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Engineering Analyses of Candidate Communication and Surveillance Techniques for the Vessel Traffic System

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16. Abstract

Coast Guard Vessel Traffic Service (VTS) facilities rely heavily on radio communications to acquire the location of vessels and disseminate this information to other interested shipping. As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. To provide a basis for future system expansion and design, this study explores the communication channels available to maritime mobile service and the impact of change from voice to voice/data and data-only communication. The analyses performed under this study were divided into two tasks: Task I is a review of all frequency bands available for maritime service, identifying for each band all permissable transmission methods. Task II considers three candidate systems. The performance of these systems was analyzed with respect to present and future communications requirements using statistical VTS communication data. The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment. As a result of this study, the following conclusions are stated: (1) The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels. (2) There are digital communication systems capable of expanding the capacity of existing communication channels.

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PREFACE

Coast Guard Vessel Traffic Service (VTS) facilities are established in several of the major U.S. ports, to prevent loss of life and property that could result from an accident involving ships. In performing the advisory service, a VTS relies heavily on radio communications to acquire the location of vessels and disseminate the information to other interested shipping. As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. Such expansion is projected to involve a change from voice reporting of position to automatic retransmission of the Loran-C coordinates from the ship's receiver.

To provide a basis for future system expansions and design, this study explores the communication channels available to maritime mobile service and the impact of change from voice to voice/data and data-only communication. The analysis performed under this study is divided into two tasks. Task I is a review of all frequency bands available for maritime service, identifying for each band all permissable transmission methods. Task II considers three candidate systems. The performance of these systems was analyzed with respect to present and future communications requirements using statistical VTS communication data.

The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment.

As a result of this study, the following conclusions are stated:

- -The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels.
- -There are digital communication systems capable of expanding the capacity of existing communication channels. These range from the introduction of short burst messages of digital data onto existing voice channels, through the introduction of 'mid-channel' single sideband data channels which are transparent to the existing FM voice channels and which provide data capacities in excess of those required for the growth envisioned at this time.

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1. INTRODUCTION

Coast Guard Vessel Traffic Service (VTS) facilities are established in several of the major U.S. ports. The purpose of the VTS is to prevent loss of life and property including environmental damage, that could result from an accident involving ships. Each VTS provides an advisory service to shipping in its service area. The advisories contain information concerning traffic conditions and hazards to navigation. In performing the advisory service, a VTS relies heavily on radio communications to acquire the location of vessels and disseminate it to other interested shipping.

Current VTS operations are centered primarily in the harbor areas. These operations make exclusive use of voice communications in the 156 to 160 MHz maritime mobile band, In some areas, the channels available in this band are already overcrowded. Looking into the future, it can be shown that there will be an increase in both the number of users communicating in the band and in the number of communications per user. It is anticipated that communications traffic at each VTS will also increase to keep pace with increases in shipping activity in the ports where they are established and as more precise information is required by the mariner.

Additionally, interest in offshore traffic management is rising. Although the requirements of such an effort are somewhat different from a port area VTS, the reliance on radio communications for effective operation appears to be the same. However, due to an extended range of communications from 20 nm (the practical limit of shore-based VHF communications) to 200 nm, the nature of the communication systems required for offshore traffic management would be substantially changed.

As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. Such expansion is projected to involve a change from voice reporting of position to automatic

The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. When the channel is co-occupied by voice, the effect of message length on expected data loss due to interference by voice transmissions has been analyzed. Each system is analyzed assuming current communications loads and increases of 10%, 25%, 50% and 100% in both the number of users and the time spent in communication with each user. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment.

Candidate systems are:

- -Systems which add data to existing narrow-band FM (NBFM) VHF voice equipment, including the possibility of voice and data co-existing in the same channel.
- -Systems which employ an NBFM transmitter and receiver which has been modified to permit wide-band data modulation. This modification eliminates the bandwidth restriction placed on the first system by the voice channel audio filters. Again, data with voice and data only variants are possible.
- -Systems which drop the requirements for NBFM modulation and the use of existing radios. Three variations of this approach are possible:
  - (a)the occupation of the entire allotted channel with directly modulated high-speed data
  - (b)the use of frequency-hopped FSK within the assigned channel to provide for multi-user random access communications
  - (c)the subdivision of the channel or the insertion between two existing channels of single-sideband channels in a manner currently being proposed for land mobile use.

As a result of this study, the following conclusions are stated:

- -The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels.
- -There are digital communication systems capable of expanding the capacity of existing communication channels. These range from the introduction of

2. SPECTRUM AND TRANSMISSION ANALYSIS

2.1 Introduction

This section presents a summary of the frequency bands available to the maritime service, the authorized classes of emission in each band, and a preliminary assessment of the applicability of each band to the VTS problem. Due to the large number of frequency bands and even larger number of specific channel assignments within each band, the main body of this section does not attempt a detailed listing, but rather refers the reader to references W and X. These references list, in detail, frequencies allocated to the maritime mobile service, and the types of modulation permitted in each band. These regulations are referenced in the text by part, paragraph and page number (e.g. *2.106 pg.22*).

This summary divides the maritime mobile frequency allocations into the following categories:

- -VLF and LF low speed telegraphy frequencies
- -Groundwave over the horizon frequencies
- -HF ionospheric frequencies
- -Radio line-of-sight frequencies (e.g. VHF)
- -Satellite frequencies.

The authorized modulation techniques are divided into the following categories:

- -Voice
- -Low speed telegraphy (Morse code)
- -Narrow-band direct-printing data transmission systems
- -Wide-band telegraphy, facsimile transmission and special transmission systems.

2.2 Overview of the Maritime Frequency Allocations

Figure 2.1 is an overview of the maritime mobile radio frequency allocations. The low end of the maritime communication band technically starts at 110 kHz (*2.106 pg.22-23*). In practice, however, the frequencies below 490 kHz are limited to low-speed, keyed carrier communications (A-1 emissions), with telegraphy by means of on-off keying of an amplitude modulated audio frequency (A-2) permitted at the high end of the band (*81.132 pg.39-40 and 83.132 pg.150*).

The frequency bands extending from 2000 kHz to 2850 kHz (some 1600-2000 kHz available in Alaska) are the main coastal zone communication frequencies (*2.106 pg.24-25*). In these bands, provisions are made for virtually all modes of communications which can be supported by the media, including single sideband voice transmission, keyed carrier Morse code, and, of special interest to the VTS project, narrow-band direct-printing data transmission, wide-band data telemetry, facsimile and special transmission systems.

The HF bands grouped at 4 MHz, 6 MHz, 8 MHz, 12 MHz, 16 MHz, 22 MHz and 25 MHz comprise the primary high seas communication band (*2.106 pg.27-36A*). As for the coastal band, each of these high frequency bands has allocations which accomodate simple Morse code telegraphy, single sideband voice and a variety of data transmission systems.

The VHF marine band, including frequencies in the range of 156 MHz to 162 MHz (*2.106 pg.43-44*), includes the main ship-to-coast communication channels. At these frequencies, line-of-sight communications is possible to a range of at least 20 nm, and commonly to distances of 40-70 nm where land-based antennas are positioned on top of high locations. Frequencies in the VHF band are channelized and provide for a variety of frequency modulated communications including voice and data transmission.

Frequencies in the microwave region (*2.106 pg.49,63,66*) are allocated for ship-to-satellite communication as well as satellite-to-ship transmissions. In general, the authorization of such frequencies is academic, as their use is dependent upon the availability of a suitable communications satellite. At the present time, coverage of the U.S. Coast areas (except the Gulf of Mexico) is provided by MARISAT satellites. These satellites provide for both voice and data

2.3.1.2 0-200 Nautical Mile Range

For the purposes of this report, the communications considered in this range shall be construed to be the range from the limits of VHF communications to the 200 nm limit. Within this range, MF, HF or satellite communications must be relied upon. Typically, communications in this range are accomplished using the 2 MHz to 3 MHz MF frequency band. This band is capable of providing communications out to a minimum range of 100 nm, and normally to the required 200 nm range. Increased reliability of communications in the 100-200 nm range could be obtained through the use of the 4 MHz high seas band.

If links which do not provide direct communications between the VTS station and the ship are considered, the use of other high-seas HF bands, relaying messages through the geographically disbursed HF communication nodes and/or the use of satellite systems may be considered. However, while these indirect systems will be capable of getting a message through, the data transmission techniques employed must be compatible with much larger, existing communication nets than those designed to communication directly between the ship and the VTS center. For example, a data link using the MARISAT satellite would be required to meet all of the technical specifications set up by the MARISAT Joint Venture, in addition to using a communications format which has been optimized for the VTS system.

2.3.2 Relative Performance of Voice and Data Systems

Studies of vessel population profiles indicate that a reasonably active VTS center must be capable of handling between 30 and 100 vessels. A detailed analysis of the VTS data message structure is presented in section 3.

To determine the applicability of various communication modes (e.g. voice, Morse code) a simplified position only configuration is assumed. This approach permits the relative effectiveness of each mode to be studied, without presupposing a message format. For a Loran-C position only system, data required from each ship to establish ship's position is assumed to be:

TABLE 2-1 : ESTIMATED POSITION REPORTING TIMES

(A) Voice (assuming ship's station at watch)....Estimated time = 30 seconds

Establish contact (including ID)
Read 3 time differences
Read 3 signal quality numbers

(B) Morse Code..................................Estimated time = 27 seconds

Message length: 9 letter ID + space x 2 = 20
TD ident (2+space)x3 = 9
TD value (7+space)x3 = 24
End of Message = 3
56 characters

(25 words/min x 5 char/word = 125 characters/minute)

(C) Narrow-Band Direct-Printing Telegraphy......Estimated time = 7.5 seconds

Message length: Call 9 digits = 9
Delay = (1 second)
Response, 9 digits = 9
Type of msg, 8 digit= 8
TD ident (2+spc)x3 = 9
TD value (7+CRLF)x3 = 27
End of message = 3
65 Characters + 1 second delay

(Rate, 10 characters/second) (CRLF = 'carriage return, line feed')

(D) Voice Band Digital (2400 Baud)..............Estimated time 78-2468 msec (dependent on squelch)

Call Message:	bits	time
break squelch & front porch		5-1200 msec
sync word	8	
request	16	
identification number	8	
check sum	8	
	(36)	
Response:		
break squelch & front porch		5-1200 msec
sync word	8	
identification	8	
Loran-C TD's	84	(7 digits) - 28 x 3
Loran Quality	24	(2 digits) - 8 x 3
	(124)	
Parity or check sum	4	

TOTAL BITS.............................164 (@2400 b/s) = 68 msec

2.3.3.2 0 - 200 Nautical Mile Range

The most applicable system for the 0-200 nm range appears to be the MF 2 MHz band. Paragraph 83.132.a.1.i of the Radio Regulations provides for the transmission of wide-band telegraphy, etc. on the frequency bands between 2070 kHz and 2080 kHz. The major question raised regarding the use of this frequency is the reliability with which the 200 mn limit can be reached, especially near the periods of local noon and local midnight.

A secondary, or backup set of frequencies could be considered, which used both the 2 MHz and 4 MHz band. However, the 4 MHz band ionospheric skips can provide some fairly long ranges (4000 nm) which could create an interference problem.

The use of the 4 MHz - 25 MHz high-seas bands to fill in a small area between the limits of the 2 MHz coverage and the 200 nm limit is considered undesirable, due to its inconsistency with the nature of the communications assigned to these channels, i.e., long range high-seas communications through centralized communications nodes. This use of satellite communication as the main communication link out to 200 nm is considered least desirable, due to high equipment and channel usage costs.

Meteor burst communication may be used to fill in the line-of-sight 200 nm range. The use of meteor burst communications is the subject of a separate, parallel study.

As a result of a preliminary study review, a decision was made to limit further system analyses to systems which would operate over VHF communication channels. Thus, the baseline system analysis pursued in the remainder of this report considers systems and data modulation techniques that transmit the digital VTS data over VHF links. By the nature of these systems, it is assumed that the messages are of a short, or burst, nature. The three baseline systems analyzed and their variants are discussed in section IV.

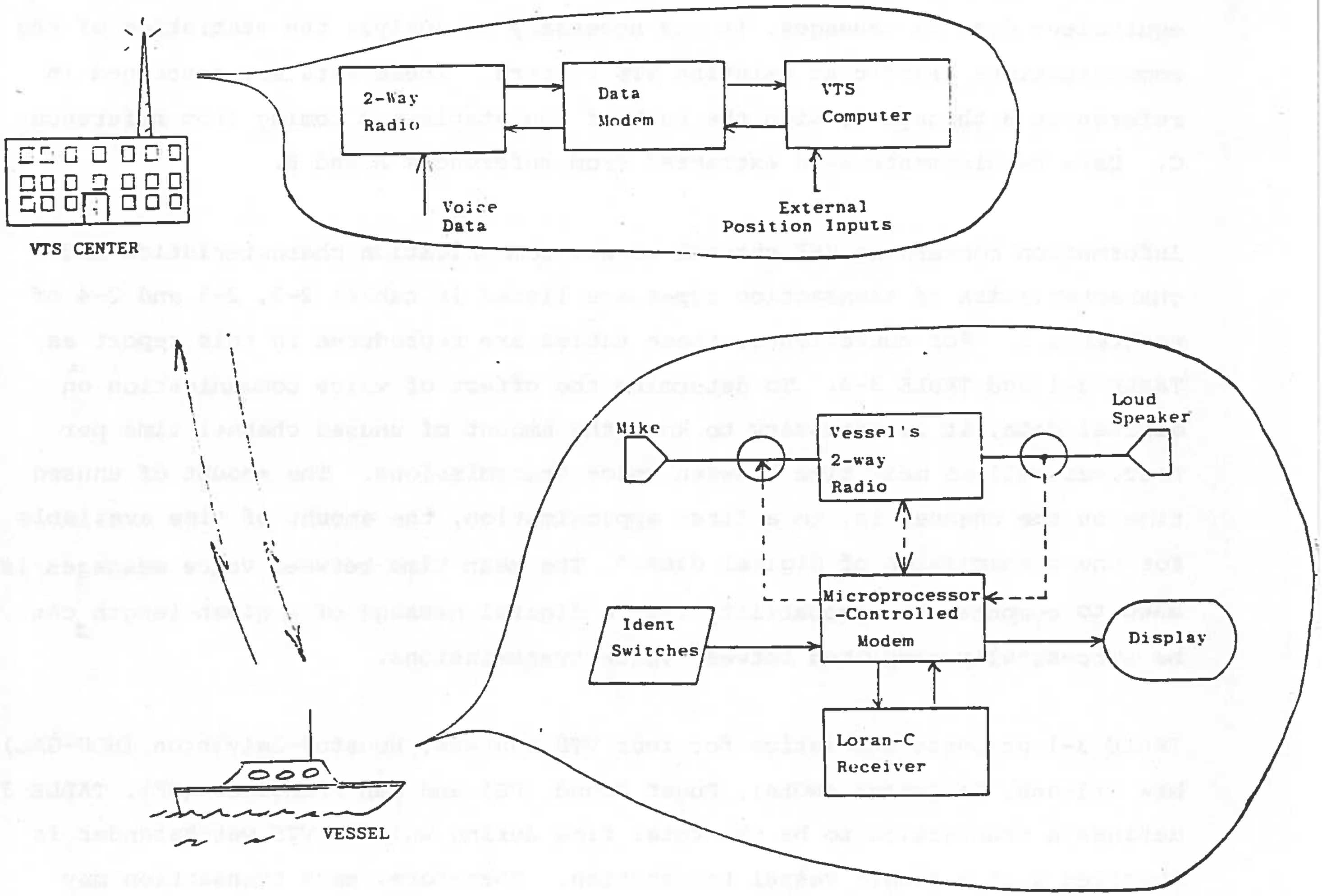

FIGURE 3-1 : OVERVIEW OF VTS DIGITAL DATA SYSTEM

TABLE 3-1a. VHF RADIO CHANNEL USE

	HOU-GAL	NOLA	PS	SF
Percent channel utilization	54	20	30	12
Number of channels	1	3	1	1

TABLE 3-1b. COMMUNICATIONS CHARACTERISTICS

Average Hourly Characteristic	HOU-GAL	NOLA	PS	SF
Number of transactions	96	45	46	20
Number of transactions per vessel	3.2	0.8	1.2	2.5
Time per Transaction (sec)	22	53	30	21
"Dead time" per transaction (sec)	12	29	6	5
"Dead time" per transaction (%)	55	55	20	24
Communication time per vessel (sec)	70	42	35	53
Percent vessel-initiated transactions	90	91	73	76

TABLE 3-2 : VOICE CHANNEL STATISTICS DERIVED FROM TABLE 3-1

LOCATION	VESSELS PER HOUR	(A) TRANSACTIONS PER HOUR	(B) COMMUNICATION TIME SEC/TRAN	(C) DEAD TIME SEC/TRAN	(D) CHANNEL TIME SEC/TRAN	(E) TOTAL SEC/HR	(F) FREE TIME PER HOUR	(G) MEAN TIME BETWEEN MSG. SEG. (SEC)
HOU-GAL	30	96	22	12	10	960	2640	14.
NOLA*	56	45/3=15	53	29	24	360	3240	108
PS	38	46	30	6	24	1104	2496	27
SF	8	20	21	5	16	320	3280	82

*three equally used channels

TABLE 3-3 : VOICE CHANNEL STATISTICS FOR HOU-GAL FROM TABLE 3-2, EXPANDED FOR GROWTHS OF 10%, 25%, 50% and 100%

CURRENT	30	96	22	12	10	960	2640	14
+10%	33	106	24	13	11	1166	2434	11
+25%	37.5	120	28	15	13	1560	2040	8.5
+50%	45	144	33	18	15	2160	1140	4
+100%	60	192	44	24	20	3840	----	0

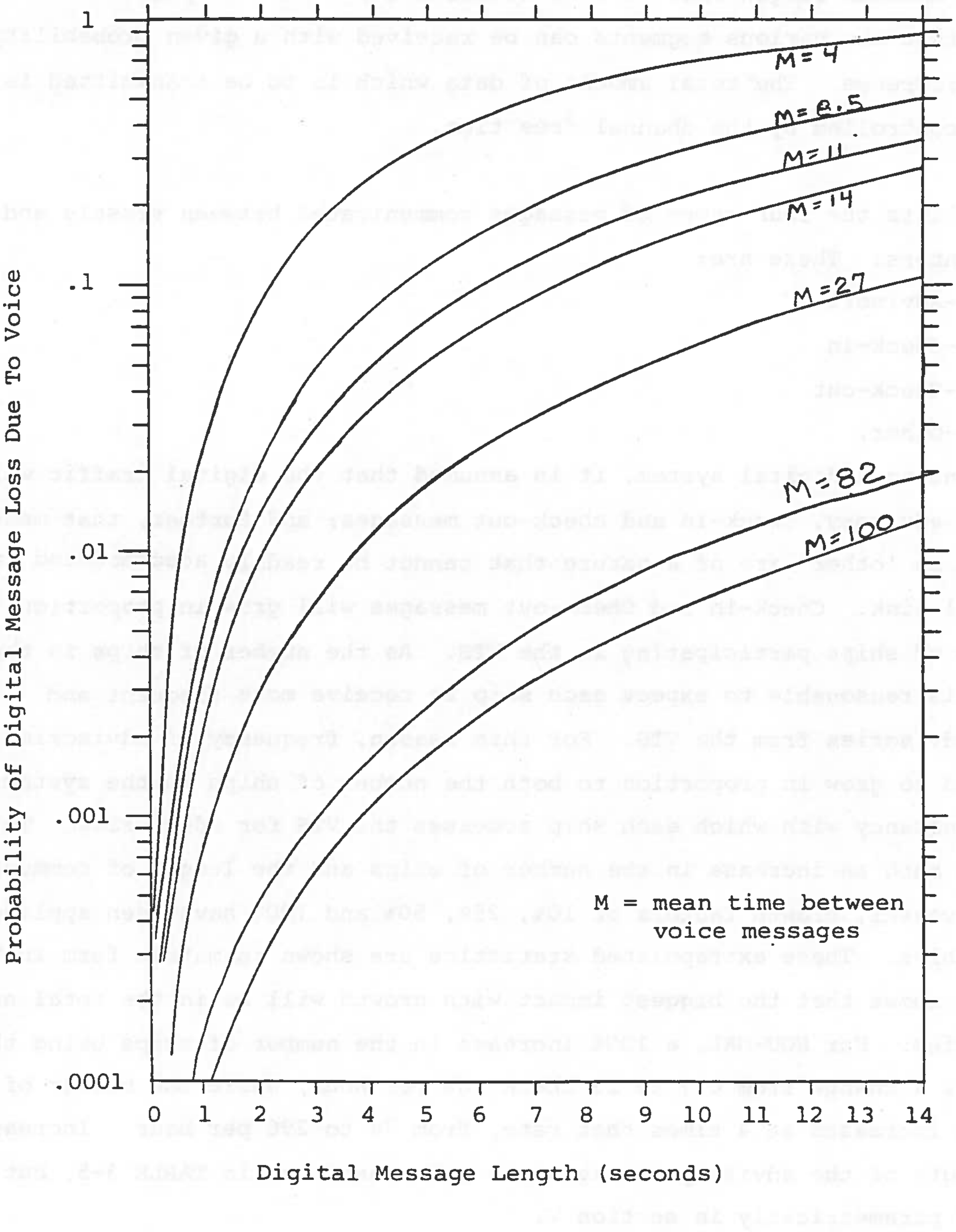

Figure 3-2 : PROBABILITY OF DIGITAL MESSAGE LOSS DUE TO VOICE VS DIGITAL MESSAGE LENGTH IN SECONDS

TABLE 3-4. CHARACTERISTICS OF TRANSACTION TYPES

TYPE	AVERAGE LENGTH OF TRANSACTION (SEC.)			
	HOU-GAL	NOLA	PS	SF
Advisories	20	56	34	21
Check-ins	76	88	27	25
Check-outs	21	24	17	23
Other	8	34	46	16
	FREQUENCY OF TRANSACTION TYPES (%)			
	HOU-GAL	NOLA	PS	SF
Advisories	77	58	33	15
Check-ins	5	13	37	42
Check-outs	7	9	18	7
Other	11	20	12	36

in both the New York and Prince William Sound VTS operating manuals (ref. A and B) were analyzed. These messages, along with the time required to read the message at a moderate rate and the elements which comprised the message are contained in TABLE 3-6. This table also contains typical "other" or special messages which are not easily accommodated as structured digital messages. The time required to read each message was measured to compare it to the mean time shown for Check-in, Check-out and advisory messages in TABLE 3-4. Although the times vary widely, the sample messages seem to be typical.

From the sample messages, five prototype digital messages have been constructed, three vessel messages and two VTS messages. The vessel messages are:

- -a check-in
- -a followup message
- -a check-out.

The VTS messages are:

- -request for status
- -general acknowledge message to acknowledge check-in, status request, and check-out messages.

In constructing these messages, it was necessary to assume a coding for each of the message elements. The tradeoff here is between minimizing message transmission time and transmitting data in a form which is easy for the vessel and the VTS to interpret. For example, referring to the check-in message shown in TABLE 3-7a, items such as the sync word, message type, the check sum, as well as the item separators are system control characters and may be specified without concern for the operator's ability to interpret them. The next level of characters are those which can be abbreviated through convention. For example, vessel type can be limited to several classes of vessel and abbreviated in a standard format. Similarly, status, cargo type, communication/navigation capability can be shortened by using agreed upon abbreviations. Items such as the vessel draft, length, time parameters, location parameters and waypoints are already compact, as they are provided according to a standard measurement system of either feet or, in the case of location parameters, Loran-C time difference numbers. The vessel ID is

TABLE 3-6b : INITIAL REPORT #2 TRANSACTION

Time to read: 40 seconds

SITUATION: A tug with tow is entering the VTS area from Whittier outbound for Seattle.

CALL UP: VALDEZ TRAFFIC, this is the American Tug, Over.

REPLY: American Tug, this is VALDEZ TRAFFIC, OVER.

MESSAGE: VALDEZ TRAFFIC, this is the towing vessel American Tug abeam Smith Island with one rail barge in tow. I will enter the TSS off Smith Island at 0900. My draft is 16 feet. Barge draft is 20 feet. Speed of advance is 7 knots, overall length of tow 600 feet. No hazardous materials on board. No other communications capability. Over.

REPLY ADVISORY: American Tug, VALDEZ TRAFFIC, Roger. There is no known traffic in that area at the present time. OVER.

REPLY: This is the American Tug, Roger, Out.

MESSAGE:	VALDEZ TRAFFIC	Call
	this is the towing vessel	Vessel type
	American Tug	Vessel ID
	abeam Smith Island	Location
	with one rail barge in tow	Tow load (tug only)
	I will enter the TSS of Smith Island	Waypoint #1
	at 0900	ETA waypoint #1
	My draft is 16 feet	Draft
	Barge draft is 20 feet	Barge draft (tug only)
	Speed of advance is 7 knots	Speed
	Overall length of tow, 600 ft.	Overall Length of tow (tug only)
	No hazardous materials on board	Cargo type
	No other communications capability, Over.	Communications Capability
REPLY ADVISORY:	American Tug,	Call
	VALDEZ TRAFFIC,	ID
	Roger.	Acknowledgement
	There is no known traffic in that area at the present time, OVER.	Advisory

TABLE 3-6d : FINAL REPORT TRANSACTION

Time to read: 23 seconds

SITUATION:	Vessel leaving the TSS
CALL UP:	VALDEZ TRAFFIC, this is the American Tug, Over.
REPLY:	American Tug, this is VALDEZ TRAFFIC, Over.
MESSAGE:	VALDEZ TRAFFIC, this is American Tug abeam Schooner Rock. I am leaving the TSS at the present time. I will cross the TSS in Hinchinbrook Entrance in 10 minutes and proceed southeasterly from Cape Hinchinbrook. Over.
REPLY:	American Tug, this is VALDEZ, Roger, Out.

- -

MESSAGE:	VALDEZ TRAFFIC,	Call
	this is American Tug	Vessel ID
	abeam Schooner Rock.	Location
	I am leaving the TSS at the present time.	ETA exit
	I will cross the TSS in Hinchinbrook Entrance	Waypoint, exit
	in 10 minutes	ETA waypoint, exit
	and proceed southeasterly from Cape Hinchinbrook. Over.	Waypoint #2

Time to read: 12 seconds

SITUATION :	Vessel anchoring in the VTS area
CALL UP:	VALDEZ TRAFFIC, this is the Kristen Anne, Over.
REPLY:	Kristen Anne, this is VALDEZ TRAFFIC, Over.
MESSAGE:	This is Kristen Anne. We have anchored in Tatitlek Narrows off Ellamar, Over.
REPLY:	This is VALDEZ TRAFFIC, Roger, Out.

- -

MESSAGE:	VALDEZ TRAFFIC	Call
	this is Kristen Anne.	Vessel ID
	We have anchored in Tatitlek Narrows off Ellamar. Over.	Status/Location

TABLE 3-7a : PROTOTYPE DIGITAL MESSAGE: CHECK-IN MESSAGE (AS)

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL ID (NAME)	31
VESSEL TYPE	4
DRAFT	3
LENGTH	4
LOCATION (4 Loran-C + DS at 7 digits each)	29
STATUS (underway, holding, docking, etc)	2
ESTIMATED STATUS CHANGE TIME (xxxx)	5
VELOCITY + DIRECTION	5
CARGO TYPE	4
Additional for Tug:	
Draft of Barge	3
Total Length	4
Number of Barges	2
COMMUNICATION/NAVIGATION CAPABILITY	3
WAYPOINT #1 (2 TDs @7 digits)	15
ETA WAYPOINT #1 (time)	5
WAYPOINT #2 (2 TDs @7 digits)	15
ETA WAYPOINT #2 (time)	5
CHECK SUM + EOT	4
	150 characters
Assuming ASCII code : 10 bits/character	x 10
	1500 bits

TABLE 3-7c : PROTOTYPE DIGITAL MESSAGE: Check-Out Message (CS)

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL NAME	31
STATUS (Leaving System)	2
CHECK SUM + EOT	4
	44 characters
Assuming ASCII code : 10 bits/character	x 10
	440 bits

TABLE 3-7e : PROTOTYPE DIGITAL MESSAGE : Acknowledge, Check-in, Status Request and Check-Out Messages; VTS to Vessel

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL NAME	31
ASSIGNED VESSEL ID	4
CHECK SUM + EOT	4
	46 characters
Assuming ASCII code : 10 bits/character	x 10
	460 bits

stimated time to change in status, current velocity including direction and two nticipated waypoints including the estimated time of arrival at those waypoints. rior to checking out of the VTS system, the vessel sends a vessel check-out essage. A check-out message, which includes the vessel's intent to check out f the system and the vessel's full alpha-numeric name, is shown in TABLE 3-6b.

he VTS-generated advisory and request for status message is shown in TABLE 3-7d. ith this message, the VTS transmits to the addressed vessel the identification, ype, location and expected time and 'passage' location of the addressed vessel ith other vessels in the area. The number of vessels included in each VTS dvisory report is variable and dependent upon the density of traffic in the rea as well as the display capability of the vessel receiving the message. ABLE 3-7d divides the VTS advisory message into two parts, the first is a minimal ength 18-character message returned when no vessel status information is issued. he second shows the number of characters for the number of vessel status contained n the message. Message lengths are shown for reports containing 1, 3, 10 and 0 vessels. The second message type transmitted from the VTS to the vessel is n acknowledgement message used primarily to acknowledge check-in, by assigning he vessel a temporary identification number, and for check-out. This message ay also be used as a NACK message, to indicate that a message from the dentified vessel was not successfully received by the VTS.

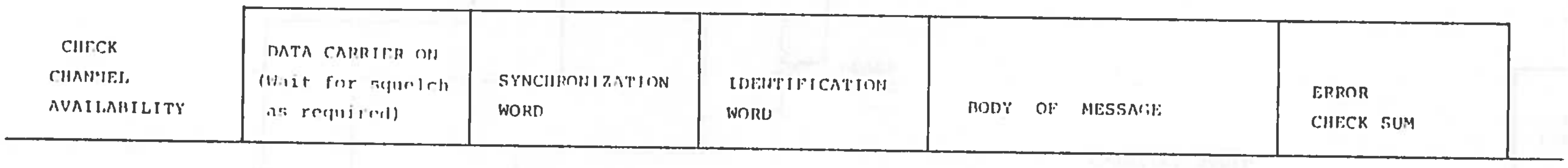

FIGURE 4-1 : PROTOTYPE MESSAGE TIME STRUCTURE rough an existing audio or microphone input jack. This is accomplished through e addition of link access circuitry in series with the microphone, which ntrols the link access, permitting either the data modem or the microphone to y the transmitter. The link access control also interfaces with the data/voice parator and squelch circuits which are located in series with the receiver audio tput. This circuitry assures that the data modulator will not attempt to ansmit data while other signals are present in the channel. Received data are tained from the audio output of the radio through circuitry which separates e voice and data tones. In the simplest case, the received data are simply pped in parallel with the loudspeaker audio. Such an adaptation would leave e receiver squelch operating in its normal mode, causing the loudspeaker to quieted when there was no received signal, and further, to operate when ther voice or data was being received. This approach has the advantage of t requiring modifications to the existing radio, and the disadvantage of troducing a long synchronization period due to the time required to break e receiver squelch. Reference R studied the squelch time constants of typical rine FM receivers, and concluded that response times ranging from .3 to 1.2 conds will be suffered when the squelch is operational, as shown in TABLE 4-1.

further modifications of an existing radio are undertaken, it is possible to rive the data signal prior to the squelch, eliminating the squelch delay d further, through detection of the data carrier it is possible to squelch the dspeaker when data are present.

haracterization of the narrow-band FM voice channel is shown in TABLE 4-2. suming that the channel is capable of providing acceptable voice communications, sufficient signal-to-noise ratio exists to provide high quality data transmission.* rate at which data may be transmitted through a voice channel is limited by channel's 0.3-3 kc audio bandwidth and the phase amplitude of the audio channel.

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*This report does not consider in detail the performance tradeoffs between various digital data modulation techniques. A review of techniques is included in references L and M

TABLE 4-2 : NARROW-BAND FM SYSTEM PARAMETERS

1. RF BANDWIDTH AUTHORIZED FOR F2 and F4 EMISSION (reference X, §83.132 and §83.133)	20 kHz
2. FREQUENCY TOLERANCE 5 x 10^{-6} * 1.5 * 108 (reference X, §83.132f)	±750 Hz
3. CARRIER DEVIATION (100% Modulation) (reference X, §83.137b)	±5 kHz
4. INPUT BANDWIDTH	
a. LOW PASS (ref X, §83.137h)	DC - ≈3 kHz
b. EIA	300 - 3000 Hz

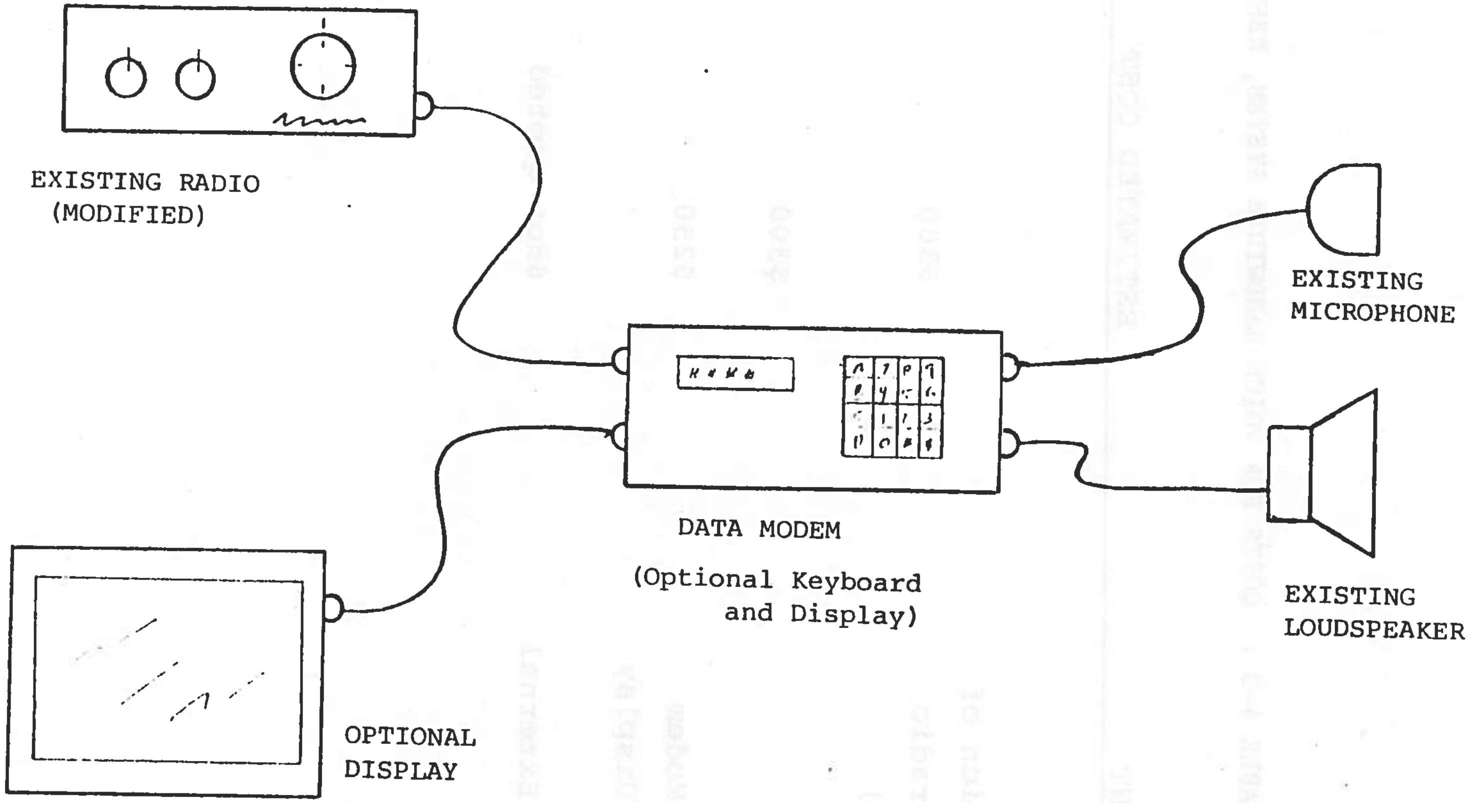

FIGURE 4-3 : NBFM VOICE CHANNEL SYSTEM ELEMENTS nstalling the required hardware. The required modification could be provided n new receivers at little or no cost. The modem costs are based on the current elling price for a similar modem available to the land radio mobile community. he input/output display is not estimated, as that estimate will reflect a wide ariation in cost as a function of desired capability.

.2 Wide-Band Modulation of Narrow-Band FM

ne second system approach considered is wide-band or direct modulation of a arrow-band FM transmitter and the detection of tones derived directly from ne discriminator. This permits the transmission of higher data rates, as the requencies are not restricted by a 3 kc voice filter. The system parameters ssumed for such a wide-band system are shown in TABLE 4-4. There is presently authorized operation of this type in the maritime band, therefore it is cessary to introduce constraints assuming that modulation techniques which d not interfere with adjacent FM channels would be acceptable. A block agram for the wide-band direct modulation system is shown in Figure 4-4. is system does not preclude the use of voice over the data channel, but does quire a more extensive modification of the existing FM radio. This is not en as a severe disadvantage, however, as it is felt that the major cost in difying an existing radio is connected with the logistics of performing e modification rather than the cost of the modification itself. A data rate 16k bits/second is assumed for the direct wide-band modulation technique. is data rate reflects actual data rates achieved over similar channels (ref.L) scaled from rates obtained in similar systems (ref.I). A suitable modulation uld be phase continuous FSK (MSK) signal, generated either through Manchester i-phase) coding or other techniques. A system similar to this is described reference G (a cellular mobile telephone system) and reference I (a high pacity microwave system). Phase continuous modulation is suggested, as it hibits minimal amplitude variation and a very well controlled and narrow nd spectrum. A block diagram showing the essential elements of a wide-band ta modulation system integrated with an existing FM radio is shown in Figure 4-5.

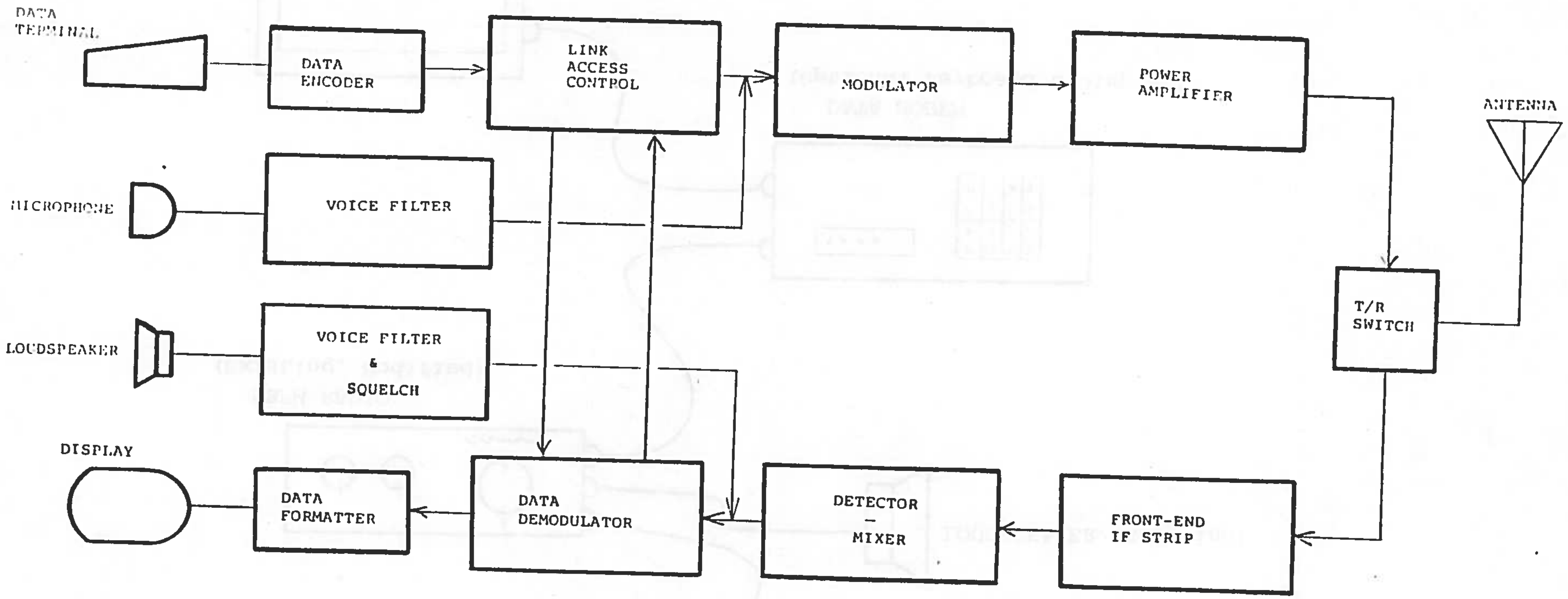

FIGURE 4-4 : BLOCK DIAGRAM OF WIDE-BANDWIDTH, NBFM DIRECT MODULATION SYSTEM

TABLE 4-5 : WIDE-BAND NBFM SYSTEM COSTS

ELEMENT	ESTIMATED COST
MODIFICATION OF EXISTING RADIO (see text)	\$350
MODEM	\$450
OPTIONAL MODEM KEYBOARD & DISPLAY	\$250
OPTIONAL EXTERNAL DISPLAY	\$not quoted

in the same channel, without significant interference. This technique permits many users to randomly access the same communication channel independent of each other with only a degradation of signal quality resulting as the numbers of users approaches the system's capacity. This technique is presently being considered for cellular mobile radio telephone systems (ref T). The system proposed in (ref T) would provide each user with a 32k bit/second channel by spreading each signal over the entire 20 MHz mobile radio telephone channel. Under these operating conditions, the system can accomodate on the order of 100-200 simultaneous users. This technique was rejected for the following reasons:

-For the system to work properly, it is necessary that the <u>received</u> signal from each user be nearly equal in intensity. In the referenced mobile radio system, the power of the transmitters is adjusted by the base station to provide this condition. Such power adjustments and equalization in a signal strength is relatively easy in the small cells assigned in mobile telephone systems, but difficult over the area covered by a single VTS.

-When the 20 MHz bandwidth allocated for the mobile radio system is scaled to 20 kHz available in a single VHF channel, the data rate is reduced to approximately 32 bits/second, which was felt to be unacceptable slow.

-Following the reasoning used for the direct modulation technique, again less than 10% of the channel capacity would be used.

-Simultaneous voice transmission would be difficult or impossible.

The use of a single sideband channel placed between two existing 25 kHz FM channels is a technique which offers the advantages of a data-only channel providing reasonable data rates with a minimal, if not negligible, effect on the existing FM voice traffic. The use of amplitude compandored, single sideband (ACSSB) has been explored as a way of expanding the number of channels available in the VHF and UHF mobile radio bands. This work is summarized in reference V. Because single sideband modulation directly translates voice and data channels up to the VHF band, a 5 kc voice channel only occupies a 5 kHz spectrum in the VHF band. Using this technique, it is possible to fit as many as five, 5 kc channels in the 25 kHz slot presently occupied by a single narrow-band FM channel.

Two figures of significance from reference V are reproduced as Figures 4-7 and 4-8. Figure 4-7 shows the relative spacing and spectrum occupation of NBFM channels with respect to single sideband channels. These channels are labeled as mid, edge and near channels to describe their relationship to the presently existing 25 kHz narrow-band FM channel. Figure 4-8 shows the effect of ACSSB on an adjacent FM channel. Specifically, this figure shows that an ACSSB channel placed between two narrow-band FM channels should cause less interference than two adjacent narrow-band FM signals.

Three technical problems which had to be considered prior to using single sideband for voice in the VHF band do not exist when data are transmitted. These are:

- -The control of both the clipping level and the level of the pilot tone sent along with the voice signal to prevent undue spectrum spreading by the non-linear final single sideband amplifier
- -The need to amplitude compress the signal to obtain an acceptable signal quality on 'weak' syllables
- -The need to transmit a pilot tone to provide automatic gain control in the face of variable audio amplitude and to provide frequency correction to eliminate the 'Donald Duck' effect from the received single sideband signals.

These problems are minimized or disappear if continuous phase data are transmitted. The transmission of continuous phase data (e.g. MSK) minimizes the spreading due to non-linearity of the final amplifier. Further, as only the frequency information is of concern, the received data are amplified to limiting, eliminating the need for automatic gain control, which, along with the ability to extract the reference carrier from the data, eliminates the need for a pilot tone.

The data rate of a single sideband channel is constrained by the final VHF signal bandwidth. If a single sideband technique is selected, the bandwidth and spacing of the proposed channels should be aligned with the proposed specifications for ACSSB for voice so that future expansions from narrow-band FM to ACSSB may be accomplished with a minimum conflict. Assuming the

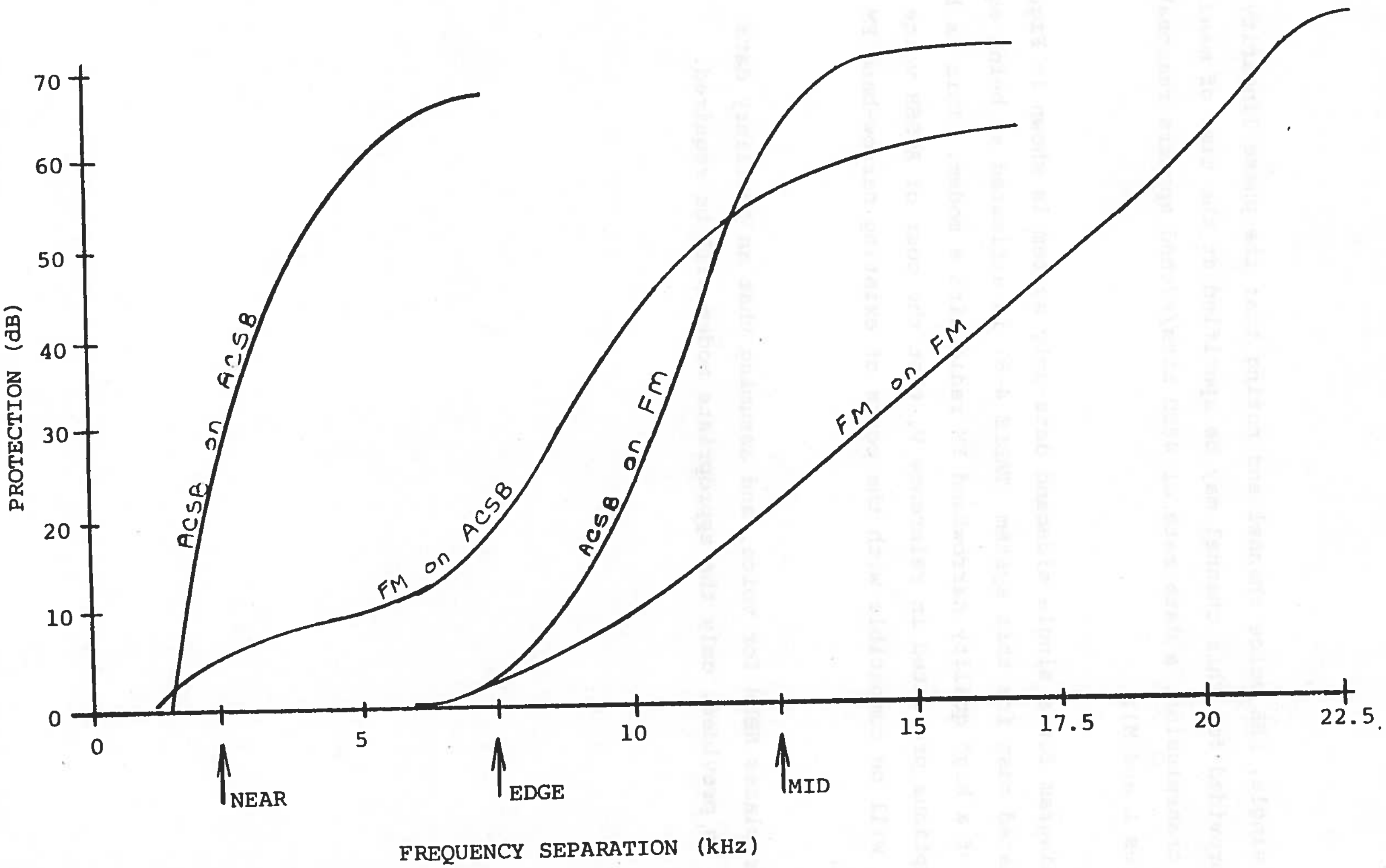

FIGURE 4-8 : PROTECTION RATIO vs FREQUENCY SEPARATION FOR NBFM & ACSB RADIOS

(After Figure 6, reference V)

TABLE 4-6. SSB DATA SYSTEM COSTS

ELEMENT	ESTIMATED COST
SSB Transmitter & Receiver	$1,500 - $3,000
MODEM	$300
Optional Modem Keyboard and Display	$250
Optional External Display	$not quoted

5. ANALYSIS OF CAPACITY

The capacities of the three VTS data systems described in section 4 are analyzed in this section. This analysis is based on:

- Channel usage statistics presented in section 2.
- Messages proposed in section 3.
- Data rates stated in section 4.

For each system, the time necessary to transmit a message of n bits is shown in TABLE 5-1. The main difference between the two first entries is the assumption concerning the system squelch. If the squelch is used, approximately 1.2 seconds must be added to each data transmission to allow for the squelch break time. The random delay shown allows for the introduction of a random wait time between the detection of a clear channel and the start of the transmission. This time helps break up races for the channel when several users are cued up waiting to transmit data. Modem synchronization time allows for several cycles of the data carrier to provide synchronization between the data transmitting clock and the receiver clock. The message duration is directly proportional to the number of bits transmitted and the reciprocal of the assumed data rate. The data rates for each channel type are listed in terms of characters/second, assuming 10 bits per character. Using the formulas of TABLE 5-1, the time necessary to transmit each of the data messages described in TABLES 3-7a through 3-7e are listed in TABLE 5-2.

The most frequently sent message and the one with most variability in the time required to send it is the VTS-to-vessel advisory update. The length of this message is proportional to the number of vessel advisories being issued. The time required to send advisories including 1, 3, 10 and 30 vessels are listed. The actual number of vessel advisories required (or desired) is an operational consideration and is not addressed in this report. When data message lengths are in excess of approximately 1-2 seconds, it may be difficult to send the data as one single message in a channel which also includes voice (see section 3). In these cases, it will be necessary to issue several shorter advisory messages in lieu of a single lengthy message.

AND DATA TRANSMISSION CHANNEL TYPE

	CHARACTERS IN MESSAGE (Table 3-7)	Duration of Message Element (seconds)			
		NBFM Data + Voice (Noise Squelch)	NBFM Data Only	WIDE-BAND Data	SSB
Vessel-to-VTS Initial Contact	150	1.836	0.633	0.101	0.319
VTS-to-Vessel Acknowledgement	46	1.402	0.199	0.036	0.103
VTS-to-Vessel Position Request	46	1.402	0.199	0.036	0.103
Vessel-to-VTS Position Update	90	1.585	0.382	0.063	0.194
VTS-to-Vessel Situation Update	18	1.285	0.082	0.018	0.044
PLUS : 1 Vessel	73	0.304	0.304	0.046	0.152
3 Vessels	219	0.913	0.913	0.137	0.456
10 Vessels	730	3.044	3.044	0.456	1.521
30 Vessels	2190	9.132	9.132	1.369	4.562
Vessel-to-VTS System Departure Message	44	1.393	0.190	0.035	0.099
VTS-to-Vessel Departure Acknowledgement	46	1.402	0.199	0.036	0.103

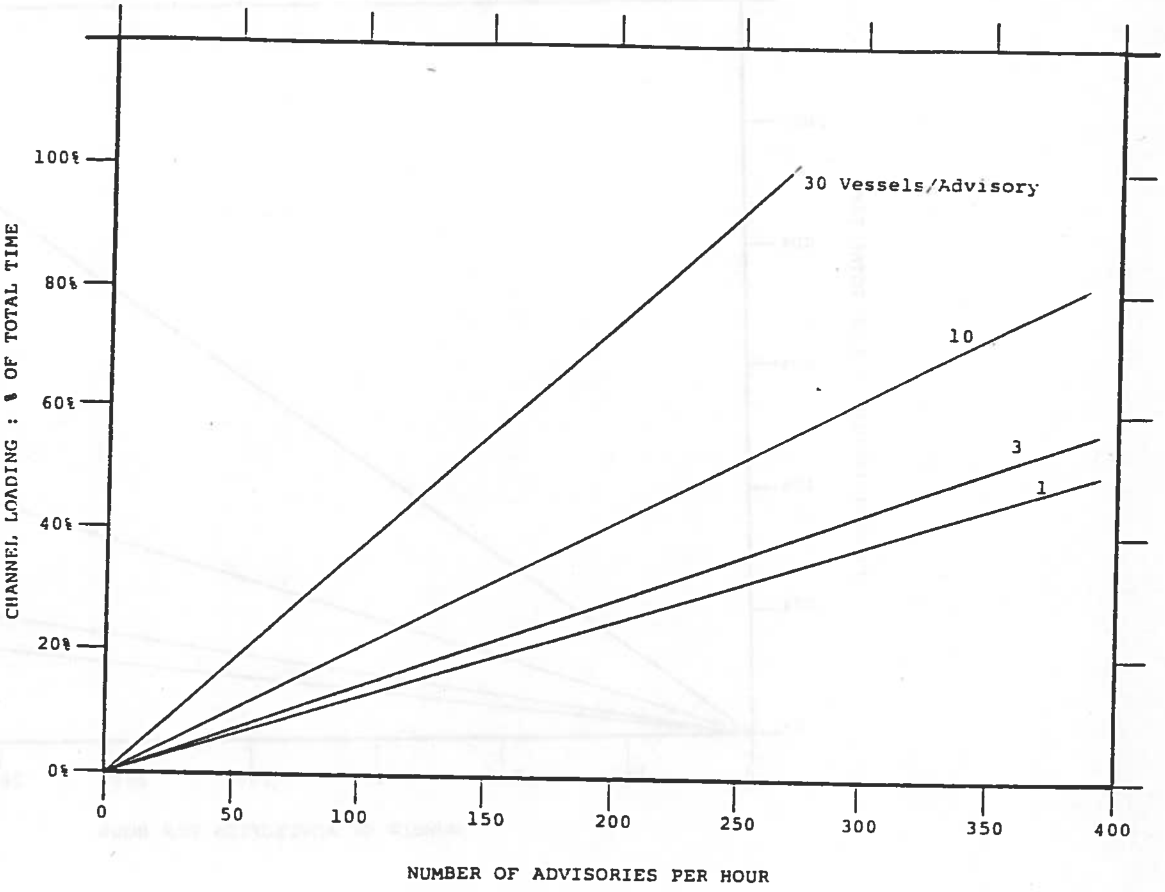

FIGURE 5-1 : NBFM, 2400 B/S DATA WITH SQUELCH
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

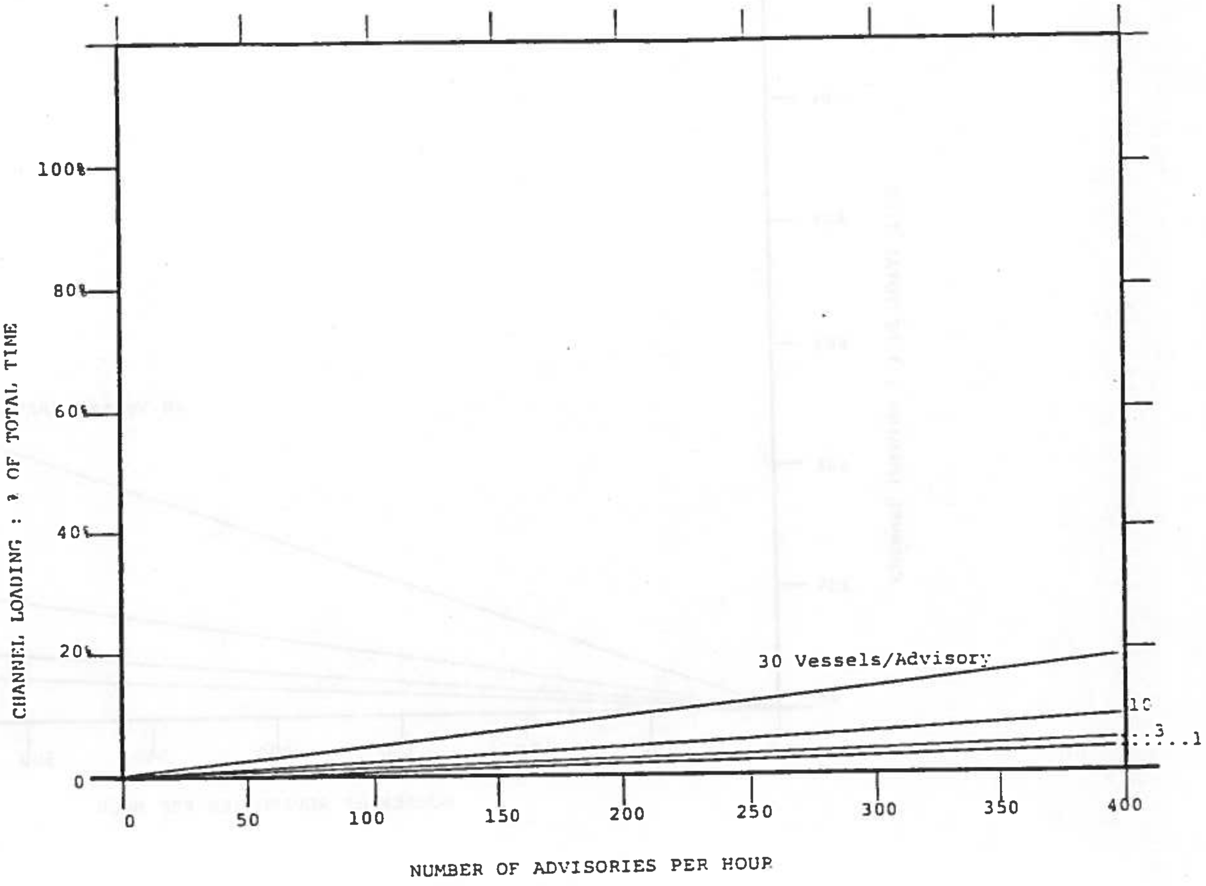

FIGURE 5-3 : WIDE-BAND NBFM, 16k B/S,
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

6. SUMMARY

Based on the data presented in this report, the following conclusions are stated:

(1) An NBFM voice plus data system which retains the use of the standard receiver squelch should be rejected in favor of adding a data-operated squelch. While this requires further modification of the existing radio, the differential cost is small for the data capacity gained.

(2) The length of the data messages can be reduced by approximately 40% if a modified ASCII code is employed. In doing this or in considering a more compact, specialized code, the advantages of maintaining a standard communication interface should be borne in mind (e.g. international use).

(3) The use of single sideband modulation is to be preferred if a data-only channel is desired, as this technology holds the promise of adding the required data channel without requiring any additional spectrum.

(4) When considered from the point of view of the overall balance between equipment costs, spectrum usage and channel effeciency, the wide-band modulation of digital data on an existing NBFM transmitter appears to be optimal.

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(P) Communications Requirements for a Loran-C Position Monitoring System for VTS Valdez, Alaska, T.M. Drown, U.S. DOT, Coast Guard Report CG-D-36-80, June 1980.

(Q) Communications Analysis for Poled Loran-C Transmission System, P.D. Engels C.J. Murphy, et.al., Project Memorandum, U.S. DOT, RASP, Report No. DOT-TSC-531:CG-09-PM-80/09.

(R) Minimum Transmit Time of VHF FM Channel 16, P.D. Engels, memorandum DOT-TSC-DTS-531 , April 14, 1978.

(S) IEEE Journal of Ocean Engineering, July 1977, Vol OE-2#3 (Joint Special Issue on Maritime Communications).

(T) Frequency-Hopped Multi-Level FSK for Mobile Radio, D.J. Goodman et.al., Bell System Technical Journal, Vol 59 #7, September 1980, page 1257.

(U) Pulse Transmission by AM, FM, and PM in the Presence of Phase Distortion, E.D.Sunde, Bell System Technical Journal, Vol XL #2, March 1961, page 353.

(V) The Use of Amplitude Compandored SSB in the Mobile Radio Bands; final report, Bruce Lusignan, Technical Report No. 29, Communications Satellite Planning Center, Stanford University, Stanford, California (FCC Contract FCCPO-0245) July 1980.

(W) Federal Communications Commission RULES AND REGULATIONS
Vol II, August 1976.
    Part 2: Frequency Allocations and Radio Treaty Matters
            General Rules and Regulations
    Part 5: Experimental Radio Services (other than broadcast)
    Part 15:Radio Frequency Devices
    Part 18:Industrial, Scientific, and Medical Equipment.

(X) Federal Communications Commission RULES AND REGULATIONS
Vol IV, March 1977
    Part 81: Stations on Land in the Maritime Services and Alaska-
             Public Fixed Stations
    Part 83: Stations on Shipboard in the Maritime Services

(Y) Federal Communications Commission RULES AND REGULATIONS
Vol VII, March 1974
    Part 21: Domestic Public Radio Services (other than maritime mobile)
    Part 23: International Fixed Public Radiocommunications Services
    Part 25: Satellite Communications

(Z) Polled Loran-C Display System (PLDS) Demonstration at VTS Valdez, Alaska, T.M. Drown, U.S. DOT Coast Guard Report CG-D-48-80, July 1980.

APPENDIX - REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new invention, has determined communication channels and modulation techniques available for future expansion of vessel position monitoring. Frequency allocations, applicable modulation techniques and the impact of change from voice only to voice/data and data-only communications were considered in determining alternative technological approaches to future system requirements.