UNDERWATER ACOUSTICS AND SONAR SIGNAL PROCESSING

SS 2018

ASSIGNMENT 7

SONAR ANTENNA DESIGN

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by

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Contents

Introduction

For directional reception of wave energy, it is necessary to use equidistantly arranged linear or planar arrays on extended antennas. The sonar transmitting/receiving antenna characteristics can be determined by the geometry and shading of the antenna aperture and also the properties of individual transducers. If simultaneous detection of signals from many directions of incidence is required, beam forming must be carried out in parallel for many direction channels. It is also possible to steer antenna in defined direction and range zones and thus process near-field signals selectively with regard to bearing and range of their source.

In this assignment we first develop a MATLAB program that determines the beam pattern. Then the graphs are plotted for beam pattern using various parameters. The parameters used in this assignment are beam forming, amplitude shading, beam shaping and electronic sheering.

Theory

0.1 Antenna Beam Pattern

0.1.1 Beam Forming

Beam forming or spatial filtering is the process by which an array of large number of spatially separated sensors discriminate the signal arriving from a specified direction from a combination of isotropic random noise called ambient noise and other directional signals.

0.1.2 Amplitude Shading

Shading is most commonly used to suppress side lobes (responses away from the main response lobe) or to suppress responses in noisy direction (known as Adaptive Beam forming). Having all coefficients equal offers the maximum array gain in an isotropic noise field. Shading increases, the width of the main lobe and decreases side lobes and reduces array gain. With the shading we are trading off the main lobe width and side lobe level.

0.1.3 Parabolic Phase Shading (Beam Shaping)

According to our requirements, the beam pattern and main lobe can be designed this is known as beam shaping. Time delaying a signal is the time-domain analog to phase shading of the signal in frequency domain.

0.1.4 Linear Phase Shading (Electronic Steering)

Electronic steering is about changing the direction of the main lobe of a radiation pattern electronically by changing magnitude and phase of the hydrophone. Since there are no moving parts in Electronic Steering as compared to Mechanical steering, this method of beam steering is more efficient.

Experimental Research

0.2 Dependence of wind speed and frequency on Ambient noise

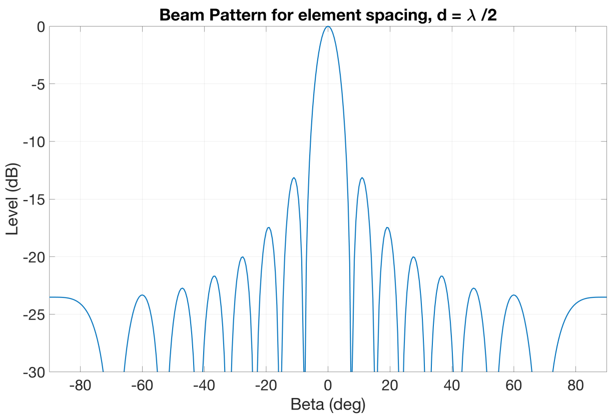
The ambient noise level versus frequency for wind speeds of 5, 10, 15, 20, 25 and 30 kn is plotted. In-order to obtain the figure (1), we assumed the biological, rainfall and self noise level to be -99 dB and the frequency in the range of 1 Hz to 1 MHz was considered.

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.

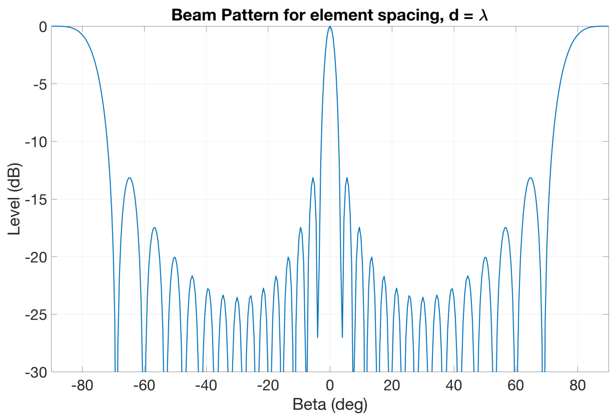
0.3 Contribution of different noise sources

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.

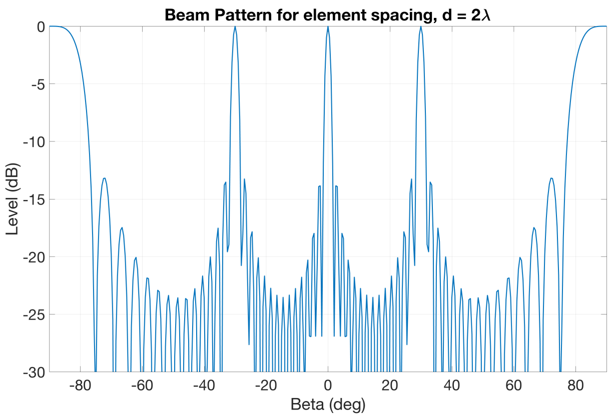
From the result shown in figure (2), we can distinguish different ambient noise, in different frequency range. We can observe the effect of turbulence noise between 1 Hz to 10 Hz. In the frequency range between 10 Hz to 300 Hz, the noise is affected by the traffic, shipping and harbours. Wind speed and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



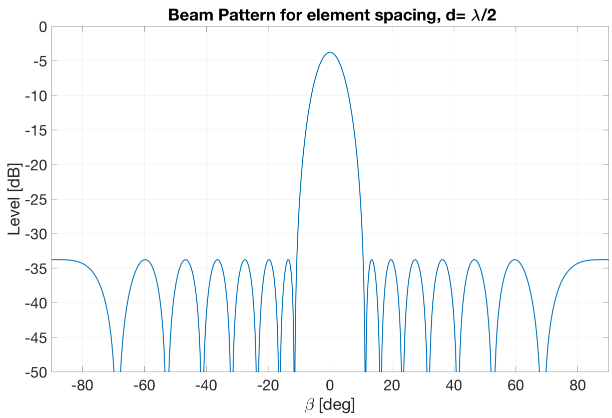
(a) Frequency, $f = 10Hz$



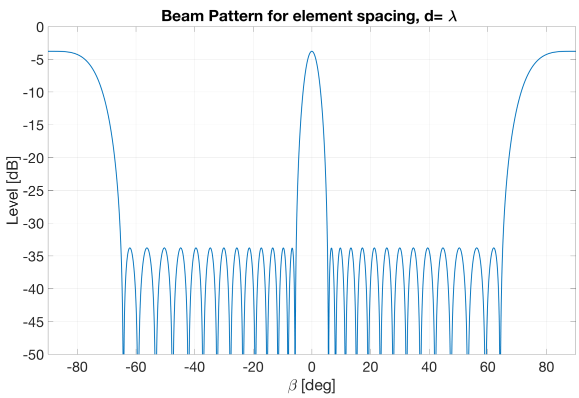
(b) Frequency, $f = 100Hz$



(c) Frequency, $f = 1kHz$



(d) Frequency, $f = 10kHz$



(e) Frequency, $f = 100kHz$

Figure 1: Pressure distribution observed at various frequencies

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

0.4 MATLAB code to determine beam pattern for different element spacing

```
N = 15;  % number of elements
k.d = [pi,2*pi,4*pi];  % multiples of k and d
beta = -90:0.5:90;
b = zeros();
q = zeros();
B = zeros();
for i = 1:3
  for bet = 1:361
      b(bet) = 0;
    for j = 0:N-1
        q(bet) = exp(-j*k.d(i)*sind(beta(bet))*1i);
        b(bet) =b(bet)+q(bet);
    end
    b(bet) = b(bet)/N;  % complex beam pattern
    B(bet) = 20*log10(abs((b(bet)))); % beam pattern
  end
  figure
  plot(beta,B,'LineWidth',2);
  if i == 1
      title('Beam Pattern for element spacing, d = \lambda/2');
```

```
  else
      if i == 2
          title('Beam Pattern for element spacing, d = \lambda');
      else
      title('Beam Pattern for element spacing, d = 2\lambda');
      end
  end
  ylim([-30 0])
  xlim([-90 90])
  grid
  xlabel('Beta (deg)');
  ylabel('Level (dB)');
end
```

0.5 MATLAB code to determine beam pattern with amplitude shading

```
deg2rad = pi/180; % conversion to rad
beta_deg = -90:0.1:90; % angle between the vector R and the x-axis [deg]
beta_rad = beta_deg*deg2rad; % angle between the vector R and the x-axis [rad]
N = 15; % number of hydrophones
lambda = 2; % Wavelength [m]
k = 2*pi/lambda; % wave number
d = [lambda/2, lambda, 2*lambda]; % distance between hydrophones (element spacing)
Qn_head = ones(1,N); % Amplitude of the n-th point source or Hydrophone
alpha = ones(1,N); % Phase of the n-th point source or Hydrophone
w = chebwin(15,30);
Q_head = 0; % initialising variable
for n = 1:N
term = Qn_head(n);
Q_head = Q_head + term;
end
for x = 1:3
 bp_sum = 0;
```

```
for n = 1:N
sum(n,:) = Qn_head(n)*w(n)*exp(1i*(alpha(n) - k*n*d(x)*sin(beta_rad)));
bp_sum = bp_sum + sum(n,:);
end
bp = 20*log10(abs(1/(Q_head)*bp_sum)); % beam pattern
figure
%subplot(3,1,x)
plot(beta_deg,bp,'linewidth',2)
grid;
axis([-90 90 -50 0])
ylabel('Level [dB]')
xlabel('\beta [deg]')
switch num2str(d(x))
case '1'
title(' Beam Pattern for element spacing, d= \lambda/2')
case '2'
title('Beam Pattern for element spacing, d= \lambda ')
case '4'
title('Beam Pattern for element spacing, d= 2\lambda')
end
end
```

0.6 MATLAB code to determine parabolic phase shaping

```
beta_deg = -90:0.1:90; % angle between the vector R and the x-axis [deg]
beta_rad = beta_deg*pi/180; % angle between the vector R and the x-axis [rad]
N = 15; % number of hydrophones
lambda = 2; % wavelength
k = 2*pi/lambda; % wave number
d= [lambda/2, lambda, 2*lambda]; % distance between hydrophones (element spacing)
Qn_head = ones(1,N); % Amplitude of the n-th point source or Hydrophone
alpha = ones(1,N); % Phase of the n-th point source or Hydrophone
scaling = [pi*2, pi, pi/2, pi/10]; % scaling factor for the parabolic shading
alpha_parabolic = zeros();
for x=1:3
```

```
 for n= -7:1:(N-1)/2
  alpha_parabolic(n+8,x) = scaling(x)*n^2/(((N-1)/2)^2);
 end
end
figure
plot(-7:7,alpha_parabolic(:,1),-7:7,alpha_parabolic(:,2),...
    -7:7,alpha_parabolic(:,3),'linewidth',2);
title('Parabolic Phase Shading ')
grid
legend('360^{\circ}','180^{\circ}','90^{\circ}');
xlabel('Hydophone (n)')
ylabel('Phase, \alpha')
Q_head = 0; % initialising variable
for n = 1:N
 term = Qn_head(n);
 Q_head = Q_head + term;
end
for x = 1:3
 bp_sum = 0;
 for n = 1:N
  sum(n,:) = Qn_head(n)*exp(1i*(alpha_parabolic(n,x) ...
     - k*n*d(1)*sin(beta_rad)));
  bp_sum = bp_sum + sum(n,:);
 end
 bp(x,:) = 20*log10(abs(1/(Q_head)*bp_sum)); % beam pattern
end
figure
plot(beta_deg,bp(1,:),beta_deg,bp(2,:),beta_deg,bp(3,:),'linewidth',2)
title('Beam Pattern for various phase shifts ')
grid;
hold on;
legend('360^{\circ}','180^{\circ}','90^{\circ}');
axis([-90 90 -30 0])
ylabel('Level [dB]')
xlabel('\beta [deg]')
```

0.7 MATLAB code to determine linear phase shading

```
stear_1 = -20; % steering angle in degrees
stear_2 = 0;
stear_3 = 20;
deg2rad = pi/180;
stear1 = stear_1*deg2rad;
stear2 = stear_2*deg2rad;
stear3 = stear_3*deg2rad;
R = 30;
f = 100000;
c = 1480;
lamda = c/f;
d = lamda/2;
N = 15;
n = 0:N-1;
rho_deg = -90:0.01:90;
rho_rad = rho_deg*deg2rad;
sinerho = sin(rho_rad');
part2 = 2*pi*d*n/lamda;
Q = exp(1i*sinerho*part2);
y1 = exp(1i*sin(stear1)*part2); %-40
B1 = (Q*y1')/N;
y2 = exp(1i*sin(stear2)*part2); %0
B2 = (Q*y2')/N;
y3 = exp(1i*sin(stear3)*part2); %20
B3 = (Q*y3')/N;
gn1 = 20*log10(abs(B1));
gn2 = 20*log10(abs(B2));
gn3 = 20*log10(abs(B3));
figure(1);
plot(rho_deg,gn1,'linewidth',2);
hold on;
plot(rho_deg,gn2,'y','linewidth',2);
hold on;
plot(rho_deg,gn3,'m','linewidth',2);
```

```
hold on;
ax = gca;
ax.FontSize = 30;
grid;
axis([-90 90 -60 15])
title('Beam Pattern for various Steering Angles');
xlabel('Angle [deg]');
ylabel('Beam intensity [dB]');
hL = legend('stearing angle = -20^{\circ}','stearing angle = 0^{\circ}','stearing angle = 20^{\circ}
    ');
hL.FontSize = 25;
```