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AD NUMBER

AD018389

CLASSIFICATION CHANGES

TO: unclassified

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LIMITATION CHANGES

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NRL ltr, 7103/128, 12 Nov 96; NRL ltr,
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NRL Report 4225

**MEASUREMENTS OF SOUND TRANSMISSION
LOSS AT LOW FREQUENCIES 1.5 TO 5 KC**

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Propagation Branch
Sound Division

September 23, 1953



NAVAL RESEARCH LABORATORY
Washington, D C.

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ABSTRACT

Sound transmission loss was measured in surface-bounded channels, over reciprocal paths southeast of Long Island 10 to 20 November, 1952. Sound pulses were used on frequencies of 1.5, 2, 2.5, 3, 4, and 5 kilocycles. Results show a decreasing transmission loss with decreasing frequency, or an average of half a decibel per kiloyard less loss for 1.5 kc as compared to 5 kc. Observed leakage out of the channel was dependent upon channel depth, sea state, and frequency. Measurements of bottom reflection loss showed a very small dependence on frequency and incident angle. For a source within the channel, the greatest concentration of sound energy was found to be in the upper fifty feet of the channel at long ranges. Shallow water measurements showed a small increase of transmission loss over surface-bounded channels in deep water.

PROBLEM STATUS

This is an interim report on one phase of the continuing problem of Ocean Sound Propagation.

AUTHORIZATION

NRL Problem S02-03
RDB Project NR 522-030

Manuscript received July 17, 1953

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MEASUREMENTS OF SOUND TRANSMISSION LOSS AT LOW FREQUENCIES 1.5 TO 5 KC

INTRODUCTION

The success attained with an experimental 10-kc long-range search sonar system has led to a study of echo-ranging possibilities at lower frequencies. As a part of this study, measurements of transmission loss in surface-bounded channels and by way of the bottom-reflected path were made at six frequencies, 1.5, 2, 2.5, 3, 4, and 5 kc in the period 10 to 20 November, 1952. This paper is a report of experimental procedures and the results obtained. Average values for transmission loss, channel leakage, bottom reflection loss, and the distribution of sound energy in and below the channel are reported.

EQUIPMENT

Duplicate equipments were installed in the USS ALLEGHENY (ATA-179) and the FWSS ALBATROSS to permit measurements over reciprocal paths. Figure 1 is a block diagram of the basic equipment. In each ship, equipment consisted of a 1-kw driver and a cylindrical barium titanate transducer, 5 inches in diameter, inside which was housed a depth gage. A manually operated pulser actuated transfer relays, and simultaneously transmitted sonar and radio pulses. Upon completion of a transmitted pulse, relays returned both sonar and radio equipment to the receive condition. The use of crystal-controlled oscillators insured close frequency tolerance for transmission and for the calibration of receiving equipment. Receiving equipment consisted of a 30-cycle-bandwidth, fixed-tuned receiver whose outputs were processed through a logarithmic amplifier, a rectifier, and a dc amplifier, and then recorded on one channel of a Brush pen-and-ink recorder. The other channel was used to record radio pulses. This procedure made possible a continuous record of the transit time of sonar pulses, and therefore indirectly the distance between ships. Transducers were equipped with 500 feet of cable and were lowered over the side to any desired depth.

The beam pattern of the transducers was essentially omnidirectional. Maximum source levels obtained at each frequency were as follows:

5.0 kc - 87 db vs. 1 μ bar at 1 yard

4.0 kc - 81 db vs. 1 μ bar at 1 yard

3.0 kc - 78 db vs. 1 μ bar at 1 yard

2.5 kc - 77 db vs. 1 μ bar at 1 yard

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2.0 kc - 74 db vs. 1 μ bar at 1 yard

1.5 kc - 71 db vs. 1 μ bar at 1 yard

The transducers were calibrated on the NRL sound barge before and after operations.

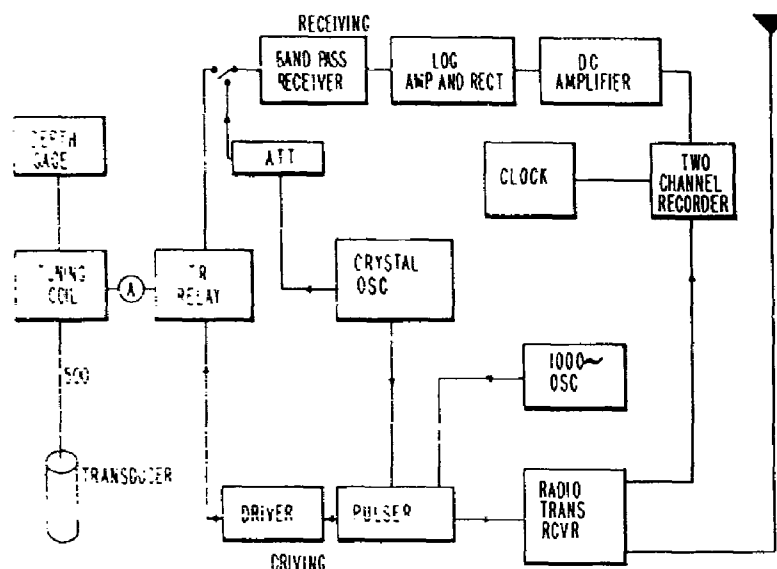


Fig. 1 - Equipment block diagram

OPERATIONS

Operations were carried out at ten locations southeast of Long Island in deep and in shallow water (Fig. 2). At each location, a short-range (750-1000 yard) calibration of equipment was made. After calibration, one ship remained on location while the other moved out in range to successive stations. The direction in which the range was opened is indicated by arrows from the locations as shown in Fig. 2. On each station groups of ten pulses at each of the six frequencies were transmitted, received, and recorded on each ship for various combinations of transducer depths. Bathythermographs, fathograms, and other oceanographic data were recorded on each location.

Figure 3 is a typical example of a data record. The record from the ALLEGHENY shows 1-second time ticks on the edge and on the recorder trace, ten outgoing pings at one frequency are shown. Nine pulses 500 ms in length were followed by a tenth pulse of 1-second duration. The long pulse indicated the end of a group of pulses and was a signal to the receiving ship to transmit a similar series. The second Brush recorder tape (Fig. 3) shows the same ten sound pulses and their corresponding radio pulses as received on the ALBATROSS. It is apparent that two sound pulses were received for each one transmitted. The first of these traveled via the channel in a direct path and the second over a longer path via the bottom. The echo following each of the transmitted pulses on the ALLEGHENY record is from the ocean bottom directly beneath the transducer.

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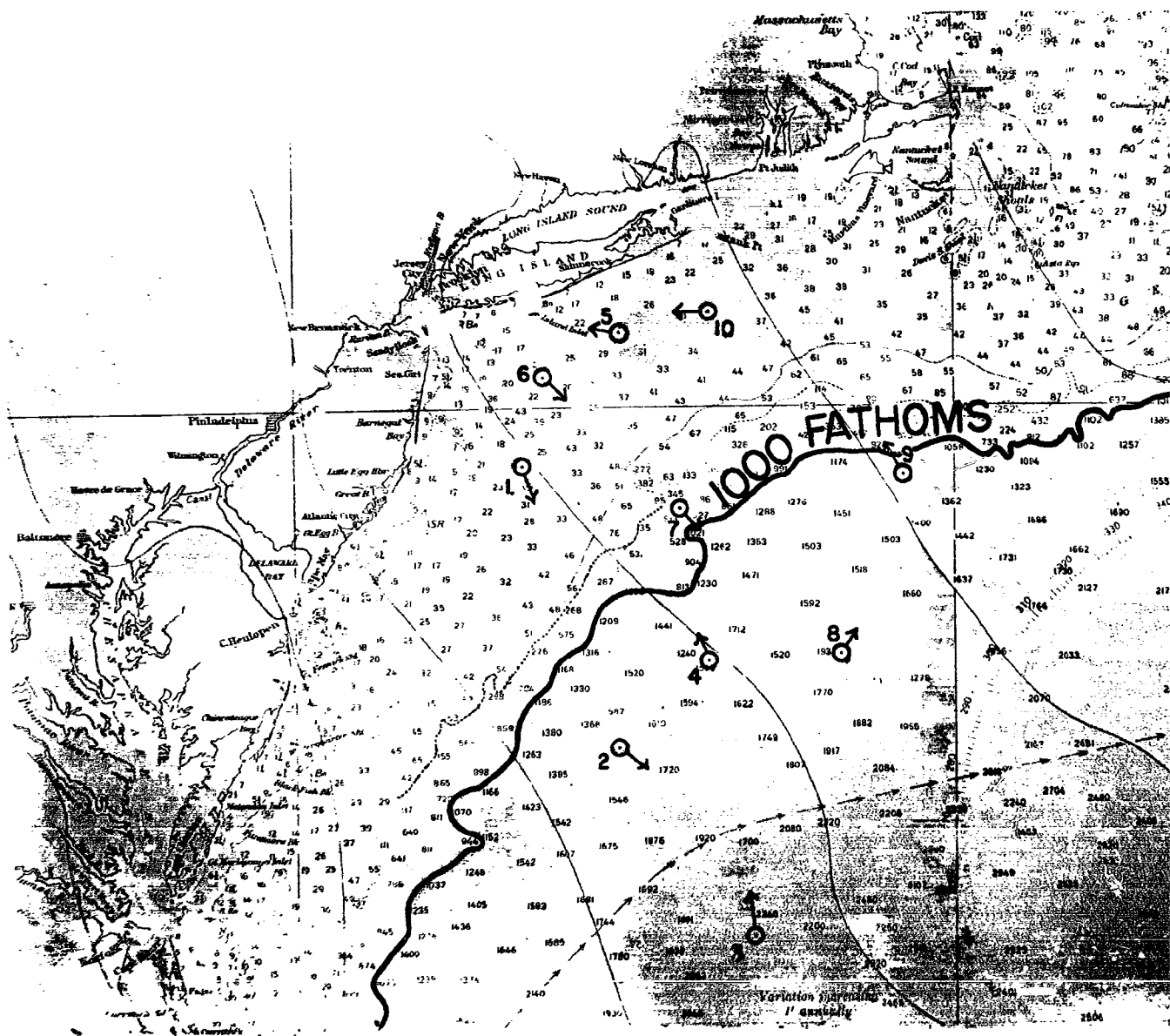
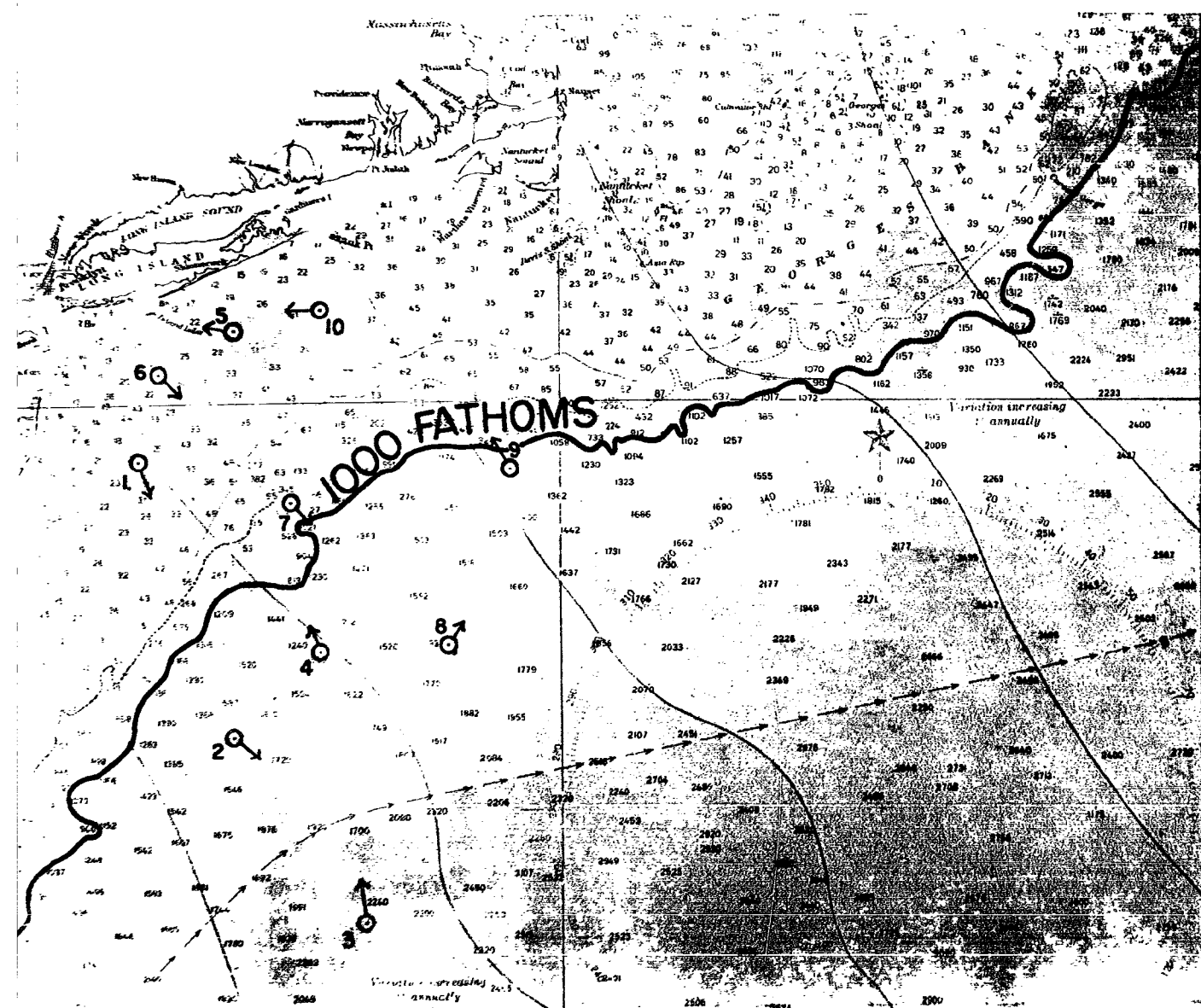


Fig. 2 - Operating area

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1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840. 84

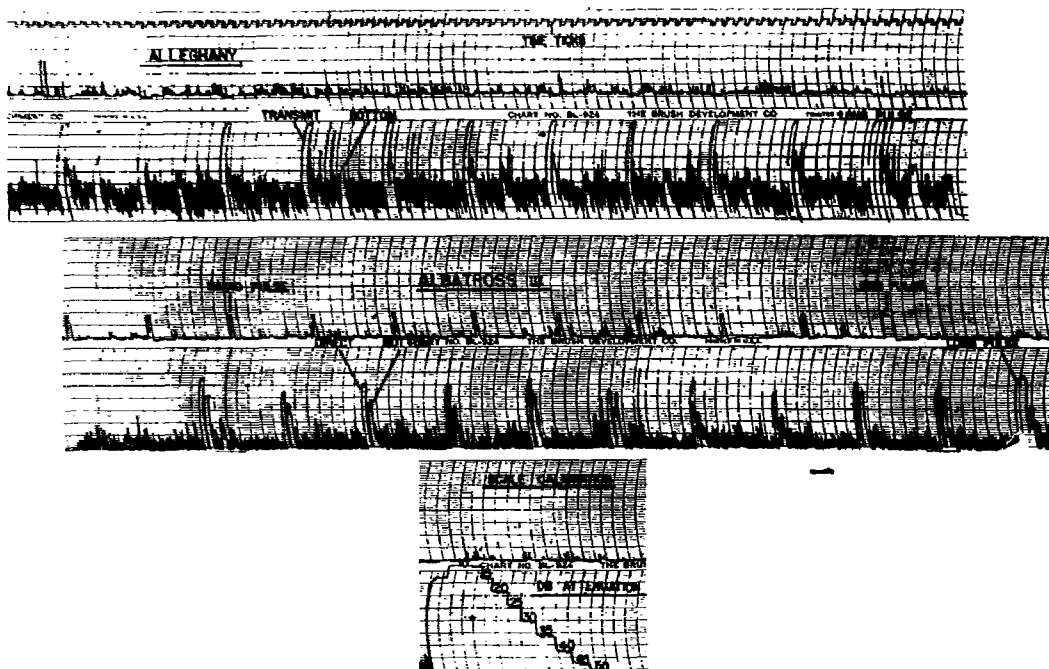


Fig. 3 - Sample data record, range 20 kyds

ANALYSIS OF DATA AND RESULTS

Transmission Loss in Surface-Bounded Channels (for Deep-Water Locations)

The procedure was for the ALLEGHENY to remain on location as the ALBATROSS opened the range to successive stations in increments of 5, 10, or in some cases 20 kyds. On each station, groups of ten pulses at each of six frequencies were sent by each ship. On some stations this procedure was repeated with transducers at different depths.

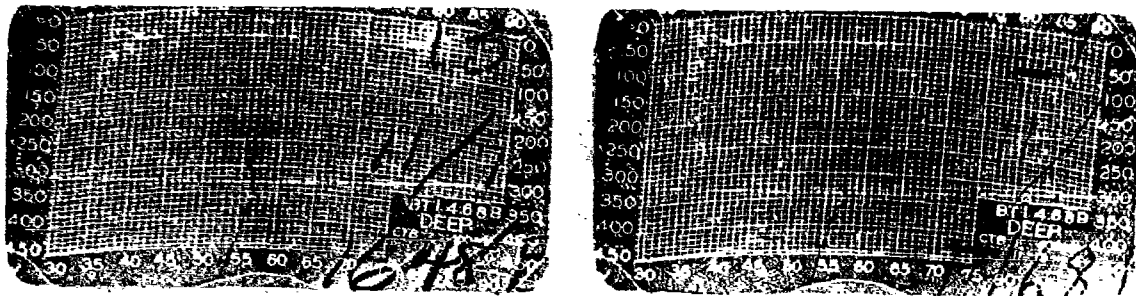
Pulses were read and recorded to a range of 60 kyds on location 4 and to 40 kyds on locations 7 and 9. Surface-bounded channels existed on these stations as can be seen from typical bathythermograms shown in Fig. 4. Channel depths were not uniform over these ranges, but the variation was not great.

Figure 5 is a plot of total transmission loss versus frequency between 1000 yards, the calibration range, and 40 kyds. A smaller transmission loss was observed when source and receiving transducer were shallow (30 to 50 feet) and the data plotted was taken under this condition. The solid line in Fig. 5 is an average of the three locations and shows 9.49 db/kyd less loss for 1.5 kc than for 5 kc. The deeper channel shows a smaller transmission loss. Although the losses at different locations are not equal, the slopes of the curves are approximately the same. This indicated that, although channel depth and bathythermograph affect the total transmission loss, the frequency dependence of this loss within the range of frequencies reported is not appreciably affected by these factors. The curves at the bottom of Fig. 5 are plots of the spreading loss and spreading loss

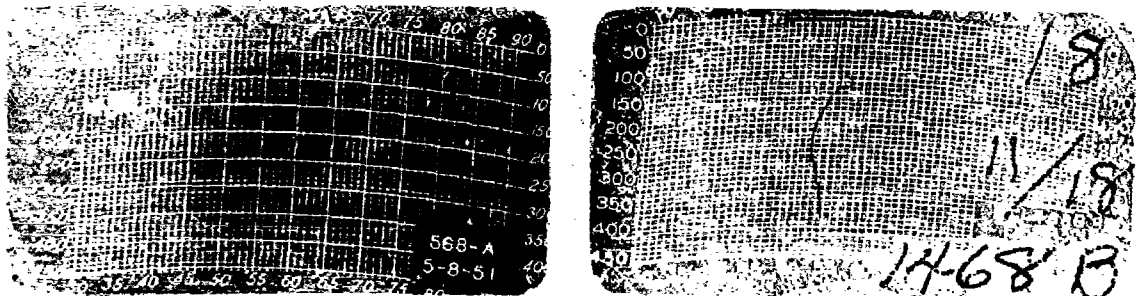
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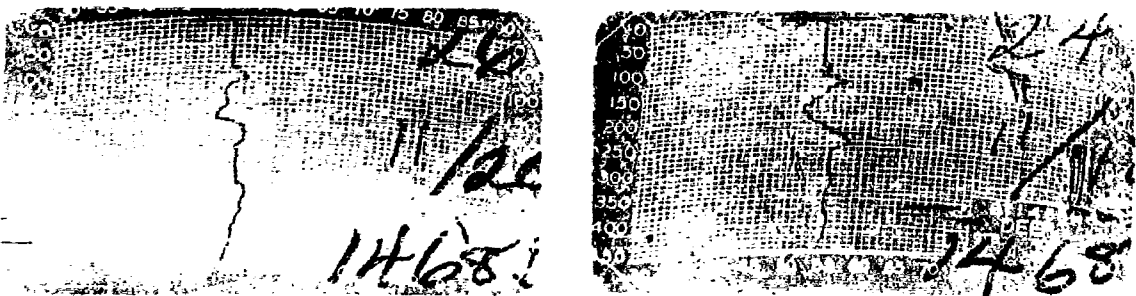
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LOCATION (4)



LOCATION (7)



LOCATION (9)

Fig. 4 - Bathythermograms for locations 4, 7, and 9

plus absorption. Cylindrical spreading was assumed and absorption was calculated from an extrapolation of Leonard's data (Fig. 7) to lower frequencies, using the temperature observed in the channel. Figure 6 is a plot of the same data from 1 yard to 40 kyds. The level of the outgoing signal at one yard, was taken from calibration data on the transducer current. This plot shows a difference of 0.58 db/kyd between 5 kc and 1.5 kc. The difference in the plots of Figs. 5 and 6 indicates that the transmission loss in the first 1000 yards is frequency dependent, 5 kc showing an average of 4 db greater loss. Spherical spreading was assumed out to 1000 yards. In the past, calibrations made at 1000 yards at higher frequencies have been consistent and have not indicated any frequency dependence. The absorption for the different frequencies used is small for this range, and cannot account for the difference observed. Further measurements of transmission loss in the first 1000 yards have already been made, and will be reported when analyzed.

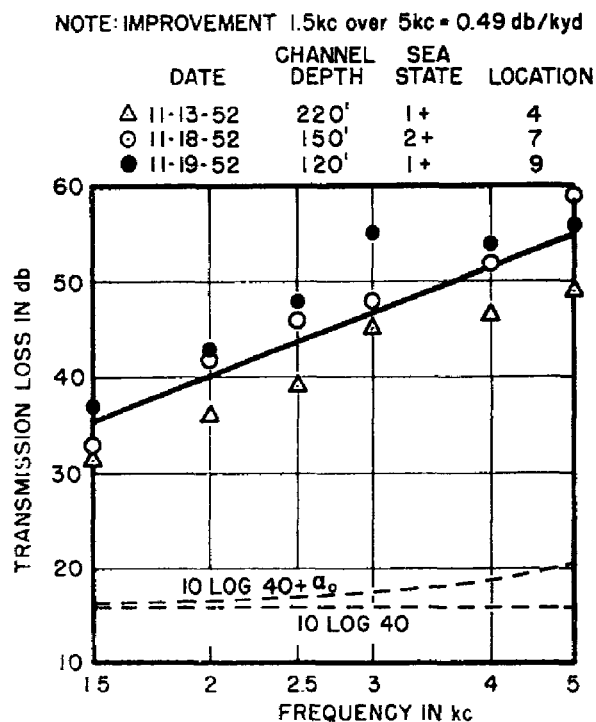


Fig. 5 - Total transmission loss from 1 kyd to 40 kyds for locations 4, 7, and 9

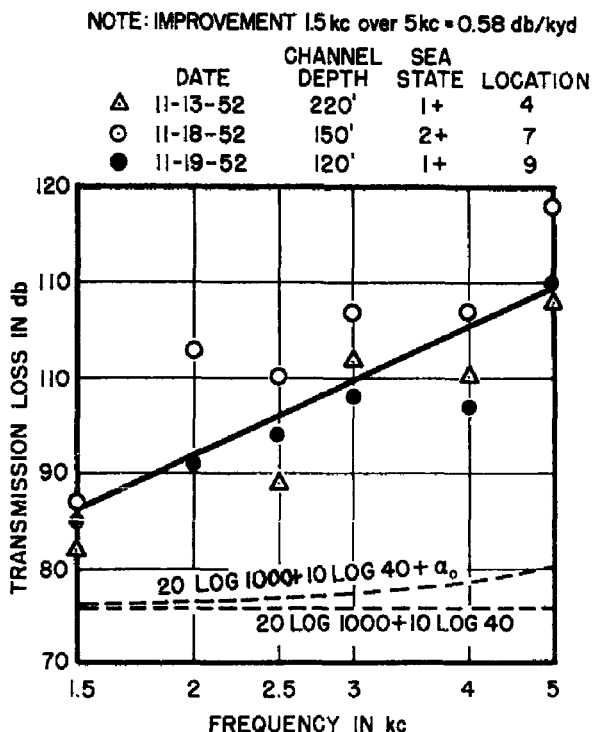


Fig. 6 - Total transmission loss from 1 yd to 40 kyds for locations 4, 7, and 9

Long ranges were not obtained on locations 2, 3, and 8. On stations 2 and 8, channels were observed but they were not continuous over great enough range. Data was taken to a range of 20 kyds and transmission loss agreed substantially with that plotted for station 4. The limited source level did not permit long ranges on station 3, where a very high noise level accompanying a state 4 to 5 sea, made it impossible to read pulses beyond 10 kyds. In the deep channel at this station, the transmission loss was lower than was observed in any other locations.

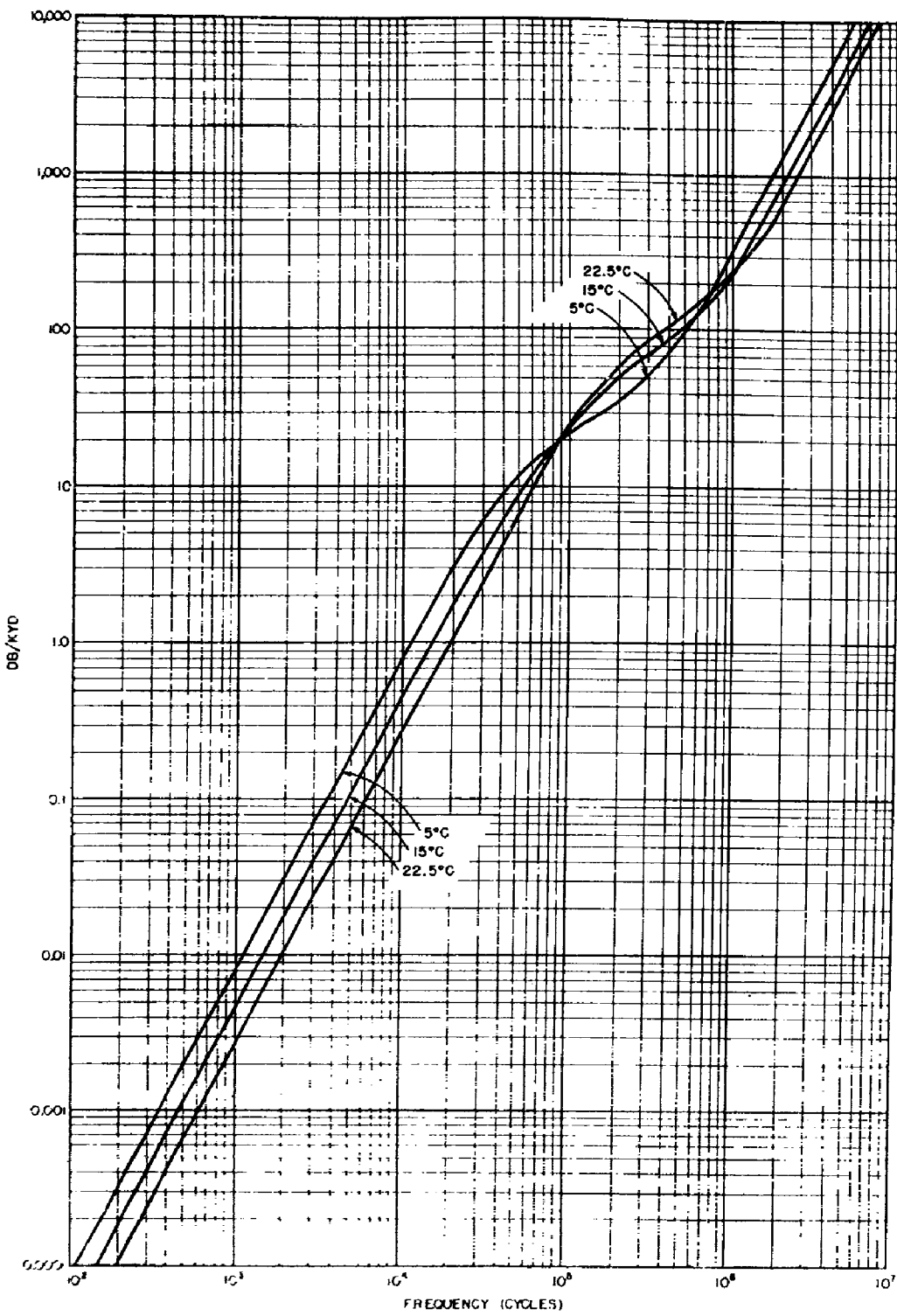
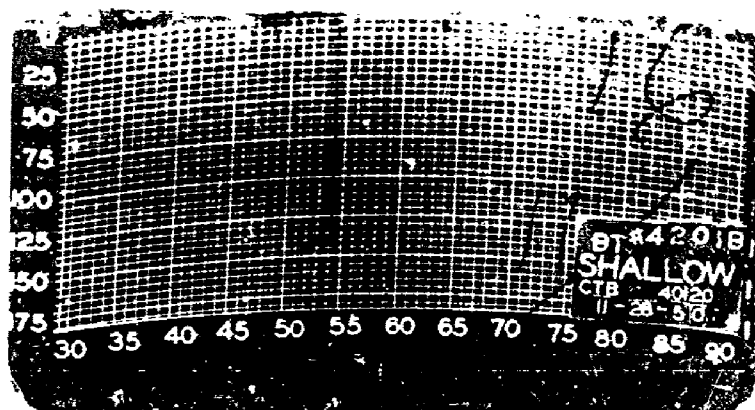


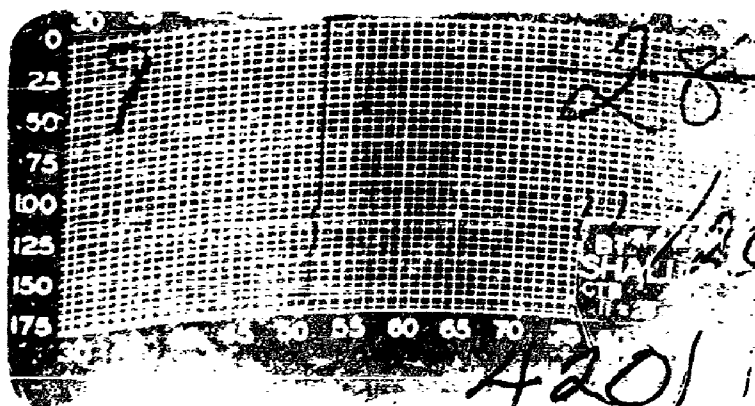
Fig. 7 Absorption in sea water

Shallow-Water Transmission Loss

Data was taken in shallow water (50 fathoms and less) and pulses were recorded in both directions out to 40 kyds. Typical shallow-water bathythermograms for stations 6 and 10 are shown in Fig. 8. Transmission loss from 1000 yards to 40 kyds and from 1 yard to 40 kyds are plotted in Figs. 9 and 10. The total transmission loss over 40 kyds was somewhat greater than was observed in deep water, but the same frequency dependence was observed. The increased transmission loss in shallow water is to be expected since there were many reflections both from the bottom and the surface in this range. The frequency dependence of transmission loss is also greater in shallow water, and is probably caused by the higher loss experienced by the higher frequencies. The transmission loss in the first 1000 yards was frequency dependent in much the same manner as was observed in deep water.



LOCATION (6)



LOCATION (10)

Fig. 8 - Bathythermograms for locations 6 and 10

NOTE: IMPROVEMENT 1.5kc over 5kc = 0.70 db/kyd

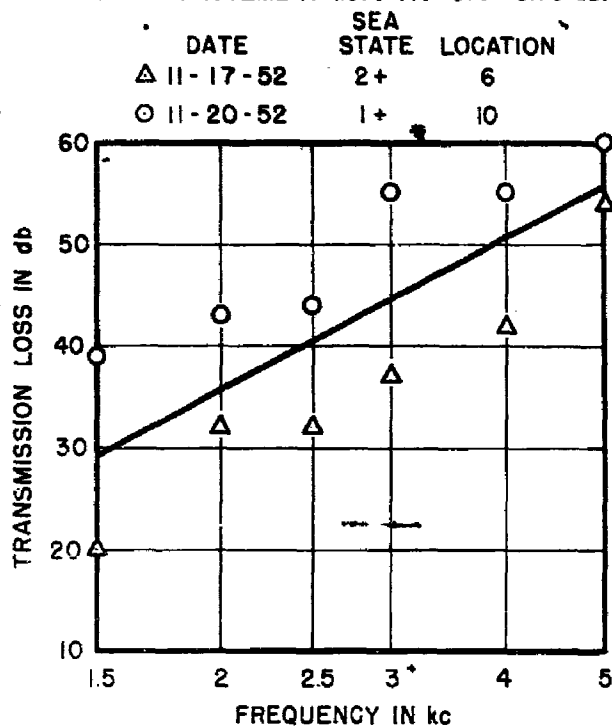


Fig. 9 - Total transmission loss from 1 kyd to 40 kyds for locations 6 and 10

NOTE: IMPROVEMENT 1.5kc over 5kc = 0.88 db/kyd

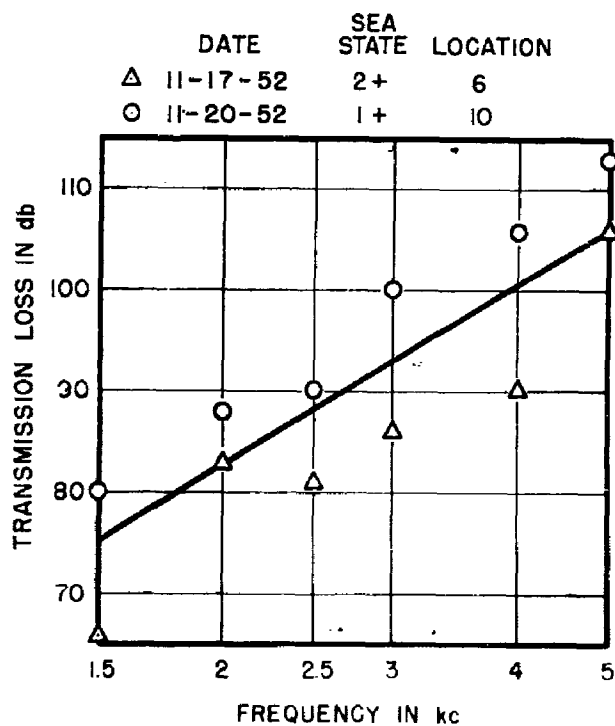


Fig. 10 - Total transmission loss from 1 yd to 40 kyds for locations 6 and 9

Leakage Out of Surface-Bounded Channels

The total transmission loss between 1000 yards and 40 kyds as plotted in Fig. 5, can be broken down into spreading loss, absorption, and scattering of energy out of the channel. Cylindrical spreading ($10 \log R$) was assumed beyond a range of 1000 yards. Absorption loss was again obtained from the extrapolated curves shown in Fig. 7, using the proper temperature for each channel. After subtracting spreading and absorption from the total transmission loss the remainder was assumed to be due to leakage. The leakage out of a channel is believed to be due to scattering from the surface and by diffraction. Figure 11 is a plot of α_L , the loss due to leakage, against frequency on a linear scale. The increase of α_L with increasing frequency is to be expected since the shorter waves are scattered more by a rough surface. The loss by diffraction should increase with decreasing frequency, but this effect is not apparent from the data. At still lower frequencies this effect is more pronounced as shown by Officer.¹ Both sea state and channel depth have an effect on leakage, the curve for location 4, where the sea state was 1 and the channel depth 220 feet shows the lowest leakage loss. Although the leakage loss is not the same for the three locations, the curves are approximately parallel. A value for channel leakage at 10 kc, when a 220-foot channel and sea state 1 existed, falls on the curve for location 4. This data was obtained in the Caribbean in 1951.

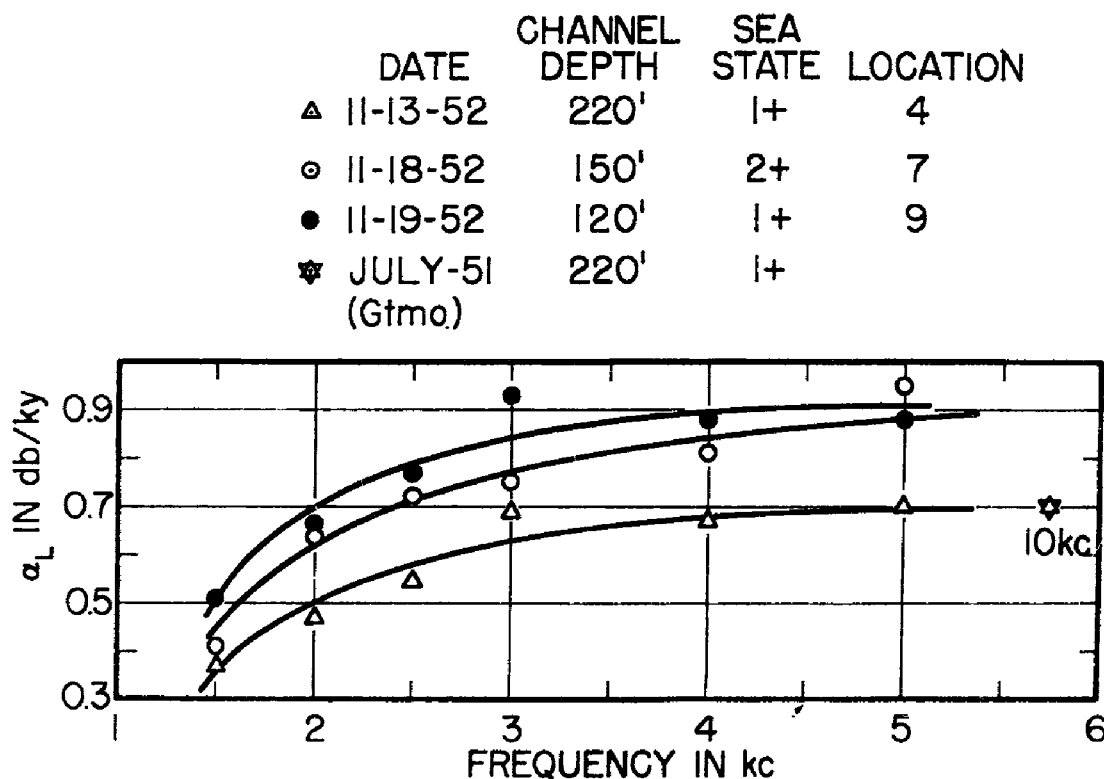


Fig. 11 - Channel leakage vs. frequency

¹ Officer, C. B., "Sound Transmission in the Surface Isothermal Channel. Part II - Experimental Measurements." WHOI Report No. 52-18 (Confidential) March 1953. See also Leonard, R. W., and Wilson, O. B., "Absorption of Ultrasonic Waves in Aqueous Solutions of Magnesium Sulfate," Univ. of Calif., Dept. of Physics, Tech. Rept. No. 4, Contract N6onr-27547, June 1951.

Sound Energy Distribution in Depth

On several stations at each operating location, groups of ten pulses for several combinations of transducer depths were sent from each ship, received, and recorded. Results show the optimum location for source and receiver to be in the top fifty feet of the channel, in the range 5 to 20 kyds. Transducer depth was not varied at ranges of less than 5 kyds. In most cases the signals were below the noise level, at the receiving transducers in the bottom half of the channel at range greater than 20 kyds. Figure 12 shows a plot of received signal level against h/H where h is the receiver depth and H is the channel depth. The source was between 30 and 50 feet. The data showed no dependence on frequency for distributions of energy within the channel. In shallow water the distribution of energy was observed to be practically uniform between the surface and the bottom beyond 5000 yards.

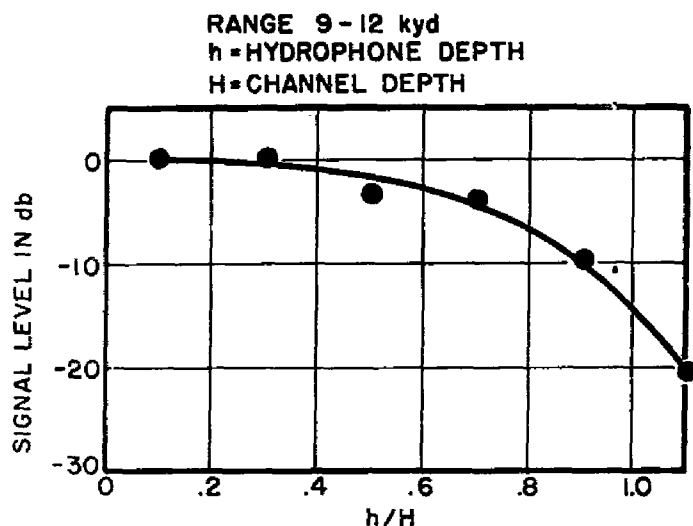


Fig. 12 - Energy distribution vs. depth in the channel

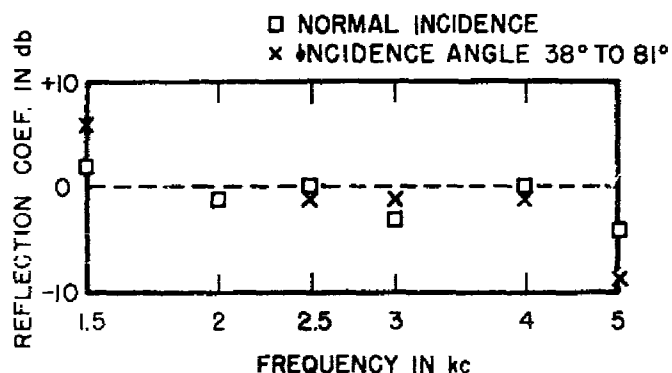


Fig. 13 - Bottom reflection loss vs. frequency

Bottom Reflection Loss

Sound pulses reflected from the bottom, directly beneath the transmitting ship, were received on all deep-water stations. Samples of these pulses can be seen on the recorder trace for the ALLEGHENY in Fig. 3. In most cases these pulses were well above the reverberation, and their levels could be read. To calculate the loss due to reflection from the bottom, spherical divergence loss and absorption were subtracted from the level of the outgoing pulse, and the received-pulse level then subtracted from this figure. Absorption was assumed to be $0.01f^2$,* which is probably too great a value; but since the temperature profile and the effects of pressure are not accurately known, it was impossible to give an accurate value for absorption. The reflection loss from normal incidence (assuming a flat bottom for the small area beneath the ship) was small for all frequencies, and only slightly dependent upon frequency. Average values of reflection coefficient are plotted against frequency in Fig. 13. The positive reflection coefficient shown for 1.5 kc may be in error and can be partially explained by a possible error in the transducer calibration at this frequency. It should also be noted that there was a wide fluctuation in received pulse levels and the points are average peak values.

* f in frequency, kc

At long ranges, transmitted pulses were received both by the direct and the bottom-reflected paths, as can be seen on the recorder trace for the ALBATROSS in Fig. 3. By the geometry of the situation, bottom-reflected pulses were received whose angles of incidence on the bottom were included between 38 and 81 degrees. In computing the transmission loss via the bottom-reflected path, spherical divergence was assumed. To calculate the total absorption loss over this path, $0.01f^2$ in db/ky was used. It is probable that the values obtained by using $0.01f^2$ include some of the loss incurred when sound is reflected from the bottom. The data indicates that it gives a maximum value, for if a higher value is used the bottom shows a positive reflection coefficient. Figure 13 shows the effects of frequency on coefficient of reflection. Each point on the curve is the average of approximately one thousand pulses spread over incident angles between 38 and 81 degrees. Figure 14 shows the coefficient of reflection plotted against incident angle for all frequencies.

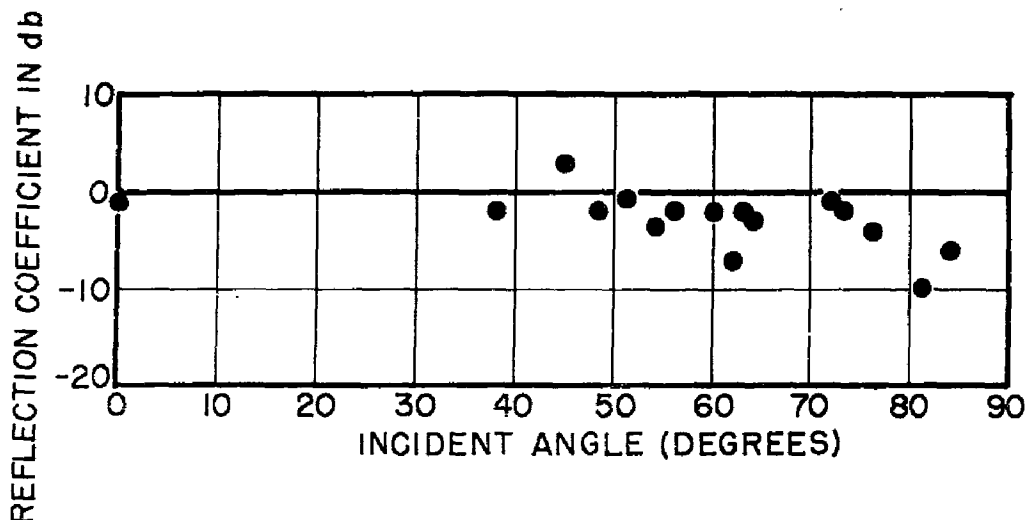


Fig. 14 - Bottom reflection loss vs. incident angle

The small dependence of reflection loss on frequency and incident angle, appears to be real. The average values plotted in Figs. 13 and 14 are not appreciably different for the same plots made for individual locations. Omnidirectional transducers were used and large areas of the bottom contributed to the reflected pulses. Measurements made in the Caribbean and in the Key West area in 1951 and 1952, with a directional transducer operating at 10 kc, showed bottom reflection loss of 11 db. In order to investigate further the possibilities of echo ranging by way of the bottom reflected path, it is desirable to make measurements of bottom reflection loss in the frequency range 1 to 5 kc using high power, and directional transducers.

OBSERVATIONS AND DISCUSSIONS

The difference in transmission loss, over reciprocal paths was small, averaging less than 1 db. At long ranges, the highest concentration of energy was found to be in the upper fifty feet of a channel for any source depth provided that the source was within the channel.

A submerged channel was indicated by bathythermograms at two stations. An effort was made to measure transmission loss in these channels, but results were inconclusive. The submerged channels were very narrow and did not persist to long ranges.

The average difference in transmission loss of 23 db between 5 and 1.5 kc over a range of 40 kyds is significant, and indicates that echo-ranging equipment operating in the vicinity of 1 kc should give very long range detection in surface-bounded channels. Echo ranging by way of the bottom-reflected path when surface-bounded channels do not exist is a promising possibility at low frequencies. More data is needed before definite conclusions can be reached. When a transducer capable of giving a high source level and some directivity becomes available, this information will be obtained.

ACKNOWLEDGMENTS

Experimental work was done by authority of assist project Bu/S215/H2 established by CNO. Ship facilities were furnished by the Office of Naval Research. Valuable assistance given by the Officers and men of USS ALEGHENY and FWSS ALBATROSS contributed materially to the results obtained. All members of the Propagation Branch contributed in the design of equipment and in the collection and analysis of data.

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UNITED STATES GOVERNMENT
memorandum

7103/128

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SUBJECT: REVIEW OF REF. (a) FOR DECLASSIFICATION

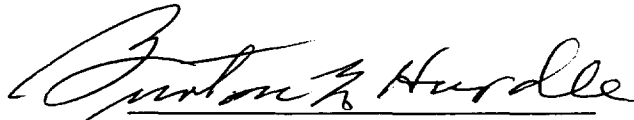
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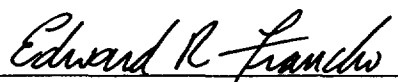
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REF: (a) NRL Unclassified Report #4225 by H.R. Baker et al, 23 Sept 1953 (U)
(b) NRL Letter dated 4/16/68

1. Reference (a) is a report on the results of propagation measurements in the development of the 5-kc long-range search sonar, a phase in the decrease of the operating frequencies of sonars following World War II. The major frequency of sonars during World War II was 25 kHz. The research and development at NRL following the war progressed to 10 kHz, 5 kHz, and 2 kHz. This report discusses the parameters to be considered in this process. This report discusses the design, configuration and performance of the 5-kc system.
2. The technology and design of this development have long been superseded. The current value of this report is historical.
3. Reference (a) was declassified by reference (b).
4. Based on the above, it is recommended that reference (a) be released with no restrictions.


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11/12/96
Date

Completed
1-24-2000
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