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MEASUREMENT AND ANALYSIS OF L-BAND (1535-1660 MHz) ELECTROMAGNETIC (EM) NOISE ON SHIPS

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16. Abstract

A program of L-band (1535-1660 MHz) electromagnetic (EM) noise measurements conducted on ships is described in this report. The magnitude and duration of EM noise on ships is of particular significance in terms of potential radio frequency interference (RFI) to future Marine Satellite (MARSAT) receiving systems on ships. The program involved the measurement and identification of EM noise levels originating at internal sources on the ships selected, and external sources at coastal locations within radio line-of-sight. The instrumentation and measurement procedures employed are described and illustrated. The predominant EM noise sources identified are discussed and illustrated graphically, and the potential RFI signal amplitude and bandwidth parameters are related to a typical MARSAT receiver sensitivity, and the communications link quality ratio C/N_o. The predominant sources of L-band noise were found to originate at ports and the adjacent cities. These sources are continuously present when the ships are docked, and can be characterized as a combination of continuous city ambient noise and intermittent broadband impulsive ignition noise from dockside unloading apparatus, automobiles and trucks. Some RFI levels 20 to 30 dB above receiver thermal noise were evident which would result in unacceptable degradation to the satellite-to-ship link C/N_o.

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PREFACE

The work described in this report was performed as part of the first phase of the ATS-6 satellite experimental program. L-band (1535-1660 MHz) electromagnetic (EM) noise measurements were conducted by the Transportation Systems Center (TSC) at ports and en-route between ports.

The measured data was analyzed in terms of potential radio frequency interference (RFI) to future Marine Satellite (MARSAT) receiving systems on ships.

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CONTENTS

CONTENTS (CONT'D)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

1. INTRODUCTION

The electromagnetic (EM) noise measurements program described herein was conducted for selected merchant ships and United States Coast Guard cutters during the period November 1972 to October 1973. The principal objective was to conduct EM noise measurements at L-band (1535-1660 MHz) on ships in order to identify and characterize potential sources of radio frequency interference (RFI) in a future Marine Satellite (MARSAT) receiving system. Potential EM noise may originate from external land based sources, primarily coastal, as well as several sources located internally on the ships.

At the 1971 ITU World Administrative Radio Conference (WARC) for Space Telecommunications held in Geneva, the 1535-1542.5 MHz band was allocated exclusively for satellite to ship transmissions, and also the 1542.5-1543.5 MHz band on a shared basis with the aeronautical mobile service (satellite to aircraft transmissions). Therefore, the 1535-1542.5 MHz portion of L-band (1535-1660 MHz) is of primary interest in terms of potential RFI to future MARSAT L-band shipboard receiving systems. Signals within this band, which may include voice, data, and teletype signals will be transmitted between ships and coastal stations via satellite.

The 1980 forecast of vessels at sea worldwide[1] indicates that the at sea population of vessels over 10,000 gross tons will double during the 1970's to a value of 8,626 vessels. When fishing vessels and fishing factories over 1000 gross tons are added the total becomes 10,128 ships compared to 5235 in 1969. The vessel categories include tankers, ore/bulk, cargo/passenger, fishing vessels, fishing factories and miscellaneous vessels.

Initially, EM noise measurements were conducted at dockside and en-route for the 378 foot USCG cutters which are the largest in use, and also for one of the modern classes of cutter employed. In addition, this class is a candidate for use of an operational MARSAT system when it becomes available. Some measurements were also performed on the older 255 foot and 327 foot cutters for comparison and this yielded some useful data. Following this, dockside and en-route measurements were performed aboard two identical Farrell Lines cargo/freighters and one representative Exxon tanker. The measured data which is discussed and illustrated later in this paper is considered representative of the general EM noise environment to be encountered by MARSAT equipped ships in the future. Furthermore, the most significant noise levels were those which prevailed at ports adjacent to cities, and data was recorded at the following Eastern United States ports: Portland, ME; Boston, MA; Newport, RI; New York, NY; Baltimore, MD; and Baytown, TX (Houston area).

Prior to commencement of the measurements program, a test plan was prepared. This included a preliminary analysis of potential internal external EM noise sources which may produce unacceptable RFI to a MARSAT receiving system on a ship [Refer to Section 2.]. Following this, a measurements program was defined and measurement procedures were established. Suitable instrumentation was obtained, and this consisted of the Singer NM-65T Radio Interference Analyzer/Receiver with a Portable Horn Antenna. In order to improve the NM-65T receiver sensitivity, an AVANTEK AS-61T preamplifier with a noise figure of 3.5 dB was also employed. The instrumentation characteristics are discussed in more detail in Section 3.

2. EM NOISE ON SHIPS (SOURCES)

2.1 INTERNAL RFI SOURCES

Potential EM noise sources* on ships can be categorized as follows:

a. Noise from electric motors and other electrical equipment. This is broadband noise (see Appendix A) and can result from commutation and circuit breaker arcing, for example. Existing data indicates that this noise can reach high levels in the HF (3-30 MHz) band with appreciable attenuation in the UHF (300-3000 MHz) band.

b. Arc discharge across insulators on HF and MF (300-3000 kHz) transmitting antennas due to moisture and salt coating. Broadband noise may be generated by these elements in the VHF (30-300 MHz) and UHF bands.

c. EM noise conducted along mast stays and wire rope live lines. This noise may be broadband or contained in discrete narrow frequency bands. Any corroded connections between wire rope, eyes and the mast act as nonlinear electrical elements. These elements can generate harmonics and intermodulation product voltages, and EM noise will be radiated at the harmonic and intermodulation frequencies. The highest noise levels will exist below UHF but significant levels can result at UHF.

d. Harmonics of MF, HF, and VHF communications transmitters. VHF-FM transmitters operate in the following maritime mobile bands:

156.250 - 157.450 MHz
161.575 - 161.625 MHz (161.6 MHz only)
161.775 - 162.00 MHz

---

*Sections 12.1.11 and 12.2.6 of the System Definition Study[1] also deal with some of the potential shipboard EM noise sources described in this section.

Within the MARSAT receiver band 1535-1543.5 MHz, it is unlikely that interference would result from harmonics of the three VHF maritime bands listed above because the MARSAT band is between the 9th and 10th harmonics. The 9th harmonic is 1406.250 MHz at the lowest frequency (156.250 MHz) 1458 MHz at the highest frequency (162 MHz). The 10th harmonic is 1562.50 MHz at the lowest frequency (156.250 MHz) and 1620 MHx at the highest frequency 162 MHz. Harmonics of MF and HF transmitters are not considered to be a source of potential RFI to the MARSAT receivers.

e. Spurious emissions at L-band from the transmitter output spectrum associated with 3 GHz (S-band) and 9 GHz (X-band) shipboard radar systems. The amplitude and pulse duration of any potential RFI signals due to spurious emissions from these sources is of primary interest.

f. Broadband impulsive intermittent noise from ignition circuits used with ship's internal unloading apparatus. (Used only when ship docked at ports.)

2.2 EXTERNAL RFI SOURCES

Potential EM noise sources external to ships can be categorized as follows:

a. L-band EM noise from external sources such as US Federal Aviation Administration (FAA) radars located at airports. These sources may include systems operating at 1300-1350 MHz and S-band. Significant upper sideband signal levels may possibly be observed within the MARSAT receiving band from emissions which originate at the 1300 MHz ground based airport radar transmitters. This RFI source will probably only be of concern when the ships are either docked or close to shore in the vicinity of major airports.

b. MF, HF, and VHF communications transmitter harmonics, particularly the latter, may produce RFI on MARSAT equipped ships. In this case, we are concerned with external sources where the transmitters are located on other ships or at shore based locations in close proximity, i.e., within radio line-of-sight.

c. Spurious out-of-band emissions at L-band from 3 GHz radars operating on other ships in close proximity, i.e., within radio line-of-sight.

d. High ambient continuous EM noise levels from cities adjacent to ports, i.e., within radio line-of-sight conditions.

e. Broadband impulsive intermittent noise from combustion engine ignition circuits used with dockside unloading apparatus at ports.

f. Broadband impulsive noise from combustion engine ignition circuits associated with automobiles and trucks on highways and bridges adjacent to ports, harbors, and canals.

3. INSTRUMENTATION AND MEASUREMENT

3.1 INTRODUCTION

The Singer NM-65T Radio Interference Analyzer/Receiver with a portable Horn Antenna was employed. (Refer to Figure 1). This is an all solid state portable instrument suitable for laboratory and field measurements. The basic receiver is tuneable over the range 1 to 10 GHz. However, the particular Horn Antenna used covers the range 1 to 2.3 GHz, which is more than adequate for the MARSAT receiving band of interest -- namely, 1535 to 1543.5 MHz. Typical applications include field strength measurements of radar and communications transmitters at varying azimuth and elevation positions, also, analysis of spectral power distribution for pulsed microwave sources. The NM-65T can provide field intensity, direct peak, and slideback peak measurements. Direct peak measurements will determine the peak values of regular or CW signals. Slideback peak measurements will determine the peak values of sporadic or random signals with time, and in this case the X and Y outputs which are available are fed into a recorder as shown because the meter readings would be very difficult to interpret and in some cases the readings could be missed entirely. The maximum voltage measurement range is 120 dB.

NOTE: Voltage measurement accuracy is ± 3 dB, and this corresponds to the same power accuracy in dB if we convert from dBuV to dBm into a known impedance Z_o.

When we are relating RFI signal levels in dBm to the MARSAT receiver sensitivity, Z_o will be 50 ohms. In other words:

3 dBuV = -104 dBm (Z_o = 50 ohms)

0 dBuV = -107 dBm (Z_o = 50 ohms)

-3 dBuV = -110 dBm (Z_o = 50 ohms).

True frequency is within 2 percent of the indicated frequency, which is satisfactory for the RFI measurements described because we are not concerned with exact frequency assignments. The selectable bandwidths are 100 kHz, 500 kHz, and 5 MHz.

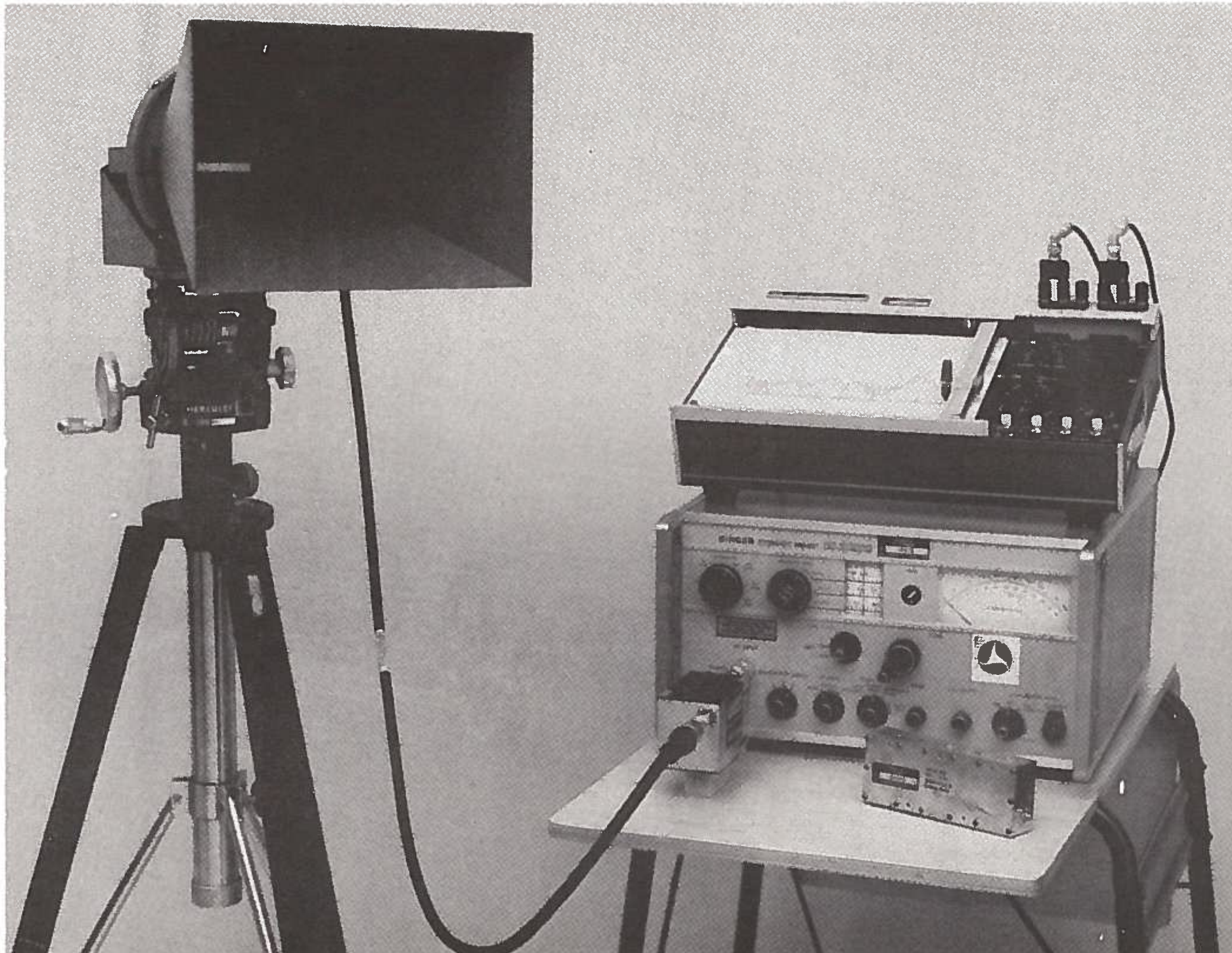


Figure 1. NM-65T Noise Measurement Instrumentation

Narrow band measurements below 100 kHz can be extrapolated. For example, the noise which would result in a 4 kHz voice channel is of specific interest. We would expect the noise power in such a voice channel to be less than that measured in a 100 kHz band by 10 log 100/4 = 14 dB.

NOTE: This is only valid for the case of a uniform flat RFI noise power density.

3.2 INSTRUMENT NOISE FLOOR CALCULATION

The sensitivities specified for the NM-65T Analyzer/Receiver are as follows:

NARROWBAND - 100 kHz Selection (S/N = 1) No Preamplifier

BAND 1)	Average	0.7 uV,	-3 dBuV,	-110 dBm,	14 dB(NF)
1-2 GHz)	Minimum	1.4 uV,	+3 dBuV,	-104 dBm,	20 dB(NF)

BROADBAND - 5 MHz Selection (Direct peak indication 3 dB over N) No Preamplifier

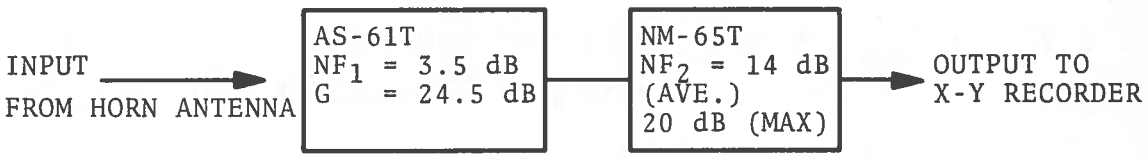
BAND 1)	Average	4.9 uV/MHz,	14 dBuV/MHz, (-93 dBm/MHz)
1-2 GHz)	Minimum	9.8 uV/MHz,	20 dBuV/MHz, (-87 dBm/MHz)

The AVANTEK AS-61T preamplifier has a noise figure less than 3.5 dB and gain of 24.5 dB at L-band (1535-1660 MHz). By inserting a preamplifier between the horn antenna and the NM-65T receiver as illustrated by Figure 1 the sensitivity should improve significantly.

It was determined that it was not possible to accurately measure the NM-65T receiver noise floor with or without the preamplifier. Therefore, the required value, corresponding to the true receiver sensitivity, was calculated for each of three (3) NM-65T receiver conditions employed for the examples of interest as follows:

For the calculation of the NM-65T noise floor calibration it is assumed that the 6 foot RF cable connecting the horn antenna is disconnected from the receiver or preamplifier, either of which is now terminated in 50 ohms (Z_o). Therefore, the NM-65T instrument noise floor calibration does not include any antenna noise contribution, and the noise floor N_o can be calculated with reference to Kraus[2] and Westman.[3] The 5 MHz broadband mode was employed primarily, and this is a selectable bandwidth mode. The NM-65T manual specifies the 6 dB bandwidth as 4.7 MHz, i.e., bandwidth between ±3 dB points. However, 5 MHz is a convenient value that is considered sufficiently accurate for the purposes of analysis in this report.

In order to calculate the measurement instrumentation system noise floor value, it is necessary initially to establish the total Noise Figure (NF) for the two cascaded RF amplifiers,[3] namely, the AS-61T preamplifier and the NM-65T receiver. This arrangement is illustrated below including the pertinent characteristics.



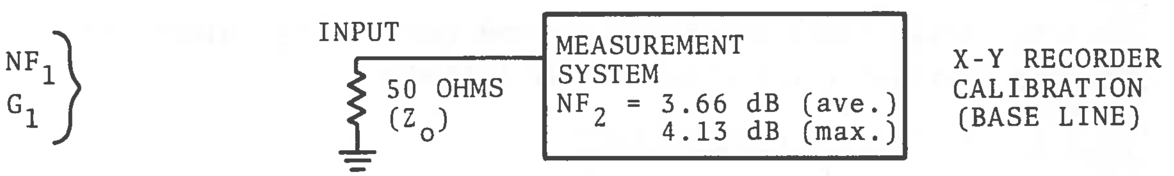
NOTE: G = preamplifier gain = 24.5 dB (1.5-1.6 GHz)

$$NF_{total} = NF_1 + \frac{NF_2}{G} \quad \text{(NF and G numerical)}$$

$$NF_{total} = 2.24 + 24/282 \text{ (ave.)} = 2.33 = 3.66 \text{ dB (ave.)}$$

$$99/282 \text{ (max.)} = 2.6 = 4.13 \text{ dB (max.)}$$

The final measurement system can now be represented as follows:



The 50 ohm termination represents a noise temperature (T_o) contribution of 290°K, i.e., NF_1 = 3 dB.

For this case $G_1 \approx 1$ $\quad NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1}$

$$NF_{total} = 2 + \begin{cases} 1.33 \text{ (ave.)} \\ 1.6 \text{ (max.)} \end{cases} = \begin{matrix} 3.33 \text{ (ave.)} \\ 5.56 \text{ (max.)} \end{matrix} = \begin{matrix} 5.22 \text{ dB (ave.)} \\ 5.56 \text{ dB (max.)} \end{matrix}$$

NOTE: With reference to the NM-65T characteristics listed above, it can be seen that a variation of 6 dB in the range of specified NF values i.e., 14 dB (ave.) to 20 dB (max.), only results in a variation of 0.34 dB in the total NF values calculated.

From the foregoing, the measurement system noise temperature (T_{sys}) can be calculated

$$T_{sys} = T_o\left(NF_{total} - 1\right) = \begin{matrix} 676°K \text{ (ave.)} \\ 754°K \text{ (max.)} \end{matrix}$$

The instrumentation noise power density N_o can now be determined

$N_o = K\,T_{sys}$ where K = Boltzmann constant

$= 1.38 \times 10^{-23}$ joules/°K - Hz

$N_o = -170.3$ dBm/Hz (ave.)

$= -169.8$ dBm/Hz (max.)

The following three operational modes were employed for the measured examples discussed in Section 5.0:

1. Broadband 5 MHz with preamplifier
2. Broadband 5 MHz without preamplifier
3. Narrowband 100 kHz with preamplifier

The noise floor power density and sensitivity values correspond to these three cases are as follows:

1. <u>5 MHz with preamplifier</u>

   $-170.3 + 10 \log 5 \times 10^6 = -103.3$ dBm (ave.)

   $-169.8 + 10 \log 5 \times 10^6 = -102.8$ dBm (max.)

NOTE: -170dBm/Hz is considered sufficiently accurate for this case and is indicated on the appropriate X-Y recordings. The noise power density value in dBm/Hz is more convenient for analysis than the noise power or sensitivity in dBm.

2. <u>5 MHz without preamplifier</u>

$-160.3 + 10 \log 5 \times 10^6 = -93.3$ dBm (ave.)

NOTE: -160 dBm/Hz is used for this case, and is calculated from KT_{sys} where T_{sys} is derived for NF = 14 dB (ave.). This value is indicated on the appropriate X-Y recordings.

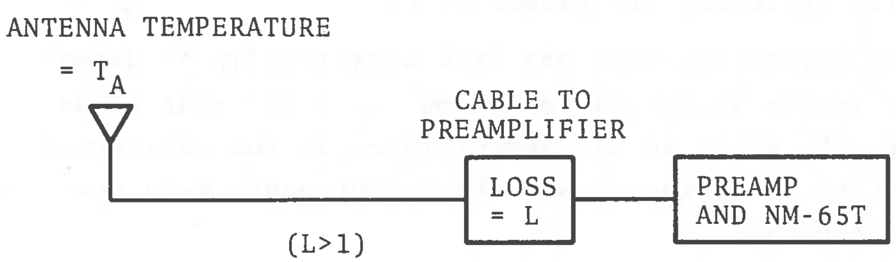
3. <u>100 kHz with preamplifier</u>

$-170.3 + 10 \log 10^5 = -120.3$ dBm (ave.)

$-169.8 + 10 \log 10^5 = -119.8$ dBm (max.)

NOTE: -170 dBm/Hz is used for this case, and this value is indicated on the appropriate X-Y recordings. (Same value as [1]).

If we now replace the 50 ohms termination (Z_o) with the horn antenna and a 50 ohm coaxial cable can now be represented as follows:



$$T_L = T_o \frac{(L-1)}{L} \qquad T_R = T_o\ (NF_2 - 1)$$

where T_R = preamplifier noise temperature, °K including contribution from NM-65T receiver

NF_2 = 3.66 dB (ave.) calculated above.

The total temperature of system (T_{sys}) is the numerical sum of the terms,[2] as indicated below. Assume T_A = 100°K and L = 1.5 dB (typical).

Referring T_{sys} to the preamplifier input:

$$T_{sys} = \frac{T_A}{L} + T_o \frac{(L-1)}{L} + T_o (NF_2 - 1)$$

$$= 71 + 85 + 384 = 540°K \text{ (ave.)}$$

The value T_{sys} = 540°K(ave.) is lower with the horn antenna than the value 676°K (ave.) calculated previously for the calculation set-up with the input terminated in Z_o. Therefore, the noise floor under actual measurement conditions would be lower by 10 log 676/540 = 1 dB. However, as the measurement accuracy is $\pm$3 dB, the noise floor values previously calculated for the three operational modes of interest will be assumed for discussion and analysis below in Sections 5 and 6. The appropriate noise floor values are indicated on the X-Y recordings.

3.3 GENERAL

Most of the noise sources measured were identified as broadband in character through the measurement procedures outlined for the NM-65T. Therefore, the 5 MHz broadband mode was mainly employed, usually including the preamplifier.

The 100 kHz narrowband mode was used occasionally to determine some noise levels which existed below the 5 MHz mode noise floor. However, the noise levels demonstrated in the narrowband mode were broadband in character and the measurements were not valid (Refer Section 5).

The direct peak selector position was employed, as this facilitates measurement of the peak values of regular or CW signals. The slideback peak position enables measurements to be made of the peak values of sporadic or random signals with time such as those generated by a switching transient. The field intensity position provides peak averaging indications with the highest available instrument sensitivity. In terms of potential RFI to a future shipboard MARSAT receiving system, we were more interested in the peak amplitude values of continuous noise sources, therefore, the direct peak measurements are of primary interest, and the direct peak mode was employed throughout.

As previously mentioned it was also found that all of the significant noise sources were broadband in character as defined in Appendix A; therefore, the 5 MHz bandwidth selector position was employed throughout.

The NM-65T instrument manual outlined procedures for determining whether a detected noise source is narrowband or broadband in character. If the noise source is narrowband, the readings will be the same in the 100 kHz or 5 MHz modes. If the source is broadband, the reading will be lower in the 100 kHz position because only a portion of the noise power will be measured.

A coaxial bandpass (L-band) filter is also shown in Figure 1 (not connected). This was employed periodically to verify that we were not recording spurious responses in the NM-65T receiver. For example, an S-band (3000 MHz) RFI signal could conceivably mix with an NM-65T Local Oscillator/Mixer internal frequency to produce a spurious response. The use of the filter eliminates this possibility. The NM-65T specifies rejection of all spurious responses as 60 dB or better for the band of interest, i.e., Band I (1.0 - 2.3 GHz). It was established beyond doubt that all noise sources identified were fundamentally L-band in origin.

3.4 HORN ANTENNA CHARACTERISTICS

The horn antenna gain and beamwidths are calculated as follows:

λ = 19 cm for 1580 MHz (MARSAT and AEROSAT receive bands 1535-1558.5 MHz).

NOTE: 1580 MHz is just below band center for L-band.

PYRAMIDAL
HORN DIMENSIONS: Horizontal (wide) a = 34.5 cm.
Vertical (narrow) b = 23.5 cm.

$$\text{GAIN (G)} = \frac{7.5\ ab}{\lambda} = 17,\ 10 \log 17 = 12.3 \text{ dB}$$

$$\text{1/2 Power beamwidth, Horizontal} = \frac{80\lambda}{a} = 44°$$

$$\text{1/2 Power beamwidth, Vertical} = \frac{53\lambda}{b} = 29°$$

The horn antenna gain G = 12.3 dB at 1580 MHz, and the attenuation of the 6-foot coaxial RF cable used is 0.6 dB. Therefore, the noise level amplitudes recorded include an effective gain of G - 0.6 = 11.7 dB. It was necessary to employ considerably longer coaxial cables for most of the measurements performed due to the required remote positioning of the horn antenna on the ships. This additional attenuation which was measured varied from 1.5 to 2.5 dB approximately. Therefore, as the accuracy of measurement is not better than ± 3 dB it has been assumed that a corrected value of $G \approx 10$ dB would be reasonable, and this has been subtracted from the Y ordinate on all of the X-Y recordings discussed in Section 5. The noise level amplitudes therefore are relative to a 0 dB gain antenna. In addition, in cases involving the use of the low noise preamplifier, the 24.5 dB gain value is also included in the Y ordinate calibration. Although the particular preamplifier employed effectively increases the RFI levels by 24.5 dB, as well as lowering the measurement system noise floor level, this approximately simulates a future MARSAT shipboard receiving system. In other words, future MARSAT receiving systems would probably employ a preamplifier with similar characteristics.

The NM-65T step attenuator can be adjusted to values of 0 dB, 20 dB, 40 dB and 60 dB depending upon the level of the signals being recorded. The noise examples of Section 5 indicate the value used if applicable.

4. MEASUREMENTS PROCEDURES FOR REPRESENTATIVE SHIPS

4.1 INTRODUCTION

Dockside measurements were performed for the older 255-foot and 327-foot USCG cutters, and the later 378-foot cutters were also measured. In addition, two (2) Farrell Lines cargo/freighters and one Exxon tanker were checked at dockside prior to departure. En-route measurements were also performed on the 327-foot cutter "BIBB", two (2) 378-foot cutters "SHERMAN" and "CHASE", two (2) identical Farrell Lines cargo/freighters SS "African Comet" and SS "African Dawn" and one oil tanker "Exxon San Francisco".

All of these classes of ships are further illustrated below, and some general data are included in the referenced appendices for the individual classes of ship under discussion.

4.2 DOCKSIDE MEASUREMENTS

Initially, measurements were conducted from different deck locations when the ships were docked, and the horn antenna was pointed in different directions over the range 0° to 360° in azimuth and 0° to 90° in elevation. It was found that high noise levels existed continuously at ports and some X-Y recordings were taken for these conditions which will be discussed in Section 5. The predominant noise sources were found to be a combination of broadband city ambient noise and broadband impulsive noise from combustion engine ignition circuits used with dockside unloading apparatus (cranes and forklifters), and automobiles and trucks in the general vicinity. During the performance of this measurements program some indication was obtained of the prevailing EM noise levels which exist at cities adjacent to the following ports: Portland, ME; Boston, MA; Newport, RI; New York, NY; Baltimore MD; and Baytown, TX (Houston area). It was possible to identify the impulsive noise sources mentioned because they were not continuous as in the case of the city ambient noise. For the older ships measured at dockside, specifically the 255-foot and 327-foot USCG cutters, broadband impulsive noise due to electric ventilation motor brush arcing was evident. The later ships employ ac induction motors and arcing is minimized.

4.3 EN-ROUTE MEASUREMENTS

Measurements were performed following departure for several of the later USCG cutters and merchant ships, and also when the ships were en-route beyond radio line-of-sight of coastal areas. This facilitated measurements of the steady state background EM noise conditions present on the ships. When the ships were en-route, measurements were recorded for any significant communications and radar spurious emissions and harmonic levels which existed. Some shipboard potential RFI sources were identified during the en-route measurements; however, it was concluded that the electronic equipment RFI sources identified could be adequately suppressed with simple filters. The en-route measurements for the shipboard radar and communications equipments were recorded with the horn antenna pointed towards the individual antennas. Of particular interest was potential L-band RFI from the AN/SPS-29 air search radar (ASR) and X-band surface search radar employed by the USCG cutters, also the X-band and S-band radar systems employed by the merchant ships. There was no evidence of any potential RFI originating at the X-band radar systems nor at the MF, HF or VHF communications equipment employed by all of the ships of interest.

It was decided early in the measurements program that the horn antenna could be located in a fixed position in the vicinity of the bridge for en-route measurements on the merchant ships (freighters and tankers). The reason for this decision was based upon the fact that the optimum location for any future MARSAT antenna on these ships would be above the bridge in close proximity to the surface search X-band and S-band radar antennas. Generally this location is the region which should experience less antenna pattern interference due to the ship's superstructure. Therefore, it was concluded that the L-band EM noise environment in the vicinity of the bridge was of primary importance.

Some of the early measurements on USCG cutters indicated that significant noise levels could originate within some ships from fluorescent lighting, and this was actually measured in the Combat Information Center (CIC) and radio room areas for the USCG cutters only. However, these sources of noise were not present externally in the vicinity of the bridge. Therefore, below deck EM noise on the ships was only of academic interest.

4.4 REPRESENTATIVE SHIPS

4.4.1 USCG Cutters

Figure 2 illustrates the 378-foot USCG cutter "CHASE". This is a high endurance vessel, and the largest class of cutter in operation. Measurements were conducted with the horn antenna located on the 01 deck which is just behind the bridge between the two masts. The NM-65T Analyzer/Receiver was located in the CIC just below the 01 deck. This class of cutter is considered a candidate class of vessel for the use of a MARSAT system in the future. Appendix B-1 lists general data for the vessel and technical data for the pertinent electronic and electrical equipment. Figure 3 illustrates the 210-foot USCG cutter "VIGILANT". This is a medium endurance cutter, and this class may also employ a MARSAT system in the future. EM noise measurements were not conducted on the 210-foot cutters.

The older 255-foot and 327-foot classes were the subject of dockside and en-route (327-foot cutter only) measurements for comparison. However, these classes are not candidates for the eventual use of a MARSAT system.

4.4.2 Cargo Freighters

Figure 4 illustrates a Farrell Lines C.4 class of cargo freighter. Dockside and en-route measurements were conducted between Boston and New York for two (2) identical ships of this class. These were the S/S "African Comet" and the S/S "African Dawn". Appendix B-2 provides general data for the S/S "African Comet", and the other ship is almost identical. The C.4 is a

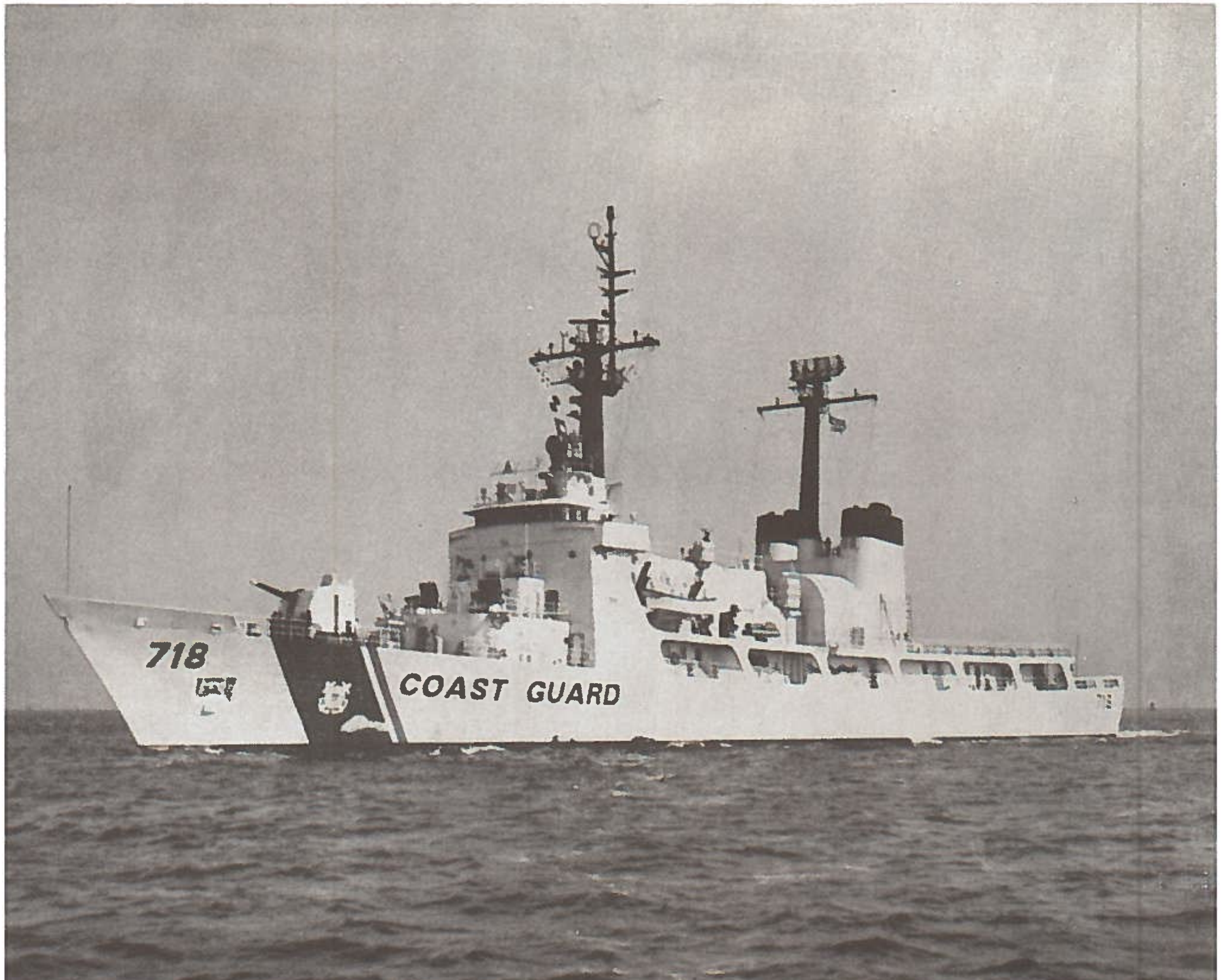


Figure 2. USCGC "CHASE" 378-Foot High Endurance Cutter

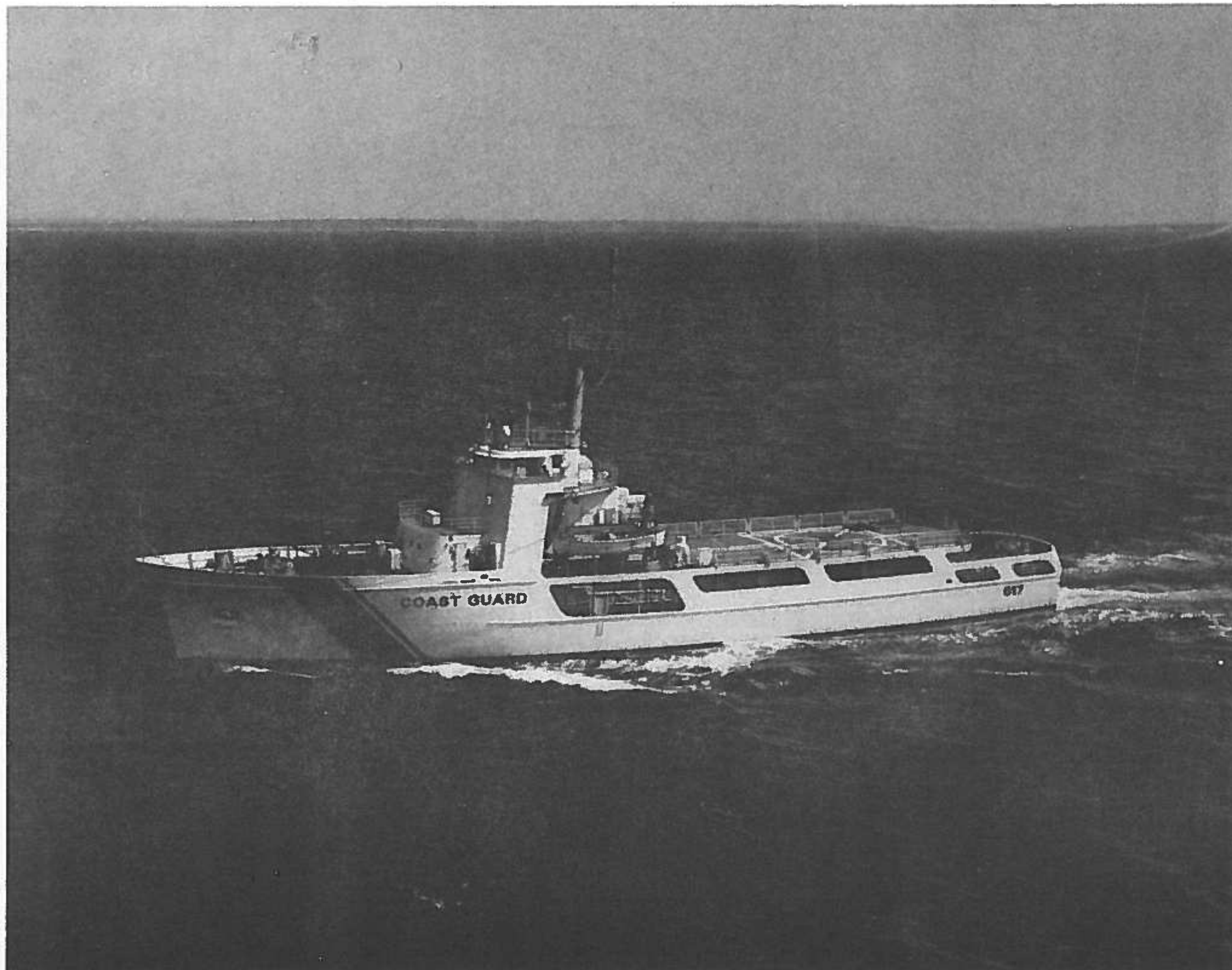


Figure 3. USCGC "VIGILANT" 210-Foot Medium Endurance Cutter

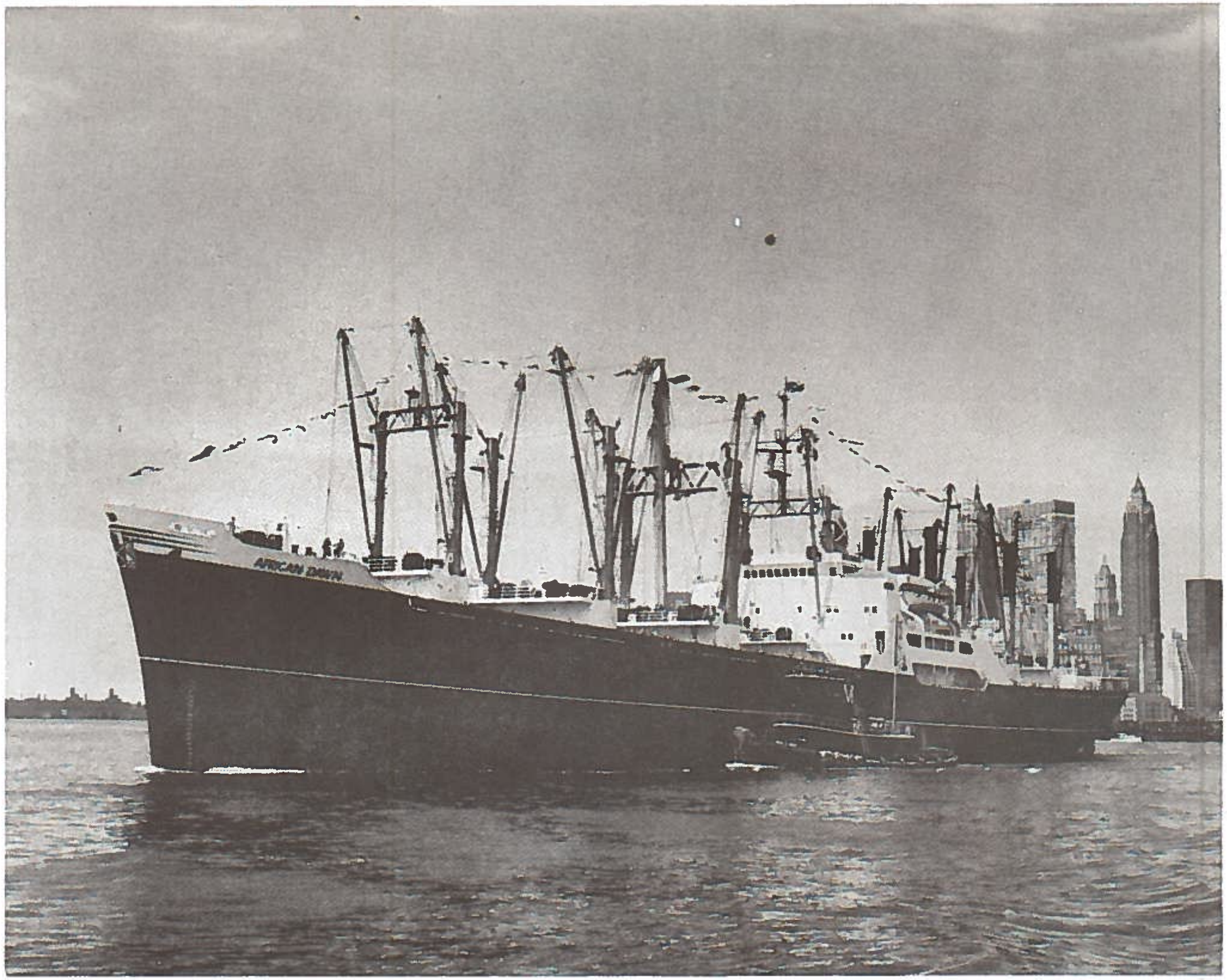


Figure 4. S/S "AFRICAN DAWN" C4 Cargo/Freighter (Farrell Lines)

fairly common size and class of freighter, and these two ships are used for transporting various cargoes between Africa and the United States by Farrell Lines. These measurements were conducted for both ships with the NM-65T instrument in a chart room at the rear of the bridge control area, and the horn antenna was located on a deck just outside this area on the starboard side.

Figure 5 illustrates the Farrell Lines C.6 fast turn-around containership S/S "Austral Envoy" at dockside. The C.6 is a more efficient class of cargo/passenger ship within this category. In other words the C.4 class spends considerably more time in port. Measurements were not conducted aboard the C.6 class because of project scheduling. Also, it was considered fairly certain that similar data would be obtained for the C.6 class as that which was previously obtained for the C.4 class.

4.4.3 Oil Tankers

Figure 6 illustrates the "EXXON San Francisco" [78,000 tons DWT) which is representative of a particular class and size of tanker used by oil companies to transport oil from the refineries to various ports in the United States and abroad. Furthermore, this is the largest size of vessel that can be accommodated at any US port because of limitations on water depth at the ports and adjacent channels. Appendix B-3 lists general data for the "EXXON San Francisco".

Periodic measurements were conducted on this ship between Boston, MA and Baytown, TX (Houston area) a distance of 2,100 nautical miles approximately. This was the normal route taken by this ship to transport oil from the Gulf coast to New England. During this voyage, the tanker was a maximum distance from land of about 250 miles off Savannah, GA in the Atlantic Ocean and about 300 miles off the Florida coast in the Gulf of Mexico. At one point, the vessel passed the Florida Atlantic coast about 18 miles east of Miami, FLA which was just within line-of-sight of the ship's bridge.

Figure 5. S/S "AUSTRAL ENVOY" C.6 Container Ship (Farrell Lines)

Figure 6. S/S EXXON "SAN FRANCISCO" Oil Tanker

The horn antenna was located on the roof of the ship's bridge as illustrated by Figure 7. This was just below the surface search X-band radar antenna, and would be fairly close to the optimum location for a future MARSAT antenna.

The NM-65T instrumentation and X-Y recorder were located just inside the bridge area as shown in Figure 8 and a coaxial cable connected this receiver input to the horn antenna located on the roof as discussed previously.

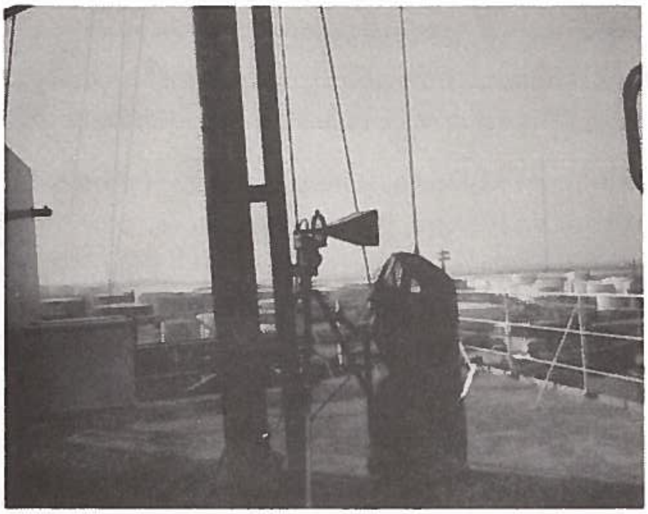


Figure 7. Horn Antenna Above Bridge

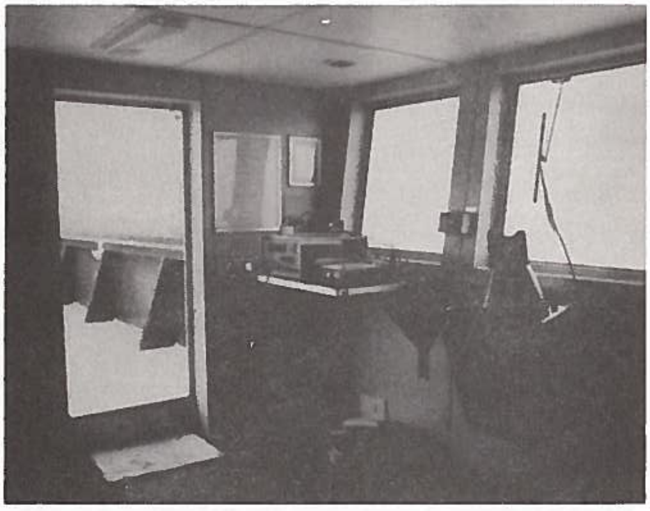


Figure 8. NM65T Instrumentation Inside Bridge Area (Beside X-Band Radar Display)

5. RECORDED DATA DISCUSSION

5.1 REPRESENTATIVE EM NOISE EXAMPLES

The result of EM noise measurements performed in the band 1500 MHz to 1600 MHz (L-band) on board various classes of ships indicate that the following are predominant sources of L-band noise:

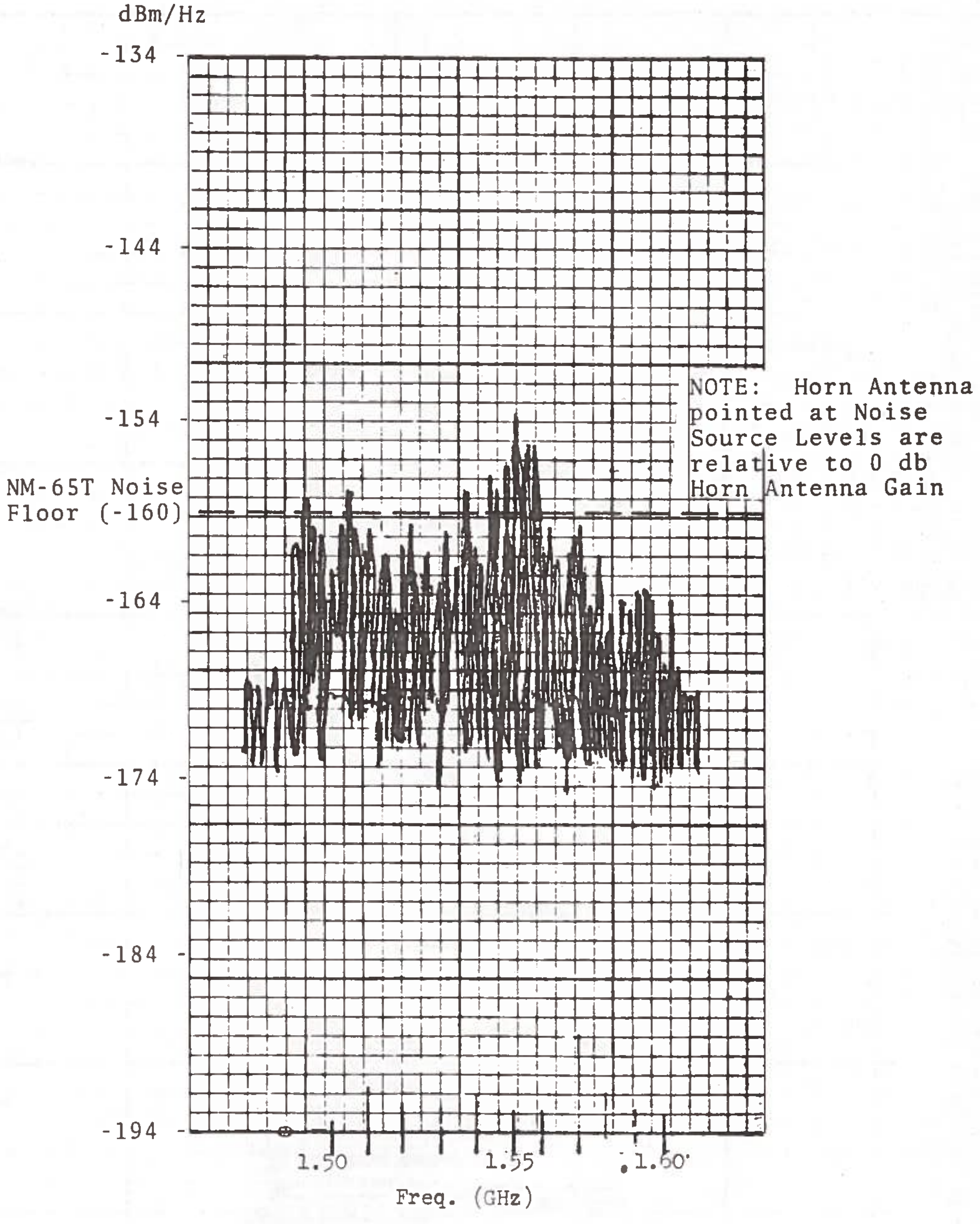
NOTE: For each example discussed it was necessary to subtract a value of 10 dB which is the effective horn antenna gain. Therefore, the noise amplitudes are referred to a 0 dB antenna gain as indicated on the X-Y recordings. This also explains why the indicated noise floor level is apparently 10 dB above the recorded noise floor baseline.

5.1.1 Noise Example, Ship in Drydock at Bethlehem Steel, Boston, MA

Figure 9 is a recorded example of broadband impulsive EM noise (refer to Appendix A) due to electric motor brush arcing. This was recorded on a fairly old (1930) 327-foot USCG cutter which was in drydock at the time. Electric motor noise is evident only on older ships. The newer ships (under 15 years) employ ac induction motors and arcing is minimized. This noise source originated at an electric ventilation motor located just below the bridge. These motors are located on both the port and starboard sides. This is a severe RFI case, and was the example cited in a 1973 US Government approved submission to the Inter-Governmental Maritime Consultative Organizations (IMCO).[4] This EM noise source was also evident during en-route measurements on another 327-foot USCG cutter.

5.1.2 Noise Example at Sea for S/S "AFRICAN COMET"

Figure 10 is an example of EM noise which was present only when an S-band (3030 MHz) radar was in operation, and the horn antenna was pointed towards the radar scanning antenna above the



EM. NOISE - Shipboard Measurements Nov. 16, 1972
Drydock - Bethlehem Steel, Boston, Mass. USA

Figure 9. Noise Example Dockside for 327' USCGC "CAMPBELL"

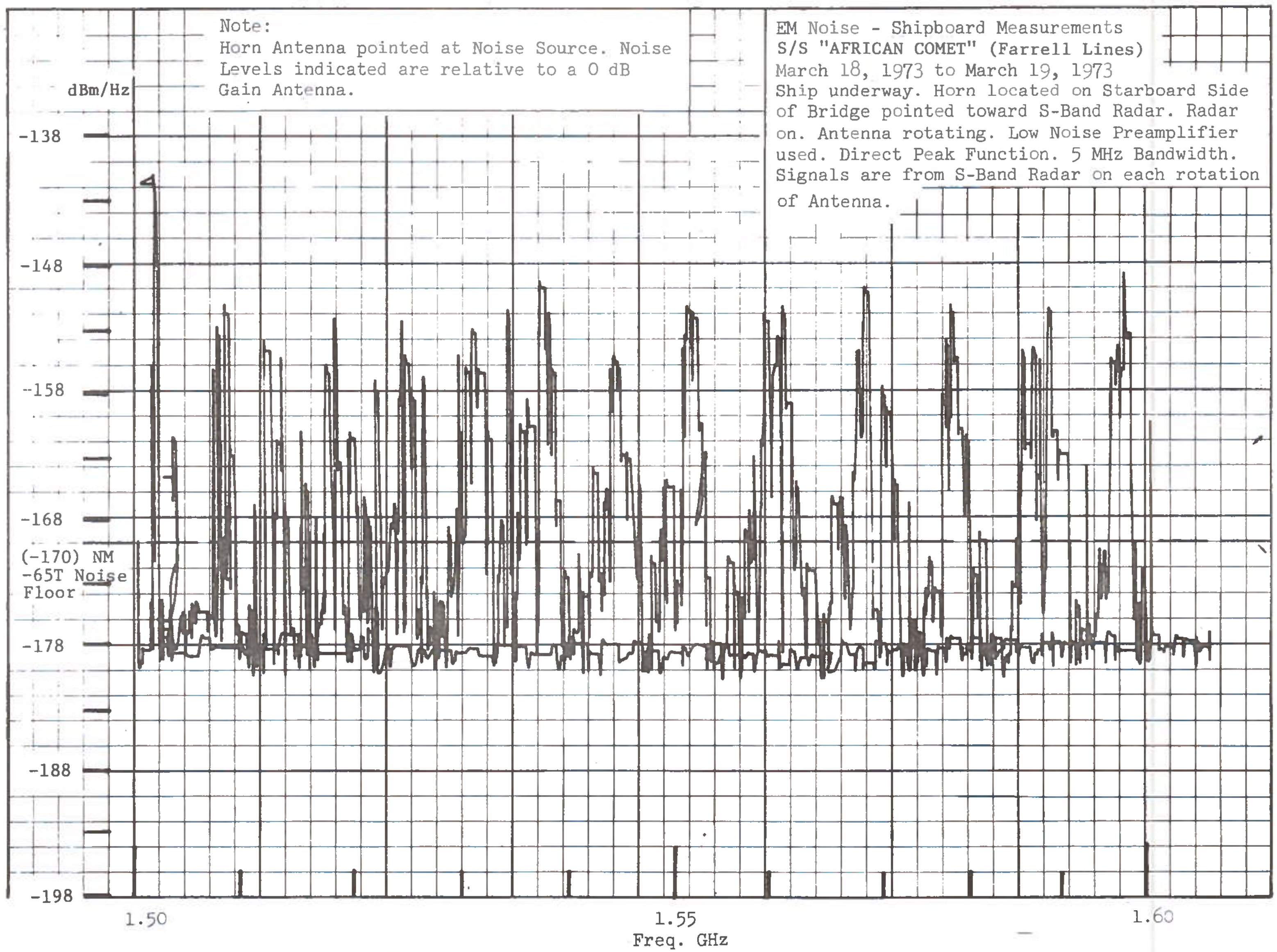


Figure 10. Noise Example at Sea (10 cm Radar) for S/S "AFRICAN COMET"

bridge. This radar is the surface search radar used on a particular C.4 cargo/freighter, and the recording was taken when the ship was out to sea, also the noise was not present when the radar was switched off. Furthermore, there were no coastal EM noise sources within radio line-of-sight of the ships. Following these particular en-route measurements, laboratory tests eliminated the possibility of this noise being the result of a spurious response within the Singer NM65T receiver from an S-band signal source. These tests actually confirmed the Singer specification of 60 dB minimum for spurious response rejection at L-band. The impulse character of this noise example was, to some extent, due to the antenna rotation of 15 RPM. This was the example cited in the 1974 US Government approved submission to the International Radio Consultative Committee[5] (CCIR). The maximum noise power density within the MARSAT receive band (1535-1543.5 MHz) is -150 dB/Hz.

5.1.3 Noise Example Dockside for 378-Foot USCG "CHASE"

Figure 11 is an example of particularly severe broadband impulsive noise originating at combustion engine ignition circuits used with dockside unloading apparatus. This was evident only when the apparatus was in operation at Prudence Island, RI. Due to the isolated location for this case, the noise can be attributed entirely to the unloading apparatus. In other cases, this type of noise is usually combined with other sources including city ambient noise for which some examples will follow. The location is in Narraganset Bay, RI, and the closest city is Portsmouth, RI, a distance of approximately 5 miles. The preamplifier was not required for this recording, and the maximum peak amplitude within the MARSAT receive band (1535-1543.5 MHz) is about -137 dBm/Hz. This is an average of the peak values detected within a 5 MHz band. This category of L-band noise was found to exist at all ports when unloading apparatus, both dockside and shipboard, was in operation. However, this was the most severe example recorded for this noise category.

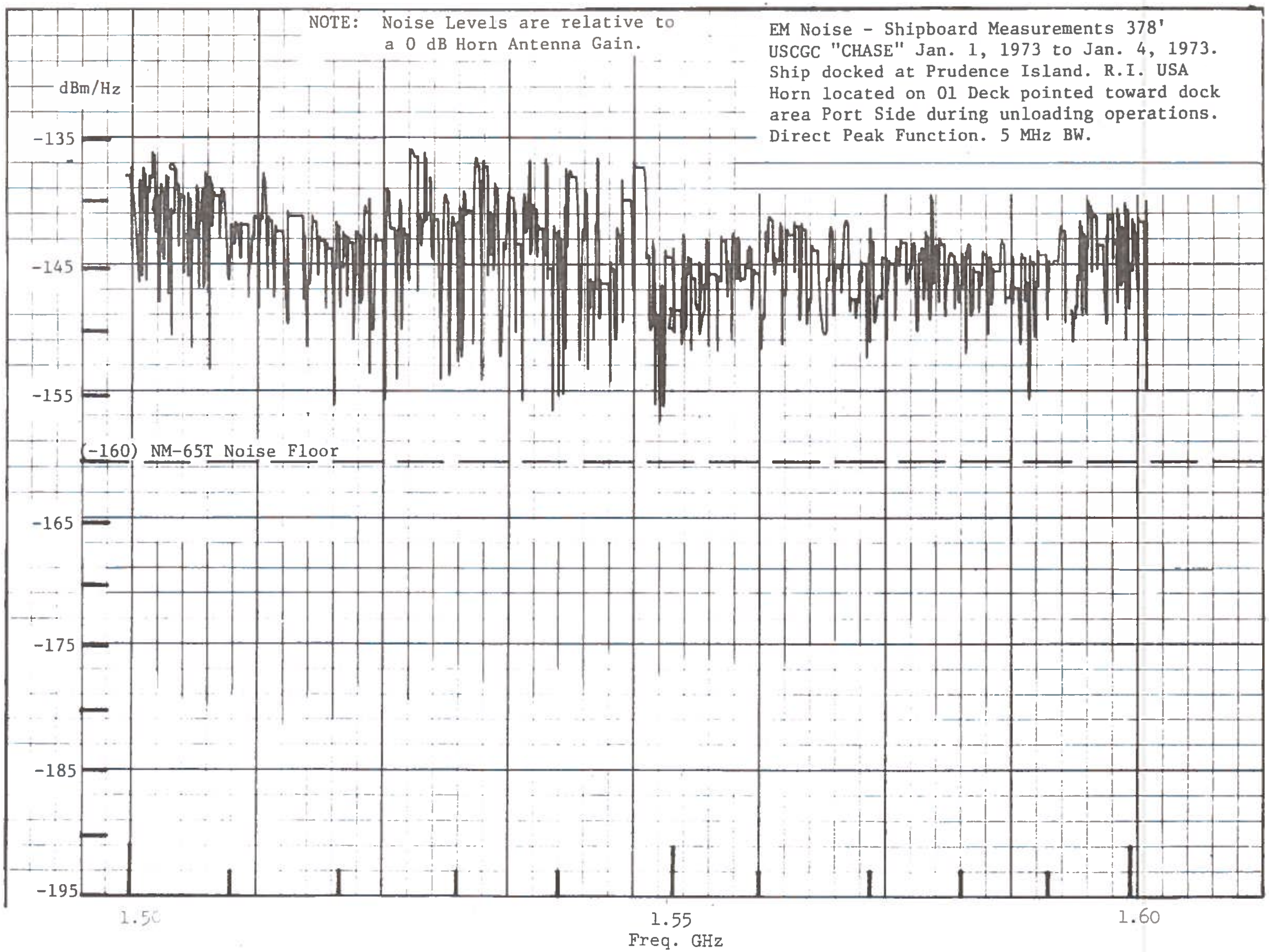


Figure 11. Noise Example Dockside for 375' USCGC "CHASE"

5.1.4 Noise Example Dockside for S/S "AFRICAN COMET"

Figure 12 was recorded from a freighter after it docked at Brooklyn, NY. The noise source is broadband impulsive ignition noise from cranes operating at dockside. The preamplifier was used, and the maximum peak amplitude is about -167 dBm/Hz in the MARSAT receive band. This is not as severe as that shown in the previous example (Figure 11). Without the preamplifier this noise would have been barely discernible, because the instrument noise level would have been -160 dBm/Hz for the 5 MHz BW position. The horn antenna was pointed towards the dock from the starboard side of bridge area.

5.1.5 Noise Example Dockside for S/S "AFRICAN COMET" (cont'd)

Figure 13 was recorded from the same freighter under the same conditions as discussed in 5.1.4. In this case the horn antenna was pointed towards the Bow which was facing the Brooklyn expressway. At the time this recording was taken the ship's cranes were in full operation, and very heavy traffic was evident on the expressway close by. It can be seen that the EM noise levels have increased about 17 dB compared to the previous example, and this can be considered a serious RFI case. This appears to be a combination of broadband impulsive ignition noise from shipbpard/dockside unloading apparatus, and automotive sources. In this case, the maximum peak amplitude within the MARSAT receive band is about 150 dBm/Hz compared to -167 dBm/Hz in the previous example.

5.1.6 Noise Example Dockside for 378-Foot USCGC "SHERMAN"

Figure 14 illustrates an example of broadband noise recorded from a 378-foot USCG cutter prior to departure from Boston, MA on a normal working day. The horn antenna was pointed towards the Boston Navy Yard which was in full operation at the time. Extremely high noise peak amplitudes of -141 dBm/Hz are evident within the MARSAT receive band. This example illustrates a combination of city ambient and industrial equipment broadband EM noise. This can be considered a serious RFI case.

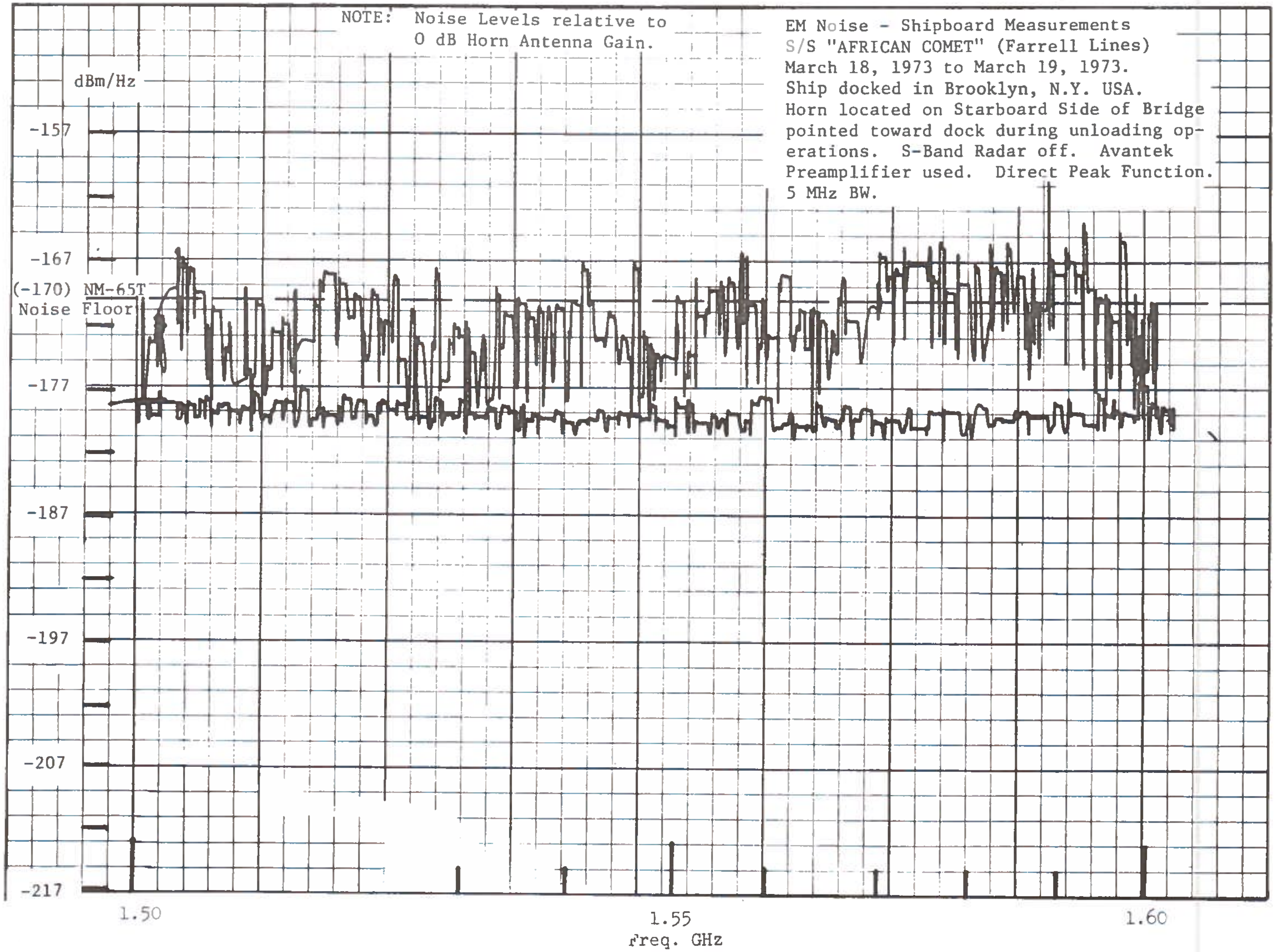


Figure 12. Noise Example Dockside for S/S "AFRICAN COMET"

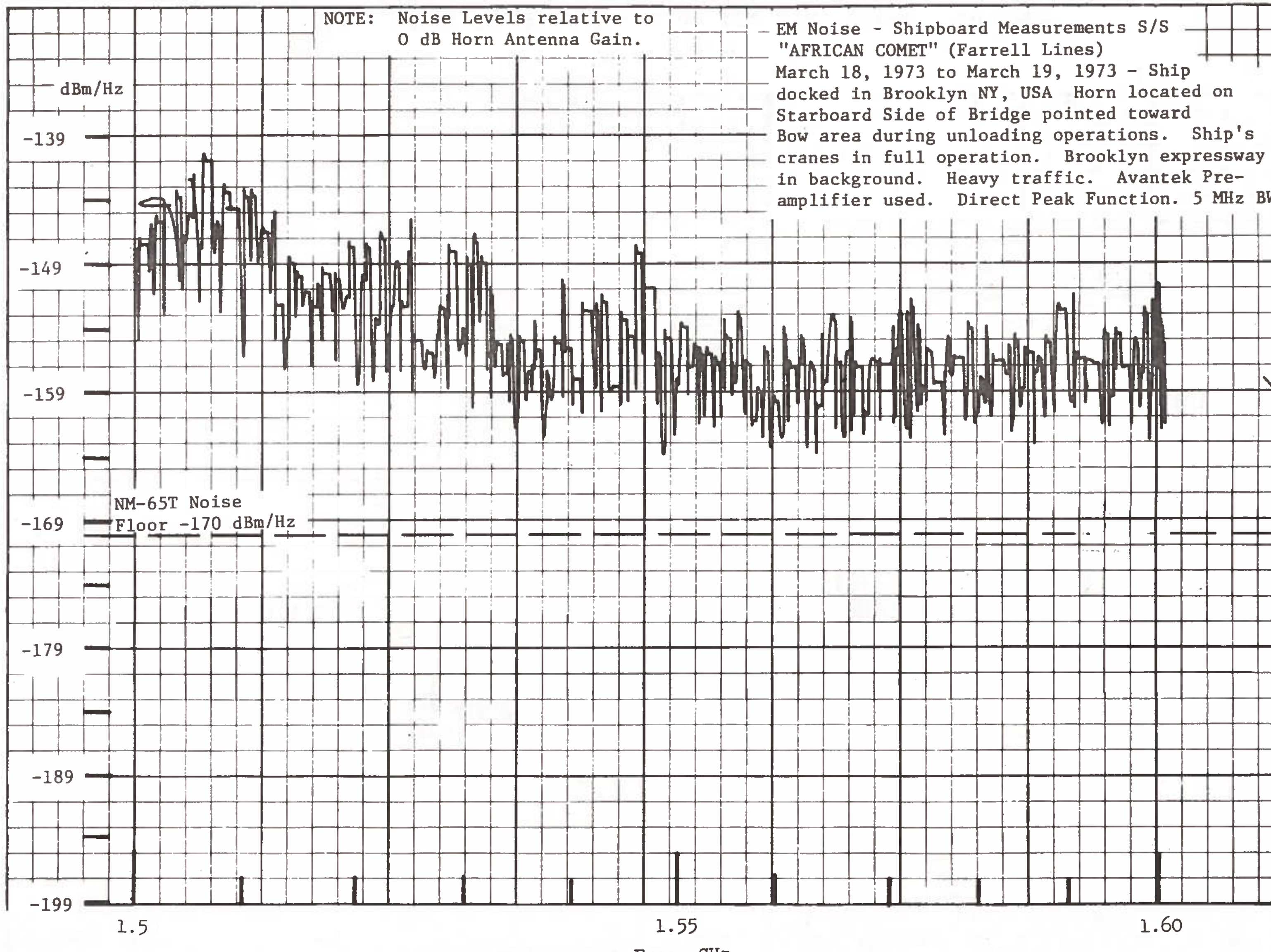


Figure 13. Noise Example Dockside for S/S "AFRICAN COMET" (Cont'd)

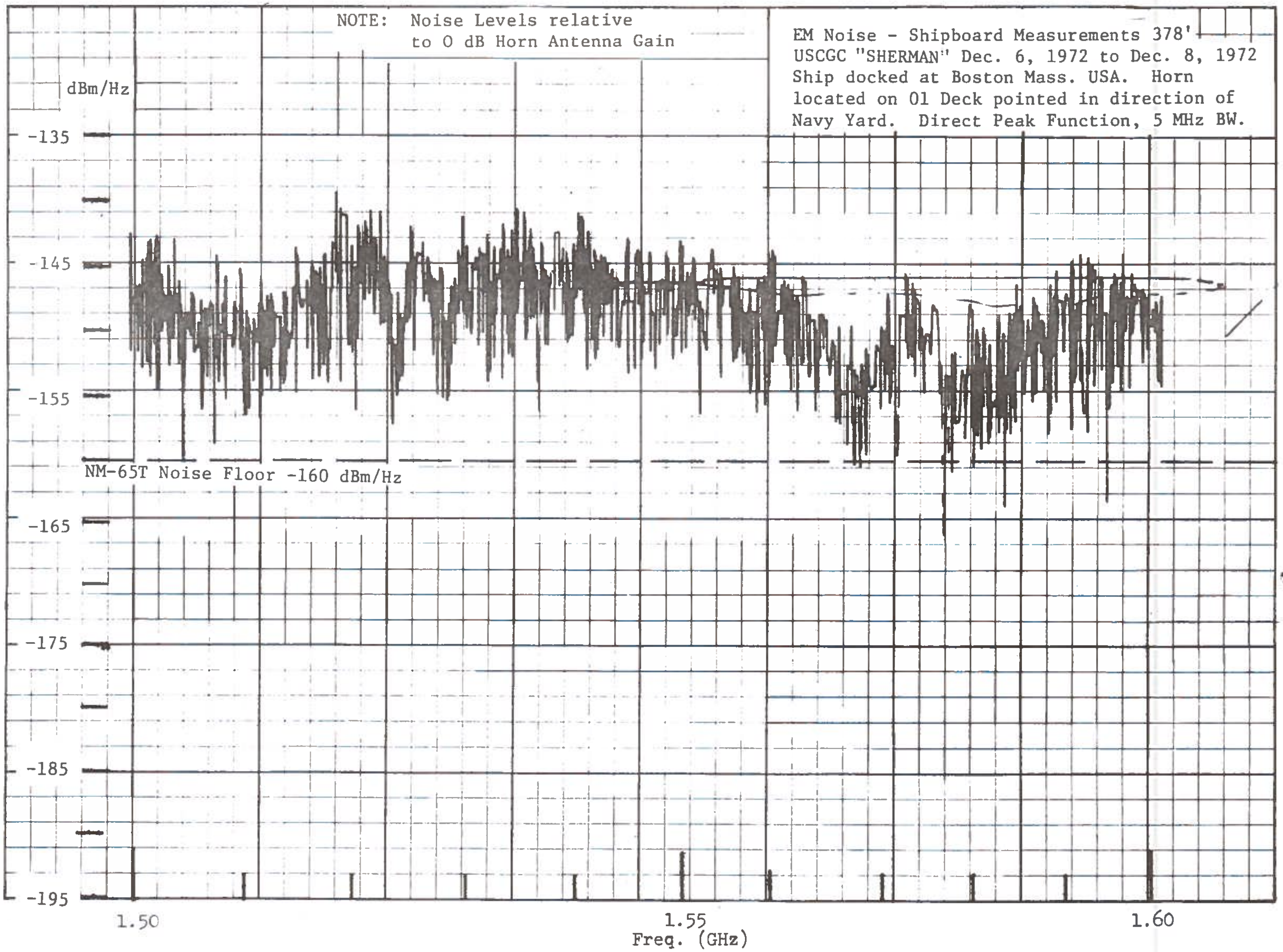


Figure 14. Noise Example Dockside for 378' USCGC "SHERMAN"

5.1.7 Noise Example Dockside for 378-Foot USCGC "SHERMAN" (cont'd)

Figure 15 was recorded under the same conditions as those for the previous example discussed in 5.1.6. The only exception was that this recording was taken on a Sunday when the Boston Navy Yard and other industrial plants were not in operation. It can be seen that the general noise level within the MARSAT receive band has dropped about 20 dB to -161 dBm/Hz compared to the previous example (Refer to Figure 14). As might be expected, it has been observed that general city ambient noise levels are lower on weekdays and holidays when industrial operations are minimal. This is a marginal RFI example which implies that some degradation in C/N_o would result in the communications channel without complete loss in communications.

5.1.8 Noise Example Near Port for EXXON "San Francisco"

Figure 16 was recorded from an oil tanker 8.5 miles off Key West, FLA. At this distance, the city ambient average noise power level within the MARSAT receive band is not too significant relative to the instrument noise floor level of -170 dBm/Hz except for an occasional narrowband non-continuous peak for which the maximum amplitude is about -169 dBm/Hz within the MARSAT receive band. If we estimate a maximum bandwidth of 100 kHz for some of the pulses indicated, the average noise power would be 17 dB below this value or -186 dBm/Hz even for a continuous signal. The duty cycle would also have to be taken into account resulting in an average noise power less than -186 dBm/Hz. It is reasonable to assume therefore that the EM noise levels shown in Figure 16 would not result in any significant RFI to a MARSAT receiver. Section 6 deals with data analysis in further detail.

5.1.9 Noise Example in Canal for 378-Foot USCGC "CHASE"

Figure 17 illustrates an example of EM noise which originated at some mercury lamps on a bridge across a canal. The ship was fairly close to the bridge for this recording. Noise generated by gas discharge tubes of this type is usually cyclical in character as indicated. This has also been observed for fluorescent lighting

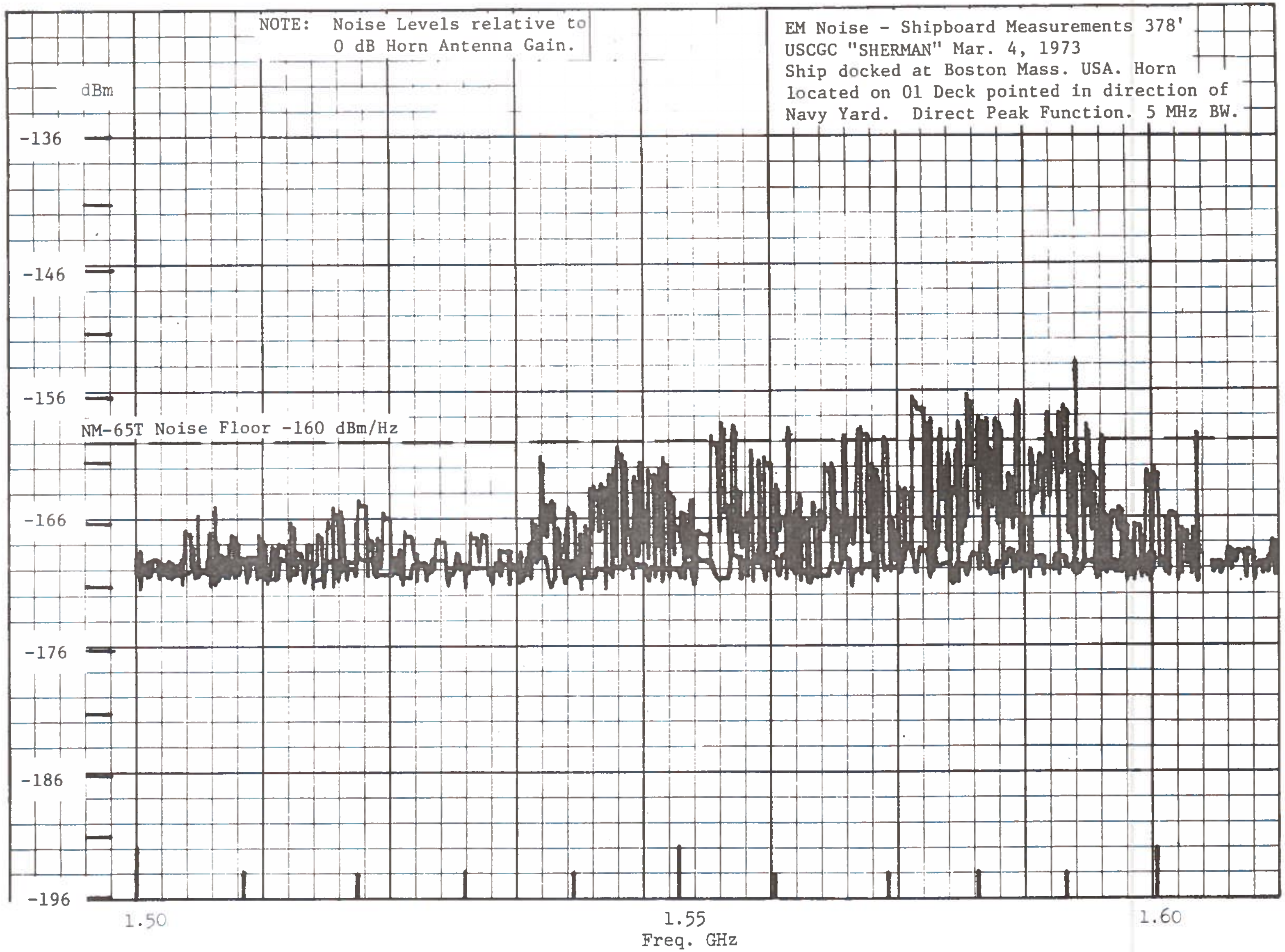


Figure 15. Noise Example Dockside for 378' USCGC "SHERMAN" (Cont'd)

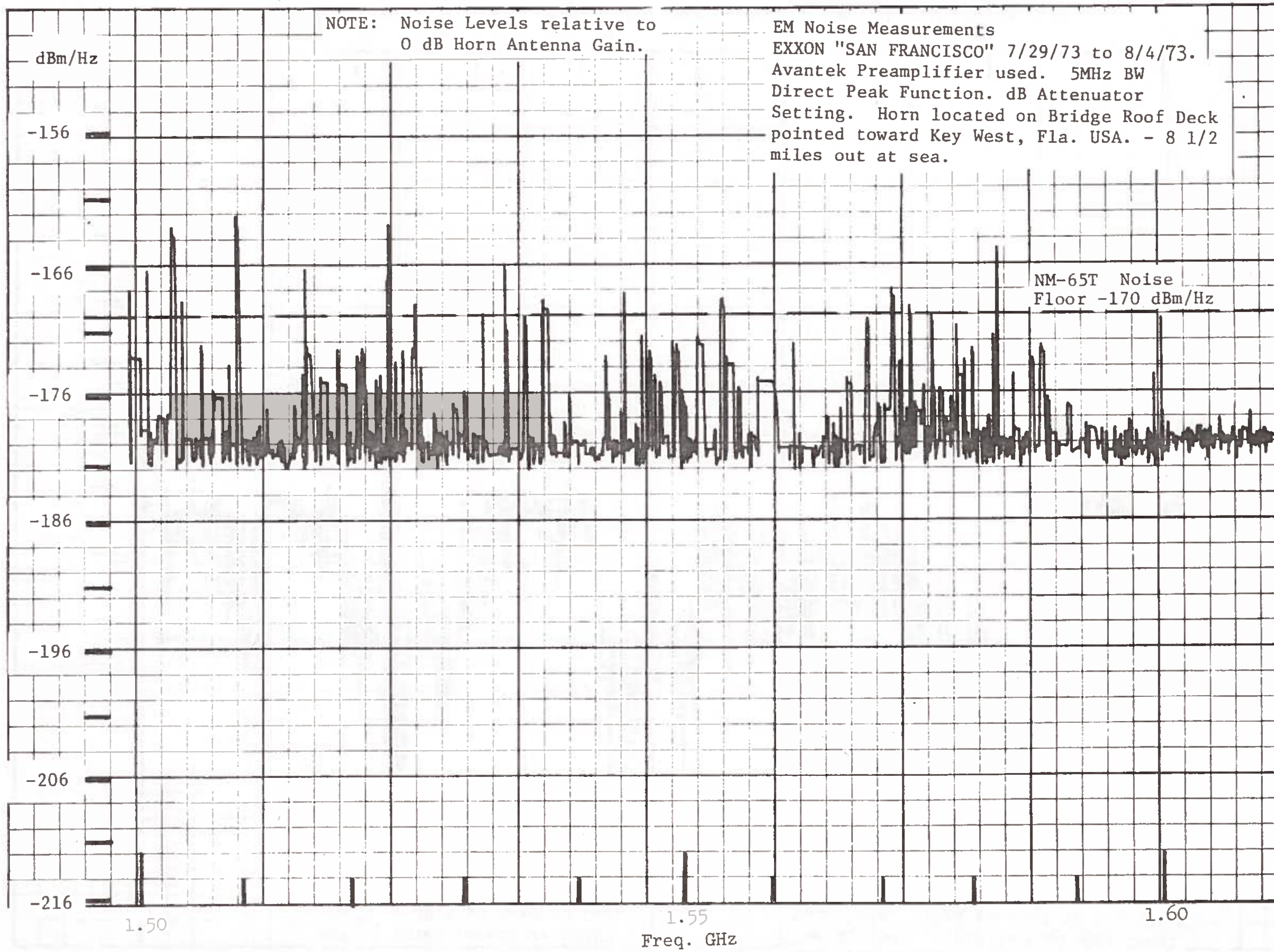


Figure 16. Noise Example Near Port for EXXON "SAN FRANCISCO"

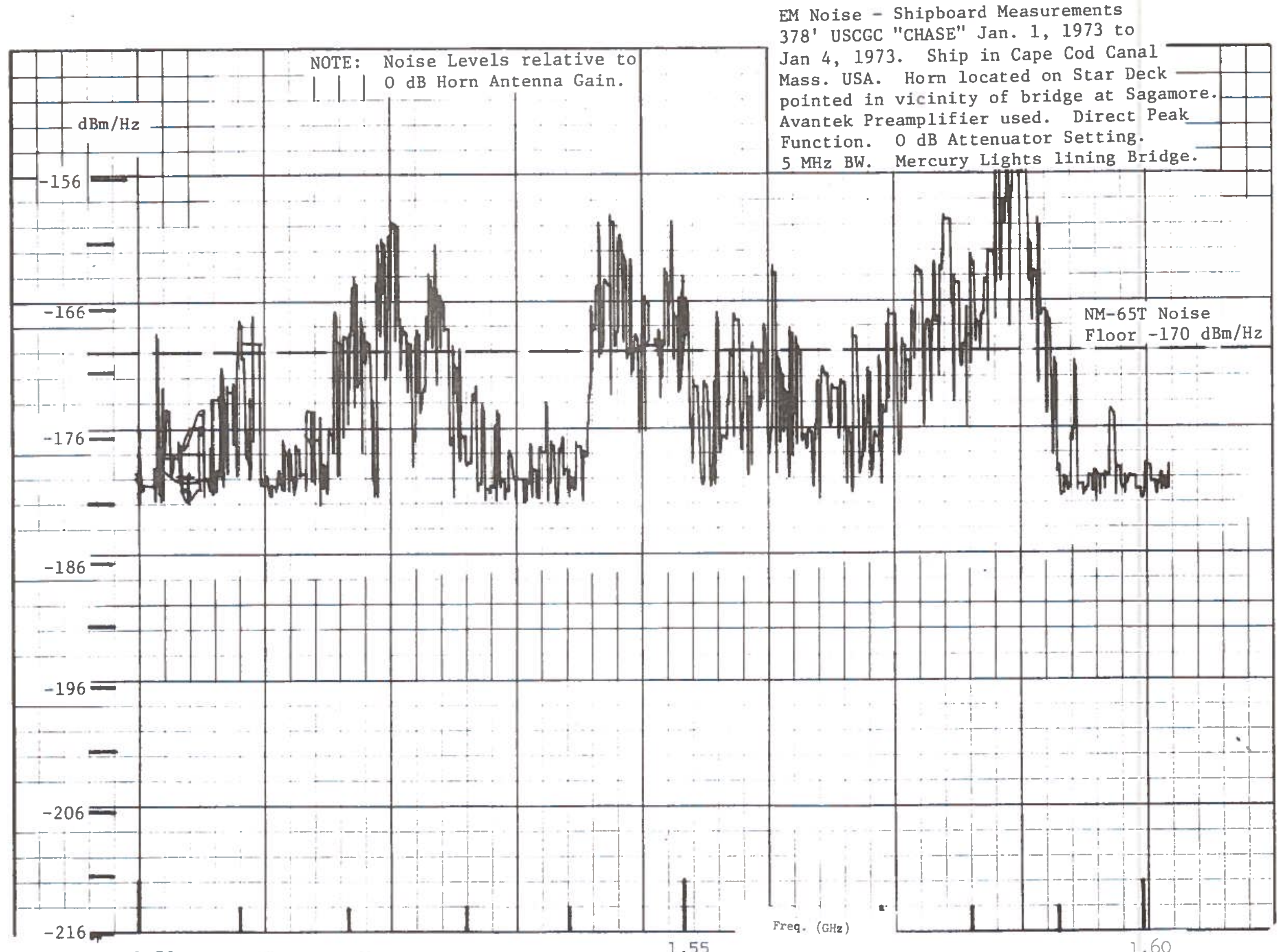


Figure 17. Noise Example in Canal for 378' USCGC "CHASE"

on other ships. It is not expected that this noise category would be encountered very often by MARSAT equipped ships in the future. Therefore, this can be considered a very low probability RFI example.

5.1.10 <u>Noise Example Near Airport for EXXON "San Francisco"</u>

Figure 18 was recorded from a ship passing within two (2) or three (3) miles of Logan Airport, Boston, MA. Some non-continuous (antenna scanning) noise peaks are evident across the MARSAT receive band and the maximum peak amplitude is about -154 dBm/Hz. This noise is identified as upper sidebands and spurious emissions from the 1330 MHz scanning air route surveillance radar (ARSR) operating at the airport. This noise category has also been evident on other ships when in close proximity to Logan Airport and other major airports, including New York and Baltimore. It is not certain that this L-band noise source would result in significant RFI to a MARSAT equipped ship in the future because the average noise power in any pulse within the band of interest (1535-1543.5 MHz) appears to be below the ship's noise floor for this and other recordings taken for the ARSR. A coaxial bandpass filter was used in this case to verify that the noise pulses were truly external L-band pulses, and not spurious responses in the instrument receiver from an S-band (3000 MHz) signal for example. The readings were identical with or without the filter and this means that the noise pulses were truly from an external L-band source, namely; the ARSR at Logan Airport. This can be considered a low probability RFI example.

5.1.11 <u>Zero Noise Example at Sea for EXXON "San Francisco"</u>

Figure 19 illustrates a zero noise condition at the -170 dBm/Hz instrument noise floor when an oil tanker was out at sea in the Gulf of Mexico, and the horn antenna was pointed south towards Cuba,a distance of ninety (90) miles. When the preamplifier is used, as in this case, there is a certain amount of X-Y recorder pen jitter which should not be mistaken for noise. (Refer to Figure 20.)

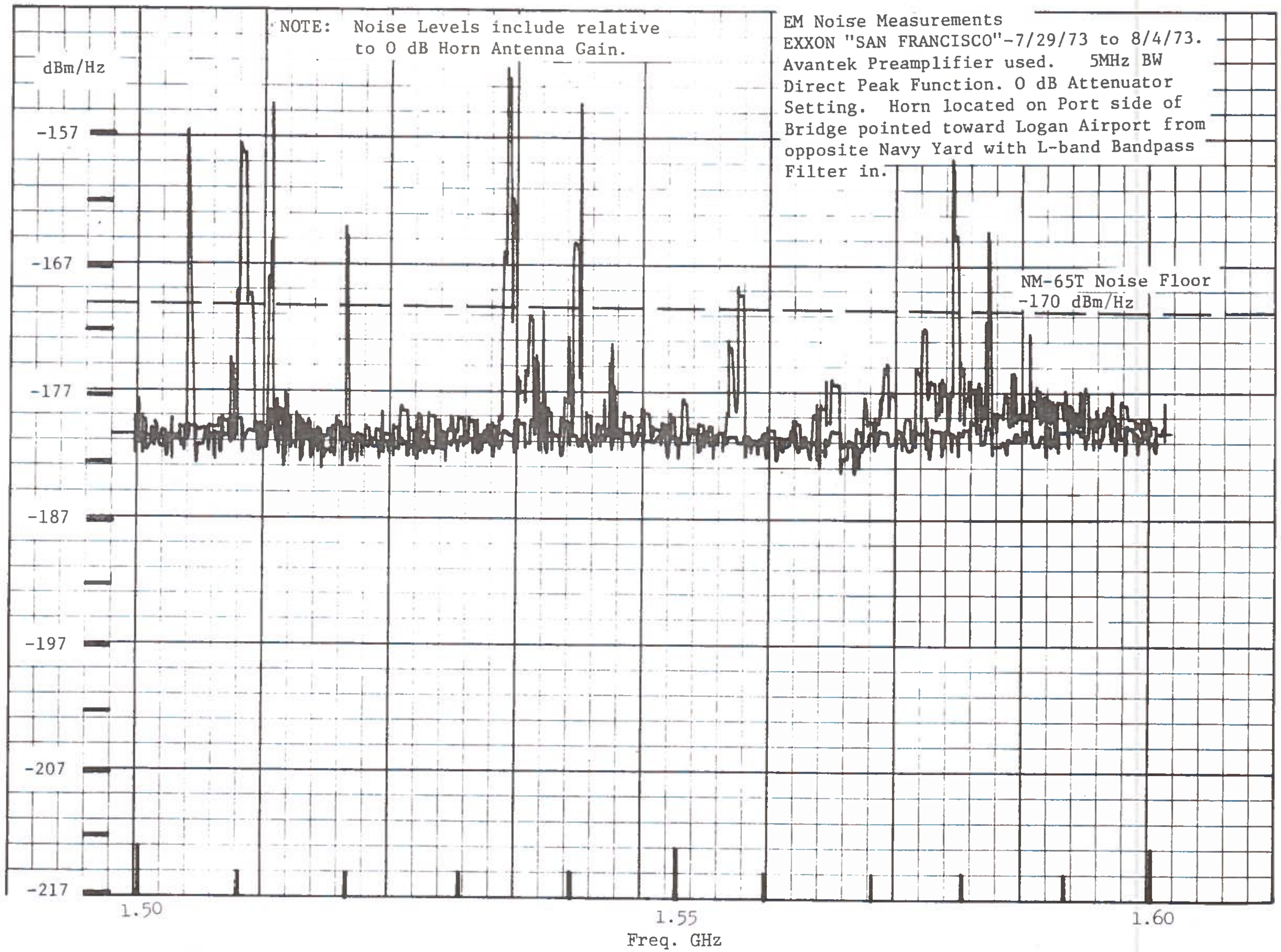


Figure 18. Noise Example Near Airport for EXXON "SAN FRANCISCO"

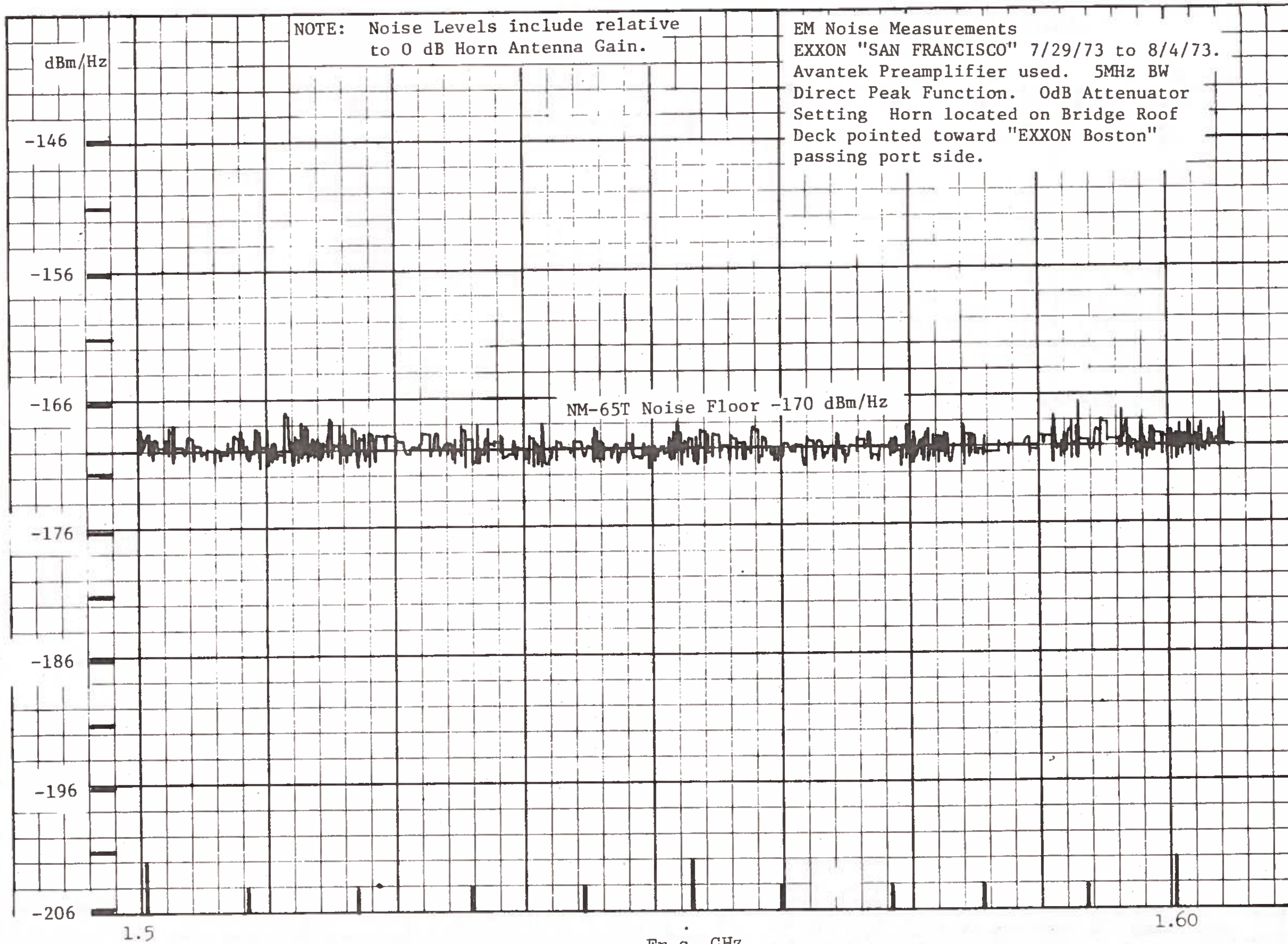


Figure 19. Zero Noise Example at Sea for EXXON "SAN FRANCISCO"

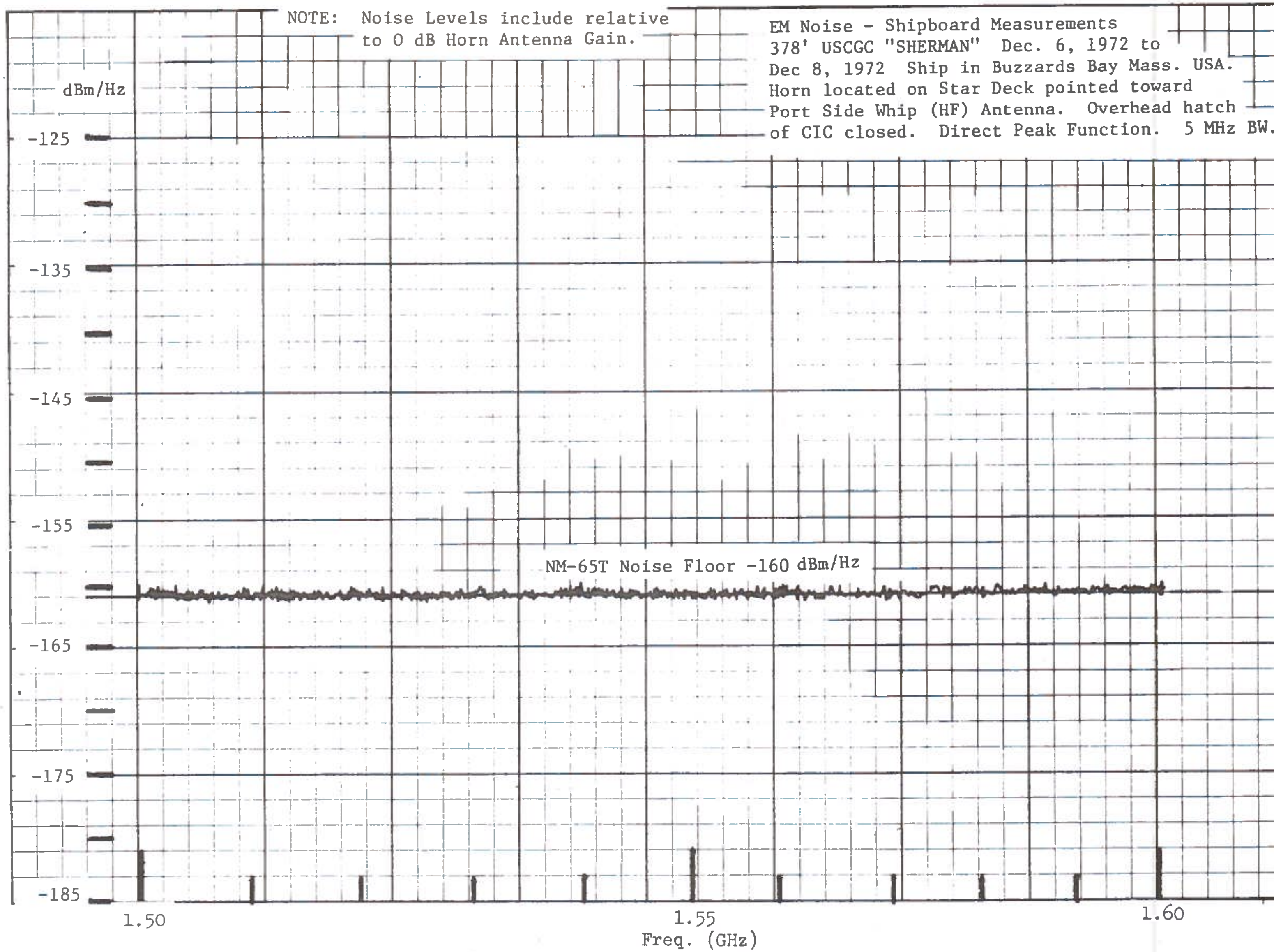


Figure 20. Zero Noise Example at Sea for 378' USCGC "SHERMAN"

5.1.12 Zero Noise Example at Sea for 378-Foot USCGC "SHERMAN"

Figure 20 is for a zero noise condition at the -160 dBm/Hz instrument noise floor recorded in Buzzards Bay. In this case the preamplifier was not used and the instrument sensitivity is less than for the previous example (Figure 19). The X-Y recorder pen jitter is not so pronounced when compared to the previous case. (Compare Figures 19 and 20.)

5.1.13 Zero Noise Example at Sea (Passing Ship) for EXXON "San Francisco"

Figure 21 was recorded from an oil tanker out at sea in the Gulf of Mexico when another ship (tanker) was passing close by on the port side. It was determined by the radio officer that the other tanker had an S-band surface search radar in operation at the time. The recording indicates a zero noise condition down to -170 dBm/Hz the instrument noise floor. The two ships were about one mile apart for this recording, and even if L-band noise was being generated by the S-band radar on the other ship, this would not be discernible since, if we refer to Figure 10 which illustrates L-band noise from an S-band radar, the noise levels indicated would be attenuated below the instrument noise floor at a distance of one mile. Figure 10 was recorded with the horn antenna only about 20 feet from the S-band radar antenna. This is significant, however, when we consider that a future MARSAT shipboard antenna would be mounted above the bridge on numerous ships in close proximity to the surface search radar antenna by necessity. Therefore, the L-band noise would have to be suppressed with a filter (see Section 7.2).

5.1.14 Noise Example at Sea (Internal Source) for EXXON "San Francisco"

Figure 22 is an example of EM noise generated by electrical apparatus on an oil tanker. If we refer to Appendix B-3, it will be noted that there are only two electrically operated ballast pumps on this particular ship, and they were in operation at the time of

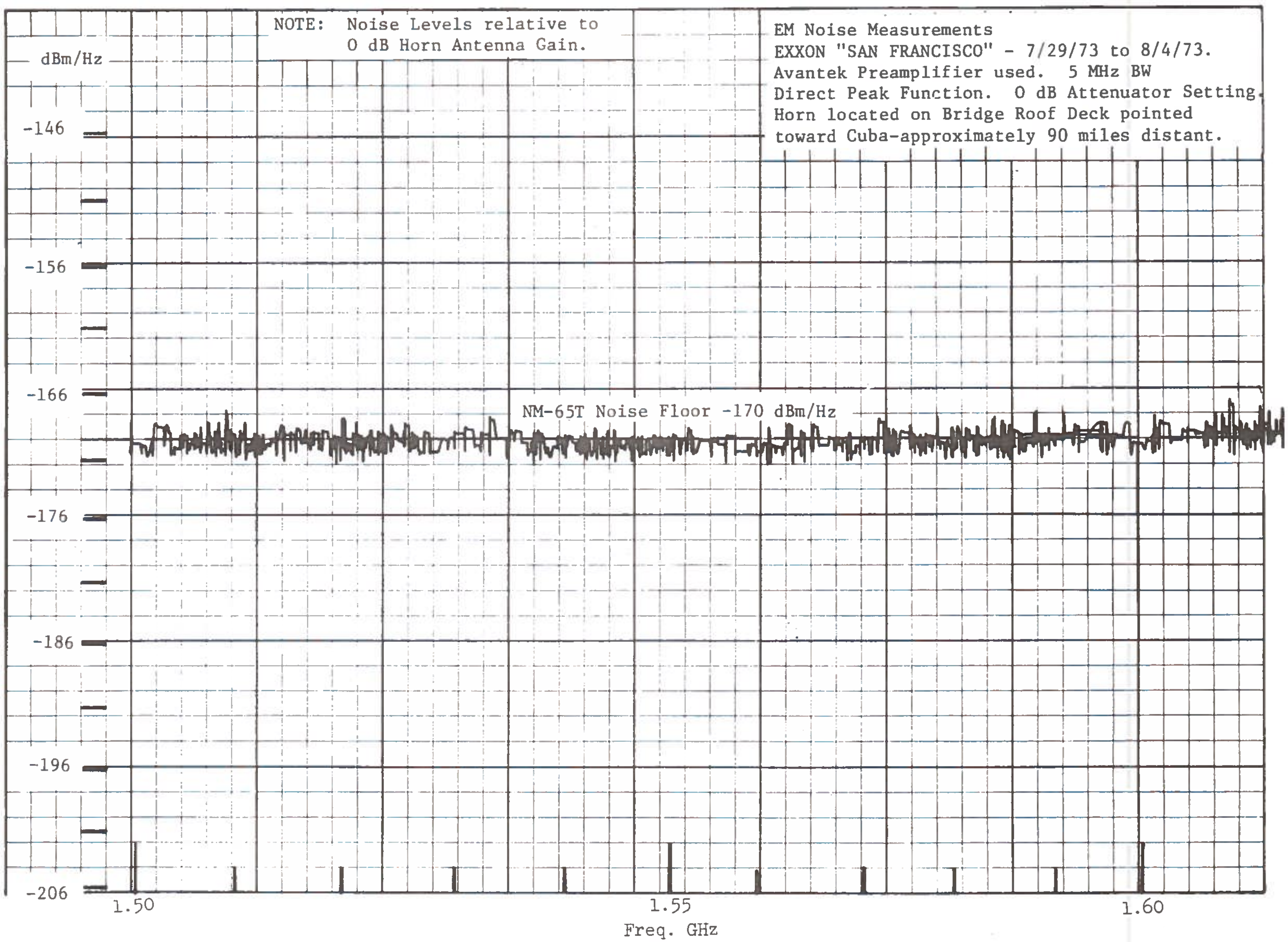


Figure 21. Zero Noise Example at Sea (Passing Ship) for EXXON "SAN FRANCISCO"

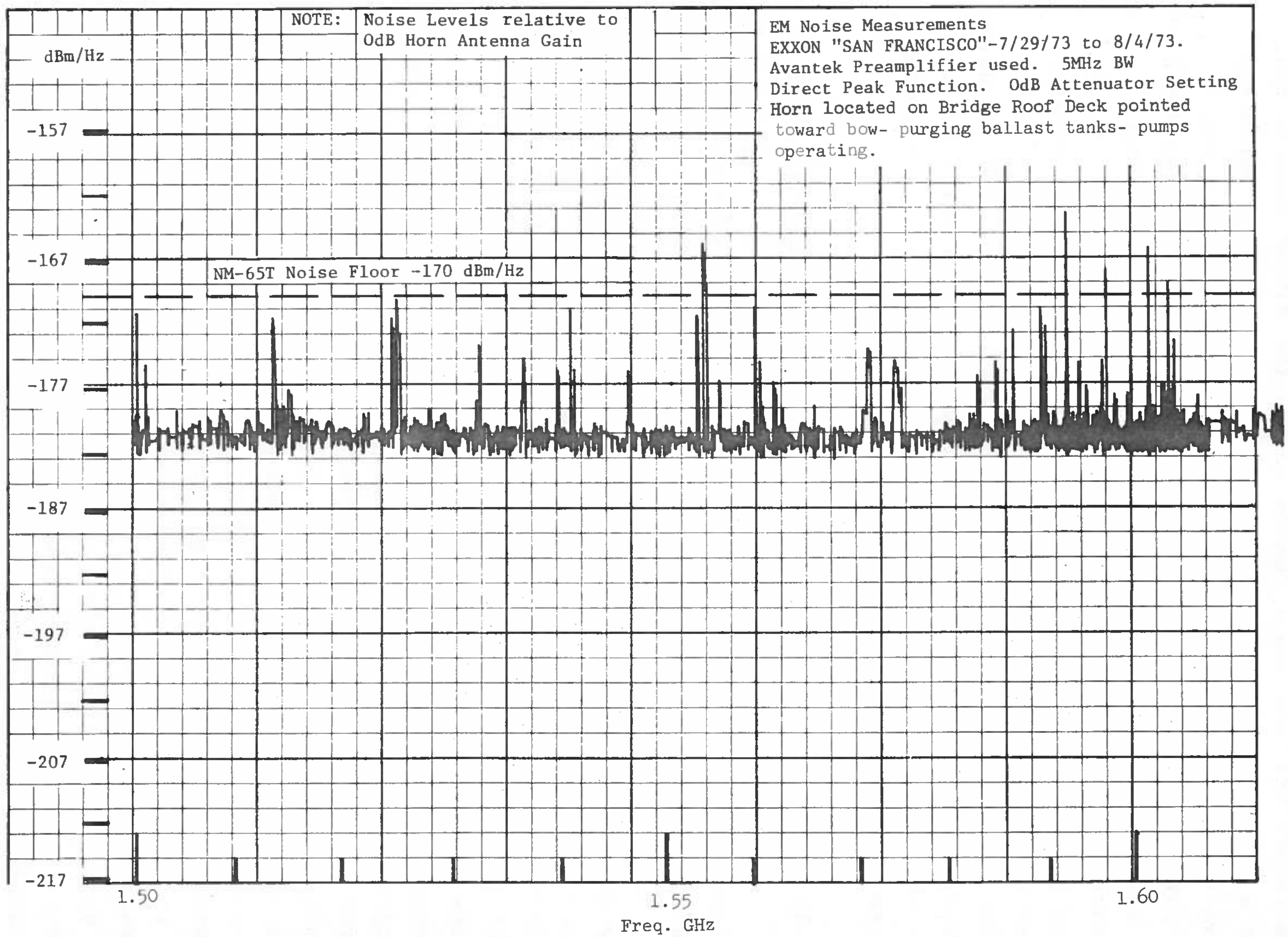


Figure 22. Noise Example at Sea (Internal Source) for EXXON "SAN FRANCISCO"

this recording. The noise pulses within the MARSAT receive band have a maximum amplitude of -171 dBm/Hz which is just below the noise floor. Due to the frequency scale resolution for the X-ordinate, it is difficult to accurately determine the bandwidth of the individual pulses which is probably less than 100 kHz. Furthermore, the duty cycle is less than 1.0, the value for CW noise sources, therefore the average power in 1 Hz will probably be well below the shipboard MARSAT receive noise floor of -171 dBm/Hz (refer to Section 6). The ship was out at sea in the Gulf of Mexico for this recording, and the L-band noise was not evident when the pumps were switched off. This example is not considered to represent a potential RFI problem.

5.1.15 Noise Example Dockside (Internal Source AN/SPS-29 Radar) for 378-Foot USCGC "CHASE"

Figure 23 illustrates an L-band harmonic and spurious emissions generated by an AN/SPS-29 air search radar (ASR) transmitter. This ASR is employed by a large number of USCG cutters, and US Navy ships, but not by merchant ships. This potential L-band RFI source was evident for all USCG cutters checked which employed the AN/SPS-29. The ASR cannot be operated in ports, and ships must be about 100 miles out at sea before the system can be used. A future MARSAT antenna would be in close proximity to the ASR antenna by necessity; therefore, ships equipped for MARSAT signal reception would have to provide for the inclusion of a coaxial filter at the AN/SPS-29 transmitter in order to suppress the L-band harmonic and spurious emissions. (Refer to Section 7.2.) The peak value of noise power for this example is -140 dBm/Hz and the average power is also high. This example was actually measured as leakage from the transmitter on standby with the horn antenna in the radio room adjacent to the AN/SPS-29 transmitter room. On one occasion when the 378-foot cutter "CHASE" was 100 miles out to sea, the transmitter was switched from standby to the scanning antenna located in a mast above the ship and the harmonic interference was measured radiating from the AN/SPS-29 antenna. US Navy ships which employ the AN/SPS-29 ASR will probably not cause interference

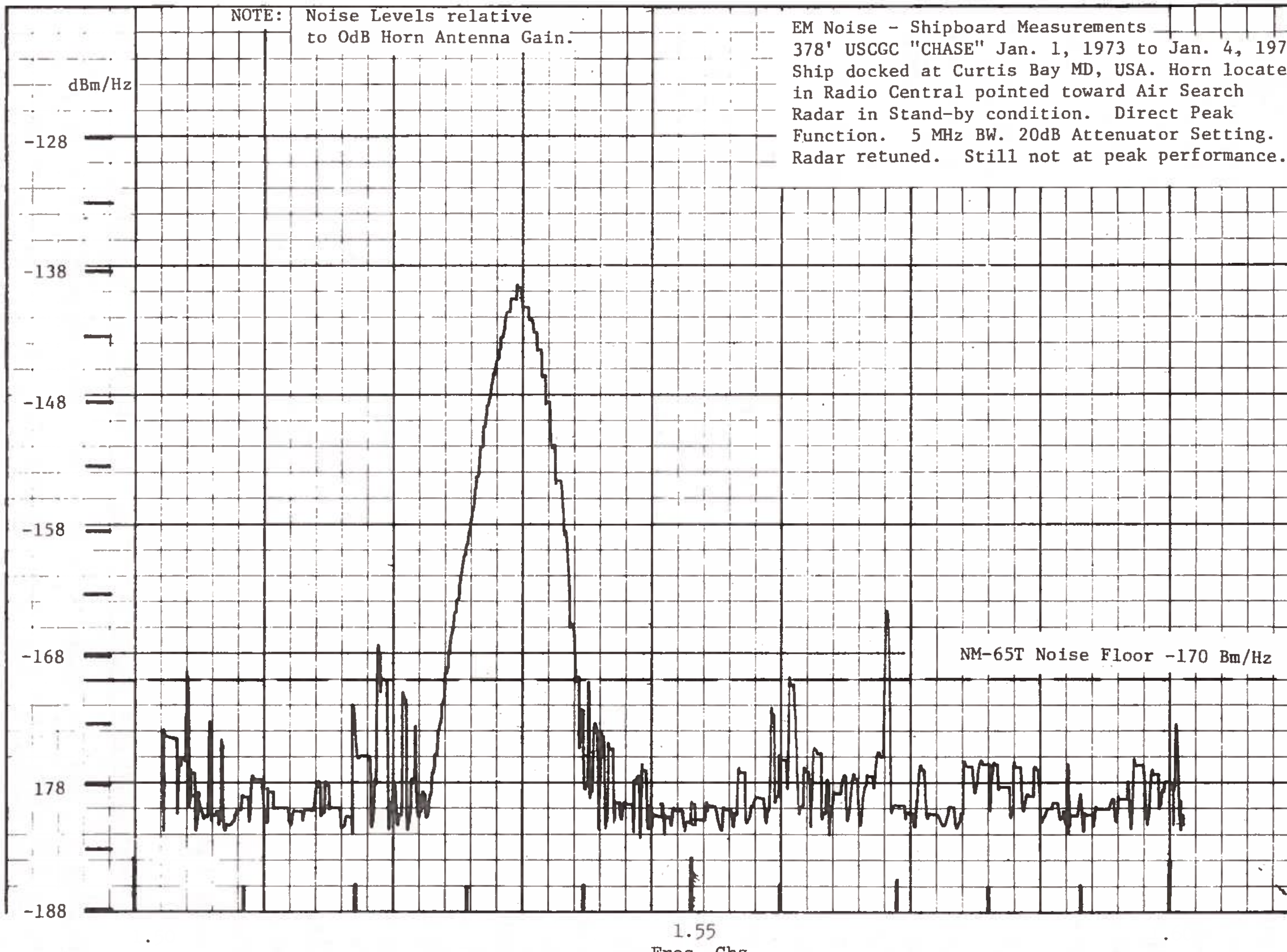


Figure 23. Noise Example Dockside (Internal Source AN/SPS-29 RADAR) for 378' USCGC "CHASE"

to MARSAT equipped ships or AEROSAT equipped aircraft (1942.5-1558.5 MHz receive band). This example (Figure 23) was measured with the horn antenna very close (20-feet) to the source. Within line-of-sight, the free space attenuation would reduce the peak power value of -140 dBm/Hz at 20-feet to about -182 dBm/Hz at a distance of 0.5 miles. Furthermore, the AN/SPS-29 is only radiating for a small percentage of the time under emergency conditions.

5.1.16 Noise Example Near Airport for 378-Foot USCGC "SHERMAN"

Figure 24 was recorded with the instrument bandwidth selector in the 100 kHz position shortly following departure of a 378-foot USCG cutter from Boston, MA. This increases the instrument sensitivity from -103 dBm/5 MHz to -120 dBm/100 kHz which is an improvement of 17 dB.

NOTE: NM-65T noise floor is -170 dBm/Hz, which is the same for both 100 kHz or 5 MHz modes with the preamplifiers when used.

The primary purpose of this example is to show some measured L-band noise pulses in the MARSAT receiver band which would not have been apparent for a 5 MHz bandwidth recording. It was previously mentioned that the instrument procedures emphasize that measurements from broadband noise sources do not yield valid data for the 100 kHz bandwidth position. The noise pulses indicated on Figure 24 are not significant in terms of potential RFI to a MARSAT receiving system, because the noise power per Hz is below the established criteria discussed in Section 6. This noise actually originated at a broadband source but the recording was taken to illustrate the detection of noise below the -103 dBm/5 MHz instrument sensitivity.

5.1.17 Noise Example at Sea for 378-Foot USCGC "CHASE"

Figure 25 was recorded for the same instrument settings as for the previous example 5.1.16 (refer to Figure 24). In this case the ship was out at sea (USCGC "CHASE"). The horn antenna

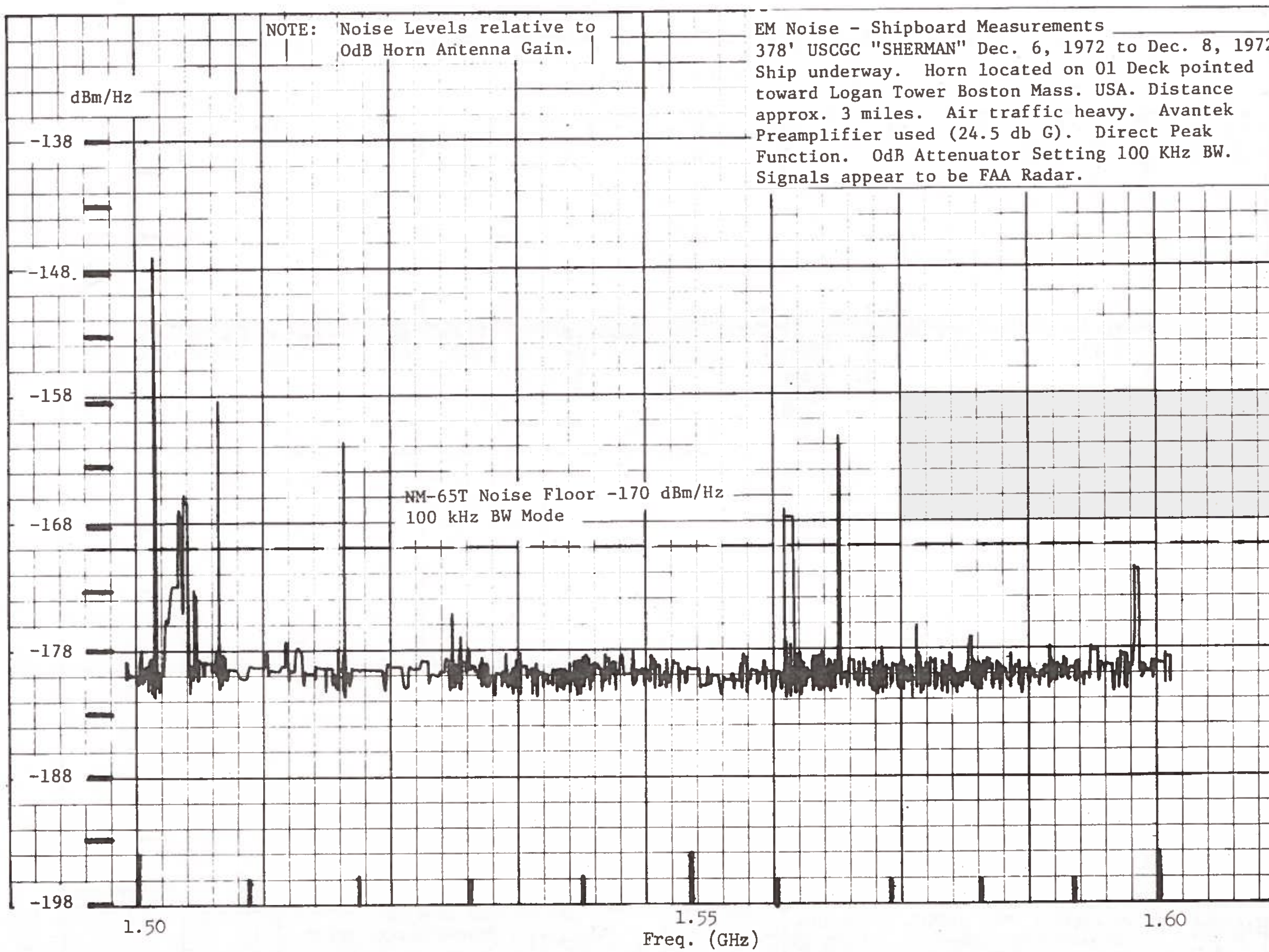


Figure 24. Noise Example Near Airport for 378' USCGC "SHERMAN"

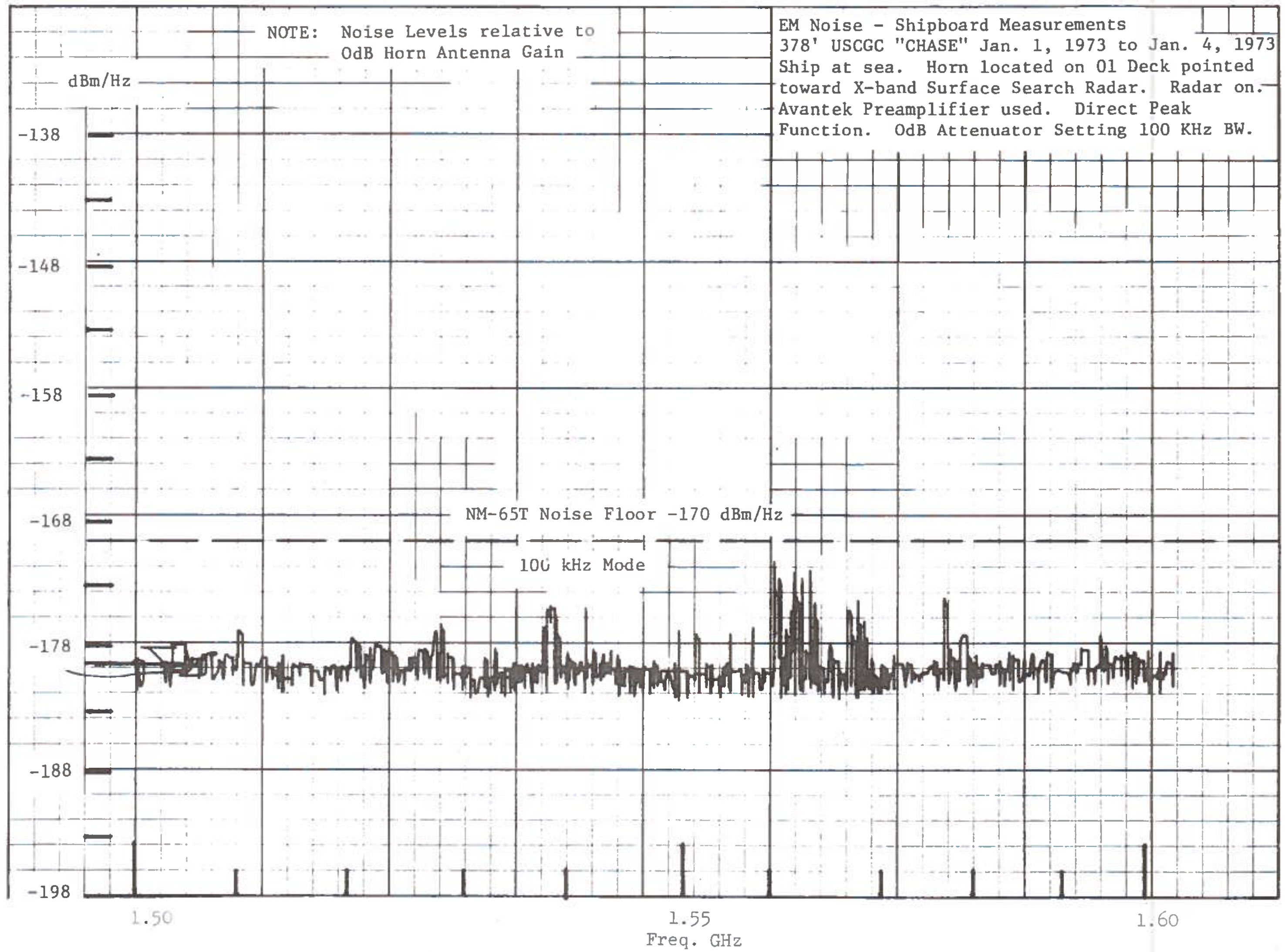


Figure 25. Noise Example at Sea for 378' USCGC "CHASE"

was pointed towards the X-band surface search radar antenna which was radiating. The L-band noise pulses shown did not originate at the X-band radar, and this plot was also the same with the radar switched off. Any L-band spurious emissions which might be generated by the X-band transmitter (refer to Appendix B-1 for characteristics) would be adequately attenuated by the cut-off characteristic of the X-band waveguide antenna feed. As the 100 kHz bandwidth position was employed for this example to illustrate higher instrument sensitivity conditions, the same comments apply as for the previous example 5.1.16 in this regard.

5.2 POTENTIAL RFI FROM IDENTIFIED EM NOISE SOURCES

The following observations are based on a limited number of RFI measurements. Dockside and en-route data were taken for approximately ten (10) different classes of ships. Based on these measurements comments presented can be made with a high degree of certainty.

5.2.1 Communications Systems

There was no evidence of any L-band harmonics or spurious emissions originating from MF, HF or VHF communications transmitters (refer to Section 2) which operate in the maritime mobile bands for ship to shore communications.

5.2.2 Radar Systems

The X-band surface search radar employed by all USCG cutters and a large number of merchant ships does not produce any measureable L-band noise. If any L-band noise is generated by the X-band transmitters, the cutoff frequency for the 1" x 0.5" waveguide antenna feed is 6556.78 MHz, and the L-band (receiver allocations within 1.5 to 1.6 GHz) attenuation is more than adequate. The S-band surface search radar has a waveguide antenna feed (3" x 1.5") cutoff frequency at 2077.85 MHz. S-band systems are employed by some merchant ships for longer range compared to X-band (X-band has higher resolution). One example of L-band noise from an S-band radar system was discussed above in 5.1.2. This was recorded for a cargo/freighter en-route. It was only possible to check one other system en-route on another cargo/freighter of the same class, and L-band noise was not present in this case. Section 7.2c provides a recommendation in regard to suppression of this L-band noise source when it exists.

The AN/SPS-29 ASR is employed by a large number of USCG cutters, and for each cutter measured, significant levels of L-band harmonic power and spurious emissions were present. Merchant ships do not employ this system, and a recommendation is included in Section 7.2b regarding suppression of this L-band noise source on USCG cutters.

5.2.3 Electrical Equipment Sources

Shipboard electric motor noise is only evident for older ships which will probably not use a MARSAT system in the future, because most of them will probably be out of commission. The older ships generally have a high EM noise level environment. This is due to electric motor brush arcing (newer ships employ ac induction motors) and the absence of suitable power line filtering. For example, just prior to docking at New Bedford, MA on an older 327-foot USCG cutter a recording was taken, and then repeated after docking from dockside power. The noise levels recorded were considerably lower for the dockside power case. These older USCG cutters are not candidates for the use of a MARSAT system in the future. The newer 210-foot and 378-foot cutters (refer to Figures 2 and 3) must conform to more stringent electromagnetic interference (EMI) specifications for electrical wiring and equipment, and this was apparent from the measured data when compared to the older cutters.

The predominant source of external L-band EM noise originates at ports, and is continuously present when the ships are docked. This noise is a combination of continuous city ambient noise and intermittent broadband impulsive ignition noise from dockside unloading apparatus, plus broadband impulsive ignition noise from automobiles and trucks on highways in close proximity. There is no conceivable method of EMI control and suppression for these sources and some further comments on this aspect are included in Section 7.

There was no evidence of EM noise originating at HF and MF insulators or corroded connections, as defined in Section 2.1b and 2.1c. However, only a small number of representative ships were subjected to measurements. Therefore, it is conceivable that EM noise could originate at those sources, particularly for some of the older ships.

6. L-BAND EM NOISE EFFECTS - ANALYSIS

6.1 INTRODUCTION

It is considered of primary interest to compare typical measured L-band EM noise levels to a set of parameters under consideration for a MARSAT shipboard receiving system.

6.1.1 Shipboard Noise Floor N_o

Section 3.2 previously dealt with the measurement system noise floor calculation. The system temperature T_{sys} was calculated at 540°K (ave.).

$$T_{sys} = \frac{T_A}{L} + T_o \frac{(L-1)}{L} + T_o (NF_2 - 1)$$

For this case, T_A is also assumed to be 100°K and L = 1.5 dB as previously. NF_2 will change from 3.66 dB (ave.) to 3.5 dB, because the preamplifier used is assumed to have a higher gain for this case, i.e., 30 dB vs. 24.5 dB, which will effectively negate the contribution of the following stages of the receiver cascaded with the preamplifier.

$$T_{sys\,(SHIP)} = 71 + 85 + 360 = 516°K$$

$$N_{o\,(SHIP)} = KT_{sys}\,(SHIP) = 10 \log (1.380 \times 10^{-23} \times 516) = -201.5 \text{ dBW/Hz}$$

$$= -171.5 \text{ dBm/Hz}$$

A value of N_o (Ship) = -171 dBm/Hz will be used for conveninece, and it will be noted that this value is 1 dB lower than the value -170 dBm/Hz calculated for the measurement system in Section 3.2.

6.1.2 Review of Satellite-to-Ship C/N_o - MARSAT

Carrier-to-noise density (C/N_o) values in the range 50 dB-Hz to 60 dB-Hz correspond to links providing high qaulity voice communications intelligibility. This C/N_o range corresponds to an articulation index (A.I.) range of values from 0.6 to 0.7 respectively. Section 6.1.2.1.2 of the System Definition Study[1] deals with a set of parameters under consideration for a satellite-to-ship digital data link. This study shows that the estimated C/N_o range of values for high quality voice communications is more than adequate for all data link services including teletype. It has been shown that all data link services including 1200 bits per second (bps), and 2400 bps links at a 99 percent link reliability and 10^{-5} bit error probability will require a received C/N_o of 43 dB-Hz. Recent advances in technology on an aeronautical satellite (AEROSAT) program indicates that it is possible to attain A.I. values of 0.5 to 0.6 in the 40-43 dB-Hz range with acceptable levels of communication quality.

If we now consider a satellite-to-ship voice link operating at C/N_o = 60 dB-Hz with N_o (the ship's noise floor) = -171 dBm/Hz, the received carrier power (C) including antenna gain would have to be -171 + 60 = -111 dBm (-141 dBW). The multifunction ATS-6 satellite was launched on May 30, 1974 by the National Aeronautics and Space Administration. A MARSAT experimental program is planned which will include an evaluation of satellite-to-ship voice and data communications links. During the performance of the MARSAT experiments an evaluation of an experimental shipboard terminal will be made, including antenna tracking techniques. The ATS-6 satellite-to-ship link is based on a C/N_o value of 63 dB-Hz derived from C = -108.8 dBm (-138.8 dBW), and N_o (Ship) = -171.8 dBm/Hz. It can be seen that this value of N_o compares quite closely with the value -171 dBm/Hz calculated above for the purposes of analysis in this report. The major concern is the effect of L-band RFI in terms of degradation to C/N_o in a future operational system. Section 7.2a provides a recommendation regarding some measurements which can be performed during the ATS-6/MARSAT experiments in order to obtain valuable data on C/N_o degradation.

6.2 ANALYSIS OF EM NOISE EXAMPLES

6.2.1 Example 1 - Severe RFI Noise

With reference to Section 5.1.3 of this report, Figure 11 illustrates an example of particularly severe broadband implusive noise originating at combustion engine circuits used with dockside unloading apparatus. Within the MARSAT receive band (1535-1543.5 MHz), noise pulses appear to exist with bandwidths in excess of 50 kHz, a typical receiver demodulator bandwidth under consideration for a MARSAT receiving system. Inspection of this X-Y plot indicates noise power densities of about -137 dBm/Hz for this example, and it is conceivable that the resultant RFI would increase the ship's noise floor N_o calculated above from -171 dBm/Hz to the value -137 dBm/Hz. The C/N_o would not be -109 + 137 = 28 dB-Hz based on C = -109 dBm and a shipboard antenna gain of 0 dB. This would result in complete loss of intelligibility in the voice or data channel based on a C/N_o criterion of 43 dB-Hz (minimum), and there is no method of RFI control for this source. (See comments in Section 7.)

6.2.2 Example 2 - Marginal RFI Case

Figure 15 of Section 5.1.7 illustrates a marginal RFI case which implies that some degradation in C/N_o would result possibly without complete loss in communications. Within the MARSAT receive band some pulses exist with bandwidths in excess of 50 kHz which is an estimated MARSAT receiver demodulator bandwidth. Inspection of this X-Y plot indicates noise power densities of about -160 dBm/Hz. The resultant RFI would increase the ship's N_o from -171 dBm/Hz to the -160 dBm/Hz noise power density. The C/N_o would now be -109 + 160 = 51 dB-Hz which corresponds to a good voice circuit intelligibility with an A.I. of 0.6. However, this is based on an 0 dB antenna gain, and it can be seen that N_o (Ship) has actually increased by 11 dB from -171 dBm/Hz to -160 dBm/Hz. The resultant C/N_o will be 40 dB-Hz which will probably be acceptable due to recent advances in technology (refer to Section 6.1.2). For the purposes of this analysis this can be considered a marginal example based on a C/N_o of 43 dB-Hz (minimum) for voice and data.

6.2.3 Example 3 - No Problem Case

Figure 22 of Section 5.1.14 illustrates a no problem case. Within the MARSAT receive band the maximum EM noise pulse amplitude, for the highest pulse which exists, is about -171 dBm/Hz. This pulse may not even have a bandwidth of 50 kHz, but this is difficult to verify. The average power in this pulse will be considerably less than the peak power value of -171 dBm/Hz depending upon the duty cycle which also cannot be determined readily. The C/N_o would now be -109 + 171 = 62 dB-Hz which corresponds to an acceptable voice circuit intelligibility with an A.I. > 0.7, i.e., based on a C/N_o criterion of 43 dB-Hz (minimum) for voice or data communications.

6.3 SUMMARY

The foregoing analysis characterizes measured L-band EM noise examples under three (3) categories, i.e., serious RFI cases, marginal RFI cases and no problem cases. Of the seventeen (17) examples discussed in Section 5, four (4) fall into the serious category, namely; 5.1.1, 5.1.3, 5.1.5, and 5.1.6. The AN/SPS-29 example 5.1.15 is not included in the serious category, nor in the S-band radar example 5.1.2 because these sources or RFI can be suppressed quite easily by the use of transmission line RF filters (refer to Section 7.2). For the remaining eleven cases, two (2) are marginal, namely; 5.1.7 and 5.1.10 and the remaining nine (9) present no RFI problem, namely; 5.1.4, 5.1.8, 5.1.9, 5.1.11, 5.1.12, 5.1.13, 5.1.14, 5.1.16 and 5.1.17. The mercury lighting example 5.1.9 would rarely be encountered, as discussed in Section 5.

It is interesting to note that the four (4) serious cases mentioned above were all recorded when the ships were docked, or within radio-line-of-sight of the particular ports and adjacent cities. The examples discussed were all recorded with a horn antenna pointed at the particular noise source, and this antenna has an effective gain of 10 dB. It will be noted that all X-Y recordings have the Y-ordinate amplitude referred to 0 dB antenna gain. In general, these types of example contain a significant component of city ambient noise which is continuous. On the other hand, the noise originating at dockside and shipboard unloading apparatus is intermittent, and only present when the apparatus is operating. Therefore, the main RFI problem to a MARSAT shipboard receiving system exists when the MARSAT equipped ships are docked, or in the vicinity of ports, i.e., within radio-line-of-sight of ports.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

a. The following conclusions are based on a limited number of RFI measurements. Dockside and en-route data were recorded for approximately ten (10) different classes of ship. Based on these measurements, the comments presented can be made with a high degree of certainty. All of the significant L-band EM noise sources measured were determined to be broadband in character relative to the link bandwidths contemplated for future system design. Accordingly, it was necessary to record the measured data in a broadband 5 MHz NM-65T Analyzer/Receiver mode. The instrument noise floor i.e., X-Y plot baseline, in this mode is -103 dBm/ 5 MHz bandwidth (-170 dBm/Hz) including a low noise (3.5 dB) preamplifier, and the sensitivity of a MARSAT 50 kHz bandwidth receiver demodulator is estimated at -123 dBm including a 3.5 dB preamplifier noise figure also. Therefore, this indicates that measurements can only be conducted when the noise power amplitude is at least 20 dB above this estimated value for MARSAT receiver sensitivity. However, it has been shown that measurements down to -103 dBm/5 MHz bandwidth are adequate for the detection of potential RFI sources, because this extrapolates to -123 dBm/50 kHz bandwidth which is the same value as that for the MARSAT sensitivity defined above.

b. The predominant sources of serious L-band EM noise were found to be associated with electrical equipment operating intermittently at ports or in close proximity. This noise is generally broadband in character; however, we are primarily concerned with the degradation effects of narrowband (50 kHz) components of this RFI on the C/N_0 in a in a MARSAT receiving channel. A high percentage of these intermittent RFI sources originated as broadband impulsive noise (Refer to Appendix A) from combustion engine ignition circuits associated with dockside and shipboard unloading apparatus. The same noise category was frequently evident for automobiles and trucks on highways and bridges adjacent to ports, harbors and canals. Also evident at ports is a component of city ambient noise which varies in amplitude from port to port, and also depends upon the time of day. This noise is also continuous and varies in magnitude by ≈ 20 dB depending upon whether it is measured on a normal working day or on weekends and holidays, when it is lower in magnitude.

It has been determined that shipping companies employing MARSAT systems in the future will definitely require the use of these systems to communicate from foreign ports to their home ports. This will enable the companies to obtain near real-time communications for urgent administrative functions, a capability which does not currently exist. As the MARSAT shipboard antennas will be directive with gain values ranging from 10 dB to 15 dB, probably some judicious, and possibly automated antenna pointing techniques may provide a partial solution to the high RFI conditions which prevail at ports. It was found that the maximum RFI level at a given time reduced considerably if the horn antenna (≈ 10 dB gain) was adjusted a few degrees in azimuth or elevation to point in a different direction. A variation of 20 dB can result, and this is illustrated by comparing Figures 12 and 13 (Sections 5.1.4 and 5.1.5). Some degree of EMI control may be possible through signal design, including coding techniques for burst error correction.

c. A high percentage of the existing merchant ships which might employ a MARSAT system in the future have been commissioned since 1960. These ships generally have a low potential RFI environment, because fairly rigid EMI specifications for electrical and electronic equipment were adhered to during the design and construction phase. This is not true of the older ships that generally have a high potential RFI environment due to inadequate power line filtering, and minimal RFI suppression for electric motors. However, it is probable that the older ships will gradually be phased out. Future merchant ships will also have to conform to appropriate EMI specifications.

When the newer ships are out at sea beyond radio line-of-sight of the ports, it is concluded, based on the analysis presented in Section 6, that any potential L-band RFI from internal or external noise sources will be at a minimum.

A very low probability exists for brief RFI from aircraft L-band radar altimeters to MARSAT equipped ships out at sea. The aircraft would have to be closer to the ship than 1,000 feet, and this was concluded in a separate study by the U.S. Department of Commerce "Spectrum Resource Assessment for the 1535-1660 MHz Band" (Phase II-Analysis. Report No. 2/71-p2, 10/31/73). Furthermore, civilian and military aircraft L-band radar altimeters will gradually be phased out during the next 15 to 20 years. This source of RFI was not detected in the performance of the measurements program under discussion.

d. The L-band noise recorded for the AN/SPS-29 air search radar used by the U.S. Coast Guard and U.S. Navy is not considered a potential RFI problem. This L-band EM noise source can be easily suppressed by the insertion of a simple commercially available RF coaxial filter, and a recommendation is included in Section 7.2 pertaining to suppression of this shipboard internal source.

Another recommendation is included in Section 7.2 concerning the suppression of L-band noise when present, from an S-band (10 cm) surface search radar which is employed by some merchant ships. It was only possible to perform en-route measurements on two (2) cargo/freighters employing this system, and L-band noise was detected for one.

When this noise source is present, it can be suppressed with a simple commercially available waveguide filter.

e. There was no evidence of any L-band noise from X-band (3 cm) surface search radars. A high percentage of all merchant ships employ the X-band system. Some merchant ships employ both. The U.S. Coast Guard employs X-band only which has a higher resolution than S-band, and the latter provides longer range.

f. There was no evidence of L-band noise originating at the MF, HF or VHF communications equipment (Refer to Section 2) employed by all ships and shore stations.

7.2 RECOMMENDATIONS

a. During the performance of the forthcoming Maritime/ATS-6 Satellite L-band experiments, it is recommended that the same NM-65T instrumentation described in Section 3 (Refer to Figure 1) be employed simultaneously. This would be of particular interest under conditions of high potential RFI environment, such as those which exist at ports. This would facilitate some degree of correlation between prevailing or intermittent conditions as discussed in earlier sections of this report. In other words, it would be of interest to relate a sudden loss in voice channel intelligibility or a sudden increase in data channel error rate to a reduction in the link C/N_o which would be the result of an increase in N_o. The horn antenna may be pointed in the same direction approximately at a given time as the MARSAT antenna on the ships. This is not a critical adjustment because of the wide half power beamwidths (horizontal and vertical) of the horn antenna. (Refer to Section 3). If a sudden increase in L-band noise should occur, small adjustments of a few degrees can be made for the horn antenna in azimuth and elevation to obtain a reduced noise level. Any variations in noise level can be related to the MARSAT antenna which will have the same range of gain and half power beamwidth values.

b. L-band harmonic EM noise originating at AN/SPS-29 radar systems employed only by the USCG or USN can be suppressed by the insertion of a commercially available coaxial high power filter following the transmitter. These filters are commercially available, and should be installed on all USCG cutters which may employ a MARSAT system in the future otherwise unacceptable L-band RFI will result to the MARSAT receivers.

c. Any merchant ships using the S-band (10 cm) surface search radar, and which may employ a MARSAT system in the future should be checked for possible L-band RFI originating at the S-band transmitter. As mentioned in Section 5, it was only possible to check two (2) merchant ships en-route that employed the S-band system, and L-band noise was evident for one of these ships. This can hardly be considered conclusive as in case b above; however, the cost of performing this measurement, and including a simple commercially available waveguide filter if required, is insignificant compared to the estimated cost of a future MARSAT shipboard terminal. Unfortunately, this L-band noise source is not easy to detect at ports because of masking by the prevailing city ambient noise and other intermittent sources which were analyzed in this report. This test procedure will require further investigation, but a simple solution should be available.

d. It is recommended that future effort should include RFI measurements in the 225-400 MHz (Navy Applications) band. This extension into the 225-400 MHz band is intended to accommodate future applications with the COMSAT MARISAT satellite program.

APPENDIX A
EM NOISE DEFINITIONS

Narrowband EM Noise Sources:

A narrowband (NB) signal is defined as a signal having a spectral power distribution that is narrow compared to the bandwidth of the receiver between the ±3 dB points. The following signals are classified as NB:

1. Continuous wave (CW) or unmodulated carrier
2. Amplitude modulated (AM) or SSB modulated carrier
3. Frequency modulated (FM) carrier.

NOTE: Theoretically, an FM signal produces an infinite number of sidebands and would not qualify as an NB signal. The bandwidth of the significant sidebands, however, is approximately $2(\Delta f + fm)$ where Δf = peak deviation and fm = modulation frequency. If $2(\Delta f + fm) < BW$ of the receiver in use, for measurement purposes the FM signal may be considered as NB.

Broadband EM Noise Sources:

Broadband signals are defined as those having a spectral power distribution that is broad compared to the impulse bandwidth of the receiver. Broadband interference can be considered as being composed of short pulses, the pulse repetition frequency determining the character of the interference. If the pulses are clearly separated, the interference is termed impulsive. Such interference is generated by motor brush sparking and by combustion engine ignition circuits. If the pulses are not clearly distinguishable and do overlap, then the interference is termed random. A good example of this is thermal noise. Other signals, not always broadband, have been assigned this classification for measurement purposes. These are pulse modulated CW signals, mainly used by radar. Radar is a prominent type of signal within the frequency range of the NM-65T Radio Interference Analyzer/Receiver which is employed.

The spectrum of a pulse modulated carrier consists of lines spaced at intervals of the repetition frequency. If the impulse bandwidth of the receiver is much wider than the pulse repetition frequency, then many spectral lines fall in the receiver passband and the signal is broadband related to the receiver. Following is a list of signals, classified as Broadband:

1. Pulse modulated CW (f.i. radar)*
2. Random noise (f.i. thermal)*
3. Impulsive noise from motor brushes
4. Impulsive noise from combustion engine ignition circuits
5. Corona discharge

NOTE: The Singer NM-65T Analyzer/Receiver has three (3) bandwidth selector positions; namely, 100 kHz, 0.5 MHz and 5 MHz. The 100 kHz position is used for narrowband measurements which generally involves communications equipments using the modulation types listed above. The 0.5 MHz and 5 MHz positions are generally used for broadband measurements from the sources categorized above.

*Field intensity (Far field conditions)

APPENDIX B-1

USCGC "SHERMAN" - GENERAL DATA

Length, Over-all	378 feet
Beam	42 feet
Draft	14 feet
Standard Displacement	2,748 tons
Full Load Displacement	3,050 tons
Engineering Plant	Two Diesels
	Two Pratt and Whitney gas turbines
	One 350 horsepower bow thruster unit
Rated speed (Diesels)	20 knots (7,000 horsepower)
Rated speed (Gas Turbines)	29 knots (36,000 horsepower)
Cruising Range	12,000 miles at 20 knots

1. Exact Operating Frequencies Used in Communication:

MF	325 to 535 kHz
HF	2 to 30 MHz
VHF	156 to 162 MHz
UHF	225 to 399 MHz

VHF FM 156 to 162 MHz, 50 kHz BW channels. Also the "SHERMAN" uses UHF 381.8 MHz and 383.9 MHz in conjunction with the US Navy. There are no other frequencies used for communications.

2. Operating Powers:

500 watts for MF CW
500 watts for HF CW
40 watts for VHF CW
16 watts for UHF CW
20 watts for VHF FM

3. Types of Modulation:
SSB AM for HF, MF, VHF, and FM for VHF.
Also HF, VHF, UHF can be FSK (TTY).

4. X-band Radar AN/SPS 51 A:

Operating frequency:	9.375 GHz ±30 MHz
Waveguide feed:	1" x 1/2"
PRR:	1200 PPS ±10%
Type of Emission:	Pulse
Peak Power Output:	75 KW min.
Range:	25 yards to 40 miles
Pulse Widths:	.1 ± .03 (1/2 to 1 and 2 mile range)
On all other ranges:	.5 ± .1 usec.

5. Air Search and Balloon Tracking Radar AN/SPS-29B:
Operating Frequency and other information about this radar is classified.

The antenna for the AN/SPS-29B radar is designated as AN/SPA 52 and is especially designed for the USCG. It has a gain of 15.2 dB with respect to an isometric source.

6. Fire Control Radar Mark 35 Mod Z:

Operating Frequency:	8500 to 9600 MHz
PRR:	2550 to 3450 PPS
Pulse Width:	.1 to .15 usec.
Peak Power:	40 KW
Ave. Power:	12 watts
Duty Cycle:	.0003
Radar Antenna:	AS 5152/SPG
Polarization:	Vertical
Range:	25 to 30,000 yards
Accuracy:	±10 yards

7. AC Generators:

   2-500 KW, 450 V, 3Ø, 60 Hz (Main generators)
   1-500 KW, 450 V, 3Ø, 60 Hz (Emergency generators)
   2-10 KW, 450 V, 3Ø, 400 Hz

8. The ship has about 200 motors, mostly induction motors single phase and three phase, 60 Hz, with exception of the synchros which use 400 Hz.

APPENDIX B-2
S/S "AFRICAN COMET" - GENERAL DATA

Length O. A. 572' ....Registered 543.3'
Breadth 75' ....Registered 75.1'
Depth Molded 42'-6"..............Registered 29.1'
Tonnage, Gross 11,309
Tonnage, Net 6,809
Height of Topmast above Keel.....144'-06" (112'-09" originally)

MARKS	DRAFT	DISPLACEMENT TONNAGE	DD/WT
W	30'-02 3/16"	19,791	12.409
S	30'-09 15/16"	20,315	12,933
T	31'-05 11/16"	20,843	13,461

S-BAND RADAR

Raytheon Model 1450

Frequency - 3030$\pm$38 MHz
Peak Power - 20 KW minimum
*PRP - 800 pps, PL. 0.42 usec.
(8, 20, 40 mile range)
*PRP - 2400 pps, PL. 0.14 usec.
(0.5, 1, 2, 4 mile range)

*duty ratio = PRP X PL X 10^{-6} = 0.000336 (both cases)
Average Power = 20 KW X 10^{3} X 336 X 10^{-6} = 6.72 watts
XMTR Model 7069 (S-band) 2J 70 magnetron
Antenna slotted waveguide (3.000" x 1.500" x 1.500") Beamwidth
H 2°$\pm$10%
V 22°$\pm$10%

Rotation 15$\pm$ 5 RPM
Height, including radome 11",
Width, 12'-3.7"

APPENDIX B-3

S/S EXXON "SAN FRANCISCO" - GENERAL DATA

Length O.A. Molded 809' - 10"
Beam Molded 125'
Depth Molded 54' - 6"

DWT AND SUMMER DRAFT	75,649 tons
Displacement at Summer Draft	90,652 tons
Gross Tonnage	38,144 tons
Net Tonnage	32,425 tons

S.H.P. 19,000

Fuel Capacity 16,600 BBLS
Fresh Water Capacity 590 tons

Height of Radar Mast above water: Light, 120'. Loaded, 94'
Radar Type: DECCA S-band (10 cm) radar

Cargo Tank Capacity @ 98%, 637,837 BBLS
@100%, 650,855 BBLS } 42 gals/BBL

Distances:

Bow to Risers 370'
Risers to Bridge 244'
Bridge to Stern 195'
Bow to Bridge (incl. Bulb) 628'. Bulb extends 14' beyond bow apron

Design Speed: 16.5 knots

Cargo Pumps:
4 Main Turbine Driven Bingham at 700 GPM @ 150 lbs. Disch.
2 Specialty Turbine Worthington Driven 1400 GPM @ 150 lbs. Disch.
1 Stern Driven Stripper Dean Bros. 50 GPM @ 60 lbs Disch.
4 Air Driven Dean Bros. 50 GPM.
2 Air Driven Dean Bros. Specialty Pumps.

Cargo Pumps: (Continued)

*2 Motor Driven Worthington Ballast Pump 800 GPM @ 30 lbs. Disch.

*Only electrically operated pumps of those listed.

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