NTIA Report 13-495

Intelligibility of Analog FM and Updated P25 Radio Systems in the Presence of Fireground Noise: Test Plan and Results

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ABBREVIATIONS/ACRONYMS

A-to-D	Analog to digital conversion
AFM	Analog frequency modulation
ANOVA	Analysis of variance
APCO	Association of Public Safety Communications Officials.
APWG	Audio Performance Working Group
BER	Bit error ratio—the ratio of errored bits to total bits in a sample
Codec	Combination of an encoder and decoder in series (encoder/decoder).
Coder	Same as encoder
C4FM	Compatible 4 level frequency modulation
CNR	Carrier to noise ratio
CRC	Cyclic redundancy check
CTCSS	Continuous tone-coded squelch system—a mechanism that allows multiple groups to use a common frequency without having to hear the other groups' messages
D-to-A	Digital to analog conversion
dB	Decibel
dBA	Sound pressure level in dB measured using the A-weighted scale.
dBC	Sound pressure level in dB measured using the C-weighted scale.
dBov	Decibels relative to overload point
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 [1]
DF	ANOVA variable: degrees of freedom (also used for Tukey Multiple Comparison Test calculations)
DHS	U.S. Department of Homeland Security
DSP	Digital signal processor
DVSI	Digital Voice Systems, Inc.
ENBW	Effective noise bandwidth
Enhanced	An updated version of the Project 25 vocoder defined in [1] with several enhancements, including soft-decision decoding, noise suppression, updated spectral masks, and echo cancellation
Encoder	Device for converting an analog signal into a digital representation. For the purposes of this document, this is a device compatible with [1]
F	ANOVA variable: f-statistic
FIR	Finite impulse response filter
FM	Frequency modulation
FPIC	Federal Partnership for Interoperable Communications
H	A hypothesis under evaluation

HATS	Head and torso simulator
HCPM	Harmonized continuous phase modulation
HDQPSK	Harmonized differential quadrature phase shift keying modulation
HPF	High pass filter
IAFC	International Association of Fire Chiefs
IF	Intermediate frequency
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
LLR	Log likelihood ratio
LPF	Low pass filter
LRP	Lip reference point of the HATS
MATLAB™	Mathematical analysis software by Mathworks, Inc.
MRT	Modified Rhyme Test as defined in [9]
MS	ANOVA variable: mean squares
NC	noise criteria
NFPA	National Fire Protection Association.
n	A value used as an index.
OBSA	Octave Band Set A
OBSB	Octave Band Set B
P	ANOVA variable: p value
P25 FR	Project 25 full-rate vocoder
P25 HR	Project 25 half-rate vocoder
PASS	Personal alert safety system, which emits a signal in the event that the user becomes incapacitated or needs assistance
PC	Personal computer
PCM	Pulse code modulation, a logarithmically companded and 64 kb/s encoded representation of speech
PNG	Pink noise generator
PSD	Power spectral density
PTT	Push to talk
R_A	Adjusted average intelligibility score
RF	Radio frequency
RMS	Root mean squared, the square root of the some of the mean values squared
SCBA	Self-contained breathing apparatus
SINAD	The ratio of signal to the summation of noise and distortion
SNR	Signal-to-noise ratio
SS	ANOVA variable: sum of squares
TIA	Telecommunications Industry Association
vocoder	Voice encoder/decoder

vox	Voice operated transmission
WAV	Waveform Audio File Format, a commonly used high-quality digital audio file format for storing high quality audio bitstreams on PCs

EXECUTIVE SUMMARY

In 2008, the Institute for Telecommunication Sciences (ITS) developed and conducted a test designed to measure the intelligibility of land mobile radio (LMR) systems in the presence of fireground noise. The test showed that fireground noise environments were especially challenging for the digital speech coder component of the Project 25 (P25) LMR system. ITS published a report describing the test [6]. This report was distributed widely among the public safety community and resulted in the establishment of a set of new best practices that were intended to increase intelligibility performance in extreme conditions [7] [8]. Additionally, the digital speech coder used in P25 LMR systems was enhanced in order to address operation in typical fireground noise environments.

In order to measure the effect of the combination of these new best practices and updated voice coder, ITS conducted a new test. The goal of this test was to compare the performance of three LMR systems in both noisy and quiet environments with and without radio channel impairments. The test compared four systems:

- Project 25 reference system with updated digital speech coder (full rate)
- Project 25 reference system with updated digital speech coder (half rate)
- 25 kHz Analog FM reference system
- 12.5 kHz Analog FM reference system

The test simulated the use of those three systems in six different noise environments:

- No noise, no mask
- No noise, mask vox port
- No noise, mask internal microphone
- Personal alert safety systems 1 and 2, mask vox port
- Personal alert safety systems 1 and 2, mask internal microphone
- Night club noise, no mask

The design of the test was informed by the design used in the 2008 test, and used a Modified Rhyme Test (MRT) to measure each reference system's intelligibility performance. An MRT is a test where a subject is asked to identify the word spoken at the end of a carrier sentence. In this case, a subject would hear the carrier sentence "Please select the word" followed by one of six rhyming words, for example: "bed," "led," "fed," "red," "wed," "shed." After hearing the sentence, the subject was then asked select the word that was spoken from a list presented through a graphical user interface (GUI).

To test the intelligibility of each reference system, recorded MRT sentences were played back through the mouth of a head and torso simulator (HATS), either directly into a microphone, through the vox port on a self-contained breathing apparatus (SCBA) and then into a microphone, or through the microphone included on an SCBA; acoustically mixed with different noise environments; and stored in high-fidelity audio files. These audio files were then processed by each reference system with and without simulated radio channel impairments. This resulted in a pool of 67,200 processed speech files that were used as stimuli during the MRT.

Fifty-two subjects participated in the test, each listening to a specific subset of 2,400 of all the processed speech files. Analysis of the test results showed that the combination of new best practices and the updated digital voice coder result in improved speech intelligibility performance when compared to the 2008 test. When tested with clean radio channels, analog systems generally performed marginally better but sometimes statistically significantly better. When each system was tested with a noisy radio channel, P25 systems performed better than analog systems in nearly every scenario. Both versions of the reference P25 system were found to be statistically similar in each scenario.

INTELLIGIBILITY OF ANALOG FM AND UPDATED P25 RADIO SYSTEMS IN THE PRESENCE OF FIREGROUND NOISE: TEST PLAN AND RESULTS

David J. Atkinson, Andrew A. Catellier[1]

This report describes a modified rhyme test (MRT) conducted to characterize the behavior of digital and analog communication in the presence of background noise and moderate RF channel degradation. This is done through the use of reference systems to provide a manufacturer-independent perspective on this issue.

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

1 INTRODUCTION

This report describes the evaluation procedure used to characterize and compare the response of digital and analog voice communication technology to public safety noise environments. 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 was designed to characterize and compare digital and analog communication technology in laboratory representations of public safety communications environments. Speech and noise from these environments were tested in a manufacturer-independent manner using reference communication systems. Reference communication systems also enabled the testing of communications technology. This is accomplished through the examination of the system performance in a subjective listening test in which the relative performance among the systems is measured in a quantitative and repeatable way.

The purpose of the subjective listening test was to evaluate reference systems under a variety of operating conditions. The operating conditions were chosen to be representative of those expected to be experienced in a public safety environment. Only a limited number of operating conditions were tested. To test all possible operating conditions would lead to a test that would be too unwieldy to conduct.

The test was designed to measure intelligibility through communication technologies being used in background noise situations. The test plan was developed in conjunction with the Audio Performance Working Group (APWG) and tests were conducted at the Public Safety

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Communications Research (PSCR)[2] Laboratories in Boulder, Colorado, by researchers from the Institute for Telecommunication Sciences (ITS), National Telecommunications and Information Administration (NTIA).

1.1 Project 25 Standardization

Project 25 is a public-private partnership established in 1989 by government entities and the Association of Public-Safety Communications Officials – International (APCO) for the primary purpose of realizing the benefits of digital narrowband land mobile radio (LMR) technologies for public safety practitioners and other users. Public safety, government, and manufacturer representatives participate in the P25 process to develop voluntary consensus standards with the support of the American National Standards Institute (ANSI)-accredited Telecommunications Industry Association (TIA). The goal of P25 is to specify formal standards for interfaces between the various components of an LMR system, commonly used by emergency responders, to enable easy interoperability of radios and other components, regardless of manufacturer.

The Project 25 (P25) vocoder standard was selected in 1992. At that time, several tests were conducted by P25 committees to ensure that the best available vocoder was selected. The selected vocoder, known as the baseline full-rate vocoder, was standardized by TIA as TIA-102.BABA [1]. Further work continued on the development of the vocoder, and a dual-rate version of the vocoder was adopted in 2009 (TIA-102.BABA-1) [2] supported by additional tests (TSB-102.BABE [3], TSB-102.BABF [4]). Additionally, TIA adopted standard performance tests (TIA-102.BABG [5]) to ensure implemented vocoder-based systems have certain performance characteristics revealed by those tests.

As P25 networks were deployed, there was a growing recognition that there were certain noisy environments that were problematic for the digital technologies. Of course, public safety practitioners can't simply choose not to operate in these noisy environments. This has appeared most consistently in tactical fireground communications, and has been raised to the national level by agencies such as Boise [Idaho] Fire, Fairfax [Virginia] Fire, Littleton [Colorado] Fire, and Phoenix [Arizona] Fire. The International Association of Fire Chiefs (IAFC) created a Digital Project Working Group (DPWG) to perform initial investigations into this issue.

The work of the DPWG resulted in publication of the results of an intelligibility test as an NTIA technical report [6], the release of an IAFC Interim Report and Recommendations [7], and publication of Portable Radio Best Practices [8] by the IAFC. In response to this issue, the APCO Project 25 Interface Committee (APIC) created the Audio Performance Working Group (APWG) to perform testing to specifically quantify the problem and identify potential solutions, and to develop testing methods that could be used to establish performance of communication technologies. These recommendations and potential solutions would be provided as recommendations to APIC and APIC Task Groups.

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[2] The PSCR program is a joint effort between the National Institute of Standards and Technology/ Law Enforcement Standards Office (NIST/OLES) and NTIA/ITS sponsored by the Department of Homeland Security, Office for Interoperability and Compatibility and Office of Emergency Communications, to advance public safety communications interoperability.

1.2 Scope of this Report

This report describes the procedures used to characterize and compare the intelligibility behavior of technologies using both analog communications and the TIA 102.BABA [1] compatible speech codec in environmental noise, moderately degraded channel conditions, and using two different self-contained breathing apparatus (SCBA) masks. The original baseline speech codec from 1992 is the baseline full rate system described in [1]. The 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.

This vocoder was updated in 2003 to what became known as the enhanced dual rate vocoder, featuring bit rates of 7200 b/s and 3600 b/s. This version of the vocoder was subject to testing from 2003 to 2007 and performance measurement methods for the enhanced version of the vocoder are included in [5]. A further updated version of the codec was subsequently released in September 2009, referred to as version 1.60,[3] and this is the codec for the Project 25 Reference System described in Section 2. This version of the vocoder was chosen because there are a limited number of conditions that can be practically included in the test and because it represents the state-of-the-art of P25 vocoders current at the time of the tests. As such, it was expected to provide the best performance of the P25 vocoder family.

The intelligibility evaluation of the digital and analog technologies under noise and degraded channel conditions is based on ANSI S3.2 and NFPA 1981 methods for speech intelligibility measurement [9] [10]. The speech preparation, processing, and presentation methods used in prior TIA subjective listening tests are appropriate for this intelligibility test and are listed in [6], [10] and [11].

This report takes the approach of comparing a reference system incorporating the speech codec with reference systems using analog frequency modulation (AFM). The experiment compared the coding mechanisms with various background noise and channel conditions as might occur on a land mobile radio channel.

1.3 Overview

During this test, the performance of a reference implementation of a P25 radio system was compared to reference implementations of AFM systems. Specifically, the test evaluated the intelligibility of these reference systems using selected background noise and channel conditions. The test results were then compared among the reference systems. There were four reference systems in this test. These reference systems are listed below and more fully described in Section 2.

1. Project 25 Full-Rate (P25 FR) Reference System with vocoder DSP version 1.60 (software version 1.40e)

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[3] Version 1.60 refers to the Digital Signal Processor (DSP) code version of the vocoder. According to Digital Voice Systems, Inc., this is equivalent to PC executable floating point version 1.40e, which is the software used to conduct this test.

2. Project 25 Half-Rate (P25 HR) Reference System with vocoder DSP version 1.60 (software version 1.40e)
3. 25 kHz AFM Reference System
4. 12.5 kHz AFM Reference System

The intelligibility of each system was subjectively rated in each environmental condition specified.

The intelligibility of a communication technology can be difficult to quantify since it is a subjective issue, relying on humans to be able to discern words. This performance evaluation relied on subjective testing using a panel of listeners who listened to speech passing through a system and attempted to understand what was said. Since discernment of listeners can vary, results were obtained from a number of listeners and averaged to obtain an overall score.

To evaluate the intelligibility it was necessary to conduct an experiment in a controlled manner so that unintentional variation in the scoring could be avoided. The purpose of the testing was to characterize and compare the behavior of analog and digital voice communication technologies in public safety noise environments. The confidence we have that any apparent differences in performance were due to communication system effects and not random statistical variation depends upon how well we prevented differences from occurring in the testing.

The statistical controls for the experiment and the analysis are given in Section 5. The listening test evaluated the reference systems under operating conditions, particularly different acoustic background noise conditions and different radio channel conditions. The acoustic background noise conditions were created from high-quality recordings of selected noisy acoustic environments encountered by LMR users in the fireground, reproduced in a laboratory environment. The radio channel conditions included an ideal channel and a moderately degraded channel and were simulated via software. This experiment used the following environmental noise conditions. Section 2.3 provides additional information about the background noises.

1. No background noise, no mask (referred to as the “clean” condition)
2. Mask voice port with no background noise
3. Mask with internal microphone with no background noise
4. Two manufacturers’ personal alert safety system (PASS) alarms, with mask using voice port
5. Two manufacturers’ PASS alarms, with mask using internal microphone
6. Night club, without mask

The experiment also used simulations of ideal and degraded channel conditions. The simulated degraded channel conditions are listed in Table 1. The noise conditions shown are static, not faded, and both ideal and degraded channels were applied to the noise conditions listed above.

Table 1. Simulated degraded static RF channel conditions.

System	RF Level	IF Noise Bandwidth	CNR
25 kHz Analog	-117 dBm	13.0 kHz	6.9 dB
12.5 kHz Analog	-117 dBm	8.0 kHz	9.0 dB
P25 FR	-117 dBm	5.8 kHz	10.4 dB
P25 HR	-117 dBm	6.0 kHz	10.2 dB

In Section 2, Figure 2 shows a schematic of the three major stages for generating the processed files that were presented to the listener: generating high-quality recordings of speech mixed with noise, processing the recordings with software-based reference systems, and finally generating high-quality recordings of the result. Note that the P25 FR and P25 HR used the same executable code, just with different flags to invoke the proper rate. The reference system output files were used for playback to the listener, who then attempted to understand the spoken words. The input, playback and reference systems are described in Section 2

The overall plan of the test is outlined in Figure 1. The test began with the source audio material. There were several conditions placed on the source material, and these are covered in Section 3. The source audio material speech files were then acoustically mixed with the environmental noise conditions in a sound isolation chamber and recorded to files on a computer. Those files were then processed by the four reference systems, with different simulated channel conditions, which produced numerous output audio files. This procedure is given in Section 4. The output audio files were then organized into randomized blocks in order to provide samples suitable for a listening test. The randomization step, the listening test, and the analysis are described in Section 5. The result of the test is then presented in Section 6, which also describes a software tool used for this analysis.

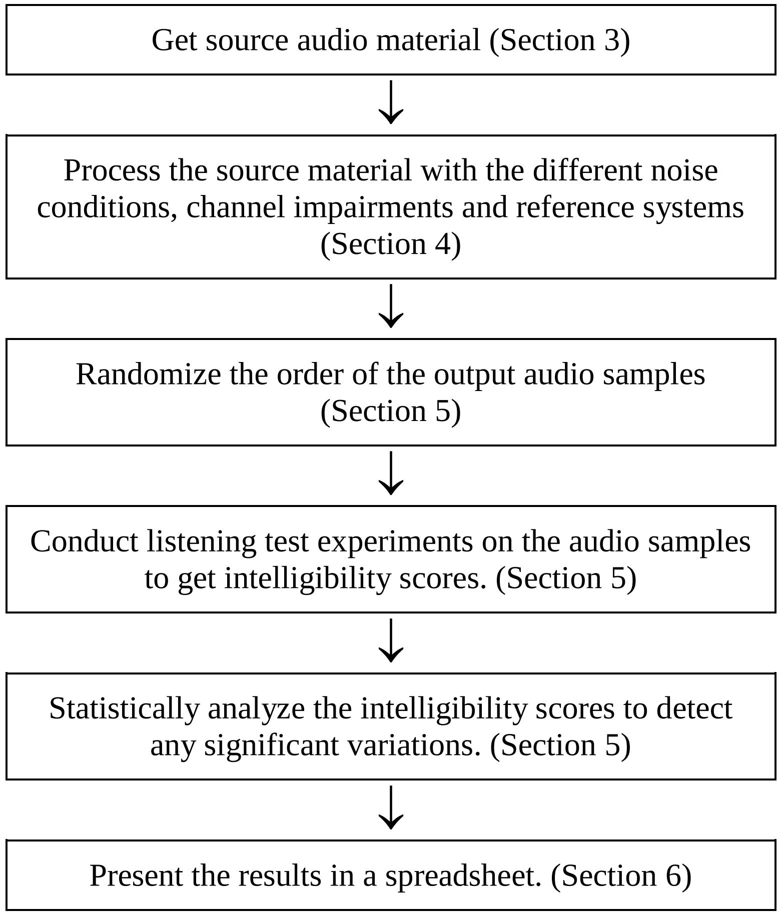

Figure 1. Test plan overview.

2 TEST ELEMENTS

Figure 2 shows a high-level schematic of the three major stages for generating the processed files that were presented to the listener. The first stage, or input system, was used to generate recordings (WAV files) of mixed speech and noise. The mixed speech and noise was then processed through the software-based reference systems (with or without channel impairments) and again recorded to WAV files. Note that the P25 FR and P25 HR used the same executable code with different flags to invoke the full-rate and half-rate options. The reference system output files were used for playback to the listener, who then attempted to understand the spoken words. Each of these components is described in more detail in the sections below.

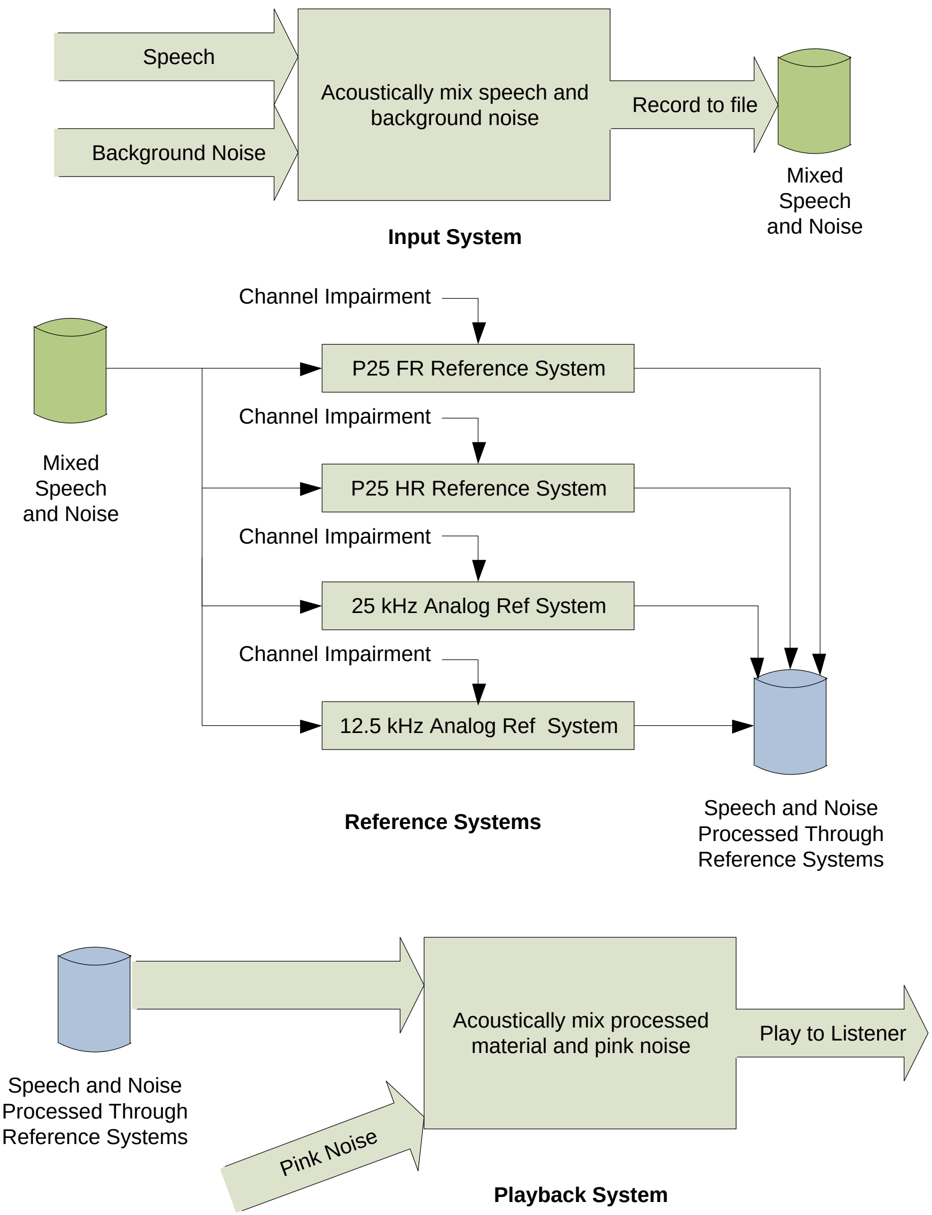

Figure 2. Schematic overview of input, reference, and playback systems.

2.1 Input and Playback Systems

The input and playback systems were used to record and play back, respectively, the audio samples for this test. A schematic diagram of the input system is shown in Figure 3; the system produced audio files that were sampled at 16 bits per sample and 48000 samples per second. The audio recorded consisted of source speech samples played through a head and torso simulator (HATS) into the acoustic environments listed in Section 1.3. This procedure is detailed in Section 4.2. The files were then processed through the reference systems and played out through the output system shown below.

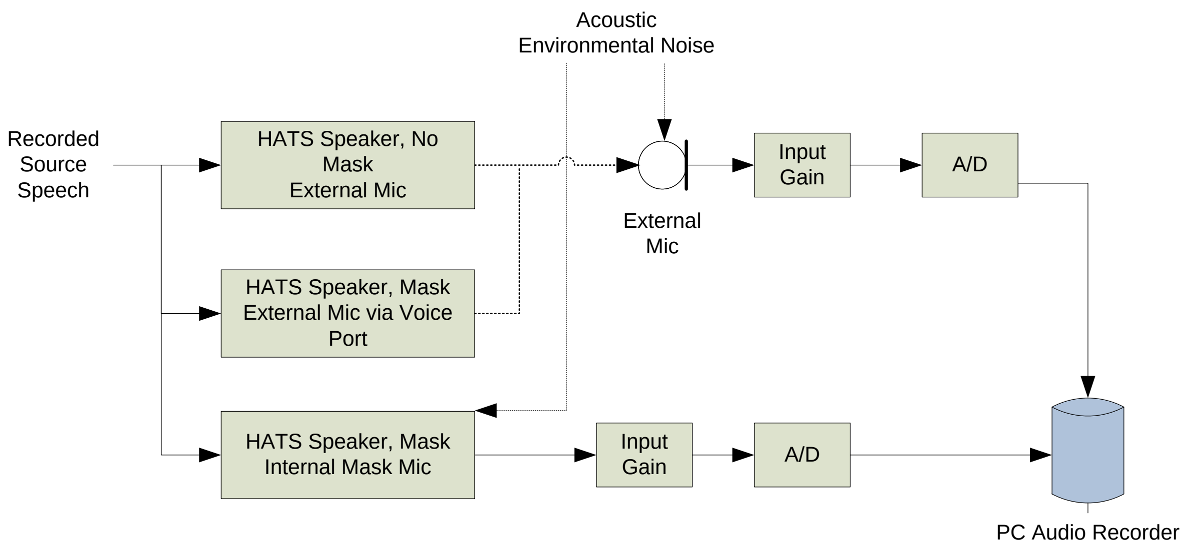

Figure 3. Input system for test. Solid lines represent electrical paths, dotted lines represent acoustic paths.

Characteristics associated with the input system are listed below:

1. A-to-D is ≥ 16 bits, ≥ 85 dB SNR
2. Input gain was set to provide active speech record level of approximately -22 dBm0
3. PC was used to record, store and play audio files
4. Ensure hum and noise were down by at least 60 dB[4]
5. External microphone was a Beyerdynamics MCD-100 cardioid electret microphone representing a high-quality version of a lapel microphone
6. Internal microphone was provided and integrated by the mask manufacturer

[4] This specification was proposed by an APWG member and agreed to by the APWG as part of the discussion during experiment planning.

The playback system is shown in Figure 4, and was used to present the audio test samples (i.e., the output of the reference systems) to the listener. Note that the listening environment (described in Section 5.3 and Appendix D) also included a pink noise generation system.

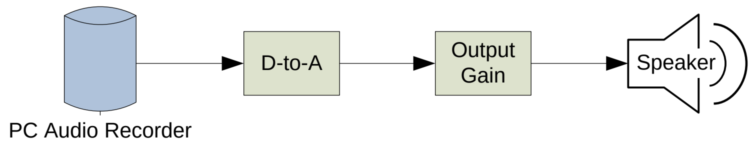

Figure 4. Output system for test.

Characteristics associated with the output system are listed below:

1. D-to-A is ≥ 16 bits, ≥ 85 dB SNR
2. Output gain set to 84 dBA[5] at Listener Reference Point.
3. Ensure hum and noise were down by at least 60 dB and preferably by at least 80 dB
4. Speaker/amplifier equalized to flat +- 3dB from 50 Hz to 10 kHz

2.2 Reference Systems

There are four reference systems defined for this test.

1. Project 25 Full-Rate (P25 FR) Reference System with vocoder DSP version 1.60 (software version 1.40e)
2. Project 25 Half-Rate (P25 HR) Reference System with vocoder DSP version 1.60 (software version 1.40e)
3. 25 kHz AFM reference system
4. 12.5 kHz AFM reference system

For each of the reference systems described below, the input file was a 48 kHz sampled 16-bit WAV file recorded as indicated in Section 2.1. The output files were the same format and were used to play out audio for the listeners.

[5] This level reflects the 85 dBA maximum speech level at the measurement point specified in section 8.25 of NFPA 1981[10], the -5 dB change in the listening environmental noise to avoid listener fatigue, an estimated +10 dB gain from the voice amplifier, and the -6 dB change caused by moving the measurement point from 1.5 m from the speech source to 3.0 m from the speech source (i.e., 85 – 5 + 10 – 6 = 84 dBA).

2.2.1 Project 25 Reference Systems

Figure 5 shows the configuration of the two P25 Reference Systems. The two P25 reference systems were the same executable code and could accept a variety of parameters as well as text files representing the bit error conditions on the RF channel for each bit in the signal. This enabled the same executable code to be used for both the P25 FR and P25 HR conditions. The only difference between them was calling the software with the "-fr" flag for full rate and the "-hr" flag for half-rate.

To incorporate bit-errored channel conditions, the software accepted two files as input. One file had values of 0 or 1 to respectively represent absence or presence of a bit error. This is often called a BER file. The other file had numbers in the range 0.000 to 1.000 to represent log likelihood ratios (LLRs) for each bit. Using an LLR value closer to unity represents greater certainty that the corresponding bit is correct.

The BER and LLR files for the P25 FR conditions assume the underlying RF channel was a 12.5 kHz channel operating at 9.6 kb/s with C4FM modulation. The BER and LLR files were sieved to produce files for 7.2 kb/s that correspond to the bits on the channel that were used by the vocoder. The vocoder bit rate was 7.2 kb/s.

The BER and LLR files for the P25 HR conditions assumed the underlying RF channel is a 12.5 kHz two-slot TDMA channel operating at 12 kb/s with HDQPSK modulation.[6] The BER and LLR files were sieved to produce files for 3.6 kb/s that correspond to the bits on the channel that were used by the vocoder. The vocoder bit rate was 3.6 kb/s.

Other parameters used default values in the software, in particular the number of soft decision bits (sdbits = 8) and the automatic gain control setting (off).

[6] HDQPSK modulation is used from the fixed station to the subscriber units in P25 Phase 2. It was chosen for this experiment because the channel models are more mature than those for HCPM, the modulation used by the subscriber units in Phase 2.

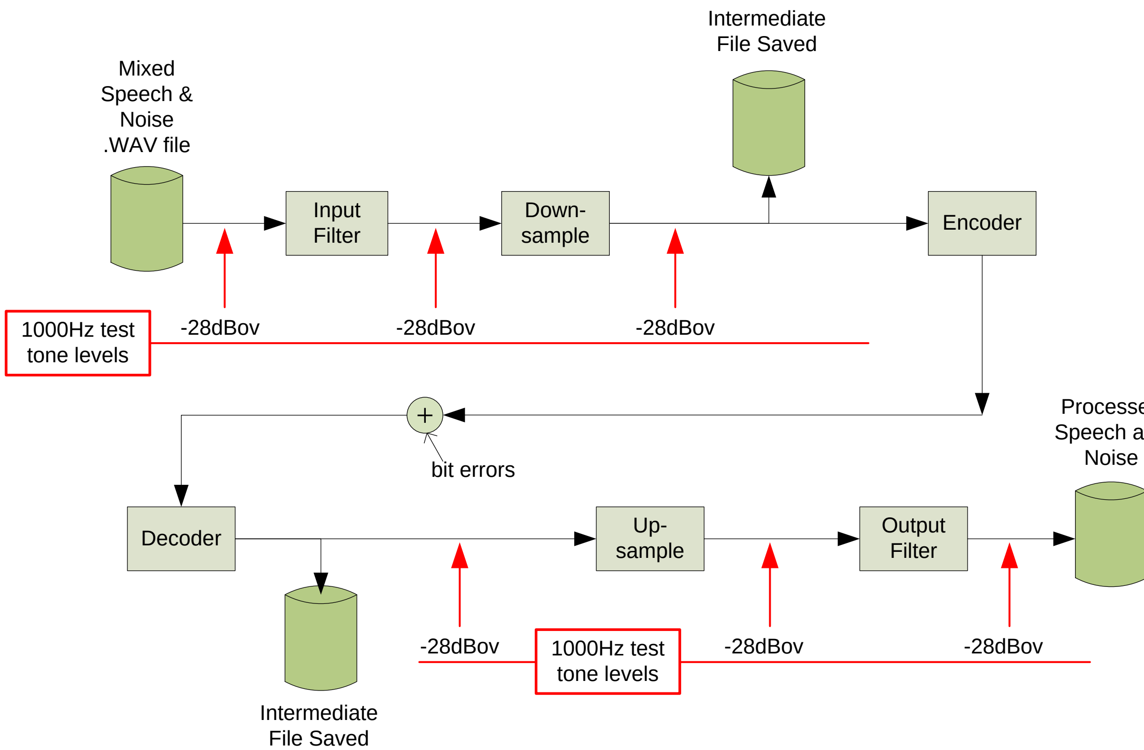

Figure 5. P25 reference systems configuration.

Characteristics associated with the P25 reference systems are listed below:

1. Input filter was a two-stage filter with high-pass and low-pass stages
    a. Low pass filter has 3700 Hz passband, ≥ 70 dB stopband attenuation (≥ 4300 Hz)
    b. High-pass filter was 2nd order DC blocking filter with 50 Hz cutoff
2. Downsampling from 48 kHz to 8 kHz sample rate was done with the change rate program defined in [16], utilizing the high-quality anti-aliasing filter
3. Vocoder was the Project 25 Dual-Rate Version 1.60 equivalent in MS-DOS executable form using command line flags to select full-rate (-fr) and half-rate (-hr)
4. Upsampling from 8 kHz to 48 kHz sample rate was done with the change rate program defined in [16], utilizing the high-quality reconstruction filter
5. Output filter had the same characteristics as input filter

2.2.2 25 kHz AFM Reference System

Figure 6 shows the configuration of the 25 kHz AFM reference system. The configuration included representative filters as would be used in typical analog transmitters and receivers, as well as frequency modulation, deviation limiting, and frequency demodulation. The 25 kHz AFM reference system passed the spec limits for audio filtering and deviation limiting given in the TIA-603 standard for 25 kHz analog channels [12]. While this is representative of typical radio designs, alternative designs are also possible.

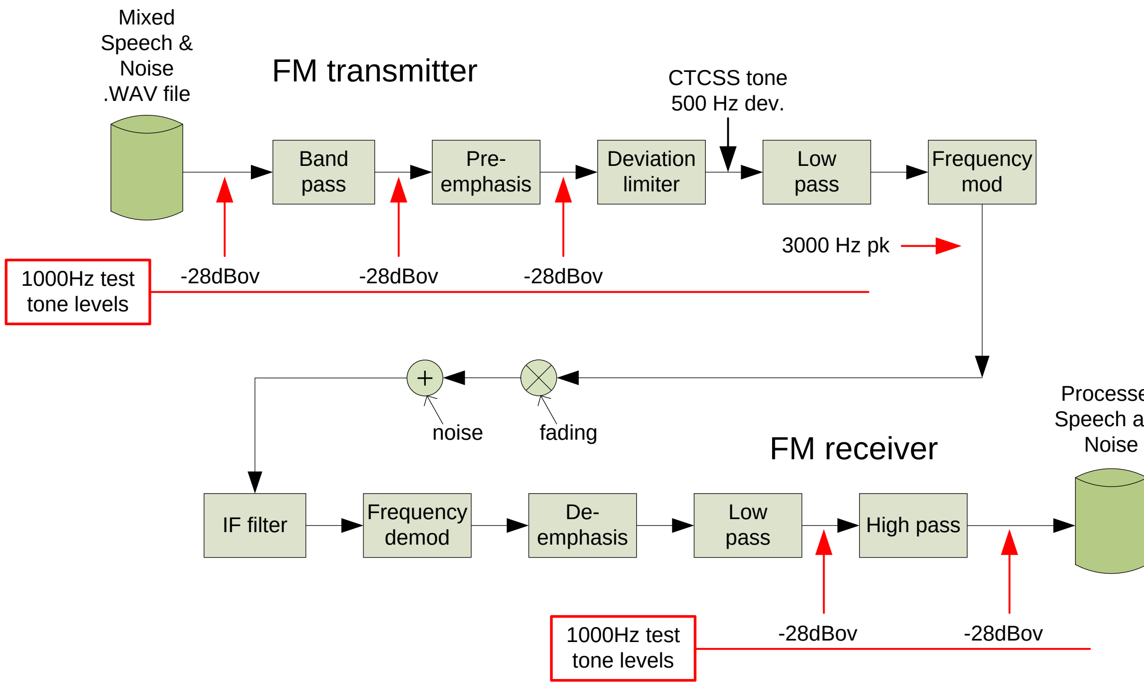

Figure 6. 25 kHz AFM reference system configuration.

The 25 kHz AFM reference system was implemented in MATLAB™ code. Characteristics associated with the 25 kHz AFM reference system are listed below:

1. Level Setting
    a. 1000 Hz tone at -28 dBov produced 60% deviation in RF modulated signal
2. Assumed equivalent of a microphone input, so guard tone notch filter not needed
3. Bandpass was a two-stage filter with high-pass and low-pass stages
    a. High pass was a Type 2 Chebyshev HP (N = 5, -40 dB at 190 Hz)
    b. Low pass was a Type 1 Chebyshev LP (N = 4, -0.5 dB at 3000 Hz)
4. Preemphasis was according to TIA 603 (1 pole at 5000 Hz, slope +6 dB/octave from 300 to 3000 Hz)
5. Assume CTCSS was used
6. Deviation limiter assumed a hard limiter at 5 kHz deviation

7. Low pass filter was a windowed FIR LPF

8. Frequency modulation responds beyond 6 kHz

9. The IF filter was a cascade of three sections. Each section was a 4 pole Butterworth design with nominal 3dB BW of 15.152 kHz. The effective noise bandwidth (ENBW) of the overall IF filter was designed to equal 13.000 kHz.

10. Frequency demodulation responded beyond IF bandwidth

11. Deemphasis was according to TIA 603 [12] (1 pole at 300 Hz, slope -6 dB/octave from 300 to 3000 Hz)

12. Low pass filter was a Butterworth (4 pole, 3000 Hz)

13. High pass filter was a Type 2 Chebyshev HP (N=5, -40 dB at 190 Hz)

14. The reference system used 48 kHz sample rate, which is more than sufficient to model the internal audio and IF signals.

2.2.3 12.5 kHz AFM Reference System

Figure 7 shows the configuration of the 12.5 kHz AFM reference system. The configuration included representative filters as would be used in typical analog transmitters and receivers, as well as frequency modulation, deviation limiting, and frequency demodulation. The 12.5 kHz AFM reference system passed the spec limits for audio filtering and deviation limiting given in the TIA-603 standard for 12.5 kHz analog channels. While this is representative of typical radio designs, alternative designs are also possible.

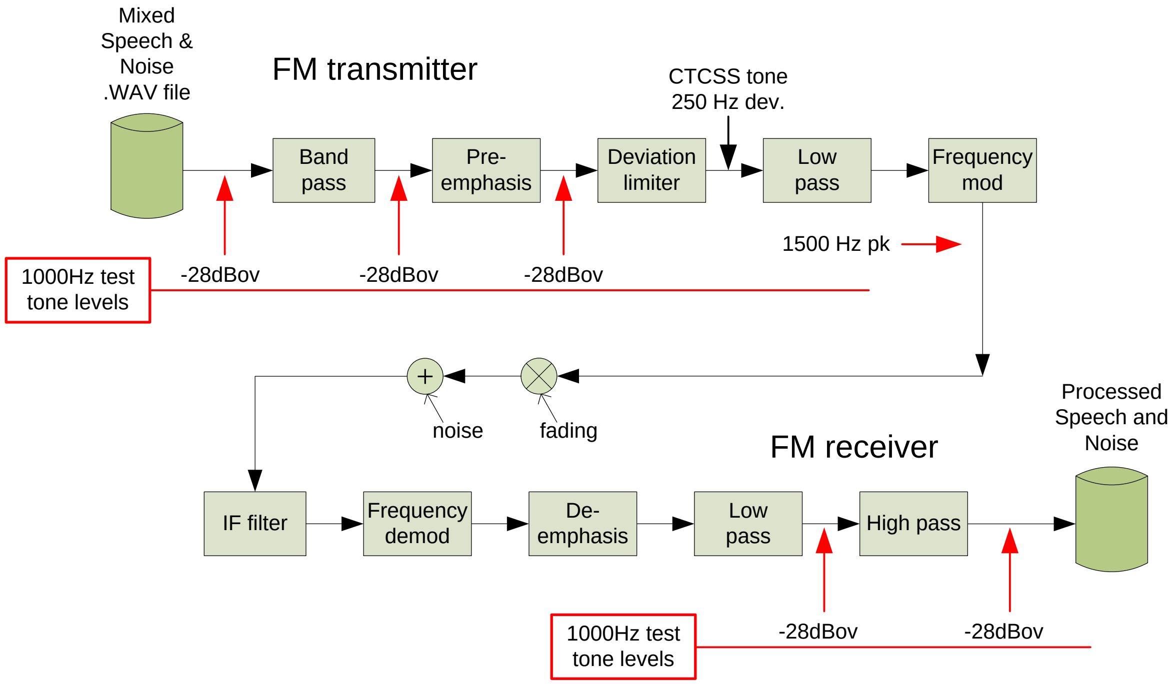

Figure 7. 12.5 kHz AFM reference system configuration.

The 12.5 kHz AFM reference system was implemented in MATLAB™ code. Characteristics associated with the 12.5 kHz AFM reference system are listed below:

1. Level Setting
    a. 1000 Hz tone at -28 dBov produced 60% deviation in RF modulated signal
2. Assumed equivalent of a microphone input, so guard tone notch filter not needed
3. Bandpass was a two-stage filter with high-pass and low-pass stages
    a. High pass was a Type 2 Chebyshev HP (N = 5, -40 dB at 190 Hz)
    b. Low pass was a Type 1 Chebyshev LP (N = 4, -0.5 dB at 3000 Hz)
4. Preemphasis was according to TIA 603 (1 pole at 5000 Hz, slope +6 dB/octave from 300 to 3000 Hz)
5. Assume CTCSS was used
6. Deviation limiter assumed a hard limiter at 2.5 kHz deviation
7. Low pass filter was a windowed FIR LPF
8. Frequency modulation responded beyond 6 kHz

9. The IF filter was a cascade of 3 sections. Each section was a 4 pole Butterworth design with nominal 3dB BW of 9.434 kHz. The ENBW of the overall IF filter was designed to equal 8.000 kHz.

10. Frequency demodulation responded beyond IF bandwidth

11. Deemphasis was according to TIA 603 [12] (1 pole at 300 Hz, slope -6 dB/octave from 300 to 3000 Hz)

12. Low pass filter was a Butterworth (4 pole, 3000 Hz)

13. High pass filter was a Type 2 Chebyshev HP (N=5, -40 dB at 190 Hz)

14. The reference system used 48 kHz sample rate, which is more than sufficient to model the internal audio and IF signals.

2.3 Acoustic Environments

The experiment tested the performance of the communication systems (and their respective vocoders) with background noise mixed in with the speech. The background noise was mixed with the speech for a specific signal-to-noise ratio. Four acoustic environments were evaluated in this experiment:

1. No background noise (no mask)

2. Mask with no background noise

3. Two PASS alarms (with mask)

4. Night club noise (with no mask).

This experiment was intended to include acoustic environments that occur with talkers who are wearing an SCBA mask as standardized in the NFPA 1981 standard [10]. The SCBA mask covers the entire face, and provides a regulated air supply for the wearer. Therefore, the SCBA mask has a significant effect on the audio to be transmitted through the radio system. That is a subject of interest to this experiment. The physical configuration used to create the acoustic environments is described in Section 4.2.

A PASS alarm is a device commonly used by fire fighters, often while an SCBA mask is also used. The PASS alarm is standardized in the NFPA 1982 standard [13]. When the PASS alarm is activated it emits a loud, high frequency audible signal. One possible scenario for having to communicate in the presence of PASS noise is for a rescue team to talk on radios while recovering a downed two-person team. This scenario involved two PASS alarms from a single manufacturer mixed together for the background noise. The PASS alarm signals were mixed to provide the most consistent noise level possible. In the case of PASS 1, the second signal was offset by 43% of the alarm cycle duration. In the case of PASS 2, the second signal was offset by 45% of the alarm cycle duration.

The noise conditions represented acoustic noise environments from which a user might be transmitting and that are commonly known to cause difficulty with communications. The SNRs were chosen to approximate sound level conditions in the application environment.

The power spectral densities (PSDs) and spectrograms of the three background noises are given in Figures 8 through 10. The PSDs show relative power versus frequency. The spectrograms show power (by color) as a function of time (on the horizontal axis) and frequency (on the vertical 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 11. There is notable signal loss in the 300–500 Hz range and the 1500–3000 Hz range. This is significant because these ranges of frequencies are important to intelligibility.

The PSDs in Figures 8 through 10 and the acoustic path loss in Figure 11 were computed using MATLAB™ mathematical analysis software. The computation method (Welch) [14], number of elements in the transform (Nfft), and the size and shape of the computational window (Hamming [14], 1024) were parameters provided to the MATLAB™ algorithms.

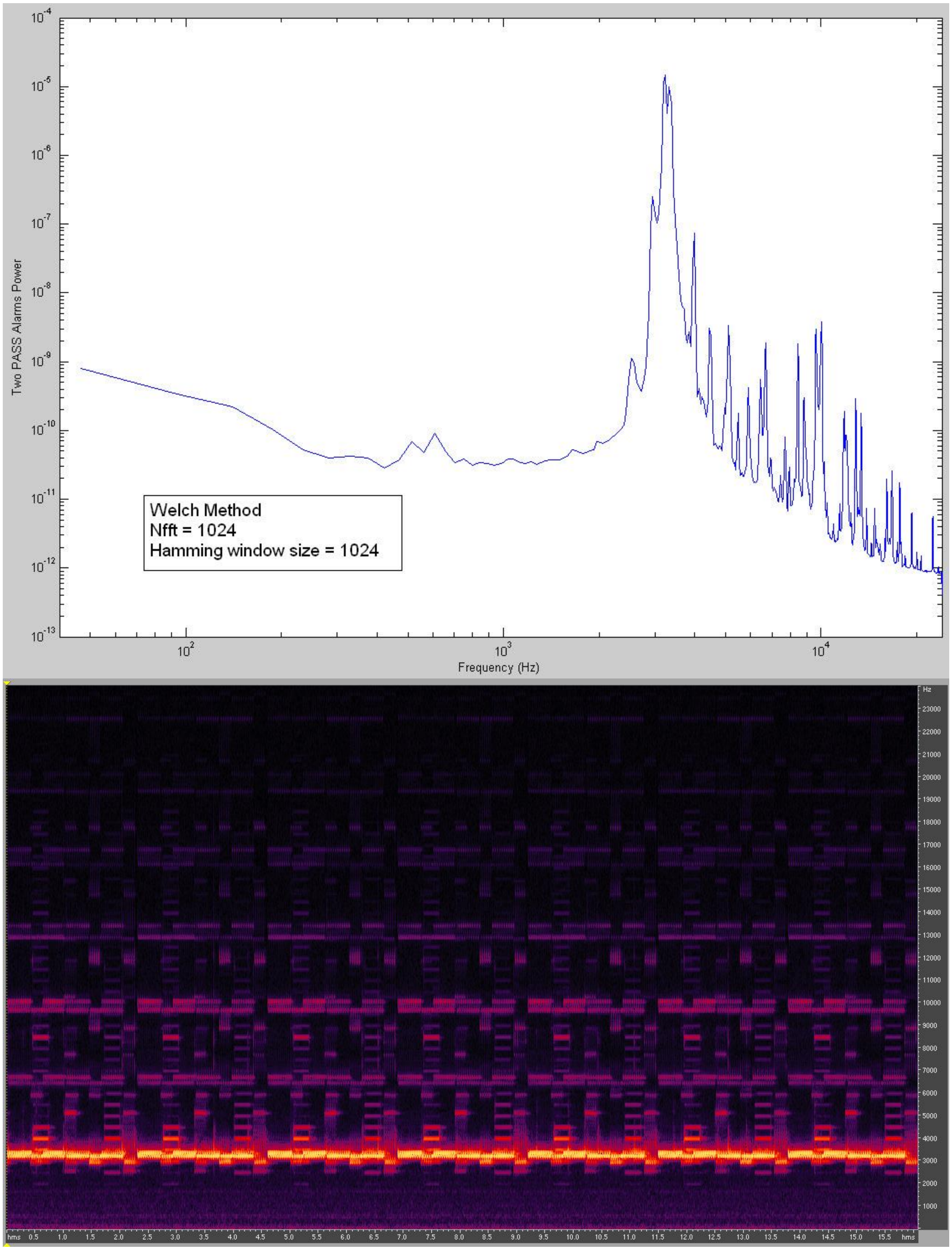

Figure 8. PSD plot and spectrogram of two PASS alarms from manufacturer 1 sounding. Spectrogram has x-axis in seconds and y-axis in Hz.

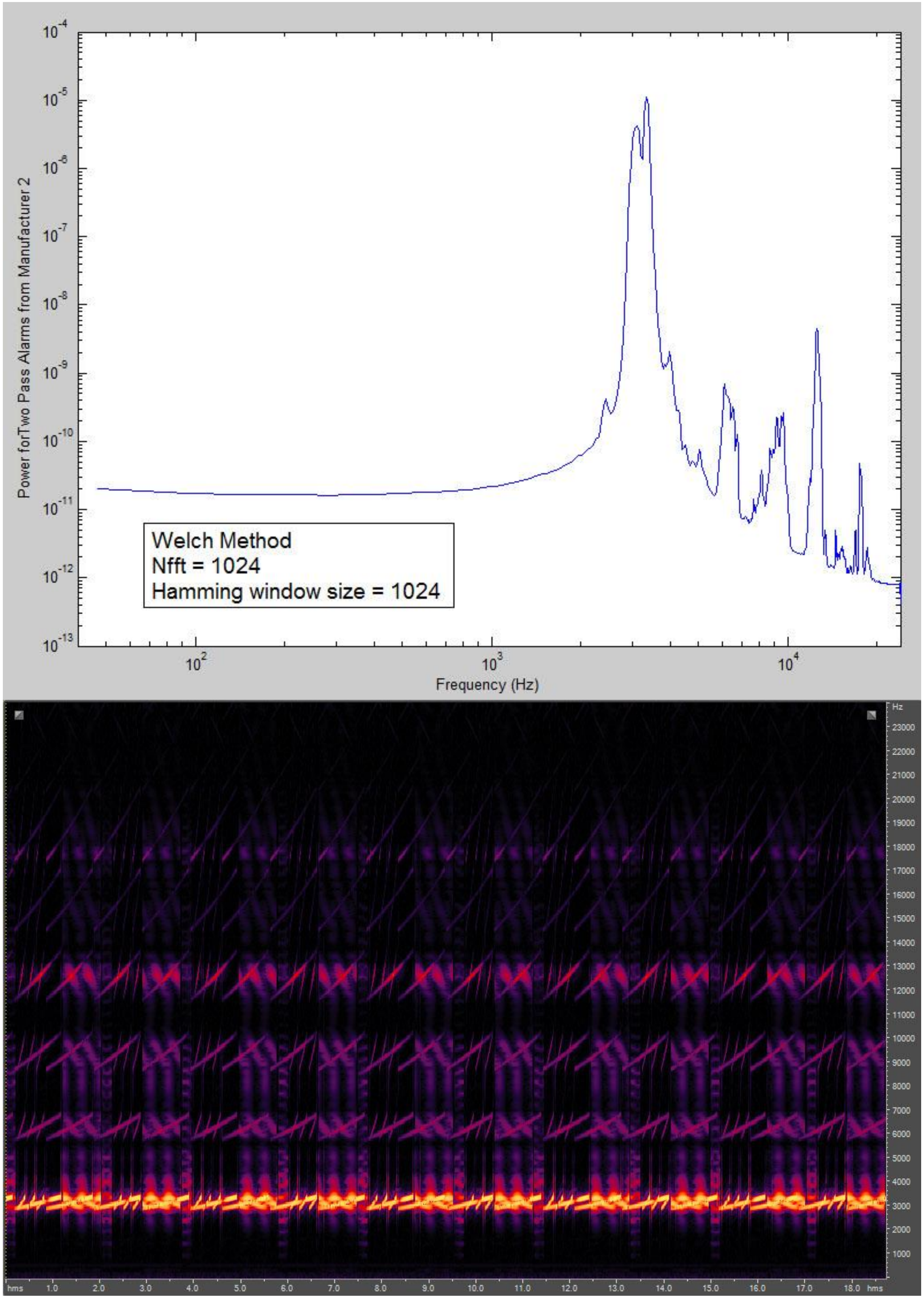

Figure 9. PSD plot and spectrogram of two PASS alarms from manufacturer 2 sounding. Spectrogram has x-axis in seconds and y-axis in Hz.

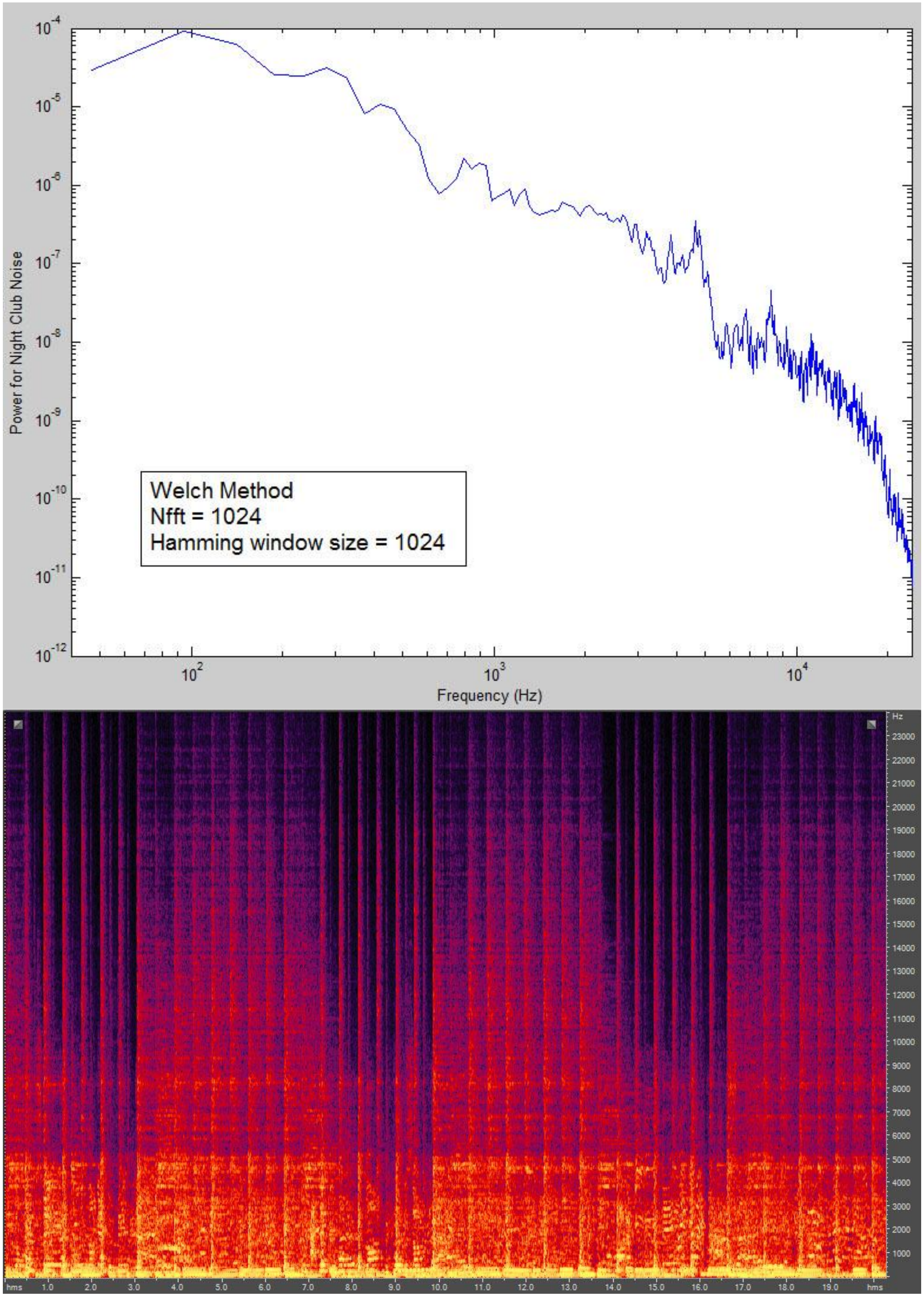

Figure 10. PSD plot and spectrogram of night club noise. Spectrogram has x-axis in seconds and y-axis in Hz.

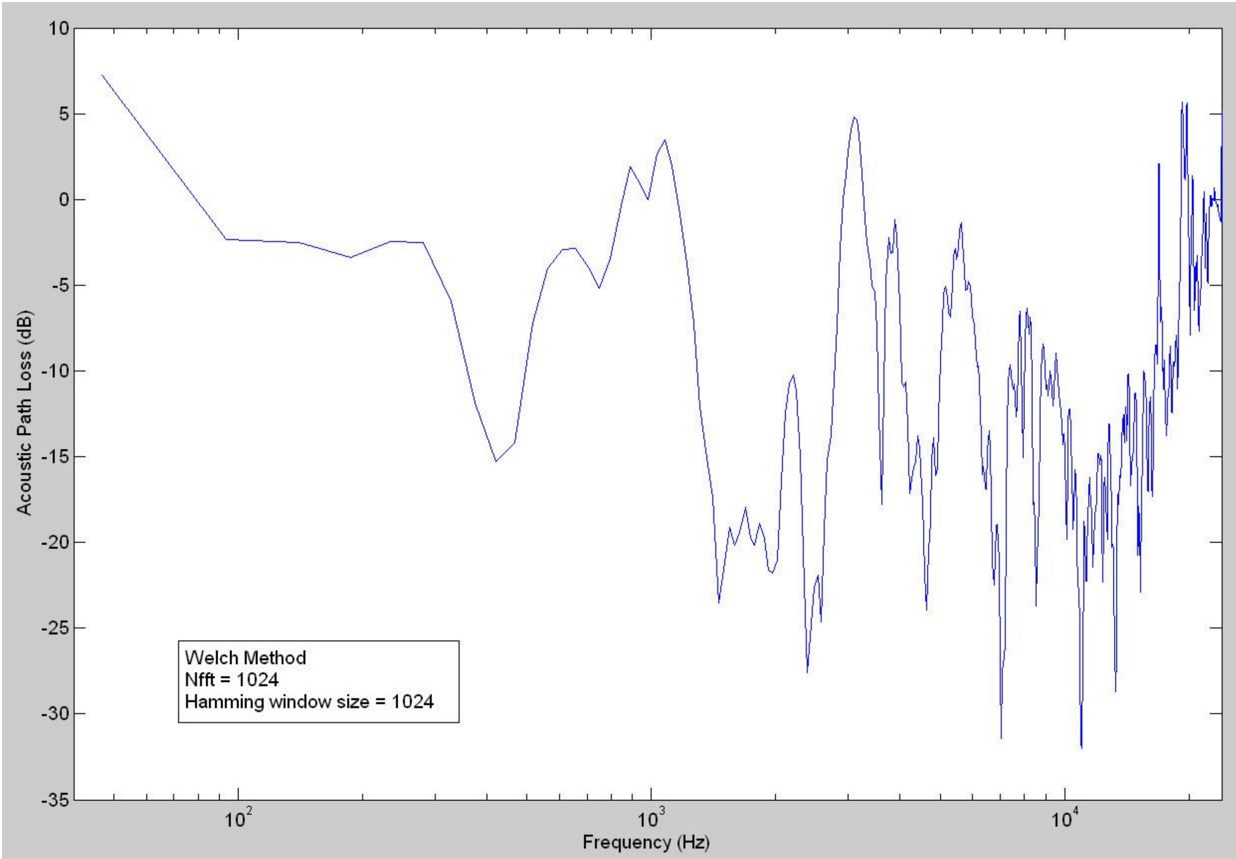

Figure 11. Acoustic path loss through SCBA mask.

2.4 Channel Impairments

In addition to emulating a clean RF channel, this experiment also used emulations of static channel degradations. Table 2 shows degraded static RF channel conditions applied to all four noise conditions.

Table 2. Degraded static RF channel conditions.

System	RF Level	IF Noise Bandwidth	CNR
25 kHz Analog	-117 dBm	13.0 kHz	6.9 dB
12.5 kHz Analog	-117 dBm	8.0 kHz	9.0 dB
P25 FR	-117 dBm	5.8 kHz	10.4 dB
P25 HR	-117 dBm	6.0 kHz	10.2 dB

2.5 Test Conditions

The noise environments, mask presence, and RF channel conditions used in the experiment are provided in the first three columns of Table 3. The noise environment, mask, and RF channel scenarios combine with the four reference systems to provide the list of conditions. Table 3 shows which noise environments and channel conditions were used with which reference systems. Appendix A contains a full list of conditions for the experiment.

Table 3. Combinations of scenarios and communication systems.

Noise Environment	Channel	SNR (dB)	25 kHz AFM	P25 FR	12.5 kHz AFM	P25 HR
No noise, no mask	Clean		X	X	X	X
Mask (vox port) with no noise	Clean		X	X	X	X
Mask (int microphone) with no noise	Clean		X	X	X	X
PASS Alarm 1, mask (vox port)	Clean	-2[(7)]	X	X	X	X
PASS Alarm 2, mask (vox port)	Clean	-2[(7)]	X	X	X	X
PASS Alarm 1, mask (int microphone)	Clean	-2	X	X	X	X
PASS Alarm 2, mask (int microphone)	Clean	-2	X	X	X	X
Night club noise, no mask	Clean	5	X	X	X	X
No noise, no mask	Degraded		X	X	X	X
Mask (vox port) with no noise	Degraded		X	X	X	X
Mask (int microphone) with no noise	Degraded		X	X	X	X
PASS Alarm 1, mask (vox port)	Degraded	-2[(7)]	X	X	X	X
PASS Alarm 1, mask (int microphone)	Degraded	-2	X	X	X	X
Night club noise, no mask	Degraded	5	X	X	X	X

[7] This does not include attenuation of the signal due to the mask (approximately 9 dB).

3 SPEECH DATA BASES

The speech source material used for the test consisted of spoken word lists from the Modified Rhyme Test (MRT) described in [9]. Source material used for the tests had a quiet acoustic background. In the experiment, acoustic background noise was added to the source material. The MRT was used for evaluation. These tests placed several conditions on the speech data base:

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

The speech source material for the test was recorded at ITS.[8] This material was the MRT word list defined in [9] using the carrier sentence, "Please select the word …" More specific information about the recording process for this source material is given in Appendix C.

3.1 Speech Data Base Properties

Fifty lists of six words from the data base were processed with each test condition. Each coding mechanism processed the same speech material under the same operating conditions. Sufficient source material was used to prevent listeners from being presented with repeat material. To reduce order bias, the presentation order of the material to the listeners was randomized by talker and condition. Within a given talker/condition, samples were also randomized, but were presented as a block to the listener.

Material for two male and two female talkers[9] was used as described in **Error! Reference source not found.**. Each talker spoke each of 300 MRT sentences. This resulted in 1200 sentences for each of the fourteen scenarios. A total of 16800 sentences were then processed with each of four reference systems, resulting in 67200 files. System 1 is 25 kHz AFM, System 2 is 12.5 kHz AFM, System 3 is P25 FR [Enhanced Dual-Rate Software Version 1.40e], System 4 is P25 HR [Enhanced Dual-Rate Software Version 1.40e].

[8] ITS and PSCR have made speech material from this test available on the internet to enable continued research in this area. The material can be found here: http://www.pscr.gov/projects/audio_quality/mrt_library/mrt_library1.php.

[9] [10] specifies an unbalanced talker pool of four male and one female talkers. To provide more gender-balanced results that could have wider applicability, a balanced talker pool of two male and two female talkers was used.

Table 4. Source audio arrangement of sentences, test conditions, and talkers.

Talker (2 male, 2 female)	**1**	**2**	**3**	**4**	
Talker Gender	**M**	**M**	**F**	**F**	
Clean RF Channel					
No noise, no mask	300	300	300	300	1200
No noise, mask (vox port)	300	300	300	300	1200
PASS Alarm 1 (-2 dB SNR) [10], Mask (vox port)	300	300	300	300	1200
PASS Alarm 2 (-2 dB SNR), Mask (vox port)	300	300	300	300	1200
Night club noise (5 dB SNR), no mask	300	300	300	300	1200
No noise, mask (int microphone)	300	300	300	300	1200
PASS Alarm 1 (-2 dB SNR), Mask (int microphone)	300	300	300	300	1200
PASS Alarm 2 (-2 dB SNR), Mask (int microphone)	300	300	300	300	1200
Static Degraded RF Channel					
No noise, no mask	300	300	300	300	1200
No noise, mask (vox port)	300	300	300	300	1200
No noise, mask (int microphone)	300	300	300	300	1200
PASS Alarm 1 (-2 dB SNR),[10] Mask (vox port)	300	300	300	300	1200
PASS Alarm 1 (-2 dB SNR), Mask (int microphone)	300	300	300	300	1200
Night club noise (5 dB SNR), no mask	300	300	300	300	1200
					16800

The speech recordings were made in controlled acoustic noise environments. The testing included two noise-free conditions, three acoustic noise environments, and two channel conditions. For the experiment, there were two male talkers and two female talkers.

The speech material was equalized across all talkers for presentation level. The material was recorded in WAV files in full audio bandwidth and dynamic range with no additional processing.

The speech material processed through the reference systems was evaluated by a total of 52 listeners. No more than five listeners were presented the same playback order randomization, no listener was presented repeated word lists, and the combinations of word list, communication technology, and condition were balanced across the total listener crew.

3.2 Speech Data Base Levels

An important attribute of the speech data base, especially for the inputs to the reference systems, was the average power level of the speech material. The nominal power level for speech followed the recommendation defined in [1] and excerpted below. This recommendation was followed for each sentence.

[10] This does not include attenuation of the signal due to the mask (approximately 9 dB).

> "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 (-22 dBm0) is designed to provide sufficient margin to prevent the peaks of the speech waveform from being clipped by the A-to-D converter."

All input, playback and reference systems were tuned to maintain the -22 dBm0 (-28 dBov) ±0.5 dB active speech level in the digital files throughout the processing and playback. This ensured that the speech was always delivered to the listeners as if the talker were speaking at a constant volume.

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. The tests reported here used the ITU-T Recommendation P.56 [17] method B to accurately measure the active speech level.

3.3 Signal and Acoustic Noise Levels

In order to construct the appropriate signal-to-noise levels for input to the reference systems, careful attention to the noise signal filtering and level adjustment of the signals was necessary. The definition for signal-to-noise ratio in dB for this test is:

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

Active speech level was computed according to [17]. The short-term power function of each noise was assumed to be much more stationary than speech, relieving the need for an activity/threshold detector. The computation for the noise levels followed an RMS algorithm that was scaled to the overload point ($A_{fullscale}$) so that dB values are negative or zero:

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

where x_i is the i^{th} sample of the noise signal x with length N samples. The noise samples were scaled by the appropriate factor to obtain the target noise level for that specific test condition, summed together acoustically as described in Section 4.2, and then recorded as WAV files to create a noise condition file for reference system input.

4 PRODUCTION OF RECORDED FILES

This section describes the test procedure that was followed in conducting the tests of the reference systems. This procedure was designed to assist interested parties to reproduce the speech files for later scoring by a listening laboratory.

4.1 Test Elements

The test used the following elements:

1. Head and torso simulators [18] [19]

2. NC-35 sound attenuated chamber

3. Representative SCBA masks

4. Ability to produce environmental noise at appropriate level within the NC-35 chamber

5. Reference systems as described in Section 2

6. Recording and playback hardware and software

4.2 Test Signal Preparation

Generating the test material was a matter of processing 300 sentences for each of the four talkers through the permutations of acoustic and channel conditions specified for the experiment. This was done in two stages. The first stage was the recording procedure described below combined with the recording system described in Section 2.1. The second stage was processing that recorded material through the four reference systems with both clean and degraded channel conditions. The output files from the reference systems were then played to the listeners as indicated in Section 5.3.

For the conditions with background noise, it was important that the background noise be active in the first sample of the recorded file 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 can lead to longer-than-normal training times once the noise starts.

Figure 12 shows the physical configuration for those conditions without a mask, and Figure 13 shows the physical configuration for those conditions with a mask and using an external microphone. The indicated microphone was used to record speech from the HATS acoustically mixed with background noise generated through the loudspeakers. Figure 14 shows the physical configuration for those conditions using a mask with an internal microphone.

For those conditions without a mask, the recording microphone was positioned 5 cm (2 in.) directly in front of the lip reference point (LRP). For those conditions using the voice port on a mask, the recording microphone was positioned against the voice transmission port on the mask.

For those conditions using a mask with an internal microphone, the manufacturer-supplied internal microphone (positioned inside the breathing cone of the mask) was used.

Because both of the background noises used in this experiment were multipoint noise sources, all five speakers were 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 was played through the HATS at a level of 100 dB_C at the LRP (measured without a mask in place). This was consistent with measurements made on behalf of TIA of users talking in a loud noise environment. For those conditions with background noise, the noise SPL was also measured in dBc at the LRP without a mask in place. These noise and speech levels were used to achieve the specified SNR and ensure that the sound levels were consistent in the chamber and the effects of the masks and microphones on the reference systems could be evaluated.

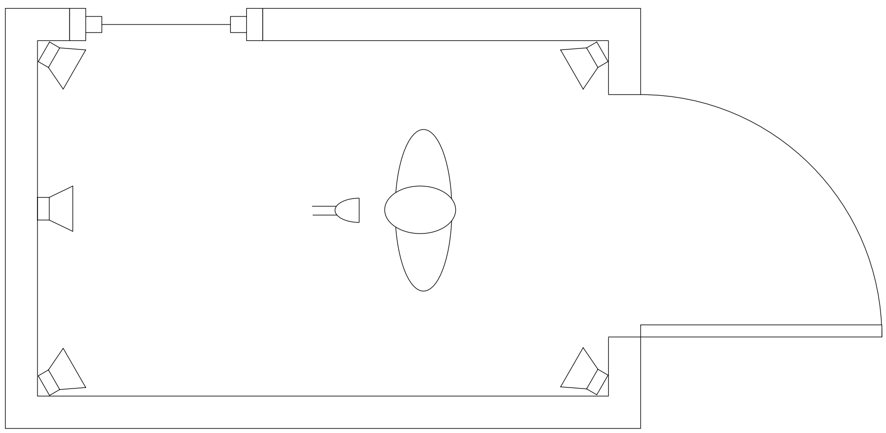

Figure 12. Physical configuration showing acoustic anechoic chamber, speakers, microphone, and HATS for non-mask conditions.

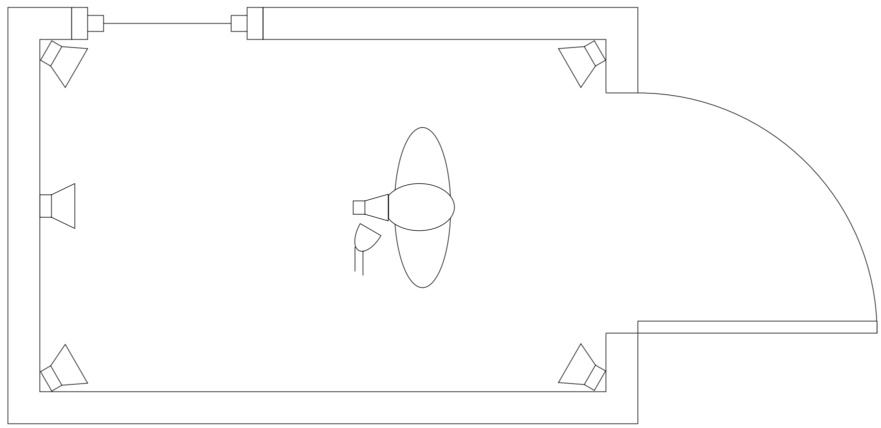

Figure 13. Physical configuration showing acoustic anechoic chamber, speakers, SCBA mask, microphone, and HATS for conditions with SCBA mask and external microphone.

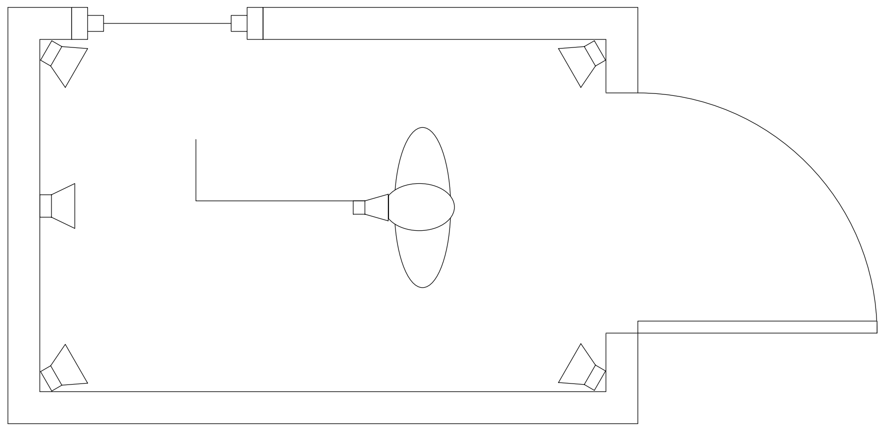

Figure 14. Physical configuration showing acoustic anechoic chamber, speakers, SCBA mask with internal microphone, and HATS for conditions with SCBA mask and internal microphone.

5 SUBJECTIVE EVALUATION OF INTELLIGIBILITY

The subjective evaluation of intelligibility using the MRT is specified in [9] and [10] and described in [6].

Subjective testing involves the use of a number of listeners who attempt to interpret the words spoken through the reference system. The processed speech samples were obtained as described in Section 4. 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 52 listeners were used. To mitigate the effects of the order of presentation of the speech samples to the listeners, a different presentation order was used with each listener.

5.1 Stimulus File Preparation

After processing the input material with all coding mechanisms for the experiment, the proper sentences needed to be assembled. This material was then randomized in its order of presentation to the listeners. Each group of listeners listened to a different subset of 2400 sentences that were drawn from the recordings made using the input, output, and reference systems described in Section 2.

5.2 MRT Evaluation Laboratory

The ITS laboratory used to perform the tests was configured to conform as closely as possible to the applicable sections of ITU-T Recommendation P.800 [15],[11] as described in Appendix D. ITS, acting as the Evaluation Laboratory under the Recommendation, both conducted the tests (as described in Section 5.3) and delivered the results of the experiment (as described in Section 5.4).

Prior to the start of the test the listeners participated in a practice session. During this practice session they were presented with 112 practice sentences, two from each condition, which they scored. The practice sentences consisted of a block of material as described in Section 3.1, but taken from the larger corpus of speech material, excluding the samples for the experimental sessions. After the practice session the listeners were asked if they understood what they were supposed to do. If there were any questions they were answered at that time. After that the formal test began. The purpose of the practice session was to: (a) expose the listener to the range of audio quality of the test, and (b) to see if they understood what they were supposed to be doing. This was in accordance with [15], clause B.4.6, Instructions to subjects.

[11] Listening tests are described in Annex B of ITU Recommendation P.800. Because P.800 was designed for telephony applications and not public safety land mobile radio applications, certain adaptations are made to accommodate other standards that are an integral part of this test. Specifically, the listening environment noise and noise levels are based on NFPA 1981-2007 (specifying pink noise), rather than those specified in P.800 (Hoth noise). Also, TIA TR-8 prefers an active speech level of -28 dBov in comparison to the -26 dBov recommended in P.800. Finally, the MRT intelligibility test from ANSI S3.2 is the method used instead of the quality methods described in P.800.

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

5.3 Intelligibility Testing

The subjective evaluation consisted of one experiment to determine effects of background noise and channel degradation.

The experiment followed the Modified Rhyme Test (MRT) method [9] to assess intelligibility. In the MRT, each listener listened to a sentence asking them to select a word from a prescribed list. The listeners' ability to select the correct word was averaged across listeners and produced a percentage of intelligibility score.

The MRT consisted of the conditions shown in Table 3.

Presentation of speech material was made via high fidelity near-field monitor speaker at a distance of 1.5 m from the listener. The playback system was calibrated to deliver an average speech listening level of 84 dBA when measured at the listening position. The equivalent acoustic noise level of the playback system did not exceed 35 dBA.

Listeners were seated in a room, with an ambient pink noise level of 65 dBA as defined in subclauses 8.10.4.11 through 8.10.4.15 of [10]. The exact configuration of the room and characterization of the noise is shown in Appendix D.

Notwithstanding that the listeners were practitioners, they were naïve with respect to communication technology issues; that is, they were not considered experts in telephone design, digital voice encoding algorithms, and so on. The sample included adults of mixed sex, age, and practitioner discipline. Persons were given a hearing screening and results were used only from those subjects who had audiometrically normal hearing as defined in subclause 8.10.4.3 of [10].

The test was conducted as described in subclauses 8.10.5.1 and 8.10.5.2 of [10], with the exceptions that the carrier sentence was "Please select the word [list word]" and that listeners selected the word on a touch screen.

The administration of the experiment was as follows: The processed speech was presented to a panel of 52 listeners. Thirty-two of fifty-two listeners heard 14 lists of 150 sentences (or 2100 sentences) for a grand total of $14 \times 150 \times 32 = 67200$ sentences. However, it was discovered that due to faulty recording equipment, all sentences for 20 conditions ($20 \times 1200 = 24000$ sentences) were recorded improperly. The sentences were re-recorded and retested. Twenty of fifty-two listeners heard 10 lists of 150 sentences (or 1500 sentences) for a grand total of $10 \times 150 \times 20 = 30000$ sentences. There was some overlap with the initial test (6000 sentences or 5 conditions) which enabled a small amount of repeatability testing.

Before starting the experiment, the subjects were given the following instructions. The instructions can be modified to allow for variations in laboratory data-gathering apparatus.

Instructions for Subjects

[Before Training Session] Welcome and thank you for coming. This experiment is seven 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 five-minute break after every 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 reported as statistics for 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 talkers. Please listen to the sentence, and then select the requested word from the list on the PDA by tapping quickly on the screen with your fingertip. 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?

5.4 Analysis and Reporting of Results

The results are reported in a series of tables in Section 6. The analysis and reporting is outlined in sections 8.10.5 and 8.10.6 of [10]. Averages were computed using the adjusted method recommended for closed set tests as described in section 10.2 of [9]. An analysis of variance (ANOVA) was computed to enable comparisons between the implementations. A more detailed description of the analysis follows.

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

The data under analysis with ANOVA and Tukey consisted of adjusted average intelligibility scores, R_A (described in section 10.2 of [9]), collected for 4 communication technologies, 4 talkers (each speaking 300 sentences), 14 acoustic noise/channel conditions (for a grand total of $4 \times (4 \times 300) \times 14 = 67200$ sentences), and a total of 52 listeners. The results presented in this report represent data collected using files from the 36 correctly-recorded conditions during the initial test and the 20 correctly-recorded conditions during the subsequent test. Together, both tests fully cover the $4 \times 14 = 56$ individual conditions contained in the test.

ANOVA compared the variance of the overall sample population with the variance within each sub-population, and if they exceeded a value given by the Fisher F-distribution, then the null hypothesis was false. In this case, the null hypothesis was that communication technologies do not make a difference in intelligibility.

The hypothesis under test, H, was that the communication system (in particular the vocoder implemented by that communication technology) affected the intelligibility, R_A, as measured by the MRT. The hypothesis can be tested for 13 of the 14 acoustic noise/channel conditions. If the hypothesis is true, it is also desired to know which communication technology is better.

For this test, $\alpha = 0.01$ was used for the F-distribution in the ANOVA for the given degrees of freedom, df, and sample size, n. These parameters were programmed into a statistical analysis package (Minitab®) for computation of the ANOVA and Tukey pairwise comparison. Analysis results are summarized in Section 6, and individual condition analyses are presented in Appendix A.

6 TEST RESULTS

This section describes the results of the experiment. One-way ANOVA results were computed using a statistical analysis package. Input to the ANOVA consisted of six adjusted intelligibility scores (R_A) per talker/noise environment/reference system. Each of those adjusted intelligibility scores were based on the intelligibility of 50 samples for that particular talker/noise environment/reference system combination that were presented to that particular listener.

The R_A listener scores for the experiment are tabulated in Appendix B. The analysis of the scores for the experiment is given in Section 6.1. The analysis given in Section 6.1 includes the analysis of the R_A scores resulting from:

- the evaluation of the 36 correctly-recorded conditions during the initial test
- the evaluation of the 20 correctly-recorded conditions during the subsequent test

The subsequent test included 6 conditions that overlapped with 6 of the 36 correctly-recorded conditions utilized during the initial test. These overlapping results were tested for statistical similarity and were found to be statistically similar. This says that the test methodology creates repeatable results, and therefore the R_A scores from the subsequent test are included with the R_A scores from the initial test.

In Table 3 a total of 56 conditions are enumerated for testing (Error! Reference source not found. details each condition more explicitly). However, an error in the file creation process resulted in an erroneous representation of conditions 13 and 27 (mask (internal microphone) with PASS 1 (-2 dB SNR) background noise and statically degraded channel for both 25 kHz and 12.5 kHz AFM). This error was not discovered until after both the initial and subsequent tests were completed. Therefore the results that follow only include the 54 remaining, valid conditions. In light of this, statistical significance tests are not available for Scenario 13.

6.1 Experiment Results by Scenario

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

6.1.1 Results for Scenario 1: "No Noise, No Mask, Clean RF Channel"

Scenario 1 consisted of the ideal communications case with no background noise, no SCBA mask, and a clean RF channel. The listening environment was as described in Section 5.3. Table 5 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 ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that only the 12.5 kHz AFM was different from the P25 HR system. All of the other five paired comparisons showed statistically similar scores.

Table 5. Intelligibility scores, ANOVA results, and Tukey results for Scenario 1.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.896	0.907	0.866	0.843

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.06082	0.02027	5.83	0.001	YES
Error	92	0.32011	0.00348			
Total	95	0.38093				

S = 0.05899 R-Sq = 15.97% R-Sq(adj) = 13.22%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.896	0.04835	NO	NO	NO	
2 - 12.5 kHz AFM	0.907	0.0497	YES	NO		
3 - P25 Full Rate	0.866	0.06483	NO			
4 - P25 Half Rate	0.843	0.07005				

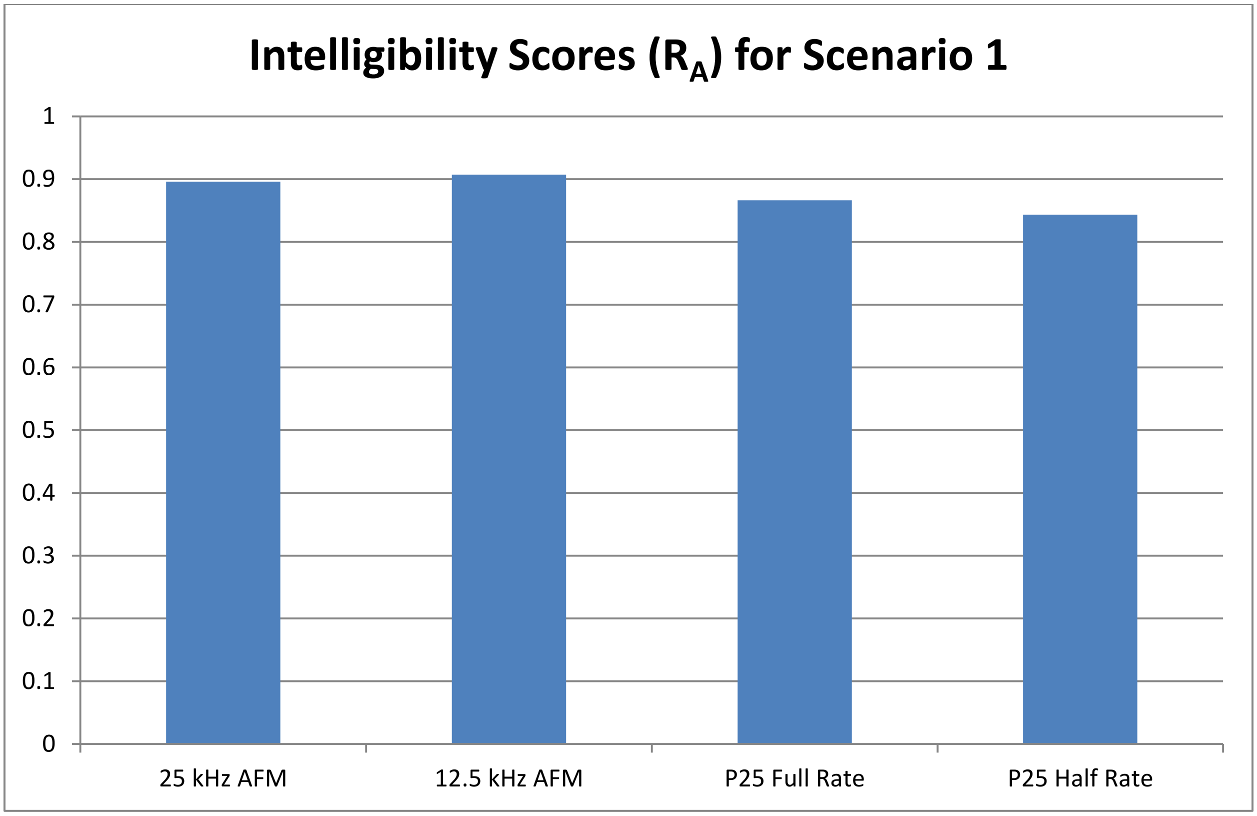

Figure 15. Intelligibility scores (R_A) for Scenario 1.

6.1.2 Results for Scenario 2: "No Noise, Mask (Vox Port), Clean RF Channel"

Scenario 2 consisted of no background noise, SCBA mask with vox port, and a clean RF channel. The listening environment was as described in Section 5.3. Table 6 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 ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that only the 12.5 kHz AFM was different from the P25 HR system. All of the other five paired comparisons showed statistically similar scores.

Table 6. Intelligibility scores, ANOVA results, and Tukey results for Scenario 2.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.754	0.771	0.692	0.672

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.16379	0.0546	6.55	0.000	YES
Error	92	0.76673	0.00833			
Total	95	0.93052				

S = 0.09129 R-Sq = 17.60% R-Sq(adj) = 14.92%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.754	0.0994	NO	NO	NO	
2 - 12.5 kHz AFM	0.771	0.06897	YES	NO		
3 - P25 Full Rate	0.692	0.1005	NO			
4 - P25 Half Rate	0.672	0.09273				

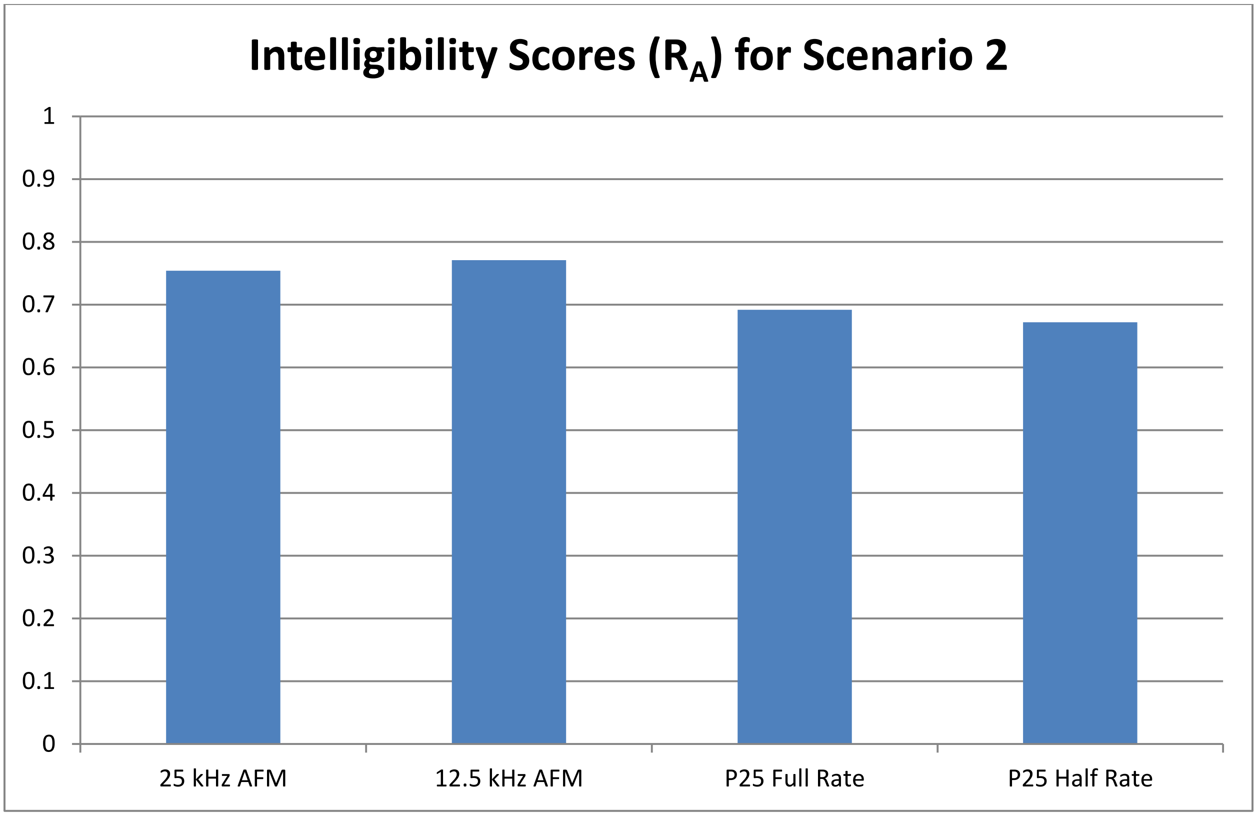

Figure 16. Intelligibility scores (R_A) for Scenario 2.

6.1.3 Results for Scenario 3: "No Noise, Mask (Int Mic), Clean RF Channel"

Scenario 3 consisted of no background noise, SCBA mask with internal microphone, and a clean RF channel. The listening environment was as described in Section 5.3. Table 7 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 ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The 25 kHz AFM and 12.5 kHz AFM are in one group with the higher scores, and the P25 FR and P25 HR are in the second group with the lower score.

Table 7. Intelligibility scores, ANOVA results, and Tukey results for Scenario 3.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.840	0.831	0.712	0.723

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.3366	0.1122	19.18	0.000	YES
Error	92	0.53813	0.00585			
Total	95	0.87473				

S = 0.05926 R-Sq = 14.82% R-Sq(adj) = 11.71%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.84	0.09698	YES	YES	NO	
2 - 12.5 kHz AFM	0.831	0.07047	YES	YES		
3 - P25 Full Rate	0.712	0.1005	NO			
4 - P25 Half Rate	0.723	0.09066				

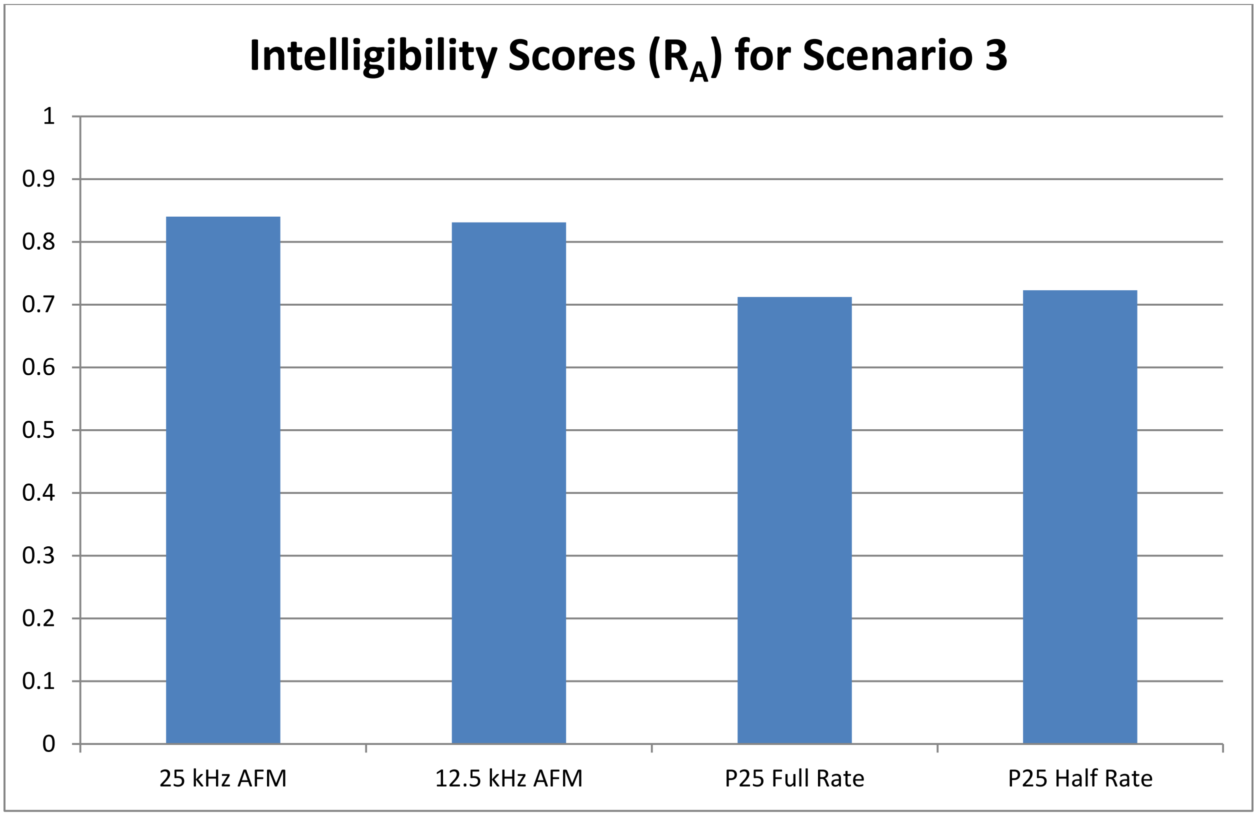

Figure 17. Intelligibility scores (R_A) for Scenario 3.

6.1.4 Results for Scenario 4: "PASS 1, Mask (Vox Port), Clean RF Channel"

Scenario 4 consisted of PASS alarm 1 background noise, SCBA mask with vox port, and a clean RF channel. The listening environment was as described in Section 5.3. Table 8 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 ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups. The 25 kHz AFM and 12.5 kHz AFM scores are in one group. The other group includes 12.5 kHz AFM along with P25 FR and P25 HR scores. The 12.5 kHz AFM score overlaps both groups. The 25 kHz analog system had higher intelligibility than the two P25 systems.

Table 8. Intelligibility scores, ANOVA results, and Tukey results for Scenario 4.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.606	0.586	0.499	0.508

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.21112	0.07037	7.06	0.000	YES
Error	92	0.91754	0.00997			
Total	95	1.12866				

S = 0.09987 R-Sq = 18.71% R-Sq(adj) = 16.05%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.606	0.09413	YES	YES	NO	
2 - 12.5 kHz AFM	0.586	0.11218	NO	NO		
3 - P25 Full Rate	0.499	0.08353	NO			
4 - P25 Half Rate	0.508	0.1071				

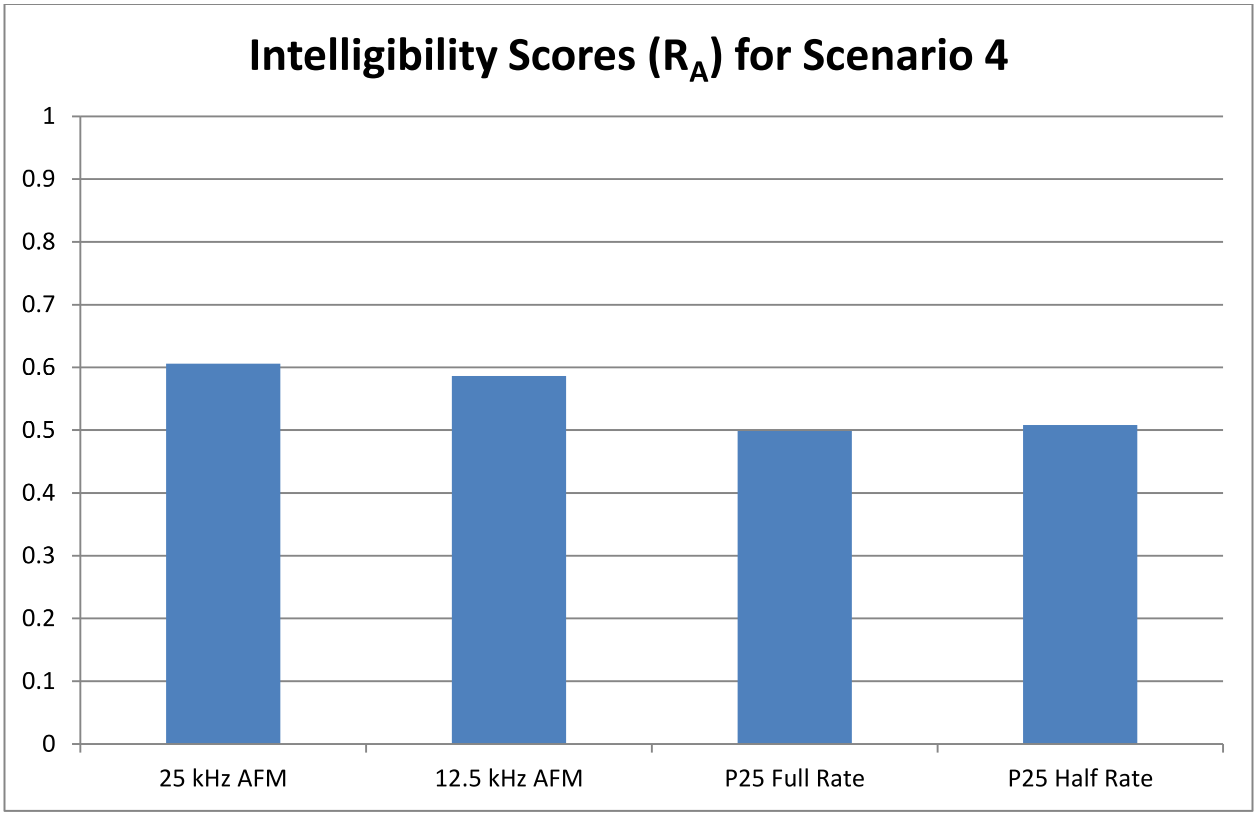

Figure 18. Intelligibility scores (R_A) for Scenario 4.

6.1.5 Results for Scenario 5: “PASS 2, Mask (Vox Port), Clean RF Channel”

Scenario 5 consisted of PASS alarm 2 background noise, SCBA mask with vox port, and a clean RF channel. The listening environment was as described in Section 5.3. Table 9 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 ANOVA did not reveal a statistically significant difference, thus a Tukey test was not performed.

Table 9. Intelligibility scores and ANOVA results for Scenario 5.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.554	0.550	0.485	0.481

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.1146	0.0382	3.3	0.024	NO
Error	92	1.0644	0.0116			
Total	95	1.179				

S = 0.1076 R-Sq = 9.72% R-Sq(adj) = 6.78%

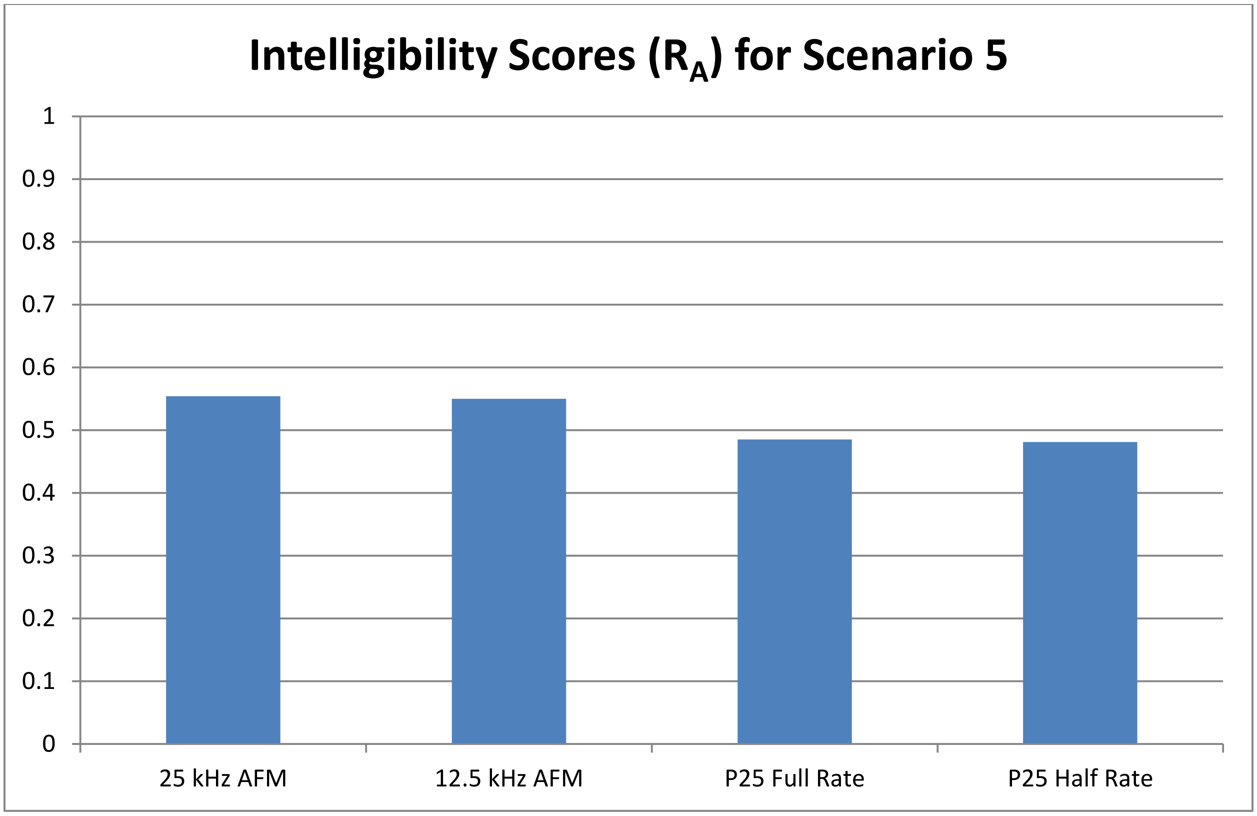

Figure 19. Intelligibility scores (R_A) for Scenario 5.

6.1.6 Results for Scenario 6: "PASS 1, Mask (Int Mic), Clean RF Channel"

Scenario 6 consisted of PASS alarm 1 background noise, SCBA mask with internal microphone, and a clean RF channel. The listening environment was as described in Section 5.3. Table 10 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 ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The 25 kHz AFM and 12.5 kHz AFM are in one group with the higher scores, and the P25 FR and P25 HR are in the second group with the lower scores.

Table 10. Intelligibility scores, ANOVA results, and Tukey results for Scenario 6.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.800	0.822	0.707	0.710

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.25807	0.08602	16.78	0.000	YES
Error	92	0.47172	0.00513			
Total	95	0.72979				

S = 0.1019 R-Sq = 9.02% R-Sq(adj) = 5.81%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.8	0.07411	YES	YES	NO	
2 - 12.5 kHz AFM	0.822	0.06405	YES	YES		
3 - P25 Full Rate	0.707	0.0788	NO			
4 - P25 Half Rate	0.71	0.06859				

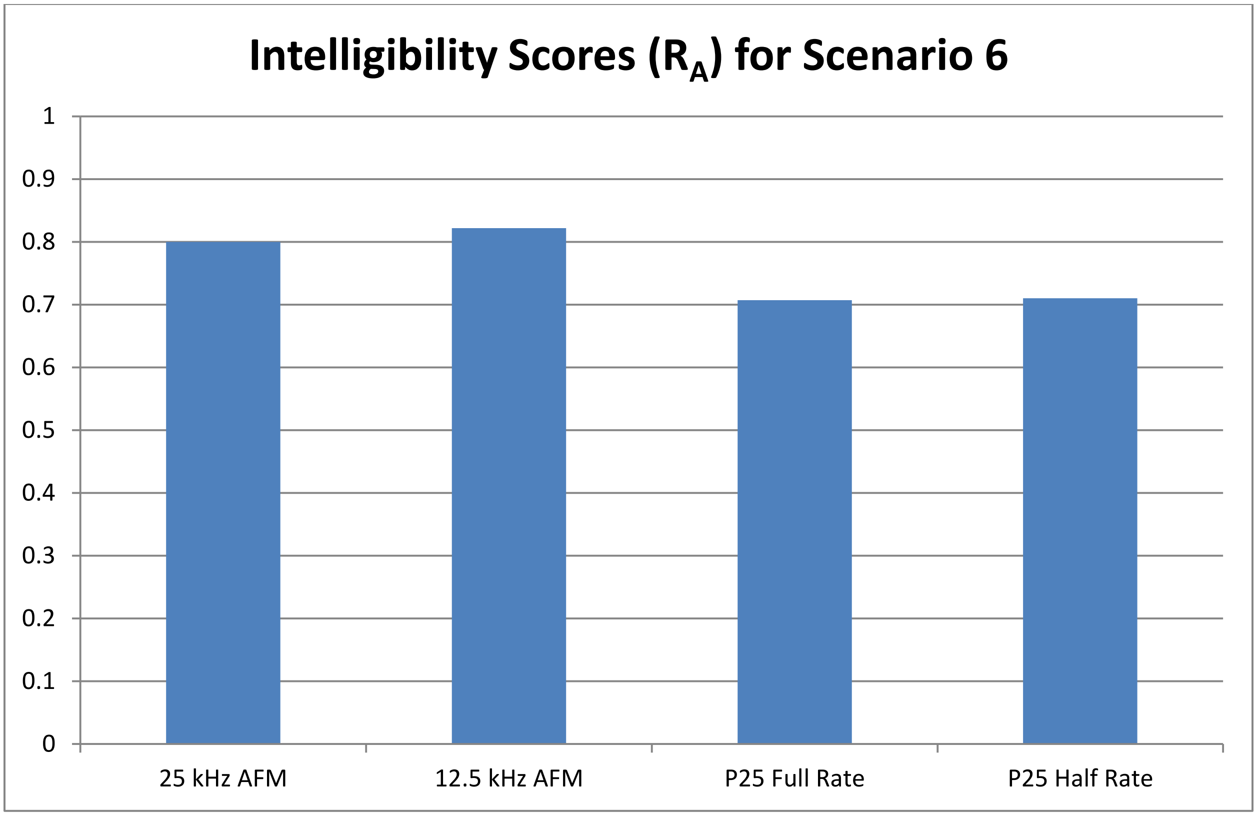

Figure 20. Intelligibility scores (R_A) for Scenario 6.

6.1.7 Results for Scenario 7: "PASS 2, Mask (Int Mic), Clean RF Channel"

Scenario 7 consisted of PASS alarm 2 background noise, SCBA mask with internal microphone, and a clean RF channel. The listening environment was as described in Section 5.3. Table 11 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 21 contains the bar chart of results for this environment. The ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The 25 kHz AFM and 12.5 kHz AFM are in one group with the higher scores, and the P25 FR and P25 HR are in the second group with the lower scores.

Table 11. Intelligibility scores, ANOVA results, and Tukey results for Scenario 7.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.817	0.817	0.715	0.711

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.25978	0.08659	17.23	0.000	YES
Error	92	0.46243	0.00503			
Total	95	0.72221				

S = 0.08876 R-Sq = 34.95% R-Sq(adj) = 32.82%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.817	0.08777	YES	YES	NO	
2 - 12.5 kHz AFM	0.817	0.07747	YES	YES		
3 - P25 Full Rate	0.715	0.05496	NO			
4 - P25 Half Rate	0.711	0.05814				

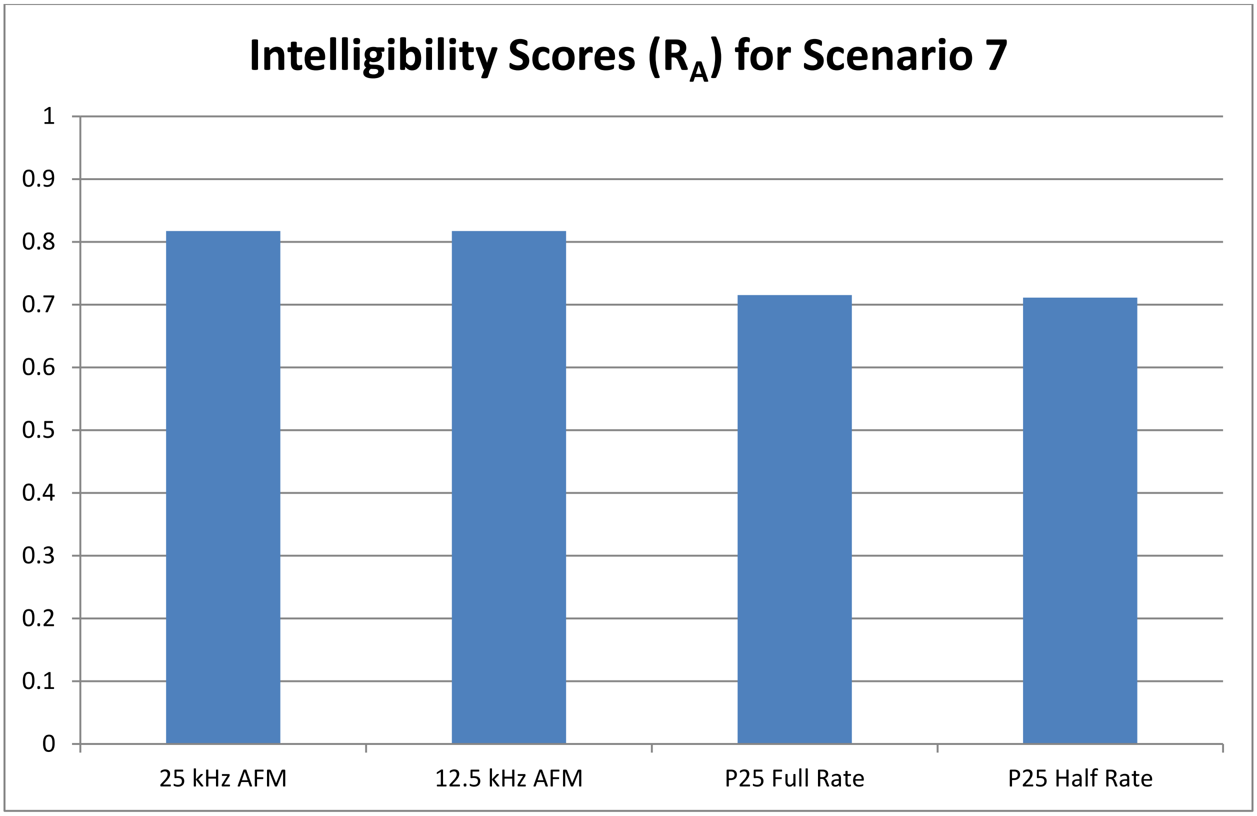

Figure 21. Intelligibility scores (R_A) for Scenario 7.

6.1.8 Results for Scenario 8: "Night Club Noise, No Mask, Clean RF Channel"

Scenario 8 consisted of night club noise, no mask, and a clean RF channel. The listening environment was as described in Section 5.3. Table 12 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 22 contains the bar chart of results for this environment The ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The 25 kHz AFM and 12.5 kHz AFM are in one group with the higher scores, and the P25 FR and P25 HR are in the second group with the lower scores.

Table 12. Intelligibility scores, ANOVA results, and Tukey results for Scenario 8.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.683	0.656	0.494	0.503

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.7115	0.2372	16.2	0.000	YES
Error	92	1.3467	0.0146			
Total	95	2.0582				

S = 0.1210 R-Sq = 34.57% R-Sq(adj) = 32.43%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.683	0.1148	YES	YES	NO	
2 - 12.5 kHz AFM	0.656	0.0992	YES	YES		
3 - P25 Full Rate	0.494	0.1454	NO			
4 - P25 Half Rate	0.503	0.12				

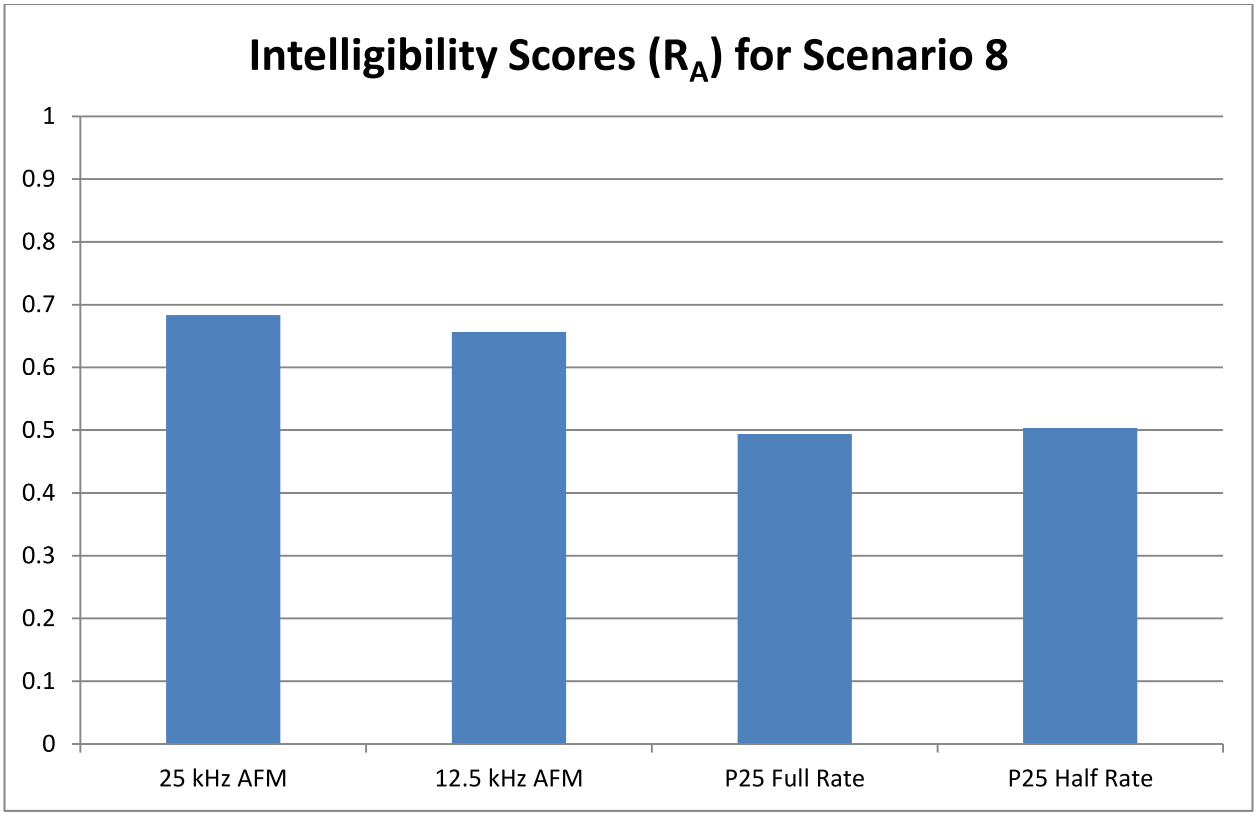

Figure 22. Intelligibility scores (R_A) for Scenario 8.

6.1.9 Results for Scenario 9: "No Noise, No Mask, Degraded RF Channel"

Scenario 9 consisted of no background noise, no mask, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 13 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 23 contains the bar chart of results for this experiment. The ANOVA results show a statistically significant difference in the scores. The Tukey comparison test shows that the scores fall into three groups with no overlap. The P25 FR and P25 HR scores are in one group with the highest scores. The 25 kHz AFM is in the second group with a lower score. The 12.5 kHz AFM is in the third group with the lowest score.

Table 13. Intelligibility scores, ANOVA results, and Tukey results for Scenario 9.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.701	0.590	0.876	0.852

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	1.30058	0.43353	57.49	0.000	YES
Error	92	0.69377	0.00754			
Total	95	1.99435				

S = 0.08684 R-Sq = 65.21% R-Sq(adj) = 64.08%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.701	0.08979	YES	YES	YES	
2 - 12.5 kHz AFM	0.59	0.12009	YES	YES		
3 - P25 Full Rate	0.876	0.05233	NO			
4 - P25 Half Rate	0.852	0.0703				

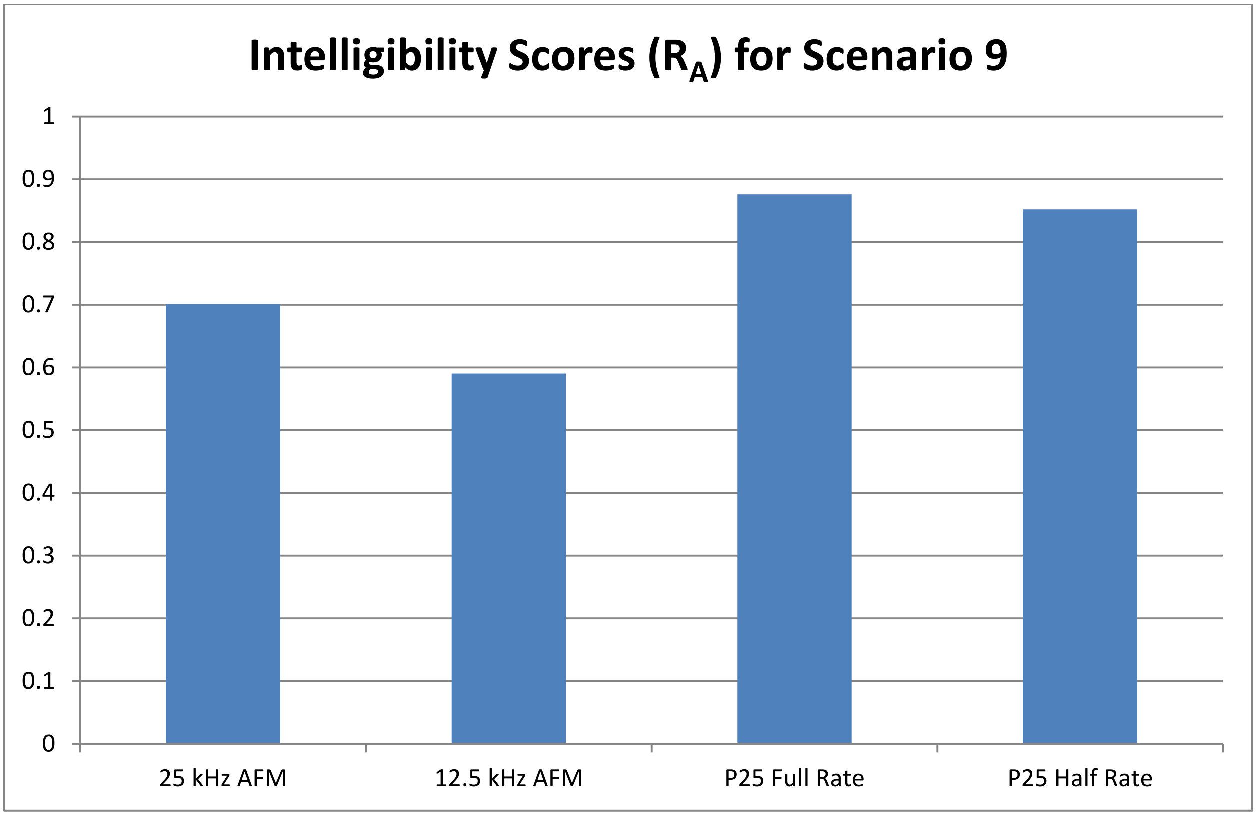

Figure 23. Intelligibility scores (R_A) for Scenario 9.

6.1.10 Results for Scenario 10: "No Noise, Mask (Vox Port), Degraded RF Channel"

Scenario 10 consisted of no background noise, SCBA mask with vox port, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 14 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 24 contains the bar chart of results for this environment. The ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The P25 FR and P25 HR are in one group with the higher scores, and the 25 kHz AFM and 12.5 kHz AFM are in the second group with the lower score.

Table 14. Intelligibility scores, ANOVA results, and Tukey results for Scenario 10.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.484	0.409	0.694	0.679

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	1.4526	0.4842	48.83	0.000	YES
Error	92	0.91224	0.00992			
Total	95	2.36484				

S = 0.09958 R-Sq = 61.42% R-Sq(adj) = 60.17%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.484	0.11948	YES	YES	NO	
2 - 12.5 kHz AFM	0.409	0.11319	YES	YES		
3 - P25 Full Rate	0.694	0.07952	NO			
4 - P25 Half Rate	0.679	0.07907				

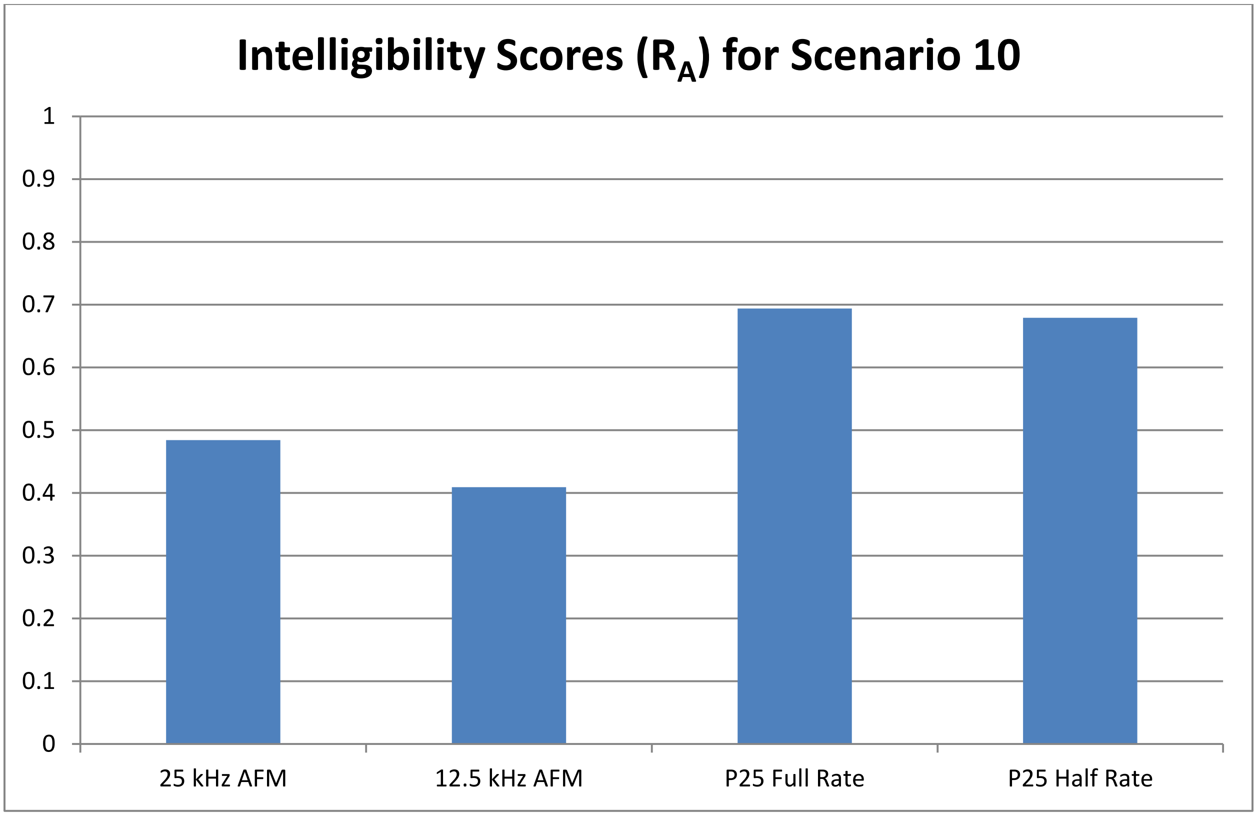

Figure 24. Intelligibility scores (R_A) for Scenario 10.

6.1.11 Results for Scenario 11: "No Noise, Mask (Int Mic), Degraded RF Channel"

Scenario 11 consisted of no background noise, SCBA mask with internal microphone, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 15 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 25 contains the bar chart of results for this environment. The ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The P25 FR and P25 HR are in one group with the higher scores, and the 25 kHz AFM and 12.5 kHz AFM are in the second group with the lower scores.

Table 15. Intelligibility scores, ANOVA results, and Tukey results for Scenario 11.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.614	0.542	0.728	0.730

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.60948	0.20316	24052	0.000	YES
Error	92	0.76234	0.00829			
Total	95	1.37182				

S = 0.08371 R-Sq = 66.26% R-Sq(adj) = 65.05%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.614	0.0944	YES	YES	NO	
2 - 12.5 kHz AFM	0.542	0.10778	YES	YES		
3 - P25 Full Rate	0.728	0.08716	NO			
4 - P25 Half Rate	0.73	0.07086				

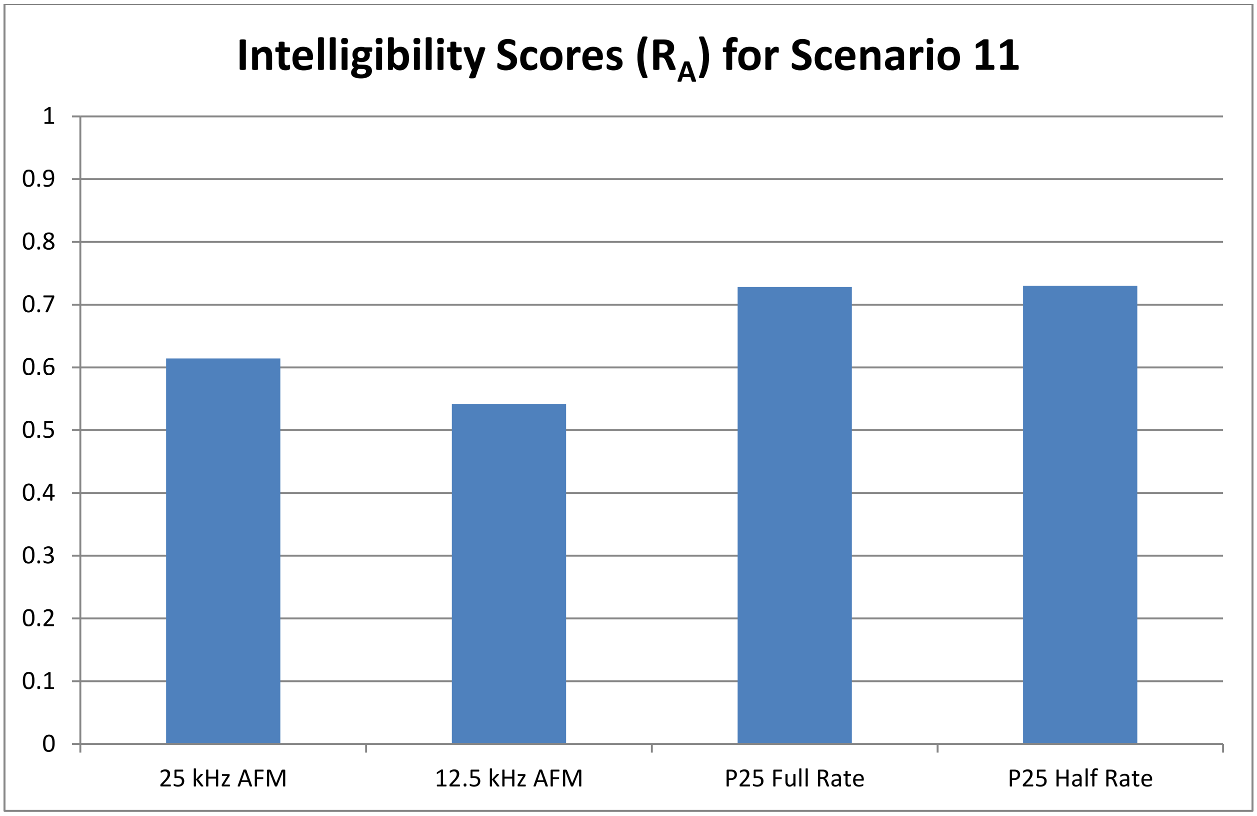

Figure 25. Intelligibility scores (R_A) for Scenario 11.

6.1.12 Results for Scenario 12: "PASS 1, Mask (Vox Port), Degraded RF Channel"

Scenario 12 consisted of PASS alarm 1 background noise, SCBA mask with vox port, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 16 contains the intelligibility scores, ANOVA, and Tukey results for this environment. The detailed Minitab report is found in Appendix A.

Figure 26 contains the bar chart of results for this environment. The ANOVA test indicates that some R_A scores are different. The Tukey comparison test shows that the scores fall into two groups with no overlap. The P25 FR and P25 HR are in one group with the higher scores, and the 25 kHz AFM and 12.5 kHz AFM are in the second group with the lower score.

Table 16. Intelligibility scores, ANOVA results, and Tukey results for Scenario 12.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.339	0.328	0.488	0.498

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.61322	0.20441	20.52	0.000	YES
Error	92	0.91649	0.00996			
Total	95	1.52971				

S = 0.09981 R-Sq = 40.09% R-Sq(adj) = 38.13%

Tukey Multiple Comparison Results "YES" means significance

System	Mean	StDev	4	3	2	1
1 - 25 kHz AFM	0.339	0.08979	YES	YES	NO	
2 - 12.5 kHz AFM	0.328	0.09416	YES	YES		
3 - P25 Full Rate	0.488	0.11205	NO			
4 - P25 Half Rate	0.498	0.1018				

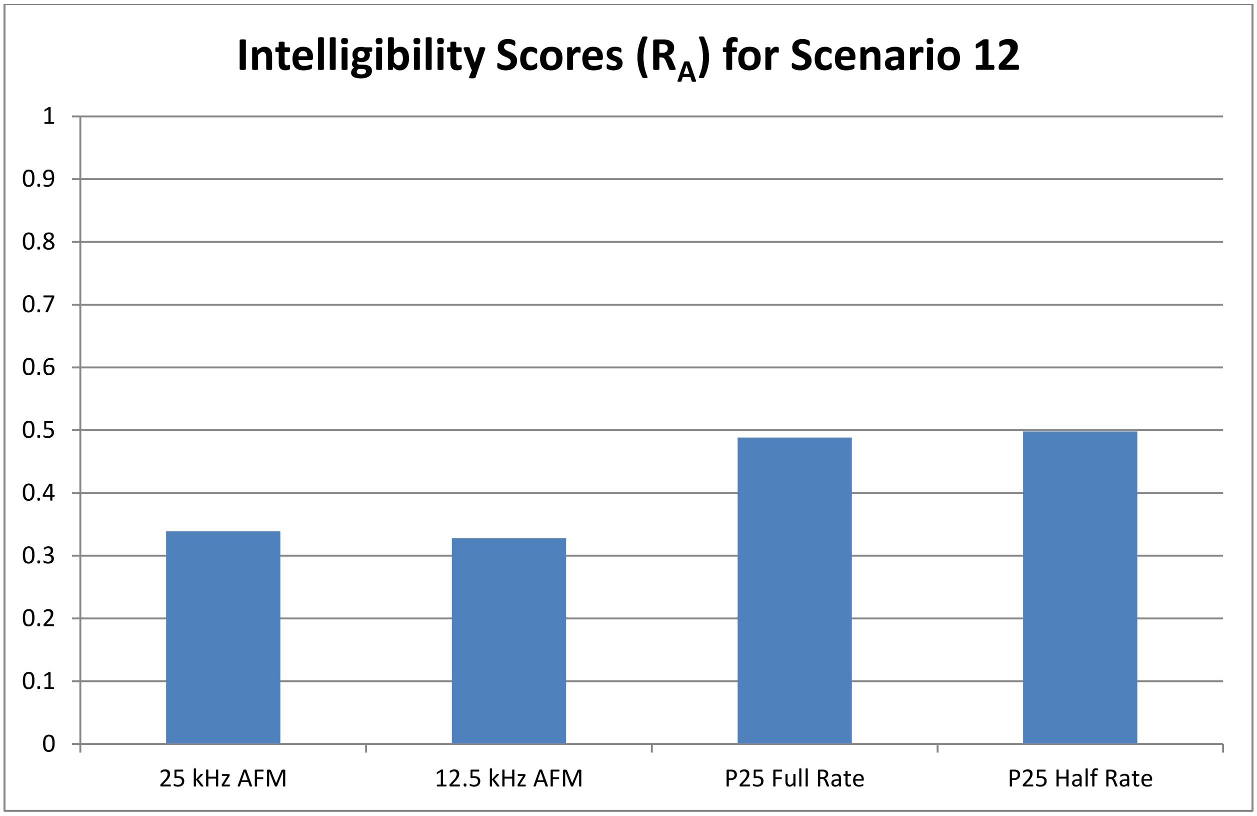

Figure 26. Intelligibility scores (R_A) for Scenario 12.

6.1.13 Results for Scenario 13: "PASS 1, Mask (Int Mic), Degraded RF Channel"

Scenario 13 consisted of PASS alarm 1 background noise, SCBA mask with internal microphone, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 17 contains the intelligibility scores for this environment. Due to an error in the file creation process, the intelligibility scores for 25 kHz and 12.5 kHz AFM are invalid and not reported. No further statistical analysis is available.

Figure 27 contains the bar chart of results for this environment.

Table 17. Intelligibility scores for Scenario 13.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
---	---	0.718	0.711

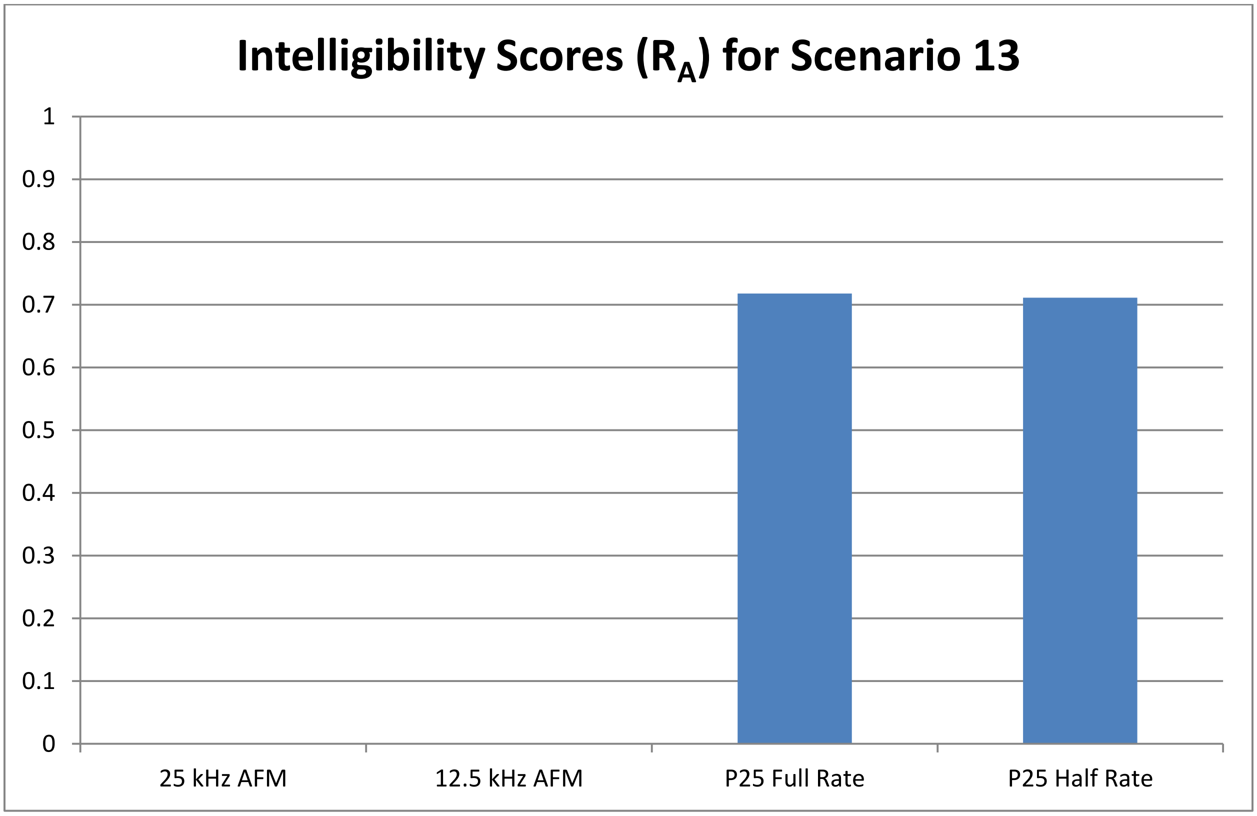

Figure 27. Intelligibility scores (R_A) for Scenario 13.

6.1.14 Results for Scenario 14: "Night Club, No Mask, Degraded RF Channel"

Scenario 14 consisted of night club background noise, no SCBA mask, and a statically degraded RF channel. The listening environment was as described in Section 5.3. Table 18 contains the intelligibility scores and ANOVA results for this environment. The detailed Minitab report is found in Appendix A.

Figure 28 contains the bar chart of results for this environment. The ANOVA did not reveal a statistically significant difference, thus a Tukey test was not performed.

Table 18. Intelligibility scores and ANOVA results results for Scenario 14.

Intelligibility Scores (R_A)

25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
0.542	0.470	0.530	0.463

One-way ANOVA: R_A versus System

Source	DF	SS	MS	F	P	Significant?
Condition	3	0.1182	0.0394	2.51	0.064	NO
Error	92	1.4464	0.0157			
Total	95	1.5646				

S = 0.1254 R-Sq = 7.56% R-Sq(adj) = 4.54%

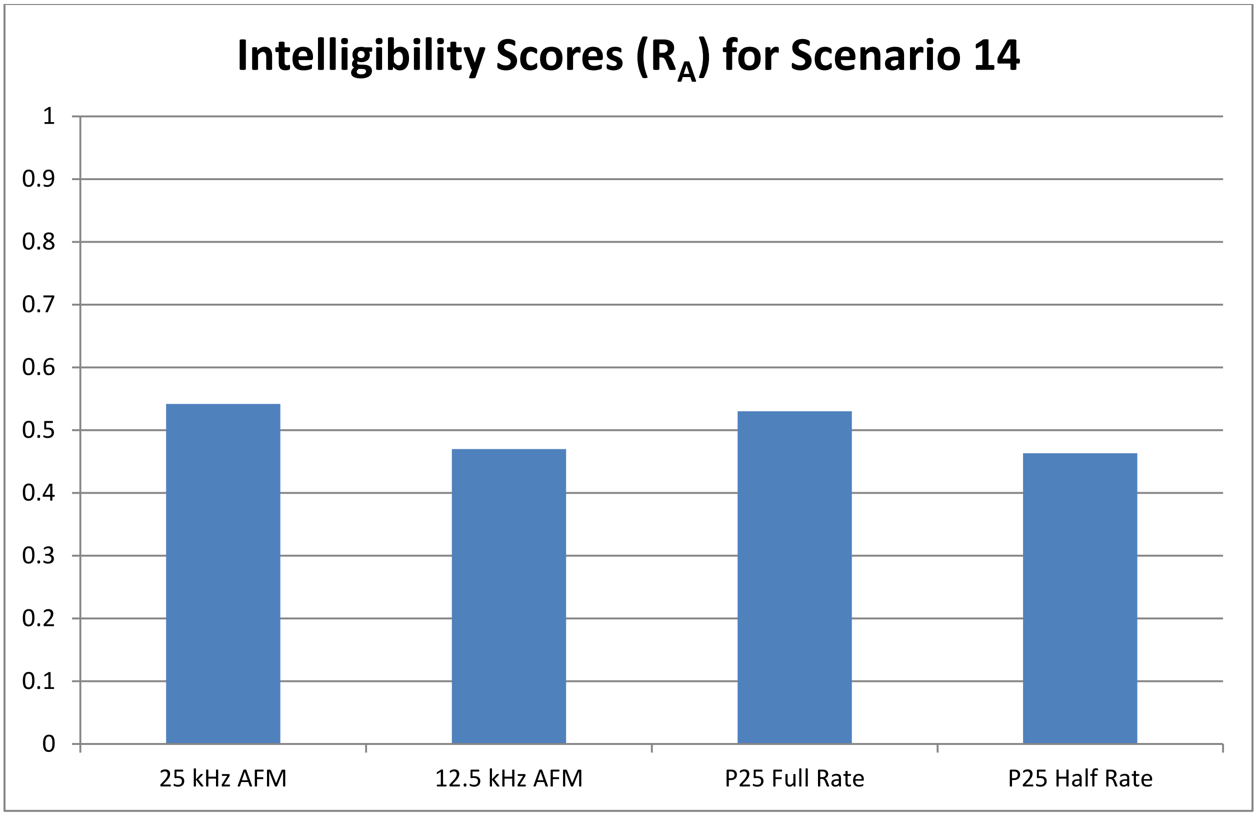

Figure 28. Intelligibility scores (R_A) for Scenario 14.

6.2 Additional Comparisons of Results

The structure of this experiment enabled some additional comparisons. Those include evaluating possible differences between the two different PASS alarms, and between the mask with a vox port and the mask with an internal microphone. Further, changes in best practices and changes in the vocoder between the test in [6] and the current test can be evaluated.

6.2.1 Comparison of Two PASS Alarms

Two comparisons can be made from the current test data regarding the use of different PASS alarms. The first is between Scenarios 4 and 5, and the second is between Scenarios 6 and 7.

Table 19 contains the intelligibility scores for this comparison. The detailed Minitab reports are in Appendix A. Figure 29 contains the bar chart of results for Scenarios 4 and 5, and Figure 30 contains the bar chart of results for Scenarios 6 and 7. The ANOVA test did not show any significant differences in intelligibility between the scenarios using PASS 1 and those using PASS 2.

Table 19. Intelligibility scores for PASS alarm comparison

Scenario	25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
PASS 1 – Vox Port	0.606	0.586	0.499	0.508
PASS 2 – Vox Port	0.554	0.550	0.485	0.481
PASS 1 – Int Mic	0.800	0.822	0.707	0.710
PASS 2 – Int Mic	0.817	0.817	0.715	0.711

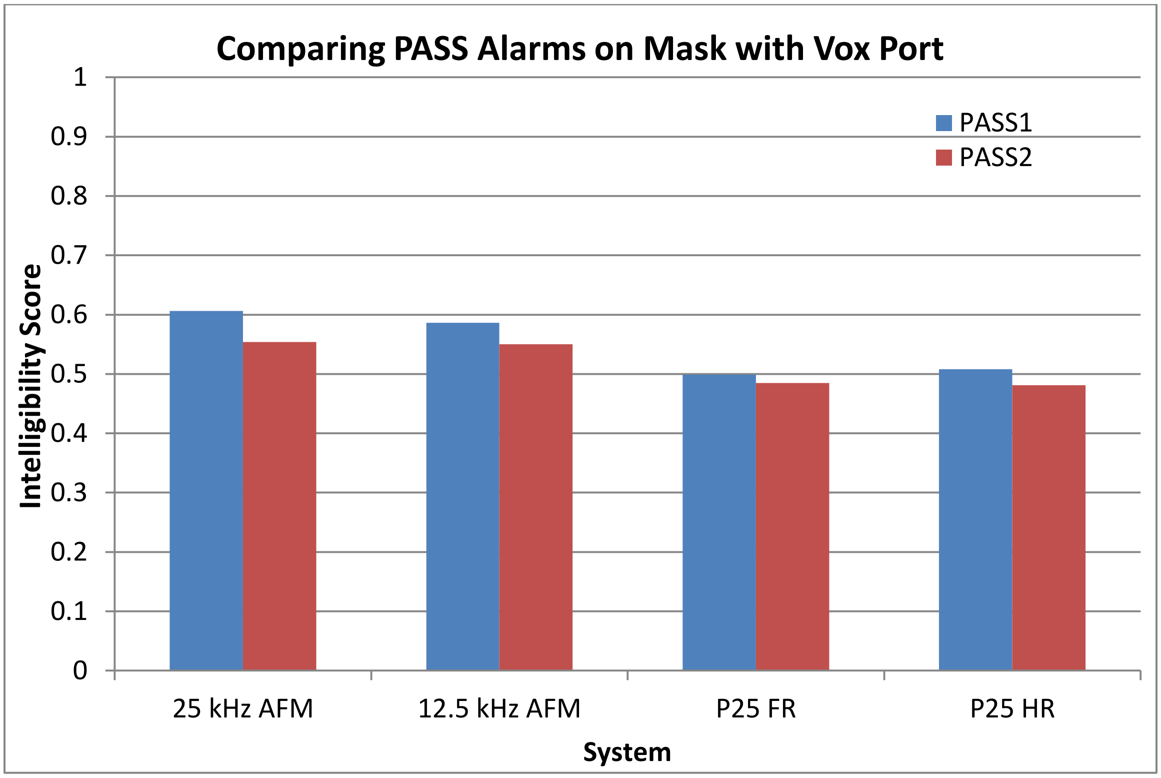

Figure 29. Intelligibility scores for PASS 1 and PASS 2 for a mask with a vox port.

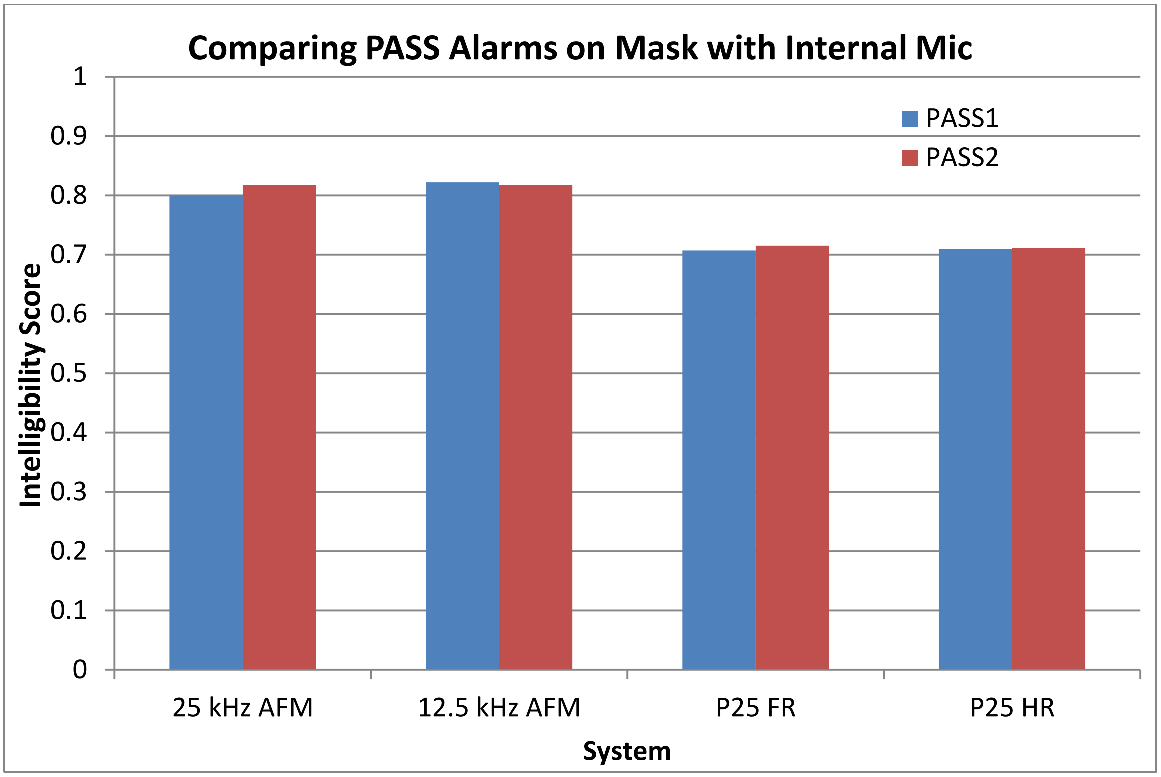

Figure 30. Intelligibility scores for PASS 1 and PASS 2 for a mask with internal mic.

6.2.2 Comparison of SCBA Masks

Five scenarios were repeated with two SCBA masks. One of the masks used a microphone held to the vox port on the mask, and the other used an internal microphone. Comparisons can be made between Scenarios 2 and 3, 4 and 6, 5 and 7, 10 and 11, and 12 and 13.

Table 20 contains the intelligibility scores for this comparison. The detailed Minitab reports are in Appendix A. Figures Figure 32 through Figure 35 contain the bar chart of results for each comparison. In all cases, the use of an internal microphone instead of the vox port resulted in a significant improvement in intelligibility for the analog systems. For the digital systems, a significant improvement was observed for those conditions with background noise. Differences in intelligibility for digital systems were not determined to be significant for those cases without background noise.

Table 20. Intelligibility scores for comparing vox port to internal microphone

Scenario	25 kHz AFM	12.5 kHz AFM	P25 Full Rate	P25 Half Rate
Vox Port – No Noise	0.754	0.771	0.692	0.672
Int Mic – No noise	0.840	0.831	0.712	0.723
Vox Port - PASS 1	0.606	0.586	0.499	0.508
Int Mic – PASS 1	0.800	0.822	0.707	0.710
Vox Port – PASS 2	0.554	0.550	0.485	0.481
Int Mic – PASS 2	0.817	0.817	0.715	0.711
Vox Port – No Noise – Degraded Channel	0.484	0.409	0.694	0.679
Int Mic – No Noise – Degraded Channel	0.614	0.542	0.728	0.730
Vox Port – PASS 1 – Degraded Channel	0.339	0.328	0.488	0.498
Int Mic – PASS 1 – Degraded Channel	---	---	0.718	0.711

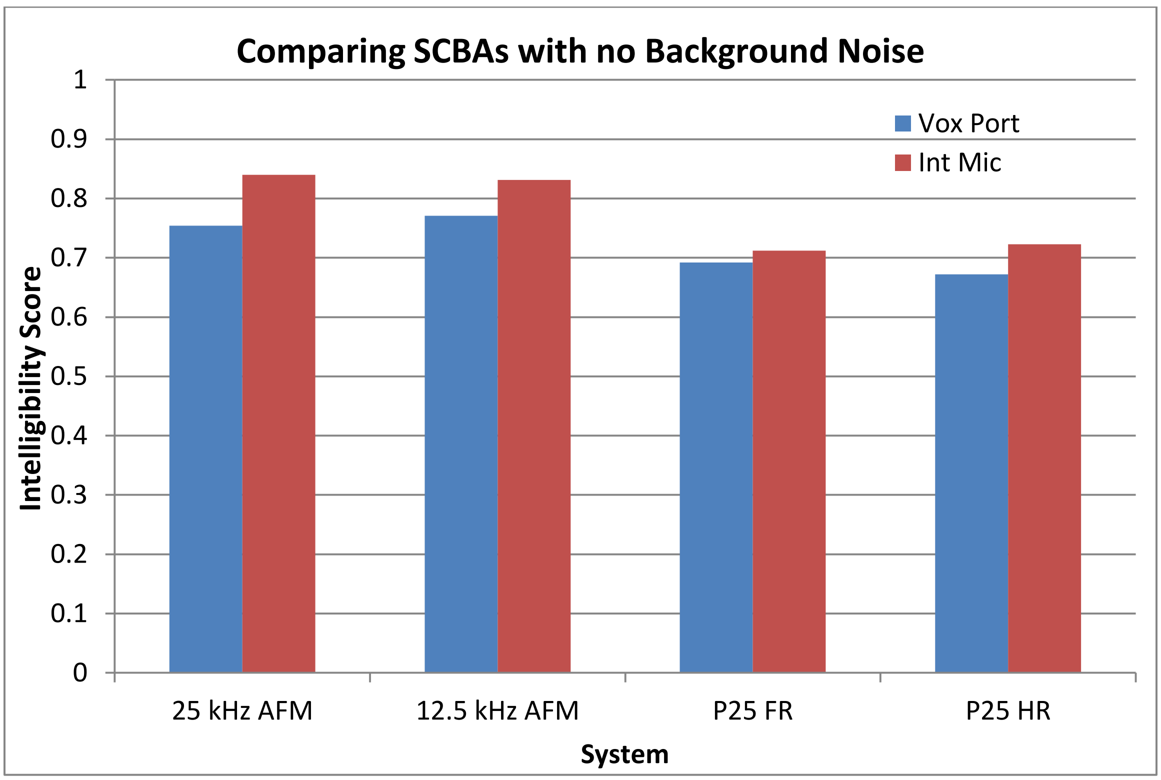

Figure 31. Intelligibility scores for SCBA mask with a vox port or internal microphone.

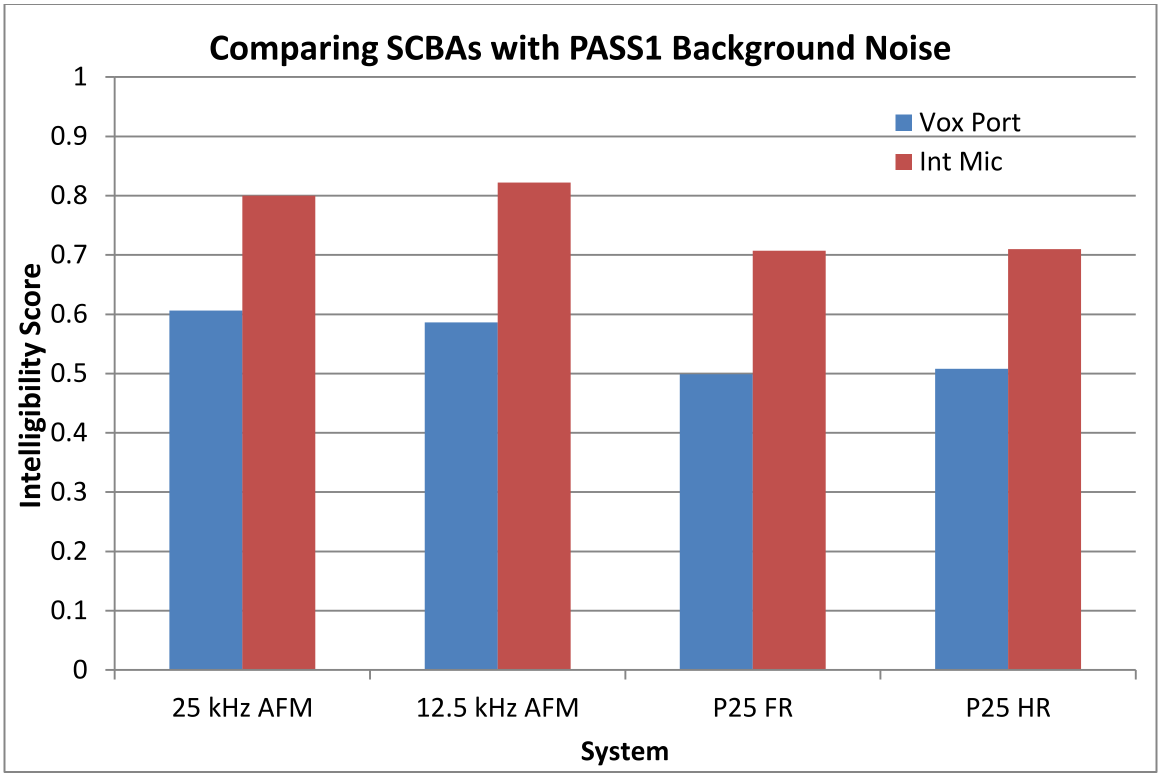

Figure 32. SCBA mask comparison with PASS 1 background noise.

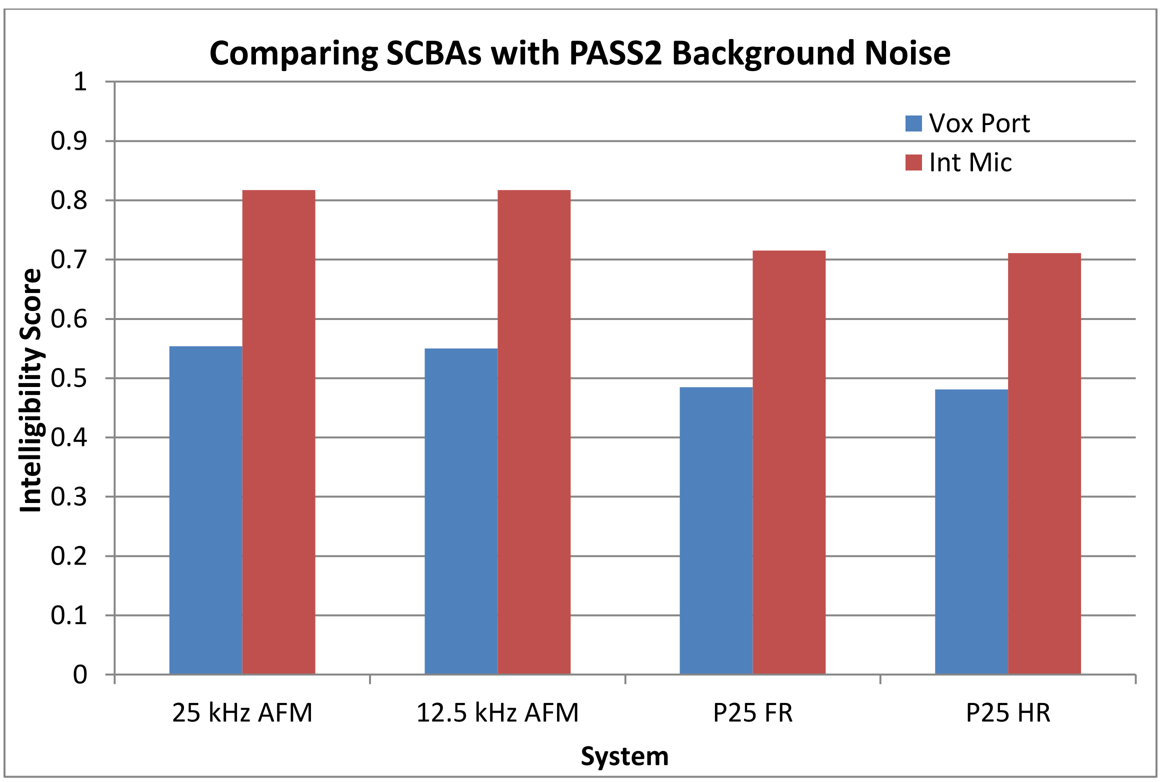

Figure 33. SCBA mask comparison with PASS 2 background noise.

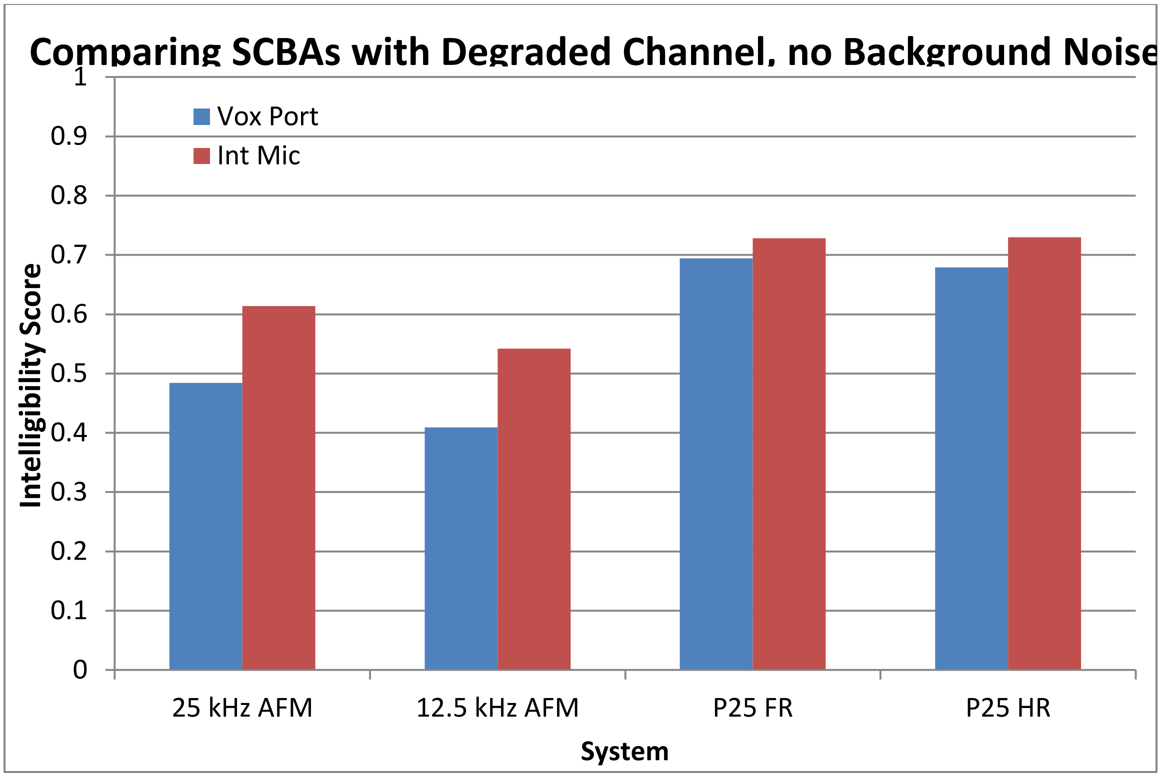

Figure 34. SCBA mask comparison with degraded channel.

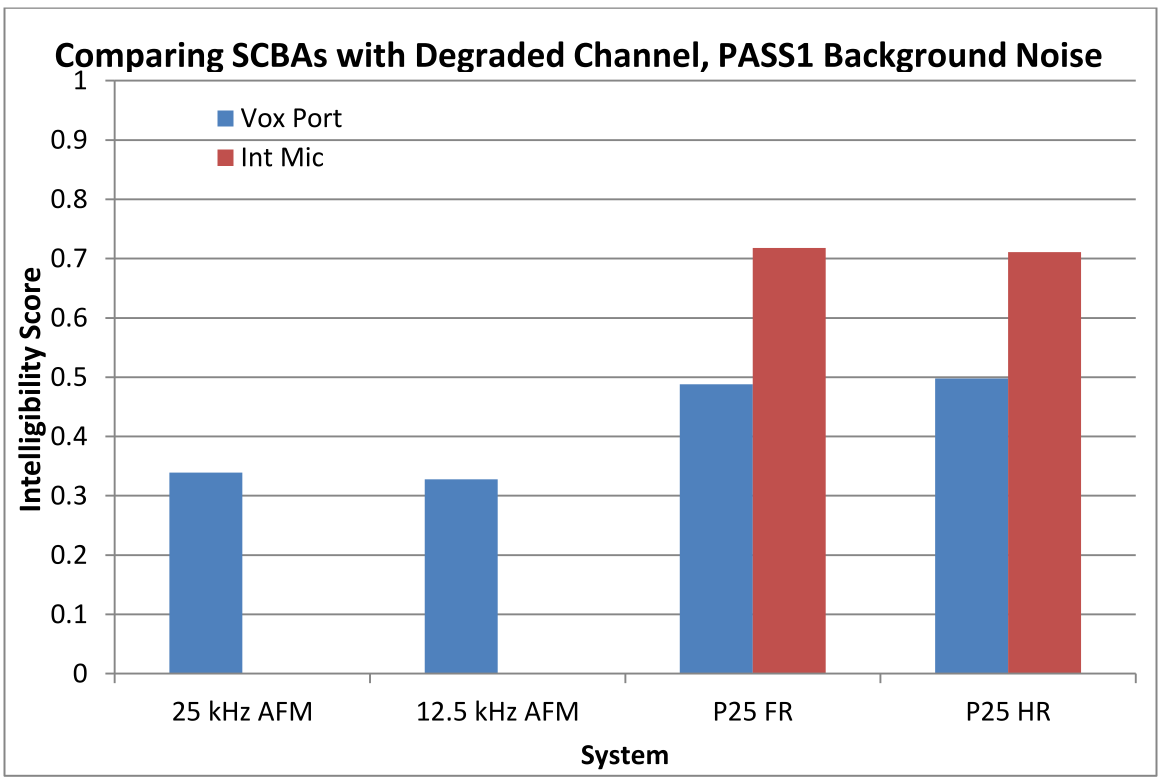

Figure 35. SCBA mask comparison with degraded channel and PASS 1 background noise.

6.2.3 Differences Between Previous and Current Test

Initially, the IAFC recommended that field users hold the radio microphone one to two inches away from the voice port on their mask. Based on the results of our previous test, reported in [6], the IAFC updated their recommendations to hold the microphone directly against the voice port.[12] In the previous test, the microphone was placed one inch away from the SCBA vox port. In the current test, the microphone was placed directly against the SCBA vox port. When the previous test was performed, the most current version of the P25 voice codec was used and can be referred to as "Enhanced Full Rate" (EFR) or QFB ("Q" for QPSK-c modulation, including C4FM and CQPSK, "F" for full rate, and "B" for enhanced). QFB was an improvement over the previously available Baseline Full Rate voice coder. The voice codec used in the current test, software version 1.40e, includes improvements to QFB. Table 21 shows additional differences between the previous test and the current test.

Table 21. Experiment configuration details for the previous and current MRT.

	Previous Test Value	Current Test Value
Distance from vox port to microphone	1 inch	0 inches
Delivered noise-free speech level	82 dBA	83.8-84 dBA
Ambient pink noise level	69.4-69.7 dBA	64.9-65 dBA
Radio implementation method	Hardware	Software
P25 voice codec implementation	QFB	Software version 1.40e

With these differences in mind, it is possible to compare three scenarios that were similar in both tests. In each test there was a scenario where no SCBA was used and no fireground noise was added, a scenario where an SCBA and its vox port were used and no fireground noise was added and a scenario where an SCBA and its vox port were used in the presence of a PASS alarm. Both studies tested 25 kHz analog, 12.5 kHz analog and P25 Full Rate in the first two scenarios. Only the current study tested 12.5 kHz analog in the third scenario.

The intelligibility scores for the analog radio systems in both tests are shown in Table 22. Figure 36 displays the intelligibility scores graphically. Table 23 and Figure 37 show the intelligibility scores achieved by P25 radio systems in both tests.

[12] Official documents [7] and [8] actually specify microphone placement to be "1 to 2 inches from the mouth or SCBA voice port," but an instructional video (linked directly from the IAFC website and available here: http://business.motorola.com/publicsafety/SayItLoud/SayItLoud.html) instructs practitioners to place a microphone directly against the voice port of the SCBA.

Table 22. Intelligibility scores achieved in three different scenarios by AFM radios in both the previous and current test.

Scenario		Previous Test	Current Test
No Mask, No Noise	25 kHz Analog	0.881	0.896
	12.5 kHz Analog	0.886	0.907
Mask (Vox Port), No Noise	25 kHz Analog	0.785	0.754
	12.5 kHz Analog	0.798	0.771
Mask (Vox Port), PASS 1	25 kHz Analog	0.581	0.606
	12.5 kHz Analog	---	0.586

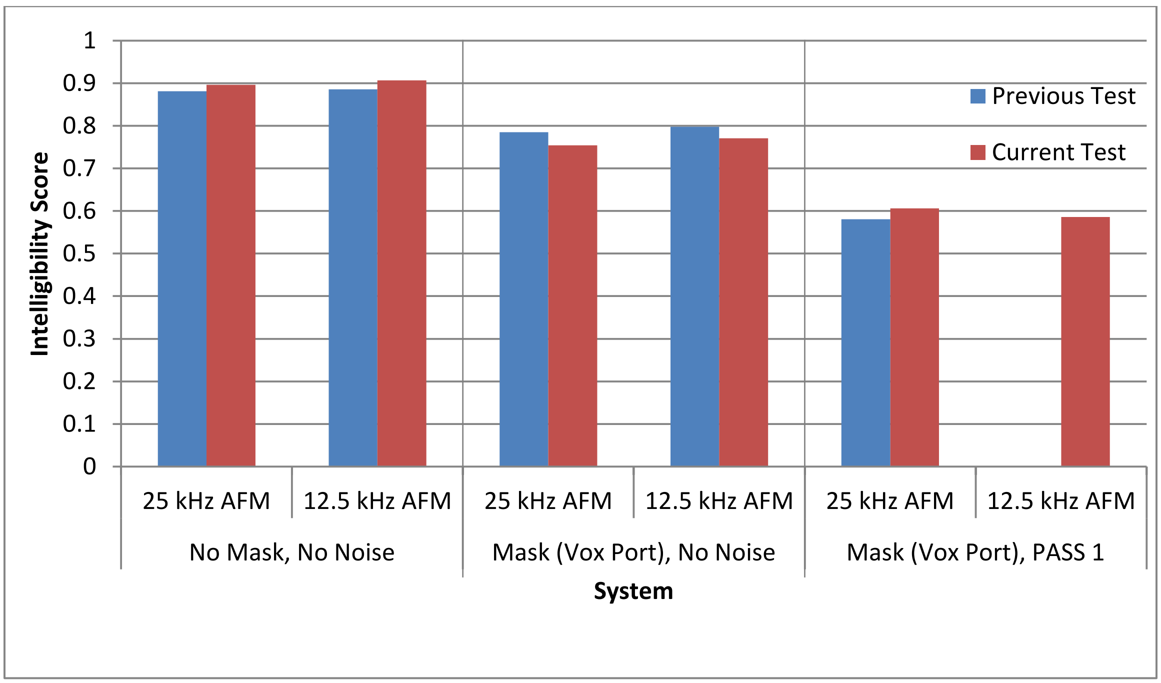

Figure 36. Graphical representation of intelligibility scores achieved in three different scenarios by AFM systems in both the previous and current test.

Table 23. Intelligibility scores achieved in three different scenarios by P25 systems in both the previous and current test.

Scenario		Previous Test	Current Test
No Mask, No Noise	P25 Full Rate	0.800	0.866
Mask (Vox Port), No Noise	P25 Full Rate	0.591	0.692
Mask (Vox Port), PASS 1	P25 Full Rate	0.206	0.499

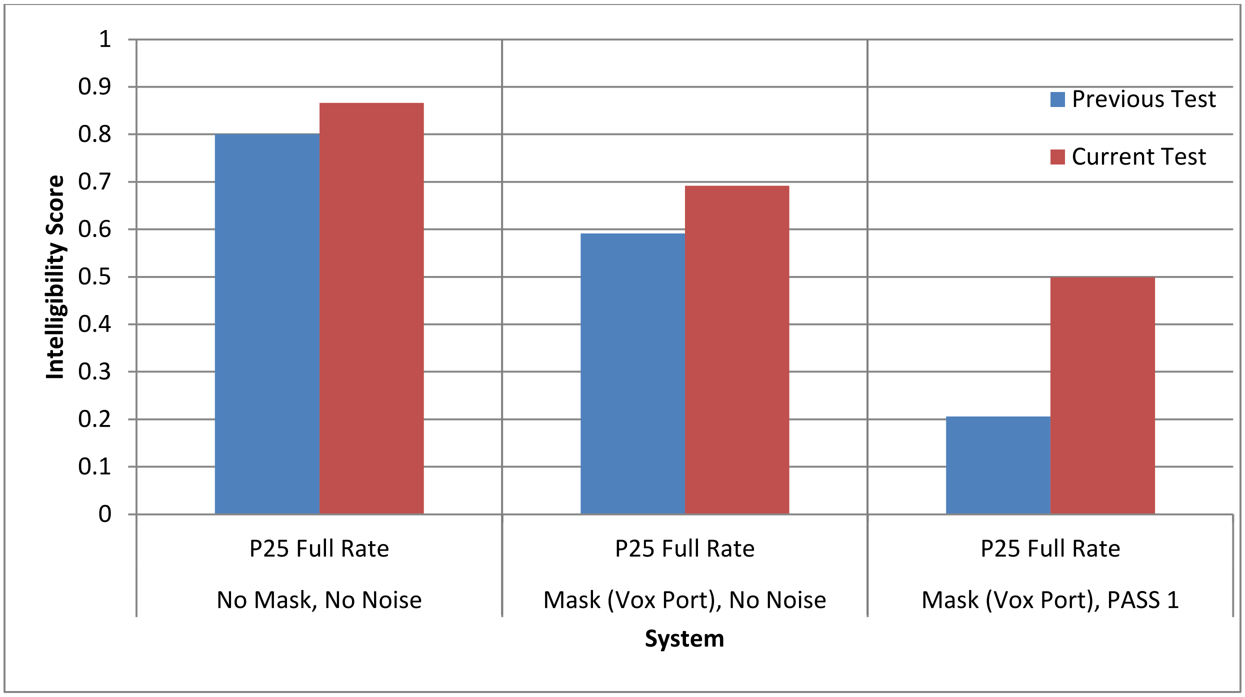

Figure 37. Graphical representation of intelligibility scores achieved in three different scenarios by P25 systems in both the previous and current test.

For the no mask, no noise scenario, in the previous experiment there was a statistically significant difference between the P25 Full Rate systems and the two AFM systems, with the P25 Full Rate system having lower intelligibility. In the current test, the 25 kHz AFM and the P25 systems were statistically similar.

For the mask, no noise scenario, in the previous experiment there was a statistically significant difference between the P25 Full Rate systems and the two analog systems, with the P25 Full Rate system having lower intelligibility. In the current test, the three systems were not statistically significantly different.

For the mask and PASS alarm scenario, in the previous experiment there was a statistically significant difference between the P25 Full Rate systems and 25 kHz AFM, with the P25 Full Rate system having lower intelligibility. In the current test, both P25 systems were statistically similar to the 12.5 kHz AFM, but statistically different from the 25 kHz AFM, having a lower score. The 25 kHz AFM and 12.5 kHz AFM systems were statistically similar.

The results show that for analog systems, the cumulative effect of all the changes between the two tests resulted in changes in intelligibility score ranging from a decrease by 0.031 R_A units to an increase by 0.025 R_A units The similarity of these intelligibility scores may validate the software implementation method. For P25 Full Rate, the cumulative effect of all changes resulted in an intelligibility score increase by 0.066 R_A units for the no mask, no noise scenario, an increase by 0.101 R_A units for the mask, no noise scenario and an increase by 0.293 R_A units for the mask and PASS alarm noise scenario. The magnitude of the change of intelligibility scores for P25 systems ranges from 2 to 10 times the size of the magnitude of the change of intelligibility scores for AFM systems. There are four changes between the two tests that are common to both the 25 kHz AFM and the P25 systems: the decrease in distance from the vox port to the microphone, the increase in delivered speech volume, the decrease in pink noise volume, and the switch from hardware to software implementations. Because of these four commonalities, it may be possible to attribute the P25 performance increases to the combination of the improved voice codec and the shorter distance between the vox port and microphone.

6.3 Summary of Observations

For the clean channel condition in scenarios 1, 2, 4, and 5, the statistical comparison showed a near equivalence between the two AFM systems and the two P25 systems. In the case of Scenario 5, the equivalence was for all four systems, while in the other three scenarios there was significant overlap to equate one or more of the systems with all the others. Three of these four scenarios used the mask with the vox port. The other four clean channel conditions in Scenarios 3, 6, 7, and 8 showed a clear separation, with the two analog systems scoring higher than the two P25 systems. It can be noted that three of these four scenarios used the mask with the internal microphone.

The largest difference in this test was observed in the night club noise scenario. This is likely due to the similarity in spectra between the speech and the background noise (music and talker babble).

For the degraded channel Scenarios 9, 10, 11 and 12, the two P25 systems were statistically better than the two analog systems. In Scenario 9, the 12.5 kHz analog system was significantly worse than the other three systems. The last degraded channel scenario, Scenario 14 with nightclub noise, showed statistical equivalence for all four systems.

For all Scenarios, the P25 full rate and P25 half-rate systems were considered equivalent, although there were two cases (Scenarios 1 and 2) where the small difference between the systems caused one of the P25 systems to be similar to one of the analog systems.

Additionally, the use of different PASS alarms had no observed significant impact on the intelligibility of the audio, but the use of a mask with an internal microphone improved intelligibility in all tested cases for the analog systems, and in most cases for the P25 systems.

Compared with the results obtained in [6], the performance of P25 Full Rate systems seems to have improved. This may be due to the cumulative effect of all the differences between the previous and current test, including experimental setup, an improved voice codec, and updated best practices.

7 CONCLUSION

The effort practitioners and manufacturers are putting into improving intelligibility is making a difference. This is fully realized by looking at all aspects of the system and making a series of small improvements that ultimately result in significant improvements. This experiment has documented the results of two such improvements, as well as performing an initial intelligibility baseline study of the P25 half-rate vocoder.

Some areas for potential future study might include noise cancelling microphones and other noise mitigating accessories. Also, it can be useful to obtain a better understanding of the impact that a range of channel impairment levels has on intelligibility.

Overall, since 2008, progress has been made to improve intelligibility in high-background-noise environments. With continued effort, there are promises of even more improvements. This will result in better communication for public safety practitioners, improving their safety and making them more effective.

8 ACKNOWLEDGEMENTS

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- Florida Department of Law Enforcement
- Littleton Colorado Fire Department
- Morris Illinois Fire Department
- New Jersey Police Task Force
- Oakland California Fire Department
- Ohio Multi-Agency Radio Communications (MARCS)
- Orlando Florida Fire Department
- Orleans County New York
- Pickaway County Ohio Sheriff's Office
- Plainfield Indiana Fire Department
- State of Colorado
- Texas Department of Transportation
- Utah Communications Agency Network

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APPENDIX A: CONDITION LABELS AND MINITAB RESULTS

This Appendix contains the condition labels and Minitab results for this experiment. Table A-1 contains the list of condition labels for this experiment. These labels are used in the file naming and are correlated to the scenario numbers used in reporting results in Section 6.

Table A-1 List of condition labels used for this experiment.

Condition Label	Reference System	RF Channel	Background Noise
c01	25 kHz AFM	Clean	No mask, no background noise
c02	25 kHz AFM	Clean	Mask (vox port), no background noise
c03	25 kHz AFM	Clean	Mask (int mic), no background noise
c04	25 kHz AFM	Clean	Mask (vox port), PASS 1 (-2 dB SNR)
c05	25 kHz AFM	Clean	Mask (vox port), PASS 2 (-2 dB SNR)
c06	25 kHz AFM	Clean	Mask (int mic), PASS 1 (-2 dB SNR)
c07	25 kHz AFM	Clean	Mask (int mic), PASS 2 (-2 dB SNR)
c08	25 kHz AFM	Clean	No mask, night club noise (5 db SNR)
c09	25 kHz AFM	Static Degraded	No mask, no background noise
c10	25 kHz AFM	Static Degraded	Mask (vox port), no background noise
c11	25 kHz AFM	Static Degraded	Mask (int mic), no background noise
c12	25 kHz AFM	Static Degraded	Mask (vox port), PASS 1 (-2 dB SNR)
c13	25 kHz AFM	Static Degraded	Mask (int mic), PASS 1 (-2 dB SNR) (creation error)
c14	25 kHz AFM	Static Degraded	No mask, night club noise (5 db SNR)
c15	12.5 kHz AFM	Clean	No mask, no background noise
c16	12.5 kHz AFM	Clean	Mask (vox port), no background noise
c17	12.5 kHz AFM	Clean	Mask (int mic), no background noise
c18	12.5 kHz AFM	Clean	Mask (vox port), PASS 1 (-2 dB SNR)
c19	12.5 kHz AFM	Clean	Mask (vox port), PASS 2 (-2 dB SNR)
c20	12.5 kHz AFM	Clean	Mask (int mic), PASS 1 (-2 dB SNR)
c21	12.5 kHz AFM	Clean	Mask (int mic), PASS 2 (-2 dB SNR)
c22	12.5 kHz AFM	Clean	No mask, night club noise (5 db SNR)
c23	12.5 kHz AFM	Static Degraded	No mask, no background noise
c24	12.5 kHz AFM	Static Degraded	Mask (vox port), no background noise
c25	12.5 kHz AFM	Static Degraded	Mask (int mic), no background noise
c26	12.5 kHz AFM	Static Degraded	Mask (vox port), PASS 1 (-2 dB SNR)
c27	12.5 kHz AFM	Static Degraded	Mask (int mic), PASS 1 (-2 dB SNR) (creation error)
c28	12.5 kHz AFM	Static Degraded	No mask, night club noise (5 db SNR)
c29	P25 FR	Clean	No mask, no background noise

Condition Label	Reference System	RF Channel	Background Noise
c30	P25 FR	Clean	Mask (vox port), no background noise
c31	P25 FR	Clean	Mask (int mic), no background noise
c32	P25 FR	Clean	Mask (vox port), PASS 1 (-2 dB SNR)
c33	P25 FR	Clean	Mask (vox port), PASS 2 (-2 dB SNR)
c34	P25 FR	Clean	Mask (int mic), PASS 1 (-2 dB SNR)
c35	P25 FR	Clean	Mask (int mic), PASS 2 (-2 dB SNR)
c36	P25 FR	Clean	No mask, night club noise (5 db SNR)
c37	P25 FR	Static Degraded	No mask, no background noise
c38	P25 FR	Static Degraded	Mask (vox port), no background noise
c39	P25 FR	Static Degraded	Mask (int mic), no background noise
c40	P25 FR	Static Degraded	Mask (vox port), PASS 1 (-2 dB SNR)
c41	P25 FR	Static Degraded	Mask (int mic), PASS 1 (-2 dB SNR)
c42	P25 FR	Static Degraded	No mask, night club noise (5 db SNR)
c43	P25 HR	Clean	No mask, no background noise
c44	P25 HR	Clean	Mask (vox port), no background noise
c45	P25 HR	Clean	Mask (int mic), no background noise
c46	P25 HR	Clean	Mask (vox port), PASS 1 (-2 dB SNR)
c47	P25 HR	Clean	Mask (vox port), PASS 2 (-2 dB SNR)
c48	P25 HR	Clean	Mask (int mic), PASS 1 (-2 dB SNR)
c49	P25 HR	Clean	Mask (int mic), PASS 2 (-2 dB SNR)
c50	P25 HR	Clean	No mask, night club noise (5 db SNR)
c51	P25 HR	Static Degraded	No mask, no background noise
c52	P25 HR	Static Degraded	Mask (vox port), no background noise
c53	P25 HR	Static Degraded	Mask (int mic), no background noise
c54	P25 HR	Static Degraded	Mask (vox port), PASS 1 (-2 dB SNR)
c55	P25 HR	Static Degraded	Mask (int mic), PASS 1 (-2 dB SNR)
c56	P25 HR	Static Degraded	No mask, night club noise (5 db SNR)

A.1 Minitab Report for Scenario 1

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS     F      P
System   3  0.06082  0.02027  5.83  0.001
Error   92  0.32011  0.00348
Total   95  0.38093

S = 0.05899   R-Sq = 15.97%   R-Sq(adj) = 13.22%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      24  0.89600  0.04835                 (--------*--------)
2      24  0.90700  0.04970                    (--------*--------)
3      24  0.86600  0.06483        (--------*--------)
4      24  0.84300  0.07005  (--------*--------)
                             --------+---------+---------+---------+-
                                   0.840     0.875     0.910     0.945

Pooled StDev = 0.05899

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       -0.04354   0.01100  0.06554
3       -0.08454  -0.03000  0.02454
4       -0.10754  -0.05300  0.00154

System     +---------+---------+---------+---------
2                       (--------*--------)
3                (--------*--------)
4            (--------*--------)
           +---------+---------+---------+---------
        -0.120    -0.060     0.000     0.060

System = 2 subtracted from:

System     Lower    Center     Upper
3       -0.09554  -0.04100   0.01354
4       -0.11854  -0.06400  -0.00946

System     +---------+---------+---------+---------
3              (--------*--------)
4          (--------*--------)
           +---------+---------+---------+---------
        -0.120    -0.060     0.000     0.060

System = 3 subtracted from:

System     Lower    Center    Upper
4       -0.07754  -0.02300  0.03154

System     +---------+---------+---------+---------
4                 (--------*--------)
           +---------+---------+---------+---------
        -0.120    -0.060     0.000     0.060
```

A.2 Minitab Report for Scenario 2

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS     F      P
System   3  0.16379  0.05460  6.55  0.000
Error   92  0.76673  0.00833
Total   95  0.93052

S = 0.09129   R-Sq = 17.60%   R-Sq(adj) = 14.92%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
1      24  0.75400  0.09940                 (---------*---------)
2      24  0.77100  0.06897                    (---------*---------)
3      24  0.69200  0.10050      (--------*---------)
4      24  0.67200  0.09273  (--------*---------)
                             -----+---------+---------+---------+----
                               0.650     0.700     0.750     0.800

Pooled StDev = 0.09129

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       -0.06741   0.01700  0.10141            (--------*-------)
3       -0.14641  -0.06200  0.02241    (--------*-------)
4       -0.16641  -0.08200  0.00241  (--------*-------)
                                     --------+---------+---------+---------+-
                                          -0.10      0.00      0.10      0.20

System = 2 subtracted from:

System     Lower    Center     Upper  --------+---------+---------+---------+-
3       -0.16341  -0.07900   0.00541    (-------*--------)
4       -0.18341  -0.09900  -0.01459  (-------*--------)
                                      --------+---------+---------+---------+-
                                           -0.10      0.00      0.10      0.20

System = 3 subtracted from:

System     Lower    Center    Upper  --------+---------+---------+---------+-
4       -0.10441  -0.02000  0.06441          (-------*-------)
                                     --------+---------+---------+---------+-
                                          -0.10      0.00      0.10      0.20
```

A.3 Minitab Report for Scenario 3

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  0.33660  0.11220  19.18  0.000
Error   92  0.53813  0.00585
Total   95  0.87473

S = 0.07648   R-Sq = 38.48%   R-Sq(adj) = 36.47%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      24  0.84000  0.08542                     (------*------)
2      24  0.83100  0.05549                    (------*-----)
3      24  0.71200  0.08754  (------*------)
4      24  0.72300  0.07320    (------*-----)
                             --------+---------+---------+---------+-
                                   0.720     0.780     0.840     0.900

Pooled StDev = 0.07648

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       -0.07972  -0.00900   0.06172
3       -0.19872  -0.12800  -0.05728
4       -0.18772  -0.11700  -0.04628

System     +---------+---------+---------+---------
2                     (------*------)
3          (------*------)
4           (------*------)
           +---------+---------+---------+---------
        -0.20     -0.10      0.00      0.10

System = 2 subtracted from:

System     Lower    Center     Upper
3       -0.18972  -0.11900  -0.04828
4       -0.17872  -0.10800  -0.03728

System     +---------+---------+---------+---------
3           (------*------)
4            (------*------)
           +---------+---------+---------+---------
        -0.20     -0.10      0.00      0.10

System = 3 subtracted from:

System     Lower   Center    Upper     +---------+---------+---------+---------
4       -0.05972  0.01100  0.08172                   (------*------)
                                       +---------+---------+---------+---------
                                    -0.20     -0.10      0.00      0.10
```

A.4 Minitab Report for Scenario 4

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS     F      P
System   3  0.21112  0.07037  7.06  0.000
Error   92  0.91754  0.00997
Total   95  1.12867

S = 0.09987   R-Sq = 18.71%   R-Sq(adj) = 16.05%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      24  0.60600  0.09413                    (--------*--------)
2      24  0.58600  0.11218                 (--------*--------)
3      24  0.49900  0.08353  (--------*--------)
4      24  0.50800  0.10710    (--------*--------)
                             ------+---------+---------+---------+---
                                 0.480     0.540     0.600     0.660

Pooled StDev = 0.09987

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       -0.11234  -0.02000   0.07234
3       -0.19934  -0.10700  -0.01466
4       -0.19034  -0.09800  -0.00566

System     +---------+---------+---------+---------
2                   (--------*--------)
3          (--------*---------)
4           (--------*--------)
           +---------+---------+---------+---------
        -0.20     -0.10      0.00      0.10

System = 2 subtracted from:

0.5
3       -0.17934  -0.08700  0.00534
4       -0.17034  -0.07800  0.01434

System     +---------+---------+---------+---------
3            (--------*---------)
4             (--------*--------)
           +---------+---------+---------+---------
        -0.20     -0.10      0.00      0.10

System = 3 subtracted from:

System     Lower   Center    Upper     +---------+---------+---------+---------
4       -0.08334  0.00900  0.10134                (--------*--------)
                                       +---------+---------+---------+---------
                                    -0.20     -0.10      0.00      0.10
```

A.5 Minitab Report for Scenario 5

One-way ANOVA: R_A versus System

```
Source  DF      SS      MS     F      P
System   3  0.1146  0.0382  3.30  0.024
Error   92  1.0644  0.0116
Total   95  1.1790

S = 0.1076   R-Sq = 9.72%   R-Sq(adj) = 6.78%

                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
1      24  0.5540  0.1061                (-----------*----------)
2      24  0.5500  0.1060               (-----------*-----------)
3      24  0.4850  0.1011  (-----------*-----------)
4      24  0.4810  0.1165  (----------*-----------)
                           -----+---------+---------+---------+----
                              0.450     0.500     0.550     0.600

Pooled StDev = 0.1076

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       -0.1035  -0.0040  0.0955         (---------*---------)
3       -0.1685  -0.0690  0.0305  (---------*---------)
4       -0.1725  -0.0730  0.0265  (---------*---------)
                                  -------+---------+---------+---------+--
                                     -0.10      0.00      0.10      0.20

System = 2 subtracted from:

System    Lower   Center   Upper  -------+---------+---------+---------+--
3       -0.1645  -0.0650  0.0345   (--------*---------)
4       -0.1685  -0.0690  0.0305  (---------*---------)
                                  -------+---------+---------+---------+--
                                     -0.10      0.00      0.10      0.20

System = 3 subtracted from:

System    Lower   Center   Upper  -------+---------+---------+---------+--
4       -0.1035  -0.0040  0.0955         (---------*---------)
                                  -------+---------+---------+---------+--
                                     -0.10      0.00      0.10      0.20
```

A.6 Minitab Report for Scenario 6

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  0.25807  0.08602  16.78  0.000
Error   92  0.47172  0.00513
Total   95  0.72979

S = 0.07161   R-Sq = 35.36%   R-Sq(adj) = 33.25%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      24  0.80000  0.07411                    (-------*-------)
2      24  0.82200  0.06405                         (------*-------)
3      24  0.70700  0.07880  (------*-------)
4      24  0.71000  0.06859  (-------*-------)
                             ------+---------+---------+---------+---
                                 0.700     0.750     0.800     0.850

Pooled StDev = 0.07161

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       -0.04421   0.02200   0.08821                 (-----*------)
3       -0.15921  -0.09300  -0.02679    (------*-----)
4       -0.15621  -0.09000  -0.02379    (------*------)
                                      --------+---------+---------+---------+-
                                           -0.10      0.00      0.10      0.20

System = 2 subtracted from:

System     Lower    Center     Upper  --------+---------+---------+---------+-
3       -0.18121  -0.11500  -0.04879  (-----*------)
4       -0.17821  -0.11200  -0.04579  (------*-----)
                                      --------+---------+---------+---------+-
                                           -0.10      0.00      0.10      0.20

System = 3 subtracted from:

System     Lower   Center    Upper  --------+---------+---------+---------+-
4       -0.06321  0.00300  0.06921              (-----*------)
                                    --------+---------+---------+---------+-
                                         -0.10      0.00      0.10      0.20
```

A.7 Minitab Report for Scenario 7

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  0.25978  0.08659  17.23  0.000
Error   92  0.46243  0.00503
Total   95  0.72221

S = 0.07090   R-Sq = 35.97%   R-Sq(adj) = 33.88%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
1      24  0.81700  0.08777                      (------*-------)
2      24  0.81700  0.07747                      (------*-------)
3      24  0.71500  0.05496  (-------*-------)
4      24  0.71100  0.05814  (------*-------)
                             -----+---------+---------+---------+----
                                0.700     0.750     0.800     0.850

Pooled StDev = 0.07090

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       -0.06556  -0.00000   0.06556            (------*------)
3       -0.16756  -0.10200  -0.03644  (------*-----)
4       -0.17156  -0.10600  -0.04044  (-----*------)
                                      -------+---------+---------+---------+--
                                          -0.10      0.00      0.10      0.20

System = 2 subtracted from:

System     Lower    Center     Upper  -------+---------+---------+---------+--
3       -0.16756  -0.10200  -0.03644  (------*-----)
4       -0.17156  -0.10600  -0.04044  (-----*------)
                                      -------+---------+---------+---------+--
                                          -0.10      0.00      0.10      0.20

System = 3 subtracted from:

System     Lower    Center    Upper  -------+---------+---------+---------+--
4       -0.06956  -0.00400  0.06156            (------*-----)
                                     -------+---------+---------+---------+--
                                         -0.10      0.00      0.10      0.20
```

A.8 Minitab Report for Scenario 8

One-way ANOVA: R_A versus System

```
Source  DF      SS      MS      F      P
System   3  0.7115  0.2372  16.20  0.000
Error   92  1.3467  0.0146
Total   95  2.0582

S = 0.1210   R-Sq = 34.57%   R-Sq(adj) = 32.43%

                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ------+---------+---------+---------+---
1      24  0.6830  0.1148                        (-------*-------)
2      24  0.6560  0.0992                     (-------*-------)
3      24  0.4940  0.1454  (-------*-------)
4      24  0.5030  0.1200   (-------*-------)
                           ------+---------+---------+---------+---
                               0.480     0.560     0.640     0.720

Pooled StDev = 0.1210

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       -0.1389  -0.0270   0.0849               (------*-------)
3       -0.3009  -0.1890  -0.0771     (------*-------)
4       -0.2919  -0.1800  -0.0681      (------*------)
                                      +---------+---------+---------+---------
                                   -0.30     -0.15      0.00      0.15

System = 2 subtracted from:

System    Lower   Center    Upper     +---------+---------+---------+---------
3       -0.2739  -0.1620  -0.0501       (------*-------)
4       -0.2649  -0.1530  -0.0411       (-------*------)
                                      +---------+---------+---------+---------
                                   -0.30     -0.15      0.00      0.15

System = 3 subtracted from:

System    Lower  Center   Upper     +---------+---------+---------+---------
4       -0.1029  0.0090  0.1209                 (-------*------)
                                    +---------+---------+---------+---------
                                 -0.30     -0.15      0.00      0.15
```

A.9 Minitab Report for Scenario 9

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  1.30058  0.43353  57.49  0.000
Error   92  0.69377  0.00754
Total   95  1.99435

S = 0.08684   R-Sq = 65.21%   R-Sq(adj) = 64.08%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
1      24  0.70100  0.08979             (----*----)
2      24  0.59000  0.12009  (----*----)
3      24  0.87600  0.05233                                (----*---)
4      24  0.85200  0.07030                              (---*----)
                             ------+---------+---------+---------+---
                                 0.60      0.70      0.80      0.90

Pooled StDev = 0.08684

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       -0.19130  -0.11100  -0.03070          (---*---)
3        0.09470   0.17500   0.25530                         (---*---)
4        0.07070   0.15100   0.23130                        (---*---)
                                      --------+---------+---------+---------+-
                                          -0.20      0.00      0.20      0.40

System = 2 subtracted from:

System    Lower   Center    Upper  --------+---------+---------+---------+-
3       0.20570  0.28600  0.36630                             (---*---)
4       0.18170  0.26200  0.34230                            (---*---)
                                   --------+---------+---------+---------+-
                                       -0.20      0.00      0.20      0.40

System = 3 subtracted from:

System     Lower    Center    Upper  --------+---------+---------+---------+-
4       -0.10430  -0.02400  0.05630            (---*---)
                                     --------+---------+---------+---------+-
                                         -0.20      0.00      0.20      0.40
```

A.10 Minitab Report for Scenario 10

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  1.45260  0.48420  48.83  0.000
Error   92  0.91224  0.00992
Total   95  2.36484

S = 0.09958   R-Sq = 61.42%   R-Sq(adj) = 60.17%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ----+---------+---------+---------+-----
1      24  0.48400  0.11948         (----*-----)
2      24  0.40900  0.11319  (----*----)
3      24  0.69400  0.07952                             (----*-----)
4      24  0.67900  0.07907                           (----*----)
                             ----+---------+---------+---------+-----
                               0.40      0.50      0.60      0.70

Pooled StDev = 0.09958

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       -0.16708  -0.07500  0.01708            (---*----)
3        0.11792   0.21000  0.30208                          (----*---)
4        0.10292   0.19500  0.28708                         (----*---)
                                     ---------+---------+---------+---------+
                                           -0.20      0.00      0.20      0.40

System = 2 subtracted from:

System    Lower   Center    Upper  ---------+---------+---------+---------+
3       0.19292  0.28500  0.37708                            (---*----)
4       0.17792  0.27000  0.36208                           (----*---)
                                   ---------+---------+---------+---------+
                                         -0.20      0.00      0.20      0.40

System = 3 subtracted from:

System     Lower    Center    Upper  ---------+---------+---------+---------+
4       -0.10708  -0.01500  0.07708               (---*----)
                                     ---------+---------+---------+---------+
                                           -0.20      0.00      0.20      0.40
```

A.11 Minitab Report for Scenario 11

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  0.60948  0.20316  24.52  0.000
Error   92  0.76234  0.00829
Total   95  1.37182

S = 0.09103   R-Sq = 44.43%   R-Sq(adj) = 42.62%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
1      24  0.61400  0.09440          (-----*-----)
2      24  0.54200  0.10778  (-----*-----)
3      24  0.72800  0.08716                        (-----*-----)
4      24  0.73000  0.07086                        (-----*-----)
                             --------+---------+---------+---------+-
                                 0.560     0.640     0.720     0.800

Pooled StDev = 0.09103

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       -0.15617  -0.07200  0.01217          (----*-----)
3        0.02983   0.11400  0.19817                      (-----*----)
4        0.03183   0.11600  0.20017                      (-----*----)
                                     --------+---------+---------+---------+-
                                         -0.15      0.00      0.15      0.30

System = 2 subtracted from:

System    Lower   Center    Upper  --------+---------+---------+---------+-
3       0.10183  0.18600  0.27017                          (----*-----)
4       0.10383  0.18800  0.27217                          (-----*----)
                                   --------+---------+---------+---------+-
                                       -0.15      0.00      0.15      0.30

System = 3 subtracted from:

System     Lower   Center    Upper  --------+---------+---------+---------+-
4       -0.08217  0.00200  0.08617              (----*-----)
                                    --------+---------+---------+---------+-
                                        -0.15      0.00      0.15      0.30
```

A.12 Minitab Report for Scenario 12

One-way ANOVA: R_A versus System

```
Source  DF       SS       MS      F      P
System   3  0.61322  0.20441  20.52  0.000
Error   92  0.91649  0.00996
Total   95  1.52971

S = 0.09981   R-Sq = 40.09%   R-Sq(adj) = 38.13%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev   -+---------+---------+---------+--------
1      24  0.33900  0.08979     (------*-------)
2      24  0.32800  0.09416   (-------*-------)
3      24  0.48800  0.11205                         (-------*------)
4      24  0.49800  0.10180                          (-------*-------)
                              -+---------+---------+---------+--------
                             0.280     0.350     0.420     0.490

Pooled StDev = 0.09981

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       -0.10329  -0.01100  0.08129           (-----*-----)
3        0.05671   0.14900  0.24129                      (-----*-----)
4        0.06671   0.15900  0.25129                      (------*-----)
                                     -------+---------+---------+---------+--
                                         -0.15      0.00      0.15      0.30

System = 2 subtracted from:

System    Lower   Center    Upper  -------+---------+---------+---------+--
3       0.06771  0.16000  0.25229                      (-----*-----)
4       0.07771  0.17000  0.26229                      (-----*-----)
                                   -------+---------+---------+---------+--
                                       -0.15      0.00      0.15      0.30

System = 3 subtracted from:

System     Lower   Center    Upper  -------+---------+---------+---------+--
4       -0.08229  0.01000  0.10229            (-----*-----)
                                    -------+---------+---------+---------+--
                                        -0.15      0.00      0.15      0.30
```

A.13 Minitab Report for Scenario 14

One-way ANOVA: R_A versus System

```
Source  DF      SS      MS     F      P
System   3  0.1182  0.0394  2.51  0.064
Error   92  1.4464  0.0157
Total   95  1.5647

S = 0.1254   R-Sq = 7.56%   R-Sq(adj) = 4.54%

                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  ----+---------+---------+---------+-----
1      24  0.5420  0.1173              (----------*-----------)
2      24  0.4700  0.1256   (----------*-----------)
3      24  0.5300  0.1331            (----------*-----------)
4      24  0.4630  0.1250  (----------*----------)
                           ----+---------+---------+---------+-----
                             0.420     0.480     0.540     0.600

Pooled StDev = 0.1254

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       -0.1879  -0.0720  0.0439  (-----------*----------)
3       -0.1279  -0.0120  0.1039        (-----------*----------)
4       -0.1949  -0.0790  0.0369  (----------*-----------)
                                  ---------+---------+---------+---------+
                                        -0.10      0.00      0.10      0.20

System = 2 subtracted from:

System    Lower   Center   Upper  ---------+---------+---------+---------+
3       -0.0559   0.0600  0.1759               (-----------*-----------)
4       -0.1229  -0.0070  0.1089         (----------*-----------)
                                  ---------+---------+---------+---------+
                                        -0.10      0.00      0.10      0.20

System = 3 subtracted from:

System    Lower   Center   Upper  ---------+---------+---------+---------+
4       -0.1829  -0.0670  0.0489   (----------*-----------)
                                  ---------+---------+---------+---------+
                                        -0.10      0.00      0.10      0.20
```

A.14 Minitab Report for PASS Alarm Comparison Using Vox Port

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF      SS      MS     F      P
Scenario   1  0.0324  0.0324  3.22  0.079
Error     46  0.4629  0.0101
Total     47  0.4954

S = 0.1003   R-Sq = 6.55%   R-Sq(adj) = 4.52%

                           Individual 99% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev    +---------+---------+---------+---------
4      24  0.6060  0.0941             (----------*----------)
5      24  0.5540  0.1061    (----------*----------)
                             +---------+---------+---------+---------
                           0.500     0.550     0.600     0.650

Pooled StDev = 0.1003

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

Individual confidence level = 99.00%

Scenario = 4 subtracted from:

Scenario    Lower   Center   Upper   --+---------+---------+---------+-------
5         -0.1298  -0.0520  0.0258   (------------*------------)
                                     --+---------+---------+---------+-------
                                    -0.120    -0.060     0.000     0.060
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF      SS      MS     F      P
Scenario   1  0.0156  0.0156  1.31  0.259
Error     46  0.5478  0.0119
Total     47  0.5633

S = 0.1091   R-Sq = 2.76%   R-Sq(adj) = 0.65%

                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -------+---------+---------+---------+--
4      24  0.5860  0.1122           (-------------*--------------)
5      24  0.5500  0.1060  (-------------*--------------)
                           -------+---------+---------+---------+--
                                0.520     0.560     0.600     0.640

Pooled StDev = 0.1091

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

Individual confidence level = 99.00%
```

```
Scenario = 4 subtracted from:

Scenario    Lower   Center   Upper     +---------+---------+---------+---------
5         -0.1206  -0.0360  0.0486     (-------------*-------------)
                                       +---------+---------+---------+---------
                                    -0.120    -0.060     0.000     0.060
```

Results for: P25 Full Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00235  0.00235  0.27  0.603
Error     46  0.39547  0.00860
Total     47  0.39782

S = 0.09272   R-Sq = 0.59%   R-Sq(adj) = 0.00%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
4      24  0.49900  0.08353      (----------------*----------------)
5      24  0.48500  0.10108  (----------------*----------------)
                             -----+---------+---------+---------+----
                                0.450     0.480     0.510     0.540

Pooled StDev = 0.09272

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

Individual confidence level = 99.00%

Scenario = 4 subtracted from:

Scenario     Lower    Center    Upper
5         -0.08592  -0.01400  0.05792

Scenario    -+---------+---------+---------+--------
5           (----------------*-----------------)
            -+---------+---------+---------+--------
          -0.080    -0.040     0.000     0.040
```

Results for: P25 Half-Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF      SS      MS     F      P
Scenario   1  0.0087  0.0087  0.70  0.407
Error     46  0.5758  0.0125
Total     47  0.5845

S = 0.1119   R-Sq = 1.50%   R-Sq(adj) = 0.00%

                           Individual 99% CIs For Mean Based on
                           Pooled StDev
Level   N    Mean   StDev  -----+---------+---------+---------+----
4      24  0.5080  0.1071         (--------------*--------------)
5      24  0.4810  0.1165  (--------------*---------------)
                           -----+---------+---------+---------+----
                              0.440     0.480     0.520     0.560

Pooled StDev = 0.1119
```

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

Individual confidence level = 99.00%

Scenario = 4 subtracted from:

Scenario    Lower   Center   Upper  ---------+---------+---------+---------+
5         -0.1138  -0.0270  0.0598  (--------------*-------------)
                                    ---------+---------+---------+---------+
                                        -0.060     0.000     0.060     0.120
```

A.15 Minitab Report for PASS Alarm Comparison Using Internal Microphone

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00347  0.00347  0.53  0.472
Error     46  0.30353  0.00660
Total     47  0.30700

S = 0.08123   R-Sq = 1.13%   R-Sq(adj) = 0.00%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
6      24  0.80000  0.07411  (--------------*--------------)
7      24  0.81700  0.08777       (--------------*--------------)
                             --------+---------+---------+---------+-
                                   0.780     0.810     0.840     0.870

Pooled StDev = 0.08123

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

Individual confidence level = 99.00%

Scenario = 6 subtracted from:

Scenario     Lower   Center    Upper  ------+---------+---------+---------+---
7         -0.04601  0.01700  0.08001      (---------------*---------------)
                                      ------+---------+---------+---------+---
                                         -0.040     0.000     0.040     0.080
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00030  0.00030  0.06  0.809
Error     46  0.23239  0.00505
Total     47  0.23269

S = 0.07108   R-Sq = 0.13%   R-Sq(adj) = 0.00%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---------+---------+---------+---------+
6      24  0.82200  0.06405    (---------------*--------------)
7      24  0.81700  0.07747  (---------------*--------------)
                             ---------+---------+---------+---------+
                                    0.800     0.825     0.850     0.875

Pooled StDev = 0.07108

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

Individual confidence level = 99.00%
```

```
Scenario = 6 subtracted from:

Scenario     Lower    Center    Upper
7         -0.06013  -0.00500  0.05013

Scenario     +---------+---------+---------+---------
7            (-----------------*------------------)
             +---------+---------+---------+---------
          -0.060    -0.030     0.000     0.030
```

Results for: P25 Full Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00077  0.00077  0.17  0.685
Error     46  0.21230  0.00462
Total     47  0.21307

S = 0.06794   R-Sq = 0.36%   R-Sq(adj) = 0.00%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --+---------+---------+---------+-------
6      24  0.70700  0.07880  (--------------*--------------)
7      24  0.71500  0.05496     (--------------*--------------)
                             --+---------+---------+---------+-------
                             0.675     0.700     0.725     0.750

Pooled StDev = 0.06794

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

Individual confidence level = 99.00%

Scenario = 6 subtracted from:

Scenario     Lower   Center    Upper  --------+---------+---------+---------+-
7         -0.04470  0.00800  0.06070     (-----------------*----------------)
                                      --------+---------+---------+---------+-
                                           -0.030     0.000     0.030     0.060
```

Results for: P25 Half Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00001  0.00001  0.00  0.957
Error     46  0.18593  0.00404
Total     47  0.18594

S = 0.06358   R-Sq = 0.01%   R-Sq(adj) = 0.00%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --+---------+---------+---------+-------
6      24  0.71000  0.06859  (----------------*----------------)
7      24  0.71100  0.05814  (----------------*-----------------)
                             --+---------+---------+---------+-------
                             0.680     0.700     0.720     0.740

Pooled StDev = 0.06358

Tukey 99% Simultaneous Confidence Intervals
```

```
All Pairwise Comparisons among Levels of Scenario

Individual confidence level = 99.00%

Scenario = 6 subtracted from:

Scenario     Lower   Center    Upper
7         -0.04831  0.00100  0.05031

Scenario     +---------+---------+---------+---------
7             (------------------*-------------------)
             +---------+---------+---------+---------
          -0.050    -0.025     0.000     0.025
```

A.16 Minitab Report for SCBA Comparison with no Background Noise

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.08875  0.08875  10.33  0.002
Error     46  0.39504  0.00859
Total     47  0.48379

S = 0.09267   R-Sq = 18.35%   R-Sq(adj) = 16.57%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---------+---------+---------+---------+
2      24  0.75400  0.09940  (---------*---------)
3      24  0.84000  0.08542                   (---------*---------)
                             ---------+---------+---------+---------+
                                    0.750     0.800     0.850     0.900

Pooled StDev = 0.09267

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

Individual confidence level = 99.00%

Scenario = 2 subtracted from:

Scenario    Lower   Center    Upper   --+---------+---------+---------+-------
3         0.01412  0.08600  0.15788                 (-----------*-----------)
                                      --+---------+---------+---------+-------
                                     -0.060     0.000     0.060     0.120
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.04320  0.04320  11.03  0.002
Error     46  0.18024  0.00392
Total     47  0.22344

S = 0.06260   R-Sq = 19.33%   R-Sq(adj) = 17.58%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev    +---------+---------+---------+---------
2      24  0.77100  0.06897    (---------*---------)
3      24  0.83100  0.05549                      (--------*---------)
                               +---------+---------+---------+---------
                             0.735     0.770     0.805     0.840

Pooled StDev = 0.06260

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

Individual confidence level = 99.00%
```

```
Scenario = 2 subtracted from:

Scenario    Lower   Center    Upper   --+---------+---------+---------+-------
3         0.01145  0.06000  0.10855                  (-----------*-----------)
                                      --+---------+---------+---------+-------
                                     -0.040     0.000     0.040     0.080
```

Results for: P25 Full Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.00480  0.00480  0.54  0.466
Error     46  0.40858  0.00888
Total     47  0.41338

S = 0.09424   R-Sq = 1.16%   R-Sq(adj) = 0.00%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -------+---------+---------+---------+--
2      24  0.69200  0.10050  (--------------*-------------)
3      24  0.71200  0.08754        (-------------*--------------)
                             -------+---------+---------+---------+--
                                  0.665     0.700     0.735     0.770

Pooled StDev = 0.09424

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

Individual confidence level = 99.00%

Scenario = 2 subtracted from:

Scenario     Lower   Center    Upper  -----+---------+---------+---------+----
3         -0.05310  0.02000  0.09310      (--------------*--------------)
                                      -----+---------+---------+---------+----
                                        -0.050     0.000     0.050     0.100
```

Results for: P25 Half Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.03121  0.03121  4.47  0.040
Error     46  0.32100  0.00698
Total     47  0.35221

S = 0.08354   R-Sq = 8.86%   R-Sq(adj) = 6.88%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---+---------+---------+---------+------
2      24  0.67200  0.09273  (----------*----------)
3      24  0.72300  0.07320              (-----------*----------)
                             ---+---------+---------+---------+------
                              0.640     0.680     0.720     0.760

Pooled StDev = 0.08354

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

Individual confidence level = 99.00%
```

```
Scenario = 2 subtracted from:

Scenario      Lower   Center    Upper  ---+---------+---------+---------+------
3          -0.01380  0.05100  0.11580           (------------*------------)
                                       ---+---------+---------+---------+------
                                       -0.050     0.000     0.050     0.100
```

A.17 Minitab Report for SCBA Comparison with PASS 1 Background Noise

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.45163  0.45163  62.93  0.000
Error     46  0.33014  0.00718
Total     47  0.78178

S = 0.08472   R-Sq = 57.77%   R-Sq(adj) = 56.85%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev    +---------+---------+---------+---------
4      24  0.60600  0.09413    (-----*-----)
6      24  0.80000  0.07411                            (-----*-----)
                               +---------+---------+---------+---------
                             0.560     0.640     0.720     0.800

Pooled StDev = 0.08472

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

Individual confidence level = 99.00%

Scenario = 4 subtracted from:

Scenario    Lower  Center    Upper  -------+---------+---------+---------+--
6         0.12829  0.19400  0.25971                     (-----*------)
                                    -------+---------+---------+---------+--
                                        0.00      0.10      0.20      0.30
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.66835  0.66835  80.10  0.000
Error     46  0.38381  0.00834
Total     47  1.05216

S = 0.09134   R-Sq = 63.52%   R-Sq(adj) = 62.73%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ------+---------+---------+---------+---
4      24  0.58600  0.11218  (----*----)
6      24  0.82200  0.06405                         (----*----)
                             ------+---------+---------+---------+---
                                 0.60      0.70      0.80      0.90

Pooled StDev = 0.09134

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

Individual confidence level = 99.00%
```

```
Scenario = 4 subtracted from:

Scenario    Lower   Center    Upper  -------+---------+---------+---------+--
6         0.16515  0.23600  0.30685                           (------*------)
                                     -------+---------+---------+---------+--
                                          0.00      0.10      0.20      0.30
```

Results for: P25 Full Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.51917  0.51917  78.74  0.000
Error     46  0.30331  0.00659
Total     47  0.82248

S = 0.08120   R-Sq = 63.12%   R-Sq(adj) = 62.32%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---+---------+---------+---------+------
4      24  0.49900  0.08353  (----*-----)
6      24  0.70700  0.07880                            (----*-----)
                             ---+---------+---------+---------+------
                              0.480     0.560     0.640     0.720

Pooled StDev = 0.08120

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

Individual confidence level = 99.00%

Scenario = 4 subtracted from:

Scenario    Lower   Center    Upper  ------+---------+---------+---------+---
6         0.14501  0.20800  0.27099                        (-----*-----)
                                     ------+---------+---------+---------+---
                                         0.00      0.10      0.20      0.30
```

Results for: P25 Half Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.48965  0.48965  60.55  0.000
Error     46  0.37200  0.00809
Total     47  0.86165

S = 0.08993   R-Sq = 56.83%   R-Sq(adj) = 55.89%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  ---+---------+---------+---------+------
4      24  0.50800  0.10710  (-----*------)
6      24  0.71000  0.06859                            (-----*-----)
                             ---+---------+---------+---------+------
                              0.480     0.560     0.640     0.720

Pooled StDev = 0.08993

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

Individual confidence level = 99.00%
```

```
Scenario = 4 subtracted from:

Scenario    Lower   Center    Upper  -------+---------+---------+---------+--
6         0.13225  0.20200  0.27175                      (------*------)
                                     -------+---------+---------+---------+--
                                          0.00      0.10      0.20      0.30
```

A.18 Minitab Report for SCBA Comparison with PASS 2 Background Noise

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.83003  0.83003  87.51  0.000
Error     46  0.43630  0.00948
Total     47  1.26632

S = 0.09739   R-Sq = 65.55%   R-Sq(adj) = 64.80%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev   +---------+---------+---------+---------
5      24  0.55400  0.10614   (----*-----)
7      24  0.81700  0.08777                            (-----*----)
                              +---------+---------+---------+---------
                             0.50      0.60      0.70      0.80

Pooled StDev = 0.09739

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

Individual confidence level = 99.00%

Scenario = 5 subtracted from:

Scenario    Lower   Center    Upper  ------+---------+---------+---------+---
7         0.18746  0.26300  0.33854                        (-----*-----)
                                     ------+---------+---------+---------+---
                                         0.00      0.12      0.24      0.36
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.85547  0.85547  99.28  0.000
Error     46  0.39636  0.00862
Total     47  1.25183

S = 0.09283   R-Sq = 68.34%   R-Sq(adj) = 67.65%

                             Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev   +---------+---------+---------+---------
5      24  0.55000  0.10598   (----*----)
7      24  0.81700  0.07747                             (----*----)
                              +---------+---------+---------+---------
                             0.50      0.60      0.70      0.80

Pooled StDev = 0.09283

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

Individual confidence level = 99.00%
```

```
Scenario = 5 subtracted from:

Scenario    Lower   Center    Upper  ------+---------+---------+---------+---
7         0.19500  0.26700  0.33900                      (-----*-----)
                                     ------+---------+---------+---------+---
                                         0.00      0.12      0.24      0.36
```

Results for: P25 Full Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.63480  0.63480  95.91  0.000
Error     46  0.30446  0.00662
Total     47  0.93926

S = 0.08136   R-Sq = 67.58%   R-Sq(adj) = 66.88%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
5      24  0.48500  0.10108  (-----*----)
7      24  0.71500  0.05496                              (----*-----)
                             -----+---------+---------+---------+----
                               0.480     0.560     0.640     0.720

Pooled StDev = 0.08136

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

Individual confidence level = 99.00%

Scenario = 5 subtracted from:

Scenario    Lower   Center    Upper  ------+---------+---------+---------+---
7         0.16689  0.23000  0.29311                       (-----*-----)
                                     ------+---------+---------+---------+---
                                         0.00      0.10      0.20      0.30
```

Results for: P25 Half Rate

One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS      F      P
Scenario   1  0.63480  0.63480  74.93  0.000
Error     46  0.38971  0.00847
Total     47  1.02451

S = 0.09204   R-Sq = 61.96%   R-Sq(adj) = 61.13%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -------+---------+---------+---------+--
5      24  0.48100  0.11647  (----*----)
7      24  0.71100  0.05814                        (----*----)
                             -------+---------+---------+---------+--
                                 0.50      0.60      0.70      0.80

Pooled StDev = 0.09204

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

Individual confidence level = 99.00%
```

```
Scenario = 5 subtracted from:

Scenario    Lower  Center   Upper  -------+---------+---------+---------+--
7         0.15860 0.23000 0.30140                       (------*------)
                                   -------+---------+---------+---------+--
                                        0.00      0.10      0.20      0.30
```

A.19 Minitab Report for SCBA Comparison with Degraded Channel and No Background Noise

Results for: 25 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF      SS      MS      F      P
Scenario   1  0.2028  0.2028  17.49  0.000
Error     46  0.5333  0.0116
Total     47  0.7361

S = 0.1077   R-Sq = 27.55%   R-Sq(adj) = 25.98%

                           Individual 99% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev  ---------+---------+---------+---------+
10     24  0.4840  0.1195  (-------*--------)
11     24  0.6140  0.0944                    (--------*-------)
                           ---------+---------+---------+---------+
                                  0.490     0.560     0.630     0.700

Pooled StDev = 0.1077

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

Individual confidence level = 99.00%

Scenario = 10 subtracted from:

Scenario   Lower  Center   Upper     +---------+---------+---------+---------
11        0.0465  0.1300  0.2135                    (---------*----------)
                                     +---------+---------+---------+---------
                                  -0.080     0.000     0.080     0.160
```

Results for: 12.5 kHz Analog
One-way ANOVA: R_A versus Scenario

```
Source    DF      SS      MS      F      P
Scenario   1  0.2123  0.2123  17.38  0.000
Error     46  0.5619  0.0122
Total     47  0.7741

S = 0.1105   R-Sq = 27.42%   R-Sq(adj) = 25.84%

                           Individual 99% CIs For Mean Based on Pooled StDev
Level   N    Mean   StDev    +---------+---------+---------+---------
10     24  0.4090  0.1132    (-------*--------)
11     24  0.5420  0.1078                       (-------*--------)
                             +---------+---------+---------+---------
                           0.350     0.420     0.490     0.560

Pooled StDev = 0.1105

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

Individual confidence level = 99.00%
```

```
Scenario = 10 subtracted from:

Scenario   Lower  Center   Upper    -+---------+---------+---------+--------
11        0.0473  0.1330  0.2187                     (----------*---------)
                                    -+---------+---------+---------+--------
                                  -0.080     0.000     0.080     0.160
```

Results for: P25 Full Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.01387  0.01387  1.99  0.165
Error     46  0.32016  0.00696
Total     47  0.33403

S = 0.08343   R-Sq = 4.15%   R-Sq(adj) = 2.07%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  -----+---------+---------+---------+----
10     24  0.69400  0.07952  (------------*------------)
11     24  0.72800  0.08716            (------------*------------)
                             -----+---------+---------+---------+----
                                0.665     0.700     0.735     0.770

Pooled StDev = 0.08343

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

Individual confidence level = 99.00%

Scenario = 10 subtracted from:

Scenario     Lower   Center    Upper  ---+---------+---------+---------+------
11        -0.03071  0.03400  0.09871         (------------*------------)
                                      ---+---------+---------+---------+------
                                      -0.050     0.000     0.050     0.100
```

Results for: P25 Half Rate
One-way ANOVA: R_A versus Scenario

```
Source    DF       SS       MS     F      P
Scenario   1  0.03121  0.03121  5.54  0.023
Error     46  0.25927  0.00564
Total     47  0.29048

S = 0.07508   R-Sq = 10.74%   R-Sq(adj) = 8.80%

                         Individual 99% CIs For Mean Based on Pooled StDev
Level   N     Mean    StDev  --------+---------+---------+---------+-
10     24  0.67900  0.07907  (-----------*-----------)
11     24  0.73000  0.07086               (-----------*----------)
                             --------+---------+---------+---------+-
                                   0.665     0.700     0.735     0.770

Pooled StDev = 0.07508

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

Individual confidence level = 99.00%
```

```
Scenario = 10 subtracted from:

Scenario      Lower   Center    Upper   --+---------+---------+---------+-------
11         -0.00723  0.05100  0.10923              (----------*-----------)
                                        --+---------+---------+---------+-------
                                      -0.050     0.000     0.050     0.100
```

APPENDIX B: LISTENER SCORES

Table B-1 tabulates the scores collected from the listener panels. Adjusted intelligibility scores (R_A) are presented by talker, condition, and listener. Each R_A in the table represents 50 trials in the listening test.

Table B-1. Listener scores by talker, condition, and listener.

Talker	Condition	Listener	R_A
F1	1	4	0.856
F1	1	21	0.952
F1	1	27	0.976
F1	1	30	0.880
F1	1	30	0.928
F1	1	32	0.832
F3	1	3	0.880
F3	1	5	0.904
F3	1	10	0.904
F3	1	18	0.880
F3	1	31	0.904
F3	1	32	0.952
M3	1	4	0.928
M3	1	6	0.880
M3	1	6	0.928
M3	1	18	0.832
M3	1	20	0.856
M3	1	31	0.904
M4	1	2	0.832
M4	1	2	0.880
M4	1	24	0.928
M4	1	24	0.928
M4	1	28	0.784
M4	1	30	0.976
F1	2	5	0.760
F1	2	13	0.736
F1	2	16	0.640
F1	2	27	0.688
F1	2	31	0.616
F1	2	31	0.856
F3	2	1	0.832
F3	2	22	0.760
F3	2	26	0.736

Talker	Condition	Listener	R_A
F3	2	28	0.688
F3	2	30	0.784
F3	2	31	0.760
M3	2	6	0.856
M3	2	11	0.520
M3	2	17	0.664
M3	2	26	0.808
M3	2	28	0.664
M3	2	32	0.664
M4	2	1	0.952
M4	2	5	0.904
M4	2	10	0.760
M4	2	10	0.784
M4	2	13	0.808
M4	2	31	0.856
F1	3	8	0.952
F1	3	14	0.904
F1	3	14	0.736
F1	3	15	0.880
F1	3	16	0.688
F1	3	17	0.952
F3	3	1	0.832
F3	3	1	0.832
F3	3	2	0.904
F3	3	4	0.712
F3	3	6	0.760
F3	3	15	0.712
M3	3	1	0.952
M3	3	2	0.832
M3	3	8	0.784
M3	3	9	0.832
M3	3	11	0.952
M3	3	14	0.928

Talker	Condition	Listener	R_A
M4	3	1	0.880
M4	3	4	0.856
M4	3	6	0.712
M4	3	9	0.904
M4	3	13	0.808
M4	3	20	0.856
F1	4	1	0.760
F1	4	10	0.712
F1	4	14	0.592
F1	4	21	0.712
F1	4	23	0.736
F1	4	31	0.616
F3	4	6	0.712
F3	4	12	0.616
F3	4	15	0.520
F3	4	16	0.448
F3	4	25	0.616
F3	4	26	0.640
M3	4	4	0.664
M3	4	4	0.448
M3	4	17	0.568
M3	4	23	0.496
M3	4	29	0.424
M3	4	32	0.520
M4	4	9	0.640
M4	4	14	0.568
M4	4	16	0.568
M4	4	25	0.640
M4	4	27	0.688
M4	4	32	0.640
F1	5	7	0.520
F1	5	10	0.592
F1	5	22	0.592

Talker	Condition	Listener	R_A
F1	5	23	0.640
F1	5	24	0.664
F1	5	25	0.616
F3	5	4	0.520
F3	5	5	0.568
F3	5	11	0.592
F3	5	16	0.376
F3	5	19	0.544
F3	5	31	0.640
M3	5	2	0.448
M3	5	4	0.544
M3	5	6	0.544
M3	5	11	0.280
M3	5	12	0.448
M3	5	17	0.448
M4	5	6	0.544
M4	5	7	0.520
M4	5	16	0.520
M4	5	22	0.760
M4	5	30	0.688
M4	5	30	0.688
F1	6	1	0.832
F1	6	7	0.856
F1	6	9	0.856
F1	6	13	0.760
F1	6	14	0.760
F1	6	20	0.784
F3	6	4	0.688
F3	6	8	0.904
F3	6	9	0.880
F3	6	10	0.616
F3	6	16	0.760
F3	6	16	0.736
M3	6	5	0.784
M3	6	7	0.856
M3	6	8	0.880
M3	6	11	0.688
M3	6	19	0.760
M3	6	20	0.760
M4	6	1	0.880
M4	6	6	0.784

Talker	Condition	Listener	R_A
M4	6	9	0.880
M4	6	12	0.784
M4	6	16	0.880
M4	6	19	0.832
F1	7	5	0.880
F1	7	6	0.760
F1	7	14	0.928
F1	7	14	0.928
F1	7	15	0.832
F1	7	15	0.808
F3	7	3	0.760
F3	7	4	0.856
F3	7	7	0.904
F3	7	11	0.856
F3	7	12	0.736
F3	7	20	0.688
M3	7	4	0.832
M3	7	6	0.856
M3	7	9	0.808
M3	7	14	0.856
M3	7	16	0.640
M3	7	20	0.808
M4	7	3	0.592
M4	7	4	0.928
M4	7	12	0.880
M4	7	14	0.760
M4	7	15	0.856
M4	7	20	0.856
F1	8	4	0.640
F1	8	10	0.568
F1	8	12	0.808
F1	8	25	0.760
F1	8	25	0.712
F1	8	30	0.808
F3	8	2	0.784
F3	8	2	0.760
F3	8	18	0.760
F3	8	19	0.736
F3	8	26	0.760
F3	8	31	0.616
M3	8	2	0.496

Talker	Condition	Listener	R_A
M3	8	10	0.568
M3	8	16	0.568
M3	8	20	0.520
M3	8	25	0.544
M3	8	27	0.496
M4	8	3	0.712
M4	8	3	0.808
M4	8	4	0.568
M4	8	17	0.784
M4	8	26	0.784
M4	8	30	0.832
F1	9	1	0.784
F1	9	5	0.712
F1	9	11	0.760
F1	9	15	0.808
F1	9	19	0.712
F1	9	22	0.856
F3	9	5	0.880
F3	9	9	0.688
F3	9	10	0.568
F3	9	17	0.568
F3	9	20	0.736
F3	9	26	0.640
M3	9	1	0.736
M3	9	2	0.664
M3	9	10	0.568
M3	9	10	0.520
M3	9	11	0.688
M3	9	25	0.640
M4	9	17	0.736
M4	9	19	0.736
M4	9	21	0.712
M4	9	23	0.640
M4	9	24	0.760
M4	9	26	0.712
F1	10	3	0.688
F1	10	8	0.544
F1	10	14	0.448
F1	10	15	0.472
F1	10	23	0.424
F1	10	25	0.592

Talker	Condition	Listener	R_A
F3	10	2	0.304
F3	10	5	0.664
F3	10	18	0.592
F3	10	28	0.544
F3	10	30	0.664
F3	10	32	0.448
M3	10	2	0.376
M3	10	13	0.256
M3	10	16	0.304
M3	10	18	0.328
M3	10	22	0.424
M3	10	26	0.400
M4	10	4	0.544
M4	10	5	0.544
M4	10	11	0.448
M4	10	18	0.592
M4	10	19	0.520
M4	10	24	0.496
F1	11	6	0.736
F1	11	6	0.784
F1	11	11	0.568
F1	11	14	0.712
F1	11	15	0.592
F1	11	18	0.688
F3	11	3	0.688
F3	11	3	0.664
F3	11	6	0.736
F3	11	12	0.616
F3	11	17	0.592
F3	11	20	0.520
M3	11	1	0.448
M3	11	4	0.544
M3	11	8	0.520
M3	11	12	0.472
M3	11	14	0.544
M3	11	19	0.592
M4	11	3	0.640
M4	11	7	0.688
M4	11	10	0.592
M4	11	14	0.712
M4	11	18	0.640

Talker	Condition	Listener	R_A
M4	11	20	0.448
F1	12	4	0.376
F1	12	5	0.520
F1	12	6	0.448
F1	12	9	0.448
F1	12	17	0.352
F1	12	29	0.304
F3	12	5	0.328
F3	12	11	0.304
F3	12	18	0.520
F3	12	19	0.376
F3	12	20	0.448
F3	12	28	0.328
M3	12	3	0.280
M3	12	4	0.232
M3	12	11	0.208
M3	12	20	0.304
M3	12	21	0.232
M3	12	25	0.280
M4	12	8	0.280
M4	12	19	0.280
M4	12	24	0.280
M4	12	24	0.448
M4	12	28	0.256
M4	12	31	0.304
F1	13	5	0.736
F1	13	6	0.784
F1	13	8	0.808
F1	13	12	0.544
F1	13	17	0.616
F1	13	19	0.544
F3	13	6	0.544
F3	13	8	0.592
F3	13	10	0.616
F3	13	12	0.664
F3	13	13	0.640
F3	13	17	0.592
M3	13	3	0.616
M3	13	4	0.592
M3	13	6	0.688
M3	13	9	0.520

Talker	Condition	Listener	R_A
M3	13	10	0.448
M3	13	13	0.424
M4	13	5	0.616
M4	13	5	0.736
M4	13	6	0.664
M4	13	8	0.712
M4	13	12	0.592
M4	13	13	0.664
F1	14	4	0.568
F1	14	11	0.496
F1	14	12	0.520
F1	14	26	0.640
F1	14	29	0.664
F1	14	31	0.712
F3	14	3	0.760
F3	14	4	0.352
F3	14	8	0.520
F3	14	12	0.616
F3	14	13	0.592
F3	14	31	0.736
M3	14	4	0.376
M3	14	6	0.424
M3	14	8	0.376
M3	14	16	0.496
M3	14	20	0.424
M3	14	26	0.496
M4	14	3	0.664
M4	14	4	0.472
M4	14	8	0.568
M4	14	10	0.592
M4	14	14	0.400
M4	14	17	0.544
F1	15	2	0.880
F1	15	8	0.928
F1	15	12	0.904
F1	15	15	0.856
F1	15	19	0.856
F1	15	27	0.952
F3	15	1	0.904
F3	15	2	0.952
F3	15	6	0.904

Talker	Condition	Listener	R_A
F3	15	22	0.880
F3	15	22	0.976
F3	15	24	0.904
M3	15	4	0.760
M3	15	10	0.904
M3	15	19	0.952
M3	15	26	0.880
M3	15	30	0.952
M3	15	31	0.856
M4	15	4	0.856
M4	15	15	0.928
M4	15	15	0.952
M4	15	21	0.976
M4	15	23	0.904
M4	15	25	0.952
F1	16	6	0.736
F1	16	10	0.592
F1	16	18	0.808
F1	16	23	0.808
F1	16	25	0.784
F1	16	26	0.688
F3	16	2	0.736
F3	16	6	0.832
F3	16	12	0.784
F3	16	21	0.928
F3	16	26	0.784
F3	16	30	0.784
M3	16	7	0.664
M3	16	9	0.760
M3	16	16	0.856
M3	16	19	0.736
M3	16	26	0.784
M3	16	26	0.784
M4	16	1	0.784
M4	16	9	0.760
M4	16	13	0.760
M4	16	14	0.712
M4	16	15	0.760
M4	16	22	0.880
F1	17	4	0.904
F1	17	7	0.808

Talker	Condition	Listener	R_A
F1	17	10	0.784
F1	17	12	0.832
F1	17	14	0.904
F3	17	4	0.736
F3	17	6	0.808
F3	17	7	0.760
F3	17	11	0.760
F3	17	13	0.856
F3	17	16	0.856
M3	17	1	0.808
M3	17	4	0.784
M3	17	4	0.928
M3	17	6	0.808
M3	17	9	0.832
M3	17	9	0.880
M4	17	2	0.856
M4	17	10	0.808
M4	17	13	0.928
M4	17	13	0.904
M4	17	15	0.808
M4	17	16	0.760
F1	17	4	0.904
F1	18	7	0.616
F1	18	11	0.496
F1	18	18	0.664
F1	18	21	0.736
F1	18	29	0.616
F1	18	31	0.784
F3	18	7	0.496
F3	18	8	0.784
F3	18	10	0.640
F3	18	15	0.736
F3	18	20	0.472
F3	18	28	0.616
M3	18	3	0.496
M3	18	4	0.544
M3	18	5	0.424
M3	18	5	0.520
M3	18	9	0.328
M3	18	20	0.520
M4	18	5	0.664

Talker	Condition	Listener	R_A
M4	18	6	0.592
M4	18	7	0.568
M4	18	8	0.592
M4	18	11	0.520
M4	18	11	0.640
F1	19	4	0.592
F1	19	6	0.664
F1	19	8	0.520
F1	19	8	0.760
F1	19	10	0.568
F1	19	14	0.592
F3	19	6	0.568
F3	19	14	0.496
F3	19	14	0.496
F3	19	30	0.736
F3	19	30	0.568
F3	19	32	0.592
M3	19	7	0.352
M3	19	7	0.376
M3	19	18	0.568
M3	19	20	0.472
M3	19	23	0.376
M3	19	29	0.496
M4	19	3	0.400
M4	19	6	0.616
M4	19	10	0.544
M4	19	18	0.616
M4	19	23	0.568
M4	19	30	0.664
F1	20	2	0.784
F1	20	5	0.904
F1	20	9	0.928
F1	20	10	0.808
F1	20	14	0.832
F1	20	15	0.880
F3	20	2	0.832
F3	20	3	0.904
F3	20	11	0.832
F3	20	17	0.880
F3	20	19	0.736
F3	20	20	0.808

Talker	Condition	Listener	R_A
M3	20	2	0.712
M3	20	7	0.856
M3	20	8	0.808
M3	20	11	0.856
M3	20	13	0.832
M3	20	14	0.688
M4	20	2	0.832
M4	20	7	0.808
M4	20	12	0.856
M4	20	16	0.880
M4	20	18	0.760
M4	20	20	0.712
F1	21	1	0.832
F1	21	2	0.832
F1	21	16	0.832
F1	21	17	0.856
F1	21	19	0.736
F1	21	20	0.856
F3	21	2	0.736
F3	21	6	0.928
F3	21	8	0.856
F3	21	9	0.784
F3	21	16	0.832
F3	21	18	0.784
M3	21	2	0.784
M3	21	3	0.808
M3	21	6	0.880
M3	21	9	0.832
M3	21	17	0.736
M3	21	20	0.712
M4	21	6	0.976
M4	21	9	0.808
M4	21	10	0.664
M4	21	11	0.712
M4	21	11	0.952
M4	21	19	0.880
F1	22	8	0.664
F1	22	16	0.664
F1	22	17	0.640
F1	22	21	0.784
F1	22	23	0.736

Talker	Condition	Listener	R_A
F1	22	26	0.736
F3	22	1	0.616
F3	22	12	0.664
F3	22	13	0.568
F3	22	29	0.640
F3	22	30	0.856
F3	22	32	0.664
M3	22	12	0.616
M3	22	14	0.424
M3	22	14	0.544
M3	22	18	0.640
M3	22	24	0.760
M3	22	31	0.448
M4	22	1	0.664
M4	22	5	0.808
M4	22	10	0.664
M4	22	11	0.664
M4	22	14	0.616
M4	22	21	0.664
F1	23	3	0.664
F1	23	5	0.808
F1	23	9	0.544
F1	23	11	0.664
F1	23	23	0.712
F1	23	30	0.736
F3	23	3	0.736
F3	23	16	0.568
F3	23	22	0.784
F3	23	24	0.544
F3	23	24	0.688
F3	23	26	0.688
M3	23	3	0.424
M3	23	8	0.472
M3	23	15	0.448
M3	23	25	0.448
M3	23	25	0.616
M3	23	31	0.472
M4	23	4	0.424
M4	23	8	0.496
M4	23	15	0.616
M4	23	22	0.592

Talker	Condition	Listener	R_A
M4	23	24	0.448
M4	23	24	0.568
F1	24	1	0.424
F1	24	7	0.520
F1	24	11	0.448
F1	24	24	0.496
F1	24	28	0.328
F1	24	29	0.472
F3	24	16	0.568
F3	24	17	0.400
F3	24	20	0.448
F3	24	20	0.400
F3	24	25	0.664
F3	24	30	0.472
M3	24	1	0.208
M3	24	6	0.424
M3	24	6	0.328
M3	24	21	0.208
M3	24	27	0.376
M3	24	29	0.304
M4	24	6	0.448
M4	24	17	0.256
M4	24	17	0.496
M4	24	22	0.520
M4	24	23	0.304
M4	24	31	0.304
F1	25	3	0.688
F1	25	3	0.568
F1	25	4	0.520
F1	25	6	0.688
F1	25	11	0.616
F1	25	18	0.688
F3	25	3	0.592
F3	25	8	0.568
F3	25	12	0.568
F3	25	12	0.568
F3	25	13	0.424
F3	25	18	0.616
M3	25	5	0.424
M3	25	6	0.424
M3	25	13	0.520

Talker	Condition	Listener	R_A
M3	25	15	0.448
M3	25	18	0.304
M3	25	20	0.472
M4	25	2	0.520
M4	25	5	0.568
M4	25	5	0.712
M4	25	14	0.448
M4	25	15	0.400
M4	25	15	0.664
F1	26	2	0.520
F1	26	2	0.400
F1	26	2	0.376
F1	26	17	0.304
F1	26	17	0.304
F1	26	23	0.304
F3	26	3	0.328
F3	26	5	0.376
F3	26	22	0.424
F3	26	24	0.280
F3	26	27	0.328
F3	26	27	0.232
M3	26	6	0.376
M3	26	21	0.256
M3	26	25	0.256
M3	26	26	0.208
M3	26	30	0.400
M3	26	30	0.328
M4	26	2	0.184
M4	26	8	0.280
M4	26	9	0.232
M4	26	15	0.208
M4	26	18	0.544
M4	26	25	0.424
F1	27	2	0.568
F1	27	3	0.640
F1	27	4	0.640
F1	27	5	0.592
F1	27	9	0.664
F1	27	10	0.376
F3	27	1	0.544
F3	27	5	0.664

Talker	Condition	Listener	R_A
F3	27	9	0.640
F3	27	11	0.664
F3	27	18	0.376
F3	27	19	0.496
M3	27	1	0.472
M3	27	7	0.544
M3	27	13	0.616
M3	27	15	0.376
M3	27	17	0.400
M3	27	17	0.352
M4	27	1	0.616
M4	27	8	0.640
M4	27	9	0.448
M4	27	10	0.472
M4	27	10	0.520
M4	27	19	0.424
F1	28	2	0.664
F1	28	3	0.520
F1	28	13	0.472
F1	28	13	0.592
F1	28	17	0.568
F1	28	22	0.664
F3	28	1	0.592
F3	28	6	0.592
F3	28	10	0.448
F3	28	14	0.424
F3	28	21	0.520
F3	28	32	0.472
M3	28	2	0.256
M3	28	6	0.232
M3	28	15	0.376
M3	28	20	0.376
M3	28	28	0.256
M3	28	31	0.352
M4	28	8	0.568
M4	28	12	0.544
M4	28	13	0.400
M4	28	19	0.376
M4	28	21	0.592
M4	28	32	0.424
F1	29	7	0.904

Talker	Condition	Listener	R_A
F1	29	11	0.928
F1	29	12	0.904
F1	29	16	0.928
F1	29	31	0.832
F1	29	31	0.904
F3	29	2	0.808
F3	29	9	0.856
F3	29	13	0.904
F3	29	18	0.856
F3	29	25	0.808
F3	29	30	0.856
M3	29	1	0.784
M3	29	7	0.736
M3	29	13	0.832
M3	29	14	0.928
M3	29	24	0.832
M3	29	30	0.760
M4	29	6	0.976
M4	29	9	0.784
M4	29	18	0.928
M4	29	24	0.952
M4	29	28	0.928
M4	29	31	0.856
F1	30	6	0.664
F1	30	10	0.760
F1	30	13	0.520
F1	30	22	0.688
F1	30	24	0.640
F1	30	32	0.640
F3	30	4	0.640
F3	30	6	0.808
F3	30	18	0.856
F3	30	22	0.712
F3	30	24	0.784
F3	30	32	0.568
M3	30	1	0.712
M3	30	3	0.736
M3	30	7	0.616
M3	30	8	0.592
M3	30	13	0.568
M3	30	20	0.544

Talker	Condition	Listener	R_A
M4	30	2	0.784
M4	30	12	0.832
M4	30	13	0.688
M4	30	20	0.784
M4	30	21	0.856
M4	30	24	0.616
F1	31	1	0.712
F1	31	5	0.808
F1	31	8	0.856
F1	31	10	0.712
F1	31	12	0.592
F1	31	17	0.736
F3	31	1	0.472
F3	31	1	0.736
F3	31	4	0.640
F3	31	13	0.760
F3	31	14	0.616
F3	31	15	0.712
M3	31	4	0.640
M3	31	5	0.712
M3	31	6	0.616
M3	31	14	0.736
M3	31	17	0.688
M3	31	19	0.664
M4	31	2	0.808
M4	31	6	0.784
M4	31	9	0.808
M4	31	12	0.808
M4	31	12	0.784
M4	31	15	0.688
F1	32	4	0.520
F1	32	7	0.496
F1	32	9	0.496
F1	32	14	0.448
F1	32	16	0.544
F1	32	20	0.472
F3	32	8	0.472
F3	32	9	0.352
F3	32	10	0.472
F3	32	12	0.592
F3	32	19	0.616

Talker	Condition	Listener	R_A
F3	32	20	0.544
M3	32	1	0.352
M3	32	3	0.520
M3	32	17	0.616
M3	32	26	0.448
M3	32	27	0.520
M3	32	32	0.376
M4	32	1	0.448
M4	32	2	0.376
M4	32	22	0.640
M4	32	27	0.496
M4	32	31	0.616
M4	32	32	0.544
F1	33	1	0.448
F1	33	11	0.376
F1	33	19	0.496
F1	33	24	0.616
F1	33	28	0.400
F1	33	32	0.448
F3	33	4	0.448
F3	33	9	0.472
F3	33	20	0.400
F3	33	27	0.520
F3	33	29	0.592
F3	33	30	0.712
M3	33	5	0.472
M3	33	12	0.424
M3	33	17	0.424
M3	33	20	0.544
M3	33	29	0.232
M3	33	29	0.472
M4	33	1	0.568
M4	33	4	0.544
M4	33	7	0.520
M4	33	8	0.376
M4	33	19	0.640
M4	33	31	0.496
F1	34	4	0.856
F1	34	7	0.832
F1	34	12	0.784
F1	34	14	0.736

Talker	Condition	Listener	R_A
F1	34	15	0.616
F1	34	16	0.688
F3	34	2	0.616
F3	34	4	0.640
F3	34	8	0.760
F3	34	13	0.760
F3	34	16	0.664
F3	34	19	0.616
M3	34	5	0.616
M3	34	13	0.712
M3	34	14	0.640
M3	34	14	0.736
M3	34	15	0.688
M3	34	20	0.640
M4	34	3	0.616
M4	34	5	0.856
M4	34	10	0.712
M4	34	10	0.712
M4	34	13	0.664
M4	34	16	0.808
F1	35	7	0.760
F1	35	9	0.664
F1	35	9	0.784
F1	35	10	0.760
F1	35	11	0.688
F1	35	11	0.736
F3	35	8	0.784
F3	35	11	0.712
F3	35	13	0.736
F3	35	16	0.664
F3	35	17	0.592
F3	35	17	0.688
M3	35	6	0.688
M3	35	7	0.784
M3	35	8	0.664
M3	35	14	0.784
M3	35	17	0.736
M3	35	18	0.736
M4	35	5	0.736
M4	35	12	0.688
M4	35	12	0.592

Talker	Condition	Listener	R_A
M4	35	13	0.688
M4	35	18	0.736
M4	35	19	0.760
F1	36	3	0.616
F1	36	5	0.736
F1	36	9	0.640
F1	36	13	0.472
F1	36	26	0.664
F1	36	31	0.616
F3	36	10	0.592
F3	36	14	0.544
F3	36	15	0.256
F3	36	17	0.520
F3	36	17	0.664
F3	36	29	0.520
M3	36	8	0.328
M3	36	12	0.472
M3	36	14	0.184
M3	36	15	0.448
M3	36	28	0.352
M3	36	29	0.256
M4	36	1	0.376
M4	36	5	0.544
M4	36	10	0.376
M4	36	22	0.544
M4	36	24	0.544
M4	36	26	0.592
F1	37	8	0.856
F1	37	10	0.832
F1	37	21	0.904
F1	37	23	0.784
F1	37	28	0.808
F1	37	31	0.952
F3	37	2	0.928
F3	37	8	0.904
F3	37	9	0.928
F3	37	22	0.904
F3	37	23	0.856
F3	37	23	0.832
M3	37	1	0.760
M3	37	8	0.832

Talker	Condition	Listener	R_A
M3	37	13	0.856
M3	37	23	0.952
M3	37	26	0.880
M3	37	30	0.928
M4	37	8	0.904
M4	37	9	0.856
M4	37	16	0.880
M4	37	20	0.856
M4	37	22	0.880
M4	37	24	0.952
F1	38	1	0.616
F1	38	11	0.568
F1	38	20	0.688
F1	38	23	0.640
F1	38	26	0.760
F1	38	26	0.736
F3	38	1	0.880
F3	38	12	0.736
F3	38	14	0.712
F3	38	15	0.640
F3	38	15	0.712
F3	38	30	0.808
M3	38	2	0.664
M3	38	4	0.568
M3	38	6	0.760
M3	38	25	0.736
M3	38	27	0.832
M3	38	31	0.616
M4	38	4	0.664
M4	38	4	0.592
M4	38	7	0.688
M4	38	7	0.712
M4	38	16	0.664
M4	38	29	0.664
F1	39	4	0.832
F1	39	8	0.832
F1	39	12	0.736
F1	39	13	0.736
F1	39	18	0.640
F1	39	19	0.640
F3	39	5	0.736

Talker	Condition	Listener	R_A
F3	39	5	0.808
F3	39	7	0.784
F3	39	10	0.544
F3	39	13	0.808
F3	39	17	0.712
M3	39	3	0.640
M3	39	6	0.832
M3	39	10	0.688
M3	39	14	0.688
M3	39	19	0.856
M3	39	20	0.592
M4	39	11	0.784
M4	39	12	0.808
M4	39	12	0.760
M4	39	13	0.688
M4	39	14	0.736
M4	39	16	0.592
F1	40	6	0.496
F1	40	8	0.208
F1	40	9	0.640
F1	40	21	0.496
F1	40	25	0.592
F1	40	30	0.424
F3	40	3	0.472
F3	40	10	0.448
F3	40	14	0.496
F3	40	18	0.496
F3	40	19	0.448
F3	40	23	0.520
M3	40	15	0.376
M3	40	16	0.424
M3	40	16	0.376
M3	40	20	0.520
M3	40	27	0.592
M3	40	32	0.424
M4	40	5	0.616
M4	40	13	0.496
M4	40	23	0.568
M4	40	29	0.328
M4	40	30	0.760
M4	40	30	0.496

Talker	Condition	Listener	R_A
F1	41	2	0.640
F1	41	4	0.880
F1	41	5	0.616
F1	41	5	0.832
F1	41	7	0.640
F1	41	9	0.712
F3	41	4	0.760
F3	41	9	0.760
F3	41	9	0.640
F3	41	18	0.760
F3	41	19	0.688
F3	41	20	0.760
M3	41	1	0.616
M3	41	2	0.712
M3	41	2	0.664
M3	41	5	0.904
M3	41	8	0.688
M3	41	20	0.784
M4	41	7	0.688
M4	41	10	0.688
M4	41	13	0.712
M4	41	17	0.664
M4	41	17	0.784
M4	41	19	0.640
F1	42	9	0.640
F1	42	11	0.640
F1	42	13	0.544
F1	42	22	0.736
F1	42	26	0.640
F1	42	28	0.784
F3	42	9	0.616
F3	42	18	0.544
F3	42	19	0.688
F3	42	20	0.472
F3	42	28	0.544
F3	42	29	0.616
M3	42	11	0.448
M3	42	12	0.424
M3	42	18	0.448
M3	42	20	0.160
M3	42	24	0.472

Talker	Condition	Listener	R_A
M3	42	25	0.400
M4	42	11	0.616
M4	42	14	0.400
M4	42	16	0.472
M4	42	22	0.496
M4	42	28	0.472
M4	42	32	0.448
F1	43	4	0.928
F1	43	10	0.760
F1	43	15	0.832
F1	43	21	0.856
F1	43	31	0.856
F1	43	32	0.832
F3	43	17	0.736
F3	43	18	0.784
F3	43	18	0.784
F3	43	21	0.928
F3	43	21	0.904
F3	43	24	0.928
M3	43	1	0.928
M3	43	9	0.880
M3	43	12	0.760
M3	43	12	0.880
M3	43	21	0.952
M3	43	31	0.760
M4	43	2	0.904
M4	43	8	0.784
M4	43	19	0.712
M4	43	20	0.832
M4	43	21	0.832
M4	43	23	0.880
F1	44	2	0.664
F1	44	3	0.688
F1	44	4	0.592
F1	44	7	0.544
F1	44	13	0.616
F1	44	32	0.568
F3	44	12	0.736
F3	44	15	0.664
F3	44	21	0.640
F3	44	25	0.712

Talker	Condition	Listener	R_A
F3	44	26	0.808
F3	44	31	0.760
M3	44	8	0.448
M3	44	9	0.688
M3	44	15	0.616
M3	44	23	0.664
M3	44	27	0.664
M3	44	28	0.568
M4	44	5	0.640
M4	44	5	0.808
M4	44	12	0.712
M4	44	19	0.736
M4	44	24	0.856
M4	44	28	0.736
F1	45	1	0.568
F1	45	2	0.664
F1	45	6	0.736
F1	45	12	0.736
F1	45	17	0.784
F1	45	19	0.592
F3	45	5	0.736
F3	45	10	0.688
F3	45	10	0.568
F3	45	12	0.640
F3	45	15	0.688
F3	45	20	0.736
M3	45	1	0.808
M3	45	3	0.784
M3	45	6	0.712
M3	45	7	0.736
M3	45	8	0.688
M3	45	12	0.784
M4	45	5	0.808
M4	45	7	0.760
M4	45	10	0.808
M4	45	15	0.784
M4	45	16	0.784
M4	45	16	0.760
F1	46	2	0.736
F1	46	5	0.496
F1	46	9	0.400

Talker	Condition	Listener	R_A
F1	46	11	0.400
F1	46	13	0.496
F1	46	20	0.640
F3	46	8	0.424
F3	46	12	0.592
F3	46	14	0.184
F3	46	23	0.400
F3	46	25	0.568
F3	46	25	0.568
M3	46	1	0.472
M3	46	3	0.472
M3	46	9	0.568
M3	46	12	0.544
M3	46	20	0.472
M3	46	27	0.448
M4	46	5	0.520
M4	46	8	0.520
M4	46	9	0.544
M4	46	14	0.520
M4	46	21	0.592
M4	46	32	0.616
F1	47	1	0.424
F1	47	11	0.568
F1	47	12	0.280
F1	47	14	0.280
F1	47	23	0.496
F1	47	24	0.616
F3	47	7	0.448
F3	47	9	0.472
F3	47	14	0.472
F3	47	14	0.328
F3	47	27	0.592
F3	47	29	0.592
M3	47	5	0.448
M3	47	6	0.448
M3	47	11	0.448
M3	47	12	0.424
M3	47	26	0.616
M3	47	29	0.448
M4	47	2	0.736
M4	47	3	0.544

Talker	Condition	Listener	R_A
M4	47	11	0.304
M4	47	14	0.400
M4	47	24	0.592
M4	47	30	0.568
F1	48	5	0.568
F1	48	10	0.664
F1	48	11	0.736
F1	48	13	0.736
F1	48	14	0.472
F1	48	16	0.544
F3	48	1	0.520
F3	48	8	0.664
F3	48	8	0.496
F3	48	18	0.664
F3	48	19	0.664
F3	48	20	0.400
M3	48	1	0.664
M3	48	7	0.616
M3	48	8	0.400
M3	48	10	0.712
M3	48	15	0.712
M3	48	16	0.568
M4	48	4	0.688
M4	48	6	0.616
M4	48	9	0.688
M4	48	9	0.616
M4	48	18	0.664
M4	48	19	0.568
F1	49	2	0.640
F1	49	3	0.568
F1	49	6	0.688
F1	49	7	0.640
F1	49	14	0.616
F1	49	18	0.568
F3	49	2	0.712
F3	49	11	0.616
F3	49	14	0.520
F3	49	15	0.688
F3	49	15	0.568
F3	49	16	0.520
M3	49	8	0.688

Talker	Condition	Listener	R_A
M3	49	8	0.520
M3	49	17	0.664
M3	49	17	0.256
M3	49	18	0.592
M3	49	18	0.664
M4	49	5	0.784
M4	49	7	0.616
M4	49	9	0.664
M4	49	15	0.616
M4	49	17	0.592
M4	49	20	0.592
F1	50	2	0.616
F1	50	3	0.544
F1	50	4	0.472
F1	50	11	0.640
F1	50	18	0.520
F1	50	26	0.592
F3	50	4	0.472
F3	50	5	0.688
F3	50	6	0.520
F3	50	16	0.448
F3	50	16	0.496
F3	50	23	0.592
M3	50	5	0.304
M3	50	10	0.424
M3	50	16	0.400
M3	50	16	0.256
M3	50	18	0.448
M3	50	21	0.232
M4	50	1	0.616
M4	50	5	0.568
M4	50	12	0.640
M4	50	22	0.448
M4	50	26	0.544
M4	50	26	0.592
F1	51	19	0.760
F1	51	19	0.952
F1	51	23	0.904
F1	51	28	0.784
F1	51	30	0.928
F1	51	32	0.904

Talker	Condition	Listener	R_A
F3	51	1	0.832
F3	51	20	0.952
F3	51	27	0.952
F3	51	29	0.784
F3	51	29	0.736
F3	51	32	0.904
M3	51	9	0.832
M3	51	10	0.736
M3	51	18	0.856
M3	51	27	0.880
M3	51	31	0.904
M3	51	32	0.784
M4	51	17	0.832
M4	51	19	0.928
M4	51	24	0.880
M4	51	29	0.784
M4	51	29	0.784
M4	51	31	0.856
F1	52	8	0.616
F1	52	16	0.832
F1	52	16	0.664
F1	52	17	0.568
F1	52	22	0.592
F1	52	27	0.616
F3	52	8	0.784
F3	52	19	0.664
F3	52	19	0.712
F3	52	25	0.784
F3	52	28	0.592
F3	52	29	0.640
M3	52	1	0.760
M3	52	13	0.544
M3	52	15	0.712
M3	52	17	0.712
M3	52	20	0.712
M3	52	30	0.664
M4	52	13	0.640
M4	52	19	0.712
M4	52	27	0.640
M4	52	28	0.736
M4	52	28	0.592

Talker	Condition	Listener	R_A
M4	52	31	0.808
F1	53	1	0.664
F1	53	5	0.736
F1	53	7	0.784
F1	53	14	0.664
F1	53	18	0.688
F1	53	18	0.688
F3	53	10	0.688
F3	53	11	0.688
F3	53	13	0.712
F3	53	13	0.712
F3	53	15	0.760
F3	53	18	0.760
M3	53	4	0.832
M3	53	11	0.736
M3	53	17	0.712
M3	53	18	0.784
M3	53	19	0.592
M3	53	20	0.736
M4	53	3	0.568
M4	53	5	0.808
M4	53	8	0.880
M4	53	12	0.760
M4	53	16	0.784
M4	53	19	0.784
F1	54	7	0.424
F1	54	7	0.472
F1	54	16	0.616
F1	54	19	0.496
F1	54	28	0.472
F1	54	29	0.544
F3	54	1	0.544
F3	54	2	0.424
F3	54	12	0.472
F3	54	16	0.376
F3	54	20	0.376
F3	54	21	0.376
M3	54	8	0.448
M3	54	13	0.328
M3	54	15	0.496
M3	54	28	0.520

Talker	Condition	Listener	R_A
M3	54	30	0.568
M3	54	32	0.400
M4	54	6	0.616
M4	54	18	0.688
M4	54	19	0.400
M4	54	26	0.664
M4	54	29	0.640
M4	54	30	0.592
F1	55	4	0.664
F1	55	5	0.712
F1	55	10	0.616
F1	55	12	0.712
F1	55	17	0.688
F1	55	18	0.688
F3	55	1	0.760
F3	55	4	0.664
F3	55	10	0.448
F3	55	11	0.568
F3	55	15	0.808
F3	55	20	0.784
M3	55	1	0.712
M3	55	2	0.664
M3	55	3	0.664
M3	55	7	0.736
M3	55	12	0.664
M3	55	17	0.760
M4	55	3	0.928
M4	55	3	0.832
M4	55	4	0.808
M4	55	11	0.640
M4	55	11	0.760
M4	55	15	0.784
F1	56	3	0.664
F1	56	4	0.448
F1	56	10	0.520
F1	56	16	0.448
F1	56	28	0.592
F1	56	29	0.664
F3	56	7	0.376
F3	56	7	0.592
F3	56	13	0.424

Talker	Condition	Listener	R_A
F3	56	19	0.424
F3	56	21	0.544
F3	56	31	0.568
M3	56	9	0.328
M3	56	13	0.208

Talker	Condition	Listener	R_A
M3	56	16	0.256
M3	56	23	0.328
M3	56	27	0.448
M3	56	29	0.256
M4	56	11	0.592

Talker	Condition	Listener	R_A
M4	56	15	0.424
M4	56	18	0.520
M4	56	19	0.520
M4	56	23	0.496
M4	56	28	0.472

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, CO. 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 [16] [17].

The speech material spoken by the talkers was the word list defined in the MRT description of [6] in the carrier sentence, "Please select the word …."

APPENDIX D: LISTENING LABORATORY CONFIGURATION

Two test chambers were set up to meet the standards set forth in subclauses 8.10.4.10–8.10.4.15 of [10] with the overall level modification as agreed to by the Audio Performance Working Group (APWG). The physical layout of the chambers is shown schematically in Figure D-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 also equidistant from the chamber side walls, and 150 cm away from the speech loudspeaker (in analogy to the talker-listener distance specified in subclause 8.10.4.10). The two loudspeakers on either side of the table were used to produce the pink noise (allowed by subclause 8.10.4.14). The loudspeakers were pointed toward the “back” of the room, and were not pointed directly at the listener, thus fulfilling subclause 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 subclause 8.10.4.13.

For Chamber 1, in order to generate a field of “broadband pink noise” in compliance with subclause 8.10.4.11 of [10], 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 then passed through a mixer, equalizer, and power amplifier and was finally delivered to the pair of loudspeakers located in Chamber 1. For Chamber 2, the “broadband pink noise” field was created by using a recording of the “broadband pink noise” obtained in [6] and played from a CD player. The signal passed through a mixer, equalizer, and power amplifier and was finally delivered to the pair of loudspeakers in Chamber 2. 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.

Subclause 8.10.4.11 specifies that the pink noise generated have a tolerance of 6 dB per octave band in the range of frequencies between 400 Hz and 4 kHz. Figure D-2 shows the 1/3 octave power levels in Chamber 1 and Figure D-3 shows the power levels in Chamber 2. Figure D-2 for Chamber 1 shows that the power level varies from -10 dB to 0 dB between 400 Hz and 4 kHz (note that the 5 dB per interval light is on). Figure D-3 shows that the power level varies between 0 dB and +3 dB between 400 Hz and 4 kHz (note that the 3 dB per interval light is on). Both of these rooms meet the ±6 dB specification of subclause 8.10.4.11, although Chamber 2 meets it more loosely than Chamber 1. This is not expected to impact results as only 11 of the 52 listeners (approximately 21%) participated via Chamber 1.

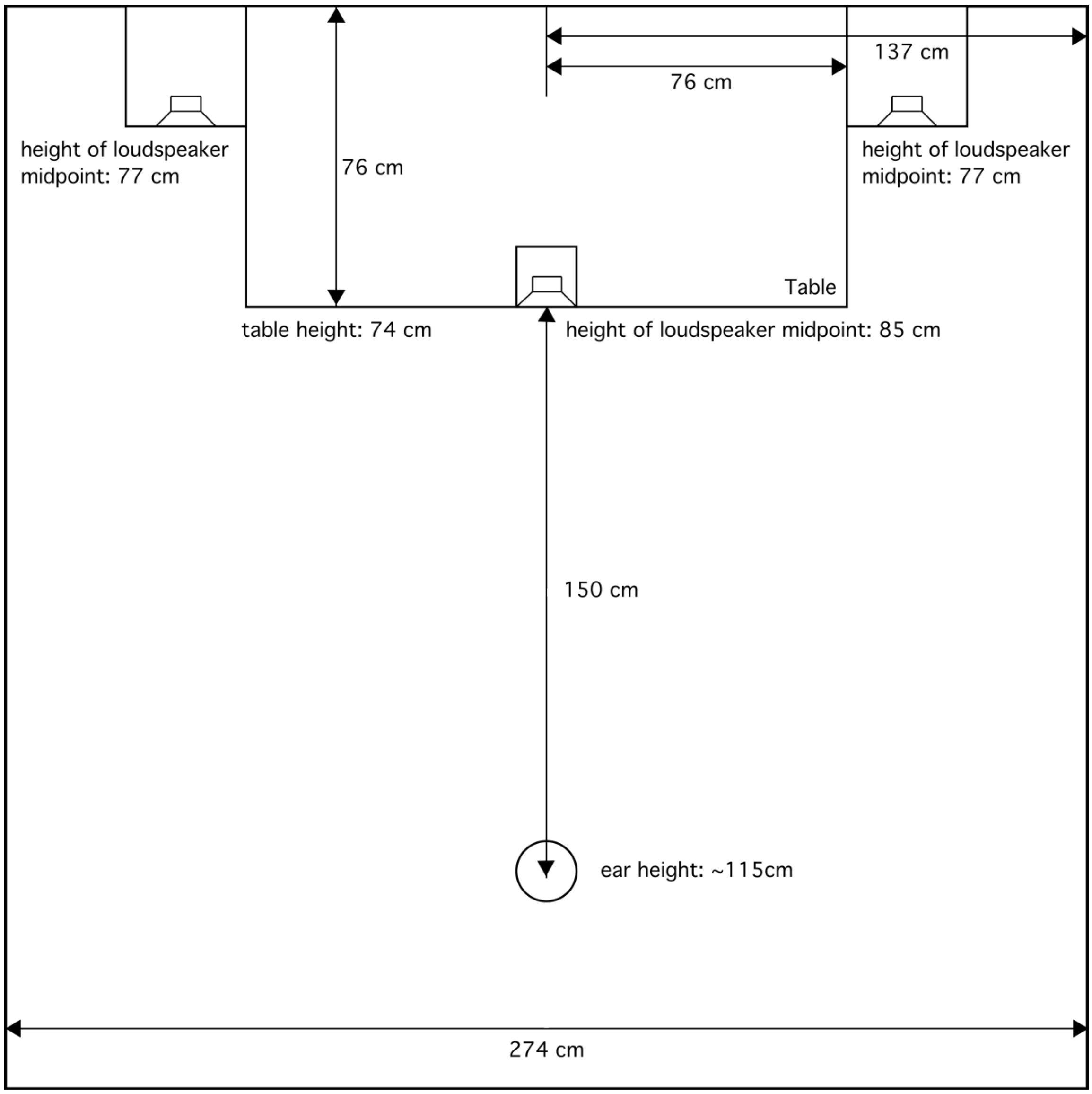

Figure D-1. Diagram showing physical layout of test chambers.

A Brüel and Kjær Model 2250 sound level meter, compliant with [20] and [21], was used to verify that the noise level met specifications. The noise level in Chamber 1 was measured to be 64.9 dBA, and the noise level in Chamber 2 was measured to be 65.0 dBA, fulfilling the modified level from 8.10.4.15, as agreed to by the APWG.

Speech was generated in the two chambers using Fostex 6301B loudspeakers. The speech signal originated in MATLAB, propagated through the PC's sound card, then to a mixer, and then 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 21.4 dBA, and the level in Chamber 2 fell to 21.9 dBA. Undistorted, noise-free speech registered 84.0 dBA in Chamber 1 and 83.8 dBA in Chamber 2.

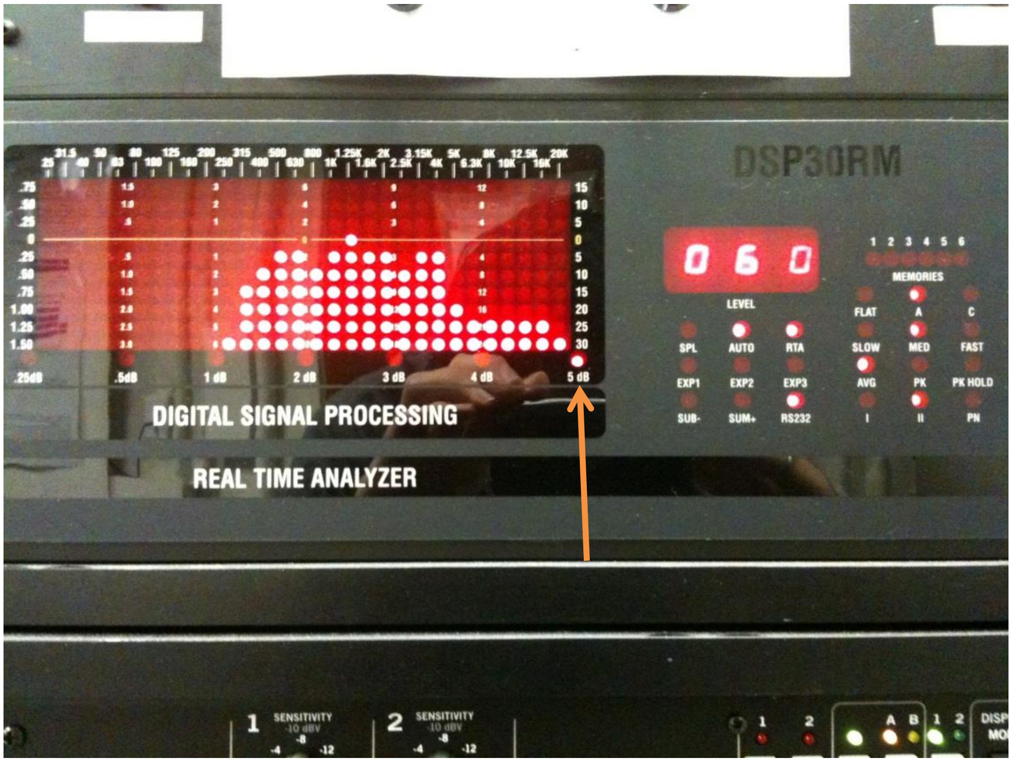

Figure D-2. Real time spectrum analysis of pink noise in Chamber 1.

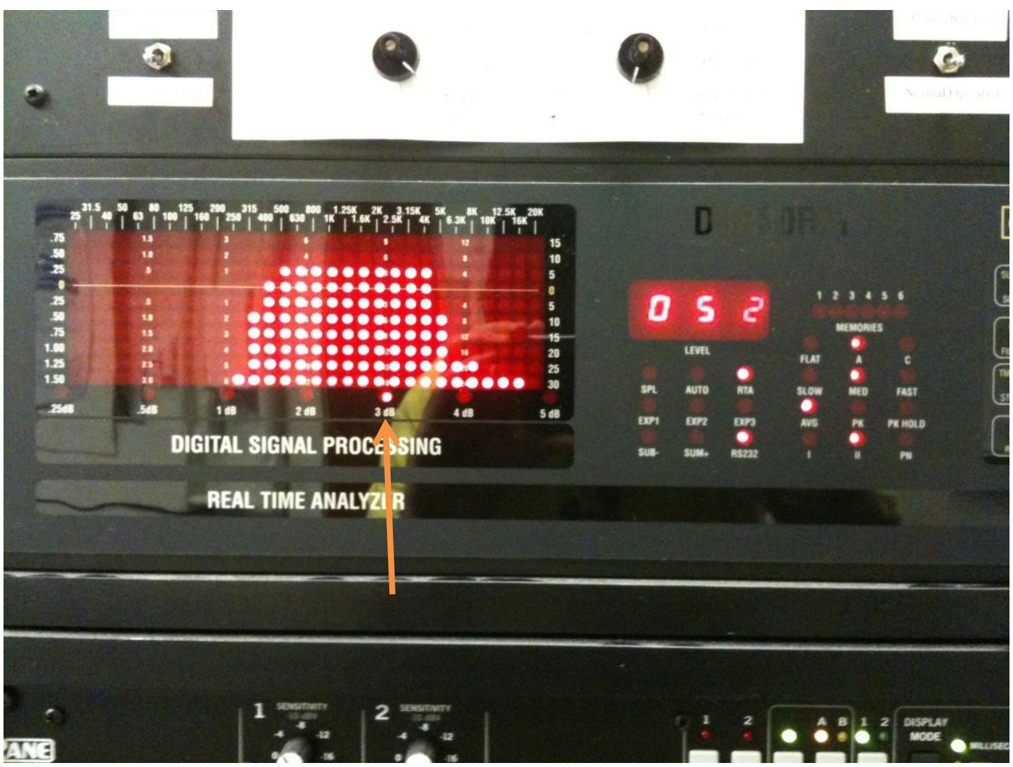

Figure D-3. Real time spectrum analysis of pink noise in Chamber 2.

APPENDIX E: COMPARISON OF TALKER VERSUS A HEAD AND TORSO SIMULATOR FOR INTELLIGIBILITY TESTING

Because of potential differences between test outcomes when using a live talker wearing an SCBA mask and outcomes when using a head and torso simulator (HATS), particularly with respect to exhalation noise and vocal tract loading under the positive air pressure of the mask, a small experiment was designed and conducted to validate the testing method using a HATS. The experiment consisted of two scenarios: wearing an SCBA mask with no background noise and wearing an SCBA mask with PASS1 background noise. The scenarios were repeated with a live talker and also using the HATS for a total of four conditions.

The "Talker" conditions were recorded with a talker speaking the MRT word list and holding a microphone while wearing a mask, with and without background noise present. The HATS conditions used recordings of the same talker, but played through the HATS as indicated in Section 2. The recordings were then played for listeners as indicated in Sections 2 and 5. The recordings were not passed through the reference systems, in order to keep this experiment as simple as possible.

The listening panel consisted of five listeners. They listened to six sessions of 200 sentences each, for a total of 1200 results per listener, 6000 results total.

Table E-1 contains the intelligibility scores for this comparison. Figure E-1 contains the bar chart of results for this environment. ANOVA showed no significant difference between a talker and a HATS. One can therefore infer that the use of the HATS is a reasonable and safe approximation of putting a real talker into a high noise environment, and can be expected to yield equivalent results.

Table E-1. Intelligibility scores for talker versus HATS

Scenario	Talker	HATS
Mask w/ no background noise	0.850	0.864
Mask with PASS1	0.852	0.889

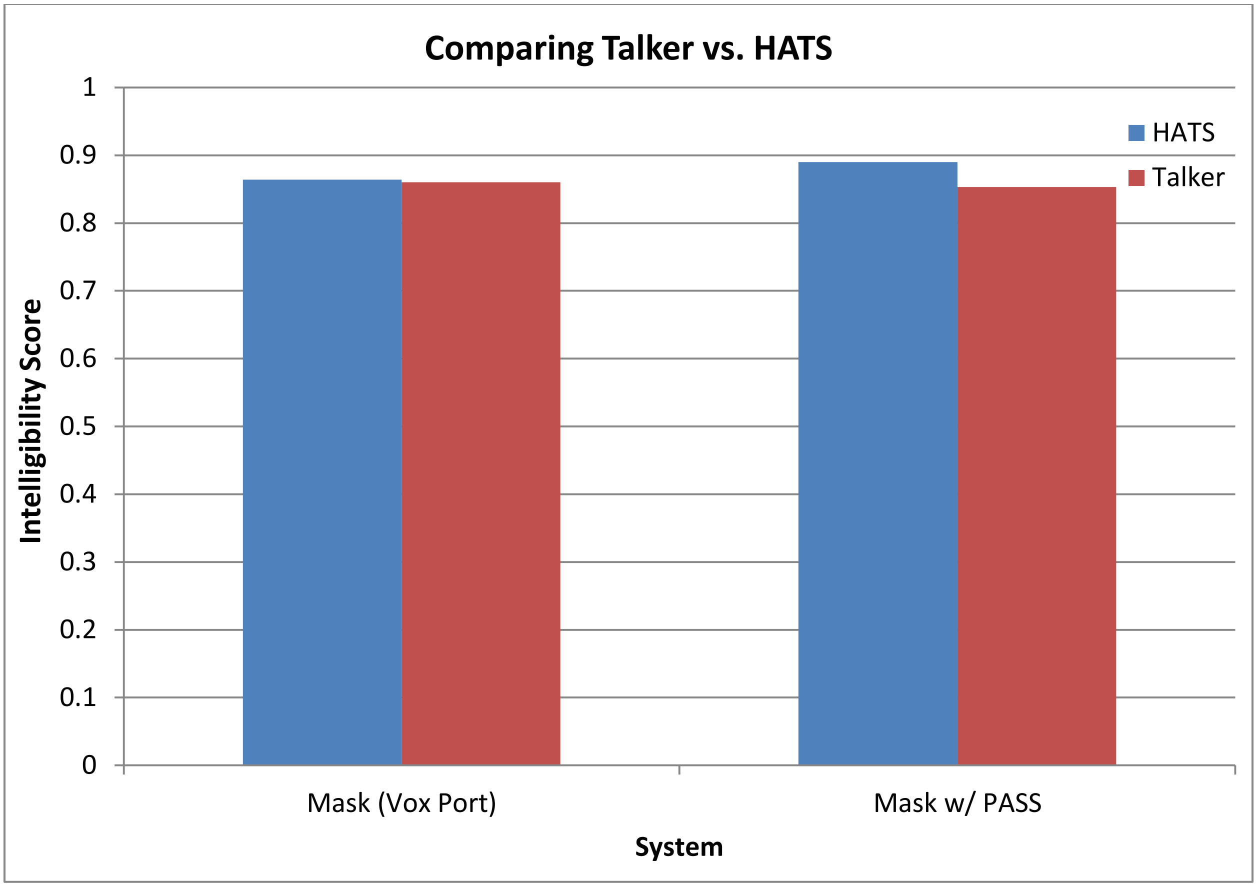

Figure E-1. Bar chart of talker vs. HATS intelligibility scores.

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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 a modified rhyme test (MRT) conducted to characterize the behavior of digital and analog communication in the presence of background noise and moderate RF channel degradation. This is done through the use of reference systems to provide a manufacturer-independent perspective on this issue.

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

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