume and their collision frequency are the largest contributors to the RF impingement problem.

Conducting particles, whether impurities or additives in the SRM propellant, can greatly affect the level of impingement. Ammonium Perchlorate used in the SRMs will produce alkali-metals in the exhaust plume. The turbulent intensity and scale of these ions combined with other relevant time dependent phenomena generate the characteristics that result in RF attenuation, multipath, and phase distortion.

Plume attenuation can be dramatically reduced by the specification of ammonium perchlorate with very low concentrations of sodium and potassium. Obviously, there is a cost increase for this enhanced grade of material, but from the standpoint of RF impingement reduction, the benefits justify the expenditure.

The exhaust plume size, temperature, density and pressure, along with atmospheric parameters, contribute to the RF impingement problem when viewed from a terrestrial-based transmitter. The choice of RF carrier frequency, transmitted power and receiver sensitivity, and aspect angle also must be factored into the overall problem.

As the vehicle altitude increases, atmospheric variations affect the size and shape of the exhaust plume. An expansion of the plume boundary occurs resulting in observed attenuation up to 17 degrees in the aspect angle.

Events such as motor staging and SRM separation rocket firing, especially considering the transverse nature of the exhaust during these events, will have serious effects upon the noise and attenuation figures as shown in Figure 2. Though these events last for only a few seconds, their effects may exceed any link margin anticipated through power or aspect angle. Also, the resultant loss in telemetry synchronization can lead to longer losses of critical data during the additional period of synchronization reacquisition.

It must be noted that during the Glory Trips, as detailed in the Memo, updated 5 November 1998, it was observed that the past method of using solely the receiver automatic gain control (AGC) level as the basis for determining adequate signal strength should be re-examined. There were observed several instances where the AGC level was within nominal range, but the receivers lost data integrity. It would appear that either multipath or differential phase distortion was sufficient to make the receiver see adequate signal energy, but not be able to properly decode the signal data. The use of a check channel for validation of proper signal reception and decoding is certainly suggested.

4.0 FLAME NOISE

The noise induced on a RF signal by a plume contains both AM (amplitude modulation) and PM (phase modulation) components. Theoretically, the two components should be about equal. In measured tests, the AM noise produced by both solid and liquid fuel motors have a probability distribution function that is very nearly Gaussian.

Regrettably, though phase modulation was observed during Project SEETHRU, no data was obtained to provide analysis due to equipment failures and the loss of calibration data at sites with advantageous aspect angles.

Flame noise amplitude modulation is highest at low frequencies and decreases with frequency. Values as high as 12 dB below the carrier per 50 Hz bandwidth at 100 Hz were obtained during Project SEETHRU from low aspect angle sites as seen in Figure 3. However, for sites with aspect angles greater than 17 degrees, the typical noise figures were about 35 dB below the carrier, and had the general appearance of white noise.

The aspect angles over which flame noise is observed is always greater than that for plume attenuation. Flame noise can extend to as far as 24 degrees from the missile roll axis. Also, where plume attenuation ceases abruptly as the thrust decays to about the 40% level, flame noise continues until thrust decays to about 25% and can extend to periods where the attenuation is less than 3 dB.

Separation rocket exhaust noise, though lasting only a few seconds, has an especially deleterious effect. Given the close proximity to the vehicle antennas and the transverse nature of the exhaust with regard to the vehicle, amplitude fluctuations as high as 12 dB below the carrier were observed. During the separation rocket event, attenuation and noise are observed at aspect angles as high as 130 degrees.

In this particular test, the transmitter RF aspect angle was 15 degrees and the quiescent noise level for the no-flame period was 45 dB below the carrier per 50 Hz bandwidth. The Titan IIIC zero-stage exhaust flame caused an increase of about 20 dB in the measured amplitude noise. The power spectral density of the separation rocket exhaust noise exceeded that of the zero-stage exhaust noise by an additional 5 dB.

5.0 PULSE DISTORTION

Measurements taken on the Titan IIIC mission during Project SEETHRU indicate that no pulse distortion by the rocket plume on the 9100 MHz, ½ usec, 2200 prf test pulses. The plume appeared to attenuate the pulse amplitude in a random manner, but did not affect the pulse shape otherwise.

Theory would predict that the plume is a dispersive medium and would affect each of the spectral components differently. However, the Titan IIIC tests would tend to suggest that the exhaust plume is not dispersive.

6.0 RE-ENTRY SKIN PLASMA ATTENUATION

Though re-entry plasma impingement topic was not an issue for this study, there is at least one point worth noting because of its contrast to the exhaust plume study. The higher the frequency, the greater the attenuation due to plume effects. The existing flight termination system (FTS) carrier frequency band is preferable to a higher frequency band with respect to plume attenuation in reference to a terrestrial-based transmitter.

However, with respect to re-entry vehicle skin plasma impingement, a carrier frequency at or above the S-band is necessary to overcome the attenuation. At the existing lower frequency of 400 to 450 MHz, the attenuation due to re-entry skin effect can be as great as 100 dB.

It should be noted that with the existing lower frequency band, data communication has been established during, or shortly after, re-entry from the antenna mounted on top of the vehicle when the terrestrial-based transmitter to vehicle antenna aspect angle was advantageous and sufficient transmit power was available. However, this should not be viewed as a viable solution for re-entry skin attenuation as this solution is dependent on the vehicle trajectory and terrestrial-based RF transmitter/receiver site geometry. Each trajectory would have its own best RF transmitter/receiver location, and few, if any, mobile transmitter/receiver options are available.

7.0 CONCLUSIONS

NOTE: The following conclusions have been distilled from the data collected from the Titan IIIC vehicle during Project SEETHRU and the Minuteman Glory Trips 20, 21, 22, and 23. It may not be prudent to consider the 17 degree value for aspect angles as the absolute maximum at which attenuation will be observed for all vehicles. Considering that RF noise is observed out to 24 degrees from the plume, it might be valuable to consider this as a more conservative figure for minimum aspect angle. However, vehicles with significantly greater thrust than a Titan IIIC or one with unique engine nozzle geometry generating a wider plume envelope may require additional consideration for minimum aspect angle.

There are no known studies to date that investigate the use of different modulation schemes and their preference for use in a Flight Termination System with regards to plume impingement mitigation.

Lower frequency band utilization for FTS is more preferable than moving to a higher frequency band in terms of mitigation of exhaust plume attenuation for terrestrial-based FTS. Figure 4 (taken from Project SEETHRU Final Report) shows a short summary of the attenuation values with respect to frequency and aspect angle.

Transmitter power alone can't ensure overcoming plume impingement. Better aspect angles with respect to the vehicle trajectory are much more desirable for impingement mitigation. See NOTE at beginning of this section.

The use of a check channel during flight is suggested to validate proper signal reception and decoding.

Vehicle mounted antennas should be positioned as far as practical from the vehicle exhaust and any motor separation rockets.

Utilization of high purity ammonium-perchlorate, very low sodium and potassium content, in the SRM fuel will effect a significant reduction in the plume impingement problem. A 10:1 reduction in sodium and potassium results in approximately a 3:1 reduction in plume attenuation.

Lower frequency band utilization for terrestrial-based FTS is inadequate for overcoming re-entry skin plasma impingement.

Monitor existing programs for possible collaborative efforts to increase knowledge and understanding of plume impingement upon different modulation schemes.

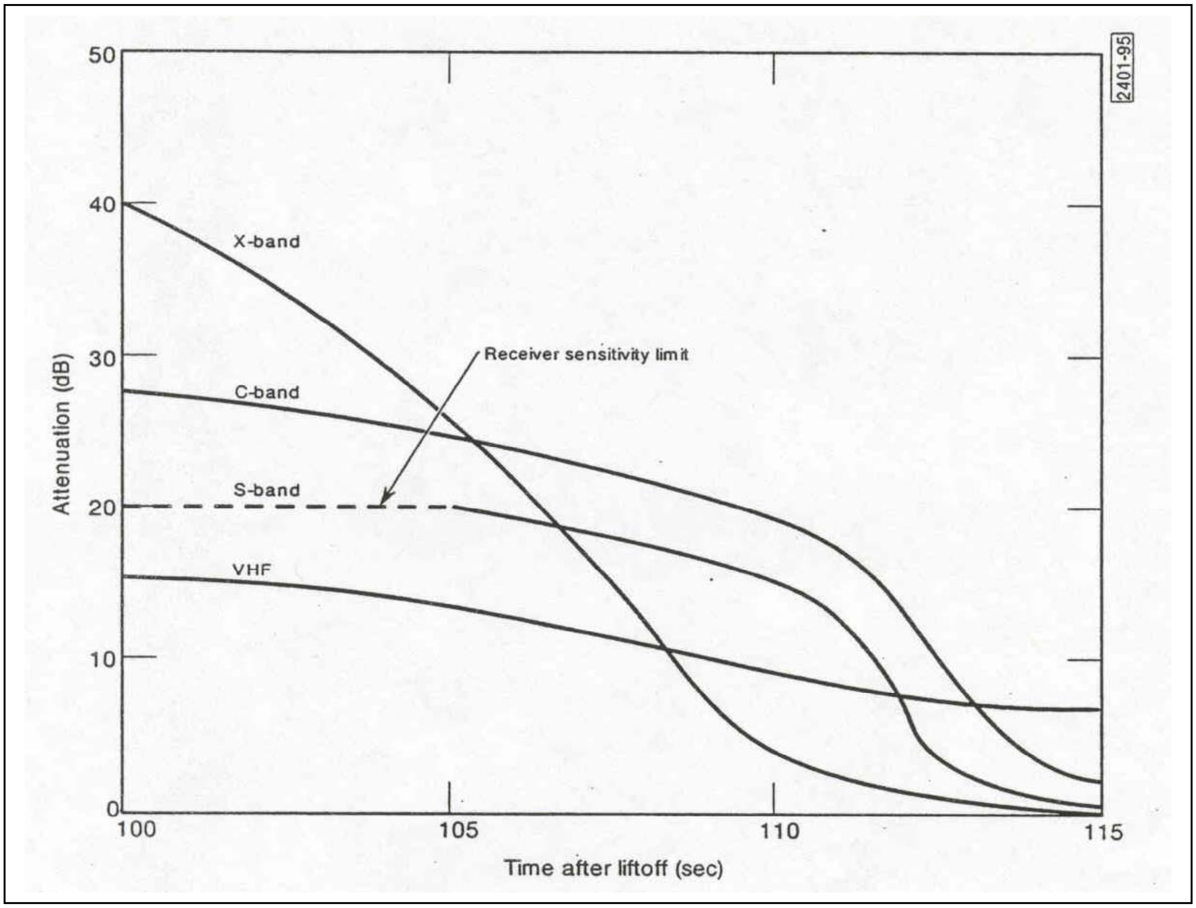

Figure 1. Plume attenuation versus time (UC-13 data, aspect angle ~ 4 - 6 degrees).[14]

This figure illustrates the plume's attenuation as a function of frequency through both solid (T<108 seconds) and liquid (T>108 seconds) propellants.

[14] From UHF Command Destruct Link Analysis Report (Figure 18).

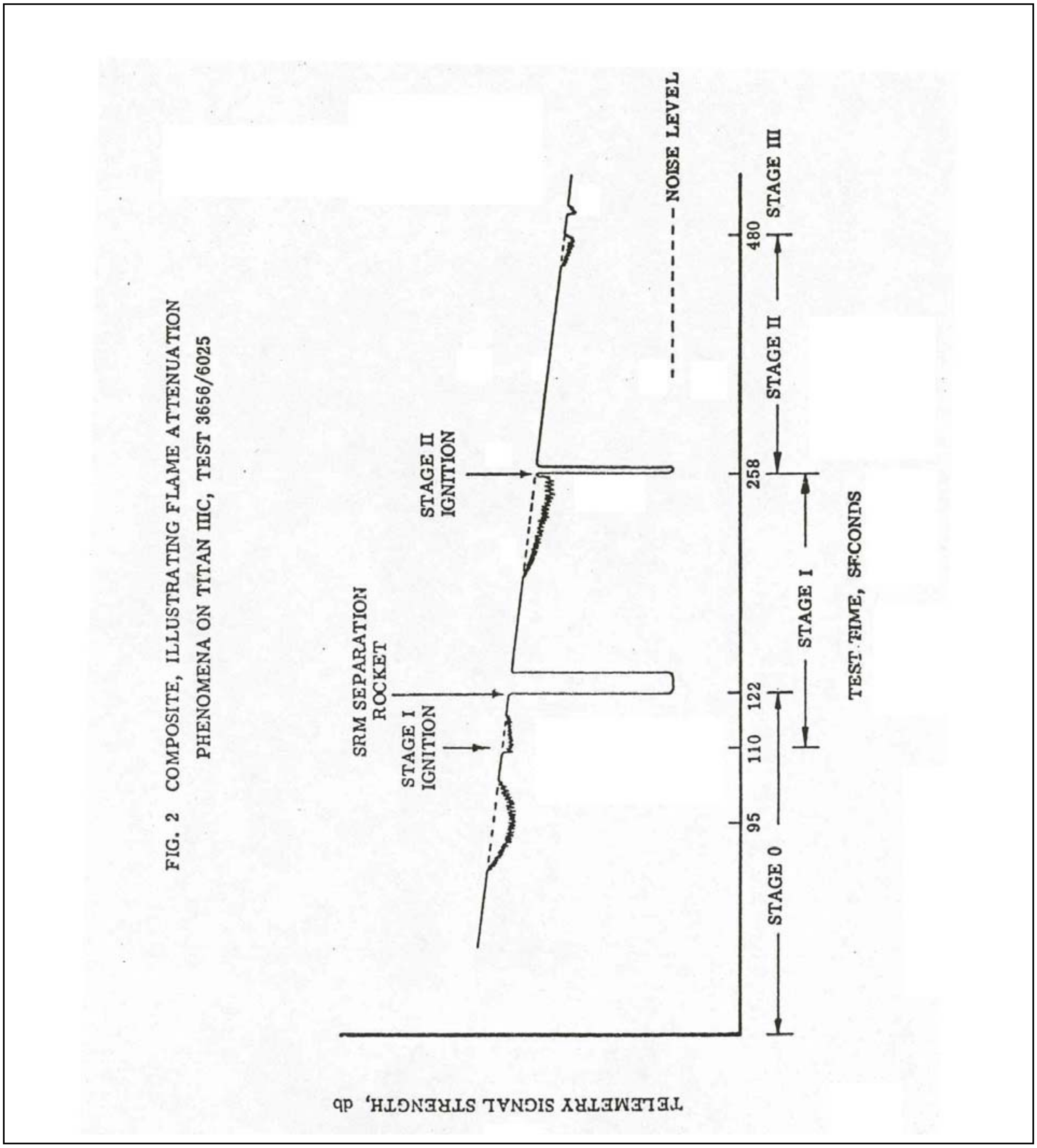

Figure 2. Composite, illustrating flame attenuation.

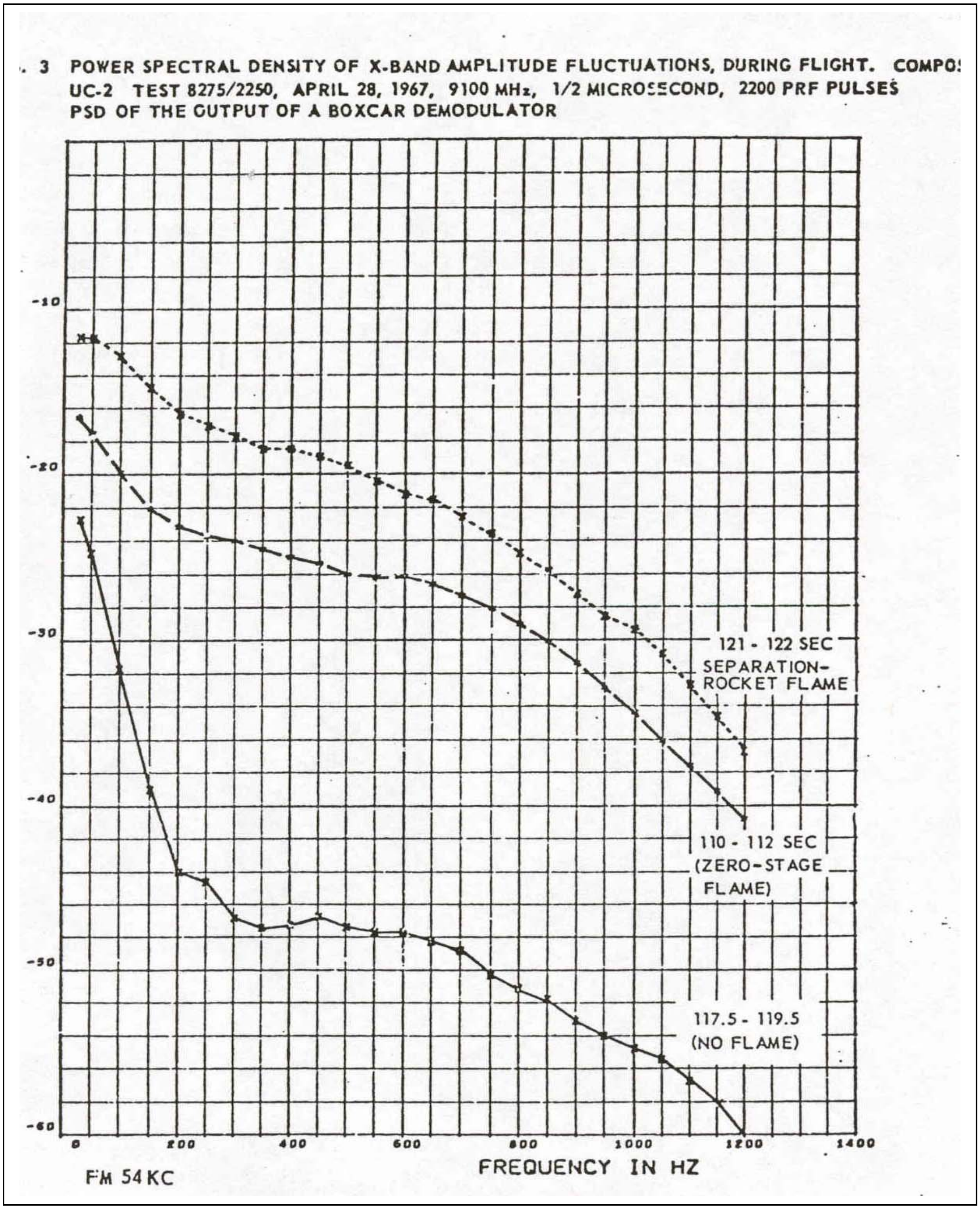

Figure 3. Power spectral density of X-band amplitude fluctuations during flight.

X-Band Signal Loss, Zero Stage

Aspect Angles* $\alpha = 180 - \theta$	ϕ	Signal Loss	Test Time	Site
> 16	70-150	0 db	0-110 sec	UC-2
16	339	> 10	+ 65	19.1
10-8	245-223	< 30	95-110	UC-11
9	186	30	108-110	19.1
4-5	199-188	40	100-110	UC-13

C-Band Attenuation, Zero Stage

		Attenuation	Test Time	Site
> 15°	50-150	0 db	0-110 sec	CIF
11	346	> 10	+ 74	UC-13
6	188	> 20	+ 110	UC-13

S-Band Attenuation, Zero Stage

> 25°	100-137	0 db	0-110 sec	STS
> 16	70-150	0	0-110	UC-2
> 15	50-150	0	0-110	CIF
15	306	> 8	+ 75	UC-11
10	346	> 12	+ 74	UC-13
8	223	> 10	+ 110	UC-11
5	188	> 20	+ 110	UC-13

P-Band Flame Attenuation, Zero Stage

> 15°	329-306	0 db	0- 75 sec	UC-11 (and UC-13)
8	223	15	+ 110	UC-11
5	191	15	+ 105	UC-13
2	281	20	+ 90	UC-13
P-Band Attenuation, Stage I				
6°	188	20 db	+ 285	UC-13

Figure 4. Summary of attenuation values with respect to frequency and aspect angle.[15]

[15] From Project SEETHRU Final Report.

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APPENDIX III-C

EFTS DATA LINK FORMAT DEFINITION

Prepared by:
Enhanced Flight Termination Study Team
Date: 18 January 2002

Document Change History

Version	Date	Comments
0.01	8 October 2001	Parsed from Operational Impact Analysis V14
0.03	11 November 2001	Preliminary Draft
1.0	21 December 2001	Final
2.0	18 January 2002	Updated with comments from Phase III close-out
2.1	29 March 2002	Comments after Phase IV close-out

EXECUTIVE SUMMARY

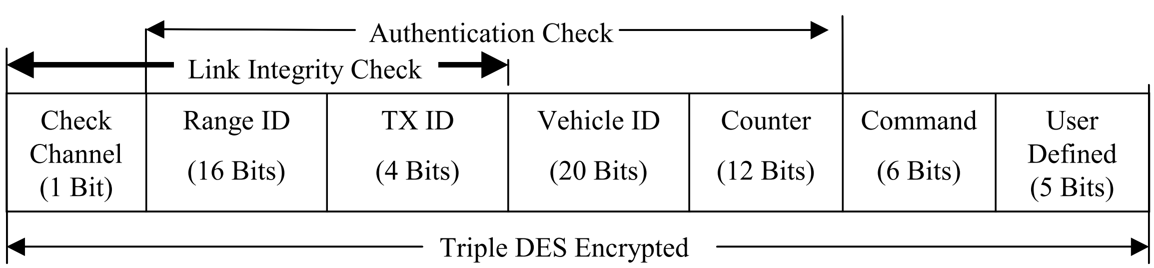
This document describes the formatting and authentication procedures for the recommended Enhanced Flight Termination System (EFTS) command link. The format is defined by a 64-bit encrypted packet that contains all required information relayed between the ground and the vehicle.

Encryption is accomplished using the Triple-DES encryption algorithm in block encryption form. Encyption allows FTRs to be stored in non-secure locations when they are not loaded with a classified key; it is not necessary to protect the algorithm. Transmitter equipment and FTRs will assume the classification of their installed key. Unclassified keys and those units in which they are installed do not require any protection beyond that which is currently required for flight termination equipment.

The attributes of the format enable the following:

- Encryption with an equivalent strength of 112 bits.
- A check channel with functionality similar to that employed today.
- A mechanism to ensure that only 1 of every $1.1 \cdot 10^{12}$ commands that contain at least one bit error would be improperly authenticated.
- 1 048 576 unique vehicle IDs.
- The ability to detect and resist the threat of record and playback of unauthorized commands.
- A user-defined field for supplementary range safety related functions.
- The recommended frame update rate of 50 frames per second.

The recommended frame appears as follows:



This document defines the 64-bit frame, and is compatible with various potential RF modulation and distribution techniques. It assumes a simplex communications link. It is anticipated that encapsulation by various fields and associated algorithms will accompany specific RF modulation techniques, as required. These will potentially accommodate frame synchronization, forward error correction, error detection, and bit synchronization.

1.0 INTRODUCTION

The Range Commanders Council (RCC) Range Safety Group (RSG) is conducting a study into the next generation of ground based flight termination technology, known as the Enhanced Flight Termination System (EFTS). The study was initiated by the RCC in April 2000 with a completion date of March 2002. Government personnel are performing the study with support from contractors and academia.

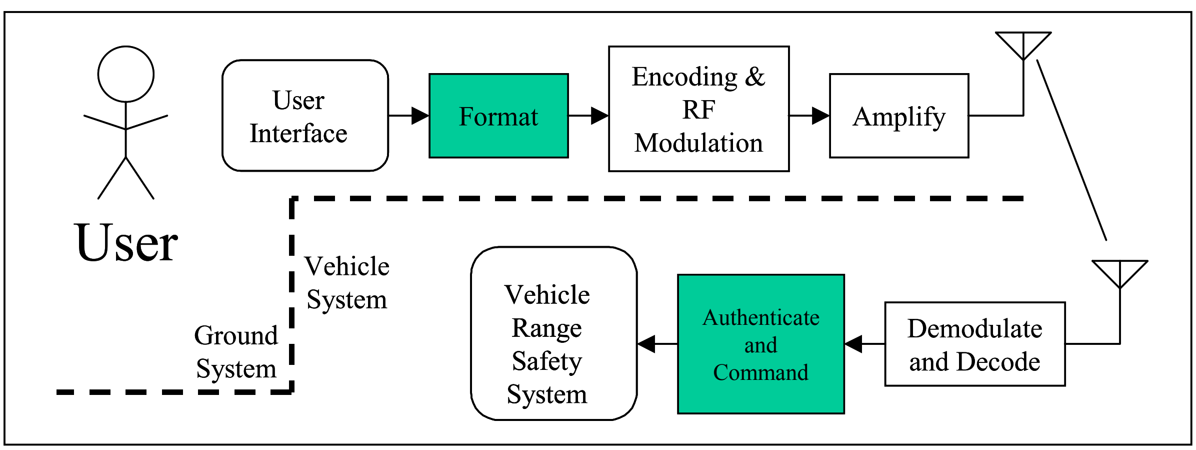
This document contains the recommendations resulting from the EFTS study. It describes the recommended EFTS message format developed for EFTS during the EFTS study Phases I, II and III. A concurrent task is being conducted to simulate potential RF modulation techniques. These tasks complement each other. Together, these two activities will form a knowledge base from which a complete EFTS data link will be recommended.

1.1 Scope. This document provides a rough overview of the EFTS data communications link in section 2. Section 3 describes the recommended EFTS format in detail.

2.0 EFTS COMMAND LINK OVERVIEW

This document defines the format of a digital signal that is used for flight termination. This overview of the EFTS Command link defines the various attributes of the system, and this format's scope within the system.

2.1 Components of EFTS System. For the purpose of this discussion, a generic EFTS system is comprised of components, each of which provides a necessary function, and may be implemented in various physical forms. The figure below depicts the major logical components in the system. It should be noted that while each range may implement its own unique system and procedures for EFTS, these basic functions are provided at each.



2.2 Attributes and Scope of EFT System

Range Infrastructure: Each range has various communications devices to ensure reliable transportation of range safety information within the range and to other ranges, as necessary. As each range has unique needs (e.g., quantity and type of transmitter sites), these components will vary from range to range.

Users: Users of the system include range safety officers (RSOs) and technicians. RSOs execute commands during a mission with the intent of ensuring public safety. Technicians monitor system performance before and during missions to ensure the system's technical reliability. In general, each range has established its own procedures and responsibilities for users. It is the goal of EFTS to use existing range safety procedures to the greatest extent possible.

User Interfaces: Interfacing is generally accomplished via panels that have command buttons and indicators. It is the goal of EFTS to utilize existing user interfaces to the greatest extent possible.

EFTS Data Formatting: This logical component puts the information into the 64-bit EFTS format as described in this document.

Encoding and Modulation: These logical components provide any necessary transport level encoding (i.e. frame synch, FEC, CRC) and modulate the data onto an RF carrier.

Amplifiers: An amplifier increases the RF signal to an acceptable power level. It is the goal of EFTS to use existing range safety amplification components to the greatest extent possible.

Transmit Antenna System: This system radiates RF power. It is the goal of EFTS to use existing antenna system components to the greatest extent possible.

Receive Antenna System: This system collects RF power and provides it to the demodulator. It is the goal of EFTS to be compatible with existing receive antenna systems.

Demodulators and Decoders: These logical components demodulate and decode an RF signal to provide a 64-bit packet to the authenticate and command functions. These functions may rely on feedback from the authenticate and command function to determine whether it has successfully demodulated and decoded the signal.

EFTS Data Authentication and Commanding: This logical component decodes the information of the 64-bit EFTS format as described in this document.

Vehicle Interface: Interfaces EFTS command to the vehicle. It is the goal of EFTS to be compatible with existing vehicle interfaces.

Vehicle Range Safety System: The system that acts upon range safety commands based on user input and the EFTS system. It is the goal of EFTS to be compatible with existing vehicle range safety systems.

Range Safety Flight Support Components: Each range safety system contains various components to support missions. These include monitoring receivers and stations, recorders, and ancillary displays.

3.0 RECOMMENDED EFTS DATA FORMAT DESCRIPTION

The following paragraphs describe the recommended data format and protocol to be employed by EFTS. This format provides encryption, vehicle addressing, link integrity, command authentication and a user-defined field for supplementary range safety related functions.

The format is digital in nature and assumes a one directional data communications link. Thus, feed-back from the vehicle is not required for its operation; however, some feedback from the vehicle will be recommended to enable range safety personnel to obtain status of the links performance during a mission. This is similar to the current method of operation for range safety communications links today.

The attributes of the format enable the following:

- Encryption with an equivalent strength of 112 bits.
- An open encryption algorithm.[16]
- A check channel with functionality similar to that employed today.
- A mechanism to ensure that only 1 of every $1.1 \bullet 10^{12}$ commands that contain at least one bit error would be improperly authenticated.
- 1 048 576 unique vehicle IDs.
- The ability to detect and resist the threat of record and playback of unauthorized commands.
- A user-defined field for supplementary range safety related functions.

The following paragraphs describe the format and its implementation in detail.

3.1 Frame Description

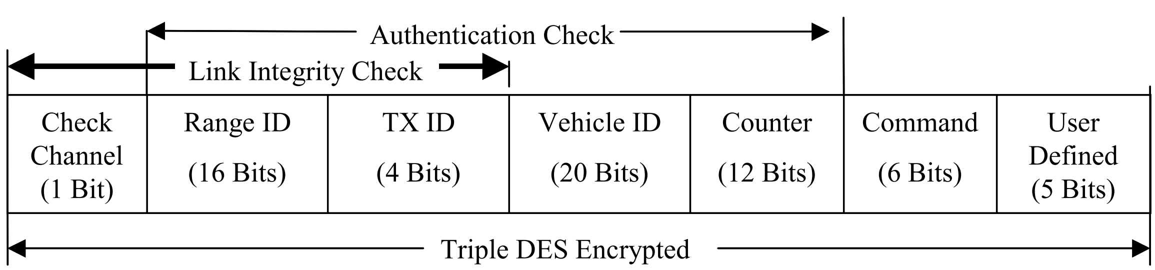


Figure 3-1. EFTS frame description.

[16] Use of open algorithms does not require the protection of the encryption device against theft.

The frame consists of a 64-bit encrypted packet that contains 40 bits of predefined data, a command counter and 3 fields that are settable in real-time by range safety personnel: check channel, command and the user-defined field.

3.1.1 Frame Update Rate and Processing Time. Each frame will be sent at a rate such that commands can be processed every 25 ms. Therefore, the frame period will be 20 ms (50 Hz rate) and the maximum processing time from end of frame to command output will be 5 ms.

3.1.2 Frames for Simultaneous Commands of Vehicles. The transmitter will send commands to multiple vehicles in different frames. It is recommended that each vehicle be commanded in alternating frames.

3.2 Encryption

The encryption algorithm used for this approach will be the 64-bit triple data encryption standard (DES) algorithm per ANSI X9.52-1998, *Triple Data Encryption Algorithm Modes of Operation.*

3.2.1 Bit Order. The frames will be encrypted with the check channel field as the field of least significance and each subsequent field identified in Figure 3.1 (range ID, TX ID, etc.) arranged as a field of higher significance. Each individual field will be arranged with its least significant bit (LSB) attached to the most significant bit (MSB) of a previous field. The encrypted packet will be sent in order, with the LSB being sent first and the MSB sent last.

3.2.2 Secure Key Assignment. Keys used for classified missions will be assigned and distributed by the NSA.

3.2.3 Standardized Key Assignment. The RSG will be allocated standardized keys by the NSA. It is intended that these keys will be assigned and used for the following purposes:

- Each U.S. range will be allocated five unique standardized keys not to be used by other ranges for the purpose of conducting unclassified missions.

- Twenty unique keys will be standardized for use by foreign interests and EFTS equipment manufactures.

- Unique encryption keys may be allocated to individual by programs that wish to use the same key by every vehicle within that program. **Warning: By implementing this method of assignment, the program will assume the risk of improper authentication of the transmission of a signal with this parameter by entities that are not connected with a specific mission.**

3.3 Check Channel Field

A user-settable check channel field will consist of one (1) bit. This field will equate to a logical one when a user sets the field and a logical zero when the field is disabled.

3.4 Range ID

A 16-bit range ID field will be set to a specific value for each mission. Only one value of range ID will be accepted by the FTR as valid for each mission.

3.4.1 Range ID Assignment. A unique range ID will be standardized by the RSG for each U.S. range. The RSG will endeavor to provide the maximum hamming distance possible between each Range ID that is standardized.

- Unique range IDs will be standardized for groups of ranges that endeavor to work together on multi-range missions.

- Unique range IDs will be standardized for use by commercial and foreign interests.

- Unique range IDs will be standardized for use by programs that wish to use the same range ID on every vehicle within that program. **Warning: By implementing this method of assignment, the program will assume the risk of improper authentication of the transmission of a signal with this parameter by entities that are not connected with a specific mission.**

3.5 Transmitter (TX) ID

Transmitter IDs will be assigned by each range. Use of separate transmitter IDs for each transmitter is optional. However, unique transmitter IDs are useful in implementing the counter authentication algorithm across multiple transmitter sites, when autonomous commands can occur. See paragraph 3.9 for a description of this process.

An FTR must be programmed to accept any transmitter ID that is valid for a mission. When multiple transmitters IDs are used on a mission, the FTR must be configured to accept only the possible transmitter IDs that are valid for that mission.

3.6 Check Channel Output

An FTR check channel output will be provided to operate in the following manner. The output will result in a logical one when this field is set, and the range ID and the transmitter IDs contain proper values as described above. If the check channel field is set to logical zero, or the range ID does not contain the proper value, or the transmitter ID does not contain a proper value, the output will be set by the FTR to a logical zero.

The check channel output will be latched for an entire frame period (20 ms). If after that time, a packet is not properly processed, the value will be set to logical zero until it is properly decoded as described above.

3.6.1 Fail-Safe. The fail-safe function shall be tied to this output. For example, the fail-safe process will initiate if the following criteria are met:

1. Fail-safe is activated in the FTR.
2. The check channel output is logical 0 for the predetermined time period.

3.7 Vehicle ID

A 20-bit vehicle ID field will be used for command authentication as described below. Vehicles will only respond to commands within the command field when a message is received with this field set to its individual value. This field will be set to the same value for all FTRs in a redundant FTR system.

3.7.1 Vehicle ID Assignment. A set of unique vehicle IDs will be standardized by the RSG for each U.S. range. The RSG will endeavor to provide the maximum hamming distance possible between each vehicle ID that is standardized.

- Unique vehicle IDs will be standardized for groups of ranges that endeavor to work together on multi-range missions.
- Unique vehicle IDs will be standardized for use by commercial and foreign interests.
- Unique vehicle IDs will be standardized for use by programs that wish to use the same vehicle ID on every vehicle within that program. **Warning: By implementing this method of assignment, the program will assume the risk of improper authentication of the transmission of a signal with this parameter by entities that are not connected with a specific mission.**
- A vehicle ID of 0 is reserved for the null command. No vehicle will be assigned a value of 0 for its vehicle ID.

3.8 Command Counter

- A 12-bit command counter field will be used for command authentication as described herein.
- The use of the command counter is optional for unclassified missions.
- A different counter value will be maintained for each vehicle ID and each transmitter. The counter field is related to the vehicle ID and the transmitter ID located in the same frame in which it is sent and received.

3.8.1 Command Counter Transmitter Characteristics – One TX ID. Missions with only one transmitter ID will synchronize command counter values at each transmit site to ensure that the command counter value that is sent by each transmitter is the same. *It is recommended that this value be generated at one site, and forwarded to any remote sites where it will be sent over the air.*

- Prior to any over-the-air testing, the transmitter value for each vehicle ID will be reset to a value of zero, and the associated command with a command counter value of zero is always the **NULL** command (take no action).

- The transmitter will increment each time a **different** command is sent over-the-air to a specific vehicle ID. For example, the following table identifies the transmitter output values for vehicle ID, command counter, and command associated with a two-vehicle mission.

- Alternating between ARM and TERMINATE will not require a change of counter value after an initial change for each.

Action	Vehicle ID	TX Command Counter	Command
Mission begins, no command	0 = No Command	0	0
(Above repeats in subsequent frames every period)	0	0	0
Vehicle #1 is sent ARM Command	Vehicle ID #1	**1**	ARM
Vehicle #1 is sent ARM Command	Vehicle ID #1	1	ARM
Vehicle #1 is sent TERMINATE Command	Vehicle ID #1	**2**	TERMINATE
Vehicle #1 is sent TERMINATE Command	Vehicle ID #1	2	TERMINATE
Vehicle #1 is sent ARM Command	Vehicle ID #1	1	ARM
Vehicle #1 is sent ARM Command	Vehicle ID #1	1	ARM
Vehicle #2 is sent ARM Command	Vehicle ID #2	**1**	ARM
Vehicle #2 is sent TERMINATE Command	Vehicle ID #2	**2**	TERMINATE

3.8.2 Command Counter Transmitter Characteristics – Multiple TX IDs. Missions with more than one transmitter ID do not need to synchronize command counter values at each transmit site. Each transmitter will operate exactly as described in paragraph 3.8.1 without any need for coordination of the counter value between them.

3.9 Receiver Command Authentication

3.9.1 Authentication without Command Counter. An FTR may be configured to operate without a command counter for non-secure missions. Command authentication without a counter is achieved by matching the predefined values in the range ID, transmit ID, and vehicle ID fields such that, when the receiver properly decodes a message with these fields matched, the command in the command field will be processed.

3.9.2 Authentication with Command Counter. For secure missions, an FTR must use the command counter field to mitigate the threat of a pre-recorded message being sent over the air by an unauthorized entity. This is accomplished by using the following procedures:

- Prior to a mission, an FTR will be configured with its vehicle ID and allowable transmitter IDs in non-volatile memory.

- FTRs will reset their command counter to zero upon power-up.

- FTRs will keep track of command counter values for each transmitter ID that they have been configured to accept. Command counter authentication is achieved when the command counter value is greater than the previous value and by matching the predefined values in the range ID, transmit ID, and vehicle ID fields. When this occurs, the command in the command counter field will be processed, and the counter value for that specific transmitter ID will be set to the ***received*** value.

- TERMINATE commands that have not been preceded by an ARM command will not be accepted and will not cause the receiver’s command counter to be set.

3.10 Command Field

The 6-bit command field will support the following values:

Binary Value (MSB… LSB)	Command	Use
000000	Default	**No action taken**
001001	OPTIONAL	Optional output
010010	ARM	Arm output
100100	TERMINATE	Terminate output if preceding ARM has been latched
000011	TEST	Used for testing
001010	DISABLE	Disables the receiver
011011	Command Counter Clear	Resets the value of the command counter to zero

3.10.1 Command Output Latching. The following command outputs will be latched on indefinitely or until a "Default" command is received: ARM, TERMINATE, OPTIONAL. A loss of power will disable all command outputs; they will be in the off position.

3.11 User-Defined Field

The 5-bit user-defined field is reserved for user specific purposes and may be implemented for use with any range safety purpose. The default, non-use binary value for this field is (MSB) 00000 (LSB).

Data output from an FTR shall be valid for one full frame from the frame period from the time the data is accepted. The external interface that transmits this data from an FTR to another range's safety component shall provide a mechanism to indicate the validity of the data.

3.11.1 User-Defined Field Authentication. This field will be tied to the vehicle ID and will be authenticated using the same process as the command field (see paragraph 3.9).

3.11.2 User-Defined Field Latching. The output of the user-defined field will be latched until another authenticated, user-defined command is received.

3.12 Required Telemetry Data

It is recommended that the following data be provided in a telemetry downlink for use by range safety personnel:

Command status: **Check Channel, Optional**, **Arm**, and **Terminate**.
Command decode valid: **1 bit**. This value would be enabled whenever the FTR is properly addressed and any valid command is received.
Transmitter ID value: **4 bits.**
Command counter value: **12 bits.**
RF attributes related to the modulation technique: **e.g. signal strength, bit error rate**

These values should be available at the output of the receiver every frame period. The rate at which this data is sent is dependent upon the available bandwidth in the telemetry field.

APPENDIX III-D

LEGACY SYSTEMS TEST REPORT

Prepared by:
EFTS Study Team
21 December 2001

1.0 INTRODUCTION

This report will document the results of testing performed on command transmit systems as part of the Range Commanders Council (RCC) Range Safety Group (RSG) Flight Termination Standing Committee (FTSC) task, RS-38. Existing flight termination systems at each range send commands to aerospace vehicles using Inter-Range Instrumentation Group (IRIG) standard tones which are frequency modulated (FM) onto carrier signals. The goal of this testing was to determine the feasibility of upgrading existing systems with equipment that would produce a digital message and transmit these tones in a more secure manner or potentially employ a different type of modulation format.

2.0 OVERVIEW

In order to minimize the amount of testing required while still providing a satisfactory cross section, testing was limited to the most commonly used systems. Zeta Corporation and Systems Planning Corporation manufacture the most frequently used command transmitters. (Paragraph 8 contains a listing of manufacturers for each range). These systems are located at the U.S. Western Range at Vandenberg AFB (VAFB), the Air Force Flight Test Center (AFFTC) at Edwards AFB, and NASA Dryden Flight Research Center (DFRC) also at Edwards AFB. The test plan was focused at these ranges and also distributed to all ranges for completion where possible. Testing began in March 2001 and was completed in November 2001.

2.1 Approach

The EFTS team members and participating vendors identified tests to be conducted to help make a final EFTS approach recommendation. The following six tests were recommended:

1. Phase Noise: This test is designed to determine if spread-spectrum modulation formats could be used with the command transmit systems. Measuring phase noise would reveal any deficiencies in the exciter components.
2. Two-tone Intermodulation Distortion: The purpose of this test is to measure bandwidth, which is defined as the range of frequencies over which the amplitude response does not decrease more than 3 dB relative to the response at the reference point over the specified

frequency band of the device under test.[17] Results would be used to determine the feasibility of using the command systems for coherent and/or spread formats.

3. Amplifier Linearity: Linearity tests measure amplifier output levels with respect to input level applied. Often these measurements are made until the output level begins to decrease by 1 dB while still increasing the input level. This is known as the 1-dB compression point. The results of the linearity tests are useful when considering using the amplifiers with coherent modulation schemes.
4. Gain Balance: Vendors participating in the EFTS study suggested that the legacy systems be tested for gain balance. This procedure refers to the matching of signal levels between channels through a given system. "If any of the components has an amplitude error relative to the others, it will affect the measured amplifier output levels with respect to input level applied."[18] This measurement is often made when considering the use of spread spectrum modulation.
5. Group Delay: Vendors participating in the EFTS study also suggested that the legacy systems be tested for group delay. This test is performed to determine phase distortion in communication systems by measuring delay in transit time using a network analyzer. This measurement is often used with fiber optic systems and when considering spread-spectrum modulation.
6. CPFSK Data Flow Check: The EFTS Legacy System Test Plan refers to this as a bit error rate (BER) test; however, BER tests are typically used to determine a minimum threshold point for data throughput. Since the intent of this portion of the testing was to determine if there would be any problems transmitting Manchester-coded CPFSK data at the expected bit rates, the title has been re-designated as CPFSK Data Flow Check.

The test plan was developed during the early stages of EFTS Phase II. At the completion of that phase, testing had already begun and the two modulation formats to be investigated further were both frequency modulated and thus, non-coherent. Since many of the tests that were planned only applied to spread spectrum formats, they were not completed.

3.0 SYSTEM DESCRIPTIONS

3.1 Introduction

The technical descriptions of the command transmit systems are provided below. Some information is a duplication of that found in the EFTS Phase I Report.

[17] RCC/TG Document 118-97, paragraph 2.2.1
[18] Tektronix Inc., Test, Measurement and Monitoring, 2001

3.2 NASA – Dryden Flight Research Center

The DFRC Command Transmitter System (CTS) consists of two redundant 1-kW transmitter systems located in the Communication Building 4824. The DFRC FTS system can be controlled simultaneously from four locations: three independent DFRC mission control rooms and the AFFTC Ridley Mission Control Center.

The ground transmitter was manufactured by System Planning Corporation (SPC). The system uses modified SPC command transmitters in conjunction with new SPC flight termination system control computers (FCPs). The FTS transmitter command functions are controlled by flight termination panels (FTPs) connected by independent links to the three DFRC mission control rooms and the AFFTC Ridley Mission Control Center. The system operates within the 406 – 550 MHz range while generating up to six IRIG tones simultaneously. Redundancy is built into subsystems comprised of control systems, tone generators/exciters and high power amplifiers. The subsystems feed automatic transfer systems, which bypass defective subsystems and route the modulated command signals to Omni or directional antennas, depending on mission requirements. The effective power output varies from 59 to 78 dBm determined by the selected antenna.

TABLE 1. DFRC TRANSMITTER PERFORMANCE SUMMARY

Transmitter power	1 kW into 2:1 maximum VSWR				
System latency	Less than 200 milliseconds				
Link distance	Line of sight				
Polarization	Left hand circular (LHC)				
Frequency range	406 to 550 MHz				
Modulation type	Frequency deviation of up to 6 simultaneous tones				
Frequency deviation	± 300 kHz				
Tones	20 standard IRIG tones 7.5 kHz to 73.95 kHz.				
Antenna type	**Omni**	**Omni**	**Omni**	**Dish**	**Dish**
Antenna MFR	Tecom	M2	M2	Tecom	RPM
Antenna gain	2 dBi	2 dBi	6 dBi	18 dBi	22 dBi
Polarization	LHC	LHC	LHC	LHC	LHC
Antenna pattern (deg.)	360 Az	360 Az	360 Az/12 El	10 Az/El	12 Az/El
Maximum EIRP (watts)	1KW	1 kW	2.5 kW	40 kW	63 kW
Maximum EIRP	60 dBm	60 dBm	64 dBm	76 dBi	78 dBi

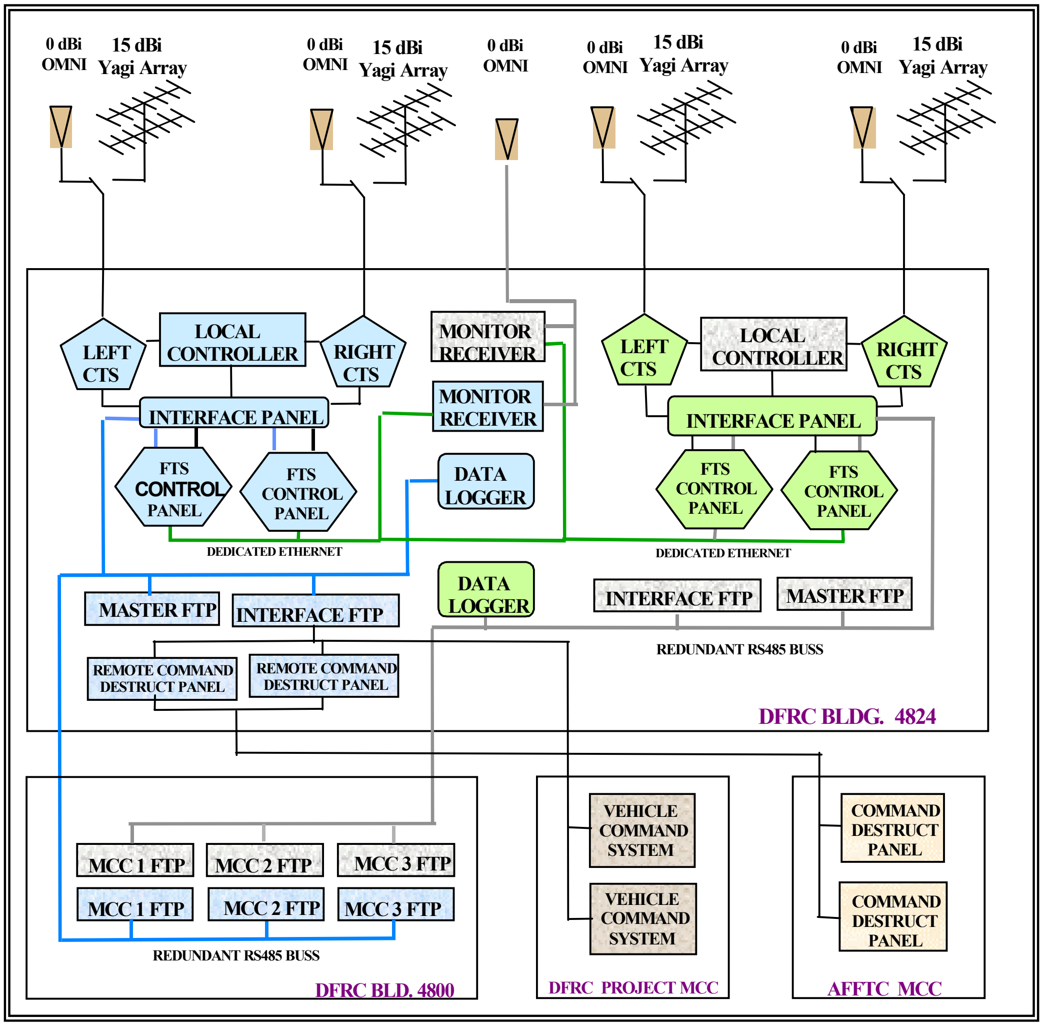


Figure 1. DFRC FTS transmitter system function block diagram.

The local controller provides for manual and automatic switching between the left and right transmitter systems. Time to switch the system is within 0.05 seconds or less. A switch from primary to backup will occur when the RF output power level drops over 3 dB at any time. The exciter is used to generate the 20 standard IRIG tones, generate and modulate the carrier. A maximum of 6 tones can be transmitted simultaneously. The modulated carrier is amplified and used to drive the power amplifier. The exciter operates in the 406 to 550 MHz range and tunes in steps of 100 kHz. The selected frequency has an accuracy of 0.0005%. The exciter is capable of accepting external inputs, if needed, to meet mission requirements.

The HPA is capable of continuous output power at a maximum level of 1000 watts into a 50-ohm load between 406 and 550 MHz. The HPAs are constructed utilizing fully solid state electronics and operate with no degradation to the signal into a VSWR of up to 1.3 to 1. The HPAs are adjustable from 100 to 1000 watts as required for operational support.

The data logger is used to monitor and record all traffic on the RS-485 bus. The bus ties the FTS control system with the flight termination panels used at all the range safety officer stations.

The command monitor computer (CMC) is SPC model 202395. It is used in conjunction with the monitor receiver to independently (over-the-air) monitor and record RF carrier and modulation characteristics. It also provides for command function verification by monitoring the intended commands and confirming that they are broadcast. In the event of command mis-compare, an alarm is triggered.

3.3 Air Force Flight Test Center – Edwards AFB, CA

The CTS van is located next to building 5780, which is on the north side of the west gate entrance to the AFFTC. The CTS is the Zeta model 1376A. It is comprised of commercial-off-the-shelf (COTS) hardware. The CTS design incorporates system redundancy and reliability.

The remote command panel (RCP) receives the command information via an RS-232 serial data stream from the master command panel (MCP) and decodes the message into a transistor logic (TTL) signal. The TTL is then sent to the Zeta switch-over unit for system distribution.

The switch-over unit continually monitors all system parameters through an IEEE-488 internal control bus. It will control and provide automatic or manual switching between the primary or backup RF transmission equipment. The switch-over unit simultaneously routes the command activation messages from the RCP to both IRIG command encoders via the internal control bus.

The IRIG command encoders are Emhiser Research model #ECTE-5R20-02. The command encoders receive the tone activation message and generate the required tones at the specified IRIG tone frequencies. The tones are then routed to the command exciter unit.

The command exciter is Emhiser Research model #ECEC-5R2B2A1R0-04. This unit operates within the frequency range of 406 to 450 MHz.

The Power Systems Technology model BHED48457-1000/5319 high power amplifiers (HPA) amplify the signal from the command exciter to a maximum level of 1000 watts CW, between 406 and 450 MHz. The HPAs have a selectable output control, which allows the amplifier to be adjusted from 100 to 1000 watts, in 100-watt intervals.

DC power is provided to the high power amplifier and the switch-over unit by the TCR 3 Phase power supply. Continuous power output is 30 Vdc to both units.

The auto transfer switch front panel displays which system is on-line (primary or backup), as well as alarm and fault conditions.

The primary RF signal is routed to the Omni antenna system, while the backup RF signal is sent to a dummy load.

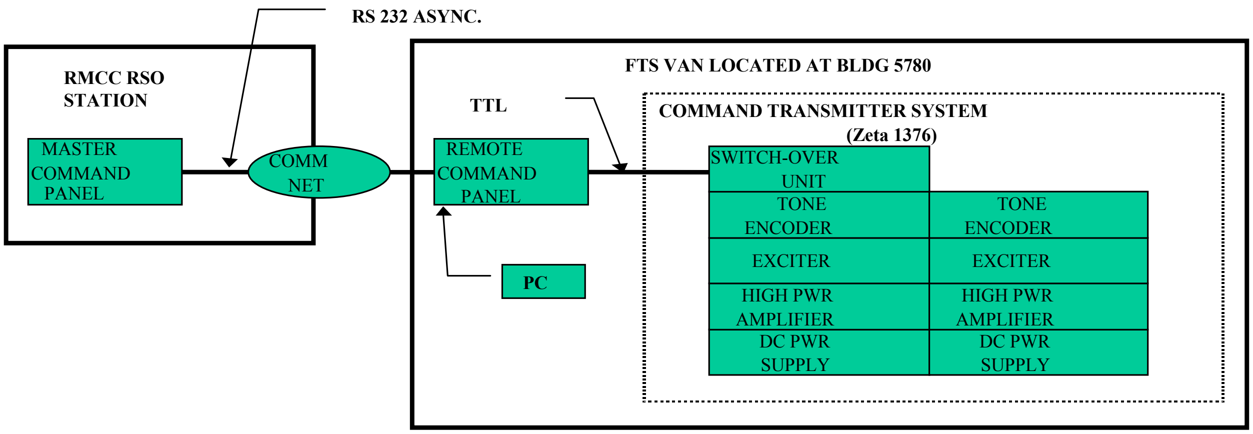


Figure 2. High level architecture of the AFFTC flight termination transmitter system.

TABLE 2. AFFTC TRANSMITTER PERFORMANCE SUMMARY	
Transmitter power	1 kW
System manufacturer	Zeta model 1376A
System latency	Less than 500 milliseconds
Polarization	Left hand circular (LHC)
Frequency range	406 to 550 MHz
Tones	20 standard IRIG tones 7.5 kHz to 73.95 kHz
Antenna type	Omni-directional
Maximum EIRP	56 dBm

3.4 Western Range – Vandenberg AFB, CA

The CTS network consists of four sites that are remotely controlled from the Range Control Center, Building 7000. CT-1 was the only fixed site visited. It is comprised of a redundant 10-kW transmitter manufactured by Aydin Corporation. The CTS utilizes Magnetron tube technology in the high power amplifiers (HPAs). The CTS, along with range tracking systems, are scheduled for modernization within a five-year period.

Operating frequency is 416.5 MHz; however, a plan is in the works to move frequency to 421 MHz. Site (carrier) switching is required to overcome plasma attenuation problems.

The Missile Flight Termination Ground System (MFTGS) is comprised of a Central Command System (CCS), located in the Mission Flight Control Center (MFCC) building 7000, and six remote command control transmitter (CCT) sites. CCT sites 1, 2 and 3 are located at VAFB. CCT site 4 is located at Pillar Point AFS; CCT site 6 is located at USN NAWC, Laguna Peak; and there is a mobile system. All CCT sites are capable of being controlled from the CCS in the MFCC. CCT site 6 is capable of supporting USN remotely-piloted vehicle operations and can be controlled from the NAWC Range Operations Display System (RODS).

Although the CCT sites are similar, CCT-1 was the only fixed system visited by the survey team and discussed in detail. CCT-1 is located on North Vandenberg at building 21200. The site control system has been modernized and has been given the flexibility to be more easily modified to support future programs.

The CCT-1 system is a redundant, multiple microprocessor system designed to prevent inadvertent commands. The site units are also designed to preclude the site from not responding to operational commands due to a failure of one of the subsystems. CCT-1 is an integral part of the MFTGS. It is capable of supporting operations locally from the control console and being remotely controlled from the CCPS located in the MFCC in building 7000. The system can also be configured to support either standard (non-secure) tone or high alphabet (secure) tone transmission. Recording system events is accomplished with a 5-1/4 inch high-density floppy disk drive and printer. Recording events are time tagged with timing derived from IRIG-B. The site is redundant and equipment strings are designated A and B.

The site utilizes two Aydin high power amplifiers (HPAs) capable of producing 10 kW. The HPAs are Varian type 4KM50000LA5 four-cavity, velocity-modulated beam klystrons. Frequency transmission is selectable between 400 and 450 MHz. The HPAs are driven by a synthesized signal source that feeds a low power amplifier to produce the drive power for the HPA klystrons. The HPA output is a nominal 10-kW CW with a 60-dB bandwidth of ±180 kHz.

A Marconi 2019A synthesized signal generator provides the base frequency. The Marconi has a frequency range of 80 kHz up to 1040 MHz. The frequency synthesizer is controlled by the RF control signal processor (RCSP) subsystem in the control console. The frequency selection is limited by firmware in the RCSP to between 400 and 450 MHz in 0.5 MHz steps. The selected frequency is dependent on the antenna type. The Omni antenna has a specified frequency band of 400 to 425 MHz. The directional antenna has a specified frequency band of 400 to 450 MHz.

The site console control system is capable of generating the following audio tones:

- IRIG (standard) tones 1 - 20 and high alphabet tones 1-7
- Standard mode
- Secure Transmission System (STS)
- Uplink mode

Three COMM processors are fully networked together so that system data is shared and the control subsystem is triple redundant. COMM processors A and B exercise overall control of the CCT-1 system and provide the interfaces for local and remote control. COMM processor C provides the CRT display and event recording and votes with the A and B processors on the site operations. The RCSP generates the modulation signals and monitors the output signals from the HPAs.

The control panel is manufactured by ITT Federal Systems and can be remotely activated by the mission flight control officers in building 7000 or locally by the system operators. Panel data format is comprised of a 40-bit high-level data link control (HDLC) message that is transmitted at 2400 bits per second. The transmission medium is a combination of fiber optic and microwave transport systems. The latency requirement (EWR 127-1) for remote command activation is approximately 55 milliseconds. The actual measured time is 70 milliseconds from button push to leading edge of CTS transmission. A new development is in the works to provide a 56K data link.

The command panel can be selected to operate either in the secure (high alphabet) or standard tone transmission modes. Code loading is accomplished via KYK-13 load device. Codes are loaded at the ROC and at the CCT site. Control panel features include the following:

- Continuous or cycle tone modes
- Selectable check (monitor) tones 4 or 5
- Fail over enable
- Carrier control per site

The RF test panel routes the system RF between the control system and HPAs. It provides test points for the site operators.

There are two FM receivers (A and B). These Marconi 2305 modulation meters are the receive units for the control system of the RF sample and are controlled by the RCSPs. The deviation level is displayed on the front panel.

The site has a dual antenna system consisting of a 10-kW Omni antenna and a 15-kW directional antenna. Both antennas are LHCP. The Omni antenna has a 3-dB beam width of 190 degrees and 1 dB of gain. The directional antenna is a 15 foot parabolic dish with 3-dB beam width of 10 degrees and 23 dB of gain. Omni and directional antennas are interfaced to the HPA through the RF switching unit. This allows the RF antenna configuration to be controlled from the control console.

The RF switching system allows the HPAs to be terminated into a 15-kW dummy load or into the site antenna system. The switching system allows the A or B system HPA to be switched to the antenna system and allows selection of either the Omni or directional antenna. RF switching is accomplished by using high power vacuum coaxial relays and vacuum coaxial isolators. These components allow the site to switch configurations with carrier blanked for less than 55 milliseconds and provide approximately 100 dB of dummy load isolation.

4.0 TEST PROCEDURES

The following procedures are used to test the legacy systems at NASA-Dryden and AFFTC-Edwards AFB. The procedures were developed by EFTS team members and participating vendors.

4.1 NASA – Dryden Testing Procedures

4.1.1 Phase Noise Test

The phase noise measurements were made on the Dryden SPC system using an HP 8561E spectrum analyzer. Software was purchased and installed to perform all measurements automatically. The results were plotted with an HP 7440A plotter and can be found in paragraph 6.

4.1.1.1 Equipment Used:

- Spectrum analyzer, HP 8561E with the HP 85671A phase noise utility installed
- Plotter, HP 7440A
- Attenuator, 30 dB, Bird model 8322
- Attenuator, 20 dB, Pasternack model PE7000-20

4.1.1.2 Test Configuration:

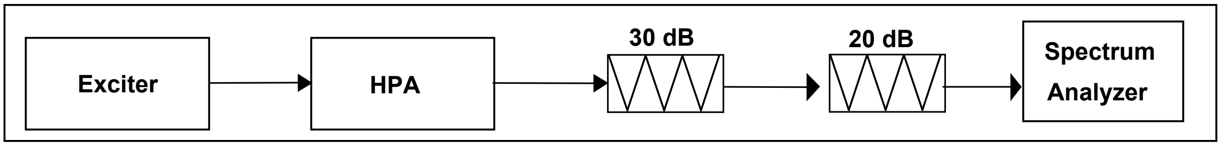


Figure 3. DFRC phase noise test setup.

4.1.1.3 Test Procedure:

4.1.1.3.1 The analyzer was configured as follows:

Freq. range	10 Hz to 1 MHz
Smoothing	12 pt.
Filtering	OFF
Ref. level	–20 dBc/Hz

4.1.1.3.2 The exciter was tuned for each of the center frequencies listed.

4.1.1.3.3 Output power was set in accordance with normal operating levels.

4.1.1.3.4 No tones or external modulation was applied.

4.1.1.3.5 Once measurements of the complete system were performed, the procedures were repeated without the HPA; in effect, measuring only the exciter.

4.1.1.4 Test Results:

Initial results showed higher levels of noise than expected below 1 kHz. In order to determine the source, the procedures were re-accomplished by measuring only the exciter. The resulting plots showed almost exactly the same pattern as the complete system so the exciter was the source of noise, as expected.

4.1.2 Two-Tone Intermodulation Distortion Test

The two-tone test procedure calls for two signal generators to produce RF outputs that are summed together in a power combiner before being applied to the HPA input. A combiner able to handle these RF inputs at the power levels required was not available. This test could not be accomplished on the SPC systems, but the results would not impact the modulation schemes being considered for EFTS.

4.1.3 HPA Linearity Test

The tests performed at Dryden were done using a power meter with a high power sensor. Input levels were monitored using a spectrum analyzer. Data points were plotted and the resulting chart can be found in paragraph 6.

4.1.3.1 Equipment Used:

- Spectrum analyzer, HP 8594E
- RF power meter, Bird model 4421
- Power sensor, Bird 1kW
- Directional coupler, Pasternack PE 2200-30

4.1.3.2 Test Configuration

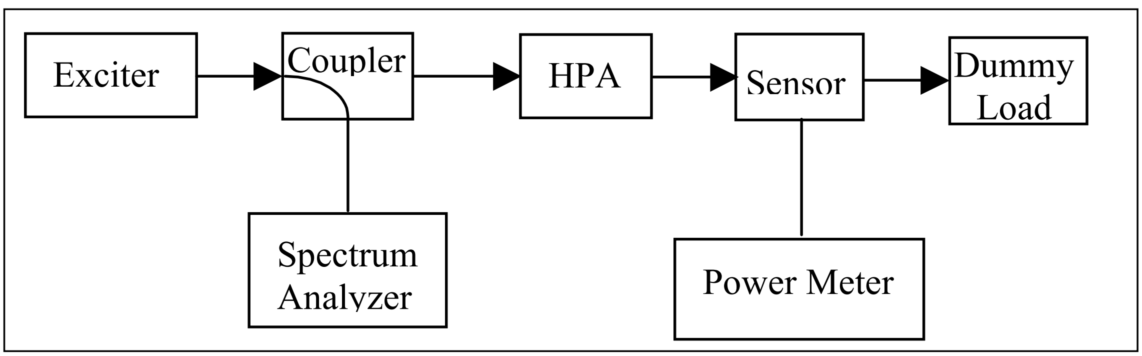


Figure 4. DFRC linearity test setup.

4.1.3.2.1 The analyzer was configured as follows:

Freq. span	400 kHz
Res. BW	10 kHz
Video BW	10 kHz

4.1.3.3 Test Procedure:

4.1.3.3.1 The exciter was tuned for each of the center frequencies listed.

4.1.3.3.2 The power meter sensor was connected to the exciter output.

4.1.3.3.3 The exciter was adjusted for the minimum acceptable level for the HPA (–10.62 dBm).

4.1.3.3.4 While measuring the HPA output level with a power meter, the input level was increased in 1-dB steps until just above typical operating range (0.35 dBm).

4.1.3.4 Test Results:

The table below illustrates the linearity of the HPA. Testing to the 1-dB compression point was not possible; however, measurement slightly above typical operating range was achieved. A chart displaying these results can be found in paragraph 6.

TABLE 3. DFRC LINEARITY TEST RESULTS	
Input (dBm)	**Output (dBm)**
–10.62	46.4
–9.62	47.5
–8.69	48.6
–7.71	49.8
–6.62	51.1
–5.69	52.2
–4.65	53.5
–3.69	54.7
–2.77	55.9
–1.74	57
–0.67	58.3
0.35	59.4

4.1.4 Gain Balance Test

Since the test equipment required is not readily available and the EFTS team is no longer pursuing a spread spectrum format, this test was not accomplished.

4.1.5 Group Delay Test

The test was performed on the Dryden SPC system prior to the EFTS selection of non-coherent modulation formats.

4.1.5.1 Equipment Used:

- Network analyzer, HP 8752C
- 30 dB 1-kW Attenuator, Bird 8322
- 30 dB 250-watt attenuator, Weinschel 58-30-43

4.1.5.3 Test Configuration:

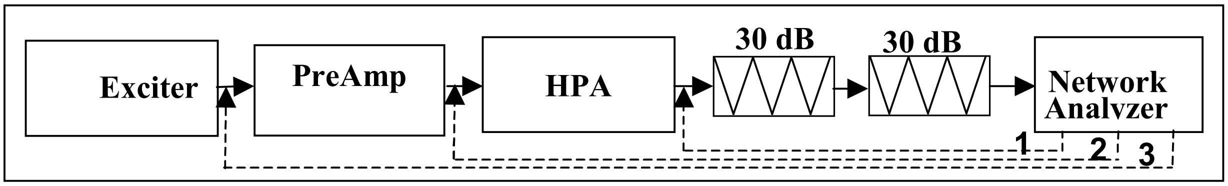


Figure 5. DFRC group delay test setup.

4.1.5.2.1 The analyzer was configured as follows:

Center freq. 421 MHz

Freq. span 407 – 432 MHz

4.1.5.3 Test Procedure:

4.1.5.3.1 An analyzer reference was set by connecting the output to the input through the two attenuators.

4.1.5.3.2 The HPA was then connected and measured at each carrier frequency.

4.1.5.3.3 The pre-amplifier and HPA were both connected and measured at all frequencies.

4.1.5.4 Test Results:

4.1.5.4.1 The table below illustrates the group delay of the SPC system.

TABLE 4. DFRC GROUP DELAY TEST RESULTS

	Reference	HPA Only	Pre-amp & HPA
421 MHz	61.9 ns ±.1	115.2 ns ±.2	136.0 ns ±.1
425 MHz	62.1 ns ±.1	115.9 ns ±.2	136.2 ns ±.1
428 MHz	62.2 ns ±.1	116.0 ns ±.3	136.0 ns ±.2

4.1.6 CPFSK Data Flow Check Test

To effectively test the entire SPC system, a bi-phase-level pseudo-random pattern from a link analyzer was inserted into the modulator and adjusted for ± 60 kHz deviation. Since a 410 to 430 MHz tuner was not available, the 21.4 MHz monitor receiver IF output was mixed with a 2221.4 MHz continuous wave (CW) signal resulting in a difference frequency of 2200 MHz. This modulated signal was injected into the telemetry receiver and the demodulated output was sent to a bit synchronizer for clock generation and to "square up" the waveform. Finally, this pseudo-random data pattern was sent to the input of the link analyzer for bit errors to be counted.

4.1.6.1 Equipment Used:

- Spectrum analyzer, HP 8594E
- Telemetry receiver, Microdyne 700-MR
- Link analyzer, DSI 7192B
- Bit synchronizer, Veda DBS-200
- Synthesized signal generator, Agilent ESG-E4432B
- Double-balanced mixer, Mini-Circuits ZAM-42

4.1.6.2 Test Configuration:

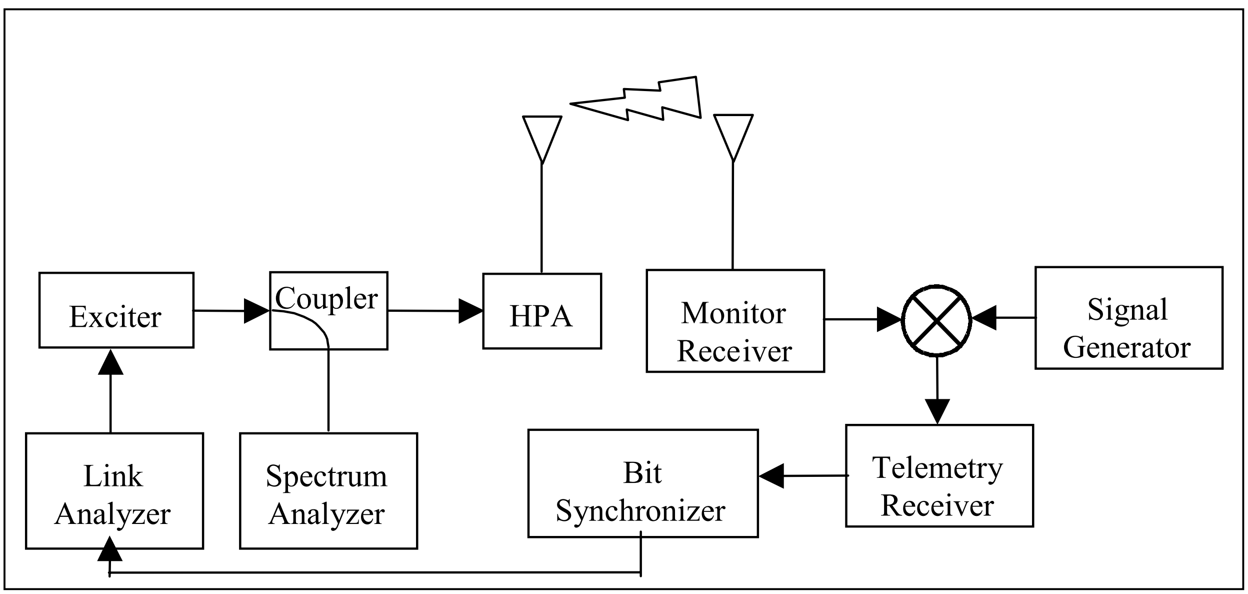


Figure 6. DFRC CPFSK data flow check setup.

4.1.6.2.1 The link analyzer was configured as follows:

Bit rate	10 kbps
Pattern	2047
Coding	Bi-Phase-L
Bit period	10^6

4.1.6.2.2 The telemetry receiver was configured as follows:

RF input	2200 MHz
IF bandwidth	1.0 MHz
Video BW	12.5 kHz
Demod.	FM (100)
AGC T.C.	0.10 ms

4.1.6.3 Test Procedure:

4.1.6.3.1 The exciter was tuned for 428 MHz and adjusted for typical operating level.

4.1.6.3.2 The link analyzer PCM output was adjusted for 1 volt pk-pk and the exciter was adjusted for ± 60 kHz as observed on the exciter front panel and the spectrum analyzer.

4.1.6.3.3 The link analyzer was reset and read no zero errors.

4.1.6.3.4 The "ERROR IN" switch was then selected to ensure the link was valid. The correct number of errors was displayed verifying the setup was correct.

4.1.6.4 Test Results:

This procedure was to be repeated at the most commonly used carrier frequencies of 421, 425 and 428 MHz. It was also to be accomplished at bit rates of 3, 5 and 8 kbps. Execution of the first run-through, however, caused the tone decoder relays in the monitor receivers to excessively activate and deactivate, a.k.a. relay "buzzing". It was decided that since continued operation of the relays in this manner would affect their life expectancy, the testing should not be prolonged. The objective to determine whether or not the SPC modulator would process CPFSK data was successfully achieved.

4.2 AFFTC – Edwards AFB Testing Procedures

4.2.1 Phase Noise Test

The phase noise measurements were made on the AFFTC mobile system using an HP 8561E spectrum analyzer. Software was purchased and installed to perform all measurements automatically. The results were plotted with an HP 7440A plotter and can be found in paragraph 6.

4.2.1.1 Equipment Used:

- Spectrum analyzer, HP 8561E with the HP 85671A phase noise utility installed
- Attenuator, 30 dB, Bird 8322
- Attenuator, 20 dB, 6 dB and 3 dB, Pasternack models PE7000-20, PE7000-6, PE7000-3

4.2.1.2 Test Configuration:

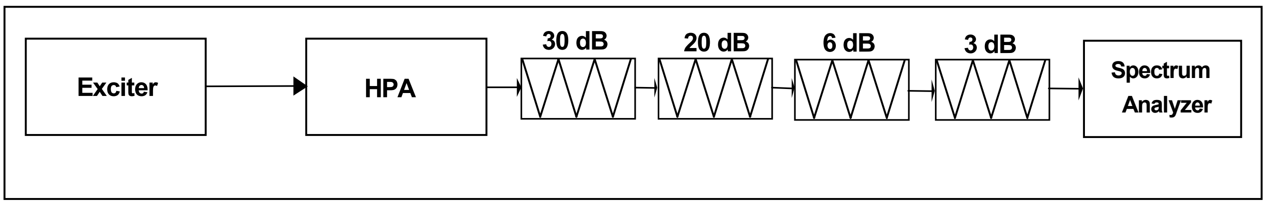


Figure 7. AFFTC phase noise test setup.

4.2.1.3 Test Procedure:

4.2.1.3.1 The analyzer was configured as follows:

Freq. range	10 Hz to 1 MHz
Smoothing	12 pt.
Filtering	OFF
Ref. level	–20 dBc/Hz

4.2.1.3.2 The exciter was tuned for each of the center frequencies listed.

4.2.1.3.3 Output power was set in accordance with normal operating levels.

4.2.1.3.4 No tones or external modulation was applied.

4.2.1.3.5 Once measurements of the complete system were performed, the procedures were repeated without the HPA— in effect, measuring only the exciter.

4.2.1.4 Test Results:

Initial results showed unreadable noise levels below 200 Hz. In order to determine the source, the procedures were re-accomplished by measuring only the exciter. The resulting plots were very similar pattern to the complete system so the exciter was the source of noise, as expected.

4.2.2 Two-Tone Intermodulation Distortion Test

According to Zeta engineers, the 1376 System is configured with a "level control loop" which means the HPA will not function without the proper power level input. The HPA input must receive the appropriate level from the pre-amplifier in order to operate. For this reason, the two-tone test could not be accomplished on the Zeta system, but the results would not impact the modulation schemes being considered for EFTS.

4.2.3 HPA Linearity Test

Since the Zeta system components cannot be tested individually for the reasons listed above, the linearity test could not be accomplished on the Zeta system, but the results would not impact the modulation schemes being considered for EFTS.

4.2.4 Gain Balance Test

Since the test equipment required is not readily available, and the EFTS team is no longer pursuing a spread spectrum format, this test was not accomplished.

4.2.5 Group Delay Test

Since the test equipment required is not readily available, and the EFTS team is no longer pursuing a spread spectrum format, this test was not accomplished.

4.2.6 CPFSK Data Flow Check Test

To effectively test the entire Zeta system, a bi-phase-level pseudo-random pattern from a link analyzer was inserted into the modulator and adjusted for ± 60 kHz deviation. Since a 410 to 430 MHz tuner was not available, the 10.7 MHz monitor receiver IF output was mixed with a 1430.7 MHz continuous wave (CW) signal resulting in a difference frequency of 1420.0 MHz. This modulated signal was injected into the telemetry receiver and the demodulated output was sent to a bit synchronizer for clock generation and to "square up" the waveform. Finally, this pseudo-random data pattern was sent to the input of the link analyzer for bit errors to be counted.

4.2.6.1 Equipment Used:

- Spectrum analyzer, HP 8594E
- Telemetry receiver, Microdyne 700-MR
- Link analyzer, DSI 7192B
- Bit synchronizer, Veda DBS-200
- Synthesized signal generator, Agilent ESG-E4432B
- Double-balanced mixer, Mini-Circuits ZAM-42
- Monitor receiver, ICOM IC-R8500

4.2.6.2 Test Configuration:

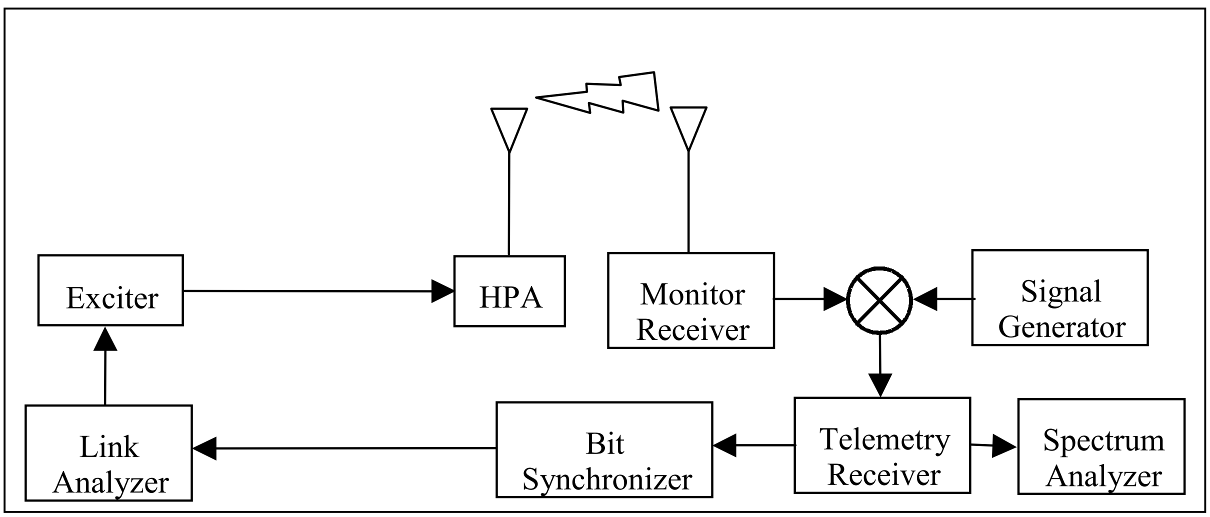


Figure 8. AFFTC CPFSK data flow check setup.

4.2.6.2.1 The link analyzer was configured as follows:

Bit rate	3 kbps
Pattern	2047
Coding	Bi-Phase-L
Bit period	10^6

4.2.6.2.2 The telemetry receiver was configured as follows:

RF input	2200 MHz
IF bandwidth	1.0 MHz
Video BW	12.5 kHz
Demod.	FM (100)
AGC T.C.	0.10 ms

4.2.6.3 Test Procedure:

4.2.6.3.1 The exciter on the primary system was tuned for 421 MHz at typical operating level.

4.2.6.3.2 The link analyzer PCM output was adjusted for 1 volt pk-pk and the exciter was adjusted for ± 60 kHz as observed on the exciter front panel and the spectrum analyzer.

4.2.6.3.3 The link analyzer was reset and read no zero errors.

4.2.6.3.4 The "ERROR IN" switch was then selected to ensure the link was valid. The correct number of errors was displayed verifying the setup was correct.

4.2.6.3.5 The above procedure was repeated for bit rates of 5 and 8 kbps.

4.2.6.3.6 The above procedure was then repeated using the backup system.

4.2.6.5 Test Results:

This was to be repeated at the most commonly used carrier frequencies of 421, 425 and 428 MHz. Frequency clearance to radiate at frequencies other than 421 was not obtained; however, since this procedure is a test of modulator performance, carrier frequency selection is not definitive. The objective of determining whether or not the Zeta 1376 modulator would process CPFSK data was successfully achieved.

4.3 Western Range – Vandenberg AFB Testing Procedures

4.3.1 Phase Noise Test

Phase noise measurements made at Vandenberg were accomplished prior to completion of the EFTS Legacy Test Plan. The results from this testing revealed that the noise levels discovered would preclude the klystron-powered systems from being used for coherent modulation formats which are not, however, being considered for EFTS.

4.3.2 Two-Tone Intermodulation Distortion Test

The Vandenberg systems are configured with a "level control loop" which means the HPA will not function without the proper power level input. The HPA input must receive the appropriate level from the pre-amplifier in order to operate. For this reason, the two-tone test could not be accomplished on the Zeta system 10 kW, but the results would not impact the modulation schemes being considered for EFTS.

4.3.3 HPA Linearity Test

The klystron-powered HPAs at Vandenberg were not tested for linearity but are reported to be non-linear, and its amplifying characteristics are frequency dependent. The amplifiers manufactured by Zeta Corporation employ a constant loop configuration, thus preventing linearity measurements.

4.3.4 Gain Balance Test

Since the test equipment required is not readily available and the EFTS team is no longer pursuing a spread spectrum format, this test was not accomplished.

4.3.5 Group Delay Test

Since the test equipment required is not readily available, and the EFTS team is no longer pursuing a spread spectrum format, this test was not accomplished.

4.3.6 CPFSK Data Flow Check Test

On-site testing of the Vandenberg 10-kW system could not be arranged; however, the purpose of this procedure is to test the ability of the modulator to process CPFSK data. Since the 10 kW system uses a Marconi 2019A signal generator, one was obtained at Dryden for testing.

A bi-phase-level pseudo-random pattern from a link analyzer was inserted into the modulator and adjusted for ± 60 kHz deviation. Since a 410 to 430 MHz tuner was not available, the modulator output was mixed with CW signals of 171, 175 and 178 MHz resulting in a difference frequency of 250.0 MHz. This modulated signal was injected into the telemetry receiver, and the demodulated output was sent to a bit synchronizer for clock generation and to ”square up” the waveform. Finally, this pseudo-random data pattern was sent to the input of the link analyzer for bit errors to be counted.

4.3.6.1 Equipment Used:

- Spectrum analyzer, HP 8565A
- Telemetry receiver, Microdyne 700-MR
- Link analyzer, Apcom Labs Data Link Test Set MITC-461
- Bit synchronizer, (internal to the link analyzer)
- Synthesized signal generator, HP 83732B
- Double-balanced mixer, Mitek

4.3.6.2 Test Configuration:

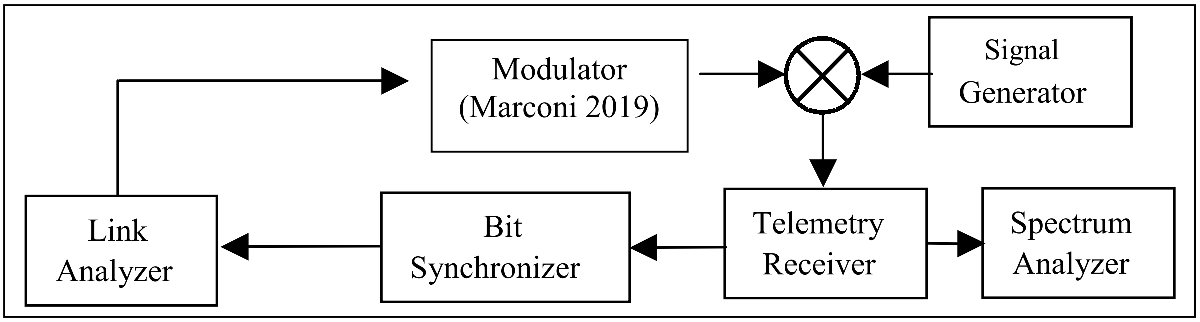


Figure 9. Vandenberg AFB CPFSK data flow check setup.

4.3.6.2.1 The link analyzer was configured as follows:

Bit rate	3 kbps
Pattern	2047
Coding	Bi-Phase-L
Bit period	10^6

4.3.6.2.2 The telemetry receiver was configured as follows:

RF input	250 MHz
IF bandwidth	500 kHz
Video BW	12.5 kHz
Demod.	FM (100)
AGC T.C.	0.10 ms

4.3.6.3 Test Procedure:

4.3.6.3.1 The modulator was tuned for 421 MHz with an output level resulting in approximately 20 dB above the telemetry receiver noise floor.

4.3.6.3.2 The link analyzer PCM output was adjusted for 1 volt pk-pk and the modulator was adjusted for ± 60 kHz as observed on the spectrum analyzer.

4.3.6.3.3 The link analyzer was reset and read no zero errors.

4.3.6.3.4 The "ERROR IN" switch was then selected to ensure the link was valid. The correct number of errors was displayed verifying the setup was correct.

4.3.6.3.5 The above procedure was repeated for bit rates of 5 and 8 kbps.
4.3.6.3.6 The above procedure was then repeated at carrier frequencies of 425 and 428 MHz.

4.3.6.4 Test Results:

The objective to determine whether or not the Marconi 2019 modulator would process CPFSK data was successfully achieved.

5.0 CONCLUSIONS

All of the tests proposed were completed within the time constraints allotted and within the system capabilities. To clarify, four of the six procedures in the test plan required that individual components be tested separately, which was not feasible with the Zeta system.

The impacts of not accomplishing these tests as they apply to this study, however, are negligible. During the testing process, Phase II of the EFTS study had been completed resulting in the selection of only two modulation schemes for consideration. Both of the schemes use frequency modulation (FM) and a form of digital data with deviation levels similar to those currently used by the legacy systems. Given that fact, engineers from SPC, Zeta, CMC and the EFTS team agree that the only procedure in the test plan that would apply to these modulation formats was the CPFSK data flow check.

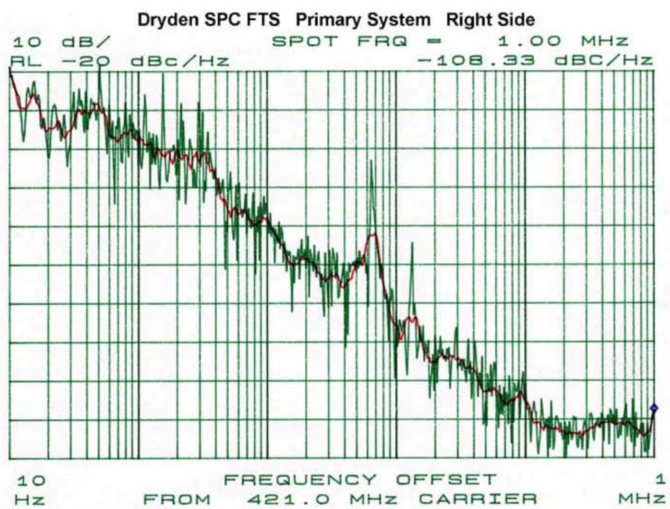
The CPFSK data flow was the only test in the test plan that yields information as to whether the legacy systems can support modulation schemes being considered for EFTS. These tests were accomplished and the results were satisfactory. It is, therefore, the EFTS team's contention that either of the FM formats being considered for EFTS will not require the replacement of any of the following:

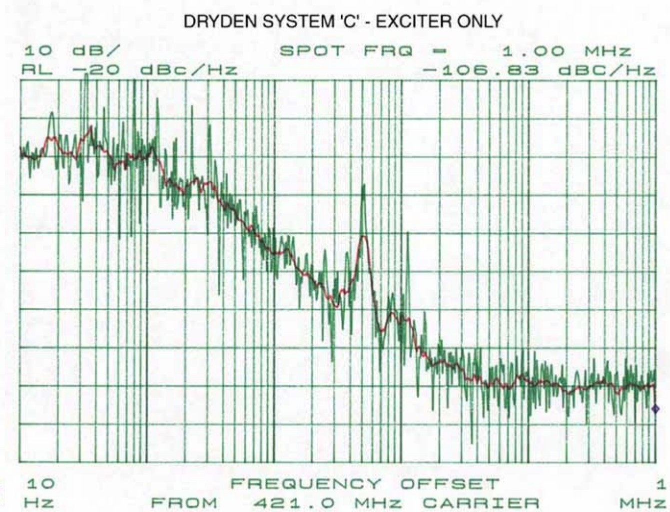
- Mission control panels
- Interface cabling
- High power amplifiers
- RF cabling
- Antenna systems

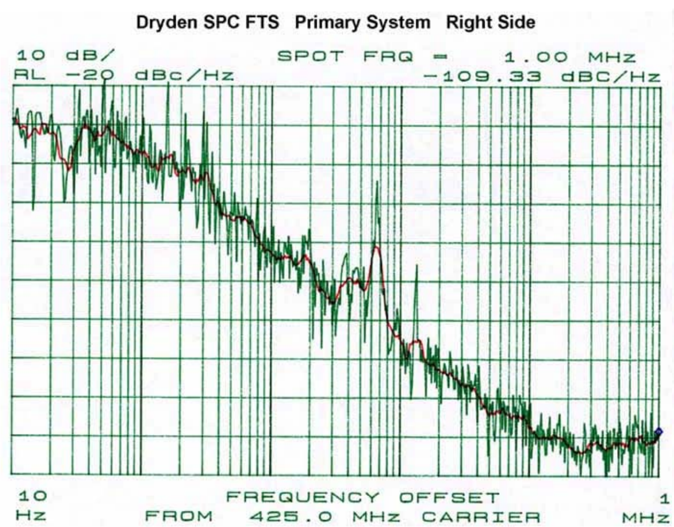
As expected, due to the advancement from tone-based commands to a digital format, the tone generators will have to be replaced with command encoders, and monitoring equipment will have to be either upgraded or replaced. A cost analysis is being conducted by the EFTS team and participating vendors to estimate these upgrade expenses.

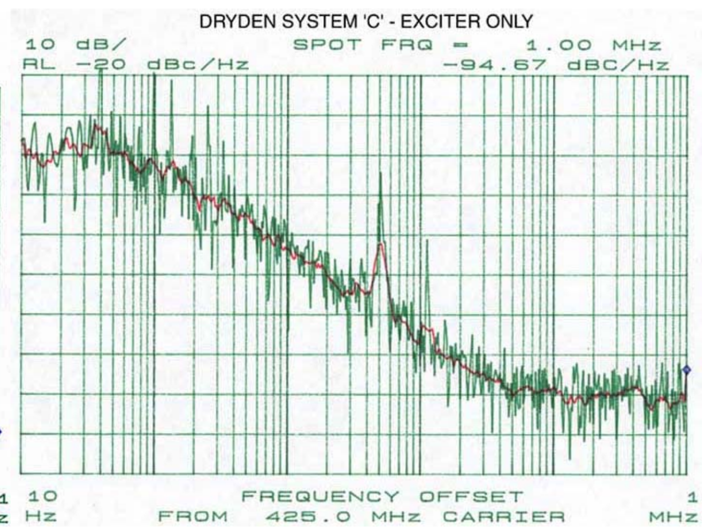
6.0 PHASE NOISE PLOTS

The following section shows the plots of phase noise measurements performed on the DFRC primary system. Measurements of the backup or bottom system were also accomplished and the results were identical.Note that the primary system was also referred to as "Alpha" but is now designated as the "Top" system in reference to the mounting position of the Dryden Range Control Officer (RCO) command panels. Each system also has a "right" and "left" side. The letter designations A through D were also used for a short period.

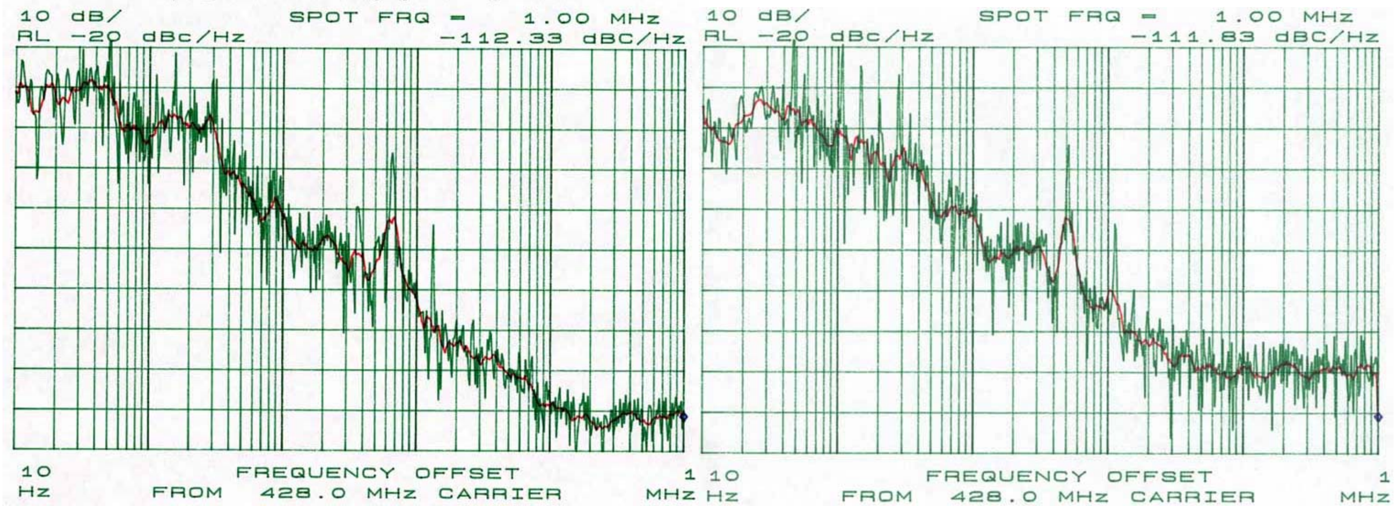

Dryden SPC FTS Primary System Right Side
10 dB/
RL -20 dBc/Hz
SPOT FRQ = 1.00 MHz
-108.33 dBC/Hz
10 Hz
FREQUENCY OFFSET
FROM 421.0 MHz CARRIER
1 MHz


DRYDEN SYSTEM 'C' - EXCITER ONLY
10 dB/
RL -20 dBc/Hz
SPOT FRQ = 1.00 MHz
-106.83 dBC/Hz
10 Hz
FREQUENCY OFFSET
FROM 421.0 MHz CARRIER
1 MHz


Dryden SPC FTS Primary System Right Side
10 dB/
RL -20 dBc/Hz
SPOT FRQ = 1.00 MHz
-109.33 dBC/Hz
10 Hz
FREQUENCY OFFSET
FROM 425.0 MHz CARRIER
1 MHz

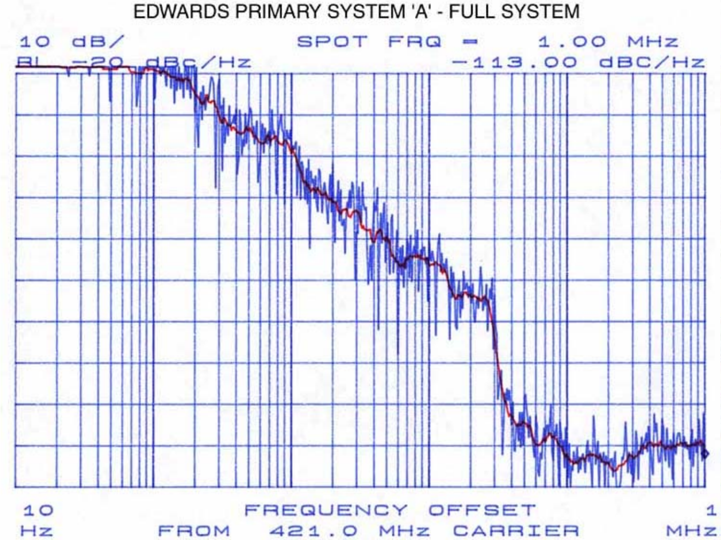

DRYDEN SYSTEM 'C' - EXCITER ONLY
10 dB/
RL -20 dBc/Hz
SPOT FRQ = 1.00 MHz
-94.67 dBC/Hz
10 Hz
FREQUENCY OFFSET
FROM 425.0 MHz CARRIER
1 MHz

Dryden SPC FTS Primary System Right Side

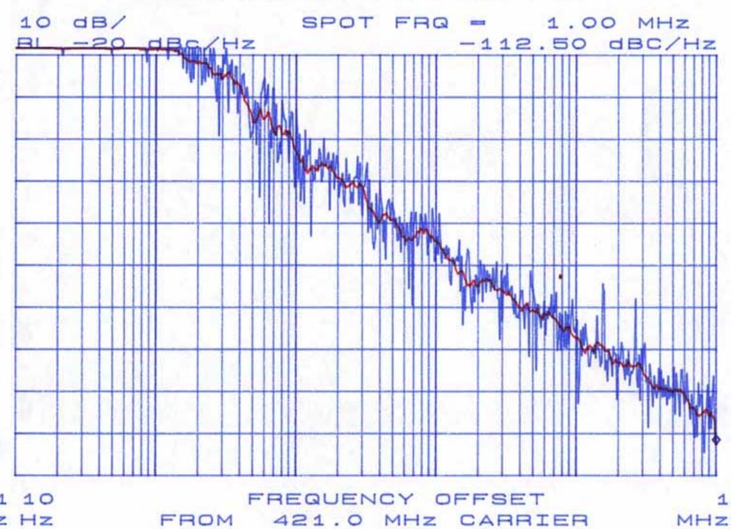


The following section shows the plots of phase noise measurements performed on the AFFTC primary system. Measurements of the backup were also accomplished and the results were identical.

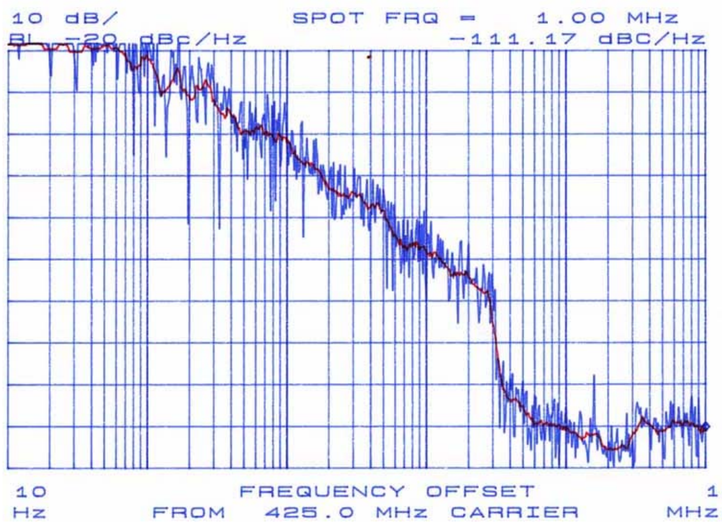
EDWARDS PRIMARY SYSTEM 'A' - FULL SYSTEM



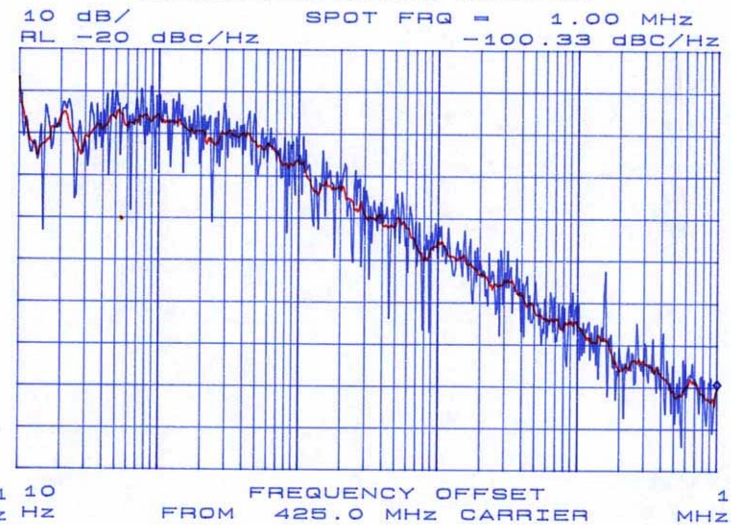
EDWARDS PRIMARY SYSTEM 'A' - EXCITER ONLY



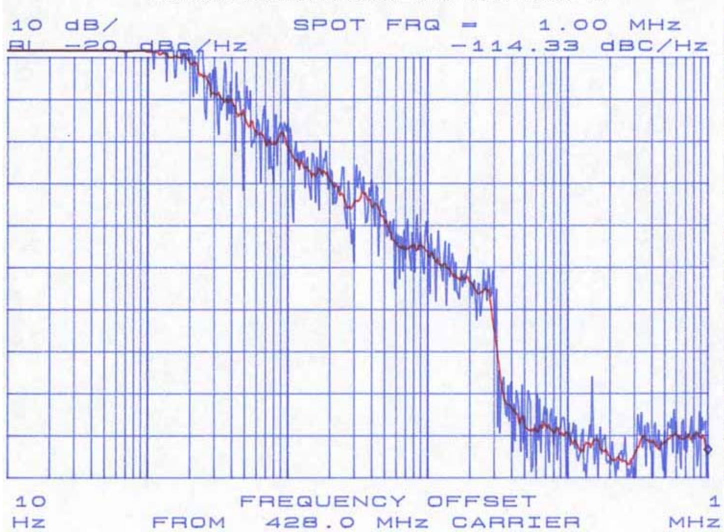
EDWARDS PRIMARY SYSTEM 'A' - FULL SYSTEM



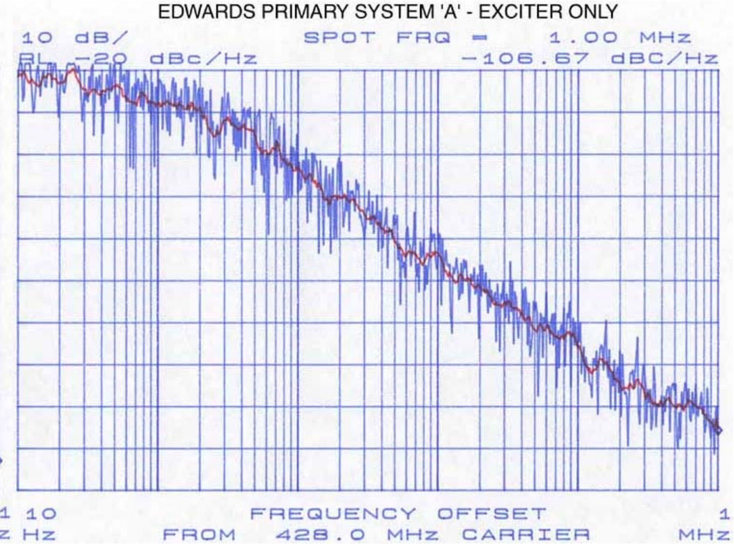
EDWARDS PRIMARY SYSTEM 'A' - EXCITER ONLY



EDWARDS PRIMARY SYSTEM 'A' - FULL SYSTEM

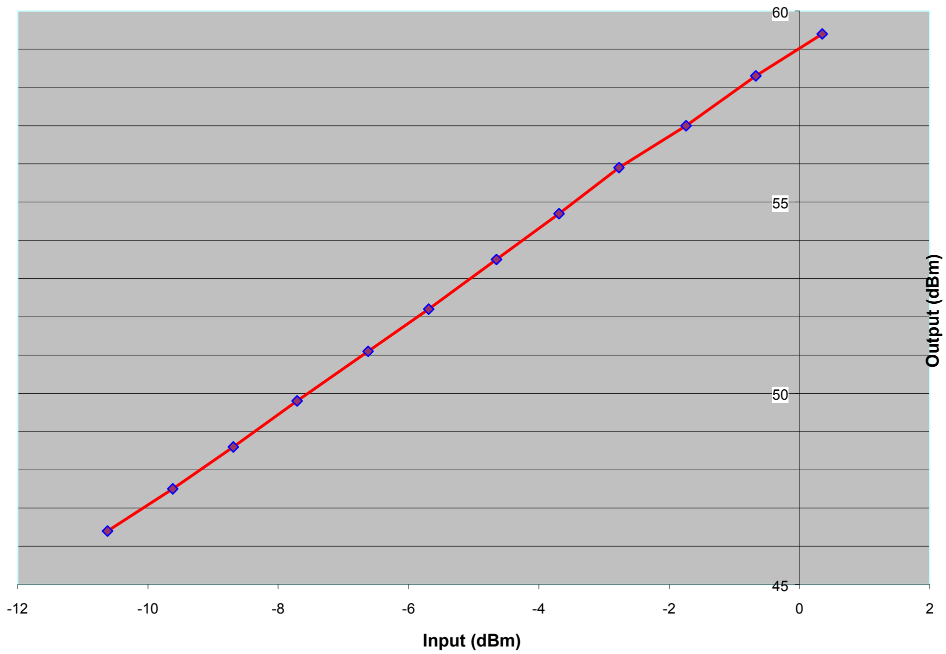


EDWARDS PRIMARY SYSTEM 'A' - EXCITER ONLY



7.0 LINEARITY CHART

The following is a chart of the data points for the linearity tests performed on the DFRC command transmit system.



8.0 SUMMARY TABLE OF GROUND SYSTEM MANUFACTURERS

Range	Manufacturer	System Integrator
AFFTC	Zeta Corp	Reliable Systems Services Corp
NASA Dryden	Systems Planning Corp.	Systems Planning Corp.
WSMR	Systems Planning Corp.	Systems Planning Corp.
China Lake NAWCWD/WD	Zeta	Pt. Mugu NAWCWD/WD
Cape Canaveral AFS	Eastern Test Range	Eastern Test Range
Eglin AFB	Aleph	Eglin AFB
NASA Wallops Flight Facility	Zeta/RSS Corp.	NASA Wallops
Tyndall AFB	Zeta	Tyndall AFB
Pt. Mugu	Zeta	Pt. Mugu NAWCWD/WD
VAFB	Zeta	VAFB

9.0 CONTRIBUTORS

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References

1. RCC Task RS-38 Enhanced Flight Termination System Command Transmitter Characterization Testing, May 2001.

2. Systems Planning Corp., *FTS Control System Operating Manual*, August 2000.

3. RCC/TG Document 118-97, *Test Methods For Telemetry Systems And Subsystems Volume 2 Test Methods For Telemetry RF Subsystems*, June 1997.

4. RCC/TTG Document 208-85, *IRIG Standards for UHF Command Systems*, March 1985.

5. EWR 127-1, *Eastern and Western Range Safety Policies and Procedures*, Chapter 4, October 1997.

6. AFFTC Mobile FTS Operational Procedures, 2001.

7. Zeta (EPSCO), *Command Transmitter System Maintenance Manual for Model 1376*, April 1989.

8. Tektronix Inc., *Test, Measurement and Monitoring*, 2001.

9. Hewlett Packard, *Model 8752C RF Network Analyzer Operating Manual*, 1995.

APPENDIX III-E

FINAL REPORT
SPREAD SPECTRUM STUDY

Kenneth P. Day
SRI International, Vandenberg AFB, CA

ABSTRACT

On 16 March 2001 the Enhanced Flight Termination System (EFTS) Team completed a technology assessment that assessed modulation techniques for more robust and secure Flight Termination Systems (FTS).[1] The assessment concluded that Modified High Alphabet and Continuous Phase Frequency Shift Keying (CPFSK) warranted additional analysis and further work. These two methods were chosen after evaluation of various perspectives including overall system attributes, environmental considerations, performance, and human factors.[2] Both methods were carried forward for eventual downselection to a final modulation technique. This report covers a follow-on study funded by NASA Dryden Flight Research Center (DFRC) and implemented by ITT Systems Division at Vandenberg AFB. The study objective was to investigate the ability of spread spectrum modulation techniques to meet EFTS objectives. In this respect the spread spectrum review closely followed the study and evaluation process used to select Modified High Alphabet and CPFSK. The exact same design guidelines and evaluation criteria used for the first selection process were applied to the spread spectrum study. The study placed special emphasis on: 1) the ability to meet performance guidelines within baseline and relaxed bandwidth objectives, 2) the ability to maintain link closure under high vehicle dynamics, and 3) the capability to operate under specified interference conditions.

BACKGROUND

ITT Systems Division, Vandenberg AFB, CA acted as NASA Dryden's representative to provide contractual implementation of the spread spectrum study and to oversee the study process. ITT chose two vendors, CMC Electronics Cincinnati and Interstate Electronics, Anaheim, CA, to provide the technical investigation. The two contractors operated independently. The study was initiated on 1 June 2001 and completed in early October 2001. The Statement of Work, Design Guidelines, and Evaluation Criteria are included in Annex A. The structure of the study included four major tasks each of which was reported to ITT, NASA DFRC, and the EFTS Team. The four tasks provided: 1) contactor review and comment on the guidelines, 2) preliminary technical proposals, 3) proposed design solutions (including interference and dynamics reports), and 4) final reports.

AREAS OF FOCUS

Bandwidth. The single most important technical subject was bandwidth. The Statement of Work provides three alternatives for bandwidth. First, the vendors were directed to comment on the ability to meet a 360 KHz, 60 dB bandwidth restriction and still meet all other guidelines. Second, vendors were directed to comment on the impact that relaxing bandwidth to 360 KHz, 20 dB. Finally, vendors were encouraged to comment on the effect of opening up bandwidth to 1 MHz, 20 dB. Note that the baseline 360 KHz, 60 dB bandwidth represents a typical allocation for current range flight termination systems.

Dynamics and Environments. The ability of coherent modulation schemes to maintain link closure under high vehicle dynamics warranted special attention. For this reason the Design Guidelines provide reference vehicle operating conditions for yaw, pitch, and roll rates as well as vibration and shock environments. While the advantages and disadvantages of coherent detection are beyond the scope of this report, it is important to note any design that employs coherent methods for flight termination must be carefully evaluated for vulnerability to dynamically-induced or environmentally-induced phase noise. This is because the airborne receiver employed in a coherent scheme would use knowledge of the carrier's phase to detect the command signals.[3] The vendors were accordingly directed to provide reports addressing the ability to operate in reference dynamics and environments.

Interference. Spread spectrum methods can, depending on the particular design, provide significant advantages in this area (typically at the expense of wider bandwidth). Note that ranges participating in the EFTS Program have been directed to migrate to a new set of carrier frequencies in the 420 – 450 MHz range. Operation in this new frequency band may confront some ranges with significantly increased interference environments. In this respect, some ranges will lose the *primary user* status they enjoyed using the old frequencies and become *tertiary users* in the new frequency band. This change in status implies far less frequency protection against competing signal sources for some ranges. For these reasons, the vendors were directed to provide interference reports based on coordinated interference threats.

PROPOSED DESIGN SOLUTIONS

Both vendors proposed variants of Code Division Multiple Access (CDMA); neither pursued frequency hopping because of bandwidth restrictions. The final reports are available upon request. While a full review of the reports is left to the reader, this paper will provide a detailed description of results for the three areas of interest described above.

Bandwidth. CMC reported that a 2.6 MHz bandwidth (double sided) would be required to meet design guidelines. The message format included 64 encrypted bits for compatibility with triple data encryption standard (DES) requirements and 16 bits dedicated to frame synchronization. The proposed chip rate was 500 kchps converted to NRZ-M and binary phase shift keyed onto an RF carrier. Acquisition time varied from 305 ms to 920 ms depending on the complexity (and cost) of the selected correlation method. CMCs proposal represents an industry standard approach to CDMA; a unique pseudo-random (PN) code is assigned to each command transmitter. All transmitters operate on the same frequency band; this method takes advantage of CDMAs ability to use independent parallel correlators in the airborne receiver to simultaneously track signals from multiple transmitters using the same frequency band.

All CDMA applications must deal with the near/far problem. The tern "near/far" denotes the possibility that a transmitter that is *near* the flight vehicle could overwhelm the signal from a transmitter that is *far* from the vehicle. Again, all transmitters use the same frequency band, so there is no frequency offset between transmitters. CMCs proposal uses industry-standard *cross-correlation* protection for isolation between the PN codes employed by transmitters; this is the same method used by the Global Positioning System (GPS) for code isolation. Note that this approach uses continuous transmissions from each transmitter and depends on unique mathematical properties of the selected code family for isolation.

During the first design review with IEC an alternative modulation technique was conceived. This innovation uses *auto-correlation* to provide a higher degree of protection from the near/far problem and decrease required bandwidth. This method does away with continuous transmission from each ground transmitter and uses a sequential method in which no two transmitters emanate at the same time. The IEC Final Report compares the two correlation methods and shows that the auto-correlation approach can greatly reduce bandwidth requirements. Like all technical tradeoffs, there is a cost; decreased bandwidth comes at the expense of acquisition time. This trade reflects the difference between a continuous signal stream (described in the cross-correlation example) and the sequential transmission method (described in the auto-correlation example). Accordingly, if all other parameters are held equal, the auto-correlation method will require a longer acquisition time. For the IEC proposal, the worst-case acquisition time can not be reduced below 1.28 seconds if the bandwidth is held at 360 kHz, 60 dB. The reader is cautioned that there are many parameters involved with the bandwidth/acquisition time trade and encouraged to review the Final Reports in detail.

Summary for Bandwidth. Throughout the EFTS evaluation process, bandwidth has been a concern for spread spectrum applications. The CMC approach shows that conventional CDMA methods will require a 2.6 MHz, 60 dB bandwidth to meet remaining applicable design guidelines. The auto-correlation approach developed by IEC and the EFTS Team offers substantial improvements in bandwidth and near/far protection at the expense of acquisition time. Neither method supports the original design guideline of 100 ms for acquisition/ reacquisition listed in the guidelines.

As an additional note on bandwidth and acquisition time, it is worth recalling the difference between guidelines and requirements. Throughout the EFTS process, guidelines have been presented to private industry as a framework to help vendors understand operational needs in the most general sense. For example, the guidelines have always encouraged vendors to answer two questions with respect to bandwidth. First; “what can you do within the 360 kHz restriction?” and second; “what could you do with wider bandwidth?” The first question allowed the team to identify immediate solutions (such as Modified High Alpha and CPFSK) that are affordable, sustainable, and well suited to all ranges. The second question stimulated innovation and provided candidate long-range proposals for a limited set of ranges that may be interested in (for example) space-based range operations. Clearly, spread spectrum belongs in the second category.

Dynamics and Environments. As described above, phase stability is a significant concern for employment of coherent detection schemes for flight termination. Both vendors acknowledged this vulnerability and suggested that critical components (such as the reference oscillator in the airborne receiver) could be mounted on shock/vibrations isolators. For an example of the effect of environmentally-induced phase noise, see page five of the CMC report. IEC suggested using new-generation fiber optic oscillators which could be less susceptible to flight environments. Additionally, both vendors noted during design reviews that 30 – 40 GRMS vibration provides a cost/performance threshold.

At this point coherency/phase noise has been identified as a concern. The next step would be testing to precisely measure the ability of coherent tracking loops to maintain track during reference environments listed in the guidelines. This testing would be neither difficult nor expensive; test tables capable of imposing reference environments are readily available as are tracking loops that represent candidate designs.

Summary for Dynamics and Environments. Phase stability has been identified as an area of concern for the two proposed designs, both of which employ coherent detection methods. The study confirmed the theoretical basis for this concern. Because confirmation testing was beyond the scope of the study, such testing would be a logical next step in the investigation.

Interference. The two proposed methods provide a traditional advantage of spread spectrum systems, the ability to reject interference. The correlation process in the receiver spreads the interfering signal to the bandwidth of the interfering signal plus the bandwidth of the desired signal.[4] For example, if the interfering signal had a 2 MHz bandwidth and the desired signal had a 2 MHz bandwidth, the interferer would be spread to 4 MHz. In other words, much of the signal power of the interferer would be spread outside the bandpass of the desired signal. Following this example, spread spectrum is most effective against wideband interferers and least effective against narrowband sources. Accordingly, the level of protection is dependent upon the nature of the interference source. While this example does not fully cover the techniques and advantages of spread spectrum for interference rejection, it does point out that such protection can be a powerful advantage, depending on the characteristics of the interferer.

To support the spread spectrum study the EFTS Team coordinated a list of four candidate interference sources; this list was provided to the two vendors. Results are included in attached vendor reports. Note that these reports do not address theoretical advantages of spread spectrum; they focus directly on the ability of proposed designs to operate in candidate interference environments. As such, they offer a reference point that any interested range can use to evaluate proposed designs against general families of anticipated interference sources.

The study paves the way for a potential next step in evaluating spread spectrum capabilities for interference rejection, to directly compare performance against other modulation techniques. This would involve a breadboard level test that would impose anticipated interference environments on the proposed spread spectrum designs as well as other modulation methods. Such testing may be particularly relevant as the ranges migrate into frequency bands that provide substantially less frequency protection than traditional bands.

Summary for Interference. Theoretical advantages for spread spectrum are well understood. However, the real merit depends on the nature of the interfering signal. Included reports show performance of proposed designs against a set of reference interference sources. Confirmation testing was beyond the scope of the study. Breadboard testing would be a logical next step to compare the capabilities of the full family of modulation techniques to operate in interference environments.

FINAL COMMENTS

The reader is encouraged to review the attached vendor reports. They provide far more detail and cover many more parameters than this report. The study process has confirmed EFTS Phase II conclusions that Modified High Alpha and CPFSK offer clear advantages for immediate, affordable, and supportable capabilities. However, it is worth considering that adherence to the immediate, affordable, and supportable inevitably lead to reliance on existing, in-place technologies. Also, it is important to note that the design guidelines have always recognized the difference between what we can achieve right now and what we may want to achieve in the future. In these respects, the study provides interested ranges with increased insight into opportunities (such as auto-correlation for decreased bandwidth), challenges (such as the need to clarify vulnerability to vibration), and potential advantages in interference rejection.

REFERENCES

1. *Enhanced Flight Termination System Study Phase II Report*, 16 March 2001, p. iii. [Editor's note: The Phase II report is incorporated into this document as Chapter 3.]

2. Ibid.

3. Sklar, Bernard. *Digital Communications Fundamentals and Applications,* Upper Saddle River, New Jersey, Prentice Hall, 1988, p. 127.

4. Dixon, Robert. *Spread Spectrum Systems,* New York, John Wiley and Sons, 1984, p. 173.

ANNEX A

STATEMENT OF WORK
SPREAD SPECTRUM TECHNOLOGY FOR COMMAND LINKS

Introduction. The Range Commanders Council (RCC) has formed an Enhanced Flight Termination System (EFTS) Team to provide information on new technologies for flight termination systems. This Statement of Work supports the EFTS by examining applications of spread spectrum technology to command links employed by RCC member ranges.

Task One: Review and Comment on Design Guidelines

The sub-contractor shall review Design Guidelines (Appendix I-A) as the basis for technical proposals. The guidelines represent general guiding principles provided by member ranges for next-generation flight control systems. As such, they should be interpreted as guidance, not as unchangeable requirements.

Because bandwidth will be a key parameter of the technical proposal the sub-contractor shall consider the following alternatives during the review: 1) comment on restrictions that the 360 kHz, 60 dB bandwidth imposes on design solutions, 2) comment on the impact of relaxing the baseline to 360 kHz, 20 dB, 3) comment on the impact of relaxing the bandwidth to 1 MHz, 20 dB, and 4) comment on the impact of using the less restrictive bandwidth description included in the second part of the Design Guidelines.

A second key requirement will be applicability of existing ground systems (example – command transmitter stations) to next-generation command links. The sub-contractor shall accordingly consider and comment on 1) restrictions imposed by Part One Guidelines that assume use of existing ground systems, and 2) Part Two Guidelines, which encourage use of new ground systems. ITT will provide a survey of existing ground systems.

The intent of placing particular emphasis on these two driving guidelines is to answer two questions. First, “what are the advantages of applying spread spectrum technology if we use today’s authorized bandwidth and ground systems”? Second, “what would be the advantages of applying spread spectrum technology with wider bandwidth and new ground systems”?

The sub-contractor should note that multiple access is of high interest to the EFTS. The EFTS Team is particularly interested in methods that permit the proposed Flight Termination Receiver (FTR) to simultaneously accept commands from multiple ground stations using the same transmit frequency (or frequency hopping scheme). Also, the EFTS Team is equally interested in the ability of individual ground stations to use a single transmit frequency (or frequency hopping scheme) to control multiple vehicles and any limitations or vulnerabilities associated with multiple access technology. The sub-contractor shall comment on these areas of interest during Task One.

The sub-contractor should also note that anti-jam capability is of interest to the EFTS Team. The sub-contractor shall comment on this area of interest during Task One. This area of interest may be emphasized in the Tailored Design Guidelines at the completion of Task One.

Task One comments shall be provided in a slide review with EFTS Team Members. Guidelines which, in the judgment of the sub-contractor, drive cost or complexity should be highlighted and discussed in detail. The EFTS Team will (as appropriate) tailor the Design Guidelines and the General Approach Description (Appendix II-B) to provide a baseline for the following tasks. Tailoring will consider sub-contractor comments, EFTS Team response to comments, and (as appropriate) areas of special interest covered above.

Task Two: Preliminary Technical Proposal

Using the tailored Design Guidelines, the sub-contractor shall examine application of spread spectrum technology and propose preliminary conceptual design solutions. This task is the sub-contractor's first response to the tailored Design Guidelines. Tailored guidelines should be addressed in a general sense to show the EFTS Team how proposed conceptual designs meet each guideline. The intent of this Task is to ensure that the team understands and concurs with the general directions that the sub-contractor has provided.

The sub-contractor's response should place particular emphasis on two areas that will become stand-alone reports for Task Three. First, ITT will provide a list that characterizes typical interference sources in the 420-450 MHz band. The response should include an estimate of the ability of each preliminary proposal to operate robustly in the reference interference environment. Second, the response should include an estimate of the ability of each preliminary proposal to operate throughout flight dynamics and environments listed in the Design Guidelines with emphasis on proposed signal tracking methods.

Task Two will be completed with a slide presentation to the EFTS Team. This presentation should be thought of as discussion with the team and an opportunity to assure consensus with the proposed direction for detailed engineering analysis in Task Three.

Task Three: Proposed Design Solutions

This task develops preliminary conceptual designs into detailed technical proposals that will be presented through the EFTS-provided General Approach Description. In this task detailed engineering-level analysis is required; dedicated testing and use of historical ground and flight test data should be employed as appropriate to clearly address each item in the General Approach Description.

The sub-contractor should complete two stand-alone reports during Task Three. The sub-contractor shall provide an Interference Report (limited to several pages) on the ability of each proposed design to operate robustly in interference environments listed in the ITT-provided list. Also, the sub-contractor shall provide a Dynamics and Environment Report (limited to several pages) on ability of each proposed design to operate throughout flight dynamics and environments listed in the Design Guidelines. Ability to maintain signal tracking through reference dynamics and environments should be covered. Acquisition time and reacquisition time should be addressed in detail.

Task Three will be completed with a Task Three Design Review attended by members of the EFTS Team. The sub-contractor shall address each of the items provided in the General Approach Description in detail during the review as well as results of the two Task Three Reports. Reports and Design Review slides shall be provided to the EFTS Team one week prior to the Design Review.

Task Four: Final Report

Following completion of Task Three the sub-contractor shall provide a written Final Report which addresses each proposed conceptual design within the framework of the General Approach Description. The report shall individually address action items provided by the EFTS Team during the Conceptual Design Review.

Program Teleconferences. The sub-contractor shall participate in short (typically one-half hour or less) bi-weekly telecons to discuss progress and resolve questions. Telecon dates and times will be "as agreed to" by ITT and the sub-contractor.

Deliverables

Task	**Product**	**Due Date** (Time from contract start—June 01)
Task 1. Review and comment on design guidelines	Slide presentation covering each design guideline	3 weeks
Task 2. Preliminary technical proposal(s)	Slide presentation covering each tailored design guideline	8 weeks
Task 3. - Proposed design solutions - Interference report - Dynamics and environments report	Written report and slide presentation covering each item in the general approach description.	13 weeks
Task 4. - Final report - Response to action items	Final report	16 weeks

Funding Source: NASA Dryden Flight Research Center will MIPR funds to VAFB using existing MIPR #E04468D.

APPENDIXES

PHASE IV

APPENDIX IV-A

TELECOMMUNICATIONS & TIMING GROUP (TTG) TASK TT-42

1. **Title:** Update/Revise Range Commanders Council (RCC) Standard 208-85.

2. **Scope and Specific Objectives**: The purpose of this task is to update the contents of RCC Standard 208-85, *IRIG Standards for UHF Command Systems,* to reflect existing range transmitting systems and where practical, include changes as a result of the Enhanced Flight Termination System (EFTS) study.

3. **Utility of End Product**: This document constitutes a guide for implementation and application of the UHF Command Transmitter Systems (CTS) on the ranges under the cognizance of the RCC.

4. **Approach**: The required data will be solicited from each member range and supplemented with data gathered by the EFTS team during the course of Task RS-38 and RS-42.

5. **Additional Coordination Required**: Coordination with all member ranges as well as the RSG/FTSC, FMG and the EFTS team will be required.

6. **Assignment and Management**: Performance of this task will be under direction/lead of the TTG coordinating with the EFTS team, FMG, and the RSG/FTSC.

7. **Resources Required**: The task will require both government and contractor personnel from the RSG/FTSC, EFTS team, FMG, and TTG.

8. **Total Cost Estimate**: No additional funding for this effort is required. This section is for information only. Funding is derived from on-going efforts of the EFTS team chartered under tasks RS-38 and RS-42. Any additional participants from the cited groups, including the TTG, would be locally funded.

9. **Milestones**:

MAY '02	Task initiated
MAY '02	Identify deficiencies, establish format
JUL '02	Begin coordination for inputs to Standard
SEP '03	Complete data collection and begin draft
MAR '04	Draft Standard available for review
SEP '04	Final review
MAR '05	To RCC Secretariat for publication, task complete.

RCC 208-XX SCHEDULE		EFTS SCHEDULE	
Date	**Milestone**	**Date**	**Milestone**
May-02	Task initiated		
May-02	Identify deficiencies, establish format	May-02	Release RFP for prototype equipment
Jul-02	Begin coordination for inputs to Std.	Jul-02	Contract award for prototype equipment
Sep-03	Complete data collection	Sep-03	Demonstration evaluation complete
Sep-03	Begin draft	Oct-03	Development starts
Mar-04	Draft Standard review		
Sep-04	Final review		
Mar-05	Submit to RCC Secretariat for publication		
May-05	Task complete	May-05	Development complete

10. **Names, Organization and Phone Number of Task Chair and Other Participants**:

Mr. Darrin Loken, WSMR, TTG/EFTS, serves as task lead
Mr. Tom McAndrews, EFTS, TYBRIN Corp., facilitator/coordinator
Mr. Ron Cofer, Eglin AFB, RSG/EFTS
Mr. Chris Sniderhan, VAFB,

11. **Completion Date**: Mar '05 – Submit to RCC for publication.

APPENDIX IV-B

RANGE SAFETY GROUP (RSG) TASK RS-XX

1. **Title:** Update/Revise RCC Standard 307-79.

2. **Scope and Specific Objectives**: The purpose of this task is to update the contents of RCC Standard 307-79, *Range Safety Transmitting Systems 406-549 MHz Band*, to reflect existing Range hardware and where practical, include latest changes due to the Enhanced Flight Termination System (EFTS) Program.

3. **Utility of End Product**: This document provides detailed descriptions of the Range Safety ground transmitter(s). This includes technical data regarding make-up of each range's command termination transmitters as well as their geographical locations and any associated mobile systems. This standard is particularly useful to potential range customers because it provides necessary information to aid in the formation of RF link budgets for the airborne systems. The geographical location data would prove beneficial in test scenario scripting with respect to RF coverage.

4. **Approach**: The required data, such as description of transmitters, antennas, read-back systems, and physical location of transmitter sites, will be solicited or confirmed from each member range and supplemented with data gathered by the EFTS team during the course of Task RS-38 and RS-42.

5. **Additional Coordination Required**: Coordination with all member ranges as well as the FMG and TTG will be required.

6. **Assignment and Management**: Performance of this task will be under direction/lead of the FTSC (coordinating with the EFTS team), and the Range Safety Group will monitor progress.

7. **Resources Required**: The task will require both government and contractor personnel from the FTSC, EFTS team, TTG and FMG.

8. **Total Cost Estimate**: No additional funding for this effort is required. This section is for information only. Funding is derived from on-going efforts of the EFTS team chartered under tasks RS-38 and RS-42.

9. **Milestones**:

APR '02	Task initiated
APR '02	Identify deficiencies, establish format
MAY '02	Begin coordination with ranges for inputs to Standard
AUG '02	Complete data collection and begin draft
OCT '02	Draft Standard available for review
APR '03	Final review
JUN '03	To RCC Secretariat for publication, task complete.

10. **Names, Organizations and Phone Numbers of Task Chair and Other Participants**:

Mr. Kevin Driscoll, WSMR, (505) 678-8838, task lead
Mr. Tom McAndrews, TYBRIN Corp., (661) 276-2381, facilitator/coordinator
Mr. Robert Craft, Pax River, (301) 342-9550 ext. 342, technical representative

11. **Completion Date**: JUN '03 – Submit to RCC for publication.

APPENDIX IV-C

RANGE SAFETY GROUP (RSG) TASK RS-XX

1. **Title**: EFTS Update of *Flight Termination Systems Commonality Standard*, RCC 319-99

2. **Scope and Specific Objectives**:

RCC Standard 319-99, *Flight Termination Systems Commonality Standard*, will be modified to reflect the studies, new technology and requirements derived the Enhanced Flight Termination System (EFTS) efforts (tasks RS-38 and RS-42). The EFTS requirements will address concerns associated with inadvertent termination caused by extraneous or interfering signals, as well as meeting NSA, NSTISSP 12 requirements for secure transmissions. The requirements developed in this task shall support existing program requirements on all ranges and contain a flexible architecture for future program capabilities.

3. **Utility Of End Product**:

The document will provide the standard design, test and operational requirements for range users and ranges planning to implement EFTS.

4. **Approach**:

A new appendix will be added to RCC 319-99 that contains EFTS design and performance requirements. The testing section, Chapter 8, will be supplemented to include new EFTS test requirements. Requirements development will be an iterative process between the working group and industry as flight hardware development matures as part of task RS-42. The updated document will be submitted to industry for review and comment to ensure technical adequacy.

5. **Assignment and Management**:

The Flight Termination Standing Committee will manage the task with progress monitored by the Range Safety Group.

6. **Other Resources**:

The document will require the use of range safety personnel with specialized knowledge in the field of flight termination systems. Manufacturers will be requested to comment on the technical adequacy of the final requirements.

7. Milestones:

APR '02	Official task statement submitted
APR '02	Approval of tasking document
OCT '03	Collection of data/input
APR '04	Draft document reviewed
OCT '04	Document finalized
OCT '04	RSG review and approval
DEC '04	To RCC Secretariat for publication, task complete

8. Participants:

Mr. Mark Gotfraind, 30th Space Wing Safety, Vandenberg AFB, will serve as the task chairman with FTSC member participation.

9. Coordination Required:

The Range Safety Group and Executive Committee Task Master.

10. Completion Date: DEC '04 – Submit final document to Secretariat.

APPENDIX IV-D

TEMPEST REQUIREMENTS FOR EFTS

Prepared by: Dennis Arce
Bourne Technologies, Inc.
18 February 2002

1.0 INTRODUCTION

1.1 Background and Purpose

A primary requirement of the EFTS is to provide a secure data link to authenticate the source of any flight termination command. To facilitate this requirement, EFTS has been exploring the requirements necessary to use encryption and encryption keys of various classifications.

To supplement this effort, the EFTS team solicited questions for range users and vendors pertaining to encryption. Various members of this "FTS community" expressed concern regarding the requirements for TEMPEST in EFT systems.

This document is the result of various discussions and reviews with the National Security Agency (NSA), held for the specific purpose of clarifying the TEMPEST requirements for EFTS.

1.2 Definition

TEMPEST is a generic term (not an acronym) used to describe systems or processes concerned with the improper emission of sensitive or classified information such that it can be obtained by an unauthorized entity.

1.3 Documentation

The formal documentation for TEMPEST relating to EFTS is the NSTISSC 7002 "TEMPEST Glossary."

1.4 TEMPEST Applicability

NSA works with system developers to ensure that a system designed for use at specific classification levels has the ability to maintain the confidentiality of the sensitive or classified information to those levels. **The decision to develop a system to NSA TEMPEST standards lies with the program office and potential users of the system**. That is, NSA does not mandate the development of a TEMPEST system except to protect classified information or key material. It advises the system developers as to the culpability of the system pertaining to electronic emissions.

2.0 EFTS and TEMPEST

EFTS will only have one piece of sensitive or classified information to protect: **the encryption key**. It has been determined that the information in the data link is not sensitive (i.e. commands and identifiers) because EFTS is using encryption and the encryption key as a mechanism for flight termination receivers (FTRs) to authenticate the source of flight termination commands.

This is a subset from what NSA is generally protecting, as encryption data links generally protect both the information and the encryption key. Therefore, the emission requirements for EFTS devices are reduced to those emission requirements that NSA may recommend for data links carrying classified key material.

2.1 Emission Mitigation

NSA has determined that the focus of TEMPEST for an EFTS system should be during key loading. The system must ensure that the key information is protected from emission during this process. There are several basic requirements that NSA has recommended:

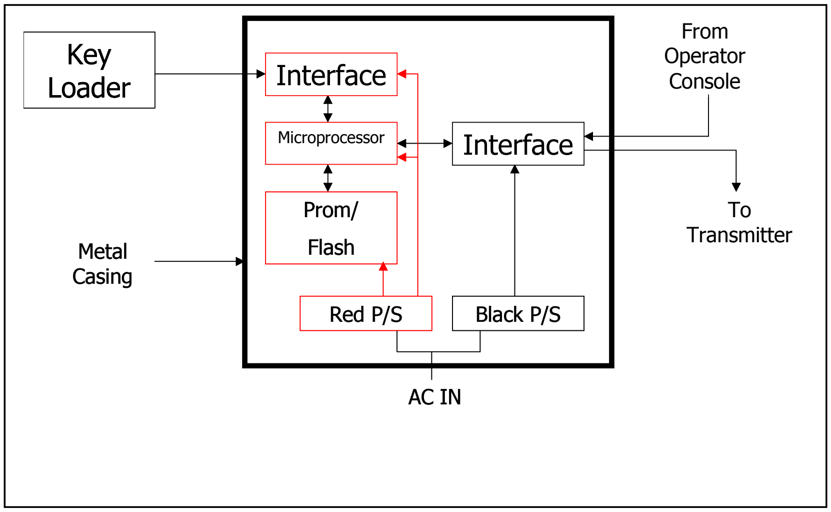
1. Power supply isolation
2. Component construction
3. Transmission muting during key loading
4. Frequent NSA reviews

2.1.1 Power Supply Isolation

NSA has recommended red/black isolation between devices that are involved with the key loading process and those that are not.

To accomplish this, all devices associated with key loading are designed to operate on one power supply (i.e. the red supply), while those that are not used during this process are on a separate supply (the black supply). The level of isolation provided by the separate supplies has not been technically specified to the EFTS study, but the general rule of "separated at the source" (e.g. the AC input) has been stated by NSA representatives. In the case of FTRs, it has been said that separate regulators for red and black devices may be sufficient. Devices on these separate supplies may be connected to one another via data pathways.

The following figure depicts the connectivity between red and black devices, their power sources, and their interconnected data pathways.



Example of Red/Black Power Supply

2.1.2 Component Construction

NSA has recommended that all components involved with key loading and storage use metal enclosures to mitigate improper electronic emissions during key loading. NSA has not identified a specification for these emissions or the type and size of metal required to the EFTS study. Cables used for key loading will require proper shielding.

2.1.3 Transmission Muting

NSA has recommended that operational procedures be in place to disallow the transmission of RF signals connected to EFTS devices during the loading of secure keys. For flight termination transmitters this would include muting any power amplifiers or exciters. For FTRs this would include muting any telemetry transmitters connected to the FTR.

2.1.4 Frequent NSA Reviews

The EFTS development plan should include design reviews that allow NSA to provide guidance for TEMPEST compliance. NSA has not specified a testing requirement for spurious emissions. However, it is thought that the impact to basic designs will be minimal due to the reduced TEMPEST requirements of EFTS as described above.

3.0 SPECIFIC QUESTIONS ASKED and ANSWERED

Q1. Do we have to worry about red/black power requirements? If so, this may be a big problem for small tactical vehicles.

A1. Only within the device for key loading purposes (as discussed above).

Q2. What about ground transmitter systems? Will they have to meet same or similar TEMPEST requirements?

A2. Yes, but only for devices involved with key loading.

Q3. If the Command Transmitter system needs to link to a LAN to effect autonomous (computer generated) destruct, does the LAN now have to meet TEMPEST?

A3. No, only devices associated with key loading need to be isolated.

Q4. What would be the ballpark cost estimate to meet TEMPEST requirements on ground systems? Are costs one-time or recurring?
A4. NSA estimates 10% cost impact to design.

Q5. Are there any special personnel requirements that would need to be met for TEMPEST?

A5. Yes/No. Each facility must develop a system key plan. Operational requirements are the same as today, based on classification of mission.

Q6. Does the EFTS have to be TEMPEST-qualified as an integral part of the platform it will be used on?

A6. There doesn't seem to be a TEMPEST qualification for the type of system required by EFTS. NSA will work with developer and define its needs within a data item description (DID), such that developer will be aware of the data required during development.

Q7. What conditions would require the system to be re-qualified?

A7. Any hardware design change to a device developed with NSA guidance should be submitted to NSA for review.

APPENDIX IV-E

EFTS RECEIVER PERFORMANCE SPECIFICATION

Prepared by: EFTS Program
Edwards AFB, California
Version 5.5
1 May 2002

1.0 INTRODUCTION

1.1 Scope

This specification is provided for the development of a flight termination receiver decoder unit for the Enhanced Flight Termination System. The unit will operate in conjunction with the ground-to-air data link transmitting stations and encoder unit specified under a separate cover. The unit hereafter is referred to as FTR.

2.0 DOCUMENTS INCORPORATED BY REFERENCE

EFTS Data Link Format Definition. Range Commanders Council, Range Safety Group, Flight Termination Standing Committee, January 2002 (see Appendix III-C).

DRAFT – AN/CYZ-10(V)3 *Data Transfer Device Interface Specification*, *Revision B*, October 1998 (to be delivered upon contract award).

MIL-STD 461-E: *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment.*

3.0 REQUIREMENTS

3.1 Data Link Properties

The FTR shall contain all of the features and meet or exceed all of the performance requirements listed in Section 3.

3.1.1 Modulation. The receiver shall be equipped to demodulate a continuous phase frequency shift keying (CPFSK) modulated carrier. This modulation technique is also known as pulse code modulation/frequency modulation (PCM/FM).

3.1.2 Coding. The format for coding and decoding shall be bi-phase level encoding (e.g. Manchester), where a Logic 1 is a transition between a positive voltage and a negative voltage and a Logic 0 is a transition between a negative voltage and a positive voltage. The duty cycle between the high and low voltage values shall be 50% ±1%.

3.1.3 Frequency. The FTR shall operate at 428 MHz for this phase of EFTS development.

3.1.4 Message Format. The format of the data shall be as defined in the *EFTS Data Link Format Definition* report.

3.1.5 Message Rate. The FTR shall process at least 50 messages per second.

3.2 FTR Physical Characteristics

3.2.1 FTR Enclosure Dimensions. The volume of the FTR shall not exceed 25 cubic inches.

3.2.2 RF Input. The RF antenna input shall be on a dedicated connector. The impedance shall be 50 ohms.

3.2.3 Input Voltage. Units shall operate from 24-32 Vdc. No inadvertent outputs shall be present when input voltage is outside this range.

3.2.4 Input Current. The FTR shall operate with a maximum current draw of 150 mA.

3.2.5 Key Loading. The FTR shall accept crypto-variable keys for the encryption method specified by the EFTS *Data Link Format Definition.* An acceptable interface may use the NSA certified data transfer device (DTD) as specified in the *Data Transfer Device Interface Specification.*

3.2.6 Outputs (discrete commands/TM serial output)

3.2.6.1 Signal strength telemetry output monitor. While operating into a 10-kilohm load, the signal strength telemetry output (SSTO) voltage of the receiver shall meet the following requirements:

3.2.6.1.1 The SSTO output level quiescent (no RF signal) condition shall be 0.5 ±0.25 Vdc.

3.2.6.1.2 The SSTO measured command threshold sensitivity input condition shall be 0.1 Vdc minimum above the quiescent value.

3.2.6.1.3 The SSTO output level shall reach a maximum of 4.5 Vdc with no less than –60 dBm or no more than –50 dBm of RF input.

3.2.6.1.4 The shape of the transfer function shall not exceed approximately 1.0 Vdc change in voltage for each 13 dB change in RF input signal over the range between threshold and saturation.

3.2.6.1.5 The maximum SSTO voltage shall not exceed 5 Vdc under all conditions.

3.2.6.1.6 The slope of the SSTO voltage shall not change polarity from measured threshold to +13 dBm.

3.2.6.2 Command and Status Outputs. The FTR shall provide isolated telemetry outputs. The function of the FTR shall not be affected by the external shorting of a monitor circuit or by the application of any positive or negative voltage between 0 and 45 Vdc for up to 5 minutes to an FTR monitor circuit. Monitor circuits shall be designed so that application of operational voltage shall not cause inadvertent function or loss of function of the FTR. An output shall be provided for each command status and the command decode valid bit as discussed in section 3.12 in the *EFTS Data Link Format Definition* report.

In addition, the FTR shall provide a mechanism to provide changes in receiver states (i.e. the counter) via telemetry while minimizing the use of discrete outputs. An example implementation is to pulse modulate a status output with information (such as the counter value) when authenticated commands are received.

3.3 Physical Operating Conditions

3.3.1 Warm-Up Time. The FTR shall meet all operational requirements within 5 seconds after application of dc power. No inadvertent outputs shall be present during the warm-up period.

3.3.2 Power Cycling. The FTR shall not be damaged by momentary interruptions in the dc power.

3.3.3 Operating Temperature. The prototype FTR shall operate normally from –40°C to +71°C.

3.3.4 Pressure/Altitude. The prototype FTR shall operate normally while exposed to altitudes up to 50 000 ft msl.

3.3.5 Humidity. The FTR shall operate normally while exposed to humidity conditions up to 95% condensing.

3.3.6 Vibration. Prototype FTR components shall be designed to withstand the following vibration levels in each of three mutually perpendicular axes of the unit:

Frequency (Hz)	SRS	Frequency (Hz)	SRS
15 to 150	.04 G^2/Hz	300 to 1000	.1 G^2/Hz
150 to 300	+4 dB/octave	1000 to 2000	–6 dB/octave

3.4 FTR Performance

3.4.1 Configuration. The contractor shall provide a configuration interface that is electrically separate from the crypto-variable interface. The following parameters as a minimum shall be configurable using this interface:

3.4.1.1 Message Parameters. The following EFTS format fields shall be configurable. The process of reconfiguring any of these fields shall not interrupt receiver operation. Acceptance of the programmed values shall be confirmed by the loading device.

3.4.1.2 Range ID. The range identifier field shall be configurable to any 16-bit value.

3.4.1.3 Quantity of Acceptable Transmitters. The FTR shall be configurable to authenticate from one to eight different transmitter identifier numbers.

3.4.1.4 Transmitter ID. Each acceptable transmitter identifier field shall be configurable to any four-bit values.

3.4.1.5 Vehicle ID. The vehicle identifier field shall be configurable any 20-bit value.

3.4.1.6 User Defined Commands. The FTR shall contain an output interface for conveying the received value of the user-defined fields.

3.4.1.7 Command Counter. The counter field shall be configurable to any 12-bit value. Upon FTR power-up, the counter field shall reset to zero.

3.4.1.8 Over-the-Air Configuration. The FTR shall accept a configuration command using the same communications link defined in section 2.1.4 that allows the unit to be configured during pre-flight checkout and testing. This command shall enable the FTR to switch to predetermined values for all authenticated fields (e.g. range ID). The activation of this command shall trigger a self-test function as defined in paragraph 3.4.2. A second configuration command shall be used to commit the first command parameters as valid; this will invalidate the FTR response to all other values.

3.4.2 Self-Test. If the component uses a microprocessor or programmable device, it shall have the capability to perform a self-test (error detection). The self-test pass/fail results shall be provided to an output interface. The self-test shall ensure proper functionality of critical hardware piece-parts and software integrity such as memory, FPGA devices, processors, firmware, and code load errors.

3.4.2.1 The self-test shall be capable of initiation by power-on and upon receiving a special test command.

3.4.2.2 Failure of a self-test shall not intentionally disable the component.

3.4.2.3 The execution of a self-test shall not inhibit processing the intended function of the unit or cause any discrete output to change state.

3.4.2.4 The self-test shall output the contents of the airborne receiver authentication and command fields. Hardware functions can include memory devices, power supply status (internal logic device and external component power within specification), invalid output (command sent inadvertently), and critical piece-parts. *Note: Contents of the crypto-variable must remain separate from this function.*

3.4.2.5 Data transfers that occur during power-up or initialization to load memory or programmable devices shall be verified to determine if the process contains an error. If an error occurs, the cause of the error shall be output to an external interface.

3.4.3 Guaranteed RF Sensitivity. The FTR shall have a maximum of one message error every 10,000 messages due to thermal noise at receiver input level of –107.0 dBm.

3.4.4 RF Threshold Sensitivity. The FTR shall have less than 50% message error rate at RF input level of –116 dBm.

3.4.5 Maximum Usable RF Input. The FTR shall be capable of operating within its specification limits during and after the application of RF signal levels between the measured threshold sensitivity and +13 dBm.

3.4.6 Acquisition and Re-acquisition Time. Upon initial RF reception, response time (including all periods such as bit synchronization, decryption, and frame synchronization) to the appropriate command output shall be no greater than 70 ms. *Note: The use of a frame synch pattern to achieve this goal is acceptable.*

3.4.7 Command Response Time. Once the EFTS signal has been acquired and is synchronized as discussed above, the FTR shall generate any appropriate command and telemetry outputs within 5 ms of the receipt of a complete message frame.

3.4.8 Processing/Memory. The FTR processor and memory devices shall utilize no more than 80% of the device's capability for worst-case processing and memory storage.

3.4.9 Bit Jitter Tolerance. The FTR shall tolerate bit jitter of at least 0.1% peak.

3.4.10 Spurious Response Rejection. The FTR shall provide at least 60 dB of rejection from 10 to 1000 MHz, excluding the frequency band within the 60 dB bandwidth at the assigned center frequency referenced to response at center frequency.

3.4.11 Electromagnetic Interference. The FTR shall be designed to meet the requirements of MIL-STD 461E methods as indicated below:

MIL-STD-461E Requirement	Curve, Limit or Condition Qualifiers
CE101	Army aircraft limit, 5.3.1.1.c.
CE102	None
CE106	None
CS101	None
CS114	To 400 MHz, curve 3
CS115	None
CS116	None
RE102	Navy and Air Force internal curve
RS103	Aircraft internal, Navy limit from 10 kHz to 40 GHz

3.4.12 Image Rejection. The FTR shall provide at least 60 dB of RF rejection at harmonics of the assigned operating frequency.

3.4.13 Capture Ratio. The application of an unmodulated RF signal shall not capture the FTR or interfere with the desired signal at the assigned frequency at levels up to 80 percent of the desired modulated RF carrier signal.

3.4.14 Interference Immunity. The unit shall overcome the interference sources listed in paragraph 2.4.14.1 such that the FTR will properly decode 9 999 out of 10 000 messages with an input signal level of –107 dBm.

3.4.14.1 Interference Sources. Interfering signal will have a peak interfering power level up to 30 dB stronger than the desired signal. See table below:

ITEM	DESCRIPTION
Frequency	Same as FTR center frequency
Modulation type	Frequency division multiplexing/time division multiplex (FDM/TDM) binary continuous phase shift modulation
Processor clock frequency (chip rate)	5 megachips per second (Mcps)
Burst repetition rate	2 bursts per EFTS message frame period at any random position in the frame.
Burst length	1.07 ms

3.4.15 Minimum Acceptable Parameters. The contractor shall determine the range of acceptable values for the following parameters, if applicable, so that a transmitter can be developed that is compatible with this device. The government shall give guidance on any safety margins required.

4.0 ACCEPTANCE TESTING

The vendor shall develop and propose acceptance test plans.

5.0 PREPARATION FOR DELIVERY

Preservation, packaging and marking shall be in accordance with requirements set forth in the acquisition documents.

APPENDIX IV-F

EFTS ENCODER PERFORMANCE SPECIFICATION

Prepared by:
Enhanced Flight Termination System Program
Edwards AFB, California
Version 5.5
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1.0 INTRODUCTION

1.1 Scope

This specification is provided for the development of a flight termination encoder unit for the Enhanced Flight Termination System (EFTS). The unit will be integrated with the ground-to-air data link transmitting stations and operate in conjunction with the flight termination receiver unit specified under separate cover. The unit hereafter is referred to as the *encoder*.

2.0 DOCUMENTS INCORPORATED BY REFERENCE

EFTS Data Link Format Definition. Range Commanders Council, Range Safety Group, Flight Termination Standing Committee, 18 January 2002 (see Appendix III-C).

DRAFT – AN/CYZ-10(V)3 *Data Transfer Device Interface Specification, Revision B*, October 1998 (to be delivered upon contract award.)

3.0 REQUIREMENTS

3.1 Data Link Properties

The encoder shall, at a minimum, contain all of the features and meet or exceed all of the performance requirements listed in Section 3. Compliance with a specific requirement also requires compliance with all supplemental requirements contained in detailed paragraphs referenced therein.

3.1.1 Coding. The format for coding and decoding shall be bi-phase level encoding (e.g. Manchester), where a Logic 1 is a transition between a positive voltage and a negative voltage and a Logic 0 is a transition between a negative voltage and a positive voltage. The duty cycle between the high and low voltage values shall be a maximum value of ±0.1 percent.

3.1.2 Message Format. The format of the data shall be as defined in the *EFTS Data Link Format Definition.*

3.1.2 Message Rate. Each message frame shall be sent a minimum of 50 times per second.

3.2 Encoder Enclosure

3.2.1 Encoder Enclosure Dimensions. Unit shall be transportable.

3.2.2 Baseband Output. The encoder shall have two baseband outputs. A high impedance output of 20 000 ohms, ±5%, and a low impedance output of 600 ohms, ±5%. The encoder output shall be fixed at 1.0 volt peak-to-peak (dc free), ± 1%, into a matched load. The individual output connectors shall be provided on the front panel of the unit and shall mate with the BNC type UG/880 coaxial cable connector.

3.2.3 Monitor Outputs. The encoder shall provide outputs to facilitate the testing of EFTS parameters using standard test equipment such as oscilloscopes or logic analyzers. At a minimum, these outputs shall accommodate the testing of the encoder command processing time, receiver command processing time, and receiver authentication.

3.2.4 Power Supply Unit. The encoder shall be designed to operate on a single-phase, 115-volt ac (± 10 percent) power source at 60 Hz (± 10 percent). A main power switch, fuse, and lamp indicator shall be located on the front panel of the command encoder. The ac power lead-in cable shall enter through the rear panel of the unit.

3.2.5 Fuses and Breakers. All electrical power circuits shall be protected against overloads by fuses/circuit breakers; each shall be positioned for ease of replacement/resetting purposes. If fuses are used, they are to be the indicating type.

3.2.6 Key Loading. The FTR shall accept crypto-variable keys for the encryption method specified by the *EFTS Data Link Format Definition.* An acceptable interface may use the NSA certified data transfer device (DTD) referenced in the *Data Transfer Device Interface Specification.*

3.3 Encoder Performance

3.3.1 Message Parameter Configuration. The contractor shall provide controls for selecting the following parameters at a minimum. The following EFTS format fields shall be configurable and the process of configuring any of these fields shall not interrupt encoder operation.

3.3.1.1 Range ID. The range identifier field shall be selectable for any 0 to 65 535 decimal value.

3.3.1.2 Transmitter ID. The transmitter identifier field shall be selectable for any 0 to 15 decimal value.

3.3.1.3 Vehicle ID. The vehicle identifier field shall be selectable for any 0 to 1 048 575 decimal value.

3.3.1.4 User-Defined Commands. The user-defined field shall be selectable for any 0 to 31 decimal value.

3.3.1.5 Command Counter. A method of incrementing a sequential counter shall be employed whereby the counter value shall increment by one after each command is sent. The counter field shall also be selectable to any 0 to 4 095 decimal value.

3.3.2 Command Processing Time. After any change in command status, the response time to the encoder output shall be no greater than 50 ms from command activation to complete frame output.

3.3.3 Pre-Modulation Filtering. The encoder output shall include a 4 pole, linear phase filter with a –3 dB point of 2 times the bit rate.

3.3.4 Bit Jitter. The encoder shall not generate bit jitter greater than 0.01% peak.

3.3.5 Baseband Output Noise. Noise level on the encoder baseband data output shall not exceed 50 mV peak-to-peak.

4.0 ACCEPTANCE TESTING

The vendor shall develop and propose acceptance test plans.

5.0 PREPARATION FOR DELIVERY

Preservation, packaging and marking shall be in accordance with requirements set forth in the acquisition documents.