

**UNDERWATER ACOUSTICS AND SONAR
SIGNAL PROCESSING**

SS 2018



ASSIGNMENT 5

SONAR EQUATION

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by

**Shinde Mrinal Vinayak (Matriculation No.: 5021349)
Kshisagar Tejashree Jaysinh (Matriculation No.: 5019958)**

guided by

M.Sc. Zimmer

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Introduction

The sonar equation is a systematic way of estimating the expected signal-to-noise ratios for sonar systems. The signal-to-noise ratio determines whether or not a sonar will be able to detect a signal in the presence of background noise in the ocean. It takes into account the source level, sound spreading, sound absorption, reflection losses, ambient noise, and receiver characteristics. The sonar equation is used to estimate the expected signal-to-noise ratios for all types of sonar systems.

In this assignment we first develop a MATLAB program for determining the signal to noise ratio. The calculations for various parameters are then carried out. We then discuss the impact of bottom type (mud, sand and gravel) and wind speed on the signal to noise ratio.

Chapter 1

Theory

1.1 Sonar performance prediction

The basic problem in sonar is to measure some signal (possibly an echo) against a background of noise (or reverberation). So that the signal may be detected above the background, the ratio of the measured signal to the measured background (signal-to-noise ratio) must be at least some minimum value that is determined by the system. The various terms in the sonar equations are called sonar parameters. These parameters may be grouped according to whether they are determined by the equipment, medium, or target. Equipment parameters are source level, detection threshold, directivity index, self-noise level, and array gain (also determined by medium). Medium parameters are transmission loss, ambient noise level, and reverberation level (also determined by equipment). And target parameters are target strength, and target source level. Oceanographic interest in marine acoustics is concentrated mostly in the parameters determined by the medium.

Sonar may be either active or passive. Active sonar provide their own sound source and listen for

echoes as they are reflected from the target which they are trying to detect. Passive sonar have no such source. They are simply listening devices that rely on the target to emit their own noise source (e.g. engine noise from an enemy ship or communication noises from a whale).

1.2 Sound propagation related parameters

The parameters described in the following sections are transmission loss (TL), isotropic noise level (NL), bottom reverberation strength (RS_B), surface reverberation strength (RS_S) and volume reverberation strength (RS_V).

1.2.1 Transmission loss

The intensity of an acoustic signal reduces with range. This observed reduction in the acoustic signal with distance from the source is due to the combined effects of spreading and attenuation and is accounted for by the transmission loss term.

The Transmission loss is given by

$$TL = \text{spreading loss} + \text{attenuation} \quad (1.1)$$

where TL is defined to be 0 dB on a sphere around the source of radius $r = 1m$.

For a constant sound velocity profile and spherical spreading the transmission loss can be determined by

$$TL(r, z) = 20\log_{10}(R) + \alpha(R - 1m) \quad (1.2)$$

with

$$R = \sqrt{(r - r_0)^2 + (z - z_0)^2} \quad (1.3)$$

where r_0, z_0 denote the horizontal and vertical coordinates of the source locations and the receiver position, respectively.

In case of depth and range dependent cylinder symmetric sound velocity profiles the TL can be calculated by

$$TL(r, z) = 20\log_{10}(R) + 10\log_{10}(F(r, z)) + \alpha(R - 1m) \quad (1.4)$$

where $F(r, z)$ denotes the so called focusing factor given by

$$F(r, z) = \frac{\text{actual spreading at } r, z}{\text{spherical spreading at } r, z} \quad (1.5)$$

Experimental Research

1.3 Dependence of wind speed and frequency on Ambient noise

The ambient noise level versus frequency for wind speeds of 5, 10, 15, 20, 25 and 30 kn is plotted. In-order to obtain the figure (1), we assumed the biological, rainfall and self noise level to be -99 dB and the frequency in the range of 1 Hz to 1 MHz was considered.

Noise Level generally decreases with increasing frequency, from figure (1) we see that between 1 Hz to 100 kHz, noise level reduces from 120 dB to 25 dB. Noise Level decreases at great depths since most noise sources are at the surface. Ambient noise is greater in shallow water (noise is trapped between sea floor and the ocean surface). From the observation, we can say that as the wind speed increases, noise level increases in the frequency range 300 Hz to 100 kHz. This is due to the bubbles created by wind generated surface agitation. At lower frequencies, it is the oscillation of bubble clouds themselves that are considered to be the source of sound, while at higher frequencies the excitation of resonant oscillations by individual bubbles is the source of sound.

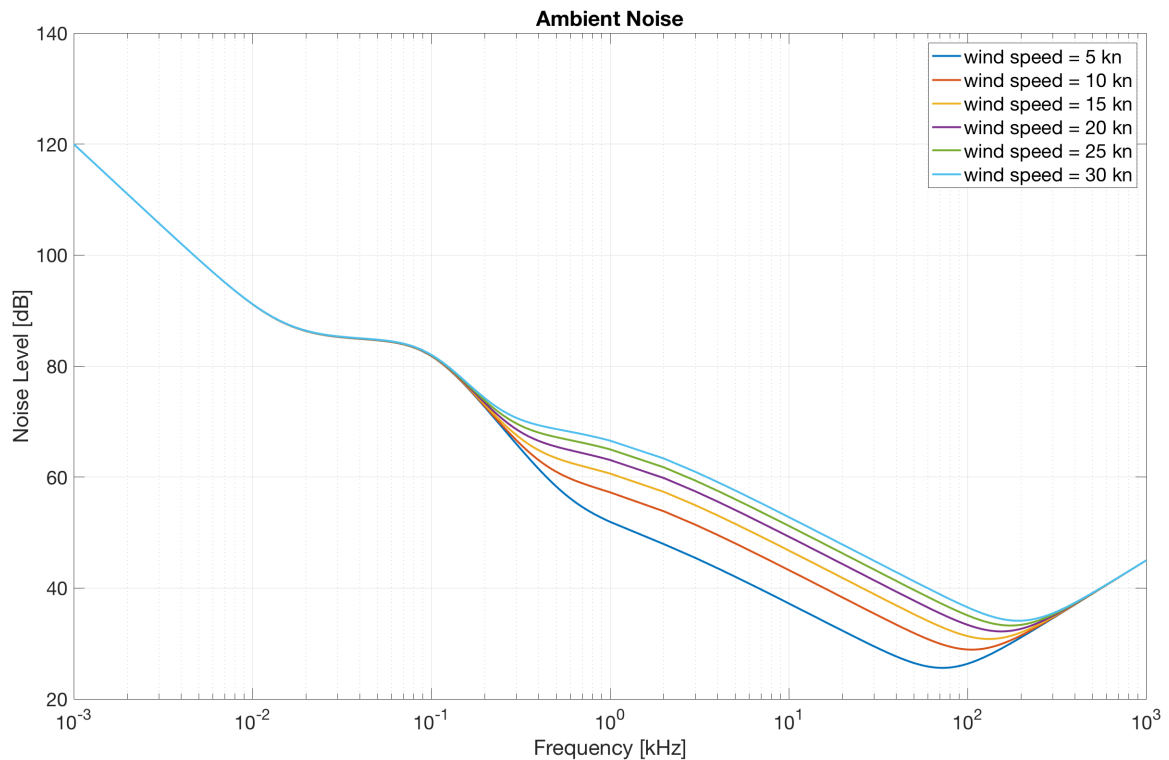


Figure 1.1: Noise level dependency on wind speed and frequency

1.4 Contribution of different noise sources

In-order to indicate the frequency domains where either traffic, turbulence, sea state or thermal noise level dominate, we assumed that contribution to noise from rainfall, shrimps and vessel are negligible. The noise isotropic levels for traffic, thermal, turbulence and sea state are computed by the mathematical models as explained in the theoretical section. Also this was plotted for the wind speed of 5 kn.

From the result shown in figure (2), we can distinguish different ambient noise, in different frequency range. We can observe the effect of turbulence noise between 1 Hz to 10 Hz. In the frequency range between 10 Hz to 300 Hz, the noise is affected by the traffic, shipping and harbours. Wind speed and

sea state contribute the noise level from 300 Hz to 100 kHz. Above 100 kHz, noise level increases due to molecular agitation in the ocean. The random motion of water molecules causes thermal noise ultimately establishing the lower limit of measurability of pressure fluctuations associated with truly propagating sound waves above 100 kHz frequency. Isotropic noise level is shown by the superposition of all these effects in the graph.

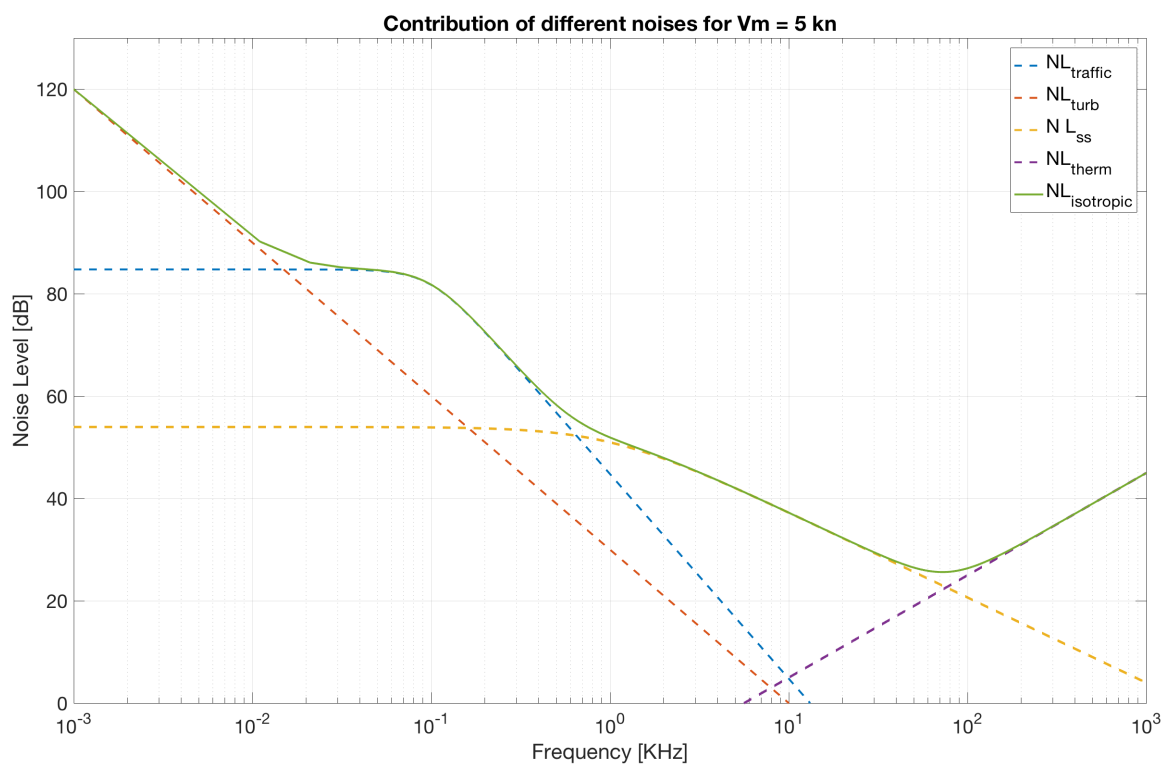


Figure 1.2: Contribution of different noise sources

Conclusion

Ambient noise due to wind at various speeds ranging from 5 knots to 30 knots is analysed and observed. The effect of wind is dominating at lower frequencies from 100 Hz to 5 kHz. The analysis shows that noise level in dB increases as the wind speed increases. Above 100 kHz, thermal noise contributes to the increase in noise level.

We have also observed range of frequencies where different types of noises such as turbulence, traffic, sea state and thermal noises dominate assuming that contribution to noise from rainfall, shrimps and vessel are negligible.

Appendix

1.5 MATLAB program to plot ambient noise level versus frequency for various values of wind speeds

```
1  ws = 5:5:30; % Wind speed in steps of 5kn
2  a(i) = [];
3  for n = 1:6
4      for i = 1:1000
5          a(i) = isotropic(i,ws(n),-999,-999,-999); % calling the nested function
6      end
7      j = 1000:1000:10^6;
8      for k = 1:1000
9          l = k+1000;
10         a(l) = isotropic(j(k),ws(n),-999,-999,-999); % calling the nested function
11     end
12     switch n
13         case 1
14             b=a;
15         case 2
16             c=a;
17         case 3
18             d=a;
19         case 4
20             e=a;
21         case 5
22             g=a;
23         case 6
24             h=a;
25     end
26 end
27 ii = 0.001:0.001:1;
28 kk = 1:1000;
```

```

29 f=[ii kk];
30 semilogx(f,b,f,c,f,d,f,e,f,g,f,h,'LineWidth',2)
31 ax = gca; % current axes
32 ax.FontSize = 20;
33 hL = legend('wind speed = 5 kn','wind speed = 10 kn',...
34 'wind speed = 15 kn','wind speed = 20 kn',...
35 'wind speed = 25 kn','wind speed = 30 kn');
36 hL.FontSize = 20;
37 grid
38 title('Ambient Noise')
39 xlabel('Frequency [kHz]')
40 ylabel('Noise Level [dB]')
41
42 %nested function
43 function [nl_iso] = isotropic(freq,ws,rain, bio, self)
44 nl_iso = 10*log10((10.^(.1*turb(freq))) + (10.^(.1*traffic(freq))) ...
45 + (10.^(.1*seaState(freq,ws))) + (10.^(.1*thermal(freq)))...
46 + (10.^(.1*rain)))+(10.^(.1*bio)))+(10.^(.1*self)));
47 function [nl_turb] = turb(f)
48 nl_turb = 30-30*log10(f./1000);
49 end
50 function [nl_traff] = traffic(f)
51 nl_traff = 10*log10((3e+8)./(1+(1e+4*((f./1000).^4))));
52 end
53 function [nl_therm]=thermal(f)
54 nl_therm=-15+20*log10(f./1000);
55 end
56 function [nl_sea] = seaState(f,vm)
57 nl_sea = 40+10*log10((vm.^2)./(1+(f./1000).^(5/3)));
58 end
59 end

```

1.6 MATLAB code to plot the contributions of different noise levels

```

1 freq = 0.001:0.01:1000; % frequency range
2 ws = 5; % wind speed set to 5kn
3 rain = -999; % Rainfall NL
4 bio = -999; % Biological NL
5 vessel = -999; % Self NL
6 traffic = 10.*log10((3.*10.^8)./(1+(10.^4.*freq.^4))); % Traffic NL
7 semilogx(freq,traffic,'--','linewidth',2)
8 hold on
9 turb = 30 - 30.*log10(freq) ;% Turbulence NL

```

```

10 semilogx(freq,turb,'--','linewidth',2)
11 hold on
12 seaState = 40 +10.*log10((ws.^2)./(1+freq.^(5/3))); % Sea state NL
13 semilogx(freq,seaState,'--','linewidth',2)
14 hold on
15 N_therm = -15 +20.*log10(freq); % Thermal NL
16 semilogx(freq,N_therm,'--','linewidth',2)
17 hold on
18 isotropic = 10.*log10((10.^(0.1.*turb)) + (10.^(0.1.*traffic))...
19     + (10.^(0.1.*seaState)) + (10.^(0.1.*N_therm)) + (10.^(0.1.*rain))...
20     + (10.^(0.1.*bio)) + (10.^(0.1.*vessel))); % Isotropic NL
21 semilogx(freq,isotropic,'linewidth',2)
22 ax = gca; % current axes
23     ax.FontSize = 20;
24     ax.YLim = [0 130];
25 xlabel('Frequency [KHz]')
26 ylabel('Noise Level [dB]')
27 title('Contribution of different noises for Vm = 5 kn')
28 grid on
29 hL = legend('NL-t-r-a-f-f-i-c','NL-t-u-r-b','N L-s-s', ...
30     'NL-t-h-e-r-m','NL-i-s-o-t-r-o-p-i-c');
31 hL.FontSize = 20;

```