UNDERWATER ACOUSTICS AND SONAR SIGNAL PROCESSING

SS 2018

ASSIGNMENT 3

SOUND SCATTERING

Date: 23/04/2018

by

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

guided by

M.Sc. Zimmer

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Chapter 1

Introduction

When an active sonar pulse is transmitted into the water, some of the sound reflects off of the target. Additionally, there are many other sources where the sound energy may reradiate a portion of the acoustic energy incident upon them. This scattering is caused by the many sources of inhomogeneities in the ocean. These sources may include fish, air bubbles, dust or dirt as well as the ocean bottom, and surface. The above scatterers can be classified into three basically different classes depending on the reverberation they produce. Scatterers occurring in the volume or body of the sea produce volume reverberation. Scatterers on or near the surface cause surface reverberation and scatterers on or near the sea bottom produce bottom reverberation.

In this assignment we first develop a MATLAB program for computing the surface, bottom and volume reverberation coefficient. Then we plot the surface and bottom reverberation coefficients versus the grazing angle for various sets of (frequency, windspeed) and (frequency, bottom type) respectively. Finally the graph for volume reverberation versus frequency for high, moderate and low particle densities is obtained.

Chapter 2

Theory

2.1 Sound Scattering

Scattering results when sound strikes foreign bodies in the water, and the sound energy is reflected. Some reflectors are boundaries (surface, bottom, and shores), bubbles, suspended solid and organic particles, marine life, and minor inhomogeneities in the thermal structure of the ocean. The amount of energy scattered is a function of the size, density, and concentration of foreign bodies present in the sound path, as well as the frequency of the sound wave. The larger the area of the reflector compared to the sound wavelength, the more effective it is as a scatterer. Part of the reflected sound is returned to the source as an echo, i.e, is backscattered, and the remainder is reflected off in another direction and is lost energy. Back-scattered energy is known as reverberation and is divided into three types: surface, bottom and volume.

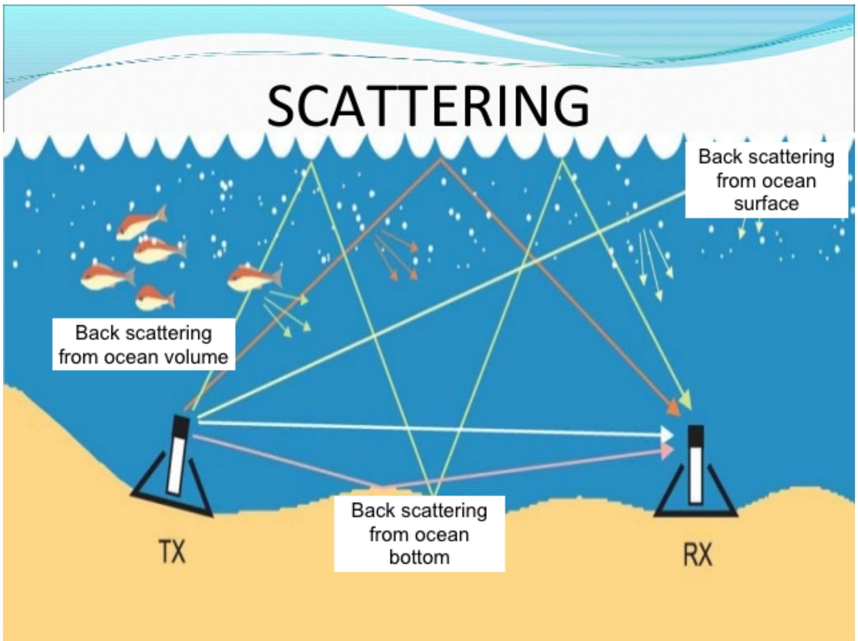

Figure 2.1: Different types of reverberations

2.1.1 Surface Backscattering

Surface reverberation is generated when transmitted sound rays strike the surface of the ocean, i.e., the underside of the waves. It is always a factor in active sonar operations, and is directly related to wind speed because it controls wave size and the angle of incidence. The effectiveness of active sonar is severely restricted in shallow waters because in very shallow water, severe reverberation levels may exist due to the presence of so many surfaces for the sound to reflect off. Experiments indicate that the backscattering strength of the sea surface varies with the grazing angle, sound frequency and wind speed induced roughness and that the collected measurements can be fitted by the following empirical expression

$$S_S = 10.log_{10}(10^{-5.05}.(1+v_W)^2.(f+0.1)^{\frac{v_W}{150}}.tan^{\beta}(\theta)) \tag{2.1}$$

with

$$\beta = 4.(\frac{v_W + 2}{v_W + 1}) + (2.5(f + 0.1)^{\frac{-1}{3}} - 4).cos^{\frac{1}{8}}(\theta) \tag{2.2}$$

where S_S represents the surface backscattering coefficient in $[dB/m^2]$. The parameters f, v_W and θ denote the sound frequency in kHz, the wind speed in knots and the grazing angle respectively.

2.1.2 Bottom Backscattering

Bottom reverberation occurs whenever a sound pulse strikes the ocean bottom. In deep water this condition normally does not cause serious problems, but in shallow water, bottom reverberation can dominate the background and completely mask a close target.

Sound reflected from the ocean floor usually suffers a significant loss in intensity. Part of this loss is caused by the scattering effects just described, but most of it results from the fact that a portion of sound energy will enter the bottom and travel within it as a new wave. The net result is that the strength of the reflected wave is greatly reduced. The amount of energy lost into the bottom varies with the bottom composition, sound frequency, and the grazing angle of the sound wave. The total of these losses can vary from as low as 2 dB/bounce to greater than 30 dB/bounce. In general, bottom loss will tend to increase with frequency and with the angle of incidence. Soft bottoms such as mud are usually associated with high bottom losses (10 to 30 dB/bounce); hard bottoms such as smooth rock or sand produce lower losses.

Furthermore, it could be observed that a Lambert?s law relationship between the backscattering strength and the grazing angle fits to many experimental data satisfactorily accurate for angles below 60°. Consequently, the backscattering strength can be described by Lamberts law and an empirically specified scattering coefficient, i.e.

$$S_B = K(f, bt) + 10.log_{10}(sine^2(\theta)) \tag{2.3}$$

This is valid for for $0 \leq \theta \leq 60°$. K(f, bt) denotes the scattering coefficient depending on the frequency of sound f and bottom type bt.

Due to the empirical definition of K(f, bt) it is evident that one will have considerable difficulty in determining an appropriate value for the backscattering strength in practice. Therefore, easier applicable and over the entire grazing angle domain sufficient accurate bottom backscattering models are of interest.

More accurate bottom scattering curves have been derived from measurements taken from SEARAY Model which is applicable for the frequency range of $20kHz \leq f \leq 500kHz$ and APL-UW Model which works for the frequency range of $1kHz \leq f \leq 500kHz$

For the SEARAY Model the reverberation coefficient is defined by

$$S_B = 10.log_{10}(3.03\beta\, f^{\,3.2-0.8bt}10^{2.8bt-12} + 10^{-4.42}) \tag{2.4}$$

with

$$\beta = \gamma(sin(\theta) + 0.19)^{btcos^{16}(\theta)} \tag{2.5}$$

and

$$\gamma = 1 + 125.exp(-2.64.(bt - 1.75)^2 - \frac{50}{bt}.cot^2(\theta)) \tag{2.6}$$

where f, bt and θ denote the sound frequency in kHz, the bottom type and the grazing angle respectively. And bt can be any real number satisfying $1 \leq bt \leq 4$.

2.1.3 Volume Backscattering

Volume reverberation is caused by various reflectors, but fish and other marine organisms are the major contributors. Additional causes are suspended solids, bubbles, and water masses of markedly different temperatures. Volume reverberation is always present during active sonar operations, but is not normally a serious factor in masking target echoes. The one exception involves the deep scattering layer (DSL), which is a relatively dense layer of marine life present in most areas of the ocean. During daylight hours, the layer is generally located at depths of about 600 meters and does not pose a serious problem. At night, however, the layer migrates toward the surface and becomes a major source of reverberation.

The volume reverberation can be modeled by the so-called volume reverberation coefficient.

$$S_V = S_p + 7log_{10}(f) \tag{2.7}$$

where f and $S_p$indicate the frequency in kHz and the particle contribution in $[dB/m^3]$. The particle contribution parameter S_p is $-50dB$ for high particle density, $-70dB$ for moderate particle density and $-90dB$ for low particle density.

Chapter 3

Experimental research

3.1 Surface Backscattering

We can see the effect of varying wind speed and frequency on surface reverberation from figure 3.1 and figure 3.2. It can be depicted that as the wind speed increases, roughness of the surface increases and hence higher is the backscattering. Surface reverberation increases non-linearly with increase in grazing angle. At a particular wind speed if the frequency is varied between 50 kHz to 400 kHz, the surface reverberation remains almost constant. For lower wind speeds surface reverberation increase is not significantly observed. At wind speed of 40 knots, we can see that with increase in frequency there is slight nonlinear increase in the surface backscattering coefficient.

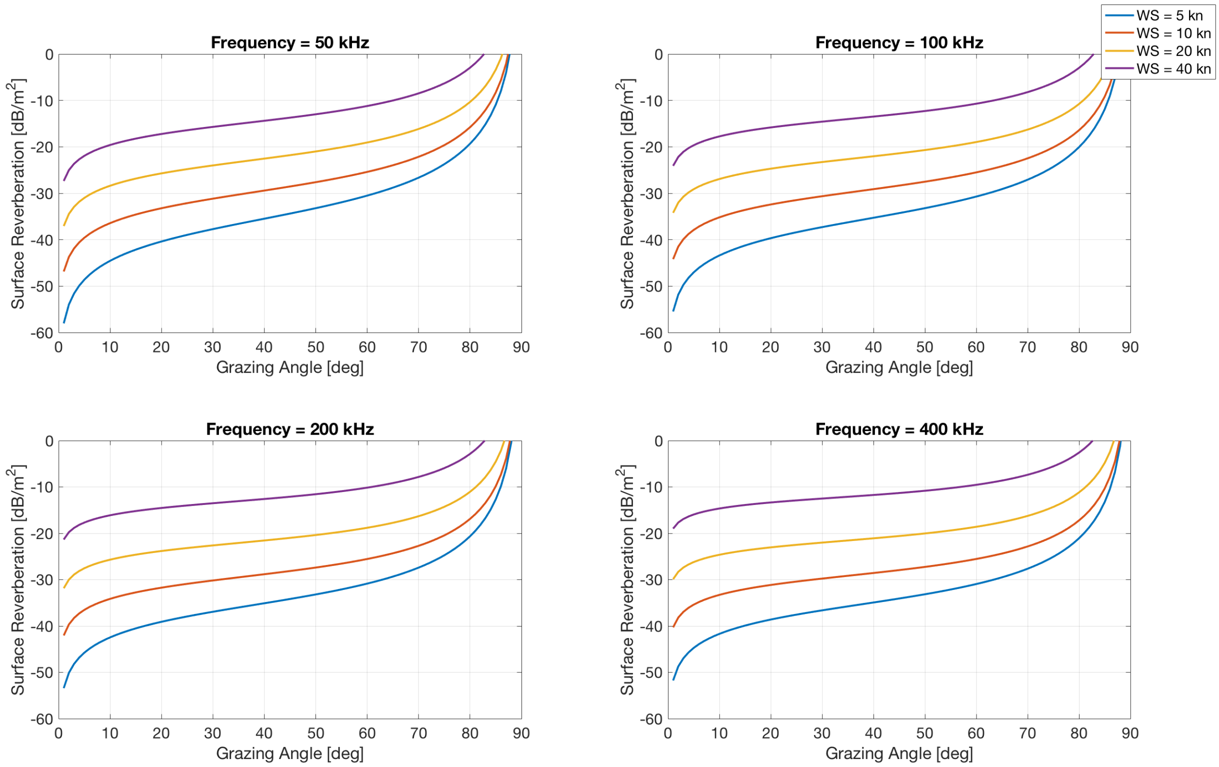

Figure 3.1: Surface reverberation versus grazing angle for frequency dependency

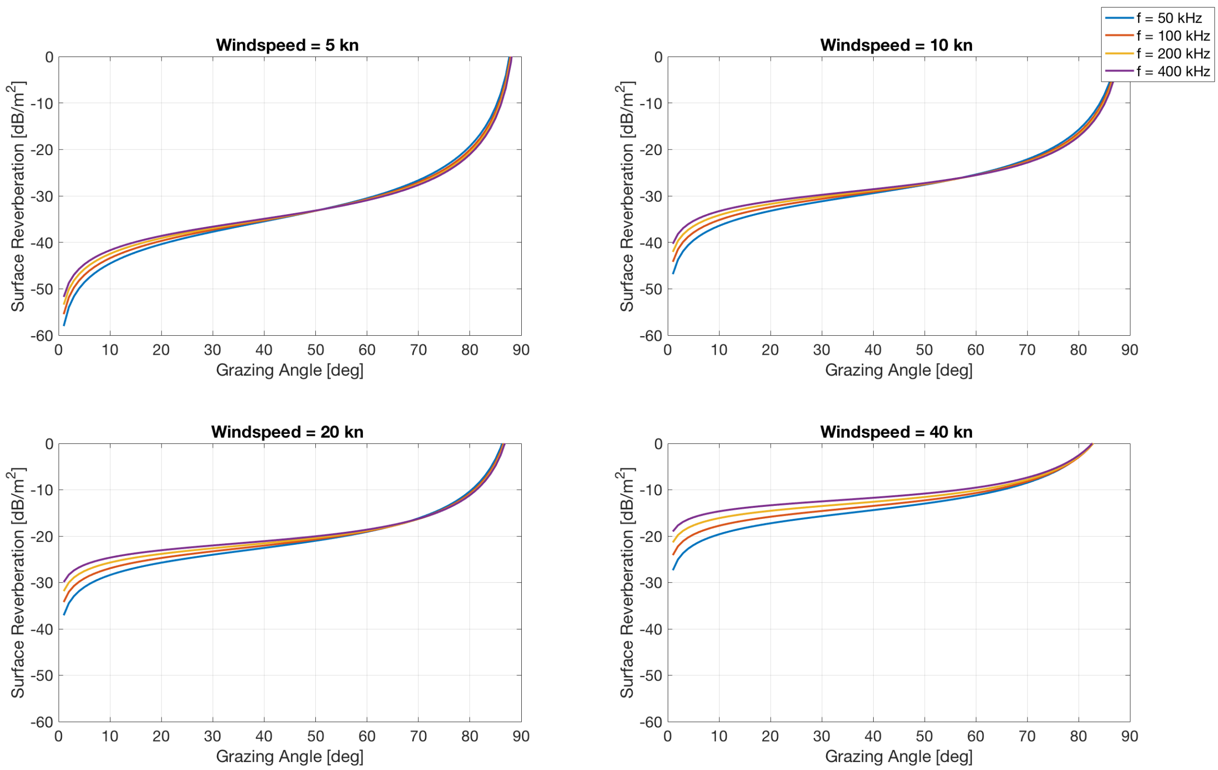

Figure 3.2: Surface reverberation versus grazing angle for wind speed dependency

3.2 Bottom Backscattering

We can see the effect of varying bottom type and frequency on reverberation from figure 3.3 and figure 3.4. Reverberation increases non-linearly with grazing angle for different bottom types. At any frequency (here 50 kHz to 400 kHz), reverberation is lowest for mud ($bt = 1$). For grazing angles between 0° to 60°, maximum reverberation is observed for rock ($bt = 4$). As the frequency increases, reverberation for the sand ($bt = 2$) increases more than other bottom types for grazing angles greater than 60°. For bottom type mud ($bt = 1$), as the frequency is increased from 50 kHz to 400 kHz, the reverberation level increases from -40 dB to -30 dB. As the bottom type becomes harder from mud to rock (bt increases from 1 to 4), we can see lesser variations in reverberation with increasing frequency. For bottom type rock ($bt = 4$), reverberation becomes independent of frequency level.

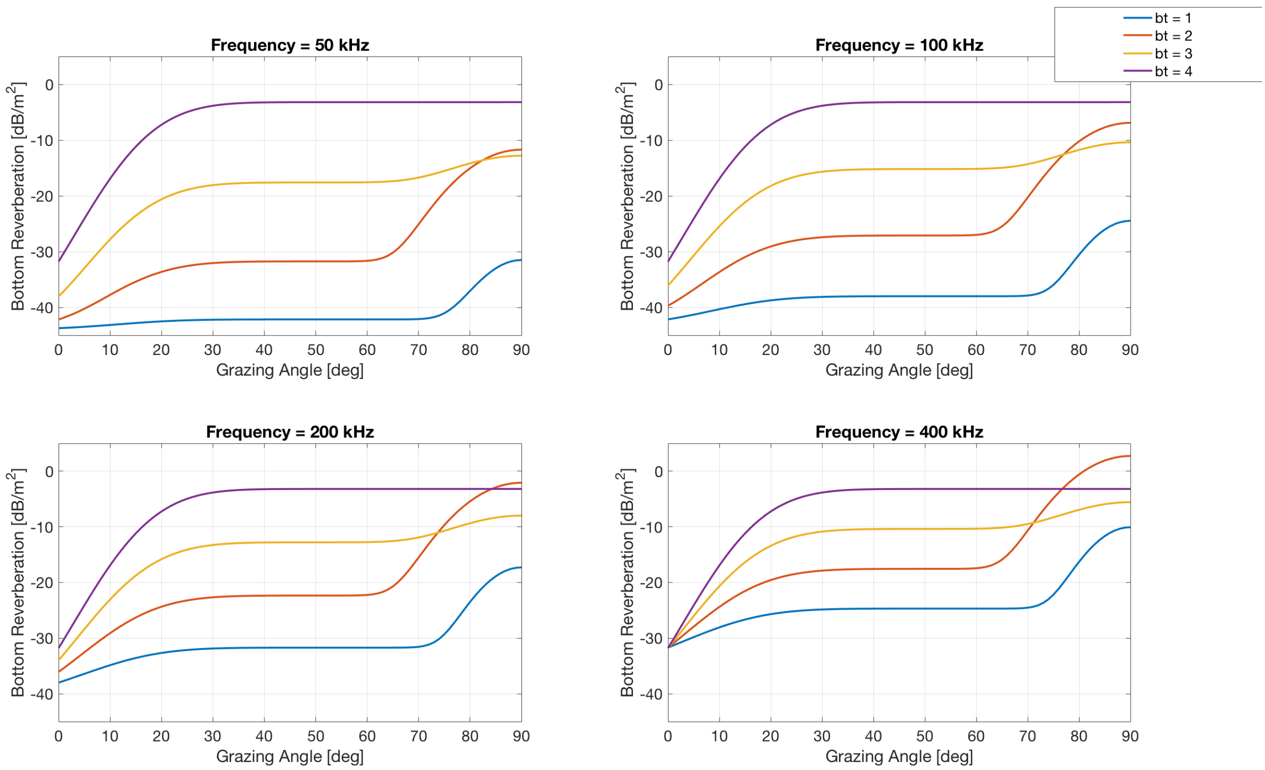

Figure 3.3: Bottom reverberation versus grazing angle for frequency dependency

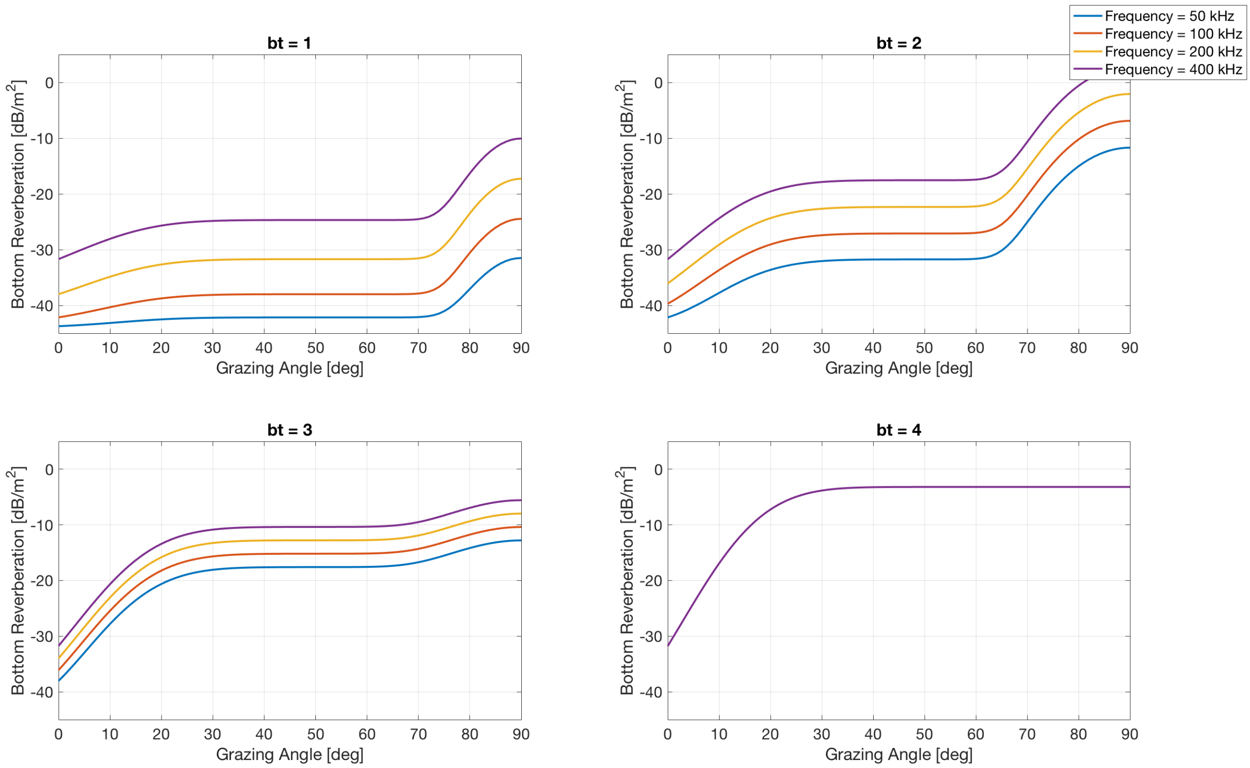

Figure 3.4: Bottom reverberation versus grazing angle for bottom-type dependency

3.3 Volume Backscattering

From figure 3.5, we can say that when the particle density is higher, then the volume reverberation is higher. Particle density can be influenced by biological organisms and turbidity underwater. Volume reverberation increases non linearly with the increase in frequency for particular particle density value.

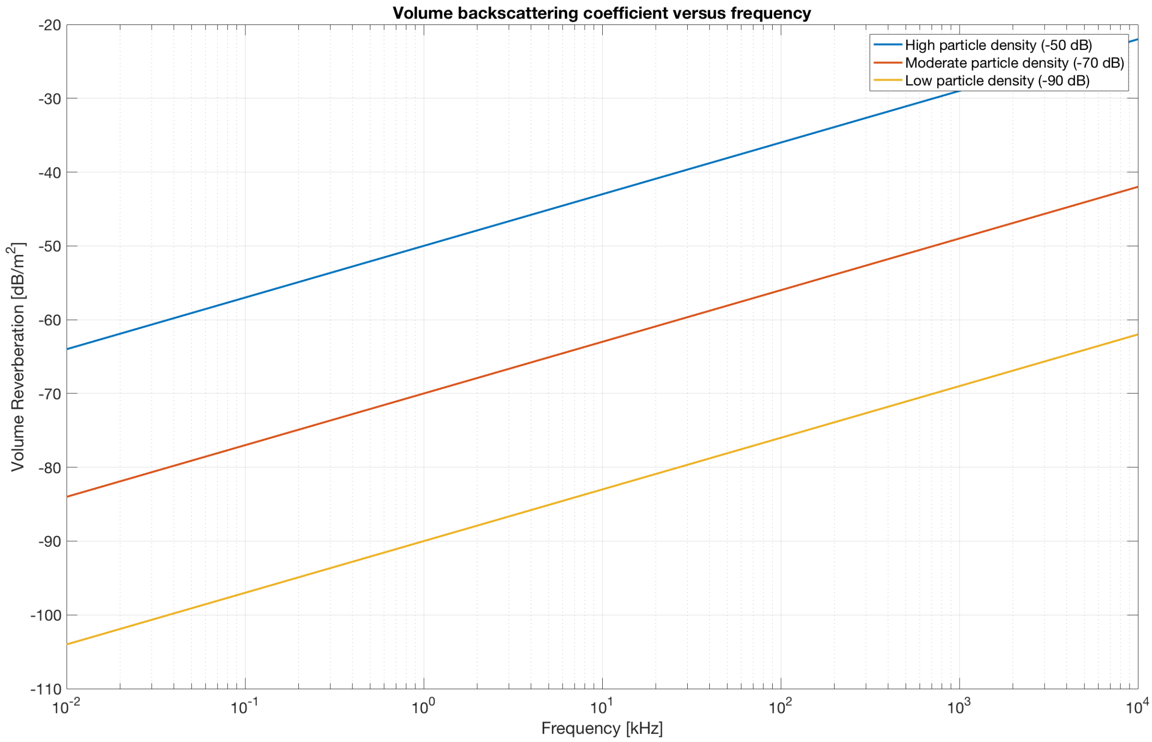

Figure 3.5: Volume reverberation versus frequency for various particle densities

Chapter 4

Conclusion

Using the equations for surface, bottom and volume reverberations, MATLAB programs were written in-order to compute various backscattering coefficients. The surface and bottom backscattering coefficients versus the grazing angle for various sets of (frequency, windspeed) and (frequency, bottom type) respectively was plotted and closely observed. Also the volume reverberation versus frequency graph was obtained and explained for high, moderate and low particle densities.

Chapter 5

Appendix

5.1 MATLAB program to compute surface, bottom and volume reverberation coefficients

5.1.1 Surface reverberation coefficient

```
% Function saved as surfaceBackScattering.m and is called from other MATLAB files
function [sS]= surfaceBackScattering(f,vW,grazingAngle)
beta = 4*((vW+2)/(vW+1)) + (2.5*((f+0.1)^(-1/3))-4) ...
    .* cosd(grazingAngle) .^ (1/8);
sS = 10*log10(((tand(grazingAngle)).^beta) ...
    .*((1+vW)^2)*((f+0.1)^(vW/150))*(10^(-5.05)));
end
```

5.1.2 Bottom reverberation coefficient

```
% Function saved as BottomBackScattering.m and is called from other MATLAB files
function [sB]= BottomBackScattering(frequency,bt,grazingAngle)
gamma = 1 + 125 ...
    .*exp(-2.64.*((bt-1.75).^2)-((50./bt).*(cotd(grazingAngle).^2)));
beta = gamma.*(sind(grazingAngle)+0.19).^(bt.*(cosd(grazingAngle).^16));
```

```
sB = 10.*log10(3.03 .* beta ...
    .* (frequency.^(3.2-0.8.*bt)) .* (10.^(2.8.*bt-12)) + 10^(-4.42));
end
```

5.1.3 Volume reverberation coefficient

```
% Function saved as volumeBackScattering.m and is called from other MATLAB files
function [S]=volumeBackScattering(sp,f)
S=sp+7.*log10(f);
end
```

5.2 MATLAB code to plot surface reverberation coefficient versus grazing angle

5.2.1 Dependency on frequency

```matlab
frequency = [50 100 200 400];
vW = [5 10 20 40];
grazingAngle = 0:90;
for i = 1:4
    subplot(2,2,i)
    sS = [];
    for j = 1:4
    sS = [sS;surfaceBackScattering(frequency(i),vW(j),grazingAngle)]; % calling the function
    end
plot(grazingAngle,sS,'LineWidth',2)
axis([0 90 -60 0])
grid on
xlabel('Grazing Angle [deg]')
ylabel('Surface Reverberation [dB/m^2]')
ax = gca;
ax.FontSize = 16;
title(sprintf('Frequency = %d kHz' ,frequency(i)))
end
hL = legend('WS = 5 kn','WS = 10 kn','WS = 20 kn','WS = 40 kn');
newPosition = [0.85 0.85 0.15 0.18];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.2.2 Dependency on wind speed

```matlab
frequency = [50 100 200 400];
vW = [5 10 20 40];
grazingAngle = 0:90;
for i = 1:4
    subplot(2,2,i)
    sS = [];
    for j = 1:4
    sS = [sS;surfaceBackScattering(frequency(j),vW(i),grazingAngle)]; % calling the function
    end
plot(grazingAngle,sS,'LineWidth',2)
axis([0 90 -60 0])
grid on
```

```
xlabel('Grazing Angle [deg]')
ylabel('Surface Reverberation [dB/m^2]')
ax = gca;
ax.FontSize = 16;
title(sprintf('Windspeed = %d kn ' ,vW(i)))
end
hL = legend('f = 50 kHz','f = 100 kHz','f = 200 kHz','f = 400 kHz');
newPosition = [0.85 0.85 0.15 0.18];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.3 MATLAB code to plot bottom reverberation coefficient versus grazing angle

5.3.1 Dependency on frequency

```
bt = [1 2 3 4];
grazingAngle = 0:90;
for i = 1:4
    subplot(2,2,i)
    sB = [];
    for j = 1:4
    sB = [sB;BottomBackScattering(frequency(i),bt(j),grazingAngle)]; % calling the function
    end
plot(grazingAngle,sB,'LineWidth',2)
axis([0 90 -45 5])
grid on
xlabel('Grazing Angle [deg]')
ylabel('Bottom Reverberation [dB/m^2]')
ax = gca;
ax.FontSize = 16;
title(sprintf('Frequency = %d kHz' ,frequency(i)))
end
hL = legend('bt = 1','bt = 2','bt = 3','bt = 4');
newPosition = [0.85 0.85 0.15 0.18];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.3.2 Dependency on bottom type

```
frequency = [50 100 200 400];
bt = [1 2 3 4];
grazingAngle = 0:90;
for i = 1:4
    subplot(2,2,i)
    sB = [];
    for j = 1:4
    sB = [sB;BottomBackScattering(frequency(j),bt(i),grazingAngle)]; % calling the function
    end
plot(grazingAngle,sB,'LineWidth',2)
axis([0 90 -45 5])
grid on
xlabel('Grazing Angle [deg]')
```

```
ylabel('Bottom Reverberation [dB/m^2]')
ax = gca;
ax.FontSize = 16;
title(sprintf('bt = %d' ,bt(i)))
end
hL = legend('Frequency = 50 kHz','Frequency = 100 kHz','Frequency = 200 kHz','Frequency = 400 kHz');
newPosition = [0.85 0.85 0.15 0.18];
newUnits = 'normalized';
set(hL,'Position', newPosition,'Units', newUnits);
hL.FontSize = 15;
```

5.4 MATLAB code to plot volume reverberation coefficient versus frequency

```matlab
frequency = logspace(1,7) * 0.001;
Sp = [-50 -70 -90];
for i = 1:3
sV(i,:)= volumeBackScattering(Sp(i),frequency);
end
semilogx(frequency,sV,'LineWidth',2)
ax = gca;
ax.FontSize = 16;
title('Volume backscattering coefficient versus frequency')
grid on
xlabel('Frequency [kHz]')
ylabel('Volume Reverberation [dB/m^2]')
hL = legend('High particle density (-50 dB)', ...
    'Moderate particle density (-70 dB)','Low particle density (-90 dB)')
hL.FontSize = 15;
```