NATIONAL INSTITUTE OF OCEANOGRAPHY

WORMLEY, GODALMING, SURREY

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B. S. McCARTNEY

N.I.O. INTERNAL REPORT No. A.29

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C O N T E N T S

1. Introduction

Hydrophones and hydrophone arrays towed from Discovery are used for a wide variety of purposes including sub-bottom profiling, pinger hunting and fish detection; frequencies extend from about 50 Hz to about 50 kHz. Usually the hydrophones consist of barium titanate spheres with a pre-amplifier in an oil filled tube towed by the electrical cable. To compare the practical achievements of these acoustic systems with their estimated theoretical performance it is necessary to know the noise levels and variations in levels which may be expected at the receiving system. It is the purpose of this report to present some noise levels measured recently on Discovery Cruise 19 under a variety of conditions, with some discussion of the possible sources of noise; it is hoped that the results will be a useful guide for calculating and optimising towed hydrophone and array performances.

2. Sources of Noise

Important possible sources of noise are listed:

(a) Due to the ship
- (i) From the main diesel engines
- (ii) Motor noise
- (iii) Propellor noise
- (iv) Auxiliary machinery noise
- (v) Wake noise

(b) Due to towing the hydrophone
- (i) Flow-induced noise
- (ii) Noise induced by accelerating forces
- (iii) Cable flexing noise
- (iv) Aeolian tones from towing cable

(c) Ambient Acoustic noise
- (i) Due to sea-state conditions
- (ii) Traffic noises
- (iii) Noises of biological origin

(d) Other noises

(i) Receiving amplifier noises

(ii) Electrical interference induced into cables

These noise sources are many and various, sometimes inter-related, and not always under control, so that it is quite difficult to separate their effects.

The purpose of the pre-amplifier near the hydrophone is to increase the signal level and to change the unbalanced capacitive source to a balanced low resistance source feeding the cable, so that effects due to cable flexing and electrical interference are minimised, and at the same time to give a low amplifier noise level. Though always an ultimate limitation on signal detectability, amplifier noise can usually be reduced below underwater acoustic noises for a given frequency band. The same hydrophone and pre-amplifier combination may not necessarily be suitable for another frequency band. In the past this has led to a number of pre-amplifier designs and occasionally, when used out of context, to severe limitation of performance due to amplifier noise. A pre-amplifier has now been designed (see Appendix 2) which has a good noise performance over all the band and several other useful features.

The use of ceramic piezo-electric spheres helps to reduce the sensitivity to forces tending to accelerate the hydrophone as a whole e.g. vibration and jerking of the cable or wave motion with shallow hydrophones. Positive forces onto the sphere are balanced by negative ones on the opposite side and the electrical output is proportional to the average pressure over the whole surface. By contrast this does not apply for all vibration axes for end-capped cylinder hydrophones, which have commonly been used by other laboratories in this application.

As the towing tensions and speeds are low, cable diameters and length appreciable, and usually the towing angle very small, aeolian tones if present must fall at frequencies well below the range of interest here.

The major sources then are ship noises (a), flow noise b(i), and ambient noise (c). Acoustic ambient sea noise in the (deep) ocean is well documented by Wenz (1) and ship noise levels from Discovery were measured in February 1964 (2) ~~are also available~~, but neither are strictly relevant to towed hydrophones at shallow depths below a rough surface and in the vicinity of a wake. Flow noise has received less attention in the literature, though the paper by Skudrzyk and Haddle (3) is useful. Calculations of noise levels to be expected in our conditions from the available data is extremely hazardous especially at low frequencies and the empirical approach can be justified. Measurements similar to those quoted here have been reported by Hudson Laboratories (4) but using cylinders instead of spheres, at a constant speed and mainly with long arrays.

3. Experimental Procedure (See Fig. 1).

The hydrophone on test was streamed from the stern with 30, 60 or 85 metres of cable out (L). The hydrophone depth, h, was unknown and presumably varied with L and towing speed; this depth uncertainty is a week point when interpretation of experimental results are considered, though the depths correspond to those used in practice. (Neutrally buoyant cable and a submerged towing point would help to define the hydrophone depth, which could also be monitored using pressure gauges if necessary.)

In the electronics laboratory the signal passed via a coupling capacitor into a wide-band balanced-to-unbalanced transformer, and then to the B. and K. Spectrometer (Type 2112). This filtered the signal in thirty three $^{1}/3$ octave bands from 25 Hz to 40 kHz, in steps

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synchronised with the frequency calibrated paper drive of the of the B. and K. Level Recorder (Type 2305), whose pen deflection is proportional to the logarithm of the r.m.s. signal level from the spectrometer. The gains of all pre-amplifiers had been measured, including the insertion loss of the transformer, so that deflections on the recorder can be reduced to an equivalent input voltage, which when divided by the square root of the bandwidth, gives the spectrum level in $V/\sqrt{Hz}$ at the hydrophone terminals. The precise hydrophone sensitivity was known only for one hydrophone so that approximate conversion to pressure levels has been based on 7μV per dyne/cm^2 (7×10^{-7} V/N/m^2) at all frequencies. At low frequencies the error due to this approximation is negligible as there are large fluctuations in the r.m.s. level as recorded. At higher frequencies the approximation can introduce appreciable errors since measurement errors are less where fluctuations are small and also because the sensitivity of a sphere in a plastic tube falls slightly above 10 kHz. Wherever possible then results are quoted as differences in level from one condition to another so that sensitivity errors cancel out.

4. Discussion of Results

A typical one third-octave level recording is shown in fig. 2. Unless indicated other recordings used the same parameters. The writing and paper speeds were a compromise between averaging time, reduction of short term fluctuations and overall analysis time. Each record took 4 minutes 10 seconds and 5 seconds was spent at each band. The readings for the wide-band weighted filter settings A, B, C and 'Lin' were not used. The recordings taken at 2, 4, 6 and 8 knots with the hydrophone streamed from a 15 ft. boom on the port quarter and at 85m astern (measured from handrail) were reduced to equivalent input noise level and are shown in fig. 3. The spectra can be separated into regions, which suggest differing predominant sources of noise. At low frequencies the speed dependence is particularly marked and spectral slopes rather variable. In the mid-frequency region (800 - 8,000 Hz) the speed dependence is much less marked especially at 6 knots or less and the spectrum slope is fairly constant around 10dB/octave. Above 8 kHz the slope steadily reduces to zero, the noise approaching first the background ambient noise as given by Wenz for conditions, estimated here to be almost 'sea-state 2', and then above 30 kHz approaching the pre-amplifier and other system noise. At 8 knots the high-frequency level is up to 10dB more than the level at 6 knots which is a very sharp increase with speed, and was consistently observed. This may have been due to propellor cavitation though there is no other evidence to support this, or to the use of two engines instead of one. In the mid-frequency range the sound pressure levels and slopes are close to those one would predict from the Sound Ranging Report. At frequencies below 100 Hz the levels are much higher than those measured on the sound range and since one would expect noise from the ship to be cancelled by its surface reflection at these wavelengths with shallow hydrophones, flow noise is suspected.

In order to attempt to separate flow and ship noise effects recordings were also made at L = 60m and 30m and the results are shown in fig. 4, where now only changes in noise levels compared with those of fig. 3 are plotted. At 8 knots and 6 knots there are no significant differences at low frequencies suggesting flow noise dominance and only above 1,000 Hz does ship noise appear to be dominant. Similarly at 4 knots an increase in level at frequencies above 500 Hz is observed as the hydrophone approaches the ship but the increases are smaller at L = 30m, and at L = 60m are not significant. The reduction in level at L = 30m (re. L = 85m) at 250 c/s is not explained. At 2 knots the situation is more complex. Significant differences are apparent as low as 100 Hz, the reduction of flow noise with speed being more rapid than the reduction of ship noise. No restrictions on the use of any machinery were applied during these measurements and the ship was running normally; this means that two main engines were running although at speeds below 7 knots only one would be generating, the other ticking over 'off-load'. The alternate reduction and increase in noise level at 2 knots and frequencies from 2 kHz - 10 kHz is not understood though the similarity between the spectra for L = 30 and L = 60m suggest that the anomaly originates from the measurement at L = 85 m.

At this point it is worth considering the level of the recorded fluctuations and repeatability of the measurements in order to assess the magnitude of change which may be considered significant and how this magnitude varies with frequency. In Fig. 5 the peak to peak fluctuation in recorded level (proportional to $20 \log_{10}$ (r.m.s. output voltage during 125μS)) for ten frequency bands has been plotted; the value given is the average of 12 recordings, individual fluctuations being up to 5dB greater. In measuring the one-third octave levels for figs 3 and 4 and subsequent figures the dB level was averaged by eye for the 5 secs period at each frequency. The errors introduced by this process can be judged by the shaded levels in fig. 5, where average differences in measured levels from recordings repeated immediately under identical conditions have been plotted. As would be expected these are less than the average peak-peak fluctuations which are present. In comparing measured spectra then differences should be greater than the shaded values at any frequency in order to have significance, even though differences may be less than some short term fluctuations which can occur. The physical causes of the fluctuations are numerous but, apart from the inherent random fluctuations of most noise sources can include the beating of vibration harmonics, the movement of the hydrophone in and out of directional sound radiation and fluctuating surface reflections. On several occasions a periodicity in the fluctuations fitted with the swell period relative to the ship. Fluctuations were greatest at lower frequencies, higher speeds, higher sea states and nearer the ship.

The changes in level shown in fig. 6 compare towing along the centre line of the ship's track with towing about 15m to port of this line. The main feature is the reduction over the 100 - 400 Hz band which is insensitive to changes in L. Masking of noise by the aerated wake which is below the hydrophone depth is a possible explanation especially for ship noise reflected from the sea bed. Advantage cannot be taken of these reduced levels as signal levels would also be reduced in a similar way. The reduced level at 6 knots for L = 30m and to a smaller extent at L = 60m in the band 3 kHz to 15 kHz suggests a predominance of noise direct from the ship, when towed from the boom as confirmed for these parameters in fig. 4. There is no evidence to suggest that the wake is a local source of noise at these distances.

Some differences observed at sea states 5 and 3 compared with the levels at sea-state 2 of fig. 3 are given in fig. 7. At 8 knots 'sea-state 5' noise only contributes significantly over the band 5 - 15 kHz but as speed is reduced this significant bandwidth increases. At 2 knots 'sea-state 3' noise contributes above 1 kHz and around 200 Hz. The low frequency increase at 6 knots and sea-state 5 may be due to flow noise in more turbulent water, though at 8 knots this increase is barely shown. The Knudsen (1) 'sea-state' noise levels refer to deep hydrophones and deep water. These towed hydrophones are much closer to the surface where different spectra and probably higher levels may be expected. The magnitudes of some of the observed increases are greater than would be predicted using Knudsen's curves for changes in sea conditions from 2 to 3 or even 5.

With the ship drifting the hydrophone was weighted to hang nearly vertical 60m below the stern and noise levels were recorded. Ideally one would like to compare these levels with those taken with the hydrophone stationary 60m from the stern horizontally, but as the ship had to be underway to keep the hydrophone horizontal, comparison must be made with the slowest towing speed. Fig. 8 indicates that, over the whole frequency band, but particularly at low frequencies, noise levels are lower astern at 2 knots than the same distance below the stationary ship. This result can be explained by the Lloyd's mirror effect, which at any frequency is the coherent vectorial summation of two incident ray pressures, one direct from a source and the other via a smooth reflecting surface, in this case the air/sea interface. The resultant pressure amplitude depends upon the phase difference between the rays and therefore upon the path length difference. There is a critical frequency for which this path length difference between the two rays is half a wavelength and, with the phase inversion at the surface the incident pressures add; below this frequency the incident pressures approach antiphase and the resultant pressure reduces, approaching a 6dB/octave slope. The critical frequency (f_c) depends upon the depth (d) and distance (L) of the source from the hydrophone at depth h, according to $f_c = \frac{cL}{4dh}$, for rays near the horizontal, and according to $f_c = {}^{c}/4h$ for rays near the vertical.

Thus for $L > d$ the critical frequency for vertical rays is lower than that for horizontal rays. Noise originating in the ship can reach the towed hydrophone along nearly horizontal paths with and without surface reflection, and along nearly vertical paths after reflection at the sea bed, again with and without surface reflection. Either the horizontal or vertical rays may predominate at the hydrophone depending upon the directionality of the noise source, the depth of sea, the bottom reflection loss and the frequency relative to the critical frequencies. For the experimental comparison here the Lloyd's mirror effect is only relavent for the hydrophone astern and near the surface. From fig. 8 there is a critical frequency in the region of 150 Hz; this cannot be explained on the basis of ship noise from horizontal rays as this would necessitate an unreasonably great hydrophone depth over

20m; on the other hand a depth of 2m would suffice if ship noise in this band arrives via reflection from the sea bed, and this is in accord with the explanation of fig. 6. Above about 400 Hz reductions in level of the horizontal rays due to this effect are apparently less than the greater spreading loss (in 50 fathoms depth) and reflection losses of the vertical rays, so that the direct and surface reflected ship-noises from horizontal directions predominate.

Directional discrimination against the latter noise can be achieved using line arrays and fig. 9 indicates just this for noise levels from a 12 ft. long array of 10 hydrophones compared with those from a single hydrophone. The theoretical endfire rejection for $^1/3$ octave bands calculated from the directional pattern of fig. 12 is also shown, the maximum rejection occurring at a frequency for which the first, and lowest, side-lobe faces the ship. Agreement in rejection band is quite good and agreement in rejection level would not be expected in the presence of other noises with different angular distributions. The reduction in level at very low frequencies is interesting and illustrates a property of one type of flow noise, which is the main source in this band; flow noise pressures are associated with local boundary layer turbulence and are mainly near-field pressures, which are not radiated to a distance. The hydrophones in the array are separated by a much greater distance than the mean turbulence diameter and therefore the pressures are uncorrelated between hydrophones. When referred to the voltages at the array or hydrophone output a 10 dB reduction in flow noise components of the array relative to a single hydrophone could be expected. By using larger diameter tubing with the same size of hydrophone sphere and thus separating the source of pressure fluctuations from the hydrophone it may be possible to reduce flow noise further. Also using more spheres in the same tube might improve the signal-to-flow-noise ratio.

Another type of flow noise, caused by disturbance of the boundary flow by surface roughness and irregularities, can become apparent at high frequencies. For the single sphere spectra these regions are masked by other forms of noise, especially ship and sea noise. However the line array discriminates against these to the extent that 'roughness' flow noise can be the residual significant noise at some frequencies. The array was coated over all its length with silicon grease and the resulting difference in noise level of fig. 10 shows some reduction over the band 2 - 10 kHz. This observation agrees with the result of a similar experiment by Skydrzyk and Haddle, who also point out that the greases and varnishes can cause increases in flow noise at low frequencies. The changes at low frequencies in fig. 10 are not significant.

Other experiments which were made were generally inconclusive. Measurements over deeper water were made in an attempt to clarify further the importance of bottom reflected noise but sea conditions changed at the same time. Comparisons were made between different types of hydrophone construction - i.e. p.v.c. tubes with tufnol end pieces and jubilee clips, the old polypropelene design with wooden ends and the newer polypropelene designs. A recent report (5) suggests that p.v.c. tubing can introduce considerable, and frequency dependent, losses reaching 10 dB at 10 kHz, and for lack of precise data on our particular materials these have not been included. In fact above 5 kHz at 8 knots the p.v.c. hydrophone showed increasing rather than decreasing levels, but this may be due to turbulence around the jubilee clip or different surface properties.

5. Summary

To summarize the results for the single hydrophone towed at L = 85m, fig. 11 has been drawn. Boundaries between one predominant source of noise and another are not sharp, and will vary with other conditions such as sea state and, it is expected, water depth. A similar summary for the array could not be completed due to insufficient measurements at different speeds. The evidence suggests that at shallow depths array directivity will not help to reduce background noise from the ship at frequencies below about 400 Hz, though in oceanic depths this will not apply and longer arrays will be useful. In fact a 50ft. array was successfully used by D. Bishop and A.R. Stubbs for sub-bottom profiling on the latter half of Cruise 19, in deeper water using the air gun source and filtering the band 100 - 300 Hz. A useful reduction in noise level compared with a 30ft. array was apparent.

For work at 10 kHz with single hydrophones sea-noise is the limiting noise level at speeds up to 6 knots and to reduce this directivity would be required; then flow noise due to surface roughness would determine the limit, and also the pre-amplifier would need to be designed for optimum noise factor at 10 kHz instead of the present wide-band compromise, which is acceptable when sea-noise is dominant.

The work reported here leaves gaps in our knowledge of hydrophone noise levels which will be filled as opportunity arises. Further laboratory work on losses in plastic tubes and simplified mechanical designs would be useful.

It is a pleasure to acknowledge the facilities and ship time kindly given by Mr. A.H. Stride, Senior Scientist on Cruise 19, and the assistance of other staff, officers and crew.

6. References

1. G.M. WENZ, Journal of the Acoustical Society of America, 34, (12), pp. 1936-1956, (1962).

2. [redacted].

3. E.J. SKUDRZYK and G.P. HADDLE, "Flow noise, theory and experiment," Lecture 14, pp. 255-278 in Underwater Acoustics, Plenum Press, Ed. V.M. Albers.

4. J.A. SMITH and E.J. O'NEILL, "Noise levels observed with ship-towed geophysical hydrophone arrays." Tech. Rept. 112, Hudson Laboratories, Columbia Univ., Dobbs Ferry, New York.

5. C.M. HUBBARD, "A towed hydrophone array", Saclant A.S.W. Research Centre Technical Memo. No. 132. (Unclassified).

APPENDIX 1.

Directional Patterns of Hydrophone Arrays

The directional patterns of arrays with uniformly spaced hydrophones have high side-lobes adjacent to the main beam. For a continuous array of length S, a well known amplitude function, which reduces side-lobe levels, at the expense of beamwidth is given by

$$\left[\tfrac{1}{2} + \tfrac{1}{2} \cos \left(\frac{2\pi x}{S}\right) \right]$$

for which the directivity function is $\dfrac{\pi^2 \sin Z}{(\pi^2 - Z^2)Z}$

shown on fig. 12, where $Z = \dfrac{\pi S . \sin \theta}{\lambda}$

An approximation to this taper function has been used at N.I.O. for many years, which consists of placing equally sensitive hydrophones at the centres of equal areas in the above taper function, at distance x from the centre given by 0·25 S, 0·077 S, 0·130 S, 0·200 S and 0·298 S. The distance between outside hydrophones is approximately 0·6 S and the actual array length T is 40% less than S. The true directivity pattern of this space tapered array has been calculated and is also shown in fig. 12. The beam width is approximately the same as that of a uniform array 0·6 S long and very close to the beamwidth of the raised cosine taper, but with very different side-lobe levels, especially at large Z. As the initial side-lobes will represent end-fire directions at low frequencies, for which noise levels are high, this seems to be a good pattern to use. From figs 9 and 12 it is apparent that such an array is useful over a 5 : 1 bandwidth, i.e. $f_1 = \dfrac{1{\cdot}2c}{T}$ to $f_2 = \dfrac{6c}{T}$.

APPENDIX 2.

New Pre-Amplifier Design

The new wide-band hydrophone design is shown in fig. 13. Basically it consists of a balanced d.c. coupled long tailed pair with emitter follower outputs. Biasing for the first stages are provided by R_1 and R_2 which require to be adjusted for each amplifier, providing d.c. feedback and stability without a.c. degeneration over the flat bandwidth. The low-frequency cut-off is determined by the capacity of the hydrophone and the input impedance. The latter is mainly determined by the collector current, which has been chosen for optimum noise conditions, and is increased by R_e. The insertion of R_e has two deleterious effects. The gain is reduced, in this case by a factor of two, and the high frequency noise level is increased slightly. If low frequencies are not required the resistors R_e can be shorted out or else the emitters of T_1 and T_4 connected together, increasing the value of R_E by $R_e/2$. The d.c. voltages on the outputs should be equal and between 3·3 and 4·0 V; these voltages are a good check on correct operation of the pre-amplifier. The main properties of the amplifier are given:

Supply Voltage	:	+12V nominal
Current Drain	:	12mA
Input Resistance	:	~100kΩ (45kΩ without R_e)
Equivalent Input Noise Resistance at f = 8kHz	:	~1·9kΩ (1·5kΩ without R_e)
Input voltage restrictions (instantaneous)	:	-2·5V < V in < +20V to prevent transistor damage
(a.c. signal)	:	-140mV < V in < 140mV to prevent overload. (≡ 1·4 x 10^4 μB r.m.s.)
Voltage Gain	:	40-50 depending upon T_1, T_4. (80-100 without R_e)
Gain Variation with Supply Voltage	:	< ±4% over 10V - 15V supply variation.
3dB bandwidths with R_e	:	20Hz to > 100kHz with 1 sphere 20Hz to > 100kHz with 10 spheres

3dB bandwidths without R_e	:	450Hz to >100kHz with 1 sphere 45Hz to >100kHz with 10 spheres
Max output voltage on o/c	:	±7V
Max output current swing on s/c	:	±7mA
Output resistance within above limits	:	100Ω
Dynamic Range in 200Hz band at 10kHz with 600Ω load	:	~ 100dB

FIGURE CAPTIONS

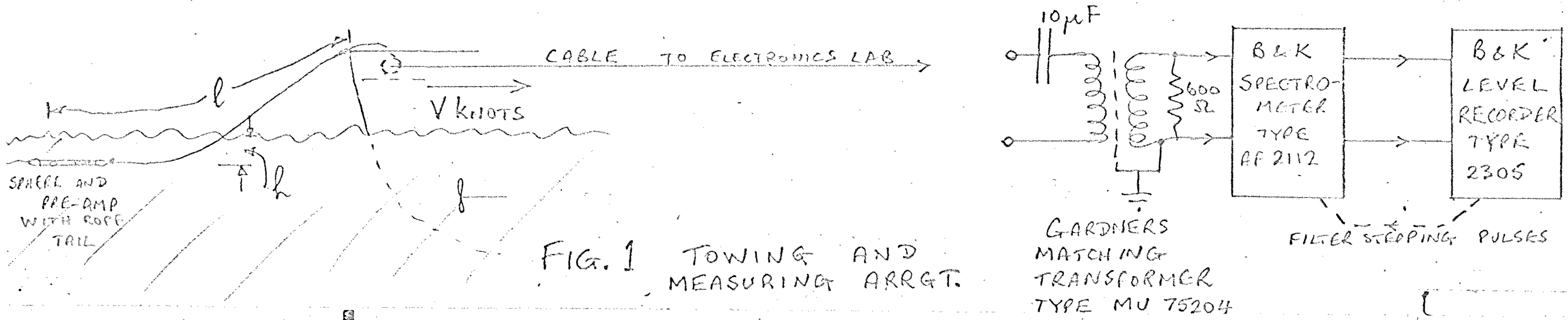


FIG. 1 TOWING AND MEASURING ARRGT.

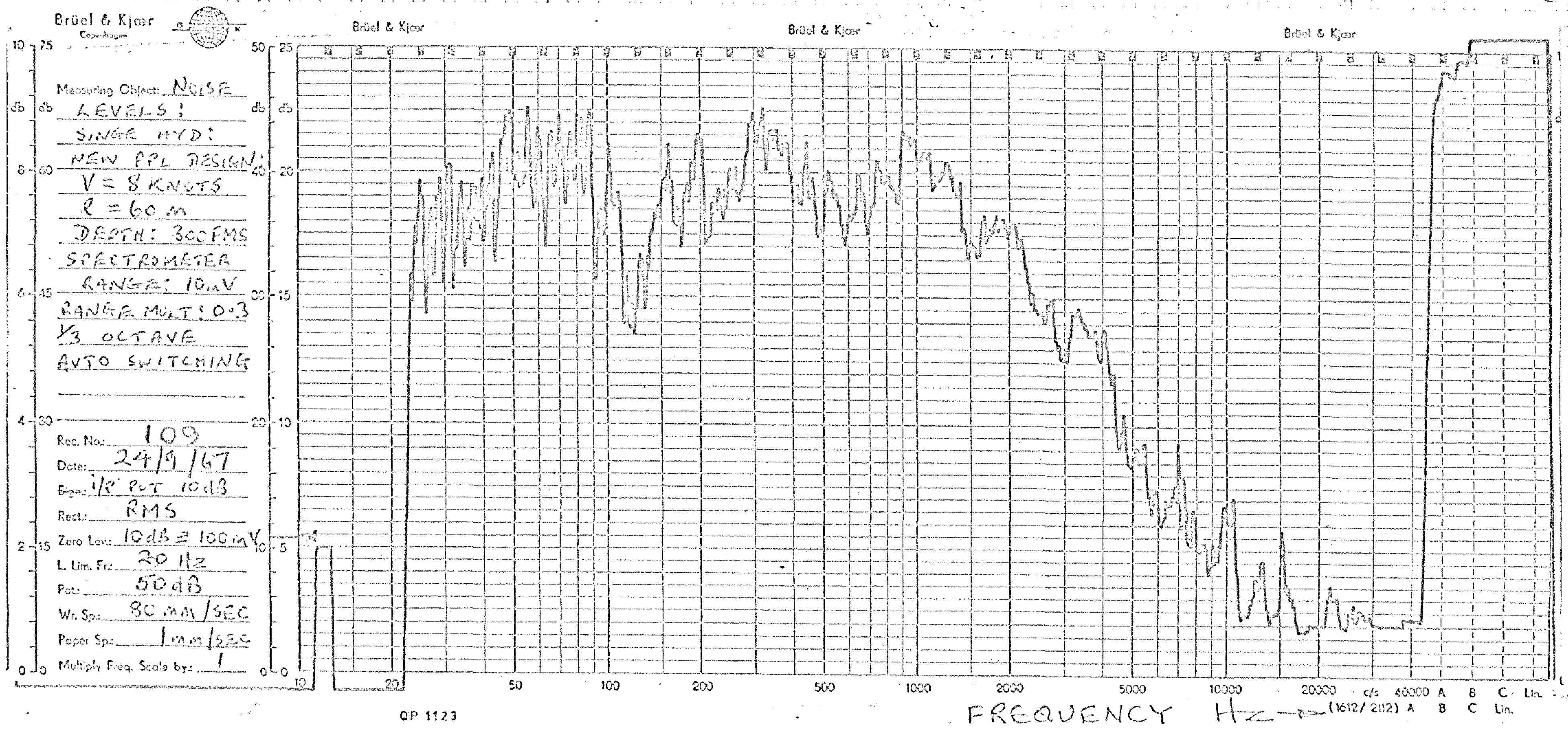


FIG. 2

TYPICAL B&K LEVEL RECORDING

FIG. 3 NOISE SPECTRA

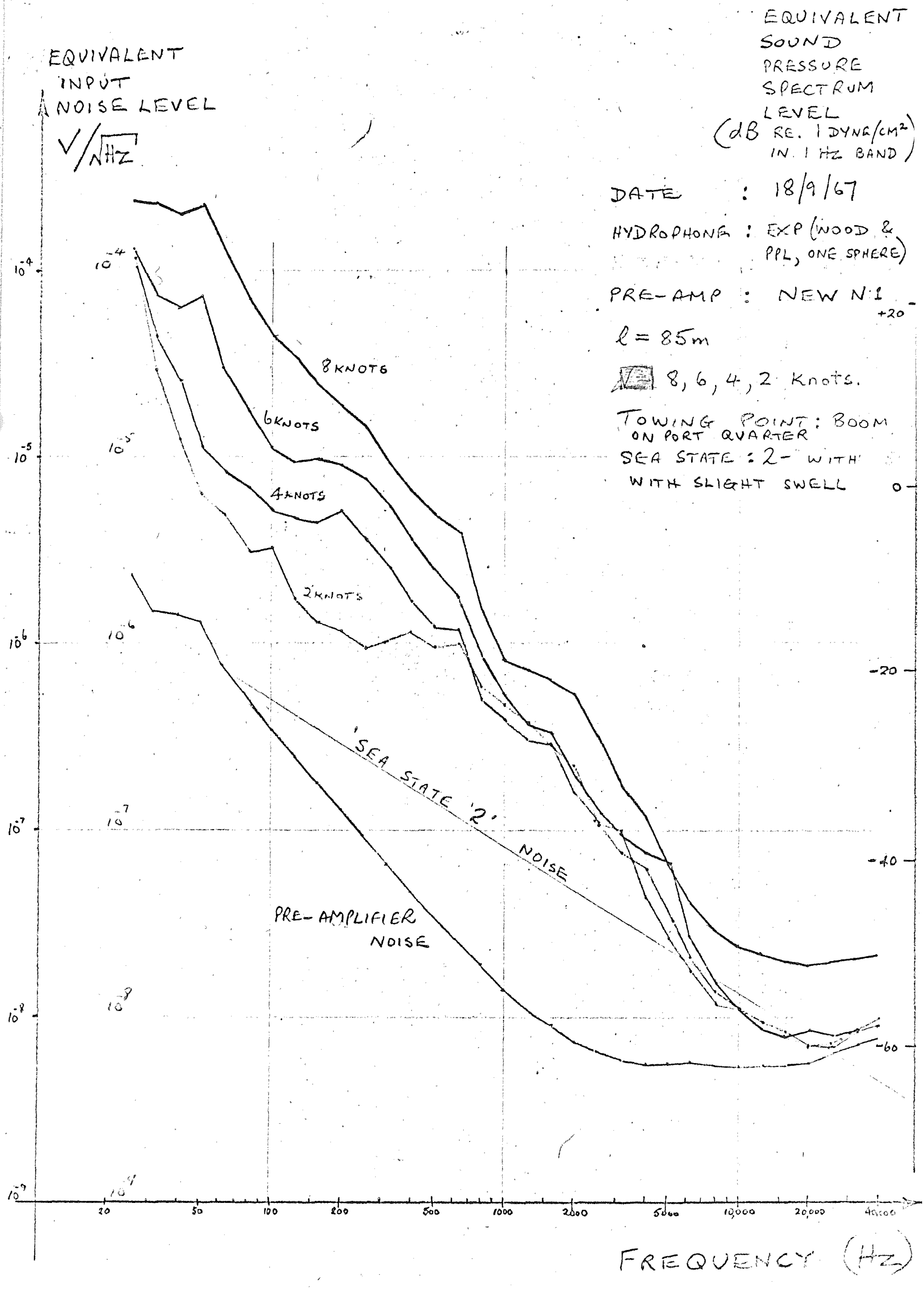


FIG. 4.

CHANGE IN NOISE SPECTRUM LEVEL OF TOWED HYDROPHONES AT 30 m AND 60m COMPARED WITH LEVELS AT 85m OUT FOR SPEEDS OF 2, 4, 6, & 8 KNOTS

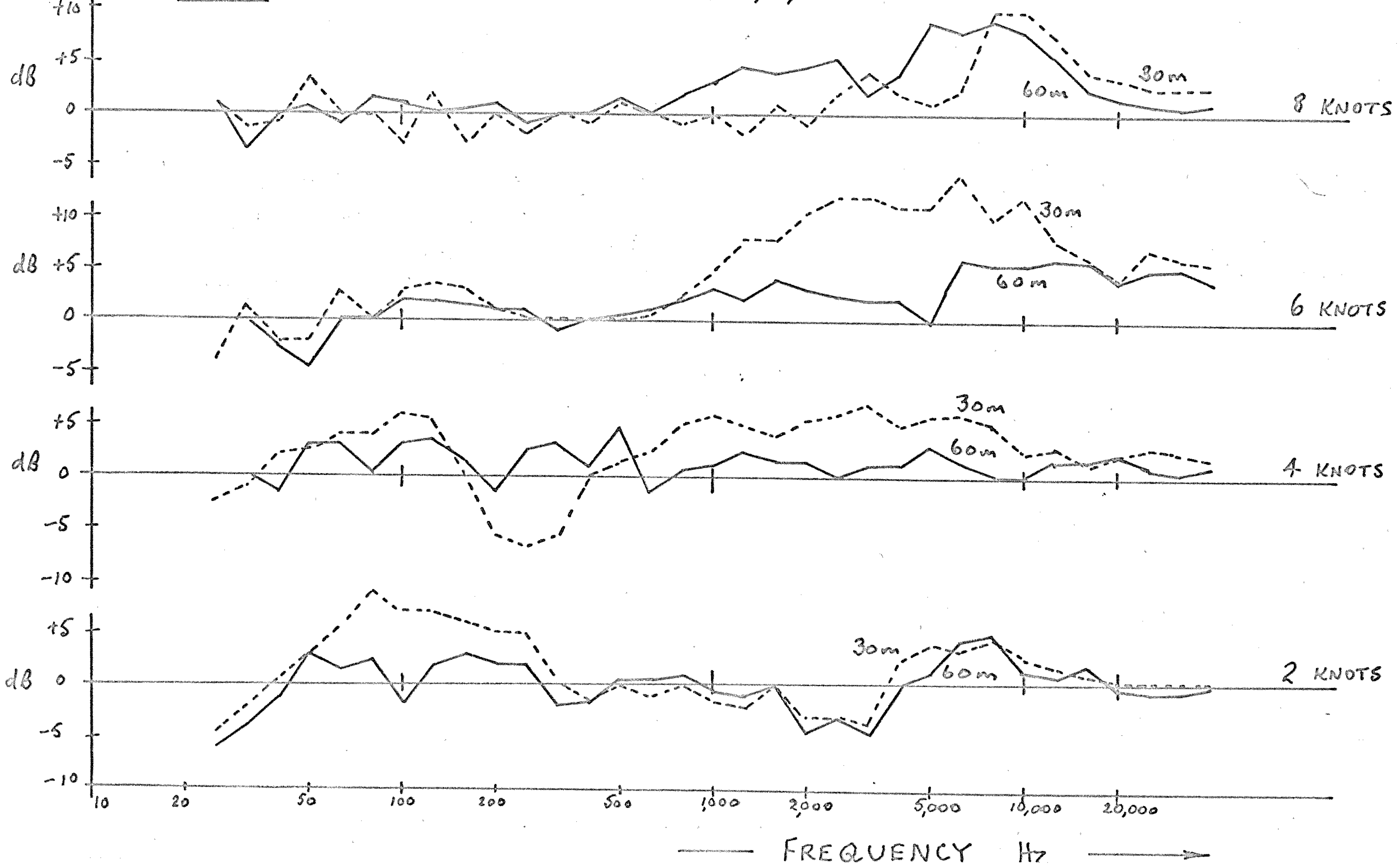


FIG. 7. CHANGE IN NOISE LEVELS AT DIFFERENT SEA STATES (RE SEA STATE 2)

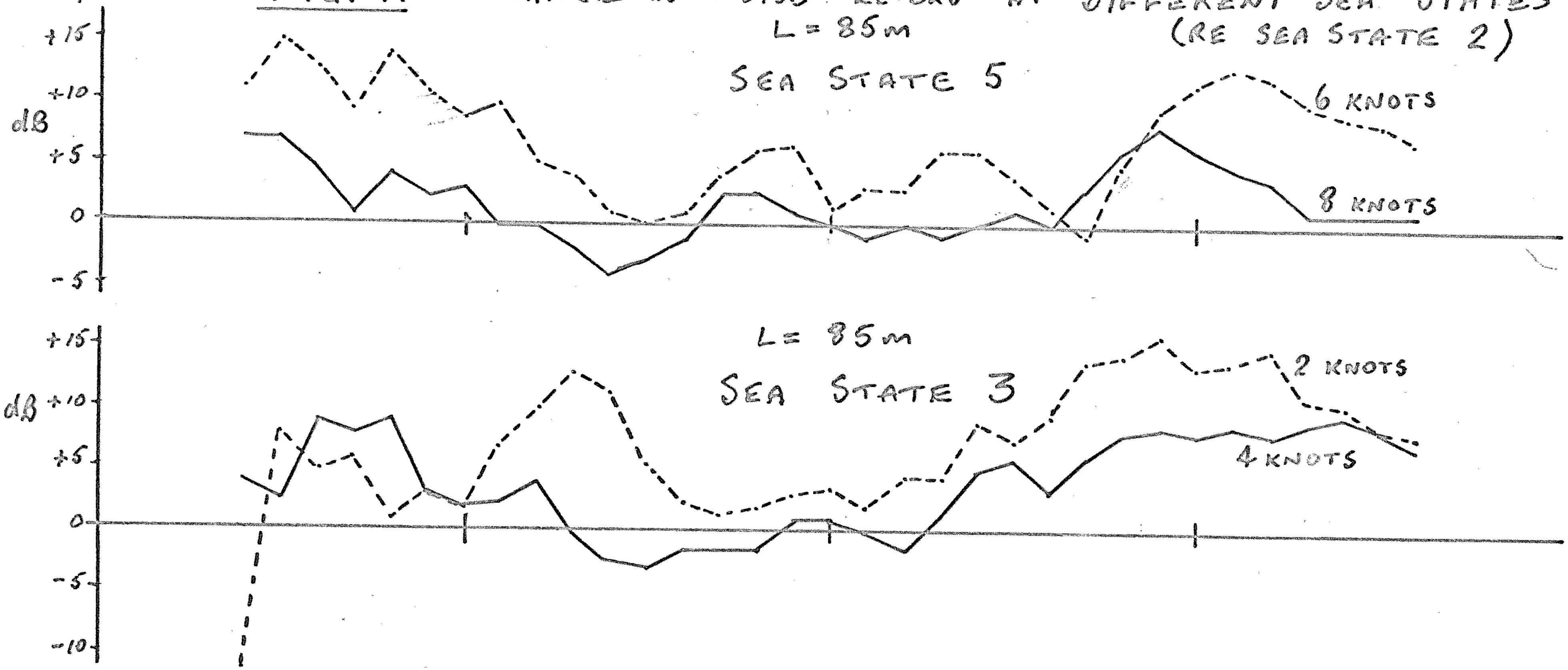
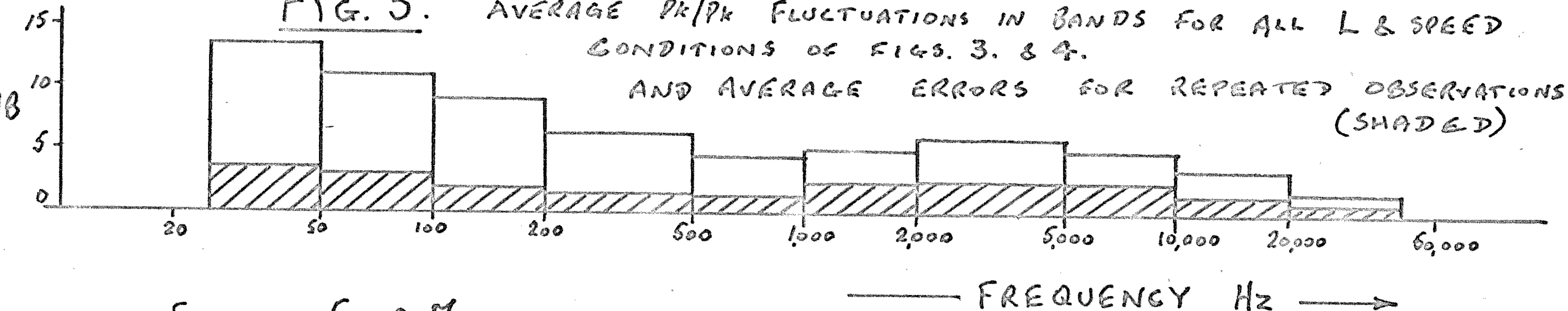


FIG. 5. AVERAGE Pk/Pk FLUCTUATIONS IN BANDS FOR ALL L & SPEED CONDITIONS OF FIGS. 3. & 4. AND AVERAGE ERRORS FOR REPEATED OBSERVATIONS (SHADED)



FIGS. 5 & 7.

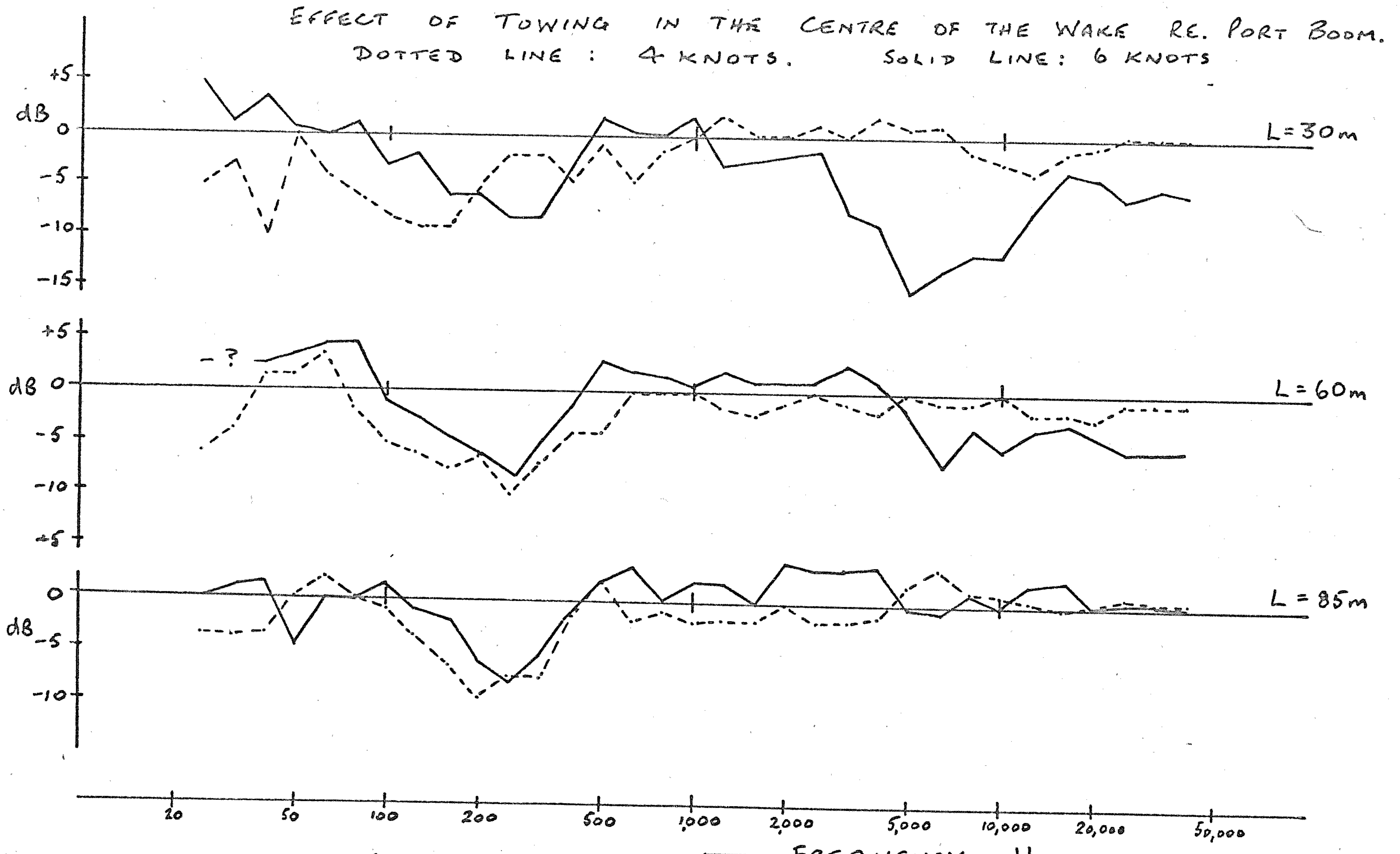

EFFECT OF TOWING IN THE CENTRE OF THE WAKE RE. PORT BOOM.
DOTTED LINE : 4 KNOTS. SOLID LINE: 6 KNOTS
dB
+5
0
-5
-10
-15
L=30m
L=60m
L=85m
- ?
20
50
100
200
500
1,000
2000
5,000
10,000
20,000
50,000
FREQUENCY, Hz

FIG. 6.

FIG. 10. CHANGE IN NOISE LEVELS DUE TO GREASING ARRAY (6 KNOTS, L = 85m)

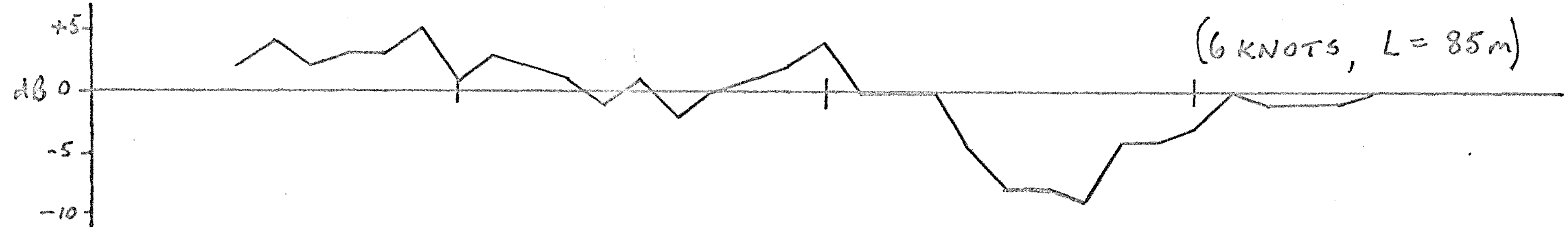
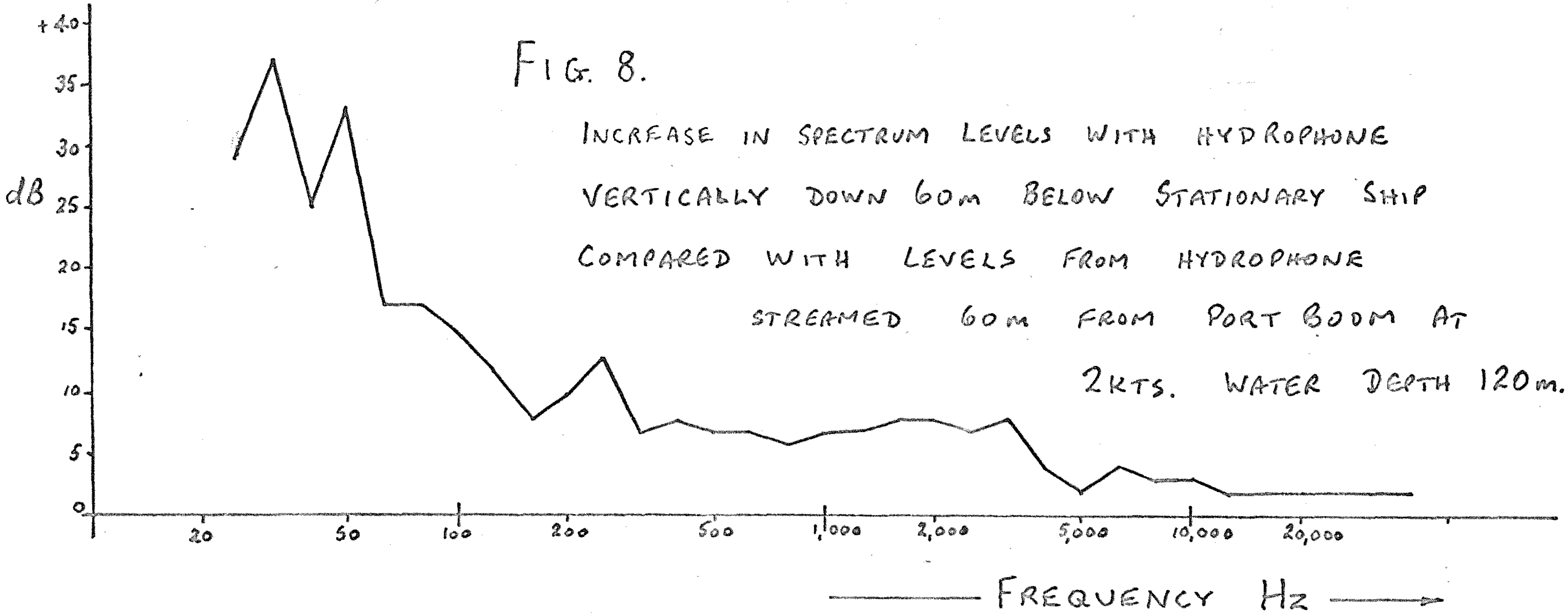


FIG. 8.

INCREASE IN SPECTRUM LEVELS WITH HYDROPHONE VERTICALLY DOWN 60m BELOW STATIONARY SHIP COMPARED WITH LEVELS FROM HYDROPHONE STREAMED 60m FROM PORT BOOM AT 2KTS. WATER DEPTH 120m.



FIGS. 8 & 10.

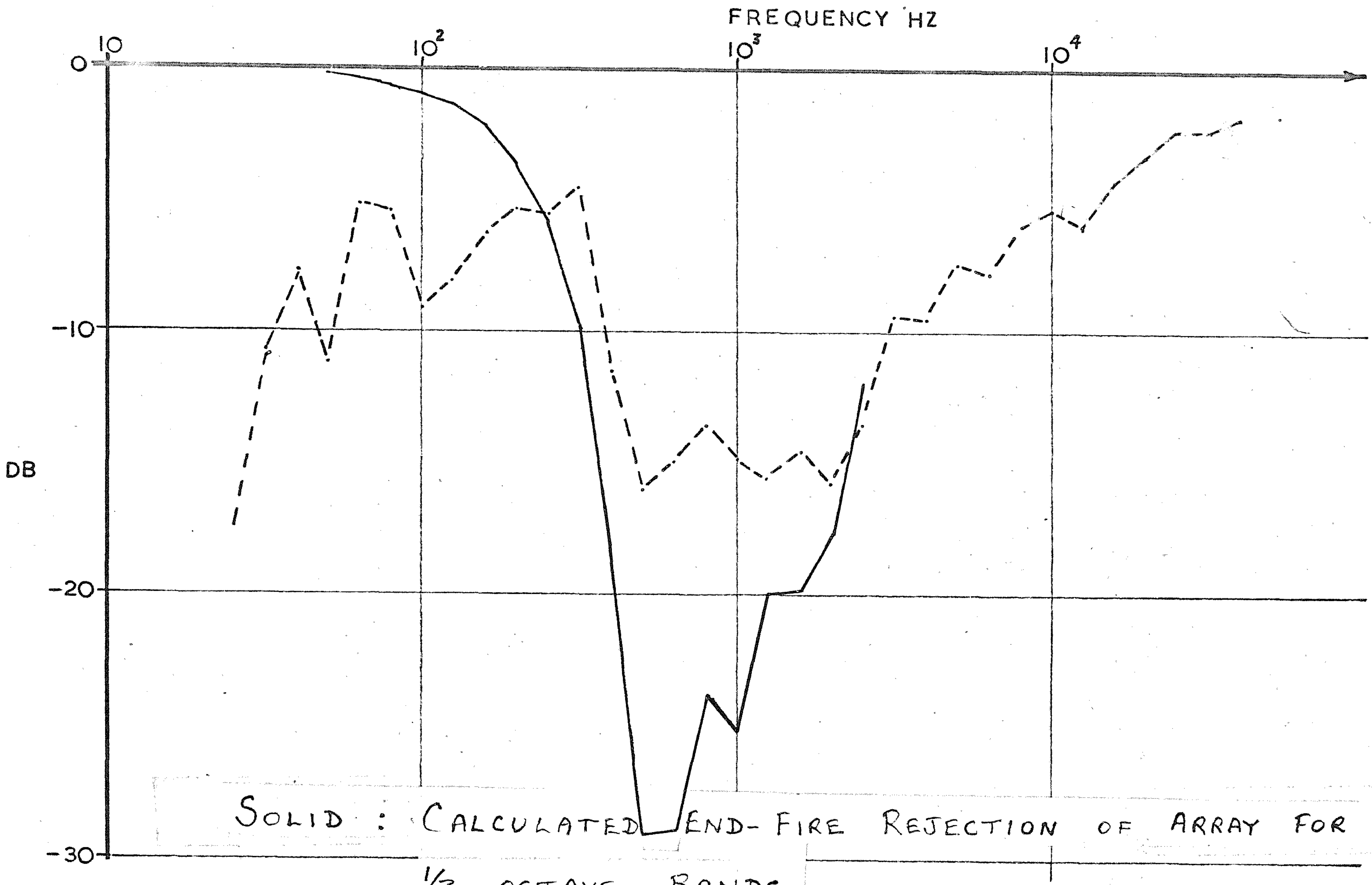


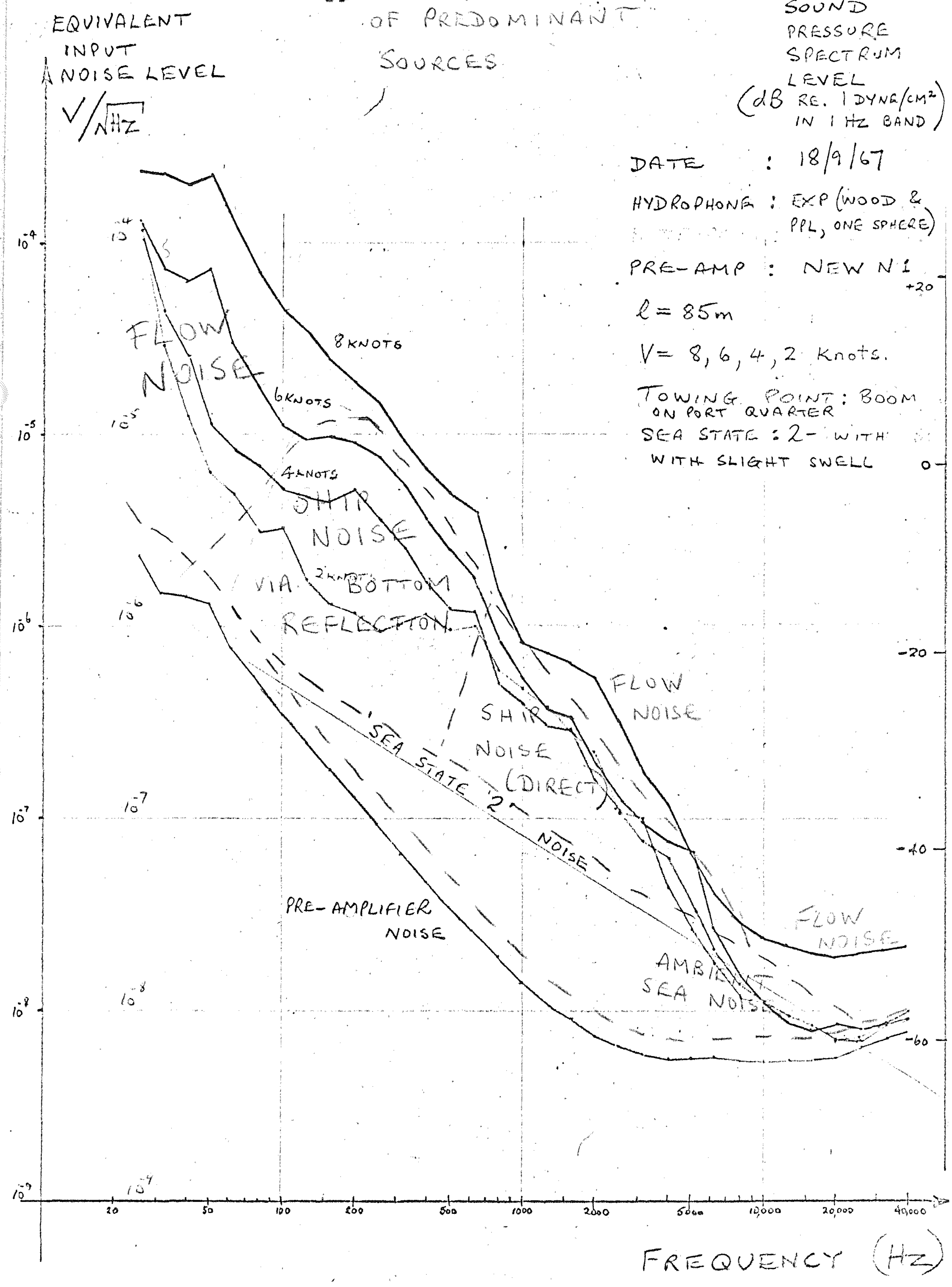
FIG. 9

SOLID : CALCULATED END-FIRE REJECTION OF ARRAY FOR 1/3 OCTAVE BANDS.

DOTTED : REDUCTION IN NOISE LEVEL OF 12 FT. HYDROPHONE ARRAY RELATIVE TO AN OMNIDIRECTIONAL HYDROPHONE.

FIG. ~~8~~ NOISE SPECTRA

11 SHOWING REGIONS OF PREDOMINANT SOURCES



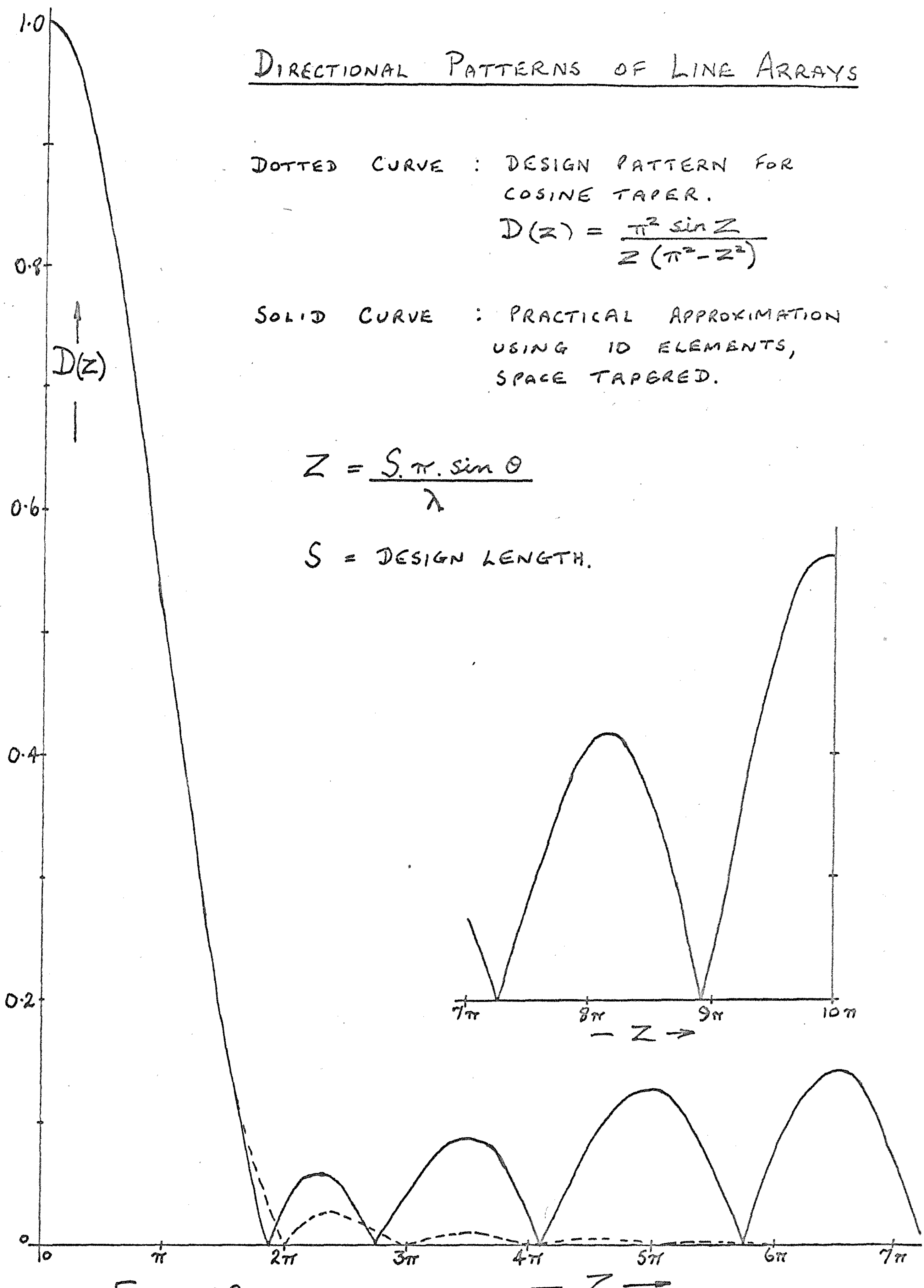
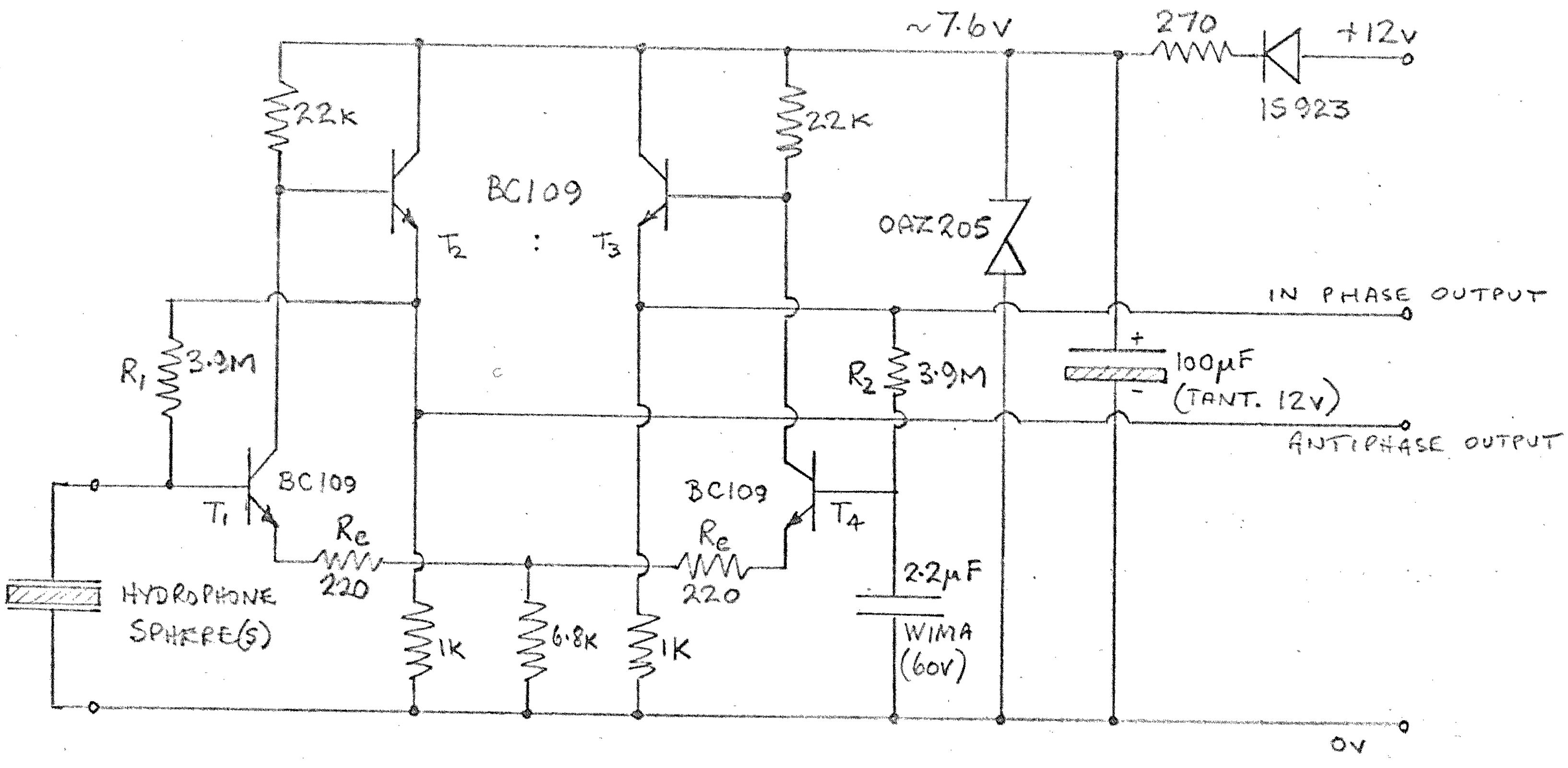

DIRECTIONAL PATTERNS OF LINE ARRAYS
DOTTED CURVE : DESIGN PATTERN FOR COSINE TAPER.
$D(z) = \frac{\pi^2 \sin Z}{Z(\pi^2 - Z^2)}$
SOLID CURVE : PRACTICAL APPROXIMATION USING 10 ELEMENTS, SPACE TAPERED.
$Z = \frac{S.\pi.\sin\theta}{\lambda}$
S = DESIGN LENGTH.
D(Z)
1.0
0.8
0.6
0.4
0.2
0
π
2π
3π
4π
5π
6π
7π
— Z →
7π
8π
9π
10π
— Z →

FIG. 12



NOTES:

RESISTANCES IN OHMS

T_1 & T_4 MATCHED FOR h_{FE} AT $I_C = 150\mu A$

R_1 & R_2 ADJUSTED FOR BALANCE ON OUTPUTS AND AT A VOLTAGE BETWEEN 3.3V & 4.0V

R_e: LOW-FREQUENCY COMPROMISE RESISTORS.

FIG. 13 WIDE-BAND PRE-AMPLIFIER