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ATTENUATION CHARACTERISTICS OF EARMUFFS AT LOW AUDIO AND INFRASONIC FREQUENCIES

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Foreword

The study on which this report is based was performed by the Biodynamics and Bionics Division, Biomedical Laboratory of the Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio. The research was conducted by Messrs. H. K. Hille and C. W. Nixon, Ph.D., Biodynamics and Bionics Division, and Mr. L. K. Kettler, Research Institute of the University of Dayton, under the Project 7231, "Biomechanics of Aerospace Operations" and Task 723103, "Biological Acoustics in Aerospace Environments." Acknowledgment is made of the assistance by Mr. Harlan Judd of the Research Institute of the University of Dayton. Research covered began in January 1966 and was completed in May 1966.

This technical report has been reviewed and is approved.

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Abstract

Sound attenuation and transmission loss characteristics of three different earmuff models were determined from (1) physical measurements of discrete frequency signals in the range from 1 to 500 Hz inside and outside earmuffs being worn by subjects and (2) psychoacoustical or subjective measurements employing the United States of America Institute of Standards "Real Ear Attenuation at Threshold Method." Evaluation of the data showed good correlation between the two measurement methods. Greater attenuation was obtained with the subjective method. It was interpreted to be due primarily to the masking effects at threshold of hearing of physiological noise present under the earcups. Findings show that typical present-day earmuffs provide approximately 10 dB of attenuation in the frequency range from 20 to 100 Hz and very little sound protection below 20 Hz. It is recommended that insert earplugs be used for sound protection in intense low audio frequency and infrasonic sound fields. Good earmuffs in combination with insert earplugs should provide more protection than earplugs alone.

List of Illustrations

SECTION I.

Introduction

Progress in the development of newer and larger aerospace propulsion systems is accompanied by new noise exposure problems (ref 2). Noise spectra generated by these systems contain intense acoustic energy in the low and infrasonic frequency ranges at higher levels than have yet been experienced routinely. The tendency to generate greater acoustic energy at the low end of the frequency spectrum is expected to continue with the use of boosters of the Nova class and engines of the commercial supersonic transport class.

Recently, a systematic study was accomplished involving whole body exposures of humans to intense low frequency and infrasonic acoustic energy (ref 5). Ear protector effectiveness in reducing noise during this study was subjectively described by participants. Insert-type earplugs (V-51R) were reported to provide appreciable attenuation of the noise. Earmuff-type protectors appeared to provide negligible attenuation and on occasion appeared to amplify the noise under the muffs at some of the frequencies. Also, the muffs were noticed to vibrate against the head during noise exposure. When worn over insert earplugs, the muffs appeared to add to the attenuation obtained by the wearer (ref 3).

The purpose of the present study was to evaluate the sound attenuation characteristics of present-day muff-type ear protectors to show what attenuation may be expected in the frequency range below 500 Hz. Three different earmuffs were arbitrarily selected for test from the current group of devices shown to provide "good" performance in the more typical frequency range from 100 to 8000 Hz. Noise reduction of the muffs by both physical and subjective measurements was determined. Implications of the findings are discussed.

SECTION II.

Physical Measurements

APPROACH

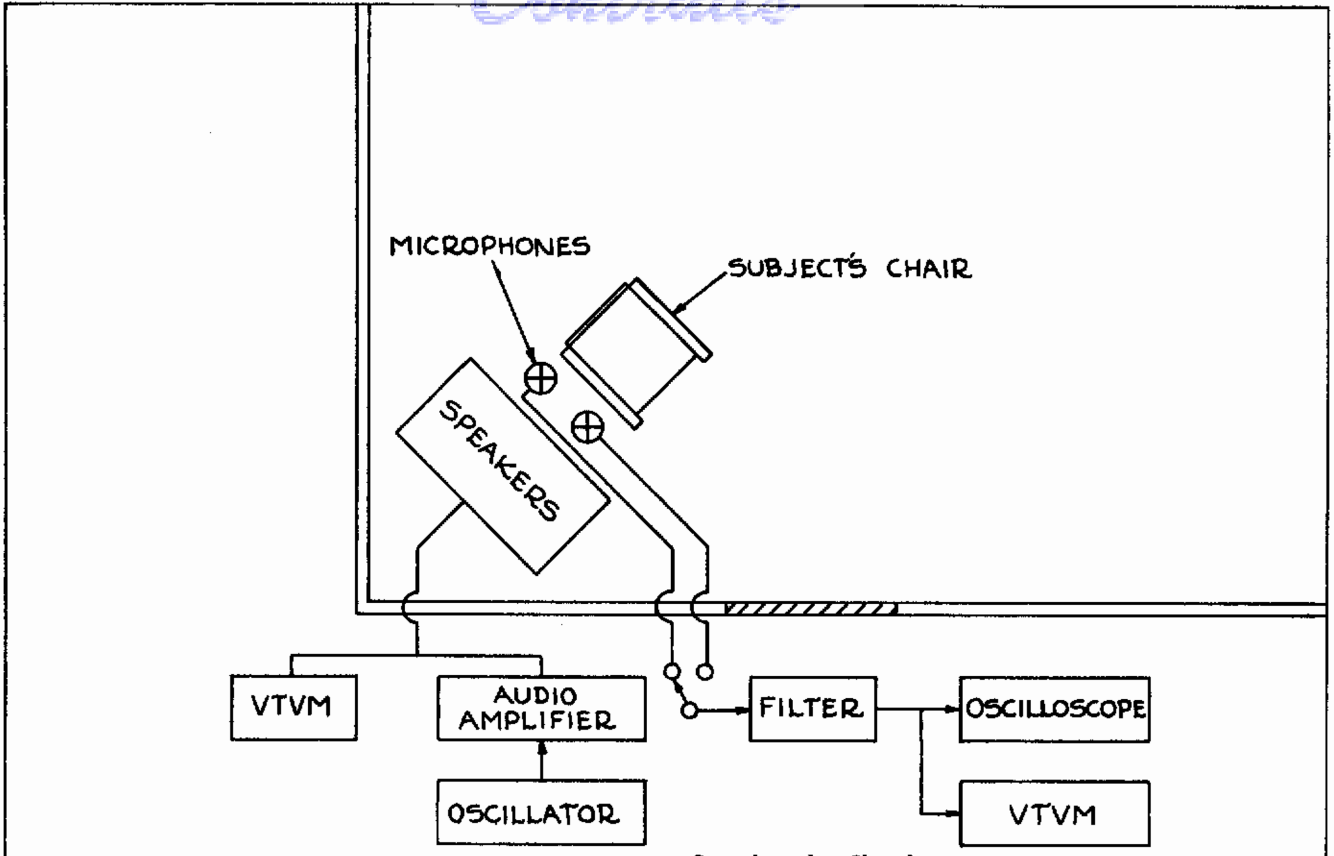
The physical evaluation consisted of measurements to determine the transmission loss through the earmuffs when actually worn by human subjects. The sound pressure levels of the test signals were measured simultaneously outside (ambient) as well as inside one of the earcups of each of the earmuffs under test. The differences between the levels of the signal outside and the levels measured inside the one earcup were defined as transmission loss characteristics.

INSTRUMENTATION

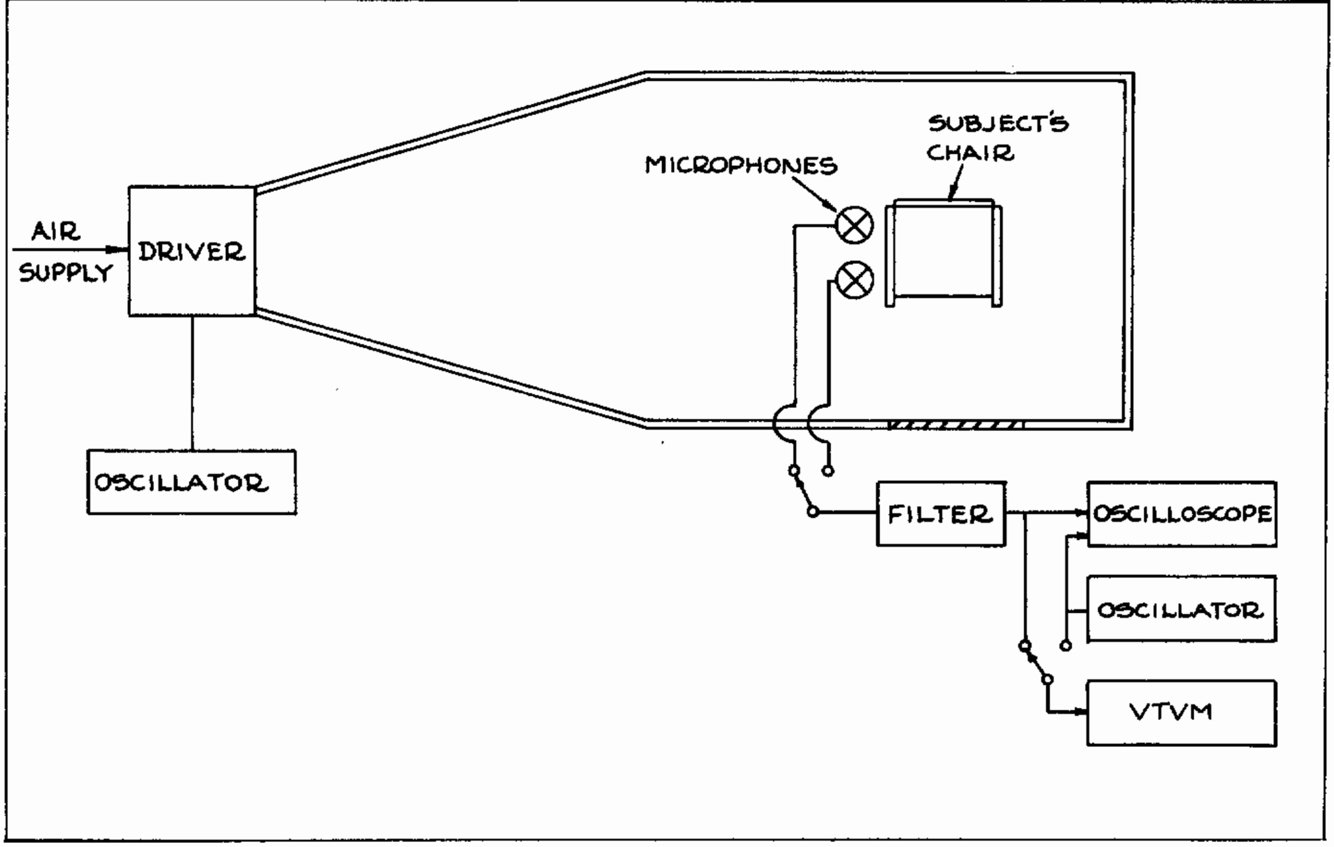
Basic instrumentation used in the Aerospace Medical Research Laboratories (AMRL) Reverberation Chamber and the Aeronautical Systems Division (ASD) Sonic Fatigue Facility (ref 4) for the measurement of transmission loss is shown in figure 1. Two condenser microphones were used as the sound field transducers. One was mounted in the vicinity of the subject's head and the instrumented earcup to measure the external sound field, but not sufficiently close to record energy reflected from the subject or earmuff being tested. The second was calibrated with a probe tube attached and used to measure the sound pressure levels inside a single earcup of each of the earmuffs being measured. The acoustic signals recorded by the microphone preamplifier units were filtered and their relative levels read from a true reading RMS voltmeter. The variable band-pass filter was used to reject harmonics and spurious peaks from the test signals and to facilitate a more accurate reading of the VTVM. The peaks occurred in the low frequency range partly from the method of generation of the low frequency test signals in the ASD facility, i.e., modulation of an air stream at a rate corresponding to the test frequencies, and also as a result of slight movements of the subject's head and shoulders.

Before selecting the small preamplifier unit with microphone and probe tube as the basic transducer, various other units and methods were evaluated. The system for measuring internal sound pressure level must not load down the muff or affect its attenuation characteristics in any way. The attenuation characteristics of a muff were measured with both a large and a small microphone preamplifier unit attached to the muff; measurements were also obtained with the preamplifiers suspended from the muff. Figure 2a represents the measurements obtained with the small (curve a) and the large preamplifiers (curve b) attached to the muff. The addition of the large preamplifier mass to the mass of the muff resulted in a change of the attenuation characteristic. In figure 2b a comparison with the small preamplifier attached (curve a) and suspended (curve b) is made. No significant change in the attenuation characteristic is observed, and the smaller preamplifier with microphone and probe tube can be attached without affecting the measurements in the range of the frequencies examined. The probe tube was inserted into the muff through a hole 1.05 mm in diameter in the manner shown in figure 3. The dimensions of the probe tube in millimeters were: length 36.20, outside diameter 1.05, inside diameter 0.62. As shown, modeling clay was used to assure a good acoustic seal around the preamplifier and probe tube.

The overall system including microphones was calibrated and the data presented were corrected for differences in microphone sensitivity and attenuation caused by the probe tube. These probe tube attenuation measurements and calibration of the outside microphone were accomplished in the frequency range from 20 to 500 Hz with the coupler system as shown in figure 4.



a. Reverberation Chamber



b. Sonic Fatigue Facility

Fig. 1. Block Diagram of Equipment for the Physical Measurements

The probe tube and the attached microphone were inserted into a known sound field and by comparing the results with the measurements of a microphone with a known sensitivity the probe tube loss was determined. In the frequency range below 20 Hz the probe tube with microphone and the outside microphone were calibrated down to 0.2 Hz with a mechanical pistonphone. In addition, standard procedures for all tests included an acoustical calibration before and after each measurement to assure knowledge of the sensitivities and proper operation of the system.

PROCEDURE

Two separate facilities were required to obtain measures of transmission loss over the desired frequency range from 1 to 500 Hz. The ASD Sonic Fatigue Facility was used to test the earmuffs at frequencies from 1 to 25 Hz and the AMRL reverberation chamber for the range of frequencies from 30 to 500 Hz.

In both facilities discrete frequency test signals were used to evaluate the earmuffs. The sound pressure levels used at each of these individual frequencies are shown for the two sound sources in figure 5. In the sonic fatigue facility the test signals were obtained by an air-modulated siren. In the reverberation chamber an oscillator-amplifier driven, wide-range loudspeaker provided the test stimuli.

The procedure for both tests was the same. After an instrumentation check, subjects were seated in the test chamber with the sound source to their right as shown in figure 1. Subjects who wore eyeglasses removed them during the test. The earmuff microphone unit was positioned on the subject's head. Instructions were to position the head relative to a head reference device on the back of the chair, then to sit as motionless as possible through the test run. The head reference device consisted of a small piece of molded styrafoam used only as a positioning reference and not as a head rest. During presentation of the individual test frequencies, the experimenter recorded the sound pressure level in the chamber as measured by the external microphone. The system was manually switched to the probe microphone and the internal sound pressure level was also recorded.

A dual beam oscilloscope was used in measuring the amplitude of frequencies below 5 Hz. One channel displayed the unknown quantity and the other displayed a variable amplitude 1000-Hz signal. The latter signal was adjusted until its amplitude equalled the amplitude of the unknown. The value of the 1000 Hz signal represented the sound pressure level measured under the earmuff. This method of recording low frequencies was employed because no voltmeter (VTVM) measuring accurate voltages below 5 Hz was available.

The procedures described above were repeated for each of the test frequencies. As mentioned earlier, differences between internal versus external sound pressure levels, corrected for microphone sensitivity and probe tube loss, were defined as transmission losses.

RESULTS

Mean transmission loss characteristics of the three representative ear protectors at the test frequencies from 1 to 500 Hz are shown in figure 6. The mean value of the transmission loss was determined from tests on nine different subjects. There is reasonably good continuity of the attenuation measured in the subsonic facility with that of the reverberation chamber. The differences may be within the tolerances to be expected from similar measurements made in two separate situations by competent personnel.

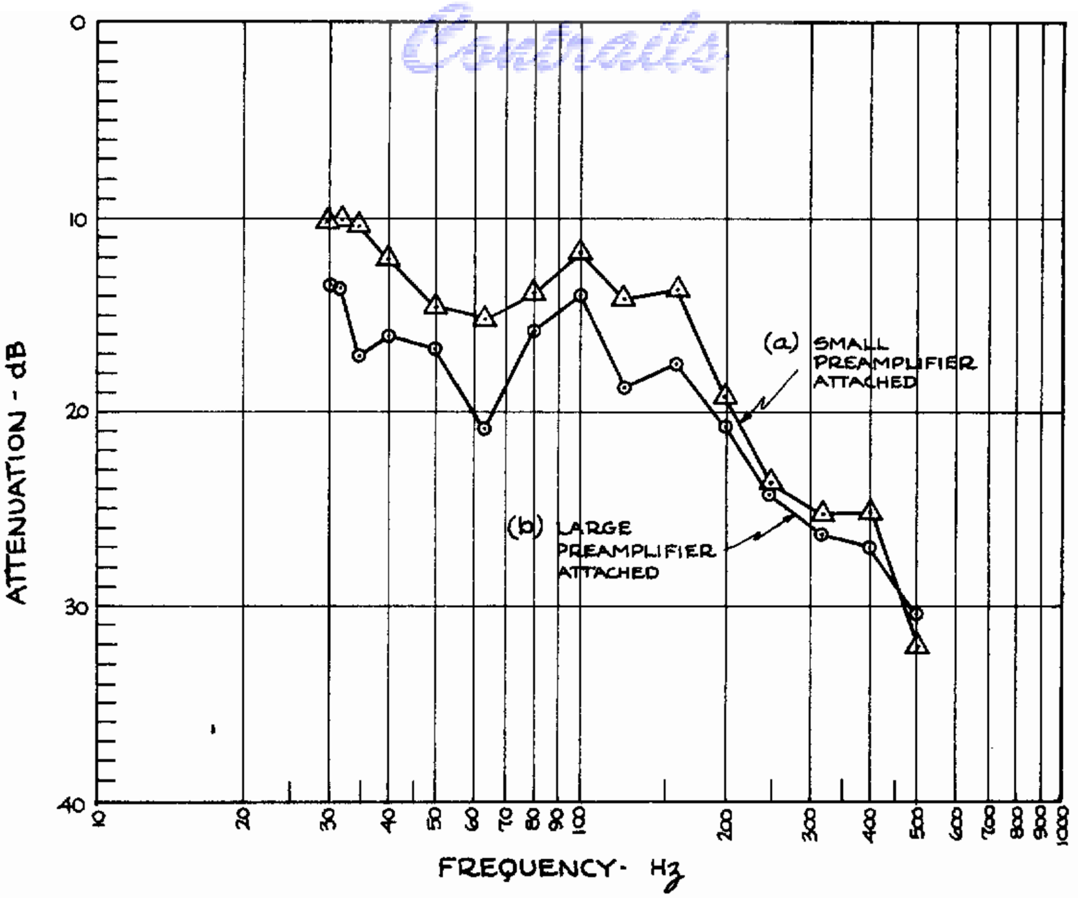


Fig. 2a

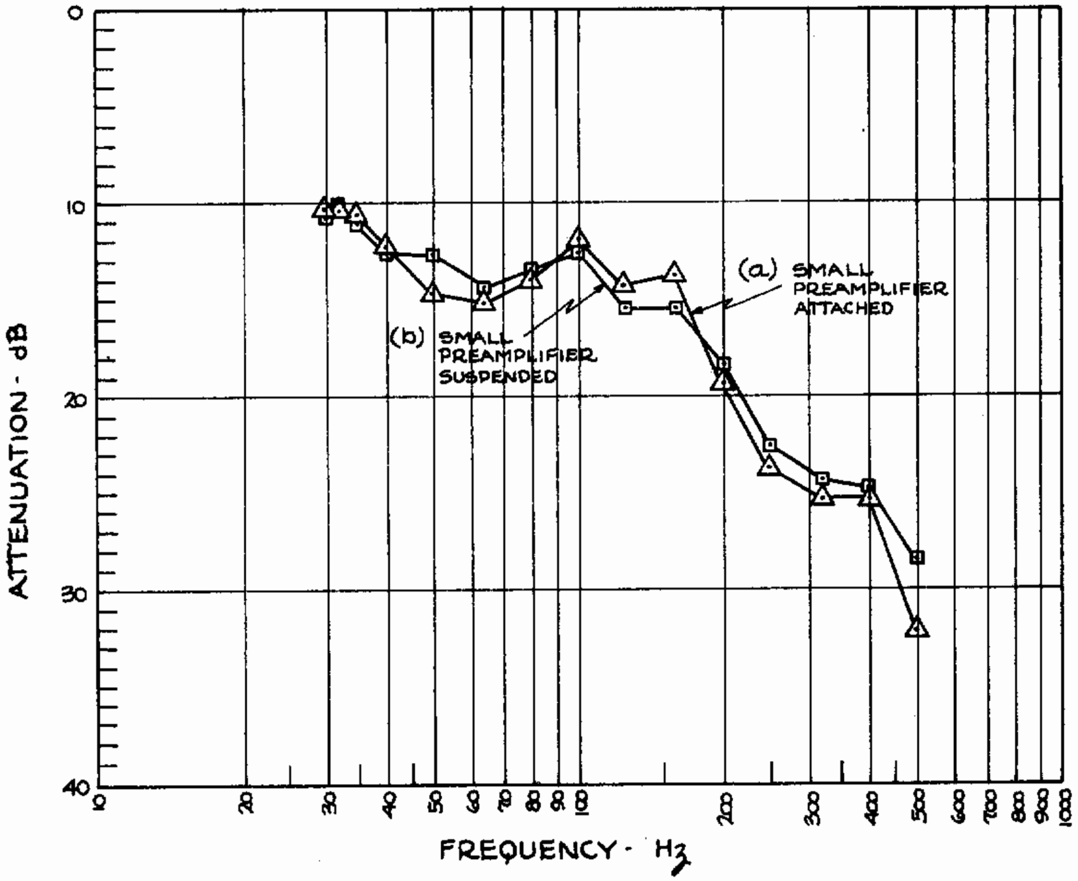


Fig. 2b

Characteristics of Earmuff with Different Preamplifiers Attached

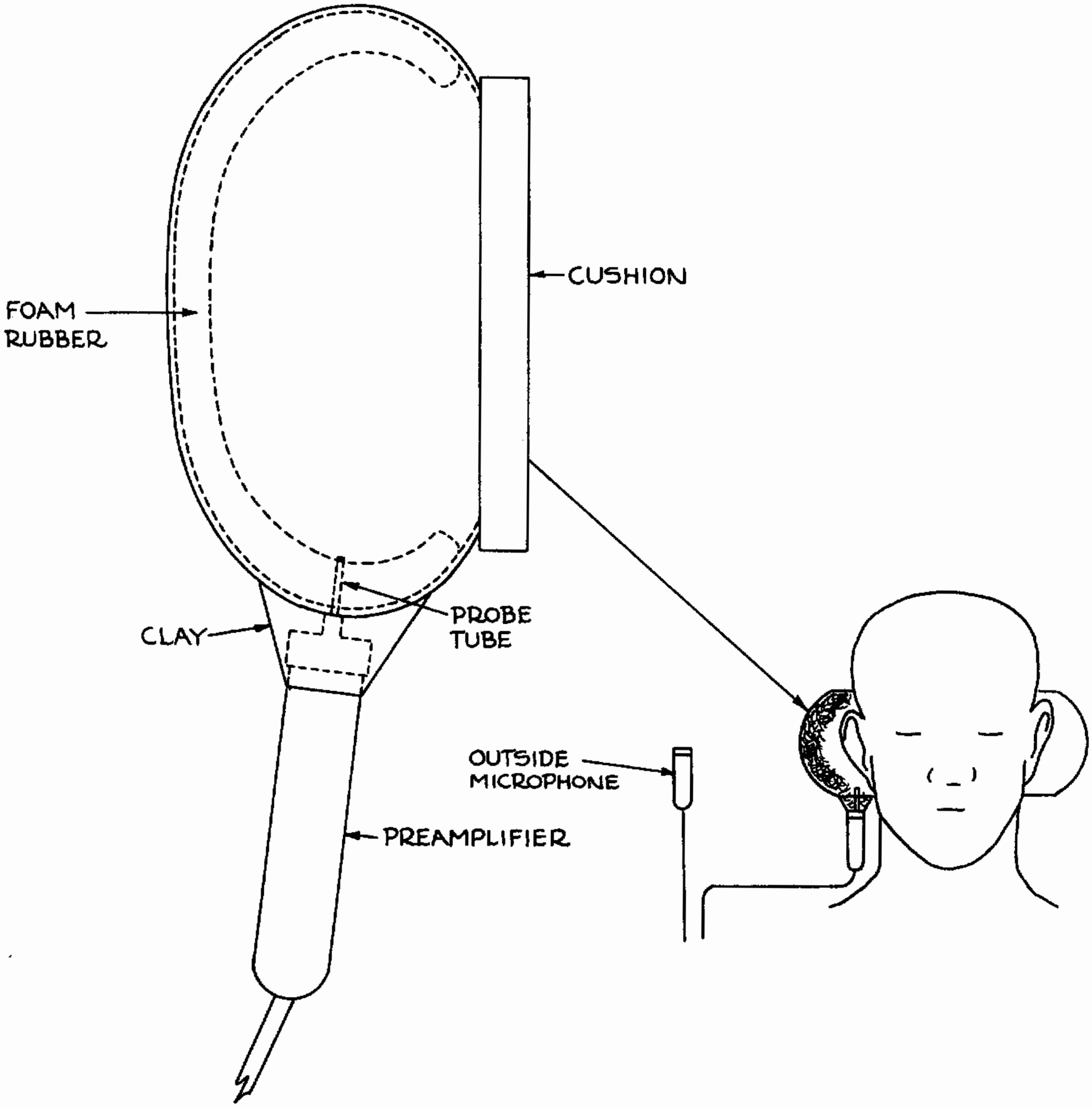


Fig. 3. Typical Instrumentation of Earmuff

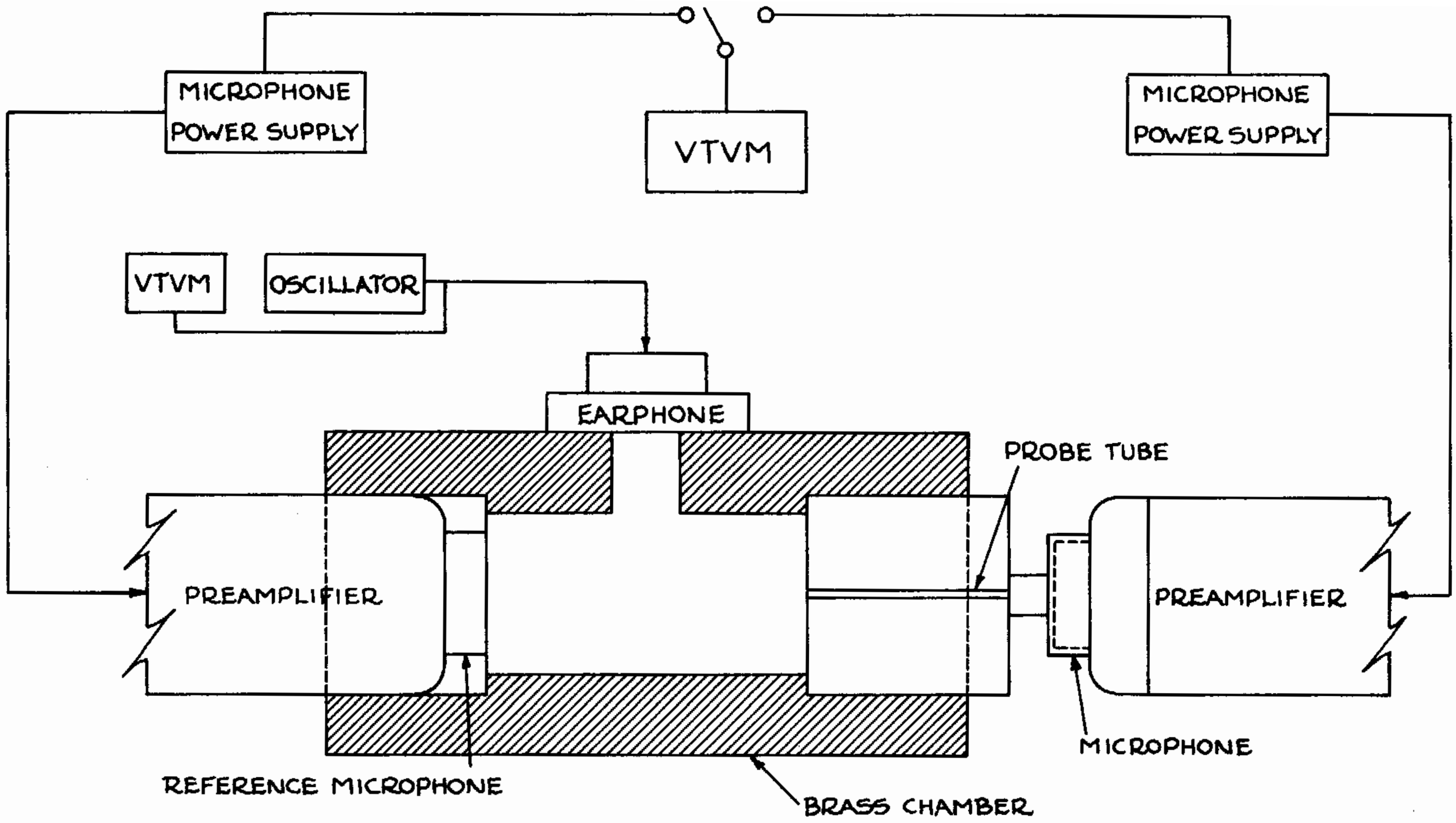


Fig. 4. Probe Tube Calibration System

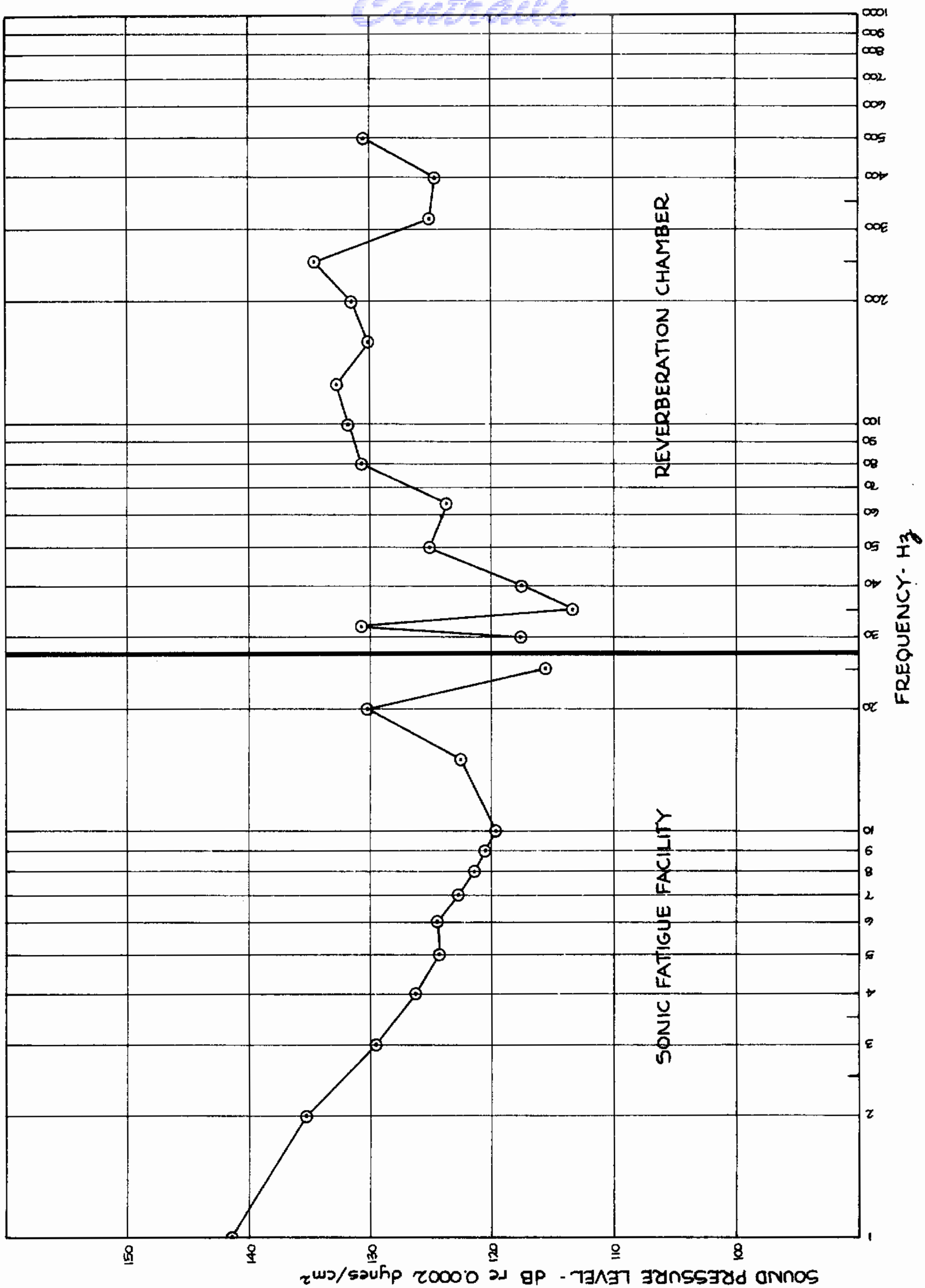


Fig. 5. Maximum Sound Pressure Levels of the Individual Test Frequencies

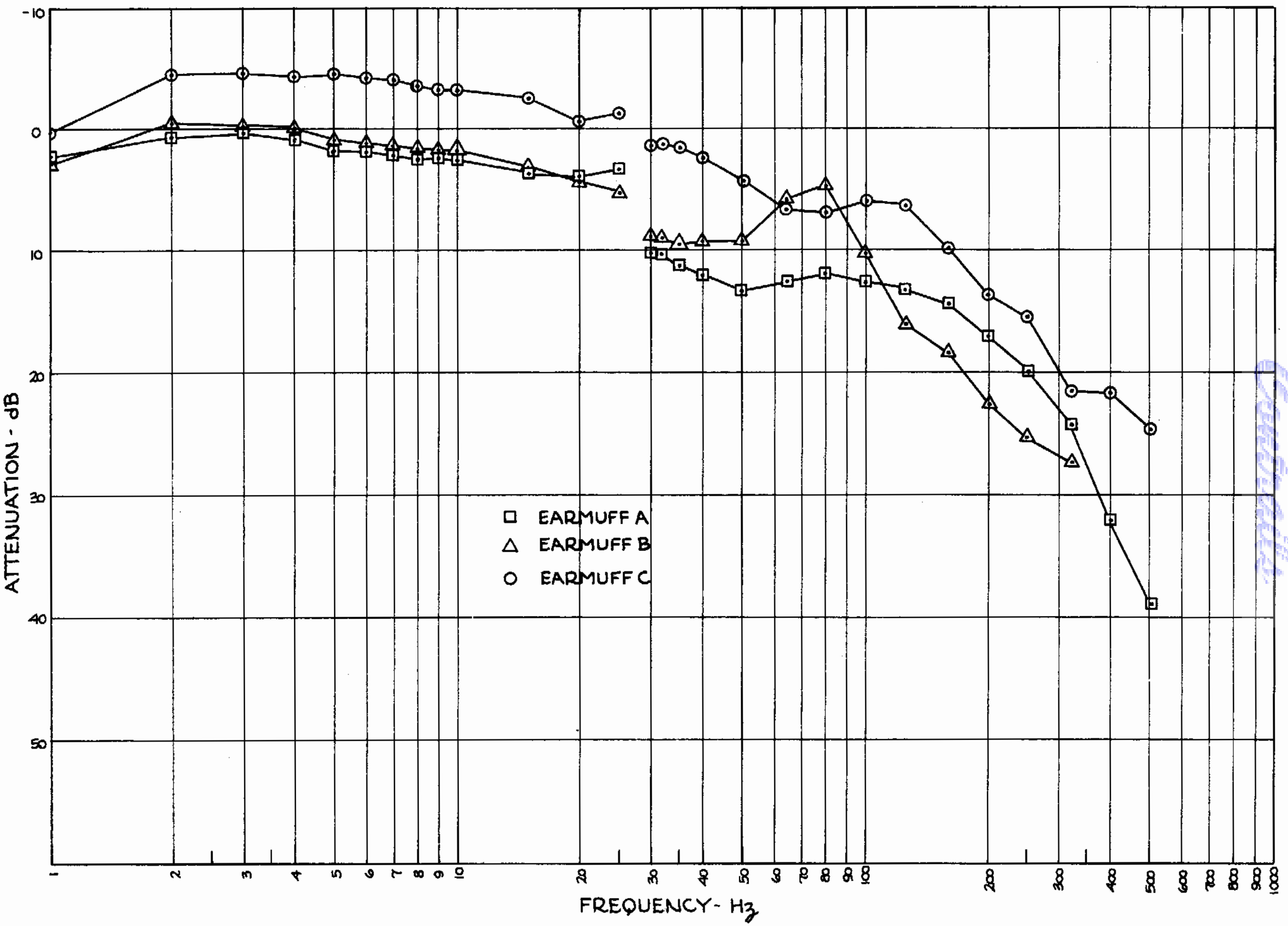


Fig. 6. Physical Measurements of Earmuff Attenuation

These results may be used to show the representative attenuation to be expected from current muff protectors. In addition, the relative effectiveness of the three units tested may be determined. All three units were reported to vibrate noticeably on the head at frequencies below 25 Hz.

In general, very little protection may be expected with these earmuffs for frequencies below 20 Hz. Between 20 and 100 Hz, roughly 5-12 dB of attenuation was measured. From 100 to 500 Hz, attenuation increased approximately 8-10 dB per octave, beginning with about 10 dB at 100 Hz and increasing to about 30 dB at 500 Hz.

From 1 to 25 Hz, earmuffs A and B showed only about 1-4 dB attenuation. Sound pressure levels measured in this range with earmuff C were actually higher inside than outside by as much as 5 dB. For the frequency range from 30 to 500 Hz the performance of muff C was again about 5 dB less than muffs A and B. From these physical measurements it is clear that muff C is not only the least desirable, but perhaps its use should be avoided in noises with intense energy below 100 Hz in view of the amplification characteristics in the low audio frequency and infrasonic regions.

SECTION III.

Psychoacoustic Measurements

APPROACH

Psychoacoustic measurements on the earmuffs were made using the USASI* "Real Ear Attenuation at Threshold Method." Unlike earlier measures wherein the subject assumed a passive role and measures were taken with microphones, this method required the subjects to actively participate.

INSTRUMENTATION

The test facility with instrumentation for the subjective measurements is shown in figure 7. The sound source consisted of three 15-inch permanent magnet loudspeakers driven by a 60-watt amplifier and located directly in front of the subject. The discrete frequency test signals were interrupted by an electronic switch to provide a signal pulse of 1-second duration occurring every 2 seconds. An attenuator was located at the subject's position to enable him to control the level of the test signals.

The subject donned the earmuff. In order to assure a good acoustic seal with the units a broad-band noise was introduced into the test chamber long enough for the subject to adjust the fit of the earmuff to maximum noise exclusion. Then the pulsed discrete frequency was adjusted by the subject until the level of the signal was "just barely audible." This was defined as his "threshold of hearing" for that signal. The procedure for adjusting the level to determine threshold was repeated until three measurements while wearing the ear protector and two while not wearing the ear protector were taken for each of the test frequencies. The mean differences between the open ear values and the protected (with muff) ear values were interpreted to be the subjective attenuation of the unit.

RESULTS

Attenuation characteristics of the earmuffs as determined by the "real ear" method for the range from 35 to 500 Hz are shown in figure 8. Below 100 Hz their effectiveness is within a range of about 5 dB of one another. Above 100 Hz, muff B consistently provided more attenuation than did the other two earmuffs.

Since the instrumented earcups of the earmuffs used for the transmission loss phases of the study were perforated to allow the probes to be positioned inside the cup, the same units were not used for the subjective tests. Models identical to the ones used for the physical tests were employed.

DISCUSSION

The findings of the two different measurement procedures may be compared in figure 9 for the three earmuff units. In general, with the exception of earmuff A above 100 Hz, the subjective method (threshold) indicates greater sound attenuation than does the physical method (above threshold). This finding is in agreement with similar studies which used threshold and above threshold methods of evaluating attenuation of ear protectors. The amount of attenuation difference varies with the earmuff and is roughly 5 dB for earmuff A, 8 dB for unit B and about 10-15 dB for unit C. Above 160 Hz the agreement between methods is reasonably good.

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*Formerly American Standards Association (ASA)

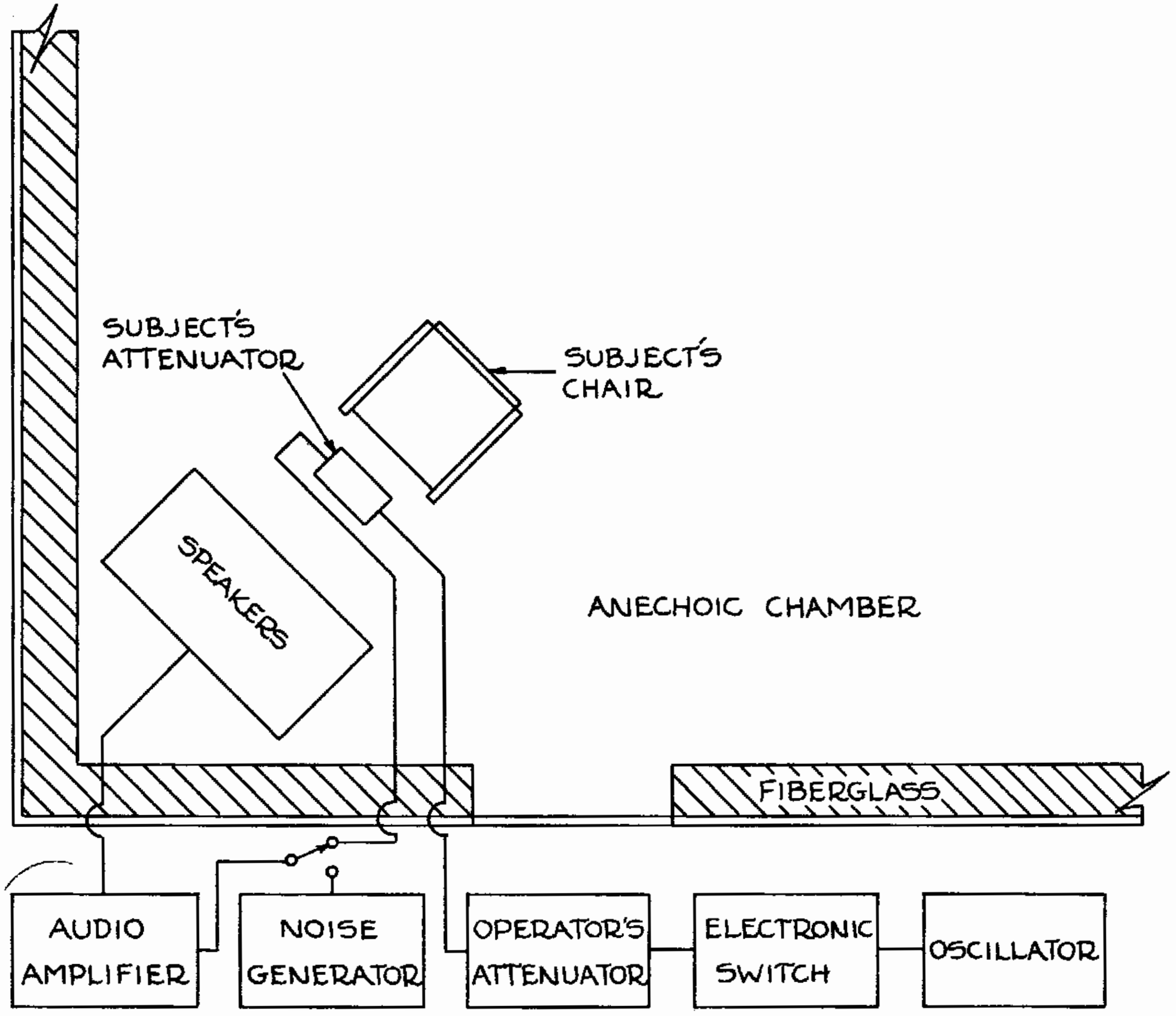

Fig. 7. Block Diagram of Instrumentation for the Subjective Measurements

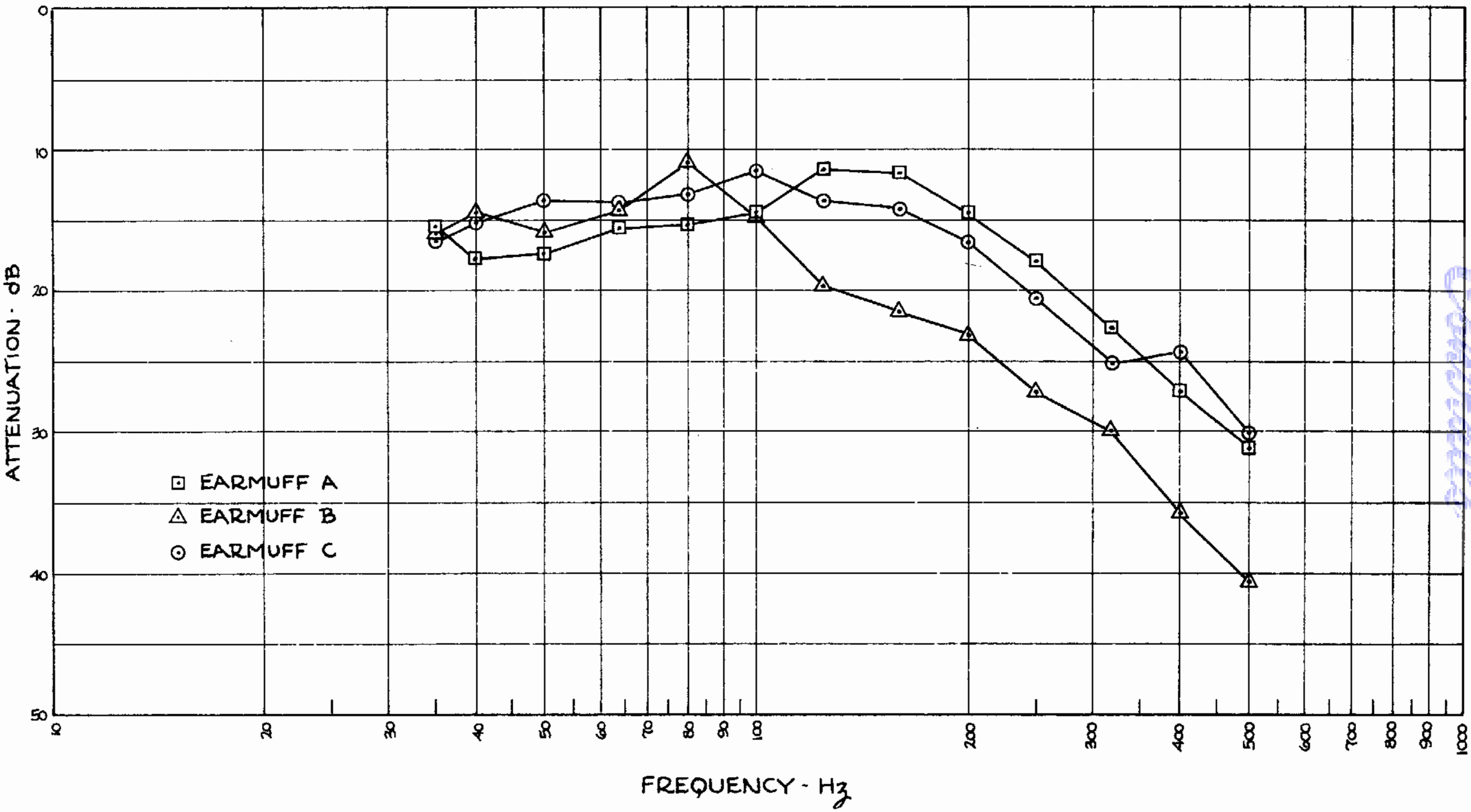

Fig. 8. Subjective Measurements of Earmuff Attenuation

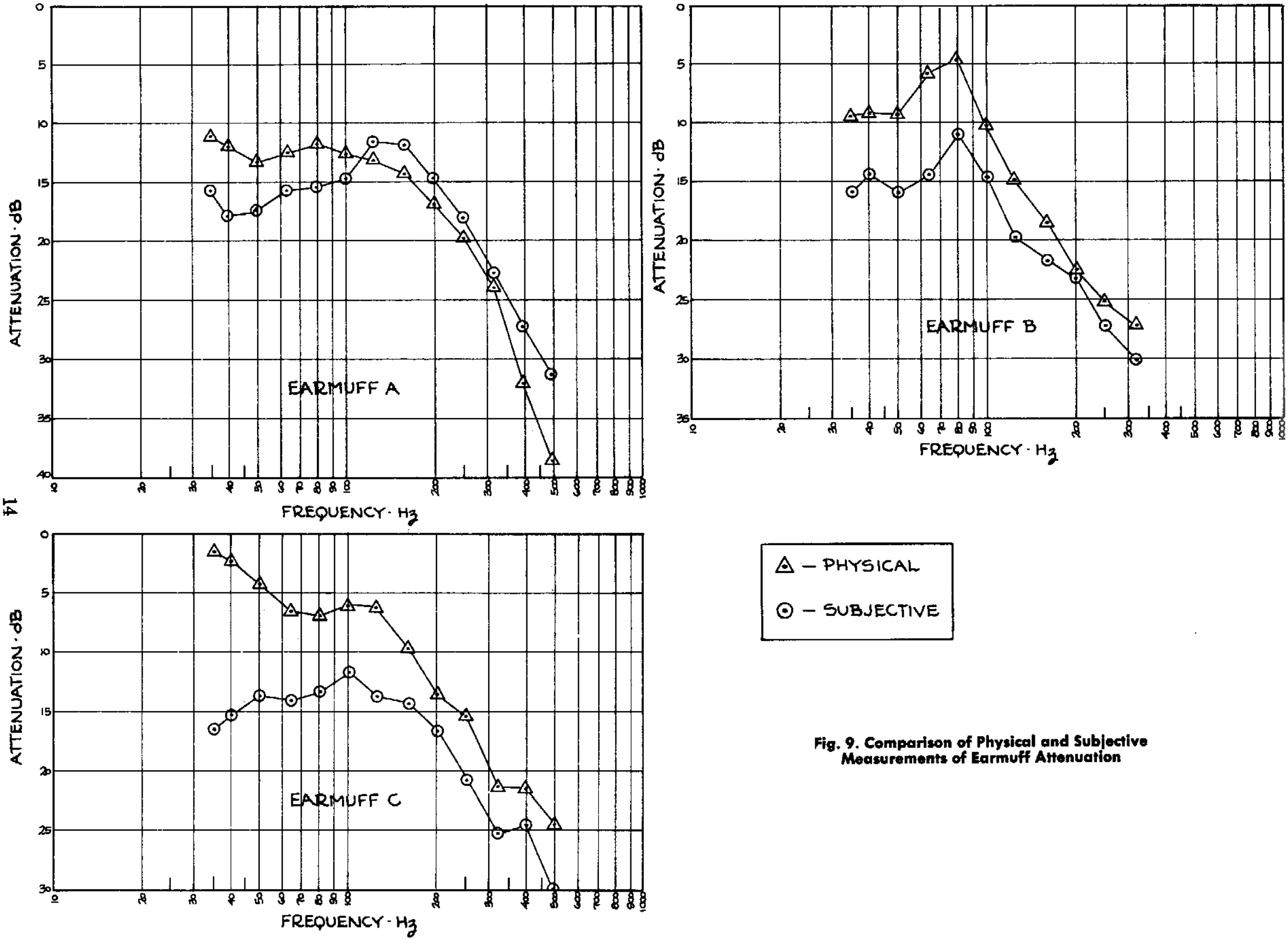

Fig. 9. Comparison of Physical and Subjective Measurements of Earmuff Attenuation

The discrepancies between the methods below the frequency of 160 Hz may be better understood in terms of characteristics of the units themselves. Physiological noise* occurs under earphone cushions in relation to the volume of the enclosed cavity (ref 1, 6). In general, the smaller the volume of the unit, the greater is the level of physiological noise. The volume of unit C is much smaller than the volume of the other two units. The subjective threshold of hearing while wearing an earphone cushion can be masked by the presence of physiological noise so that a greater signal level is necessary to overcome the masking in order to reach threshold. When this occurs the difference between the open ear and closed ear (masked) thresholds will be greater showing a higher attenuation than can actually be attributed to the unit. This ordinarily shows a higher attenuation value than is obtained with physical measures.

The findings of this investigation demonstrate that "good" present-day earmuff protectors provide about 10 dB of sound attenuation at frequencies between 20 and 100 Hz and very little attenuation below 20 Hz. For optimum ear protection in intense sound fields with high concentrations of acoustic energy in the low audio frequency and infrasonic regions, good insert earplugs are recommended for short duration exposures. For long-time exposures, the use of good earmuffs in combination with insert earplugs is recommended. These data confirm, quantitatively, subjective observations reported in reference 5 of the performance of muff-type ear protectors in intense infrasonic and low audio frequency noise environments.

Assessment of the attenuation performance of insert and semi-insert earplugs in intense low audio frequency and infrasonic sound fields was not within the scope of this study. However, quantitative evaluations in similar noise environs of earplugs, alone and in combination with earmuffs, are currently under consideration as a future effort.

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*Physiological noise is a low-level, broad-band noise generated by breathing, muscular and vascular activities, pulse action, etc., that is transmitted to the ear canal.

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13. ABSTRACT

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