Professional Development Short Course On:

Developments in Mine Warfare

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Developments in Mine Warfare

Course Outline

INTRODUCTION. Mine countermeasures doctrine. Where are the mines? What else should be measured/and the sensing means. (There is a large appendix that expands upon most of the items discussed and contains additional example of hardware.)

MINEHUNTING ENVIRONMENT AND NON-ACOUSTIC SENSORS. Review of the general oceanic environment as it relates to magnetic, optic, and acoustic sensors. Items considered are ambient noise, bottom backscattering, absorption, and simple examples of propagation. Non-acoustic sensors utilizing various magnetic methods of different sensitivities and examples of hardware. Ambient light and illumination techniques and sensing using cameras scanning lasers as well as lidar methods with examples of hardware.

BASIC ACOUSTICAL RELATIONSHIPS. Definition of acoustical terms and relationships of underwater acoustics using different modes of operation with emphasis on minehunting. Fundamentals of various sonar techniques including side looking, forward looking, nonlinear, bathymetric, CTFM, and mammal sonars. Echo, passive, shadow and sub-bottom modes will be considered. Transducer relationships, including near-field and farfield, beamforming using a single scanning beam and multiple beamforming methods will be considered. Design considerations are introduced for the conventional side looking sonar as well the synthetic aperture sonar. Examples are given of nonlinear sonar as well as a sub-bottom detection system.

TARGET CHARACTERISTICS. Characteristics of various targets are covered as well as the formation of echo structure including means of extracting target information. .

PLATFORM NOISE AND DOMES. Consideration of platform noise and individual component noise. Specific examples of vehicle noise. Helicopter noise in the ocean. Dome use and related materials for dome use.

SIGNAL PROCESSING. Consideration of signal processing initially using simple pulse operation. Detection threshold and the ambiguity function are examined. An example of utilizing the target echo structure to detect shape parameters is given. Human aural signal processing is discussed using a dolphin-like signal.

NAVIGATION. Acoustic navigation techniques involving pingers, markers, localized transponders are considered. Long and ultra-short baseline methods are introduced as well as Doppler navigation sonar. Electromagnetic methods such as parabolic, range-range, azimuthal systems are reviewed including the GPS.

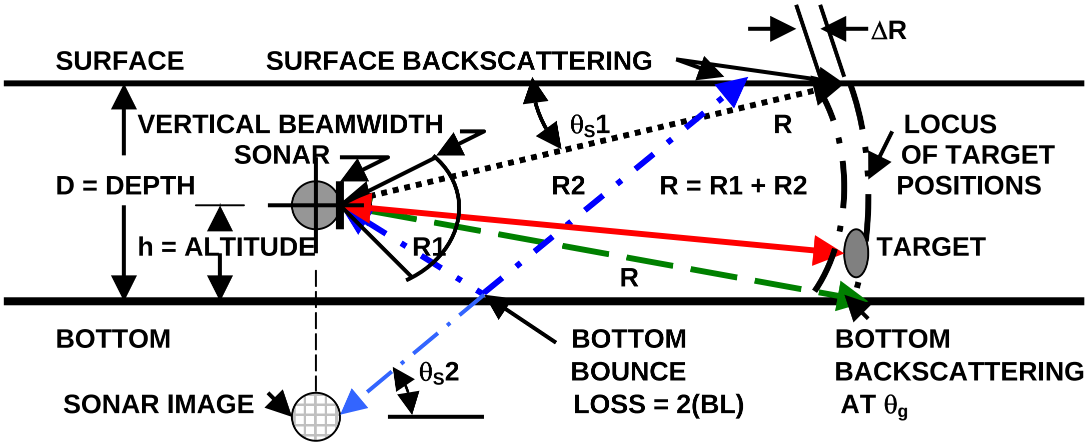
NEUTRALIZATION. Mine neutralization and removal techniques are considered as well as the means used to approach the mines. Approach methods consider divers with hand-held sonars, ROVs, tethered and untethered vehicles as well supercavitating projectiles.

MINEHUNTING SONAR SYSTEMS. Conventional U.S. surface MCM systems and systems associated with organic assets are reviewed. The U.S. Mine Countermeasures Marine Mammal Systems are considered. Some examples of newly developed MCM systems are given including a newly integrated MCM/Stealth system.

EXAMPLE OT THE USE OF SONAR EQUATIONS IN ESTIMATING SONAR PERFORMANCE.

AN EXAMPLE OF THE USE OF THE SONAR EQUATIONS IN ESTIMATING SONAR PERFORMANCE

THIS EXAMPLE WILL USE THE ECHO MODE (SEE “BASIC ACOUSTICAL RELATIONSHIPS – 1 AND –5”). THE SENSOR IS A FORWARD LOOKING SONAR (FLS) IN THE ENVIRONMENT SHOWN BELOW WITH THE VARIOUS SOUND PATHS OF CONCERN INDICATED.



THE ECHO LEVEL (EL):

- $EL(R) = SL - 2TL + TS = SL - 40\log(R) - 2aR + TS + DF_{hv} + DF_{pv}$ (1)

  WHERE DF_{hv} AND DF_{pv} ARE THE RESPECTIVE HYDROPHONE AND PROJECTOR VERTICAL DIRECTIVITY FUNCTIONS. RANGE WILL BE RECKONED FROM THE BOTTOM TO ESTABLISH A GRAZING ANGLE RELATIONSHIP. THEREFORE, EL AS A FUNCTION OF θ_g IS

- $EL(\theta_g) = SL - 40\log[h/\sin(\theta_g)] - 2a[h/\sin(\theta_g)] + TS + DF_{hv}(\theta_g) + DF_{pv}(\theta_g)$ (2)

THE INTERFERENCE LEVELS ($RL_{V.B.S}$ AND NL):

- **VOLUME REVERBERATION (RL_V) IS IGNORED HERE IN VIEW OF ITS SMALL BACKSCATTERING STRENGTH (S_V OF ABOUT –70 dB/m^3 AND LESS), BUT IT SHOULD BE CONSIDERED IN ANY DETAILED ANALYSIS.**

- **BOTTOM REVERBERATION (RL_B) AS A FUNCTION OF θ_g:**
  - $RL_B(\theta_g) = SL - 40\log[h/\sin(\theta_g)] - 2a[h/\sin(\theta_g)] + TS_B(\theta_g) + DF_{hv}(\theta_g) + DF_{pv}(\theta_g)$ (3)

WHERE $TS_B(\theta_g) = 10 \log\{[(h/\sin(\theta_g)](\beta_{hh})[\Delta R/\cos(\theta_g)]\} + S_B(\theta g)$ (4)

WHICH IS AN APPROXIMATION PROVIDING θ_g IS NOT CLOSE TO 90°.

- **DIRECT SURFACE REVERBERATION (RL_{DS}) AS A FUNCTION OF θ_g:**
  - **$RL_{DS}(\theta_g) = SL - 40 \log[h/\sin(\theta_g)] – 2a[h/\sin(\theta_g)] + TS_S(\theta_S 1)+ DF_{hv}(\theta_S 1)+ DF_{pv}(\theta_S 1)$ (5)**

WHERE $TS_{DS}(\theta_S 1) = 10 \log\{[(h/\sin(\theta_g)](\beta_{hh})[\Delta R/\cos(\theta_S 1)]\} + S_B(\theta_S 1)$ (6)

AND $\theta_S 1 = \sin^{-1}\{[(D – h)\sin(\theta_g)]/h\}$ (7)
WHERE THE MAXIMUM BOTTOM GRAZING ANGLE FOR INTERFERENCE BY THE DIRECT SURFACE RETURN IS
$\theta_{gmax}1= \sin^{-1}[h/(D – h)]$ (8)
FOR $h \leq D/2$.

- **BOTTOM-SURFACE-BOTTOM REVERBERATION (RL_{BSB}) AS A FUNCTION OF θ_g:**
  - **$RL_{BSB}(\theta_g) = SL - 40 \log[h/\sin(\theta_g)] – 2a[h/\sin(\theta_g)] + TS_{BSB}(\theta_S 2) + 2(BL) + DF_{hv}(\theta_g)+ DF_{pv}(\theta_g)$ (9)**

WHERE $TS_{BSB}(\theta_S 2) = 10 \log\{[(h/\sin(\theta_g)](\beta_{hh})[\Delta R/\cos(\theta_S 2)]\} + S_B(\theta_S 2)$ (10)

AND $\theta_S 2 = \sin^{-1}\{[(D + h)\sin(\theta_g)]/h\}$ (11)
WHERE THE MAXIMUM BOTTOM GRAZING ANGLE FOR INTERFERENCE BY THE BOTTOM-SURFACE-BOTTOM RETURN IS
$\theta_{gmax}2= \sin^{-1}[h/(D + h)]$ (12)

- **THE NOISE LEVEL (NL USING N_a AND N_t FROM “THE MINE HUNTING ENVIRONMENT – 4”) (SELF NOISE OF THE SONAR CAN BE IMPORTANT AND MUST BE USED, IF MEASURED. PLATFORM NOISE, IS NOT CONSIDERED HERE BECAUSE IT IS RARELY A KNOWN):**
  - **$NL = 10 \log[10^{(0.1Na)} + 10^{(0.1Nt)}]$ (13)**
- **THE COMBINED SURFACE BACKSCATTERING COEFFICIENT (S_{SS} USING THE S_S VALUES FROM “THE MINE HUNTING ENVIRONMENT – 4”. LET $S_S 1$ AND $S_S 2$ BE THE SURFACE AND HIGH GRAZING ANGLE SURFACE BACKSCATTERING COEFFICIENTS):**
  -
  - **$S_{SS} = 10 \log[10^{(0.1Ss1)} + 10^{(0.1Ss2)}]$ (14)**

BOTTOM BOUNCE LOSS (BL) AS A FUNCTION OF θ_g (MACKENZIE)

- $BL(\theta g) = -10\log\{[(h_r - \sigma\sin(\theta_{VS}))^2 + g^2]/[(h_r + \sigma\sin(\theta_{VS}))^2 + g^2]\}$ (15)

WHERE $h_r = [B_r + (A_r^2 + B_r^2)^{1/2}]^{1/2}$,

$g = [-B_r + (A_r^2 + B_r^2)^{1/2}]^{1/2}$,

$A_r = \alpha/\beta = \alpha v_2/2\pi f$ AND $B_r = (1/2)[1- (\cos(\theta_{VS})/n_r)^2 - (\alpha/\beta)^2]$,

n_r = ACOUSTIC INDEX OF REFRACTION = c_1/v_2, $|v_2|$ IS CONSIDERED PRACTICALLY AS THE USUAL SEDIMENT SEDIMENT SOUND SPEED, c_2,

α = ATTENUATION IN nepers/m (1 neper = 8.686 dB) IN THE SEDIMENT,

f = FREQUENCY, IN Hz,

σ = IMPEDANCE RATIO = $(\rho_2 v_2)/(\rho_1 c_1)$, WHERE ρ_1 AND ρ_2 ARE DENSITIES OF WATER AND BOTTOM, IN g/cc AND c_1 AND v_2 ARE SOUND SPEEDS OF WATER AND SEDIMENTS IN m/sec,

θ_{VS} = VERTICAL ANGLE WHICH IS THE SAME AS THE SURFACE GRAZING, AND

$\beta = \alpha/A_r$.

FOR THIS EXAMPLE, THE FOLLOWING LIST OF PARAMETERS WILL BE ASSUMED:

1. FREQUENCY (f IN kHz):	100
2. SOURCE LEVEL (SL IN dB//1μPa/m):	220
3. PULSE DURATION (T_P, IN μs):	100
4. TRANSDUCERS (ONLY THE DIRECTIVITY, FUNCTIONS USED IN THE CALCULATIONS ARE SHOWN AS FIGURES)	
CYLINDRICAL PROJECTOR:	
VERTICAL BEAMWIDTH (β_{pv}°)(FIG.1):	20
HORIZONTAL BEAMWIDTH ((β_{ph}°)	90
LINEAR HYDROPHONE:	
VERTICAL BEAMWIDTH (β_{hv}°)(FIG. 2):	30
HORIZONTAL BEAMWIDTHS (β_{hh}°)(FIG.3)	1.0/1.4
5. RECEIVING BANDWIDTH (BW IN kHz):	10
6. DETECTION THRESHOLD (FROM “SIGNAL PROCESSING – 2” FOR P_{DA} = 0.9 AND $P_{FA} = 10^{-4}$) (DT IN dB):	11.7
7. SONAR MEASURED SELF-NOISE (dB//μPa/√Hz)	50
8. ENVIRONMENTAL:	
WATER DEPTH (D IN m):	50
SONAR HEIGHT OVER THE BOTTOM (h IN m):	25
MEDIUM: SEA STATE:	3

TEMPERATURE (T IN °C):	**8**
SALINITY (S IN ppt):	**35**
HYDROGEN ION ACTIVITY (pH):	**8.1**
USING “MINE HUNTING ENVIRONMENT – 6”	
AND THE ABOVE VALUES,	
SOUND VELOCITY (c IN m/s):	**1470**
ABSORPTION (a IN dB/m):	**0.034**
BOTTOM SEDIMENT (FIG. 4):	**SAND**
PLATFORM:	**ROV**
MINE TARGET STRENGTH (dB):	**-20**

FIGURES RELATING TO THE SONAR AS WELL AS THE ENVIRONMENTAL DATA ARE SHOWN BELOW. THE CAPTIONS RELATE THE FIGURES TO THE FOREGOING DATA AND RELATIONSHIPS.

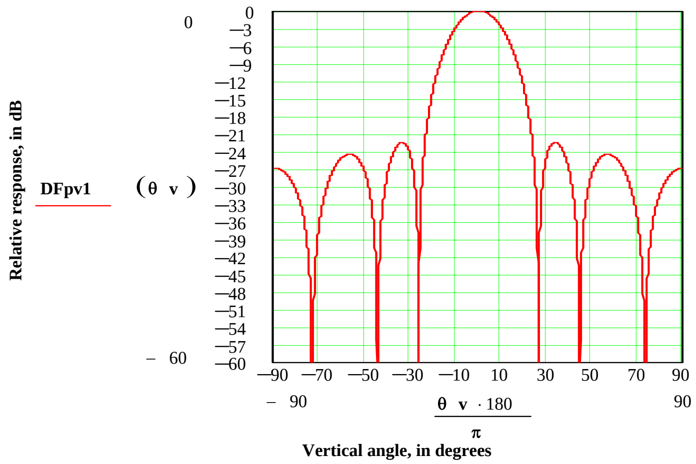


FIG. 1. PROJECTOR SHADED VERTICAL-PATTERN RESPONSE WITH NO VERTICAL STEERING. THE BEAMWIDTH IS 20.0^{o} AND THE SIDELOBE LEVEL IS -22.6 dB.

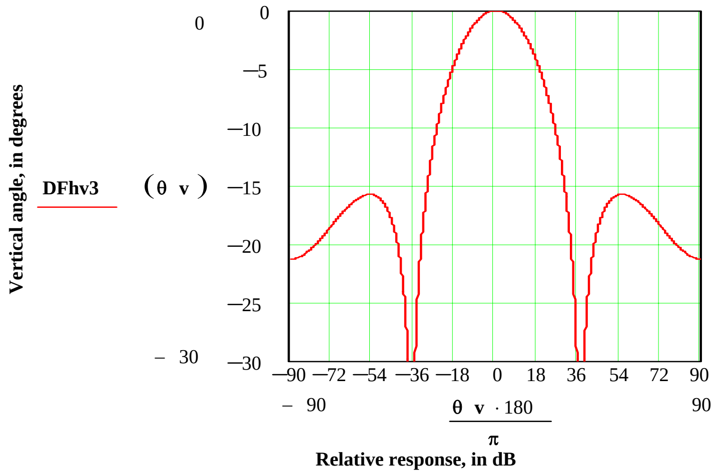


FIG. 2. HYDROPHONE SHADED VERTICAL DIRECTIVITY FUNCTION. THE BEAMWIDTH IS 30° AND THE SIDELOBE LEVEL IS –15 dB.

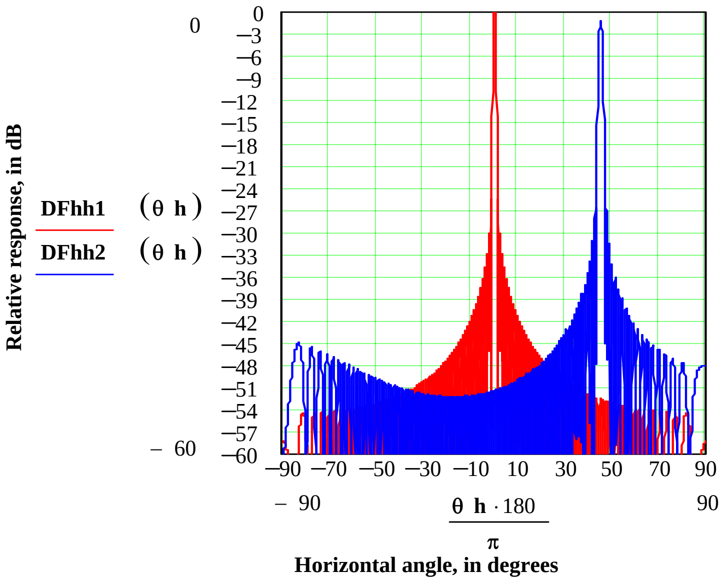


FIG. 3.HYDROPHONE SHADED AND PREFORMED HORIZONTAL DIRECTIVITY FUNCTION WITH NO STEERING AND WORST-CASE 45° HORIZONTAL STEERING. FOR THE LINEAR HYDROPHONE, THE BEAMWIDTH IS 1.4° AND THE SIDELOBE LEVEL IS -25.9 dB. AT THE 45° STEERING ANGLE, THE RESPONSE OF THE BEAM IS DOWN 1.2 dB.

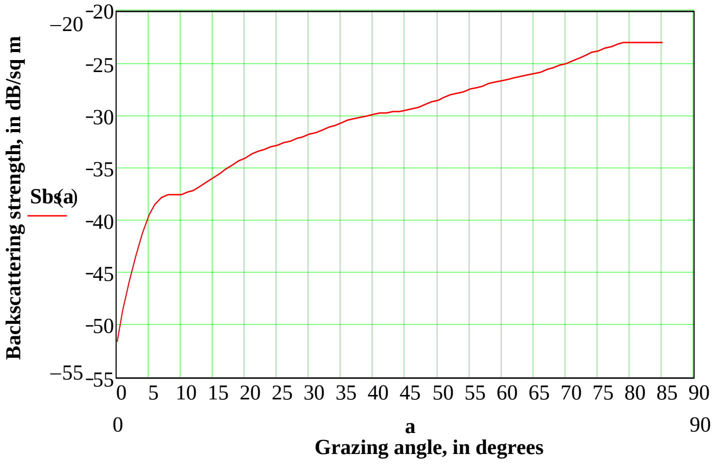


FIG. 4. BOTTOM BACKSCATTERING COEFFICIENTS FOR THE SAND BOTTOM AT 100 kHz.

IN ALL THE CALCULATIONS, THE VERTICAL DIRECTIVITY FUNCTIONS FOR BOTH THE PROJECTOR AND HYDROPHONE, FIGS. 1 AND 2, RESPECTIVELY, WERE USED TO ACCOUNT FOR THE TRANSDUCER RESPONSES WITH CHANGING VERTICAL ANGLES.

USING EQUATION (2), WITH TS = -20 dB, THE ECHO LEVEL WAS COMPUTED AND PLOTTED (SHOWN LATER). NOTE THAT THE TARGET WAS ASSUMED TO BE ON THE BOTTOM AND WAS MOVED IN POSITION TO ALWAYS BE AT THE GRAZING ANGLE θ_g AS IT DECREASED WITH INCREASING RANGE.

FOR ALL REVERBERATION CALCULATIONS, THE STEERED HYDROPHONE HORIZONTAL BEAM AT THE HORIZONTAL SECTOR EDGES ($\theta_h = \pm 45°$) WAS TAKEN AS A WORST-CASE CONDITION. THIS WAS DONE BECAUSE THE HYDROPHONE IS LINEAR AND THE WIDEST HORIZONTAL BEAMWIDTH WAS DESIRED. THE HYDROPHONE HORIZONTAL BEAMWIDTHS ARE SHOWN IN FIG. 3.

USING EQUATION (3), THE BOTTOM REVERBERATION WAS COMPUTED AND PLOTTED (SHOWN LATER). FOR THE SAND BOTTOM BACKSCATTERING STRENGTH VERSUS θ_g, FIG. 4 WAS USED.

WHEN BACKSCATTERING FROM THE SEA SURFACE WAS INVOLVED, IT WAS NECESSARY TO COMPUTE THE SURFACE BACKSCATTERING COEFFICIENTS, S_S, VERSUS GRAZING ANGLE WITH THE SURFACE, θ_s. THIS INFORMATION WAS REQUIRED FOR BOTH THE DIRECT SURFACE AND BOTTOM-SURFACE-BOTTOM MULTIPATH REVERBERATION LEVELS OF EQUATIONS (5) AND (9), RESPECTIVELY. A COMBINED SURFACE BACKSCATTERING COEFFICIENT WAS COMPUTED USING EQUATIONS (14) AND (15). IN ADDITION, THE BOTTOM BOUNCE LOSS USING EQUATION (15) WAS REQUIRED FOR THE BOTTOM-SURFACE-BOTTOM MULTIPATH. THE RESULTS OF THE COMPUTATIONS FOR THE SURFACE BACKSCATTERING AND THE BOTTOM BOUNCE LOSS ARE SHOWN IN FIGS. 5 AND 6, RESPECTIVELY. THE PLOTS FOR THE DIRECT SURFACE AND BOTTOM-SURFACE-BOTTOM REVERBERATION LEVELS WILL BE SHOWN LATER.

NOTE THAT THE SURFACE BACKSCATTERING IS FREQUENCY SENSITIVE UNTIL THE SURFACE GRAZING ANGLE, θ_s, GETS LARGE IN THE REGION OF THE HUMP IN THE CURVE IN FIG. 5.

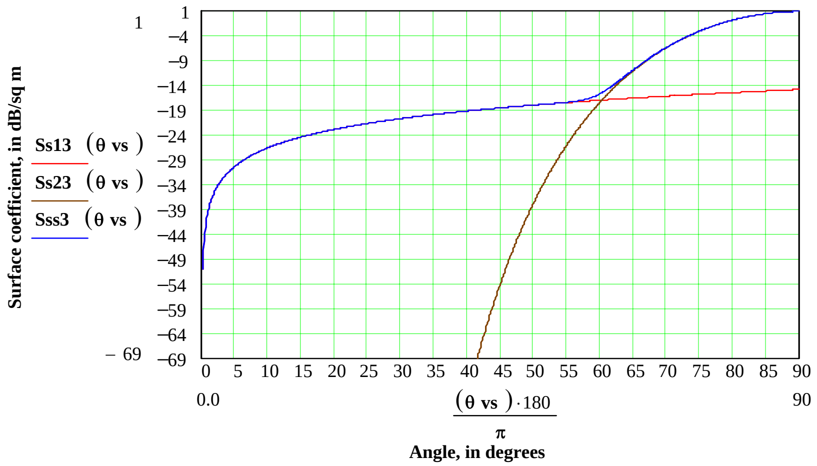


FIG. 5. SURFACE REVERBERATION COEFFICIENTS FOR THE CHAPMAN-HARRIS (C&H), CHAPMAN-SCOTT WITH COX-MUNK (CSCM) RELATIONSHIPS AND THEIR POWER SUM (PS) FOR SEA STATE 3 AND 100 kHz. THE CURVE THAT STARTS AT THE SMALL GRAZING ANGLES AND SLOWLY APPROACHES –14 d B, IS THE FREQUENCY SENSITIVE C & H BACKSCATTER, THE CURVE STARTING ABOUT 41° IS THE FREQUENCY INSENSITIVE CSCM RELATIONSHIP. THE HUMP IN THE PLOT IS THE POWER SUN OF THE TWO CURVES.

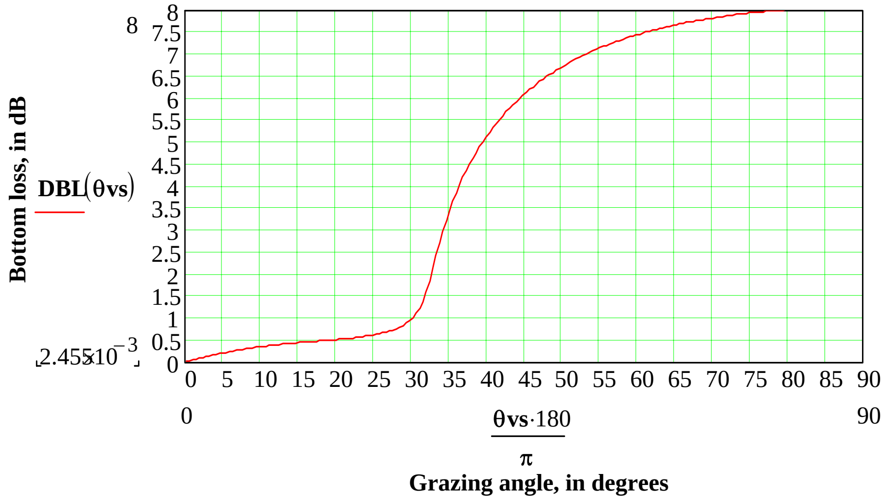


FIG. 6. BOTTOM LOSS COEFFICIENT FOR SAND SEDIMENT USING THE FOLLOWING CHARACTERISTICS: c_1 = 1480 m/sec, c_2 = 1749 m/sec, ρ_1 = 1026 kg/m^3, ρ_2 = 2003 kg/m^3, AND a = 5.52 nepers/m AT 100 kHz.

THE CURVES FOR THE VARIOUS REVERBERATION LEVELS AS WELL AS THE ECHO LEVEL AND SONAR NOISE PLUS DT ARE ALL SHOWN IN FIG. 7.

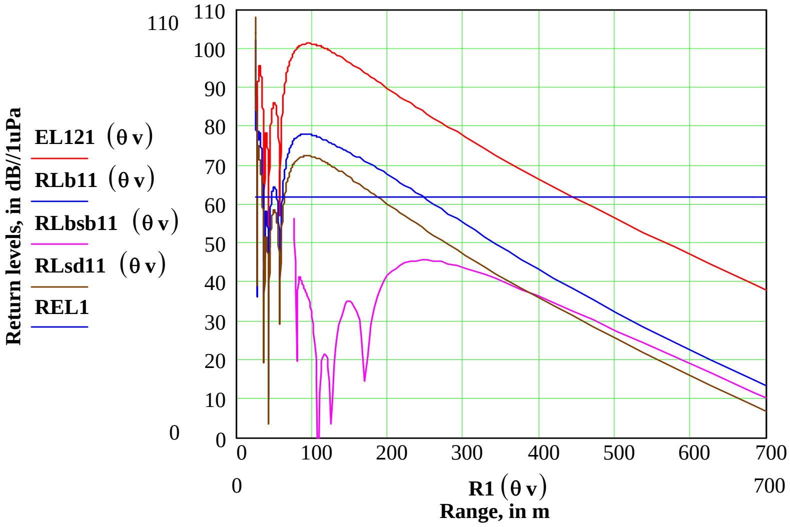


FIG. 7. CURVES FROM TOP TO BOTTOM (IGNORING THE HORIZONTAL SONAR NOISE PLUS DT) AT A RANGE OF 200 m ARE ECHO LEVEL AND REVERBERATIONS FROM THE BOTTOM, DIRECT SURFACE, AND BOTTOM-SURFACE-BOTTOM. NOTE THAT THE ALTITUDE OF h = D/2 HELPS TO REDUCE THE BOTTOM-SURFACE-BOTTOM REVERBERATION LEVEL.

WITH HYDROPHONE AT 45^o HORIZONTAL BEAM STEERING AND NO PROJECTOR STEERING, FIG. 8 SHOWS THE SIGNAL-TO-NOISE RATIOS (SN, IN

dB) FOR THE POWER SUM OF BOTTOM REVERBERATION (RL_b), DIRECT SURFACE REVERBERATION (RL_{sd}), MULTIPATH SURFACE REVERBERATION (RL_{bsb}) AND THE SONAR MEASURED NOISE, ALL SUBTRACTED FROM THE ECHO LEVEL (EL) ARE SHOWN FOR h = 25 m. THE DATA RELATING TO THE FIGURE ARE f = 100 KHz, SL = 220 dB//1μPa/m, DT = 11.7 dB, SEA STATE 3, a = 0.032 dB/m, $\beta_{pv} = 20^o$, $\beta_{hh} = 1.4^o$ DUE TO STEERING, $\theta_{vo} = 0$ (NO PROJECTOR VERTICAL STEERING), $\theta_h = 45^o$ (HORIZONTAL HYDROPHONE STEERING), ΔR = 0.074 m, AND A SAND BOTTOM. THE INTERSECTION OF THE TWO CURVES INDICATES A MAXIMUM RANGE OF 446 m UNDER THE ASSUMED CONDITIONS.

THE RESULTS OF THE ANALYSIS ARE REPRESENTED BY FIG. 8, WHICH SHOWS THE SIGNAL-TO-NOISE RATIO, IN dB, VERSUS RANGE

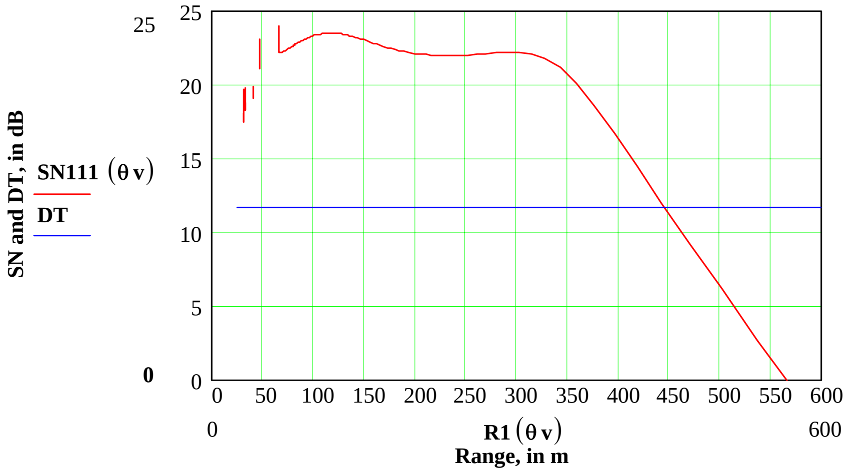


FIG. 8. SIGNAL-TO-NOISE RATIO AND DT VERSUS RANGE.

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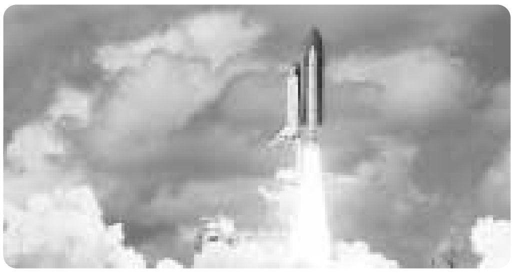

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