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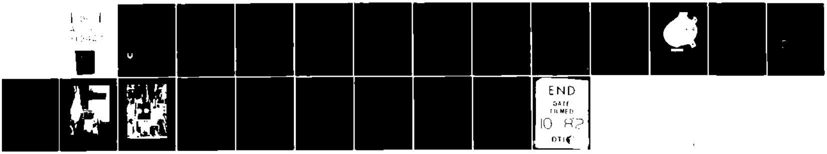

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AVRADCOM

Technical Report - 81-E-1

ELECTRONIC VOICE COMMUNICATIONS IMPROVEMENTS FOR ARMY AIRCRAFT

MITCHELL S. MAYER
US ARMY AVIONICS R&D ACTIVITY

AUGUST 1982

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER AVRADCOM TR-81-E-1	2. GOVT ACCESSION NO. AD-A119427	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Electronic Voice Communications Improvements for Army Aircraft		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mitchell S. Mayer		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Headquarters US Army Avionics R&D Activity ATTN: DAVAA-E Fort Monmouth, NJ 07703		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Headquarters US Army Avionics R&D Activity ATTN: DAVAA-E Fort Monmouth, NJ 07703		12. REPORT DATE August 1982
		13. NUMBER OF PAGES 16
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Microphone	Pink Noise	Coupler
Attenuator	Earcup	Noise
Earphone	Real-Ear	Headset

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The communications systems on all Army aircraft flying today are based on design concepts that are over 50-years old. The wide use of positive-peak-clipping (which introduces up to 50-percent distortion), limited bandwidths (300-3000 Hz), and unsophisticated AGC circuits reduce speech intelligibility and impact severely on aviator hearing loss. Outmoded test procedures, such as limited volume Kruff boxes for testing pressure gradient (noise canceling) mircophones and 6-cc couplers for testing earphone elements, used in large volume circumaural

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) earcups, remain in use through all branches of the service. These concepts and procedures are used because they have been standardized during the early years of communications electronics, and after many years of use, were accepted as sacrosanct.

After 8 years of research and development, we have designed a totally modern, state-of-the-art communications system for Army aircraft, and have published two new specifications which contain many of the modern test procedures required to accurately test and evaluate the various components of the communication system.

As a first step in the development of new test procedures, we evaluated both ASA and ANSI standards and found them lacking. Their procedures for measuring the noise attenuation of hearing protective devices totally ignored the effects of the aircraft noise environment on microphone noise cancellation and earcup pumping, and the addition of necessary speech communications in the earcup, which must be at least 6-10 dB above the noise level in the earcup for adequate speech intelligibility.

The components of the new state-of-the-art communications system will include, as a minimum: high impedance DC powered noise canceling microphones (using piezoelectric ceramic, electret, or PVF_2 diaphragms); earphone elements designed and tested to have flat frequency response when inside the circumaural earcup of the hearing protective device; and intercoms which replace positive peak-clipping with fast-acting AGC circuits and expander/compander circuits for maximum output signal without distortion, even under conditions of extreme stress.

In the future, audio signals in the microphone will be converted into the digital mode or directly into the optical spectrum for high efficiency, and secure communications inside the aircraft. The savings in weight and security improvements will be considerable. Digitizing the speech signals will require research into minimum bit rates necessary for required speech intelligibility and time-sharing requirements when interfacing into the digital data bus (MIL-STD-1553B). Optical communications will require light-weight, efficient audio-to-optical or digital-to-optical converters. These converters along with optical amplifiers, couplers, and splitters will be required to meet the same MIL-STD's all other airborne audio equipment must meet, and be easy to install and repair.

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1. INTRODUCTION

The future battle scenario is envisioned to be a medium-intensity environment fought on or near the ground. This means that our aircraft will be flying and fighting in an NOE (Nap-of-the-Earth) environment, drastically increasing the aviator's already heavy workload. The fatiguing effects of High Noise and poor communications (at NOE altitudes, line-of-sight radios work very poorly and for only short ranges) will have a deleterious effect on the aviator's combat effectiveness; therefore, the ability to communicate effectively in this harsh environment is essential to the successful accomplishment of his combat mission.

Military aircraft are designed for maximum capabilities in areas of performance, armament, and endurance. Acoustic noise suppression considerations, such as sub-chassis isolation of engines and transmissions, noise damping structural panels, and helmholtz resonator traps, impact on performance (added weight), as well as cost. (Total acoustic protection for the aircrew is not allowed to exceed 1-1.5 percent of the aircraft gross weight.) With these severe restrictions on noise attenuation at the source, personal aircrew protection is the only other avenue of approach. This sole protection, therefore, must be provided by the electronics package of the aviator's flight helmet.

The two major elements of the helmet electronics package are the noise-canceling microphone and the earcup/transducer assembly. For years these elements have been designed and tested to meet standard requirements and test procedures which do not realistically or accurately reflect the conditions under which they must operate. Before new communications elements can be designed and developed to meet the challenges of the high noise environments of military aircraft, there must be a clear understanding of those standards and their shortcomings.

2. BRIEF HISTORY OF CURRENT STANDARDS

a. 300-3000 Hz Bandwidth. In the 1920's the Army began to realize the importance of speech communications in the battlefield. Bell Laboratories (Research Facility of the Bell Telephone Company) was tasked to supply the Army with the design considerations that must be applied to their communications system, in order for a successful system to be developed. One of these major design considerations was the requirement of a 300 to 3000 Hz communications bandwidth for the electronic transmission of human speech.

It is unfortunate that the 300 to 3000 Hz limited bandwidth, which worked so well for the telephone, is not adequate when communication is attempted while the talker or the listener is in a high noise environment. (Speech intelligibility becomes severely degraded when the ambient noise environment of user exceeds 75 dBA.) After the first communications systems were in use in the Army, however, their shortcomings became apparent. One stopgap measure (still in use today) was the use of a phonetic alphabet. This allowed a low intelligibility system to operate effectively in the military enviroment of that time.

Today, more than 50 years later, we still use this limited bandwidth in our communications systems; however, the use of the phonetic alphabet is not acceptable because it is slow and cumbersome, seriously degrading critical information acquisition in the medium-intensity NOE battlefield environment. The aviator (operating in the high-noise environment of Army aircraft) must be able to communicate effectively the first time. He does not have the luxury of repeating messages or using phonetically spelled words.

b. Coupler Calibration of Earphones (NSI 224.9-1949). The use of the 6-cc (or Mott) coupler is another example of continuing to follow an outmoded "standard." The US Army, as with the bandwidth question, went to Bell Laboratories for a method of testing the frequency response of their communications headsets. Bell Laboratories recommended the 6-cc coupler. (A detailed test procedure incorporating the 6-cc coupler became ANSI 224.9-1949.)

The 6-cc coupler was developed for use as a 100-percent production-line test of Western Electric (manufacturing arm of the Bell Telephone Company) telephone handsets, because the closed volume between the earphone element and the eardrum approximates 6-cubic centimeters.

With today's large volume circumaural earcups, the use of the 6-cc coupler for testing the frequency response of the installed earphone elements is highly misleading. The earphone element itself can still be measured using the 6-cc coupler; however, when the earphone is placed into position inside the circumaural earcup, its frequency response is radically changed. These changes in the earphone frequency response impact significantly on speech intelligibility and cannot be seen when measuring the earphone as a separate entity in a 6-cc coupler. A test procedure which measures the response characteristics of the complete earcup/transducer assembly is essential if realistic data is to be obtained.

c. Real-Ear Attenuation of Hearing Protective Devices (ASA STD 1-1975 and Z-24, 22-1957, which it replaces). These two standards were excellent attempts to develop test procedures which would accurately test all types of hearing protective devices, including circumaural earcups. In most cases, these standards produce realistic results. The areas where these standards fall apart, however, are in high noise environments such as those that exist in military aircraft and when communications is included in the earcup. A hearing protective device that demonstrates acceptable attentuation values when tested by the threshold technique used in these standards, shows much lower values when tested in a high noise environment.

In a high noise environment, noise reaches the aviator's ears by several paths:

(1) Intense noise will penetrate the earcup directly, sending the entire assembly into sympathetic vibration. This "pumping" action causes the earcup to respond like a transducer, reproducing the noise inside the earcup.

(2) The "pumping" action of the assembly will cause the soft earcushion (resting against the head) to lift off the head, producing leaks in the seal which allow noise to enter the earcup. Leaks in the earcushion seal can also be caused by improper helmet fit. An improper fit usually is the result of the user not fitting the helmet properly, or a user with a head size that does not fit properly into the two helmet sizes available to him.

(3) The noise canceling microphone, when keyed, will detect the noise and pass it through to the communications system to be amplified and sent to the earphones in the aviator's helmet, as sidetone. It will also include this detected noise, along with the speech information, in the transmitted signal.

d "Signal-to-Noise" Test Box (Kruff Box). While this procedure can compare two different noise canceling microphones and tell the tester that one may cancel noise better than the other, the data obtained using this procedure does not realistically reflect the operation of the microphone as it is used by an aviator. In actual use, the microphone is not inclosed in a limited volume, but is inside a large semi-reverberant chamber (the aircraft), with one end of the microphone brushing against the aviator's lips and the other end surrounded by the noise field. The aviator's head acts as a partial block to the noise field, preventing the noise from impinging on both surfaces of the microphone equally, and thus severely limiting the noise canceling capability of the microphone. The Kruff box does not take into account the interaction of the human head and noise canceling microphone in an intense semi-reverberant noise field.

e. Positive-Peak-Clipping. Another standard that has been in use for 50 years is the concept of positive-peak-clipping. When first introduced, it was thought that a square-wave audio output would provide the maximum signal strength to human speech, increasing the speech intelligibility of the transmitted voice to acceptable levels for radio communication. This technique is based on the fact that, while constants provide the major portion of sounds required for speech intelligibility, vowel sounds, being louder, mask the consonants in a sinusoidal signal. Using positive-peak-clipping, approximately 20 percent of the upper portion of the sinusoidal signal is clipped; next, the consonant sounds are increased to fill this gap in an attempt to achieve high speech intelligibility. (This technique, coupled with a fast rise and slow delay AGC circuit, is still in wide use today.)

The major problem with positive-peak-clipping is that, when the amplifier gain is increased into clipping, distortion of the audio signal will increase to levels approaching 50 percent. These very high levels of distortion decrease speech intelligibility so severely, that almost all the gains of increased consonant signal levels are lost. In some cases, this distortion can be so severe as to almost completely destroy all the speech intelligence. This condition exists when the aviator transmits a "panic message"; the one time that high speech intelligibility is essential.

Today there are clamping circuits, such as "expander/compander" circuitry, that can give maximum signal strength, while still retaining a sinusoidal output even under "panic" situations. By expanding the frequency response of the communication system from 300-3000 Hz to 300-4500 Hz, the lost consonant sounds can be brought back into the transmitted signal without the need to positive-peak-clip the audio signal.

3. NEWLY DEVELOPED (REALISTIC) TEST PROCEDURES

Now that an understanding of the shortcomings of current standards has been presented, a discussion of newly developed standards and test procedures can commence.

a. Increased Audio Bandwidth (300 to 4500 Hz). High speech intelligibility in the military aircraft noise environment requires that all essential parts of the human speech spectrum (for both male and female voices) be reproduced and processed through the communication system. Since positive-peak-clipping has been eliminated in our new communication system design, this extended bandwidth is required to process the consonants in human speech which provide the speech intelligibility necessary in high noise environments. (Most consonants occur between 3000 and 4500 Hz.)

In addition to a broader bandwidth for the communications system, the bandpass of the entire system should be relatively flat. This flat response, especially at frequencies below 1 KHz, increases speaker recognition which has proved to be an aid to increasing speech intelligibility in high noise environments.

b. Real Head Attenuation of Hearing Protective Devices in Pink Noise. This procedure adds the requirement of a pink noise environment to the current standards for testing hearing protective devices. The sound pressure level of the pink noise in the test chamber should approximate the sound pressure levels experienced by aircrews during the performance of their missions. Two microphones are then used for measuring both the "ambient" noise environment and the "attenuated" environment at the ear. The use of a condenser microphone in the ambient environment and a miniature electret condenser placed on the chonchea of the ear, protected by the circumaural earcup, are effective in obtaining the measurements required. If a 2-channel real-time analyzer is available, a real-time noise attenuation chart of the hearing protective device can be produced. The effects of helmet fit and movement inside the noise environment can then be evaluated in real-time and recorded on a time histogram plot.

Figure 1 shows the earcup/transducer assembly of a SPH-4 helmet with a miniature electret microphone placed in the assembly. The charts in Figures 2, 3, and 4 of this report were obtained from data supplied by a Two-Channel FFT (Fast Fourier Transform) Real-Time Analyzer (Spectral Dynamics Model SD-360). The same test subject wore both a standard SPH-4 aviator's helmet and a modified SPH-4 which contained a prototype MK-1564( )/AIC Headset-Microphone Kit. A 1/2-inch B&K condenser microphone was used to measure the ambient environment (Pink Noise at 105-dB SPL in the anechoic chamber and CH-47 helicopter noise at 115-dBA SPL in the aircraft noise environnent simulator) and was connected to Channel A of the analyzer. A miniature electret condenser microphone was used to measure the "attenuated" noise at the subject's ear and was connected to Channel B of the analyzer. The analyzer then performed the transfer function: B/A. The data was plotted on linear paper and then transferred to semilogarithmic paper for this report.

Figure 2 shows the differences in the attenuation characteristics of the US Army's SPH-4 aviator's helmet when measured according to ASA STD 1-1975 and when measured by the Real-Head procedure in pink noise at 105-dB SPL (average sound pressure level of US Army aircraft.) (Note that the ASA standard procedure shows helmet attenuation at low frequencies to be greater than actually experienced in an intense noise environment. This difference is mainly due to the "pumping" action of the earcups which can not be seen in the low level noise environments.)

Figure 3 compares the "real-head" in pink noise procedure to a "real-head" procedure in a simulated CH-47 helicopter noise environment. (Note that these procedures compare favorably. There are differences of high frequencies because the CH-47 noise environment is at 115-dBA SPL compared to the pink noise at 105-dB SPL. Figure 5 shows the inside of our noise environment simulator.

c. Microphone Noise Cancellation Procedure. Microphone noise cancellation procedure requires two measurements, nearfield and farfield. The nearfield measurements are made using an artificial voice (Bruel and Kjaer Type 4219, or equivalent), while the farfield measurements require the use of an 8-inch speaker (normalized to a flat response, preferably by a digital computer) inside an anechoic chamber. The microphone under test must be at least one meter away from the sound source to be in its "farfield." Figure 6 shows the inside of our anechoic chamber as it is set up for these tests.

Noise canceling microphones generally exhibit a cardioid polar response. To evaluate a microphone under "worst-case" conditions, the farfield response should be measured with the microphone facing the sound source. This measurement should not be averaged with measurements taken at the microphone's null point (90° or 270°

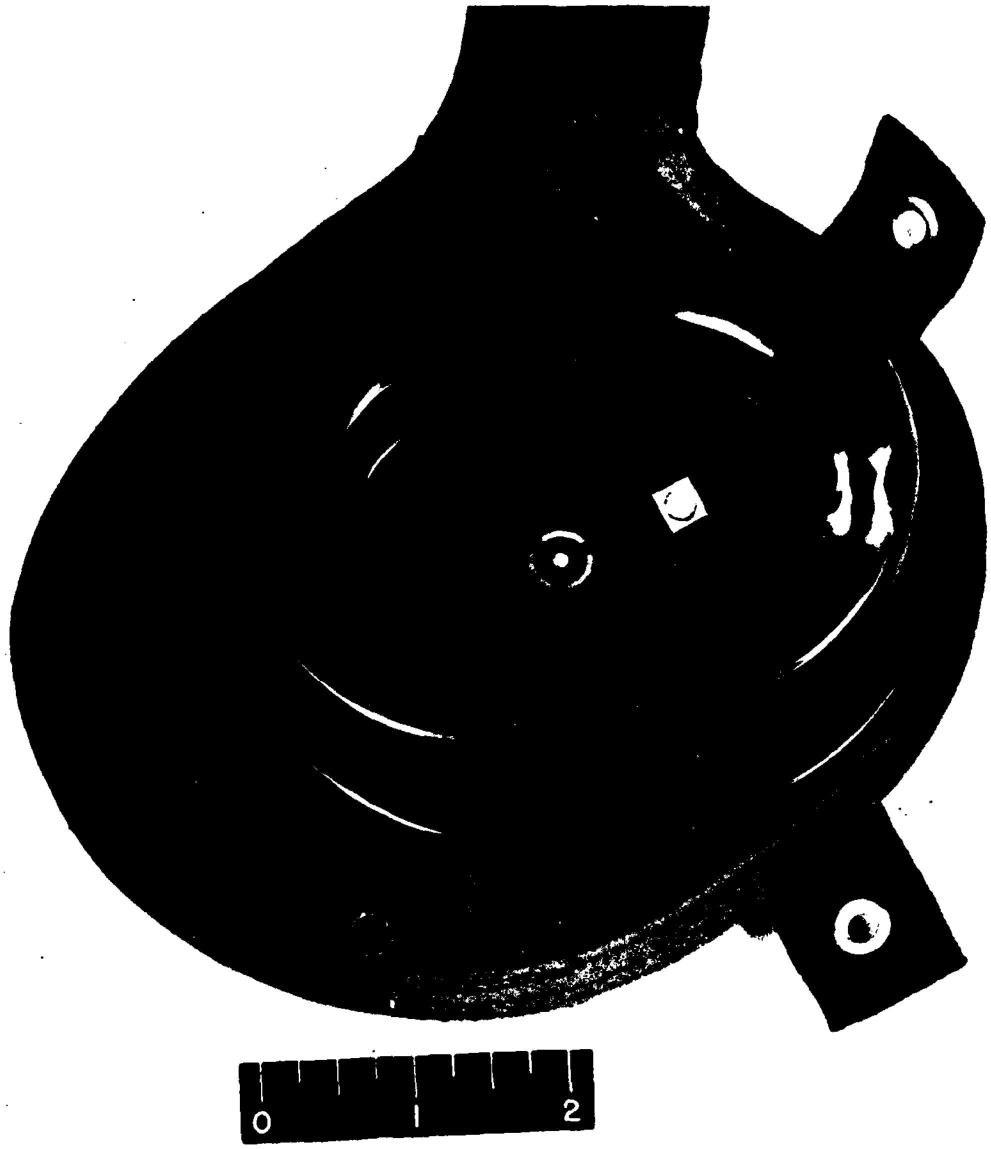

Figure 1. Miniature Electret Microphone Inside SPH-4 Earcup Assembly

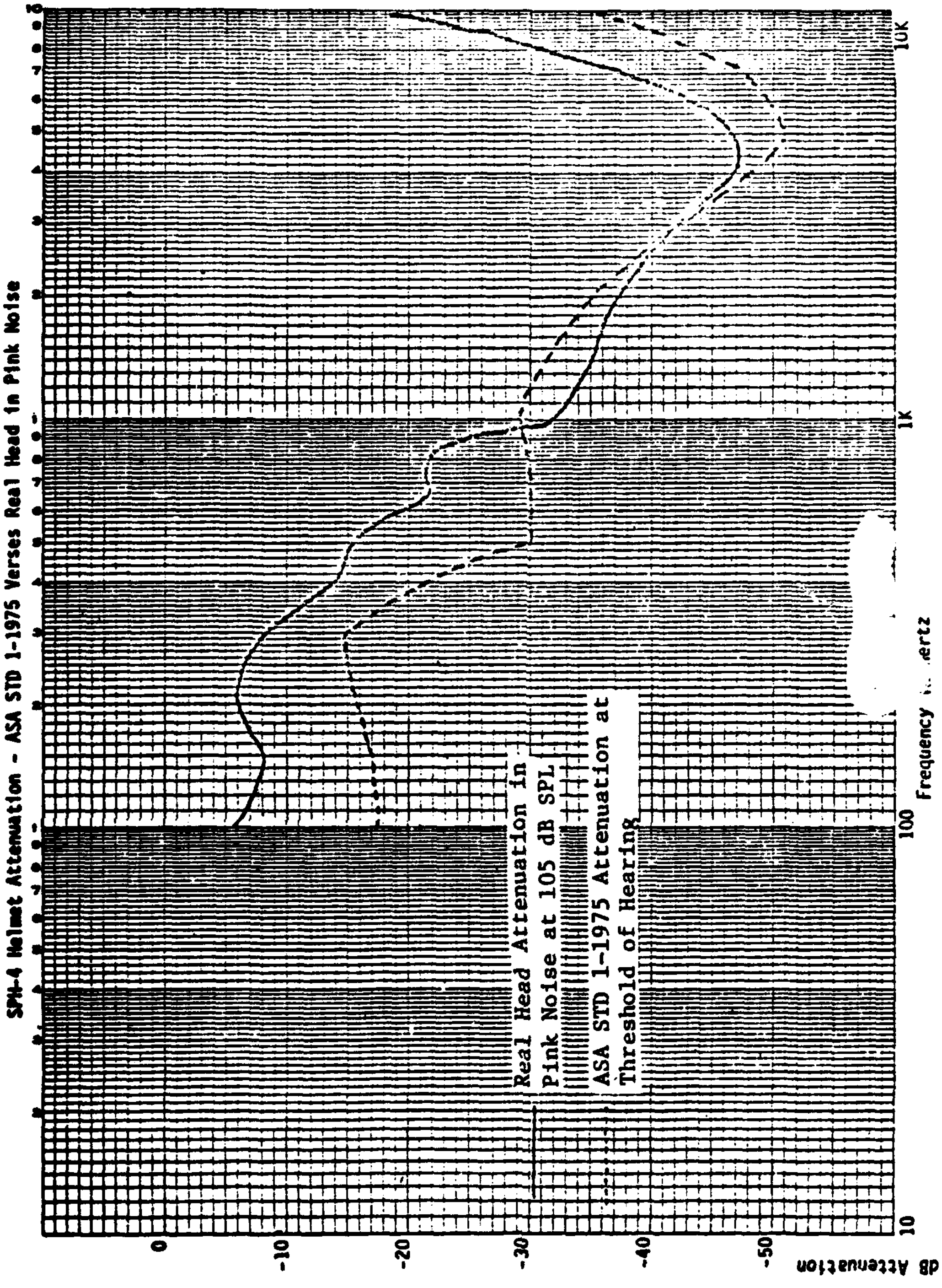

Figure 2. SPH-4 Helmet Attenuation - ASA STD 1-1975
Versus Real Head in Pink Noise

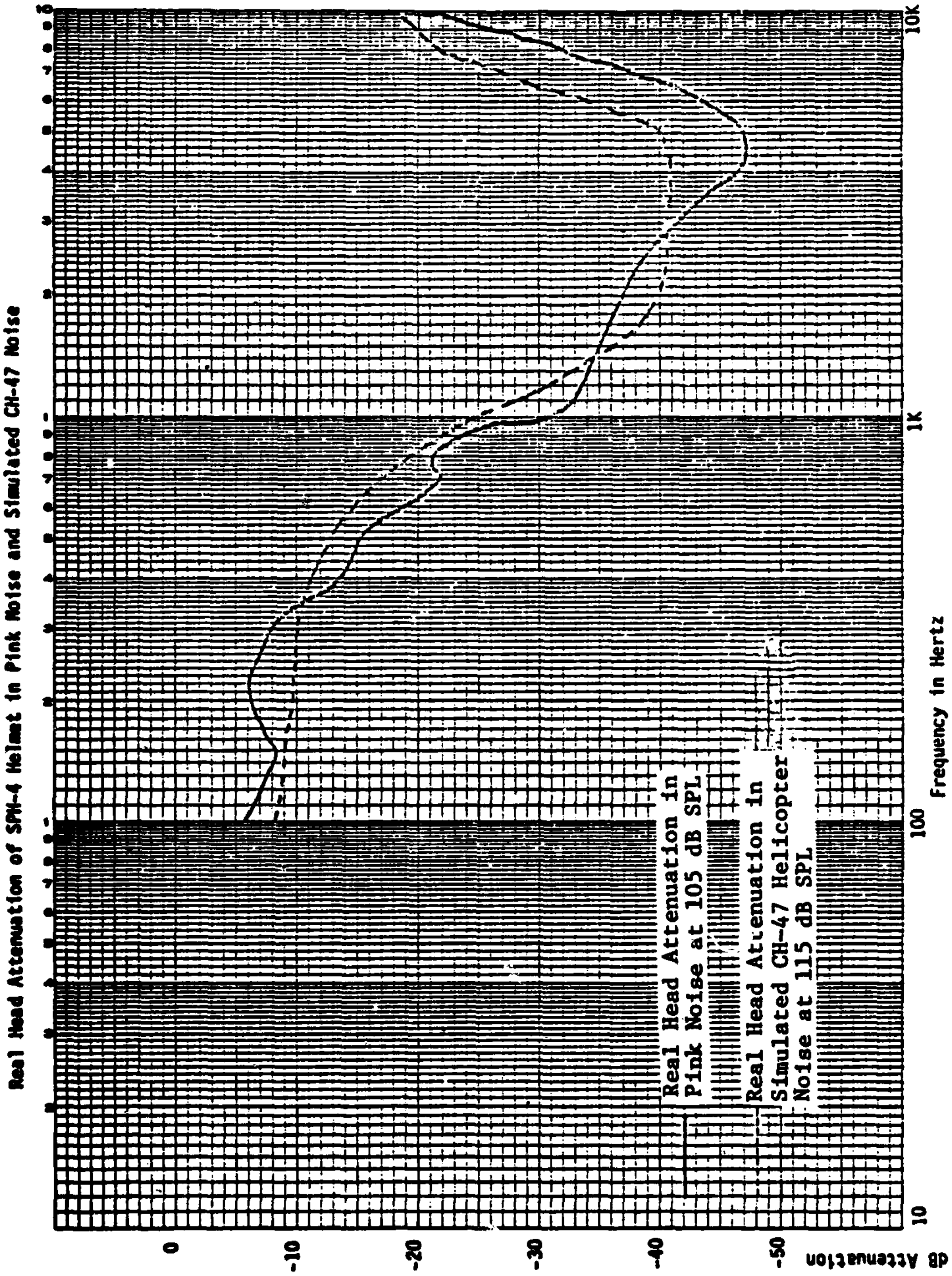

Figure 3. Real Head Attenuation of SPH-4 Helmet in Pink Noise and Simulated CH-47 Noise

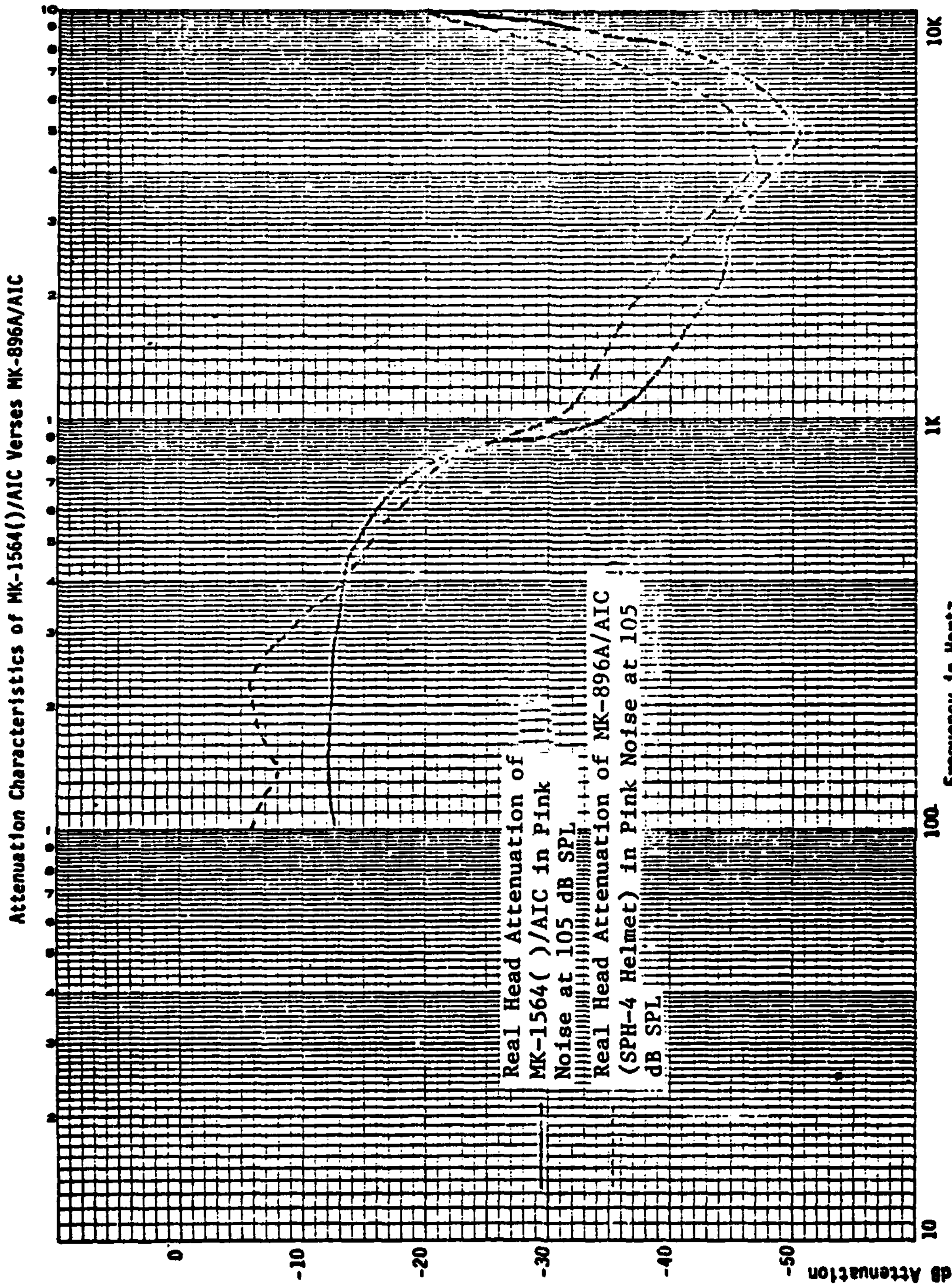

Figure 4. Attenuation Characteristics of MK-1564( )/AIC Versus MK-896A/AIC

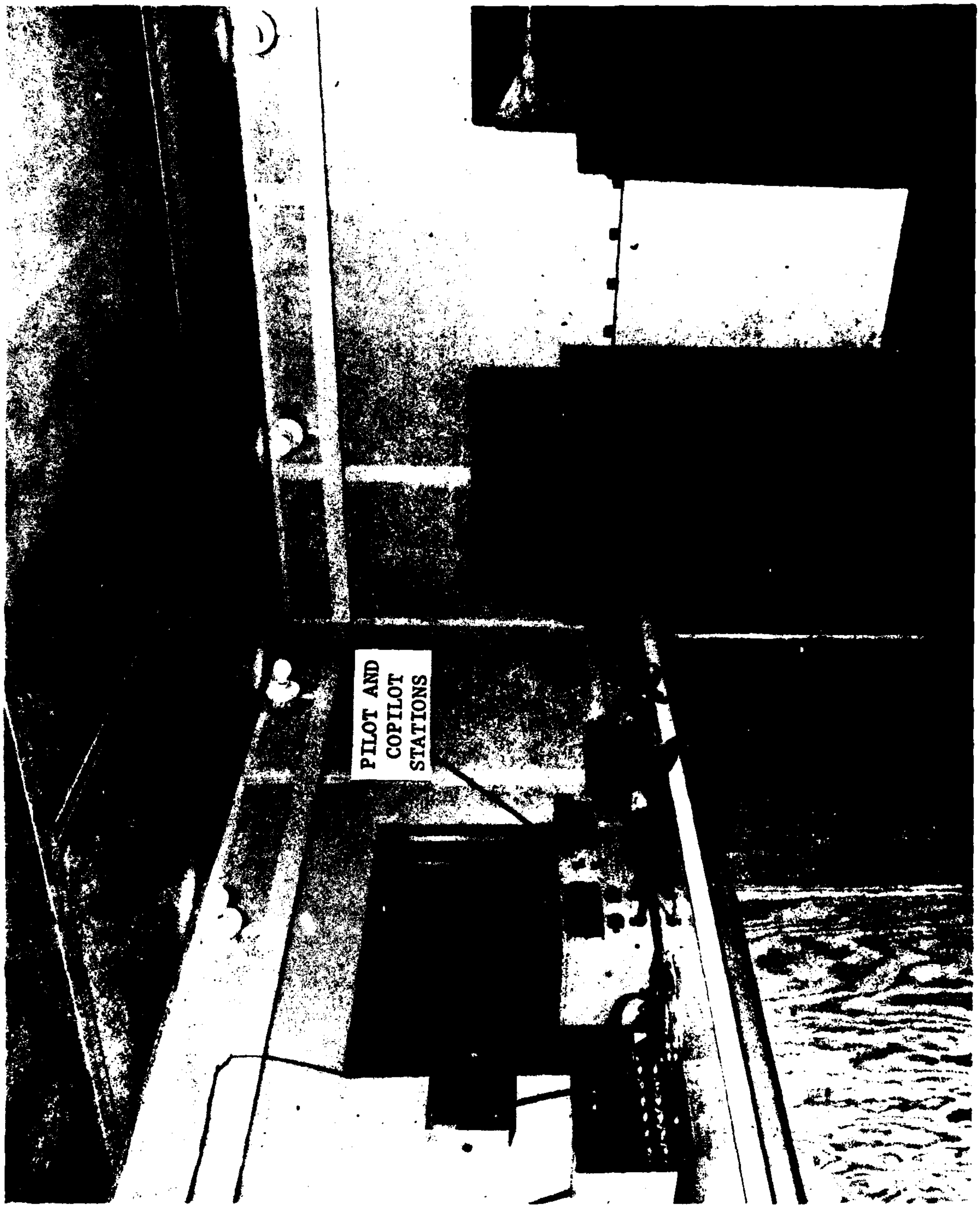

Figure 5. AVRADA Noise Environment Simulator

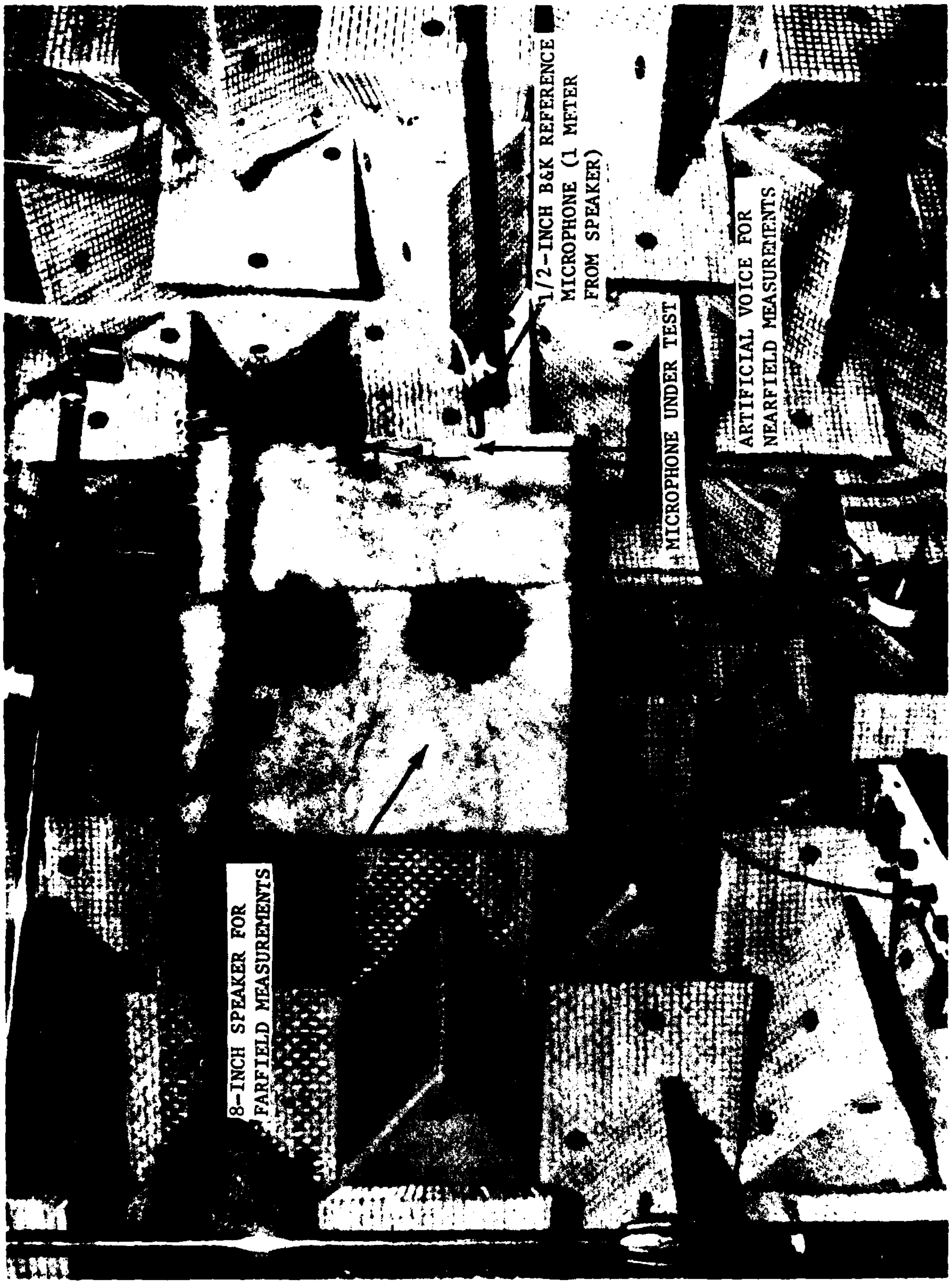

Figure 6. Anechoic Chamber Prepared for Microphone Tests

incidence). This second method of measurement averaging shows greater noise cancellation for the microphone; however, the first method more closely represents the microphone's actual capabilities in a high noise environment.

d. "Expander/Compander" Amplifier Circuitry. The microphone amplifiers contained in the intercommunications controls should contain "expander/compander" circuitry to give maximum, distortion-free audio output to the transmitted signal. This circuitry should provide distortion-free sinusoidal output at the maximum voltage level necessary for proper transmitter modulation, regardless of whether the voice input is at a low level or at an extremely high level (as under emergency or panic situations).

4. COMPONENTS OF THE NEW AIRCRAFT COMMUNICATIONS SYSTEM

No one area of improvement previously mentioned can increase speech intelligibility) to an acceptable level (ideally 90 percent for high speech intelligibility). It takes improvements in all these areas, incorporated into a new communications system to achieve the necessary intelligibility levels. In the development of this system, old ideas have to be changed and new test procedures developed, to more accurately test and evaluate communications system components.

Three new specifications have been written to provide the US Army with a totally new communications system that will provide high speech intelligibility in the noise environments of military aircraft. These specifications are as follows:

MIL-C-49227(AV); Control, Communication System C-10414( )/ARC; 8 Sep 80

MIL-M-49199(CR); Microphone, Linear, M-162/AIC; 30 May 80

MIL-H-49198(AV); Headset-Microphone Kit MK-1564( )/AIC; 22 Oct 80

(These specifications contain detailed descriptions of the new testing procedures briefly described in this report.)

a. C-10414( )/ARC Intercommunication Control. The C-10414( )/ARC is a combination microphone and headset amplifier which operates as a switchboard for each aviator. The C-10414( )/ARC, in that sense, is the same as its predecessors. The major improvements include the incorporation of "expander/compander" circuitry and a fast-acting AGC (automatic gain control) in the microphone amplifier; high isolation circuitry to eliminate cross-talk problems; audio limiting in the headset amplifier (this is necessary to prevent excessively high audio communications levels from damaging the aviator's hearing by adding to the existing high ambient noise and increasing hearing damage risk); and circuitry to power the FET (field-effect transistor) amplifier and impedance matching circuitry in the new M-162/AIC mircrophones. This intercommunication control, in conjunction with a new aircraft wiring harness which incorporates "balanced-line" techniques and a high isolation audio junction box has greatly improved the audio quality of speech communications, both inside the aircraft and that being transmitted out.

b. M-162/AIC Linear, High-Gain, DC Powered, Microphone. The M-162/AIC incorporates a high-impedance voltage generating element (electret condenser, piezoelectric ceramic, or PVF_2) with an internal amplifier, to produce a flat nearfield frequency response (400 Hz to 6000 Hz ± 3 dB). This microphone also provides a noise cancellation capability approximately twice as great as the currently fielded dynamic microphones. The nearfield and farfield frequency responses of a typical dynamic microphone (M-87) and a M-162 appear in Figures 7 and 8. (Note that the crossover point for the M-87 occurs at 1150 Hz, while for the M-162 it occurs at 2662.5 Hz.

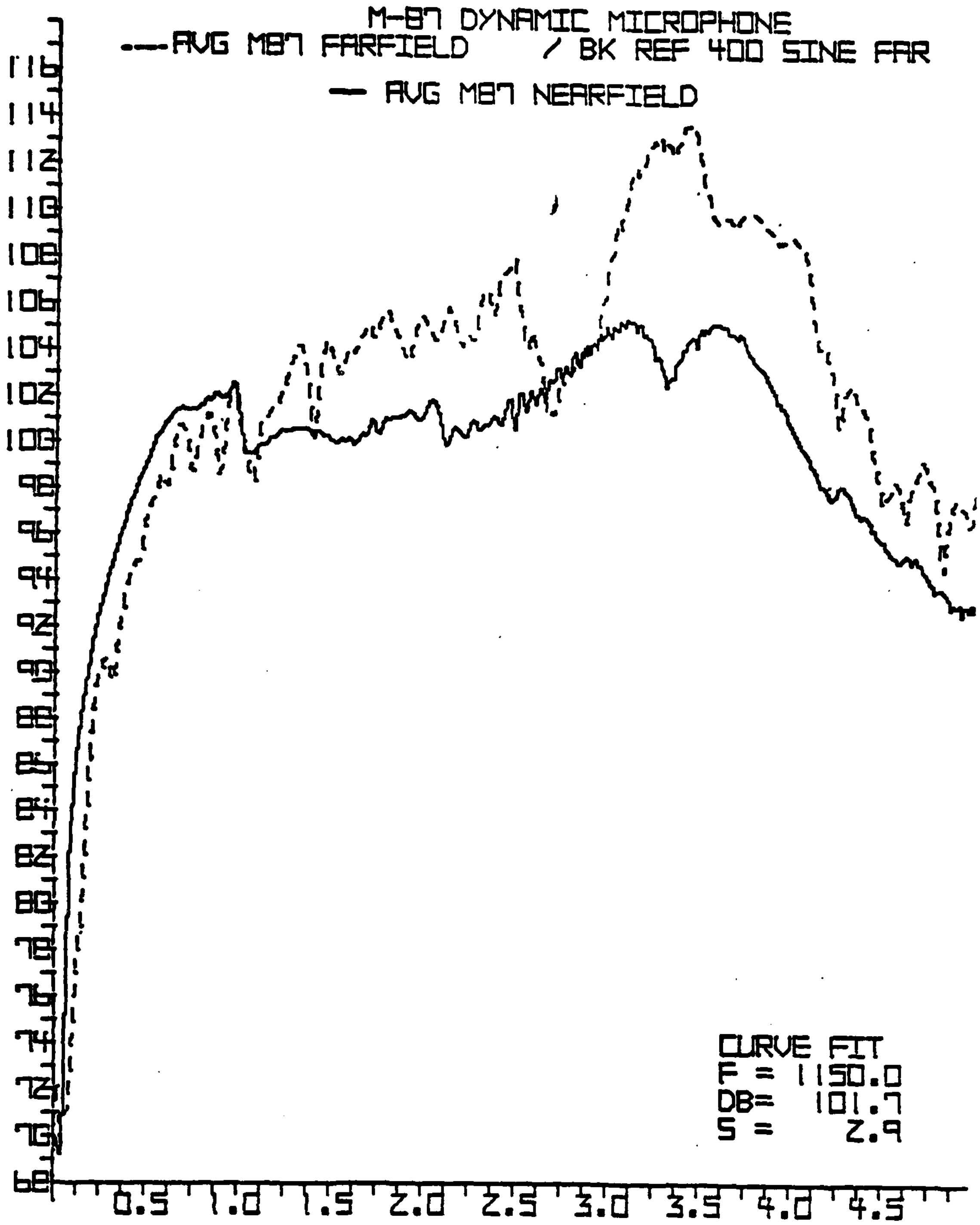

Figure 7. M-87 Dynamic Microphone

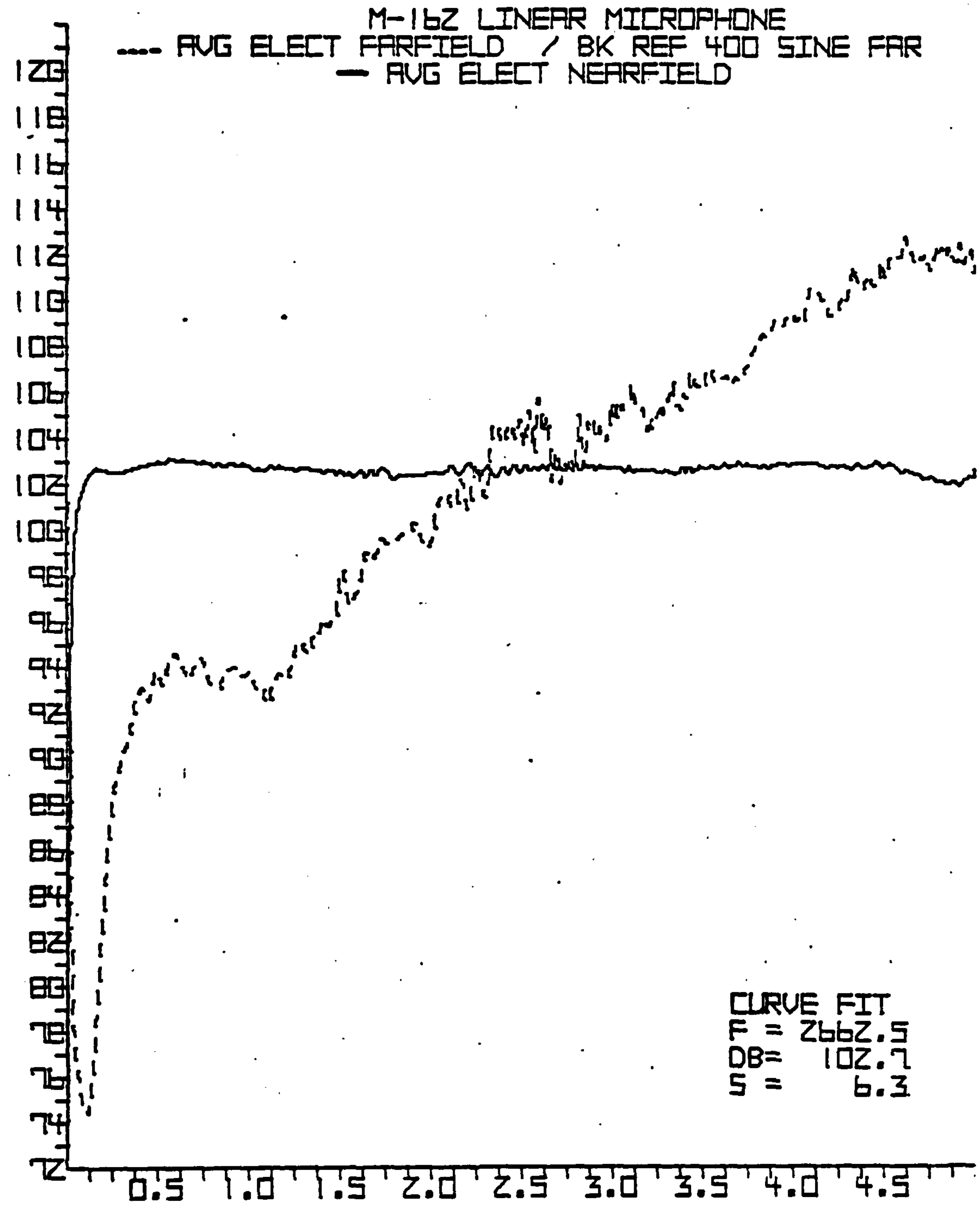

Figure 8. M-162 Linear Microphone

The area between the nearfield and farfield curves is the noise cancellation capability of the microphone. This capability is usually specified as the slope of the farfield curve starting at the crossover point and measured in dB/octave. For the M-87 microphone, the average slope is: -2.9-dB/octave; for the M-162, it is: -6.3-dB/octave.)

c. MK-1564( )/AIC Headset-Microphone Kit. The MK-1564( )/AIC will be the electronics package that will become part of the new product improved Army aviator's helmet designated as the SPH-4A, providing the improvements of the M-162 microphone and new linear earcup/transducer assemblies. These linear earcups provide improvements in noise attenuation over the existing earcups found in the SPH-4 aviator's helmet, as shown in Figure 4. These improvements, while significant, are in addition to improvements in the frequency response of the earphone elements when they are tested inside the new earcups. These improvements can be clearly seen in Figure 9 which compares the frequency response of the old earcup transducer assembly to the earcup transducer assembly of the MK-1564( )/AIC.

5. FUTURE PROGRAMS

a. Voice Interactive Systems Technology Avionics (VISTA). The Avionics Research and Development Activity (AVRADA) has just initiated a program entitled "Voice Interactive Systems Technology Avionics." The VISTA program will take a phased approach to the introduction of voice I/O equipment into the Army aircraft environment. The first phase of the VISTA program will utilize the extensive acoustical analysis and simulation facility of AVRADA to systematically evaluate the performance of candidate, off-the-shelf, voice I/O equipments in various Army aircraft noise environments.

Testing in the environmental simulation chamber began in February 1981.

The subsequent phases of the VISTA program will include the interface of selected voice I/O equipments with the AVRADA developed Integrated Avionics Control System (IACS). This will permit the evaluation of the voice I/O equipments in the simulated noise environment while actually performing voice-controlled aircraft radio and frequency selection. As the predictability of the voice I/O equipment in the simulated aircraft noise environment is established, the testing of selected voice I/O equipments will begin in actual aircraft. It is hoped that this testing will provide a baseline of information from which specifications and requirements for the development of Army aircraft unique voice I/O equipment can be generated. The aircraft testing will culminate in the integration of voice I/O equipment in AVRADA's System Test Bed for Avionics Research (STAR) aircraft.

The STAR aircraft is a UH-60 Blackhawk helicopter which will be configured to include a 1553 multiplexed data bus and a multiplexed digital audio bus (DMAS). In this environment the voice I/O system will have access to all the audio intercom systems for voice I/O purposes and all the avionics for control applications. Applications testing will be performed in the STAR aircraft to determine which aircraft operational functions would be suitable for voice control and response.

b. Digital Multiplexed Audio System (DMAS). The DMAS program will develop a bus-structured, digitized audio processing and distribution system to achieve maximum reduction in aircraft system wiring effort and cost. DMAS will integrate the communication system operational control functions into the aircraft system standardized bus structure (e.g., MIL-STD-1553( )).

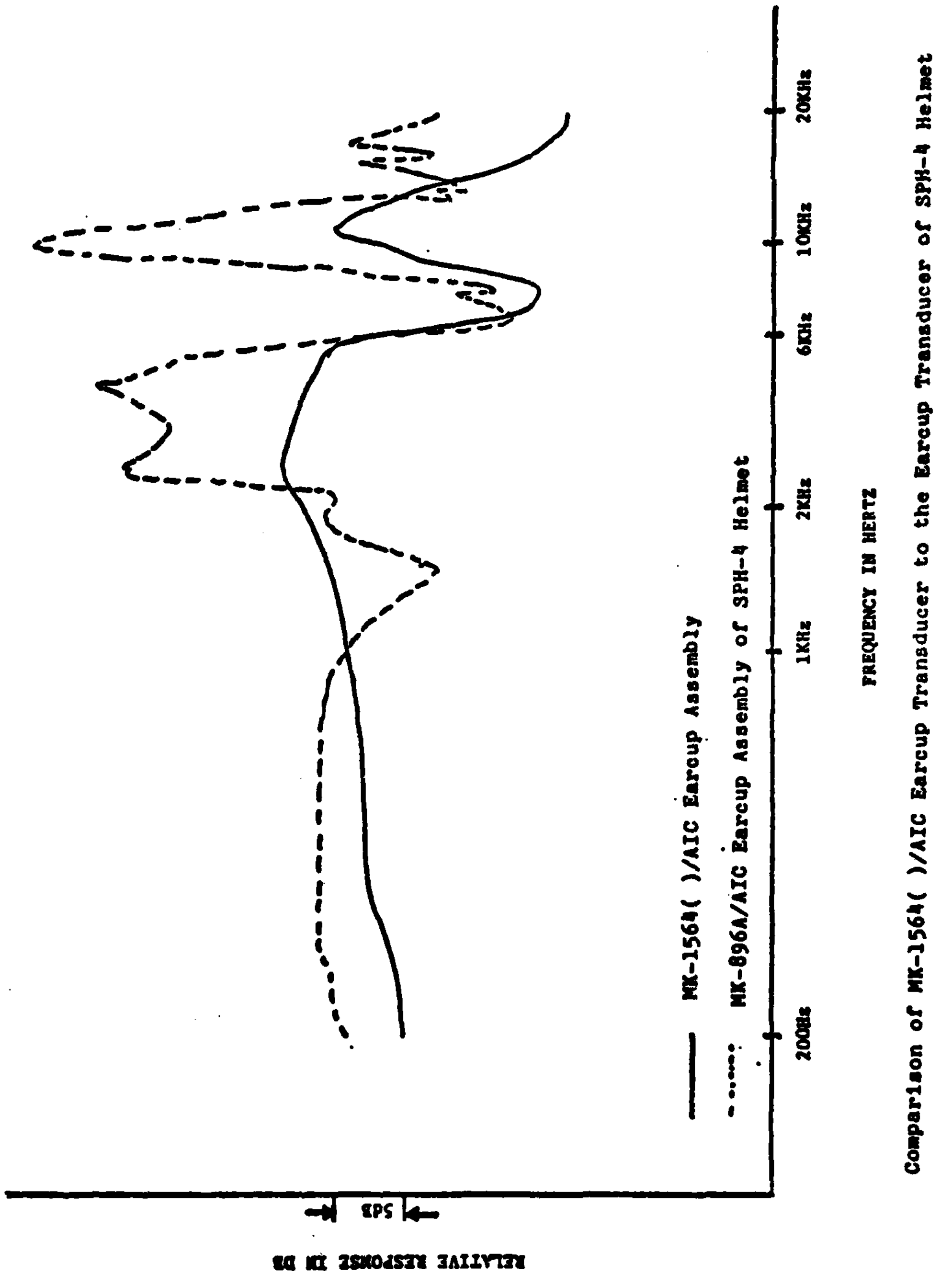

Figure 9. Comparison of MK-1564( )/AIC Earcup Transducer to the Earcup Transducer of SPH-4 Helmet

Optical communications links will also be evaluated in DMAS because they can add additional redundancy and further reduce the weight of the aircraft wiring harness over a conventional wire system. Optical systems, however, have their own unique design barriers, which must be overcome to enable their efficient and effective use in the adverse environment of military aircraft.

The DMAS program will investigate various bus structures as well as digitizing techniques to determine the most cost-effective and efficient system for implementation into future aircraft designs and retrofit programs.

DMAS will be designed with a modular structure to permit incorporation of future design improvements with minimum impact on the system.

4. CONCLUSIONS

Outmoded standards and testing techniques must be replaced with modern test procedures which can more accurately test and evaluate the various components of the communications system. These new test procedures must be carefully designed so that they more closely reflect conditions that exist in the actual flight environment.

The total communications system must be investigated in order to improve electronic voice communications in the high noise environment of military aircraft. Improvements made to only one or two elements of the system will most likely have little or no impact on the overall system response characteristics.

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