NAVY EXPERIMENTAL DIVING UNIT

TECHNICAL REPORT NO. 3-97

INTELLIGIBILITY ASSESSMENT OF EBS-II DIVER COMMUNICATIONS USING AN AMRON COMMUNICATION AMPLIFIER WITH NITROX AND HELIOX BREATHING MEDIUMS

NAVY EXPERIMENTAL DIVING UNIT

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In January and March 1997, manned dives were conducted at the Navy Experimental Diving Unit (NEDU) to test the intelligibility of the EBS-II communication system using a new, candidate, AMRON communication amplifier. The goal was to gather data on the round-robin intelligibility of the communication system while using nitrox and heliox breathing mediums and to use this data to support an intelligibility recommendation for the amplifier.

Objective and subjective evaluation methods were used to determine intelligibility. The first dive series tested intelligibility using nitrox at 100 fsw, the other using heliox at 300 fsw. During each series, two versions of the MK-24 microphone were tested, type A and type B.

The AMRON communication amplifier produced acceptable round-robin intelligibility results in the nitrox mode. Intelligibility using the type B microphone was at least as good as with the type A microphone.

In the heliox mode, using the helium speech unscrambler (HSU), the amplifier produced acceptable diver-to-topside and topside-to-diver intelligibility results but failed to produce acceptable diver-to-diver results. In this mode the type B microphone provided better intelligibility than the type A microphone.

Based on the findings of this report, it is recommended that the AMRON Model 2825/24/26 two-diver communications amplifier, with helium speech unscrambler (HSU), be approved for use with the EBS II Divers Communications Umbilical, the MK-24 FFM Piezoelectric microphone (types A and B), and the AN/PQS-2A Headset.

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INTRODUCTION

There is a need to provide intelligible and reliable round-robin diver communication to 300 fsw and shallower using systems currently deployed, and expected to be deployed, to Naval Explosive Ordnance Disposal (EOD) units.

The currently deployed EOD Emergency Breathing System Type II (EBS II) has a communication system that comprises four main components; a surface communications amplifier, diver headset, diver microphone and communication cable. The current Approved for Navy Use (ANU) HYDROCOM surface communication amplifier is no longer in production and a new amplifier must be identified and tested. The other system components must be verified to work adequately with this new amplifier to depths of up to 300 fsw using both nitrox and heliox breathing mediums.

Recent manned testing[1] at the Naval Diving and Salvage Training Center (NDSTC) using the discontinued HYDROCOM amplifier verified acceptable round-robin intelligibility performance of all EBS II communication system components to depths of 150 fsw using a nitrox breathing medium. 300 fsw manned heliox dives done at the same time verified acceptable diver-to-topside and topside-to-diver performance using these same components. Having verified that the individual system components can provide acceptable performance, an alternate communication amplifier can now be integrated into the system and it's performance evaluated.

An incremental step in providing an operational level of communication for the EBS II systems was to first evaluate round-robin communication system performance at 100 fsw. This is the deepest decompression stop allowed for EOD divers using the MK-16 MOD 0 UBA with a nitrox breathing medium. For this evaluation it was not required that the communication amplifier's helium speech unscrambler (HSU) electronics be used. A favorable recommendation will allow EOD units to use this amplifier for EBS-II nitrox diving. The follow on step was to test the same communication system with a heliox breathing medium at 300 fsw, only this time the amplifier's HSU electronics is used to provide intelligible speech.

OBJECTIVES

This test report documents two, manned, in-water dive series conducted at different times at the Navy Experimental Dive Unit (NEDU). The first dive series was conducted at a depth of 100 fsw using a nitrox breathing medium. The second dive series was conducted using the same components at a depth of 300 fsw with a heliox breathing medium.

The objective of both dive series was to gather data on the round-robin intelligibility of the EBS-II communication system using a new candidate communication amplifier and two versions of the diver microphone. This data was used to support a recommendation for the amplifier.

EVALUATION METHODS

The manned dives were conducted under two NEDU test plans[2,3] in the wet pot of the Ocean Simulation Facility (OSF). Testing evaluated the round-robin intelligibility of the EBS-II communication system using a modified AMRON model 2825/24/26, two diver communication amplifier with an HSU. A standard AMRON model 2400-28 light duty headset with a boom microphone was used by topside. The AMRON communication amplifier was modified so that it would work with the preamplified MK-24 microphone. An internal dc power supply circuit was added to each microphone channel to provide the correct bias voltages to the microphone.

Each diver used a MK-16 MOD 0 underwater breathing apparatus (UBA) with a MK-24 full face mask (FFM). In this configuration the MK-24 microphone is screwed into the switchover block of the FFM and each speaker element of an AN/PQS-2A sonar headset is secured over the diver's ears using a skull cap. The sonar headset is used for voice communications to meet the EOD low magnetic signature requirements. A detailed description of the headset and the MK-24 microphone is found in Appendix E.

All divers were young adult, male or female divers with current audiograms and normal hearing. All were qualified Navy divers experienced in the use of diving equipment. There were no common divers between the heliox and nitrox dive series. Divers wore wetsuits for both dive series and the water was no less than 70° F. Wetsuit hoods were not worn so that the headset speaker elements could be placed over the divers ears with only the skull cap material in between (with one exception for the heliox dives). Divers remained submerged throughout the tests and sat or stood in a comfortable position with the best possible lighting while performing the test procedures. Prior to testing each diver was instructed to ensure they had adequate visibility through the FFM to conduct the tests.

For these tests each diver had a separate 4-wire communication cable connecting their microphone and headset to an individual channel on the communication amplifier. This is consistent with EOD's plan to allow only single diver communication on the cable assembly currently deployed with the EBS-II. A full length EBS-II umbilical comprising a 4-wire communication cable, an air hose and a strength member was used between each diver and the OSF trunk. Permanently installed OSF cabling was used to connect each of the diver communication channels from the OSF trunk electrical penetrator to the breakout panels located on the medical deck. The AMRON communication amplifier was setup on the medical deck and wired into the breakout panels. There were no observed problems during the testing, however, no attempt was made to measure or determine the effects of externally generated EMI on this communication system.

A digital audio tape (DAT) recorder was connected to the tape output jack of the amplifier for purposes of recording all diver conversation. The line output of the DAT recorder was connected to the OSF's Tethered Diver Communication System (TDCS). This allowed control room personnel to directly monitor diver communications produced by the EBS-II system components via headset or overhead speaker. They were not able to talk directly to the divers. A DAT player was connected to the tender headset microphone input jacks to allow topside to play pre-recorded DAT tapes to the divers for the intelligibility tests.

Because each EBS-II cable assembly was originally designed to support communications for two divers it has two sets of microphone and headset connectors at the diver end. For these dives only one set of connectors was used and the other set was waterblocked using dummy mating connectors.

For each dive series, testing was done with two types of MK-24 microphones; the existing, currently issued microphone (type A) that was evaluated in a previous manned intelligibility study[1] and the same style microphone with a new preamplifier design (type B). The type B microphone was tested as a possible replacement for the type A microphone. Both microphones were tested in the same way except for additional scrambled helium speech data that was collected at the end of each dive for the type B microphone.

Speech intelligibility was evaluated using both objective and subjective methods. Objective evaluation methods included use of the Modified Rhyme Test (MRT) and the Speech Perception in Noise (SPIN) test. Subjective evaluation methods included use of questionnaires, and post-dive evaluation of the DAT recordings that were made throughout the dives. A description of these methods follows.

MRT

The Griffith (1967) version of the MRT was used as an objective method for evaluating round-robin communication intelligibility between divers and topside for both dive series. It was chosen for its ease of administration and scoring, its stability with respect to learning effects, and because it requires minimal listener training. Although the MRT is not phonetically balanced and does not present words in a contextual format to represent everyday speech, it is efficient and useful because it requires perception of consonantal sounds (sounds that are difficult to transmit successfully) and are thus more important than vowels to intelligibility.

For diver-to-diver testing, each diver reads a different word list to his partner who responds on the appropriate response sheet. The rate of reading is controlled at one word every six seconds by a cuing tape played by topside. For topside-to-diver testing, topside plays a tape of a word list to both divers simultaneously who respond on the appropriate response sheet. Diver-to-topside testing was not conducted during the dive series. Instead, diver-to-topside tests were conducted post-dive using selected

DAT recordings of the diver-to-diver MRTs. The topside listeners, six males and two females, were chosen from available civilians in the Diving and Life Support Division at Coastal Systems Station, Panama City. None had any significant previous experience with this type of diver communications and most had no diving experience at all. Each test subject was tested individually in a quiet room using the same headset as used by topside during the dives. The DAT was played at a volume adjusted to suit the needs of the subject and no filtering was applied during recording or playback of the DAT.

A number of different word lists and response lists were used during the testing. These lists were distributed among the tests so that no dive pair ever repeated a test using the same word list, response sheet combination. All test divers were given practice MRT sheets to familiarize themselves with the MRT test procedure prior to the dives.

An MRT reading list (appendix A) contains 50 monosyllabic words each. Talkers preface each test word on a reading list with the phrase "The word is _____." This procedure serves to alert the listener and allows the talker to adjust his voice level. Each listener responds on a response sheet (appendix A) matched to the word list. For each word on a word list, the listener has five possible words on the response sheet to select from. The listener then circles the word he hears from the five and goes to the next line. For each word list there are six different response sheets that each change the order of words within the set of possible responses to the corresponding word on the word list.

To determine the percent correct for the MRT tests, the following formula, which takes into account the 20% guessing factor, is used (Van Cott and Kinkade, 1972):

% correct = 2 x (number right - number wrong/4)

If a full reading list is not completed a correction factor is applied to the above formula so that:

% correct = (100/total number of words completed) x (number right - number wrong/4)

The intelligibility criteria for military voice communications systems is set forth in MIL-STD-1472D[4]. This standard sets 75% as the minimum acceptable intelligibility score when using the MRT as the evaluation criteria. This standard also indicates that a 75% score is not acceptable (too low) for operational equipment, however, the discontinued HYDROCOM Model UDC-225 communication amplifier was recommended for approval by NEDU[5,6] using this minimum scoring criteria and subsequently approved for Navy use by NAVSEA. For heliox diving, NEDU technical memorandum[7] indicates that NAVSEA has approved an MRT score of 60% as the minimum passing criteria for diver operational equipment. Therefore, the minimum acceptable MRT intelligibility criteria used for this testing was 75% for nitrox speech and 60% for heliox speech.

SPIN

A contextual only version of the SPIN test was also used for the 300 fsw heliox dives as an objective method for evaluating diver-to-diver and diver-to-topside intelligibility. The SPIN test was originally designed to assess hearing-impaired patients in a clinical setting. The original SPIN test employs 50 sentences in which the target word is either contextually related to the sentence, e.g., "The doctor gave the boy a shot." or contextually unrelated to the sentence, e.g., "He was discussing the lion". In general, the target words are fairly common and familiar words. The modified version of the SPIN test used only sentences where the target word was contextually related to the sentence. Contextual sentences, selected from the 8 SPIN lists, were recombined to form 4 modified SPIN lists with 50 contextual sentences each (appendix B). The modified version of the SPIN test was used to quickly get a large amount of contextual word intelligibility data so that a comparison could be made to the non-contextual word intelligibility data acquired during the MRTs. This testing was not conducted in noise as suggested by the name of the test.

For diver-to-diver testing, each diver reads the 50 sentences from a different SPIN list to their partner who writes the target word that is heard in the appropriate numbered blank on the response sheet. The rate of reading is controlled at one sentence every six seconds by a cuing tape played by topside. Topside-to-diver SPIN testing was not considered to be necessary since MRT results obtained during work up dives indicated very good topside-to-diver intelligibility. Diver-to-topside SPIN testing was not conducted during the dive series. Instead, diver-to-topside tests were conducted post-dive using selected DAT recordings of the diver-to-diver SPIN tests. The topside listeners were the same as used for the diver-to-topside post-dive MRTs. The SPIN reading lists were distributed among the tests so that no dive pair ever repeated a test using the same list.

No minimum acceptable intelligibility criteria is established for the SPIN test as modified and used in these tests. The SPIN scores were used only to rank the relative performance between test subjects and not as a pass/fail criteria for intelligibility. The calculation used for determining SPIN score was:

$$\% \text{ correct} = (\text{number right} / \text{total number of words completed}) \times 100$$

QUESTIONNAIRES

Subjective evaluation of topside-to-diver, diver-to-topside and diver-to-diver intelligibility was done using responses from questionnaires that were filled out by the divers and topside after each dive. Many of the questions came from a study on helium speech intelligibility[8], and were tailored to suit these tests. The questions probed perceptions of the communication system. The responses served to supplement the objective data from the MRT and SPIN tests, however, by themselves they can provide a very good subjective indicator of intelligibility. Test divers were given copies of the questionnaires prior to the dives so that they would know what to look for during the dives.

A six point scale (6 being best, 1 being worst) was used to rate different perceptual aspects of the system, such as background noise, level of speech distortion, clarity, and ability to understand individual words and conversation. Refer to questionnaire average response figures for lists of rated questions. Responses from questions 2, 3 and 4 provide the most direct subjective rating of speech intelligibility and a score of four or higher could be considered acceptable. For the heliox dives only, another question asks for a rating of confidence in using the communication system in that particular mode. A rating of four or higher could be considered acceptable here also. The other rated questions addressed background noise and comparative speech distortion which are symptoms effecting speech intelligibility. Because of the nature of these questions and the rating scale it is more problematic to assign an acceptable rating level. For example, background noise could be obviously disruptive (i.e. inhalation noise in open-circuit mode) yet word and speech intelligibility could be acceptable. Generally speaking, a rating of 4 or higher would indicate that there is a higher probability of acceptable speech intelligibility but it is not necessarily a prerequisite.

There were also questions that invited written comments about which speech sounds came through best and worst, how the communication system effected the speech, and what discomfort might have been experienced. For a list of these questions refer to Appendices C and D.

DAT RECORDINGS

Throughout all dives, DAT recordings were made of all communications. These tapes were used for both subjective and objective post-dive evaluation of round-robin communications. In particular, objective diver-to-topside MRT and SPIN test results were obtained by playing the tapes of diver-to-diver MRT and SPIN tests to post-dive test subjects who responded on the appropriate test response sheets.

The DAT tapes also provide a valuable means of subjective post-dive evaluation of round-robin intelligibility during normal conversation that occurred throughout the dives. This ranged from diving related procedural conversation to casual social conversation. It is easy to get an idea of the level of intelligibility during these conversations by listening to the response of the listener after being spoken to. If the listeners respond in a logical fashion and the talker is not asked to repeat himself then intelligibility could be considered adequate. If the talker is often asked to repeat himself then the intelligibility could be considered poor. Post-dive test subjects who listen to these tapes would be qualified to fill out diver-to-topside questionnaires thus adding to the evaluation data base. As with the questionnaires, these tapes supplement the objective data from the MRT and SPIN tests, however, by themselves they can be a very good subjective indicator of intelligibility.

PROCEDURES

100 FSW NITROX DIVES

The 100 fsw nitrox dive series for manned intelligibility testing of the EBS II communication system was conducted from 22 through 24 January 1997. This series comprised 8 bounce dives with bottom times of approximately 40 minutes. During each dive, the EBS-II communication system was tested in closed- and open-circuit modes. Switching between modes was made using the switchover block on the MK-24 FFM. Open-circuit nitrox gas was provided via the air hose in the EBS-II umbilical.

The first four dives were conducted using the type A microphone while the last four dives were conducted using the type B microphone. Eight qualified male divers were used for the type A microphone tests and seven for the type B after one diver dropped out due to sinus congestion. The same dive pairs were used for each microphone except that one diver had to dive twice for the type B microphone tests. No special effort was taken to secure an "all quiet" condition during these tests, however there were no overt noise problems. Each diver wore a wetsuit without a hood. Test conditions were the same for all dives.

The test procedure for each diver pair for both types of microphones was the same although different MRT reading lists and response sheets were used for each microphone. Testing was conducted as follows:

1. Closed-circuit mode; perform communication check, adjust diver and topside volumes.

2. Green diver reads a MRT word list to Red diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

3. Red diver reads a MRT word list to green diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

4. Topside plays tape of MRT word list to red and green divers who respond on their MRT response sheets.

5. Switch to open-circuit mode. Perform communication check, adjust diver and topside volumes.

6. Green diver reads a MRT word list to Red diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

7. Red diver reads a MRT word list to green diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

8. Topside plays tape of MRT word list to red and green divers who respond on their MRT response sheets.

9. Before the next dive each diver fills out the provided questionnaire.

300 FSW HELIOX DIVES

The 300 fsw heliox dive series for manned intelligibility testing of the EBS II communication system was conducted on 21 and 22 March 1997. These tests were conducted as Annexes 3 and 5 of a 300 fsw heliox saturation dive. Eight dives were conducted during this series at a depth of 296 fsw with bottom times ranging from approximately 60 to 90 minutes. During each dive, the EBS-II communication system was tested in closed-circuit mode using the AMRON communication amplifier with the HSU on. Open-circuit heliox was provided to the MK-24 as an emergency gas supply only.

The test plan called for the wet pot water temperature to be maintained at 40 degrees Fahrenheit during the 300 fsw dives and for the divers to be dressed in hot water suits. However, during the nitrox work-up dives it was found that noise from the hot water pump was being mechanically coupled to the wet pot and into the water where it was being picked up by the divers microphones. This noise sounded like an air leak and, while noticeable, was not bad enough to significantly impact intelligibility during the work-up dives. It was, however, considered to be excessive for purposes of the upcoming heliox test since it was not designed to evaluate the effects of external noise sources on intelligibility. The decision was made to increase the wet pot water temperature during the communications testing portion of the 300 fsw dive to at least 70 degrees Fahrenheit so the divers could wear wetsuits and the hot water pump would not be needed. Mr. Jerry Pelton (NEDU 03D) reported that this is the only time a diver microphone used in a communication study has picked up this much noise from the hot water pump. High microphone sensitivity and noisy pump bearings were discussed as possible explanations.

The first four dives were conducted on the first day using the type A microphone and the last four dives were conducted on the second day using the type B microphone. Six qualified male and 1 qualified female diver were used. During each of the four dive sets one diver had to dive twice. The intention was to repeat the same dive pairs for both the type A and B microphones tests, however, only one of the dive pairs remained the same. "All quiet" conditions were maintained throughout these tests.

There were two differences between the test conditions on the first and second day. On the first day two of the four bicycle ergometers were leaking air badly enough to be able to hear the bubble noise through the divers' microphones depending on the position of the diver in relation to the bikes. The air supply to these could not be lowered enough to reduce the bubble rate to an acceptable level so on the second day, prior to testing, the leaking units were removed from the water. Also, many divers commented that they were cold on the first day so on the second day the water temperature was increased by 5-8 degrees Fahrenheit. After this, all divers indicated they were comfortable.

As part of the procedures, there was an HSU familiarization and adjustment period for each diver prior to each set of MRT/SPIN tests. During this period, the diver designated to be the reader in the upcoming MRT/SPIN tests read some paragraphs from the supplied general reading material. While this diver was reading, the other diver (listener) instructed topside on how to adjust the HSU controls to give him what he considered to be the best intelligibility from the reading diver. Some divers provided a lot of direction on HSU adjustment while others provided little. The divers also got a chance to get familiar with the qualities of HSU speech during this period. The intention was to optimize diver-to-diver intelligibility.

The only difference between the test procedures for the type A and B microphones is that an additional diver-to-diver MRT test using scrambled helium speech was conducted for microphone Type B. To obtain accurate recordings of the scrambled helium speech produced by microphone Type B, the additional MRT was conducted using a Hydrocom communication amplifier with the HSU turned off. The non-reading divers for these tests were not required to respond to the word lists that were read. Testing was conducted as follows:

Type A Microphone

1. Divers enter the OSF wet pot and perform communication checks using AMRON communication amplifier with HSU on.

2. Red diver conducts HSU speech familiarization and adjustment period with Green diver reading paragraphs. Topside adjusts AMRON HSU controls for best intelligibility for Red diver.

3. Green diver reads a MRT word list to Red diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

4. Green diver reads a SPIN word list to Red diver who records his responses on the SPIN response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

5. Green diver conducts HSU speech familiarization and adjustment period with Red diver reading paragraphs. Topside adjusts AMRON HSU controls for best intelligibility for Green diver.

6. Red diver reads a MRT word list to Green diver who records his responses on the MRT response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

7. Red diver reads a SPIN word list to Green diver who records his responses on the SPIN response sheet. Reading rate is dictated by a cuing tape played to divers from topside.

8. Topside plays tape of MRT reading list to red and green divers who respond on their MRT response sheets.

9. Before the next dive each diver fills out the provided questionnaire.

Type B Microphone

1. Divers perform Type A microphone test procedure with Type B microphone installed in the MK-24 FFM.

2. Topside switches from AMRON to HYDROCOM communication amplifier, perform communication checks and adjust volumes.

3. Switch HYDROCOM HSU off. The INAC feature is also turned off.

4. Green diver reads a MRT reading list to topside for purposes of recording raw helium speech. Red diver does not response.

5. Red diver reads a MRT reading list to topside for purposes of recording raw helium speech. Green diver does not respond.

RESULTS AND ANALYSIS

100 FSW NITROX DIVES

Speech intelligibility results and analysis is divided into three sections; topside-to-diver, diver-to-topside, and diver-to-diver. Open- and closed-circuit modes are addressed in each section.

Note that the scores for diver number 4 were eliminated from all the MRT averages after it was learned that his hearing levels were less than acceptable.

1. Topside-to-diver

MRT Scores. Topside-to-diver speech intelligibility was objectively measured using the individual and combined average of MRT scores for the type A and B microphones (Figures 1 and 2).

A high degree of intelligibility was indicated with combined averages ranging from 89.1% in closed-circuit mode to 90% in open-circuit mode, a negligible difference. Typically one would expect the open-circuit scores to be reliably lower than closed-circuit because of breathing inhalation noise that occurs in open-circuit mode. However, it is apparent that most divers were able to effectively synchronize their breathing to maximize intelligibility. The reason for the low closed-circuit score for diver #5 may have been due to a fogged face mask which he was heard to comment about before the test or from other unknown distractions. Dive team #2 (divers #2 and #6) did not perform the open-circuit topside-to-diver MRTs due to time constraints.

As would be expected, since the diver microphone is not used in topside-to-diver communications, there is no significant difference in average scores between the type A and type B microphones during these tests. Neither microphone produced any observable background noise that might have interfered with topside-to-diver communication.

Questionnaire Ratings. Topside-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 3) for each question in open- and closed-circuit modes and for each type microphone. The average scores ranged from 3.8 on question 5 for the type A microphone in open-circuit mode to 6.0 on question 2 for the type B microphone in closed-circuit mode. A high degree of intelligibility was indicated with 70% of the scores 5.0 or higher and with only one score below 4.0.

The overall scores for the type A and B microphones were better in closed-circuit mode versus open-circuit mode which is to be expected due to the perceived effects of open-circuit inhalation noise on speech intelligibility. In closed-circuit mode the average scores for the type A and B microphones were essentially the same as would be expected since the microphone is not directly tested in topside-to-diver tests. In open-circuit mode, however, the averages for microphone type B improved over type A by an average of 0.6 (10%). This perceived improvement may be due to the divers being more familiar with testing on the second day and more experienced with breathing synchronization to minimize breathing noise interference with topside speech.

Diver	Mic. A	Mic. B
1	82.1	90.0
2	90.0	87.5
3	97.5	95.0
4	47.5	47.5
5	65.0	90.0
6	94.9	82.5
7	95.0	95.0
8	95.0	87.5
Average:	**88.5**	**89.6**
Mic. A&B Combined Avg:		**89.1**

FIGURE 1. TOPSIDE-TO-DIVER; NITROX CLOSED-CIRCUIT MRT TEST RESULTS (%)
Diver #4 scores not included in averages
Dive pairs: 1/5 (mic. a), 3/5 (mic. b), 2/6, 3/7, 4/8

Diver	Mic. A	Mic. B
1	85.0	91.1
2	-----	77.0
3	100.0	92.2
4	28.6	28.6
5	95.0	91.1
6	-----	84.7
7	92.2	94.8
8	90.4	81.6
Average:	**92.5**	**87.5**
Mic. A&B Combined Avg:		**90.0**

FIGURE 2. TOPSIDE-TO-DIVER; NITROX OPEN-CIRCUIT MRT TEST RESULTS (%)
Diver #4 scores not included in averages
Dive pairs: 1/5 (mic. a), 3/5 (mic. b), 2/6, 3/7, 4/8

Question	Mic. A closed-ckt	Mic. B closed-ckt	Mic. A open-ckt	Mic. B open-ckt
1	5.1	5.4	4.3	4.6
2	5.8	6	5	5.3
3	5.9	5.9	4.5	5.3
4	5.8	5.9	4.3	5.1
5	5.4	5.3	3.8	4.6

(Sample size = 8)

Key to rated questions; 1 - 5:

Question #1: How would you rate the background noise from topside?
Question #2: How would you rate the overall clarity of speech from topside?
Question #3: How would you rate your ability to understand single words from topside?
Question #4: How would you rate your ability to understand conversation from topside?
Question #5 How would you rate the level of speech distortion from topside compared to speech you hear on the surface in a normal conversation?

Key to answers: 1 is worst, 6 is best

1= extremely disruptive		1= extremely poor
2= obviously disruptive		2= poor
3= slightly disruptive	**OR**	3= not quite adequate
4= present but not disruptive		4= adequate
5= barely present		5= good
6= not present		6= excellent

FIGURE 3. TOPSIDE-TO-DIVER; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE

Questionnaire Comments. Written diver comments to the questionnaire are provided in Appendix C. These comments support the assessment of good topside-to-diver intelligibility as indicated by the other evaluation methods. It is clear from these comments that in open-circuit mode diver breathing noise interfered with good topside-to-diver intelligibility unless the divers properly synchronized their breathing while topside was talking.

DAT Recordings. Post-dive evaluation of DAT recordings also documents a high degree of intelligibility from topside-to-diver. During the course of normal conversation the topside speaker was rarely, if ever, asked to repeat himself.

2. Diver-to-topside

MRT Scores. No MRTs were conducted with topside test subjects during the dives. MRT scores were obtained with post-dive test subjects listening to selected DAT recordings of diver-to-diver MRT tests in both open- and closed-circuit modes for microphone types A and B (Figures 4 and 5). These test subjects used the same headset as used by topside during the dives. DAT recordings used for these tests were selected based on the diver-to-diver MRT test scores and the PI's judgment of which were the most intelligible. The talking divers and the MRT reading lists were different for each of the four tests; microphone A open-circuit, microphone A closed-circuit, microphone B open-circuit and microphone B closed-circuit. This means that a direct comparison of performance between microphones within a particular breathing mode or between breathing modes is difficult.

A high degree of intelligibility was indicated with combined averages ranging from 93.6% in closed-circuit mode to 91.1% in open-circuit mode, a negligible difference. In open-circuit mode divers were able to effectively synchronize their breathing to maximize topside intelligibility.

Questionnaire Ratings. Diver-to-topside speech intelligibility was subjectively measured using topside responses to five questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 6) for each question. The seven topside personnel used to provide these ratings were closely involved either directly with the intelligibility testing or with the general supervision of the dives. Each was able to monitor diver communications clearly enough via either a topside headset or overhead speakers to provide useful ratings. The ratings were provided based on interpretation of diver-to-topside intelligibility in open- and closed-circuit modes. No distinction was made between microphone types.

The average scores ranged from 3.4 for question 1 in open-circuit mode to 5.3 for questions 2 and 4 in closed-circuit mode. Good intelligibility was indicated for both open- and closed-circuit modes with higher scores for closed-circuit. For the questions directly related to speech intelligibility; 2, 3 and 4, the average scores clustered around 5.0 for both modes with no scores below 4.6. The effects of inhalation noise in

Topside listener	Mic. A	Mic. B
1	100.0	95.0
2	95.0	90.0
3	97.5	95.0
4	90.0	92.5
5	85.0	87.5
6	97.5	92.5
7	97.5	95.0
8	90.0	97.5
Average:	**94.1**	**93.1**
Mic. A&B Combined Avg:		**93.6**

FIGURE 4. DIVER-TO-TOPSIDE; NITROX CLOSED-CIRCUIT MRT TEST RESULTS (%)
Test results obtained post-dive using taped diver-to-diver MRT recordings
There were different divers reading the word lists for each type microphone

Topside listener	Mic. A	Mic. B
1	100.0	95.0
2	95.0	90.0
3	97.5	95.0
4	90.0	92.5
5	85.0	87.5
6	97.5	92.5
7	97.5	95.0
8	90.0	97.5
Average:	**94.1**	**93.1**
Mic. A&B Combined Avg:		**93.6**

FIGURE 5. DIVER-TO-TOPSIDE; NITROX OPEN-CIRCUIT MRT TEST RESULTS (%)
Test results obtained post-dive using taped diver-to-diver MRT recordings
There were different divers reading the word lists for each type microphone

Question	closed-ckt	open-ckt
1	5.0	3.4
2	5.3	4.6
3	5.1	4.9
4	5.3	4.7
5	4.6	3.6

(Sample size = 7)

Key to rated questions; 1 - 5:

Question #1: How would you rate the background noise from the diver?
Question #2: How would you rate the overall clarity of speech from the diver?
Question #3: How would you rate your ability to understand single words from the diver?
Question #4: How would you rate your ability to understand conversation from the diver?
Question #5: How would you rate the level of speech distortion from the diver compared to speech you hear on the surface in a normal conversation?

Key to answers: 1 is worst, 6 is best

1= extremely disruptive		1= extremely poor
2= obviously disruptive		2= poor
3= slightly disruptive	**OR**	3= not quite adequate
4= present but not disruptive		4= adequate
5= barely present		5= good
6= not present		6= excellent

FIGURE 6. DIVER-TO-TOPSIDE; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE
No distinction between microphones type A and B

open-circuit mode are evidenced by the scores for questions 1 and 5 that address background noise and comparative distortion. They are a full point (1.0) or more lower than in closed-circuit mode.

Questionnaire Comments. Written topside comments to the questionnaire are provided in Appendix C. These comments support the assessment of good diver-to-topside intelligibility as indicated by the other evaluation methods. It is clear from these comments that in open-circuit mode diver breathing noise interfered with good topside intelligibility unless the divers properly synchronize their breathing while talking.

DAT Recordings. Post-dive evaluation of DAT recordings also documents a high degree of intelligibility from diver-to-topside. During the course of normal conversation the topside speaker rarely, if ever, had to ask divers to repeat themselves.

2. Diver-to-diver

MRT Scores. Diver-to-diver speech intelligibility was objectively measured using the individual and combined average of MRT scores for the type A and B microphones (Figures 7 and 8).

The combined averages yielded results of 78.5% in closed-circuit mode and 74.4% in open-circuit mode. The low (<75%) score in open-circuit mode was likely due to problems with particular diver pairs being able to synchronize their breathing to minimize inhalation and exhalation noise. In open-circuit mode, dive pairs 2/6 and 4/8 consistently scored poorly regardless of microphone type whereas this was not the case in closed-circuit mode.

Individual averages for the different microphones indicated an acceptable degree of intelligibility for the type B microphone with a score of 83.2% in closed-circuit mode and 76.4% in open-circuit mode. The scores for the type A microphone fell just below the 75% intelligibility requirement (for nitrox speech) with 73.8% in closed-circuit mode and 72.3% in open-circuit mode. The average score for the type B microphone was 9.4% higher than that for the type A in closed-circuit mode and all but one of the individual scores were higher for type B. This is a reliable difference and is a likely indication of slightly better performance from the type B microphone even though this microphone was tested on the second day when the divers had more experience with the test procedures. In open-circuit mode the average score for type B was 4.1% higher and again all but one of the individual scores were higher for type B.

Questionnaire Ratings. Diver-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 9) for each question in open- and closed-circuit modes and for each type microphone. The low average was 2.5 on question 1 for the type A microphone in open-circuit mode. The

Diver	Mic. A	Mic. B
1	52.5	87.5
2	75.0	77.5
3	87.5	90.0
4	23.5	45.0
5	52.5	77.5
6	69.4	75.0
7	90.0	85.0
8	90.0	90.0
Average:	**73.8**	**83.2**
Mic. A&B Combined Avg:		**78.5**

FIGURE 7. DIVER-TO-DIVER; NITROX CLOSED-CIRCUIT MRT TEST RESULTS (%)
Diver #4 scores not included in averages
Dive pairs: 1/5 (mic. a), 3/5 (mic. b), 2/6, 3/7, 4/8

Diver	Mic. A	Mic. B
1	82.5	82.5
2	72.5	65.0
3	75.0	90.0
4	40.0	50.0
5	92.4	85.0
6	56.5	62.5
7	75.0	85.0
8	51.9	65.0
Average:	**72.3**	**76.4**
Mic. A&B Combined Avg:		**74.3**

FIGURE 8. DIVER-TO-DIVER; NITROX OPEN-CIRCUIT MRT TEST RESULTS (%)
Diver #4 scores not included in averages
Dive pairs: 1/5 (mic. a), 3/5 (mic. b), 2/6, 3/7, 4/8

Question	Mic. A closed-ckt	Mic. B closed-ckt	Mic. A open-ckt	Mic. B open-ckt
1	5.0	5.4	2.5	3.0
2	5.4	5.6	3.5	5.1
3	5.5	5.6	4.3	5.1
4	5.6	5.6	3.8	5.0
5	4.9	5.0	2.7	4

(Sample size = 8)

Key to rated questions; 1 - 5:

Question #1: How would you rate the background noise from the other diver?
Question #2: How would you rate the overall clarity of speech from the other diver?
Question #3: How would you rate your ability to understand single words from the other diver?
Question #4: How would you rate your ability to understand conversation from the other diver?
Question #5: How would you rate the level of speech distortion from the other diver compared to speech you hear on the surface in a normal conversation?

Key to answers: 1 is worst, 6 is best

1= extremely disruptive		1= extremely poor
2= obviously disruptive		2= poor
3= slightly disruptive	**OR**	3= not quite adequate
4= present but not disruptive		4= adequate
5= barely present		5= good
6= not present		6= excellent

FIGURE 9. DIVER-TO-DIVER; NITROX, AVERAGE OF RESPONSES TO QUESTIONNAIRE

high average of 5.6 occurred a number of times in closed-circuit mode; questions 2,3,4 for the type B microphone and question 4 for the type A microphone.

Good intelligibility was indicated in closed-circuit mode for both microphones. For the questions directly related to speech intelligibility; 2, 3 and 4, the average scores were between 5.4 and 5.6 while those dealing with background noise and comparative speech distortion were between 4.9 and 5.4.

In open-circuit mode the average scores indicate better intelligibility from the type B microphone. The scores for questions 2,3 and 4 are no lower than 5.0 while for the type A microphone the scores for the same questions range from 3.5 to 4.3. Here, unlike with the MRT scores, the apparent improvement in intelligibility of type B over type A is more pronounced in the open-circuit mode.

The effects of inhalation noise in open-circuit mode are evidenced by the average scores for questions 1 and 5 that address background noise and comparative distortion. The scores are 20% to 50% lower than in closed circuit mode.

Questionnaire Comments. Written topside comments to the questionnaire are provided in Appendix C. These comments support the assessment of adequate to good diver-to-diver intelligibility as indicated by the other evaluation methods. It is clear from these comments that in open-circuit mode diver breathing noise interfered with intelligibility unless the divers properly synchronized their breathing while talking.

DAT Recordings. Post-dive evaluation of DAT recordings documents adequate to good intelligibility from diver-to-diver. During the course of diving operations divers were observed to be able to successfully converse with each other without any obvious difficulty in open- and closed-circuit modes.

300 FSW HELIOX DIVES

Speech intelligibility results and analysis is divided into three sections; topside-to-diver, diver-to-topside, and diver-to-diver.

1. Topside-to-diver

MRT Scores. Topside-to-diver speech intelligibility was objectively measured using the individual and combined average of MRT scores for the type A and B microphones (Figure 10).

A high degree of intelligibility was indicated with a combined average of 92.2% The average score for the type B microphone, tested on the second day, was 8.2% higher than for the type A microphone. Since the diver microphone does not play a direct role in the topside-to-diver MRTs this difference is likely to be attributable to a change in test conditions from day 1 to day 2 and/or the increased experience level of the divers.

Diver	Mic. A	Mic. B
1	92.5	97.5
2	90.0	100.0
3	80.0	97.5
4	92.5	97.5
5	92.5	92.5
6	75.0	95.0
7	95.0	92.5
8	87.5	97.5
Average:	**88.1**	**96.3**
Mic. A&B Combined Avg:		**92.2**

FIGURE 10. TOPSIDE-TO-DIVER; HELIOX, CLOSED-CIRCUIT MRT TEST RESULTS (%)
DIVE PAIRS: Mic. A: 1/5, 2/6, 3/7, 4/8, where diver 1 repeats as diver 8
Mic. B: 2/5, 6/3, 4/7, 1/8, where diver 5 repeats as diver 8

On the second day, two bubbling bicycle ergometer units were removed, the water was warmer, and the divers were more experienced. Neither microphone produced any observable background noise that might have interfered with communication.

Questionnaire Ratings. Topside-to-diver speech intelligibility was subjectively measured using diver responses to six questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 11) for each question for each type microphone. Better-than-adequate intelligibility was indicated for both type microphones with average scores ranging from 4.3 to 5.4.

For the questions directly related to speech intelligibility; 2, 3 and 4, the average scores were between 5.0 or better while those dealing with background noise and comparative speech distortion, questions 1 and 5, were between 4.3 and 4.9. For question 10, divers indicated better-than-adequate (4.5) and better-than-good (5.1) confidence in topside-to-diver communications for microphone types A and B respectively.

As with the MRT averages, average scores for perceived topside-to- diver intelligibility were generally higher for microphone type B. The same explanation applies.

Questionnaire Comments. Written diver comments to the questionnaire are provided in Appendix D. These comments support the assessment of good topside-to-diver intelligibility as indicated by the other evaluation methods.

Several divers commented on an occasional buzzing/fuzz sound that was self limiting. This was also observed topside. It sounded like white noise and typically lasted 4-5 seconds with the amplitude tapering off until it could not be heard any more. The origin of this sound artifact could not be isolated during the tests and seemed to occur randomly. It was most likely produced by the HSU electronics on the AMRON communication amplifier acting either alone or in combination with the attached test equipment. It was not experienced during the 100 fsw nitrox dives using the same amplifier (HSU off) along with some different test equipment. It also had never been previously observed during bench testing. Judging from the results of the other intelligibility evaluation methods, the presence of this sound did not appear to impact intelligibility.

One diver commented on discomfort caused by background noise that sounded like boxcars passing by at a train crossing. This noise is an artifact of the communication amplifier's HSU processing electronics and is sometimes referred to as an electronic "beating" noise.

Another diver commented on discomfort caused by umbilical and bicycle ergometer unit bubbling noises. As discussed in the methods section, the bubbling ergometer units were removed on the second day for the type B microphone tests. The umbilical

Question	Mic. A	Mic. B
1	4.4	4.5
2	5.0	5.0
3	5	5.4
4	5	5.3
5	4.3	4.9
10	4.5	5.1

(Sample size = 8)

Key to rated questions; 1 - 5, 10:

Question #1: How would you rate the background noise from topside?
Question #2: How would you rate the overall clarity of speech from topside?
Question #3: How would you rate your ability to understand single words from topside?
Question #4: How would you rate your ability to understand conversation from topside?
Question #5 How would you rate the level of speech distortion from topside compared to speech you hear on the surface in a normal conversation?
Question #10: What is your confidence in the ability of this system configuration to support working dive communications from topside-to-diver?

Key to answers: 1 is worst, 6 is best

1= extremely disruptive
2= obviously disruptive
3= slightly disruptive
4= present but not disruptive
5= barely present
6= not present

OR

1= extremely poor
2= poor
3= not quite adequate
4= adequate
5= good
6= excellent

FIGURE 11. TOPSIDE-TO-DIVER; HELIOX, AVERAGE OF RESPONSES TO QUESTIONNAIRE

bubbling noise was eliminated after it was reported by securing the gas to this umbilical.

DAT Recordings. Post-dive evaluation of DAT recordings also documents a high degree of intelligibility from topside-to-diver. During conversation the topside speaker was rarely, if ever, asked to repeat himself.

2. Diver-to-topside

MRT Scores. No MRTs were conducted with topside test subjects during the dives. Diver-to-topside MRT scores were obtained with post-dive test subjects listening to selected DAT recordings of diver-to-diver MRT tests for microphone types A and B (Figure 12). These test subjects used the same headset as used by topside during the dives.

DAT recordings used for these tests were selected based on the PI's judgment of which were the most intelligible. During the diver-to-diver MRT and SPIN tests, the HSU was set for the "best" intelligibility of the listening diver, not topside. Therefore, the recordings were screened to find the tests with HSU settings that resulted in the "best" intelligibility for topside (the PI) as well as the listening diver. The talking divers and the MRT reading lists were different for each of the four tests; microphone A SPIN, microphone A MRT, microphone B SPIN and microphone B MRT. This means that a direct comparison of performance between microphones is difficult especially because of the sensitivity of the HSU adjustment for each particular diver to get the "best" intelligibility.

The MRT test results indicate acceptable (>60%) diver-to-topside intelligibility with a combined average of 76.1% for the type A and B microphones. The small difference in averages between the two types of microphones indicates that, for each test, the divers voice, microphone, test conditions, reading list, HSU settings and the topside listeners hearing combined to give approximately equal intelligibility results.

SPIN Scores. No SPIN tests were conducted with topside test subjects during the dives. Diver-to-topside SPIN scores were obtained with post-dive test subjects listening to recordings of diver-to-diver SPIN tests for microphone types A and B (Figure 13). These test subjects used the same headset as used by topside during the dives. DAT recordings used for these tests were selected in the same way as for the heliox diver-to-topside MRTs.

The SPIN test results indicate good diver-to-topside intelligibility with a combined average of 89.4 for the type A and B microphones. The large difference in averages between the two types of microphones, 17.2%, indicates that, for each test, the divers voice, microphone, test conditions, reading list, HSU settings and the topside listeners hearing combined to give very different (yet good) intelligibility results. The diver's voice and HSU settings likely contributed the largest amount to this difference.

Topside listener	Mic. A	Mic. B
1	82.5	77.5
2	77.5	62.5
3	80.0	80.0
4	75.0	72.5
5	85.0	75.0
6	70.0	77.5
7	67.5	67.5
8	90.0	77.5
Average:	**78.4**	**73.8**
Mic. A&B Combined Avg:		**76.1**

FIGURE 12. DIVER-TO-TOPSIDE; HELIOX, CLOSED-CIRCUIT MRT TEST RESULTS (%)
Test results obtained post-dive using taped diver-to-diver MRT recordings
There were different divers reading the word lists for each type microphone

Topside listener	Mic. A	Mic. B
1	92.0	98.0
2	86.0	96.0
3	76.0	98.0
4	88.0	100.0
5	68.0	100.0
6	70.0	96.0
7	72.0	96.0
8	94.0	100.0
Average:	**80.8**	**98.0**
Mic. A&B Combined Avg:		**89.4**

FIGURE 13. DIVER-TO-TOPSIDE; HELIOX, CLOSED-CIRCUIT SPIN TEST RESULTS (%)
Test results obtained post-dive using taped diver-to-diver SPIN test recordings
There were different divers reading the word lists for each type microphone

Apparently the reading diver for the type A microphone test was more intelligible to some topside listeners than others resulting in a wide range of scores from 68% to 94%. The reading diver for the type B microphone test was more universally intelligible resulting in scores from 96% to 100%.

Questionnaire Ratings. Diver-to-topside speech intelligibility was subjectively measured using topside responses to seven questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 14) for each question.

Only three topside personnel, including the PI were used to provide these ratings. This was because, unlike with nitrox, a higher degree of concentration is required to be able to clearly understand helium speech and the HSU settings need to be tuned at least close to the listener's preference. Only a limited number of topside personnel had this opportunity. For the most part, other topside personnel in the control room were unable to give their full attention to these communications and even if they were able to, they did not necessarily have adequate volume or the preferred HSU settings.

Good intelligibility was indicated with average scores ranging from 3.0 for question 5 to 4.7 for questions 1 through 4. For the questions directly related to speech intelligibility; 2, 3 and 4, the average scores were all 4.7. For question 12, topside indicated good (5.0) confidence in diver-to-topside communications.

Questionnaire Comments. Written topside comments to the questionnaire are provided in Appendix D. These comments support the assessment of adequate to good diver-to-topside intelligibility as indicated by the other evaluation methods.

DAT Recordings. Post-dive evaluation of DAT recordings indicates a high degree of intelligibility from diver-to-topside. During the course of normal conversation the topside rarely had to ask divers to repeat themselves and if he did it was only because he did not have the HSU adjusted for best diver-to-topside intelligibility but rather best diver-to-diver intelligibility. For some of the dives, the recordings document that supervisory personnel in the control room were readily able to understand speech from the divers.

2. Diver-to-diver

MRT Scores. Diver-to-diver speech intelligibility was objectively measured using the individual and combined average of MRT scores for the type A and B microphones (Figure 15).

Unacceptable (<60%) intelligibility was indicated with a combined average of 47.6% There were, however three instances of passing MRT scores indicating that acceptable diver-to-diver intelligibility could be achieved. The average score for the type B microphone, tested on the second day, was 4.9% higher than that for the type A

Question	Average
1	4.7
2	4.7
3	4.7
4	4.7
5	3.0
6	4.3
12	5.0

(Sample size = 3)

Key to rated questions; 1 - 6, 12:

Question #1: How would you rate the background noised from the diver?
Question #2: How would you rate the overall clarity of speech from the diver?
Question #3: How would you rate your ability to understand single words from the diver?
Question #4: How would you rate your ability to understand conversation from the diver?
Question #5: How would you rate the level of speech distortion from the divers with this HSU compared to speech you hear on the surface in a normal conversation?
Question #6: How would you rate the level of speech distortion from the divers with this HSU, compared to speech you hear using air communication systems during a working dive?
Question #12: What is your confidence in the ability of this system configuration to support working dive communications from diver-to-topside?

Key to answers: 1 is worst, 6 is best

1= extremely disruptive		1= extremely poor
2= obviously disruptive		2= poor
3= slightly disruptive	**OR**	3= not quite adequate
4= present but not disruptive		4= adequate
5= barely present		5= good
6= not present		6= excellent

FIGURE 14. DIVER-TO-TOPSIDE, HELIOX, AVERAGE OF RESPONSES TO QUESTIONNAIRE
No distinction between microphone types A and B

Diver	Mic. A	Mic. B
1	57.5	77.5
2	55.0	62.5
3	32.5	55.0
4	67.5	50.0
5	42.5	52.5
6	25.0	50.0
7	55.0	20.9
8	30.0	27.5
Average:	**45.6**	**49.5**
Mic. A&B Combined Avg:		**47.6**

FIGURE 15. DIVER-TO-DIVER; HELIOX, CLOSED-CIRCUIT MRT TEST RESULTS WITH HSU (%)
DIVE PAIRS: Mic. A: 1/5, 2/6, 3/7, 4/8, where diver 1 repeats as diver 8
Mic. B: 2/5, 6/3, 4/7, 1/8, where diver 5 repeats as diver 8

microphone and is not considered a reliable difference on which to base any conclusions. Any improvement is likely attributable to differences in test conditions between days 1 and 2 as noted previously.

An explanation for poor diver-to-diver intelligibility is based on a combination of factors, the most influential being the HSU adjustment. Adequate diver-to-topside intelligibility scores indicate that intelligible heliox speech could make it from the diver's microphone, through the cable to the amplifier HSU and to the tenders headset. For this same signal to get back to the listening diver it must pass through the cable once again, to the divers headset and finally to the divers ears. The cable is not considered a source of degradation so we are left with the headset, the divers ears (i.e. his hearing ability at depth and HSU adjustment preferences) and the listening environment as potential sources of intelligibility degradation.

The range of speech frequencies reaching the divers headsets and ears for HSU processed helium speech is the same as that for unprocessed nitrox speech. Therefore, since the divers ears and headsets performed well on nitrox speech they should be able to perform well on processed helium speech. This is also supported by the fact that some divers could achieve acceptable MRT scores and high SPIN scores on heliox. The listening environment, namely background noise, could have played a role. However, by the second day conditions were very quiet for the majority of the dives and still the majority of test scores fell below 60%.

The HSU adjustments probably play the largest role in the degradation of speech intelligibility from the talking to the listening diver. For these tests the listening diver was given the opportunity to have the HSU adjusted by topside so he could hear the talking diver at his preferred settings. This was not a perfect adjustment procedure but it was better than assuming that the HSU adjustments for best topside intelligibility are also the best for the listening diver. Some divers participated significantly in this adjustment process while others seemed willing to just accept the settings as they were. There were three instances of passing scores for the MRTs indicating that acceptable diver-to-diver intelligibility could be achieved with optimal HSU adjustment. During operations, a tedious HSU adjustment procedure may not be practical. However, as divers and topside operators gain more experience with HSU processed helium speech, intelligibility is likely to improve.

SPIN Scores. Diver-to-diver speech intelligibility was also objectively measured using the individual and combined average of SPIN scores for the type A and B microphones (Figure 16).

Even though the SPIN test presented the target word in a contextual setting, which one would think would improve intelligibility, the scores indicated a low degree of intelligibility with a combined average of 38%. This is lower than the average for the non-contextual diver-to-diver MRTs. There were, however three instances of passing SPIN scores indicating that acceptable diver-to-diver intelligibility could be achieved.

Diver	Mic. A	Mic. B
1	42.0	94.0
2	n/c	28.0
3	40.0	74.0
4	36.0	36.0
5	12.0	76.0
6	0.0	12.0
7	16.0	42.0
8	34.0	40.0
Average:	**25.7**	**50.3**
Mic. A&B Combined Avg:		**38.0**

FIGURE 16. DIVER-TO-DIVER; HELIOX, CLOSED-CIRCUIT SPIN TEST RESULTS WITH HSU (%)
DIVE PAIRS: Mic. A: 1/5, 2/6, 3/7, 4/8, where diver 1 repeats as diver 8
Mic. B: 2/5, 6/3, 4/7, 1/8, where diver 5 repeats as diver 8

The average score for the type B microphone, 50.3%, was nearly twice as high as that for the type A microphone, 25.7%, and was nearly identical to the average MRT score. Also all the passing scores were for the type B microphone. This can be considered a reliable difference in microphone performance even when considering the differences in test conditions between days 1 and 2 as noted previously. It is curious to note that the type B microphone did not show this degree of performance improvement over the type A microphone on the diver-to-diver MRT tests.

Questionnaire Ratings. Diver-to-diver speech intelligibility was subjectively measured using diver responses to five questions that required a numeric rating from a six-point scale. An average of these ratings was calculated (Figure 17) for each question and for each type microphone.

Extremely-poor to poor intelligibility was indicated for the type A microphone with all average scores except for question 1 below 2.0. Nearly adequate intelligibility was indicated for the type B microphone. For the questions directly related to speech intelligibility; 2, 3 and 4, the average scores were between 3.6 and 3.9 while those dealing with background noise and comparative speech distortion; questions 1,5, and 6, were between 2.9 and 4.5. Divers rated their confidence in the system for diver-to-diver communications as nearly adequate at 3.6.

These ratings indicate that the perceived intelligibility from the type B microphone was nearly twice that from the type A microphone.

Questionnaire Comments. Written topside comments to the questionnaire are provided in Appendix D. The comments are presented for the type A and type B microphones separately. These comments generally support the assessment of intelligibility made by the other evaluation methods. It is clear from these comments that some divers were more successful in achieving intelligible communication than the others. The diver comments indicate that microphone B performed better than microphone A. There was a wide range of opinions on what speech sounded good and bad, a clear reflection of individual HSU adjustment preferences.

DAT Recordings. Post-dive evaluation of DAT recordings documents poor to adequate intelligibility from diver-to-diver. During diving operations some dive pairs were observed to be able to successfully converse with each other without any obvious difficulty. Others had a more difficult time. At the end of some of the tests, Red diver was requested by topside to ask Green diver a particular question. This was done with Green divers headset turned off so he wouldn't hear the question. Intelligibility could be judged by the response of Green diver to the question by Red diver. This was repeated with diver roles reversed. For some diver pairs, the questions were logically answered in both directions, for others the questions were logically answered in one direction and not understood in the other. This again highlights the sensitivity of diver-to-diver intelligibility to HSU adjustment.

Question	Mic. A	Mic. B
1	3.6	4.5
2	1.7	3.9
3	1.8	3.9
4	1.8	3.6
5	1.6	3.1
6	1.8	2.9
11	1.8	3.6

(Sample size = 8)

<u>Key to rated questions; 1 - 6, 11:</u>

Question #1: How would you rate the background noise from the other diver?
Question #2: How would you rate the overall clarity of speech from the other diver?
Question #3: How would you rate your ability to understand single words from the other diver?
Question #4: How would you rate your ability to understand conversation from the other diver?
Question #5: How would you rate the level of speech distortion from the other diver compared to speech you hear on the surface in a normal conversation?
Question #6: How would you rate the level of speech distortion from the other diver compared to speech you hear using air communication systems during a working dive?
Question #11: What is your confidence in the ability of this system configuration to support working dive communications between divers?

<u>Key to answers: 1 is worst, 6 is best</u>

1= extremely disruptive		1= extremely poor
2= obviously disruptive		2= poor
3= slightly disruptive	<u>OR</u>	3= not quite adequate
4= present but not disruptive		4= adequate
5= barely present		5= good
6= not present		6= excellent

FIGURE 17. DIVER-TO-DIVER; HELIOX, AVERAGE OF RESPONSES TO QUESTIONNAIRE

CONCLUSIONS

Conclusions on speech intelligibility with the EBS-II communication system using the AMRON communication amplifier are presented below for both dive series. Comments and conclusions are also presented on the general performance of the communication amplifier. For each of the dive series, a general conclusion is followed by more detailed conclusions for topside-to-diver, diver-to-topside and diver-to-diver intelligibility and finally conclusions on microphone performance. These conclusions are based on the PI's interpretation and analysis of the objective and subjective test data using the methods described earlier.

100 FSW NITROX DIVES

1. General

The EBS-II communication system, as tested, provided acceptable (adequate to good) levels of round-robin speech intelligibility in a nitrox environment at 100 fsw in both open- and closed-circuit modes. During open-circuit testing, many of the divers and topside personnel complained that it was impossible to understand speech that was presented to them at the same time a diver was inhaling or exhaling. However, proper synchronization of breathing and talking, a technique typically used in open-circuit working dives, allowed acceptable intelligibility results to be obtained. As a result, there was only a small difference in measured intelligibility levels between open- and closed-circuit modes. The type B microphone was found to perform at least as well as the type A microphone.

2. Topside-to-diver

All data supports the conclusion of acceptable (good) intelligibility in open- and closed-circuit modes. MRT scores in closed-circuit mode were only marginally better than in open-circuit. Questionnaire ratings indicated lower intelligibility for open-circuit mode. DAT recordings repeatedly document successful, normal, topside-to-diver conversations in either breathing mode.

3. Diver-to-topside

All data supports the conclusion of acceptable (good) intelligibility in open- and closed-circuit modes with both type microphones. Questionnaire ratings indicated lower intelligibility for open-circuit mode. DAT recordings repeatedly document successful, normal, diver-to-topside conversations in either breathing mode.

4. Diver-to-diver

The overall data supports the conclusion that acceptable (adequate) intelligibility can be achieved in open- and closed-circuit modes. When the type B microphone was tested, MRT intelligibility results were acceptable, however, they were just below acceptable for the type A microphone. Questionnaire ratings found the type B microphone intelligibility to be good or better in both breathing modes while the type A microphone received less-than-adequate ratings in open-circuit mode and good ratings in closed-circuit mode. The lower MRT score and questionnaire ratings for the type A microphone could be attributable to training effects. With both microphones in either breathing mode the DAT recordings repeatedly document successful, normal, diver-to-diver conversations.

5. Microphones

Objective and subjective test results indicate that the performance of the type B microphone for all nitrox breathing modes is at least as good as the performance of the type A microphone. Any apparent improvement may have been due to training effects.

300 FSW HELIOX DIVES

1. General

The EBS-II communication system, as tested, provided acceptable (adequate to good) levels of topside-to-diver and diver-to-topside intelligibility in a heliox environment at 300 fsw with both type microphones. Diver-to-diver intelligibility was generally found to be unacceptable (poor), however, there were some data indicating acceptable intelligibility could be achieved. The type B microphone was found to perform better than the type A microphone.

2. Topside-to-diver

All data supports the conclusion of acceptable (good) intelligibility. MRT scores indicate better performance the second day which is largely attributable to improvements in test conditions between the first and second day. Questionnaire ratings were good (5.0) or better for the questions directly related to intelligibility and diver confidence in the communication system was between adequate and good. DAT recordings repeatedly document successful, normal, topside-to-diver conversations.

3. Diver-to-topside

All MRT and SPIN test results support the conclusion of acceptable (adequate to good) intelligibility with both type microphones. Questionnaire ratings also indicate better than adequate intelligibility and good confidence in communication system performance. DAT recordings also document a high degree of intelligibility from diver-to-topside.

After only a short amount of time working with the HSU on the communication amplifier it becomes obvious that diver-to-topside intelligibility is very sensitive to the

HSU settings, the voice qualities of the individual divers and the listening preferences of the topside operator. Typically there is only one HSU in a communication amplifier and the topside operator will set the HSU controls so that he has either the best intelligibility from one of the divers or moderate intelligibility from both of the divers. If both divers have approximately the same voice qualities then a single setting can work well for both divers. Often, however, voice qualities are different enough so that intelligibility with one of the divers suffers unless the topside operator continuously makes adjustments depending on who is talking. The magnitude of these differences in voice qualities was highlighted by the male, female dive team used for these tests. The HSU settings for best diver-to-topside intelligibility were vastly different for each diver.

4. Diver-to-diver

The overall data supports the conclusion of unacceptable (poor) intelligibility. However, there are specific objective and subjective results that indicate that acceptable diver-to-diver intelligibility is possible with the right microphone and with dive personnel that are experienced with helium speech and adjusting the communication equipment. DAT recordings of conversations during the dives document that intelligible diver-to-diver communications can and did take place. Also, there were three instances of divers exceeding (in most cases by a comfortable margin) the minimum required MRT scores for heliox speech. All but one of these was achieved with the type B microphone.

Obtaining adequate, direct, diver-to-diver communications on heliox is probably the greatest challenge for a round-robin diver communication system. The ideal way to do this would be to have the communication amplifier automatically adjust the HSU on the communication amplifier to the listening divers preferred settings while the other diver is talking. This may be possible with the next generation of programmable, digital signal processor based, communication amplifiers but is not possible with the current analog units. Therefore, it is up to topside to perform this adjustment. With the divers providing direction to topside on how to adjust the HSU it is likely that acceptable diver-to-diver intelligibility can be achieved, at least in one direction at a time. However, this is time consuming and not very practical in an operational environment.

Probably the best solution is to circumvent direct diver-to-diver communication and have the divers relay messages to each other via topside. That way topside optimizes the HSU for his best intelligibility and makes use of the intelligible diver-to-topside and topside-to-diver communication links to pass the message along. This relaying of information is easily achieved if topside simply repeats everything that is heard from the divers.

5. Microphones

Objective and subjective test results and diver comments indicate that the type B microphone provided better intelligibility than the type A microphone. There was nearly a factor of two improvement in diver-to-diver SPIN scores and questionnaire ratings for the type B microphone over the type A microphone. Given that the type B microphone was tested on the second day when the test conditions were better and the divers were more experienced, some improvement would be expected. However the diver-to-diver MRT results show only a 5 percentage point advantage for the type B microphone which indicates that these factors did not play a substantial role.

AMRON COMMUNICATION AMPLIFIER

Throughout these tests the modified AMRON communication amplifier exhibited good, consistent performance. Controls and connections are logically arranged and were easy to use.

One weakness, not related to the modifications, was marginally adequate tender-to-diver headset volumes. Throughout both dive series, the individual diver's tender-to-diver headset volume controls had to be set at 100% with the tender's tender-to-diver volume control set at the maximum level allowable while still preventing clipping. Even with these maximum settings the divers occasionally requested that the topside-to-diver volume be turned up a bit when topside was speaking. For purposes of these tests, an adequate solution was for topside to position the headset microphone closer to the lips and/or speak a bit louder. However, for operational use there should be more reserve topside-to-diver volume available. The lack of reserve volume is attributable to the high input impedance of the diver AN/PQS-2A sonar headsets as compared to headsets used by typical commercial divers. It is recommended that the AMRON communication amplifier be modified to increase the output volume to the individual diver headsets. Adequate volume at the diver headset should be achieved with the diver's tender-to-diver volume controls set at 60% to 70% of maximum and the tender's tender-to-diver volume control set well below the level of any signal clipping.

For the 300 fsw heliox dives with the HSU on, there were comments of an occasional, random, self-limiting, white noise "buzzing/fuzzy" sound that lasted up to 5 seconds. This did not appear to significantly affect intelligibility and may have been caused by the HSU and/or the test equipment connected to the communication amplifier. Should it occur in subsequent testing the source of this sound will be identified and eliminated if possible.

Also during heliox dives with the HSU on, one diver commented on discomfort caused by background noise that sounded like boxcars passing by at a train crossing. This noise, created by the communication amplifier's HSU electronics, is sometimes referred to as an electronic "beating" sound. Judging from the results of the intelligibility evaluation methods, the presence of this sound did not appear to significantly affect intelligibility. There are currently no plans to try to reduce or eliminate it.

RECOMMENDATIONS

Based on the findings of this report, it is recommended that the AMRON Model 2825/24/26 two-diver communications amplifier, with helium speech unscrambler (HSU), be approved for use with the EBS II Divers Communications Umbilical, the MK-24 FFM Piezoelectric microphone (types A and B), and the AN/PQS-2A Headset. This unit is considered satisfactory for use in accordance with diving parameters as outlined in the Underwater Breathing Apparatus MK-16 Operations and Maintenance Manual[9], Revision 2 of 16 December 1996.

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8. Mendel, L.L., Hamill, B.W., Crepeau, L.J., Fallon, E., "Speech Intelligibility Assessment in a Helium Environment, " *Journal of the Acoustical Society of America*, Vol. 97, No. 1, January 1995

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APPENDIX A

Figure A1
MRT Reading List

MRT LIST R1-E

1	badge	18	has	35	veal
2	lob	19	wean	36	tame
3	wick	20	sap	37	then
4	dove	21	sheaf	38	fin
5	cud	22	sick	39	gin
6	dill	23	sung	40	zee
7	dug	24	tap	41	tent
8	fib	25	teeth	42	lip
9	lead	26	fed	43	shop
10	tog	27	gold	44	roar
11	lath	28	pig	45	high
12	mass	29	sick	46	ship
13	bays	30	thin	47	west
14	pat	31	park	48	dust
15	peat	32	male	49	rat
16	pitch	33	keel	50	nay
17	pus	34	bill		

Figure A2
MRT Response Sheet

NAME: ______________________ RIG OR LOCATION: ____________ DATE______

RESPONSE SHEET 2-R1

	A	B	C	D	E		A	B	C	D	E
1	bat	batch	badge	bass	bash	26	wed	red	led	fed	shed
2	lob	log	lodge	laws	long	27	sold	cold	hold	gold	told
3	wit	wig	wick	with	witch	28	big	wig	dig	rig	pig
4	duff	doth	dove	dumb	dub	29	kick	chick	pick	thick	sick
5	cup	cuff	cub	cud	cut	30	thin	tin	kin	fin	shin
6	dig	dill	din	dim	did	31	bark	mark	park	lark	dark
7	dung	dun	dud	dug	dub	32	tale	pale	bale	gale	male
8	fin	fill	fig	fib	fizz	33	keel	peel	eel	heel	feel
9	leash	leave	lead	liege	leach	34	hill	till	kill	will	bill
10	tog	toss	taj	talks	tong	35	reel	veal	feel	zeal	seal
11	lash	lath	lass	laugh	lack	36	game	shame	came	tame	same
12	mat	mass	man	mad	math	37	den	pen	hen	ten	then
13	bayed	base	bathe	bays	beige	38	win	fin	sin	pin	tin
14	pad	pass	pat	pack	path	39	shin	chin	thin	tin	gin
15	peat	peak	peal	peas	peace	40	knee	dee	thee	zee	lee
16	pick	pit	pip	pitch	pig	41	went	tent	bent	rent	dent
17	pup	pus	pub	puck	puff	42	rip	dip	tip	hip	lip
18	has	have	half	hash	hath	43	cop	hop	top	shop	pop
19	weed	wean	we're	weave	weal	44	yore	gore	wore	lore	roar
20	sack	sap	sat	sad	sag	45	fie	vie	high	thy	thigh
21	sheathe	sheave	sheaf	sheath	sheen	46	ship	lip	gyp	zip	nip
22	sin	sit	sing	sick	sip	47	best	west	vest	nest	rest
23	sun	sung	sud	sum	sub	48	dust	just	gust	bust	rust
24	tan	tab	tap	tang	tam	49	rat	mat	vat	that	fat
25	tear	teeth	tease	teel	teethe	50	may	they	gay	way	nay

APPENDIX B

Figure B1
SPIN Reading List

Contextual SPIN Test # 2

1. Kill the bugs with this SPRAY.
2. How much can I buy for a DIME.
3. We shipped the furniture by TRUCK.
4. My TV has a 12-inch SCREEN.
5. That accident gave me a SCARE.
6. The king wore a golden CROWN.
7. The girl swept the floor with a BROOM.
8. The nurse gave him first AID.
9. She faced them with a foolish GRIN.
10. Watermelons have lots of SEEDS.
11. Use this spray to kill the BUGS.
12. The teacher sat on a sharp TACK.
13. The sailor swabbed the DECK.
14. He tossed the drowning man a ROPE.
15. The boy gave the football a KICK.
16. The storm broke the sailboat's MAST.
17. Mr. Brown carved the roast BEEF.
18. The glass had a chip on the RIM.
19. Her cigarette had a long ASH.
20. The soup was served in a BOWL.
21. The lonely bird searched for its MATE.
22. Please wipe your feet on the MAT.
23. The pond was full of croaking FROGS.
24. He hit me with a clenched FIST.
25. A bicycle has two WHEELS.
26. The doctor X-rayed his CHEST.
27. The workers are digging a DITCH.
28. The duck swam with the white SWAN.
29. Your knees and your elbows are JOINTS.
30. Raise the flag up the POLE.
31. The detectives searched for a CLUE.
32. The steamship left on a CRUISE.
33. Tree trunks are covered with BARK.
34. The meat from a pig is called PORK.
35. Ruth poured herself a cup of TEA.
36. We saw a flock of wild GEESE.
37. How did your car get that DENT.
38. She made the bed with clean SHEETS.
39. The team was trained by their COACH.
40. I've got a cold and a sore THROAT.
41. She wore a feather in her CAP.
42. The bread was made from whole WHEAT.
43. Spread some butter on your BREAD.
44. The cabin was made from LOGS.
45. The lion gave an angry ROAR.
46. The sandal has a broken STRAP.
47. He's employed by a large FIRM.
48. Her entry should win first PRIZE.
49. The airplane dropped a BOMB.
50. A zebra has black and white STRIPES.

APPENDIX C

WRITTEN COMMENTS FROM QUESTIONNAIRES, 100 FSW NITROX

The comments from the questionnaires used for the 100 fsw nitrox dives are presented here. In some cases comments were identical between respondents. These are only listed once. Comments enclosed in "{}" are those of the Principal Investigator added for clarity.

100 fsw Nitrox:

DIVER-TO-TOPSIDE, CLOSED-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All
- All about the same

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None
- All about the same

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- None
- Occasionally some intermittent buzzing/clicking during sound tests.

ADDITIONAL COMMENTS.

- Words and conversation seemed clear
- Good comm. system

DIVER-TO-TOPSIDE, OPEN-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All except during exhalation {breathing noise}
- All about the same

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Only when exhaling {breathing noise}
- All about the same

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- Breathing noise.
- Diver exhaust
- Some intermittent clicking and buzzing

ADDITIONAL COMMENTS.

- When breathing was synchronized, words/sentences were easily readable.
- Ability to hear the divers was hindered only by the open-circuit noise.
- Great comms.

TOPSIDE-TO-DIVER, CLOSED-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Recorded {topside tapes} and spoken
- All speech sounds came out excellent.
- Words ending in "P" or "K"
- "C's" and "K's"
- "H" at the beginning of a word.
- All
- All were good.

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None
- Words beginning with "F"
- Ending "G's", "N's"
- "THE" and "F" at the end of a word

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- None
- Earphones gradually started to smash my ears without a hood {diver place earphones under MK-24 straps}.
- Yes, speaker buzz we talked about {referring to "bad speaker" distortion sound produced when over driving the tenders' tender-to-diver preamplifier. This was eliminated by turning down tenders' tender-to-diver volume}

ADDITIONAL COMMENTS.

- Should use skull cap {this diver placed headset earphones over ears

by putting them under the MK-24 straps.}
- Earphones must be installed in the skull cap prior to connecting comms. to the rig. They are in-line. If they were on separate lines it wouldn't matter.
- Much better that at 300 fsw {referring to 300 fsw heliox bounce dives during previous NDSTC testing}
- Extremely clean comms. both pre-recorded {topside tapes} and live.
- Clearest comms. I've ever used
- Best comms. I've ever used

TOPSIDE-TO-DIVER, OPEN-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All
- Words ending in "P" or "K"
- "C's" and "K's"
- "H" at the beginning of a word.

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None
- None except on inhalation and exhalation
- Words beginning with "F"
- Ending "G's", "N's"
- "THE" and "F" at the end of a word

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- Open circuit noise was disruptive. Inhalation noise from myself and other diver was the source of distortion.
- Yes, open circuit breathing noise

ADDITIONAL COMMENTS.

- The earphones should be more comfortable, made of a pliable jell of some sort, easily molded to the outer ear.
- Need to hold breath {while listening}
- {From experience with} using other open-circuit comm. systems, this system was as good or better in my opinion.
- Breathing had to be timed and synchronized between divers as not to be breathing in or out while being spoken to.
- Can't hear while exhaling
- Breath noise only
- {Performed test} while skip breathing
- Background noise from topside was due to breathing only.
- Speech intelligibility was very good with little or no distortion. The only problem was the inability to hear due to open-circuit

breathing noise.
- Excellent comms.

DIVER-TO-DIVER, CLOSED-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All conversation
- Words that ended with a "T"
- Words ending in "P" or "K"
- "C's" and "K's"
- "IP" sounds (i.e. NIP, PIP, TIP)
- All

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None
- Words beginning with "F"
- Ending "G's", "N's"
- "ease" sounds

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- None

ADDITIONAL COMMENTS.

- Good system
- A#1 comms.
- This dive partner {team 3) was easier to understand than other dive partner {team 1}. {This was comment from the repeat diver on mic. B}
- Noticed slight distortion of my own speech through the headset.

DIVER-TO-DIVER, OPEN-CIRCUIT

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Conversation, you can get the meaning of what the other diver is saying.
- None
- All
- Words ending in "P" or "K"
- "C's" and "K's"
- "IP" sounds (i.e. NIP, PIP, TIP)

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- None
- All
- Single words
- Just when breathing
- Words beginning with "F"
- Ending "G's", "N's"
- "ease" sounds

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- No
- None
- Yes, a lot of inhalation noise as well as bubble noise
- Yes, breathing noise
- Yes, open-circuit breathing noise

ADDITIONAL COMMENTS.

- Move the microphone to eliminate noise from inhalation. Redirect exhaust bubbles to eliminate noise from exhalation.
- Need to hold breath {while listening}
- Breathing had to be timed and synchronized between divers as not to be breathing in or out while being spoken to.
- Note: the divers speech was not distorted but was difficult to hear due to open-circuit noise.
- Difficult to hear while exhaling
- Good {comms.}
- Background noise from the other diver was due to breathing only. Tough to hear own annunciation.
- Best comms. ever

APPENDIX D

WRITTEN COMMENTS FROM QUESTIONNAIRES, 300 FSW HELIOX

The comments from the questionnaires used for the 300 fsw heliox dives are presented here. In some cases comments were identical between respondents. These are only listed once. Comments enclosed in "{}" are those of the Principal Investigator added for clarity.

300 fsw Heliox

DIVER-TO-TOPSIDE

HOW WOULD YOU DESCRIBE WHAT THIS HSU DOES TO THE SPEECH YOU HEARD?

- Distorts it to a different pitch from the diver's normal voice
- Provided the divers speak slowly, {HSU works} very well.
- Makes it clearer.

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- Could not distinguish
- Low voice is best. High tones are less effective.
- One syllable words

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Could not distinguish
- N/A
- Multiple syllable words

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- Occasional short duration (~5 sec.) buzzing sound but did not appreciably diminish intelligibility of divers.
- No
- No discomfort

ADDITIONAL COMMENTS.

- HSU adjustment is critical and it takes an experienced operator to find a setting that works will with both divers. If one diver has a significantly different pitch voice (i.e. a male and female team) it makes HSU adjustment very difficult.
- The HSU worked extremely well off the shelf. I would use it on dive station anytime.

- I'd use it in the fleet.

TOPSIDE-TO-DIVER

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All about the same
- Low {pitch} tones
- All equal to me
- Hard consonants, single syllables (k, t, b, d), "i"," a"
- All speech sounds came through good
- Higher pitch tones over bass
- No problems hearing from topside.
- Speech was OK, background noise was 10 on a 10 scale.
- From topside everything was fine.
- All fine
- All sounds adequate
- All comms. were good from topside.

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- All about the same
- High pitch
- All equal to me, Occasionally pick up other conversations, I could hear other voices (no I'm not schizophrenic).
- Soft consonants (p, sh, w, h)
- None
- Lower pitch tones
- No problems hearing from topside.
- Speech was good
- None were bad
- All fine
- "the"," f", "sh" and plurals
- All sounds adequate

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None
- Not discomfort but occasional aggravating loud popping/clicking
- Yes, bubbling from umbilical and bikes {ergometer units}.
- No
- No discomfort, sounded like some of the prompting tapes and the conversation tape {had} some poor quality buzzes imperfections in them.
- Yes, It was like sitting at a train crossing with boxcars passing by.
- No. But once, very loud buzz, it seemed to occur after you spoke and would resolve before you spoke next (5-6 times).
- Yes, occasional "fuzz" {sound} which was self limiting

- Feedback vibration on low tones {buzzing sound}
- Wore a hood and occasionally had gas burping near my ears which made hearing Difficult

ADDITIONAL COMMENTS.

- I could hear topside very well when I wasn't breathing but I caught myself skip breathing so I could clearly hear.
- Anti-fog in the mask would help.
- You need to slow the prompting tapes down, allow more time between required responses - let you electronics complete their response functions before overloading with more input - more of a pause between {SPIN} sentences.
- Simplify the test and concentrate on getting a reliable, dependable rig in the fleet.

DIVER-TO-DIVER

Type A microphone:

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- "R's" and "T's"
- Low tones {pitch}
- Hard consonant sounds at the beginning or end of a word when articulated with emphasis.
- Hard consonants (k, b, d)
- None
- Normal eye to eye conversation that would be expected on a working dive which would also be associated with some body language.
- Diver-to-diver during testing portions was terrible.
- All about the same

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Higher pitch sounds
- High {pitch}
- Words without hard consonants at the end like "hoe" or "stone"
- Soft consonants, vowels, (some hard consonants)
- All sounds
- Low base tones
- Diver-to-diver during testing portions was terrible.
- All about the same

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None
- Sometimes a buzzing was present
- Yes, bubbling from umbilical and bikes

- No
- Yes, It was like sitting at a train crossing with boxcars passing by.

ADDITIONAL COMMENTS.

- You can't do high level comms., general established word lists might work.
- Couldn't understand the other diver at all most of the time but sometimes I could pick out words.
- The only way I could find understanding was to concentrate very hard and not breathe myself. Contextual words or a list of choices helped a lot but all bets were off if I had to breathe.
- Communication was not quite adequate but better than nothing, certainly better than SCUBA using a mouthpiece but I hope we could do better.
- The mask fog was inconvenient an distracting but did not interfere with response. The lighting was adequate, the books were well organized, easy to see and write on. Although I wear glasses, I was able to read well enough. Water was coooold!
- Had to hold breath to try to understand speech

Type B microphone:

WHICH SPEECH SOUNDS CAME THROUGH THE BEST?

- All sounds were good.
- Hard consonants
- There was no obvious pattern.
- High pitch tones
- About the same, need to learn how to adapt your in water skills to overcome the weak points in the equipment. If diction was mediated and deliberate, and sentences simple everything comes across okay.

WHICH SPEECH SOUNDS CAME THROUGH THE WORST?

- Complex sounds
- Soft endings (i.e. stow, through, hoe)
- Mostly all the sounds were distorted.
- None
- Low bass tones
- Don't' remember specific bad speech sounds, when it was bad, it was all mumbled together.

DID YOU EXPERIENCE ANY DISCOMFORT DURING COMMUNICATION?

- None
- No
- Yes, occasional "fuzz" which was self limiting

ADDITIONAL COMMENTS.

- Today was much better. {referring to previous days testing with type A microphone}
- It is too difficult to try to understand consistently.
- Unreliable and distorted communication
- You need to adapt your test to a more "field" type test of the performance: i.e.: topside to Red: "Red, tell me what size wrench you need". Have topside and diver repeat back all comms. and check for accuracy.
- Think the problems are more a product of the tests rather than actual deficiencies in the equipment.

APPENDIX E

DETAILED DESCRIPTION OF DIVER HEADSET AND MICROPHONES

Diver Headset

The diver headset used for the EBS-II diver communication system is the same as that designed for use with the AN/PQS-2A sonar. It is waterproof to 500 psi, features left and right ear pieces fabricated using piezo-ceramic crystal speaker elements and meets the magnetic signature requirements for contact items as per MIL-M-19595C Amendment 1. The headset is designed to have a capacitance between .135 microfarads and .215 microfarads at a frequency of 1 kHz. This presents a nominal load impedance of approximately 1K Ohm to the communication amplifier at this frequency. It is also designed to be driven by the sonar with an AC sine wave between 7 volts and 14 volts peak-to-peak. The headset cable has an underwater mateable, 2 contact, male connector on the end. The ear pieces are typically put in a skull cap and the skull cap is placed over the diver's head. The part number is 1100-5002-1. It is listed in the national stock system under NSN #5965-01-278-2082 and is manufactured by either Datasonics Inc., FSCM No. 4U270, or SeaBeam Instruments Inc., FSCM No. 02131.

Diver Microphones

Type A

This is a preamplified, piezoelectric compression type microphone detailed in CSS drawing #6696997. It is currently issued with the MK-24 FFM. It screws into the side of the open/closed-circuit switchover block on the MK-24 FFM so that the front face is oriented perpendicular to the sound source in the oral/nasal cavity of the mask and flush with the interior surface. The preamplifier for this microphone is bipolar and is based on a discrete transistor design. It requires a minimum of 6.5 volts DC and 2.3 milliamperes from the communication amplifier's powered microphone bias circuit to operate properly. The preamplifier frequency response curve peaks at approximately 4 kHz and is -3 dB at 1.3 kHz and 10.1 kHz with a slope of $\pm$ 20 dB/decade at these points. The microphone cable has an underwater mateable, 2 contact, female male connector on the end.

Type B

This is also a preamplified, piezoelectric compression type microphone like type A and, except for the preamplifier, it is the same as detailed in CSS drawing #6696997. It is not currently issued but is a candidate to replace or supplement the type A microphone for use with the MK-24 FFM. The preamplifier for this microphone is unipolar and based on an operational amplifier design. It requires a minimum 7.4 volts DC and 3.9 milliamperes from the communication amplifier's powered microphone bias circuit to operate properly. The preamplifier frequency response curve peaks at approximately 3.7 kHz and is -3 dB at 1.2 kHz and 11.5 kHz with a slope of $\pm$ 20 dB/decade at these points. The main advantages of this preamplifier design over that for the type A microphone are; consistent performance from unit to unit, and a non-proprietary design that is fully documented, tested over temperature and simpler to manufacture and test.