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A COMPARISON OF THE FREQUENCY REQUIREMENTS OF AN EARLIER DESIGN--ETC(U)
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A COMPARISON OF THE FREQUENCY REQUIREMENTS OF AN EARLIER DESIGN MLS AND THE TRSB MLS

IIT Research Institute
Under Contract to
DEPARTMENT OF DEFENSE
Electromagnetic Compatibility Analysis Center
Annapolis, Maryland 21402

March 1976

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16. Abstract

Channel assignments for an earlier design Microwave Landing System (MLS) and the Time Reference Scanning Beam (TRSB) MLS are compared. This comparison shows the advantages of the TRSB MLS signal format and channel plan over that of the earlier design system format and channel plan.

NOTE

This report considers the TRSB MLS design as it was at the time the study was completed. Since that time a number of design changes have been made and are not addressed in this report.

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PREFACE

The Electromagnetic Compatibility Analysis Center (ECAC) is a Department of Defense facility, established to provide advice and assistance on electromagnetic compatibility matters to the Secretary of Defense, the Joint Chiefs of Staff, the military department and other DoD components. The Center, located at North Severn, Annapolis, Maryland 21402, is under executive control of the Office of the Secretary of Defense, Director of Telecommunications and Command and Control Systems and the Chairman, Joints Chiefs of Staff, or their designees, who jointly provide policy guidance, assign projects, and establish priorities. ECAC functions under the direction of the Secretary of the Air Force and the management and technical direction of the Center are provided by military and civil service personnel. The technical operations function is provided through an Air Force sponsored contract with the IIT Research Institute (IITRI).

This report was prepared for the Systems Research and Development Service of the Federal Aviation Administration in accordance with Interagency Agreement DOT-FA70WAI-175, as part of AF Project 649E under Contract F-19628-76-C-0017, by the staff of the IIT Research Institute at the Department of Defense Electromagnetic Compatibility Analysis Center.

To the extent possible, all abbreviations and symbols used in this report are taken from American Standard Y10.19 (1967) "Units Used in Electrical Science and Electrical Engineering" issued by the United States of America Standards Institute.

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ENGLISH/METRIC CONVERSION FACTORS

LENGTH

From \ To	Cm	m	Km	in	ft	s mi	n mi
Cm	1	0.1	1×10^{-5}	0.3937	0.0328	6.21×10^{-6}	5.39×10^{-6}
m	100	1	0.001	39.37	3.281	0.0006	0.0005
Km	100,000	1000	1	39370	3281	0.6214	0.5395
in	2.540	0.0254	2.54×10^{-5}	1	0.0833	1.58×10^{-5}	1.37×10^{-5}
ft	30.48	0.3048	3.05×10^{-4}	12	1	1.89×10^{-4}	1.64×10^{-4}
S mi	160,900	1609	1.609	63360	5280	1	0.8688
n mi	185,200	1852	1.852	72930	6076	1.151	1

AREA

From \ To	Cm^2	M^2	Km^2	in^2	ft^2	$S\ mi^2$	$n\ mi^2$
Cm^2	1	0.0001	1×10^{-10}	0.1550	0.0011	3.86×10^{-11}	5.11×10^{-11}
m^2	10,000	1	1×10^{-6}	1550	10.76	3.86×10^{-7}	5.11×10^{-7}
Km^2	1×10^{10}	1×10^{6}	1	1.55×10^{9}	1.08×10^{7}	0.3861	0.2914
in^2	6.452	0.0006	6.45×10^{-10}	1	0.0069	2.49×10^{-10}	1.88×10^{-10}
ft^2	929.0	0.0929	9.29×10^{-8}	144	1	3.59×10^{-8}	2.71×10^{-8}
$S\ mi^2$	2.59×10^{10}	2.59×10^{6}	2.590	4.01×10^{9}	2.79×10^{7}	1	0.7548
$n\ mi^2$	3.43×10^{10}	3.43×10^{6}	3.432	5.31×10^{9}	3.70×10^{7}	1.325	1

VOLUME

From \ To	Cm^3	Liter	m^3	in^3	ft^3	yd^3	fl oz	fl pt	fl qt	gal
Cm^2	1	0.001	1×10^{-6}	0.0610	3.53×10^{-5}	1.31×10^{-6}	0.0338	0.0021	0.0010	0.0002
liter	1000	1	0.001	61.02	0.0353	0.0013	33.81	2.113	1.057	0.2642
m^2	1×10^{6}	1000	1	61,000	35.31	1.308	33,800	2113	1057	264.2
in^3	16.39	0.0163	1.64×10^{-5}	1	0,0006	2.14×10^{-5}	0.5541	0.0346	2113	0.0043
ft^3	28,300	28.32	0.0283	1728	1	0.0370	957.5	59.84	0.0173	7.481
yd^3	765,000	764.5	0.7646	46700	27	1	25900	1616	807.9	202.0
fl oz	29.57	0.2957	2.96×10^{-5}	1.805	0.0010	3.87×10^{-5}	1	0.0625	0.0312	0.0078
fl pt	473.2	0.4732	0.0005	28.88	0.0167	0.0006	16	1	0.5000	0.1250
fl qt	948.4	0.9463	0.0009	57.75	0.0334	0.0012	32	2	1	0.2500
gal	3785	3.785	0.0038	231.0	0.1337	0.0050	128	8	4	1

MASS

From \ To	g	Kg	oz	lb	ton
g	1	0.001	0.0353	0.0022	1.10×10^{-6}
Kg	1000	1	35.27	2.205	0.0011
oz	28.35	0.0283	1	0.0625	3.12×10^{-5}
lb	453.6	0.4536	16	1	0.0005
ton	907,000	907.2	32,000	2000	1

TEMPERATURE

$^{o}F = 5/9\ (^{o}C - 32)$

$^{o}C = 9/5\ (^{o}F) + 32$

FAA-RD-77-108

FEDERAL AVIATION ADMINISTRATION
SYSTEMS RESEARCH AND DEVELOPMENT SERVICE
SPECTRUM MANAGEMENT STAFF

STATEMENT OF MISSION

The mission of the Spectrum Management Staff is to assist the Department of State, Office of Telecommunications Policy, and the Federal Communications Commission in assuring the FAA's and the nation's aviation interests with sufficient protected electromagnetic telecommunications resources throughout the world to provide for the safe conduct of aeronautical flight by fostering effective and efficient use of a natural resource--the electromagnetic radio-frequency spectrum.

This objective is achieved through the following services:

- Planning and defending the acquisition and retention of sufficient radio-frequency spectrum to support the aeronautical interests of the nation, at home and abroad, and spectrum standardization for the world's aviation community.

- Providing research, analysis, engineering, and evaluation in the development of spectrum related policy, planning, standards, criteria, measurement equipment, and measurement techniques.

- Conducting electromagnetic compatibility analyses to determine intra/inter-system viability and design parameters, to assure certification of adequate spectrum to support system operational use and projected growth patterns, to defend the aeronautical services spectrum from encroachment by others, and to provide for the efficient use of the aeronautical spectrum.

- Developing automated frequency-selection computer programs/routines to provide frequency planning, frequency assignment, and spectrum analysis capabilities in the spectrum supporting the National Airspace System.

- Providing spectrum management consultation, assistance, and guidance to all aviation interests, users, and providers of equipment and services, both national and international.

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) has proposed a precision, non-visual, approach and landing guidance system called the Time Reference Scanning Beam (TRSB) system for the 1980's. This system differs in signal format, channel plan, and coverage volume from an earlier system design.

The number of channels required by each system for a frequency assignment to an environment of MLS equipments deployed in Southwestern U.S.A. was determined. A comparison of the results indicated that the TRSB MLS required 40% to 53% fewer channels than the earlier designed system. This was a result of better selectivity and emission characteristics, smaller bandwidth, and in some cases a smaller coverage volume for the TRSB. The TRSB MLS then has a greater potential for growth than the earlier system. The reduced number of required channels, as well as the reduction in channel width from 600 kHz for the earlier system to 300 kHz for the TRSB system, will provide additional flexibility in avoiding interference in high density areas.

This report does not consider DME (C-band or L-band) or take into account any of the frequency assignment constraints that DME will require.

TABLE OF CONTENTS

LIST OF ILLUSTATIONS

TABLE OF CONTENTS (Continued)

Table | Page

LIST OF TABLES

SECTION 1

INTRODUCTION

BACKGROUND

The Federal Aviation Administration (FAA) has proposed a non-visual approach and landing guidance system, the Time Reference Scanning Beam (TRSB) Microwave Landing System (MLS).[1] This system differs from a conventional scanning beam system previously proposed[2] in its signal format, coverage volumes and utilization of spectrum in the 5.0-5.25 GHz band. The earlier system used a frequency division multiplex technique for angle guidance which required 600 kHz channels. The TRSB MLS uses a time reference technique for angle guidance which requires only 300 kHz channels.

Previous analyses[3,4] of the earlier system concept showed that 200 angle guidance channels, 600 kHz apart could sustain MLS operation in a postulated future environment of 455 MLS-equipped runways.

The FAA expressed an interest in determining whether the TRSB MLS would reduce the number of channels required to sustain operation in the postulated environment along with reducing the total allocated spectrum. ECAC was tasked[5] to make this determination.

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[1]Department of Transportation, Federal Aviation Administration, *Time Reference Scanning Beam Microwave Landing System: A New Non-visual Precision Approach and Landing Guidance System for International Civil Aviation*, December 1975.

[2]Radio Technical Commission for Aeronautics, *Special Committee-117 Report (RTCA SC-117): A New Guidance System for Approach and Landing*, Volume II, Document Number DO-148, December 1970.

[3]Frazier, R. A., *In-Band Compatibility Analyses of the RTCA-Proposed Microwave Landing Guidance System (LGS) and Candidate Interim System*, FAA-RD-72-62, ECAC, Annapolis, MD, July 1972.

[4]Frazier, R. A., *Compatibility Analysis of the Texas Instrument, IIT/Gilfillan, Bendix, and Hazeltine Microwave Landing System Proposals*, FAA-RD-74-98, ECAC, Annapolis, MD, June 1974.

[5]Department of Transportation, Federal Aviation Administration, Interagency Agreement DOT-FA-70WAI-175, *Task Assignment No. 29 for Microwave Landing System (MLS) Electromagnetic Compatibility (EMC) Studies*.

OBJECTIVE

The objective of this analysis is to compare the number of channel assignments required to support the TRSB MLS configuration with that required for an earlier design MLS configuration in the same specified environment.

APPROACH

The analyses of the earlier design system employed an automated channel assignment model (References 3 and 4). This computer program was developed for the FAA by ECAC to establish angle guidance channel assignments for proposed precision landing systems. The model is used to generate the channel assignments for landing systems operating in a specified environment of 455 runways located in the Southwestern U.S. The equipment parameters with the associated transmitter spectra and receiver selectivities and a channel separation plan are required model inputs. The outputs from the model are a frequency assignment for each equipment in the environment and the number of frequencies or channels used in the assignment.

This analysis employed the channel assignment capability to compare the number of channels required to support the TRSB MLS with that required for an earlier design MLS. To apply the assignment model it was necessary to list the pertinent characteristics of each system. A comparison of these characteristics showed differences in spectra and in azimuth guidance sector width. The earlier design system had a sector width of ±60° while the TRSB MLS proposed to ICAO (Reference 1) has a sector width of ±40°. Reference 1 also stated that the TRSB MLS design could, if desired, operate with a sector width of ±60°. To demonstrate the effect of spectrum differences and sector width on MLS frequency requirements the model was employed to make channel assignments for landing systems on each of 455 runways (Reference 3) for the following conditions:

1. all runways equipped with the earlier design MLS.
2. all runways equipped with the TRSB MLS assumed to have a ±60° azimuth sector width. This system is referred to as TRSB MLS I in this report.
3. all runways equipped with the TRSB MLS as proposed to ICAO (i.e. ±40° azimuth sector width). This system is referred to as TRSB II in this report.

For each condition the computer model could use frequencies from a list of 200 equally spaced channels; 600 kHz apart for the earlier design system and 300 kHz apart for the TRSB.

The frequency assignments and number of channels required were compared for each condition and conclusion developed.

This report does not consider the impact of the frequency assignment constraints that will be imposed on operational MLS assignments by the implementation of DME (L-band or C-band).

SECTION 2

ANALYSIS

MLS DESCRIPTION

Each landing-guidance system consists of a ground-based Angle-Guidance Transmitter and an Angle-Guidance Receiver/Processor located in the aircraft. The guidance system provides the pilot, or autopilot, with the magnitude and direction of deviation between an approaching aircraft's position and the desired runway approach path.

With respect to each runway, there exists a volume of air-space in which the approaching or departing aircraft is to receive azimuth and elevation-guidance signals. The coverage volume for TRSB II MLS as presented to the International Civil Aviation Organization (ICAO) is shown in Figure 1. This approach volume is defined in azimuth by an angle (40°) to the right and left of the runway centerline, and a maximum range from the runway (20 nmi). The elevation coverage is bounded by the maximum elevation angle from the ground (20°) and the limits of the sector.

The desired path is the selected course in space which leads to the touchdown point on the runway. The pilot or autopilot receives proportional instructions to "fly down" or "fly up" and "fly left" or "fly right" depending on the instantaneous elevation and azimuthal relationship between the position of the aircraft and the desired path.

The MLS also provides missed-approach guidance. The missed-approach or back azimuth coverage volume is opposite in direction and defined in the same terms as the approach coverage volume. Back azimuth coverage could be from $\pm 20°$ to $\pm 40°$.

The earlier design MLS and the FAA selected TRSB MLS use different techniques to provide guidance in the coverage volume. Descriptions and characteristics of each may be found in References 1 through 3.

TABLE 1 lists the parameters and parameter values used in this analysis for the three systems. The parameter values for the earlier design MLS and the TRSB I MLS are essentially the same. The major difference between these systems are the transmitter spectra and receiver selectivities shown in Figures 2, 3, 4, and 5. The parameter values for the system labeled TRSB II MLS are essentially those for the FAA selected system (Reference 1).

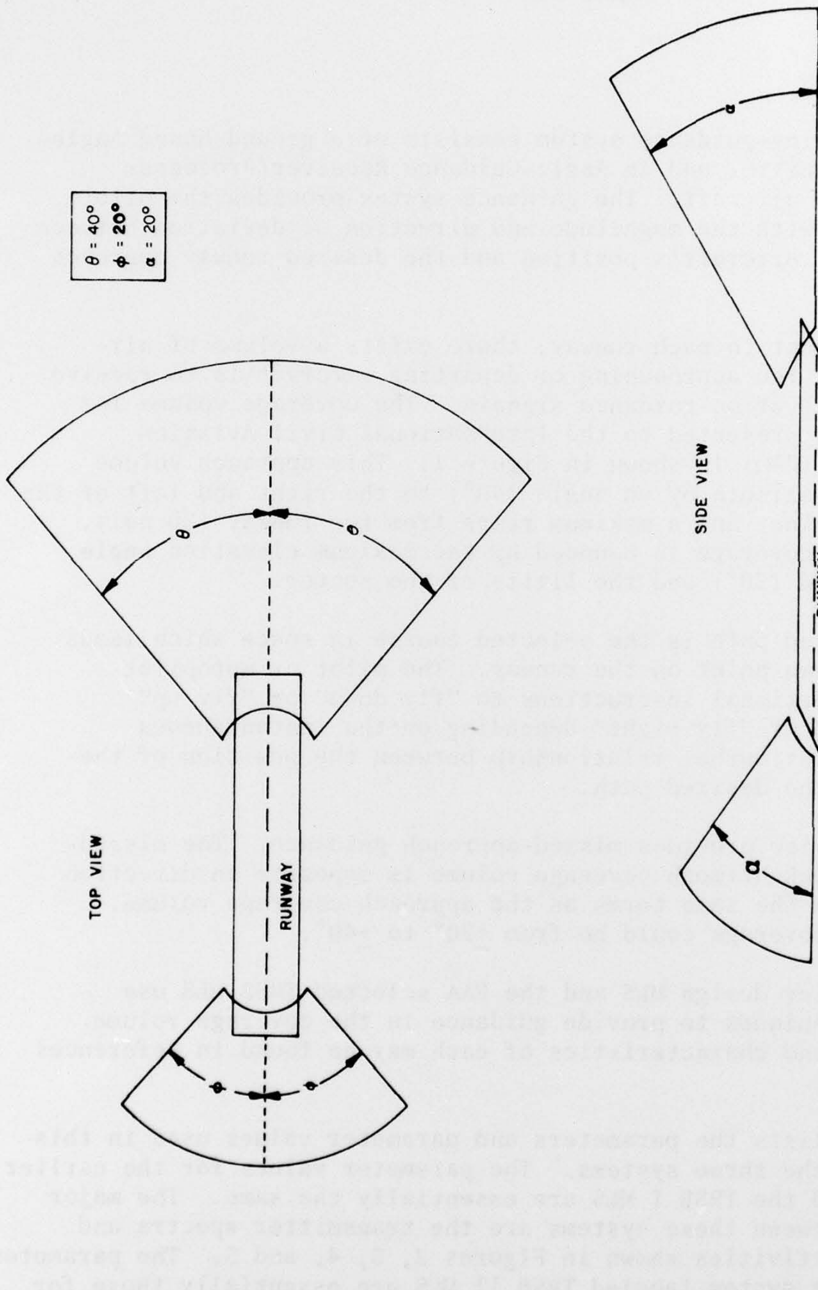

Figure 1. Pictorial representation of MLS coverage volume.

TABLE 1

TRSB I & II MLS AND EARLIER DESIGN MLS PARAMETERS USED FOR THIS ANALYSIS

Parameters	Earlier Design MLS	TRSB I MLS	TRSB II MLS[d]
Front coverage, degrees	40/120[a]	40/120[a,c]	40/80[a]
Back coverage, degrees	0/80[b]	0/80[b,c]	0/40[b]
Transmitter peak power, dBm	40	40	40
Mainbeam gain, dBi	32	32	32
Sidelobe gain, dBi	0	-10	-10
Backlobe gain, dBi	-32	-27	-27
Receiver sensitivity, dBm	-104	-103	-103
Aircraft mainbeam gain, dBi	10	10	10
Aircraft backlobe gain, dBi	0	0	0
Aircraft beamwidth, degrees	70	70	70
Signal-to-interference degradation threshold, dB	23	23	23

[a]The small community airports have front coverage of 40° and the large community airports have front coverage of either 120° or 80°, depending on the system.

[b]The small community airports have no back azimuth coverage and the large community airports have back azimuth coverage of either 80° or 40°, depending on the system.

[c]Assumed values for comparison purposes.

[d]TRSB MLS as proposed to ICAO (December 1975).

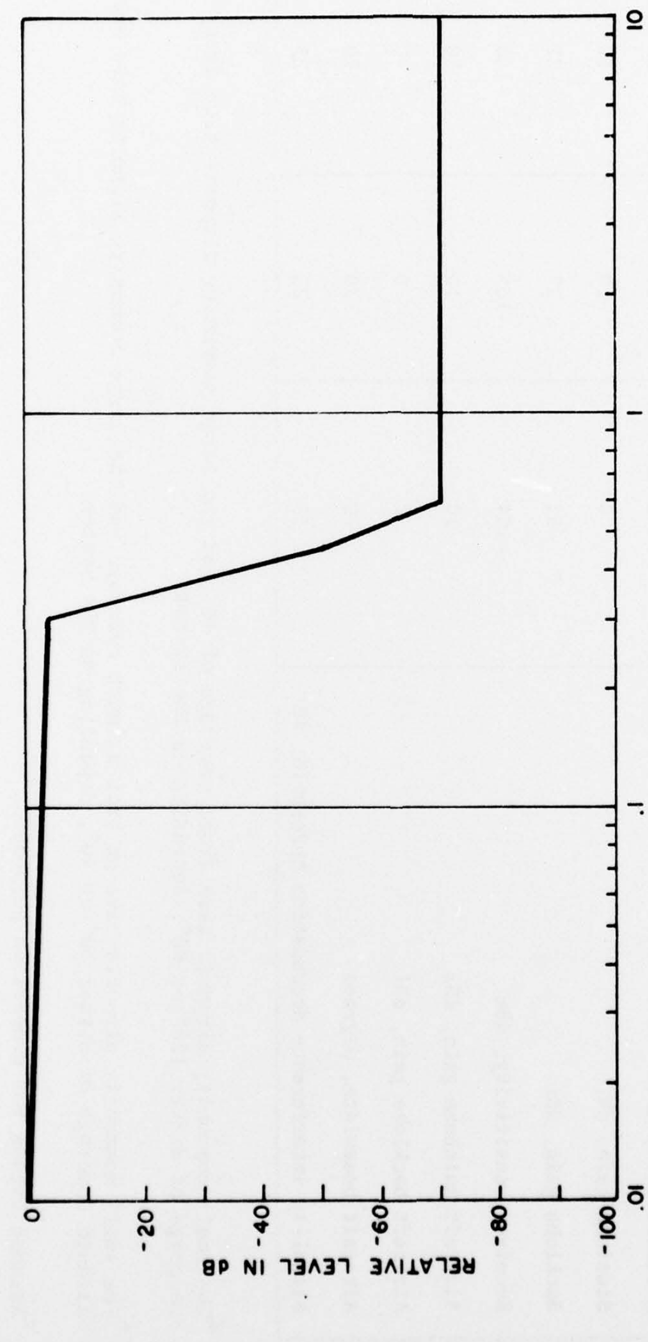

Figure 2. Earlier design MLS Angle Data Receiver selectivity (Reference 3).

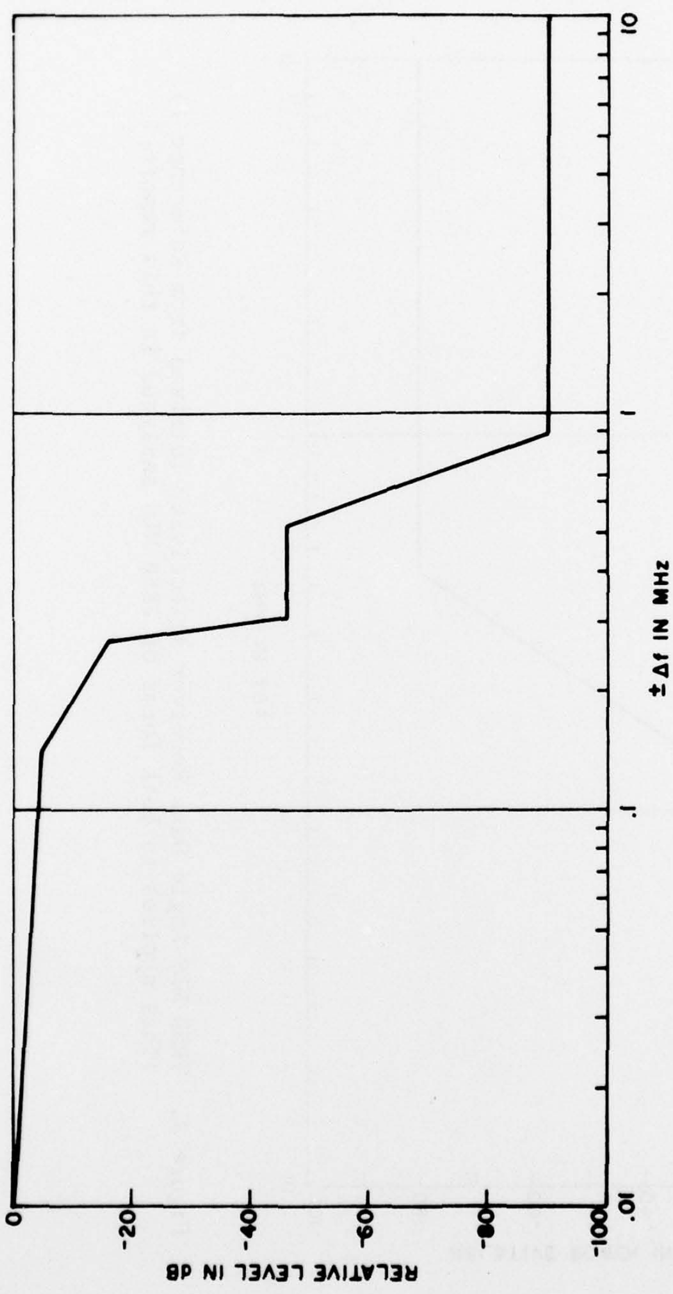

Figure 3. Earlier design MLS Angle Data Transmitter emission specturm (Reference 3).

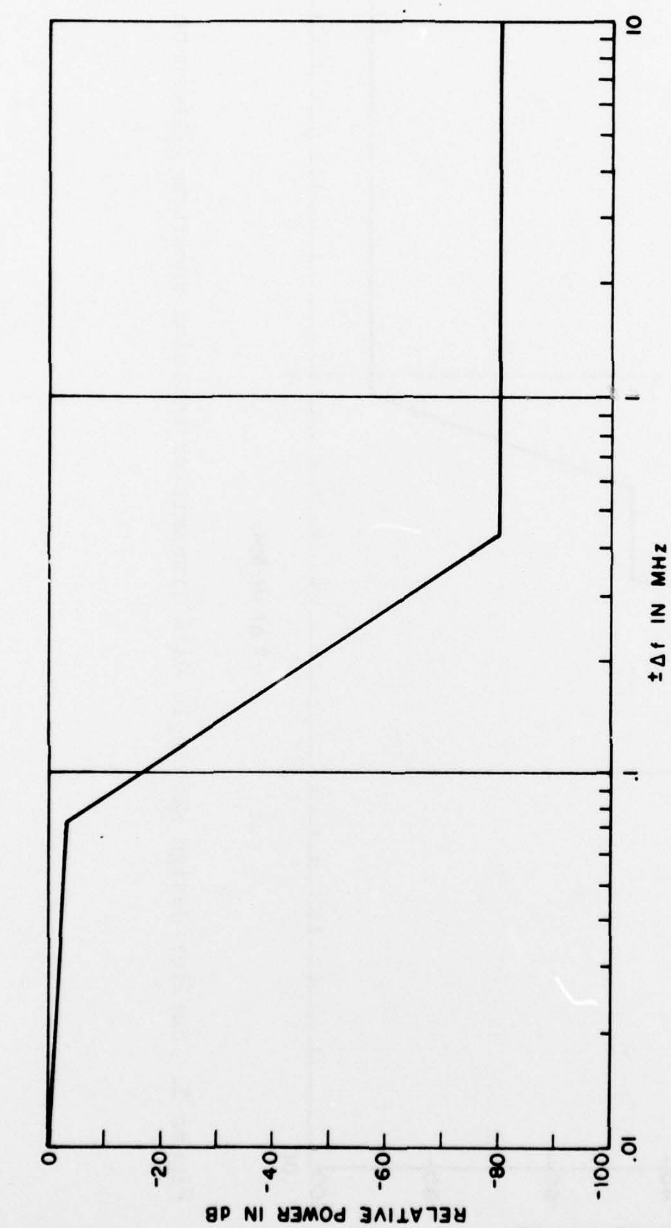

Figure 4. TRSB MLS Angle Data Receiver selectivity (derived from Reference 1). (This applies to both forms of TRSB MLS analyzed in this report.)

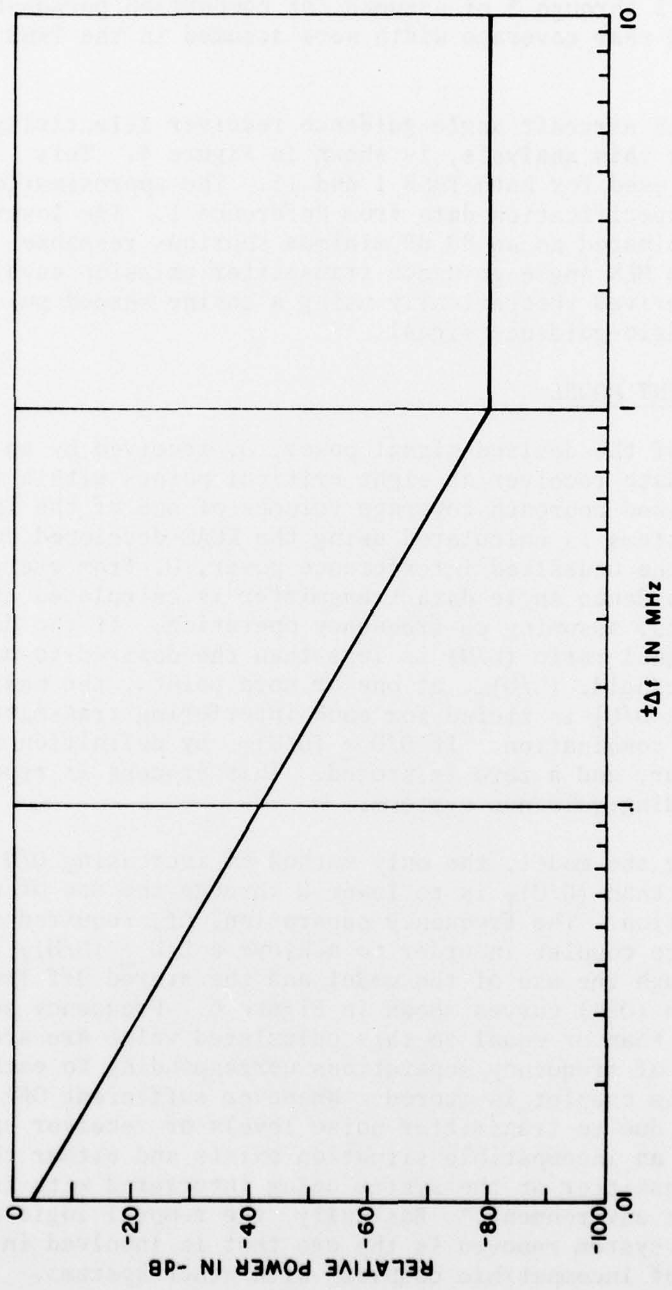

Figure 5. TRSB MLS Angle Data Transmitter synthesized emission spectrum.
(This applies to both forms of TRSB MLS analyzed in this report.)

All pertinent data needed for this analysis was either extracted from References 1 through 3 or assumed for comparison purposes only (i.e., front and rear coverage width were assumed in the TRSB I MLS System).

The TRSB MLS aircraft angle-guidance receiver selectivity, approximated for this analysis, is shown in Figure 4. This selectivity was used for both TRSB I and II. The approximation was made using specification data from Reference 1. The lower limit was approximated as an 80 dB minimum spurious response level. The TRSB MLS angle-guidance transmitter emission envelope, Figure 5, was derived theoretically using a cosine shaped pulse to represent the angle-guidance signal.

CHANNEL ASSIGNMENT MODEL

The level of the desired-signal power, D, received by an airborne angle data receiver at eight critical points within the approach and missed approach coverage volumes of one of the landing guidance systems is calculated using the ECAC-developed computer program. Then the undesired interference power, U, from every other landing-guidance angle data transmitter is calculated at these same points, assuming co-frequency operation. If the desired-to-undesired signal ratio (D/U) is less than the desired-to-undesired degradation threshold, $(D/U)_T$, at one or more points, the maximum value of $[(D/U)_T\ D/U]$ is stored for each interfering transmitter and victim receiver combination. If $D/U \geq (D/U)_T$, by definition no interference can occur, and a zero is stored. This process is repeated for all 455 landing-guidance systems.

While using the model, the only method of increasing D/U to a value greater than $(D/U)_T$ is to lower U through the use of off frequency rejection. The frequency separation, Δf, required for each interference couplet in order to achieve a $D/U \geq (D/U)_T$ is determined through the use of the model and the stored Off frequency Rejection (OFR) curves shown in Figure 6. Frequency separations greater than or equal to this calculated value are acceptable. A matrix of frequency separations corresponding to each interferer/victim couplet is stored. Whenever sufficient OFR cannot be obtained due to transmitter noise levels or receiver spurious response levels an incompatible situation exists and either the interfering transmitter or the system being interfered with is removed from the environment.* Basically, the removal logic requires that the system removed is the one that is involved in the largest number of incompatible couplets with other systems.

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*Removal from the environment is equivalent to not having a frequency assigned, i.e., the system cannot function.

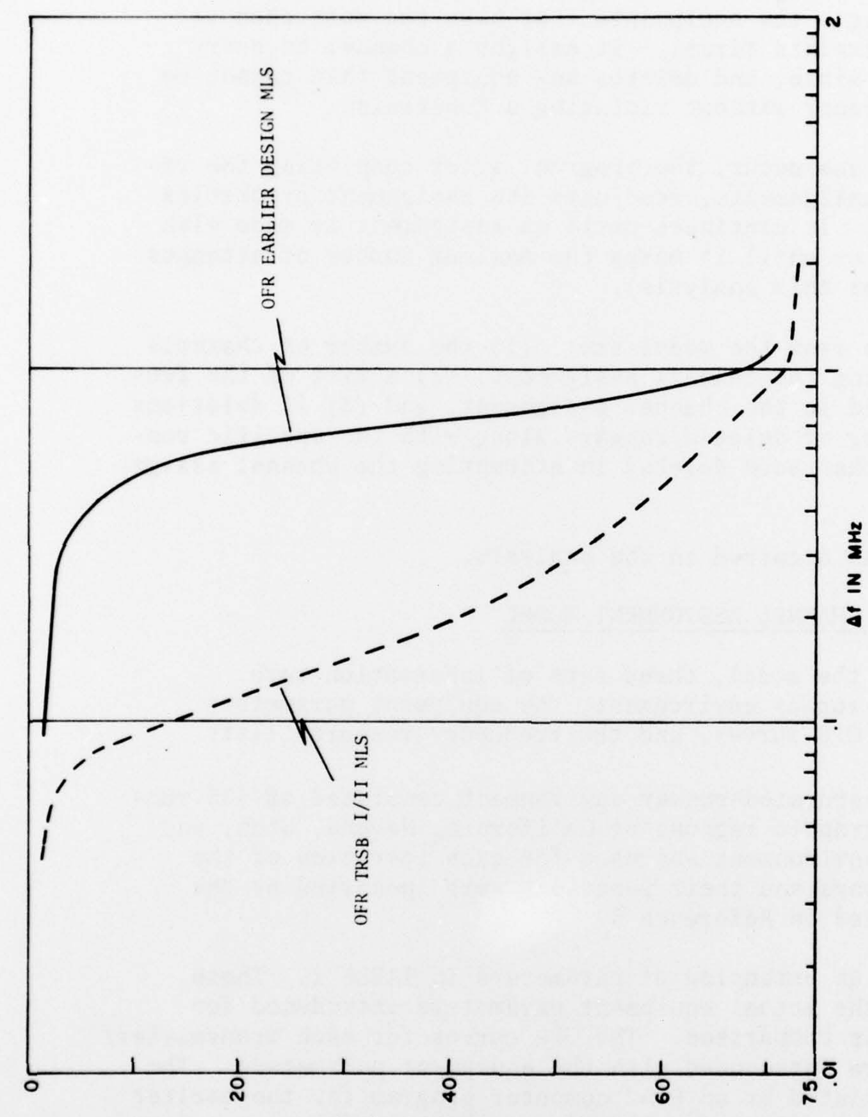

Figure 6. OFR of the proposed (TRSB) vs. the OFR of the earlier design MLS.

For all systems that remain in the environment, a channel assignment is attempted such that no channel separation constraints (matrix corresponding to each interferer/victim couplet) are violated. These assignments are made on a priority basis (i.e., the program assigns the equipments that have the most channel assignment constraints first). It assigns a channel to every equipment if possible, and deletes any equipment that cannot be assigned a frequency without violating a constraint.

When deletions occur, the program, after completing the remainder of the assignments, readjusts its assignment priorities and tries again. It continues until an assignment is made with zero deletions, or until it makes the maximum number of attempts permitted (10 for this analysis).

The outputs from the model are: (1) the number of channels used in attempting the channel assignment, (2) a list of the frequencies assigned in the channel assignment, and (3) if deletions exist, the number of deleted runways along with the specific runway equipments that were deleted in attempting the channel assignment process.

No deletions occurred in the analysis.

ENVIRONMENT FOR CHANNEL ASSIGNMENT MODEL

To utilize the model, three sets of information were necessary: the runway environment, the equipment parameters with associated OFR curves, and the frequency resource lists.

The 1980-postulated-runway environment consisted of 455 runways in the geographic regions of California, Nevada, Utah, and Arizona. This environment was used for each iteration of the model. The runways and their locations were specified by the FAA and are listed in Reference 3.

TABLE 2 is an extension of parameters in TABLE 1. These parameters are the actual equipment parameters introduced for computer analysis comparison. The OFR curves for each transmitter/receiver pair are introduced with the equipment parameters. The OFR values calculated by an ECAC computer program for the earlier design MLS and the TRSB I and II MLS are shown in Figure 6. Since the earlier design MLS (column 1 of TABLE 2 and Figure 6) and the TRSB II MLS (column 3 of TABLE 2 and Figure 6) differ as to the coverage volumes and channel plans, two comparisons of channel assignments were necessary. The first comparison was between the earlier design MLS and the TRSB I MLS. This comparison dealt with

TABLE 2

COMPUTER PARAMETERS

Parameters	Earlier Design MLS	TRSB I MLS	TRSB II MLS[d]
Front coverage, degrees	40/120[a]	40/120[a,c]	40/80[a]
Back coverage, degrees	0/80[b]	0/80[b,c]	0/40[b]
Mainbeam sensitivity radius, n. miles	250	232	232
Sidelobe sensitivity radius, n. miles	250	232	232
Rear lobe sensitivity radius, n. miles	250	232	232
Transmitter peak power, dBm	40	40	40
Mainbeam gain, dBi	32	32	32
Sidelobe gain, dBi	0	-10	-10
Backlobe gain, dBi	-32	-27	-27
Front course sensitivity radius, n. miles	23	22	22
Rear course sensitivity radius, n. miles	6	5	5
Front course sector width, degrees	120	80	80
Rear course sector width, degrees	80	80	40
Signal-to-interference degradation threshold, dB	23	23	23
Receiver sensitivity, dBm	-104	-103	-103
Aircraft mainbeam gain, dBi	10	10	10
Aircraft backlobe gain, dBi	0	0	0
Aircraft beamwidth, degrees	70	70	70

[a] The small community airports have front coverage of 40° and the large community airports have front coverage of either 120° or 80°, depending on the system.

[b] The small community airports have no back azimuth coverage and the large community airports have back azimuth coverage of either 80° or 40°, depending on the system.

[c] Assumed values for comparison purposes.

[d] TRSB MLS as proposed to ICAO (December 1975).

the fact that the channel plans are different. The second comparison was between the earlier design MLS and the TRSB II MLS. This comparison dealt with the fact that both the coverage volumes and channel plans were different.

The frequency resource lists have 200 channels available. The earlier design MLS list has channels separated by 600 kHz, and the TRSB I/II MLS list has channels separated by 300 kHz.

INTERFERENCE CRITERION

The assumption is made, in the computer model that acceptable operation results when the average power of the desired angle-guidance signal, D, received by the airborne unit is greater, by some fixed amount, than the average on-frequency power of a signal from another angle-guidance transmitter, U. This fixed amount is called the desired-to-undesired threshold ratio $(D/U)_T$, given in decibels (dB). The $(D/U)_T$ values used in this analysis are shown in TABLE 1. The $(D/U)_T$ of 23 dB or the earlier design MLS came from Reference 3. The $(D/U)_T$ for the TRSB I/II MLS was assumed to be 23 dB.

COMPARISON OF MODEL RESULTS

Channel assignments for the earlier design MLS, the TRSB I MLS, and the TRSB II MLS were made using the automated model. The number of channels (out of a maximum of 200) required for operation of 455 systems in the Southwestern U.S. are shown in TABLE 3 for each system considered.

TABLE 3

NUMBER OF CHANNELS REQUIRED
FOR OPERATION OF 455 SYSTEMS

System	# Channels
Earlier Design MLS	170
TRSB I MLS ($\pm 60°$)	103
TRSB II MLS ($\pm 40°$)	81

Comparing the number of channels required for the earlier design MLS with that required for the TRSB I MLS shows that the TRSB I MLS requires 40% fewer channels. This difference is due to the spectra and selectivities of the equipments since essentially all other parameters are the same. Figure 6 shows the OFR curves for both systems. For the earlier design MLS at 600 kHz or 1 channel separation, the rejection is 22 dB. However, for the TRSB I MLS the rejection at 1 channel separation (300 kHz) is 52 dB. The additional 30 dB of rejection available with the TRSB MLS is the mechanism which allows fewer channels to be used in the TRSB MLS assignment than in the earlier design MLS assignment.

A further reduction in the number of channels required occurs when comparing the earlier design MLS assignment with that of the TRSB II MLS assignment. The reduction of 53% in the number of channels is attributed to the 30 dB of additional rejection and the reduced coverage volume (see TABLE 1).

The consequences of this significant difference between earlier design MLS and TRSB MLS assignments are twofold. First, more systems could be added to the environment without prompting concern for exceeding the 200 channel limit. Second, the TRSB MLS may allow more flexibility in frequency assignment to protect MLS from intersystem interference.

SECTION 3

CONCLUSIONS

The following conclusions are presented based on a comparison of results from an automated channel assignment model:

1. The TRSB MLS in the ±40° azimuth sector width requires approximately 50% fewer channels to implement in the selected area than the earlier design MLS (±60° azimuth sector width) in the same environment.
2. More TRSB MLS equipments regardless of azimuth sector width could operate in a given geographic area than earlier design MLS systems.
3. The problems associated with the introduction of new or existing systems in the same frequency band will be reduced due to the flexibility of frequency assignments afforded by the TRSB MLS.

ABBREVIATIONS AND ACRONYMS

DoD	-	Department of Defense
ECAC	-	Electromagnetic Compatibility Analysis Center
FAA	-	Federal Aviation Administration
ICAO	-	International Civil Aviation Organization
IITRI	-	Illinois Institute of Technology Research Institute
MLS	-	Microwave Landing System
OFR	-	Off Frequency Rejection
TRSB	-	Time Reference Scanning Beam