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AUTHOR(S):

NP COLEY

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INSTITUTE FOR MARITIME TECHNOLOGY (PTY) LTD

P O Box 181
Simon's Town
7995
Republic of South Africa

Tel 786-1092, 786-1527, 786-1521 Fax 786-3634

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SUMMARY

This report documents the additional measurements of low frequency and transponder noise levels radiated by off-shore mining operations. Contained are the spectra, amplitudes and propagation predictions of noise produced by the two mining processes. These results substantiate the previously published data, in that the radiated noise produced is mainly broadband, having similar amplitude to merchant shipping.

KEYWORDS

Off-shore mining, low frequency propagation, underwater radiated noise, De Beers Mining, Environmental noise, Transponder Communication.

1. INTRODUCTION

De Beers Marine requested the Environmental Evaluation Unit (EEU), University of Cape Town, to study the effect off-shore diamond mining has on the local environment. IMT was subcontracted by EEU to measure and characterise the underwater radiated noise produced by the mining process. This report appends to the initial study [Ref 1.] and completes the radiated noise measurement and analysis.

2. OBJECTIVES

The objective of this report is to document the additional measurements of noise radiated by mining vessels identified in the previous study [Ref 1].

The additional information required was:

- a. Low frequency noise levels.
- b. High frequency noise levels.
- c. Additional vessel measurements.

3. TRIAL CONFIGURATION

The radiated noise levels of three vessels were measured. Figure 1 below illustrates the relative position of each ship and the prevailing weather conditions. The vessels measured were the Coral Sea, Louis G Murray and Atlantic Dunbar. tape failure

The planned measurement procedure was to record the underwater radiated noise on the lee-ward side of each vessel. Distance from the target vessel was measured approximately every fifty meters by a hand held laser range finder, as the monitoring vessel drifted away from the mining vessel. The distance measured was correlated with the tape counts to aid analysis.

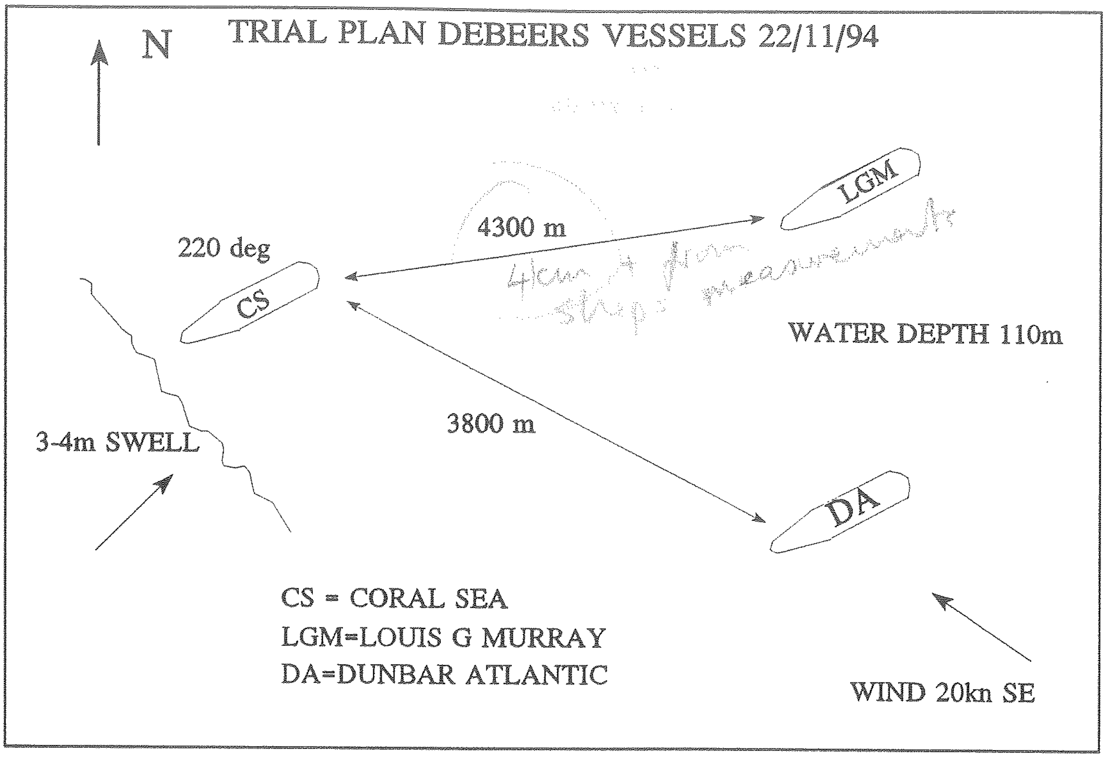

Figure 1: Trial plan.

4. MEASUREMENT SYSTEM

The noise monitoring system consisted of a broadband hydrophone with integral preamplifier/line driver, a low frequency noise cancellation system (to reduce the effect of the wave action), a receive/amplifier and two tape recorders.

4.1 Technical specifications

Hydrophone	Type:	IMT measurement
	Sensitivity:	-165 dB re 1 V/μPa (with pre-amp)
	Directionality:	Omni-directional
	Frequency band:	6 Hz to 12.5 kHz (3 dB points)

Recorders

a.	Type:	AIWA DATA HD-S1 (digital)
	Frequency Range:	20 Hz to 22.5 kHz
b.	Type:	Brüel and Kjaer 7005 (Analog)
	Frequency Range:	0 Hz to 12.5 kHz (FM)
		300 Hz to 60 kHz (DIR)

Analysis

Type:	HP 3582A Spectrum analyzer
Averaging:	RMS (32)
Window:	Hanning

Spectrum levels reported as:

0 to 10 Hz - 40 mHz Bandwidth
0 to 100 Hz - 400 mHz Bandwidth
0 to 1 000 Hz - in 1 Hz Bandwidth (corrected)
0 to 10 kHz - in 1 Hz Bandwidth (corrected)

5. RESULTS

Attached in the appendix, are graphs produced from analysis of the latest series of measurements. No results are available for the Atlantic Dunbar due to tape recorder failure.

5.1 Low frequency measurements

The IMT measurement system, used for the LF recordings, has a low frequency cut-off at 6 Hz. Any results below this frequency are uncalibrated.

In figure 2 the amplitude and frequency content of the radiated noise is given for a band from 0 to 10 Hz. This is typical of all the vessels measured. The 5.68 Hz and 6.04 Hz components translate to 340 rpm and 362 rpm respectively. These rotational components do not correspond directly to any machinery generally used onboard the vessels. Table 1 lists the larger noise producing machinery of the Coral Sea, these are likely to be common to all the vessels (with the exception of the drill rotational speed which is not present on the Louis G Murray).

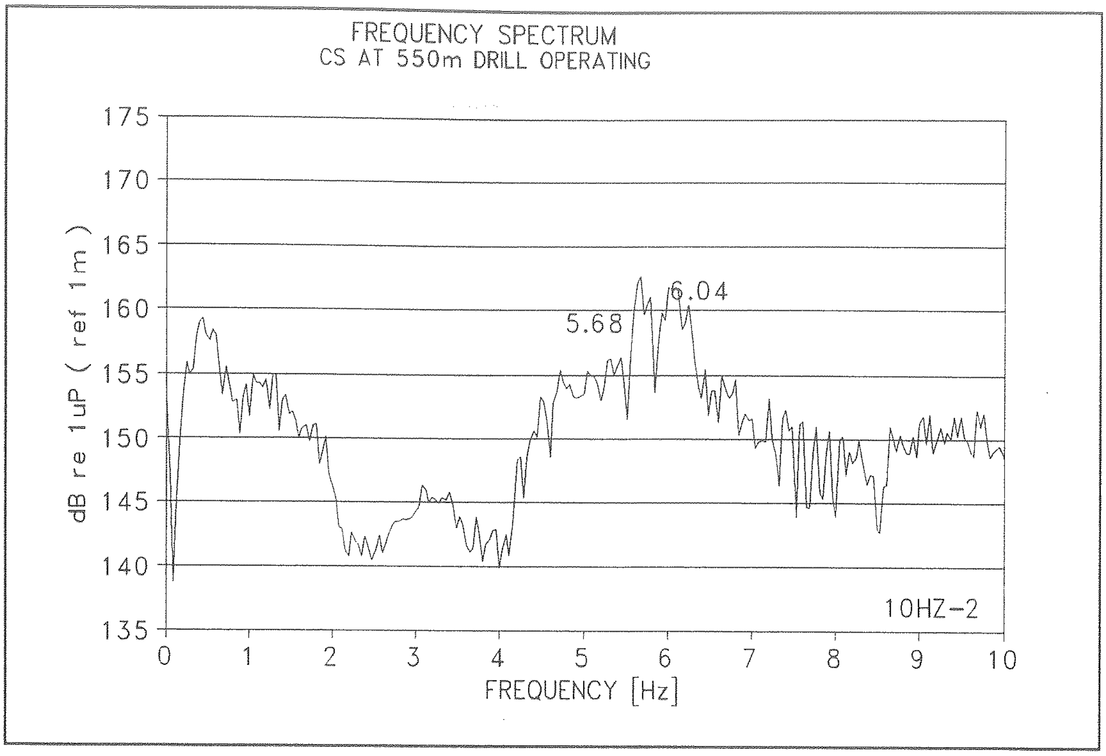

Figure 2: Typical low frequency components.

Table 1: Large rotational machinery - Coral Sea

EQUIPMENT	RPM	FREQUENCY [Hz]	* APPROXIMATE LEVELS [dB re 1 μPa ref 1 m]
Main generator	1200	20	155
Pump motor	1700 - 1800	28 - 30	150
Pump	800 - 950	13 - 16	155
Drill	7	0.12	-
Draw motors	600 - 700	10 -12	155
Hydraulic motors	1500 - 2000	25 - 33	150
Winches	2500	42	145
Hydraulic drives (pumps)	1700 - 2000	28 - 33	150

* These levels are of tonals occurring within a few Hertz of the identified machinery. They cannot be attributed to individual machines as these measurements were taken at a distance from the vessel.

There are also 50 Hz and 60 Hz tonals which generally have the largest amplitude. These correspond to the line frequency of the ship's power supplies.

5.3 Correlation of data

The results from two recording systems used in this set of measurements have been compared, the only difference is the levels of noise below 20 Hz. This is to be expected as the AIWA digital recorder has a low frequency cut-off at 20 Hz (figure 3).

The latest set of recordings were also compared to the previous levels reported in the initial study [Ref. 1 - Environmental Impact Study]. A small difference was noted, the first series of measurements are 3 dB lower than the following series. This discrepancy was a product of recalibration and has little effect on the overall results.

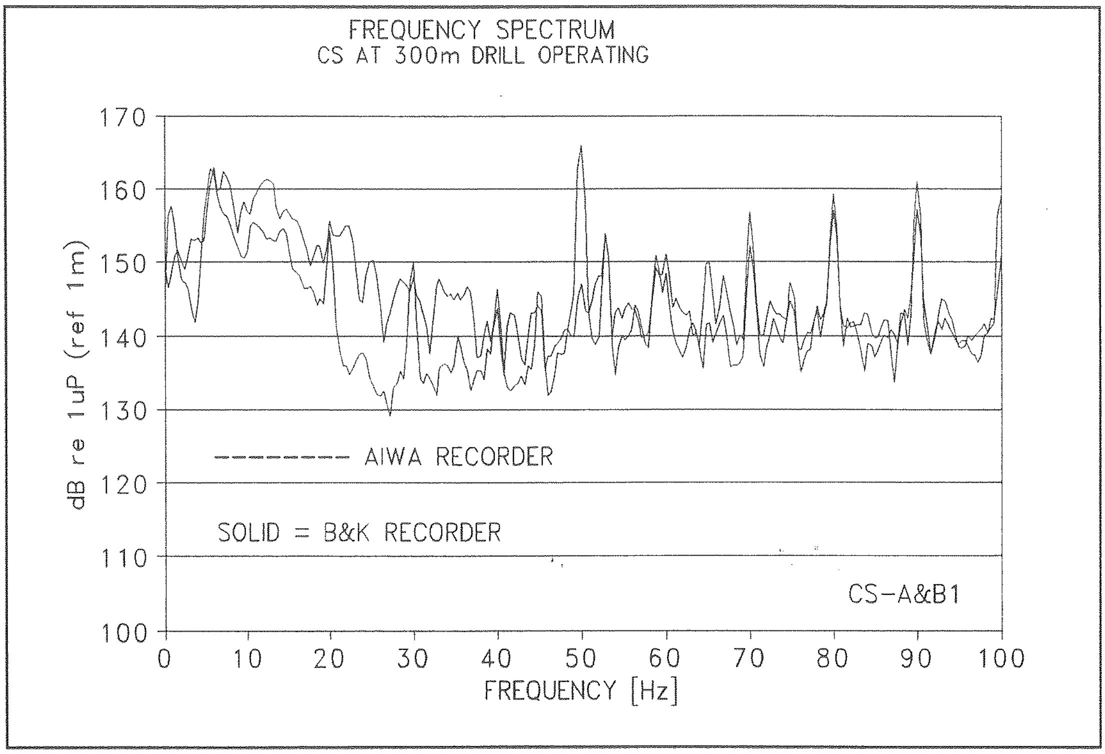

Figure 3: Comparison of recorded signals.

5.3 Noise levels 0 -10 Hz

In figure 4 below a combined graph of several low frequency noise spectra is compared to the background noise (Coral Sea). The 6 Hz cut-off of the hydrophone system is clearly visible which decreases in sensitivity at 12 dB per octave.

If the background level is adjusted to account for the distance between the point of measurement and the vessel (+ 62 dB) then the background and measured noise level will be approximately equal. The only significant difference being the two peaks at 5.68 Hz and 6.04 Hz. This indicates the majority of low frequency noise is a product of the ambient conditions rather than generated by mining vessels.

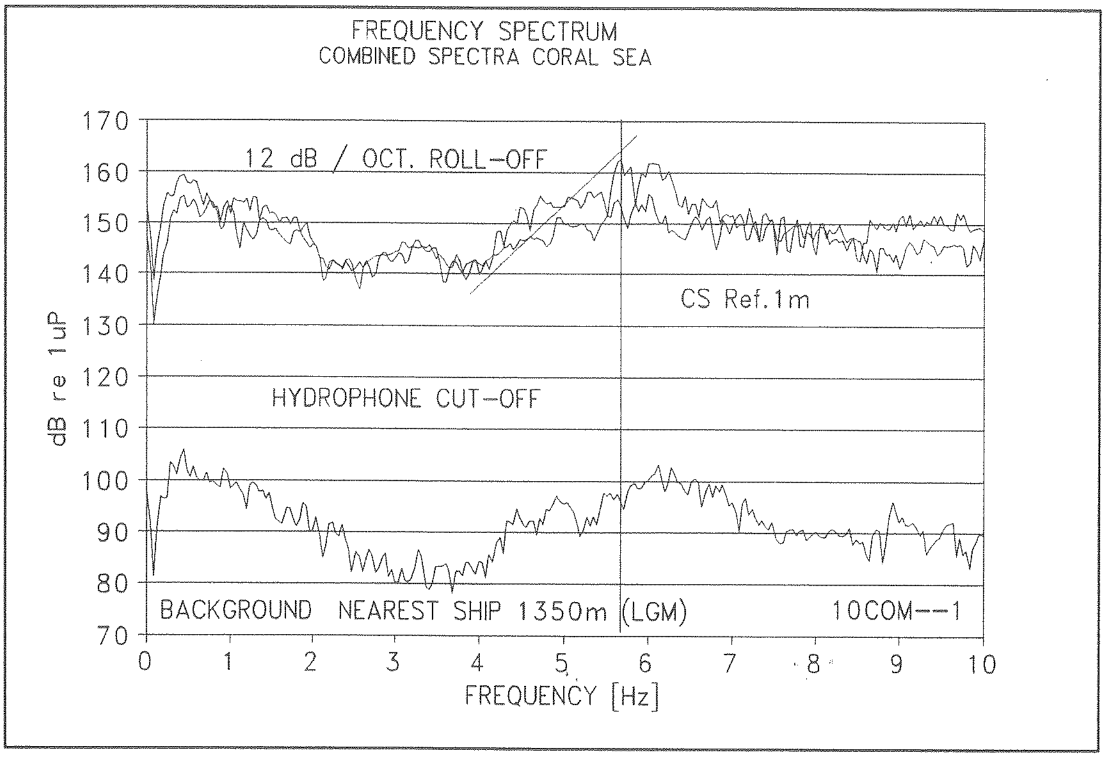

Figure 4: LF combined spectra.

Figure 5 is a shallow water model [Ref. 5 SMOD] predicts the levels of ambient noise. This graph confirms the measured levels of background noise. There is a marginal increase below 20 Hz, this is due to the proximity of the mining vessels. To achieve a quieter background measurement the monitoring vessel must measure the background levels at 5 kilometres or more from any industrial noise. This is discussed in more detail under low frequency propagation in appendix B.

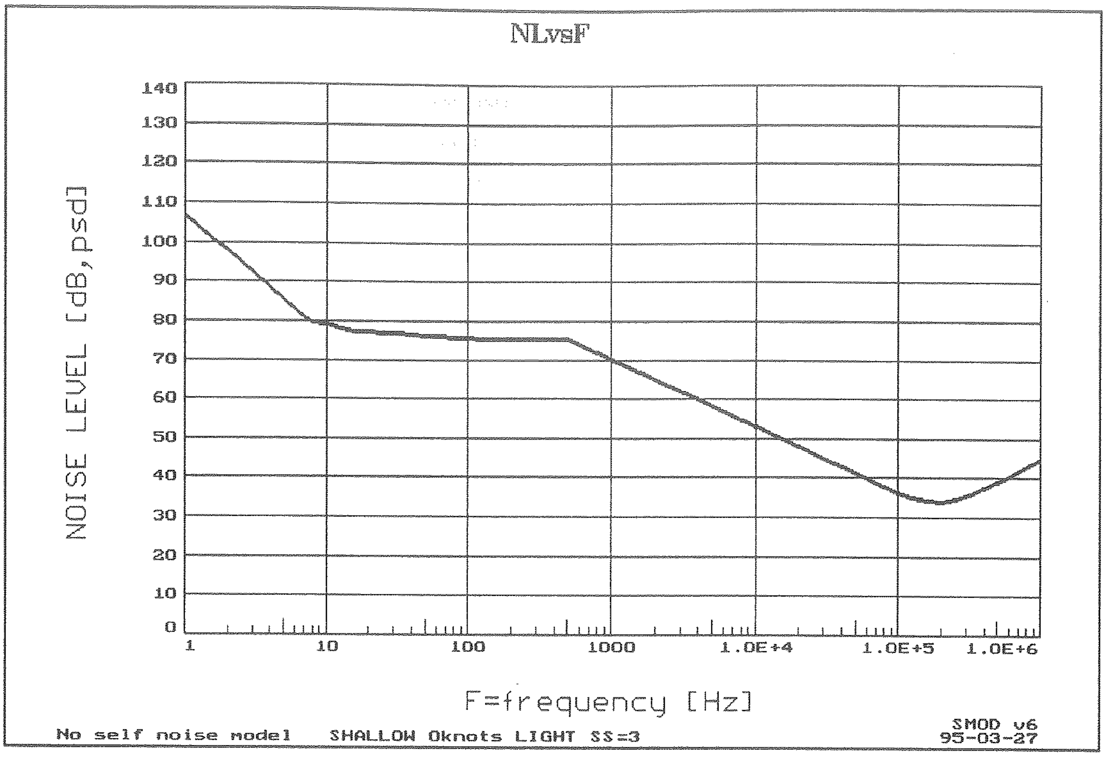

Figure 5: Shallow water ambient noise.

5.4 Measurements above 10 Hz

Attached in appendix A are additional measurements for the frequency bands 0 to 100 Hz and 0 to 10 kHz. These have been included as a reference. These sections of the spectrum were discussed in the previous report. [Ref. 1 - Environmental Impact Study]

5.5 High frequency noise levels

The high frequency noise emitted by the mining operation is produced by the underwater navigation system. This transponder network is used to accurately position the drill or crawler in relation to the mining vessel. The operational frequencies are between 19 kHz and 36 kHz. Attached in appendix B are the specification for the Sonardyne system currently used by the De Beers vessels.

The nature of the transmitted pulses, i.e. very short (4 ms) at a combination of frequencies, makes accurate operational measurements difficult to achieve. The noise levels produced by these transponders have therefore been taken from the Sonardyne handbook [Ref. 2] which give an accurate source level of the transmissions.

6. DISCUSSION

The graph below (figure 6) is an updated version of the results presented in the previous report. Included on this graph are the extended low frequency amplitudes plus the source level of the transponder. (The previous results were limited to a bandwidth of between 100 Hz and 20 kHz.) The transponder level is exceptionally high, in comparison with the merchant and mining vessel levels. This level of noise will have limited propagation due to absorption of signals at these high frequencies. This is discussed further in appendix B.

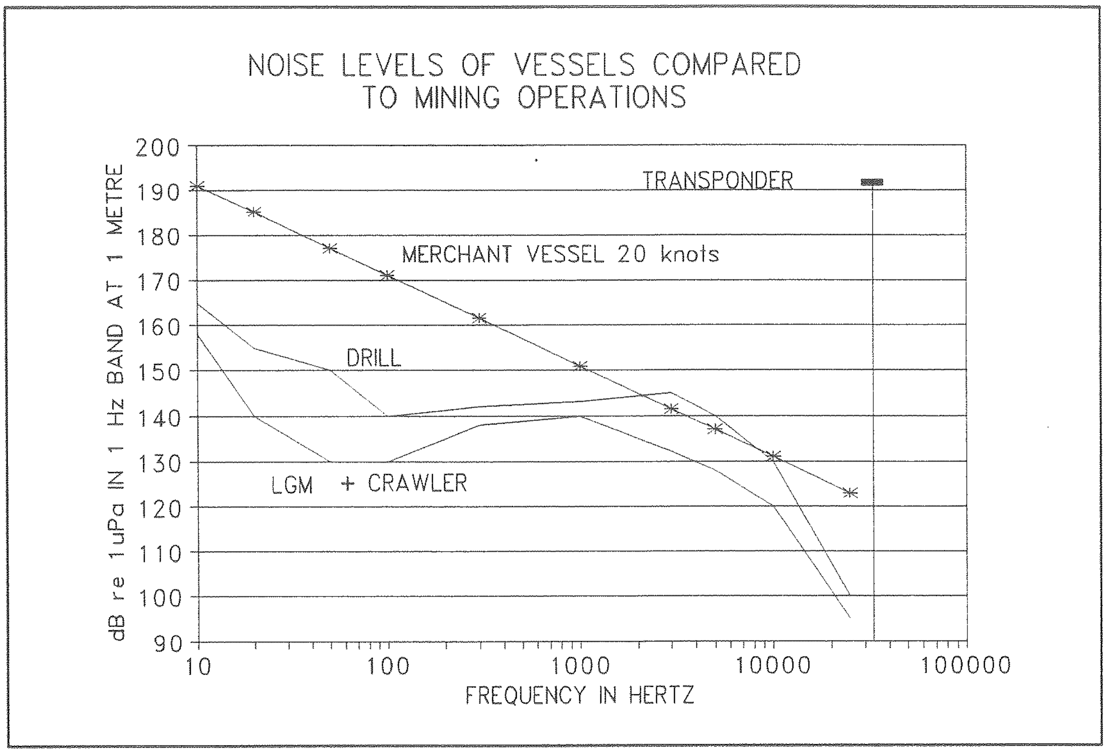

Figure 6: Compared levels.

In comparing the radiated noise levels one must remember that a mining vessel is stationary and is radiating noise at a constant level. The merchant vessel is moving, producing a more variable noise levels due to propagation conditions.

7. CONCLUSION

The levels of low frequency noise produced by vessels of the off-shore mining industry are essentially the same as merchant vessels. The main difference being that mining operations are conducted in relatively shallow water which restrict the propagation of any frequencies below 10 Hz to within a few kilometres of the vessels. The low frequency produced by merchant shipping can propagate 100's of kilometres, under favourable conditions. The high frequency transponder communication is also limited by the sea, this time by the absorption rather than propagation limitations of the low frequencies.

8. RECOMMENDATION

If it is felt necessary to quantify the noise below 6 Hz then a series of measurements must be undertaken using a purpose built system that would monitor levels from the sea floor rather than the existing dipping hydrophone.

9. REFERENCES

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[2] Sonardyne, An information package Ref: P/84/160 Sonardyne's underwater acoustic navigation systems

[3] Urick RJ, Principles of underwater sound, 3rd Edition, Mcgraw-Hill book company.

[4] La Grange, PL, Sonar Handbook. IMT Report KT076-060000-731001 Issue 5, February 1993.

[5] SMOD - program disk, IMT Doc No. KT076-04000-401001, Confidential.

[6] Stander MP, Norman V4 User Manual. IMT Document No. P0014-011000-429002, March 1995, Confidential.

APPENDIX A

GRAPHS PRODUCED BY ANALYSIS OF THE RECORDED DATA

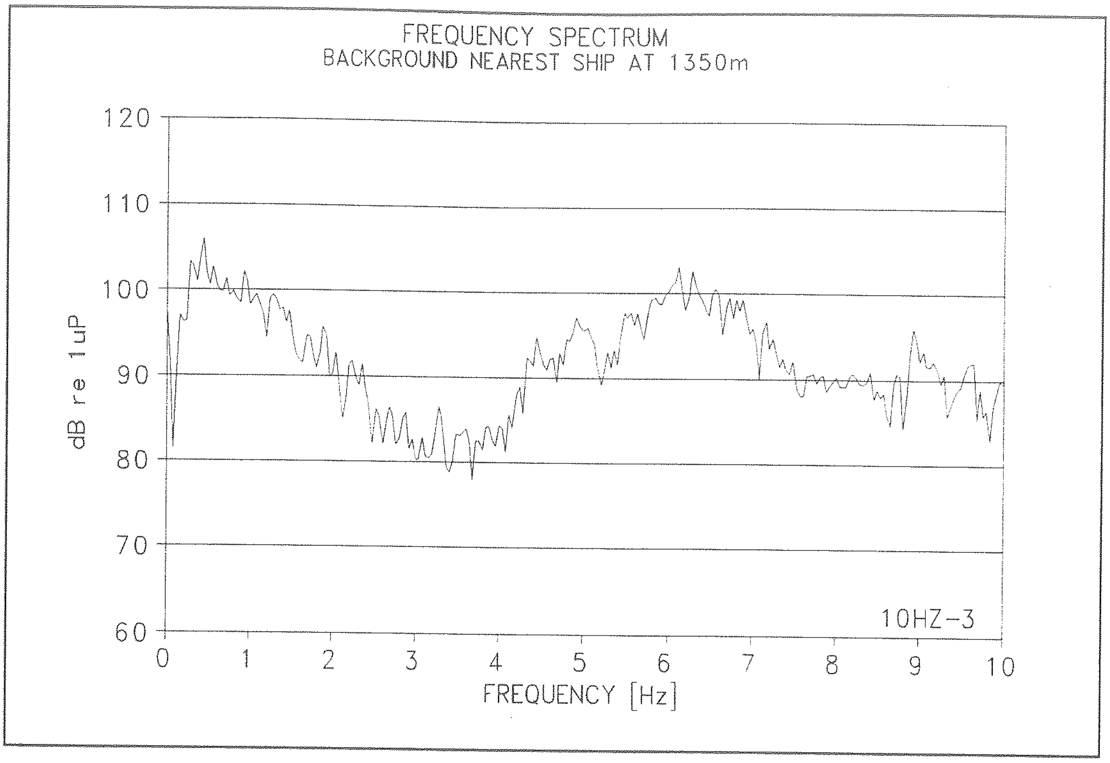

Figure 7: Background - nearest ship 1350 (10 Hz).

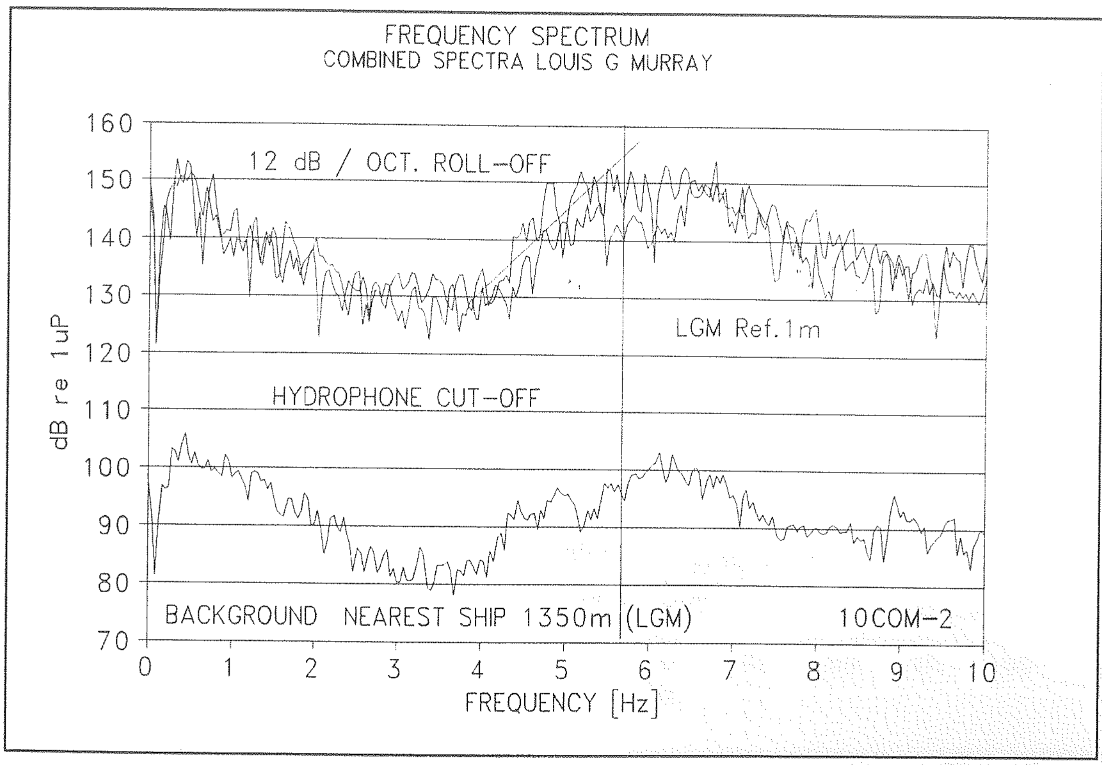

Figure 8: Combined spectra LGM (10 Hz).

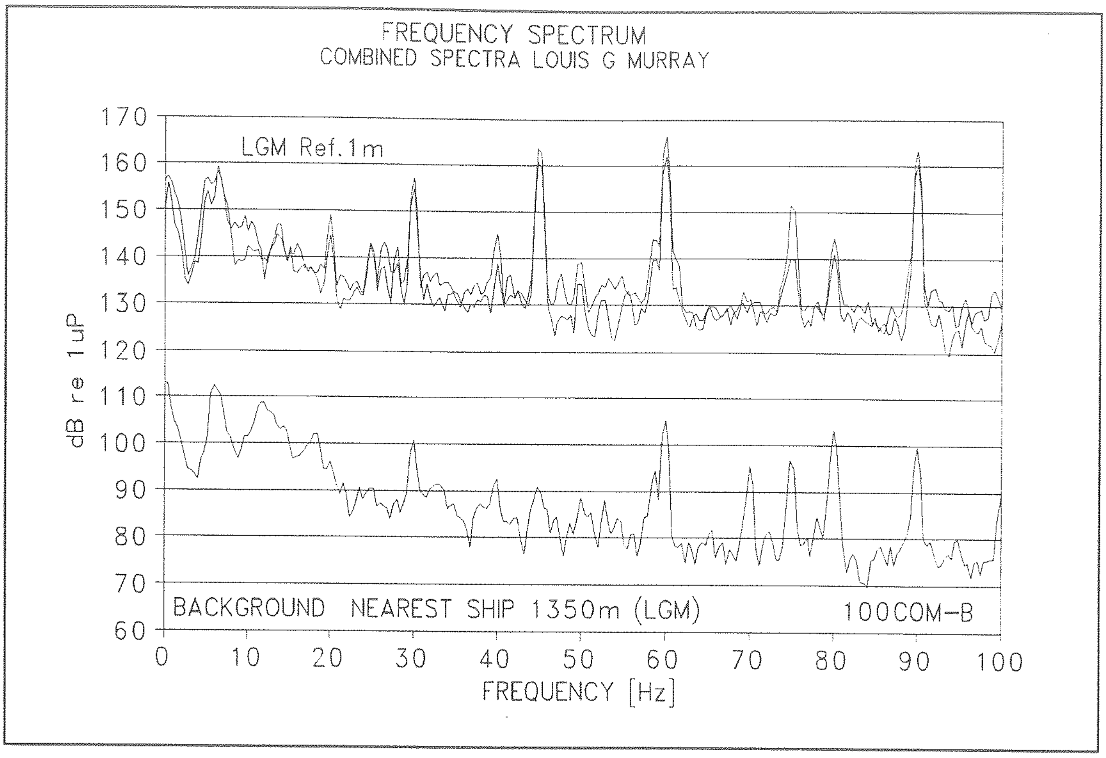

Figure 9: Combined spectra LGM (100 Hz)

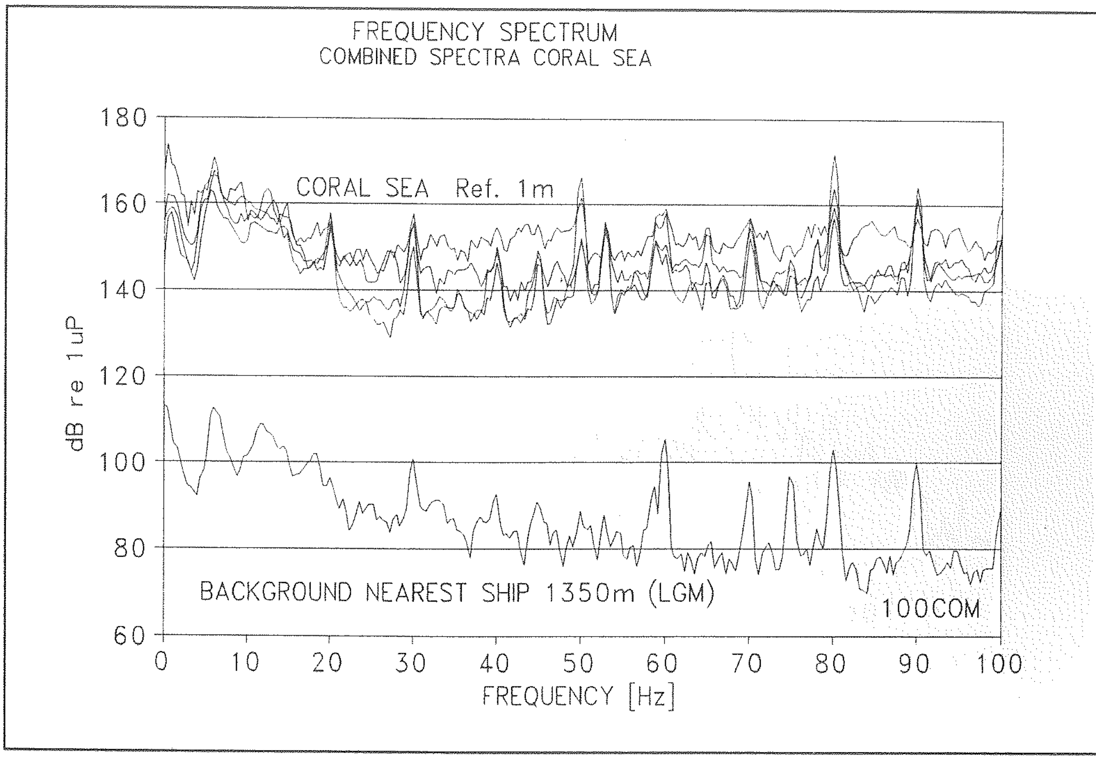

Figure 10: Combined spectra Coral Sea (10 Hz)

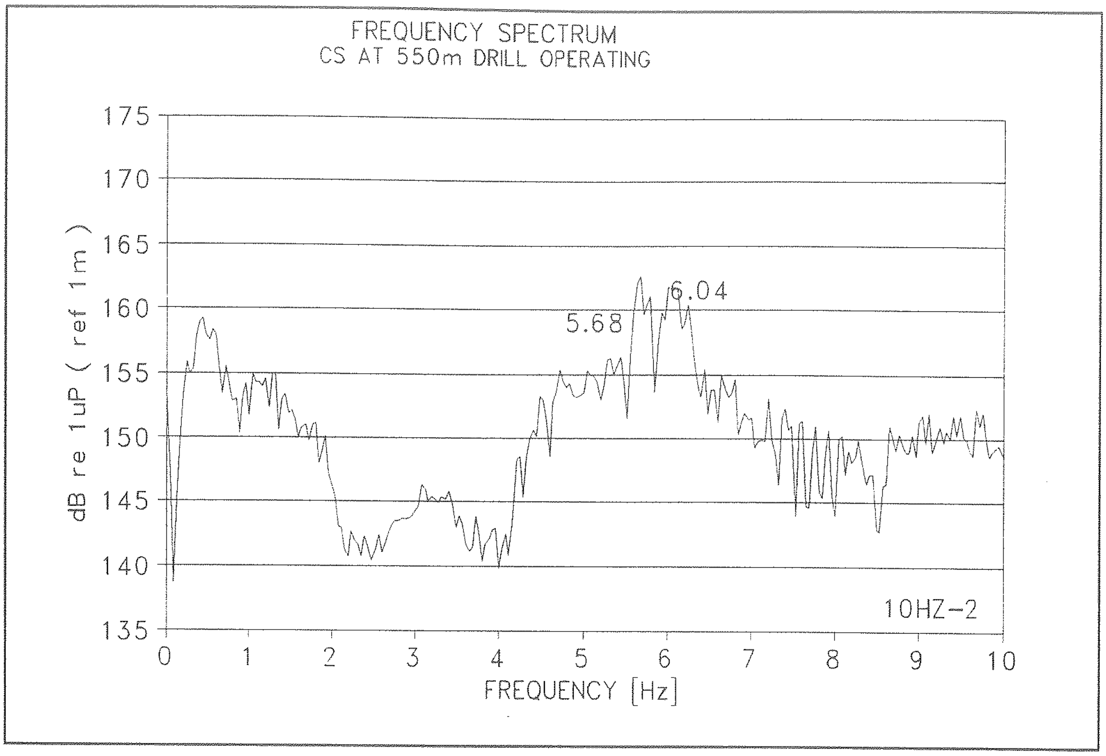

Figure 11: Coral Sea at 550 m drill operating

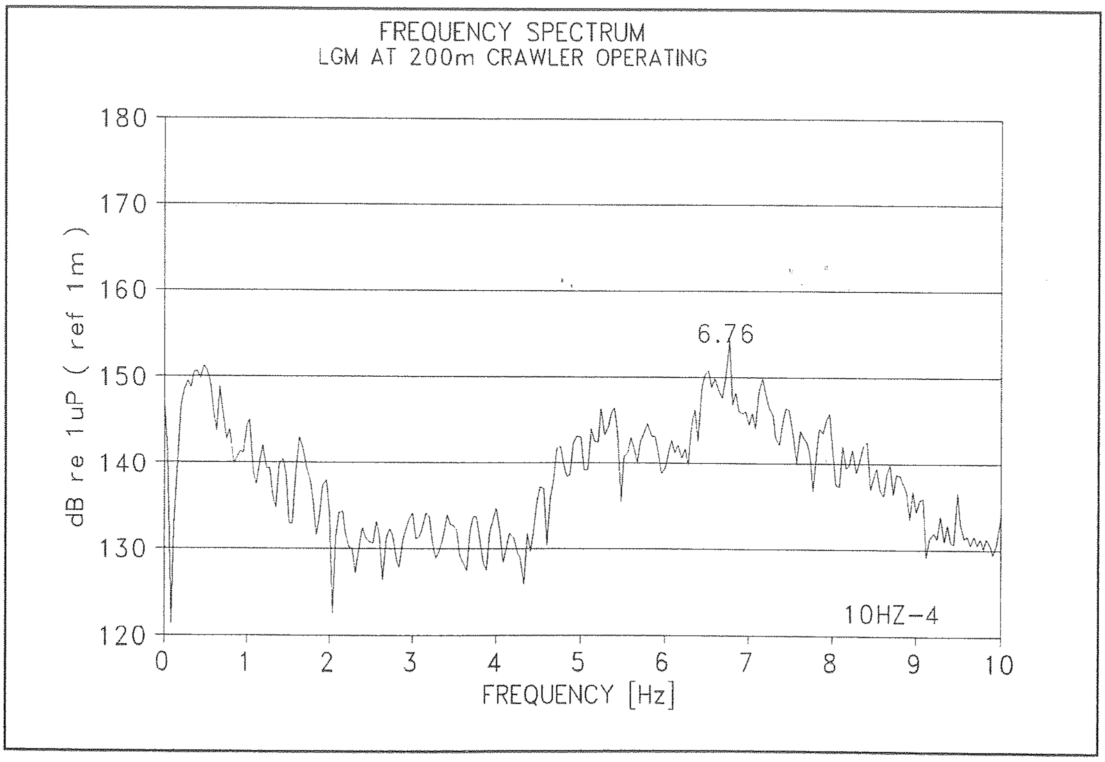

Figure 12: LGM at 200 m crawler operating

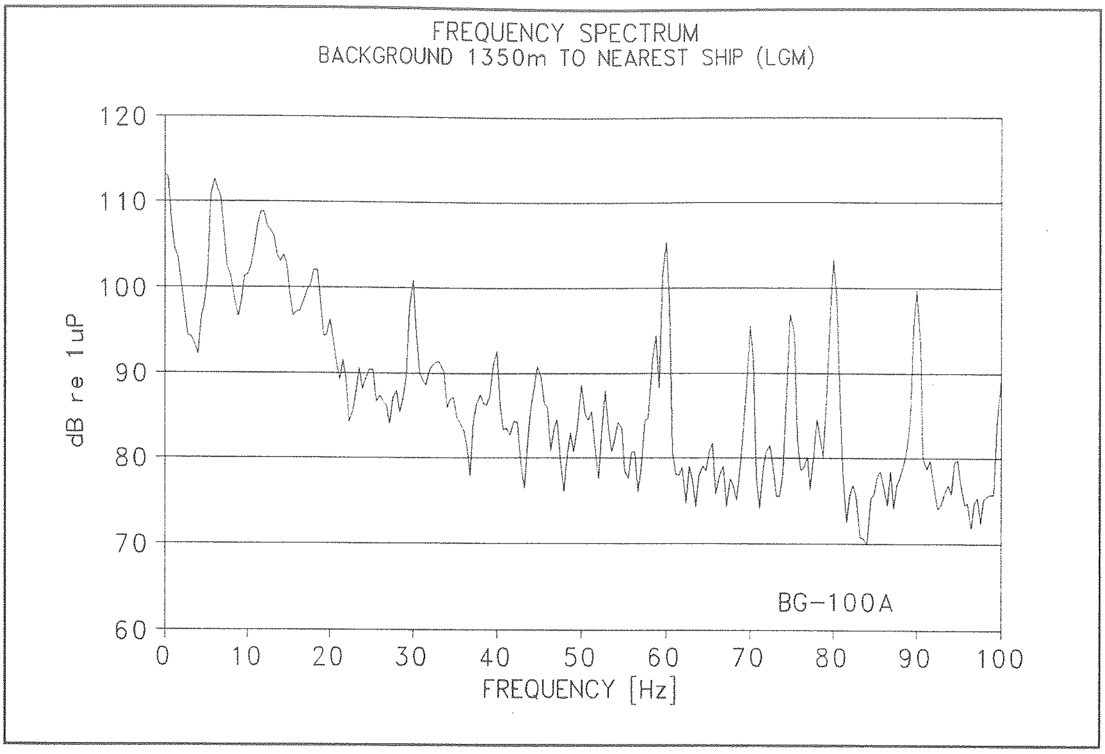

Figure 13: Background - nearest ship 1350 (100 Hz)

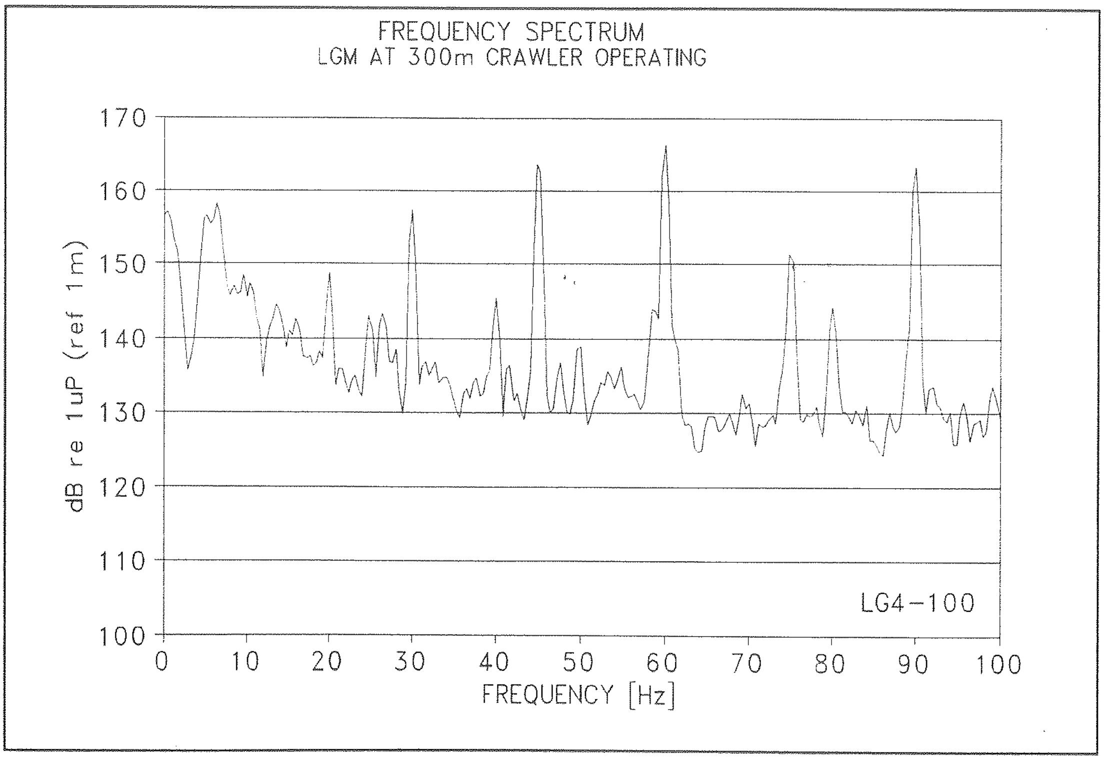

Figure 14: LGM at 300 m crawler operating (100 Hz)

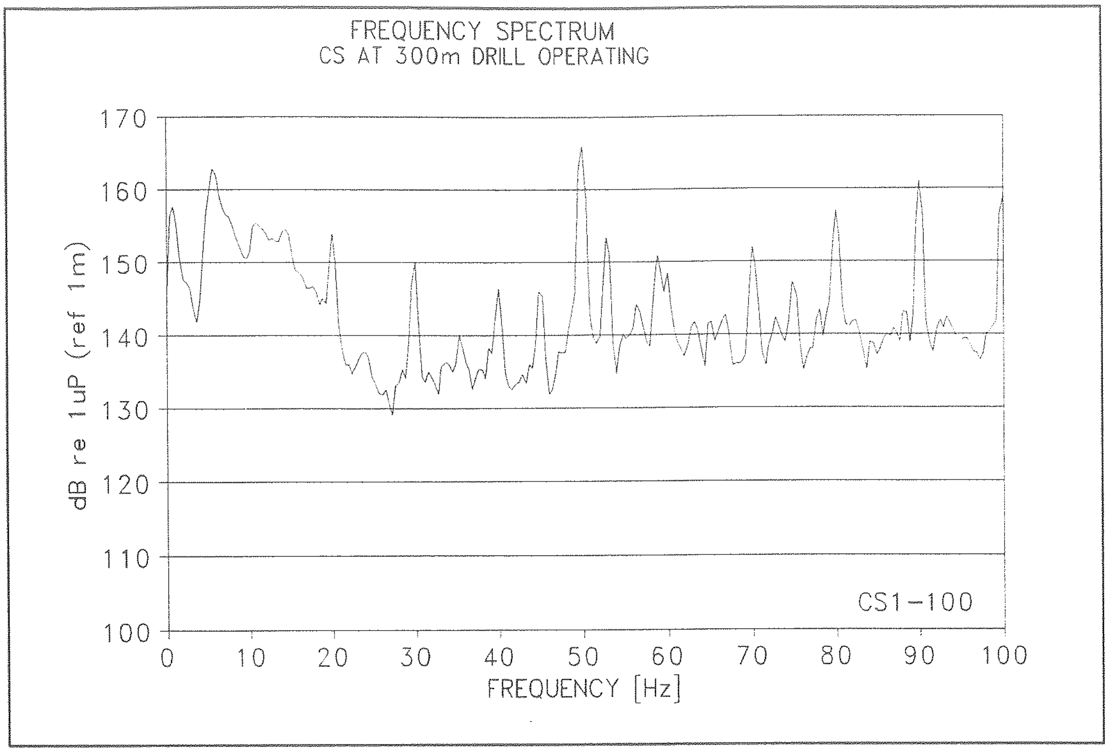

Figure 15: Coral Sea at 300 m drill operating (100 Hz)

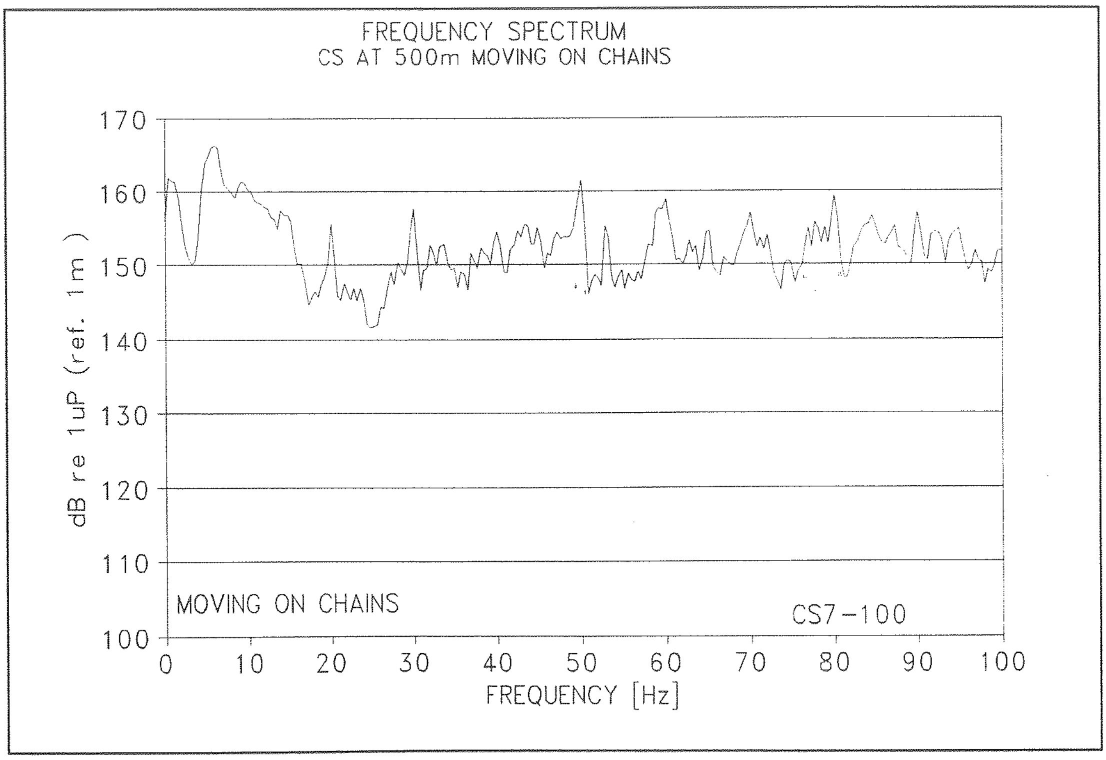

Figure 16: Coral Sea at 500 m, moving on chains (100 Hz)

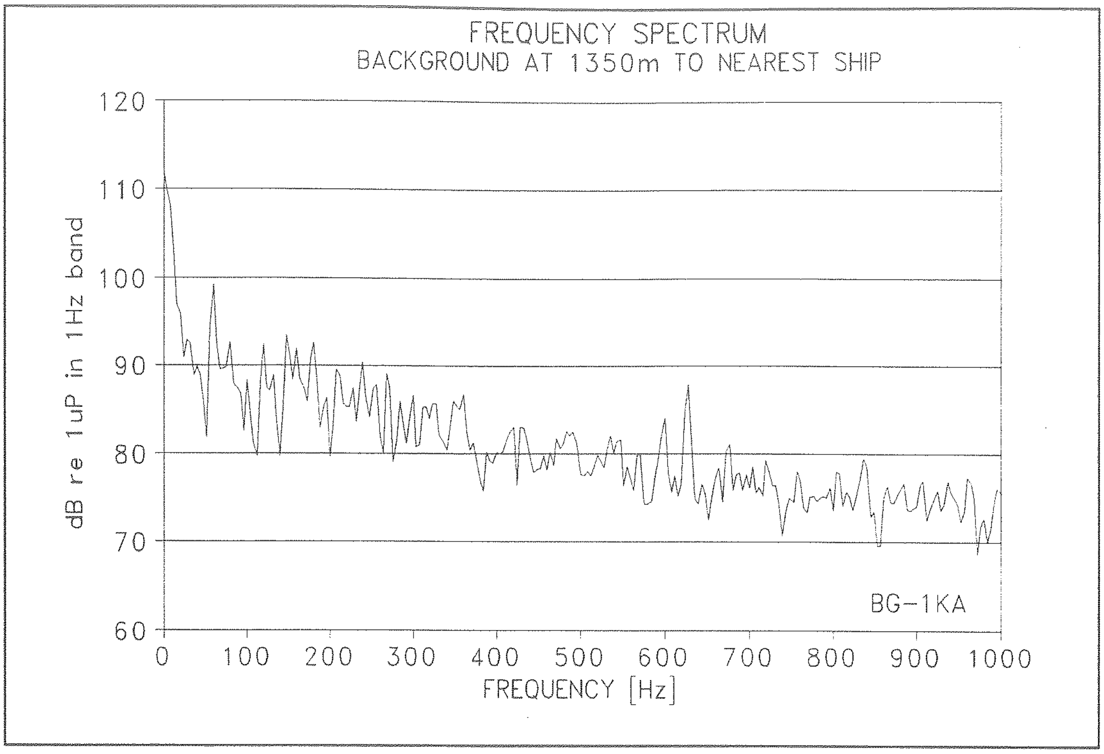

Figure 17: Background - nearest ship 1350 m (1 000 Hz)

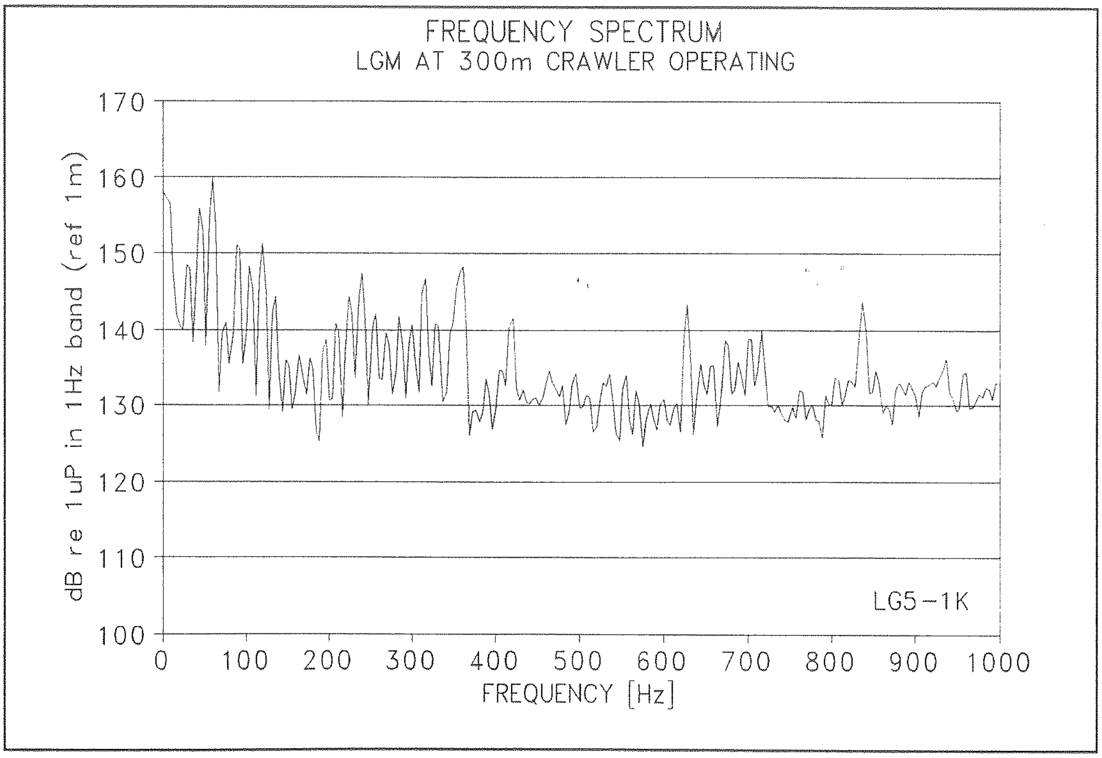

Figure 18: LGM at 300 m crawler operating (1 000 Hz)

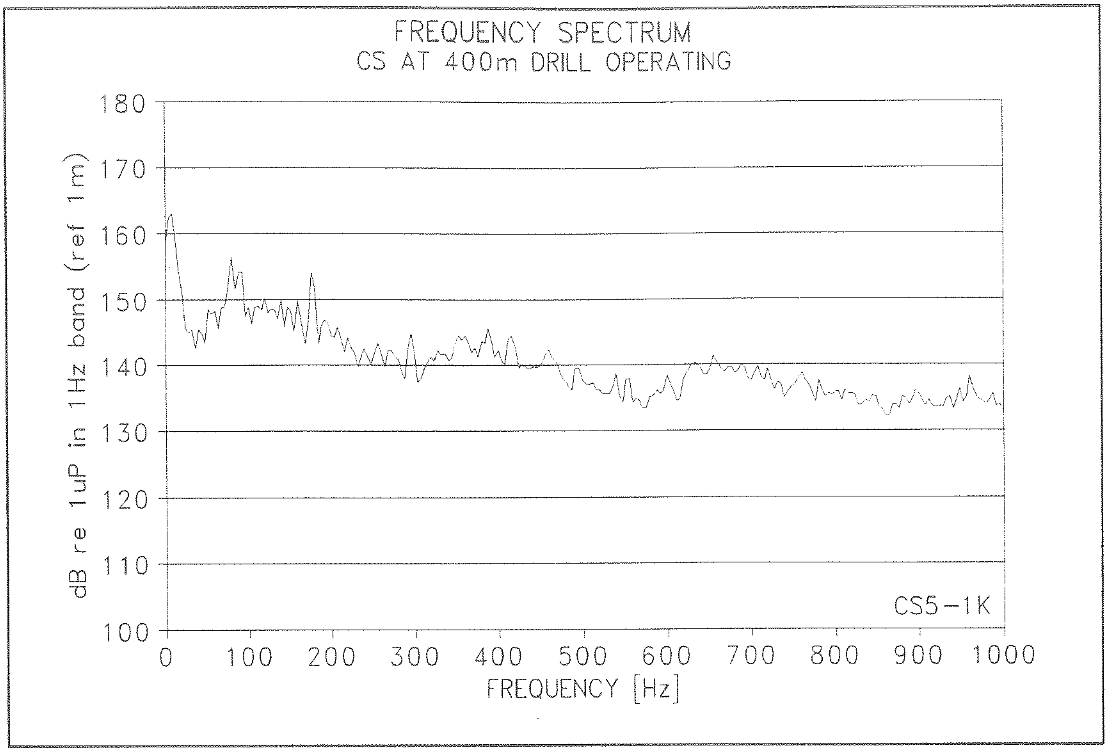

Figure 19: Coral Sea at 400 m drill operating (1 000 Hz)

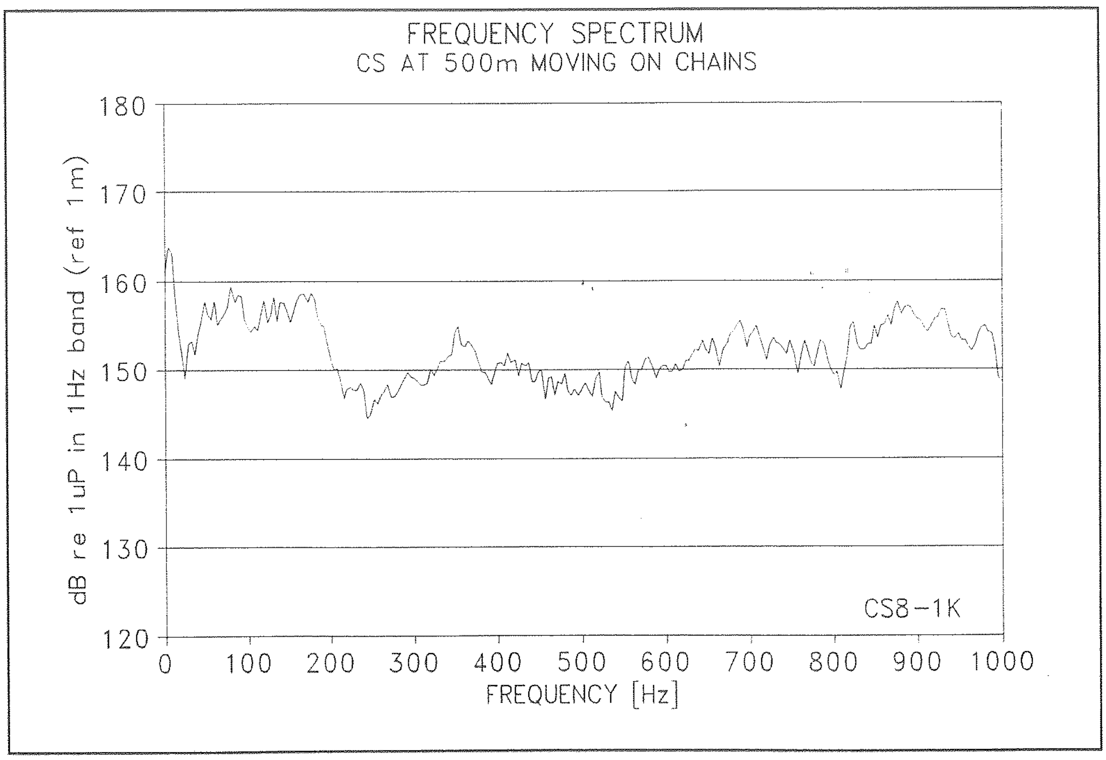

Figure 20: Coral Sea at 500 m, moving on chains (1 000 Hz)

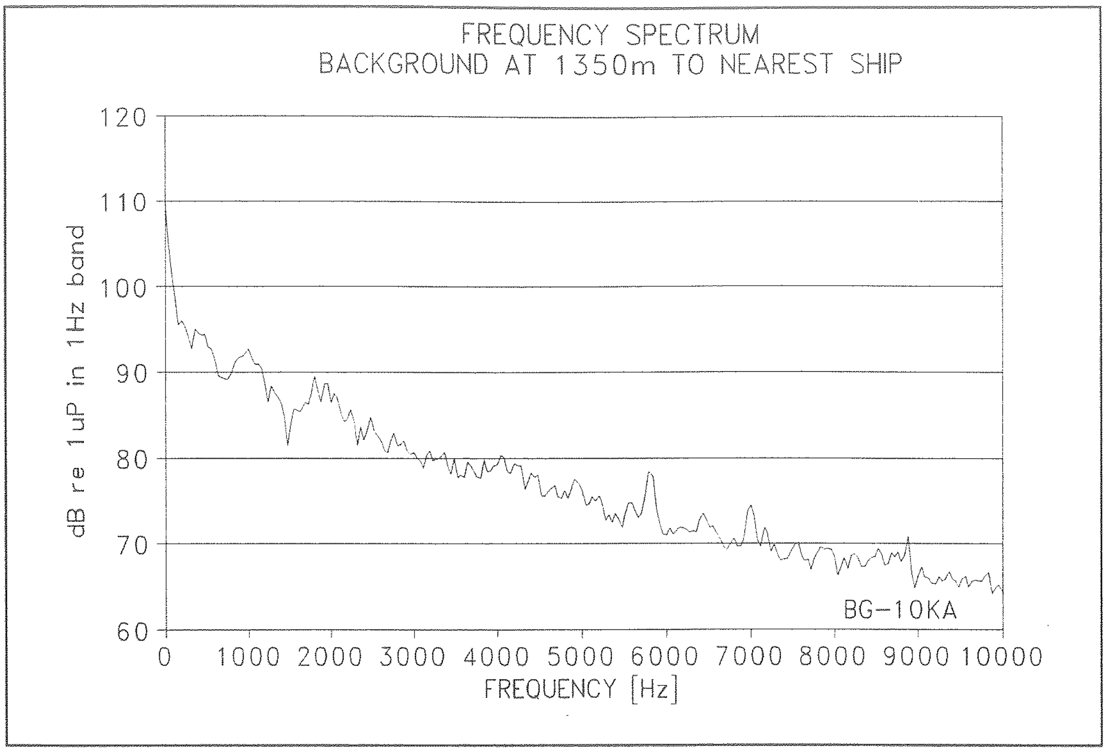

Figure 21: Background - nearest ship 1 350 m (10 kHz)

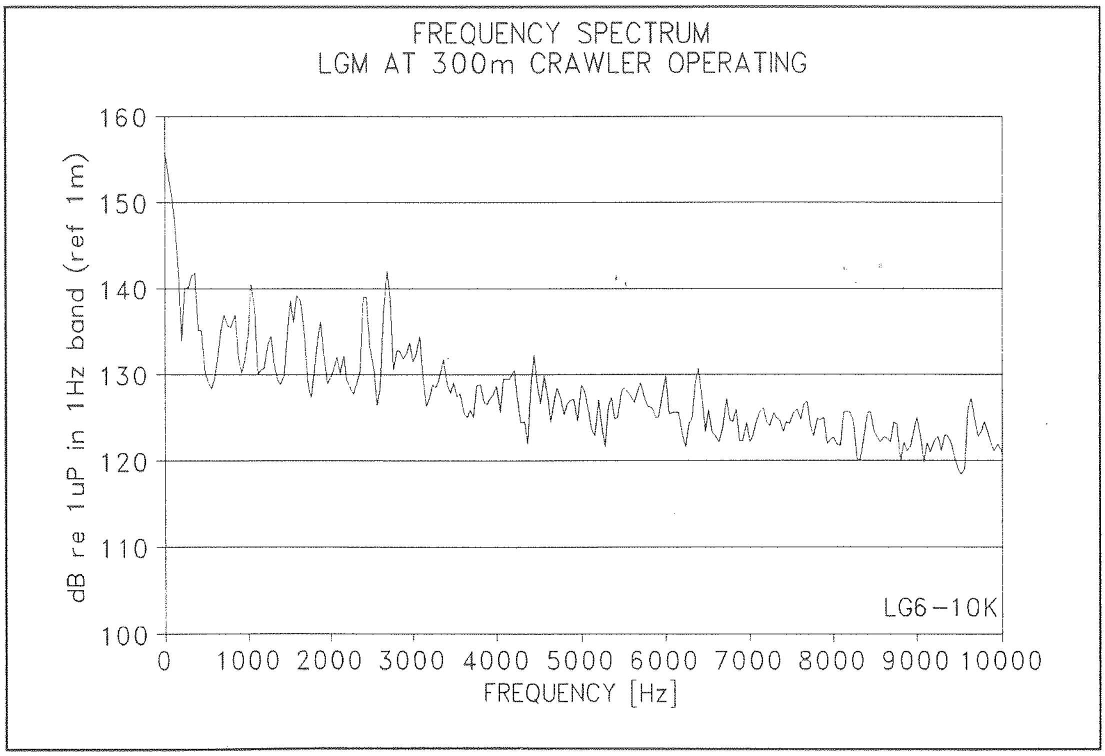

Figure 22: LGM at 300 m crawler operating (10 kHz)

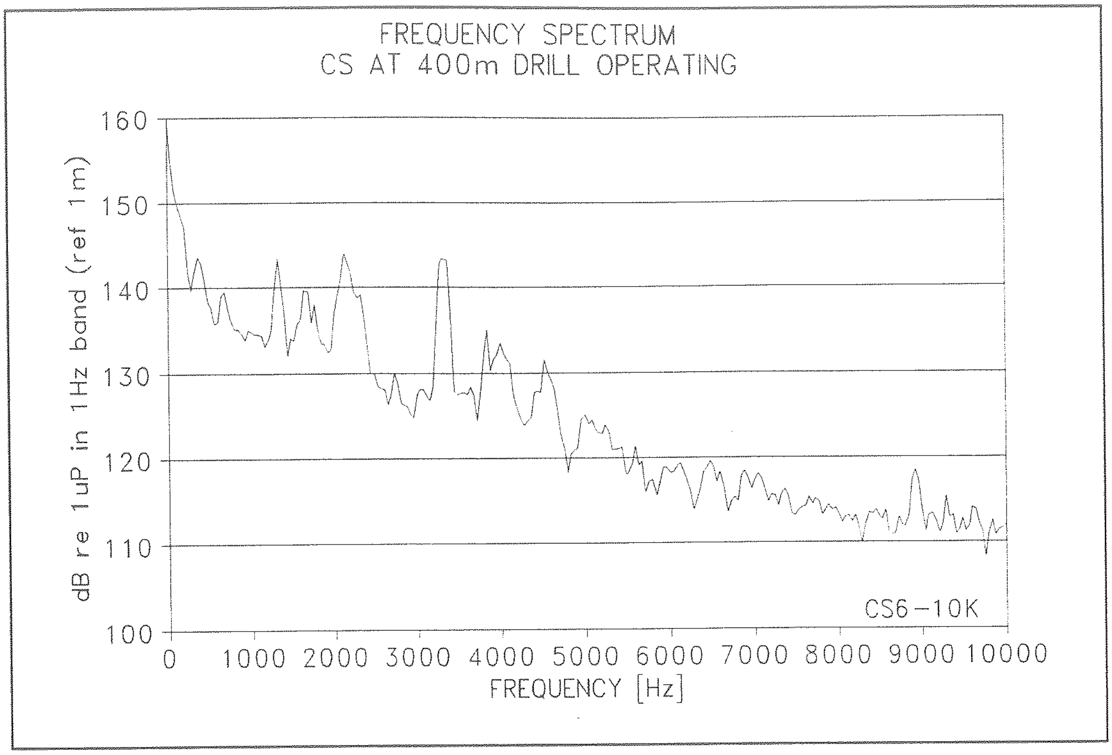

Figure 23: Coral Sea at 400 m drill operating (10 kHz)

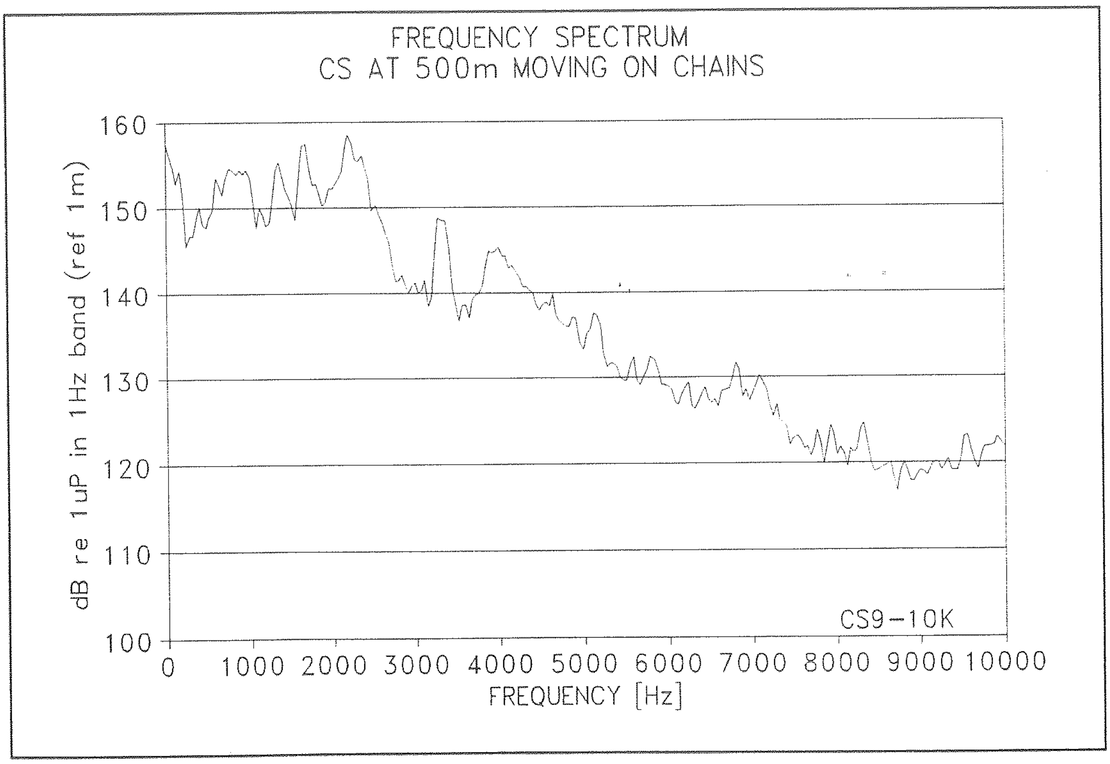

Figure 24: Coral Sea at 500 m, moving on chains (10 kHz)

APPENDIX B

- Low frequency propagation

- High frequency attenuation

B.1 LOW FREQUENCY PROPAGATION

The amount of low frequency sound propagated by the sea is controlled by several factors. These are water depth, temperature, salinity and sea floor topography. The water depth will have the highest effect in a shallow water situation. The water depth is 110 metres in the vicinity of the mining vessels, this corresponds to a low frequency propagation limit of approximately 11 Hertz. Figures 25 to 28 illustrate the effect that depth of water has on propagation. These were calculated by using the IMT sound propagation model Norman [Ref. 6]. Figure 25 indicates the number, and type of modes that 50 Hz produces in 110 meters of water. Figure 26 shows to what distance this frequency will propagate for a predicted level of attenuation i.e. 150 km the original signal will have been attenuated by 110 dB. (A mode is a vertical standing wave presenting a distribution of sound pressure versus water depth.)

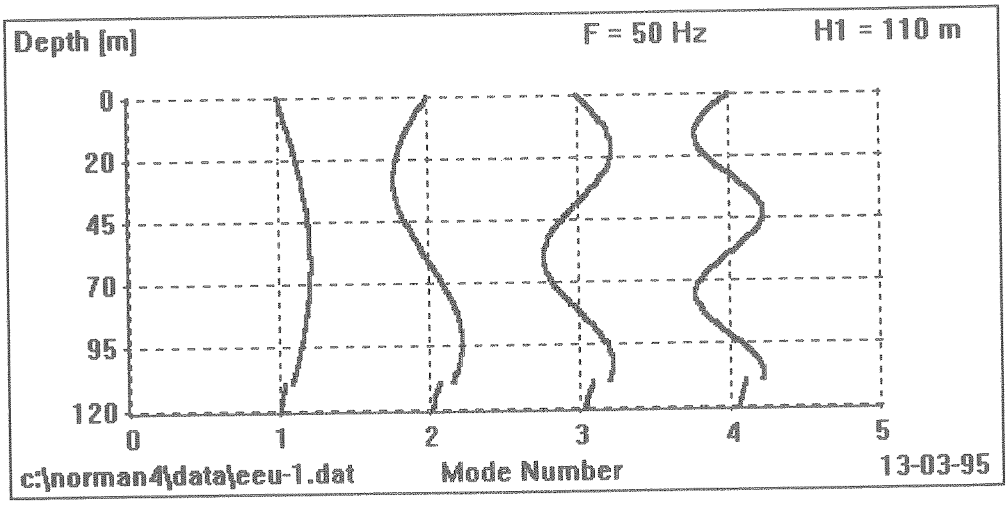

Figure 25: Modes at 50 Hz.

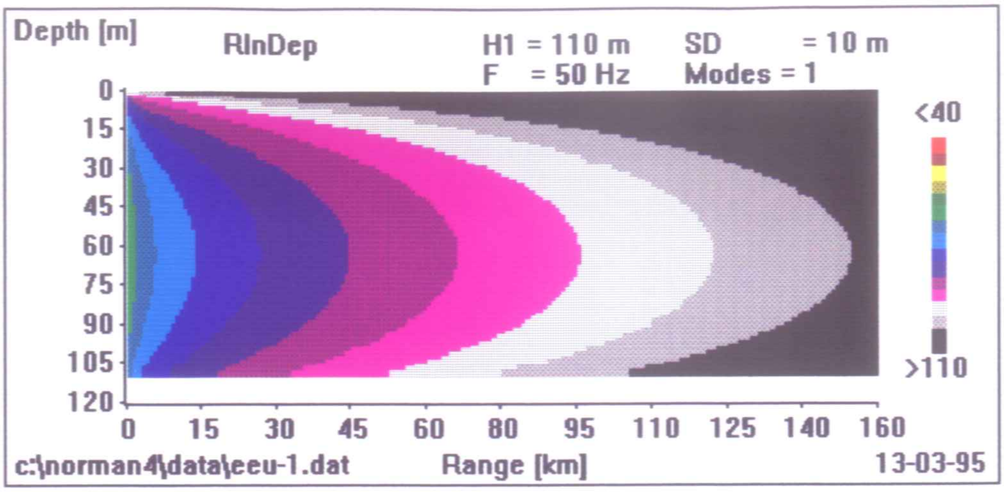

Figure 26: Propagation at 50 Hz.

In the next graph (figure 27) the number of modes for 11 Hz is only one. This wave will only propagate a short distance from the source. In figure 28 it can be seen that this lower frequency will only travel 30 km before being attenuated by 110 dB.

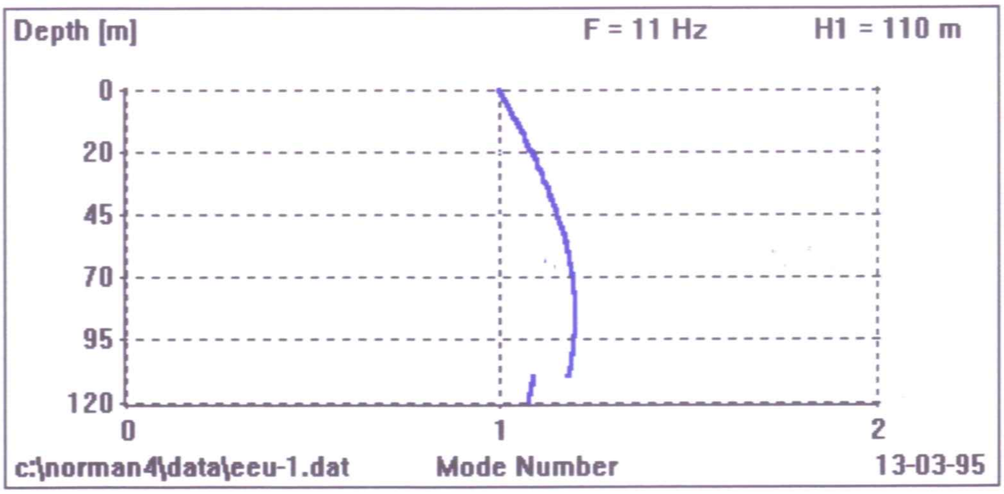

Figure 27: 11 Hz mode.

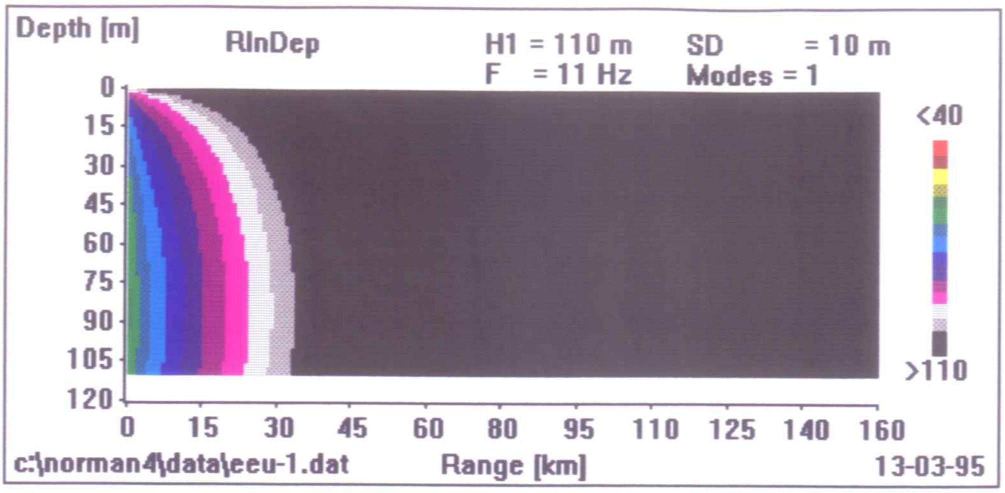

Figure 28: Propagation at 11 Hz.

B.1.1 11 Hz component

To bring this into perspective, if the mining vessel is producing a noise level of 160 dB (from figure 10) at 11 Hz then the sound will only travel approximately 2 km before it is equal to the level of the background noise. (See figure 7 and figure 28 for background levels and attenuation versus distance.)

B.1.2 50 Hz component

If one compares the 50 Hz component, at a level of 165 dB, (from figure 14) with a corresponding background level of 85 dB (from figure 13). Then the sound waves will now propagate 20 km before attenuating to the same level as the background noise (figure 26).

B.2 HIGH FREQUENCY NOISE PROPAGATION

B.2.1 Sonardyne Transponder specifications

Frequency Range	MF 19 - 36 kHz LF 8 - 16 kHz HF 33 - 65 kHz
Interrogation Source Level	MF 192 dB re 1 μPa at 1 m LF 192 dB re 1 μPa at 1 m HF 189 dB re 1 μPa at 1 m
Pulse length	MF 4 ms LF 8 ms HF 2 ms

MF = Medium frequency
LF = Low frequency
HF = High frequency

These levels are taken from the SONARDYNE Handbook and are an accurate description of the transmitted pulses. [Ref. 2].

B.2.2 Attenuation

The attenuation of the transponder signals will be at a rate corresponding to the formula $TL = 20 \log R + \alpha R$

Where TL = transmission loss, R = range and α = absorption coefficient. Illustrated in figure 29 is the transmission loss versus range for a frequency of 34 kHz. If we assume a source level of 192 dB re 1 μPa at 1 m then this level would be 147 dB above the predicted shallow water ambient noise level, for sea state 3 (from figure 6). The pulses produced by the transponder system are only 4 ms (medium frequency) in duration. This is effectively a bandwidth of 250 Hz which limits the energy radiated by a further 24 dB. The pulse is now only 123 dB above sea state 3. The range, from figure 29, is approximately 8 kilometres before the transmitted pulses from the transponders is equal to the background noise.

The detection threshold is normally 10 dB above the background levels, additional to this the signal could be masked by noise produced by rain (15 dB above the background). The net result is a possible detection range of approximately 5 kilometres.

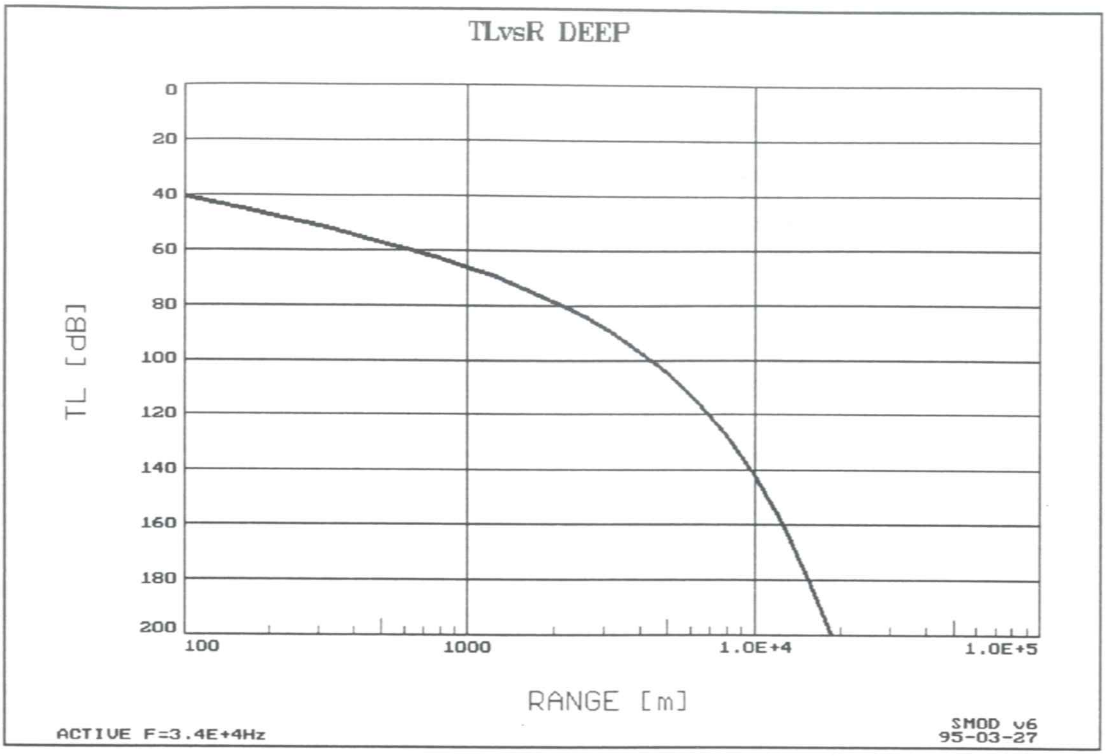

Figure 29: Transmission loss versus depth.

B.2.3 Optimum frequency

Figure 30 depicts frequency versus range giving the optimum range of propagation for a water depth of 110 meters.

From the graph this frequency would be approximately 200 Hz.

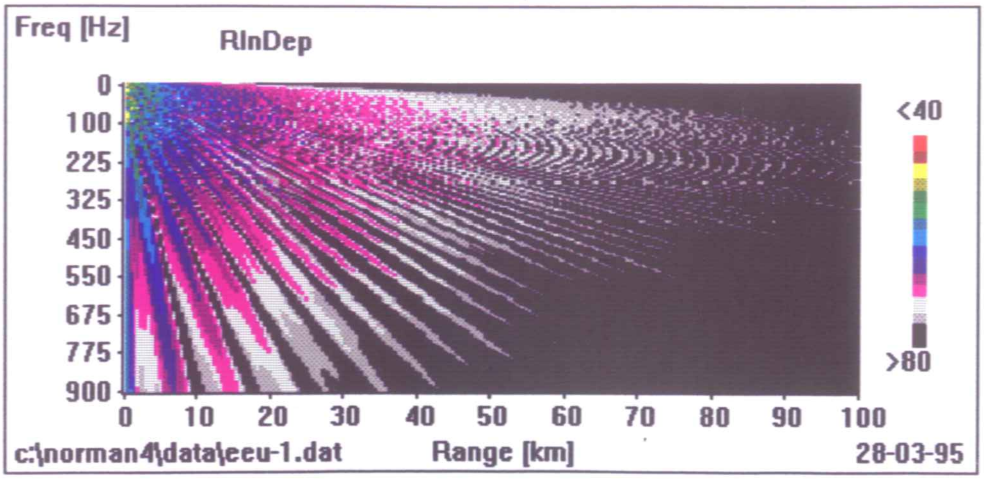

Figure 30: Frequency versus range.