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Test Results for Developing Revised LORAN-C Protection Criteria

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Transportation Systems Center
Cambridge MA 02142

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Final Report

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Abstract

This report presents the results obtained from a series of tests and related analyses studying the effect of harmful RF interference on LORAN-C receivers. The effects of interference in the 70 to 130 kHz band on typical LORAN-C receivers were assessed. Recommendations were developed for signal-to-interference ratios and protection boundaries that would permit proper receiver operation during conditions of interference.

Key Words

Radionavigation, RF Interference, LORAN-C, CCIR, ITU, International Radio Consultative Committee, International Telecommunication Union

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PREFACE

This report presents the results obtained from a series of tests and related analyses detailing the effect on LORAN-C receivers of unwanted interference similar to that which can be created by radio communications and radionavigation facilities operating within the 70 kHz to 130 kHz frequency band.

While LORAN-C transmitters are required to transmit a minimum of 99 percent of their radiated power within the band 90 to 110 kHz, LORAN-C receiver bandwidths must be greater than this amount in order for the receiver to effectively operate. Thus, the receivers should be regarded as vulnerable throughout the broader frequency band 70 to 130 kHz.

The results of this activity are to be utilized by the U.S. Coast Guard in preparing a set of recommendations to be presented to the International Radio Consultative Committee of the International Telecommunications Union in support of the U.S. Government's request for protection of the LORAN-C radionavigation system.

The principal data gathering effort was accomplished by the USCG Electronics Engineering Center (EECEN) in accordance with a Test Plan prepared by the U.S. DOT/Transportation Systems Center.

Personnel from the Transportation Systems Center, Cambridge Engineering, Polhemus Associates, Inc., and the USCG EECEN were participants in the project. Subsequent analyses and preparation of the report were the responsibilities of the Transportation Systems Center and the cited Contractors. Special thanks is expressed to M.C. Poppe of Cambridge Engineering, W.L. Polhemus of Polhemus Associates, Inc., and Lt. David Beard of the USCG EECEN for their outstanding contributions to this project.

The project was sponsored by DOT/U.S. Coast Guard, Radionavigation Division, G-NRN.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. INTRODUCTION

This report describes the results obtained from a series of tests conducted by the U.S. Coast Guard and the Department of Transportation (DOT) Transportation Systems Center (TSC) contractor personnel at the USCG Electronics Engineering Center in Wildwood, N.J., in accordance with instructions contained in DOT/TSC, "Test Plan to Develop Revised LORAN-C Protection Criteria".

The purpose of the tests was to subject five typical LORAN-C receivers to harmful radio communications interference. The conclusions derived from this effort have been utilized by DOT/TSC and the USCG to support the U.S. Government's request for protection of the LORAN-C radio frequency (RF) band 70 to 130 kHz.

Between frequencies 70 kHz and 130 kHz, a number of different radiocommunications and radionavigation services worldwide have been approved for transmission on specific frequencies by the International Telecommunications Union (ITU). When these signals overlap with sufficient intensity, they produce harmful interference affecting these services.

The International Radio Consultative Committee (CCIR) of the ITU has responsibility for formulating recommendations on an international level regarding use of the radio communications and radionavigation frequency spectrum. Because of the adverse consequences of some types of RF interference on radionavigation systems, particularly the Decca Navigator system and the LORAN-C radionavigation service, the CCIR solicited technical advice from the advocates of the Decca system and from the U.S. Coast Guard regarding the LORAN- C system.

It is necessary to recognize that safety considerations relevant to performance of the LORAN-C radionavigation service (and also the Decca system) make it essential that they be able to operate free from harmful interference.

While LORAN-C transmitters are required to transmit a minimum of 99 percent of their radiated power within the band 90 kHz to 110 kHz, LORAN-C receivers require bandwidths greater than 20 kHz in order for the receiver to be effective.

The problem of providing suitable protection to the LORAN-C and Decca Navigator systems has been under study by the International Telecommunications Union (ITU). During its 15th Plenary Assembly (Geneva, 1982) the CCIR concluded in Report 915[1] that for planning purposes, when acceptance of a new transmitting signal is considered within the 70 kHz - 130 kHz band, the Decca Navigator system should be protected by assuring a nominal relative signal-to-interference buffer or ratio between the system and the new transmission of + 15 dB. An additional allowance of + 6 dB was allocated to protect the Decca system from skywave interference at night. The criteria were developed from data obtained in laboratory testing.

2. BACKGROUND

2.1 GENERAL

LORAN-C receiver performance is susceptible to two general types of radio frequency interference:

- Those of an amplitude form which modulate the LORAN-C signal envelope or mask the desired zero crossing (tracking) point due to the signal strength of the interfering RF transmission;
- Those which are synchronous or near-synchronous, in the time domain, with the spectral lines associated with the LORAN-C pulse rate in use.

Because the ITU authorizes several radionavigation, fixed, and maritime mobile services in the bands between 70 kHz and 130 kHz; and because these radionavigation systems may be either pulse or continuous wave (CW); and because typical LORAN-C receiver systems must be capable of acquiring and subsequently tracking relatively weak transmissions, it was necessary that the interference tests be capable of measuring receiver performance under varying but known and controlled conditions of relative signal-to-interference field strength and interfering frequency.

2.2 TYPES OF INTERFERENCE

The recognized reference for defining LORAN-C signal characteristics, required receiver performance, types of interference and their potential effects is the RTCM SC-70 publication, Minimum Performance Standards (MPS) for Marine LORAN-C Receiving Equipment[2] as described in RTCM Paper 12-78/DO-100.* There are three categories of interference and three types of emissions of concern to LORAN-C receivers discussed therein and reviewed below.

2.2.1 Synchronous Interference

Synchronous transmissions are those which produce spectral lines which are in phase with those of the LORAN-C pulse pattern. They cause a constant error in the measured LORAN-C time difference (TD) and thus in radionavigation accuracy.

2.2.2 Near-Synchronous Interference

Near-synchronous transmissions, while not in phase with the LORAN-C pulse pattern, are those whose spectral lines fall within the bandwidth of the servo tracking loop of the receiver.

Note: Synchronous/near-synchronous interfering signals cause increases in the mean time difference error (MTDE) of the receiver through their effect on the signal phase tracking circuits.

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* A separate MPS is being prepared for avionics receivers by the Radio Technical Commision for Aeronautics. When completed, separate tests may be appropriate for avionics LORAN-C receivers.

3. TECHNICAL APPROACH

3.1 GENERAL

Facilities at the USCG's Electronics Engineering Center (EECEN) were utilized for the tests since they offered the capability to simulate unwanted RF interference, the specified LORAN-C signals and the environmental conditions of interest.

3.2 FACILITIES AND EQUIPMENT

3.2.1 Navigation System Simulator

The simulator complex, which employs the LORAN-C Receiver Test Complex (LRTC II)[3] as its primary instrument, also includes:

- Rockland Remotely Programmable Frequency Synthesizer, Model 110 narrowband CW generator
- Hewlett-Packard Automatic Synthesizer, Model 33038 wideband, multi-channel, FSK emulator
- Wavetek HF Sweep Generator - narrowband FSK emulator.

The LRTC II is a second generation (Coast Guard designed) receiver test facility located in a dedicated facility within the EECEN. The simulator provides repeatable (and fully documented) signal conditions for measuring the performance of LORAN-C (and LORAN-D) receivers. It features high accuracy and resolution and provides means for complete control of the LORAN pulse. In addition, it offers a full complement of interference sources, including a simulated atmospheric noise source. The system is buss oriented with all parameters controllable from a central location.

3.2.2 LRTC II Setup

The LRTC II was set up as follows (see Figure 3-1):

Control Parameter	Setting
• Group Repetition Interval (GRI)	9960
• Stations	M,W,X,Y,Z (M is the master station) (W,X,Y,Z are secondary stations) (W is used to evaluate performance)
• Signal Strength	M-70, W-40 (Referenced to dB/1 microvolt/meter)
• Atmospheric Noise	50 dB/1 microvolt/meter (1/3 SNR for 9960-W)
• Gaussian Noise	OFF (except as noted in Section 4)
• Skywave Interference	OFF
• Envelope-to-cycle differences	M 1.0µs; W,X,Y,Z -1.5µs
• Cross-rate Interference	OFF
• RF Interference	As necessary to determine receiver error.

(1) Relative field strength or Signal-to-Interference Ratio (SIR) - varied within the range +30 dB to -50 dB.

(2) Kinds of Interference - LRTC II adjusted to simulate near-synchronous and non-synchronous interference in accordance with the Test Plan.

(3) Types of Emissions - LRTC II inputs varied to produce CWI, narrowband and wideband FSK in accordance with the Test Plan.

- Specific Interferences:
  - CWI, near-synchronous to be set within 0.006 Hz of the LORAN spectral line; e.g., within the servo bandwidth of the receivers.
  - Frequency Shift Keying, (FI) (narrowband); set up a single channel with 170 Hz shift, one tone to be near-synchronous.
  - Multiple-Channel Frequency Shift Keying, (F9); set up utilizing 11 channels, 3 kHz total bandwidth.

3.2.3 State-of-the-art LORAN-C Receivers

Five LORAN-C receivers were provided to the USCG by TSC: three marine and two airborne radionavigation (RNAV) systems. The receivers were of hard limited design and were selected because they were typical of those available in the marketplace. The three marine receivers represented the high, medium, and low ends of the market while the two airborne receivers represented the medium and low end of their respective market. Thus, their response to the RFI tests were representative of the manner in which most state-of-the-art receivers would behave under similar circumstances.

3.3.3 Test Criteria

The principal criteria of testing were:

1) verification of the characteristics of receiver tracking bandwidths of less than 0.01 Hz for marine receivers and 0.1 Hz for airborne receivers;
2) determination of the combinations of emitter frequency and relative signal strength at which the LORAN-C test receiver accuracy degraded to 0.3 microsecond.

The 0.3 microsecond time difference error is that which is allowed in the RTCM Minimum Performance Standards,[2] the U.S. standard for measuring performance of LORAN-C receivers.

3.3.4 Test Procedures

3.3.4.1 Receiver Biases. All identified receiver biases, determined before introduction of any interference, were tagged and eliminated from the data before assessing TD error performance. The Test Plan required that the receiver undergoing test be held at the correct tracking point, i.e., nominal 0.0 microsecond TD error.

3.3.4.2 Tracking Bandwidth. The tracking bandwidth of each receiver was established in accordance with the procedures outlined in the Coast Guard's standard "Five Day Test Plan". The objective of this test was to confirm that the 'typical' receiver servo bandwidth was less than 0.01 Hz for marine receivers and 0.1 Hz for airborne units.

3.3.4.3 Independence of Measurements. All observations and measurements taken during the nterference tests were controlled and or timed to be statistically independent (95 percent confidence).

3.3.4.4 Validation Tests. The TSC team returned to EECEN following assessment of the data gathered during the principal signal-to-interference ratio tests for the purpose of conducting a series of test validation measurements. These tests included a limited sample of receiver acquisition tests as well as a repetition of selected sets of SIR tracking measurements. Gaussian and atmospheric noise sources were employed. Correlation of required signal to noise levels with selected noise sources was made.

3.3.4.5 Retention of Data. All test instrumentation set-ups and tests were documented so that they could be repeated at a later date as required. All raw data acquired during the test program and related project notebooks will be retained for a period of 5 years. This will insure that supportive data is available throughout the next CCIR 4-year cycle.

3.5 FREQUENCY ASSIGNMENT

3.5.1 Nominal Assignment

Frequency assignments for the signal to interference tests were spread throughout the 70 to 130 kHz band. Ten frequencies were evaluated for CW and wideband FSK interference. Evaluation of only five frequencies for narrowband FSK were made since performance patterns became obvious after conducting the CW and wideband FSK tests.

The nominal frequencies of the interferences selected were:

a. 72 kHz
b. 78 kHz
c. 84 kHz
d. 90 kHz
e. 96 kHz
f. 101 kHz
g. 107 kHz
h. 113 kHz
i. 119 kHz
j. 125 kHz

3.5.2 Specific Frequency Assignment

The specific frequencies selected are shown in Table 3-1 and were derived as follows:

a. For near-synchronous types of interference, the specific frequency was selected from: $f_I = f_s + 0.006$ Hz, where f_s was the closest spectral line to the nominal frequency.

b. For non-synchronous types of interference, the specific frequency was identified from: $f_I = f_s + 1/2$ spectral spacing.

c. Frequency Calculations: Since Loran is a pulse modulated transmission, it has discrete spectral lines. The spectral line spacing is inversely proportional to the pulse rate or Phase Code Interval (PCI):

$$f_{sp} = \frac{1}{PCI} \text{ or } \frac{1}{2\,GRI} \qquad (1)$$

where: f_{sp} = spectral line spacing
PCI = Phase Code Interval
GRI = Group Repetition Interval

for: GRI = 99600 microseconds

$$f_{sp} = \frac{1}{2\,(99600\ \mu s)} \qquad (2)$$

$$f_{sp} = 5.0201\ Hz \qquad (3)$$

This effect was avoided by the choice of out-of-phase frequency selection, partly because of an amplitude difference between master and secondary, and partly because selection of interference frequency was restricted to an out-of-phase criterion.

That is:

$$\frac{n+1/2}{f_i} = TD \qquad (5)$$

where: f_i = interference frequency
n = an integer
TD = time difference

or:

$$TD\,(f_i) = n + 1/2 \qquad (6)$$

d. Modulation Calculations - A Frequency Shift Keyed (FSK) or F1 signal was also used in the tests. A binary FSK waveform with a continuous phase and constant envelope was used. The general expression for the waveform is:

$$Z(t) = A\cos(2\pi f_c t + 2\pi f_d(D(t)) + \theta) \qquad (7)$$

where: $D(t)$ = a random binary waveform with levels + 1 when $b_k = 1$ and -1 when $b_k = 0$
f_c = carrier frequency
f_d = frequency deviation
b_k = bit stream, 0's or 1's

The instantaneous frequency, f_j, is:

$$f_j = f_c + f_d(D(t)), \text{ or} \qquad (8)$$

$$= f_c + f_d \text{ for } D(t) = 1, \text{ or } bk = 1; \text{ or} \qquad (9)$$

$$= f_c - f_d \text{ for } D(t) = -1, \text{ or } bk = 0 \qquad (10)$$

For the tests,

f_d = 85 Hz
b_k = alternating 1's and 0's (squarewave), simulating a 100 baud data rate, 10 ms per bit.

For a large frequency shift compared to the data rate, major peaks in the power spectral density curve occur at the frequencies, $f_c + f_d$ and $f_c - f_d$. Impulses corresponding to the discrete frequency sinusoid components are not present because:

4. OBSERVATIONS

4.1 GENERAL

On-site review of the EECEN data and data-taking procedures, undertaken as directed in the Test Plan, revealed several unexpected observations:

1) Remarkably robust performance of marine receiver M_2 in the presence of near-synchronous continuous wave interference (CWI).
2) A high degree of sensitivity to CWI exhibited by marine receiver M_1, in light of the more typical performance measured when it was subjected to other types of interference.
3) A relative decrease in the sensitivity exhibited by several receivers to interference at 113 kHz.

In all cases a detailed review of the EECEN data, and a verification of the data through spot measurements, has shown the EECEN data-taking process to be sound.

4.2 RECEIVER TRACKING BANDWIDTHS

The tracking bandwidths of the test receivers were estimated from measurements of the receiver servo loop constants. The response time of each receiver to a step change in phase is shown in Table 4-1. Using the approximation f = (1/2 T), the bandwidths range from 0.07 Hz for the airborne receivers, to 0.01 Hz for the marine receivers.[4] These bandwidths are in agreement with the range of bandwidths assumed in the Test Plan, and validate the selection of frequencies 0.006 Hz from the synchronous lines as "near-synchronous".

TABLE 4-1. SERVO LOOP TIME CONSTANT

Receiver	Time Constant	Overshoot Average	Maximum Overshoot
A_1	2.4 seconds	14.0 seconds	0.3 seconds
A_2	2.2 seconds	8.0 seconds	0.2 seconds
M_1	4.0 seconds	0.2 seconds	0.1 seconds
M_2	12.0 seconds	0.0 seconds	0.0 seconds
M_3	7.0 seconds	5.6 seconds	0.1 seconds

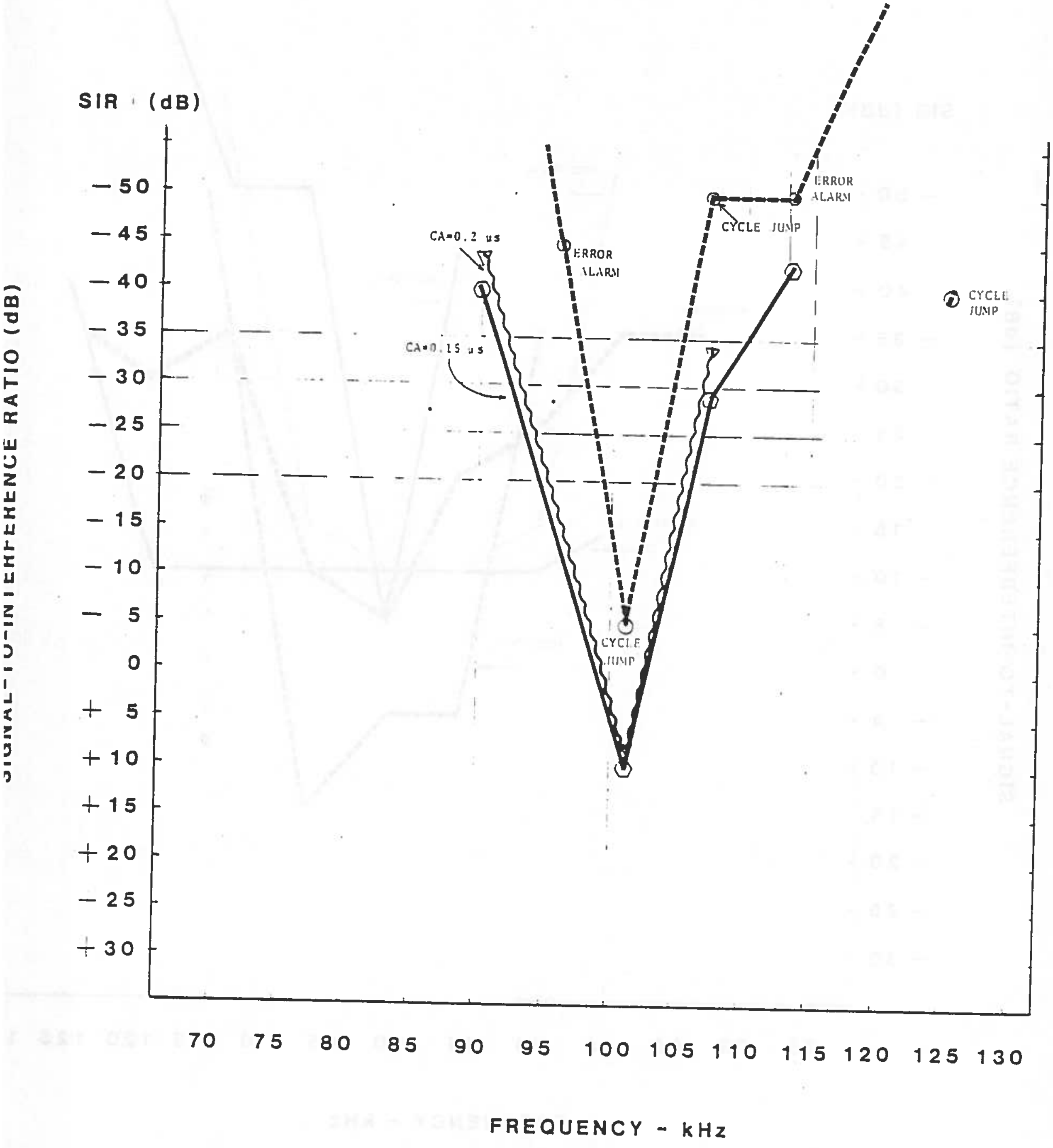

FIGURE 4-1. RECEIVER M_2 RESPONSE TO NEAR-SYNCHRONOUS CWI

In an attempt to understand the frequency sensitivity of the measured receiver performance, the frequency was readjusted to a near-synchronous frequency of approximately 97 kHz. At this frequency the sensitivity of the receiver to interference was typical of other receivers.

Next, the frequency was adjusted to a near-synchronous frequency of approximately 96.5 kHz. Again, typical performance was observed. Upon returning to the original 96 kHz near-synchronous frequency, the original measurement could not be repeated, and the measured effect of interference was observed to be typical of other receivers tested. Further, it was no longer possible to repeat the original 96 kHz measurement.

In a further attempt to understand the receiver's performance, the skywave interference measurement data obtained during the Coast Guard's "5-day receiver test" was examined. These data showed a very large affect from simulated skywave interference, the time difference being shifted as much as 0.82 microseconds. This performance is indicative of narrow RF bandwidth on the part of the receiver. Time constraints prevented further investigation of receiver M_2 behavior.

4.3.2 Critique of Marine Receiver M_1 Performance

The EECEN data for receiver M_1 showed a very high sensitivity to near-synchronous CWI (Figure 4-3). To verify the original EECEN measurement, several points were spot checked. These checks validated the original data.

4.3.3 Decreased Sensitivity at 113 kHz

The DOT/TSC Test Plan required that all fixed, manually-tuned and automatic notch filters be removed from the 70 kHz - 130 kHz band.* During the validation test series, it was determined that notch filters remained operational in several receivers during both the original EECEN tests and the later TSC validation tests.

Receiver A_1 was equipped with four fixed and four automatic notches. The four automatic notches were disabled using a procedure provided by the manufacturer. Subsequent discussions with the manufacturer indicated that the notch disabling procedure resulted in movement of two of the notches to positions at 50 kHz and two to positions at 114 kHz. Contrary to plan, the four fixed notches were not disabled; these had been adjusted at the factory to 88.0, 113.0, 87.3 and 123.0 kHz.

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*Receivers were ordered with these stipulations. Initial data analysis indicated decreased sensitivity to interference at 113 kHz for several receivers and this was verified during the validation tests.

The notches at 113 and 114 kHz appear to have had an effect on data taken at 113 kHz, see Figure 4-4 and Table 4-2. The effect of the notches at 113 and 114 kHz are evident in the three curves for CWI and NB FSK in the region of SIR -10 dB to -25 dB versus frequency 110 kHz. Comparing points for these three curves at 110 kHz with points at 90 kHz the following differences are shown in Table 4-3:

TABLE 4-2. COMPARISON OF LIMITING SIRS - RECEIVER A_1

	Frequency kHz					
	85	90	95	105	110	115
Near-synchronous CWI	-45 dB	-15 dB	-12 dB	-13 dB	-36 dB	-55 dB
Non-synchronous CWI	-50 dB	-21 dB	-12 dB	-10 dB	-34 dB	-55 dB
NB FSK	-12 dB	- 5 dB	- 3 dB	- 8 dB	-20 dB	-25 dB
WB FSK	-14 dB	- 5 dB	- 2 dB	- 3 dB	- 5 dB	-10dB

TABLE 4-3. COMPARISON OF RELATIVE SIRS - RECEIVER A_1

	Δ SIR 110 versus 90 kHz	Δ SIR 115 versus 85 kHz
Near-synchronous CWI	21 dB	10 dB
Non-synchronous CWI	13 dB	5 dB
NB FSK	15 dB	13 dB
WB FSK	± 0 dB	-4 dB

Airborne receiver A_2 was equipped with nine notches. These had been factory set to 73.6, 77, 88, 113.2, 115.3, 119.85, 124, 128.25 and 134.9 kHz. As with receiver A_1, the notch at 113.2 kHz appears to have affected the data taken at 113 kHz.

Marine receiver M_2 was equipped with four automatic and several optional fixed notch filters. During the EECEN tests, the automatic notches were disabled. Two fixed notches, tuned to 88 and 113 kHz, were present. Again, the 113 kHz data were affected, although to a much lesser extent and then only the NB FSK data disclosed a meaningful displacement.

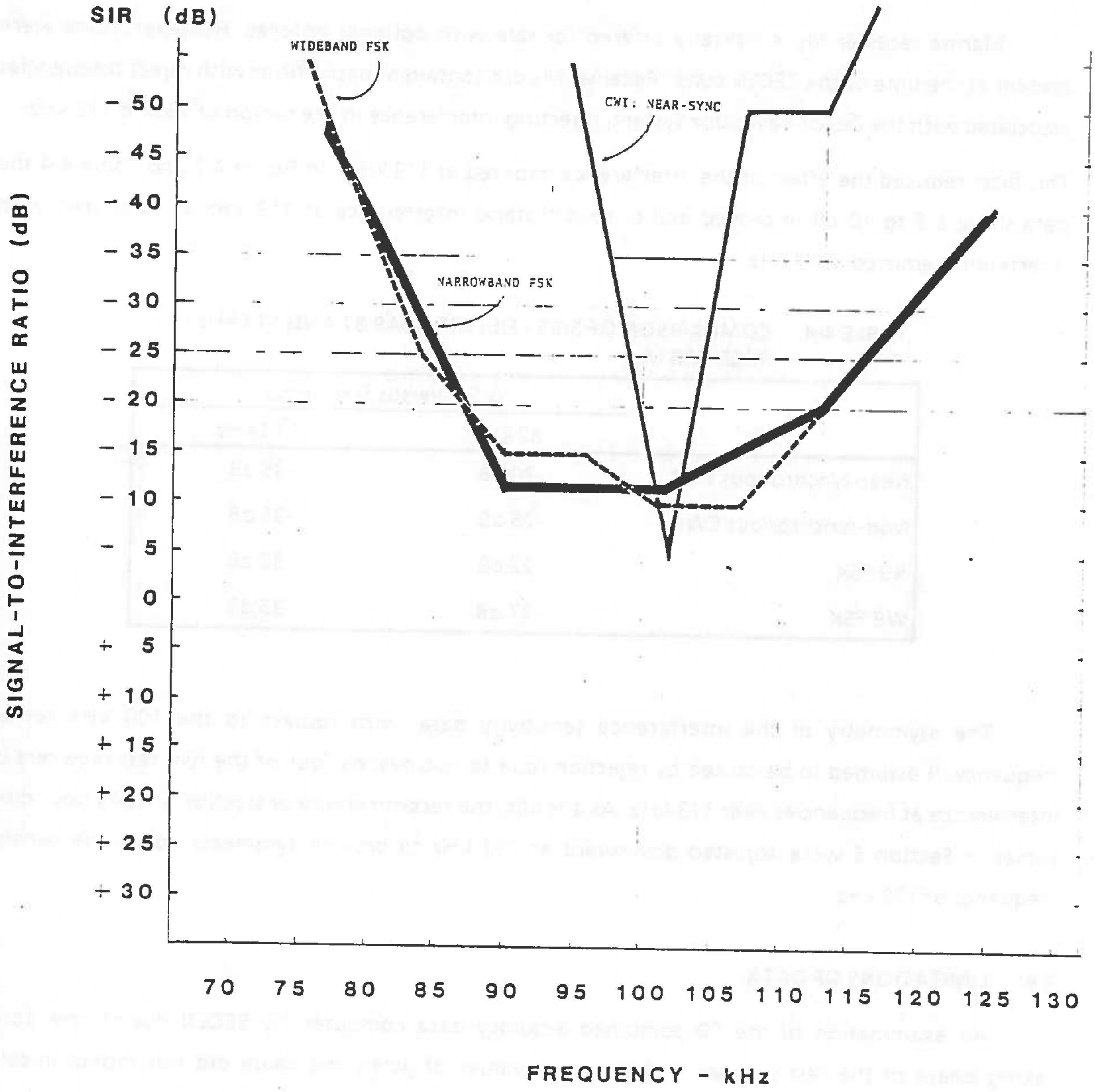

FIGURE 4-5. COMPARISON OF RESPONSE OF RECEIVER M_2 TO THREE TYPES OF INTERFERENCE

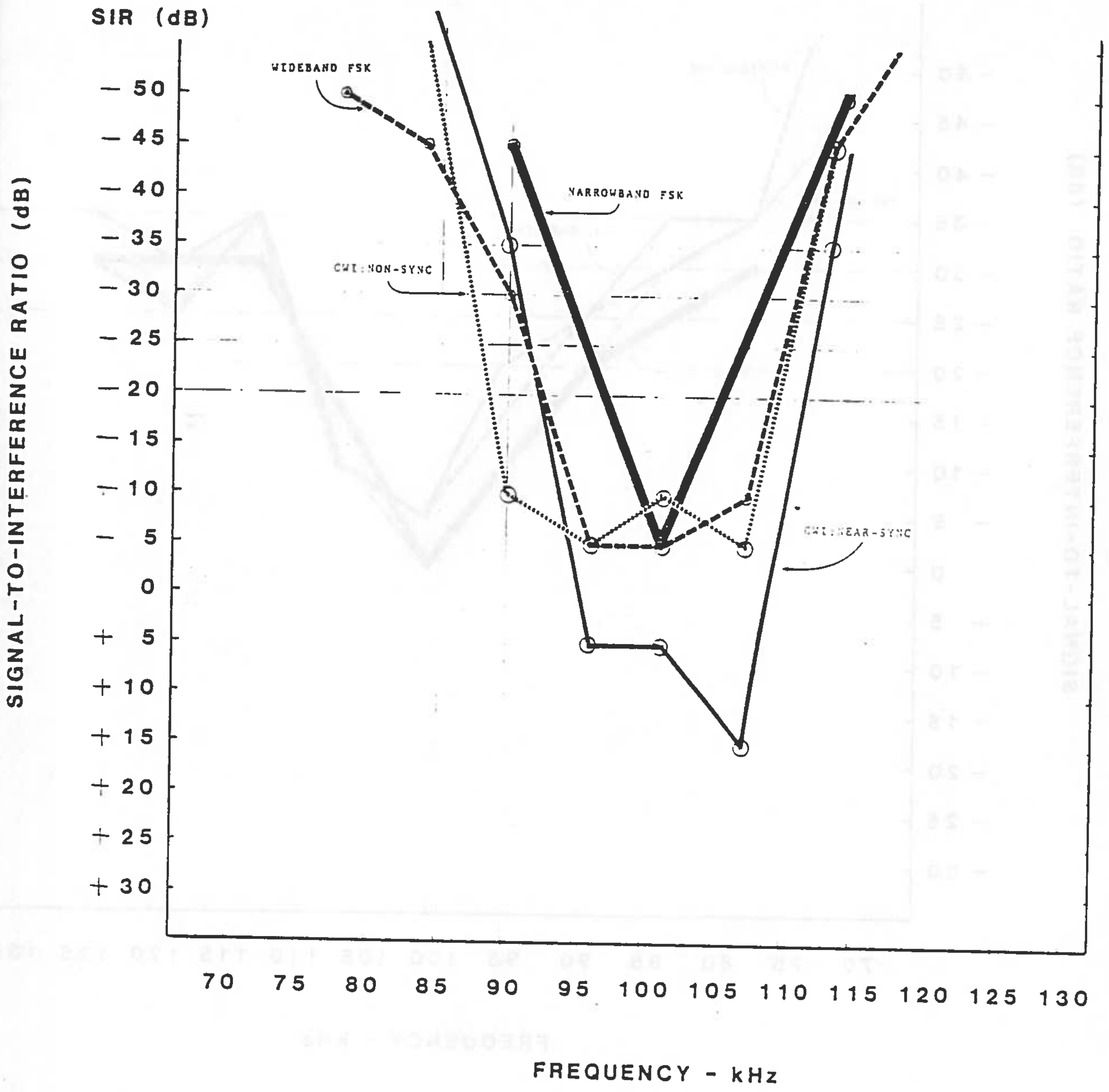

FIGURE 4-6. COMPARISON OF RESPONSE OF RECEIVER M_1 TO FOUR TYPES OF INTERFERENCE

4.4.1 LORAN-C Receiver Resolution

Several of the receivers tested provided TD outputs with a resolution of 0.1 microsecond. Examination of the raw data showed that in some cases these receivers held a constant 0.1 microsecond TD value throughout the 300-second interval of measurement, while in other cases, perhaps due to a slight change in the mean time difference error (MTDE), the output would jump (dither) by ± 0.1 microsecond. In those cases where the output dithered by ± 0.1 microsecond, the TD CA value was dramatically increased. It was concluded that TD CA values of less than 0.1 microsecond could be biased as much as 0.1 microsecond by resolution of the display.

4.4.2 LORAN-C Receiver Jitter

The interference measurements were made while the receiver was subjected to a 'background' noise of -10 dB 'atmospheric', produced by the atmospheric noise simulator of the LRTC II. Measurements derived using receiver M_3 equate a -10 dB LRTC II atmospheric noise level to a 0 dB Gaussian noise level. A GRI of 9960 and a 0 dB Gaussian signal-to-noise ratio (SNR) yielded an expected jitter in the range of 0.073 to 0.103 microseconds for a receiver with a time constant of 2.2 seconds (typical of the two airborne receivers), while an 8 second time constant (typical of a marine set) will yield a jitter of 0.038 to 0.053 microseconds. Thus, atmospheric noise can affect the CA readings in a random fashion until the applied interference causes the measured CA to exceed either 0.05 or 0.1 microseconds, depending upon receiver type.

It was concluded that TD CA values of less than approximately 0.1 microsecond were strongly affected by the measurement technique, and changes in TD CA in this range were not necessarily indicative of the effects of interfering signals.

4.4.3 Change to Original Test Plan

The original test plan called for the interference tests to be accomplished at decreasing Signal-to-Interference ratios until a point where the TD CA was greater than or equal to 0.3 microsecond. During the testing, a CA value of 0.3 microsecond was seldom realized, as most receivers indicated a flag condition of either BLINK, CYCLE or low SNR at values of CA well below 0.3 microsecond. This is indicated in Figures 4-1, 4-3, 4-8, and 4-9.

For purposes of analyzing the data, either a TD CA value of 0.3 microsecond or excitation of a receiver alarm, whichever was experienced first, was used as the limit of tracking. It was assumed that an operator would consider the TD data unusable in the presence of a receiver alarm even though the system might continue to track. The receiver sensitivity curves and minimum performance curves appearing in sections 4 and 5 are plotted to reflect the TD CA boundary of 0.3 microsecond and/or a receiver flag condition.

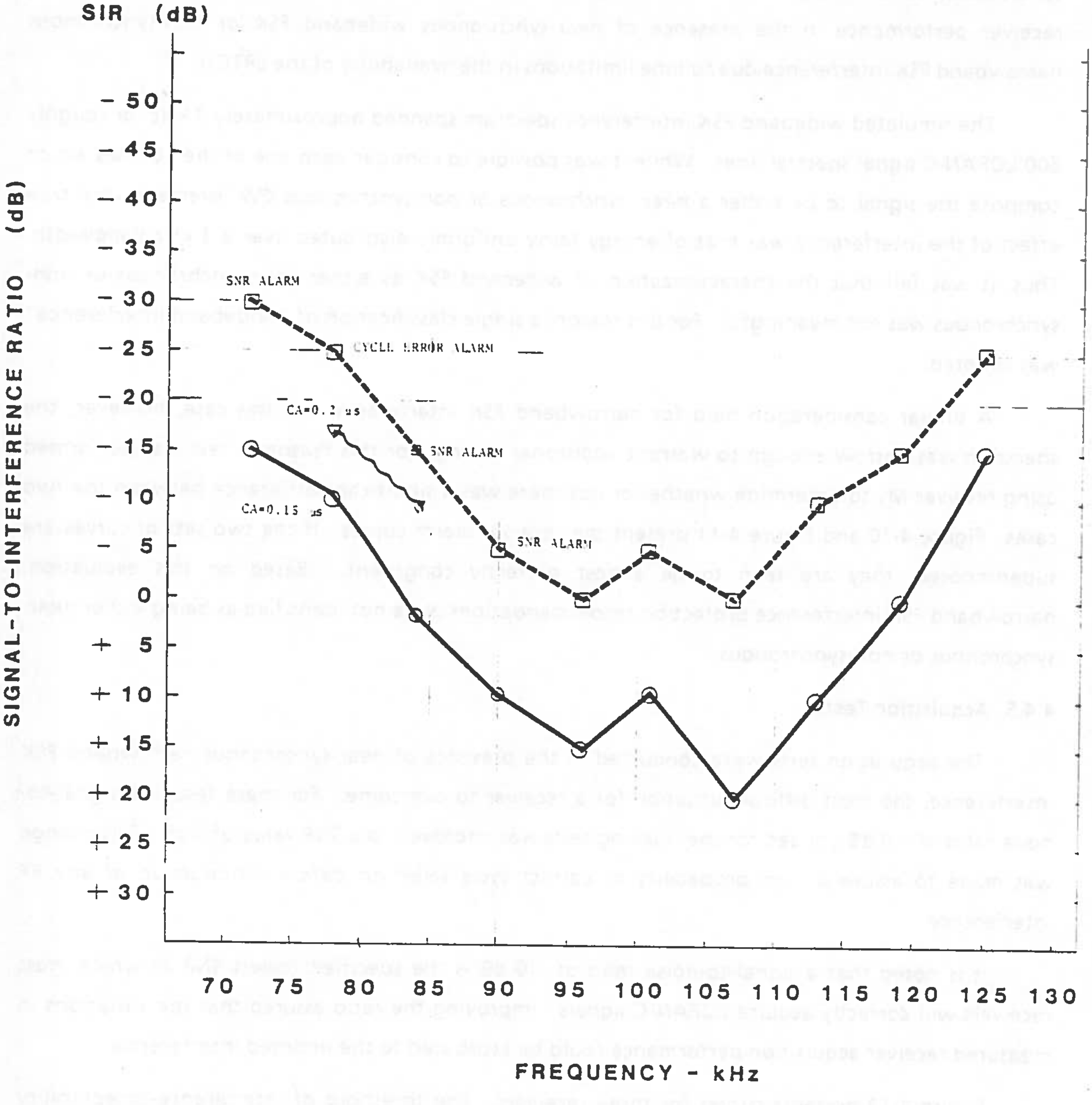

FIGURE 4-9. RECEIVER A_1 RESPONSE TO WIDEBAND FSK INTERFERENCE

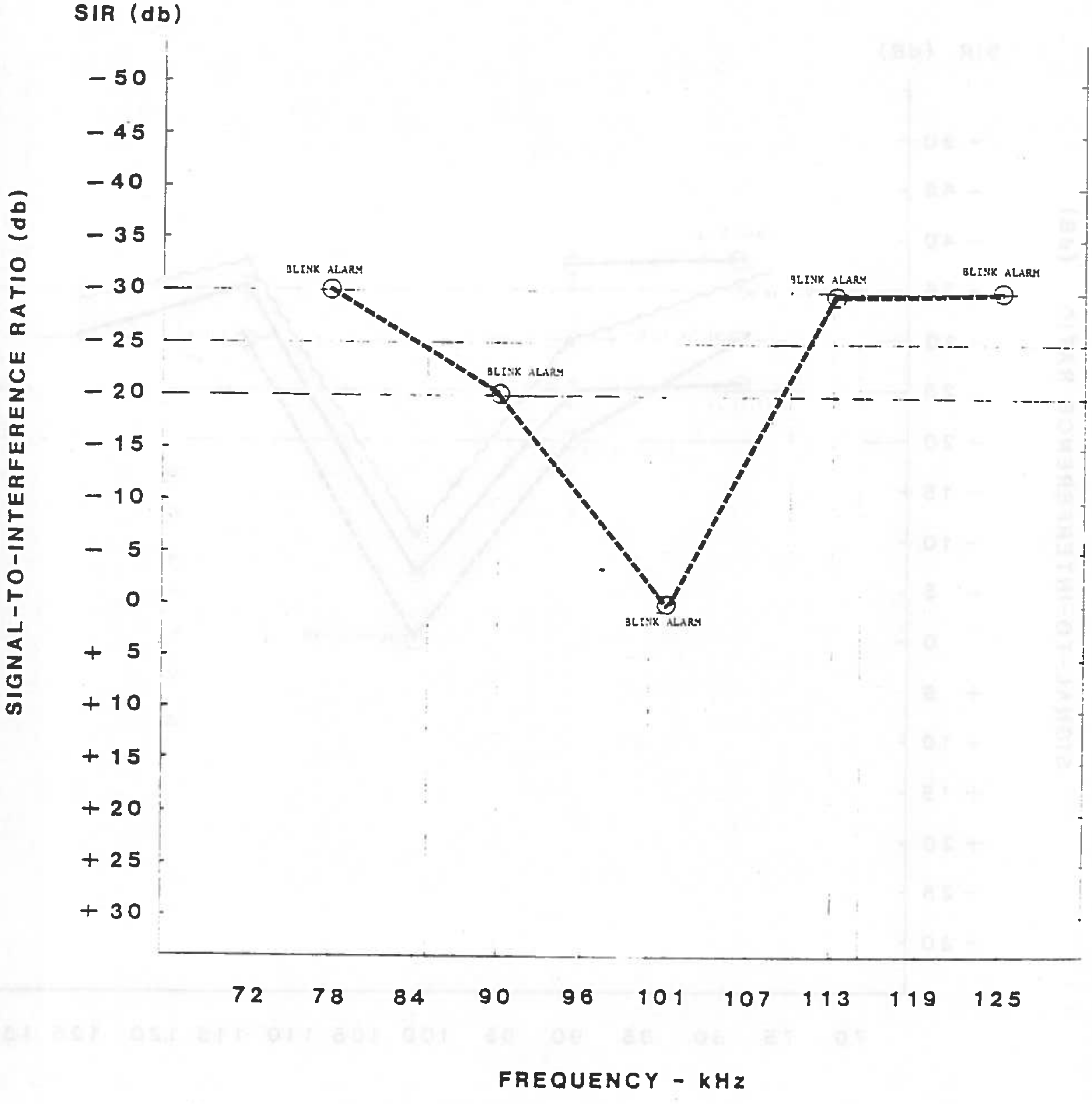

FIGURE 4-10. RECEIVER M_3 RESPONSE TO NARROWBAND FSK NEAR-SYNCHRONOUS INTERFERENCE

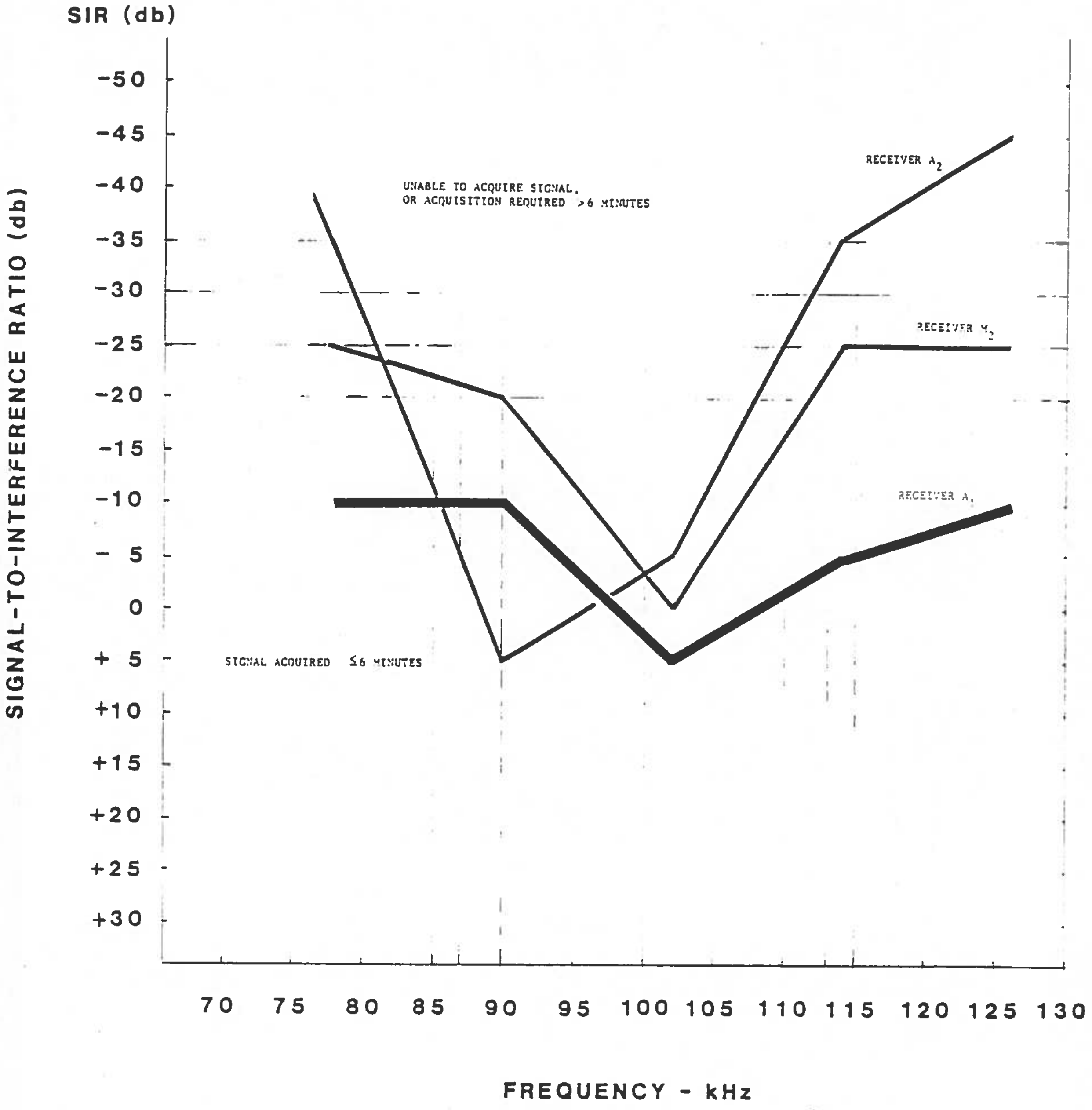

FIGURE 4-12. EVALUATION OF THE LIMITS OF ACQUISITION CAPABILITY - NARROWBAND FSK INTERFERENCE

5. RESULTS

5.1 GENERAL

This section presents composite results for each type of interference, recommended protection criteria and concludes with a proposed procedure to analyze the effects of interference on LORAN-C receivers.

5.2 COMPOSITE RESULTS FOR EACH INTERFERENCE TYPE

After completion of all tests, data for receivers was compared for each type of interference. Performance between different receivers varied over a 40 dB range. Some receivers which showed extra sensitivity to one type of interference were less affected by other types. In the previous section, Figure 4-2 was a composite plot of the performance of all five receivers when subjected to near-synchronous CWI. Further study of the data showed that if a limit was placed at the point where the most sensitive receiver had a combined accuracy of 0.3 microsecond or an alarm condition, a symmetrical envelope could be developed. Figure 5-1 is the composite envelope for all receivers for the case of near- synchronous CWI. Figures 5-2 through 5-4 presents composite envelopes for each of the remaining interference types. Tick marks on the vertical axis indicate where some type of alarm was noted. Actual descriptions were omitted to avoid unnecessary detail in the figure.

5.3 MINIMUM PERFORMANCE CURVES

Each of the composite envelopes or curves shown in Figures 5-1 through 5-4 represents a threshold. When the signal to interference ratio is greater than the threshold, all of the receivers performed within acceptable limits. The threshold ratio was chosen as a minimum for acceptable performance.

5.3.1 Continuous Wave Interference Curves

Comparison of receiver performance for near-synchronous versus non-synchronous interference showed that the receivers needed a 5 dB improvement in signal level to achieve normal performance. Minimum performance curves were prepared for each type of continuous wave interference and are presented in Figure 5-5. The format of the curve is that used by the CCIR in Report 915.

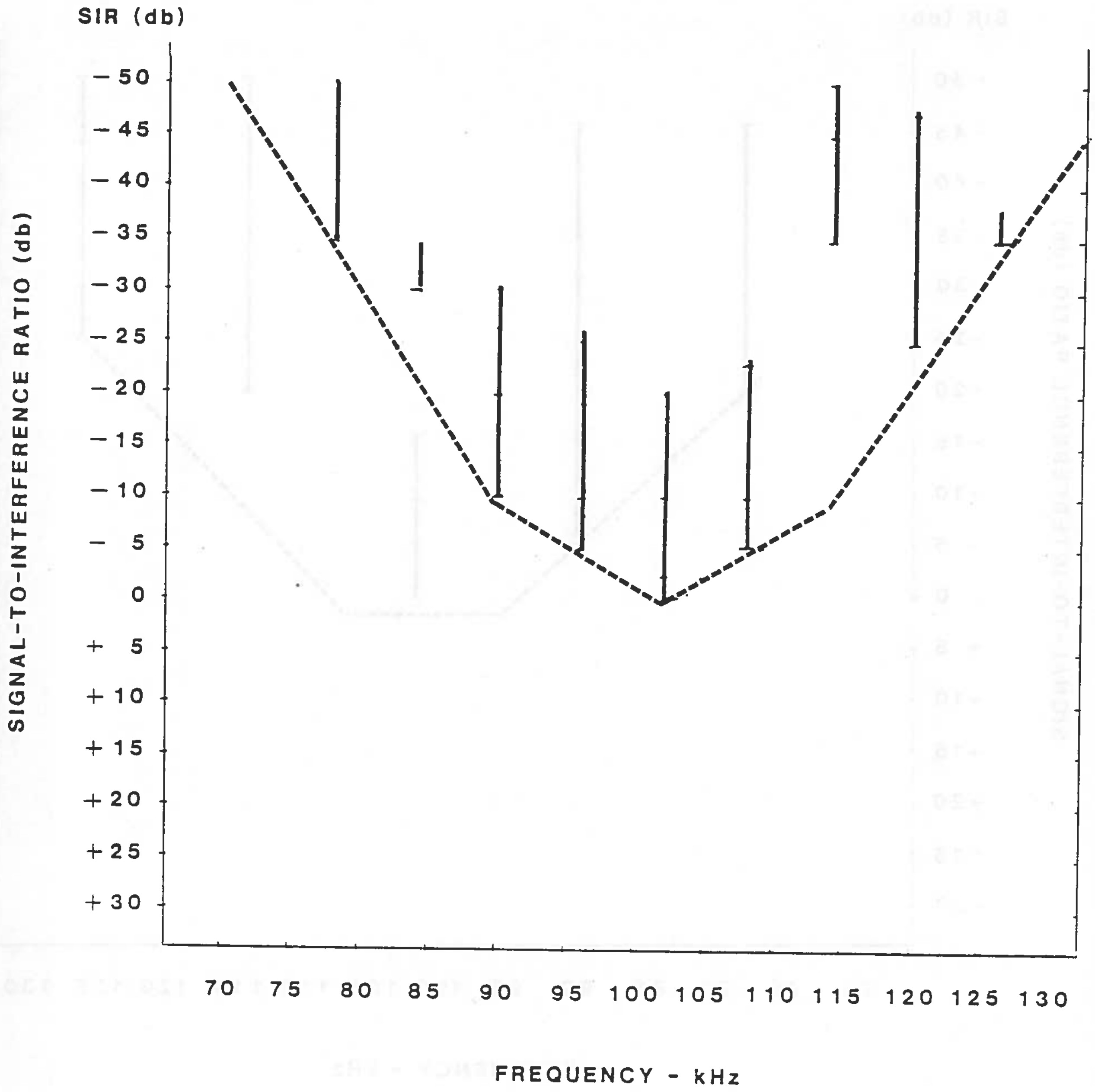

FIGURE 5-2. COMPARISON OF THE RESPONSE OF RECEIVERS TO NON-SYNCHRONOUS CWI

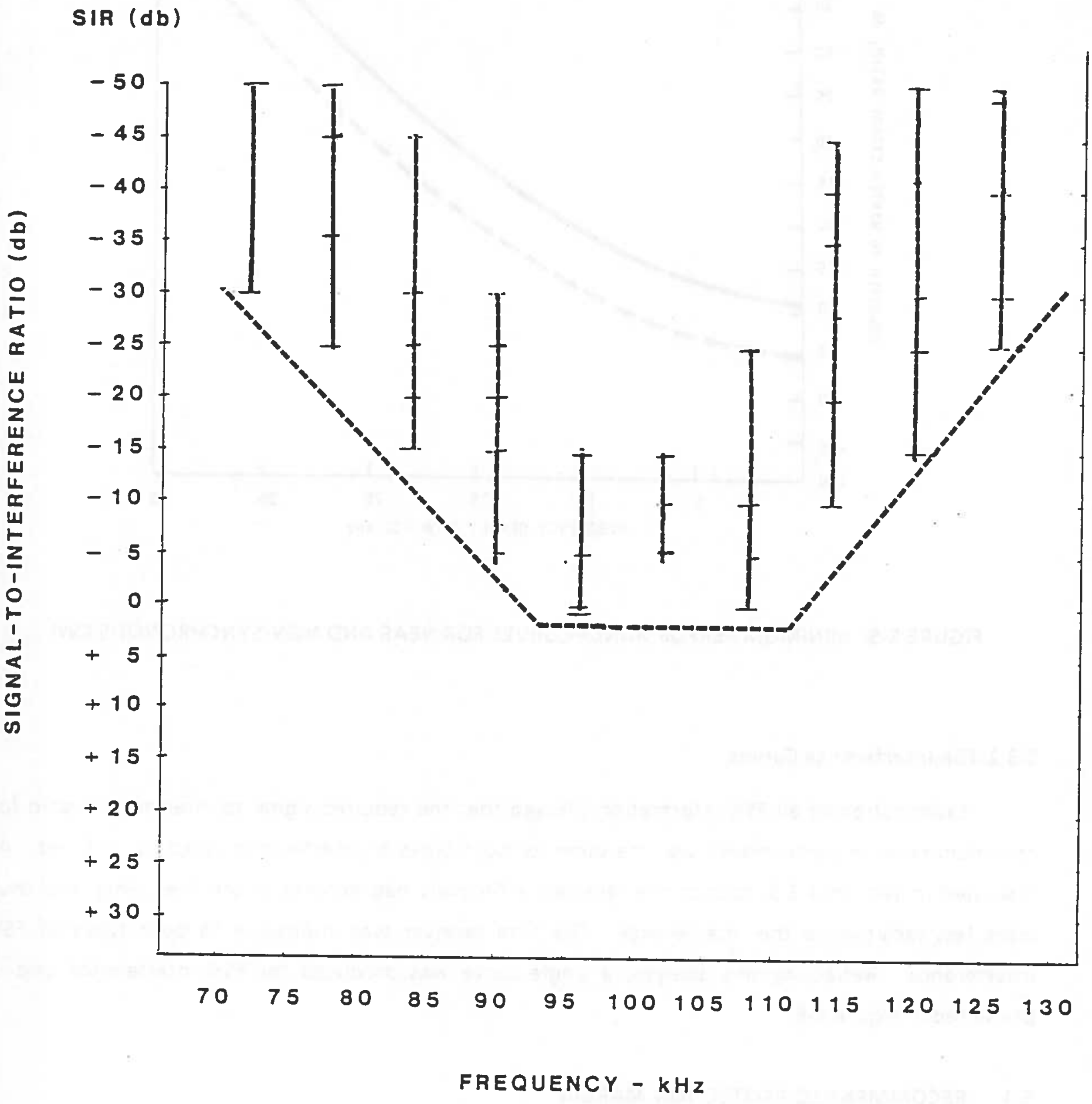

FIGURE 5- 4. COMPARISON OF THE RESPONSE OF RECEIVERS TO WIDEBAND FSK INTERFERENCE

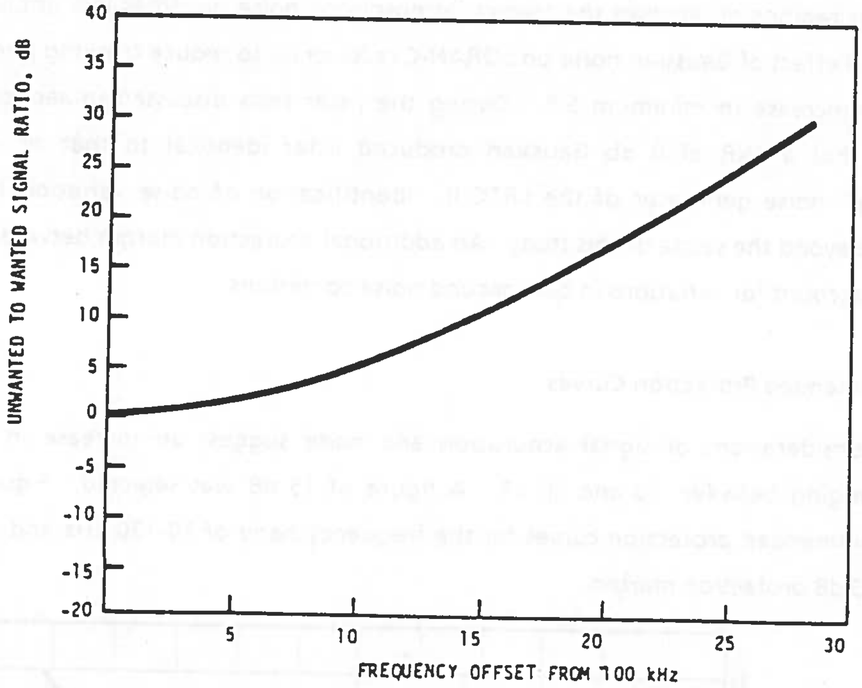

FIGURE 5-6. MINIMUM PERFORMANCE CURVE FOR FSK INTERFERENCE

5.4.1 Receiver Acquisition

Receiver acquisition in the presence of noise is a more difficult task than continued tracking when noise is introduced. The acquisition tests discussed in Section 4.4.5 provided data to establish an additional protection margin. Comparison of the acquisition versus tracking performance of the receivers tested indicated that at least a 5 dB higher SIR was required to correctly acquire a signal than was required to track. The observed limit was smaller than expected. Re-examination of tracking data showed that most receiver failures occurred due to issuing of one of the receiver alarms rather than loss of signal track. The mechanisms which trigger the CYCLE, BLINK AND SNR alarms are related to signal amplitude rather than cycle tracking and reflect a measurement similar to that involved in the cycle identification task. A margin between 5 to 10 dB is desirable for acquisition protection.

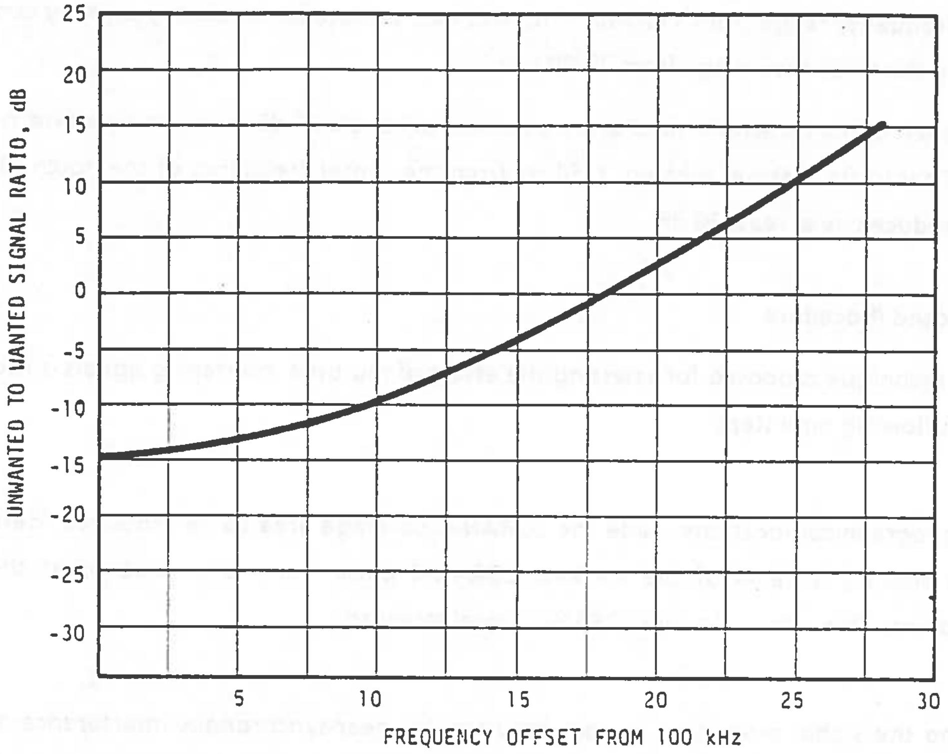

FIGURE 5-8. SUGGESTED PROTECTION BOUNDARY FOR FSK INTERFERENCE

5.5 PROPOSED TECHNIQUE FOR ASSESSING EFFECTS OF MULTIPLE INTERFERENCE

The testing used to develop the Loran-C interference sensitivity curves shown in Section 4 and summarized above, employed a single interfering signal for each of the types of interfering signals tested. This section describes a technique which could be used to assess the overall effect of a multiplicity of interfering signals (more representative of real-world conditions) which vary both in frequency and type. The technique was developed after completion of interference tests and can be verified through future tests.

5.5.1 Assumptions

- Due to the pulse nature of the Loran-C signal, the effect of a multiplicity of interferers on the sampling point will add in a root sum square manner, according to their effective levels during post sampling signal processing.

- The Loran-C receivers subject to protection by this criteria are designed to include at least four notch filters. Two of these filters are located above the Loran-C band in the bandwidth less than 100 Hz. (Note: It may be desirable to place both notches on the interfering frequency.)

STEP 7

In certain circumstances, it may be desirable to use the two notches to eliminate a single interferer of bandwidth greater than 100 Hz by placing the two notches side by side. If this appears to be the case, it may be necessary to repeat this interference sensitivity assessment process twice, once notching out two individual narrowband signals and once using both notches to minimize the effect of a single broader band interferer.

STEP 8

Repeat steps 5, 6 and 7 for interfering signals in the frequency band from 110-130 kHz.

STEP 9

Finally, compute the square root of the sum of the squares of the field strengths of the weighted interfering signals to obtain an effective interfering signal level. If this level exceeds the maximum acceptable level computed in step 2, the LORAN-C system performance will be reduced to an unacceptable level.

5.5.3 Example of the Use of Protection Curves

Step 1. Assume that the LORAN-C signal strength is 1.0 millivolts/meter (mV/m).

Step 2. From Figure 5-9, the protection required at 100 kHz against near- synchronous CW interfering signals is 20 dB, or a voltage ratio of 10:1. Thus, for a 1.0 mV/m LORAN-C signal, the maximum weighted rss interference level is 0.1 mV/m. Figure 5-10 presents the example for FSK interference.

Step 3. The assumed interference sources are shown in Table 5-1 below.

TABLE 5-1. DATA FOR EXAMPLE

Interference	Frequency	Type of Interference	Level
#1	113 kHz	Near-synchronous CWI	7 mV/m
#2	117 kHz	NB FSK	7 mV/m
#3	87 kHz	Near-synchronous CWI	16 mV/m
#4	80 kHz	Non-synchronous CWI	1.4 mV/m
#5	96 kHz	NB FSK	0.3 mV/m

Steps 4 through 6 are considered for three examples. Table 5-2 summarizes the calculations. The first four columns list the characteristics of the assumed interference sources. Columns five to eight show the reduction of the effect of the interference due to the type of modulation, frequency of the signal, and the application of notch filters. The last column lists the final effective level of each interference, and the total effective rss level for all assumed interfering signals.

Example A in Table 5-2 shows an acceptable situation of 0.068 millivolts/meter rss, compared to the limit of 0.1 millivolts/meter rss calculated in step 2. Note that two notches were placed on interferer #3.

In example B, a fourth interfering signal of relatively low level is added to the signals assumed in example A. Due to the low level of the new signal when compared to interferer #3, both notches are again placed on interferer #3, leaving interferer #4 unnotched The equivalent level of the interference is still acceptable at 0.076 millivolts/meter rss.

Example C in Table 5-2 shows the effect of a single relatively low level interferer when it occurs in the band from 90-110 kHz. As most receivers do not permit notch filters to be tuned inside this band, the assumed 96 kHz NB FSK interfering signal only benefits from the 6 dB relative sensitivity protection of the receiver against NB FSK modulation. The net effect of this single interferer is an effective interference level of 0.15 millivolts/meter, 50 microvolts/meter above the limit of 0.1 millivolts/meter.

6. CONCLUSIONS

The test program conducted at the EECEN provided a data base for the establishment of interference protection boundaries. Basic assumptions regarding receiver performance proved sound. As with any test program where only a sample of products is tested, appropriate care should be exercised when the results are extended to other conditions.

Step response tests showed that the receiver tracking bandwidths varied between 0.01 Hz for marine receivers to 0.07 Hz for avionics receivers. These results provide support for the 1.0 Hz spectral spacing between Loran-C and synchronous interference proposed in the U.S. Government amendment to CCIR Report 915.

Tracking tests showed that receiver sensitivity to interference is greatest at 100 kHz and decreases as an interference signal gets farther from 100 kHz. Receivers are most sensitive to near-synchronous CWI, requiring 5 dB protection at 100 kHz. Curves were developed which present the minimum acceptable interference levels. Acquisition tests and uncertainties associated with background noise variation indicate that an additional 15 dB protection margin should be provided. Curves which include this additional margin were also produced.

LORAN-C receivers were also shown to be sensitive to interference beyond the authorized 90-110 kHZ emission band. A technique for analysis of the effects of emissions was developed and presented.

In view of the effect of interference. measures should be taken to prevent harmful interference through continuous monitoring of the Mobile Maritime Band and cooperation between operating agencies.

REFERENCES

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