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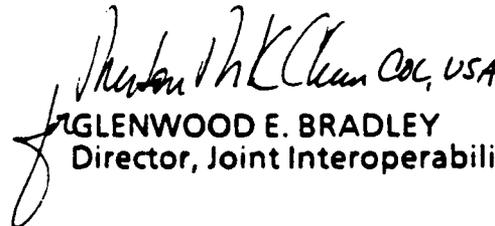
C3A-TEE

SUBJECT: ANDVT and HF Serial Tone (P5254A) Modem Voice Intelligibility Test Results

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1. During 1987, the Joint Tactical Command, Control and Communications Agency (JTC3A) Joint Interoperability Test Center (JITC) conducted comparative Voice Intelligibility tests between the Advanced Narrowband Digital Voice Terminal with its Linear Predictive Coding (LPC-10) voice processor and 39 tone modem and the Harris HF Serial-tone modem (P5254A) with the ANDVT LPC-10 voice processor providing the digitization of the voice signal.
2. The purpose of the test was to determine if LPC-10 digitized voice, at 2400 bits per second (bps) could be transmitted over High Frequency (HF) radio links using an LPC-10 voice processor and the new P5254A modem without degrading the Voice Intelligibility of that provided by the current ANDVT system. The P5254A modem is an experimental version of the Harris MD-1230 which is currently under development by the Army.
3. The enclosed MITRE Corporation analysis of the test results is provided for your information and retention.
4. The JITC point of contact is Mr. Query, C3A-TEE, AUTOVON 821-3294.

Enclosure


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Subject: Analysis of Test Data: Voice Intelligibility Tests of the ANDVT
and the ANDVT-Hybrid System

To: Charles V. Moran

From: David L. Portigal

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ABSTRACT:

Test data comparing the intelligibility of digitized voice transmitted on over-the-air and simulated high frequency (HF) links, using either the Advanced Narrow Band Digital Voice Terminal (ANDVT) or a test configuration in which the ANDVT parallel-tone modem was replaced by the Harris P5254A serial tone modem, was analyzed. This data had been obtained under the management of the Joint Test Element of the Joint Tactical Command, Control, and Communications Agency. Intelligibility had been measured using both the Phonetically Balanced Words Test and the Diagnostic Rhyme Test. An analysis of results taken over nine categories of over-the-air HF links demonstrated that the intelligibility of voice transmitted using the test configuration was never worse than the intelligibility of voice transmitted using the ANDVT. In some circumstances, performance of the test configuration was superior. However, an analysis based on published data as well as HF simulator measurements taken in this test series indicated that, under marginal signal to noise conditions, voice transmitted using the ANDVT would be more intelligible than voice sent over the test configuration.

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EXECUTIVE SUMMARY

1.0 BACKGROUND

The Advanced Narrow Band Digital Voice Terminal (ANDVT) is a standard processor for the transmission of digitized secure voice over narrowband high frequency (HF) radio links. A recent JTC³A test program demonstrated that several other modems, most particularly the experimental Harris P5254A serial-tone modem, provide improved performance over that of the ANDVT modem in its data mode. Accordingly, the tests described in this report were conducted in order to assess the capability of a system integrating the ANDVT's LPC-10 voice processor and KYV-5 COMSEC device with the Harris P5254A serial-tone modem (hereafter referred to as the LPCOMSER system) to provide comparable or improved voice performance with respect to the ANDVT. Performance was assessed in terms of standardized intelligibility test measures that are discussed later (Section 1.3) in this report.

Under test management of the JTE, comparison tests were conducted in several phases between June and November, 1987. MITRE did not participate in the test planning, data collection, or original analysis of the raw data. MITRE was provided, in August of 1988, data that was a synopsis of the raw data and asked to analyze and report on the significance of that data. This report provides the results of MITRE's analysis.

2.0 TEST CONDUCT

Two separate sets of measurements were conducted on an HF path simulator. Additional sets of measurements were taken over each of three over-the-air HF links. The HF simulator tests were conducted by the United States Army Electronic Proving Ground (USAEPG), using an HF channel simulator provided by the United States Army Communications Electronics Command (USACECOM) at Fort Monmouth, New Jersey. Link tests were accomplished by the USAEPG, Digital Systems Branch, on a Near Vertical Incidence Skywave (NVIS) Link at Fort Huachuca, Arizona; between White Sands Missile Range, New Mexico, and Fort Huachuca, Arizona; and between Fort Monmouth, New Jersey, and Fort Huachuca, Arizona.

Voice intelligibility performance was measured by the USAEPG Electro-magnetic Environmental Test Facility (EMETF), using two standardized tests of voice intelligibility, namely the Phonetically Balanced (PB) Words test, and the Diagnostic Rhyme Test (DRT). In both tests, word lists processed by the ANDVT and LPCOMSER equipment configurations and transmitted over the simulated or HF Links were taped. Voice intelligibility scores were derived from the proportion of correct responses given by panels of trained assessors who listened to these tapes. BER measurements and other link characteristics were also recorded. However, it was not feasible to

SECTION 1

INTRODUCTION

1.1 BACKGROUND

The Joint Tactical Command, Control and Communications Agency (JTC³A) has conducted a Voice Intelligibility Test of an LPC-10/Serial-Tone Modem. Secure, intelligible voice communications are needed for the effective command and control of all forces, and, in the past decade, there has been renewed interest in the use of HF as a medium for both voice and data communications. The Advanced Narrowband Digital Voice Terminal (ANDVT), consisting of an LPC-10 voice processor, KYV-5 communications security (COMSEC) equipment, and a multitone HF modem has proven to provide enhanced secure voice and data capability over HF channels.

A recent JTC³A test program demonstrated that several High Frequency (HF) modems, most particularly the experimental Harris P5254A serial-tone modem, provide improved error performance over that of the ANDVT modem in its data mode⁽²⁾. Accordingly, the tests described in this report were conducted in order to assess the capability of a system integrating the LPC-10 voice processor and the KYV-5 COMSEC device with the Harris P5254A serial-tone modem to provide comparable or improved voice performance with respect to the ANDVT. Performance was assessed in terms of standardized intelligibility test measures of performance that are discussed later (Section 1.3) in this report.

The intelligibility tests were conducted in several steps between June and November 1987 on the basis of a test plan promulgated in Reference 1. The test program was conducted with the support of the United States Army Electronic Proving Ground (USAEPG) Digital System Branch and Electromagnetic Environmental Test Facility (EMETF), and the United States Army Communications Electronics Command (USACECOM), as well as other services and agencies.

MITRE did not participate in the test planning, data collection, or original analysis of the raw data. MITRE was provided data that was a synopsis of the raw data and asked to analyze and report on the significance of that data. This report provides the results of MITRE's analysis.

SECTION 2

DESCRIPTION OF TEST SYSTEMS

2.1 INTRODUCTION

The ANDVT and the LPC-10/COMSEC/Harris P5254A units are designed to encode 2400 bits per second (bps) digital information for transmission over HF radio links that are subject to severe multipath and fading conditions. Descriptions of each of the test units are provided below.

2.2 ANDVT

The ANDVT is a half-duplex device providing COMSEC, voice processor, and modem for the transmission of voice and data over narrowband (3 kHz) communications circuits. The standard operating configuration consists of the basic terminal unit (BTU) CV-3591 and the plug-in COMSEC module, KYV-5. The BTU provides the voice processing (LPC-10), modem functions [HF/line-of-sight (LOS)], error protection coding and the interfaces to terminal and radio equipment. The COMSEC module provides for the encryption and decryption of information transmitted and received by the BTU. The BTU can be used in either a voice-processor-only mode or in a HF/LOS-only mode when operating with an optional plug-in module in place of the COMSEC module.

2.3 LPC-10/COMSEC/P5254A UNIT

The test item configuration consists of the Harris serial-tone modem, the ANDVT voice processing (LPC-10), and COMSEC (KYV-5) functions. The P5254A modem is a full-duplex unit capable of transmitting data at rates up to 3600 bps over narrowband (3 kHz) communications circuits. The unit employs a single, phase-modulated carrier of 1500 Hz. The modem has integral interleaver and convolutional encoding functions to combat HF multipath and fading conditions. The ANDVT LPC-10 (Voice Processor) and COMSEC (KYV-5) are as described above.

The interleaver depth was set to approximately 1 second. All reported measurements were taken with the COMSEC unit connected, since preliminary tests showed no significant differences in the equipments BER performance with or without the KYV-5 COMSEC in the test configurations.

SECTION 3

TEST ISSUES AND CRITERIA

3.1 TEST ISSUES

The principal issue was whether the LPCOMSER configuration would perform as well as or better than the ANDVT in transmitting intelligible voice in the HF environment. Assessment of this issue was to be based on controlled laboratory testing and on live transmissions over various HF links. Performance of each configuration was assessed using standard intelligibility tests. Such tests use sets of equivalent lists of word-sets that are selected to be representative of some aspect of spoken language⁽³⁾.

The Test Plan contained a secondary task to analyze voice scoring data relative to the BER data taken on the HF Link Tests and compare results of that analysis to published data on voice intelligibility scores versus BER. For reasons discussed in Section 5.2, the data obtained in the tests described here could not support that task.

3.2 TEST METHODOLOGY

To conduct these tests, word lists were transferred from master tapes onto test tapes. The contents of these test tapes were processed and transmitted over both simulated and real HF links. The received transmissions were decoded and recorded onto other test tapes. Panels of eight selected and trained listeners responded to each word by indicating, from a list projected onto consoles at listener stations, which word was heard.

Two tests of intelligibility were used in this test program. The Harvard Phonetically Balanced (PB) Words Test is the American Standard method for intelligibility testing. It consists of 1000 monosyllabic words, chosen to approximately represent the distribution and proportions of sounds that occur in normal speech, that are grouped into 20 lists of 50 words each. Words on a given list are randomized each time the list is used, and each word is embedded in a carrier phrase⁽³⁾. This test is favored by the Scoring Facility (SF) at the EMETF⁽⁴⁾.

The Diagnostic Rhyme Test (DRT) is a two-alternative test based on 96 rhyming word pairs differing only in their initial consonants. Members of a pair differ only in a single phonemic feature. Each feature contrast occurs in eight vowel contexts. In a test of 192 words, members of each pair are randomly assigned to each half of the test so that the entire test includes all words, but listeners do not know which member of a pair to expect, since this changes from list to list. This test is favored by the

SECTION 4

TEST PROCEDURES

4.1 TEST SCHEDULE

The voice intelligibility tests described here were based on the USAEPG test plan. Referenced testing was accomplished in five parts.

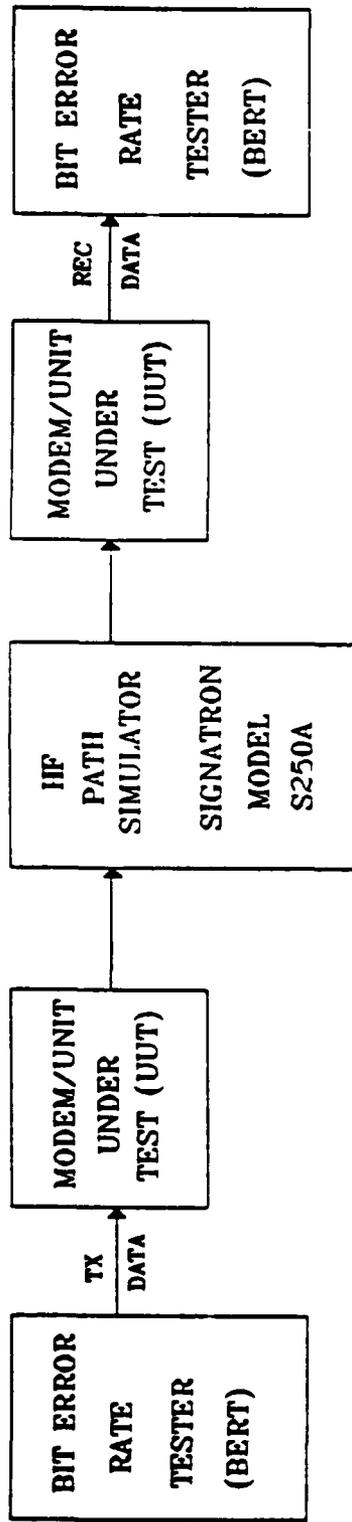
- a. Part I - Phase I Simulator Tests on the ANDVT Testing was conducted using the USACECOM path simulator at Fort Monmouth, New Jersey, from 8 - 13 June 1987.
- b. Part II - NVIS HF Link Tests Tests were conducted on an HF radio link of 30 km between Parker Lake and the Joint Test Facility (JTF), both at Fort Huachuca, Arizona. Testing was conducted during 17-25 August 1987. In this and all other HF Link Tests, the receiver was located at Fort Huachuca, Arizona.
- c. Part III - Short-Haul HF Link Tests Tests were conducted between White Sands Missile Range (WSMR), New Mexico, and the JTF, Fort Huachuca, Arizona, during 3-6 September 1987.
- d. Part IV - Long-Haul HF Link Tests Tests were conducted between Fort Monmouth, New Jersey, and the JTF, Fort Huachuca, Arizona, from 30 September 1987 to 3 November 1987.
- e. Part V - Phase II Simulator Tests Tests were conducted on both the ANDVT and the LPCOMSER at USACECOM, Fort Monmouth, New Jersey, during 9-13 November 1987.

4.2 TEST SYSTEM CONFIGURATION

For the initial Phase I tests, the following items were used:

- o Two ANDVT BTUs (serial numbers 205 and 210); both XN-3 models
- o ANDVT COMSEC (KYV-5) units (serial nos 063 and 031); both E-2 models
- o DS-10 BER Test sets (BERTs)
- o Reel-to-reel voice recorders

For the over-the-air and Phase II testing the following test items were used in place of or in addition to those used in the initial testing:



General Simulator Capabilities*

3dB Bandwidth (300 to 12,000 Hz)

Doppler Spread per Path (0-10 Hz RMS)

Doppler Shift per Path (-100 Hz to + 100 Hz)

Delay Range (± 10 ms)

Number of Paths (6 maximum)

* The tests used only a subset of these capabilities

FIGURE 4-1
USACECOM HF PATH SIMULATOR TEST SETUP

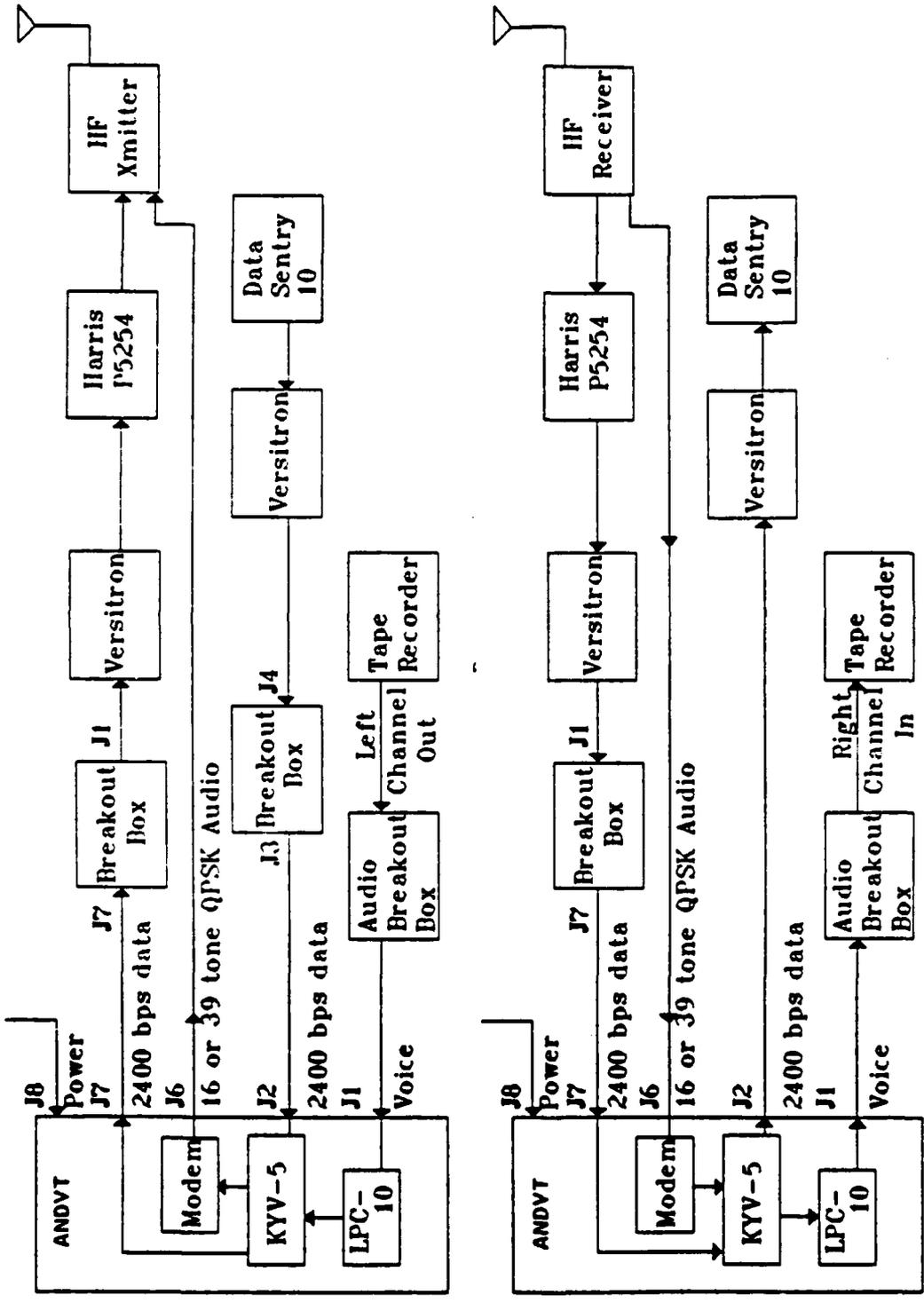


FIGURE 4-2
OVER-THE-AIR TEST CONFIGURATION

SECTION 5

TEST RESULTS

5.1 COMPARISON OF ANDVT AND LPCOMSER PERFORMANCE

5.1.1 Analysis of Link Tests

The basic analysis of the data from the tests is predicated on the assumption that, however the channel characteristics might vary during a test or between tests, the alternation between the ANDVT and the LPCOMSER units on all test runs provides a sampling of each link environment in such a way that results are not biased in favor of one or the other module. It is further assumed that, though different sets of PB and DRT test lists were used with each test system, the intelligibility scores of different lists are essentially equivalent, or, at least, that, by randomly choosing the lists used for each test system, no systematic bias is introduced.

With three types of links, and three basic environments on each link, nine categories of link transmissions were considered. Within each category, the AS and VIS scores from all listeners were used to calculate sample averages and standard deviations. Table 5-1 gives the averages and standard deviations for the ANDVT tests. The number of transmissions averaged is given in parenthesis. Table 5-2 gives the same type of data for LPCOMSER transmissions.

For each of the nine categories and for each of the two measures of intelligibility, the measured performance of the LPCOMSER exceeded that of the ANDVT. Standard statistical techniques were used to assess whether the amount by which the LPCOMSER exceeded the ANDVT was significant.

The t-distribution^{7,8} was used to test the hypothesis that the voice intelligibility of the ANDVT and LPCOMSER are the same. This is accomplished by evaluating the t-statistic (defined to be the ratio of the difference in the sample means to the sample standard deviation of that difference⁸) and looking up the associated confidence levels in standard tables⁷ that list the confidence levels as a function of the value of the t-statistic and the number of degrees of freedom associated with the data⁸ (in this case, the sample size minus one). The confidence levels, by category and voice intelligibility score type, are found in Table 5-3.

The t-distribution is appropriate when the intelligibility measures (AS and VIS) used to test the two systems are normally distributed. However, because of the small number of data points that were obtained from the tests, it was impossible to ascertain, with any degree of confidence, whether the assumption of normality was reasonable. Consequently, two

TABLE 5-3
 CONFIDENCE LEVEL OF HYPOTHESIS THAT INTELLIGIBILITY IS EQUAL

Link	Environment-->		Daylight		Night		Transition	
	PB	DRT	PB	DRT	PB	DRT	PB	DRT
NVIS	0.43	0.640	0.16	0.160	0.024	0.680		
Short Haul	0.18	>0.900	0.31	>0.900	0.150	0.048		
Long Haul	0.30	0.071	0.82	0.017	0.096	0.130		

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TABLE 5-4
 CONDITIONS UNDER WHICH THE HYPOTHESIS THAT THE ANDVT AND THE
 LPCOMSER HAVE EQUAL INTELLIGIBILITY IS REJECTED AT THE .10 LEVEL

Environment → Test →	Daylight		Night		Transition	
	PB	DRT	PB	DRT	PB	DRT
<u>Link</u>					◊●	
NVTS					◊●	
Short-Haul	◊					◊●
Long-Haul		◊●		◊●	◊●	◊

Legend:

- t-test
- Rank-sum
- ◊ Terry-Hoeffdig

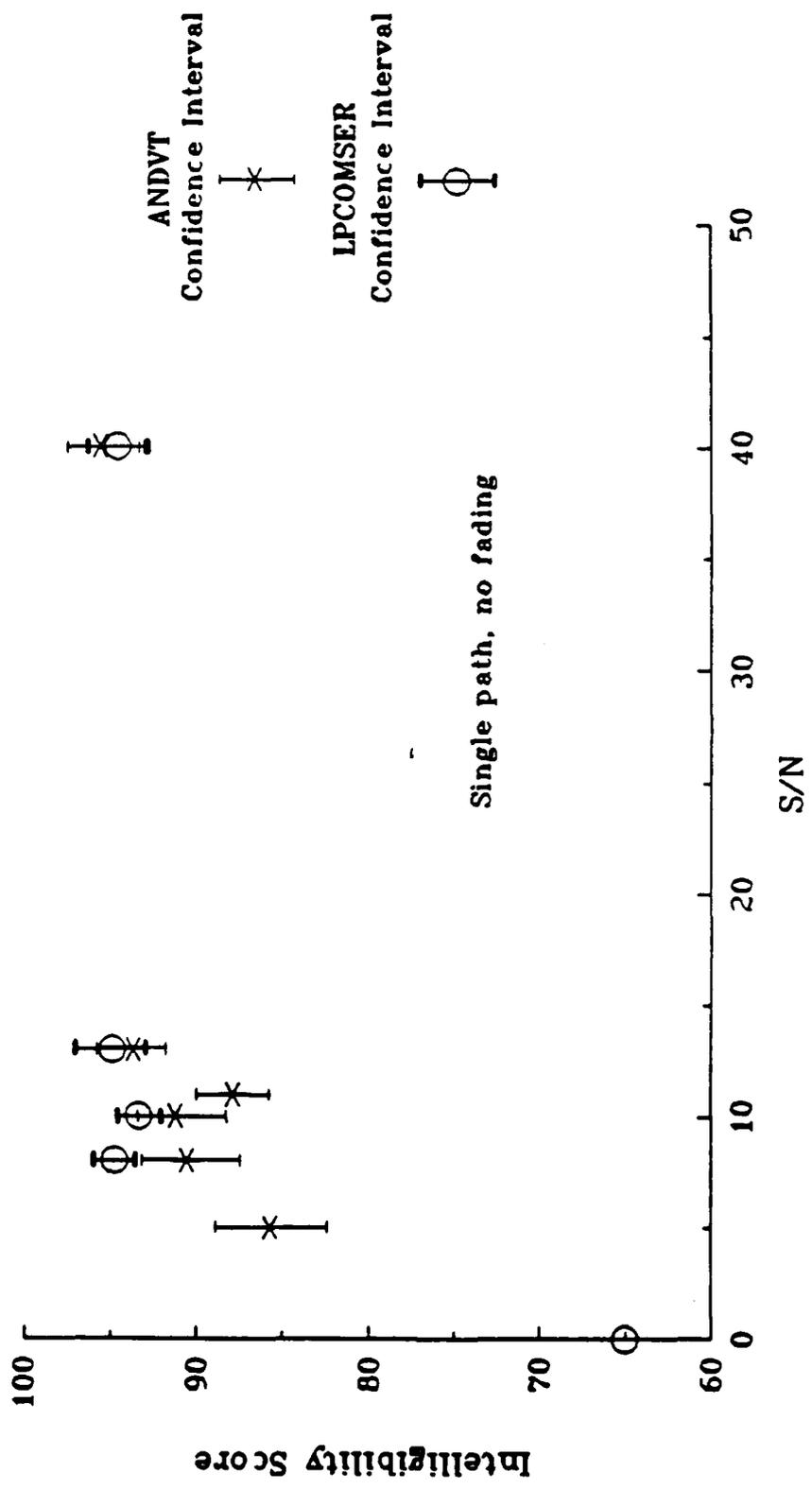


FIGURE 5-2
INTELLIGIBILITY TEST RESULTS: PHONETICALLY BALANCED

More interestingly, the simulator data, taken in conjunction with other published data, strongly suggests that the ANDVT would be useable at lower values of S/N. The maximum allowable BER as a function of S/N for the ANDVT data mode operating at 2400 bps⁵ is plotted in Figure 5-1. The equipment used in this test does not quite meet this requirement, since it is approximately 1 db worse at any BER value (Figure 5-1). The maximum allowable BER versus S/N for the ANDVT voice mode⁵ is also plotted in Figure 5-1, together with published simulator measurements on the experimental serial modem⁽¹⁰⁾. These published results are consistent with those obtained from the current tests. Note that the ANDVT voice mode should outperform the serial modem by approximately 3.5 db.

When is this difference significant? At low values of BER, the intelligibility is not sensitive to error rate variations. The Digital Voice Processor Consortium fitted regression lines to their data on the variation of VIS with BER for various voice processors⁽¹¹⁾. They found, for the LPC-10 processor used in these tests, that, under the conditions in which the master tapes for these tests were prepared, that the best fit was given by:

$$S = 89.2 - 2.16X \quad (2)$$

where S is the VIS for a typical DRT test, and X is the BER, stated in percent. With a typical standard deviation in the DRT score of 1-2 percentage points, the effect of BER on the VIS should not be apparent unless the BER was at least 0.5' - 1.0 percent in magnitude. From Figure 5-1, it is apparent that the effect of bit errors should become observable on the LPCOMSER when the S/N decreases below approximately 8.5 db, and observable on the ANDVT when the S/N decreases below approximately 5 db. Using the above regression equation, the BER versus S/N Curve for the Harris modem, and the specification limiting curve for the variation of BER with S/N for the ANDVT voice mode, the expected variations of VIS versus S/N were plotted in Figure 5-3.

In this test series, the ANDVT VIS exceeded the theoretical values at low S/N, while the LPCOMSER VIS were generally worse than the values projected from these theoretical considerations. The reasons for these differences are not known. Nevertheless, the test data consistently demonstrate that the ANDVT transmits intelligible data at S/N values 2 db less than the LPCOMSER modules would. This result was true not only on the Gaussian channel, but on the two other channels as well. For the Gaussian channel this 2 db difference is consistent with theoretical results, if it is assumed that, as in the data mode, the actual performance for the tested equipment in the voice mode is 1 db worse than the specification requirement.

category, and fit a linear regression curve between those values and the intelligibility scores found in Tables 5-1 and 5-2. However, simple inspection of the BER data shows that not only does the BER change noticeably from run to run (typically 20-30 minutes apart), but that the nature of the noise statistics, as characterized by the number of EFS and the proportion of 100-bit blocks that contain errors, varies quite drastically between runs. Therefore, though the categorization used in Section 5.1.1 is useful for the general comparison of the performance of two different modules, we should be wary of attempting to derive detailed quantitative relationships when characteristics of the variables differ drastically among individual data observations taken over a given category of link. Moreover, in the case of the ANDVT, it is not realistic to compare BER data taken on the data mode with voice intelligibility scores where the coded voice data was sent over the ANDVT voice mode.

The variation of the DRT VIS with BER was derived from the Gaussian channel simulator data, using a linear regression fit. In the case of the ANDVT, the VIS was poorly correlated to the data mode BER. For the LPCOMSER, based on three data points.

$$S = 87.3 - 2.49X \quad (3)$$

The intercept is two percentage points lower than that of Equation (2), but the slopes are comparable.

SECTION 6

CONCLUSIONS

6.1 RELATIVE PERFORMANCES OF THE ANDVT AND LPCOMSER

Based on the data provided to MITRE by the JTE, the following conclusion can be drawn about the relative performances of the ANDVT and LPCOMSER:

- o For the wide range of conditions sampled in the HF lab tests, the LPCOMSER equipment (LPC-10 voice processor, KYV-5 COMSEC, and Harris P5254 serial-tone modem) transmitted and processed voice at least as intelligibly as the standard ANDVT.
- o In many of the over-the-air tests, particularly in the transition environment between daylight and darkness, the performance of the LPCOMSER appears to have been better than that of the ANDVT.
- o Where the S/N at the receiver is marginal, the analysis, together with simulator results, indicates that the ANDVT has a small advantage over the LPCOMSER. Under such circumstances, it appears that the ANDVT can maintain a given level of intelligibility at an S/N value that is 2 db lower than that of the LPCOMSER.

6.2 USE OF BER TO ESTIMATE INTELLIGIBILITY SCORES

These tests could not demonstrate whether it would be feasible to estimate intelligibility scores of voice transmitted over an HF link from the BER data alone.

APPENIDX A

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APPENDIX B

GLOSSARY

ANDVT	Advanced Narrow Band Digital Voice Terminal
AS	Articulation Score
BER	Bit Error Rate
BERT	Bit Error Rate Test Set
bps	Bits per second
BTU	Basic Terminal Unit
COMSEC	Communications Security
DRT	Diagnostic Rhyme Test
EFS	Error Free Seconds
EMETF	Electromagnetic Environmental Test Facility
HF	High Frequency
ISB	Independent Sideband
JTC ³ A	Joint Tactical Command, Control, and Communications Agency
JTE	Joint Test Element
Kw	Kilowatt
LOS	Line of Sight
LPCOMSER	LPC-10/COMSEC/Harris Serial Modem
MHz	Megahertz
NVIS	Near Vertical Incidence Skywave
PB	Phonetically Balanced
PEP	Peak Effective Power
SF	Scoring Facility
S/N	Signal to Noise
USAECOM	United States Army Communications Electronics Command
USAEPG	United States Army Electronic Proving Ground
VIS	Voice Intelligibility Score

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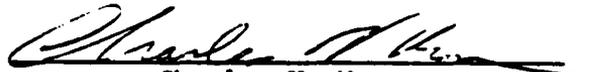
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