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Airport Capacity Program Office
Washington DC 20591

Analysis of MLS Based Surveillance System (MLSS) Concepts

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Cambridge, MA 02142

April 1989
Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

NOTICE

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16. Abstract

This report examines a number of surveillance system concepts to support safe independent runway approaches and converging runways under weather conditions. All surveillance concepts are based on the use of MLS signals. The resulting surveillance is available at the runway selected reference point in real time. The three major MLS-based Surveillance Sytem (MLSS) concepts are: data link, translator, and reflection. Of these three concepts, the data link is the most promising one where aircraft position is determined by onboard elections and CDM technique is used to send the data on 12.8 MHz channel back to ground. Reflection method is the weakest one due to high gain, a pencil beam antenna requirement and a lack of aircraft identity. The translator concept requires addtional electronics to be placed onboard an aircraft to enhance and retransmit MLS signals back to ground. Predicted accuracies and analysis are presented in sufficient detail.

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PREFACE

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The work was performed by the Transportation System's Center Surveillance and Sensors Division (DTS-53). This report represents six months effort in performing analysis of the various concepts of implementing an aircraft surveillance system for use during final approach and landing using MLS signals.

The concept of rising the MLS as an independent aircraft surveillance system was first proposed by John C. Heurtley of the FAAs Airport Capacity Office. Mr. Heurtley is also the originator of the translator concept.

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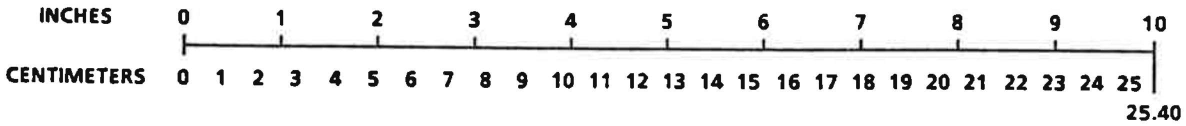

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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EXECUTIVE SUMMARY

Aircraft delays at major airports are a significant problem. The FAA is examining various techniques to increase the capacity of airports when operations are being conducted under Instrument Meteorological Conditions (IMC). One such technique is the development of simultaneous independent IFR approaches to closely spaced parallel and converging runways. The ability to use a second parallel or converging runway in IMC would significantly increase the capacity of more than 60 major airports resulting in substantial reductions in delays due to weather.

The use of parallel and converging runway approaches has been the subject of considerable study, analysis, simulation, and experimentation by the FAA. These studies indicate the need for a high accuracy and wide bandwidth surveillance sensor for monitoring aircraft on the simultaneous approaches. The principal surveillance sensor requirements were identified as:

Coverage: Approach and missed approach corridors
Range: 15 nm
Accuracy: 1-2 mr in azimuth (1 sigma)
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250 ft in range (1 sigma)

Update Rate: 1 per second (minimum)
Target ID: Positive identification of each target
Number of Targets: Track simultaneously 10 targets per runway, 20 targets maximum for a parallel or a converging runway configuration

The Microwave Landing System (MLS) generates a signal-in-space which can be utilized to implement a surveillance system meeting the above requirements. This paper examines a number of surveillance system concepts based on the use of MLS. The three major MLS-based Surveillance System (MLSS) concepts examined were:

Data Link - aircraft position is monitored by transmitting to the ground the aircraft's position as determined by the onboard MLS avionics.

Translator - Aircraft position is monitored by retransmitting to the ground the MLS signals received aboard the aircraft and performing the necessary MLS signal processing on the ground.

Implementation consideration of each major MLSS concept resulted in the development of a number of subconcepts. The MLSS alternatives which were examined in detail in this study consisted of:

3. Translator Concept - Data Link Using Code Division Multiplexing (CDM). The aircraft is not equipped with MLS avionics. Instead the aircraft's onboard equipment consists of an MLSS avionics unit whose function is to retransmit the received MLS angle guidance signals on a separate frequency to the ground (i.e. the aircraft acts as a signal repeater). In order to transmit MLS signal data via a CDM data link the onboard MLSS avionics must first digitize the data. The CDM data link utilizes the spread spectrum transmission technique and orthogonal (P/N) codes to reduce the number of required data link frequencies. Aircraft range is determined by measuring the time delays in receipt of the encoded MLS data words, similar to the FDM-II concept. The CDM technique requires more complex MLSS avionics than those required for the FDM concept.

Table ES-1 summarizes the characteristics of each MLSS concept.

TECHNICAL ASSESSMENT OF THE MLSS CONCEPTS

Data Link - CDM - This concept offers the "cleanest" MLSS implementation method. The system has no potential for interfering with any existing ATC system. The only possible difficulty with this approach is finding an available 12.8 MHz bandwidth channel.

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Data Link - TDM - The TDM concept utilizes the ATCRBS reply frequency for downlinking MLSS data. As in the concept of utilizing Mode-S, it can interfere with the operation of this system. The concept requires modification of the ATCRBS interrogators and transponder as well as controller interaction to assign time slots thus making this a less attractive approach.

Data Link - FDM - The FDM approach is also a "clean" MLSS implementation approach, since it will not interfere with the operation of any ATC system. However, the requirement for a number of channels makes its implementation difficult.

Translator - FDM - The use of discrete frequencies for each aircraft leads to a straightforward design approach which results in a system performance which exceeds the MLSS requirements. The need for a large number of frequencies does however make implementation of this approach a difficult task.

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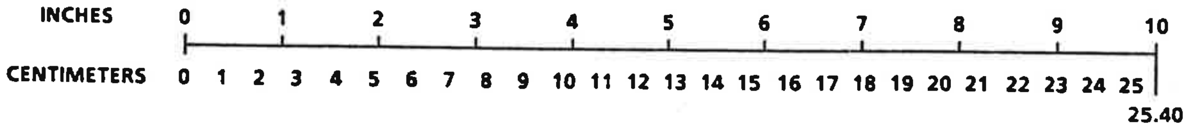

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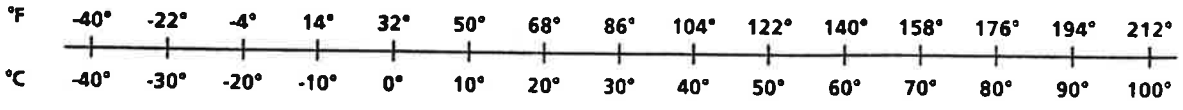

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MLSS CONCEPTS BASED ON AIR DERIVED AIRCRAFT POSITION INFORMATION

1. Data Link - Code Division Multiplexing (CDM). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived aircraft position information is transmitted to the ground over a dedicated MLSS data link. A single MLSS data link frequency is used in the entire CONUS. Each aircraft transmits its position using randomly distributed short data bursts. Orthogonal (P/N) codes are used to separate the replies from individual aircraft.

2. Data Link - Mode-S. The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is retransmitted to the ground over the Mode-S data link at a higher update rate than that normally used in Mode-S.

3. Data Link - Time Division Multiplexing (TDM)(Crossbanding). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is transmitted to the ground over a modified ATCRBS downlink reply. Each aircraft transmits in a preassigned time slot, a form of time division multiplexing.

4. Data Link - Frequency Division Multiplexing (FDM). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is transmitted to the ground on a dedicated data link with frequency channels assigned to each runway. Each aircraft transmits its position using randomly distributed short data bursts.

MLSS CONCEPTS BASED ON GROUND DERIVED AIRCRAFT POSITION INFORMATION

1. Translator Concept - Data Link Using Frequency Division Multiplexing (FDM). The aircraft is not equipped with MLS avionics. Instead the aircraft's onboard equipment consists of an MLSS avionics unit whose function is to translate the received MLS signal to a different (higher or lower) frequency, and retransmit the received MLS signals to the ground (i.e. the aircraft acts as a signal repeater). The aircraft's azimuth and elevation are determined on the ground using the same signal processing techniques utilized in airborne MLS avionics. Aircraft range is determined by measuring the time delays in receipt of the angle guidance signals generated by the TO-FRO scans (FDM-I Concept), or the time delays in receipt of the MLS data words (FDM-II Concept). Each aircraft is assigned a separate frequency on which to retransmit the MLS signals (FDM).

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TABLE ES-1. MLSS CONCEPT COMPARISON CHART

	MLS EQUIPPED AIRCRAFT **CDM DATA LINK CONCEPT**	MLS EQUIPPED AIRCRAFT **MODE-S DATA LINK CONCEPT**	MLS EQUIPPED AIRCRAFT **TDM DATA LINK CONCEPT** (CROSSBANDING)	MLS EQUIPPED AIRCRAFT **FDM DATA LINK CONCEPT**	AIRCRAFT NOT EQUIPPED WITH MLS **FDM-I CONCEPT** (RANGE DETERMINED FROM TO - FRO SCANS)	AIRCRAFT NOT EQUIPPED WITH MLS **FDM-II CONCEPT** (RANGE DETERMINED FROM DATA WORDS)	AIRCRAFT NOT EQUIPPED WITH MLS **TDM-I CONCEPT** (RANGE DETERMINED FROM TO - FRO SCANS)	AIRCRAFT NOT EQUIPPED WITH MLS **TDM-II CONCEPT** (RANGE DETERMINED FROM DATA WORDS)	MLS EQUIPPED AIRCRAFT **CDM CONCEPT**
ACCURACY	AZIMUTH- 1.0 mr (1σ) ELEVATION- 1.2 mr (1σ) RANGE (DME/P)- 20FT (1σ) FA; 100FT (1σ) IA RANGE (DME/N)- 300FT (1σ)	AZIMUTH- 1.0 mr (1σ) ELEVATION- 1.2 mr(1σ) RANGE (DME/P)- 20FT (1σ) FA; 100FT (1σ) IA RANGE (DME/N)- 300FT (1σ)	AZIMUTH- 1.0 mr (1σ) ELEVATION- 1.2 mr (1σ) RANGE (DME/P)- 20FT (1σ) FA; 100FT (1σ) IA RANGE (DME/N)- 300FT (1σ)	AZIMUTH- 1.0 mr (1σ) ELEVATION- 1.2 mr (1σ) RANGE (DME/P)- 20FT (1σ) FA; 100FT (1σ) IA RANGE (DME/N)- 300FT (1σ)	AZIMUTH- 0.6 mr (1σ) (BASED ON MLS PFN SPEC) ELEVATION- 0.8 mr (1σ) (BASED ON MLS PFN SPEC) RANGE- 190FT (1σ)	AZIMUTH- 0.6 mr (1σ) (BASED ON MLS PFN SPEC) ELEVATION- 0.8 mr (1σ) (BASED ON MLS PFN SPEC) RANGE- 200FT (1σ)	AZIMUTH- 3.0 mr (1σ) (BASED ON MLS PFN SPEC) ELEVATION- 4.0 mr (1σ) (BASED ON MLS PFN SPEC) RANGE- 560FT (1σ)	AZIMUTH- 3.0 mr (1σ) (BASED ON MLS PFN SPEC) ELEVATION- 4.0 mr (1σ) (BASED ON MLS PFN SPEC) RANGE- 1600FT (1σ)	AZIMUTH- 0.6 mr (1σ) (BASED ON MLS PFN SPEC) ELEVATION- 0.8 mr (1σ) (BASED ON MLS PFN SPEC) RANGE- 290FT (1σ)
UPDATE RATE	3-4 PER SECOND	1 PER SECOND	1 PER SECOND	3-4 PER SECOND	1 PER SECOND	>1 PER SECOND	>1 PER SECOND	>1 PER SECOND	>1 PER SECOND
CHANNEL / SPECTRUM REQUIREMENTS	1P/N CODE / RUNWAY 200 P/N CODES FOR CONUS ONE 12.8 MHz WIDE, FREQUECY CHANNEL FOR ENTIRE CONUS	USE MODE-S DATA LINK FOR DOWNLINKING OF MLSS DATA RANDOM ACCESS)	USE ATCRBS TRANSPONDER REPLY CHANNEL TO DOWNLINK MLSS DATA	1 CHANNEL/RUNWAY 100 KHz /CHANNEL 2 MHz CHANNEL SEPARATION	1 CHANNEL/AIRCRAFT 10 CHANNELS/RUNWAY 400 KHz /CHANNEL 4.0 MHz CHANNEL SEPARATION	1 CHANNEL/AIRCRAFT 10 CHANNELS/RUNWAY 400 KHz /CHANNEL 4.0 MHz CHANNEL SEPARATION	1 TIME SLOT/AIRCRAFT 10 TIME SLOTS/ RUNWAY 400 KHz /CHANNEL 400 KHz CHANNEL SEPARATION	1 TIME SLOT/AIRCRAFT 10 TIME SLOTS/RUNWAY 400 KHz /CHANNEL 400 KHz CHANNEL SEPARATION	1 P/N CODE/AIRCRAFT 10 P/N CODES/RUNWAY ONE 1.0 MHz CHANNEL/ RUNWAY
STANDARD AVIONICS	MLS ANGLE RECEIVER DME/P OR DME/N INTERROGATOR	MLS ANGLE RECEIVER MODE-S TRANSPONDER	MLS ANGLE RECEIVER DME/P OR DME/N INTERROGATOR ATCRBS TRANSPONDER	MLS ANGLE RECEIVER DME/P OR DME/N INTERROGATOR	STANDARD AVIONICS SET NO MLS AVIONICS	STANDARD AVIONICS SET NO MLS AVIONICS	STANDARD AVIONICS SET NO MLS AVIONICS	STANDARD AVIONICS SET NO MLS AVIONICS	STANDARD AVIONICS SET NO MLS AVIONICS
REQUIRED MLSS AVIONICS	MLSS DATA ENCODER AND TRANSMITTER INTERFACE TO DATA BUS (SHARES MLS ANTENNA)	MLSS DATA CONTROLLER INTERFACE TO MLS AND MODE-S	MLSS DATA ENCODER AND TRANSMITTER INTERFACE TO DATA BUS (SHARES MLS ANTENNA)	MLSS DATA TRANSMITTER INTERFACE TO DATA BUS MLSS ANTENNA	MLSS TRANSLATOR MLSS TRANSMITTER AND ANTENNA	MLSS TRANSLATOR MLSS TRANSMITTER AND ANTENNA	MLSS TRANSLATOR MLSS TRANSMITTER AND ANTENNA	MLSS TRANSLATOR MLSS TRANSMITTER AND ANTENNA	MLSS DATA ENCODER AND TRANSMITTER RECEIVER AND TRANSMITTER ANTENNA
STANDARD GROUND EQUIPMENT	MLS EQUIPPED RUNWAY	MLSS EQUIPPED RUNWAY MODE-S INTERROGATOR	MLSS EQUIPPED RUNWAY ATCRBS INTERROGATOR	MLS EQUIPPED RUNWAY	MLS EQUIPPED RUNWAY	MLS EQUIPPED RUNWAY	MLS EQUIPPED RUNWAY	MLS EQUIPPED RUNWAY	MLS EQUIPPED RUNWAY
REQUIRED MLSS GROUND EQUIPMENT	MLSS RECEIVER AND ANTENNA ATC INTERFACE DATA PROCESSOR AND DISPLAY	MLSS PROCESSOR AND DISPLAY MODE-S INTERFACE	MLSS PROCESSOR AND DISPLAY INTERFACE TO ATCRBS	MLSS RECEIVER MLSS OMNI ANTENNA ATC INTERFACE DATA PROCESSOR AND DISPLAY	MLSS MULTICHANNEL RECEIVER & ANTENNA ATC INTERFACE MLSS DATA PROCESSOR AND DISPLAY	MLSS MULTICHANNEL RECEIVER & ANTENNA ATC INTERFACE MLSS DATA PROCESSOR AND DISPLAY	MLSS RECEIVER AND ANTENNA ATC INTERFACE MLSS DATA PROCESSOR AND DISPLAY	MLSS RECEIVER AND ANTENNA ATC INTERFACE MLSS DATA PROCESSOR AND DISPLAY	MLSS RECEIVER AND OMNI ANTENNA ATC INTERFACE DATA PROCESSOR AND DISPLAY
REQUIRED EQUIPMENT MODS	MLSS AVIONICS CONNECT TO MLS ANTENNA MLSS GROUND EQUIPMENT INTERFACE TO ATCRBS/ MODE-S DATA	MLSS AVIONICS INTERFACE TO MODE-S MLSS GROUND EQUIPMENT INTERFACE TO MODE-S	MLSS AVIONICS INTERFACE TO ATCRBS TRANSPONDER MLSS GROUND EQUIPMENT INTERFACE TO ATCRBS	MLSS AVIONICS INTERFACE TO DATA BUS MLSS GROUND EQUIPMENT INTERFACE TO ATCRBS / MODE-S DATA	MLSS GROUND EQUIPMENT INTERFACE TO ATCRBS / MODE-S	MLSS AVIONICS CONNECT TO MLS ANTENNA MLSS GROUND EQUIPMENT INTERFACE TO ATCRBS/ MODE-S DATA	MLSS EQUIPMENT INTERFACE TO ATCRBS / MODE-S	MLSS EQUIPMENT INTERFACE TO ATCRBS / MODE-S	MLSS GROUND EQUIPMENT INTERFACE TO ATC SYSTEM
REQUIRED PILOT / CONTROLLER ACTIONS	NONE	NONE	PILOT- NONE CONTROLLER- TIME SLOT ASSIGNMENT	NONE	CONTROLLER- ASSIGN FREQUENCY CHANNEL PILOT- INPUT ASSIGNED FREQUENCY CHANNEL	CONTROLLER- ASSIGN FREQUENCY CHANNEL PILOT- INPUT ASSIGNED FREQUENCY CHANNEL	CONTROLLER- ASSIGN TIME SLOTS PILOT- INPUT ASSIGNED TIME SLOT TO MLSS	CONTROLLER- ASSIGN TIME SLOTS PILOT- INPUT ASSIGNED TIME SLOT TO MLSS	CONTROLLER- CODE ASSIGNMENT TO AIRCRAFT PILOT- CODE ENTRY
POSITIVE AIRCRAFT IDENTIFICATION	YES, AIRCRAFT RESPOND WITH DISCRETE ID	YES, AIRCRAFT RESPOND WITH DISCRETE ID	YES, AIRCRAFT RESPOND WITH ID	YES, AIRCRAFT RESPOND WITH ID IDENTIFICATION	YES, EACH AIRCRAFT ON ONE CHANNEL	YES, EACH AIRCRAFT ON ONE CHANNEL	YES, EACH AIRCRAFT ON ONE TIME SLOT	YES, EACH AIRCRAFT ON ONE TIME SLOT	YES, AIRCRAFT ASSIGNED INDIVIDUAL CODE
ISSUES	ASSIGNMENT OF A 12.8 MHz CHANNEL TO MLSS	POTENTIAL INTERFERENCE WITH MODE-S	POTENTIAL INTERFERENCE WITH MODE-S	AVAILIBILITY OF A SUFFICIENT NUMBER OF FREQUENCIES TO MEET CONUS REQUIREMENTS	REQUIRES LARGE FREQUENCY SPECTRUM	REQUIRES LARGE FREQUENCY SPECTRUM	REDUCED SAMPLING RATE DEGRADES PERFORMANCE TO AN UNACCEPTABLE LEVEL	REDUCED SAMPLING RATE DEGRADES PERFORMANCE TO AN UNACCEPTABLE LEVEL	ACQUISITION OF A SUFFICIENT NUMBER OF FREQUENCIES EFFECT OF SIGNAL DYNAMIC RANGE ON CODE ISOLATION FOR NEAR AND FAR TARGETS

Translator - TDM - The TDM concept results in a low data rate resulting in an unacceptable degradation in system performance.

Translator - CDM - The CDM concept can be implemented with a reduced set of frequencies. However, the signal digitizing requirements results in much more complex and costly MLSS avionics than a simple translator approach.

CONCLUSIONS

An MLS based aircraft surveillance system is feasible and can be readily implemented with current technology. The study concluded that there are three leading candidate MLSS concepts:

The Data Link - CDM - MLSS concept imposes the least restrictions on implementation. Its operation is well isolated from the other ATC systems, and as such it can not cause any interference in their operations. The system meets all MLSS requirements.

The Data Link - Mode-S - MLSS concept use of the Mode-S data link requires a detailed investigation and test to insure that the transmission of MLSS data over the link does not degrade the performance of the Mode-S. This, and the ease of interfacing the airborne and ground MLSS equipment with Mode-S are the only concerns with this approach. The system meets all MLSS requirements.

The Translator - FDM - MLSS concept represents the most original approach to MLSS implementation. Retransmitting the translated MLS signals on a frequency well removed from the C-band at which MLS operates will insure non-interference with the MLS operation and no self-interference. The concept of performing the aircraft position calculations on the ground rather than in the aircraft as well as the determination of range from the retransmitted angle guidance signals represent a novel approach, but poses no technical risks. The system meets all MLSS requirements.

RECOMMENDED PROGRAM APPROACH

The recommended approach to the next phase of the MLSS program is to proceed with concept demonstration and evaluation resulting in one of the three candidate MLSS concepts being selected for deployment. The following approach is recommended:

DETAILED SYSTEM ANALYSIS AND DESIGN - Perform a detailed system analysis and preliminary design of the three concepts. The design shall include all system hardware and software components and system interfaces. The result of the system design phase shall be a documented system design which will be used to order the system components and build the demonstration systems.

The system analysis and design phase will require a nine (9) month effort.

LABORATORY TEST AND EVALUATION - All MLSS concepts which emerge from the detailed analysis and design phase as still viable approaches will be built and tested in the laboratory in order to determine as much as possible about their performance before proceeding to the more costly field and flight tests. Commercially available MLS simulators can be used to simulate the MLS environment. Similar simulation techniques will be used to simulate traffic and ATC system interfaces. The result of the laboratory test phase will be the confirmation of the feasibility of the proposed approach and finalization of the system designs.

The system build and laboratory test and evaluation phase will require a twelve (12) month effort.

SYSTEM DEMONSTRATION - FIELD AND FLIGHT TESTS - Following the completion of the laboratory phase of the program, the successful MLSS candidates will undergo a field and flight test program. The demonstration program can take place at a Government facility such as the the FAATC or the NASA Wallops Island station, since the airports of both are equipped with MLS. Alternately, the demonstration can take place at a commercial airport with parallel or converging runways and equipped with MLS. The system demonstration phase shall be designed to evaluate the candidate systems performance under operational conditions. The result of the system demonstration phase will be the operational evaluation of the concepts, final selection of a candidate system and preparation of a system specification.

The system demonstration phase will require a twelve (12) month effort.

1.0 INTRODUCTION

This study was performed for the Federal Aviation Administration's Office of Airports. It examines and evaluates alternative implementations of Microwave Landing System-based Surveillance Systems (MLSS) that could provide precise three dimensional surveillance of landing aircraft under Instrument Meteorological Conditions (IMC). Specifically, the system could be applied in monitoring and controlling independent (simultaneous) approaches to closely spaced parallel and converging runways.

1.1 STATEMENT OF THE PROBLEM

Weather-related aircraft delays at major airports are a significant problem. The FAA is examining various techniques to increase the capacity of airports when operations are being conducted under IMC. One such technique is the development of simultaneous, independent IFR approaches to closely spaced parallel and converging runways. The ability to use a second parallel or converging runway in IMC would increase the IFR capacity of more than 60 major airports (References 1 and 2), resulting in substantial reductions in delay due to weather. The use of such approaches has been the subject of considerable study, analysis, simulation, and experimentation by the FAA (References 2-11). These studies indicate the need for an improved surveillance sensor for monitoring these simultaneous operations.

1.2 SURVEILLANCE SYSTEM REQUIREMENTS

The results of the studies referenced above indicate that for monitoring simultaneous approaches to closely spaced parallels, a surveillance system should approach the requirements shown in Table 1-1.

The traffic control issues associated with approaches to converging runways appears quite similar to approaches to closely spaced parallels. However, issues of separation assurance are quite different.

In the case of closely spaced parallels, aircraft streams merge somewhere near the outer markers of each runway and then fly in parallel at 3000 - 4300 feet of lateral separation. Missed approaches for the two streams generally proceed in directions that result in diverging departure paths; thus increased lateral separation is rapidly attained. The major separation assurance concern is to ensure that separation is maintained during the converging of the arrival streams and the approach phase.

In the case of the converging approaches, aircraft streams do not get close to each other until very near the airport. Because the arrival path extensions tend to intersect (converging runway centerlines), the problems of missed approaches creates a more difficult separation assurance problem than the parallel approach. Therefore more attention is focused on the final phases of the approach and the initial missed approach areas.

There have not been any comprehensive studies of the surveillance requirements to support approaches to converging runways. It is likely that surveillance

during final approach and initial phases of the missed approach will be less stringent than the requirements for parallel runway operations. For the purposes of this study, we will assume that the surveillance requirements for converging approaches are the same as those for parallel runway operations. These requirements can then be the basis of surveillance sensor development efforts and form a hypothesis that can be tested in real time simulations or other analytical studies.

Table 1-1 Surveillance System Requirements

Coverage:	Approach and missed approach corridors
Range:	15 nm.
Accuracy:	1-2 milliradian in azimuth (1 sigma) 250 feet range (1 sigma) 100 foot altitude (1 sigma)(see note)
Update Rate:	1 second or less
Two Target : Resolution	Two targets must be resolved when they are as close as 600 feet apart at 10 nm.
Target : Acquisition, Tracking and Identity	Target acquisition and tracking must be automatic; positive identification of the aircraft must be obtained and correlated with the aircraft identity obtained from the air traffic control system.
Targets :	Maximum number of targets simultaneously tracked: 10 per runway, 20 maximum for parallel and converging runway situations

Note: Altitude accuracy based upon Mode-C barometric altitude accuracy

1.3 MLSS CONCEPTS

Figure 1-1 illustrates the MLSS concepts considered in this report. The left side of the figure indicates the choices available using primary and secondary radars. The right side of the figure shows the options available if one takes advantage of capabilities of the airborne Microwave Landing System (MLS) as a position sensor. Three MLS-based sensor concepts are shown, with several sub-concepts identified. The purpose of this study is to examine the technical feasibility of these MLS based surveillance system concepts. The three concepts examined are:

1. Translator concept - a system which receives and retransmits MLS data messages and scanning-beam angle information back to the ground where azimuth, elevation, and range are determined; three methods for communicating between the airborne and ground systems were examined: Frequency Division Multiplexing (FDM), Time Division Multiplexing (TDM), and Code Division Multiplexing (CDM).

2. Data Link concept - a system which transmits via data link MLS derived angle and DME derived range data measured by existing on-board MLS/DME avionics; four types of data links were examined: Frequency Division Multiplexed (FDM), Pseudo Random Noise Code Spread Spectrum (CDM), a TDM technique based upon a special use of ATCRBS transponder replies (Crossbanding), and use of the Mode-S data link.

3. Reflection concept - a passive system which utilizes MLS signals reflected off arriving aircraft to permit determination of range and azimuth to the aircraft.

A familiarity with the basic MLS signal structure and format may be helpful to fully understand the operation of these concepts. Appendix A presents MLS signal formats and a summary of MLS operation.

In subsequent sections, each of these three concepts is discussed and recommendations made as to which concepts to pursue via a feasibility demonstration program.

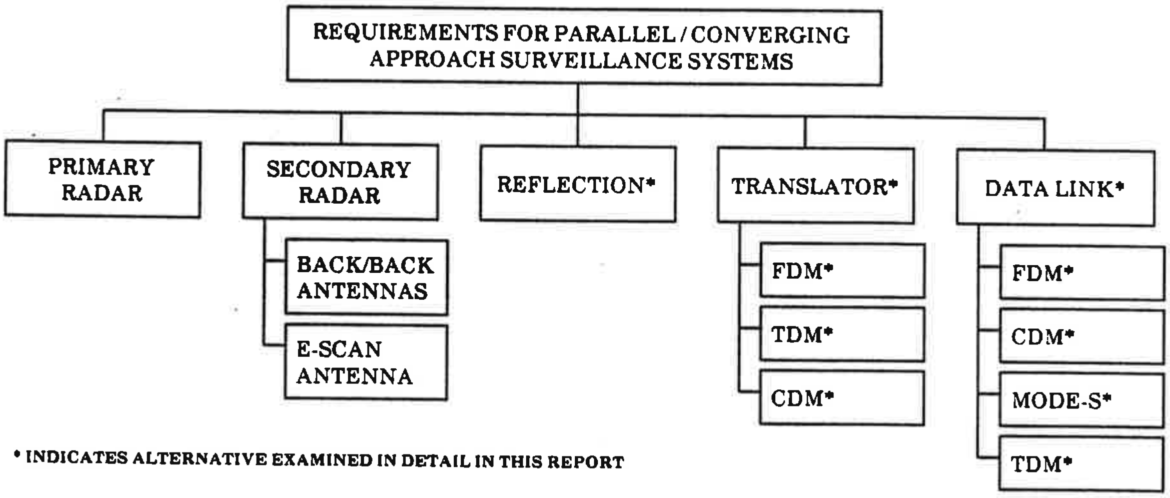


FIGURE 1-1. SURVEILLANCE SYSTEM ALTERNATIVES

2.0 TRANSLATOR CONCEPT

A Microwave Landing System-Based Surveillance System (MLSS) translator concept emulates functions of the airborne MLS receiver on the ground. This concept involves:

1. A separate airborne translator which receives and translates MLS data messages and the scanning beam angle signals and retransmits these signals to ground.

2. A ground receiver which receives the same signal over two paths: directly from the nearby MLS transmitter site and the translated signal from the aircraft. Conventional airborne MLS signal processing is used on the ground to determine the aircraft azimuth and elevation angles. Correlation and timing of the signals of both paths provide an independent aircraft range measurement.

Two variations of the basic translator concept are examined. Each of the variations utilizes a different technique to encode and transmit the MLS data and angle information to the ground.

2.1 CONCEPT DESCRIPTION

2.1.1 Frequency Division Multiplexing

In the simplest form of the translator concept, each arriving aircraft uses a different frequency to re-transmit MLS data and scanning beam information back to ground. Up to ten frequencies per approach are needed in order to achieve a 20 aircraft capacity for the airport. The aircraft translator consists of a solid state varactor converter with a low code distortion and delay characteristics. A block diagram showing the basic elements of the system is shown in Figure 2-1.

The angle measurements are determined by the ground-based MLS angle processor while the range measurements are determined by crosscorrelating MLS and MLSS downlinked signals either in a phase-locked loop envelope tracker/discriminator or by integrating noncoherently and comparing with the time references.

To ascertain the feasibility of this concept, a number of analyses were performed. The basic equations governing the translator angle and range measurements were derived. These are shown in Appendix B.

A power budget was established to determine the airborne transmitter power levels necessary to achieve reliable signal detection on the ground. The required transmitter power at C-band is on the order of 30 dBm for a range of 15 nmi. This analysis is given in Appendix C. Permitted power levels at other frequency bands are provided in Appendix D.

An analysis of the potential interference with the aircraft's MLS receiver by the airborne transmitter was performed. The results of this analysis indicate that if the frequency band just above the MLS band (5091 to 5250 MHz) is used for transmission, the transmitter power must be limited to 25 dBm. This permits operation at ranges of up to 15 nm. If another frequency band is used,

range is extended beyond the MLS range of 15 nm. This analysis is given in Appendix D. Tradeoffs of power, interference, and accuracy with MLSS downlink frequency choice are presented in Appendix O.

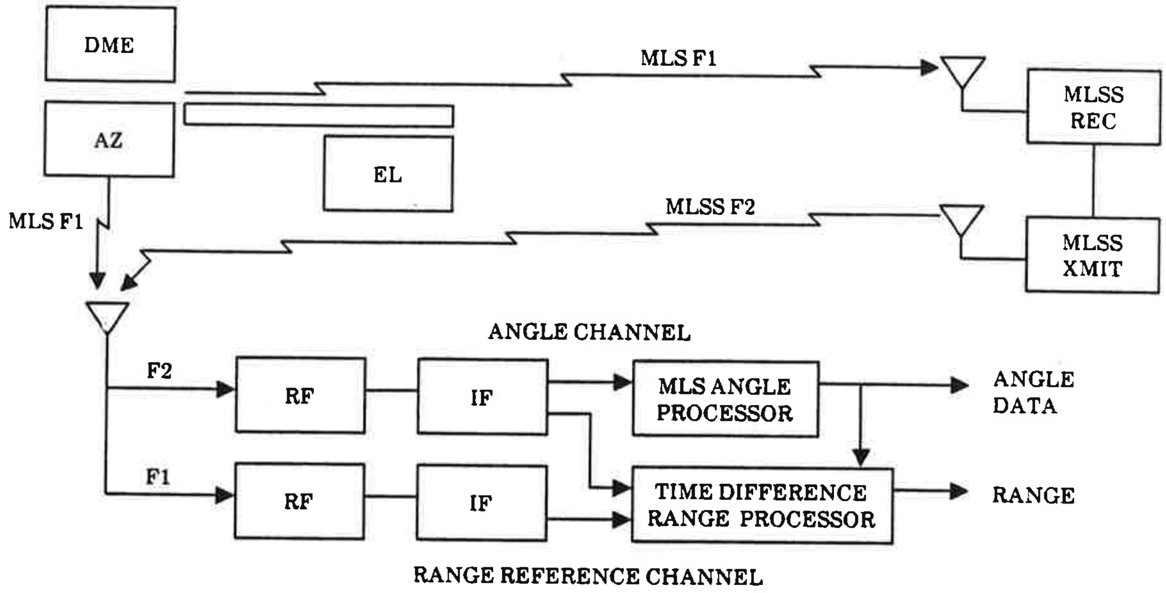


FIGURE 2-1. FDM TRANSLATOR CONCEPT BLOCK DIAGRAM

An initial analysis of the <u>accuracy with which range can be determined</u> was conducted. It was concluded that the range accuracies on the order of 202 feet (1 sigma) could be obtained with this basic system. Multipath effects may degrade accuracy to some degree. The range accuracy analysis is presented in Appendix E.

Finally, an analysis of the <u>number of communication channels</u> required for multiple approaching aircraft was performed. In the case of multiple aircraft making an approach, their replies will seriously overlap (garble) if they transmit on the same frequency.

In a practical Frequency Division Multiplexed (FDM) system, each aircraft will be assigned a downlink frequency to be used to send the MLS data back to the ground facility. The ground receiving site employs a multichannel receiver. The number of channels needed is estimated to be 10 per approach and missed approach. Assuming a maximum of two sets of parallels or converging runways, the required number of channels is 20 channels per airport. A frequency analysis to determine the maximum number of channels required so that operations at adjacent airports will not interfere with each other is shown in Appendix F. The analysis shows that if the frequency band 5091 MHz to 5250 MHz is available for MLSS operation, nineteen sub-bands can be generated to serve nineteen adjacent airports.

In an attempt to reduce the large number of channels required by the FDM concept, two other translator concepts were examined.

2.1.2 Time Division Multiplexing

The first alternative technique is to assign downlink reply slots to each arriving aircraft (Time Division Multiplexing or TDM) and utilize a single frequency downlink channel per runway. This concept is shown in Figure 2-2. The purpose of the TDM Translator approach is to reduce the number of communication channels required for aircraft to retransmit to the ground the received MLS azimuth and elevation scans. If all aircraft making a particular approach "time share" one communications channel, the number of channels required could be reduced by a factor of 10.

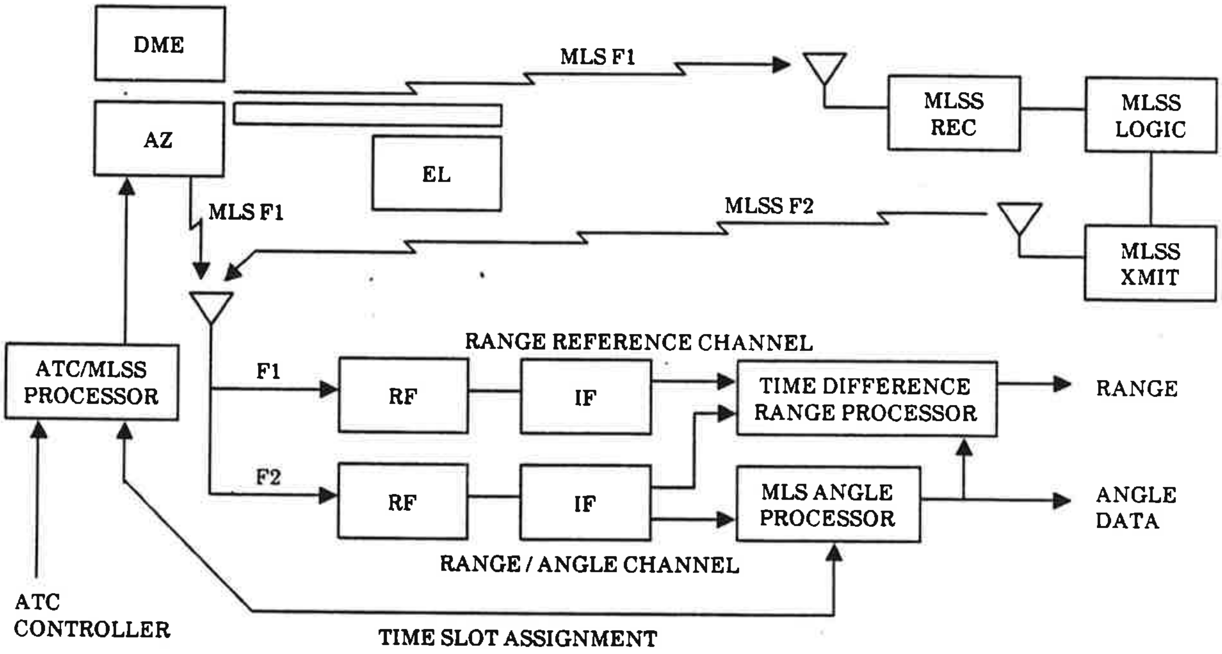


FIGURE 2-2. TDM TRANSLATOR CONCEPT BLOCK DIAGRAM

In the TDM Translator approach, each aircraft only replies during a time slot assigned by the ground system. There are 39 time slots (scans) per second available from the MLS for high rate azimuth and elevation scans respectively, which means that the product of the update rate times the number of aircraft handled cannot exceed 39. For example, if the number of slots assigned is to be 10 (for up to 10 aircraft), then the maximum update rate of the system in azimuth and elevation would be approximately 4 replies per second. Because range can be determined during both azimuth and elevation scans, the range update rate could be 8 replies per second. Details of operation of the TDM concept are given in Appendix G.

2.1.3 Code Division Multiplexing

The second alternative technique is to utilize spread spectrum and orthogonal codes for the downlink transmissions (Code Division Multiplexing or CDM) and utilize a single wide bandwidth channel for all aircraft. This concept is shown in Figure 2-3. With the CDM concept the airborne MLSS equipment directly measures the received azimuth and elevation angles and encodes this as data in a fixed portion of the downlink message. Range is not measured onboard the aircraft, but is measured on the ground as in the FDM and TDM concepts. The uplink DPSK and downlink encoded data are then encoded using orthogonal Gold codes and transmitted to the ground using spread spectrum techniques. The CDM concept is further discussed in Appendix H. This technique introduces considerable complications in system design and receiver costs.

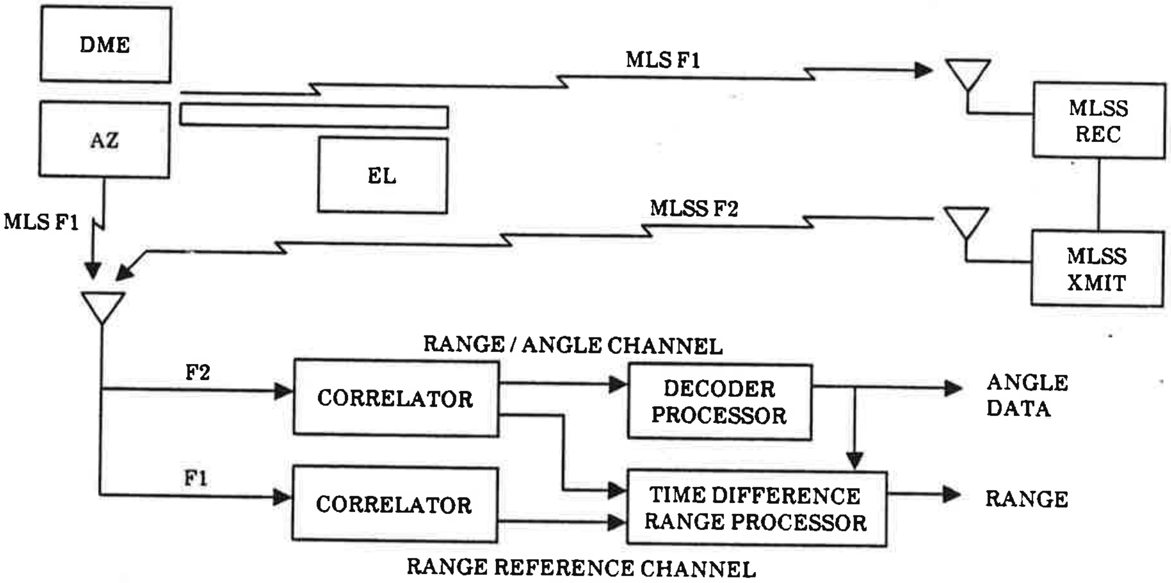


FIGURE 2-3. CDM TRANSLATOR CONCEPT BLOCK DIAGRAM

2.2 SYSTEM ELEMENTS

The translator concept is analyzed further by an examination of its six elements: MLS ground equipment, ground-air link, aircraft translator, air-ground link, MLSS receiver, and MLSS interfaces with air traffic control. In the following discussions, commonalities and differences among the various concepts will be identified and addressed in some detail.

2.2.1 MLS Ground Equipment

The translator concept utilizes the MLS generated signals in space and their timing and mode function sequencing. Therefore, uplink signal power levels

received at the aircraft and data formats and data rates are set by the MLS ground system and are not altered. Both MLS data and scanning beam signals radiated on wide and narrow-beam antennas are essential for MLSS range and angle determination on the ground. The ground MLSS translator timing is based on the receiver reference time contained in the MLS preamble as received in the range reference channel. Major elements of the MLS ground equipment are described below.

MLS TRANSMITTER AND ANTENNA The MLSS utilizes a solid-state, C-band transmitter with a frequency stability of 10kHz ($1x10^8$ short term, 1-second) (Reference 18, par. 4.1.4.3) at a nominal power level of 20 watts. A typical data transmission spectrum is shown in Figure 2-4. for a PSK code. Sidelobe levels at spectrum band edges of ± 150 kHz are down at least -33 dB. The scanning beam power spectrum is a typical "raised cos" beam with a sidelobe level of -23 dB and antenna beamwidth at -3 dB of 2 degrees as described in FAA-STD-022c, Figure 18, par. 4.5 and is shown here as Figure 2-5. It is a computed spectrum which is 45 dB down the band edges and which levels off at-55 dB. In Figures 2-4 and 2-5 measured spectra are also shown which agree well with the computed spectra.

MLS signals are transmitted on two types of antennas: a static antenna with ±40 degrees coverage for all data transmission, and an electronically scanned 2 degree beam width antenna that has a scan rate of 39 scans/per second for the azimuth, and a similar number for elevation coverage and scan range of ± 40 degrees. Antenna coverage and location are described in FAA-STD-022c, par 4.2.

SIGNAL POWER COVERAGE Minimum power spectral densities specified within coverage boundaries are as follows (FAA-STD-022c, Table 4).

Code Signals	- 89 dBW/m^2
Azimuth Scanning Beam Signals	- 79 dBW/m^2
Elevation Scanning Beam Signals	- 86 dBW/m^2

The limiting signal power at the aircraft is the power of the code data signals. The specified power densities may be converted to received power by use of a zero degree isotropic antenna where received power is given by:

$$\text{Received power} = -89\ dBW/m^2 + 10 \log (L^2/4\pi) = -94.4\ dBm$$

where L = wavelength

Representative power levels expressed in dBm at 5 and 15 nmi range are:

	5 NMI	15 NMI
Code Data Signals	- 83 dBm	- 92 dBm
Azimuth Scanning Beam Signals	- 77 dBm	- 86 dBm
Elevation Scanning Beam Signals	- 79 dBm	- 88 dBm

A 9 dB improvement in the signal power levels is evident when the coverage range is reduced from 15 nautical miles to 5 nautical miles coverage.

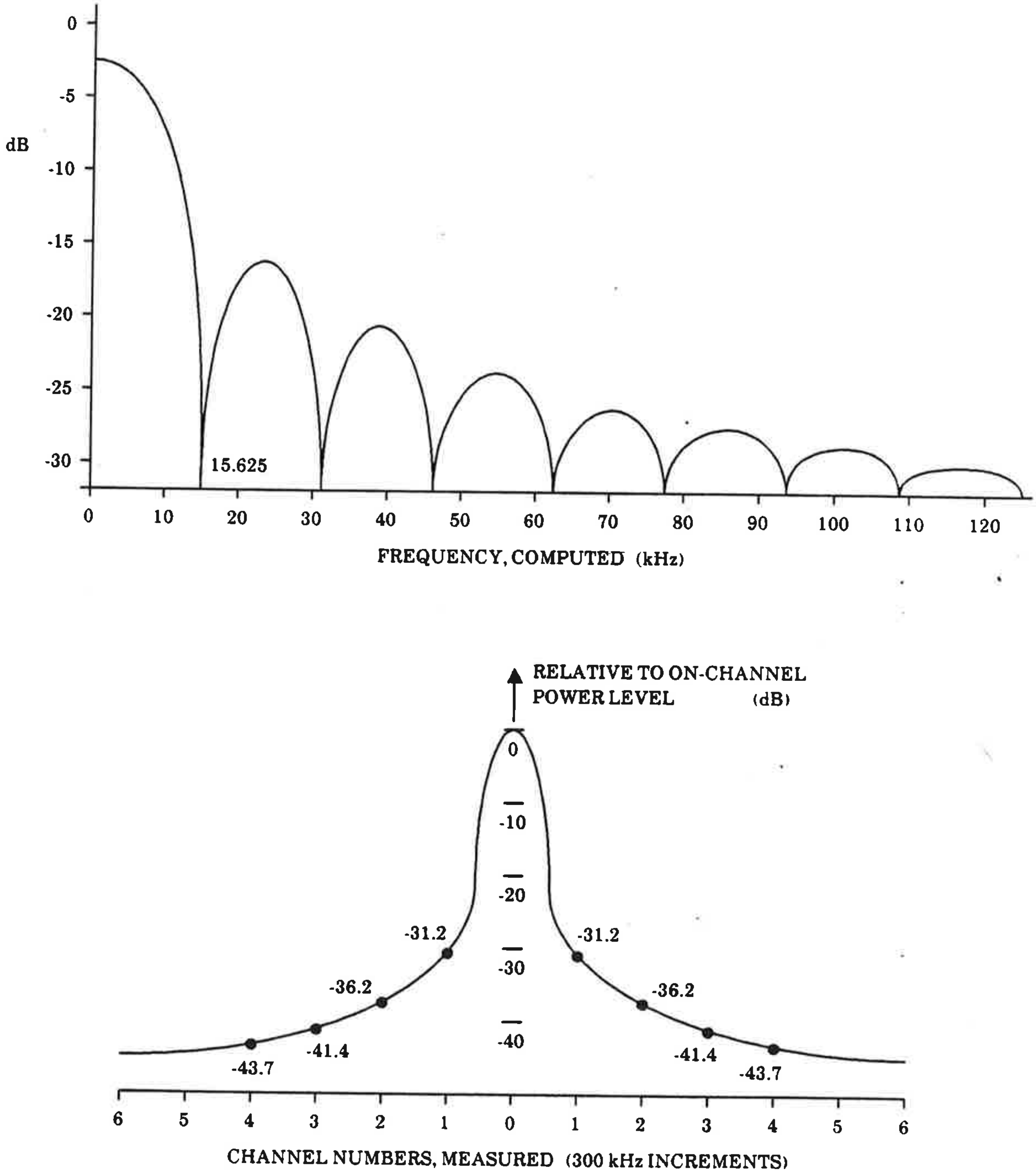


FIGURE 2-4. POWER SPECTRUM OF DATA CODES

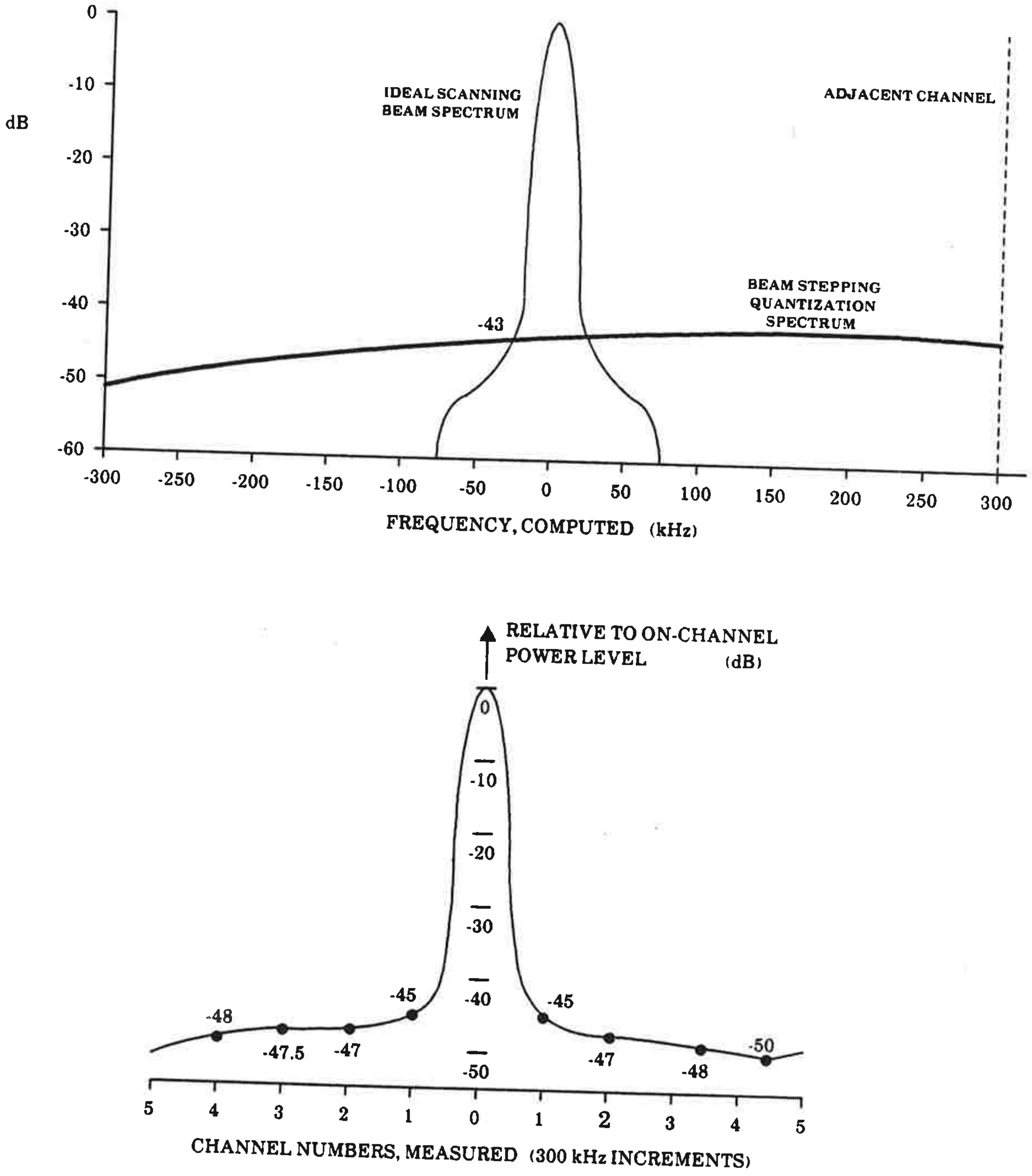


FIGURE 2-5. SCANNING BEAM TRANSMITTER OUTPUT

<u>SIGNAL FORMATS AND RATE</u> MLS data formats and rates are described in FAA-STD-022c. Data are encoded in a Differential Phase Shift Keying (DPSK) where "a 'zero' shall be represented by a 0 degree plus or minus 10 degrees phase shift and a 'one' shall be represented by a 180 degree plus or minus 10 degrees phase shift", (FAA-STD-022c, par. 3.2.2.1.1). Angle scanning beam signals and code acquisition preamble are unmodulated CW signals. Signal formats are discussed in Appendix A.

2.2.2 Ground-Air Link

Atmospheric and weather losses and multipath are the dominating factors in the uplink. These problems are addressed in ICAO Annex 10 (Reference 15) in the power estimates for the MLS. Additional requirements are specified in DO-177 (Reference 13).

2.2.3 MLSS Translator

2.2.3.1 FDM Translator

The FDM MLSS translator is a self-contained unit which can use an existing aircraft MLS receiver's antenna for signal reception, but which uses a separate antenna for downlink transmissions as shown in Figure 2-6.

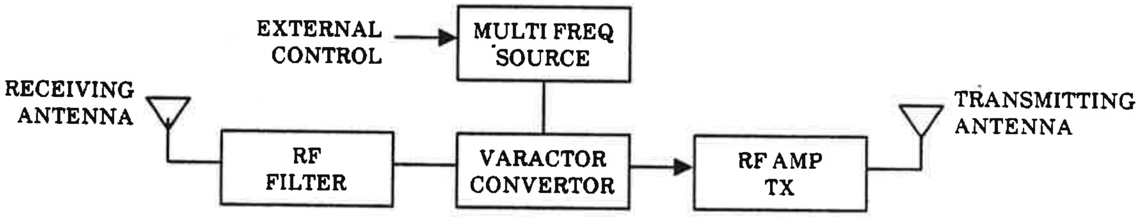


FIGURE 2-6. FDM TRANSLATOR AVIONICS

The MLSS translator receives both MLS data signals and scanning beam signals. Received signals are filtered in a 150 kHz band-pass filter, upconverted to the assigned downlink frequency, amplified to the proper level to assure 7.6 dB SNR at the signal level of -115.6 dBm at the ground antenna input port.

The uplink MLS signal has a 6 dB difference in signal power between the DPSK data and scanning beam signals.

2.2.3.2 TDM Translator

To employ the TDM technique, the airborne unit must have the ability to decode the DPSK data words (to sense the timing reference signal) and then count scans up to a predetermined and manually input count. At that time, its downlink transmitter is enabled and a downlink transmission sent which is similar to that sent by the FDM system.

2.2.3.3 CDM Translator

To employ the CDM technique, a 9-bit shift register would replace the multifrequency source to generate 20 511-bit Gold codes. These codes would provide over -23 dB isolation between the channels and -21 dB isolation in the worst case under the multiple access operational environment. The aircraft transmitter power budget is discussed in the Appendix E.

2.2.4 Air-Ground Link

Similar losses due to rain and atmospheric conditions are encountered in the downlink as in the uplink. Bistatic operation (transmitter and receiver at separate locations) does not present back scattering, only signal attenuation. At C band, the effect of this is minimal. Multipath problems are more severe. The MLS signal structure can be of little help because of the code rate and low altitude operation conditions. Some signal protection is possible by using receiving antenna patterns with a sharp cut-off and low sidelobe levels.

Range and angle error accuracies are discussed in Appendix E. It appears that angle error contribution due to downlink is minimal because of the errors are symmetric with respect to the TO and FRO scans and thus cancel out when processed. However, the range error is of concern because of receiver noise and the range delay variations in the measurements. A discussion of these effects as a function of MLSS frequency choice is given in Appendix O.

2.2.5 MLSS Ground Receiver

Two types of airborne translated signals are received on the ground: data messages and the angle scanning beam signals. Typical problems associated with each technique studied are discussed in the following sections.

2.2.5.1 FDM Receiver

The FDM receiver block diagram is shown in Figure 2-7. Received signals in the correlator arrive in staggered bursts; the signal is not continuous. The carrier lock preceding each burst is achieved within 12 clock pulse intervals or in 768 microseconds at the SNR levels specified. The downlink SNR is largely determined by the uplink SNR, which is a function of range. Appendix E addresses the MLSS receiver range and angle measurements in greater detail. Appendix O expands on the dependency of SNR upon range.

2.2.5.2 TDM Receiver

In the TDM translator concept only one downlink frequency is used which is shared (time multiplexed) among ten aircraft. The ground based receiver is similar to that of one of the FDM receiver channels. The order of the aircraft replies are set by use of the MLS auxiliary word which establishes a time reference to begin a roll-call count similar to the Crossbanding approach discussed in Section 3.1.2 and in Reference 14.

The TDM receiver performs the following functions: the IF/Demodulator filters and amplifies incoming RF signals, heterodynes the desired signal to baseband, demodulates the coded signal in a correlator pair which provides integration

over the pulse duration. The simplified receiver diagram is shown in Figure 2-8. The analog output of the combiner is converted into digital samples and fed into a synch delay circuit and a time-of-arrival special detection logic. In the shift register, a point in time will occur when sync pulses appear at all taps of the register simultaneously. This will be the time used in range detection when compared with the delay required to achieve the best coincidence of pulses.

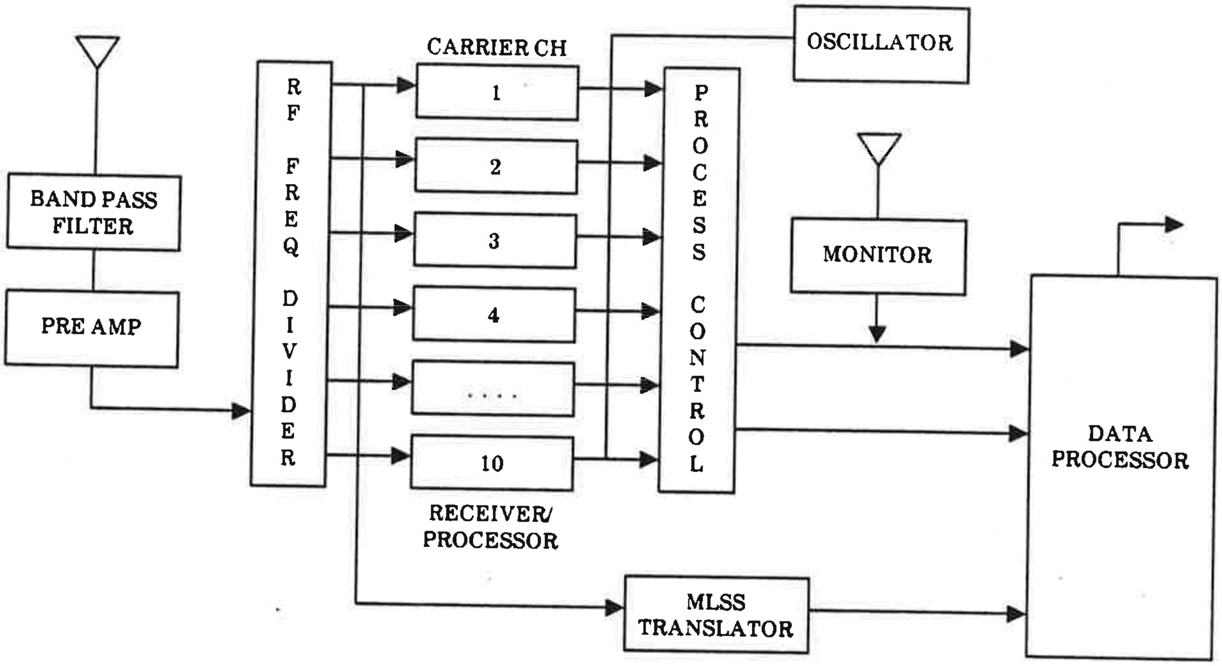


FIGURE 2-7. FDM GROUND RECEIVER BLOCK DIAGRAM

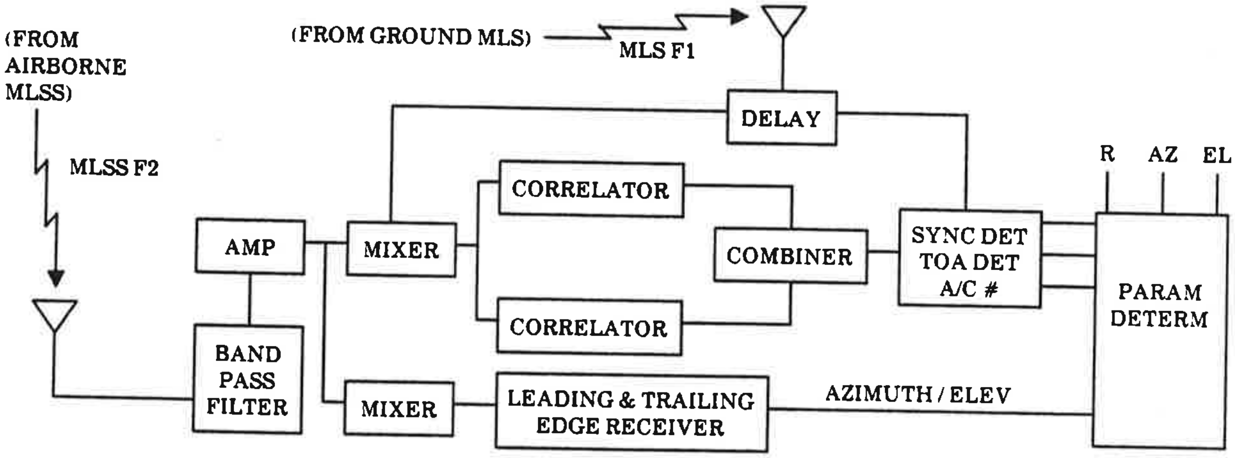


FIGURE 2-8. TDM GROUND RECEIVER BLOCK DIAGRAM

2.2.5.3 CDM Receiver

An alternative approach to FDM is the CDM receiver as shown in Figure 2-9. In this mode of operation, all aircraft are using the same frequency but each is using a different code. There are notable differences between these two methods. The CDM-spread spectrum is used to transmit multiple aircraft replies. CDM avoids garble between multiple aircraft by using a unique code (instead of frequency as in the FDM concept) for each approaching aircraft.

For CDM implementation, a possible downlink carrier frequency band could be the C-Band just above the assigned MLS channels. A bandwidth of 1.2 MHz would be required. The twenty PN (Gold) codes selected are of 511-bit length and transmitted at a rate of 511 KHz. The unique points of the CDM are:

1. There are no other changes in the MLS uplink data sequences except for the Auxiliary Word B, which is explicitly used to provide better time references to the system, in addition to 109 frames of 5-bit Barker codes. The Auxiliary Word B may use a long string of 13-bit Barker code combinations. The arrival of the Barker code at the aircraft will trigger the start of the Gold Code sequences on which MLS scanning beam "to-fro" timing data are encoded. The sequence will realign once every second with the arrival of the Auxiliary code.

2. The ground-based MLS translator CDM receiver divides incoming signals into 10 channels and by doing so accepts a 10 dB loss in SNR.

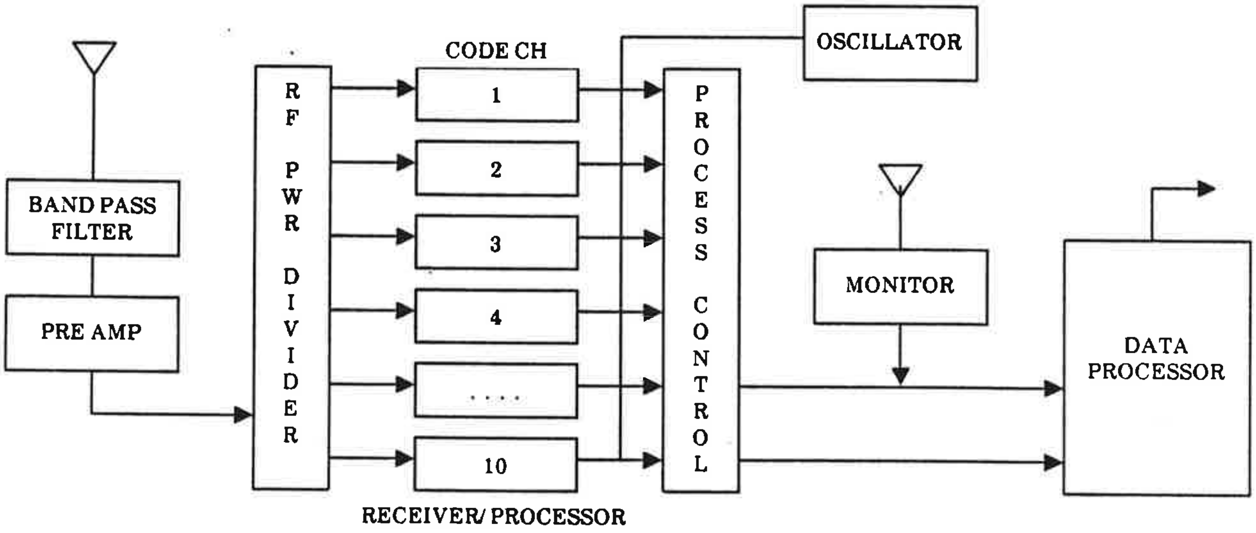


FIGURE 2-9. CDM GROUND RECEIVER BLOCK DIAGRAM

3. By synchronizing received replies with the MLS code from the MLS site, the range to the aircraft may be calculated. Decoded data from the Gold code sequences, when processed, will provide angle information.

4. The CDM code concept provides the following advantages:

   a) the CDM concept reduces aircraft peak power by 18 dB;
   b) Gold codes are proven and have good isolation between codes or orthogonality characteristics with sidelobe levels of -23.8 dB and a highest cross-correlation peak of -21.0 dB (Reference 23);
   c) Gold codes are less affected by the multipath interference.

5. A potential problem with the CDM concept is the interference of distant targets by targets near the ground receiver. For example, targets at 15 nmi have a signal level 23.5 db below targets at 1 nmi. This exceeds the 21 db isolation between Gold codes and could result in interference. This problem is similar to GPS pseudolite problem addressed in Reference 25 with potential solutions.

More information about the CDM alternative is given in Appendix H.

3.0 DATA LINK CONCEPT

The Data Link concept is based on the usage of the existing airborne MLS avionics derived azimuth, elevation and DME data for retransmission to the ground. This range and angle information is transmitted to the ground along with additional information such as aircraft and airport ID and landing runway via the data link. This concept requires:

1. Encoding the airborne derived azimuth, elevation, range and other data onto a downlink

2. On the ground, receiving the signal from each aircraft, decoding it, and determining the azimuth, elevation, and range of the aircraft

There are four variations in the concept depending upon the specifics of the particular data link employed. Two of the links rely on a dedicated data link on which aircraft send down their data on a channel contention basis. The third employs the MLS to assign reply time slots for an ATCRBS transponder which encodes range, elevation, and azimuth data for downlink. This concept is called Crossbanding. The fourth data link employs the Mode-S data link operating at a higher position update rate than normally employed in the normal Mode-S surveillance mode. Each concept will be discussed below.

3.1 CONCEPT DESCRIPTION

3.1.1 Dedicated Data Link

The dedicated data link concept is shown in Figure 3-1. It employs a spread spectrum transmission technique, where all aircraft employ a single frequency for transmission. A Pseudo random Noise code (PN) technique is employed where a unique PN code is assigned to a particular airport and runway configuration obtained from the decoded MLS receiver data. Thus, all aircraft approaching the same airport/runway have the same PN code and frequency channel. Appendix I shows the suggested data format/packet definition for the dedicated link, and Appendix J presents the expected channel access performance for the link. The results of these analyses is a suggested 172 bit packet transmitted at least four time per second for each aircraft using 12.8 MHz chip rate. This results in a probability of 99.98% that a valid reply will be obtained from up to 10 aircraft every second.

This system is adaptable to various techniques to reduce the number of transmissions from aircraft not of concern to the MLSS function. For example, logic could be built into the airborne unit to inhibit transmissions unless the range to the airport (as measured by the DME) is less than a threshold (say 15 nmi), or if the azimuth (as measured by MLS) is outside a range (say ± 30°). However, from the analysis, these methods do not seem to be necessary.

Appendix K presents the power budget for the dedicated link. The analysis shows that the required transmitter power is on the order of 25 dBm for a 15 nmi range and a 12.8 MHz channel bandwidth at C-band. Appendix L analyzes the potential interference between the dedicated data link and the airborne MLS receiver.

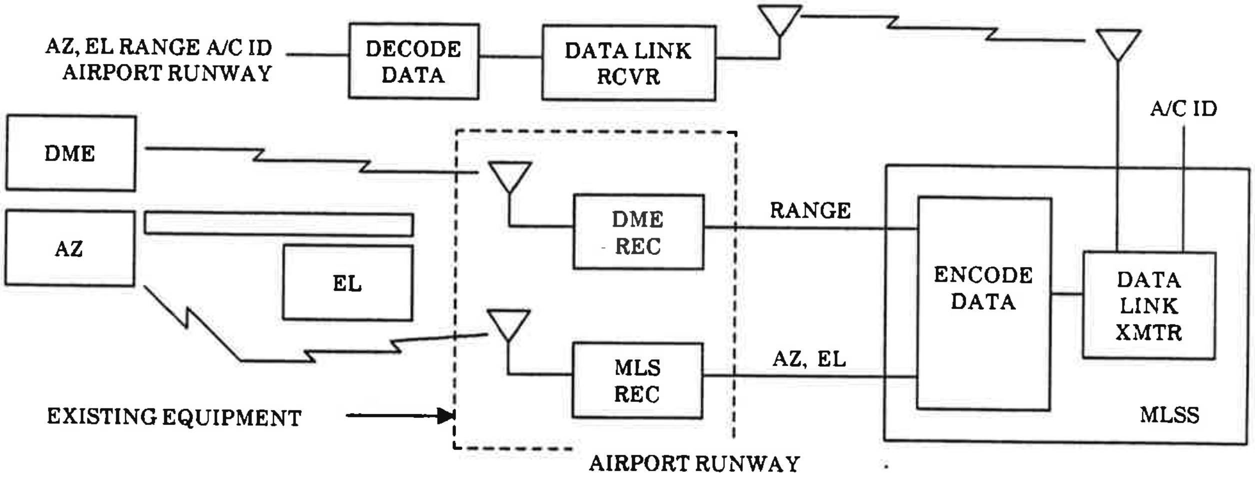


FIGURE 3-1. DEDICATED DATA LINK CONCEPT BLOCK DIAGRAM

3.1.2 Crossbanding

The Crossbanding concept is shown in Figure 3-2. It is a concept proposed by Bendix Communications Division (Reference 14) as a technique to improve surveillance of closely spaced aircraft. The concept is based on angle and range measurement by existing on board airborne MLS and DME receivers and retransmission of this information to the ground. The Bendix scheme involves encoding the airborne MLS derived azimuth, elevation, and range into an ATCRBS downlink format and retransmitting it at the ATCRBS reply frequency of 1090MHz. An omni directional antenna is utilized on the ground to receive the replies from each aircraft which contain MLS azimuth, elevation, and range.

Synchronous garble interference is avoided by scheduling aircraft replies. Reply time slots are assigned by the ground ATC system via voice link, keyboard entry, or by prearrangement. Within a full cycle of MLS sequences (592 msec), each aircraft receives ground originated synchronization time reference once and also originates an aircraft reply.

The Auxiliary Word is transmitted within a time gap of 1 millisecond between the first and the second sequence and is the only one which carries an 8-bit aircraft address code. Therefore a ground controller can assign a selected aircraft a code or change to a new code as required.

3.1.3 Mode-S Data Link

The Mode-S data link concept is shown in Figure 3-3. It employs the data link function of the Mode-S surveillance system (References 15 and 16) to transmit air derived MLS and DME range information to the ground. It is similar to, but has distinct advantages over, the Crossbanding concept discussed in Section 3.1.2.

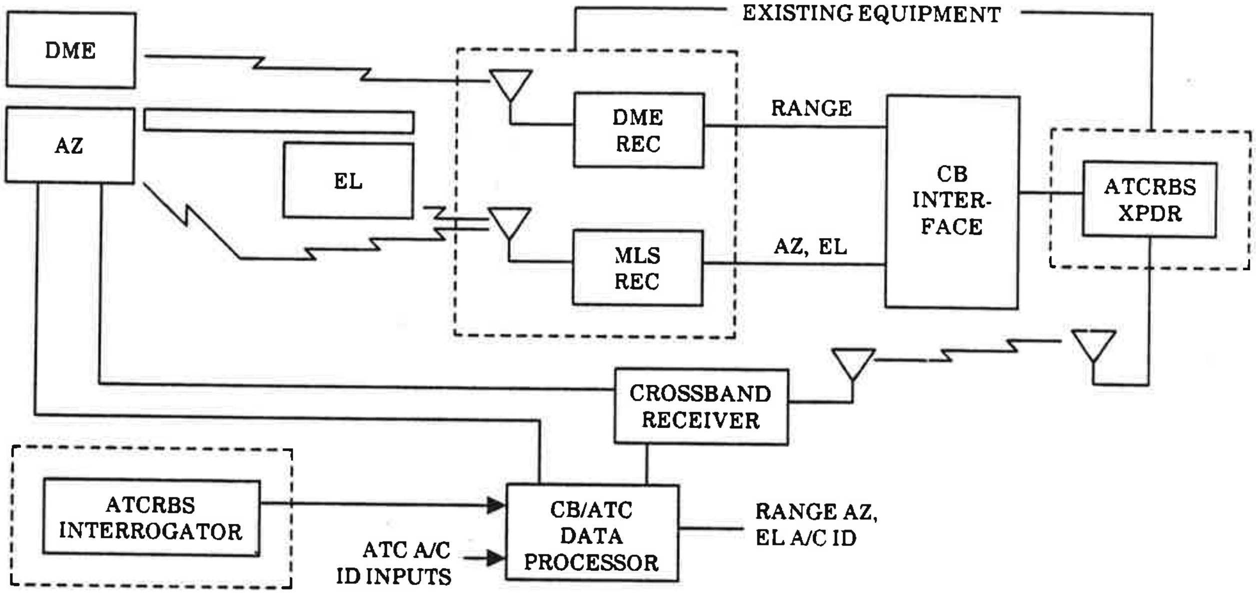


FIGURE 3-2. CROSSBANDING CONCEPT BLOCK DIAGRAM

In its simplest form, an aircraft would employ the Mode-S data link to transmit to the ground its azimuth, elevation, and range as derived from the airborne MLS and DME. It could use the Mode-S format DF-24 (ELM) which is designed for long message data transfers. For example, up to 16 segments of 112-bits length can be transferred in a single Mode-S sweep. If we assume that the airborne MLSS system employs the packet format of Appendix I, a message length of 172 bits will be employed to send azimuth, elevation, range, and identification. This can easily be accommodated by using two segments of a 112 bit format.

The biggest problem with this simplest form of the Mode-S concept deals with update rate. With the normal terminal Mode-S system, the antenna sweep rate is nominally once per 4 to 5 seconds. This rate does not satisfy the minimum update rate of once per second required for monitoring closely spaced parallel runways. Even if back-to-back antennas are employed in the Mode-S interrogator (as is being tested), the surveillance system update rate is still once per 2 to 2.5 seconds, which is probably inadequate.

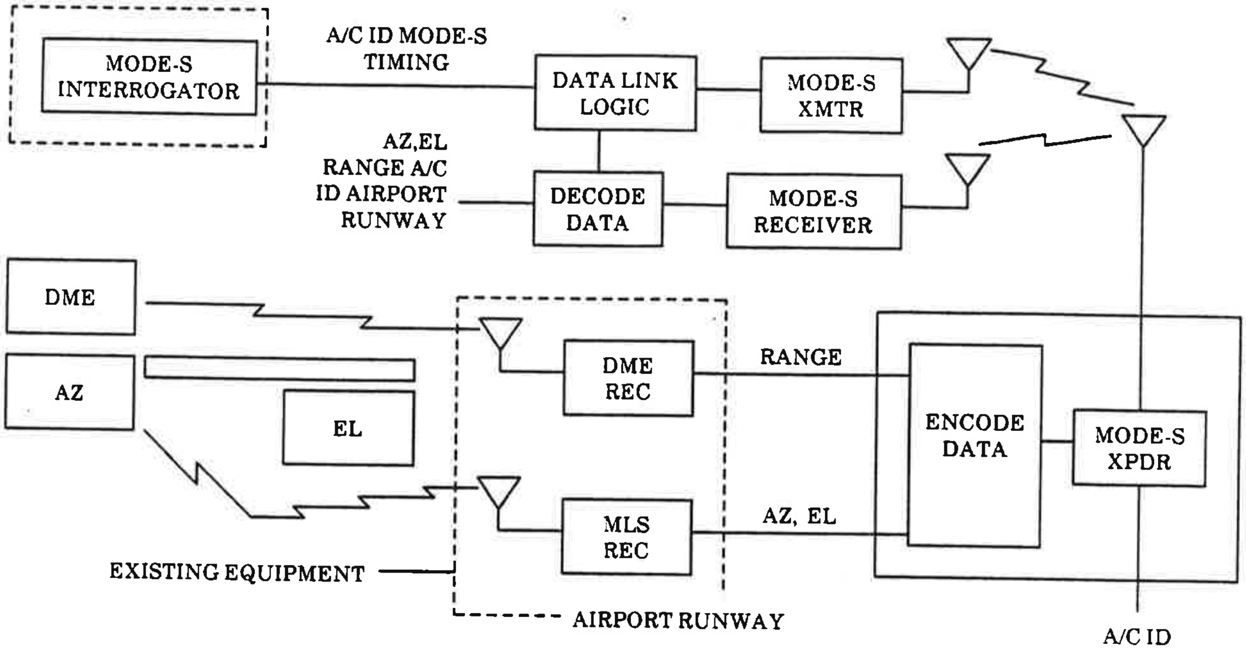


FIGURE 3-3. MODE-S DATA LINK CONCEPT BLOCK DIAGRAM

There is a way around this problem which forms the basis for the MLSS Mode-S data link concept. Basically, this involves additional Mode-S interrogations of up to 20 aircrafts by the MLSS ground station at a rate of 4 interrogations per aircraft per second. This would work as follows:

The MLSS would obtain certain information from the Mode-S interrogator serving an airport in question. This information would be the position and identification (and discrete address) of all aircraft for which MLSS surveillance is desired. This data would be send to the MLSS ground system every 4-5 seconds. Mode-S timing data is sent to the MLSS ground station so it can determine when the Mode-S antenna is illuminating each target. The MLSS ground station would then schedule interrogations of the selected aircraft at a time other than when the Mode-S interrogator is illuminating the target and at a rate which satisfies the MLSS requirement, i.e. two to four times per second. These interrogations would be made by a separate Mode-S transmitter using an omnidirectional or wide beam horn antenna used for SLS transmissions.

The airborne Modes-S transponder would reply whenever interrogated, with air-derived range, azimuth, and elevation, aircraft ID, airport and runway data with the data encoded onto the Mode-S datalink. One interrogation per update period will be needed to initiate the ELM message format which is used to transmit the 172 bit MLSS message to the ground.

A concern with this concept is how to avoid introducing additional fruit and interference into the ATCRBS and Mode-S systems. The interrogation rate required by the MLSS system (say 80 per second) is low enough to not become a major factor. However, further analysis of this is required to ensure compatibility with ATCRBS and Mode-S signals.

3.2 SYSTEM ELEMENTS

3.2.1 MLS Ground Equipment

MLS ground equipment was discussed in detail in Section 2.2.1. The DME system and its accuracy considerations are discussed in Appendix A. Ground equipment originated signals do not affect MLSS data link system performance, this being governed by the accuracy of the airborne MLS derived data. For a description of the Mode-S system see References 15 and 16.

3.2.2 Ground-Air Link

Atmospheric and weather losses and multipath are the dominating factors in the MLS uplink. These problems are addressed in ICAO Annex 10 (Reference 15) in the power estimates for the MLS. Additional requirements are specified in DO-177 (Reference 13). For the Mode-S data link concept, interference, fruit, and garble are the principal concerns caused by introducing another Mode-S interrogator which transmits on an omni-directional antenna. A full assessment of these problems requires additional analysis; however, this situation is not unlike that caused by airborne TCAS interrogators which has been analyzed extensively and appears to present manageable problems.

3.2.3 Airborne Equipment

The airborne elements of all three MLSS Data Link concepts rely upon the use of the existing MLS receiver and DME interrogator. Interfaces to the airborne MLSS element is via a standard ARINC buss.

All three concepts employ a special purpose data encoding device to take the MLS/DME and identity information and encode it onto a dedicated data link, ATCRBS, or Mode-S formats, depending upon the particular concept. In the cases of the dedicated data link and Crossbanding concepts, this encoding device also serves to control the transmissions from the data link transmitter or ATCRBS transponder. In the case of the Crossbanding, the ATCRBS reply timing is derived from timing information sent via the MLS Auxiliary Data Words. In the case of the Mode-S data link, the ground interrogator scheduling determines the transponder reply timing.

The interface to the airborne MLS is achieved through a data bus. Timing of the downlink transmissions will vary, depending upon the particular concept in use. Crossbanding techniques use time division multiplexing by providing a reference time in the form of auxiliary word received once a second. The ground ATC system assigns time slots.

3.2.4 Air-Ground Link

The various data link concepts utilized different air ground transmission techniques, i.e., PN data link, FDM data link, encoded ATCRBS and encoded Mode-S.

3.2.5 MLSS Ground Receiver

3.2.5.1 PN Data Link Receiver

A single frequency is used to receive all replies. A spread spectrum PN code is used to minimize peak power and protect messages against interference. The runway in use is obtained from the MLS receiver and encoded along with the aircraft ID onto the downlink data.

3.2.5.2 FDM Data Link Receiver

All aircraft approaching a single airport/runway utilize the same frequency and contend on this single channel.

3.2.5.3 Crossbanding Receiver

A modified ATCRBS or Mode-S receiver is used for receiving extended ATCRBS-like messages at allocated time slots for a given aircraft. Performance of this receiver is discussed in Reference 14 and a functional block diagram is shown in Figure 3-2.

3.2.5.4 Mode-S Receiver

A Mode-S receiver has been developed for airport surveillance and aircraft collision avoidance functions within the 1090 MHz band with a 10 MHz total bandwidth. Downlink signal is pulse position modulated (PPM) with extended data rate capability and protection against interference, Reception of the aircraft originated signals will be during the off cycles of the normal Mode-S ground antenna interrogations.

4.0 THE REFLECTION CONCEPT

4.1 CONCEPT DESCRIPTION

In the Reflection concept, a MLSS ground receiver detects reflected MLS narrow-beam radiated signals from various aircraft during the approach. An MLSS receiver may use the same MLS antenna with proper gating or use a second narrow beam antenna electronically steered and synchronized to MLS antennas with adequate gain. The narrow beam detection provides spatial filtering to minimize multipath by having low side lobe levels.

The first step in the analysis was to determine if the reflected MLS signal can be received on the ground with an adequate signal to noise ratio to permit reliable detection. Appendix M presents this analysis with the conclusion that from a reflected power basis only, an adequate reflected signal is present at a 5 nautical mile range.

With the reflection technique, there is no need for any airborne equipment. However, there are serious problems with the basic concept, ranging from multipath effects, the lack of positive identity in the reply, and in coverage range.

The first problem is in detection by sharing the same MLS narrow beam antenna in the presence of the high power transmitted signal. The reflected signal (at very low signal amplitudes) would have to be detected in the presence of full MLS transmitter power at the same frequency and at the same time and would be impossible to isolate except by blanking.

The second problem is overlapping replies from aircraft in trail. The MLS code bits are 64 microseconds long equivalent to 5 nautical miles. The reflections received from aircraft within this range will overlap.

Assuming that aircraft detection within the bit overlap is difficult or impossible, the first problem can be solved, but the second problem would make range determination in dense target environment impossible. The ground site can determine the azimuth and elevation to an aircraft by noting the azimuth and elevation of the scanning receiving antenna when the reflected signal is detected. However, if two aircraft are within the uplink beam at the same time, their reflections will overlap in space and make determination of range impossible. Each reflected TO-FRO pulse is 100 microseconds long which translates into approximately 8.3 miles. Ignoring the problem of the overlapping DPSK bits, the TO-FRO bits from aircraft within 8.3 miles of each other in trail will overlap and be garbled.

4.2 SYSTEM ELEMENTS

With the reflection concept, there is no required airborne equipment. The system is entirely passive with respect to the aircraft. The equipment on the ground utilizes the MLS transmitting antenna with proper gating or uses a second narrow beam electronically steered antenna. The ground equipment must possess sophisticated detection processing in order to overcome the detection problems outlined in Section 4.1

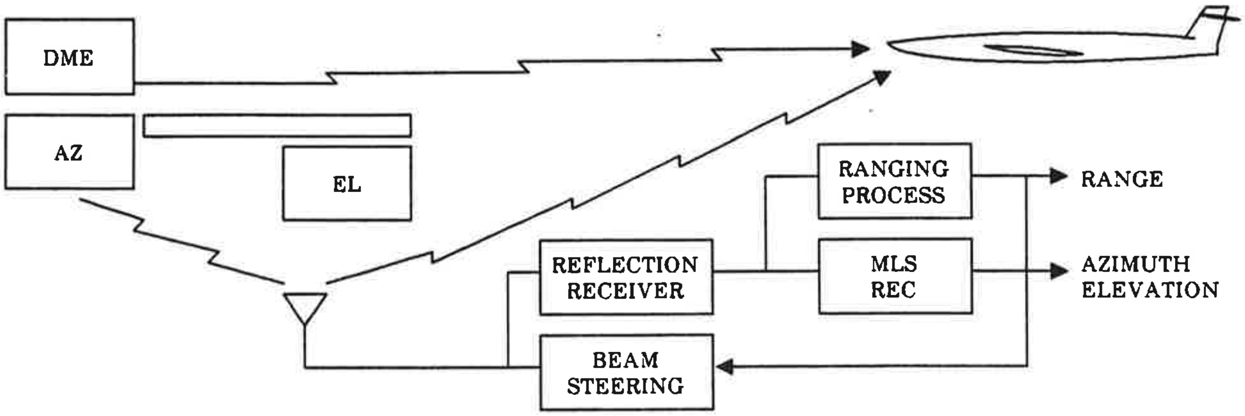


FIGURE 4-1. REFLECTION CONCEPT BLOCK DIAGRAM

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCEPT REVIEW

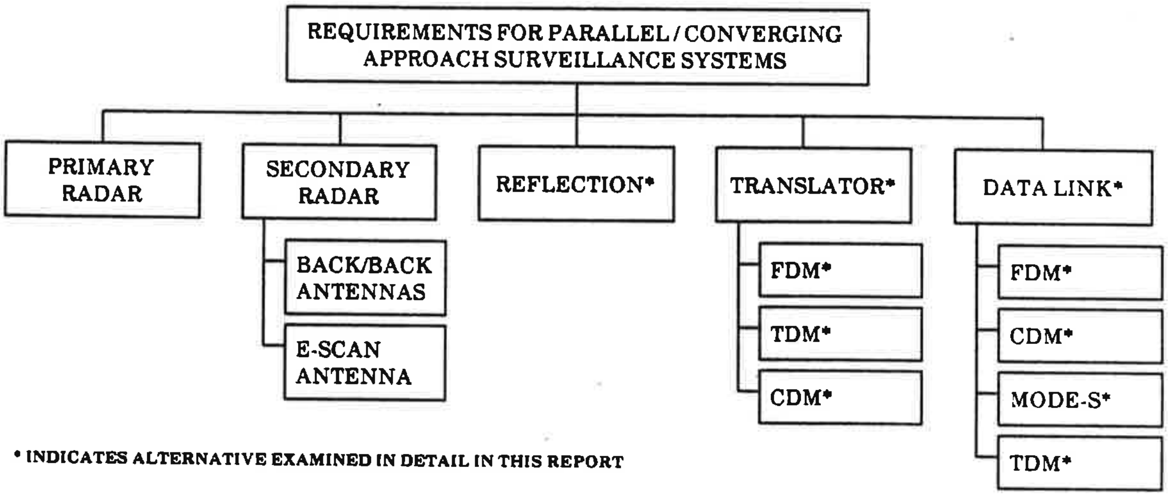
This paper examined three major surveillance system concepts based upon the use of the MLS, namely the Data Link, Translator and Reflection concepts:

Data Link - aircraft position is monitored by transmitting to the ground the aircraft's position as determined by the onboard MLS avionics.

Translator - aircraft position is monitored by retransmitting to the ground the MLS signals received aboard the aircraft and performing the necessary MLS signal processing on the ground.

Reflection - aircraft position is monitored by detecting the MLS signals reflected off the aircraft when the aircraft is illuminated by the MLS scanning beams.

Implementation consideration of each concept resulted in the development of a number of subconcepts, shown in Figure 5.1. The surveillance system alternatives which were examined in detail in this study consisted of:



* INDICATES ALTERNATIVE EXAMINED IN DETAIL IN THIS REPORT

FIGURE 5-1. SURVEILLANCE SYSTEM ALTERNATIVES

5.1.1 MLSS Concepts Based on Air Derived Aircraft Position Information

<u>Data Link - Code Division Multiplexing (CDM) (Table 5-1A)</u>. The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived aircraft position information is transmitted to the ground over a dedicated MLSS data link. A single MLSS data link frequency is used in the entire CONUS. Orthogonal (P/N) codes are used to separate the replies from individual aircraft.

Data Link - Mode-S (Table 5-1B). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is retransmitted to the ground over the Mode-S data link at a higher update rate than that normally used in Mode-S.

Data Link - Time Division Multiplexing (TDM)(Crossbanding) (Table 5-1C). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is transmitted to the ground over the ATCRBS downlink. Each aircraft transmits in a preassigned time slot, a form of time division multiplexing.

Data Link - Frequency Division Multiplexing (FDM) (Table 5-1D). The aircraft position (azimuth, elevation and range) is determined by the onboard MLS angle and DME avionics. The air derived position information is transmitted to the ground over frequency channels assigned to each runway. Each aircraft transmits its position using randomly distributed short data bursts.

5.1.2 MLSS Concepts Based on Ground Derived Aircraft Position Information.

Translator Concept - Frequency Division Multiplexing (FDM-I and II) (Tables 5-1E and 5-1F) The aircraft is not equipped with MLS avionics. Instead the aircraft's onboard equipment consists of an MLSS avionics unit whose function is to translate the received MLS signal to a different (higher or lower) frequency, and retransmit the received MLS signals to the ground (i.e. the aircraft acts as a signal repeater). The aircraft's azimuth and elevation are determined on the ground using the same signal processing techniques utilized in airborne MLS avionics. Aircraft range can be determined by measuring the time delays of the angle guidance signals generated by the TO-FRO scans (FDM-I Concept) Table 5-1E, or the time delays of the MLS data words (FDM-II Concept) (Table 5-1F). Each aircraft is assigned a separate frequency on which to retransmit the MLS signals (FDM).

Translator Concept - Time Division Multiplexing (TDM-I and II) (Tables 5-1G and 5-1H) The aircraft is not equipped with MLS avionics. Instead the aircraft's onboard equipment consists of an MLSS avionics unit whose function is to retransmit the received MLS angle guidance signals on a separate frequency to the ground (i.e. the aircraft acts as a signal repeater). Each aircraft transmits in a preassigned time slot (TDM). The aircraft's azimuth and elevation are determined on the ground using the same signal processing techniques utilized in airborne MLS avionics. Aircraft range can be determined by measuring the time delays of the angle guidance signals generated by the TO-FRO scans (TDM-I Concept) (Table 5-1G), or the time delays of the MLS data words (TDM-II Concept) (Table 5-1H).

Translator Concept - Code Division Multiplexing (CDM) (Table 5-1I) The aircraft is not equipped with MLS avionics. Instead the aircraft's onboard equipment consists of an MLSS avionics unit whose function is to retransmit the received MLS angle guidance signals on a separate frequency to the ground (i.e. the aircraft acts as a signal repeater). In order to transmit MLS signal data via a CDM data link the onboard MLSS avionics must first digitize the data. The CDM data link utilizes the spread spectrum transmission technique and

orthogonal (P/N) codes to reduce the number of required data link frequencies. The CDM technique requires more complex MLSS avionics than those required for the FDM concept.

5.1.3 MLSS Concept Based on Using the MLS in a Primary Radar Mode.

Reflection Concept (Table 5-1J) The reflection concept utilizes multiple ground receiving antennas to detect the narrow-beam MLS azimuth and elevation signals reflected back to the ground off the aircraft. No airborne equipment is required. The reflected MLS azimuth and elevation guidance signals are processed on the ground to determine aircraft position.

5.2 CONCEPT EVALUATION

The following assessment of each of the MLSS concepts was performed using the criteria defined below:

A. Accuracy	-achievable azimuth, elevation and range accuracy (1 sigma).
B. Update Rate	-number of complete aircraft position updates (per second)
C. Spectrum Requirements	-data link frequency channel requirements and channel bandwidth.
D. Standard Avionics	-standard avionics required, independent of the the MLSS function.
E. Required MLSS Avionics	-additional avionics required for the performance of the MLSS function
F. Standard Ground Equipment	-standard ground equipment required, independent of the MLSS function.
G. Required MLSS Ground Equipment	-additional ground equipment required for the performance of the MLSS function.
H. Required Equipment Mods	-required modifications to the standard airborne or ground equipment for the MLSS function.
I. Required Pilot/Controller Actions	-what actions are required of the pilot and/or controller by the MLSS function
J. Positive Aircraft Identification	-does the concept provide for a positive identification of each aircraft
K. Issues	-the major issues associated with each concept

The results of the evaluation are summarized in Table 5-1. Analyses supporting the projected performance of each concept can be found in the appendices.

5.3 RECOMMENDATIONS

Three concepts are considered viable MLSS candidates; the Data Link - CDM, the Data Link - Mode-S and the Translator - FDM concepts. The first two require that the aircraft be equipped with MLS avionics, the third requires equipping aircraft with a translator device. All three can be implemented with current off-the-shelf technology, and as such represent.a low risk technical approach.

Use of the Mode-S data link requires a detailed investigation and test to insure that the transmission of MLSS data over the link does not degrade the performance of Mode-S. A demonstration of the other two concepts is necessary to verify the validity of the performance predictions. Recommendations for a follow on detailed analysis and test program.

TABLE 5-1A

MLS EQUIPPED AIRCRAFT - DATA LINK CDM CONCEPT

A. Accuracy	Azimuth = 1.0 mr (1 sigma) Elevation = 1.2 mr (1 sigma) Range(DME/P) = 20 ft FA (1 sigma) 100 ft IA (1 sigma) Range(DME/N) = 300 ft (1 sigma)
B. Update Rate	3-4 per second
C. Channel/Spectrum Requirements	1 P/N code per runway 200 P/N codes for CONUS One 12.8 MHz wide, frequency channel for entire CONUS
D. Standard Avionics	MLS Angle Receiver DME/P or DME/N interrogator
E. Required MLSS Avionics	MLSS data encoder and transmitter Interface to data bus (shares MLS antenna)
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS receiver and antenna ATC interface Data processor and display
H. Required Equipment Mods	MLSS avionics connect to MLS antenna MLSS ground equipment interface to ATCRBS/ Mode-S data
I. Required Pilot/Controller Actions	None
J. Positive Aircraft Identification	Yes, aircraft respond with ID
K. Issues	Assignment of a 12.8 MHz channel to MLSS

TABLE 5-1B

MLS EQUIPPED AIRCRAFT - DATA LINK MODE-S CONCEPT

A. Accuracy	Azimuth = 1.0 mr (1 sigma) Elevation = 1.2 mr (1 sigma) Range(DME/P) = 20 ft FA (1 sigma) 100 ft IA (1 sigma) Range(DME/N) = 300 ft (1 sigma)
B. Update Rate	1 per second
C. Channel/Spectrum Requirements	Use Mode-S data link for downlinking of MLSS data (random access)
D. Standard Avionics	MLS Angle Receiver Mode-S transponder
E. Required MLSS Avionics	MLSS data controller Interface to MLS and Mode-S data bus
F. Standard Ground Equipment	MLS equipped runway Mode-S interrogator
G. Required MLSS Ground Equipment	MLSS processor and display Mode-S interface
H. Required Equipment Mods	MLSS avionics interface to Mode-S MLSS ground equipment interface to Mode-S
I. Required Pilot/Controller Actions	None
J. Positive Aircraft Identification	Yes, aircraft respond with discrete ID
K. Issues	Potential interference with Mode-S

TABLE 5-1C

MLS EQUIPPED AIRCRAFT - DATA LINK TDM (CROSSBANDING) CONCEPT

A. Accuracy	Azimuth = 1.0 mr (1 sigma) Elevation = 1.2 mr (1 sigma) Range(DME/P) = 20 ft FA (1 sigma) 100 ft IA (1 sigma) Range(DME/N) = 300 ft (1 sigma)
B. Update Rate	1 per second
C. Channel/Spectrum Requirements	Use ATCRBS transponder reply channel to downlink MLSS data
D. Standard Avionics	MLS Angle Receiver DME/P or DME/N interrogator ATCRBS transponder
E. Required MLSS Avionics	MLSS data encoder and transmitter Interface to data bus (shares MLS antenna)
F. Standard Ground Equipment	MLS equipped runway ATCRBS Interrogator
G. Required MLSS Ground Equipment	MLSS processor and display Interface to ATCRBS
H. Required Equipment Mods	MLSS avionics interface to ATCRBS xpnder MLSS ground equipment interface to ATCRBS
I. Required Pilot/Controller Actions	Pilot - None Controller - time slot assignment
J. Positive Aircraft Identification	Yes, aircraft respond with ID
K. Issues	Potential interference with ATCRBS

TABLE 5-1D

MLS EQUIPPED AIRCRAFT - DATA LINK FDM CONCEPT

A. Accuracy	Azimuth = 1.0 mr (1 sigma) Elevation = 1.2 mr (1 sigma) Range(DME/P) = 20 ft FA (1 sigma) 100 ft IA (1 sigma) Range(DME/N) = 300 ft (1 sigma)
B. Update Rate	3-4 per second
C. Channel/Spectrum Requirements	1 channel per runway 100 kHz per channel 2 MHz channel separation
D. Standard Avionics	MLS angle receiver DME/P or DME/N interrogator
E. Required MLSS Avionics	MLSS data transmitter Interface to data bus MLSS antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS receiver MLSS omni antenna ATC interface Data processor and display
H. Required Equipment Mods	MLSS avionics interface to data bus MLSS ground equipment interface to ATCRBS/Mode-S data
I. Required Pilot/Controller Actions	None
J. Positive Aircraft Identification	Yes, aircraft respond with ID
K. Issues	Availability of a sufficient number of frequencies to meet CONUS requirements

TABLE 5-1E

AIRCRAFT NOT EQUIPPED WITH MLS - TRANSLATOR CONCEPT FDM-I (RANGE DETERMINED FROM TO-FRO SCANS)

A. Accuracy	Azimuth = 0.6 mr (1 sigma) Elevation = 0.8 mr (1 sigma) Range = 187 ft (1 sigma)
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	1 channel per aircraft 10 channels per runway 400 kHz per channel / 4.0 MHz per runway
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	MLSS translator MLSS transmitter and antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS multichannel receiver and antenna ATC interface MLSS data processor and display
H. Required Equipment Mods	MLSS ground equipment interface to ATCRBS/Mode-S
I. Required Pilot/Controller Actions	Controller - assign frequency channel Pilot - input assigned frequency channel
J. Positive Aircraft Identification	Yes, each aircraft on one channel
K. Issues	Requires large frequency spectrum

TABLE 5-1F

AIRCRAFT NOT EQUIPPED WITH MLS - TRANSLATOR CONCEPT FDM-II (RANGE DETERMINED FROM DATA WORDS)

A. Accuracy	Azimuth = 0.6 mr (1 sigma) Elevation = 0.8 mr (1 sigma) Range = 202 ft (1 sigma)
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	1 channel per aircraft 10 channels per runway 400 kHz per channel / 4.0 MHz per runway
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	MLSS translator MLSS transmitter and antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS multichannel receiver and antenna ATC interface MLSS data processor and display
H. Required Equipment Mods	MLSS avionics connect to MLS antenna MLSS ground equipment interface to ATCRBS/Mode-S data
I. Required Pilot/Controller Actions	Controller - assign frequency channel Pilot - input assigned frequency channel
J. Positive Aircraft Identification	Yes, each aircraft on one channel
K. Issues	Requires large frequency spectrum

TABLE 5-1G

AIRCRAFT NOT EQUIPPED WITH MLS - TRANSLATOR CONCEPT TDM-I (RANGE DETERMINED FROM TO-FRO SCANS)

A. Accuracy	Azimuth = 3.0 mr (1 sigma) Elevation = 4.0 mr (1 sigma) Range = 561 ft (1 sigma)
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	1 time slot per aircraft 10 time slots per runway 400 kHz per channel / 400 kHz per runway
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	MLSS translator MLSS transmitter and antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS receiver and antenna ATC interface MLSS data processor and display
H. Required Equipment Mods	MLSS equipment interface to ATCRBS/Mode-S
I. Required Pilot/Controller Actions	Controller - assign time slots Pilot - input assigned time slot to MLSS
J. Positive Aircraft Identification	Yes, each aircraft on one time slot
K. Issues	Reduced sampling rate degrades performance to unacceptable level

TABLE 5-1H

AIRCRAFT NOT EQUIPPED WITH MLS - TRANSLATOR CONCEPT TDM-II (RANGE DETERMINED FROM DATA WORDS)

A. Accuracy	Azimuth = 3.0 mr (1 sigma) Elevation = 4.0 mr (1 sigma) Range = 1600 ft (1 sigma)
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	1 time slot per aircraft 10 time slots per runway 400 kHz per channel / 400 kHz per runway
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	MLSS translator MLSS transmitter and antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS receiver and antenna ATC interface MLSS data processor and display
H. Required Equipment Mods	MLSS equipment interface to ATCRBS/Mode-S
I. Required Pilot/Controller Actions	Controller - assign time slots Pilot - input assigned time slot to MLSS
J. Positive Aircraft Identification	Yes, each aircraft on one time slot
K. Issues	Reduced sampling rate degrades performance to unacceptable level

TABLE 5-1I

AIRCRAFT NOT EQUIPPED WITH MLS - TRANSLATOR CONCEPT CDM

A. Accuracy	Azimuth = 0.6 mr (1 sigma) Elevation = 0.8 mr (1 sigma) Range = 286 ft (1 sigma)
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	1 P/N code per aircraft 10 P/N codes per runway One 1.0 MHz channel per runway
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	MLSS data encoder and transmitter Receiver and transmitter antenna
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	MLSS receiver and omni antenna ATC interface Data processor and display
H. Required Equipment Mods	MLSS ground equipment interface to ATC system
I. Required Pilot/Controller Actions	Controller - code assignment to aircraft Pilot - code entry
J. Positive Aircraft Identification	Yes, aircraft assigned individual code
K. Issues	Acquisition of a sufficient number of frequencies Effect of signal dynamic range on code isolation for near and far targets.

TABLE 5-1J

AIRCRAFT NOT EQUIPPED WITH MLS - REFLECTION CONCEPT

A. Accuracy	unknown
B. Update Rate	>1 per second
C. Channel/Spectrum Requirements	not required
D. Standard Avionics	Standard avionics set No MLS avionics
E. Required MLSS Avionics	none
F. Standard Ground Equipment	MLS equipped runway
G. Required MLSS Ground Equipment	Multiple MLSS antennas Signal processor and display MLSS interface to ATC
H. Required Equipment Mods	none
I. Required Pilot/Controller Actions	none
J. Positive Aircraft Identification	No
K. Issues	High risk new concept/technology

5.3 RECOMMENDATIONS

5.3.1 RECOMMENDED CONCEPTS

The MLSS study analyzed ten (10) system concepts. The feasibility of each approach was reviewed resulting in three (3) of the concepts being considered viable MLSS candidates; the Data Link - CDM, the Data Link - Mode-S and the Translator - FDM concepts. The first two require that the aircraft be equipped with a standard set of MLS avionics and the addition of a means to transmit MLSS data to the ground; the third requires equipping aircraft with a translator device to transmit the unprocessed MLS signals to the ground. All three can be implemented with current off-the-shelf technology, and as such represent a low risk technical approach.

The Data Link - CDM concept imposes the least restrictions on implementation. Its operation is well isolated from the other ATC systems, and as such it can not cause any interference in their operations. The system meets all MLSS requirements.

The Data Link - Mode-S concept use of the Mode-S data link requires a detailed investigation and test to insure that the transmission of MLSS data over the link does not degrade the performance of the Mode-S. This, and the ease of interfacing the airborne and ground MLSS equipment with Mode-S are the only concerns with this approach. The system meets all MLSS requirements.

The Translator - FDM concept represents the most original approach to MLSS implementation. Retransmitting the translated MLS signals on a frequency well removed from the C-band at which MLS operates will insure non-interference with the MLS operation and no self-interference. The concept of performing the aircraft position calculations on the ground rather than in the aircraft as well as the determination of range from the retransmitted angle guidance signals represent a novel approach, but poses no technical risks. The system meets all MLSS requirements.

5.3.2 CONCEPT DEMONSTRATION

The next phase of the MLSS program requires the implementation of demonstration systems and an evaluation of their performance. The recommended approach is to perform detailed designs of the recommended MLSS concepts, perform a laboratory test/simulation of the systems and, depending on the test results, perform a field and flight test of the concepts.

DETAILED SYSTEM ANALYSIS AND DESIGN - Perform a detailed system analysis and preliminary design of the three concepts. The design shall include all system hardware and software components and system interfaces. The result of the system design phase shall be a documented system design which will be used to order the system components and build the demonstration systems.

The system analysis and design phase will require a nine (9) month effort.

LABORATORY TEST AND EVALUATION - Assuming that all three recommended MLSS concepts emerge from the detailed analysis and design phase as still viable

approaches, the systems shall be built and tested in the laboratory in order to determiné as much as possible about their performance before proceeding to the more costly field and flight tests. Commercially available MLS simulators can be used to simulate the MLS environment. Similar simulation techniques will be used to simulate traffic and ATC system interfaces. The result of the laboratory test phase will be the confirmation of the feasibility of the proposed approach and finalization of the system designs.

The system build and laboratory test and evaluation phase will require a twelve (12) month effort.

SYSTEM DEMONSTRATION - FIELD AND FLIGHT TESTS - Following the completion of the laboratory phase of the program, the successful MLSS candidates will undergo a field and flight test program. The demonstration program can take place at a Government facility such as the the FAATC or the NASA Wallops Island station, since the airports of both are equipped with MLS. Alternately, the demonstration can take place at a commercial airport with parallel or converging runways and equipped with MLS. The system demonstration phase shall be designed to evaluate the candidate systems performance under operational conditions. The result of the system demonstration phase will be the operational evaluation of the concepts, final selection of a candidate system and preparation of a system specification.

The system demonstration phase will require a twelve (12) month effort.

APPENDIX A

MLS ACCURACY AND SIGNAL STRUCTURE

The MLS system concept uses two narrow scanning beams to provide multiple two dimensional approach path guidance for IFR aircraft operations and a full sector coverage beam for data transmission. The MLS system also provides a DME-based precision range determining system. The narrow azimuth and elevation coverage beams are shown in Figures A-1 and A-2, and the wide angle coverage is shown in Figure A-3.

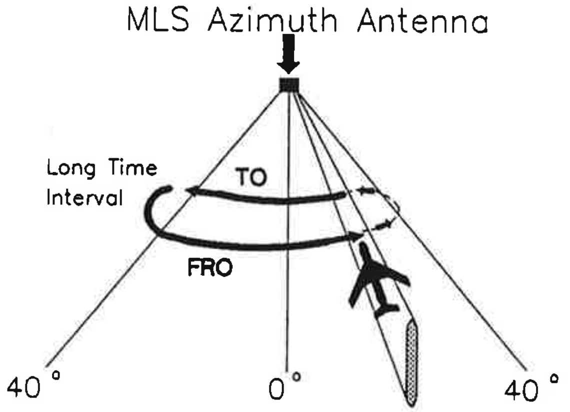


FIGURE A-1. MLS AZIMUTH ANTENNA COVERAGE

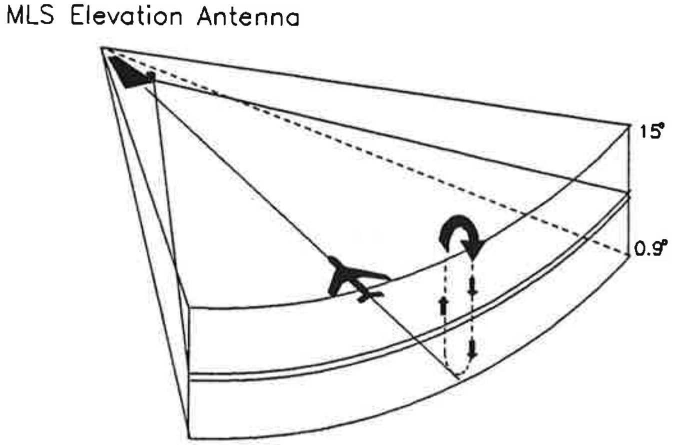


FIGURE A-2. MLS ELEVATION ANTENNA COVERAGE

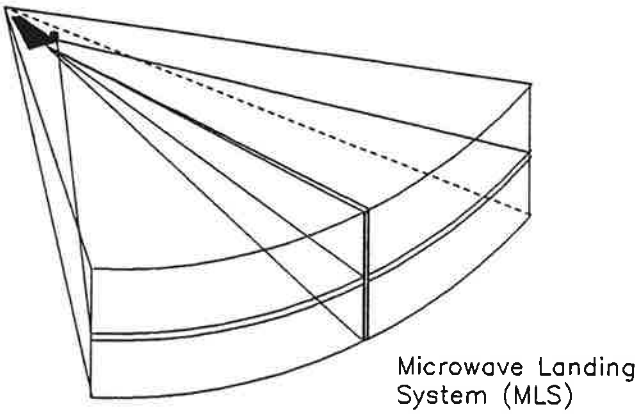


FIGURE A-3. MLS WIDE ANGLE ANTENNA COVERAGE FOR DATA TRANSMISSION

MLS transmits sequences of various angle guidance functions such as azimuth, back azimuth, and approach elevation in an interleaved pattern shown in Figures A-4 and A-5.

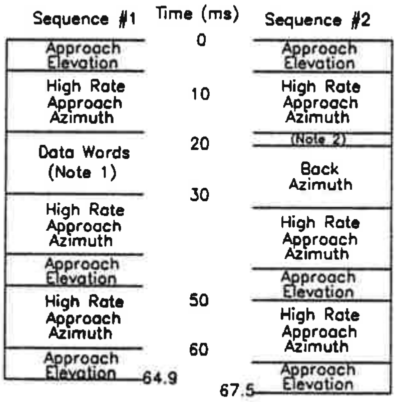


FIGURE A-4. TRANSMISSION SEQUENCE PAIR WHICH PROVIDES FOR ALL MLS ANGLE GUIDANCE FUNCTIONS

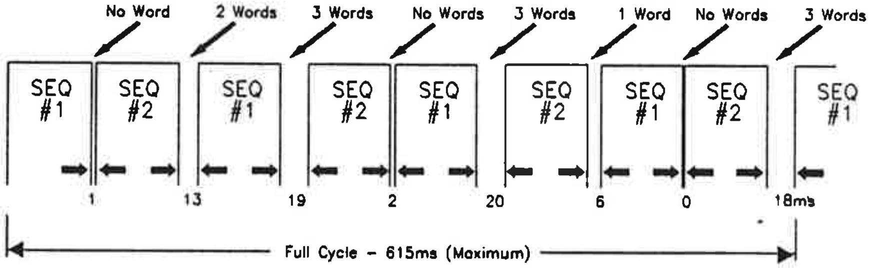


FIGURE A-5. COMPLETE MULTIPLEX TRANSMISSION CYCLE

The time sequence of a representative azimuth or elevation scan is shown in Figure A-6.

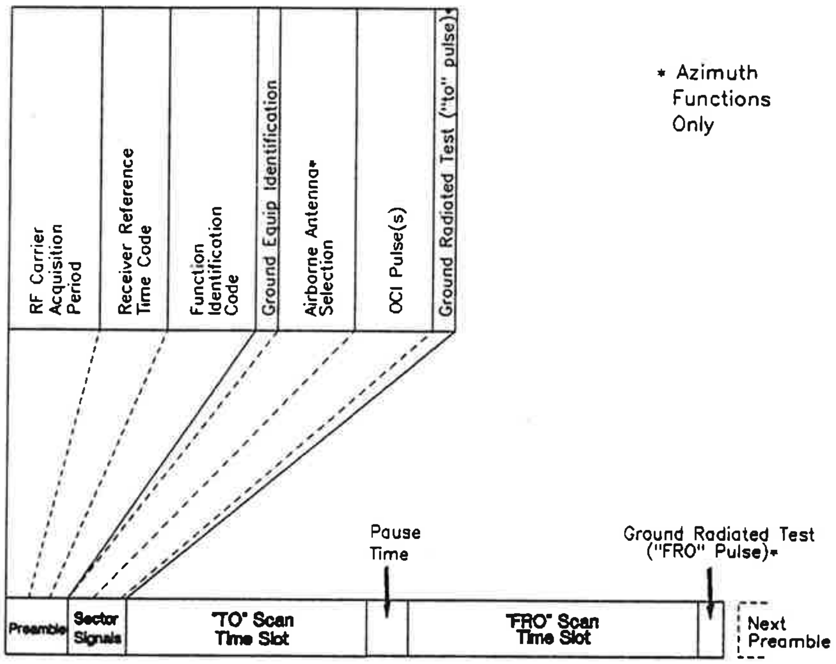


FIGURE A-6. ANGLE FUNCTION ORGANIZATION

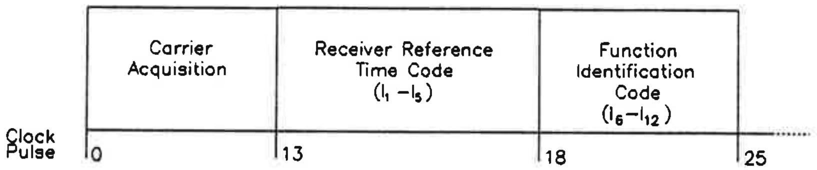


FIGURE A-7. PREAMBLE ORGANIZATION

During the initial shaded period of time, the MLS transmitter transmits CW modulated signals from the wide angle antenna (for the preamble) followed by DPSK modulated data as shown in Figures A-6 and A-7. Then CW "to" and "fro" scans are transmitted using the scanning azimuth (and elevation) antennas.

The basic MLS system characteristics are as follows (References 13 and 17):

Frequency: C-Band 200 channels within 5031 to 5090.7 GHz

Power: 20 watts Bandwidth: 26 kHz

Data rate: 15,625 Hz   Data modulation: DPSK

Antenna Beamwidth: $15^o \times 124^o$ (wide coverage)

Azimuth Beamwidth: $2^o \times 15^o$ Elevation Beamwidth: $2^o \times 124^o$

Update/FastScan Rate: Azimuth 39 scans/second
Elevation 39 scans/second

Aircraft Antenna Beamwidth: $35^o \times 140^o$

MLS Sensor Accuracy

The MLS error budgets are shown in Tables A-1 through A-4. The Path Following Error (PFE) is the component which affects the aircraft position (or path); this component is characterized by the output of a low-pass filter with a corner frequency of 0.5 radians/second for an azimuth frame rate of 13 Hz and 1.5 radians/second for an azimuth and elevation frame rate of 39 Hz. The PFE is composed of a bias component and a time varying component, Path Following Noise (PFN). The DME IA (Initial Approach) mode corner frequency is 0.6 radians/second and FA (Final Approach) mode is 1.5 radians/second.

The second component is Control Motion Noise (CMN), which affects aircraft control surfaces. The CMN is characterized by the output of a band-pass filter with corner frequencies of 0.3 radians/second and 10 radians/second for an azimuth frame rate of 13 Hz and the DME IA mode, and at 0.5 radians/second and 10 radians/second for elevation and azimuth frame rates of 39 Hz and the DME FA mode.

Table A-1 is the azimuth PFE and CMN error budget at the reference datum. Degradation with range and angle is shown in Figure 8. Table A-2 shows the PFE and CMN error budget for elevation. Degradation with elevation angle and range is shown in Figure A-9.

The DME system PFE is shown in Tables A-3 and A-4. Table A-3 is the error budget of the DME system using a DME/P transponder and a general aviation interrogator. Table A-4 is the error budget for the IA and FA modes for a DME/P transponder and interrogator.

In the MLSS application, the primary error component that affects the position accuracy of the surveillance system is the lower frequency component (e.g. PFE), although the higher frequency error component (CMN) could affect ground tracker performance.

TABLE A-1. FULL CAPABILITY AZIMUTH PFE AND CMN 95% PROBABILITY ERROR BUDGETS

ERROR COMPONENT	ERROR COMPONENT PARTITION	LINEAR ERROR (FT)	ANGULAR ERROR (DEG)		
			1° BW	2° BW	3° BW
PATH FOLLOWING ERROR	GROUND		0.037	0.069	0.117
	AIRBORNE		0.017	0.017	0.017
	PROPAGATION		0.033	0.066	0.102
	SYSTEM (RSS)	13.6	0.052	0.097	0.151
CONTROL MOTION NOISE	GROUND		0.010	0.016	0.024
	AIRBORNE		0.015	0.015	0.015
	PROPAGATION		0.036	0.072	0.096
	SYSTEM (RSS)	10.5	0.040	0.075	0.100

TABLE A-2. FULL CAPABILITY APPROACH ELEVATION PFE AND CMN 95% PROBABILITY ERROR BUDGETS

ERROR COMPONENT	ERROR COMPONENT PARTITION	LINEAR ERROR (FT)	ANGULAR ERROR (DEG)	
			1° BW	2° BW
PATH FOLLOWING ERROR	GROUND		0.053	0.095
	AIRBORNE		0.017	0.017
	PROPAGATION		0.121	0.091
	SYSTEM (RSS)	2.000	0.133	0.133
CONTROL MOTION NOISE	GROUND		0.010	0.020
	AIRBORNE		0.010	0.010
	PROPAGATION		0.056	0.054
	SYSTEM (RSS)	0.870	0.058	0.058

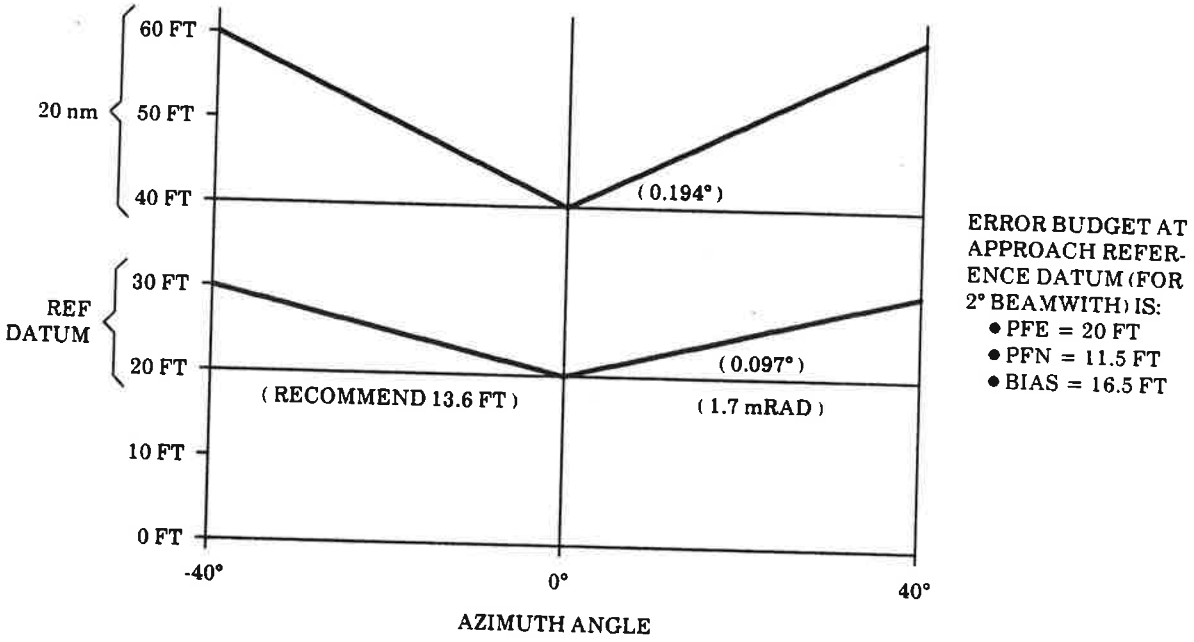


FIGURE A-8. AZIMUTH ERROR DEGRADATION VS RANGE AND AZIMUTH ANGLE

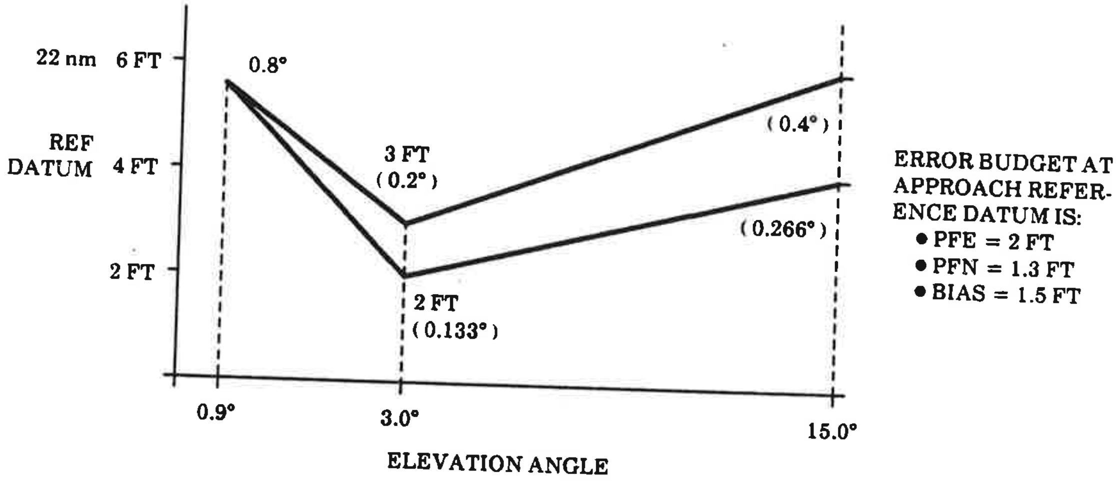


FIGURE A-9. ELEVATION ERROR BUDGET VS RANGE AND ELEVATION ANGLE

TABLE A-3
DME SYSTEM PFE 95% PROBABILITY ERROR BUDGET
(WITH DME/N INTERROGATOR)

		ERROR (FT)
INSTRUMENTATION	TRANSPONDER	± 50
	INTERROGATOR	± 600
SITE RELATED	DOWNLINK MULTIPATH	± 142
	UPLINK MULTIPATH	± 121
	NON-SPECULAR MULTIPATH	± 0
	GARBLE	± 20
TOTAL ERROR		± 630 FT

TABLE A-4
DME SYSTEM PFE 95% PROBABILITY ERROR BUDGET
(WITH DME/P INTERROGATOR)

		FA	IA
INSTRUMENTATION	TRANSPONDER	± 16	± 50
	INTERROGATOR	± 23	± 100
SITE RELATED	DOWNLINK MULTIPATH	± 10	± 121
	UPLINK MULTIPATH	± 10	± 121
	NON-SPECULAR MULTIPATH	± 10	± 10
	GARBLE	± 20	± 20
TOTAL ERROR		38 FT	200 FT

APPENDIX B

TRANSLATOR ANGLE AND RANGE EQUATIONS

The translator range and angle measurements are performed on the ground as follows. Assume that the airborne transmitter initiates retransmission of the received "to" and "fro" signals with a fixed and known time delay, D after receipt of the signals. The signal representing the passage of the "to" signal at the aircraft reaches the ground site at a time

$$T_{RT} = T_T + D + R/c \qquad \text{(Equation 1)}$$

where $T_T = T_A + R/c + A/V$ (Equation 2)

and T_A = the absolute time when the ground transmitter initiated the "to" scan

Therefore

$$T_{RT} = T_A + A/V + D + 2\,R/c \qquad \text{(Equation 3)}$$

The time of passage of the "fro" signal reaches the ground site at a time

$$T_{RF} = T_{RT} + T_0/2 - A/V \qquad \text{(Equation 4)}$$

If the ground site processes the time difference $T_{RF} - T_{RT}$ in the same way as an airborne MLS receiver, it can derive the azimuth A in the same way.

$$T_{RF} - T_{RT} = T_0/2 - A/V \qquad \text{(Equation 5)}$$

From which A can be calculated. An identical process is used to determine elevation.

Deriving the range to the aircraft requires an additional step and is performed as follows. The ground site measures the time from the initiation of the transmission of the "to" scan by the MLS ground site to the reception of the retransmitted signal "to" scan on the ground. Therefore it must measure the time from T_A to T_{RT}. From Equation 7, this time difference is

$$T_{RT} - T_A = A/V + D + 2\,R/c \qquad \text{(Equation 6)}$$

Since A was calculated from Equation 5 and D is a known and fixed time delay, it is now possible to calculate the range R to the aircraft.

Thus the ground site can uniquely identify the range, azimuth, and elevation to the target.

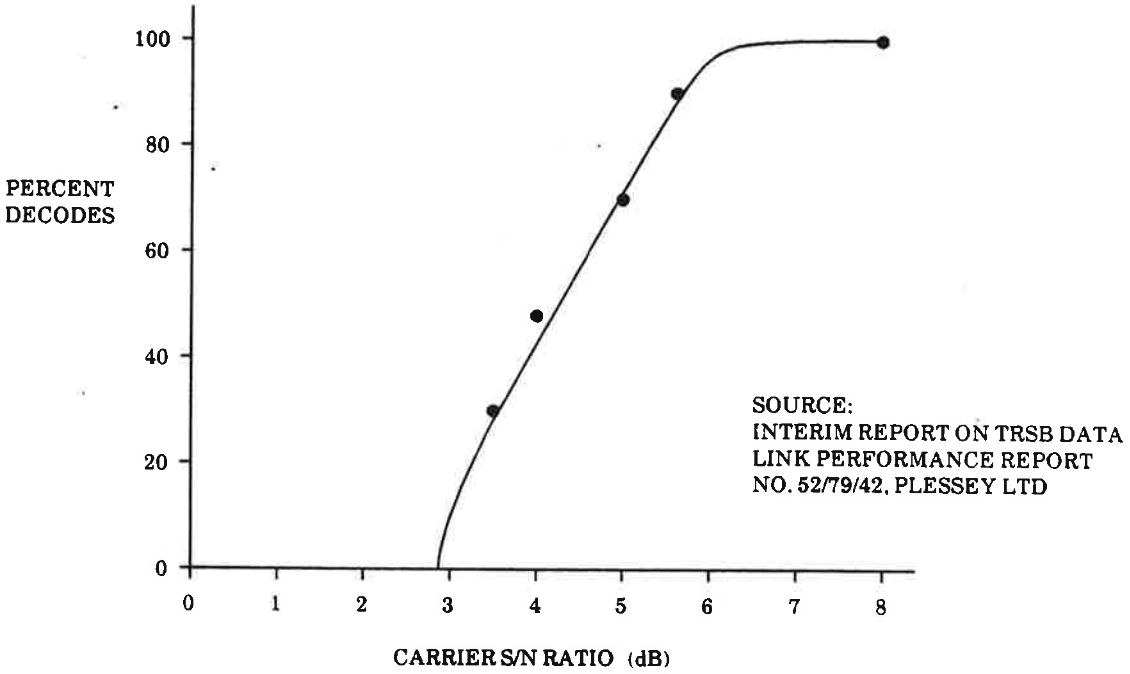
APPENDIX C
TRANSLATOR POWER BUDGET

The translator concept power budget will be treated in two parts: the uplink power budget and the downlink power budget. From the downlink power budget and DO-177 (Reference 13) requirements for out-of-band and in-band interference, the allowable power/frequency allocations can be determined.

1. Uplink Power Budget

The uplink power budget of the MLS system is specified in ICAO Annex 10 Tables G_1 and G_2. The minimum signal to noise ratio is specified in DO-177 Section 2.2.1.1.

At a 20 nmi range the signal required at the aircraft is -95 dBm for preamble and data and -89 dBm for scanning beamwidth of two degrees. This results in a signal-to-noise ratio (SNR) in a 150 kHz filter of 5 dB for data and 11 dB for scanning beam. The SNR of 5 dB results in a 75% decode and control motion noise as shown in Figure C-1.



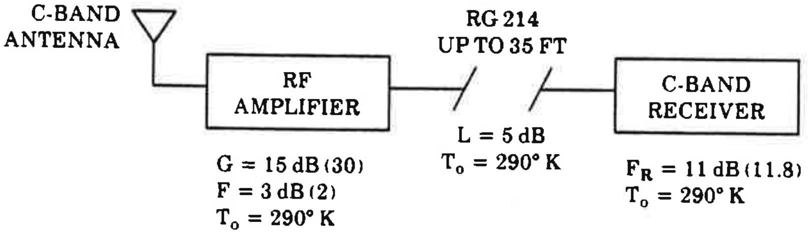
SOURCE:
INTERIM REPORT ON TRSB DATA
LINK PERFORMANCE REPORT
NO. 52/79/42, PLESSEY LTD

FIGURE C-1. PERCENT DECODES AS A FUNCTION OF SNR

2. Downlink Power Budget

Ground Receiver Configuration Noise Figure

Figure C-2 is a block diagram of the ground receiver configuration used in the down link power budget calculations. A C-Band low noise amplifier is mounted at the output of the antenna to overcome the C-Band losses of a long RF cable between the antenna output and the C-Band receiver input. C-Band pre-amplifiers are available with noise figures of 3 dB or less. If a noise figure of 3 dB is assumed, an overall system noise figure of 5 dB can be achieved using 35 feet of RG 214 coaxial cable.



$$F_T = F + (L-1)/G + (F_R-1)L/G$$
$$= 2 + (0.068) + (0.728)$$
$$= 2.796 \text{ OR } 4.5 \text{ dB}$$

FIGURE C-2. MLSS RECEIVER BLOCK DIAGRAM (C-BAND)

Ground Receiver IF Bandwidth

The minimum IF bandwidth for the ground receiver is taken as that required to pass the scanning beam signal since it occupies more bandwidth that the data signal. The IF bandwidth is calculated by root sum square of the various frequency shifts (uncorrelated sources) and adding the result to the MLS scanning beam bandwidth and Doppler shift as follows:

$$BW_G = \left[BW_S^2 + \left(\sqrt{(F_D)^2 + (\delta f_{GT})^2 + (\delta f_{ALO})^2}\right)^2 + \left(\sqrt{(F_D)^2 + (\delta f_{AT})^2 + (\delta f_{GLO})^2}\right)^2 \right]^{1/2}$$

where BW_G = Ground receiver IF bandwidth
BW_S = MLS scanning beam bandwidth = ± 27 kHz
F_D = Doppler shift = ±2 KHz
δf_{GT} = Ground transmitter stability = ± 10 kHz*
δf_{ALO} = Airborne receiver Local Oscillator stability = ± 47 kHz*
δf_{AT} = Airborne re-transmit stability = ± 47 kHz*
δf_{GLO} = Ground receiver stability = ± 47 kHz*

* values based upon experience with off-the-shelf commercial equipment

Thus, the IF bandwidth of the ground receiver is a minimum of ± 100 kHz

Since the MLS SNR is 5 dB (at 20 nmi) for 72% data decodes, the down link degradation should be very small or the decode as shown in Figure C-2 will be less than the required 72%. The signal to noise ratio of the MLS signal in the airborne receiver at 15 nmi is 7.6 dB. This is the signal that is re-transmitted to the ground receiver and thus is composed of MLS signal plus airborne receiver noise (thermal, etc.) Thus, the best signal to noise ratio that can be received at the ground receiver is 7.6 dB. Figure C-3 presents a curve of ground receiver's SNR as a function of re-transmitted MLS MLSS data SNR. This curve is obtained as follows:

$$\text{SNR MLSS} = \left[\frac{1}{\dfrac{1}{\text{SNR}_A{}^2} + \dfrac{1}{\text{SNR}_G{}^2}} \right]^{1/2}$$

where SNR_A = MLS S/N at the aircraft = 7.6 dB = 5.76

and SNR_G = S/N at the MLSS ground receiver

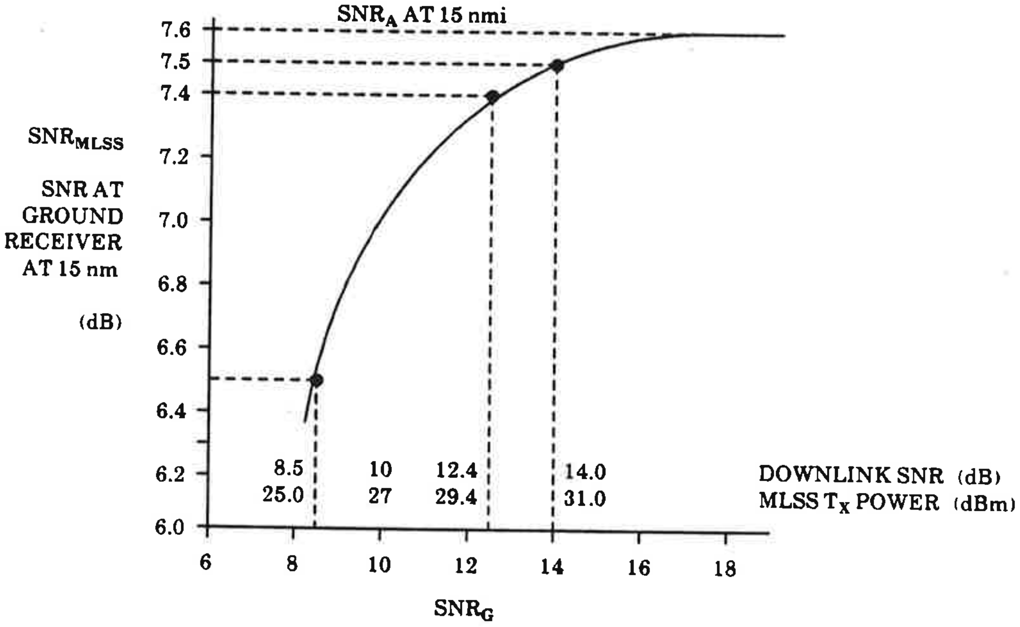


FIGURE C-3 GROUND RECEIVER S/N VS DOWNLINK SNR

The resultant decrease in the percentage of decodes should not exceed 2 %, i.e. 70% instead of 72%. Figure C-3 indicates that a downlink SNR of 13 dB will cause a 0.1 dB degradation in the MLSS SNR. Using this assumption, the power budget can be generated as shown in Table C-1.

The downlink power budget of Table C-1 shows that the re-transmitter aboard the aircraft must be capable of providing 35.4 dBm (3.47 W) of peak power during the scanning beam. This power requirement will preclude the use of the available 5091 MHz to 5250 MHz band for the translator transmitter due to interference constraints. For this reason, several alternative approaches are presented that reduce the transmitter power requirements.

Alternatives

a. Reduce Range

An obvious alternate to reduce transmitter power is to reduce the operating range, and hence the transmitted power. Table C-2 presents the power requirements for 15 nmi, 10 nmi and 5 nmi. The power is that required to provide the ground receiver with a data SNR of 7.6 dB (includes ground/air receiver noise) and a scanning beam SNR of 12.4 dB.

TABLE C-1 DOWNLINK POWER BUDGET

	DPSK	ANGLE
SNR REQUIRED (DB)	13	19
NOISE FIGURE (DB)[1]	5	5
NOISE POWER IN 200 KHZ	-121	-121
ANTENNA GAIN (DB)[2]	-12	-12
SIGNAL REQUIRED AT GROUND RECEIVER ANTENNA INPUT	-115	-109
PROPAGATION LOSS (DB)[3]	135.4	135.4
PROBABILISTIC LOSSES (DB)		
POLARIZATION 0.5		
RAIN 1.7		
ATMOSPHERIC 0.3		
HORIZONTAL MULTIPATH 3.0		
VERTICAL MULTIPATH 2.0		
RSS OF PROBABALISTIC LOSSES (DB)	4.0	4.0
AIRBORNE ANTENNA GAIN (DBI)	0	0
CABLE LOSS (AIRCRAFT) (DB)	5	5
REQUIRED TRANSMITTER POWER (dBm)	29.4	35.4

1. Assumes an MLSS receiver is used on the ground with an RF amplifier noise figure of 3 dB and a gain of 15 dB.

2. A DPSK antenna is used as a receiving antenna on the ground.

3. Distance to the ground antenna is taken to be 15 nmi.

$$\text{Loss}^{*} = 32.45 + 20 \log f(\text{MHz}) + 20 \log R(\text{km}) = 135.4$$

$$f = 5031 \text{ MHz}$$

$$R = 1.852 * 15 = 27.78 \text{ km}$$

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[*] Reference Data for Radio Engineers, Fifth Edition, ITT, Section 34.3, Eqn 9.

TABLE C-2 TRANSMITTER POWER VS RANGE		
RANGE (NM)	DATA POWER (DBM)	SCANNING BEAM POWER (DBM)
15	29.4	35.4
10	25.8	31.8
5	19.1	25.6

b. Equalize Data and Scanning Beam Powers

It should be recognized that the transmitter power requirement at 15 nmi is limited by the data decoding. It has been shown in the down link power budget for 15 nmi that the data transmitted power is 29.4 dBm and the scanning beam transmitted power is 35.4 dBm. If the scanning beam power is also limited to 29.4 dBm, the same as that for the data, a savings of 6 dB in power is obtained. The result of limiting the scanning beam power is to lower the down link scanning beam SNR at the ground receiver from 19.4 dB to 13.4 dB. As a result the control motion noise measured in a 10 radian filter will be

$$\delta\theta^{*} = \frac{\theta_{BW}}{\sqrt{2}\sqrt{S/N * g}} = \frac{\theta_{BW}}{\sqrt{2}\sqrt{(BW_{IF}/BW_{VID})(C/N)(R/2)(2\pi/BW_{CMN})}}$$

where θ_{BW} = beamwidth in degrees = 2°

BW_{IF} = IF bandwidth = 200 kHz

BW_{VID} = Video bandwidth = 26 kHz

C/N = carrier to noise ratio = 13.4 dB

R = data rate = 39 Hz

BW_{CMN} = Noise BW of CMN filter = π/2 x (Filter BW at - 3 dB)
= 15.7 radians

$g = (R/2)(2\pi/BW_{CMN})$

The $1/\sqrt{2}$ factor arises because the sidelobes independently disturb the leading and trailing edges.

---

[*] Reference 12, Equation 5

Evaluating

$$\delta\theta = 0.03^\circ \quad (1\ \sigma) \text{ or } .68 \text{ mrad } (1\ \sigma)$$

This is within the accuracy specification for the MLSS system.

This alternate can be combined with the alternate (a) above to reduce the transmit power requirement from that of the scanning beam to that of the data.

As a result of this discussion, it is recommended that a technique be used in the MLSS transmitter to reduce the scanning beam power to that of the data. One possible technique is to sense the Barker decode at the output of the modulator. A clock would then count down the remainder of the data (function, ID, etc.) to the start of the scanning beam minus the delay from the MLSS pick-off to the decoder output. A 6 dB pad would then be activated in the MLSS signal path to reduce the power level of the scanning beam to that of the data.

APPENDIX D
TRANSLATOR AIRBORNE INTERFERENCE

This analysis was performed to ensure that the airborne MLSS transmitter does not interfere with the operation of the MLS receiver.

First, we assume that the transmitter operates outside of the MLS band. DO-177 (Reference 12) specifies four levels of interference that are allowed with no degradation in the MLS receiver operation, depending upon the frequency of the interfering signal. These levels are shown in Figure D-1.

Two parameters have to be met. First, the signal power outside the MLS band, but within the range 5000 to 5250 MHz, excluding the MLS band, should not exceed -55 dBm. Second, signal power due to spectrum within the MLS band and within 1.2 MHz of any MLS channel should not exceed -62 dBm. When the interference level is -40 dBm or less and the frequency is greater than 1.2 MHz from the channel operating frequency, the receiver should also meet the DO-177 requirement.

If the 5091 to 5250 MHz band is used for the translator down link, the -55 dBm requirement will be the critical parameter. If the frequency band chosen is outside this band, the signal power within the MLS band will be the driver.

Let us assume that the 5091 to 5250 MHz band will be used. If we assume that the same aircraft antenna will be used to receive the MLS signal as well as transmit the MLSS signal, a circulator will be needed. In order to meet the-55 dBm requirement, no more than -35 dBm can be transmitted. This is based on a circulator isolation between the MLSS transmitter and the MLS receiver of 20 dB. Since the power requirement, even for a 5 nmi range is in excess of -35 dBm, the same antenna cannot be used.

Next let us consider the use of two antennas. If the transmitting antenna is separated from the MLS antenna by 2 meters or more, this will ensure that the two antennas are separated outside the Fresnel zone. At a frequency of 5150 MHz, we can calculate the loss due to this antenna separation:

$$L_S = (32.45 + 20 \log D_{KM} + 20 \log F_{MHz}) \quad dB$$

where D_{KM} = separation of the two antennas in Km
F_{MHz} = frequency in MHz

In this case, $L_S = 52.8$ dB

For 15 nm range and 35.4 dBm (scanning beam) power shown in Table C-1 of Appendix C, the input to the receiver will be -45.4 dBm. If the MLSS transmitter operates at a frequency outside of C-band, this input power level satisfies all interference requirements as stated in DO-177.

If operation at C-band is desired, two additional measures must be taken to permit operation to a 15 nmi range. First, a technique is required to equalize the scanning beam power to that of the data; and second, the signal to noise ratio must be reduced from 13 db to 10 db (this reduces the MLSS SNR at

the ground receiver by 0.4 dB). This results in a possible transmitter power of 25.6 dBm.

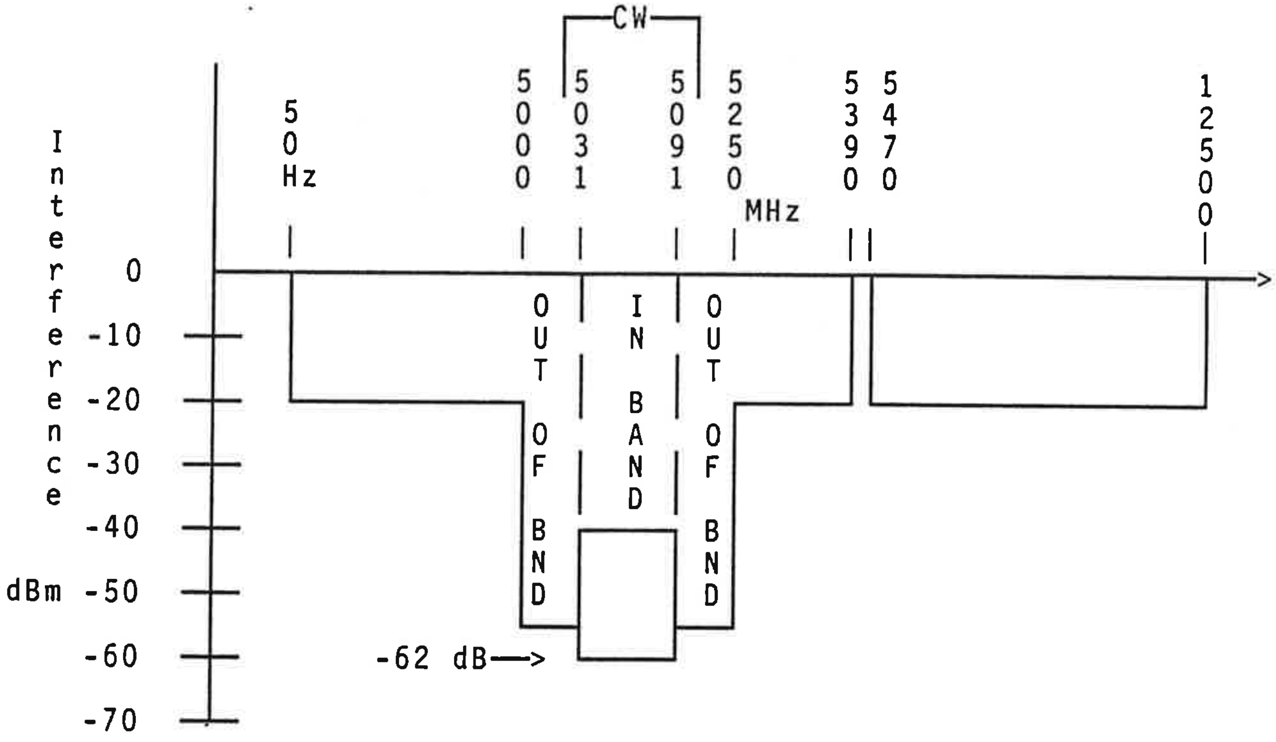


FIGURE D-1. MOPS SPECIFIED INTERFERENCE LEVELS

If the signal is within the MLS band but beyond 1.2 MHZ of the particular MLS channel being used, an interfering level of -40 dB is allowed.

If the signal is outside of the MLS band, but within the range 5000 to 5250 MHz, an interfering level of -55 dBm is allowed.

And lastly, if the signal is outside of the MLS band and within the range 50 kHz to 5000 MHz and 5250 MHz to 12.4 GHz, an interfering level of -20 dBm is allowed.

From the above, it can be seen that with a transmitter power of + 5 dBm, no interference with the MLS receiver will occur.

If we postulate transmitting on a frequency outside of the MLS band, but within the range 5000 to 5250 MHz (allowable interference level of -55 dBm), we have a margin of over 31 dBm to either increase the transmitted power or decrease our assumed antenna isolation losses.

The frequency band of the downlink was chosen to ensure that the downlink transmission does not interfere with the airborne MLS operation. A preliminary

analysis, presented in Appendix C, showed that at a power level high enough to be received on the ground with adequate signal to noise, minimal out-of-band interference with the MLS receiver will occur if the MLSS range is limited to 15 nmi or less. This is in accordance with the RTCA DO-177 which limits transmitter power of the out-of-band interference to -55 dBm.

Since the retransmitted signal has the same spectrum characteristics of an MLS signal, and because its level is set to be a maximum of -55 dBm, a frequency separation between the top MLS channel and the lowest MLSS channel should be greater than 1.2 MHz, i.e., the lowest channel frequency for MLSS should be greater than 5092 MHz.

APPENDIX E
TRANSLATOR RANGE AND ANGLE ACCURACY

E.1 TRANSLATOR RANGE ACCURACY

Two range measurement techniques are discussed and the accuracy of each estimated. The first range measurement technique uses the received scanning beam pulse pairs from the airborne MLSS and compares that with the received scanning beam pulse pairs received directly from the MLS ground site. The second range measurement technique correlates the MLS DPSK code signals received from the airborne MLSS with the MLS DPSK code signals received directly from the MLS ground site.

E.1.1 Range Accuracy Using Scanning Beam Pulses

The Path Following Noise as defined in Appendix A is used as the appropriate measure of system accuracy. From this, the timing error in the ground MLSS receiver can be estimated. From this timing error, the error in range determination is estimated.

From Figure A-8, the 95% path following noise (2 σ) at the Reference Datum is:

$$2\,\sigma_{PFN} = 11.5 \text{ ft.}$$

This error is then converted to degrees by dividing by the distance to the Reference Datum (10,000 feet) and converting from radians to degrees. This angle error is converted to a time error by dividing by the azimuth beam speed of 20,000°/sec.

$$2\,\sigma_{PFN}(\text{degrees}) = (11.5/10{,}000) \times 57.3 = .065895^\circ$$

Then $2\,\sigma_{PFN}(\text{sec}) = 2\,\sigma_{PFN}(\text{degrees})\,/20{,}000$

$= 3.2948\ \mu\text{sec}$

Therefore $\sigma_{PFN} = 1.6474\ \mu\text{sec}$

If a sliding window detector is used with a 1 second averaging period, the total CMN error is given by

$$\sigma_{T(CMN)} = \frac{1.6474}{\sqrt{39}} = .264\ \mu\text{sec } (1\ \sigma)$$

The total error in range is given by root sum squaring this error with the error in the site reference (assumed to be equal to the path following noise).

$$\sigma_{TOT} = \sqrt{(.264)^2 + (.264)^2} = .373\ \mu\text{sec } (1\ \sigma) = 187 \text{ ft.}$$

This error will increase with range from the MLS azimuth antenna because the path following error increases with range.

E.1.2 Range Accuracy Using Data Words

A range measurement is derived by correlating MLS code signals received over two different paths: directly from the MLS site with a known time reference and the translated MLS signal by an airborne MSS translator with a known arrival time. The received signals are in short bursts representing preamble code replies.

In the detection process, each frame, a preamble code, is synchronized by the use of 12 clock-bit CW carrier. The CW signal is immediately followed by the coded messages. In the total a one-second interval, at least 39 such sequences are tracked using a quasi delay-locked loop envelope correlator as shown in Figure E-1. A range and range error in the measurement may be estimated by the following equation*.

$$\sigma_R = \delta \left[\frac{B_L}{2\,C/N_o} \left(1 + \frac{2\,B_{IF}}{C/N_o}\right) \right]^{1/2}$$

Where δ = chip length in μsec

B_L = closed loop noise bandwidth (1 Hz)

B_{IF} = predetection IF bandwidth (31,250 Hz)

Required SNR at the receiver input $= \frac{C}{N} = 7.6$ dB

IF bandwidth 200 kHz = 53 dB.Hz

Energy spectral density $= \frac{C}{N/BW} = \frac{C}{N_o} = 60.6$ dB.Hz

To compute energy spectral density in the tracking loop corrections for the burst-type signals are compensated by reducing signal energy level in the tracking loop for 1-second integration time: reduction in C/N_o is equal to 10 $\log(12 \times 15 \times 64 \mu\text{sec})^{-1} = -14.0$ dB.

$$\left[\frac{S}{No}\right]_{Loop} = 60.6 \text{ dB.Hz} - 14.0 \text{ dB} = 45.4 \text{ dB.Hz } (35{,}000)$$

---

* Reference 19, p.567, Equation 18-100

Using the above parameter values the error in the range measurement is as follows:

$$\sigma_R = 64 \left[\frac{1}{2 \times 35{,}000} \left(1 + \frac{2 \times 31{,}250}{35{,}000} \right) \right]^{1/2}$$

$$= .403\ \mu\text{sec}\ (1\ \sigma) = 202\ \text{ft}\ (1\ \sigma)$$

There will be a slight improvement in the range error with a reduced distance from the runway.

E.1.3. Comparison of Measurement Errors Using Alternative Methods

Alternatives to the delay loop envelope correlator are illustrated for comparison.

1. Detecting by a single pulse by using chip-splitting technique*

$$\sigma_{CN} = \frac{\delta}{\sqrt{2\ E_b/N_o}}$$

where E_b/N_o** = signal energy over noise spectral density in a chip

$$= \frac{C/f_b}{N/BW} = \frac{C}{N} \times \frac{\text{Bandwidth}}{\text{Bit Rate}} = 7.6+11=18.6\ \text{dB.Hz}\ (72.5)$$

$$\sigma_{CN} = \frac{64}{\sqrt{2 \times 72.5}} = 5.3\ \mu\text{sec}\ (1\ \sigma)$$

Corresponding sampling error sampled at five times the code frequency is

$$\sigma_{CS} = \frac{1}{5\sqrt{12}} = \frac{64}{17.3} = 3.69\ \mu\text{sec}\ (1\ \sigma)$$

---

* Reference 25, p.25

**Reference 26, Equation 1.25

The uncertainty in a single pulse/frame measurement is given by:

$$\sigma_C = ((\sigma_{CN})^2 + (\sigma_{CS})^2)^{1/2} = (5.3^2 + 3.69^2)^{1/2} = 6.46\ \mu\text{sec}\ (1\ \sigma)$$

$$= 3{,}230\ \text{ft}\ (1\sigma)$$

2. A comparison of range errors in time interval indicated are shown in Table E-1. In most cases they are just an approximation.

TABLE E-1 COMPARATIVE RANGE ERRORS
(ONE SIGMA ERROR)

	SINGLE MEASUREMENT (ft)	KALMAN FILTER Note 1 (ft)	TRACKER Note 2 (ft)	VIDEO INTEGRATOR 39 FRAMES		ENVEL CORRELATOR (ft)
				Note 3 (ft)	Note 4 TABLE* (ft)	
ERROR AT 15 NMI	3,230	1,077	1,615	517	294	202

Note 1. Single Measurement/3
Note 2. Single Measurement/2
Note 3. Single Measurement/√39
Note 4. Single Measurement/11

E.2 TRANSLATOR ANGLE ACCURACY

Many factors affect angle measurement accuracy: airborne and ground time references, antenna beam symmetry, errors in detecting edges of the scanning antenna beam, and the errors introduced in the retransmission of the signal. Total angle error computation is presented by parts.

For measurements derived on the ground - Leading-and-trailing edge tracking** is used to determine beam arrival times.

$$\sigma_B' = \frac{1}{BW\sqrt{2\ S/N}}$$

---

* Reference 21, p.37
**Reference 22, p.366, Equation 11.14

where BW = 26 kHz

$$\frac{S}{N} = 7.6 + 6 + 8.9 = 22.5 \text{ dB } (178)$$

$$\sigma_B{}' = \frac{10^{-3}}{26\sqrt{2 \times 178}} = 2.0\ \mu\text{sec}$$

Each measurement point is derived from two independent measurements - TO and FROM, therefore errors in both measurements

$$\sigma_B = 2.0 \times \sqrt{2} = 2.83\ \mu\text{sec}$$

Angle measurement also includes time reference, therefore both errors are summed via the RMS. The single angle measurement then becomes, using reference time for a single pulse derived in E.1.1, as follows

$$\sigma_{B(SINGLE)} = (6.46^2 + 2.83^2)^{1/2} = 7.05\ \mu\text{sec}\ (1\ \sigma)$$

single measurement

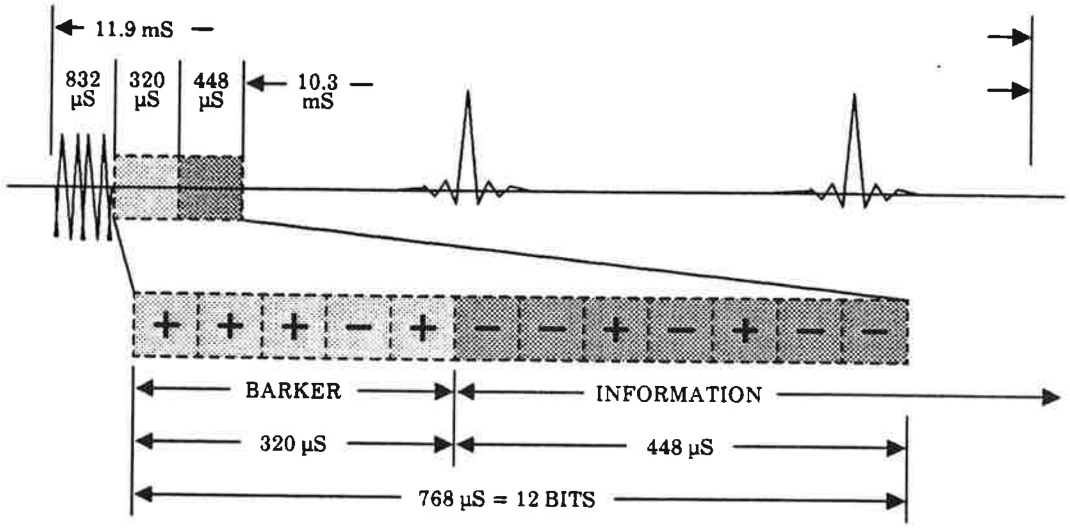
$$\sigma_{B(TOTAL)} = 7.05/\sqrt{39} = 1.13\ \mu\text{sec}\ (1\ \sigma)$$

Changing time error into angle error

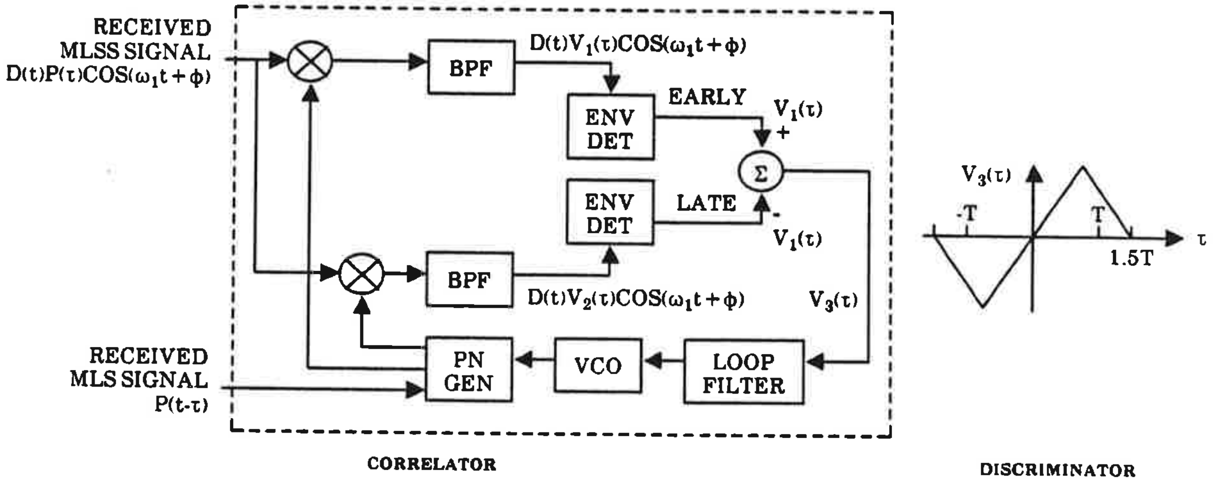
$$\sigma_{\theta TOTAL} = 20{,}000\ (\text{DEG/SEC}) \times 1.13\ (\mu\text{sec}) = .023^\circ\ (1\ \sigma)$$

$$= .40 \text{ mrad } (1\ \sigma)$$

This measurement does not include multipath effect.



A. MLS AZIMUTH SIGNAL



B. CORRELATOR AND DISCRIMINATOR

FIGURE E-1. NONCOHERENT DELAY LOCK LOOP

FIGURE E-1. DELAY-LOCKED LOOP ENVELOPE CORRELATOR

Reference 19, Figures 18-13 and 18-14(b)

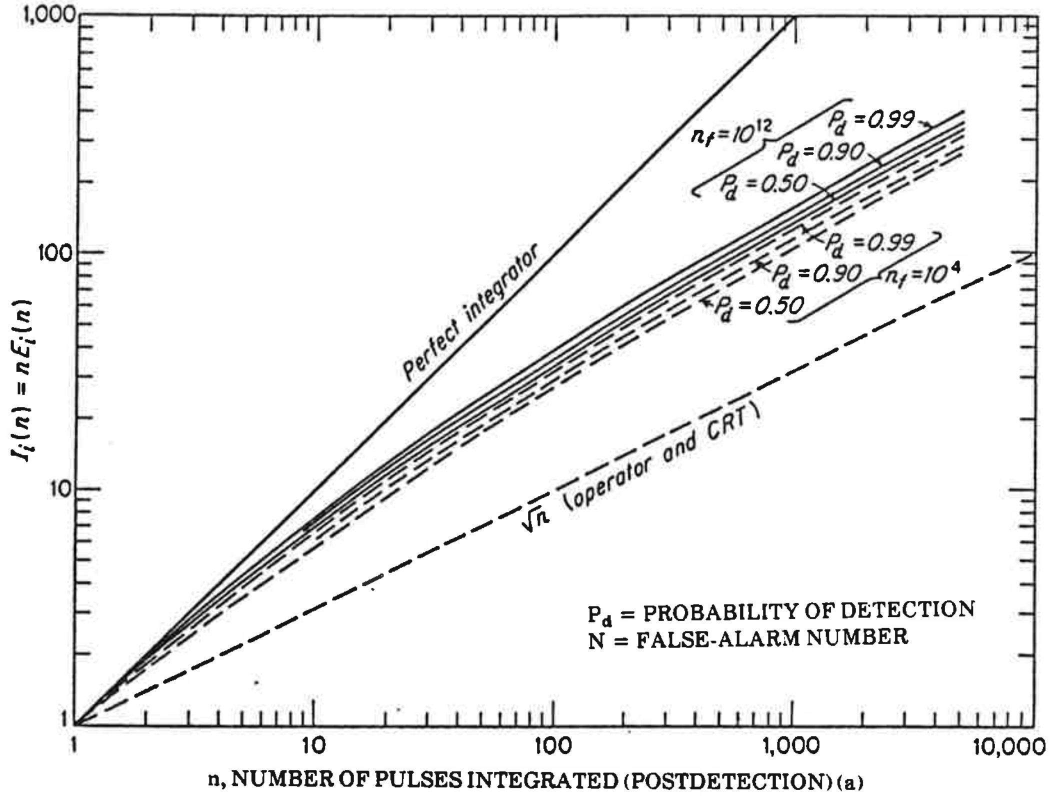


FIGURE E-2. INTEGRATION IMPROVEMENT FACTOR, SQUARE LAW DETECTOR*

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* Reference 21

APPENDIX F
TRANSLATOR FDM CHANNEL ASSIGNMENT

This appendix address the channel separations required to meet the operational requirements. Since the transmitted MLSS signal exhibits the same spectrum as the MLS signal, the channel separation could be 400 kHz. The channel separation includes ± 10 kHz ground frequency stability, ± 2 kHz Doppler shift and ± 47 kHz ground receiver stability for MLSS, this will result in a channel bandwidth of ± 100 kHz for the ground receiver. A 400 kHz channel separation is needed to provide the performance required (Appendix C).

For the Frequency Division Multiplexing (FDM) approach, twenty channels are needed to support the operational requirements of ten aircraft per runway. This results in a bandwidth of 8 MHz per airport. The band allocated for the translator is 159 MHz. Taking into account the need for 1.2 MHz separation between the MLS and MLSS bands, a band of 157.8 MHz is available for MLSS. This results in the availability of nineteen sets of fequencies that can be used to serve nineteen airports adjacent to each other without interference.

The final step is to ensure that the spectrum of the nearest MLSS channel to the MLS highest channel will not introduce any power in excess of -62 dBm if the separation is less than 1.2 MHz and, less than -40 dBm if the separation is more than 1.2 MHz.

Since the -55 dBm requirement for the 5091 MHz to 5250 MHz band is met as shown in Appendix D for 25 dBm MLSS transmitter power, it is recommended that the first MLSS channel should be separated from the highest MLS channel by at least 1.2 MHz. This results in a margin of 15 dB (-40 dBm - (-55 dBm)). This will ensure that the MLSS channels will not affect the MLS receiver. Figures F-1 and F-2 represents the proposed MLSS channel plan. Each airport would be allocated channels from each set such that the near-far effects will have minimum interference. For example, such channels can be chosen as follows:

1-1, 1-2,...,1-10,1-11,...,1-20,...19-1,..19-9,..19-10,..19-20

In this case the minimum channel separation is 4 MHz. Since the received signal ratio from an aircraft at 15 nmi to an aircraft at 1 nmi is about 24 dB, the IF filter with a bandwidth of 200 kHz should provide attenuation in excess of 40 dB for a channel frequency of 4 MHz away from the desired one.

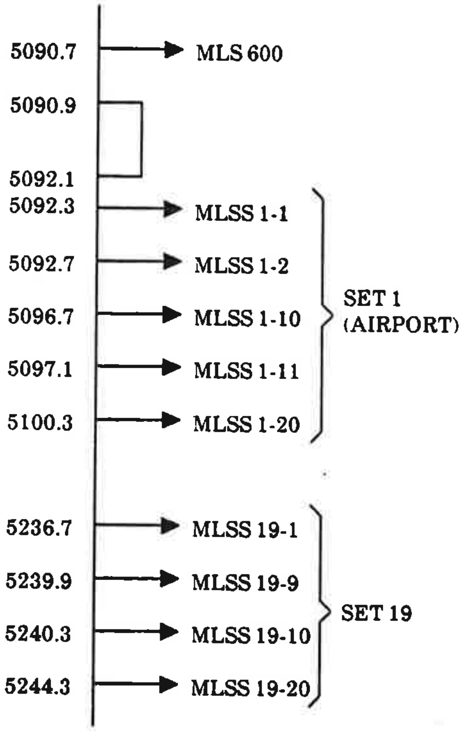

FIGURE F-1. DETAIL MLSS CHANNELIZATION

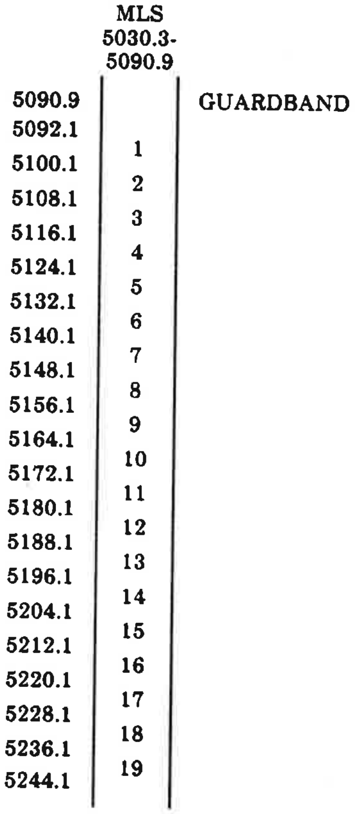

FIGURE F-2. MLSS CHANNEL PLAN

APPENDIX G

TIME DIVISION MULTIPLEXED (TDM) TRANSLATOR

The purpose of the TDM Translator approach is to reduce the number of communication channels required for aircraft to retransmit to the ground the received MLS azimuth and elevation scans. If all aircraft making a particular approach "time share" one communications channel, the number of channels required could be reduced by a factor of 10.

In the TDM Translator approach, each aircraft only replies during a time slot assigned by the ground system. There are 39 time slots (scans) per second available from the MLS for high rate azimuth and elevation scans respectively, which means that the product of the update rate times the number of aircraft handled cannot exceed 39. For example, if the number of slots assigned is to be 10 (for up to 10 aircraft), then the maximum update rate of the system in azimuth and elevation would be approximately 4 replies per second. Because range can be determined during both azimuth and elevation scans, the range update rate could be 4 replies per second.

Now let us examine how this scheme might work. Figure 5 of Appendix A shows the complete multiplex MLS transmission sequence. During each transmission sequence pair (Seq # 1 and Seq #2), azimuth and elevation are sent six times each. There are four such sequence pairs during a full 615 ms cycle. This means a total of 24 azimuth scans and 24 elevation scans every 615 ms. This works out to be 39 azimuths and 39 elevations per second. If we could "mark" a beginning point in this sequence, the airborne system could count scans and then reply when the count got to a specified number.

We can "mark" the beginning of a sequence by sending an Auxiliary Data B or C word once per complete sequence (615 ms) or at some other time interval (say every second). Currently there is no defined use for Auxiliary Data words B or C. Even if there were a use for Data B or C, if the timing of their transmission could be constrained to be once per sequence, this scheme will work. We are not concerned with what data is contained in the Auxiliary Data Word; we are merely using its transmission timing as a "mark" to count scans. (See Section 3.1.2 Crossbanding Concept)

The ground would tell the aircraft (via voice) which scan to reply to. The pilot would "dial in" this assigned scan number and the aircraft would only reply to scans that so assigned. The airborne translator receiver would have to have the capability to decode the DPSK function identification codes (to detect the presence of Auxiliary Data B or C) and the ability to count scans between resets via Auxiliary Data B or C transmissions.

This technique will work as long as any aircraft does not miss any scans and reply at the wrong time. In this case, there is a likelihood that two aircrafts' replies may garble. However, it is unlikely that this even will reoccur on the following scan sequence.

Nominally, 24 scans are available during a complete sequence, or 39 scans per

second. The definition of a complete frame of scans is determined solely by how frequently the Auxiliary Data B or C words are sent. If fewer than 39 aircraft were to be tracked, more than one scan number could be assigned to a particular aircraft, resulting in two replies per scan cycle. However, the capacity of this scheme is clearly a major drawback.

APPENDIX H

CODE DIVISION MULTIPLEXED TRANSLATOR

Spread spectrum and orthogonal code techniques can be used to permit simultaneous retransmission on a single frequency by multiple aircraft. These techniques also permit reducing the transmitted power required, minimizing interference with the airborne receiver. This overcomes the most serious problem of the basic concept (the need for multiple frequencies) while providing additional processing gains and signal protection while permitting low transmitter power operation.

In order to use spread spectrum, all air derived data will have to be reduced to a digital representation. This includes some way to encode the CW "to" and "fro" signals. One way to do this is to encode the to/fro times as the zero crossing times of a bit in a sequence of bits that is sent during the scan period. Another way would be to have the airborne system actually compute the azimuth and elevation as a conventional MLS receiver would, and then encode this information in a fixed portion of the downlink message.

The use of spread spectrum transmissions would permit 16 to 36 dB of processing gain. The 16 dB figure is obtained from calculating the effect of the spectral compression ratio, that is, the effect of collapsing the spread spectrum signal (assumed to be spread over a 1200 kHz band) to the signal bandwidth of 26 kHz. The additonal 20 dB is based upon the cross correlation properties of the Gold codes, where the theoretical 30 dB of isolation may be degraded by the side lobes of cross correlated codes. If we assume 10 aircraft simultaneously transmitting using different Gold codes, the multiple access interference degrades the theoretical 23.8 dB to approximately 17.8 dB.

CDM CODE ERROR BUDGET

The isolation between codes or possible cross correlation level is given in Reference 20 as:

For n = 9 (number of bits used in the shift register)

$L = 2^9 - 1 = 511$ bits, code length

$K = -[2^{(9+1)/2} + 1]/L = -33/511$ or -23.8 dB, 25%, cross correlation level

$= -[1]/L = -1/511$ or -54.2 db, 50%, cross correlation level

$= -[2^{(9+1)/2} - 1]/L = -31/511$ or -24.4 dB, 25%, cross correlation level

CDM SYSTEM ERROR BUDGET

Reference time is measured in an aircraft and on the ground using a correlator technique similar to that used with the FDM translator. Then the downlink is initiated at one-second intervals. Ground-derived time reference accuracy is given in Table E-1 (202 feet = 403 μsec (1 σ)).

Additional errors are caused by synchronization error for aligning the data codes with the PN code for downlink:

$$\sigma_S = .06\ \mu\text{sec}\ (1\ \sigma)$$

Error in delivering the aircraft derived time refernce to ground receiver at a code rate of 511 Kbs is given by:

$$\sigma_C = \delta \times [B_L/(C/N_o) \times (1 + 2\ B_L/CT/N_o)]^{1/2}$$

$$= 1.96 \times [\ (1/400{,}000) \times (1 + 2 \times 1/400{,}000 \times .001)]^{1/2}$$

$$= .003\ \mu\text{sec}\ (1\ \sigma)$$

where C/N_o = 51 dB Hz

$T = 1/BW_{IF}$, predetection observation time

The total range error for 15 nautical miles is

$$\sigma_{TOTAL} = [\ (\sigma_T)^2 + (\sigma_{TGROUND})^2 + (\sigma_S)^2 + (\sigma_C)^2\ ]^{1/2}$$

$$= [\ (.403)^2 + (.403)^2 + (.06)^2 + (.003)^2\ ]^{1/2} = .573\ \mu\text{sec}\ (1\ \sigma)$$

$$= 286\ \text{ft}\ (1\ \sigma)$$

APPENDIX I
PACKET FORMAT FOR DEDICATED DATA LINK CONCEPT

Figure I-1 depicts the proposed packet format for the dedicated data link concept. The format contains a preamble of 12 bits, a target identification of 32 bits and text of 96 bits, ending with a 32 bit CRC.

This format allows achieving acquisition and synchronization requirements via a short preamble and a demodulator that is simple and efficient to implement. The format provides sufficient error detection to all but eliminate the charge that erroneous data bits will be accepted as valid by the ground receiver.

If spread spectrum transmission techniques are not employed, the twelve preable bits can be used for phase lock loop decoding similar to how the MLS receiver decodes its DPSK data. If spread spectrum is employed, the preable will consist of:

- o 7 zeros used for AGC settling and bit synchronization
- o 5 bit Barker codeword used for frame synchronization

The Barker code is chosen because of its well-known optimal properties. A 5-bit Barket code is selected because it is the shortest Barker code that can tolerate a single bit error.

The 32 bits allocated to target identification are more than adequate for uniquely identifying each aircraft.

Azimuth, elevation, and range are each allocated 32 bits which is consistent with the ARINC 429 bus data format which is employed in this concept.

The Cyclic Redundancy Check (CRC) function is used to decrease the probability of accepting invalid data to less than 1 in 10^9.

PREAMBLE	AIRCRAFT	AZIMUTH	ELEVTN	RANGE	CRC
12 bits	32 bits	32 bits	32 bits	32 bits	32 bits

FIGURE I-1. PACKET FORMAT FOR DEDICATED DATA LINK CONCEPT

APPENDIX J
CHANNEL ACCESS PERFORMANCE FOR THE DEDICATED DATA LINK CONCEPT

The simplest data link concept is for all aircraft to share the same channel. This will result in overlap of transmissions if more than one aircraft transmits at the same time. The probability of overlap will depend upon the number of transmitters, i.e. aircraft, sharing the channel, packet duration, and packet rate.

If we assume that the start of transmission from each aircraft occurs independently, then the time distribution of packets is governed by a Poisson probability distribution. The probability of receiving ungarbled packets is given by:

$$\text{Probability of No Overlap} = e^{-2LMN/U}$$

where
U = Bit rate = 100 kbits/second
L = Packet length = 172 bits
M = Packet transmission rate
N = Number of aircraft served

The output data of the MLS receiver is the output of an alpha/beta tracker with a bandwidth of 10 radians per second. If the data received from the MLS digital output is passed through a PFE filter before transmission, an update rate of no more than two per second will be required. This is due to the fact that the PFE filter bandwidth is 1.5 radians/sec. To avoid loss of any information due to overlap, it is recommended that a packet transmission rate of 4 per second be used. The probability of no overlap versus the number of aircraft sharing the channel is shown in TableJ-1for bit rates of 100 kb/s and 200 kb/s.

TABLEJ-1.PROBABILITY OF NO OVERLAP FOR A SINGLE TRANSMISSION

NUMBER OF AIRCRAFT	PROBABILITY OF NO OVERLAP	
	100 KB/S	200 KB/S
10	86.9%	93.3%
20	75.6%	86.9%
40	57.0%	75.6%
80	32.0%	52.0%
160	10.6%	32.0%

It can be seen from this table that at a packet transmission rate of 4 per second and a bit rate of 100 Kb/s, there is a 86.9% probability of having no collision on a single packet and the update rate will not be less than three per second for ten aircraft. The probability of receiving at least one packet per second is 99.98. This is more than that required to meet the MSS requirement. The probability of overlap such that the update rate is less than one valid reply per second is remote. However, if necessary to reduce this

small probability even more, a 200 kb/s rate can be implemented at a cost of 3 dB increase in transmitter power.

APPENDIX K
POWER BUDGET FOR THE DEDICATED DATA LINK

A spread spectrum technique is ideal for the down link operation. It provides transmission protection against interference, mitigates against multipath fading, increases throughput, and allows unique identification via the PN code.

The amound of spread spectrum processing gain is determined by the time-bandwidth product. For a matched filter receiver, the bit error rate (BER) is dependent upon the energy ratio E_b/N_o where E_b is the energy per bit and N_o is the thermal noise spectral density. In turn $E_b = S\ T$, where S is the signal power and T is the bit time duration.

Figure 1 shows that for a bit error rate of 10^{-5}, the required E_b/N_o is 10.3 dB for down link parameters of:

E_b/N_o = 10.3 dB
Bit rate = 100 kbits/second
Chip rate = 12.8 MHz
Range = 15 nmi

The power budget is then as follows:

Required E_b/N_o (dB)		10.3
Receiver Noise Figure (dB)		5.0
Thermal Noise (dBm) -121		-124.0
Receiving antenna gain		- 12.0
Signal Required at Receiving Antenna		-120.7
Propagation loss (15 nmi)		135.4
Polarization	0.5	
Rain	2.2	
Atmospheric	0.3	
Horizontal Multipath	3.0	
Vertical Multipath	2.0	
RSS (dB)		4.3
Airborne antenna gain (dBi)		0.0
Aircraft cable losses (dB)		5.0
Required Transmitter Power (dBm)		24.0

Next we analyze the effects of doppler and frequency upon BER.

Velocity Effects

At the maximum relative velocity between the transmitter and receiver, i.e. when the aircraft is flying directly towards the receiver during the approach, the maximum Doppler shift is 2 kHz. For a bit duration of 10 µseconds, the resulting phase change is:

$$\text{Theta} = 2\,\pi\, f_d\, T \text{ or } 7.2 \text{ degrees} \quad (360^\circ \times 2000 \times .0001)$$

While the matched filter decorrelation due to this phase error is negligible, that is not the case for BER degradation. Figure K-1 depicts the BER vs SNR for various phase errors. Ths case at hand corresponds approximtely to $\pi/32$. It can be seen that an additional 0.25 dB is required to achieve a 10^{-5} BER as compared to the stationary case ($\theta = 0$).

Frequency Effects

The effects of offsets in the frequency of both transmitter and receiver are now considered. With a 1 part per million reference, the maximum frequency error is ± 5100 Hz. Assuming that the two frequencies have worst case errors in the opposite directions, the maximum frequency error including Doppler, is

$$f_{MAX} = 2\,(5100) + 2000 = 12 \text{ kHz}$$

For this case, the phase error is $\pi/4$. From Figure K-1, the maximum additional SNR required is about 4 dB.

Measures to compensate for this Doppler loss, such as coherent demodulation are not required for the proposed design nor are they cost effective.

However, the relative motion of the aircraft does result in a need for tracking of data bits during a transmission. At 2 kHz Doppler shift, the bit transitions slide at a rate of 1 ns/ms. For a maximum message length of 1.28 ms, the total movement is 1.28 ns. This is very small compared to a chip time of 78 ns. An open loop synchronization scheme is suggested for this application.

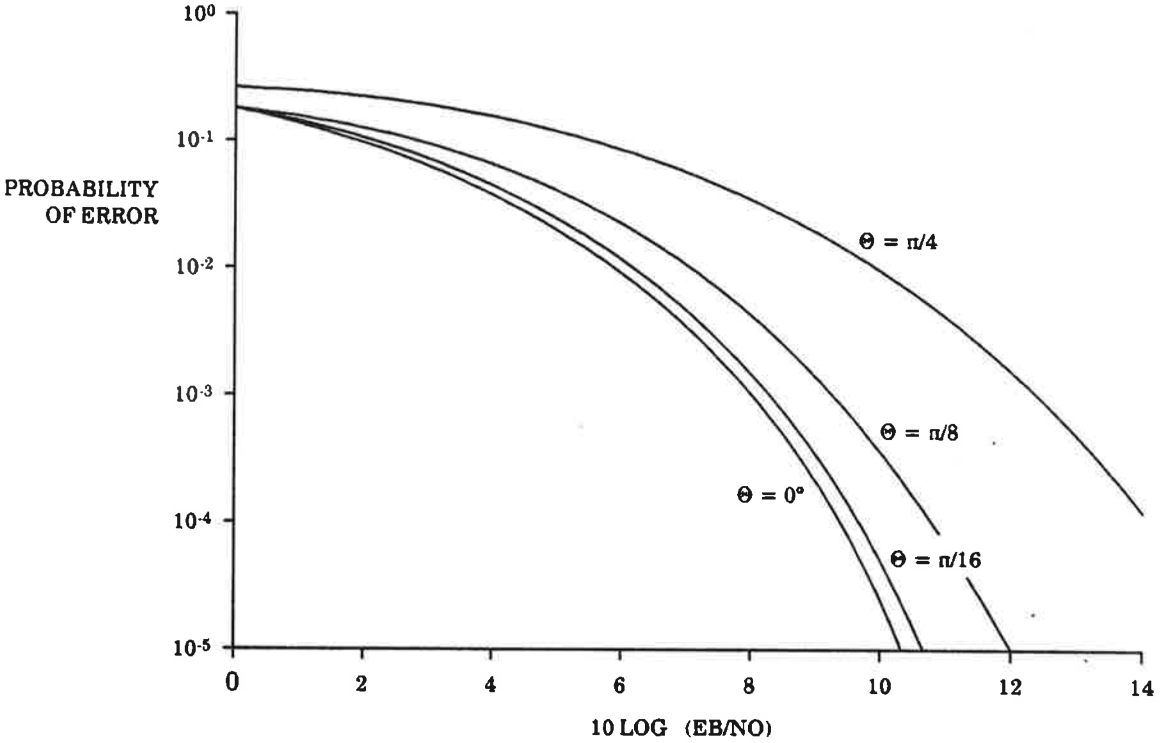

FIGURE K-1. EFFECTS OF PHASE ERRORS ON DPSK BER

APPENDIX L

DEDICATED DATA LINK AIRBORNE INTERFERENCE WITH MLS RECEIVER

Figure 1 of Appendix D shows the levels of interference that are allowed with no degradation in the MLS receiver operation. Two parameters have to be considered. Firstly, the CW signal power outside the MLS band but within the range 5000 to 5250 MHz, excluding the MLS band should not exceed -55 dBm. Secondly, signal power due to spectrum within the MLS band and within 1.2 MHz of any MLS channel should not exceed -62 dBm. When the interference level is-40 dBm or less and the frequency is greater than 1.2 MHz from the channel operating frequency, the receiver should also meet the requirement. This is based on the assumption that the interfering signal has the same spectrum as the MLS signal.

Two approaches for the MSS are proposed with both approaches having a bit rate of 100 kb/s. One approach uses a spread spectrum technique and the other does not. Because of the difference of the spectrum properties of each approach, they should be considered separately.

No Spread Spectrum

In the case of no spread spectrum, the power requirement is shown to be 24.0 dBm in a spectrum width of 100 kHz, compared to the MLS receiver IF bandwidth of 150 kHz.

Since the signal bandwidth is less than the IF bandwidth, no reduction in power will be encountered.

Using the same rationale, the input to the receiver will be -56.6 dBm which is below the specified -55 dBm.

In order to meet the in-band interference of -40 dBm with a 100 kb/s bit rate, the separation between the top MLS channel and the lowest MSS channel should be greater than 8 MHz. The 8 MHz is arrived at by proportionately increasing the 1.2 MHz MLS/MSS guard band stated in Appendix F for the translator concept by the ratio of the data link spectrum (100 kHz) to the translator spectrum (16 kHz).

Spread Spectrum

In the case of spread spectrum, the power requirement is still 24.0 dBm. The spectrum width is 12.8 MHz compared to the MLS receiver IF bandwidth of 150 kHz. This results in a peak power reduction of about 18 dB. The CW signal is then the equivalent of 6 dBm. Hence a reduction of 60.7 dB is needed to meet the -55 dBm requirement. This reduction is practically achieve by using two antennas separated by two meters.

If a single antenna is used for both the MLS receiver and the data link, the interference level specification will not be met. The signal level into the MLS receiver will be about 0 dBm (24 dBm - 20 dB isolation - 4 dB cable loss).

RTCA DO-177 Sections 2.2-1,2,3 states that the MLS receiver design will contain protection to safeguard against damage from a C-band power signal level of 0 dBm.

A packet duration of 1.72 milliseconds is small compared to the azimuth and elevation frames (15.9 and 5.6 milliseconds). Failure to meet the in-band and out-of-band interference requirement will result in a reduction in the MLS receiver update rate of four per second, i.e., two updates for azimuth and elevation. This is a reduction of 5 percent. Figure L-1 shows that the CMN degradation due to a reduction of update rate of 50% is insignificant compared to the 100% update rate. Based on these results, -40 dBm (in excess of -50 dBm) will not affect the performance of the MLS receiver. As a result, it is recommended that for the data link concept, a single antenna be used for both the MLS and the MSS transmitter.

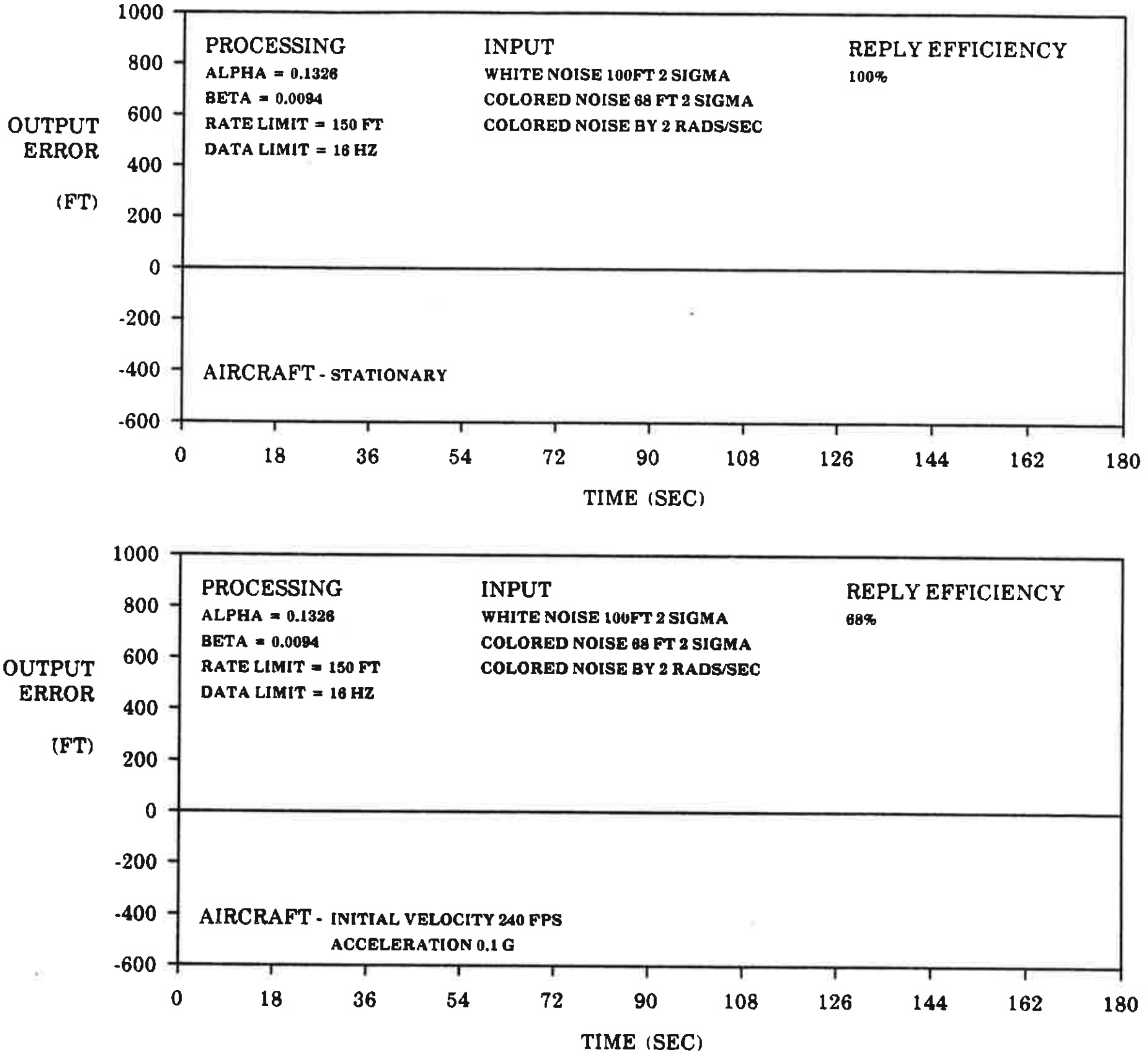

FIGURE L-1. CMN PERFORMANCE DEGRADATION DUE TO REDUCTION IN UPDATE RATE

APPENDIX M

REFLECTION POWER BUDGET

The signal power level reflected from the aircraft can be estimated using the equation:

$$S = \left[\frac{P_T\ G_T}{4\ \pi\ R^2}\right]*\left[\frac{\sigma_T}{4\ \pi\ R^2}\right]*\left[\frac{G_R\ L^2}{4\ \pi}\right] = \frac{P_T G^2 L^2 \sigma_T}{(4\pi)^3\ R^4} \qquad \text{(Equation 1)}$$

A * B * C

where S = received signal power in watts

A = transmitted power flux at the aircraft R nmi away

B = backscatter from the aircraft

C = effective area of the receiving antenna

P_T = transmitter peak power = 13 dBw

G_T = transmitter antenna gain = 29 dB

R = range = 7 dB nmi

σ_T = radar cross section = 0 dB m^2

G_R = receiver antenna gain = 29 dB

L = wavelength = 7.8 dB cm

The noise power at the ground receiver output can be calculted as follows:

N_o = KT_o noise spectral density = -204 dBw/Hz

N_{in} = $KT_o\ B$

where B is the equivalent noise bandwidth

N_{out} = $KT_o\ B\ F\ L_T$ watts = the output noise power (Equation 2)

where F = the receiver noise figure (+ 5 dB)

L_T = total transmission loss (multipath,rain,cable) (15 dB)

Dividing the signal in Equation 1 by the output noise in Equation 2,

$$(S/N)_{out} = \left[\frac{P_T G^2 L^2 \sigma_T}{(4\pi)^3 R^4 K T_o B F L_T} \right] \qquad \text{(Equation 3)}$$

We assume a matched filter is used in the ground receiver, in which case the receiver is matched to the spectrum of the reflected signal. For detecting a pulse of length tau, the bandwidth of the filter is selected so that

$$tau * B = 1$$

Therefore $B = 1/tau$

Substituting in Equation 4-3

$$(S/N)_{out} = \left[\frac{tau*P_T G^2 L^2 \sigma_T}{(4\pi)^3 R^4 K T_o F L_T} \right] \qquad \text{(Equation 4)}$$

We next express the signal to noise power ratio in terms of energy ratios. For a pulsed system, the energy to noise power ratio is defined as

$$R \equiv 2 (E/N_o) = 2 n (S/N)_{out} \qquad \text{(Equation 5)}$$

where 2E is the peak energy in the pulses and n is the number of pulses.

If t_o is defined as the observation time, and PRF is the pulse repetition frequency, then

$$n = PRF * t_o \qquad \text{(Equation 6)}$$

Using Equations 4-4 and 4-6 in Equation 4-5,

$$R = \left[\frac{2*PRF*t_o*tau*P_T*G^2*L^2*\sigma_T}{(4\pi)^3 R^4 K T_o F L_T} \right] \qquad \text{(Equation 7)}$$

Substituting the appropriate values in Equation 4 (using dB):

$$R = 3\,[2] + 19\,[PRF] + 0\,[t_o] - 40\,[tau] + 13\,[P_T]$$
$$+ 58\,[G^2] + 15.6\,[L^2] + 0\,[\sigma_T] - 28\,[1/R^4]$$
$$- 5\,[1/F] - 15\,[1/L_T]$$
$$+ 0\,[H/((4\pi)^3 K T_o)]$$

The terms inside the [] are the terms in Equation 7 that correspond to the value before the []. H is a constant to account for units used in the equation.

From this R is calculated.

$$R = 20.6 \text{ dB}$$

This is an adequate power signal to noise ratio for reliable detection.

APPENDIX N
DEDICATED DATA LINK CHANNEL ASSIGNMENT

In order to address the channel separating needed to meet the operational requirements, two factors have to be addressed. Firstly, the guard band needed between the MLSS and MLS bands to meet RTCA DO-177 requirements must be specified. Secondly, the MLSS channel separation to insure that adjacent channels will not affect the performance of MLSS in any way must be specified. Both guard band and channel separation are dependent on the channel spectrum occupancy. Channel access for the dedicated data link can be achieved by either frequency assignment or PN code assignment. In each case, the spectrum occupancy is different and they should be treated differently.

Frequency Assignment Technique

A synthesizer is used in both airborne and ground equipment. The channel is assigned by frequency. The data rate is 100 kb/s.

It has been shown in Appendix L that a 8 MHz guard band is needed in order to meet RTCA requirements. The channel separation remains to be defined. In the case of MLS, the data rate is 15.625 kb/s and channel separating is 300 kHz. The IF filter bandwidth is assumed to be 150 kHz. The data link receiver bandwidth is assumed to be 100 kHz. As a good approximation it can be assumed that the data link channel separation is equal to the MLS channel separating multiplied by the ratio of the data link to MLS data rate. This results in a channel separation of 2 MHz.

The frequency band width needed to support hard pairing between MLSS and MLS is 400 MHz. Since the band available to MLSS is 160 MHz wide, hard pairing cannot be achieved.

The proposed MLSS channel plan is shown in Figure N-1. Two channels are needed for each runway pair. After 8 MHz has been taken to provide the guard band needed between MLS and MMS, 76 sets of channels can be generated. Since the number of sets of channels are almost four times the sets available for the translator concept, it will be much easier to assign channels for the data link than the FDM translator.

PN Code Assignment Technique

In this approach a PN generator is employed in both the airborne transmitter and the ground receiver. A unique PN code is assigned to each MLS channel. If two hundred orthogonal codes can be generated, the data link transmitter would decode the MLS channel off the digital bus and the PN code is chosen from a look-up table without pilot intervention. Since there are 128 chips per bit, generating 200 codes with at least 40 dB isolation is relatively easy. 40 dB isolation is needed in order to compensate for the near far effects, i.e., if an aircraft is at 15 nmi away on one channel and another aircraft 1 nmi away on another channel, its signal will be about 23 dB higher than the desired channel. Isolation of the order of 40 dB will result in a desired to undesired signal ratio of 17 dB. Since the signal to noise ratio needed for

the link is 10.5 dB, no degradation in performance will be encountered.

The guard band needed between the MLS and MLSS can be found if the PN code spectrum is defined.

For example if a MSK modulation technique is used, the spectrum of the first sidelobe is less than 24 dB down. It is recommended that the PN code channel be assigned near the tope of the MLSS band, i.e. about 5200 MHz, and the modulation technique should be chosen to give minimum spectrum side lobes.

It has to be recognized that since the duty cycle for the data link is very small, degradation due to spectrum overlay will be minimized because the probability of time overlap is very small.

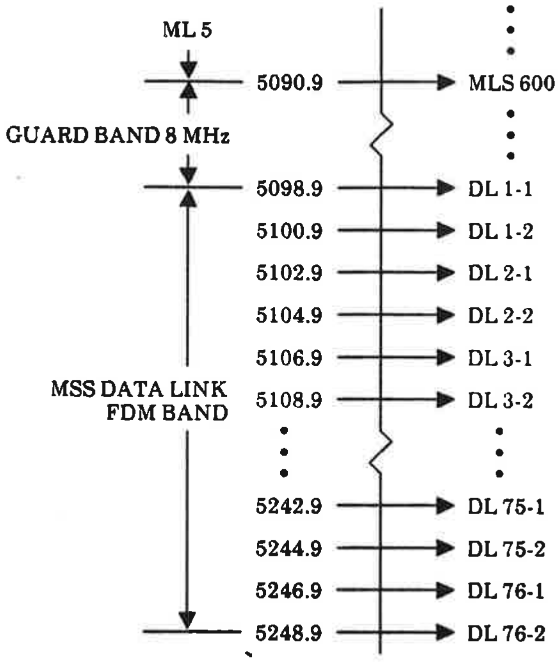

FIGURE N-1. MLSS DATA LINK FDM CHANNEL ASSIGNMENT

APPENDIX O

MLSS FREQUENCY CHOICE CONSIDERATIONS

Four frequencies were considered for downlinking the translated or data link messages from the aircraft. Frequency bands considered were L, S, C, and X bands. Some critical signal characteristics and propagation values are summarized in Table O-1.

The MLS uplink is fixed in power levels and in operating frequency. The resultant signal-to-noise ratio (SNR) is primarily a function of range to the transmitter. Translated signals at the aircraft will possess this SNR with slight degradation, provided that the transmitted signals on a new carrier frequency is sufficiently strong as discussed in Appendix C. Therefore, the downlink for all practical purposes will repeat the same SNR values as in the uplink, ranging from a SNR of 7.6 db at 15 nmi to 17.5 db at 5 nmi. This is shown in Figure O-1. The figures shown show the theoretical limits which can be approached but not improved upon.

In the data link concept, SNR of the downlink is not decided by the MLS uplink SNR. In this case, the SNR will be determined by the propagation laws where signal power, frequency, environment, and receiver sensitivity play a direct role in establishing the ground received SNR. In this case, the selection of the carrier frequency for the data link will be critical and will have no dependency on the MLS uplink frequency, except for the accuracy of the aircraft MLS receiver processed data. In the translator concept, the downlink is dominated by the MLS uplink signal characteristics, especially by the SNR at the aircraft receiver.

TABLE 0-1 MSS DOWNLINK FREQUENCY CHOICE CONSIDERATIONS

NO.	PARAMETER	L-BAND 1090 MHZ (MODE S)	S-BAND 2300 MHZ	C-BAND 5150 MHZ (MLS)	X-BAND 10000 MHZ
1	AIRCRAFT XMTR PWR*				
	CLEAR	14.5 mW 11.6 dBm	63 mW 18 dBm	320 mW 25 dBm	1200 mW 30.8 dBm
	RAIN	14.5 mW 11.6 dBm	64.5 mW 18.1 dBm	470 mW 20.7 dBm	130 W 21.1dbW
2	PROPAGATION LOSS	122.1dB	128.5dB	135.5dB	141.3dB
3	RAIN LOSS,16 MM/HR	<.1dB	.1dB	1.7dB	20.3dB
4	RECEIVER ISOLATION BY DISTANCE	Need 13.4 more dB	Need 7 more dB	OK	5.8 dB more than needed
5	BANDWIDTH	HARD	EASIER	OK	GOOD
6	DOPPLER	LOW	MEDIUM	HIGHER	HIGH
7	RECEIVER NOISE FIGURE	1.5dB	2.5dB	3.0dB	4.0dB
8	RF SOLID-STATE SOURCE AVAILABLE	EASY	OK	HARD	MAYBE
9	MULTIPATH	SPECULAR (HIGHER EFFECT)	SPECULAR DIFFUSED (LESS EFFECT)	DIFFUSED SPECULAR (EVEN LESS EFFECT)	DIFFUSED (LEAST EFFECT)
10	INTERFERENCE WITH COMMERCIAL EQUIP	HIGH	BETTER	MEDIUM	LOW
11	ACCURACY	SAME	SAME	SAME	SAME

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* Power required to reach 15mi with SNR of 10dB under rain and multipath conditions

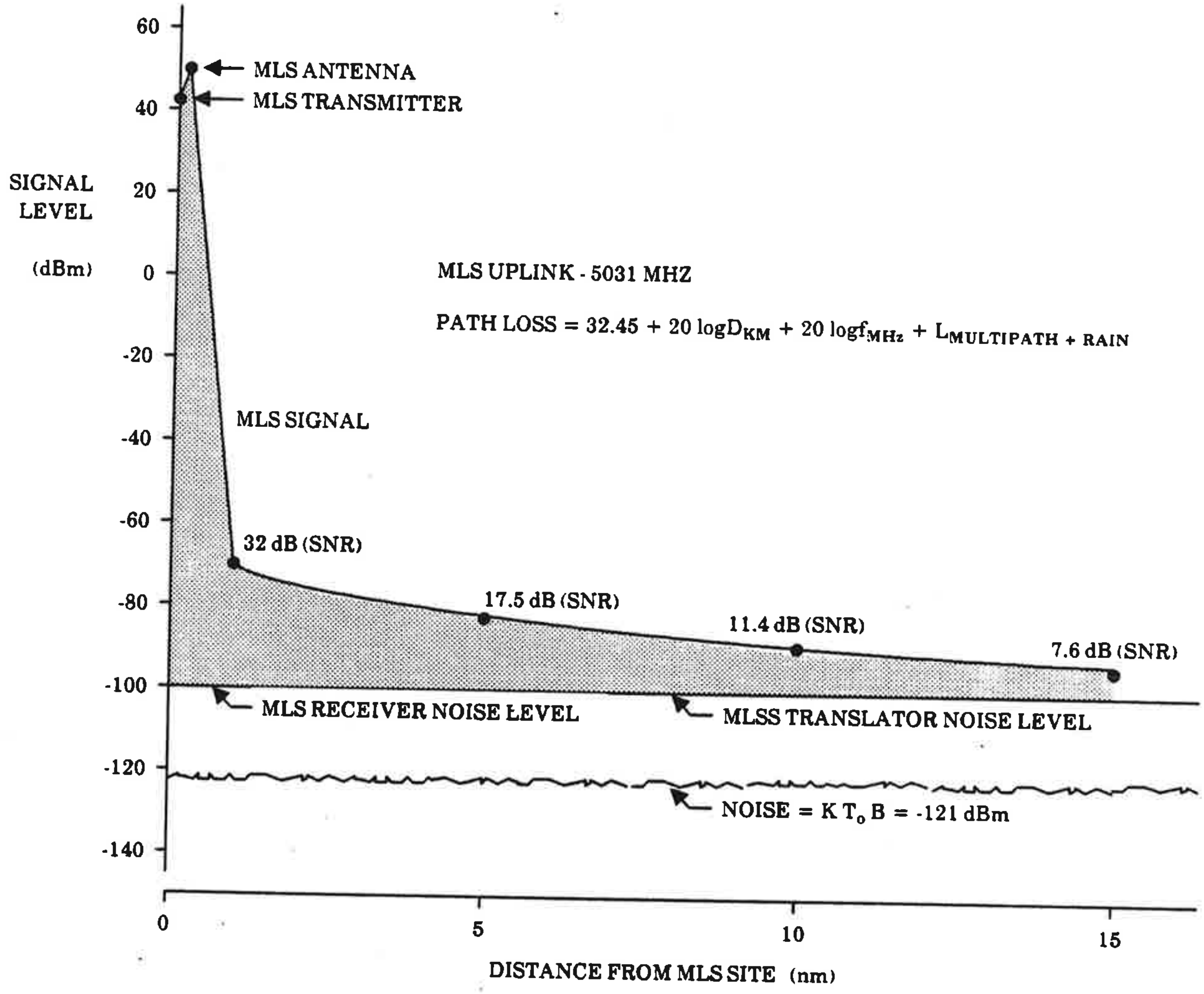

FIGURE 0-1. SNR VS RANGE FROM THE MLS SITE FOR TRANSLATOR CONCEPT

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