Enhanced Flight Termination System Study - Phase II and III Status

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ABSTRACT

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) study. The study was initiated by the RCC in April 2000 with a scheduled completion of March 2002. The Government is performing the study with support from contractors and academia.

This paper will discuss specific details of phase II and III of the EFTS study. The description of phase II will include details on the down-selected approaches and reason for the selection. The phase III description will include the methods of analysis, simulation, experimentation, and verification that are used to refine the phase II recommendations.

ACRONYMS

AFFTC	Air Force Flight Test Center
BPSK	Binary Phase Shift Key
BYU	Brigham Young University
CDMA	Code Division Multiple Access
CPFSK	Continuous Phase Frequency Shift Keying
DES	Data Encryption Standard
DFRC	Dryden Flight Research Center
DOD	Department of Defense
EAFB	Edwards Air Force Base
EFTS	Enhanced Flight Termination System
FM	Frequency Modulation
FTS	Flight Termination System,
FMG	Frequency Management Group
FTSC	Flight Termination Standing Committee
NASA	National Aeronautics and Space Administration
NRZL	Non Return to Zero Level
PCM	Pulse Code Modulation
RCC	Range Commanders Council
RF	Radio Frequency
RSG	Range Safety Group
UAV	Unmanned Aerial Vehicle

BACKGROUND

The EFTS study (under the auspices of the Range Commanders Council (RCC), Range Safety Group (RSG), Task RS-38) was formed to provide an analysis of the requirements and approaches to a next generation of Range Safety Flight Termination System. Recent incidents involving flight termination systems that resulted in catastrophic loss of government capital have yielded the need for such a study. A comprehensive overview of the study can be found in the International Telemetry Conference 2001 proceedings paper titled "*EFTS Study: Overview and Status*."

Task RS-38 has been structured in a phased approach. The results of each phase will culminate in a report, describing the salient facts and outcome of the effort, and will have appropriate recommendations. Participation and coordination with the RCC groups including the RSG, Frequency Management Group (FMG), Telecommunications and Timing Group, and Telemetry Group are imperative to the success of this study.

The objective of this paper is to describe the phase II technical assessment process and phase III test and analysis methodology used to perform a practical technology demonstration of the selected candidates.

PHASE II - TECHNICAL ASSESSMENT

Approach Evaluation. During phase II of the EFTS study, technical approaches were developed and evaluated to meet the guidelines that were developed during the initial phase of the study. Industry, range safety representatives from each range, and EFTS team members developed the approaches.

The final step in the phase II technical assessment was the evaluation of the approaches.
The evaluator's independent assessments were consolidated and a meeting was held to arrive at a consensus on which of the technical approaches should be further analyzed in phase III of the study.

Seven different approaches were submitted, however, they consisted of four basic modulation techniques: binary phase shift keying (BPSK), continuous phase frequency shift keying (CPFSK), code division multiple access (CDMA), and Modified High Alphabet. Each was evaluated for its strengths and weaknesses in relation to the flight termination environment. After evaluating the proposed seven approaches and discussing the advantages, disadvantages, and risks, the modulation schemes that were determined to warrant additional analysis in phase III were the CPFSK and Modified High Alphabet schemes. The following sections describe each of the modulation techniques and their attributes relative to EFTS.

<u>Binary Phase Shift Keying</u>: Coherent BPSK is a technology that is in widespread commercial and military use as are other phase shift key modulation techniques such as quadrature phase shift keying and its variants. The evaluation team determined that coherent BPSK is not ideally suited to EFTS primarily due to its relatively poor interference rejection characteristics and its long synchronization period. (Some estimates put a minimum carrier to interference threshold as high as 1 0 dB) Further, the increased time required for synchronization of coherent phase modulated signals makes this technique impractical for range safety applications.

Other contributing factors were the lack of range experience with this technology, its higher bandwidth requirements, and the extensive design requirements for both ground-based transmitters and airborne receivers. Band-limited BPSK signals also require linear amplifiers that are not currently available at all ranges. Thus, the ground-based high power amplifiers would need to be replaced if this approach were selected.

Code Division Multiple Access: Use of CDMA technology for range safety command destruct systems was an attractive option because of its interference rejection characteristics and its potential ability to allow multiple transmitters to operate simultaneously. The latter might have been especially appealing to ranges that currently require break-before-make handoffs from different transmitters at various geographic locations.

While having its benefits, CDMA was not selected as a primary approach to be investigated in phase III of the study for various reasons. The development of CDIVIA for this application would require a complete design of a system that includes all primary transmitter and receiver components; that is, there is little reuse of existing range certified technology that could support this option. Also, there are technical risks that would have to be overcome such as power control from various transmitters. [Range Safety currently employs simplex radio frequency (RF) links, while most terrestrial CDMA systems have bidirectional links with power control to allow multiple transmitters to communicate with the same receiver.] Other technical risks include the identification of orthogonal codes and cold-start synchronization time. Constrictive schedule and funding were additional factors in not selecting CDMA for further analysis in phase III.

Continuous Phase Frequency Shift Keying: Sometimes referred to as pulse code modulation/frequency modulation (FM) or PCM/FM, CPFSK has been used as the primary modulation technique used by range telemetry systems for decades. CPFSK is a digital FM technology that has demonstrated relatively high immunity to multipath and interference. An EFTS system using this technology would also impose minimum impact to existing ground assets and the development of airborne receivers. It is thought that a high degree of receiver design can be maintained since the primary modulation technique (FM) is the same as the existing FM base tone systems. Similarly, much of the ground transmit system equipment could be reused. For these reasons, biphase CPFSK was selected for further evaluation in phase III.

NOTE: CPFSK approaches were presented with both non return to zero level (NRZL) and Manchester, or biphase, techniques for baseband coding. To avoid the inherent problems of direct current shift with NRZL and to keep synchronization time to a minimum, the EFTS team opted to incorporate biphase coding if the CPFSK scheme is used.

Modified High Alphabet: The high alphabet command destruct system is a proven technology that has been used in range safety systems for several decades. This system sends a sequence of tone pairs on a FM modulated carrier. The large number of possible combinations of sequenced tone pairs has the effect of providing a secure system.

The modified high alphabet system, selected for further evaluation in phase III, is a variant on the existing high alphabet system. It uses frequency-modulated combinations of orthogonal tone pairs to transport a digital frame of information between the ground and the vehicle. This technology is attractive to EFTS for similar reasons to CPFSK--it is a time-proven technology that would allow both a high amount of reuse in existing ground assets and receiver design. It also has a demonstrated high resistance to interference and multipath and has a relatively short cold-start data synchronization period. One disadvantage of this approach, though, might be that high alphabet receivers are currently built by one vendor, which could deter other vendors from entering this market. Ultimately, the reduced cost, impact to schedule, and minimal implementation risk led the EFTS team to select this scheme for further evaluation.

The seven approaches contained various methods to implement the content of the data between the ground and airborne units. Each of them proposes a departure from simple analog systems by using digital data streams. This will permit message authentication and more adaptability for future requirements. The formulation of the exact content of the premodulated data stream will be a primary focus for phase III of the study.

Security. Another benefit to using a digital format is added security feature of link encryption. A summary of the approaches leads to two basic encryption methods: the 64-bit Triple Data Encryption Standard (3-DES) and the 128-bit Advanced Encryption Standard. Both methods have advantages and will be considered during phase III of the study. phase II studies also resulted in a complete description of the National Security Agency recommended security approach for EFTS. This paper was refined and documented as the "*EFTS Recommended Security Approach Description*" dated February 2001.

PHASE III - TECHNOLOGY DEMONSTRATION

phase III of the study expands upon the work of the previous phases to further develop EFTS through studies, simulation, and testing. The following tasks will be conducted to meet this end.

Concept of Operations. A concept of operations (CONOPS) that describes the various operational procedures required for the EFTS system is being developed. The CONOPS is intended to cover all potentially impacted operational aspects of EFTS versus the current operation of flight termination systems (FTSs). This includes procedures that cover receiver and ground system qualification, preflight setup and checkout, mission operations and postflight operational procedures. The CONOPS will include web-based procedural flows that enable various EFTS data approach techniques to be simulated and refined to a conclusive recommendation.

Data Format and Bandwidth Requirements. In conjunction with the CONOPS, a definition of the data format recommended for EFTS will be developed. Using the two primary techniques recommended in phase II, the 64-bit triple-DES frame and the 128-bit AES frame, the content of the premodulated data will be described and modeled. The web-based software developed for the CONOPS will also provide a graphical depiction of the ground and airborne message. The software will allow users to become familiar with various technical and operational aspects of the technology. Features include: injection of bit-errors between the air and various transmitters on the ground, real-time parameter setting and viewing, real-time and accelerated message monitoring, adjustable frame size, adjustable authentication parameters, and command output indicators. A result of this will be the definition of the bandwidth requirements for EFTS.

Computer Modeling & Simulation. Through a grant to Brigham Young University (BYU), a model to simulate the RF environment using the modulation schemes selected during phase II will be generated. The simulation environment uses real antenna gain pattern data to simulate the gain and phase shifts due to vehicle tumbling. It also adds Doppler shifts, phase noise, thermal noise, and simulated radar pulses. Ranges have provided antenna pattern data at the request of BYU to ensure realistic modeling. The two primary models under development are CPFSK (i.e., PCM/FM) and a modified high alphabet system.

RF Link Analysis. Additionally, through the grant with BYU, a study conducting a link analysis of various approaches against program requirements for safety margin given various mission trajectories and distances from ground transmitters will be performed. Approaches are analyzed for resistance to interference and potential noise impacts such that the operational concerns of programs are addressed prior to final approach selection. Through this analysis, a comparison of the new technique against margins currently used on existing high alphabet and standard tone-based systems will also be achieved.

Plume Effects. The EFTS study contains a task to consolidate and expand upon known data dealing with the signal loss due to plume from solid rocket motors that eject hundreds of pounds of ionized particles per second. The intent of this task is to quantify the problem and potentially answer questions such as how often, which ranges, and what aspect angles affect this phenomenon. This study is intended to specifically examine the EFTS proposed modulation methods and characterize their susceptibility to plume effects.

Frequency Allocation. Current encroachment trends and competing programs indicate that the existing allocated frequency band may be too restrictive in the future. The EFTS team, in conjunction with the FMG, will pursue a separate task to determine the technical, operational, and economic impacts of changing the current frequency to a dedicated frequency for use by Range Safety flight termination systems.

Survey. A survey of each range and its users is being conducted to provide prospective vendors with receiver purchase expectations and to determine specific airborne receiver and operational requirements. The unique operational needs of each range and program will be used to develop the digital data format structure and the vehicle operating environments will ultimately drive the design specifications. Additional survey questions will be included for range frequency managers that may help determine the extent of potential interference.

Testing. The existing FTS ground transmit systems must be properly characterized in order to estimate the impact due to modification. Since the ranges use either Systems Planning Corp or ZETA developed command transmitters, testing will be limited to Vandenberg AFB and either the Edwards AFB or NASA Dryden FTS to provide a satisfactory cross-section.

The EFTS team members and participating vendors identified tests that need to be conducted to help make a final EFTS approach recommendation. They are:

- Measuring phase noise from 10 Hz to 1 MHz and checking for two-tone intermodulation distortion to help determine whether coherent modulation schemes can be used with existing amplifiers.
- Plotting linearity up to the 1 -dB compression-point to reveal the amplifiers overall limitations.
- Gain balance and group delay measurements to uncover any frequency response problems.
- Measuring the maximum bit error rate capabilities of the systems to provide upper limitations for processing digital data streams.

Other benchmark testing will be necessary to determine which technologies may be viable solutions and to what level the impact of implementation will be. Specifically, a noise floor test will show how strong the FTS signals have to be for the receivers to operate adequately. Test plans will be developed to identify existing noise and interference characteristics in the frequency band currently used for FTS. The plan will consist of a multistep process to measure and record spectral qualities using a directional antenna, low-noise amplifier, and spectrum analyzer. Further studies will be conducted to determine how well ground transmission systems would perform at minimum and maximum frequency shifts.

Cost Analysis. Projected costs to develop and test the new flight termination receiver will be determined based on the approaches pursued and from the results of range user surveys. Reports from at least one vendor claim that the two approaches being considered make use of commonly used modulation formats and therefore should not require the development of new manufacturing technologies unless severe environmental requirements are imposed. Flight termination ground equipment upgrade costs will also be investigated. The addition of encryption apparatus to facilitate the link security features may be required and the use of a CPFSK scheme, if selected, may also impose additional cost due to the necessity for some type of message encoding device.

SUMMARY

EFTS phase II further refined the system's requirements as well as incorporated input from various industry, range, and EFTS team sources of a system to incorporate these approaches. phase II culminated in a down-selection process of techniques that will be expanded in phase III of the study. The results of phase III are a further refinement of the recommendations that are based on in-depth analysis, simulation, and testing. The primary activities of phase III are CONOPS, data format structure, bandwidth requirements, computer modeling and simulation, RF link analysis, plume effects study, frequency allocation investigations, a refined range survey, empirical testing of existing systems, and a cost analysis that estimates the required funding. Final recommendations derived from phase III information will be utilized to produce a performance specification for the implementation of EFTS on DOD ranges and at NASA facilities. In conclusion, phase III of the EFTS study will provide a validated solution for a robust flight termination link. The EFTS team will remain in constant communication with participating organizations and industry to ensure this task yields the best possible outcome.

REFERENCES

1. RCC/RSG Document 319-99, Flight Termination Systems Commonality Standard, September 1999.

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

3. EFTS Team Document, EFTS Recommended Security Approach Description, February 2001.

4. ITC 2001 proceeding, EFTS Study: Overview and Status, April 2001.