UNDERWATER ACOUSTICS AND SONAR SIGNAL PROCESSING

SS 2018

ASSIGNMENT 4

AMBIENT NOISE

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by

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Introduction

The ocean ambient noise is the unwanted background noise. They are due to constant sea surface agitation, marine mammals, and man-made sources. Ambient noise is used as an input of sonar equation to predict the performance of underwater acoustical equipment, such as sonar.

In this assignment we first develop a MATLAB program for calculating the isotropic ambient noise level. Then we plot the ambient noise level versus frequency for different values of wind speeds. And finally we plot a graph to indicate the frequency domains where either noise level from turbulence, traffic, thermal or sea state dominate.

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

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

Experimental Research

0.1 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.

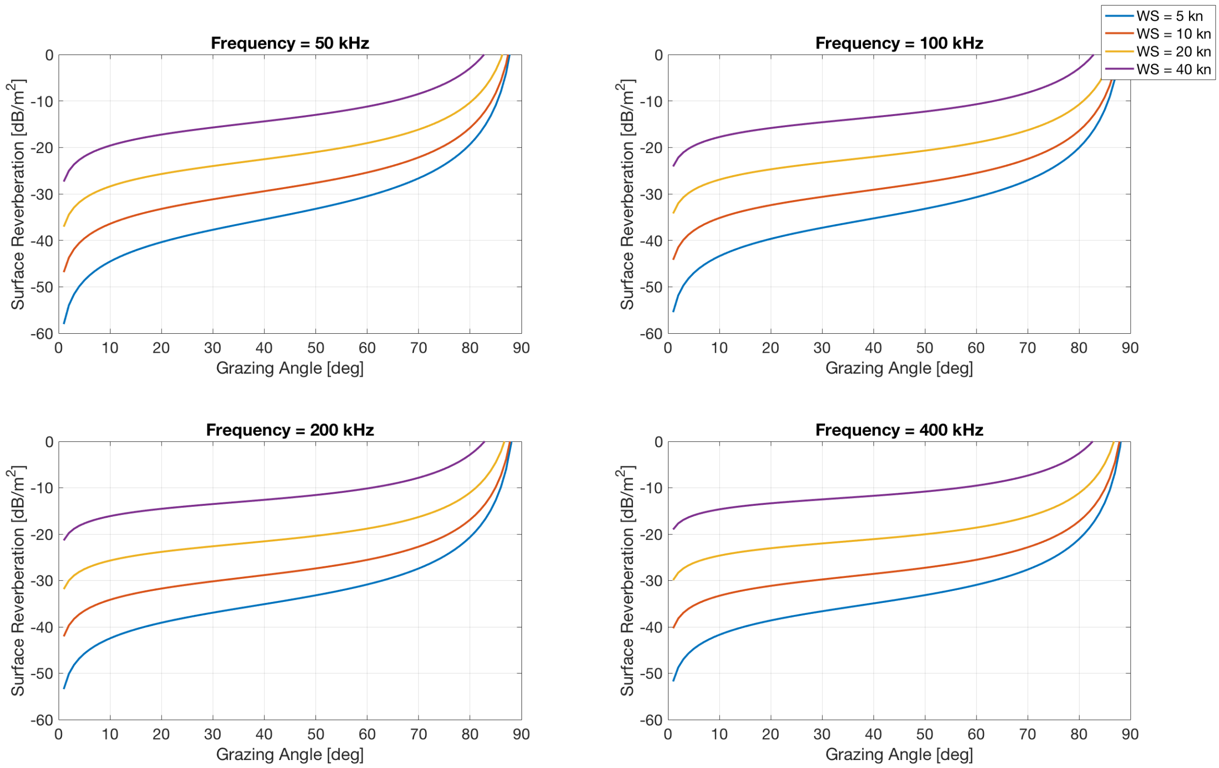

Figure 1: Surface reverberation versus grazing angle for frequency dependency

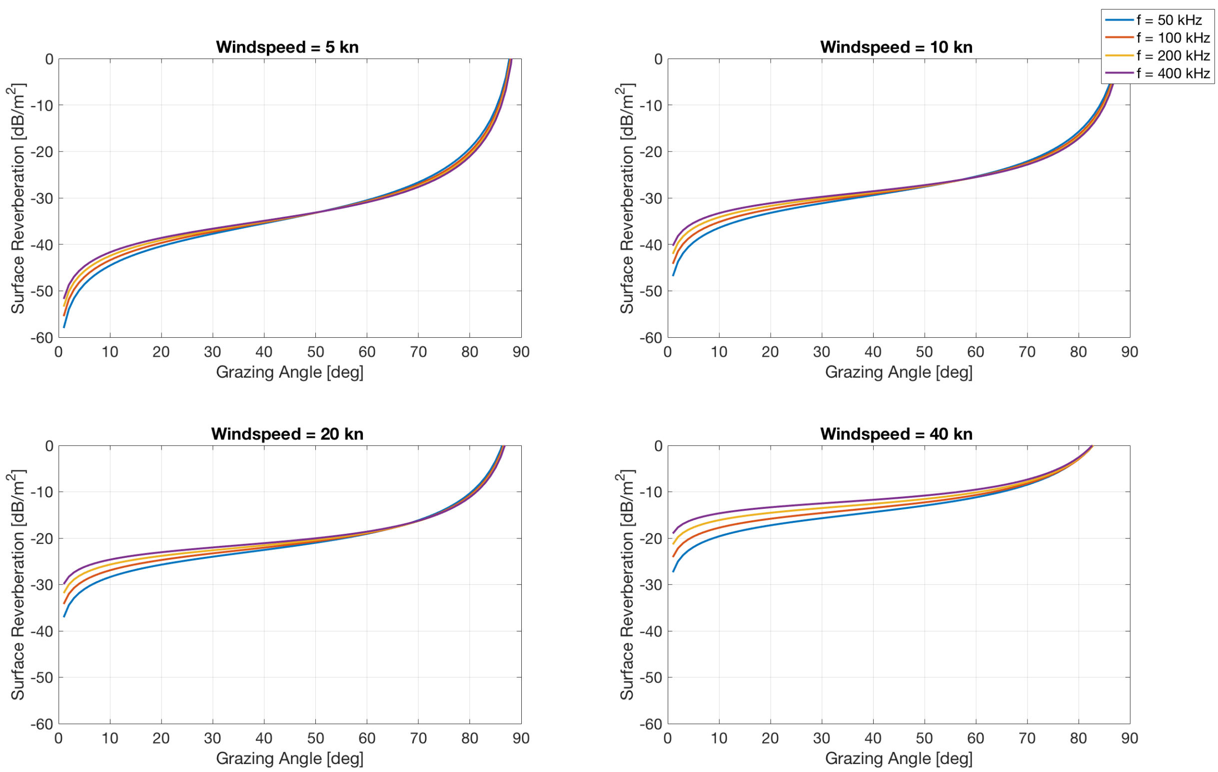

Figure 2: Surface reverberation versus grazing angle for wind speed dependency

0.2 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.

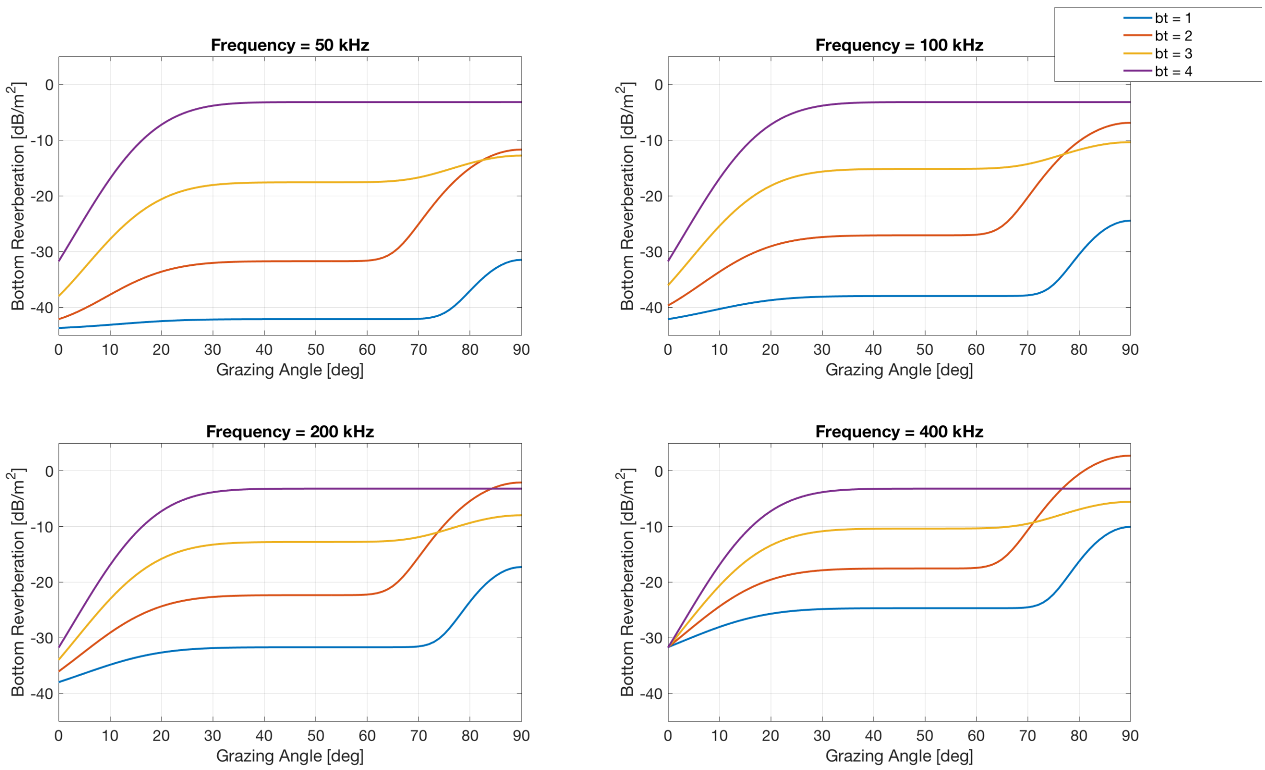

Figure 3: Bottom reverberation versus grazing angle for frequency dependency

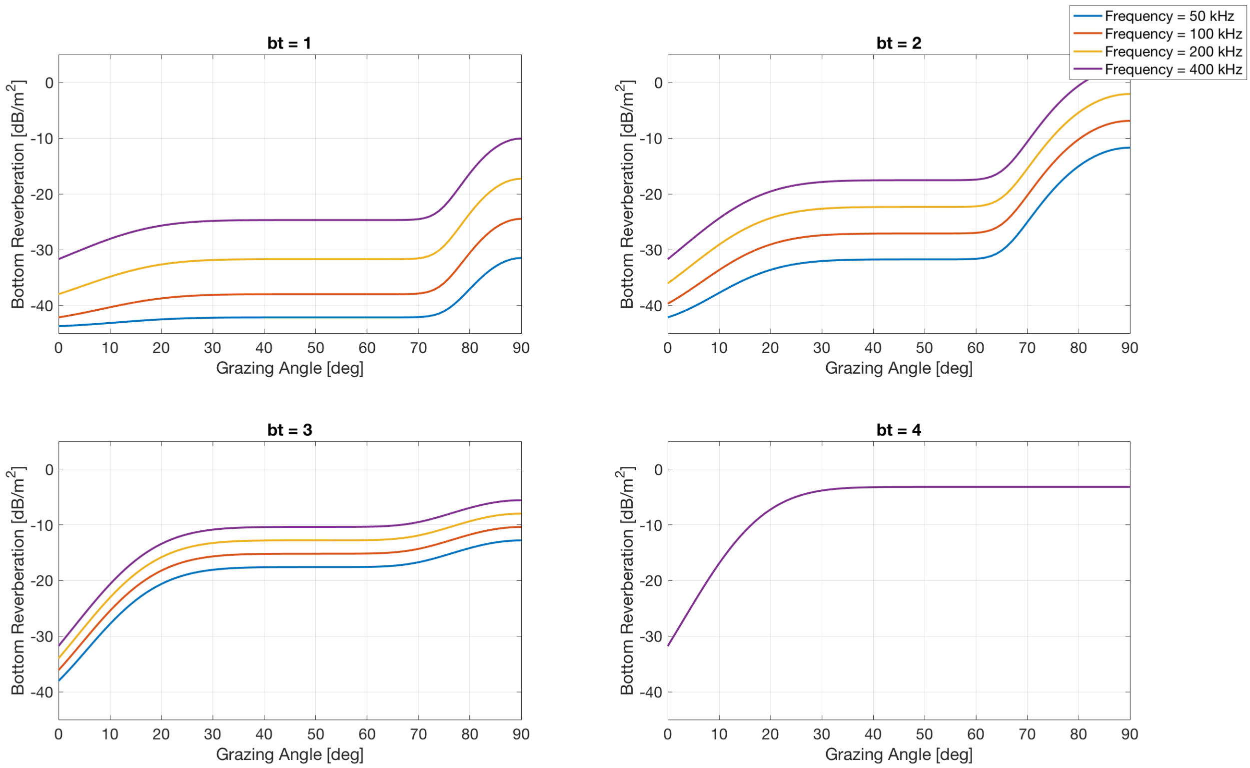

Figure 4: Bottom reverberation versus grazing angle for bottom-type dependency

0.3 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.

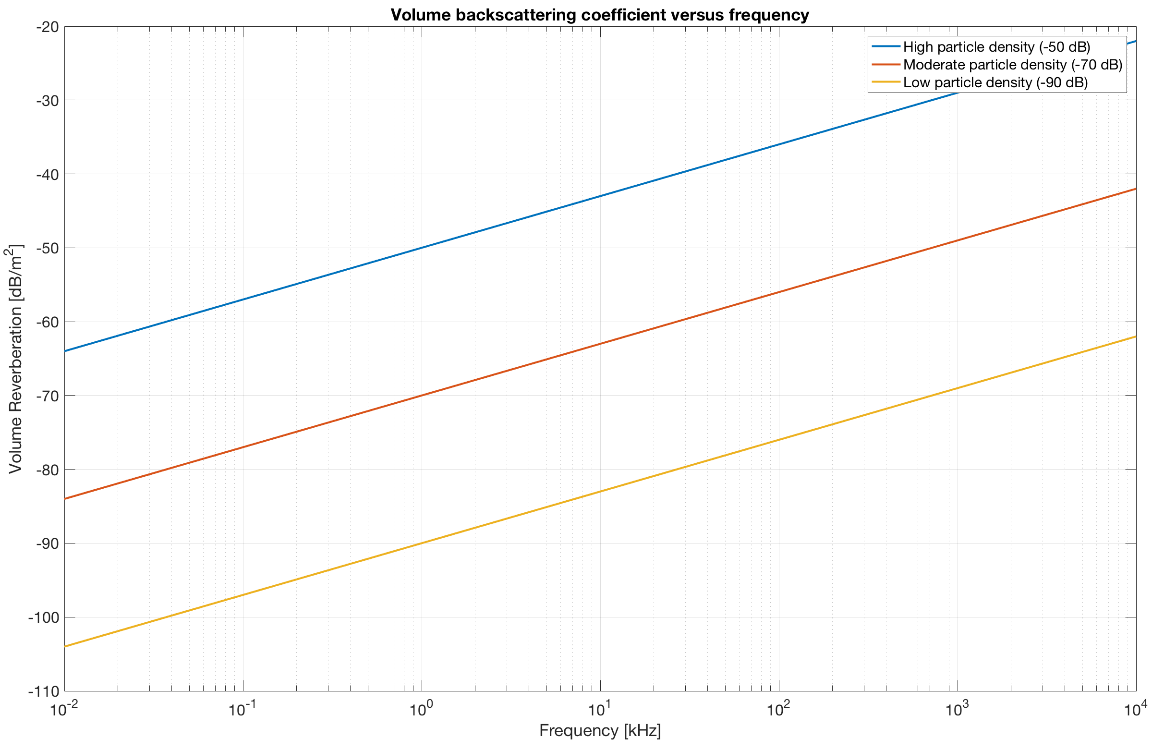

Figure 5: Volume reverberation versus frequency for various particle densities

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.

Appendix

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

0.4.1 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
```

0.4.2 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
```

0.4.3 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
```

0.5 MATLAB code to plot surface reverberation coefficient versus grazing angle

0.5.1 Dependency on frequency

```
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;
```

0.5.2 Dependency on wind speed

```
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;
```

0.6 MATLAB code to plot bottom reverberation coefficient versus grazing angle

0.6.1 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;
```

0.6.2 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;
```

0.7 MATLAB code to plot volume reverberation coefficient versus frequency

```
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;
```