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FY77 SUBSEA SLOW-SCAN ACOUSTIC TELEVISION (SUBSAT) TESTS.(U)

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Technical Report 217

FY 77 SUBSEA SLOW-SCAN ACOUSTIC TELEVISION (SUBSAT) TESTS

A. Gordon

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Technical Director

ADMINISTRATIVE INFORMATION

This document reports on work performed during FY 77 on SUBSAT (SUBSEA Slow-Scan Acoustic Television). This work was funded by NOSC Independent Research funds as project 521-765139.

This report was reviewed for technical accuracy by Mr. Stanley J. Watson.

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Experiments were conducted in December 1976 and January 1977 to test the feasibility of transmitting and receiving slow-scan television (SSTV) through existing underwater telephones (UQCs). Off-the-shelf monitors, recorders, and scan converters were installed on two submersibles and two surface craft. The slow-scan hardware was installed without modification to the UQCs and without disabling the normal UQC voice function. The slow-scan data rate was 7200 baud and occupied a 2.5-MHz bandwidth, fully compatible with existing UQC equipment. Twenty-six test transmissions, each consisting of a number of slow-scan frames, were made during the tests. While some of the pictures were of excellent quality, most were degraded → next page

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because of multipath effects. Analysis of the data indicates that better pictures would have been obtained had the acoustic path been more nearly vertical. Further experiments are planned.

CONTENTS

1. INTRODUCTION AND BACKGROUND

1.1 SCOPE OF REPORT

This report presents the results of two separate experiments conducted in fiscal year 1977 designed to investigate the feasibility of reception and transmission of 7200-baud slow-scan video using an underwater acoustic link. These experiments were primarily motivated by an existing need for U. S. Navy manned submersibles to transmit video information, in real or near-real time, to their surface support ships. Other motivating factors included the future need for video information from unmanned, untethered submersibles as well as from potential remote undersea observation sites. These requirements, coupled with the recent availability of comparatively inexpensive off-the-shelf scan converters and microprocessors, seemed to demand a further look into the feasibility and practicality of acoustic slow-scan television.

The remainder of this section will concern itself with a review of past slow-scan work pertinent to the present experiments. In Section 2 the present experimental equipment will be detailed and our two experiments will be summarized. The results of these experiments will be discussed in Section 3. Conclusions based on these experiments and recommendations for future experiments appear in Section 4.

1.2 PRIOR ACOUSTIC SLOW-SCAN TELEVISION EFFORTS

During the last two decades there has been considerable progress in transmitting video and other data via reduced-bandwidth formats. Most of this work has been directed towards electromagnetic transmissions over hard-wired or radio frequency links. However in 1967 the Ball Brothers Research Corporation of Boulder, Colorado, began a study of the advantages to be gained from a cableless underwater television system. This study led to their development of the "CUTLINK" acoustic slow-scan television system (Ref. 1), the first cableless system to transmit television pictures in near-real time from ocean depths to the surface (Ref. 2). The characteristics of the CUTLINK system are displayed in Table 1.

TABLE 1. CUTLINK CHARACTERISTICS.

Design Depth	20,000 ft
Raster and frame transmission time	80 lines, 10 sec/frame 200 lines, 57 sec/frame 500 lines, 342 sec/frame
Illumination	200 W-sec
Modulation Methods	Analog FM, Δ modulation, PCM
Carrier Frequency	14.5 kHz
Receiver Bandwidth	3 kHz
Digital Bit Rate	2.5 K bits/sec
Transducer Beamwidth	70 deg at 3 dB down

CUTLINK was designed to telemeter acoustic television signals over nearly vertical paths from abyssal depths (≤20,000 ft) to a surface platform. Telemetry was centered at 14.5 kHz with a nominal bandwidth of 3 kHz and either analog FM, delta modulation, or pulse code modulation were available. Command and control channels were available for functions such as picture initiate, video gain, contrast, etc. Relatively inexpensive broadly directional (70 deg at 3 dB down) transducers were used for both sending and receiving.

During tests off Hawaii CUTLINK demonstrated its capability for transmitting video acoustically. Two-hundred-line FM analog pictures were successfully transmitted from both 200 and 1300 ft. An image of the vidicon target was transmitted from 15,200 ft. The published examples of video imagery shown are quite good; however there were some problems with line synchronization, ghost images, and granulation. These were attributed to multipath interference from a bottom-reflected ray (Ref. 3). The pioneering accomplishments of the CUTLINK system attracted much attention, and it received an award from *Industrial Research* magazine (Ref. 4).

Another development that had a strong influence on our SUBSAT tests was the development of amateur radio slow-scan television (SSTV). In 1957 a student at the University of Kentucky, Copthorne MacDonald, realized that it would be possible to transmit video over voice-grade radio frequency channels. His paper describing the design and development of the first amateur SSTV system was awarded the 1958 National AIEE (now IEEE) first prize. Since 1958 amateur SSTV has progressed to where it is a commonly used mode of communication and employs the standard format shown in Table 2. During this period successive generations of relatively inexpensive commercially built amateur SSTV equipment using this format have become available. The earliest equipment, both privately and commercially built, used charge-storage vidicons as cameras and cathode ray tubes with slowly decaying phosphors as monitors. The present state-of-the-art is to use conventional fast-scan cameras and monitors and to use scan converters to go from the slow to fast and fast to slow formats. The latest scan converter designed for the amateur market, the Robot Model 400, features all solid state scan conversion, with each TV frame being completely digitized and stored in memory. This scan converter was used in the SUBSAT tests.

TABLE 2. AMATEUR RADIO SLOW-SCAN TV FORMAT.

Number of Scan Lines	120
Number of Horizontal-Resolution Elements	120
Aspect Ratio	1:1
Time Per Frame	8 sec
Horizontal Sweep Frequency	15 Hz
Vertical Sync Burst Duration	30 msec
Horiz. Sync Burst Duration	5 msec
Sync Subcarrier Freq	1200 Hz
Black Subcarrier Freq	1500 Hz
White Subcarrier Freq	2300 Hz
Bit Rate	7200 baud

In another recent acoustic television experiment Conrad and Moffet (Ref. 5) used a Model 400 scan converter and a parametric sonar to transmit slow-scan video over a horizontal path. The purpose of this experiment was to show the feasibility of transmitting video over a long horizontal path in a shallow (i.e., 600 ft) lake, a path which is prone to severe multipath from surface and bottom reflections and multipath from multiple refracted paths. The transmissions were successfully accomplished using two primary mixing frequencies centered on 65 kHz with input powers of 5 kW apiece, resulting in a difference frequency of 10 kHz with a beamwidth of 2 deg. With this small a beamwidth, multipath effects were minimized and good video was received. The experiment used amateur radio slow-scan format and Robot Model 400 scan converters to produce the slow-scan signals.

1.3 RELATION OF SUBSAT TO PREVIOUS WORK

In view of the past work in acoustic SSTV as outlined above it is important to present the relationship of SUBSAT to these previous experiments. Essentially CUTLINK and the work of Conrad and Moffet showed the initial feasibility of transmitting acoustic SSTV; SUBSAT's aims are to show that these transmissions can be made reliably, cost-effectively and with maximum use of off-the-shelf and already-installed equipment.

In particular, the unique characteristics of the SUBSAT program are:

(a) Maximum use of already-installed equipment: The prime application envisioned for SUBSAT is between manned or unmanned submersibles and their surface support craft. Existing craft of this class are more likely than not outfitted with standard UQC (underwater telephone) gear. One of SUBSAT's main objectives is to determine the feasibility of transmitting slow-scan video over such gear without the need for its modification. If successful this would obviously reduce the cost of a slow-scan installation.

(b) Determination of slow-scan operational envelope: If acoustic slow-scan television is to be used routinely as an adjunct to UQC communication, the lateral range and depths at which successful transmission is possible need to be made available to the user. SUBSAT's principal goal during FY 78 will be the experimental determination of this operational envelope.

(c) Maximum use of existing scan-conversion technology and standardized SSTV format: Use of scan converters allows the use of fast-scan cameras and monitors. In particular the enormous sensitivity of silicon-intensified target cameras can be used to advantage in undersea applications. Scan converters also allow utilization of ordinary closed-circuit monitors, which have good performance under ambient illumination, rather than low-luminosity P7 phosphor cathode ray tubes. By retaining the amateur radio slow-scan format, SUBSAT can use the modern, relatively inexpensive scan converters designed for that market. In particular the Robot 400's full-frame digital memory allows easy interfacing with microprocessors. Software programs have already been designed to do simple processing such as interline interpolation and frame averaging, and work is continuing in this active area.

2. SUBSAT EXPERIMENTS

Two SUBSAT experiments were conducted during FY 77. The first, in December 1976, which will be referred to as the SEACLIFF experiment, tested acoustic video transmission between the submersible SEACLIFF and its surface support ship, MAXINE D. The second was conducted in January 1977 between the USS DOLPHIN and a Box L boat and will be referred to as the DOLPHIN experiment. In both experiments the submerged platform transmitted while the surface platform received. Since the SUBSAT equipment installations were quite similar on all four platforms, a single description will be given.

2.1 SUBSAT EQUIPMENT

2.1.1 ACOUSTIC SOURCE AND RECEIVER

The Straza ATM-504A underwater telephone was used as the acoustic source and receiver on all platforms. This unit was already installed on all platforms except the Box L, where a 504A was installed for the DOLPHIN experiment.

The 504A specifications are shown in Table 3. Basically this unit accepts audio baseband information from 500 to 3000 Hz and converts this to a single sideband acoustic signal appearing between 8.587 and 11.087 kHz. Although this unit was primarily designed to operate on voice inputs, the 500- to 3000-Hz range is more than adequate to accommodate the slow-scan format (Table 2). Since the slow-scan signal is essentially a constant-amplitude, frequency-modulated signal it requires a higher duty factor than low-duty-cycle (i.e., high peak to average) voice transmissions. No adverse effects, such as overheating on the 504A, were noted during slow-scan transmissions. Except for a loose edge connector on one of the boards on the Box L, all the 504A units performed reliably.

TABLE 3. STRAZA MODEL ATM 504A ACOUSTIC UNDERWATER TELEPHONE.

Transmitter:	
Carrier Frequency	8.087 ±1 kHz
Upper Sideband Passband	8.587 to 11.087 kHz ±3 dB
Baseband Passband	500 Hz to 3 kHz
Acoustic Output	100 W, 25 W, 10 mW, selectable
Source Level (Conical)	203 dB re 1 μPa at 100 W
(Omni)	196 dB re 1 μPa at 100 W
Receiver:	
Frequency Response	8.587 kHz to 11.087 kHz
Sensitivity (Conical)	+70 dB re 1 μPa
(Omni)	+74 dB re 1 μPa
Audio Bandwidth	500 Hz to 3000 Hz ±3 dB
Weight, Size and Power:	
Weight	37 lb
Overall Dimensions (inches)	5.2 high by 19 wide by 15.4 deep
Input Power: (Far Mode)	490 W
(Med. Mode)	220 W

Except for the Box L boat, all platforms had the option of using either the hull-mounted conical or omni transducers. On the Box L boat a SP23LT conical transducer was lowered and used for receiving at a depth of 200 ft. A painted plywood baffle was mounted to the rear of this transducer. Both the 200-ft depth and baffle were selected to minimize the entry from above of surface-reflected sound to the rear of the transducer. The beam pattern of the baffled conical transducer is shown in fig. 1.

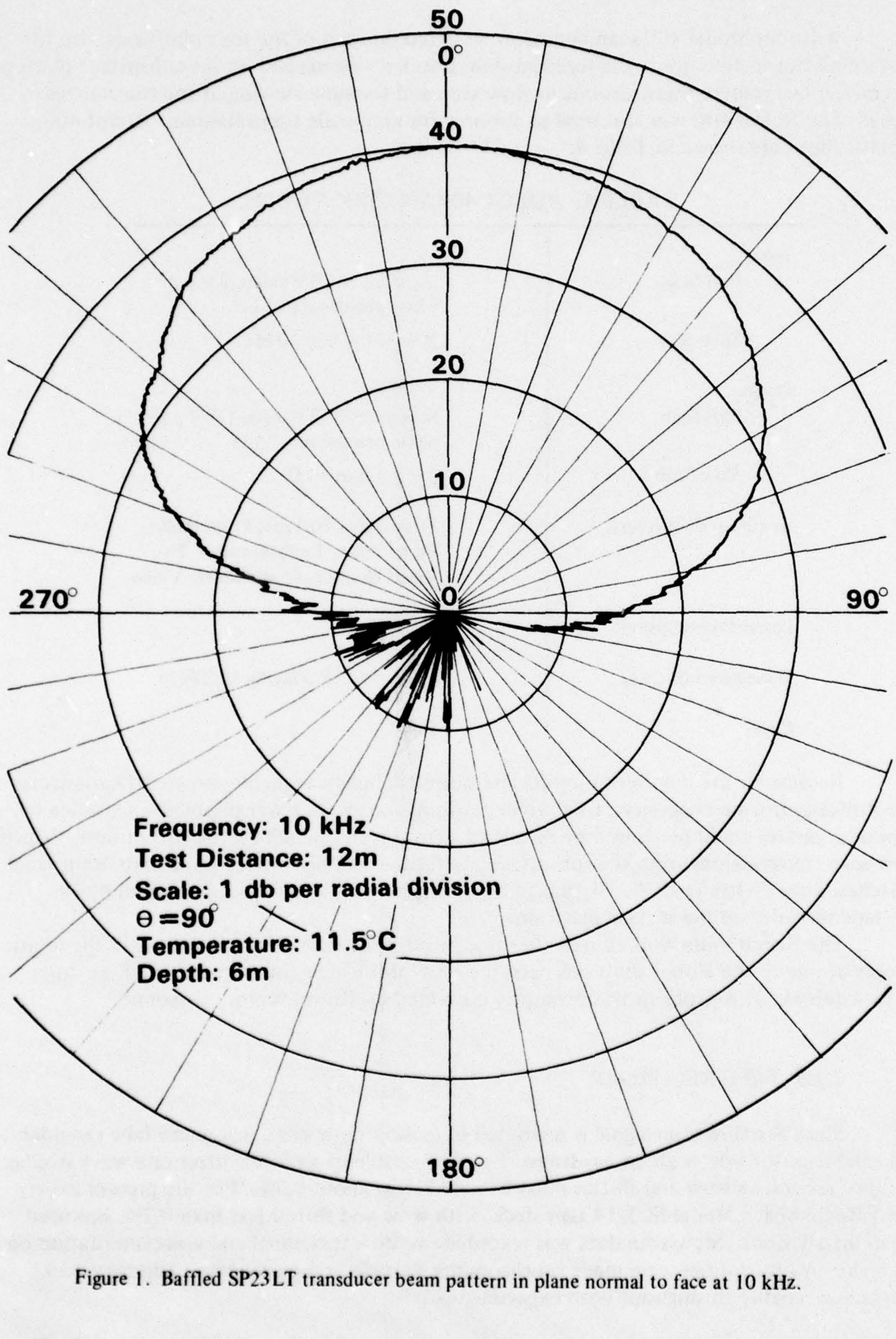


Figure 1. Baffled SP23LT transducer beam pattern in plane normal to face at 10 kHz.

2.1.2 SCAN CONVERTER

A Robot Model 400 scan converter was used on each of the four platforms: on the surface platforms to convert the received slow scan for viewing and on the subsurface platforms to convert live camera transmissions to slow scan and to allow viewing of the transmitted signal. The Robot 400 was also used as a source for gray-scale transmissions. Robot 400 specifications are shown in Table 4.

TABLE 4. ROBOT 400 SPECIFICATIONS.

Input:	
Fast Scan	Standard 525 TV video, 1 V p-p white positive into 1 kΩ
Slow Scan	20 mV-1 V into 10 kΩ
Output:	
Fast Scan	Standard 525 TV video 1.4 V p-p white positive into 75 Ω
Slow Scan	2 V p-p into 1 kΩ
Auxiliary Connectors:	From Tape, To Tape, From Radio, From Other, To Transmitter, To Video Monitor, From Camera Video
Power Consumption:	33 W
Dimensions (inches):	6 high by 12½ wide by 11¾ deep
Price:	$695

Because of the number of inputs and outputs already available, no modifications to the Robot unit were necessary. UQC voice transmissions were never disabled since voice or slow-scan modes could be chosen by means of a front panel switch on the Robot unit. Taped slow-scan transmissions from the subsurface platform could be routed, via Robot front panel switches, directly to the UQC. Similarly, received slow scan could be routed directly to the tape recorder on the surface platform.

The Robot units worked reliably throughout both at-sea tests. A failure in the input limiter of one of the Robot units has been the only problem encountered since these units were acquired. This problem was promptly corrected by Robot factory personnel.

2.1.3 TAPE RECORDER

Since the slow-scan signal is restricted to audio frequencies, any audio tape recorder is a candidate for slow-scan applications. To avoid problems with line jitter or a wavy display, the tape recorder's wow and flutter must be held below about 0.3%. For the present experiment Radio Shack Model SCT-14 tape deck, with wow and flutter less than 0.2%, was used on all installations. Slow-scan data was recorded on the left channel and voice annotation on the right. All recordings were made on chromium dioxide audio cassettes. The tape decks performed reliably throughout both experiments.

2.1.4 MONITORS AND CAMERA

Unmodified closed-circuit fast-scan TV monitors and cameras were used. These interface directly with the appropriate connectors on the Robot 400. Panasonic TN-63 and Sony PVJ-3030 video monitors were used on the surface and submerged platforms respectively. During the SEACLIFF experiment a VC-1150 video camera was installed on the SEACLIFF so that live pictures could be taken and transmitted. All cameras and monitors functioned reliably throughout both tests.

2.1.5 EQUIPMENT INTERCONNECTION

Figures 2a and 2b show the interconnection diagrams for the surface and subsurface installations, respectively. All interconnections were made using existing connectors: no modification of any of the equipment was necessary. Received audio was obtained through the unused headphone jack on the UQC. Normal operation of the UQC was never disabled.

Figure 3 shows the equipment used, except for the UQC. Note the scale provided by the ruler below the Robot 400.

2.2 SEACLIFF EXPERIMENT

The first at-sea test of SUBSAT occurred on 8 and 9 December about 13 miles west of Point Loma. The Navy submersible SEACLIFF and its support ship MAXINE D were scheduled to be operating in this area on a training mission and NOSC personnel received permission from SUBDEVGRU ONE to conduct acoustic slow-scan tests between these vessels on a not-to-interfere basis.

SUBSAT equipment was installed on the MAXINE D bridge on 8 December 1976. MAXINE D, with NOSC personnel and SEACLIFF aboard, departed North Island Naval Base on 9 December 1976. Permission to install SUBSAT aboard SEACLIFF required consent from Washington authorities, which was received enroute to the operating area. NOSC and SEACLIFF personnel then installed the slow-scan gear aboard the SEACLIFF, completing this task before arrival at the operations area. The bridge and SEACLIFF installations averaged about an hour each.

Since slow-scan transmissions were to occur on a not-to-interfere basis, no chronological test plan was used. Rather a series of written procedures, reproduced here as Appendix A, for transmitting slow scan, both pre-recorded and live, was devised for use by SEACLIFF personnel. When the surface controller decided it was appropriate, SEACLIFF personnel would transmit the desired video according to the written instructions while NOSC personnel aboard the MAXINE D's bridge received, recorded, and monitored the transmissions.

As indicated in Appendix A, procedure A merely returns the UQC to its normal function. Procedure B allows transmission of pre-recorded slow-scan video from the tape recorder aboard SEACLIFF. This pre-recorded tape consisted of a sequence of three pictures, which were repeated for the length of the tape. The three pictures were (1) gray scale (fig. 4a), (2) a girl (fig. 4b), and (3) a test pattern (fig. 4c). The closed-circuit quality pictures in fig. 4 can be compared with the pictures shown in Section 3, which were acoustically transmitted through the water.

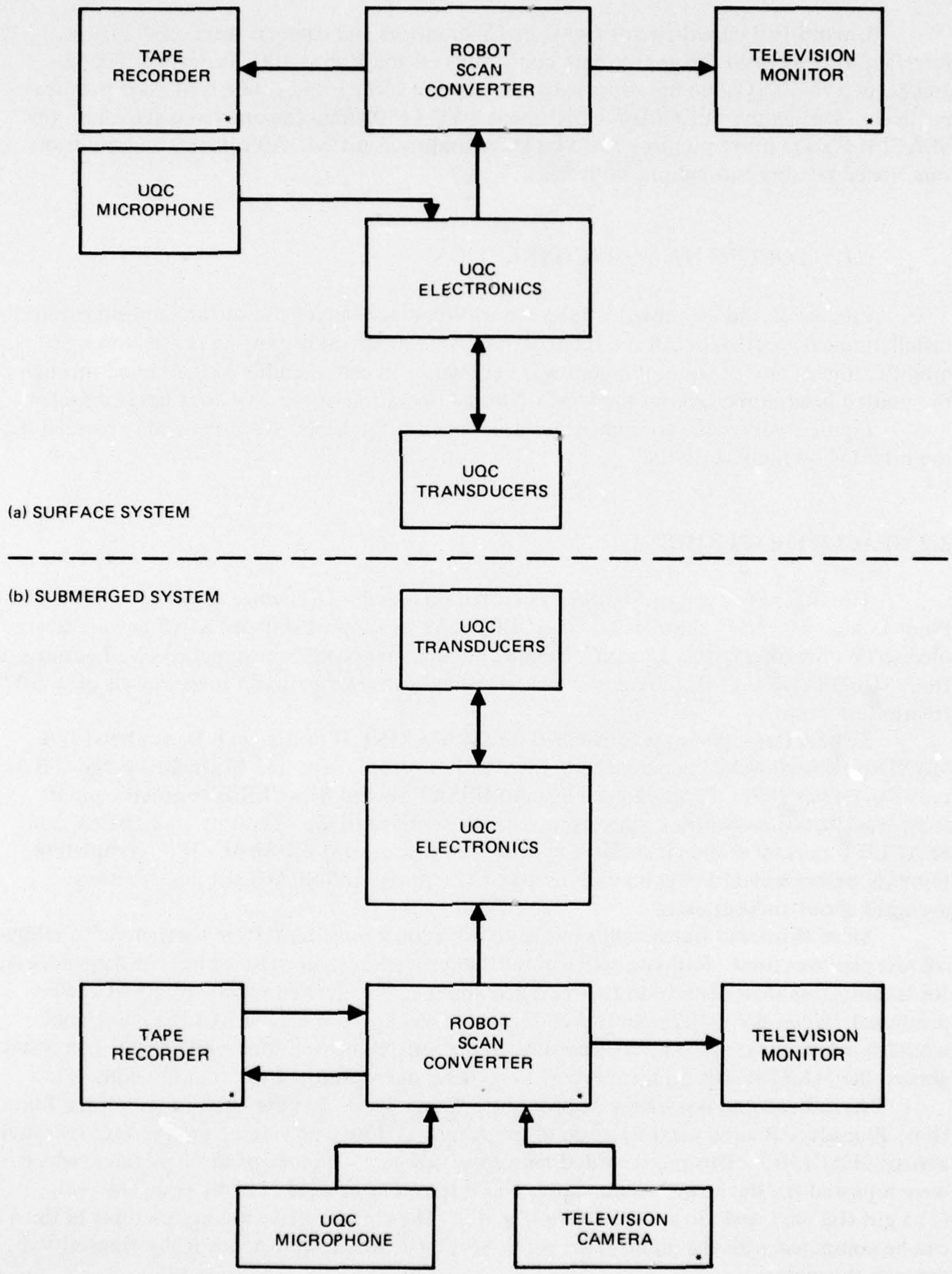


Figure 2. System interconnection diagram.

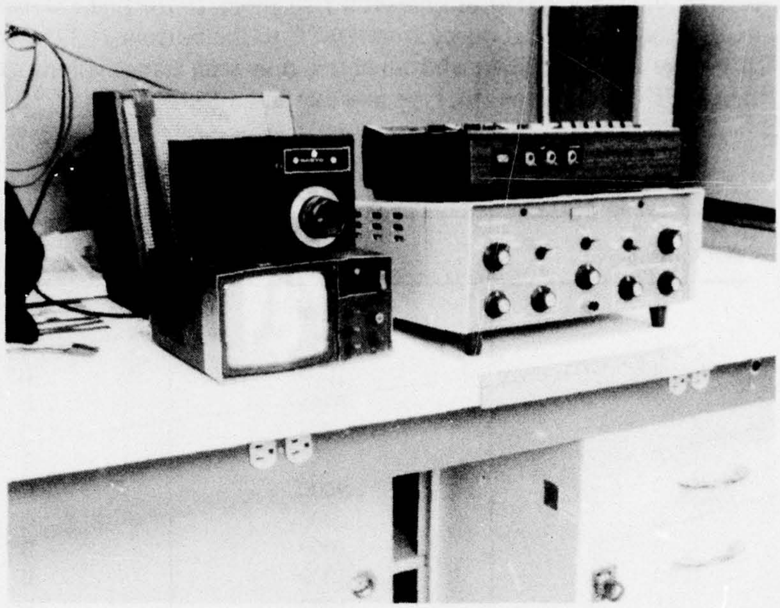


Figure 3. SUBSAT hardware.

(a) Gray scale (b) Girl (c) Test pattern

Figure 4. Closed-circuit quality slow-scan frames.

Procedure C provided for acoustic transmission of live video from the SEACLIFF while at the same time recording the transmission locally so that comparisons could be made with the received image. Procedure D allowed transmission of an extended period of gray scale directly from the Robot 400. This allowed for extended transmissions of known material even in the event of a tape recorder malfunction.

Once the equipment was installed, NOSC personnel trained SEACLIFF enlisted personnel on procedures A-D. After a 20-minute instructional period personnel originally unfamiliar with the slow-scan equipment were able to perform all procedures. A written copy of the procedures was left aboard SEACLIFF for reference during the dive. No problems traceable to improper operation of the slow-scan equipment by SEACLIFF personnel were evident.

SEACLIFF dove at 1300 local time on 9 December 1976. Eight slow-scan transmissions were made on that day at depths ranging from 900 ft to the bottom at 3755 ft. On the next day SEACLIFF dove at 0835 and an additional five slow-scan transmissions were made. Table 5 lists the SEACLIFF transmissions by type and depth.

TABLE 5. SEACLIFF SLOW-SCAN TRANSMISSIONS – DEC 9 & 10, 1976

Transmission No.	Depth, ft	Procedure
1	900	B
2	950	B
3	1000	B
4	3755	B
5	3755	B
6	3755	B
7	2000	C
8	2000	C
9	1000	B
10	1000	B
11	1000	B
12	1000	D
13	3500	C

In order to reduce multipath interference it was desirable to have the MAXINE D position herself as nearly vertically above the SEACLIFF as possible. The MAXINE D had a short baseline system which was, in principle, capable of providing the necessary positioning information. However this gear was not operational during the SUBSAT tests. Intermittent slant range information was available, however, although receipt of this information did not always coincide with a slow-scan transmission. Best estimates are that there was a horizontal separation between SEACLIFF and MAXINE D of 400 to 1300 yards. If so, most of the slow-scan transmissions took place with the direct path outside the main lobe of the sending and receiving transducers.

2.3 DOLPHIN EXPERIMENT

In early January the NOSC SUBSAT team was advised that the deep-diving submarine DOLPHIN would be transiting from San Diego in late January and the possibility existed for additional SUBSAT tests. A test plan (Appendix B) was devised for rendezvous with the DOLPHIN off San Clemente Island with NOSC's Box L boat as the surface vessel. The DOLPHIN would proceed to make a series of straight-line passes designed to pass directly beneath the Box L boat. NOSC civilian personnel aboard both boats would originate and receive the slow-scan transmissions at various points along each pass.

Equipment installation on the Box L and DOLPHIN was completed by 21 January. The DOLPHIN setup was very similar to that on SEACLIFF, with camera, monitor, recorder, and Robot 400 being brought aboard and interfaced with each other and the DOLPHIN's ATM504A UQC. Since the Box L had no UQC, an ATM504A was installed there in addition to the slow-scan equipment. Two SP23LT conical transducers, one with baffle and one without, were taken aboard. Using each transducer at depths of 20 and 200 ft would allow four different receiving conditions to be tested. A 4- to 6-kHz noise source was brought aboard Box L to serve as a beacon for DOLPHIN to align itself on prior to beginning a run. In addition, a 9-kHz acoustic pinger system was installed aboard Box L and DOLPHIN. Prior synchronization of these units with WWV would, in principle, allow continuous measurement of slant range between these two platforms.

Box L left San Diego on 24 January for Wilson Cove, San Clemente Island, where it spent the night. DOLPHIN left San Diego with NOSC SUBSAT personnel aboard later that day for its rendezvous with Box L the next morning off San Clemente Island. Box L left Wilson Cove at 0600, 25 January and rendezvoused with DOLPHIN off the southeast coast of San Clemente Island. DOLPHIN dived in 2620 ft of water at 0825.

At 0923 DOLPHIN was at one-half test depth, the desired operating depth, and began her first run. The actual test depths of DOLPHIN are classified and therefore all depths are referred to here as fractions of test depth. At 1000 it became evident to DOLPHIN personnel that DOLPHIN was not on the right course, and she requested Box L to put the broadband noise source in the water. At 1020 a second run was begun and two slow-scan transmissions were made. Since the slant range to DOLPHIN was opening rather than closing, this run was aborted after the second transmission. At 1045 DOLPHIN turned to begin its third run. Four video transmissions were made and again indications were that the range was opening rather than closing, since the transmission which was supposed to have occurred at a horizontal range of 0 ft actually occurred at a horizontal range in excess of 5000 ft. Two more runs were attempted, the second of these at one-quarter test depth. Although the CPA of these runs came closer to directly below the Box L, it was evident from voice range marks and the variation of the received signal strength that even these runs occurred at a considerable horizontal offset. The test ended at 1310.

A total of 13 slow-scan transmissions were made and received during the DOLPHIN tests. All transmissions were received with the baffled hydrophone at a depth of 200 ft, since there were not enough close-in runs to compare different hydrophones and depths. Although a TV camera was provided aboard the DOLPHIN, all transmissions were from pre-recorded tape (see Procedure B, Appendix A).

Post-exercise debriefing of personnel aboard DOLPHIN revealed that neither the 9-kHz pinger nor the 4- to 6-kHz noise source could be used as intended. Throughout the exercise no valid range reading could be obtained from the 9-kHz pinger, and the only range information available was from intermittent and relatively inaccurate oral time marks. The broadband noise source apparently suffered from multipath, and this – coupled with other noise sources in the vicinity (i.e., a fishing boat) – led to grossly inaccurate bearings on the first three passes. The last two passes apparently began on the proper headings, but from the measured ranges near the end of the runs it was apparent that DOLPHIN did not pass directly beneath Box L. Thus, just as in the SEACLIFF experiment, most acoustic transmissions from DOLPHIN were at angles far from the vertical, that is, far from the main lobe of the sending and receiving transducers.

3. RESULTS

3.1 EXAMPLES OF SUBSAT VIDEO

A total of 26 video transmissions, each consisting of a number of pictures, were sent and received during the DOLPHIN and SEACLIFF operations. Although each picture was "received" in the sense that observing the monitor indicated the presence of a slow-scan picture, most of the pictures suffered from distortion and were severely degraded below laboratory quality (see fig. 4). The primary source of distortion was loss or displacement of horizontal lines. This effect has been seen previously in both the CUTLINK experiments (Ref. 3) and amateur radio transmission (Ref. 7). Both of these references attribute line loss or displacement to multipath arrivals that affect the line sync signal. In our experiments the severity of line sync problems varied widely. In a few worst-case examples, half the lines were missing, resulting in a picture highly compressed in the vertical direction. In the best pictures (e.g., fig. 8b) only a single line displacement occurred out of 120 transmitted lines. The LOFARGRAM analysis of the next section also shows the effects of multipath on the received power spectrum.

Commenting on his CUTLINK results, Mr. Guthals of Ball Brothers Research Corporation noted that in their slow-scan images "distortion was displayed in the form of ghost images, waviness, line sync irregularities and granulation" (Ref. 3). It is interesting to note that aside from "waviness," all these effects were noted during our experiments. Next to line sync irregularities, graininess was the most persistent distortion observed in our pictures. Graininess is generally attributed to a low signal-to-noise ratio. The LOFARGRAM analysis below indicates that in our case the "noise" is probably signal multipaths. Just as in photography, the effect of graininess is to lower resolution. Unlike line sync irregularities, which produce an abrupt and total loss of information (as far as the eye is concerned), graininess causes a gradual deterioration as the signal-to-noise ratio degrades. Ghost images, also caused by multipath in time synchronization with the main signal, were barely in evidence in some of the pictures and proved the least objectionable of the various distortions.

Figures 5a, 5b, and 5c are SUBSAT pictures received aboard Box L during the second transmission of the third pass while DOLPHIN was at one-half test depth. Figure 5a, the gray scale, shows almost no sync problems but is considerably more grainy than the original (see fig. 4a) as are 5b and 5c. The girl, fig. 5b, shows numerous line sync problems due to an early sync trigger. Indeed, in the line tear near the middle of the picture the actual sync pulse appears as a block line segment about one-quarter the way across the screen. Early sync triggers are the major line sync irregularities in figs. 5a and 5b, though some jitter due to late sync triggering is evident upon close inspection.

(a) Gray scale (b) Girl (c) Test pattern

Figure 5. Pictures from DOLPHIN at one-half test depth.

Figures 6a, b, and c are the received video recorded during DOLPHIN's fifth pass when she was at one-quarter test depth. Note the generally improved picture quality, especially the decreased graininess. It is not clear whether the decreased depth or a fortuitous decrease in lateral range accounted for the superior imagery. Some ghosting, evidenced by faint vertical lines near the left edge of figure 6b, is apparent.

(a) Gray scale (b) Girl (c) Test pattern

Figure 6. Pictures from DOLPHIN at one-quarter test depth.

Figure 7 is gray scale received aboard MAXINE D and transmitted during SEACLIFF's fourth transmission, when she was on the bottom at 3755 ft. Although this picture exhibits sync problems and granulation, it is the best video obtained from so great a depth.

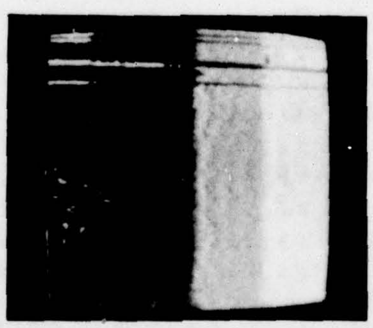
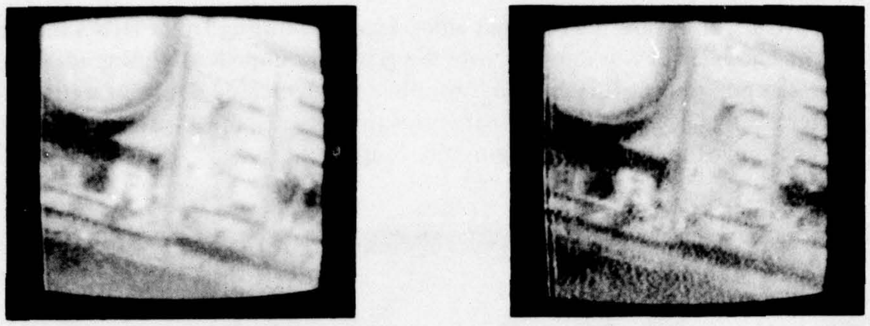


Figure 7. Gray scale from SEACLIFF at 3755 ft.

Figures 8a and b show live camera video sent from SEACLIFF from a depth of 2000 ft according to procedure C of Appendix A. Figure 8a is the picture as sent from the SEACLIFF. It shows a portion of the SEACLIFF's sonar screen and electronics console and was produced from the tape aboard the SEACLIFF, which recorded the locally generated live camera video. Figure 8b is this same scene as received aboard MAXINE D. This picture



(a) SEACLIFF. (b) MAXINE D.

Figure 8. Live camera video from SEACLIFF at 2000 feet.

exhibits only one line sync problem plus very slight granulation and ghosting. Comparison with the locally recorded frame, fig. 8a, shows that very little visual information has been lost. Fig. 8b represents the highest quality acoustically transmitted picture observed during the SEACLIFF or DOLPHIN experiments.

3.2 LOFARGRAM ANALYSIS

All cassette tapes of received video during both experiments, as well as the tapes of live camera video were subjected to LOFARGRAM analysis. Both problems with the hardware, such as excessive tape recorder flutter, and problems with acoustic propagation can often be detected by such an analysis.

Figure 9a is a LOFARGRAM of Procedure D, the GREY SCALE transmission by SEACLIFF from a 1000-ft depth. This figure is the analysis of the locally recorded signal aboard SEACLIFF, i.e., the video prior to entering the acoustic path.

Since GREY SCALE is a sync pulse (1200 Hz) plus four other discrete frequencies, it might be expected that the LOFARGRAM would consist of the five discrete lines corresponding to these frequencies. What is actually observed is five frequency bands; each band is split into equally spaced components modulated by an envelope function which decays outwards from the center of each band. A little thought reveals that the splitting is due to the analysis of a series of identical slow-scan lines, i.e., the splitting occurs at the line rate of 15 Hz. The envelope function is a $(\mathrm{sinc})^2$ function having a width inversely dependent on the duration of the individual frequency burst. Note the envelope of the 5-msec sync tone is much wider than that associated with any of the 16-msec GREY SCALE tones.

Figure 9b is a LOFARGRAM of the same transmission represented in fig. 9a but as received and recorded aboard the MAXINE D. Figure 9b shows obvious amplitude variation throughout in the form of many white, nearly horizontal interference bands, which are best seen by viewing the figure edge-on from the side. These interference regions are characteristic of "selective fading," which is caused by destructive multipath interference. Although the selective fading was most evident in fig. 9b, because of the simple and repetitive nature of its video content, it was noted on most of the DOLPHIN and SEACLIFF LOFARGRAMS, indicating that multipath effects were a main factor in degrading picture quality.

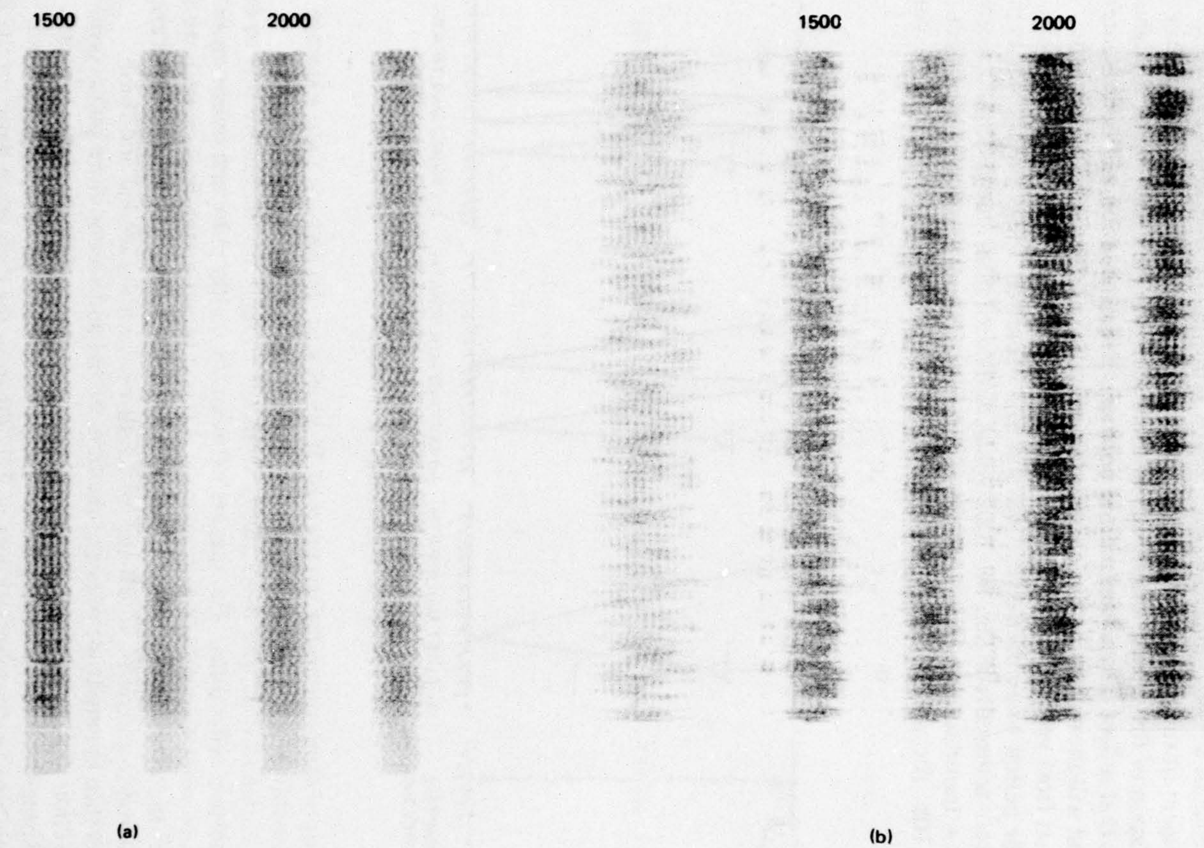


Figure 9. LOFARGRAM of GRAY SCALE. (a) as generated by Robot 400. (b) as received aboard MAXINE D.

3.3 SURFACE-BOTTOM MULTIPATH

The presence of a 9-kHz pinger aboard the Box L during the DOLPHIN experiment allowed measurement of the normal-incidence bottom reflection coefficient. This in turn allows the calculation of the relative magnitude of the direct-path slow-scan signal to higher order multipaths that reflect off the surface and bottom. This calculation will be presented in this section and will show that the direct-to-multipath ratio can degrade rapidly as the direct path departs from vertical.

During the period when the 9-kHz pinging was in operation, the geometry was as in fig. 10a. Pings were transmitted from the 200-ft-deep baffled conical transducer and received by another conical transducer near the surface and recorded. Figure 10a shows the direct path, while figs. 10b, 10c, and 10d show multipaths with single, double, and triple bottom reflections.

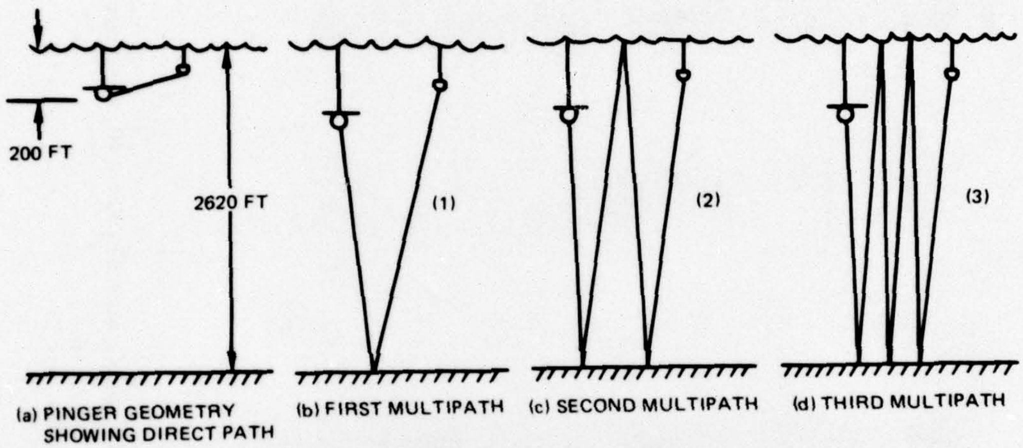


Figure 10. 9-kHz pinger geometry.

A segment of tape containing in excess of 20 pings was played back onto a storage scope. The horizontal sweep was triggered on the direct-path arrival. Figure 11 is the resulting storage-scope record. The three pulses, from left to right are the returns due to one, two, and three bottom reflections. The spacing between the center pulse and pulses on either side corresponds to twice the 2620-ft water depth. After subtracting the background, we find the amplitudes of the three pings to be in the ratio 4.38:1.13:0.348. The decibel difference between the first and second is 11.77 dB and 10.22 dB between the second and third.

The difference in amplitude between the first-second and second-third pulses is due to a surface reflection loss, a round trip from surface to bottom to surface, and a bottom reflection loss. Using the known depth and an absorption coefficient of 0.8 dB/kiloyard, we calculate a combined surface-bottom loss of 2.97 dB from the difference between the first and second pings and 5.28 dB between the second and third pings, yielding an average of 4.13 dB for the combined normal-incidence bottom and surface reflection losses. Considering the glassy seas experienced during the DOLPHIN experiment, this figure agrees well with coastal type bottom loss measurements (Ref. 6).

By means of the transducer directivity response and the measured bottom loss, the transmission loss for the direct path or any multipath can be computed for the SUBSAT geometry. In particular, we will calculate the signal-to-noise ratio between the direct path

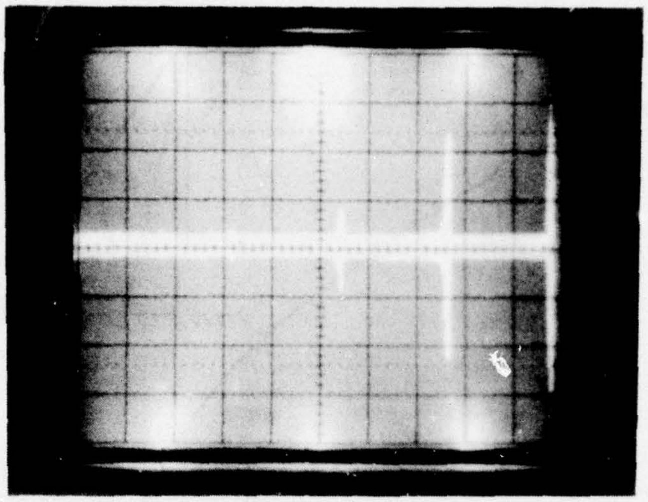


Figure 11. Storage scope record at 9 kHz. Pings 0.5 sec per division. Figure shows direct path and three lowest order multipaths.

and the multipath arising from a single reflection off the surface and bottom. The calculation was done for a combined surface bottom loss of 4.13 dB (assumed independent of angle) at 10 kHz for a slow-scan source near the bottom transmitting to a near-surface receiver. Although these conditions do not apply directly to either experiment, they serve to illustrate the effect of rapidly increasing multipath with horizontal offset. Figure 12 is the result of this calculation and shows the rapid dropoff of the signal-to-noise ratio as the direct path departs from the vertical (i.e., as the horizontal offset increases). In order to maintain a signal-to-multipath level sufficient to yield reasonable picture quality (10 dB, for example) it is necessary to keep the vertical angle less than about 30 deg. Control over horizontal offset was not possible during the SEACLIFF and DOLPHIN experiments and leads us to conclude that multipath contributed to the observed degradation in picture quality.

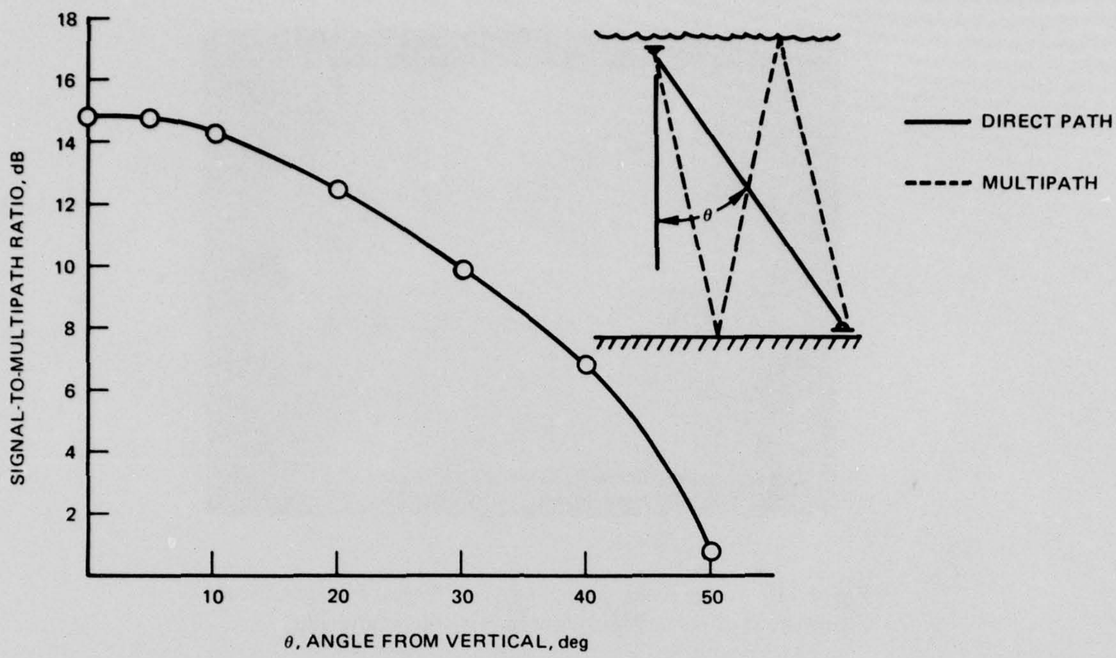


Figure 12. Signal to multipath ratio as a function of angle from the vertical.

4. CONCLUSION

The FY 77 SUBSAT experiments presented herein have shown the feasibility of transmitting 7200-baud acoustic slow-scan television using off-the-shelf equipment to generate and receive the slow-scan video in conjunction with existing UQC gear. The cost of the slow-scan equipment was approximately $1000 per transmitting or receiving installation. Equipment installation can be accomplished within an hour by simple cable interconnection. No modification of the UQC is necessary nor is its usual voice function disabled. In 26 separate acoustic video transmissions during the SEACLIFF and DOLPHIN tests no hardware failures were encountered.

All of the acoustic video transmitted from depth was received on the surface; received in the sense that from the marking of the video monitor it was clear that a video transmission was occurring. However, most of the received transmissions were noticeably degraded compared to the transmitted picture quality, the most persistent problems being line sync failures and granulation. Evidence gathered during the experiments suggests that the observed image degradations were due to a low signal-to-multipath ratio, which in turn was caused by a large horizontal offset between sending and receiving platforms.

The FY 1978 SUBSAT program, already underway, will be directed at obtaining additional data under more carefully controlled conditions. In particular it will attempt to show what is currently predicted from the FY 1977 experiments: that useful acoustic slow-scan imagery can be transmitted reliably, provided that undue horizontal offsets between sending and receiving platforms can be avoided. Such a demonstration would validate the SUBSAT hardware approach and indicate that a video imagery capability can be added to existing UQCs at modest cost by using off-the-shelf units.

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APPENDIX A-SLOW-SCAN TV TEST OPERATING INSTRUCTIONS

A. TO SEND VOICE AT ANY TIME

1. Turn TRANSMIT SELECT on Robot to VOICE.
2. Use UQC as usual.

B. TO SEND VIDEO FROM TAPE*

1. Make sure cassette recorder is on and TEST TAPE is rewound and ready. If not turn POWER (T 1) on then STOP (T 11) then EJECT (T 12) and insert TEST TAPE. Close lid and hit REWIND (T 7) until tape is rewound. Hit STOP.
2. On cassette recorder make sure CRO_2 (T 3) is down and DOLBY (T 2) is up.
3. Adjust OUTPUT (T 5) on cassette recorder to match red index.
4. On Robot make sure DISPLAY (R2), POWER (R 4) and MEMORY INPUT (R 5) toggles are up and MEMORY INPUT (R 7) switch is at TAPE.
5. Make sure WIDTH (R 10), RECEIVE CONTRAST (R 9) and RECEIVE BRIGHTNESS (R 8) on Robot are pointing to red index.
6. Turn monitor on and align to red indices on all front panel controls.
7. You are now ready to send video. To send video hit UQC mike button (push to talk button must be held on for duration of video transmission) turn Robot TRANSMIT SELECT (R 1) to TAPE and depress PLAY (T 9) on tape recorder. Pictures will appear on monitor in a few seconds.
8. Terminate video by pressing STOP (T 11) on cassette recorder and turning TRANSMIT SELECT (R 1) on Robot to VOICE (UQC normal operation is now enabled).
9. Rewind tape by pressing REWIND (T 7) on cassette recorder and STOP when rewound.

C. TO SEND VIDEO FROM CAMERA WHILE RECORDING**

1. Make sure a RECORD TAPE is in cassette recorder and recorder is stopped. If not depress STOP (T 11) then EJECT (T 12) and insert RECORD TAPE. Do not rewind RECORD TAPES. Use RECORD TAPES in indicated order as needed.
2. Make sure on cassette recorder POWER (T 1) and CRO_2 (T 3) are down and DOLBY (T 2) is up.
3. Align LEFT RECORD LEVEL (T 4) slide control on cassette recorder to red index.
4. On camera make sure POWER is on, ALC is ON and SYNC is LINE.
5. Make sure monitor is on and all front panel controls are aligned to red indices.

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*Steps 1 through 9 are required for initial tape transmissions. For each subsequent tape transmission only steps 7 through 9 are required provided that only voice transmissions have occurred since last tape transmission.

**Steps 1 through 12 are required for initial transmissions from camera. For each subsequent transmission from camera only steps 8 through 12 are required provided that only voice transmissions have occurred since last camera transmission.

6. On Robot adjust SNATCH CONTRAST (R 13) and SNATCH BRIGHTNESS (R 12) and WIDTH (R 10) to red indices.
7. Make sure POWER (R 4) and MEMORY INPUT (R 5) toggles are up, DISPLAY (R 2) toggle down and MEMORY INPUT (R 7) on CAMERA.
8. Point camera at scene and adjust its LENS for sharpest image on monitor. Adjust Robot SNATCH BRIGHTNESS (R 12) for good overall brightness on monitor. Adjust SNATCH CONTRAST (R 13) for most pleasing picture.
9. You are now ready to send and record camera video. To do this depress RECORD (T 6) and PLAY (T 9) simultaneously on cassette recorder, turn TRANSMIT SELECT (R 1) to MEMORY and hit UQC mike button (push to talk button must be held on for duration of video transmission).
10. If necessary adjust LEFT RECORD LEVEL (T 4) to indicate 50% of VU meter (T 13).
11. Terminate video by hitting STOP (T 11) on cassette recorder and changing TRANSMIT SELECT (R 1) on Robot to VOICE. (UQC normal operation is now enabled.)
12. Do not rewind RECORD TAPE.

D. <u>TO SEND GRAY SCALE WHILE RECORDING*</u>

1. Make sure a RECORD TAPE is in cassette recorder and recorder is stopped. If not depress STOP (T 11) then EJECT (T 12) and insert RECORD TAPE. Do not rewind RECORD TAPES. Use RECORD TAPES in indicated order as needed.
2. Make sure on cassette recorder POWER (T 1) and CRO_2 (T 3) are down and *DOLBY (T 2) is up.*
3. Align LEFT RECORD LEVEL (T 4) slide control on cassette recorder to red index.
4. On Robot make sure DISPLAY (R 2), POWER (R 4) and MEMORY INPUT (R 5) toggles are up.
5. Make sure monitor is on and all front panel controls are aligned to red indices.
6. You are now ready to send and record gray scale video. To do this depress RECORD (T 6) and PLAY (T 9) simultaneously on cassette recorder, turn TRANSMIT SELECT (R 1) to MEMORY and hit UQC mike button (push to talk button must be held on for duration of video transmission).
7. If necessary adjust LEFT RECORD LEVEL (T 4) to indicate 50% of VU meter (T 13).
8. Terminate video by hitting STOP (T 11) on cassette recorder and changing TRANSMIT SELECT (R 1) on Robot to VOICE. (UQC normal operation is now enabled.)
9. Do not rewind RECORD TAPE.

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*Steps 1 through 9 are required for initial transmissions of gray scale. For each subsequent transmission of gray scale only steps 6 through 9 are required provided that only voice transmissions have occurred since last gray scale transmission.

APPENDIX B – TEST PLAN FOR SUBSAT DOLPHIN OPS – 19 JAN 1976

1. PURPOSE – The purpose of this test is to investigate what conditions if any, are suitable for transmitting slow-scan video over a standard UQC from a submerged platform to a near-surface transducer. Transducer depth, d, transducer baffling, and horizontal offset will be varied to ascertain what conditions are necessary for good video quality.

2. EQUIPMENT – Video will be transmitted by the submerged platform (DOLPHIN) and received by the surface support craft (BOX-L). NUC Code 6511 will provide and interconnect its equipment to the UQC's aboard DOLPHIN and BOX-L. Each installation weighs approximately 35 lb, occupies 2 cu ft and draws 0.7 A of 115 VAC. NUC Code 2563 is requested to provide aboard BOX-L: (1) UQC with TIPE option, (2) UQC compatible transducer with removable baffle capable of being deployed at either 20 ft or 200 ft, (3) a secondary method (besides UQC TIPE) for allowing DOLPHIN to ascertain slant range to BOX-L, and (4) a method for allowing DOLPHIN to obtain bearing of BOX-L.

3. MEASUREMENT RUNS (See fig. B-1) – Each measurement run will take place with DOLPHIN at one-half test depth. For each run DOLPHIN will start at a horizontal range somewhat in excess of 2000 ft. It will obtain bearing to BOX-L and come about to heading so as to pass vertically beneath BOX-L. It will then proceed at 2 kt on this heading until it has completed sending five video transmissions. Video transmissions will be initiated at horizontal ranges of 2000 ft, 1000 ft, minimum range, 1000 ft and 2000 ft. As each of these points is passed, the video operator will announce over UQC the run and horizontal range. BOX-L and DOLPHIN will then terminate any acoustic transmissions. BOX-L will then signal Morse "R" (short-long-short). Upon receipt of "R" video operator aboard DOLPHIN will transmit approximately 1 minute and 20 seconds of video (three repetitions of three slow-scan frames) from video cassette. DOLPHIN operator will signal BOX-L by UQC voice at end of transmission. BOX-L will acknowledge and resume transmitting ranging information while DOLPHIN continues on to next transmission point. At the end of each run DOLPHIN will come about, hover, and wait for BOX-L to announce COMEX of run. After announcing COMEX of next run, BOX-L will initiate short noise-source transmission so that DOLPHIN can come to exact heading for this run, after which DOLPHIN commences run. The runs are:

ALPHA:	Transducer hung 200 ft below BOX-L with baffle.
BRAVO:	Transducer hung 20 ft below BOX-L with baffle.
CHARLIE:	Transducer hung 20 ft below BOX-L w/o baffle.
DELTA:	Transducer hung 200 ft below BOX-L w/o baffle.

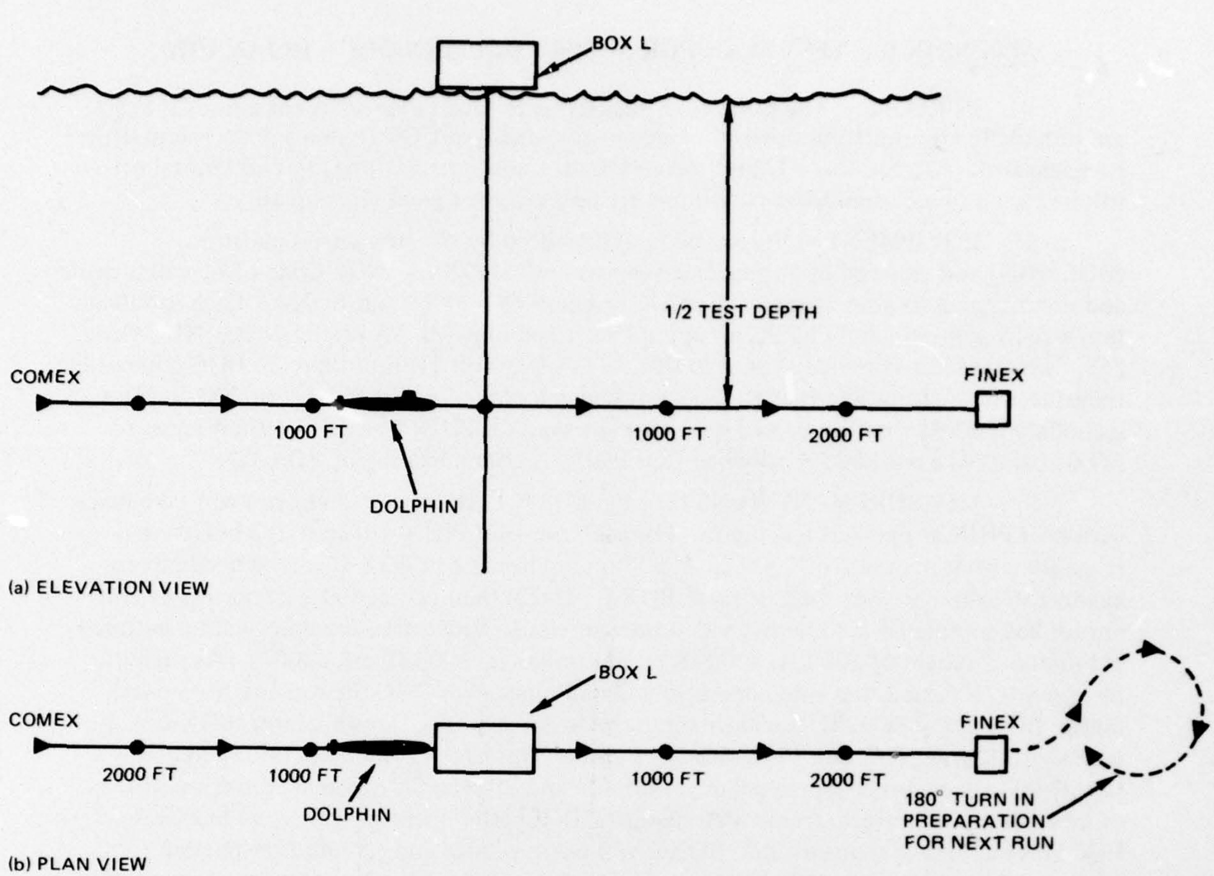

Figure B-1. Run geometry.