MODELING OF SIDE - SCAN SONAR FIELD

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Tihomir Trifonov¹, Yassen Siderov², Kamen Simenov³

¹Vassil Levski Land Forces Academy, Faculty of Communication and Information Systems, Dep. of Radioelectronics, 5007 Veliko Turnovo, Bulgaria,
²University of Veliko Turnovo “St. st. Cyril and Methodius”, Fac. of Mathematics and Informatics, 5003 Veliko Turnovo, Bulgaria
³P.O. Box 341, 5000 Veliko Turnovo, Bulgaria

Abstract. Analytical and experimental results of side-scan sonar field are presented. Nearfield and far-field simulation programs are used. A simple technique for measuring the width of the directivity pattern in an acoustic tank is offered.

Key words: side-scan sonar, antenna system, directivity pattern

1. INTRODUCTION

The creation of the side-scan sonars (SSS) in 1958 is a crucial point in the designing of technical devices for visualization of underwater objects, especially of objects near the sea bottom. The image obtained by SSS is in the usual for humans orthoscopic projection with much better resolution ability than the known by now have [1,2,3].

By these reasons different types SSS are widely used not for civil purposes only, but in military domain for detection and localization of objects on the sea floor or near it: wrecks, sea-bottom pipelines, mine belts etc.

One of the most significant systems of the SSS is the antenna system (transducer arrays). The main parameters of the sonar depend to a great extend on its optimal design and measurement [4].

2. OBSERVATION METHOD

The observation method is schematically shown in Fig. 1. The tow-fish is moved with a constant speed on a determined altitude above the sea bottom \( h \). The image of the two
side bands is obtained up to the distance $r_{\text{max}}$.

Fig. 1.

Under the condition that $r_{n}/h$ is too big, it can be accepted that $r_{\text{max}}$ is equal to the slope distance $r_n$. The investigation, taking place at Radio-Technical Equipment Institute - Veliko Turnovo showed that the optimal relation is:

$$\frac{r_n}{h} = 8$$  \hspace{1cm} (1)

The width of the directivity pattern (DP) for each antenna in the azimuthal plane is about $1^\circ$, and in the vertical one - about $60^\circ$, and it can be recommended its form to satisfy the requirement [1]:

$$R(\theta) = \left( \frac{\cos \sec \theta}{\sec \theta_{\text{max}}} \right)^3$$ \hspace{1cm} (2)

This DP provides steadiness of the investigated band radiation.

The indication of the sea floor, together with the adjacent sound-reflecting objects is realized in Cartesian coordinates "slope distance - tow distance". The information is memorized periodically on TV type indicators or electronic-chemical recorders, using electrochemical paper.
3. ANTENNA SYSTEM FIELD MODELING

Because of the big directivity of the antennas in azimuthal (horizontal) plane, their main parameters can be obtained by approximation with the discrete linear antenna grid and can be measured by simple method, described below [4].

This problem is more complicated in the vertical plane. In this case it can be assumed that DP is formed by a pulsing strip, Build on an absolutely rigid in acoustical sense cylinder - Fig. 2.

The general solution of the Helmholtz equation for a two-dimensional boundary-value problem (no dependence on "z" coordinate) is as follows [5]:

\[
\Phi(r, \theta) = \sum_{m=0}^{\infty} (C_m \cos m\theta + D_m \sin m\theta)[E_m J_m(\rho r) + F_m N_m(\rho r)] 
\]

where \( J_m(\rho r) \) and \( N_m(\rho r) \) - Bessel functions of the first and second kind \( m \)-th order.

\( \Phi(r, \theta) \) - field potential.

In order to satisfy the Sommerfeld condition, \( F_m=i. E_m \) is assumed and then:

\[
\Phi(r, \theta) = \sum_{m=0}^{\infty} (C_m \cos m\theta + D_m \sin m\theta)H_m^{(1)}(\rho r) 
\]

where \( H_m^{(1)}(\rho r) \) is Bessel function of the third kind \( m \)-th order (also called the first Hankel function).

In the case shown in Fig. 2, the velocity of vibration depends on the angle \( \theta \) by low \( U_0 = U_0(\theta) \) and in (4) it can be separates the solutions that satisfy the boundary condition (5) only:

\[
U_0 = -k \sum_{m=0}^{\infty} H_m^{(1)}(ka)(C_m \cos m\theta + D_m \sin m\theta) 
\]
If (5) is considered as Fourier Series, it can be obtained:

\[
C_0 = -\frac{1}{2k\pi h_0^{(1)}(ka)} \int_{\alpha}^{\alpha + \pi} U_0(\theta) d\theta ;
\]

\[
C_m = -\frac{1}{k\pi h_m^{(1)}(ka)} \int_{\alpha}^{\alpha + \pi} U_0(\theta) \cos m\theta d\theta ;
\]

\[
D_m = -\frac{1}{k\pi h_m^{(1)}(ka)} \int_{\alpha}^{\alpha + \pi} U_0(\theta) \sin m\theta d\theta ;
\]

\[m = 1, 2, 3, \ldots\]

\[k - \text{wave number}, \quad k = \frac{2\pi}{\lambda}\]

For this problem:
\[U_a = U_0, \text{ when } \theta \leq \frac{\theta_1 - \theta_0}{2}\]
\[U_a = 0, \text{ when } \theta > \frac{\theta_1 - \theta_0}{2}\]

Solving (6,7,8) and substituting in (4), for the potential \(\Phi(r, \theta)\) in the outside domain it can be written:

\[
\Phi(r, \theta) = \frac{U_0}{2\pi k} \left(\theta_1 - \theta_0\right) \sum_{m=0}^{\infty} \varepsilon_m H_m^{(1)}(kr) \cos[m(\theta - \theta_0)]
\]

where \(\varepsilon_m = 1, \text{ when } m \neq 0\)
\(\varepsilon_m = 0, \text{ when } m = 0\)
\[\theta_n = \theta_0 + \frac{\theta_1 - \theta_0}{2}\]

Using the known relation between the potential \(\Phi\) and the sound pressure \(p\) for harmonic excitation

\[
p = p \left(\frac{\partial \Phi}{\partial t}\right)
\]

where \(p\) - mass density of the medium and between the potential and the velocity of vibration \(\vec{u}\)
\[\vec{u} = -\text{grad} \Phi\]

it can be obtained all characteristics of the field, inclusively near-field and far-field DP.

4. NUMERICAL AND EXPERIMENTAL RESULTS AND CONCLUSION

The modeling was carried out in MATLAB-a widely used medium for scientific computation and visualization (See Appendix 1). The DPs were calculated for the following input data:
Modeling of Side-Scan Sonar Field

\[ a = 0.1m, \quad \theta_a = \frac{11\pi}{8}, \quad \frac{\theta - \theta_a}{2} = \frac{\pi}{9} (i.e., 20^0), \quad \frac{2\pi}{\lambda} = 440 \]

in a near \( r = 2a \) and a far \( r = 100a \) field.

These DPs are presented in Fig. 3 and Fig. 4.

The complete results of testing show a good concidence with the measurement in the hydroacoustic measuring tank, in accordance with the current standards.

A simple method to the vertical coordinate device of the tank (Fig. 5).

While shifting the antenna in the direction of its vertical axis, the level of the signal at the output of the measuring hydrophone is being watched. After reaching a certain level (e.g., 0.7 of the base maximum), linear shifting of the antenna in relation to the position of the main lobe of the DP is calculated by solving the obtained triangle. To evaluate the error, the continuous antenna is approximated with discrete with virtual element from \(-N\) to \(+N\), with distance between them \( \lambda/2 \) [4].

The theoretical calculations are restricting the applicability of the method only in the near area of the main lobe of the DP, where the error is acceptable.

Conditions of a free field were created in a measuring tank: inner dimensions 14×7×7 m; sound-absorbing rubber panels;
sound-absorbing pontoons on the surface; vibroisolating foundations ensuring low level of the environmental noises; vertical thermal gradient lesser that 0.05 deg/m. The measurements were made with "Bruel&Kaer" measuring hydrophones and equipment, using the impulse technique. The achieved relative error in measuring the width of the main lobe of the DP was only 1.5% higher than the one, achieved by using the classical method.

It's also important to mention, that the expenses using the offered methods for modeling and DP measurement, are lesser that the ones expenses made using the classical methods.

**APPENDIX**

```matlab
% Program for calculation of
% Re Pr(tita)=i.w.roc(2(tita))
% tita modifies from 0 to 360 % degrees
format compact
r=1000; %kg/m^3
A=105*10^-3; % frequency
w=2*pi*f;
A0=0.1;
r=100*a;
deltatita=pi/9;
tita0=2*pi/3;
tita=0.5*pi/9;
titaH=0.5*(tita1-tita0);
v0=1;
m=1;
while m <= 8
end
m=m+1

%new 'k', 'new a', 'new delta tita', 'new tita0', 'new tita1', 'new v0', 'END';
if m == 2
end

disp('The current value is: ');
sprintf('%3.3f, k])', k); input('Enter new k =1;')

while isan(k)
k=input('Enter k =1;')
end

if m == 3
end

disp('The current value is: ');
sprintf('%3.3f, a)]=

a=input('Enter new a =1;')
while isan(a)
a=input('Enter a =1;')
end

r=100*a
end
if m == 4
end
if m == 5
end

disp('The current value is: ');
sprintf('%3.3f, tita0

tita0 = input('Enter new tita0 =1;')
while isan(tita0)
tita0=input('Enter tita0 =1;')
end

titaH-tita0=0.5*(tita1-

disp('The current value is: ');
sprintf('%3.3f, tita1

int2str(tita*180/pi)'
degrees')
end

if m == 6
end

disp('The current value is: ');
sprintf('%3.3f, tita1

int2str(tita*180/pi)'
degrees')
end

if m == 7
end

disp('The current value is: ');
sprintf('%3.3f, tita1

int2str(tita*180/pi)'
degrees')
end

if m == 8
end

disp('Calculation time:
numstr(ptime-0)'

seconds')

disp('PRESS A KEY')

pause
p=p=max(p); tita=0; step=2*pi; hold on

% in cartesian coordinate % system Real part
ylabel('Re P');
xlabel('tita [rad]');
% text(1,1,'DEKART; Real')
real_p=real(p(1:mm)); plot(tita,real_p)

% in cartesian coordinate % system Abs
figure
ylabel('P'); xlabel('tita [rad]');
real_p=abs(p(1:mm)); plot(tita,real_p)

% in polar coordinates Real part
figure
real_p=real(p(1:mm)); polar(tita,real_p)

% in polar coordinates Abs
figure
real_p=abs(p(1:mm)); polar(tita,real_p)
end

% while m <= 7
```
REFERENCES


MODELIRANJE POLJA SONARA SA BOČNIM SKENIRanjEM

Tihomir Trifonov, Yassen Siderov, Kamen Simeonov

Prezentirani su analitički i eksperimentalni rezultati polja sonara sa bočnim skeniranjem. Korišćeni su programi za simulaciju bliskog i dalekog polja. Nudi se prosta tehnika za merenje širine uzorka direktivnosti u akustičkim tankovima.