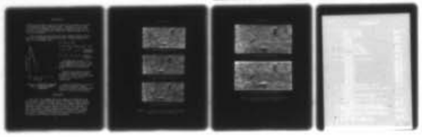
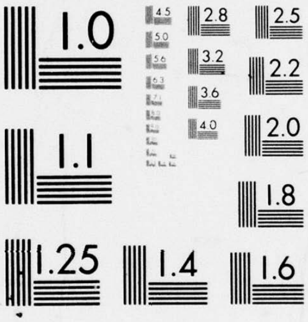
AD-A045 043   NAVAL COASTAL SYSTEMS LAB PANAMA CITY FLA   F/G 17/1
HIGH RESOLUTION SONAR SIMULATION TECHNIQUES.(U)
SEP 77 D L FOLDS, N F ANDERSON
UNCLASSIFIED   NCSL-TR-322-77   NL

1 OF 1
AD
A045043



END
DATE
FILMED
10-77
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3

12

TECHNICAL
REPORT
NCSL 322–77

SEPTEMBER 1977

HIGH RESOLUTION SONAR SIMULATION TECHNIQUES

D.L. FOLDS
N.F. ANDERSON

NAVAL COASTAL SYSTEMS LABORATORY
NCSL
PANAMA CITY, FLORIDA 32407

APPROVED FOR PUBLIC RELEASE
DISTRIBUTION UNLIMITED

copy 37

[illegible]

[illegible]

[illegible]   [illegible]
[illegible]   Technical Director

ADMINISTRATIVE INFORMATION

[illegible] during 1976 under Subproject SF 11 121 [illegible] [illegible], Task [illegible]. [illegible] and continuing during 1977 under SF 11 121 [illegible], Task [illegible].

Released by   Under Authority of
[illegible]   [illegible]
[illegible] Department   [illegible]
September 1977

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(14)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NCSL-TR-322-77 ✓
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): (6) HIGH RESOLUTION SONAR SIMULATION TECHNIQUES.
5. TYPE OF REPORT & PERIOD COVERED: (9) Technical Report.,
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): (10) D. L. Folds, N. F. Anderson
8. CONTRACT OR GRANT NUMBER(s): (16) F11121, F11121 (17) SF11121401, SF11121491
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Naval Coastal Systems Laboratory ✓
Panama City, Florida 32407
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
Subproject SF 11 121 401
Task 19251-3
62711N
11. CONTROLLING OFFICE NAME AND ADDRESS:
12. REPORT DATE: (11) Sep~~tember~~ 1977
13. NUMBER OF PAGES: 12 (12) 15p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE: N/A
16. DISTRIBUTION STATEMENT (of this Report):
Approved for Public Release; Distribution Unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):

DDC
OCT 11 1977
C

18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

High Resolution Sonar Simulation
Computerized Simulation
Mathematical Models
Side Looking Sonar
Forward Looking Sonar
Identifiers:
Target Echo

407 276

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A mathematical model developed for a computer simulation of both side-looking and forward-looking high resolution sonar systems is described. The purpose of the simulation is to permit systematic examination of the effects of first-order parameter variations on sonar image quality and target detection capability. The model permits specification of the major parameters such as height above bottom, bottom reflectivity, projector power and directivity function, receiver array geometry, number of receiver elements, shading detection bandwidth, and display characteristics. Details of the model and

20.

representative simulated displays for various sonar parameter combinations are presented.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

(Reverse Page ii Blank)

INTRODUCTION

High resolution sonar systems are used for bottom mapping, small object location, and other underwater tasks requiring high quality images. The term *high resolution sonar* is used here to describe systems operating in the frequency range of 100 kHz and greater, with beamwidths of less than 2 degrees and range resolution of better than 1 metre. Unfortunately, most theoretical, high resolution sonar design and performance evaluations are based on solution of the "sonar equation," and many important phenomena are not considered when only energy relationships are evaluated. Examples are: the relative importance of sidelobe levels and sonar beamwidth, display dynamic range, and range resolution.

The work presented here is the result of a preliminary investigation of advanced simulation of high resolution sonar systems and the operating environment. The purpose of this basic model is to demonstrate the feasibility and versatility of such a computer simulation and to provide a foundation for a more detailed model.

The major elements of the model are the target area, the projector-hydrophone arrays, the beamformer, and the display. A schematic of the simulation concept is shown in Figure 1. The target area is modeled by defining a reflectivity amplitude and phase for incremental elements within the target region. The projector array is modeled by describing a line array length in coordinates of the array center. The hydrophone array is modeled by a number of discrete elements of finite length and a three dimensional coordinate for each element. The beamformer is modeled as either an FFT algorithm using outputs of the discrete hydrophone elements as inputs, or as a convolution of the hydrophone array spatial impulse response with a target reflectivity distribution. The display is driven by a mini-computer which can be programmed to scale, expand, or compress image data as desired.

TARGET ECHO SIMULATION

The geometry of the target and array simulation is shown in Figure 2. The target area is modeled by defining a reflectivity amplitude and phase

(Text Continued on Page 3)

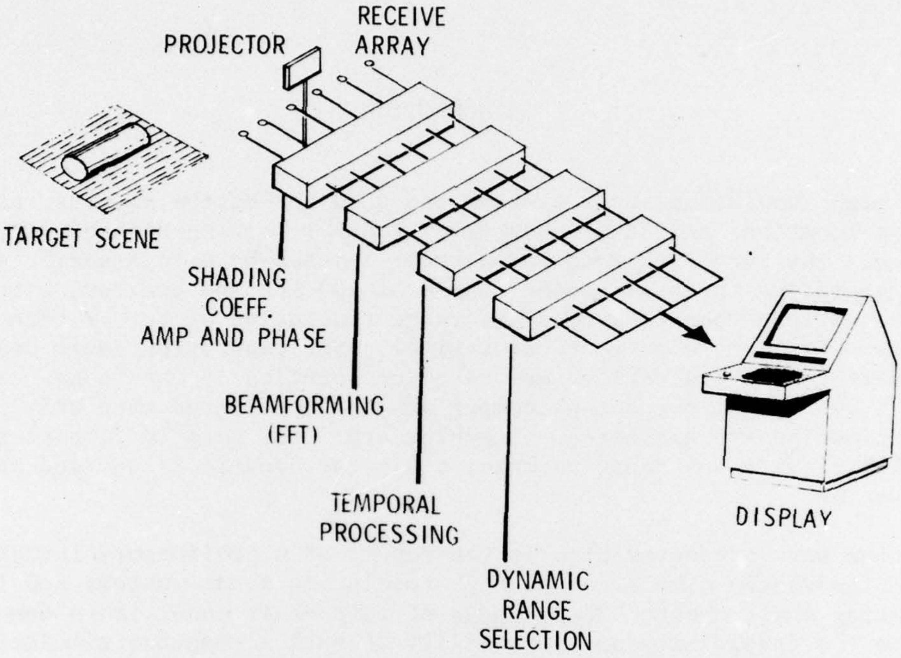


FIGURE 1. BASIC ELEMENTS OF SONAR SIMULATION

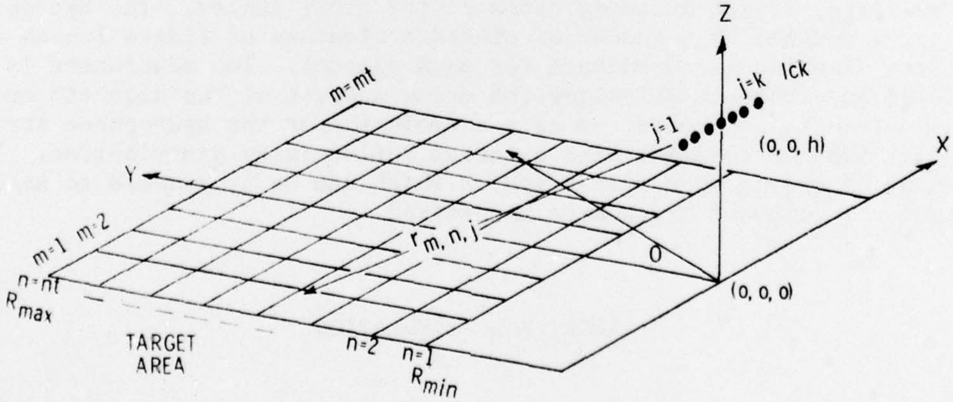


FIGURE 2. GEOMETRY OF SONAR TARGET AND ARRAY SIMULATION

for incremental elements within the target region. These arrays are designated $T_A(m,n)$ and $T_p(m,n)$ for the amplitude and phase components, where (m,n) represent coordinate points in the target area. Empirical data were used to establish echo levels from various bottom types as a function of frequency, grazing angle, and bottom type such as sand, mud, etc.; however, the statistics of this reverberation are not well defined. Therefore, a random number procedure with only upper and lower bounds specified was used to fill the target arrays with the background amplitude. Background amplitude numbers were in the range 0.05 to 0.2 and the target amplitude numbers in the range 0.5 to 1.0. Phases were taken as constant or random from 0 to π.

The projector is modeled by assuming a line array length L_p positioned at a point $(0,0,h)$. The directional response of the projector array is computed by

$$P_A(\theta) = \sin(\pi(L_p/\lambda) \sin \theta)/(\pi(L_p/\lambda) \sin \theta)$$

$$P_p(\theta) = \mathrm{sgn}(P_A(\theta)) \qquad (1)$$

where θ is measured from the origin with respect to the y axis, and λ is the wavelength. The letters sgn $(P_A(\theta)$ denote the signum function and is +1 if $P_A(\theta) \geq 0$, -1 if $P_A(\theta) < 0$. By using Equation (1), the assumption is made that the target area is in the projector far field; i.e., $R_{max} > L_p^2/\lambda$, where range R is measured from the origin and is given by $R = (x^2 + y^2)^{\frac{1}{2}}$. The complex amplitude, A_t, reflected from a target point as measured in the plane of the target, is given by

$$A_t(m,n) = \frac{T_A[m,n] \mid P_A(\theta) \mid}{r_p} 10^{-\left(\frac{r_p \cdot \alpha - S_p}{20}\right)} e^{-i\left(\frac{2\pi}{\lambda} r_p + P_p(\theta)\right)} \qquad (2)$$

where θ_p is the slant range from projector center to target point, α is absorption coefficient in dB/unit distance, and S_p is the projector source level in dB.

TARGET ECHO PROCESSING

Echo processing simulation includes sonar beamforming and the effects of a finite pulse length. Included are the parameters of the hydrophone, aperture apodization or shading, FFT characteristics, pulse shape, and display characteristics.

The receive hydrophone is modeled by assuming k number of elements each of receiving length ℓ_h, and center-to-center separation, s_h. The total length L_h of the hydrophone is given by $L_h = k \cdot s_h + \ell_h$.

Discrete elements of finite length are assumed so the reflected wavefront may be properly sampled and beamforming may be simulated using a Fourier Transform algorithm. Focusing may be accomplished by placement of element coordinates to achieve array curvature.

The complex amplitude, $A_h\,(n,j)$, output of a discrete element j resulting from returns from reflectors in target row n may be computed as

$$A_h(n,j) = \sum_{m=1}^{m_t} A_t[m,n]\; 10^{-\left(\frac{r_{m,n,j}\,\cdot\,\alpha}{20}\right)}\; e^{-i\left(\frac{2\pi}{\lambda}\, r_{m,n,j}\right)} \qquad (3)$$

where $r_{m,n,j}$ is the slant range from target element (m,n) to hydrophone element j.

In many systems, aperture apodization or shading is used to reduce sidelobe (first diffraction order) levels(1). Shading is accomplished normally by amplitude shading, but any complex operation on the outputs of discrete elements may be simulated by multiplying $A_h(j)$ by the appropriate complex function $S_h(j)$.

Beamforming is accomplished by the Cooley-Tukey FFT algorithm(2). The FFT, of single dimension N, is performed using as input data one range increment n at a time. Using the values calculated for discrete transducer element outputs A_h as the input array, the operation performed by the discrete FFT operation is

$$Q[n,q] = \sum_{j=1}^{k} A_h[n,j]\; S_h[j]\; e^{-i\left(\frac{2\pi kq}{N}\right)} \qquad (4)$$

where Q is a complex number representative of the beamformer output. In the computer model the complex value of Q is contained in the real and imaginary arrays Q_R and Q_I, each having dimension n_t x N.

Each element of the array represents a sonar beam output in the direction given by the expression

$$\theta = \arcsin\;(q \cdot \lambda/N \cdot S_h) \qquad (5)$$

where q is the q*th* array element in the FFT output and takes on values -N/2 to +N/2 .

---

(1) R. C. Hansen, *Microwave Scanning Apertures,* Vol. 1, Academic Press, New York (1964).

(2) J. W. Cooley and J. W. Tukey, *Mathematics of Computation,* Vol. 19, p. 297 (1965).

The beamforming or FFT operation is carried out separately for each target row, n. Therefore, the arrays Q_R and Q_I are two-dimensional where the parameter n is representative of range and q is representative of azimuth. To simulate a pulse echo system having a pulse length exceeding the length of incremental range elements, it is necessary to compute a running sum or convolution on Q, with a rectangular function representing the length of the pulse. If a pulse of length v incremental range units is to be simulated, the values contained in the Q arrays are modified as follows

$$Q' [n,q] = \sum_{n}^{n+v} Q[n,q] \tag{6}$$

where Q represents the results of the running sum over the pulse length v.

The image amplitude of the target region can now be written as

$$I[n,q] = (Q_R^2[n,q] + Q_I^2[n,q])^{\frac{1}{2}} . \tag{7}$$

This amplitude represents a degraded version of the target region reflectivity which has been degraded first by the impulse response of the array, and secondly by the finite pulse length. An image of the target area may be obtained by converting the numerical values in array I to density variations on photographic film or by intensity modulation on a CRT. The original and undegraded target data can be compared by translating the numerical values in array T to object amplitudes O[m,n] by

$$O[m,n] = \left| T_A e^{-i(\frac{2\pi}{\lambda} T_p[m,n])} \right| \tag{8}$$

and using these values to intensity modulate a CRT.

CONVOLUTION MODEL

The model previously described is suitable for forward-looking, multibeam sonar systems. In side-looking systems, a single beam is formed by the sonar array and is caused to scan the sea bottom by forward motion of the sonar platform. For this geometry, a model based on convolution is more suitable.

In this model, a target array is defined in Equation (1). A directional response of the projector is calculated and the complex reflectivity distribution, A_t, is determined from Equation (2). A receiving array directional response, $P_h(\theta)$, is computed from receiving array geometry or data from measured patterns are used if they are available. The beamforming process is described by the convolution of $P_h[m,n]$ and $A_t[m,n]$, where $P_h[m,n]$ is the hydrophone array response transformed to target coordinates with the response curve maximum centered at m_o. The convolution is accomplished through solution of

$$Q[m_o,n] = \sum_m A_t[m,n]\; P_h[m-m_o,n] \tag{9}$$

where $[m_o,m]$ represents the image of the point m_o in the target area. This summation must be carried out for each of the points (m,n) in the target array. The results of this calculation are stored in arrays Q_R and Q_I, and pulse length effects can be simulated by Equation (6). The image is then described by Equation (7).

APPLICATION OF SONAR MODELS

A simulation was made of a sonar target configuration to demonstrate the results of applying the FFT model:

$m_t = 60$, $n_t = 40$, $N = 128$

$H = 10$ metres, $R_{min} = 20$ metres, $R_{max} = 60$ metres

$L_p = 20\lambda$

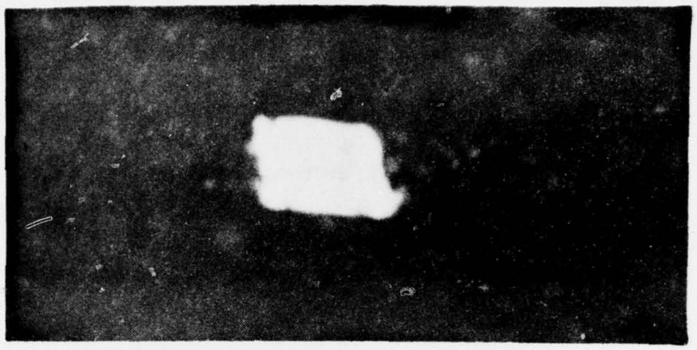
$s_h = 0.5\lambda$, $\ell_h = 0.1\lambda$, $k,v =$ variable

$0.5 < T_A < 0.2$, $0 < T_P < \pi$ (background parameters)

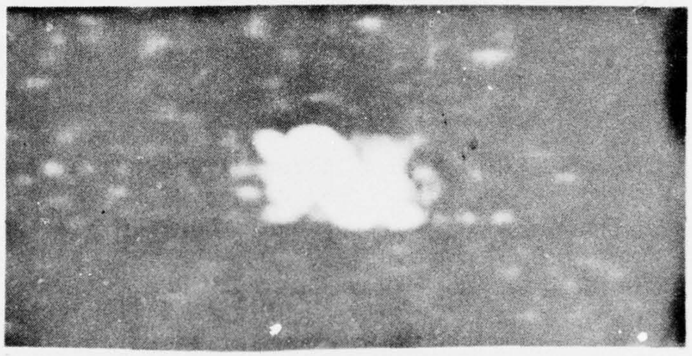
$T_A = 1$, $T_p = 0$ (target parameters) .

For the simulation results shown in Figure 3, a target of 8 x 8 metres was simulated by a reflectivity value of unity with a constant phase angle. The background was assigned a random amplitude and phase value where the amplitude was taken in the range 0.05 to 0.2 and the range of phases taken was 0 to π. Figure 3(a) illustrates the image resulting from simulating a receiving array with a beamwidth of 1.3 degrees at -3 dB and a 1-metre pulse length. Figures 3(b) and (c) show the same image assuming increases by a factor of 2 and 4, respectively, in both beamwidth and pulse length. The target area shown represents a sector coverage of 60 degrees. The target is stretched in azimuth due to the reduced effective aperture and broadened beamwidth for off-axis beams; i.e., $BW = \lambda/(L_h \sin\theta)$. Note that interference effects in this

(Text Continued on Page 8)



a. k = 86, v = 1



b. k = 43, v = 2

c. k = 21, v = 4

FIGURE 3. FFT MODEL SIMULATION

coherent sonar system can be seen in Figure 3(a) even where the target is approximately eight "beamwidths" wide. Recognition of the target as a square or rectangle is not possible in Figures 3(b) and 3(c) because of the loss of sharp edge information, although target detection is obviously possible.

The receiving and projector directional responses shown in Figure 4 were used in simulating the convolution model. Target information is given in the following values.

$n_t = 64$, $m_t = 256$

$h = 10$ m, $R_{min} = 106.5$, $R_{max} = 110$ m

$0 < T_A < 1.0$, $T_p = 0$; background parameters

$0.7 < T_A < 1.0$, $T_p = 0$; target parameters

The dimensions of each of the three targets were 30 by 96 cm. The -3 dB beamwidth of the receive directional response was approximately 20 cm.

Figure 5 illustrates the effect of using the directional response (curve b) of Figure 4 with range resolution of 6, 12, and 24 cm, respectively.

Figure 6 illustrates the effect of using the directional response (curve a) of Figure 4 with range resolution of 6 and 12 cm respectively.

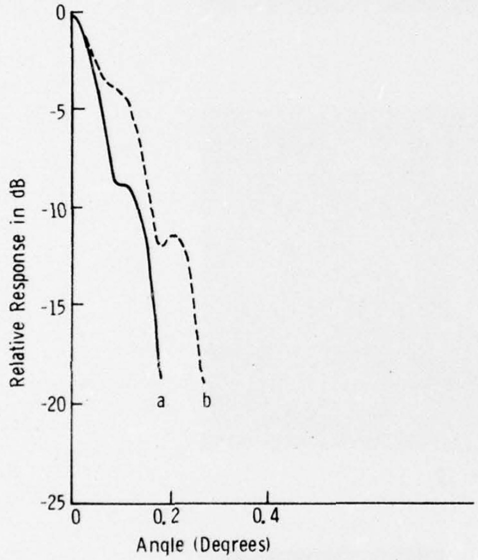
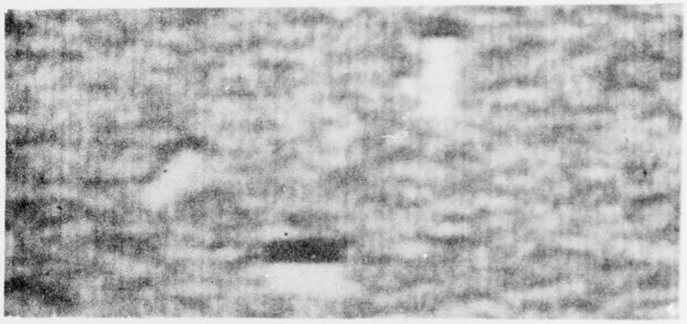


FIGURE 4. DIRECTIONAL RESPONSES USED IN CONVOLUTION MODEL SIMULATION

CONCLUSIONS

The effects of beamshape and pulse length can be observed in the target images. Subtle degrading effects, difficult to express mathematically, are observed as range resolution is degraded and as sidelobe levels are increased. It is conceded that the image is "fuzzier" or defocused as these degrading effects are applied. This obviously is due to the absence of sharp gradients in the degraded image. Though these effects can be observed subjectively, it remains to establish criteria for "adequacy" of resolution for detection of specific object shapes in the presence of the reverberation.

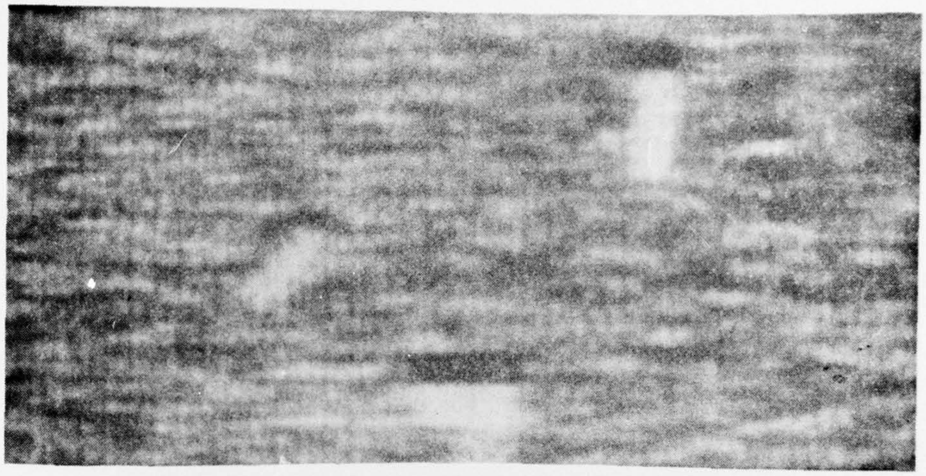
a. Range resolution of 6 cm



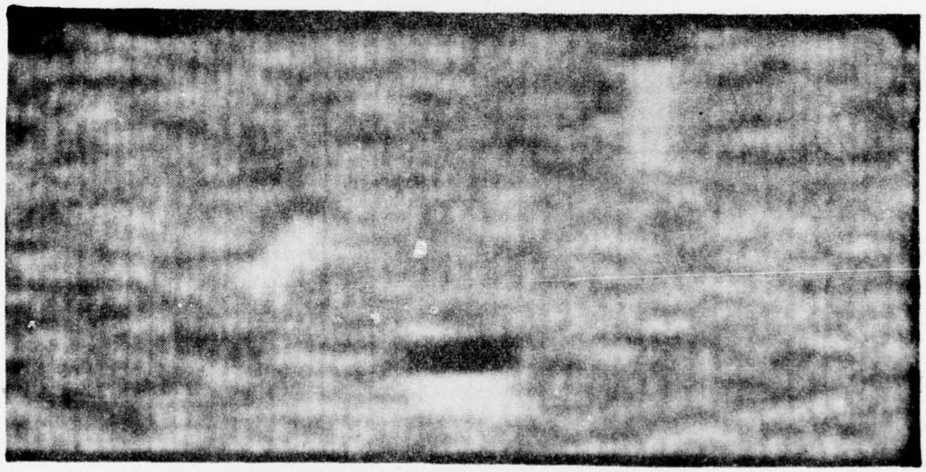
b. Range resolution of 12 cm

c. Range resolution of 24 cm

FIGURE 5. CONVOLUTION MODEL SIMULATION DIRECTIONAL RESPONSE OF CURVE (b) OF FIGURE 4



a. Range resolution of 6 cm



b. Range resolution of 12 cm

FIGURE 6. CONVOLUTION MODEL SIMULATION DIRECTIONAL RESPONSE OF CURVE (a) OF FIGURE 4