NTIA Technical Report TR-08-453

Intelligibility of Selected Radio Systems in the Presence of Fireground Noise: Test Plan and Results

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report series

U.S. DEPARTMENT OF COMMERCE • National Telecommunications and Information Administration

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U.S. DEPARTMENT OF COMMERCE
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June 2008

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ABBREVIATIONS/ACRONYMS/GLOSSARY

Codec	Combination of an encoder and decoder in series (encoder/decoder).
Coder	Same as "encoder".
Decoder	Device for translation of a signal from a digital representation into an analog format. For the purposes of this document, this is a device compatible with TIA-102.BABA [1].
df	Degrees of freedom for ANOVA or Newman-Keuls calculations.
Encoder	Device for converting an analog signal into a digital representation. For the purposes of this document, this is a device compatible with TIA-102.BABA[1].
Fireground	The fire service term for an active fire scene.
FM	Frequency modulation.
HATS	Head and torso simulator.
IMBE™	Improved Multi-Band Excitation. A speech encoder which divides the audio spectrum into bands and generates speech model parameters based upon these spectral bands. In the speech decoder, the model parameters are used to synthesize speech for each of the spectral bands.
LLR	Log likelihood ratio.
LRP	Lip reference point of the HATS.
MRT	Modified rhyme test as defined in [3].
PASS	Personal alert safety system, which emits a signal in the event that the user becomes incapacitated or needs assistance.
PCM	Pulse coded modulation, a logarithmically companded and 64 kb/s encoded representation of speech.
Pink Noise	Acoustic noise that has equal power per octave band as frequency increases.
QFA	Full-rate baseline codec with no modulation (7200 bps).
QFB	Enhanced full-rate codec with no modulation (7200 bps).
RF	Radio frequency.
Vocoder	Voice encoder / decoder.

EXECUTIVE SUMMARY

Project 25 (P25) is an initiative to develop a standardized digital radio and promote interoperability among digital land mobile radio (LMR) systems. The Association of Public Safety Communications Officials (APCO) and the Telecommunications Industry Association (TIA) cooperated to form this initiative in 1988. An integral part of the initiative, the digital voice coder/decoder pair (or vocoder for short) was selected in 1992, based on the results of several tests. This vocoder is named for the technology it uses, Improved Multi-Band Excitation (IMBE™), and was standardized by the TIA as TIA-102.BABA.

The performance of the IMBE vocoder has proven to be problematic in tactical fireground communications, where considerable background noise may be present. Several fire agencies have brought this problem to public attention (Boise, Fairfax, Littleton, and Phoenix Fire). The Digital Problem Working Group (DPWG) was formed by the International Association of Fire Chiefs (IAFC) in response to the problem, and is designed to provide input to testing procedures. The purpose of DPWG is to define the problem, identify potential solutions, and recommend best practices that could mitigate issues identified by first responders.

One such testing procedure has been conducted. The Institute for Telecommunication Sciences in Boulder, Colorado developed the test plan in conjunction with the DPWG Testing Subcommittee. The goal of this experiment was to measure the intelligibility of communication systems operating in high acoustic noise environments typical of those encountered by firefighters. The three primary communication systems consist of:

- 25 kHz analog FM radio pair (a.k.a. 25 kHz Analog)
- Baseline full rate IMBE vocoder radio pair (a.k.a. P25 Full Rate)
- Enhanced full rate IMBE vocoder radio pair (a.k.a. P25 Enhanced Full Rate)

A modified rhyme test (MRT) was used to evaluate each communication system in each of nine environmental noise conditions (described below). The MRT method is more completely described in ANSI S3.2, and is required in the evaluation of self-contained breathing apparatus (SCBA) by the National Fire Protection Association (NFPA) 1981-2007 standard.

In short, a basic MRT is a test where speakers are instructed to say "Please select the word," followed by one of any number of words that "rhyme" on either the first or last consonant (e.g., one group of six words includes bed, led, fed, red, wed, and shed). These utterances are recorded, and later played back to test subjects, or listeners. The listeners are asked to select the word they heard at the end of the sentence. There are specific methods used to interpret this data, due to the situation where the listener has a limited set of possible answers to choose from, advance knowledge of the majority of the incoming sentence, as well as other constructs of the testing environment.

In this test, the recorded utterances were processed using the vocoders on the aforementioned radio pairs. That processing took place while the radio pair was in the presence of one of the following nine environmental noise conditions:

- No background noise, no mask (or the Clean condition)
- Fire truck pump panel, no mask
- Mask with no background noise
- Two Personal Alert Safety System (PASS) alarms, with mask
- In-mask low-air alarm
- Rotary saw cutting metal garage door, with mask
- Chainsaw cutting wood, with mask
- 2 1/2” hose with fog nozzle, with mask
- Rotary saw cutting metal garage door, with amplified mask

Those processed files were played back to listeners in a sound-isolated room. For the duration of the test, the room was filled with a field of pink noise. This test also evaluated a 12.5 kHz analog FM radio pair on three of the nine environmental noise conditions. The inclusion of this radio pair was to evaluate the intelligibility of this communication system, which meets an FCC mandate requiring narrowband devices.

After 30 listeners participated in the test, the results were processed and some interesting conclusions can be drawn. The performance of the 25 kHz Analog system was either statistically similar to or better than the P25 systems for all environments. Four of the nine environments were too difficult for intelligible communication using all tested systems (i.e., less than 10% intelligibility). The 12.5 kHz Analog system was statistically similar to the 25 kHz Analog system.

This testing examined fire safety equipment used in conjunction with these systems. In the case of voice transmissions while using a mask, there was a significant degradation in intelligibility for the P25 vocoders. The PASS alarm, designed to augment safety of first responders, significantly degraded intelligibility of both P25 vocoders. The low air alarm was effectively too difficult a noise environment for all of the tested communications systems, but it is worth noting that the 25 kHz Analog system and the P25 Enhanced Full Rate system preserved the noise characteristics of the low air alarm sufficiently well that a listener could determine what type of alarm was sounding.

While this information may be useful to those planning to purchase and deploy new radio systems for their agencies, these results should not be the sole source of information. Other decision factors should include which agencies are involved, their current assets, their operating procedures, policies, and budget plans, spectrum availability in their locale, State Communications Interoperability Plans (SCIPs), and other, more specific situations that are beyond the scope of this document.

INTELLIGIBILITY OF SELECTED RADIO SYSTEMS IN THE PRESENCE OF FIREGROUND NOISE: TEST PLAN AND RESULTS

David J Atkinson, Andrew A. Catellier[1]

This report describes an experiment conducted to measure the intelligibility of selected radio communication systems when those systems are employed in high-background-noise environments experienced by firefighters. The test plan for a Modified Rhyme Test (MRT) is detailed, including requirements for source material preparation and listening test conduct. Finally, the results of the test are presented, along with the data analysis. The results indicate that in some environments analog radios performed better than digital radios, and in some environments no radios performed well. This information should be considered whenever an agency is preparing to purchase and deploy a new communications system.

Key words: intelligibility; Project 25; vocoder; modified rhyme test; noise; analog FM; land mobile radio; LMR; public safety; fire service

1 INTRODUCTION

Project 25 was initiated in 1998 as a cooperative agreement between the Association of Public Safety Communications Officials (APCO) and the Telecommunications Industry Association (TIA). The purpose of Project 25 was to develop a standardized digital radio to promote interoperability among digital land mobile radio (LMR) systems. One element of the Project 25 suite, the vocoder, was selected in 1992. At that time, several tests were conducted by the Project 25 committees to ensure that the best available vocoder was selected. The selected vocoder, known as the Improved Multi-Band Excitation (IMBE™, a trademark of Digital Voice Systems Inc.), was standardized by TIA as TIA-102.BABA.

As P25 networks were deployed, it became evident that certain noisy environments in which public safety must communicate are problematic for the vocoder. This has appeared most consistently in tactical fireground communications, and the issue has been raised to the national level by agencies such as Boise [Idaho] Fire, Fairfax [Virginia] Fire, Littleton [Colorado] Fire, and Phoenix [Arizona] Fire. In response to this issue, the International Association of Fire Chiefs (IAFC) created a Digital Problem Working Group (DPWG) to provide expert input into the testing to specifically identify the problem and potential solutions as well as to develop best practices that could mitigate some of the problematic issues in the communications environment.

This document provides the test plan and results of the first test undertaken at the request of the DPWG. The test was designed to compare intelligibility of communication systems being used in fireground noise situations. The test plan was developed in conjunction with the Testing Subcommittee of the DPWG and the testing was conducted at the Institute for Telecommunication Sciences in Boulder, Colorado. This document describes the evaluation procedure used to characterize the response of digital voice coding technology to public safety

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noise environments, as well as the results of that procedure. The report specifically focuses on those background noise environments experienced in the fireground. Understanding the characteristics of a digital voice coder is essential to enabling effective communication in the environment in which public safety personnel must operate.

The evaluation procedure is designed to give a fair characterization of the communication system. This is accomplished through the examination of the system performance in a subjective listening test in which the relative performance among the enhancements is measured in a quantitative way.

The purpose of the subjective listening test is to evaluate communication systems under a variety of operating conditions. The operating conditions were chosen to be representative of those experienced in a fireground environment. Only a limited number of operating conditions are tested. A test of all possible operating conditions would be too unwieldy to conduct.

Section 4 describes the communication systems (and their respective vocoders) that are the subject of this test. Section 2 also discusses any background noise for the test conditions. Section 3 discusses the speech database used in the testing and comparison. Section 4 contains the details of the testing procedure as well as the speech database used for the testing. Section 5 discusses the design of the listening tests themselves, including the analysis of results. Section 6 describes the disclosure of the test results. Lastly, appendices are included which contain additional detail.

1.1 Scope

This document specifies the procedures to be employed to characterize the behavior of TIA 102.BABA compatible speech codecs in environmental noise conditions. The original baseline speech codec from 1992 is the IMBE described in TIA 102.BABA, Project 25 Vocoder Description. The IMBE speech codec is used to digitally encode the speech signal and provide forward error control for transmission at a data rate of 7200 b/s. The baseline speech codec is defined as the reference codec for the Project 25 MOS Conformance Test [2].

The testing of the codecs is performed using subjective listening tests that judge overall speech intelligibility [3].

Where possible, this study compares systems incorporating the speech codecs with those using analog FM. The baseline speech codec is based upon the Digital Voice Systems Incorporated implementation of the IMBE algorithm on the VC 20 Project 25 hardware card, or the equivalent software version. The software version is of primary interest in this test. The experiment compares the coding mechanisms with various channel conditions as might occur on a land mobile radio channel.

1.2 Overview

Speech coders are tested by comparing their performance with a reference implementation such as analog FM. The test evaluates the intelligibility of communication systems using different vocoder technologies, including reference communication systems. The test results are then compared against the reference. There are four communication systems (with 4 different coding technologies) in this test. These mechanisms are listed below, and they are also described in Section 4.

System 1. 25 kHz analog FM radio pair.

System 2. Radio pair implementing the baseline full rate IMBE vocoder. This is referred to as the “P25 Full Rate” throughout this report.

System 3. Radio pair implementing the enhanced full rate. This is referred to as the “P25 Enhanced Full Rate” throughout this report.

System 4. The experiment will also evaluate the viability of 12.5 kHz analog FM radio in three of the background noise conditions.

The inclusion of the 12.5 kHz analog FM system provides an indication of whether or not that might be a viable alternative that meets the narrowbanding mandate of the FCC while still providing a required level of intelligibility to the communication system user.

The intelligibility of each communication system is subjectively rated in each environmental noise condition specified.

The intelligibility of a communication system can be difficult to quantify since it is a subjective issue, relying on humans to be able to discern words. This performance evaluation relies upon subjective testing using a panel of listeners who listen to speech passing through a system and attempt to understand what was spoken. Since discernment of listeners may vary, the results from a number of listeners are obtained and averaged to obtain an overall score.

To evaluate the intelligibility, it is necessary to conduct an experiment in a controlled manner so that unintentional variation in the scoring is avoided. The purpose of the testing is to provide understanding of the behavior of communication systems in noisy environments and to determine differences in performance among the different speech coding mechanisms. The confidence we have that any apparent differences in performance are due to communication system effects and not random statistical variation depends upon how well we prevent differences from occurring in the testing. The statistical controls for the experiment and the analysis are given in Section 5. The listening test evaluates the communication systems under operating conditions, particularly different acoustic background noise conditions on the transmitting end of the communication path. The acoustic background noise conditions represent some noisy acoustic environments encountered by land mobile radio users in the fireground. This experiment uses the following noise environments on the transmitting end of the communication path:

Environment 1. No background noise, no mask (referred to as the Clean condition)

Environment 2. Fire truck pump panel, no mask

Environment 3. Mask with no background noise

Environment 4. Two Personal Alert Safety System (PASS) alarms, with mask

Environment 5. In-mask low air alarm

Environment 6. Rotary saw cutting metal garage door, with mask

Environment 7. Chainsaw cutting wood, with mask

Environment 8. 2½" hose with fog nozzle, with mask

Environment 9. Rotary saw cutting metal garage door, with amplified mask

Section 4.3 provides additional information about the background noise.

The system implementations are executed in hardware and recorded to generate test material. The test material consists of a series of computer files in WAV format, and the output files are in the same format for use in the listening test.

The overall plan of the test is outlined in Figure 1. The test begins with the source audio material. There are several conditions that the source material must satisfy, and these are covered in Section 3. The source audio material is then passed through the different communication systems, with different operating conditions, to produce numerous output audio files. This procedure is given in Section 4. The output audio files are then randomized in order to provide samples suitable for a listening test. The randomization step, together with the listening test and the analysis, is described in Section 5. The result of the test is then presented in Section 6, which describes a spreadsheet for this analysis.

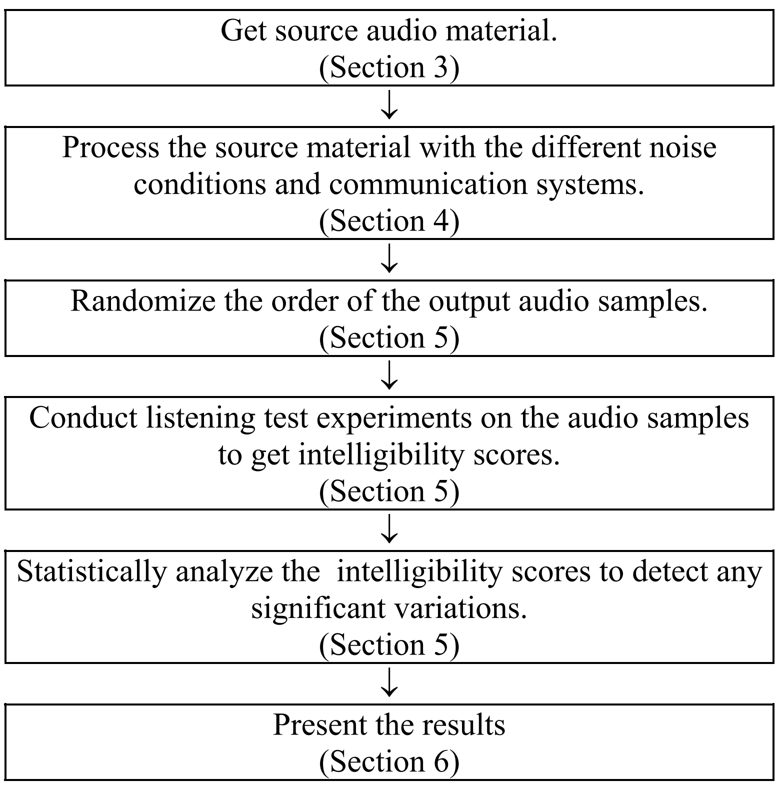

Figure 1. Test plan overview.

2 COMMUNICATION SYSTEMS AND NOISE ENVIRONMENTS

This section describes the speech coding mechanisms evaluated in this test in a general way. The acoustic environments for the test are also described.

2.1 Communication Systems

There are four communication systems defined for this test.

System 1. 25 kHz analog FM radio pair. This is the reference standard for fire agencies because it is the technology that they have been using since the mid-20th century.

System 2. Radio pair implementing the baseline full rate IMBE vocoder (QFA)[2], equivalent to the vocoder selected by Project 25 in 1992. This is described as a Full Rate vocoder. It operates at a gross bit rate of 7200 b/s, a net bit rate of 4400 b/s, with 2800 b/s of parity checks for channel error correction. This includes speech processing enhancements that have been incorporated by the radio manufacturer. This combination of a baseline vocoder with optional speech processing enhancements is referred to as the "P25 Full Rate" throughout this report.

System 3. Radio pair implementing the enhanced full rate vocoder (QFB), interoperable with the baseline full rate vocoder. This vocoder operates at a gross bit rate of 7200 b/s, a net bit rate of 4400 b/s, with 2800 b/s of parity checks for channel error correction. It includes non-essential improvements developed since 1992 for improved audio quality built directly into the vocoder as well as any enhancements that may have been incorporated by the manufacturer. This combination of the enhanced vocoder with any manufacturer enhancements is referred to as the "P25 Enhanced Full Rate" throughout this report.

System 4. 12.5 kHz analog FM radio pair limited to three noise conditions. This is a system that could provide similar characteristics to 25 kHz Analog FM but still meet the impending 12.5 kHz narrowbanding requirements.

The radio frequency (RF) communication path between transmit and receive units will be an ideal (cabled) path.

2.2 Acoustic Environments

The experiment tests the performance of the communication systems (and their respective vocoders) with background noise mixed in with the speech at the transmitting radio for a specific signal to noise ratio. There are nine acoustic environments to be evaluated in this experiment: no background noise (no mask), fire truck pump panel (no mask), mask with no background noise, two PASS alarms (with mask), in-mask low air alarm, rotary saw cutting metal garage door (with mask), chainsaw cutting wood (with mask), a 2½" hose with a fog nozzle (with mask), and rotary saw cutting a metal garage door (with amplified mask).

[2] Appendix D contains a description of the notation used to identify codecs being tested in the TIA/Project 25 community. In this case, the notation means: QPSK-c modulation ("Q"), full rate ("F"), baseline ("A").

The noise conditions represent common acoustic noise environments where a user might be transmitting, and were chosen as representative by a panel of fire practitioners participating in the IAFC testing committee. The samples were taken as high-quality digital recordings made at an agency training facility. The signal-to-noise ratios (SNRs) are chosen to approximate sound level conditions that were measured in the application environment.

The power spectral densities (PSDs) and spectrograms of the six background noises are given in Figure 2 to Figure 7.

The PSDs in Figures 2-7 and the Acoustic Path Loss in Figure 8 were computed using Matlab™ mathematical analysis software. The computation method (Welch)[4], number of elements in the transform (Nfft), and the size and shape of the computational window (Hamming [5], 1024) were parameters provided to the Matlab algorithms.

The spectrograms in Figures 2-7 are plots of frequency content (on the vertical axis) versus time (on the horizontal axis).

Together the PSDs and spectrograms provide an indication that the noise environments cover a wide range of frequency characteristics, impulse characteristics, and amplitudes.

The mask acoustic transfer characteristic is given in Figure 8. There is notable signal loss in the 1,500 – 3,000 Hz range. This is significant because this range of frequencies is significant to intelligibility.

2.3 Test Conditions

The available systems combine with the noise environments to provide the array of conditions for the experiment. Table 1 shows which environments are used with which communication systems. Appendix A contains a full list of conditions for the experiment.

Table 1. Combination of Noise Environments and Communication Systems

Environment	SNR (dB)	25 kHz Ana FM	P25 Full Rate	P25 Enh Full Rate	12.5 kHz Ana FM
Clean		X	X	X	X
Fire truck pump panel, no mask	4	X	X	X	
Mask with no noise		X	X	X	X
Two PASS Alarms, mask	-2[3]	X	X	X	
In-mask low air alarm, mask	15[3]	X	X	X	
Rotary saw cutting metal garage door, mask	4[3]	X	X	X	X
Chainsaw cutting wood, mask	5[3]	X	X	X	
2½” fog nozzle, mask	9[3]	X	X	X	
Rotary saw cutting metal garage door, amplified mask	4	X	X	X	

[3] Plus attenuation of the signal due to the mask. This is approximately 9 dB.

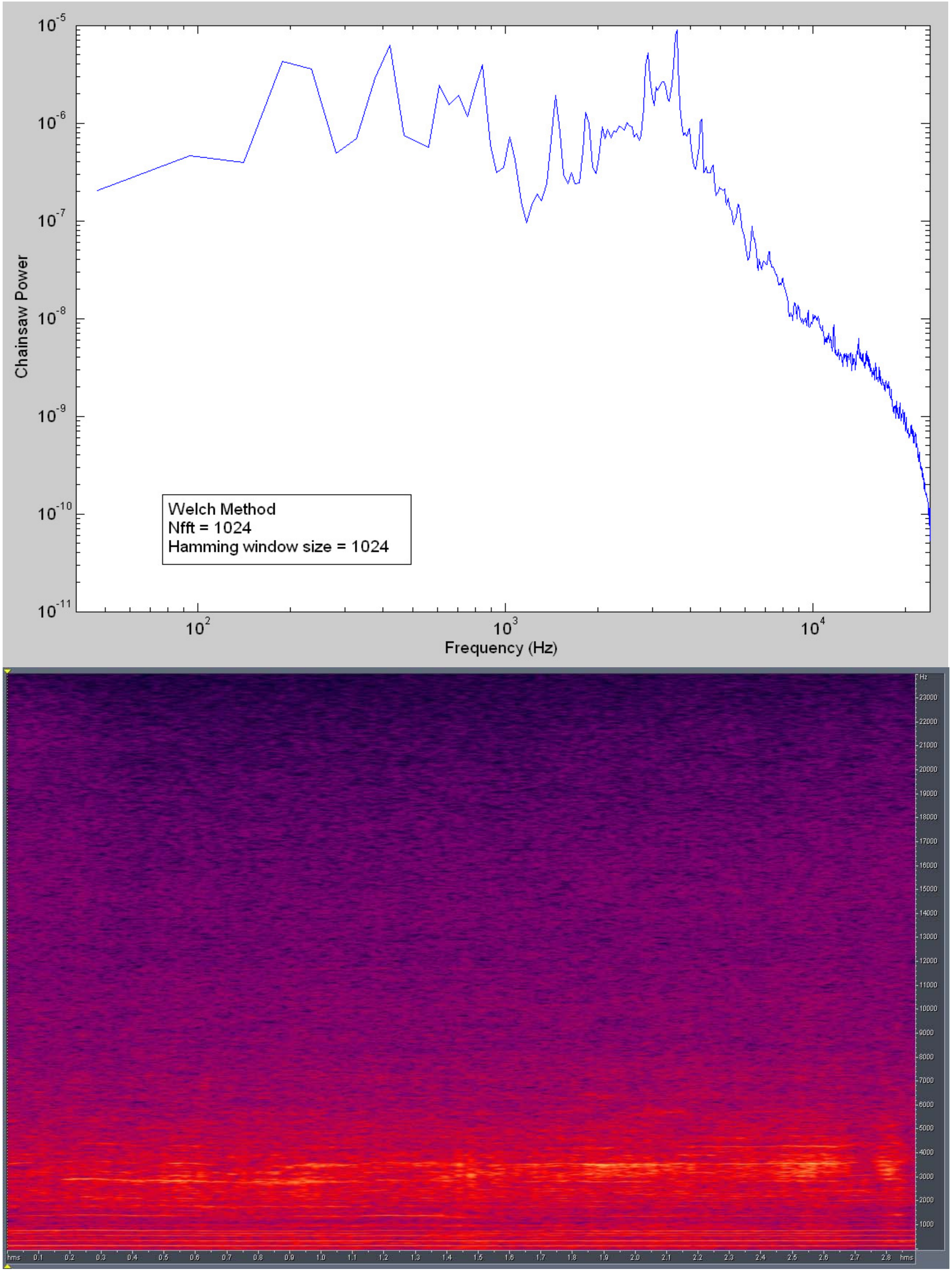

Figure 2. PSD and spectrogram of a chainsaw cutting a wood roof.

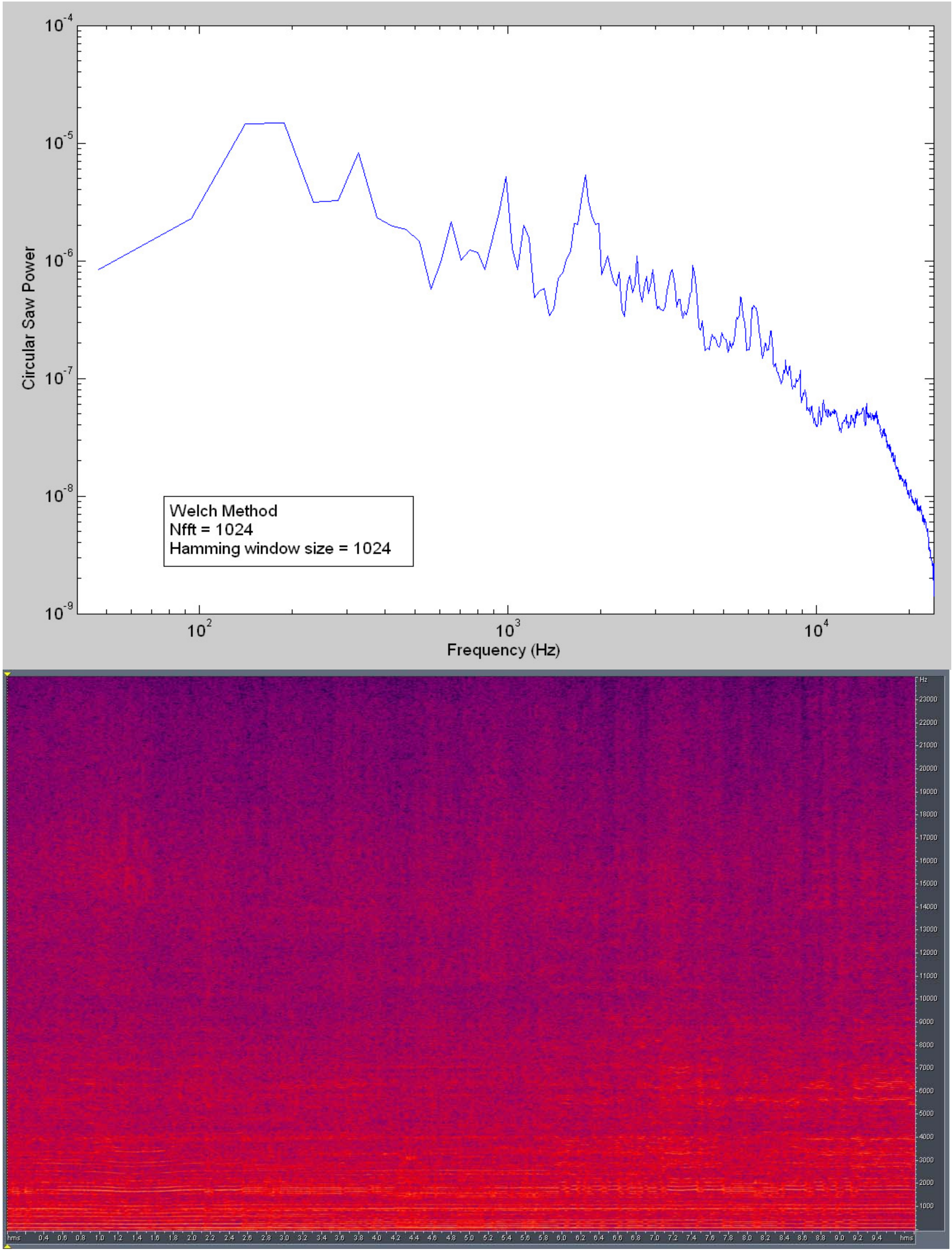

Figure 3. PSD plot and spectrogram of circular saw cutting a metal garage door.

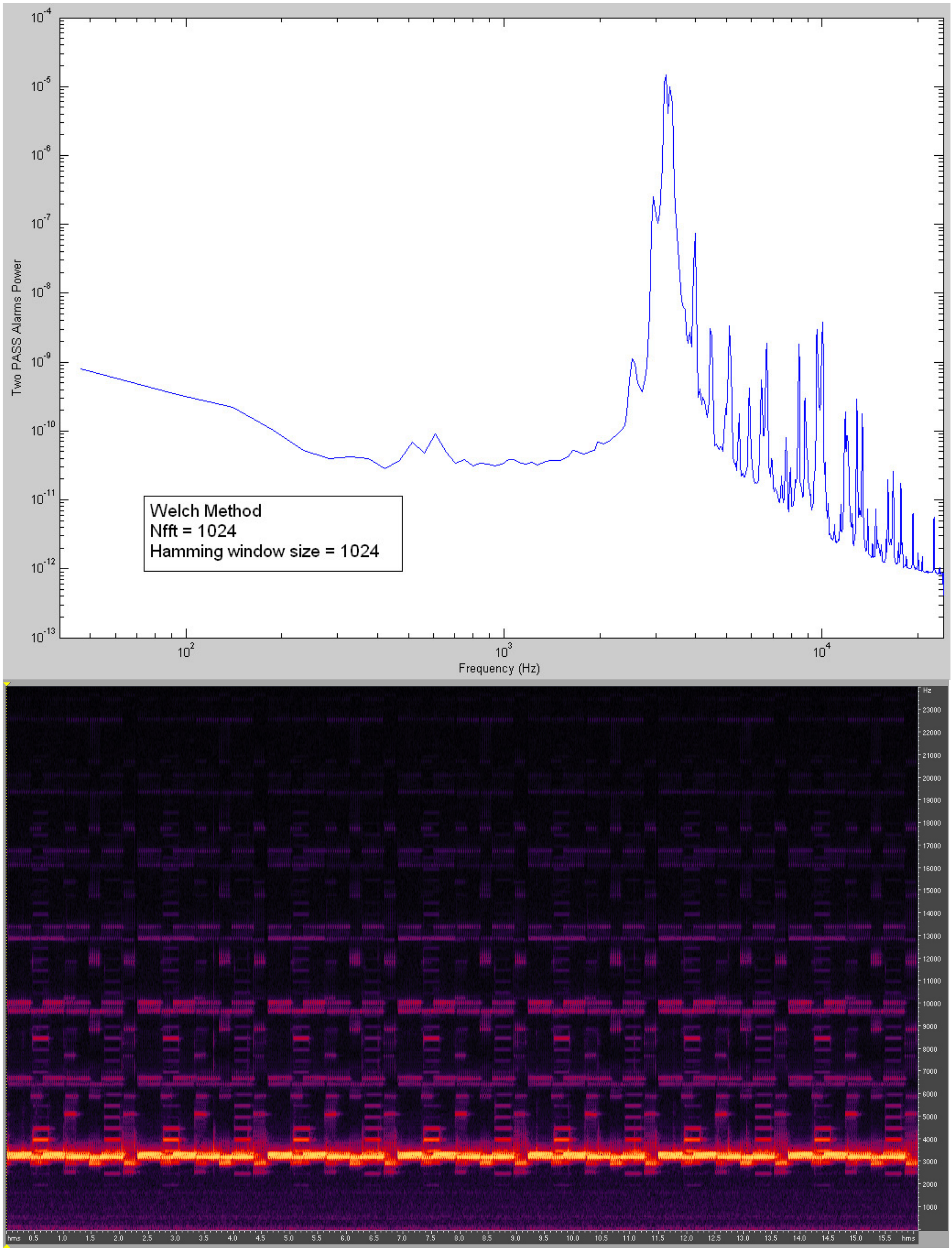

Figure 4. PSD plot and spectrogram of two PASS alarms sounding.

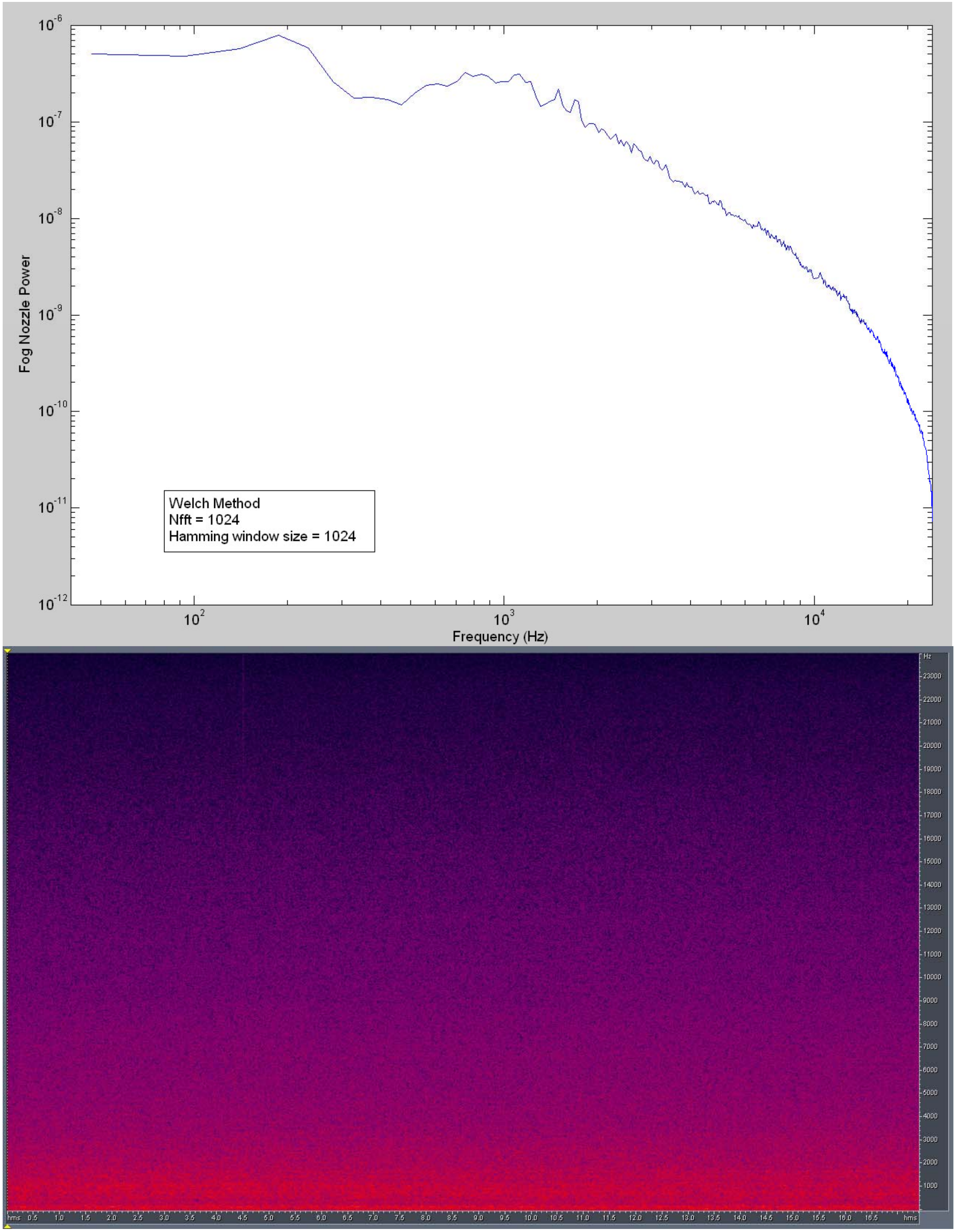

Figure 5. PSD plot and spectrogram of a 2½ inch fire hose with fog nozzle.

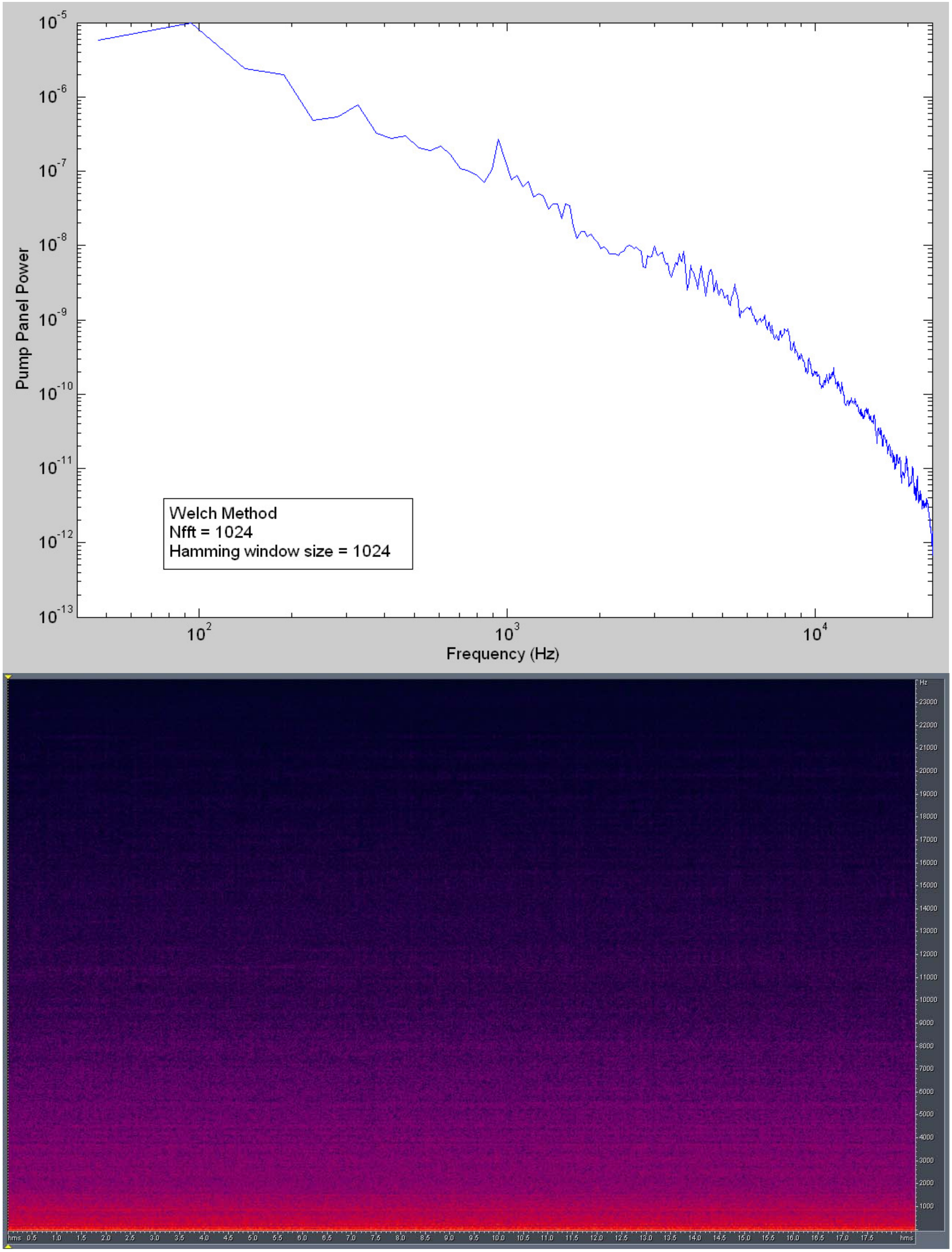

Figure 6. PSD plot and spectrogram of a fire truck pump panel.

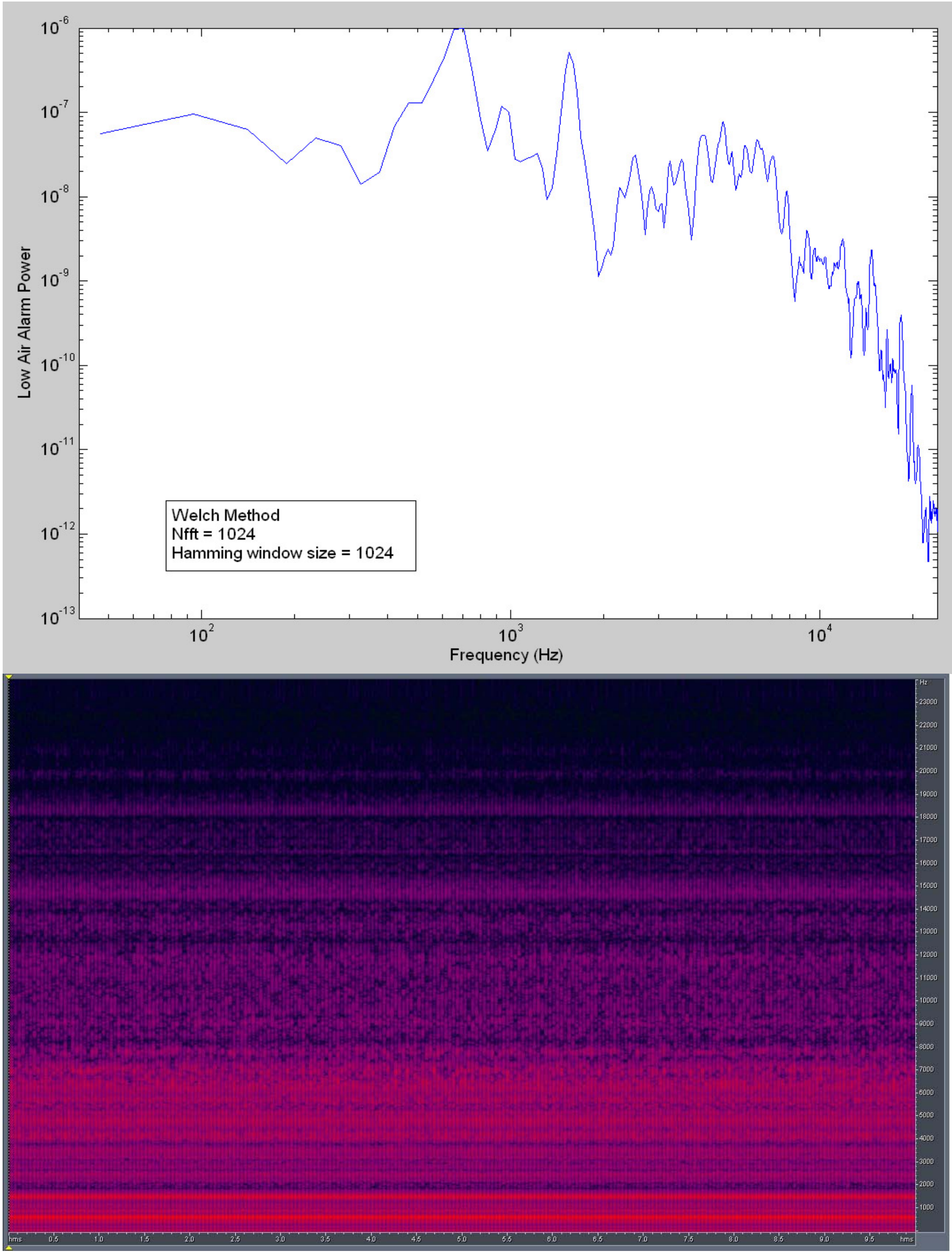

Figure 7. PSD plot and spectrogram of in-mask low air alarm.

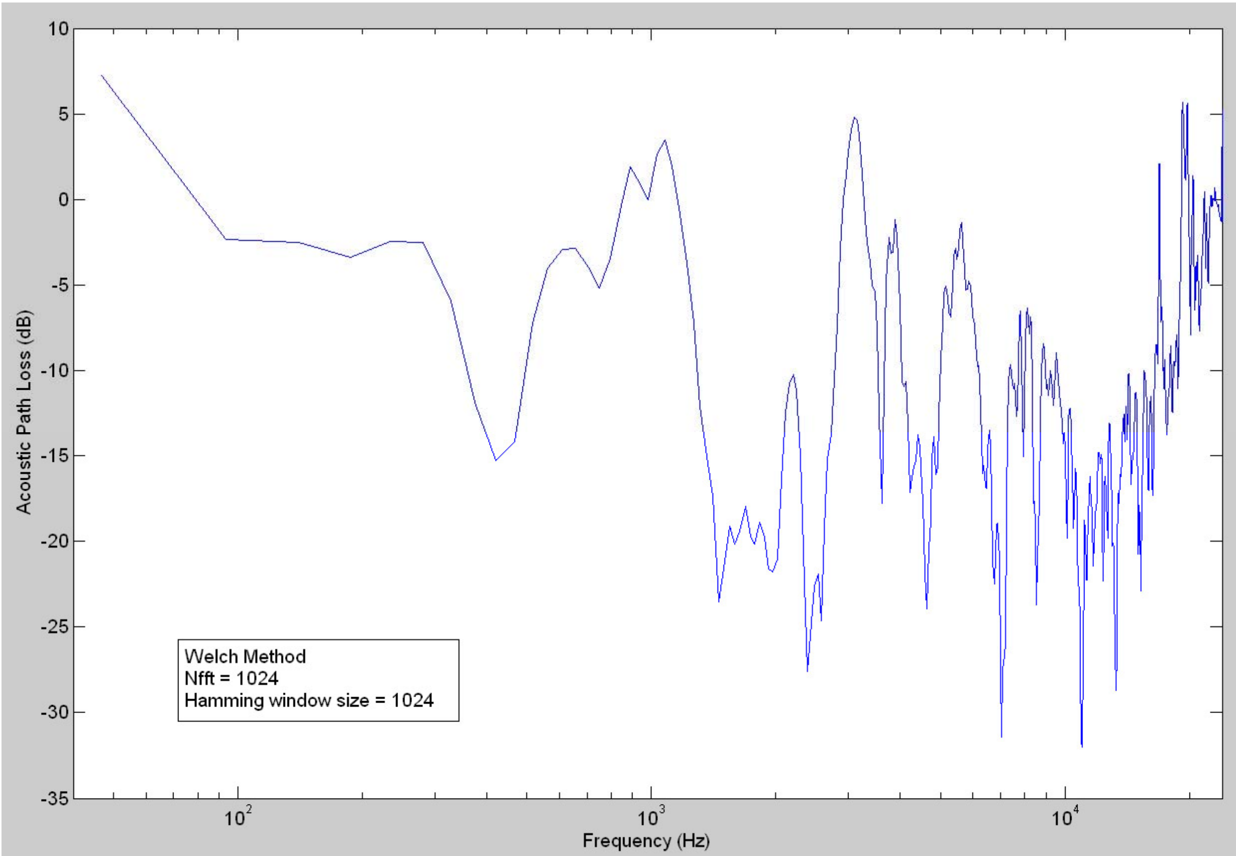

Figure 8. Acoustic path loss through SCBA mask.

3 SOURCE SPEECH DATABASES

The speech source material used for the test consists of spoken word lists from the Modified Rhyme Test (MRT) described in [3] (e.g., one group of six rhyming words includes bed, led, fed, red, wed, and shed). Source material used for the tests has a quiet acoustic background. In the experiment, acoustic background noise is added to the source material. The MRT is used for evaluation. These tests place several requirements on the speech database:

1. Large numbers of words,
2. Equalized presentation levels,
3. Sentences of equivalent content and structure.

The speech source material for the test has been recorded at ITS. This material is the MRT word list defined in [3] using the carrier sentence, "Please select the word …" More specific information about the recording process for this source material is in Appendix C.

3.1 Speech Database Requirements

Each test condition uses the six lists of 50 words each defined in [3]. Each coding mechanism processes the same speech material under the same operating conditions. Sufficient source material is used to ensure listeners are not presented repeat material. To reduce order bias, the presentation order of the material to the listeners is randomized.

The experiment utilizes speech recorded in a quiet acoustic noise environment. The testing includes a clean condition, and seven acoustic noise environments. For the experiments, there are three male talkers and three female talkers.[4] All talkers speak the same six lists of 50 words and are required by [3] to have little or no discernable accent.

The speech material is equalized across all talkers for presentation level. The material is provided in WAV files in full audio bandwidth and dynamic range. There are no limitations on the speech material other than those imposed by the microphone and recording system.

3.2 Speech Database Levels

An important attribute of the speech database, especially for the encoding procedure, is the average power level of the speech material. The nominal power level for speech follows the recommendation defined in [1] and excerpted below. This recommendation is followed for each sentence.

"It is recommended that the analog input gain be set such that the RMS speech level under nominal input conditions is 25 dB below the saturation point of the A-to-D converter. This level (-25 dBm0) is designed to provide sufficient margin to prevent the peaks of the speech waveform from being clipped by the A-to-D converter."

A further specification is given for the measurement method to determine the average speech power level. The varying nature of speech signal amplitude presents a difficulty for accurately measuring the level using an arbitrary method. This document uses the ITU-T Recommendation P.56 [6], method B to accurately measure the active speech level.

[4] [9] specifies an unbalanced talker pool of 4 male and 1 female talkers. To provide more gender-balanced results that could have wider applicability, a balanced talker pool of 3 male and 3 female talkers is used.

4 PRODUCTION OF PROCESSED FILES

This section describes the test procedure to be followed to conduct the tests of the encoding technologies. These procedures have been designed to assist interested parties in reproducing the speech files for later scoring by a listening laboratory.

4.1 Required Elements

The production of the mixed speech and noise files requires the following elements.

1. Head and torso simulators [7][8]
2. NC-35 sound attenuated chamber
3. Representative SCBA mask with in-mask low-air alarm
4. Ability to produce environmental noise at appropriate level within the NC-35 chamber
5. Radios that can implement the coding technologies specified
6. Recording and playback hardware and software

4.2 Test Signal Preparation

The test material generation procedure is most simply described as passing 300 sentences from each talker through nine noise environments and either three or four coding technologies for each speaker as identified in Table 1. This results in 54,000 processed sentences.

For production of processed files, clean speech is played through a HATS speaking into a radio microphone while background noise is generated by loudspeakers in the attenuated chamber. Depending on the environment, there may be a SCBA mask installed on the HATS.

For the conditions with background noise, it is important that the background noise be active before the push-to-talk is initiated to avoid potential false training of features of the codec (i.e., mislead the coder into thinking it is starting in a quiet environment), which may lead to longer-than-normal training times once the noise starts.

Figure 9 shows the physical configuration for those conditions without a mask, and Figure 10 shows the physical configuration for those conditions with a mask. The figures show the HATS in the middle of the attenuated chamber with loudspeakers around the perimeter. For those conditions without a mask, the transmitting microphone for the communication system will be positioned 5 cm (2 in.) directly in front of the lip reference point (LRP). For those conditions with a mask, the transmitting microphone of the communication system will be positioned 2.5 cm (1 in.) directly in front of the voice transmission port on the mask.

For single point background noise sources, the sound will be generated by the loudspeakers at the front of the room (in front of the HATS). For multipoint noise sources, all five speakers will be used to generate the noise.

For the purposes of this experiment, the artificial mouth of the HATS was equalized to flat ± 1 dB in the band of 160 Hz to 10 kHz. Speech is played through the HATS at a level of 100 dBC.[5] This is consistent with measurements made on behalf of TIA of users talking in a loud noise environment.

For the receiving end, the speaker of the receiving radio will be positioned at the ear reference point (ERP). Volume on the receive radio will be set such that a 1011 Hz P25 test tone generates an acoustic signal of 85 dBA at 1" from the speaker grille. Recording will be done through the artificial ear of the second HATS in a "quiet" environment. This enables any listening environmental noise to be inserted during the actual listening experiment.

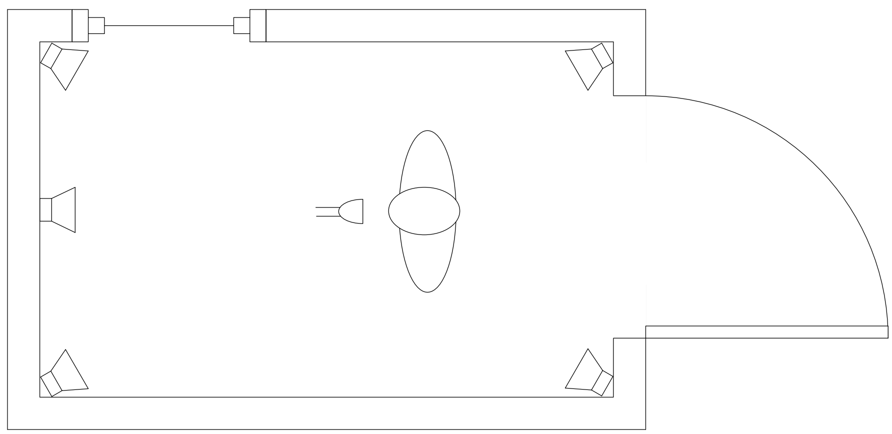

Figure 9. Physical configuration for non-mask conditions.

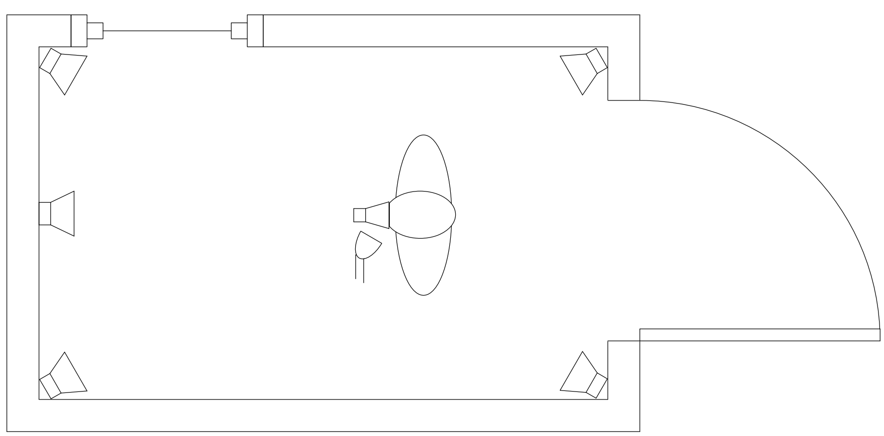

Figure 10. Physical configuration for conditions with SCBA mask.

[5] dBC refers to a specific weighting function applied to a sound pressure level measurement. The "C" weighting function includes a broader spectrum of sound waves in the computation than the "A" weighting function. The "A" weighting function emphasizes the speech band and measurements using this function are measured in dBA.

4.3 Signal and Acoustic Noise Levels

In order to construct the appropriate signal to noise levels for voice coder encoding, careful attention to the noise signal filtering and level adjustment of the signals is required. The definition for signal to noise ratio in dB for this test is given in (1).

$$SNR = ActiveSpeechLevel - 20\log_{10}(NoiseLevel) \quad (1)$$

Active speech level is computed according to [6]. The short-term power function of each noise is assumed to be much more stationary than speech, relieving the need for an activity/threshold detector. The computation for the noise levels follows a root mean square (RMS) algorithm that is scaled to the overload point so that dB values are negative or zero and is shown in (2).

$$NoiseLevel = \frac{1}{A_{fullscale}}\sqrt{\frac{\sum_{i=1}^{N} x_i^2}{N}} \quad (2)$$

where $A_{fullscale}$ is the fullscale amplitude of the signal, N is the number of samples, and x_i is the value of the ith sample.

The noise samples are scaled by the appropriate factor to obtain the target noise level for that specific test condition and summed together to create a noise condition file for voice coder input.

5 SUBJECTIVE EVALUATION OF INTELLIGIBILITY

The subjective evaluation of intelligibility using the MRT is specified in [9] and described in [3].

Subjective testing involves the use of a number of listeners to attempt to interpret the words spoken through the communication system. The processed speech samples are obtained as described in Section 6. Because intelligibility is subject to individual abilities to interpret spoken words, reliable results are obtained when a number of listeners are used. For this assessment a total of 30 listeners are used in 6 groups of 5 listeners. To mitigate the effects of the order of presentation of the speech samples to the listeners, different presentation orders are used with each listener.

5.1 Experiment Randomization

The listening material consists of 6 lists of 50 words from each of 6 talkers (3 male, 3 female). This listening material is processed for each of the 30 test conditions yielding a total of 54,000 test samples (50 words x 6 lists x 6 talkers x 30 test conditions). Each listener will score the intelligibility of 25 words from one list for one male and one female talker for each condition.

To ensure that there are no effects of the order of presentation, the material used in the listening tests is presented to each listener in a different, randomized order.

Randomization is constrained in the following ways.

1. 25 words from one male and one female speaker for each test condition (combination of system and impairment) are presented exactly once to each listener such that no words are repeated (25x2x30 = 1500 samples per listener).

2. Listeners are effectively paired in that consecutive odd/even numbered listeners will collectively hear all 50 words from one male and one female speaker for each test condition.

3. Randomization is done in blocks of 60 test samples, such that one sample of each combination of codec, talker gender, and impairment is presented once, in each block, to each listener. There are 5 blocks in each listening session. This means that the listeners rate each combination of codec and impairment approximately equally in the beginning, middle, and end of the session. Each listener participates in 5 sessions during the experiment.

4. The selection of the particular test samples for each block and their presentation order within a block is randomized.

5. Consecutive talkers are always different. This is accomplished by alternating the gender of the talker.

5.2 MRT Evaluation Laboratory

The Evaluation Laboratory conforms where possible to the applicable sections of ITU-T Recommendation P.800 [10]. An Evaluation Laboratory is chosen to perform the evaluations. The Evaluation Laboratory is responsible for conducting the tests as described in Section 5.3 and the delivery of the results of the experiment as described in Section 5.4.

Prior to the start of the test the listeners participate in a practice session. During this practice session they are presented with 60 practice sentences which they score. The practice sentences consist of a block of material as described in Section 7.1.1 item 3, but taken from the larger corpus of speech material, excluding the samples that they score for the experimental sessions. After the practice session the listeners are asked if they understand what they are supposed to do. If there are any questions they are answered at that time. After that the formal test begins. The purpose of the practice session is to: (a) expose the listener to the range of audio quality of the test, and (b) to see if they understand what they are supposed to be doing. This is in accordance with P.800, clause B.4.6, "Instructions to Subjects."

The experimental results are presented, while the data from the practice sessions is discarded. The results from the listening test are then permuted to undo the randomization described in Section 5.1 so that the results can be reported as described in Section 5.4.

5.3 Intelligibility Testing

The subjective evaluation consists of one experiment to determine effects of background noise and talker variability.

The listening test for the intelligibility test follows the Modified Rhyme Test (MRT) method [3]. In this type of test, each listener listens to a sentence asking them to select a word from a prescribed list. The listeners' ability to select the correct word is averaged across listeners and produces a percentage of intelligibility score.

The MRT consists of the test conditions shown in Table 1.

5.3.1 Conducting the Listening Test

Presentation of speech material is made via high fidelity near-field monitor speaker at a distance of 1.5m from the listener. The delivery system is calibrated to deliver an average speech listening level of 75 – 85 dBA when measured at the listening position. The equivalent acoustic noise level of the delivery system does not exceed 35 dBA.

Listeners are seated in a room, with an ambient pink noise level of 70 dBA as defined in Sections 8.10.4.11 through 8.10.4.15 of [9]. The exact configuration of the room and characterization of the noise is shown in Appendix E.

That the listeners are practitioners notwithstanding, the listeners should be naïve with respect to communication technology issues; that is, they are not experts in telephone design, digital voice encoding algorithms, and so on. The sample includes adults of mixed sex, age, and practitioner discipline. Persons have audiometrically normal hearing as defined in 8.10.4.3 of [9].

The test is conducted as described in Sections 8.10.5.1 and 8.10.5.2, with the exceptions that the carrier sentence will be "Please select the word [list word]" and that listeners will select the word on a touch screen.

The administration of the experiment is as follows. The processed speech is presented to a panel of 30 listeners. The 30 listeners are segmented into five listening group sessions {A B C D E F} of 6 members each. Each listening group session contains 9,000 sentences out of the possible pool of 54,000[6] sentences to evaluate. The 9,000 listening session sentences are further divided into 6 groups of 1,500 sentences for each listener of the group. Each listener will hear 5 lists of 300 sentences.

Before starting the test, the subjects are given the instructions in Figure 11. The instructions may be modified to allow for variations in laboratory data-gathering apparatus.

> [Before Training Session]
>
> Welcome and thank you for coming.
>
> This experiment is five sessions of approximately 20 minutes each. You will be able to take a break after each session, and we will have you take at least a 5 minute break after the second session. This experiment involves no risk or discomfort, and you are free to leave the experiment at any time for any reason, it will not be a problem for us. If you have any questions about the experiment, please feel free to ask them before the experiment starts. Your responses will be kept confidential, and will only be used as part of this experiment.
>
> This experiment uses the speakers in the room, so you will not be able to adjust the volume.
>
> The purpose of this experiment is to gather intelligibility information on systems that might be used for communications service between separate locations. You will be hearing a number of samples of speech reproduced in the speaker. Each sample will consist of the sentence "Please select the word X" spoken by male or female speakers.
>
> Please listen to the sentence, and then select the requested word from the list on the PDA. You may hear background noise in some of the samples. Please do your best to pick the requested word.
>
> Any questions?
>
> [Between Training Session and Session 1]
>
> Any problems during the training session?
>
> We will now do the first session of 300 samples. Any questions before we begin?

Figure 11. Instructions to test subjects.

5.4 Analysis and Reporting of Results

The results are reported in a series of tables and figures in Section 6. The analysis and reporting is outlined in Sections 8.10.5 and 8.10.6 of [9]. Averages are computed using the adjusted method recommended for closed set tests as described in Section 10.2 of [3]. An analysis of

[6] Note that only 45,000 of the 54,000 sentences will be used. This corresponds to 5 words from each block of 6 words, defined in [3], for each talker for each condition. Selections from the extra words are used for training.

variance (ANOVA) will be computed to enable comparisons between the implementations. A more detailed description of the analysis follows.

5.4.1 Intelligibility Scores

The first result presented for each environment is a table of intelligibility scores. The intelligibility score represents the fraction of words that were selected correctly. This is the modified intelligibility score (RA) that accounts for potential correct guessing in the limited set of choices given to the listeners. This is either reported as a decimal number between 0.0 and 1.0 or as a percentage.

5.4.2 Background Information for ANOVA

ANOVA and a multiple comparison test can assist in the determination of whether there is a significant variation between the speech outputs of the three communication systems (and their respective vocoder technologies), and if so, which is better. A common multiple comparison test used in previous tests is the Tukey test.

The data under analysis with ANOVA and Tukey consists of adjusted average intelligibility scores, RA (described in Section 10.2 of [3]), collected for 3 communication systems, 6 talkers, 8 acoustic noise conditions, and 30 listeners. ANOVA compares the variance of the overall sample population with the variance within each sub-population, and if those variances exceed a value given by the Fisher F-distribution, then the null hypothesis is false. In this case, the null hypothesis is that communication systems do not make a difference in intelligibility.

The hypothesis under test, H, is that the communication system (in particular the vocoder implemented by that communication system) affects the intelligibility, RA, as measured by the MRT. The hypothesis can be tested for each of the 8 acoustic noise conditions. If the hypothesis is true, it is also desired to know which communication system is better.

For this test, the $\alpha = 0.01$ for the F-distribution in the ANOVA for the given degrees of freedom, df, and sample size, n.

5.4.3 Input to ANOVA

A table is generated for each noise condition that includes the per-talker and per-communication-system average and standard deviation.

Averages of means and standard deviations are computed for a sample size of 6 talkers and 30 listeners, $N_{sample} = 180$. Representative calculations of mean and standard deviation for each noise condition, for a communication system is shown in Equation 3 and Equation 4, respectively.

$$R_A(v) = \frac{\sum R_A(v,t,L)}{N_{sample}} \tag{3}$$

for vocoder v. Sum is over talkers, t=1..6, and listeners, L=1-30.

$$S(v) = \sqrt{\frac{\sum\left[(R_A(v,t,L) - R_A(v))^2\right]}{N_{sample} - 1}} \tag{4}$$

From the listening test description in 5.3.1, each listener will hear 25 words (½ of a 50-word list) for each talker for each condition. An RA value is computed for each talker for each condition. To achieve the required sample indicated in 5.3.1, 10 different listeners will hear different groups of 25 words for each talker and condition. This results in 10 RA values for each talker and condition.

5.4.4 Example ANOVA Calculation and Multiple Comparison Test

The analysis of data will be done in the statistical analysis package Minitab™. A sample Minitab report of the computation of the ANOVA and the Tukey test is shown below. Annotations are provided after each section of the report.

One-way ANOVA: RA versus System

```
Source   DF       SS       MS      F      P
System    3  0.31772  0.10591  13.40  0.000
Error   236  1.86493  0.00790
Total   239  2.18266

S = 0.08889   R-Sq = 14.56%   R-Sq(adj) = 13.47%
```

The above represents the ANOVA results. The value of P is compared with the statistical significance of α=0.01. If P < α, statistically significant differences exist.

```
                               Individual 99% CIs For Mean Based on
                               Pooled StDev
Level   N     Mean    StDev  -------+---------+---------+---------+--
1      60  0.88080  0.07830                      (------*-------)
2      60  0.82560  0.08924        (------*-------)
3      60  0.80000  0.11184  (------*------)
4      60  0.88560  0.07075                       (------*-------)
                             -------+---------+---------+---------+--
                                  0.800     0.840     0.880     0.920

Pooled StDev = 0.08889
```

The above shows a rough graphic of the mean values and standard deviations for each of the four systems (Levels) in the test. The definition of each system is not important for this example. A pooled standard deviation value is also presented.

```
Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.81%
```

Corresponding to the α=0.01, the Tukey simultaneous confidence interval is set to 99%. This provides an individual comparison confidence interval of 99.81%.

```
System = 1 subtracted from:

System     Lower    Center     Upper
2       -0.10627  -0.05520  -0.00413
3       -0.13187  -0.08080  -0.02973
4       -0.04627   0.00480   0.05587

System     +---------+---------+---------+---------
```

```
2              (------*------)
3          (------*-------)
4                      (-------*------)
          +---------+---------+---------+---------
       -0.140    -0.070     0.000     0.070
```

This first comparison is System 1 to the other systems. If the other systems' values are all either above or below zero, then there is a statistically significant difference. If the other systems upper and lower values cross zero, then no statistically significant difference was detected. In this case, System 2 and System 3 are statistically significantly different from System 1. System 4 is not significantly different from System 1; this can also be stated as System 1 and System 4 are statistically similar.

```
System = 2 subtracted from:

System     Lower    Center    Upper
3       -0.07667  -0.02560  0.02547
4        0.00893   0.06000  0.11107

System    +---------+---------+---------+---------
3                 (------*-------)
4                             (-------*------)
          +---------+---------+---------+---------
       -0.140    -0.070     0.000     0.070
```

The second comparison is System 2 to System 3 and System 4. In this case System 2 and System 3 are statistically similar, but System 2 and System 4 are statistically significantly different. System 1 is not included in this graph because it was previously compared to System 2.

```
System = 3 subtracted from:

System    Lower   Center    Upper     +---------+---------+---------+---------
4       0.03453  0.08560  0.13667                              (------*-------)
                                      +---------+---------+---------+---------
                                   -0.140    -0.070     0.000     0.070
```

The third comparison is System 3 to System 4. In this case, System 3 and System 4 are statistically significantly different. System 1 and System 2 are not included in this graph because they were compared with System 3 in previous sections of this Minitab report.

Once the comparisons are made, the information can be synthesized into a more readable format as demonstrated in Table 2. A tabular result is presented in Section 6 for each environment in which the ANOVA detected a significant difference. Full Minitab reports for each environment are included in Appendix A.

Table 2. Example Presentation of Tukey Results

Tukey Multiple Comparison Results

"YES" means significant difference

System	4	3	2	1
1	NO	YES	YES	
2	YES	NO		
3	YES			
4				

6 DISCLOSURE OF TEST RESULTS

This section describes the results of the experiment. One-way ANOVA results and Tukey comparisons were computed using the Minitab statistical analysis package. Input to the ANOVA consisted of 10 adjusted intelligibility scores (RA) per talker/noise environment/system. Each of those adjusted intelligibility scores were based on the intelligibility of 25 samples for that particular talker/environment/system combination that were presented to that particular listener.

The RA listener scores for the experiment are tabulated in Appendix B. The analysis of the scores for the experiment is given in Section 6.1.

6.1 Experiment Results Detail

Experimental results are presented below for each noise environment in the test. For each noise environment, a table of the adjusted intelligibility scores (RA) and an analysis of the one-way ANOVA ($p=0.01$) is presented. If a statistically significant difference was detected by the ANOVA, a Tukey comparison analysis ($\alpha = 0.01$) follows to reveal which elements are different, from a statistical standpoint.

Finally, the results for the noise environment are presented in bar charts with statistically similar systems linked together by a horizontal red bar. If the red bar includes a dotted line, the systems crossed by the dotted portion of the line are not included in the statistical similarity. For example, in Figure 12, the top red bar indicates that the 25 kHz Analog FM and the 12.5 kHz Analog FM are statistically similar and the bottom horizontal red bar is used to indicate that the P25 Full Rate and P25 Enh Full Rate are statistically similar.

6.1.1 Results for Noise Environment 1 – "Clean"

The "clean" noise transmission environment consisted of the ideal communications case with no background noise and no SCBA mask. The listening environment was as described in 5.3.1. Table 3 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 12 contains the bar chart of results for this environment. The solid portions of the top horizontal red bar in Figure 12 are used to indicate that the two analog systems are statistically similar in this environment. The bottom horizontal red bar is used to indicate that the two digital systems are statistically similar. Both of the analog systems are statistically better than the digital systems.

Table 3. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 1

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate	12.5 kHz ANA FM
0.881	0.826	0.800	0.886

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.31772	0.10591	13.4	0.000	YES
Error	236	1.86493	0.0079			
Total	239	2.18266				

S = 0.08889 R-Sq = 14.56% R-Sq(adj) = 13.47%

Tukey Multiple Comparison Results

System	4	3	2	1
	"YES" means significant difference			
1 - 25 kHz ANA FM	NO	YES	YES	
2 - P25 Full Rate	YES	NO		
3 - P25 Enh Full Rate	YES			
4 - 12.5 kHz ANA FM				

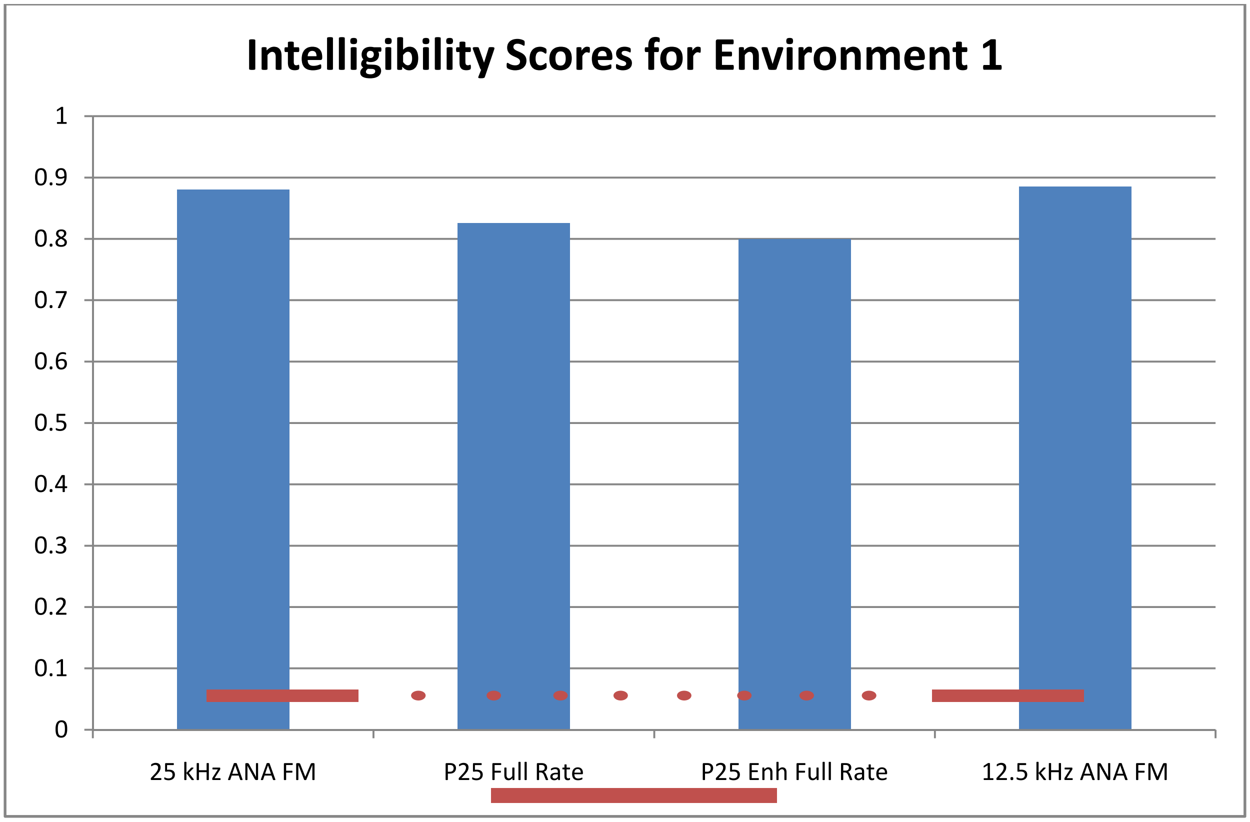

Figure 12. Intelligibility scores and statistical equivalences for environment 1.

6.1.2 Results for Noise Environment 2 – Fire Truck Pump Panel

The fire truck pump panel noise transmission environment consisted of the communications case with 4 dB SNR and no SCBA mask. The listening environment was as described in 5.3.1. Table 4 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 13 contains the bar chart of results for this environment. The solid portions of the horizontal red bar in Figure 13 are used to indicate that the 25 kHz Analog FM and the P25 Enhanced Full Rate are statistically equivalent in this environment. Both of these are statistically better than the P25 Full Rate.

Table 4. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 2

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.437	0.341	0.470

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	2	0.5376	0.2688	11.07	0.000	YES
Error	177	4.3	0.0243			
Total	179	4.8376				

S = 0.1559 R-Sq = 11.11% R-Sq(adj) = 10.11%

Tukey Multiple Comparison Results

"YES" means significant difference

System	3	2	1
1 - 25 kHz ANA FM	NO	YES	
2 - P25 Full Rate	YES		
3 - P25 Enh Full Rate			

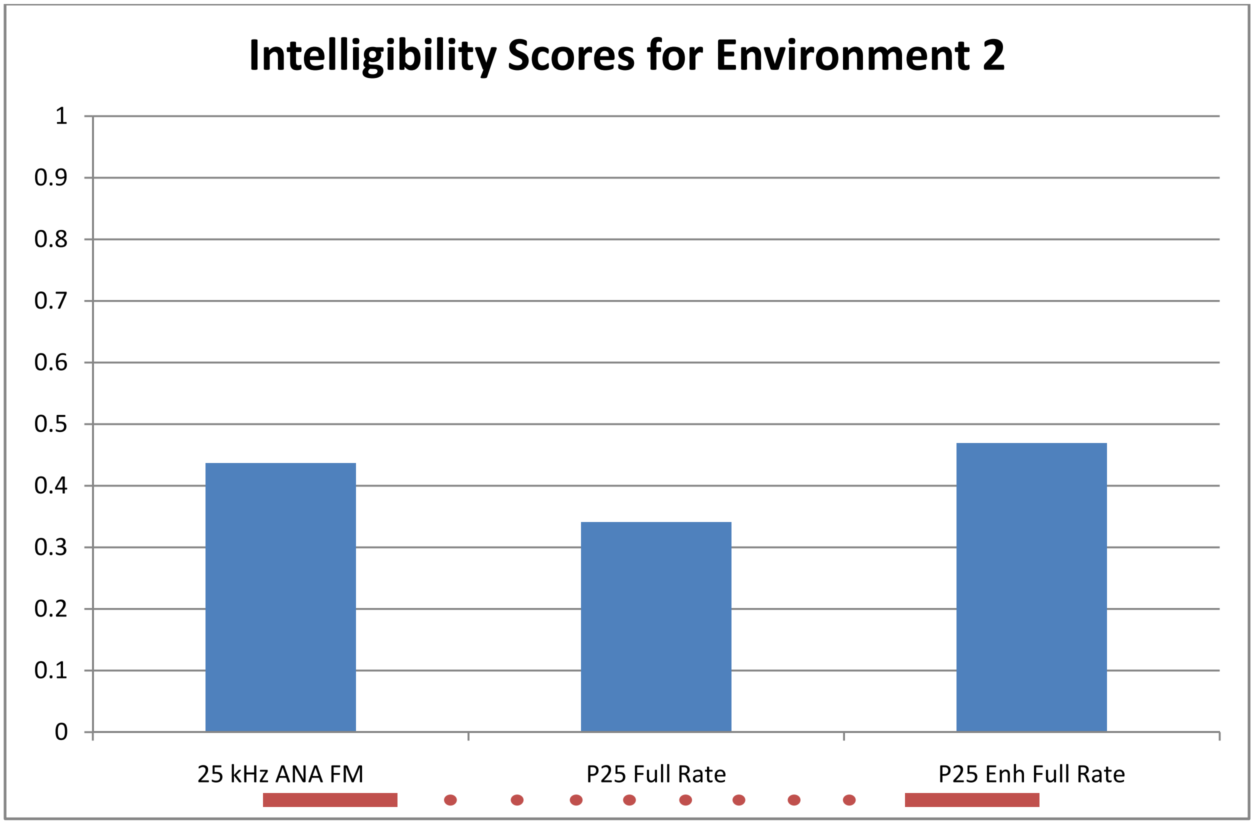

Figure 13. Intelligibility scores and statistical equivalences for environment 2.

6.1.3 Results for Noise Environment 3 – SCBA Mask

This noise transmission environment consists of the communications case with a user wearing an SCBA mask with no additional background noise. The listening environment was as described in 5.3.1. Table 5 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 14 contains the bar chart of results for this environment. The solid portions of the top horizontal red bar in Figure 14 are used to indicate that the two analog systems are statistically equivalent in this environment. The bottom horizontal red bar is used to indicate that the two digital systems are statistically equivalent. Both of the analog systems are statistically better than the digital systems.

Table 5. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 3

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate	12.5 kHz ANA FM
0.785	0.522	0.591	0.798

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	3	3.47	1.1567	73.16	0.000	YES
Error	236	3.7313	0.0158			
Total	239	7.2013				

S = 0.1257 R-Sq = 48.19% R-Sq(adj) = 47.53%

Tukey Multiple Comparison Results

"YES" means significant difference

System	4	3	2	1
1 - 25 kHz ANA FM	NO	YES	YES	
2 - P25 Full Rate	YES	NO		
3 - P25 Enh Full Rate	YES			
4 - 12.5 kHz ANA FM				

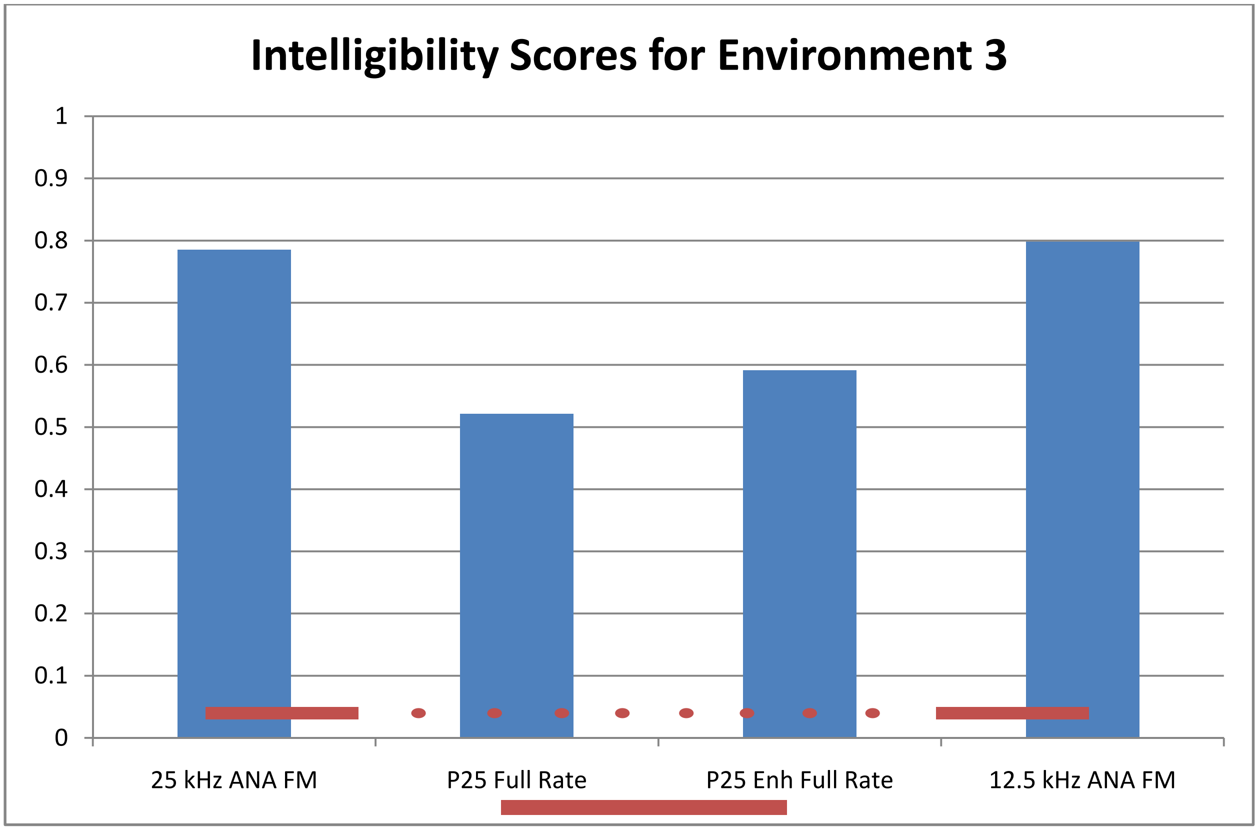

Figure 14. Intelligibility scores and statistical equivalences for environment 3.

6.1.4 Results for Noise Environment 4 – Low-Air Alarm

The low air alarm noise transmission environment consisted of the communications case where a user would be wearing a mask and need to communicate while the low-air alarm was sounding. The listening environment was as described in 5.3.1. Table 6 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 15 contains the bar chart of results for this environment. The solid portions of the top horizontal red bar in Figure 15 are used to indicate that the 25 kHz Analog FM and P25 Enhanced Full Rate systems are statistically equivalent in this environment. The bottom horizontal red bar is used to indicate that the two digital systems are statistically equivalent in this environment. The 25 kHz Analog FM performs significantly better than the P25 Full Rate.

Table 6. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 4

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.165	0.058	0.115

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	2	0.3454	0.1727	11.1	0.000	Yes
Error	177	2.7534	0.0156			
Total	179	3.0988				

Tukey Multiple Comparison Results

	"YES" means significant difference		
System	3	2	1
1 - 25 kHz ANA FM	NO	YES	
2 - P25 Full Rate	NO		
3 - P25 Enh Full Rate			

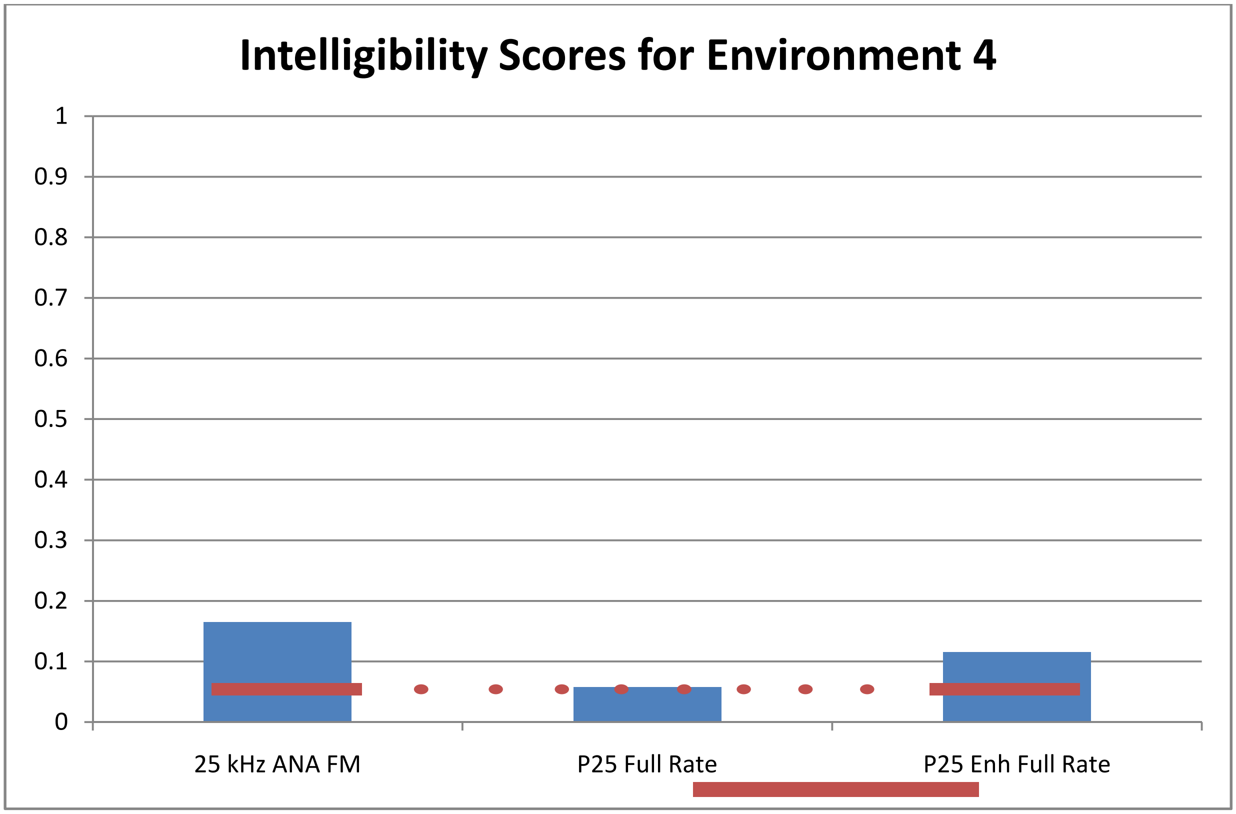

Figure 15. Intelligibility scores and statistical equivalences for environment 4.

6.1.5 Results for Noise Environment 5 – PASS Alarms

This noise transmission environment consisted of the communications case where a SCBA clad person would need to communicate upon finding two downed firefighters with their SCBA alarms sounding. The listening environment was as described in 5.3.1. Table 7 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 16 contains the bar chart of results for this environment. The horizontal red bar in Figure 16 is used to indicate that the P25 Full Rate and the P25 Enhanced Full Rate are statistically equivalent in this environment. The 25 kHz Analog FM performed significantly better than either of the two digital systems.

Table 7. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 5

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.581	0.152	0.206

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Signficant?
System	2	6.5503	3.2752	178.71	0.000	YES
Error	177	3.2438	0.0183			
Total	179	9.7942				

S = 0.1354 R-Sq = 66.88% R-Sq(adj) = 66.51%

Tukey Multiple Comparison Results

"YES" means significant difference

System	3	2	1
1 - 25 kHz ANA FM	YES	YES	
2 - P25 Full Rate	NO		
3 - P25 Enh Full Rate			

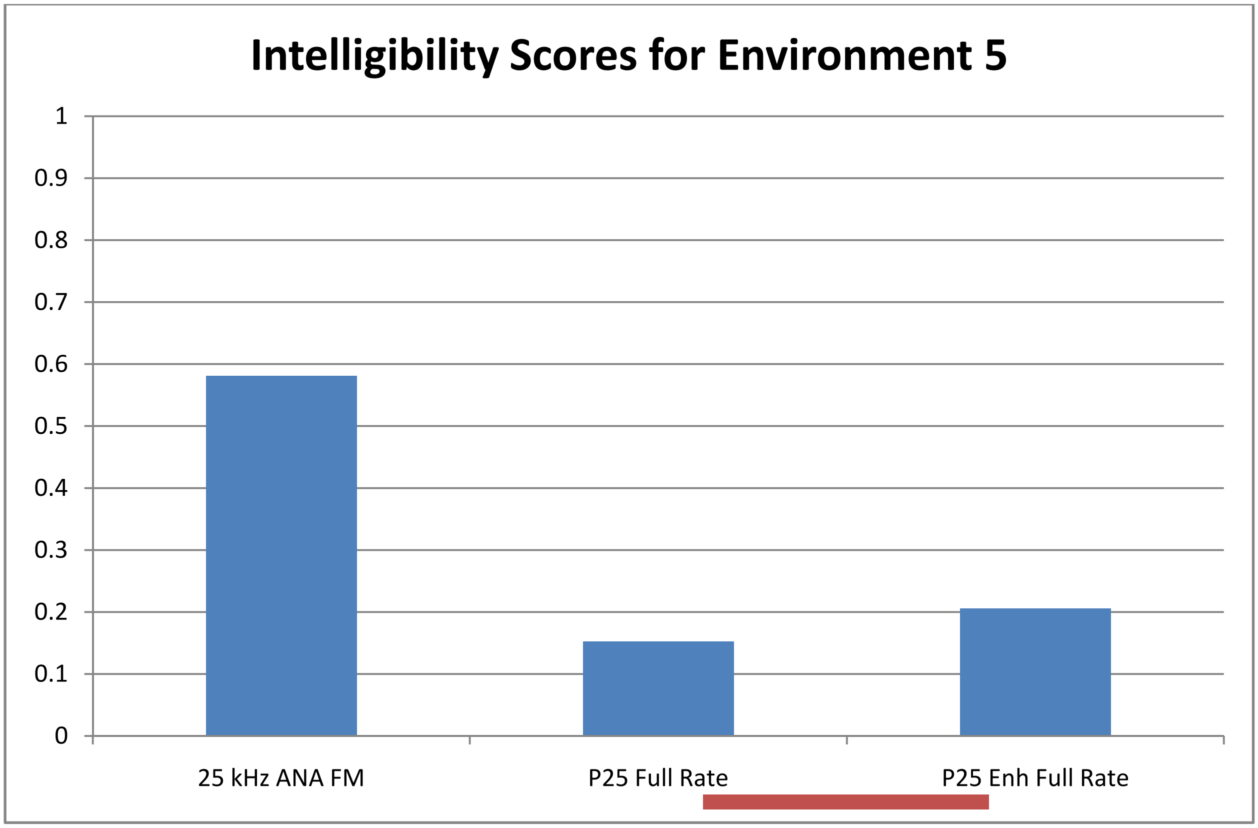

Figure 16. Intelligibility scores for environment 5.

6.1.6 Results for Noise Environment 6 – Rotary Saw

This noise environment represents the communications case where a person wearing a mask would need to communicate in the vicinity of someone operating a gas-powered rotary saw. The listening environment was as described in 5.3.1. Table 8 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 17 contains the bar chart of results for this environment. The horizontal red bar in Figure 17 is used to indicate that the four systems perform in a statistically equivalent manner in this environment.

Table 8. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 6

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate	12.5 kHz ANA FM
0.046	0.015	0.005	0.059

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	3	0.11807	0.03936	3.95	0.009	YES
Error	236	2.3502	0.00996			
Total	239	2.46827				

S = 0.09979 R-Sq = 4.78% R-Sq(adj) = 3.57%

Tukey Multiple Comparison Results

"YES" means significant difference

System	4	3	2	1
1 - 25 kHz ANA FM	NO	NO	NO	
2 - P25 Full Rate	NO	NO		
3 - P25 Enh Full Rate	NO			
4 - 12.5 kHz ANA FM				

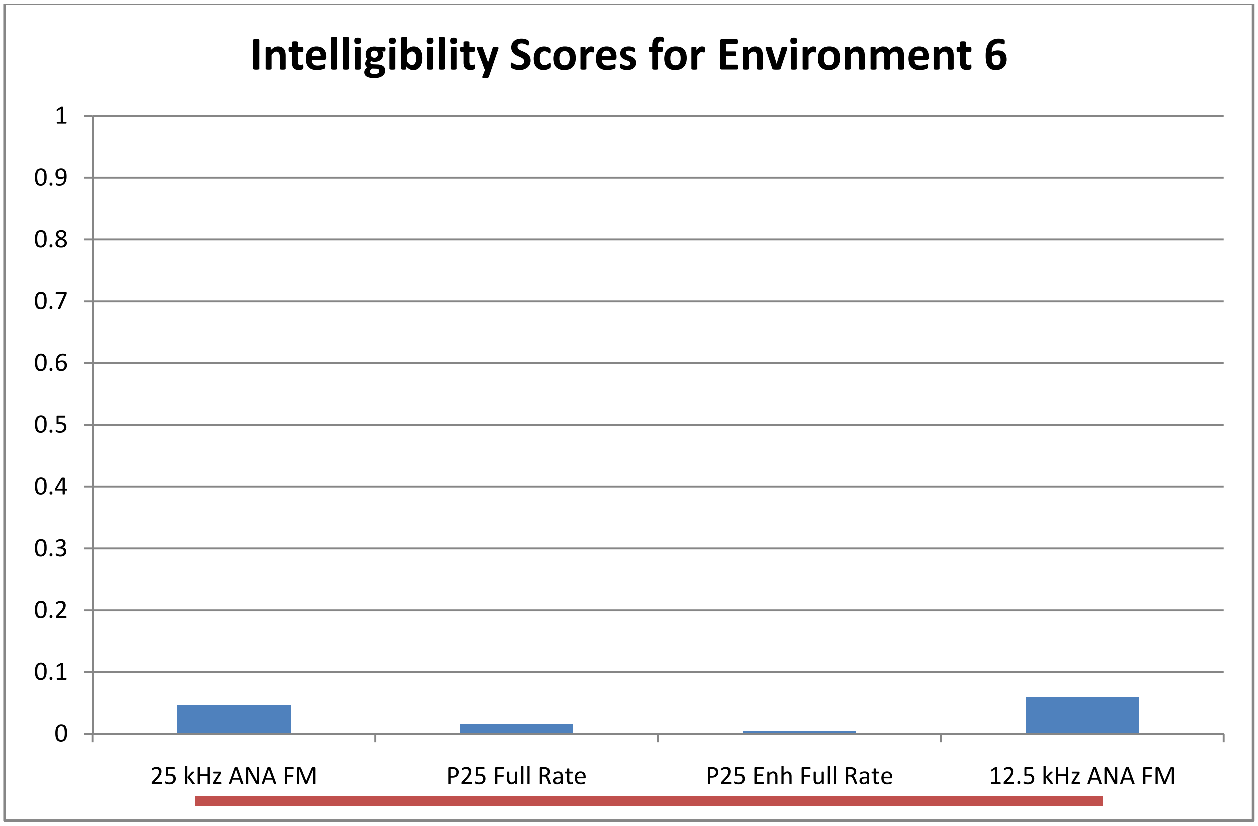

Figure 17. Intelligibility scores and statistical equivalences for environment 6.

6.1.7 Results for Noise Environment 7 - Chainsaw

This noise transmission environment represents the communications case where a person wearing a mask needs to communicate near someone operating a chainsaw. The listening environment was as described in 5.3.1. Table 9 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 18 contains the bar chart of results for this environment. The top horizontal red bar in Figure 18 is used to indicate that the 25 kHz Analog FM system and the P25 Full Rate system are statistically equivalent. The bottom horizontal red bar is used to indicate that the P25 Full Rate and P25 Enhanced Full Rate systems are statistically equivalent in this environment. The 25 kHz Analog FM performs significantly better than the P25 Enh Full Rate.

Table 9. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 7

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.064	0.019	-0.002

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	2	0.1349	0.0674	5.99	0.003	YES
Error	177	1.9922	0.0113			
Total	179	2.1271				

S = 0.1061 R-Sq = 6.34% R-Sq(adj) = 5.28%

Tukey Multiple Comparison Results

"YES" means significant difference

System	3	2	1
1 - 25 kHz ANA FM	YES	NO	
2 - P25 Full Rate	NO		
3 - P25 Enh Full Rate			

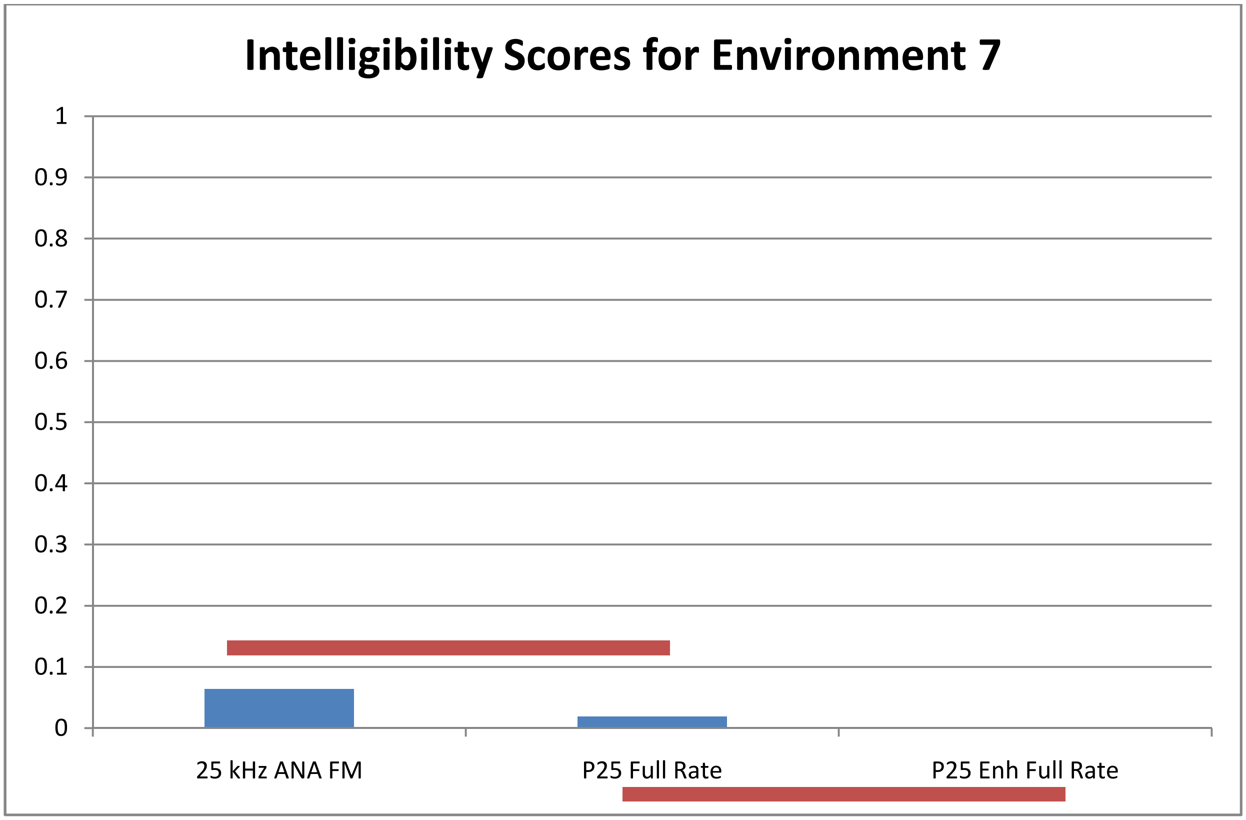

Figure 18. Intelligibility scores and statistical equivalences for environment 7.

6.1.8 Results for Noise Environment 8 – Fog Nozzle

This noise transmission environment represents the communications case where someone wearing a mask would need to communicate near a fire hose operating with a fog nozzle. The listening environment was as described in 5.3.1. Table 10 contains the intelligibility scores and ANOVA results for this environment. The detailed Minitab report is found in Appendix A.

Figure 19 contains the bar chart of results for this environment. The horizontal red bar in Figure 19 indicates that there were no detectable differences between the systems.

Table 10. Intelligibility Scores and ANOVA Results for Environment 8

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.110	0.068	0.075

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	2	0.0593	0.0297	2.35	0.098	NO
Error	177	2.233	0.0126			
Total	179	2.2923				

Tukey analysis is not presented because the ANOVA did not detect a significant difference.

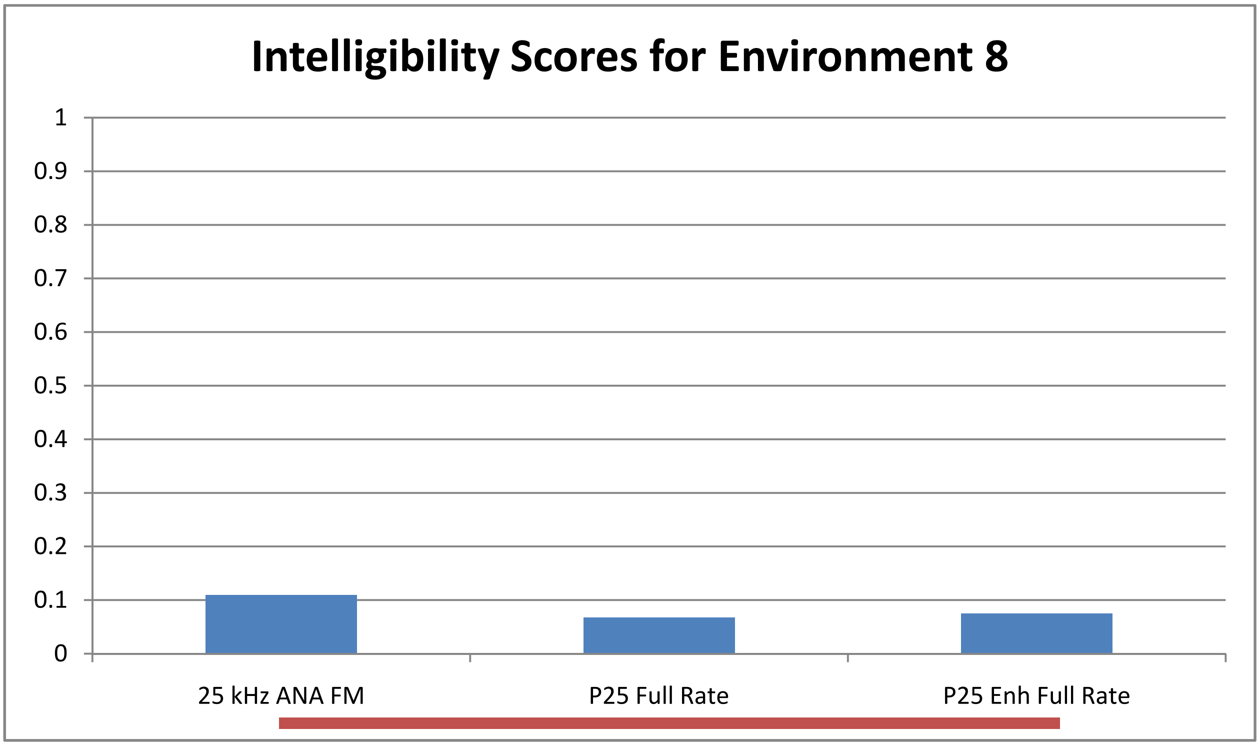

Figure 19. Intelligibility scores and statistical equivalences for environment 8.

6.1.9 Results for Noise Environment 9 – Amplified Mask

This noise transmission environment represents the communications case where a person with a voice amplifier attached to their mask would need to communicate near a person operating a rotary saw. The listening environment was as described in 5.3.1. Table 11 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 20 contains the bar chart of results for this environment. The horizontal red bar in Figure 20 is used to indicate that the 25 kHz Analog FM is statistically equivalent to the P25 Full Rate and P25 Enhanced Full Rate systems for this environment. The P25 Enhanced Full Rate system performs significantly better than the P25 Full Rate system.

Table 11. Intelligibility Scores, ANOVA Results, and Tukey Results for Environment 9

Intelligibility Scores (RA)

25 kHz ANA FM	P25 Full Rate	P25 Enh Full Rate
0.039	0.015	0.092

One-way ANOVA: RA versus Condition

Source	DF	SS	MS	F	P	Significant?
System	2	0.1852	0.0926	7.27	0.001	YES
Error	177	2.2546	0.0127			
Total	179	2.4398				

S = 0.1129 R-Sq = 7.59% R-Sq(adj) = 6.55%

Tukey Multiple Comparison Results

"YES" means significant difference

System	3	2	1
1 - 25 kHz ANA FM	NO	NO	
2 - P25 Full Rate	YES		
3 - P25 Enh Full Rate			

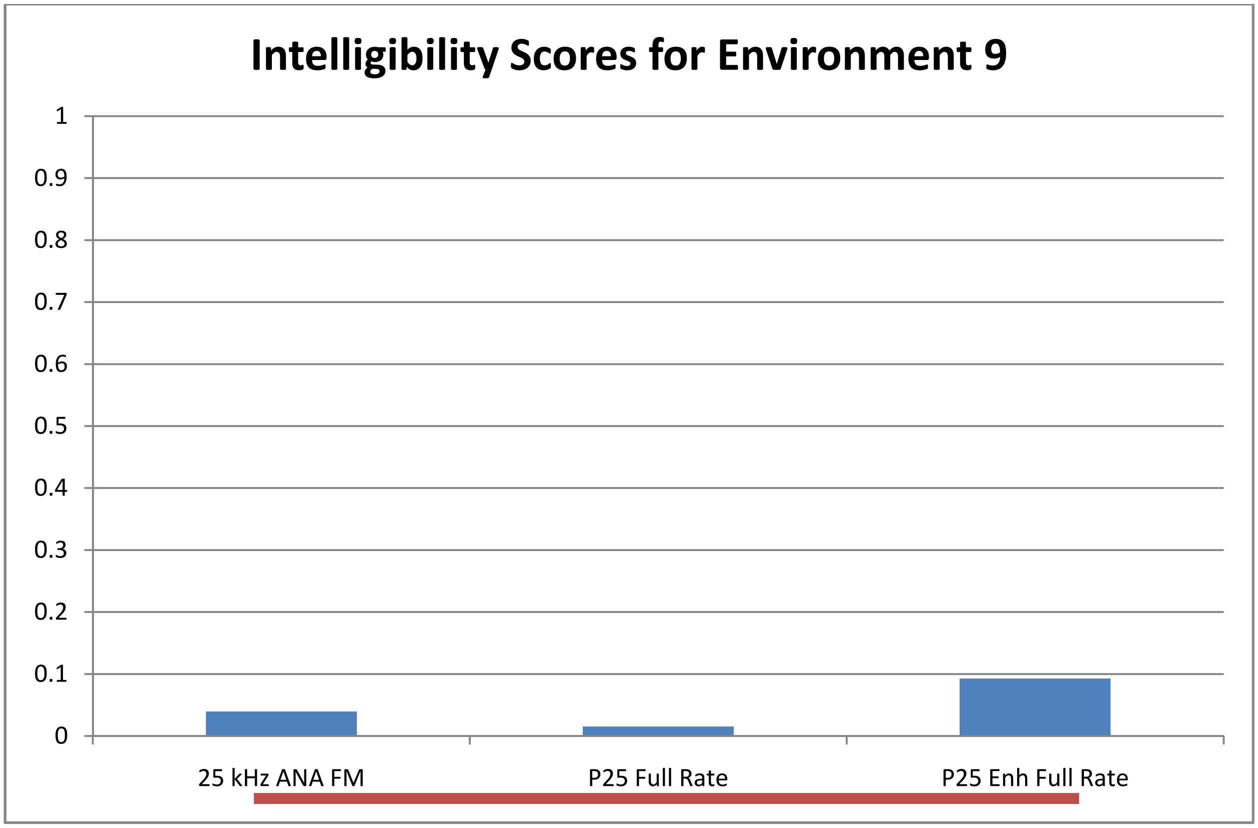

Figure 20. Intelligibility scores and statistical equivalences for environment 9.

7 SUMMARY AND CONCLUSIONS

Based on emerging concerns among fire service practitioners, this report describes an experiment that was conducted to measure intelligibility of radio systems in the presence of fireground noise. The test method selected to evaluate intelligibility was the Modified Rhyme Test.

Four communication systems (25 kHz analog, 12.5 kHz analog, Project 25 Full Rate, and Project 25 Enhanced Full Rate) were included in the test. Nine transmission environments (listed below) were also identified for the test.

Environment 1. No background noise, no mask (referred to as the Clean condition)

Environment 2. Fire truck pump panel, no mask

Environment 3. Mask with no background noise

Environment 4. Two Personal Alert Safety System (PASS) alarms, with mask

Environment 5. In-mask low air alarm

Environment 6. Rotary saw cutting metal garage door, with mask

Environment 7. Chainsaw cutting wood, with mask

Environment 8. 2½" hose with fog nozzle, with mask

Environment 9. Rotary saw cutting metal garage door, with amplified mask

The report describes the method for generating the recordings of noisy speech data, the requirements of the listening environment, and the process for presenting the recorded speech to listeners.

The results of the subjective testing show that there are environments where analog radios had higher intelligibility than the digital radios, and also that there are environments where none of the systems perform very well. Observations included the following:

- The MRT test seems to be significantly more sensitive (i.e., more able to discriminate) to differences in communication paths than MOS tests. This is evidenced by the much greater number of occurrences of statistically significant differences between the P25 Full Rate and P25 Enhanced Full Rate vocoder systems and between the analog and digital systems than has occurred in previous MOS-based tests such as [12] and [13].

- Without masks or background noise (i.e., Environment 1) all four communication systems effectively meet the NFPA 1981-2007 goal of 80% intelligibility.

- Four of the nine noise environments were effectively too difficult for all tested communication systems, with all systems well below 10%. In future testing, either noise reduction technologies may be employed to evaluate these environments, or the environments may be adapted to provide more useful results. Another alternative might be context-based intelligibility testing.

- In environment 3 (SCBA mask with no additional background noise), the two analog systems effectively maintain the NFPA 1981-2007 goal of 80%[7] intelligibility through a mask, while the digital systems were 52% for the P25 Full Rate vocoder system and 59% for the P25 Enhanced Full Rate vocoder system. This implies that there may need to be some additional considerations when using these digital communication systems in environments where a communicator must wear a SCBA mask for safety purposes.

- In environment 2 (fire truck pump panel noise without an SCBA mask), both the analog system and the P25 Enhanced Full Rate system vocoder performed significantly better than the P25 Full Rate system.

- The largest performance difference between the analog and digital systems was environment 5 (SCBA mask with two PASS alarms).

- Analog FM outperformed P25 Full Rate 5 of the 9 environments tested. In the remaining four environments, all radios had equivalent performance in three of them. In one environment, the performance of the P25 Full Rate system was equivalent to that of Analog FM.

- Analog FM outperformed P25 Enhanced Full rate in 4 of the 9 environments tested. In the remaining 5 environments, all radios had equivalent performance in three of them. In two environments, the performance of the P25 Enhanced Full Rate system was equivalent to that of Analog FM.

- In the case of P25 Full Rate and P25 Enhanced Full Rate, the two were statistically equivalent in 8 of 9 environments, with the P25 Enhanced Full Rate system performing better than the P25 Full Rate in 1 of the 9 environments.

- In the three environments where 12.5 kHz Analog FM was included, it performed equivalent with 25 kHz Analog FM. This system should be evaluated further.

- The testing indicated that there are significant communication challenges regarding SCBA and other fire safety equipment. In the case of a mask with no additional background noise at the transmission site, there was a notable degradation in intelligibility for the digital systems. In addition, some low air alarm designs and PASS alarms may interfere with communications intelligibility.

The information contained in this report may be of value to those planning to purchase and deploy new radio communication systems in their agencies. The information here should NOT be the only factor utilized in the purchasing process. Other factors should include agencies involved, current assets, departmental operating procedures and policies, budgeting plans, spectrum availability, State Communications Interoperability Plans (SCIPs), and specific situations faced by the purchasing agency that are not covered in this report.

[7] While the actual value of the 25 kHz Analog FM system was 78%, this was statistically equivalent to 80% as computed by the T-test defined in [9].

8 ACKNOWLEDGEMENTS

Funding for this effort was provided jointly by the Department of Homeland Security Office of Interoperability and Compatibiliy, the National Institute of Standards and Technology Office of Law Enforcement Standards, and the Federal Partnership for Interoperable Communications. The work was conducted at the Institute for Telecommunication Sciences under the supervision of J.R. Bratcher.

The authors of this report wish to express gratitude to the following organizations, whose help was instrumental in the conduct of this experiment:

- The City of Boise, Idaho and the Town of Plainfield, Indiana for providing opportunities to record high-quality public safety environmental noise.
- The following communities/agencies for adjusting schedules and allowing their public safety personnel to travel to Boulder to participate in the experiment:
    - The City of Boise, Idaho
    - The County of Fairfax, Virginia
    - The Town of Plainfield, Indiana
    - The City of Littleton, Colorado
    - The City of Plainfield, Illinois
    - The City of Coeur d’Alene, Idaho
    - The City of Philadelphia, Pennsylvania
    - The City of Riverside, Ohio
    - The City of Englewood, Ohio
    - The City of Huber Heights, Ohio
- The following companies who loaned equipment or provided support for the experiment:
    - Scott Health and Safety
    - Motorola
    - Draeger Safety
    - EF Johnson
    - International Safety Instruments

9 REFERENCES

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[6] ITU-T Recommendation P.56, "Objective measurement of active speech level."

[7] ITU-T Recommendation P.57, "Artificial Ears."

[8] ITU-T Recommendation P.58, "Head and Torso Simulator (HATS) for Telephonometry."

[9] NFPA 1981 Standard on Open-Circuit Self-Contained Breathing Apparatus (SCBA) for Emergency Services, 2007 Edition.

[10] ITU-T Recommendation P.800, "Methods for subjective determination of transmission quality."

[11] ITU-T Recommendation G.191, "Software Tools for Speech and Audio Coding Standardization."

[12] Project 25 Vocoder Evaluation Mean Opinion Score Test, TIA TSB 102.BABE.

[13] Experiment 3 MOS Test Plan for Vocoder Technology for Project 25, TIA TSB 102.BABF.

APPENDIX A: CONDITION LABELS AND MINITAB REPORTS

This appendix contains the representation of specific condition number to a communication system and background noise. Table A-1 contains the list of condition numbers for this experiment.

Table A-1. Condition Number, Communication System, and Noise Environment

Condition Label	Communication System	Background Noise
1	25 kHz Analog FM	No mask, no background noise
2	25 kHz Analog FM	No mask, fire truck pump panel (4 dB S/N)
3	25 kHz Analog FM	Mask, no background noise
4	25 kHz Analog FM	Mask, in-mask low air alarm (15 dB S/N)
5	25 kHz Analog FM	Mask, two PASS alarms (-2 dB S/N)
6	25 kHz Analog FM	Mask, rotary saw (4 dB S/N)
7	25 kHz Analog FM	Mask, chainsaw (5 dB S/N)
8	25 kHz Analog FM	Mask, 2½" hose with fog nozzle (9 dB S/N)
9	25 kHz Analog FM	Amplified mask, rotary saw (4 dB S/N)
10	P25 Full Rate	No mask, no background noise
11	P25 Full Rate	No mask, fire truck pump panel (4 dB S/N)
12	P25 Full Rate	Mask, no background noise
13	P25 Full Rate	Mask, in-mask low air alarm (15 dB S/N)
14	P25 Full Rate	Mask, two PASS alarms (-2 dB S/N)
15	P25 Full Rate	Mask, rotary saw (4 dB S/N)
16	P25 Full Rate	Mask, chainsaw (5 dB S/N)
17	P25 Full Rate	Mask, 2½" hose with fog nozzle (9 dB S/N)
18	P25 Full Rate	Amplified mask, rotary saw (4 dB S/N)
19	P25 Enh Full Rate	No mask, no background noise
20	P25 Enh Full Rate	No mask, fire truck pump panel (4 dB S/N)
21	P25 Enh Full Rate	Mask, no background noise
22	P25 Enh Full Rate	Mask, in-mask low air alarm (15 dB S/N)
23	P25 Enh Full Rate	Mask, two PASS alarms (-2 dB S/N)
24	P25 Enh Full Rate	Mask, rotary saw (4 dB S/N)
25	P25 Enh Full Rate	Mask, chainsaw (5 dB S/N)
26	P25 Enh Full Rate	Mask, 2½" hose with fog nozzle (9 dB S/N)
27	P25 Enh Full Rate	Amplified mask, rotary saw (4 dB S/N)
28	12.5 kHz Analog FM	No mask, no background noise
29	12.5 kHz Analog FM	Mask, no background noise
30	12.5 kHz Analog FM	Mask, rotary saw (4 dB S/N)

Sections A.1 through A.9 contain the full Minitab reports for Environments 1 through 9, respectively. For help interpreting the Minitab reports, see Section 5.4.4.

A.1 Minitab Report for Environment 1

One-way ANOVA: RA versus System

```
Source   DF       SS       MS      F      P
System    3  0.31772  0.10591  13.40  0.000
Error   236  1.86493  0.00790
Total   239  2.18266

S = 0.08889   R-Sq = 14.56%   R-Sq(adj) = 13.47%


                             Individual 99% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  -------+---------+---------+---------+--
1      60  0.88080  0.07830                    (------*-------)
2      60  0.82560  0.08924        (------*-------)
3      60  0.80000  0.11184  (------*------)
4      60  0.88560  0.07075                     (------*-------)
                             -------+---------+---------+---------+--
                                 0.800     0.840     0.880     0.920

Pooled StDev = 0.08889


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.81%


System = 1 subtracted from:

System     Lower    Center     Upper
2       -0.10627  -0.05520  -0.00413
3       -0.13187  -0.08080  -0.02973
4       -0.04627   0.00480   0.05587

System     +---------+---------+---------+---------
2               (------*------)
3           (------*-------)
4                       (-------*------)
           +---------+---------+---------+---------
        -0.140    -0.070     0.000     0.070


System = 2 subtracted from:

System     Lower    Center    Upper
3       -0.07667  -0.02560  0.02547
4        0.00893   0.06000  0.11107

System     +---------+---------+---------+---------
3                   (------*-------)
4                               (-------*------)
           +---------+---------+---------+---------
        -0.140    -0.070     0.000     0.070


System = 3 subtracted from:

System    Lower   Center    Upper     +---------+---------+---------+---------
4       0.03453  0.08560  0.13667                               (------*-------)
                                      +---------+---------+---------+---------
                                   -0.140    -0.070     0.000     0.070
```

A.2 Minitab Report for Environment 2

One-way ANOVA: RA versus System

```
Source   DF      SS      MS      F      P
System    2  0.5376  0.2688  11.07  0.000
Error   177  4.3000  0.0243
Total   179  4.8376

S = 0.1559   R-Sq = 11.11%   R-Sq(adj) = 10.11%


                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
1      60  0.4368  0.1383                 (--------*--------)
2      60  0.3408  0.1815  (--------*--------)
3      60  0.4696  0.1443                       (-------*--------)
                           --+---------+---------+---------+-------
                           0.300     0.360     0.420     0.480

Pooled StDev = 0.1559


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.64%


System = 1 subtracted from:

System    Lower   Center    Upper  --------+---------+---------+---------+-
2       -0.1799  -0.0960  -0.0121     (------*------)
3       -0.0511   0.0328   0.1167                (------*------)
                                   --------+---------+---------+---------+-
                                        -0.12      0.00      0.12      0.24


System = 2 subtracted from:

System   Lower  Center   Upper  --------+---------+---------+---------+-
3       0.0449  0.1288  0.2127                       (------*------)
                                --------+---------+---------+---------+-
                                     -0.12      0.00      0.12      0.24
```

A.3 Minitab Report for Environment 3

One-way ANOVA: RA versus System

```
Source   DF      SS      MS      F      P
System    3  3.4700  1.1567  73.16  0.000
Error   236  3.7313  0.0158
Total   239  7.2013

S = 0.1257   R-Sq = 48.19%   R-Sq(adj) = 47.53%


                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  --+---------+---------+---------+-------
1      60  0.7848  0.1010                            (---*----)
2      60  0.5216  0.1600  (---*---)
3      60  0.5912  0.1353         (---*---)
4      60  0.7984  0.0955                              (---*---)
                           --+---------+---------+---------+-------
                           0.50      0.60      0.70      0.80

Pooled StDev = 0.1257


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.81%


System = 1 subtracted from:

System    Lower   Center    Upper  -------+---------+---------+---------+--
2       -0.3354  -0.2632  -0.1910  (---*--)
3       -0.2658  -0.1936  -0.1214      (--*---)
4       -0.0586   0.0136   0.0858                (---*--)
                                   -------+---------+---------+---------+--
                                       -0.20      0.00      0.20      0.40


System = 2 subtracted from:

System    Lower  Center   Upper  -------+---------+---------+---------+--
3       -0.0026  0.0696  0.1418                  (--*---)
4        0.2046  0.2768  0.3490                            (---*--)
                                 -------+---------+---------+---------+--
                                     -0.20      0.00      0.20      0.40


System = 3 subtracted from:

System   Lower  Center   Upper  -------+---------+---------+---------+--
4       0.1350  0.2072  0.2794                         (--*---)
                                -------+---------+---------+---------+--
                                    -0.20      0.00      0.20      0.40
```

A.4 Minitab Report for Environment 4

One-way ANOVA: RA versus System

```
Source   DF      SS      MS      F      P
System    2  0.3454  0.1727  11.10  0.000
Error   177  2.7534  0.0156
Total   179  3.0988

S = 0.1247   R-Sq = 11.15%   R-Sq(adj) = 10.14%


                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
1      60  0.1648  0.1450                        (-------*-------)
2      60  0.0576  0.1086  (--------*-------)
3      60  0.1152  0.1177              (-------*-------)
                           -------+---------+---------+---------+--
                                0.050     0.100     0.150     0.200

Pooled StDev = 0.1247


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.64%


System = 1 subtracted from:

System    Lower   Center    Upper   --+---------+---------+---------+-------
2       -0.1743  -0.1072  -0.0401   (--------*-------)
3       -0.1167  -0.0496   0.0175          (--------*-------)
                                    --+---------+---------+---------+-------
                                   -0.160    -0.080     0.000     0.080


System = 2 subtracted from:

System    Lower  Center   Upper   --+---------+---------+---------+-------
3       -0.0095  0.0576  0.1247                       (-------*--------)
                                  --+---------+---------+---------+-------
                                 -0.160    -0.080     0.000     0.080
```

A.5 Minitab Report for Environment 5

One-way ANOVA: RA versus System

```
Source   DF      SS      MS       F      P
System    2  6.5503  3.2752  178.71  0.000
Error   177  3.2438  0.0183
Total   179  9.7942

S = 0.1354   R-Sq = 66.88%   R-Sq(adj) = 66.51%


                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ---+---------+---------+---------+------
1      60  0.5808  0.1259                              (--*--)
2      60  0.1520  0.1255  (--*--)
3      60  0.2056  0.1529      (--*--)
                           ---+---------+---------+---------+------
                            0.15      0.30      0.45      0.60

Pooled StDev = 0.1354


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.64%


System = 1 subtracted from:

System    Lower   Center    Upper    -+---------+---------+---------+--------
2       -0.5017  -0.4288  -0.3559    (---*----)
3       -0.4481  -0.3752  -0.3023       (----*---)
                                     -+---------+---------+---------+--------
                                   -0.48     -0.32     -0.16      0.00


System = 2 subtracted from:

System    Lower  Center   Upper    -+---------+---------+---------+--------
3       -0.0193  0.0536  0.1265                               (---*----)
                                   -+---------+---------+---------+--------
                                 -0.48     -0.32     -0.16      0.00
```

A.6 Minitab Report for Environment 6

One-way ANOVA: RA versus System

```
Source   DF       SS       MS     F      P
System    3  0.11807  0.03936  3.95  0.009
Error   236  2.35020  0.00996
Total   239  2.46827

S = 0.09979   R-Sq = 4.78%   R-Sq(adj) = 3.57%


                             Individual 99% CIs For Mean Based on
                             Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      60  0.04640  0.11125              (--------*---------)
2      60  0.01520  0.08636     (--------*---------)
3      60  0.00480  0.09263  (--------*---------)
4      60  0.05920  0.10686                 (---------*--------)
                             --------+---------+---------+---------+-
                                   0.000     0.035     0.070     0.105

Pooled StDev = 0.09979


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.81%


System = 1 subtracted from:

System     Lower    Center    Upper  ---------+---------+---------+---------+
2       -0.08853  -0.03120  0.02613      (---------*--------)
3       -0.09893  -0.04160  0.01573     (--------*---------)
4       -0.04453   0.01280  0.07013              (--------*---------)
                                     ---------+---------+---------+---------+
                                           -0.060     0.000     0.060     0.120


System = 2 subtracted from:

System     Lower    Center    Upper  ---------+---------+---------+---------+
3       -0.06773  -0.01040  0.04693          (--------*---------)
4       -0.01333   0.04400  0.10133                   (--------*---------)
                                     ---------+---------+---------+---------+
                                           -0.060     0.000     0.060     0.120


System = 3 subtracted from:

System     Lower   Center    Upper  ---------+---------+---------+---------+
4       -0.00293  0.05440  0.11173                    (--------*---------)
                                    ---------+---------+---------+---------+
                                          -0.060     0.000     0.060     0.120
```

A.7 Minitab Report for Environment 7

One-way ANOVA: RA versus System

```
Source   DF      SS      MS     F      P
System    2  0.1349  0.0674  5.99  0.003
Error   177  1.9922  0.0113
Total   179  2.1271

S = 0.1061   R-Sq = 6.34%   R-Sq(adj) = 5.28%


                            Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean   StDev    -+---------+---------+---------+--------
1      60   0.0640  0.1181                       (---------*---------)
2      60   0.0192  0.0990          (---------*----------)
3      60  -0.0016  0.1002    (----------*---------)
                              -+---------+---------+---------+--------
                            -0.035     0.000     0.035     0.070

Pooled StDev = 0.1061


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.64%


System = 1 subtracted from:

System    Lower   Center    Upper     +---------+---------+---------+---------
2       -0.1019  -0.0448   0.0123        (---------*--------)
3       -0.1227  -0.0656  -0.0085     (--------*---------)
                                      +---------+---------+---------+---------
                                   -0.120    -0.060     0.000     0.060


System = 2 subtracted from:

System    Lower   Center   Upper     +---------+---------+---------+---------
3       -0.0779  -0.0208  0.0363            (---------*--------)
                                     +---------+---------+---------+---------
                                  -0.120    -0.060     0.000     0.060
```

A.8 Minitab Report for Environment 8

One-way ANOVA: RA versus System

```
Source   DF      SS      MS     F      P
System    2  0.0593  0.0297  2.35  0.098
Error   177  2.2330  0.0126
Total   179  2.2923

S = 0.1123   R-Sq = 2.59%   R-Sq(adj) = 1.49%


                           Individual 99% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev    +---------+---------+---------+---------
1      60  0.1096  0.1187                (------------*-----------)
2      60  0.0680  0.1020    (------------*-----------)
3      60  0.0752  0.1155      (------------*------------)
                             +---------+---------+---------+---------
                           0.030     0.060     0.090     0.120

Pooled StDev = 0.1123
```

A.9 Minitab Report for Environment 9

One-way ANOVA: RA versus System

```
Source   DF      SS      MS     F      P
System    2  0.1852  0.0926  7.27  0.001
Error   177  2.2546  0.0127
Total   179  2.4398

S = 0.1129   R-Sq = 7.59%   R-Sq(adj) = 6.55%


                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1      60  0.0392  0.1113        (---------*--------)
2      60  0.0152  0.0768  (---------*--------)
3      60  0.0920  0.1412                      (--------*--------)
                           ------+---------+---------+---------+---
                               0.000     0.040     0.080     0.120

Pooled StDev = 0.1129


Tukey 99% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of System

Individual confidence level = 99.64%


System = 1 subtracted from:

System    Lower   Center   Upper     +---------+---------+---------+---------
2       -0.0848  -0.0240  0.0368             (--------*-------)
3       -0.0080   0.0528  0.1136                        (--------*-------)
                                     +---------+---------+---------+---------
                                  -0.140    -0.070     0.000     0.070


System = 2 subtracted from:

System   Lower  Center   Upper     +---------+---------+---------+---------
3       0.0160  0.0768  0.1376                           (--------*--------)
                                   +---------+---------+---------+---------
                                -0.140    -0.070     0.000     0.070
```

APPENDIX B: LISTENER SCORES

This appendix tabulates the scores collected from the listener panels. It contains the listener number, the talker number, the condition number, and the adjusted intelligibility score (RA).

Table B-1. Scores Collected from Listener Panels

Listener	Talker	Condition	RA
1	F1	4	0.28
1	F1	12	0.616
1	F1	15	0.04
1	F1	16	-0.008
1	F1	18	0.088
1	F1	19	0.856
1	F1	22	0.232
1	F1	28	0.856
1	F3	1	0.904
1	F3	2	0.52
1	F3	5	0.664
1	F3	6	-0.008
1	F3	7	0.088
1	F3	8	0.136
1	F3	10	0.808
1	F3	13	0.088
1	F3	14	0.328
1	F3	23	0.088
1	F3	25	0.088
1	F3	26	0.136
1	F3	27	0.328
1	F4	3	0.76
1	F4	9	-0.104
1	F4	11	0.568
1	F4	17	0.04
1	F4	20	0.664
1	F4	21	0.568
1	F4	24	0.04
1	F4	29	0.904
1	F4	30	0.136
1	M1	4	-0.104
1	M1	12	0.568
1	M1	15	0.136
1	M1	16	0.088
1	M1	18	0.088
1	M1	19	0.76
1	M1	22	0.088
1	M1	28	0.856
1	M3	1	0.712
1	M3	2	0.088
1	M3	5	0.568
1	M3	6	-0.008
1	M3	7	0.04
1	M3	8	0.04
1	M3	10	0.808
1	M3	13	-0.104
1	M3	14	0.04
1	M3	23	-0.008
1	M3	25	0.04
1	M3	26	-0.008
1	M3	27	0.184
1	M4	3	0.76
1	M4	9	-0.008
1	M4	11	0.232
1	M4	17	-0.008
1	M4	20	0.52
1	M4	21	0.76
1	M4	24	-0.008
1	M4	29	0.808
1	M4	30	-0.056
2	F1	4	0.616
2	F1	12	0.808
2	F1	15	-0.056
2	F1	16	0.136
2	F1	18	0.136
2	F1	19	1
2	F1	22	0.232
2	F1	28	0.952
2	F3	1	0.856
2	F3	2	0.568
2	F3	5	0.76
2	F3	6	0.184
2	F3	7	0.184
2	F3	8	0.04
2	F3	10	0.76
2	F3	13	0.088
2	F3	14	0.28
2	F3	23	0.376
2	F3	25	0.088
2	F3	26	0.04
2	F3	27	0.472
2	F4	3	0.856
2	F4	9	0.136
2	F4	11	0.616
2	F4	17	0.088
2	F4	20	0.616
2	F4	21	0.664
2	F4	24	-0.056
2	F4	29	0.808
2	F4	30	0.088
2	M1	4	0.136
2	M1	12	0.568
2	M1	15	0.184
2	M1	16	0.088
2	M1	18	0.04
2	M1	19	1
2	M1	22	0.28
2	M1	28	0.904
2	M3	1	0.952
2	M3	2	0.184
2	M3	5	0.712
2	M3	6	0.04
2	M3	7	0.04
2	M3	8	0.088
2	M3	10	0.856
2	M3	13	0.088
2	M3	14	0.088
2	M3	23	0.04
2	M3	25	0.04
2	M3	26	0.136
2	M3	27	-0.008
2	M4	3	0.952
2	M4	9	-0.008
2	M4	11	0.472
2	M4	17	0.088
2	M4	20	0.232
2	M4	21	0.568
2	M4	24	0.088
2	M4	29	0.952
2	M4	30	0.04
3	F1	3	0.712
3	F1	8	0.04
3	F1	9	0.184
3	F1	10	0.856
3	F1	17	-0.056
3	F1	21	0.76
3	F1	25	-0.056
3	F1	26	-0.008
3	F1	27	0.184
3	F1	30	0.232
3	F3	11	0.136
3	F3	12	0.424
3	F3	20	0.616
3	F3	24	-0.104
3	F3	28	0.712
3	F3	29	0.856
3	F4	1	0.856
3	F4	2	0.472
3	F4	4	-0.008
3	F4	5	0.472
3	F4	6	0.184
3	F4	7	0.04
3	F4	13	0.136
3	F4	14	0.28
3	F4	15	0.088
3	F4	16	0.088
3	F4	18	-0.152
3	F4	19	0.904
3	F4	22	0.184
3	F4	23	0.136
3	M1	3	0.616
3	M1	8	0.136
3	M1	9	-0.008
3	M1	10	0.904
3	M1	17	-0.056
3	M1	21	0.568
3	M1	25	0.088
3	M1	26	0.04
3	M1	27	0.088
3	M1	30	-0.104
3	M3	11	0.04
3	M3	12	0.424
3	M3	20	0.424
3	M3	24	0.04
3	M3	28	0.904

Listener	Talker	Condition	RA
3	M3	29	0.664
3	M4	1	0.952
3	M4	2	0.424
3	M4	4	0.088
3	M4	5	0.424
3	M4	6	-0.008
3	M4	7	-0.056
3	M4	13	-0.056
3	M4	14	-0.104
3	M4	15	-0.008
3	M4	16	-0.104
3	M4	18	-0.008
3	M4	19	0.76
3	M4	22	-0.008
3	M4	23	-0.056
4	F1	3	0.808
4	F1	8	0.328
4	F1	9	0.328
4	F1	10	0.904
4	F1	17	0.088
4	F1	21	0.712
4	F1	25	-0.056
4	F1	26	0.376
4	F1	27	0.52
4	F1	30	0.232
4	F3	11	0.472
4	F3	12	0.568
4	F3	20	0.568
4	F3	24	-0.008
4	F3	28	0.904
4	F3	29	0.856
4	F4	1	0.904
4	F4	2	0.568
4	F4	4	0.136
4	F4	5	0.424
4	F4	6	-0.008
4	F4	7	0.088
4	F4	13	0.232
4	F4	14	0.088
4	F4	15	-0.008
4	F4	16	-0.056
4	F4	18	-0.008
4	F4	19	0.808
4	F4	22	-0.104
4	F4	23	0.088
4	M1	3	0.808
4	M1	8	0.136
4	M1	9	0.184
4	M1	10	0.904
4	M1	17	-0.056
4	M1	21	0.616
4	M1	25	-0.152
4	M1	26	0.04
4	M1	27	0.136
4	M1	30	0.04
4	M3	11	0.136
4	M3	12	0.184
4	M3	20	0.424
4	M3	24	-0.008
4	M3	28	0.808
4	M3	29	0.664
4	M4	1	0.952
4	M4	2	0.52
4	M4	4	0.136
4	M4	5	0.52

Listener	Talker	Condition	RA
4	M4	6	-0.056
4	M4	7	0.088
4	M4	13	-0.008
4	M4	14	0.232
4	M4	15	-0.104
4	M4	16	-0.008
4	M4	18	-0.008
4	M4	19	0.952
4	M4	22	0.184
4	M4	23	0.184
5	F1	1	0.952
5	F1	2	0.424
5	F1	5	0.424
5	F1	6	-0.008
5	F1	7	0.088
5	F1	11	0.76
5	F1	13	0.328
5	F1	14	0.184
5	F1	20	0.568
5	F1	23	0.472
5	F1	24	-0.056
5	F1	29	0.856
5	F3	3	0.808
5	F3	4	0.232
5	F3	9	-0.152
5	F3	15	-0.056
5	F3	16	0.04
5	F3	17	-0.056
5	F3	18	0.088
5	F3	19	0.808
5	F3	21	0.616
5	F3	22	0.088
5	F3	30	0.04
5	F4	8	0.184
5	F4	10	0.856
5	F4	12	0.52
5	F4	25	0.088
5	F4	26	0.088
5	F4	27	-0.008
5	F4	28	0.808
5	M1	1	0.952
5	M1	2	0.328
5	M1	5	0.52
5	M1	6	-0.056
5	M1	7	-0.056
5	M1	11	0.136
5	M1	13	0.088
5	M1	14	0.136
5	M1	20	0.328
5	M1	23	0.136
5	M1	24	-0.056
5	M1	29	0.712
5	M3	3	0.664
5	M3	4	-0.056
5	M3	9	-0.056
5	M3	15	0.04
5	M3	16	0.28
5	M3	17	0.088
5	M3	18	-0.056
5	M3	19	0.76
5	M3	21	0.28
5	M3	22	0.232
5	M3	30	-0.056
5	M4	8	-0.008
5	M4	10	0.664

Listener	Talker	Condition	RA
5	M4	12	0.328
5	M4	25	0.136
5	M4	26	0.328
5	M4	27	0.184
5	M4	28	0.952
6	F1	1	0.856
6	F1	2	0.28
6	F1	5	0.76
6	F1	6	0.088
6	F1	7	0.088
6	F1	11	0.52
6	F1	13	0.04
6	F1	14	0.568
6	F1	20	0.616
6	F1	23	0.52
6	F1	24	0.04
6	F1	29	0.808
6	F3	3	0.664
6	F3	4	0.136
6	F3	9	0.088
6	F3	15	-0.056
6	F3	16	-0.056
6	F3	17	0.136
6	F3	18	-0.008
6	F3	19	0.904
6	F3	21	0.472
6	F3	22	0.28
6	F3	30	0.136
6	F4	8	0.04
6	F4	10	0.856
6	F4	12	0.52
6	F4	25	-0.056
6	F4	26	0.088
6	F4	27	-0.056
6	F4	28	0.904
6	M1	1	0.856
6	M1	2	0.616
6	M1	5	0.712
6	M1	6	-0.104
6	M1	7	0.04
6	M1	11	0.232
6	M1	13	0.04
6	M1	14	0.232
6	M1	20	0.52
6	M1	23	0.328
6	M1	24	0.088
6	M1	29	0.856
6	M3	3	0.856
6	M3	4	0.04
6	M3	9	-0.008
6	M3	15	0.04
6	M3	16	0.04
6	M3	17	0.328
6	M3	18	-0.008
6	M3	19	0.76
6	M3	21	0.568
6	M3	22	-0.104
6	M3	30	0.04
6	M4	8	0.136
6	M4	10	0.952
6	M4	12	0.76
6	M4	25	-0.008
6	M4	26	-0.008
6	M4	27	-0.008
6	M4	28	0.856

Listener	Talker	Condition	RA
7	F1	2	0.328
7	F1	4	0.184
7	F1	5	0.856
7	F1	6	0.28
7	F1	7	0.136
7	F1	8	0.184
7	F1	9	0.328
7	F1	10	0.856
7	F1	11	0.424
7	F1	13	-0.008
7	F1	17	0.136
7	F1	19	0.712
7	F1	20	0.616
7	F1	27	0.136
7	F3	1	0.712
7	F3	12	0.712
7	F3	14	0.136
7	F3	16	-0.008
7	F3	18	-0.056
7	F3	21	0.568
7	F3	23	0.28
7	F3	24	0.04
7	F3	25	-0.104
7	F4	3	0.712
7	F4	15	0.04
7	F4	22	0.136
7	F4	26	0.136
7	F4	28	0.856
7	F4	29	0.856
7	F4	30	0.04
7	M1	2	0.424
7	M1	4	0.04
7	M1	5	0.616
7	M1	6	0.184
7	M1	7	0.04
7	M1	8	-0.056
7	M1	9	-0.008
7	M1	10	0.856
7	M1	11	0.328
7	M1	13	0.04
7	M1	17	0.04
7	M1	19	0.76
7	M1	20	0.424
7	M1	27	-0.056
7	M3	1	0.856
7	M3	12	0.328
7	M3	14	0.04
7	M3	16	0.088
7	M3	18	-0.008
7	M3	21	0.328
7	M3	23	-0.008
7	M3	24	-0.104
7	M3	25	0.04
7	M4	3	0.76
7	M4	15	-0.056
7	M4	22	-0.056
7	M4	26	-0.008
7	M4	28	0.856
7	M4	29	0.856
7	M4	30	0.088
8	F1	2	0.52
8	F1	4	0.376
8	F1	5	0.808
8	F1	6	0.232
8	F1	7	0.184
8	F1	8	0.28
8	F1	9	0.232
8	F1	10	0.808
8	F1	11	0.616
8	F1	13	0.136
8	F1	17	-0.056
8	F1	19	0.712
8	F1	20	0.568
8	F1	27	0.136
8	F3	1	0.856
8	F3	12	0.52
8	F3	14	0.088
8	F3	16	-0.104
8	F3	18	-0.056
8	F3	21	0.568
8	F3	23	0.232
8	F3	24	-0.056
8	F3	25	0.088
8	F4	3	0.856
8	F4	15	0.088
8	F4	22	0.136
8	F4	26	0.184
8	F4	28	0.952
8	F4	29	0.952
8	F4	30	0.088
8	M1	2	0.424
8	M1	4	0.184
8	M1	5	0.616
8	M1	6	0.088
8	M1	7	0.04
8	M1	8	0.136
8	M1	9	-0.104
8	M1	10	0.904
8	M1	11	0.184
8	M1	13	0.088
8	M1	17	-0.008
8	M1	19	0.904
8	M1	20	0.76
8	M1	27	-0.2
8	M3	1	0.904
8	M3	12	0.28
8	M3	14	-0.008
8	M3	16	0.136
8	M3	18	-0.056
8	M3	21	0.568
8	M3	23	0.184
8	M3	24	-0.056
8	M3	25	-0.104
8	M4	3	0.856
8	M4	15	-0.152
8	M4	22	0.136
8	M4	26	0.136
8	M4	28	0.904
8	M4	29	0.904
8	M4	30	-0.008
9	F1	15	0.04
9	F1	16	0.088
9	F1	18	-0.008
9	F1	25	0.184
9	F1	29	0.952
9	F3	2	0.472
9	F3	3	0.856
9	F3	4	0.088
9	F3	6	0.184
9	F3	8	0.088
9	F3	9	-0.056
9	F3	10	0.904
9	F3	11	0.472
9	F3	17	-0.008
9	F3	22	0.136
9	F3	26	0.04
9	F3	27	0.136
9	F3	28	1
9	F3	30	0.136
9	F4	1	1
9	F4	5	0.616
9	F4	7	0.04
9	F4	12	0.568
9	F4	13	-0.008
9	F4	14	0.136
9	F4	19	0.808
9	F4	20	0.616
9	F4	21	0.664
9	F4	23	0.088
9	F4	24	0.136
9	M1	15	-0.008
9	M1	16	0.136
9	M1	18	0.04
9	M1	25	0.088
9	M1	29	0.76
9	M3	2	0.328
9	M3	3	0.856
9	M3	4	0.136
9	M3	6	0.136
9	M3	8	0.28
9	M3	9	-0.008
9	M3	10	0.856
9	M3	11	0.232
9	M3	17	0.04
9	M3	22	-0.104
9	M3	26	-0.008
9	M3	27	-0.056
9	M3	28	0.904
9	M3	30	0.088
9	M4	1	0.904
9	M4	5	0.568
9	M4	7	0.184
9	M4	12	0.52
9	M4	13	0.04
9	M4	14	0.088
9	M4	19	0.856
9	M4	20	0.376
9	M4	21	0.712
9	M4	23	0.136
9	M4	24	-0.008
10	F1	15	-0.056
10	F1	16	-0.056
10	F1	18	0.136
10	F1	25	0.088
10	F1	29	0.76
10	F3	2	0.376
10	F3	3	0.664
10	F3	4	0.184
10	F3	6	-0.008
10	F3	8	-0.008
10	F3	9	-0.056
10	F3	10	0.856
10	F3	11	0.328
10	F3	17	-0.008
10	F3	22	0.184

Listener	Talker	Condition	RA
10	F3	26	-0.056
10	F3	27	0.184
10	F3	28	0.952
10	F3	30	-0.056
10	F4	1	0.856
10	F4	5	0.664
10	F4	7	0.136
10	F4	12	0.664
10	F4	13	0.184
10	F4	14	0.088
10	F4	19	0.808
10	F4	20	0.52
10	F4	21	0.568
10	F4	23	0.184
10	F4	24	0.04
10	M1	15	-0.008
10	M1	16	0.04
10	M1	18	0.04
10	M1	25	-0.008
10	M1	29	0.712
10	M3	2	0.184
10	M3	3	0.808
10	M3	4	-0.056
10	M3	6	-0.152
10	M3	8	0.088
10	M3	9	0.088
10	M3	10	0.808
10	M3	11	-0.008
10	M3	17	0.136
10	M3	22	0.04
10	M3	26	0.04
10	M3	27	-0.104
10	M3	28	0.76
10	M3	30	-0.056
10	M4	1	0.856
10	M4	5	0.616
10	M4	7	-0.056
10	M4	12	0.568
10	M4	13	-0.104
10	M4	14	0.088
10	M4	19	0.904
10	M4	20	0.52
10	M4	21	0.808
10	M4	23	0.04
10	M4	24	0.184
11	F1	1	0.76
11	F1	3	0.952
11	F1	12	0.808
11	F1	14	0.328
11	F1	21	0.568
11	F1	22	0.232
11	F1	23	0.376
11	F1	24	0.136
11	F1	26	0.04
11	F1	28	0.952
11	F1	30	0.328
11	F3	5	0.712
11	F3	7	0.136
11	F3	13	-0.008
11	F3	15	-0.008
11	F3	19	0.712
11	F3	20	0.472
11	F3	29	0.808
11	F4	2	0.52
11	F4	4	0.136

Listener	Talker	Condition	RA
11	F4	6	-0.104
11	F4	8	0.184
11	F4	9	0.184
11	F4	10	0.904
11	F4	11	0.616
11	F4	16	0.088
11	F4	17	-0.056
11	F4	18	0.184
11	F4	25	-0.008
11	F4	27	0.088
11	M1	1	0.904
11	M1	3	0.76
11	M1	12	0.424
11	M1	14	0.136
11	M1	21	0.376
11	M1	22	0.136
11	M1	23	0.136
11	M1	24	-0.152
11	M1	26	0.04
11	M1	28	0.808
11	M1	30	0.04
11	M3	5	0.616
11	M3	7	-0.104
11	M3	13	0.184
11	M3	15	-0.008
11	M3	19	0.856
11	M3	20	0.28
11	M3	29	0.664
11	M4	2	0.424
11	M4	4	0.232
11	M4	6	0.184
11	M4	8	0.088
11	M4	9	-0.056
11	M4	10	0.712
11	M4	11	0.328
11	M4	16	0.04
11	M4	17	0.184
11	M4	18	0.184
11	M4	25	0.088
11	M4	27	0.088
12	F1	1	0.904
12	F1	3	0.904
12	F1	12	0.568
12	F1	14	0.328
12	F1	21	0.616
12	F1	22	0.136
12	F1	23	0.28
12	F1	24	0.04
12	F1	26	0.136
12	F1	28	0.76
12	F1	30	0.088
12	F3	5	0.712
12	F3	7	0.04
12	F3	13	-0.104
12	F3	15	-0.104
12	F3	19	0.712
12	F3	20	0.712
12	F3	29	0.76
12	F4	2	0.184
12	F4	4	0.088
12	F4	6	0.184
12	F4	8	0.136
12	F4	9	0.136
12	F4	10	0.856
12	F4	11	0.376

Listener	Talker	Condition	RA
12	F4	16	-0.008
12	F4	17	0.04
12	F4	18	0.088
12	F4	25	0.232
12	F4	27	0.088
12	M1	1	1
12	M1	3	0.616
12	M1	12	0.616
12	M1	14	0.136
12	M1	21	0.76
12	M1	22	-0.104
12	M1	23	0.376
12	M1	24	-0.008
12	M1	26	-0.104
12	M1	28	0.904
12	M1	30	0.04
12	M3	5	0.568
12	M3	7	-0.152
12	M3	13	-0.152
12	M3	15	-0.056
12	M3	19	0.76
12	M3	20	0.328
12	M3	29	0.76
12	M4	2	0.52
12	M4	4	0.088
12	M4	6	-0.008
12	M4	8	0.136
12	M4	9	0.28
12	M4	10	0.856
12	M4	11	0.52
12	M4	16	0.232
12	M4	17	0.136
12	M4	18	0.04
12	M4	25	0.136
12	M4	27	-0.056
13	F1	1	1
13	F1	4	0.376
13	F1	11	0.616
13	F1	18	-0.008
13	F1	21	0.808
13	F1	22	0.28
13	F1	23	0.328
13	F1	25	0.088
13	F1	28	1
13	F3	2	0.376
13	F3	3	0.904
13	F3	7	0.136
13	F3	8	0.28
13	F3	14	0.232
13	F3	15	-0.056
13	F3	17	0.04
13	F3	26	0.04
13	F3	29	0.856
13	F3	30	0.04
13	F4	5	0.664
13	F4	6	0.088
13	F4	9	0.04
13	F4	10	0.904
13	F4	12	0.712
13	F4	13	0.184
13	F4	16	-0.104
13	F4	19	0.952
13	F4	20	0.616
13	F4	24	-0.104
13	F4	27	-0.056

Listener	Talker	Condition	RA
13	M1	1	1
13	M1	4	0.136
13	M1	11	0.184
13	M1	18	-0.008
13	M1	21	0.568
13	M1	22	0.376
13	M1	23	0.04
13	M1	25	-0.056
13	M1	28	0.856
13	M3	2	0.424
13	M3	3	0.712
13	M3	7	-0.008
13	M3	8	-0.056
13	M3	14	-0.056
13	M3	15	0.136
13	M3	17	0.28
13	M3	26	-0.104
13	M3	29	0.808
13	M3	30	-0.008
13	M4	5	0.376
13	M4	6	-0.104
13	M4	9	-0.104
13	M4	10	0.952
13	M4	12	0.664
13	M4	13	0.088
13	M4	16	0.04
13	M4	19	0.76
13	M4	20	0.328
13	M4	24	-0.008
13	M4	27	0.088
14	F1	1	0.856
14	F1	4	0.472
14	F1	11	0.616
14	F1	18	0.088
14	F1	21	0.616
14	F1	22	0.184
14	F1	23	0.424
14	F1	25	0.088
14	F1	28	0.952
14	F3	2	0.328
14	F3	3	0.808
14	F3	7	0.04
14	F3	8	-0.056
14	F3	14	0.28
14	F3	15	-0.2
14	F3	17	0.136
14	F3	26	0.136
14	F3	29	0.76
14	F3	30	0.136
14	F4	5	0.712
14	F4	6	-0.008
14	F4	9	0.088
14	F4	10	0.856
14	F4	12	0.472
14	F4	13	0.232
14	F4	16	-0.056
14	F4	19	0.808
14	F4	20	0.424
14	F4	24	-0.056
14	F4	27	0.088
14	M1	1	0.904
14	M1	4	0.28
14	M1	11	0.28
14	M1	18	0.088
14	M1	21	0.616

Listener	Talker	Condition	RA
14	M1	22	-0.008
14	M1	23	0.328
14	M1	25	-0.008
14	M1	28	0.904
14	M3	2	0.472
14	M3	3	0.856
14	M3	7	-0.152
14	M3	8	0.088
14	M3	14	-0.008
14	M3	15	0.088
14	M3	17	0.136
14	M3	26	0.04
14	M3	29	0.52
14	M3	30	0.136
14	M4	5	0.472
14	M4	6	-0.056
14	M4	9	-0.056
14	M4	10	0.904
14	M4	12	0.472
14	M4	13	0.088
14	M4	16	-0.056
14	M4	19	0.904
14	M4	20	0.328
14	M4	24	0.04
14	M4	27	0.328
15	F1	5	0.52
15	F1	7	0.136
15	F1	12	0.664
15	F1	13	0.184
15	F1	15	0.184
15	F1	19	0.952
15	F1	20	0.472
15	F1	24	0.04
15	F1	26	0.328
15	F1	27	0.232
15	F1	29	0.712
15	F1	30	0.28
15	F3	4	0.328
15	F3	6	0.088
15	F3	9	0.136
15	F3	10	0.856
15	F3	11	0.328
15	F3	16	0.04
15	F3	18	-0.104
15	F3	25	-0.152
15	F3	28	0.952
15	F4	1	1
15	F4	2	0.664
15	F4	3	0.712
15	F4	8	0.232
15	F4	14	0.232
15	F4	17	0.136
15	F4	21	0.424
15	F4	22	0.184
15	F4	23	0.088
15	M1	5	0.424
15	M1	7	-0.104
15	M1	12	0.568
15	M1	13	0.136
15	M1	15	-0.008
15	M1	19	0.712
15	M1	20	0.616
15	M1	24	-0.008
15	M1	26	-0.008
15	M1	27	0.184

Listener	Talker	Condition	RA
15	M1	29	0.904
15	M1	30	0.088
15	M3	4	-0.104
15	M3	6	-0.152
15	M3	9	-0.008
15	M3	10	0.856
15	M3	11	-0.008
15	M3	16	-0.056
15	M3	18	-0.056
15	M3	25	-0.104
15	M3	28	0.952
15	M4	1	0.712
15	M4	2	0.472
15	M4	3	0.76
15	M4	8	0.232
15	M4	14	0.184
15	M4	17	0.04
15	M4	21	0.568
15	M4	22	0.136
15	M4	23	0.28
16	F1	5	0.664
16	F1	7	0.088
16	F1	12	0.76
16	F1	13	0.136
16	F1	15	-0.104
16	F1	19	1
16	F1	20	0.616
16	F1	24	-0.056
16	F1	26	-0.056
16	F1	27	0.28
16	F1	29	0.808
16	F1	30	0.232
16	F3	4	0.088
16	F3	6	0.184
16	F3	9	-0.152
16	F3	10	0.76
16	F3	11	0.232
16	F3	16	-0.056
16	F3	18	0.04
16	F3	25	-0.008
16	F3	28	0.856
16	F4	1	0.952
16	F4	2	0.52
16	F4	3	0.664
16	F4	8	0.184
16	F4	14	0.088
16	F4	17	-0.056
16	F4	21	0.424
16	F4	22	0.28
16	F4	23	0.136
16	M1	5	0.472
16	M1	7	-0.008
16	M1	12	0.424
16	M1	13	0.136
16	M1	15	0.088
16	M1	19	0.856
16	M1	20	0.424
16	M1	24	0.04
16	M1	26	-0.008
16	M1	27	0.088
16	M1	29	0.76
16	M1	30	-0.008
16	M3	4	0.04
16	M3	6	-0.008
16	M3	9	0.04

Listener	Talker	Condition	RA
16	M3	10	0.856
16	M3	11	0.184
16	M3	16	-0.008
16	M3	18	0.04
16	M3	25	-0.104
16	M3	28	0.808
16	M4	1	0.904
16	M4	2	0.472
16	M4	3	0.808
16	M4	8	0.088
16	M4	14	0.088
16	M4	17	0.04
16	M4	21	0.712
16	M4	22	0.088
16	M4	23	0.136
17	F1	2	0.424
17	F1	3	0.712
17	F1	6	0.088
17	F1	8	-0.008
17	F1	9	0.04
17	F1	10	0.856
17	F1	14	0.184
17	F1	16	-0.008
17	F1	17	0.04
17	F3	1	0.808
17	F3	5	0.52
17	F3	12	0.28
17	F3	13	0.088
17	F3	19	0.808
17	F3	20	0.424
17	F3	21	0.712
17	F3	22	-0.104
17	F3	23	0.28
17	F3	24	-0.008
17	F3	27	0.136
17	F4	4	0.28
17	F4	7	0.136
17	F4	11	0.52
17	F4	15	-0.008
17	F4	18	-0.056
17	F4	25	-0.056
17	F4	26	0.04
17	F4	28	0.856
17	F4	29	0.904
17	F4	30	0.088
17	M1	2	0.376
17	M1	3	0.664
17	M1	6	-0.008
17	M1	8	-0.104
17	M1	9	-0.056
17	M1	10	0.856
17	M1	14	0.184
17	M1	16	0.184
17	M1	17	0.136
17	M3	1	0.76
17	M3	5	0.472
17	M3	12	0.376
17	M3	13	-0.056
17	M3	19	0.616
17	M3	20	0.28
17	M3	21	0.424
17	M3	22	0.088
17	M3	23	-0.056
17	M3	24	0.04
17	M3	27	0.04

Listener	Talker	Condition	RA
17	M4	4	0.184
17	M4	7	0.088
17	M4	11	0.376
17	M4	15	0.136
17	M4	18	-0.056
17	M4	25	-0.152
17	M4	26	0.04
17	M4	28	0.904
17	M4	29	0.712
17	M4	30	-0.056
18	F1	2	0.568
18	F1	3	0.904
18	F1	6	0.232
18	F1	8	0.136
18	F1	9	0.088
18	F1	10	0.808
18	F1	14	0.184
18	F1	16	-0.008
18	F1	17	0.328
18	F3	1	1
18	F3	5	0.472
18	F3	12	0.808
18	F3	13	0.184
18	F3	19	0.904
18	F3	20	0.472
18	F3	21	0.712
18	F3	22	0.04
18	F3	23	0.232
18	F3	24	-0.056
18	F3	27	0.232
18	F4	4	0.184
18	F4	7	0.184
18	F4	11	0.52
18	F4	15	0.136
18	F4	18	-0.008
18	F4	25	0.04
18	F4	26	0.28
18	F4	28	1
18	F4	29	0.952
18	F4	30	0.04
18	M1	2	0.472
18	M1	3	0.904
18	M1	6	-0.008
18	M1	8	0.04
18	M1	9	-0.008
18	M1	10	0.904
18	M1	14	0.088
18	M1	16	-0.152
18	M1	17	0.136
18	M3	1	0.904
18	M3	5	0.52
18	M3	12	0.136
18	M3	13	0.088
18	M3	19	0.712
18	M3	20	0.424
18	M3	21	0.568
18	M3	22	-0.008
18	M3	23	0.376
18	M3	24	0.088
18	M3	27	-0.008
18	M4	4	0.328
18	M4	7	-0.056
18	M4	11	0.52
18	M4	15	0.136
18	M4	18	-0.008

Listener	Talker	Condition	RA
18	M4	25	0.088
18	M4	26	0.04
18	M4	28	0.904
18	M4	29	0.904
18	M4	30	0.04
19	F1	1	0.808
19	F1	2	0.568
19	F1	8	0.136
19	F1	14	0.328
19	F1	15	0.04
19	F1	20	0.472
19	F1	22	0.232
19	F1	26	0.184
19	F1	28	0.76
19	F3	4	0.088
19	F3	6	0.136
19	F3	7	-0.152
19	F3	11	0.088
19	F3	12	0.424
19	F3	13	0.04
19	F3	17	0.088
19	F3	19	0.712
19	F3	21	0.52
19	F3	25	-0.2
19	F4	3	0.712
19	F4	5	0.808
19	F4	9	-0.008
19	F4	10	0.808
19	F4	16	-0.056
19	F4	18	-0.008
19	F4	23	0.184
19	F4	24	0.088
19	F4	27	0.136
19	F4	29	0.76
19	F4	30	-0.056
19	M1	1	0.76
19	M1	2	0.424
19	M1	8	-0.008
19	M1	14	0.04
19	M1	15	0.136
19	M1	20	0.568
19	M1	22	0.232
19	M1	26	-0.008
19	M1	28	0.856
19	M3	4	0.088
19	M3	6	-0.008
19	M3	7	-0.056
19	M3	11	0.184
19	M3	12	0.376
19	M3	13	-0.056
19	M3	17	0.232
19	M3	19	0.52
19	M3	21	0.328
19	M3	25	-0.104
19	M4	3	0.712
19	M4	5	0.568
19	M4	9	0.04
19	M4	10	0.856
19	M4	16	-0.056
19	M4	18	0.088
19	M4	23	0.136
19	M4	24	-0.008
19	M4	27	-0.056
19	M4	29	0.76
19	M4	30	-0.056

Listener	Talker	Condition	RA
20	F1	1	0.952
20	F1	2	0.472
20	F1	8	0.232
20	F1	14	0.184
20	F1	15	-0.008
20	F1	20	0.424
20	F1	22	0.184
20	F1	26	0.328
20	F1	28	0.952
20	F3	4	0.328
20	F3	6	-0.056
20	F3	7	0.136
20	F3	11	0.184
20	F3	12	0.472
20	F3	13	-0.056
20	F3	17	-0.104
20	F3	19	0.904
20	F3	21	0.568
20	F3	25	0.04
20	F4	3	0.808
20	F4	5	0.664
20	F4	9	-0.056
20	F4	10	0.76
20	F4	16	-0.008
20	F4	18	0.136
20	F4	23	0.088
20	F4	24	0.04
20	F4	27	0.088
20	F4	29	0.808
20	F4	30	-0.152
20	M1	1	0.76
20	M1	2	0.52
20	M1	8	-0.056
20	M1	14	0.28
20	M1	15	-0.056
20	M1	20	0.328
20	M1	22	-0.056
20	M1	26	0.088
20	M1	28	0.856
20	M3	4	0.04
20	M3	6	0.04
20	M3	7	0.04
20	M3	11	0.232
20	M3	12	0.376
20	M3	13	-0.056
20	M3	17	-0.008
20	M3	19	0.76
20	M3	21	0.472
20	M3	25	-0.056
20	M4	3	0.664
20	M4	5	0.376
20	M4	9	-0.008
20	M4	10	0.664
20	M4	16	-0.056
20	M4	18	0.04
20	M4	23	0.232
20	M4	24	-0.008
20	M4	27	0.088
20	M4	29	0.808
20	M4	30	-0.056
21	F1	3	0.76
21	F1	4	0.472
21	F1	5	0.76
21	F1	12	0.712
21	F1	16	0.04

Listener	Talker	Condition	RA
21	F1	17	0.088
21	F1	24	0.136
21	F1	25	0.232
21	F1	30	0.184
21	F3	1	0.952
21	F3	8	-0.008
21	F3	9	0.04
21	F3	10	0.712
21	F3	18	-0.008
21	F3	23	0.328
21	F3	26	0.088
21	F3	27	-0.008
21	F3	28	0.76
21	F3	29	0.808
21	F4	2	0.424
21	F4	6	0.04
21	F4	7	0.184
21	F4	11	0.52
21	F4	13	0.136
21	F4	14	0.184
21	F4	15	0.136
21	F4	19	0.712
21	F4	20	0.472
21	F4	21	0.904
21	F4	22	0.184
21	M1	3	0.856
21	M1	4	0.232
21	M1	5	0.376
21	M1	12	0.52
21	M1	16	-0.008
21	M1	17	-0.008
21	M1	24	0.04
21	M1	25	-0.056
21	M1	30	0.28
21	M3	1	1
21	M3	8	-0.056
21	M3	9	-0.008
21	M3	10	0.808
21	M3	18	-0.008
21	M3	23	0.088
21	M3	26	-0.008
21	M3	27	0.088
21	M3	28	0.856
21	M3	29	0.856
21	M4	2	0.376
21	M4	6	0.088
21	M4	7	0.28
21	M4	11	0.28
21	M4	13	-0.008
21	M4	14	-0.008
21	M4	15	-0.104
21	M4	19	0.616
21	M4	20	0.52
21	M4	21	0.664
21	M4	22	0.28
22	F1	3	1
22	F1	4	0.328
22	F1	5	0.664
22	F1	12	0.808
22	F1	16	0.04
22	F1	17	0.04
22	F1	24	-0.008
22	F1	25	-0.008
22	F1	30	0.232
22	F3	1	0.856

Listener	Talker	Condition	RA
22	F3	8	-0.008
22	F3	9	0.184
22	F3	10	0.808
22	F3	18	-0.008
22	F3	23	0.424
22	F3	26	0.04
22	F3	27	0.04
22	F3	28	0.952
22	F3	29	0.808
22	F4	2	0.424
22	F4	6	0.136
22	F4	7	-0.008
22	F4	11	0.328
22	F4	13	0.136
22	F4	14	0.328
22	F4	15	-0.008
22	F4	19	0.76
22	F4	20	0.472
22	F4	21	0.856
22	F4	22	0.088
22	M1	3	0.76
22	M1	4	0.28
22	M1	5	0.568
22	M1	12	0.472
22	M1	16	-0.008
22	M1	17	-0.008
22	M1	24	-0.056
22	M1	25	-0.008
22	M1	30	0.04
22	M3	1	0.904
22	M3	8	-0.104
22	M3	9	-0.008
22	M3	10	0.424
22	M3	18	0.136
22	M3	23	0.28
22	M3	26	0.04
22	M3	27	-0.056
22	M3	28	0.952
22	M3	29	0.952
22	M4	2	0.232
22	M4	6	0.04
22	M4	7	0.088
22	M4	11	0.328
22	M4	13	0.088
22	M4	14	0.184
22	M4	15	-0.008
22	M4	19	0.616
22	M4	20	0.328
22	M4	21	0.568
22	M4	22	0.136
23	F1	6	0.136
23	F1	7	0.184
23	F1	9	0.184
23	F1	10	0.664
23	F1	11	0.376
23	F1	13	-0.056
23	F1	18	-0.008
23	F1	19	0.712
23	F1	21	0.808
23	F1	23	0.52
23	F1	27	0.088
23	F1	29	0.856
23	F3	2	0.376
23	F3	3	0.856
23	F3	5	0.472

Listener	Talker	Condition	RA
23	F3	14	0.184
23	F3	15	-0.008
23	F3	16	0.04
23	F3	20	0.424
23	F3	22	0.088
23	F3	24	-0.104
23	F3	30	0.088
23	F4	1	0.808
23	F4	4	0.088
23	F4	8	0.136
23	F4	12	0.52
23	F4	17	0.136
23	F4	25	-0.2
23	F4	26	-0.008
23	F4	28	0.76
23	M1	6	0.088
23	M1	7	0.232
23	M1	9	-0.008
23	M1	10	0.76
23	M1	11	0.136
23	M1	13	-0.104
23	M1	18	0.088
23	M1	19	0.712
23	M1	21	0.376
23	M1	23	0.28
23	M1	27	-0.008
23	M1	29	0.664
23	M3	2	0.28
23	M3	3	0.664
23	M3	5	0.328
23	M3	14	0.184
23	M3	15	0.04
23	M3	16	0.04
23	M3	20	0.184
23	M3	22	-0.152
23	M3	24	-0.152
23	M3	30	-0.152
23	M4	1	0.904
23	M4	4	0.04
23	M4	8	0.088
23	M4	12	0.424
23	M4	17	-0.008
23	M4	25	-0.008
23	M4	26	0.04
23	M4	28	0.856
24	F1	6	-0.104
24	F1	7	-0.056
24	F1	9	-0.008
24	F1	10	0.856
24	F1	11	0.28
24	F1	13	0.136
24	F1	18	-0.104
24	F1	19	0.952
24	F1	21	0.808
24	F1	23	0.184
24	F1	27	-0.008
24	F1	29	0.904
24	F3	2	0.76
24	F3	3	0.808
24	F3	5	0.376
24	F3	14	-0.008
24	F3	15	-0.008
24	F3	16	-0.104
24	F3	20	0.616
24	F3	22	0.088

Listener	Talker	Condition	RA
24	F3	24	0.04
24	F3	30	0.136
24	F4	1	0.76
24	F4	4	-0.008
24	F4	8	0.232
24	F4	12	0.616
24	F4	17	0.04
24	F4	25	0.04
24	F4	26	0.136
24	F4	28	1
24	M1	6	-0.104
24	M1	7	-0.104
24	M1	9	0.04
24	M1	10	0.808
24	M1	11	0.328
24	M1	13	-0.008
24	M1	18	-0.008
24	M1	19	0.712
24	M1	21	0.472
24	M1	23	0.088
24	M1	27	0.088
24	M1	29	0.712
24	M3	2	0.472
24	M3	3	0.856
24	M3	5	0.472
24	M3	14	-0.056
24	M3	15	0.04
24	M3	16	-0.104
24	M3	20	0.424
24	M3	22	0.136
24	M3	24	-0.056
24	M3	30	-0.056
24	M4	1	0.904
24	M4	4	0.04
24	M4	8	0.088
24	M4	12	0.376
24	M4	17	0.04
24	M4	25	-0.008
24	M4	26	-0.008
24	M4	28	0.76
25	F1	2	0.52
25	F1	3	0.76
25	F1	7	0.424
25	F1	8	0.232
25	F1	9	0.04
25	F1	10	0.808
25	F1	11	0.616
25	F1	14	0.424
25	F1	16	0.232
25	F1	17	0.136
25	F1	20	0.52
25	F1	24	-0.056
25	F1	30	0.04
25	F3	1	0.856
25	F3	5	0.568
25	F3	6	-0.008
25	F3	12	0.472
25	F3	13	0.04
25	F3	18	0.088
25	F3	19	0.856
25	F3	21	0.664
25	F3	22	0.088
25	F3	23	0.136
25	F3	29	0.808
25	F4	4	0.088

Listener	Talker	Condition	RA
25	F4	15	-0.008
25	F4	25	-0.2
25	F4	26	0.136
25	F4	27	0.136
25	F4	28	0.808
25	M1	2	0.328
25	M1	3	0.76
25	M1	7	-0.104
25	M1	8	0.28
25	M1	9	0.136
25	M1	10	0.856
25	M1	11	0.136
25	M1	14	0.136
25	M1	16	-0.152
25	M1	17	-0.056
25	M1	20	0.28
25	M1	24	0.328
25	M1	30	-0.056
25	M3	1	0.856
25	M3	5	0.616
25	M3	6	-0.056
25	M3	12	0.568
25	M3	13	-0.008
25	M3	18	-0.008
25	M3	19	0.664
25	M3	21	0.424
25	M3	22	0.088
25	M3	23	-0.056
25	M3	29	0.76
25	M4	4	0.232
25	M4	15	0.088
25	M4	25	-0.104
25	M4	26	0.04
25	M4	27	-0.056
25	M4	28	0.952
26	F1	2	0.76
26	F1	3	0.664
26	F1	7	0.376
26	F1	8	0.424
26	F1	9	-0.008
26	F1	10	0.904
26	F1	11	0.424
26	F1	14	0.28
26	F1	16	0.136
26	F1	17	0.184
26	F1	20	0.808
26	F1	24	0.136
26	F1	30	0.184
26	F3	1	0.76
26	F3	5	0.664
26	F3	6	0.328
26	F3	12	0.76
26	F3	13	-0.056
26	F3	18	0.136
26	F3	19	0.76
26	F3	21	0.616
26	F3	22	0.184
26	F3	23	0.184
26	F3	29	0.808
26	F4	4	0.184
26	F4	15	-0.152
26	F4	25	-0.056
26	F4	26	0.28
26	F4	27	0.28
26	F4	28	0.952

Listener	Talker	Condition	RA
26	M1	2	0.424
26	M1	3	0.856
26	M1	7	-0.008
26	M1	8	0.04
26	M1	9	0.232
26	M1	10	0.76
26	M1	11	0.472
26	M1	14	0.088
26	M1	16	-0.104
26	M1	17	-0.056
26	M1	20	0.568
26	M1	24	0.04
26	M1	30	0.136
26	M3	1	0.856
26	M3	5	0.568
26	M3	6	-0.008
26	M3	12	0.232
26	M3	13	0.088
26	M3	18	0.04
26	M3	19	0.616
26	M3	21	0.52
26	M3	22	-0.056
26	M3	23	0.136
26	M3	29	0.616
26	M4	4	0.184
26	M4	15	0.04
26	M4	25	-0.008
26	M4	26	0.328
26	M4	27	-0.056
26	M4	28	0.952
27	F1	6	0.136
27	F1	15	-0.056
27	F1	18	-0.104
27	F1	22	0.088
27	F1	25	-0.056
27	F1	26	0.04
27	F3	2	0.472
27	F3	4	0.04
27	F3	11	0.52
27	F3	14	0.136
27	F3	16	-0.008
27	F3	27	0.04
27	F3	28	0.952
27	F3	30	0.04
27	F4	1	0.856
27	F4	3	0.856
27	F4	5	0.664
27	F4	7	0.04
27	F4	8	0.184
27	F4	9	-0.104
27	F4	10	0.952
27	F4	12	0.616
27	F4	13	0.136
27	F4	17	0.088
27	F4	19	0.664
27	F4	20	0.472
27	F4	21	0.568
27	F4	23	0.04
27	F4	24	-0.056
27	F4	29	0.664
27	M1	6	-0.104
27	M1	15	0.04
27	M1	18	0.04
27	M1	22	0.088
27	M1	25	-0.104

Listener	Talker	Condition	RA
27	M1	26	-0.008
27	M3	2	0.328
27	M3	4	0.136
27	M3	11	0.088
27	M3	14	0.232
27	M3	16	0.04
27	M3	27	0.04
27	M3	28	0.856
27	M3	30	-0.056
27	M4	1	0.904
27	M4	3	0.712
27	M4	5	0.568
27	M4	7	0.184
27	M4	8	-0.056
27	M4	9	-0.008
27	M4	10	0.904
27	M4	12	0.424
27	M4	13	-0.056
27	M4	17	-0.056
27	M4	19	0.904
27	M4	20	0.568
27	M4	21	0.664
27	M4	23	0.184
27	M4	24	-0.008
27	M4	29	0.952
28	F1	6	0.088
28	F1	15	-0.008
28	F1	18	-0.152
28	F1	22	0.184
28	F1	25	0.04
28	F1	26	0.04
28	F3	2	0.664
28	F3	4	0.088
28	F3	11	0.28
28	F3	14	0.136
28	F3	16	0.28
28	F3	27	0.088
28	F3	28	0.904
28	F3	30	-0.008
28	F4	1	0.808
28	F4	3	0.904
28	F4	5	0.52
28	F4	7	0.04
28	F4	8	0.04
28	F4	9	0.04
28	F4	10	0.808
28	F4	12	0.568
28	F4	13	0.04
28	F4	17	0.184
28	F4	19	0.76
28	F4	20	0.52
28	F4	21	0.472
28	F4	23	0.52
28	F4	24	-0.152
28	F4	29	0.712
28	M1	6	-0.056
28	M1	15	-0.008
28	M1	18	-0.008
28	M1	22	0.088
28	M1	25	-0.056
28	M1	26	-0.056
28	M3	2	0.424
28	M3	4	0.088
28	M3	11	0.136
28	M3	14	-0.008

Listener	Talker	Condition	RA
28	M3	16	-0.104
28	M3	27	0.04
28	M3	28	0.856
28	M3	30	-0.056
28	M4	1	0.856
28	M4	3	0.904
28	M4	5	0.664
28	M4	7	0.04
28	M4	8	0.328
28	M4	9	-0.008
28	M4	10	0.712
28	M4	12	0.424
28	M4	13	-0.152
28	M4	17	0.04
28	M4	19	0.808
28	M4	20	0.472
28	M4	21	0.616
28	M4	23	-0.008
28	M4	24	-0.008
28	M4	29	0.712
29	F1	1	0.952
29	F1	4	0.472
29	F1	5	0.52
29	F1	12	0.616
29	F1	13	0.232
29	F1	19	1
29	F1	21	0.568
29	F1	23	0.52
29	F1	27	0.424
29	F1	28	0.904
29	F1	29	0.904
29	F3	3	0.904
29	F3	7	0.136
29	F3	8	0.136
29	F3	9	0.088
29	F3	10	0.808
29	F3	15	0.184
29	F3	17	0.184
29	F3	20	0.376
29	F3	24	0.136
29	F3	25	0.04
29	F3	26	0.184
29	F4	2	0.136
29	F4	6	0.136
29	F4	11	0.424
29	F4	14	0.04
29	F4	16	-0.008
29	F4	18	-0.056
29	F4	22	0.184
29	F4	30	0.04
29	M1	1	0.904
29	M1	4	0.184
29	M1	5	0.808
29	M1	12	0.328
29	M1	13	-0.008
29	M1	19	0.712
29	M1	21	0.52
29	M1	23	0.136
29	M1	27	-0.008
29	M1	28	0.952
29	M1	29	0.76
29	M3	3	0.616
29	M3	7	0.088
29	M3	8	0.088
29	M3	9	0.088

Listener	Talker	Condition	RA
29	M3	10	0.904
29	M3	15	-0.008
29	M3	17	0.088
29	M3	20	0.088
29	M3	24	-0.2
29	M3	25	0.088
29	M3	26	-0.152
29	M4	2	0.664
29	M4	6	0.088
29	M4	11	0.232
29	M4	14	0.136
29	M4	16	-0.008
29	M4	18	0.04
29	M4	22	0.088
29	M4	30	0.136
30	F1	1	0.904
30	F1	4	0.136
30	F1	5	0.472
30	F1	12	0.616
30	F1	13	0.28
30	F1	19	0.904
30	F1	21	0.616
30	F1	23	0.28
30	F1	27	0.184
30	F1	28	0.856

Listener	Talker	Condition	RA
30	F1	29	0.664
30	F3	3	0.904
30	F3	7	-0.008
30	F3	8	0.28
30	F3	9	-0.056
30	F3	10	0.856
30	F3	15	0.088
30	F3	17	0.28
30	F3	20	0.424
30	F3	24	0.136
30	F3	25	0.088
30	F3	26	0.184
30	F4	2	0.376
30	F4	6	0.088
30	F4	11	0.472
30	F4	14	0.088
30	F4	16	0.088
30	F4	18	-0.008
30	F4	22	0.088
30	F4	30	0.088
30	M1	1	0.952
30	M1	4	0.136
30	M1	5	0.568
30	M1	12	0.376
30	M1	13	-0.008

Listener	Talker	Condition	RA
30	M1	19	0.904
30	M1	21	0.472
30	M1	23	0.232
30	M1	27	-0.104
30	M1	28	0.904
30	M1	29	0.76
30	M3	3	0.52
30	M3	7	0.088
30	M3	8	0.04
30	M3	9	-0.056
30	M3	10	0.664
30	M3	15	0.04
30	M3	17	-0.056
30	M3	20	0.136
30	M3	24	-0.104
30	M3	25	-0.056
30	M3	26	-0.008
30	M4	2	0.52
30	M4	6	-0.056
30	M4	11	0.28
30	M4	14	-0.008
30	M4	16	0.04
30	M4	18	-0.104
30	M4	22	0.232
30	M4	30	0.04

APPENDIX C: SOURCE SPEECH RECORDING INFORMATION

Some speech material in this test was recorded in the laboratory at the Institute for Telecommunication Sciences in Boulder, Colorado. Recordings were performed in an NC-35-rated sound isolation chamber according to the following.

The microphone used in the source recording was a Shure Beta 53A microphone sampled at 48 kHz/16 bit on a Windows-based computer using commercially available software. Active signal level was normalized to -28 dB below overload using the ITU-T Recommendation P.56 voltmeter software [6] [11].

The speech material spoken by the talkers was the word list defined in the MRT description of [3] in the carrier sentence, "Please select the word …."

APPENDIX D: VOICE CODER SHORTHAND NOTATION

Table D-1. Voice Coder Shorthand Notation Used by TIA

New Name	Modulation	Name in 2003	Gross b/s	Net b/s	FEC	Back Ground Noise	Tones
QFA	QPSK-c	Baseline	7200	4400	Hard Dec		
QHA	QPSK-c	HR	3600	2450	Soft Dec		
FFB	F4FM	--	6300	4400	Soft Dec	X	X
FHB	F4FM	--	6300	2450	Soft Dec	X	X
QDB	QPSK-c	--	7200 / 3600	4400 / 2450	Soft Dec	X	X
QFB	QPSK-c	EFR	7200	4400	Soft Dec	X	X
QHB	QPSK-c	EHR	3600	2450	Soft Dec	X	X
QHC	QPSK-c	EHRS	3300	2250	Soft Dec	X	X

First Character		Modulation
	Q	QPSK-c modulation, includes C4FM and CQPSK
	F	F4FM modulation
Second Character		Full Rate/Half Rate/Dual Rate
	F	Full Rate
	H	Half Rate
	D	Dual Rate (Full and Half)
Third Character		Suffix Enhancement/Bit Stealing
	A	Basic, not enhanced
	B	Enhanced
	C	Enhanced with bit stealing

APPENDIX E: LISTENING LABORATORY CONFIGURATION

Two test chambers were set up to meet the standards set forth in Sections 8.10.4.10 - 8.10.4.15 of [9]. The physical layout of the chambers can be seen in Figure E-1. The loudspeaker carrying the speech signal sat on a table and was placed equidistant from the chamber side walls, on the edge of the table nearest the listener. The listening position was equidistant from the chamber side walls, and 150 cm away from the speech loudspeaker (in analogy to the talker-listener distance specified in 8.10.4.10). The two loudspeakers on either side of the table were used to produce the pink noise (allowed by 8.10.4.14). The loudspeakers were pointed toward the "back" of the room, and were not pointed directly at the listener, thus fulfilling 8.10.4.12. The combination of using two loudspeakers to produce the pink noise and the distance from the loudspeakers to the listening position created a quasi-uniform field of sound, thus satisfying 8.10.4.13.

In order to generate a field of "broadband pink noise" in compliance with section 8.10.4.11 of [9], a Gold Line Model PN2 Pink Noise Generator (PNG) was used. The PNG was modified to accept an external power source so any possible effect of a non-constant battery voltage could be avoided. The output of the PNG was fed into a General Radio Model 1952 Universal Filter, which was tuned to have a bandpass characteristic for the interval between 400 Hz and 4 kHz. The signal was then split into two signals in order to supply two different test chambers. After splitting, each signal passed through a mixer, equalizer, power amplifier and was finally delivered to the pair of loudspeakers located in a chamber. A Gold Line Model DSP30RM realtime spectrum analyzer was used to analyze the resulting acoustic pink noise spectrum in each chamber. Using information from the spectrum analyzer, the equalizers were tuned to achieve the best possible response for each test chamber.

Section 8.10.4.11 specifies that the pink noise generated should have a tolerance of 6 dB per octave band in the range of frequencies between 400 Hz and 4 kHz. In this range there are eleven third-octave bands. This means that only three full octave bands can be measured in this range, yet three octave bands do not fully cover the region of interest. However, it is possible to analyze two different sets of three full octave bands by grouping third-octave bands as shown in Tables E-1 and E-2. These two sets of bands are called octave band set A (OBSA) and octave band set B (OBSB).

After equalization was performed for each experimental chamber, the pink noise in each chamber was recorded and analyzed. A third octave analysis was performed in MATLAB. Energy in OBSA and OBSB were calculated by calculating the sum of the three third-octave bands included in their respective octave band. The relative noise power results for OBSA and OBSB are shown in Table E-1 and Table E-2 respectively for each chamber. For each chamber the 0 dB reference point is the midpoint between the highest and lowest measured octave band noise power. These tables show that 8.10.4.11 is satisfied in all cases.

A Brüel and Kjær Model 2250 sound level meter was used to verify that the noise level met specifications. The noise level in Chamber 1 was measured to be 69.4 dBA, and the noise level in Chamber 2 was measured to be 69.7 dBA, fulfilling 8.10.4.15.

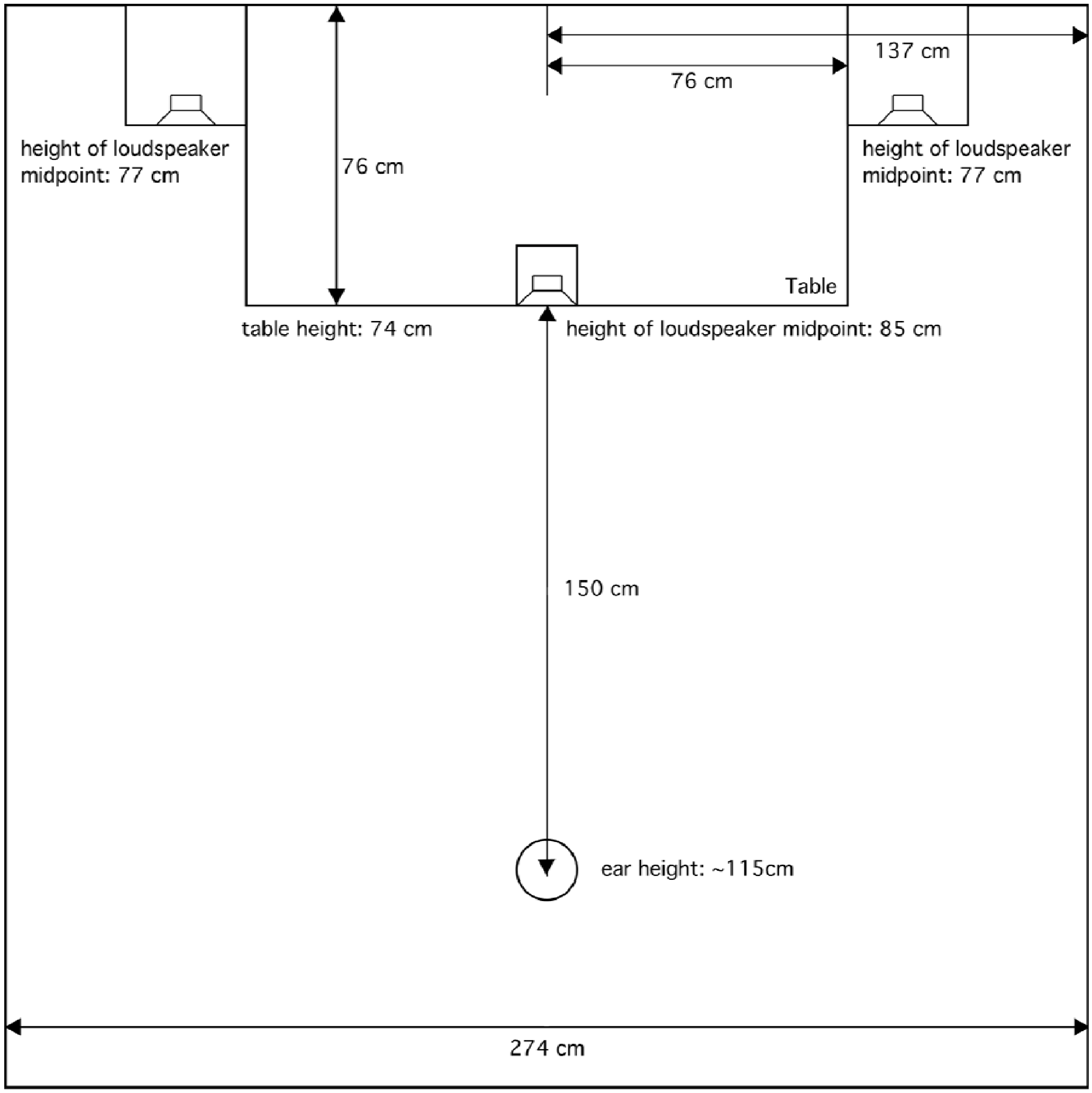

Figure E-1. Listening laboratory layout.

Table E-1. Relative RMS Noise Power per Octave in Two Chambers Using OBSA

Third Octave Bands	Chamber 1	Chamber 2
400, 500, 630 Hz	+4.1 dB	+4.0 dB
800,1000, 1250 Hz	+1.6 dB	+2.9 dB
1600, 2000, 2500 Hz	-0.5 dB	+1.3 dB

Table E-2. Relative RMS Noise Power per Octave in Two Chambers Using OBSB

OBSB	Chamber 1 (in dB RMS)	Chamber 2 (in dB RMS)
630, 800, 1000 Hz	+2.1	+3.0
1250, 1600, 2000 Hz	+0.2	+2.4
2500, 3150, 4000 Hz	-4.2	-4

Speech was generated in the two chambers using Fostex 6301B loudspeakers. The speech signal originates in MATLAB, propagates through the PC's sound card, then to a mixer, and finally to the loudspeaker. When the signal path was active but no signal was being sent to the speakers, the noise level in Chamber 1 fell to 22.3 dBA, and the level in Chamber 2 fell to 20.3 dBA. When speech was active in Chamber 1, speech levels ranged from 67-88 dBA, with undistorted, noise-free speech registering around 82 dBA. Similarly, active speech levels in Chamber 2 ranged from 70-86 dBA, and undistorted, noise-free speech registered around 82 dBA.

FORM **NTIA-29** (4-80)	U.S. DEPARTMENT OF COMMERCE NAT'L. TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION

BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION NO. TR-08-453	2. Government Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Intelligibility of Selected Radio Systems in the Presence of Fireground Noise: Test Plan and Results		5. Publication Date June 2008 6. Performing Organization Code
7. AUTHOR(S) David J. Atkinson, Andrew A. Catellier		9. Project/Task/Work Unit No. 3141000-300
8. PERFORMING ORGANIZATION NAME AND ADDRESS Institute for Telecommunication Sciences National Telecommunications & Information Administration U.S. Department of Commerce 325 Broadway Boulder, CO 80305		10. Contract/Grant No.
11. Sponsoring Organization Name and Address National Telecommunications & Information Administration Herbert C. Hoover Building 14th & Constitution Ave., NW Washington, DC 20230		12. Type of Report and Period Covered

14. SUPPLEMENTARY NOTES

15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

This report describes an experiment conducted to measure the intelligibility of selected radio communication systems when those systems are employed in high-background-noise environments experienced by firefighters. The test plan for a Modified Rhyme Test (MRT) is detailed, including requirements for source material preparation and listening test conduct. Finally, the results of the test, along with the data analysis, are presented. The results indicate that in some environments analog radios performed better than digital radios, and in some environments no radios performed well. This information should be considered whenever an agency is preparing to purchase and deploy a new communications system.

16. Key Words (Alphabetical order, separated by semicolons)

Intelligibility; Project 25; vocoder; modified rhyme test; noise; analog FM; land mobile radio; LMR, public safety, fire service

17. AVAILABILITY STATEMENT	18. Security Class. (This report)	20. Number of pages
☐ UNLIMITED.	Unclassified	87
	19. Security Class. (This page) Unclassified	21. Price:

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