UNDERWATER ACOUSTICS AND SONAR SIGNAL PROCESSING

SS 2018

ASSIGNMENT 5

SONAR EQUATION

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by

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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.

Theory

The ocean is filled with different kinds of sounds. Underwater sound is generated by a variety of natural sources, such as breaking waves, wind, rain, and marine life. It is also generated by a variety of man-made sources, such as ships and sonars. This background sound in the ocean is called ambient noise. The isotropic noise level consists of the following components

1. Turbulence noise

   This can be a significant factor in ambient noise levels at very low frequencies, between 1Hz to 10 Hz. Equation 1 is a function of frequency, f which is in kHz.

$$NL_{turb}(f) = 30 - 30.log_{10}(f) \tag{1}$$

2. Far shipping (traffic) noise

   There can be more than 1000 ships underway at any one time. The noise from this shipping traffic can sometimes travel up to distances of 1000 miles or more. The frequency range where this man-made noise is most dominant is from 10 Hz to 300 Hz. Noise levels depend on area operating in and shipping density. Close proximity to shipping lanes and harbors increases noise levels. Equation 2 is a function of frequency, f which is in kHz.

$$NL_{traffic}(f) = 10.log_{10}(\frac{3.10^8}{1 + 10^4.f^4}) \tag{2}$$

3. Sea state noise

   Sea State (or more importantly wind speed) is the dominant factor in calculating ambient noise levels between 300 Hz to 100 kHz. The noise levels depend on wind speed, v_W in kn and frequency, f in kHz.

$$NL_{ss}(f) = 40 + 10.log_{10}(\frac{{v_w}^2}{1 + f^{\frac{5}{3}}}) \tag{3}$$

4. Thermal noise

   At frequencies between 100 kHz and 1 MHz, the noise generated by the random motion of water molecules is called thermal noise. This noise depends upon frequency, f which is in kHz.

$$NL_{therm}(f) = -15 + 20.log_{10}(f) \tag{4}$$

5. Rainfall noise

   It is dominant at frequencies between 1 kHz to 5 kHz. It is denoted by $NL_{rain}(f, r)$ where f and r denote the frequency and rainfall rate, respectively.

6. Biological noise

   Noise produced by snapping shrimp and other fishes typically comprises of biological noise. It is denoted by $NL_{bio}(f, s)$ where f and s denote the frequency and season, respectively.

7. Self (vessel) noise of sonar platform

   It is denoted by $NL_{vessel}(f, v_V)$ where f and v_V denote the frequency and vessel speed, respectively.

Thus the isotropic noise level can be determined by

$$NL(f, v_W, r, s, v_V) = 10.log_{10}(10^{0.1.NL_{turb}} + 10^{0.1.NL_{traffic}} + 10^{0.1.NL_{ss}}$$
$$+ 10^{0.1.NL_{therm}} + 10^{0.1.NL_{rain}} + 10^{0.1.NL_{bio}} + 10^{0.1.NL_{vessel}}) \tag{5}$$

Experimental Research

0.1 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.

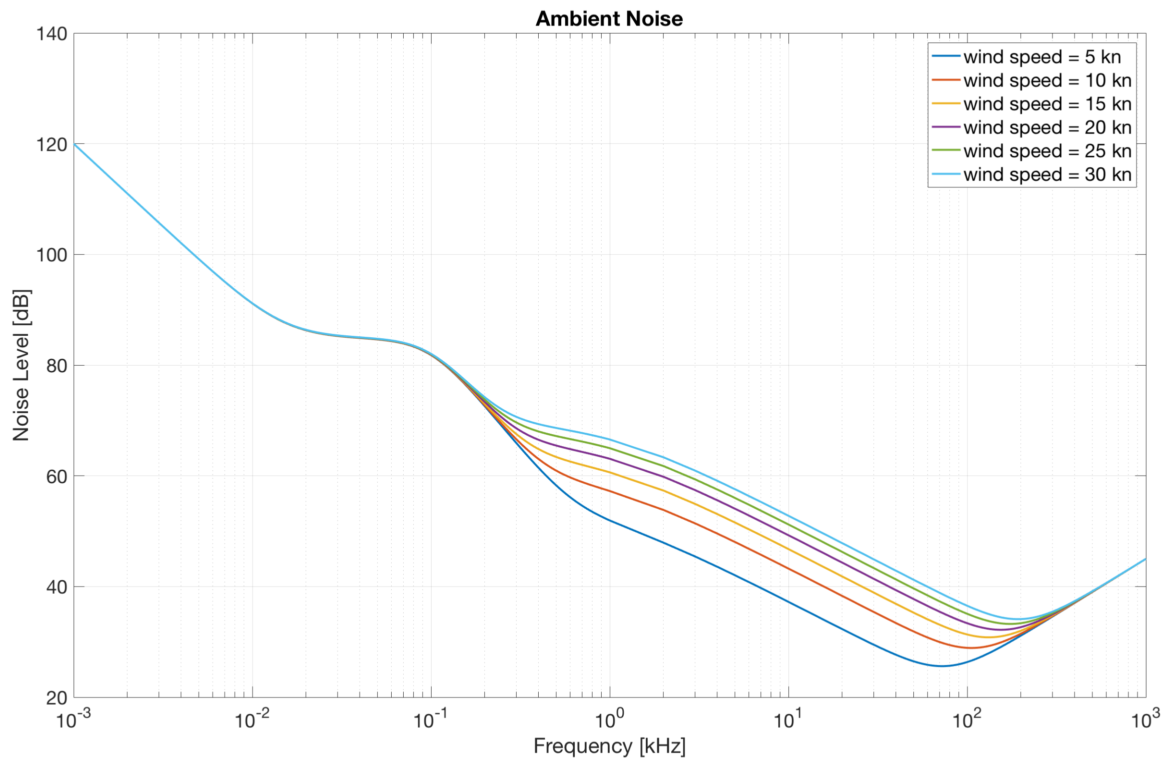

Figure 1: Noise level dependency on wind speed and frequency

0.2 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.

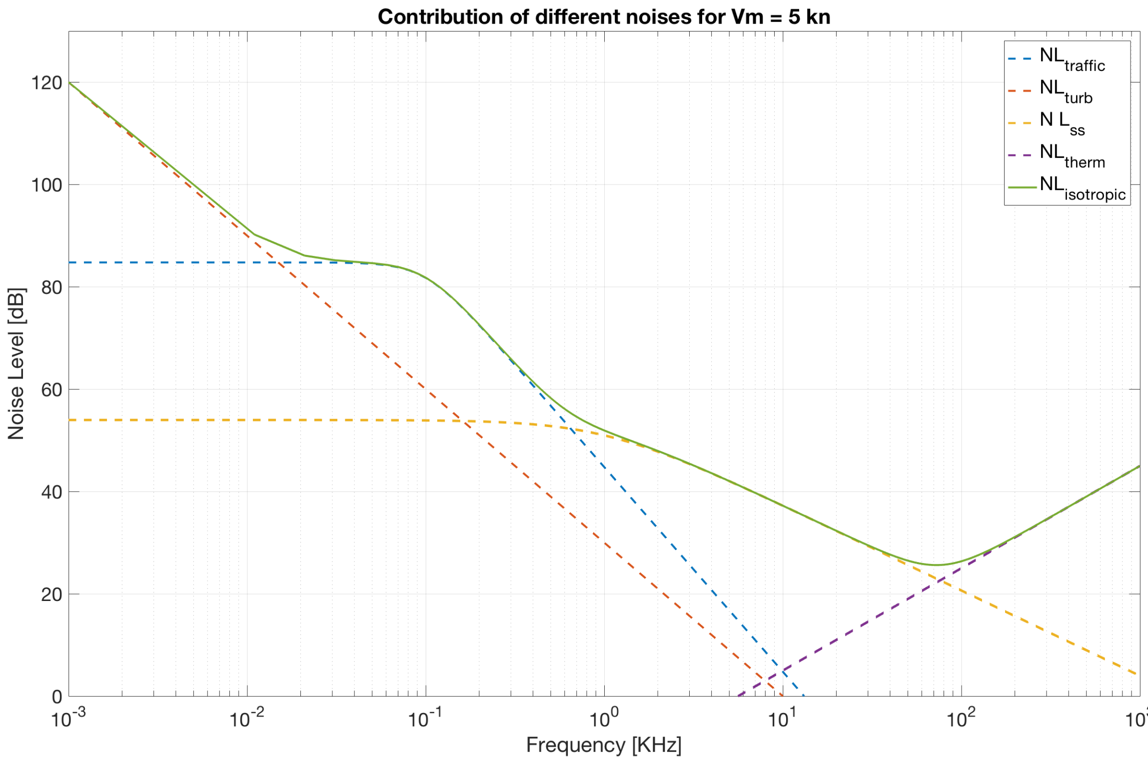

Figure 2: Contribution of different noise sources

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

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

```
ws = 5:5:30; % Wind speed in steps of 5kn
a(i) = [];
for n = 1:6
for i = 1:1000
a(i) = isotropic(i,ws(n),-999,-999,-999); % calling the nested function
end
j = 1000:1000:10^6;
for k = 1:1000
l = k+1000;
a(l) = isotropic(j(k),ws(n),-999,-999,-999); % calling the nested function
end
 switch n
    case 1
        b=a;
    case 2
        c=a;
    case 3
        d=a;
    case 4
        e=a;
    case 5
        g=a;
    case 6
        h=a;
end
end
ii = 0.001:0.001:1;
kk = 1:1000;
```

```
f=[ii kk];
semilogx(f,b,f,c,f,d,f,e,f,g,f,h,'LineWidth',2)
ax = gca; % current axes
        ax.FontSize = 20;
hL = legend('wind speed = 5 kn','wind speed = 10 kn',...
    'wind speed = 15 kn','wind speed = 20 kn',...
    'wind speed = 25 kn','wind speed = 30 kn');
hL.FontSize = 20;
grid
title('Ambient Noise')
xlabel('Frequency [kHz]')
ylabel('Noise Level [dB]')

%nested function
function [nl_iso] = isotropic(freq,ws,rain, bio, self)
nl_iso = 10*log10((10.^(.1*turb(freq))) + (10.^(.1*traffic(freq))) ...
    + (10.^(.1*seaState(freq ,ws))) + (10.^(.1*thermal(freq)))...
    +(10.^(.1*rain))+(10.^(.1*bio))+(10.^(.1*self)));
function [nl_turb] = turb(f)
    nl_turb = 30-30*log10(f./1000);
end
function [nl_traff] = traffic(f)
    nl_traff = 10*log10((3e+8)./(1+(1e+4*((f./1000).^4))));
end
function [nl_therm]=thermal(f)
    nl_therm=-15+20*log10(f./1000);
end
function [nl_sea] = seaState(f,vm)
    nl_sea = 40+10*log10((vm.^2)./(1+(f./1000).^(5/3)));
end
end
```

0.4 MATLAB code to plot the contributions of different noise levels

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

```
semilogx(freq,turb,'--','linewidth',2)
hold on
seaState = 40 +10.*log10((ws.^2)./(1+freq.^(5/3))); % Sea state NL
semilogx(freq,seaState,'--','linewidth',2)
hold on
N_therm = -15 +20.*log10(freq); % Thermal NL
semilogx(freq,N_therm,'--','linewidth',2)
hold on
isotropic = 10.*log10((10.^(0.1.*turb)) + (10.^(0.1.*traffic))...
    + (10.^(0.1.*seaState)) + (10.^(0.1.*N_therm)) + (10.^(0.1.*rain))...
    + (10.^(0.1.*bio)) + (10.^(0.1.*vessel))); % Isotropic NL
semilogx(freq,isotropic, 'linewidth',2)
ax = gca; % current axes
        ax.FontSize = 20;
        ax.YLim = [0 130];
xlabel('Frequency [KHz]')
ylabel('Noise Level [dB]')
title('Contribution of different noises for Vm = 5 kn')
grid on
hL =legend('NL_t_r_a_f_f_i_c','NL_t_u_r_b','N L_s_s', ...
    'NL_t_h_e_r_m','NL_i_s_o_t_r_o_p_i_c');
hL.FontSize = 20;
```