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ACTIVE EAR DEFENDER SYSTEMS: DEVELOPMENT OF A LABORATORY MODEL

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FOREWORD

The work reported here was done by the Radio Corporation of America under Contract AF 33(616)-3051, Project 7231, "Acoustic Energy Control", Task 71786, "Biological Aspects of Vibration and Acoustic Energy". This contract was initiated December 1954 and terminated in 1959. The resulting information is reported in two parts. Part I "Component Consideration and Theory" was published in September 1958. The contract was administered under direction of the Biological Acoustics Section, Bio-Acoustics Branch, Aero Medical Laboratory, Wright Air Development Center, with Lt. David T. Blackstock, Mr. Charles W. Nixon and Mr. Donald J. Baker as project engineers for the Air Force.

RCA personnel responsible for the work reported here were M. L. Touger, Leader, W. F. Meeker, Project Engineer, E. D. Simshauser, R. M. Carrell, E. W. McMorrow and E. R. Ware.

ABSTRACT

A laboratory model active ear defender using negative acoustic feedback to provide noise reduction was constructed. Approximately 15 db of active noise reduction was achieved in the 100-200 cps range with appreciable noise reduction outside this range, falling to zero at approximately 600 cps. Improved transducer arrangements were developed. An arrangement for insert or semi-insert use should permit 20 db of active noise reduction from 100 to 400 cps. An arrangement similar to a conventional over-the-ear headset should provide 20 db of active noise reduction from 100 to 300 cps. Extension of active noise reduction to higher frequencies will require an increase in microphone bandwidth and the use of very wide band amplifiers.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

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Assistant Chief
Aerospace Medical Laboratory

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I. INTRODUCTION

A. OBJECTIVES

An electronic noise reducing system designed to reduce noise at a user's ears has been termed an "active ear defender." The theory of the active ear defender was developed in Part I of this report (Reference 1). It was the purpose of the phase of the work reported here to develop a laboratory model of an active ear defender to permit some degree of evaluation.

The initial developmental objective for noise reduction for the laboratory model was 25 db from 50 to 1000 cps in addition to any attenuation provided by the earcushion. This was to be accomplished with a minimum of earphone or microphone development. It was realized, however, after completion of the analysis (Part I) that this objective could not be met without additional transducer development.

B. APPROACH

Three types of noise reducing systems were considered in the first phase (Reference 1). These were arbitrarily designated System I, II and III as follows:

System I.	Cavity Open-loop, or Forward Acting System
System II.	Cavity Feedback System
System III.	Free-field Feedback System.

It appeared that System II, the cavity feedback system, was the most desirable arrangement since it is much less sensitive to amplitude and phase errors. This system is illustrated in Figure 1. A microphone is located under each earphone of a headset. Each microphone feeds a separate amplifier whose output goes to the corresponding earphone. The microphone, amplifier and earphone are connected to produce negative acoustic feedback, thus reducing the noise under the earcushion.

A negative feedback noise reducing system must be designed to avoid oscillation and undesired noise amplification outside the useful band as well as noise reduction within a desired band. The principal requirements may be summarized as follows:

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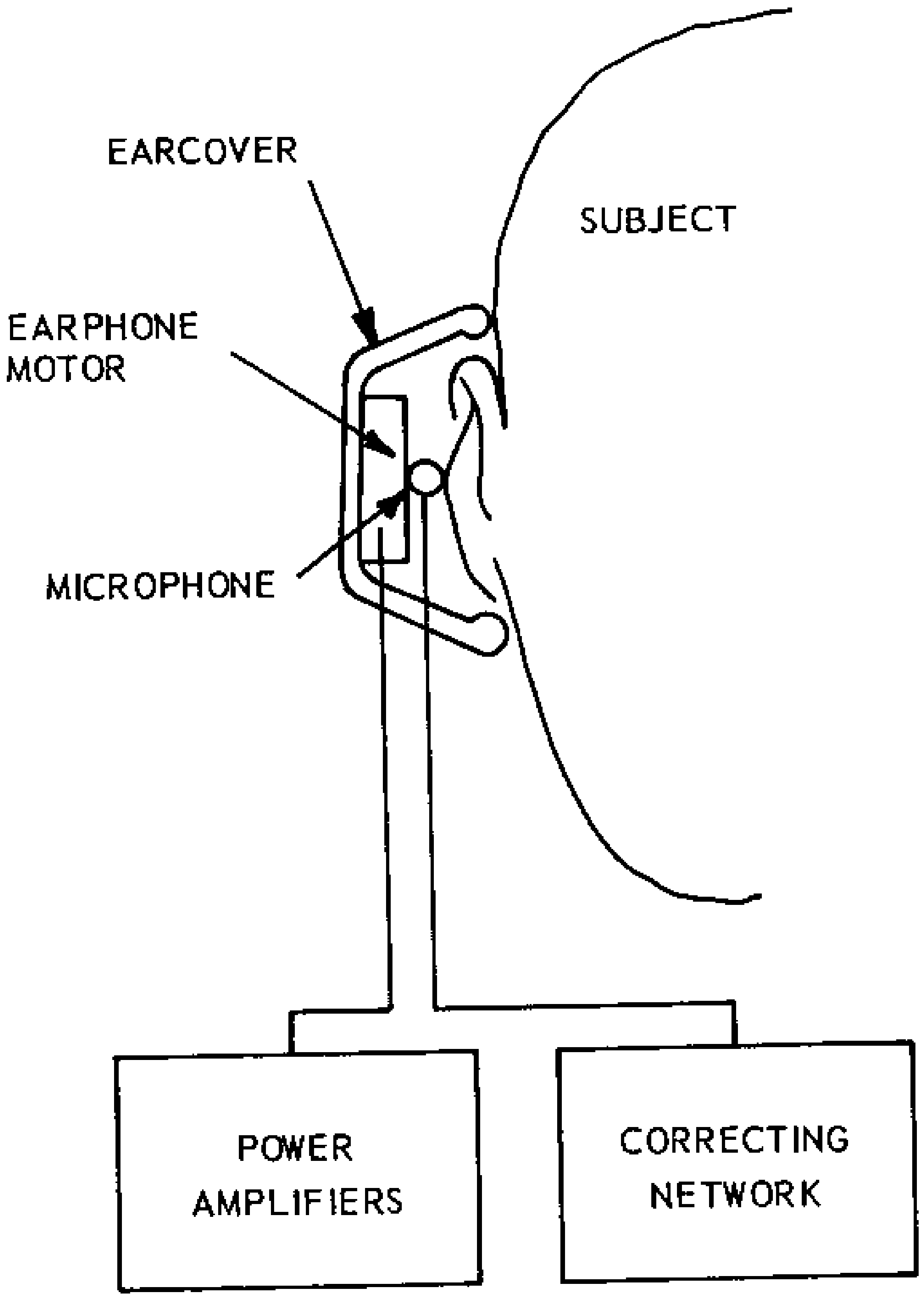


Figure 1. Headset Feedback Noise Reduction System

(1) Within the frequency range in which noise reduction is desired, the amount of noise reduction obtained is approximately equal to the open-loop gain.

(2) Within the frequency range in which noise reduction is desired, the phase shift should not exceed ±90°.

(3) Outside the frequency range in which noise reduction is desired, the open-loop gain should fall off as rapidly as possible consistent with the following:

  (a) the open-loop gain should not exceed 0 db when the phase shift reaches 138°,

  (b) the open-loop gain should not exceed -10 db when the phase shift reaches 180°, and

  (c) beyond 180°, the open-loop gain should be maintained at -10 db to as high a frequency as possible.

Although a study of the transfer characteristics of available transducers indicated that only a moderate amount of noise reduction could be obtained, and that over a limited bandwidth, it seemed desirable to proceed with a model making use of available transducers in order to allow demonstration of the principle and to gain some experience with such a device.

II. LABORATORY MODEL

The transducer arrangement for Laboratory Model No. 1 was the same as described in Part I of this report and is shown in Figure 2. The earphone was an H-136(XA)/AIC mounted in an MX-2088/U earcushion. The microphone was a Turner No. 23 replacement cartridge using a Rochelle salt crystal element. The overall response of this combination is shown in Figure 3. Rather than develop amplifiers specifically for this model, commercial high-fidelity amplifiers (RCA SVP-10A) were modified for this purpose. The modifications consisted of inserting appropriate electrical networks to produce the desired frequency response, adding an output pad to prevent damage to the earphone in case of oscillation, providing for a disabling switch, and adding test jacks. Two amplifiers were used and mounted back-to-back, providing a portable, a. c. operated unit.

The schematic of the modified amplifier circuit is shown in Figure 4. The networks enclosed by dashes are for the purpose of altering the over-all loop response as outlined in Part I. RC networks were used because of their availability; somewhat better results might have been obtained with RLC networks. It was not considered desirable to expend effort upon circuit refinements at this time, however.

The frequency response characteristics of the amplifiers themselves are shown in Figure 5. Figure 6 shows the noise reduction obtained at each ear on one subject in a noise field of approximately 100 db. This was measured by adjusting the gain in the feedback loop to produce the maximum amount of noise reduction without any indication of instability and then observing the microphone output - first with the system operating and then with it disabled by disconnecting the earphone. The noise reduction thus observed is that due to the active portion of the device and is in addition to any attenuation supplied by the earphone cushion. The total estimated noise reduction, obtained by adding the noise reduction produced by the active portion of the circuit to that previously measured for a headset with this type earphone cushion is shown in Figure 7.

Subjectively, the change in noise when the active portion of the circuit was switched in and out was quite marked. The only adjustment provided was that of the gain of each channel. Occasional amplifier overload was observed when the head was shaken or jarred, or when the headset was pressed or readjusted. This was attributed to low frequency overload of the amplifier and it produced a "crackling" sound. That is, movement of the headset produced a very low-frequency "noise" which exceeded the output capability of the amplifier. In order to eliminate this difficulty, it will be necessary to design the system to accommodate noise produced in this manner as well as ambient acoustical noise.

The performance of Laboratory Model No. 1 was limited in two respects. First, the amount of noise reduction attainable was limited because of the transducer response and phase shift characteristics. Second, the maximum noise level in which the device was effective was limited by the earphone power handling capacity to approximately 110 db. While the possibility for minor improvements was evident, it became apparent that a major improvement would require transducers with more suitable characteristics. Therefore, no further effort was put on this model, but instead, effort was devoted to the development of transducers more suitable for active ear defender use.

Figure 2. Transducers for the Laboratory Model Active Ear Defender

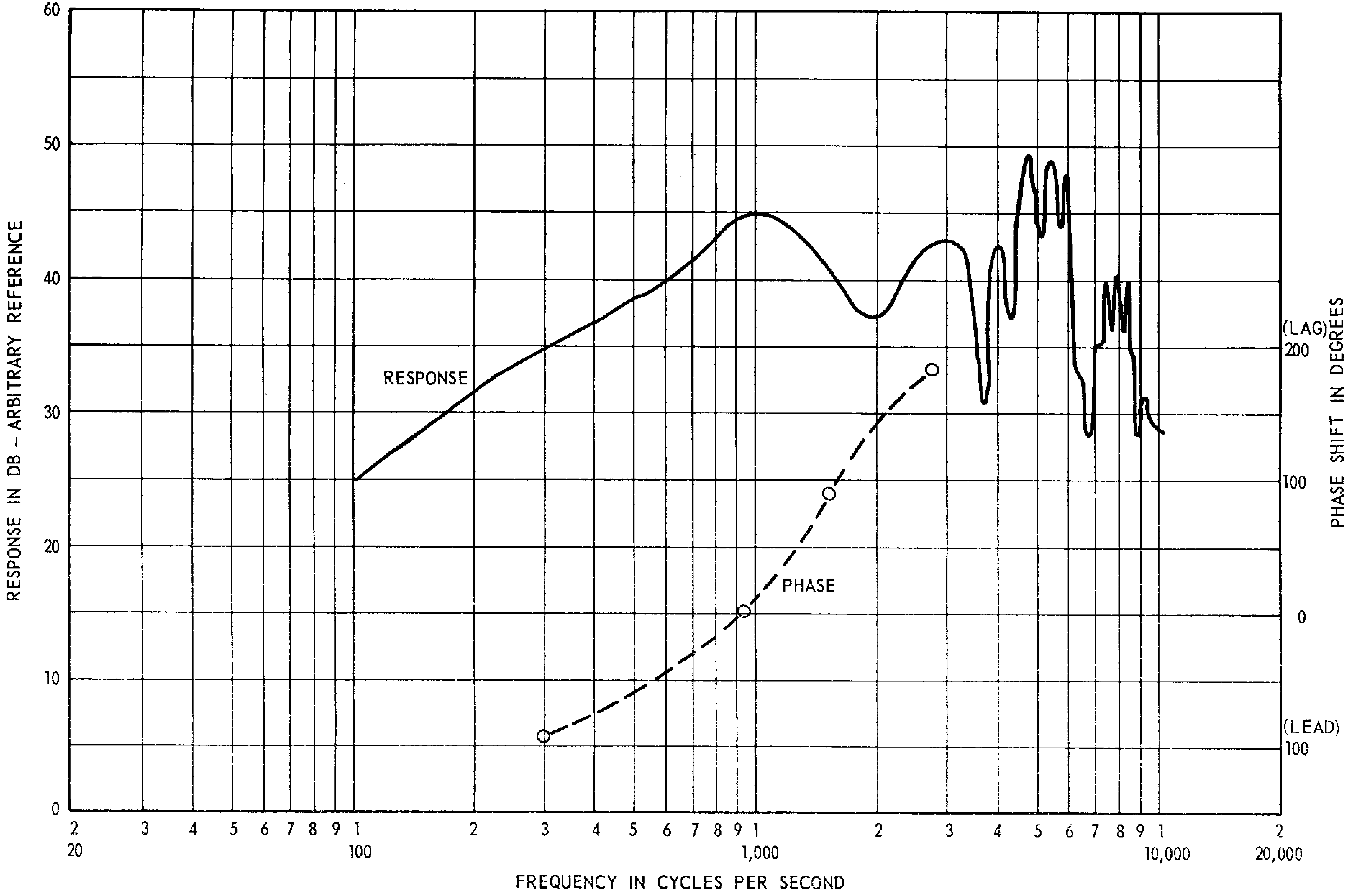
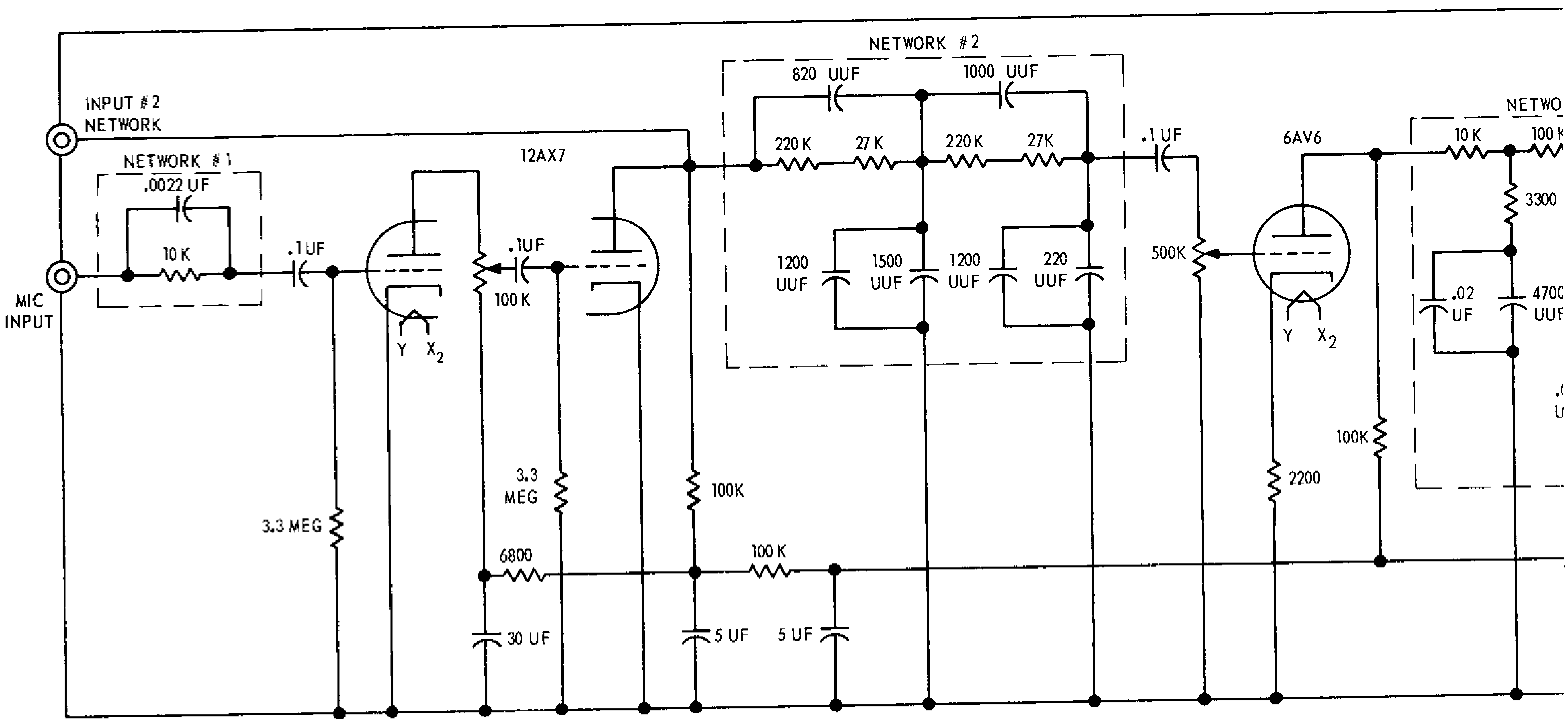


Figure 3. Overall Response and Phase Characteristics of H–136(XA)/AIC Earphone in MX–2088/U Earcushion and Turner No. 23 Microphone


INPUT #2
NETWORK
NETWORK #1
.0022 UF
10 K
MIC
INPUT
.1UF
12AX7
Y
X2
.1UF
100 K
3.3 MEG
3.3
MEG
6800
30 UF
100K
100 K
5 UF
5 UF
NETWORK #2
820 UUF
1000 UUF
220 K
27 K
220 K
27K
1200
UUF
1500
UUF
1200
UUF
220
UUF
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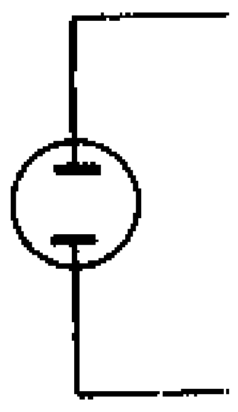

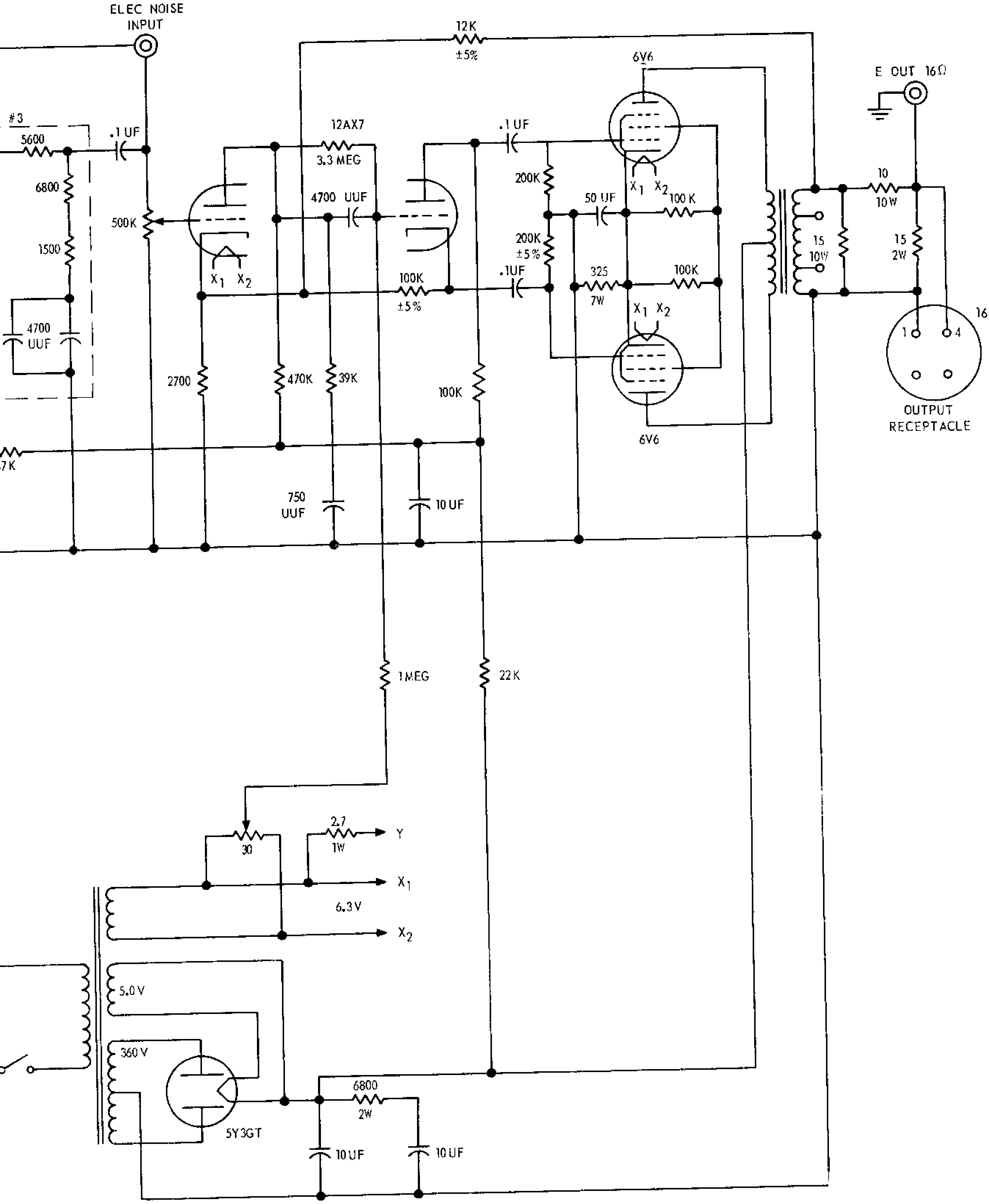

Figure 4. *Schematic of Modified SVP–10A Amplifier Used in Laboratory Model Active Ear Defender*

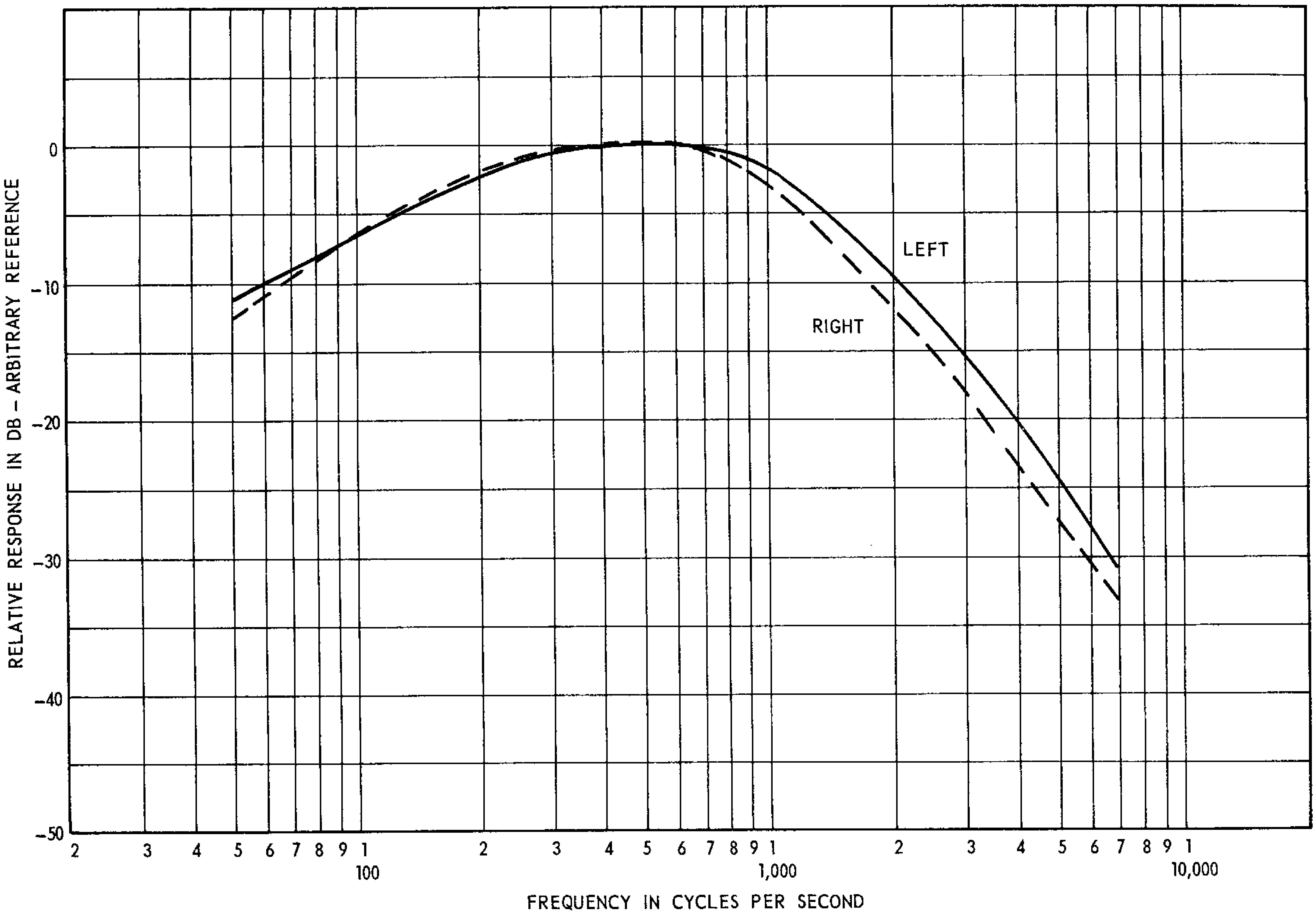

Figure 5. Response of SVP–10A Amplifiers as Modified for Laboratory Model of Active Ear Defender

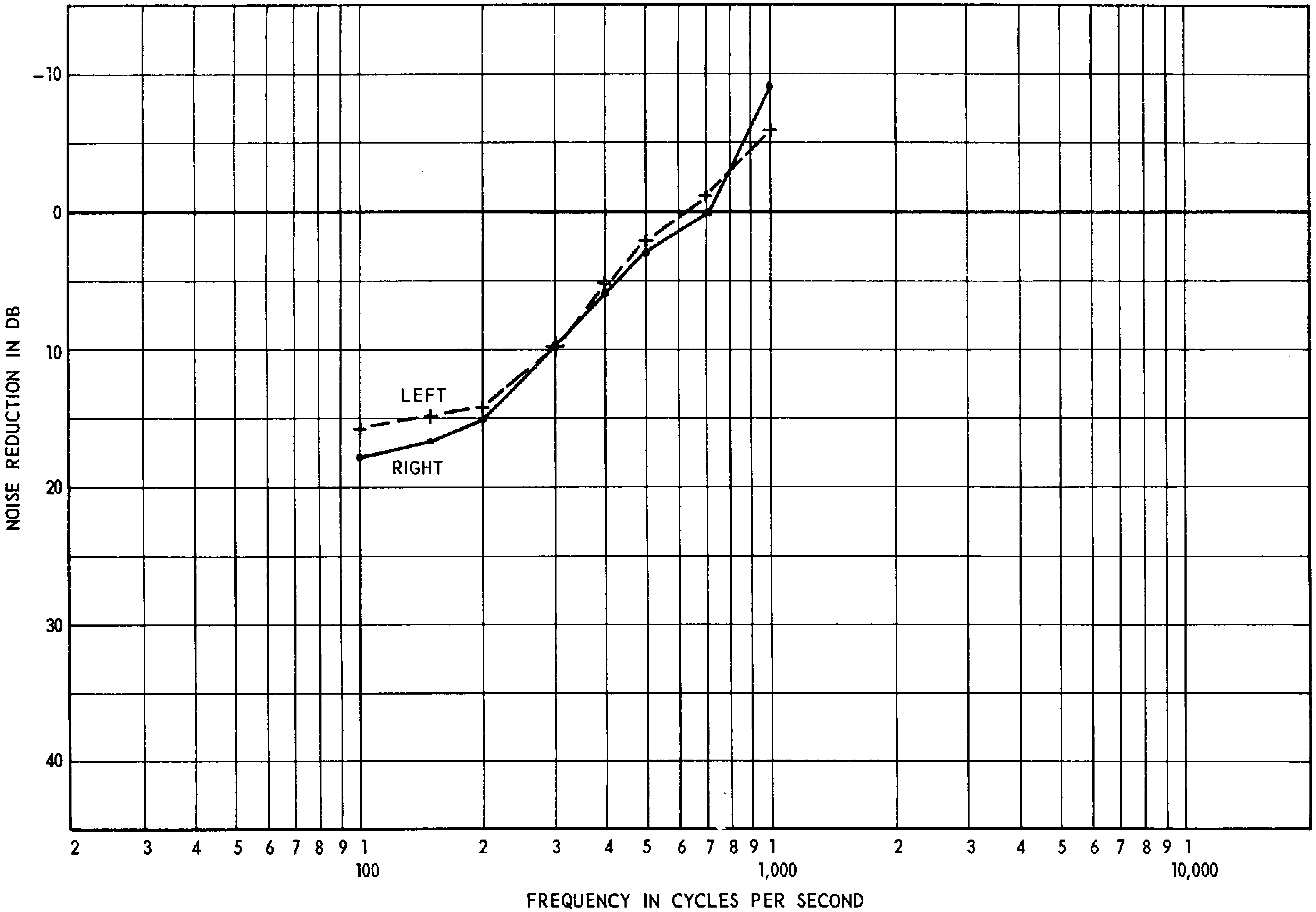

Figure 6. Noise Reduction Obtained with Experimental Active Ear Defender On One Subject

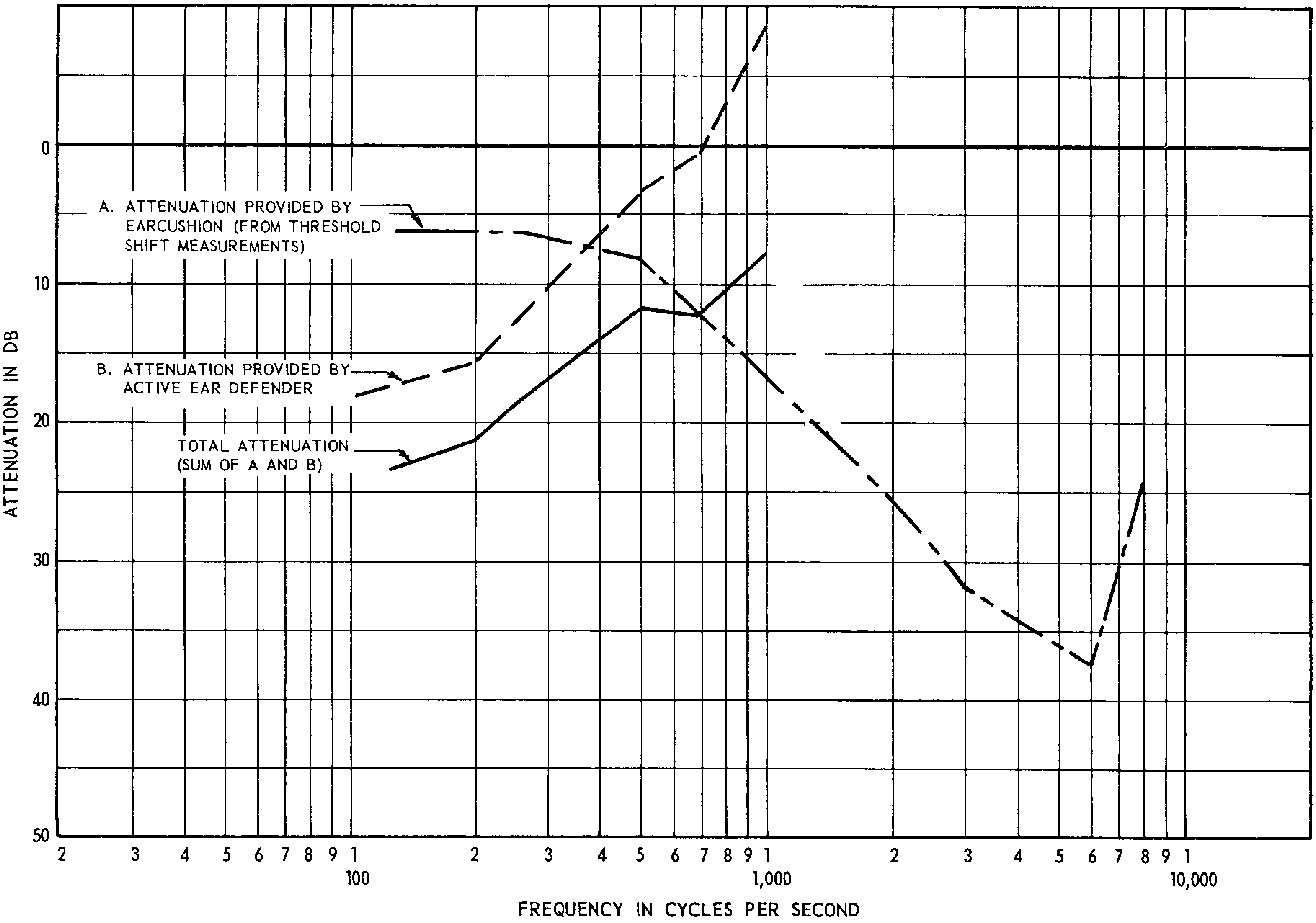

Figure 7. *Total Noise Attenuation Provided By Laboratory Model No. 1*

III. TRANSDUCER DEVELOPMENT

A. REQUIREMENTS

The major factor which limits the performance of an active ear defender is excess phase shift. If all components in the system were minimum phase shift networks (mechanical, acoustical and electrical), much more could be accomplished by equalization and the ultimate limitation on noise reduction would be imposed by factors such as electrical noise or power handling capacity. However, it is not possible to compensate for excess phase shift. Therefore the first requirement for transducers is to minimize excess shift. This, in turn, requires that the transducer size be held to a minimum.

Since the performance is determined by the over-all openloop characteristics, there is not a unique set of requirements for the components. For example, if the earphone and microphone had the proper characteristics, no correcting network would be required, only a "flat" amplifier. On the other hand, if the microphone or earphone had "flat" response characteristics, the necessary reduction in response outside the noise reduction band could be accomplished with electrical networks. In determining the approach to be taken in the transducer design, a study was made of the possibility of using relatively simple transducer characteristics to provide the necessary response and phase characteristics. The response of a simple dynamic earphone, consisting of a resonant diaphragm driving a cavity, is flat below resonance and falls off at 12 db per octave above resonance barring diaphragm breakup, standing waves or other such effects. The phase shift introduced by such a characteristic is 90° at resonance and approaches 180° at high frequencies. This suggests that the earphone response might be made to provide the required cutoff. The fundamental resonance of most earphone diaphragms is in the 700-2000 cps range although acoustical stiffness is sometimes used to raise the resonance further. While the bandwidth is usually increased further by an additional acoustical circuit consisting of a cavity and an inertance, this results in a 24 db per octave ultimate cutoff with a correspondingly greater phase shift. There appears to be no advantage in added bandwidth obtained in this manner because of the increased phase shift unless the bandwidth is increased by a factor of 2 or more.

The response of a condenser or crystal microphone will also be flat below resonance and fall off at 12 db per octave above resonance. The corresponding phase characteristic again has 90° phase shift at resonance and approaches 180° at high frequencies. Thus, the resonant frequency of the microphone must be high enough that it does not add appreciably to the earphone phase shift in the critical region about unity gain. Placement of the microphone resonance in the 10,000 cps region will accomplish this. In each case, the damping constant is very important since it determines the shape of the phase characteristic.

Figure 8 shows an assumed earphone response and corresponding phase characteristic. These arise from the transfer function $T^2P^2 + STP + 1$ (for a series RLC circuit, $T = \sqrt{LC}$, $S = R/2\sqrt{C/L}$, and $P = jw$). The earphone response is assumed to be well damped $(S = 1.00)$ as shown.

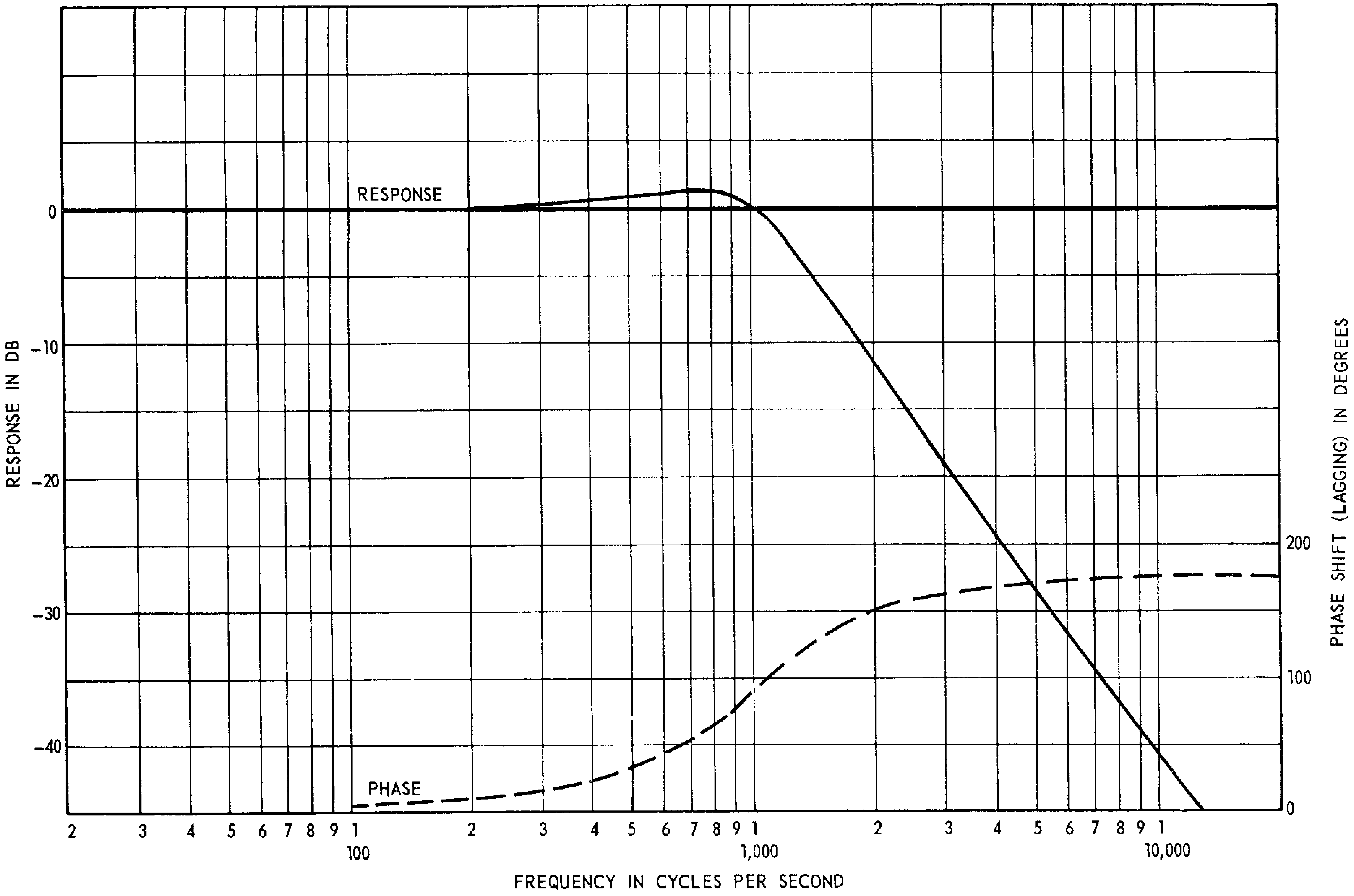

Figure 8. Assumed Earphone Response and Phase Characteristics

Figure 9 shows an assumed microphone response and corresponding phase shift. The same type of response is assumed. In this case only a small amount of damping is assumed $(S = 0.1)$ in order to minimize phase shift below resonance. The resonant frequency was placed at 10,000 kc since it was believed that this is about the frequency which would be realized in a practical unit.

Figure 10 shows the combined earphone and microphone response and phase shift. The gain scale was determined by making the gain -10 db at the frequency at which the phase shift reached 180°. The system would thus be stable and would provide slightly over 17 db of noise reduction to 1000 cps. It is to be noted however, that the phase shift is 160° at 0 db gain, which (from Figure 27, Part I) would result in about 9 db of noise amplification in that region. This could be reduced with additional damping at the cost of slightly less noise reduction in the neighborhood of 1000 cps. The calculated noise reduction (obtained by use of Equation 18 of Reference 1) is shown in Figure 11.

While it would seem logical to start with the developmental objectives for noise reduction, determine the required response and phase characteristics and then the component characteristics, this approach is somewhat less informative than might be expected. The reason for this is that specification of gain and phase characteristics within some frequency range does not uniquely determine the characteristics outside of that range. It is necessary to know the ultimate rate of cutoff at high and low frequencies in order to specify the required response, even for minimal phase shift networks. When the circuit includes nonminimal phase shift networks, the phase characteristic must also be known. It is necessary to start with the characteristics of existing transducers and then determine the direction and degree of improvement needed.

B. MINIATURE MICROPHONE

The foremost requirement for the microphone is that it be of minimum size in order that it can be placed under an earphone and earcushion or otherwise combined with an earphone to couple to the ear with the minimum enclosed volume. It should have uniform response over a wide range. The actual range required depends upon the ultimate rates of cutoff, but for a 6 db per octave cutoff at low frequencies and a 12 db per octave cutoff at high frequencies, the range should extend from 50 to 10,000 cps or more. The phase shift should be the minimum possible associated with the response characteristics.

In addition to the response requirements, the microphone should be reasonably rugged and unaffected by humidity and moderate temperature changes. The electrical impedance should preferably be low enough to permit convenient use of transistors.

These requirements of size and wide frequency range pointed to the use of a condenser or activated ceramic microphone. It was believed that the requirement of low frequency response ruled out dynamic elements. It appears that an activated ceramic element would be somewhat more desirable from the standpoint of impedance and stability; consequently, development of a miniature microphone using an activated ceramic element was undertaken.

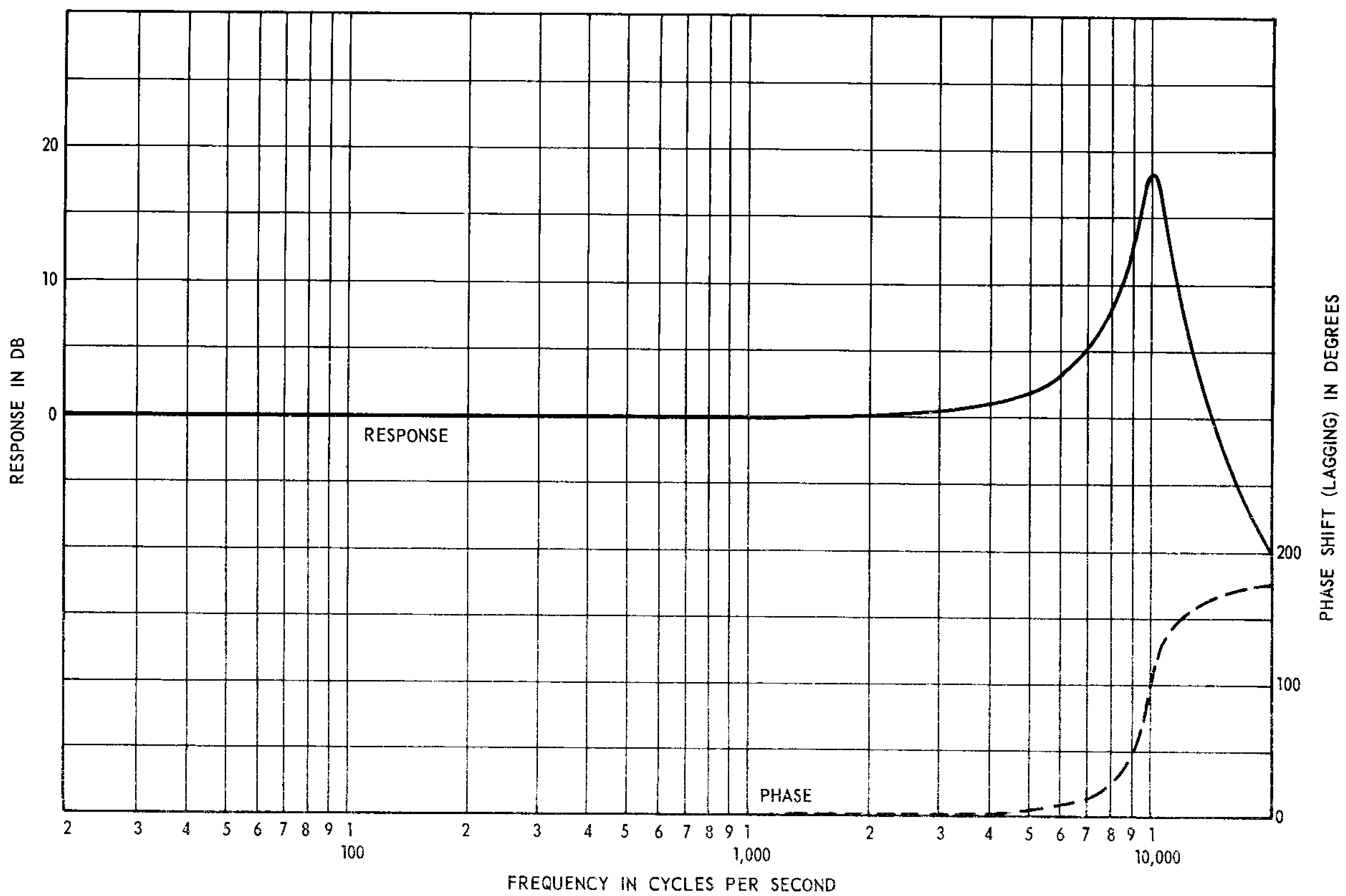

Figure 9. Assumed Microphone Response and Phase Characteristics

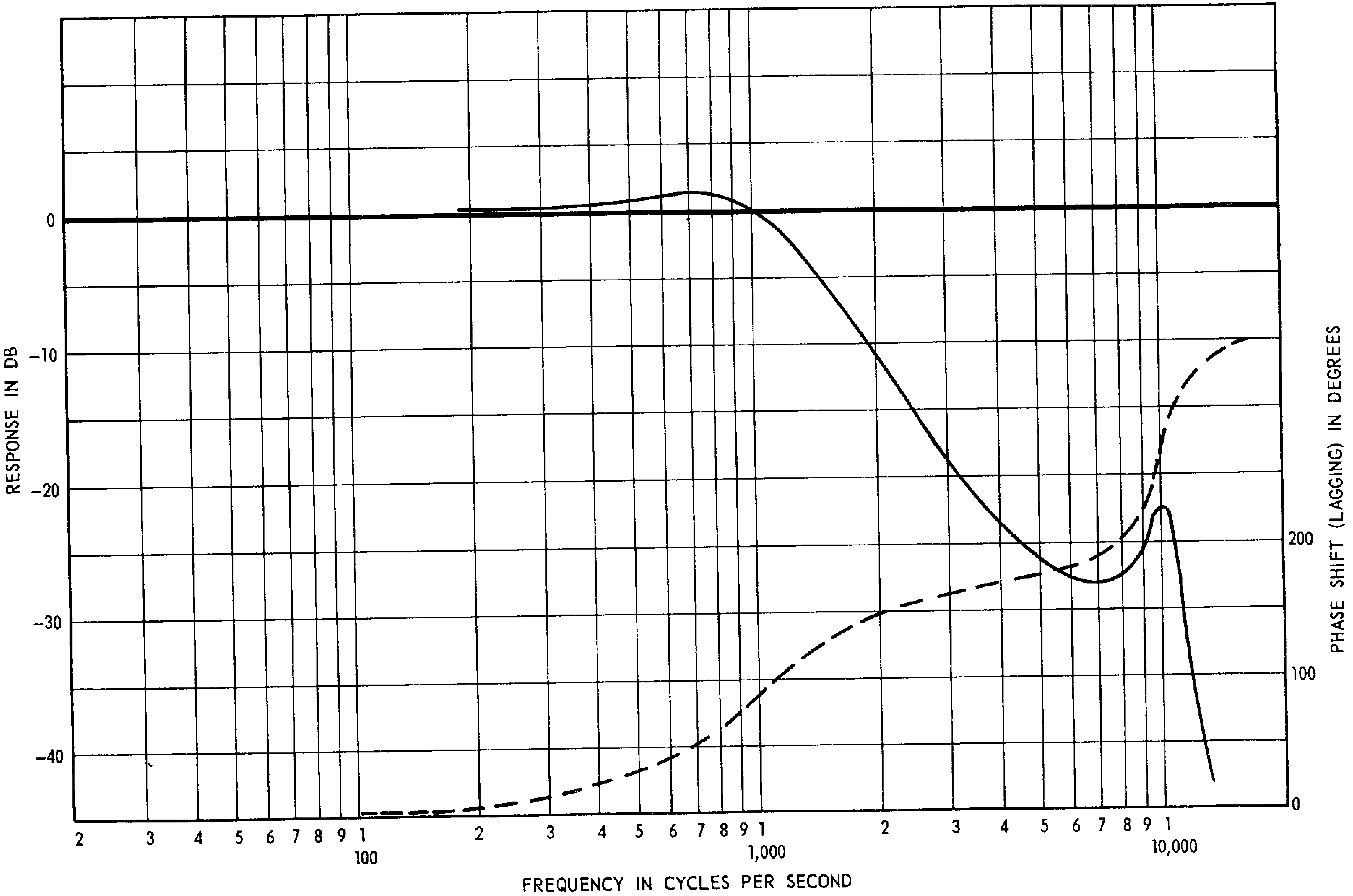

Figure 10. Combined Microphone and Earphone Response and Phase Characteristics

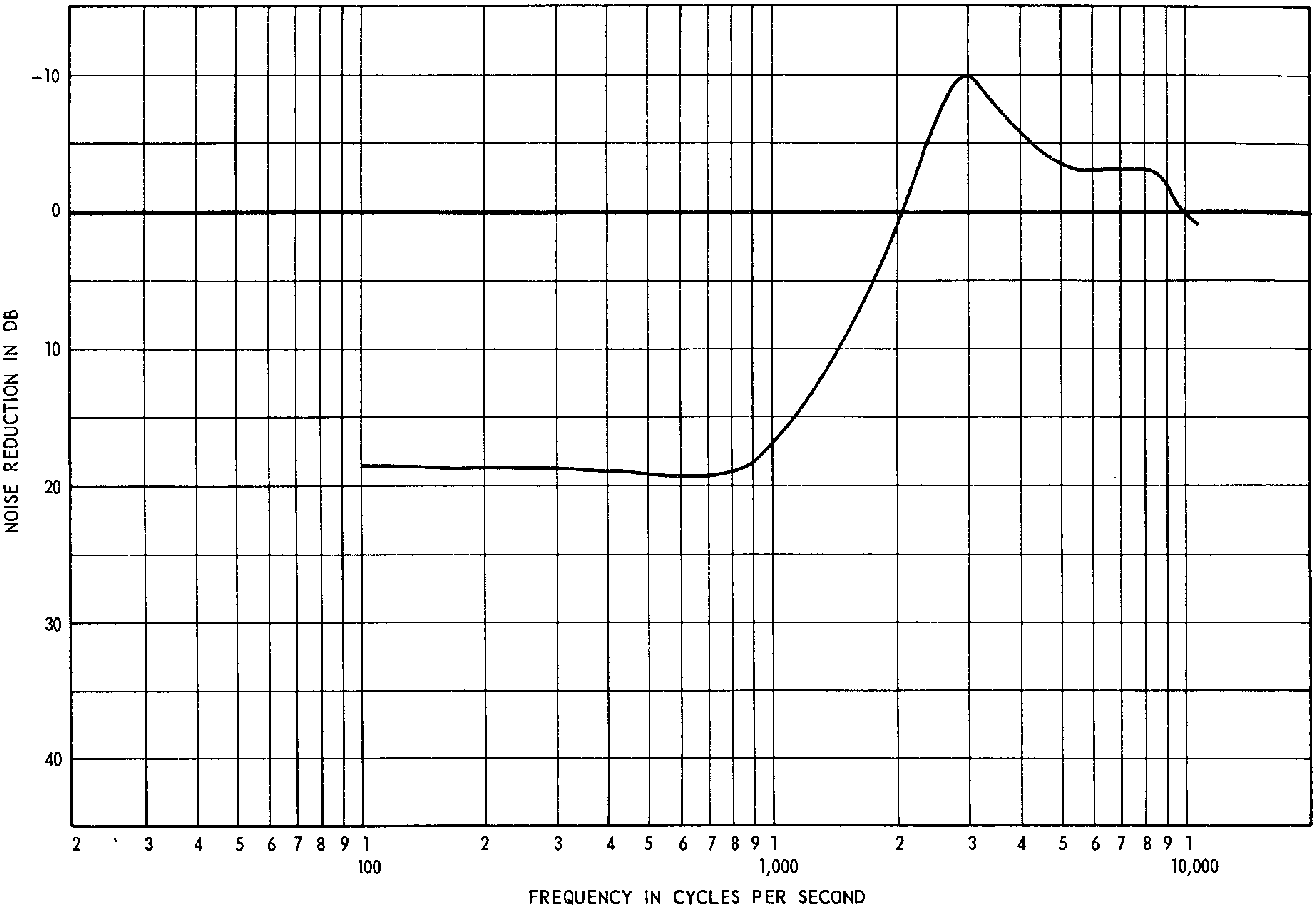

Figure 11. Calculated Noise Reduction for the Transducers of Figure 10

Initial experimental models were constructed with barium titanate elements. However, lead zirconium titanate elements became available. Since this material provides higher sensitivity, it was incorporated in later models.

Figure 12 shows a diagram of the microphone. It is 0.550 inch in diameter and 0.165 inch thick. The active element is a lead zirconium titanate (PZT) piezoelectric ceramic bimorph supported on two small rubber pads. Electrical connections are soldered to the element's active faces and to two insulated terminals on the housing wall.

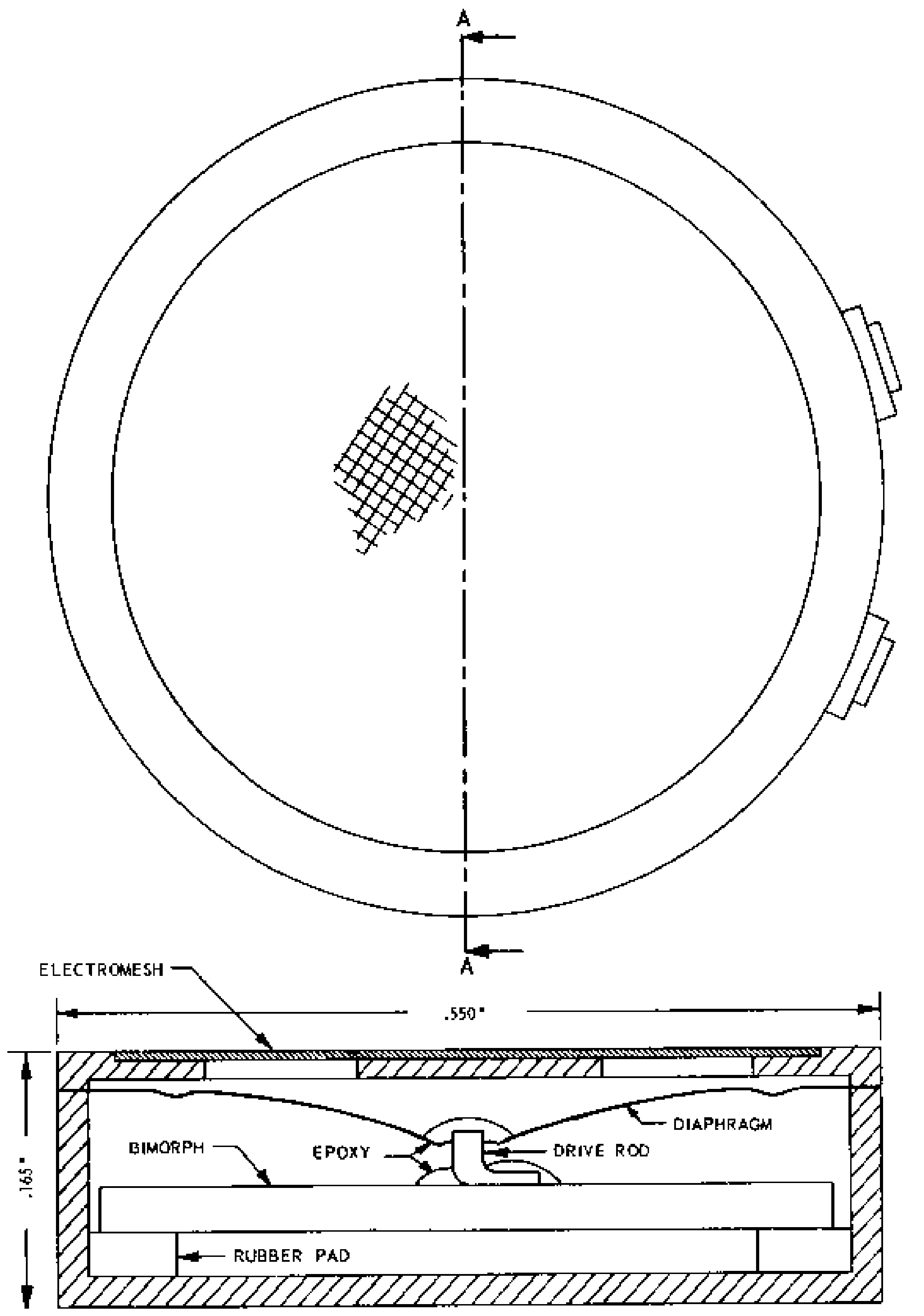

Figure 12. Miniature Microphone Using Lead Zirconium Titanate (PZT) Element

The diaphram is coupled to the center of the bimorph. The mass of the diaphragm was held to a minimum by using 0.0005 inch thick aluminum. The diaphragm is connected to the bimorph by means of a 0.020-inch-diameter drive rod cemented to both the diaphragm and the bimorph by means of epoxy resin cement.

The front cover is formed by an electromesh damping screen. This partially damps the main resonance which occurs at approximately 9000 cps. This resonance is damped only lightly in order to minimize the amount of phase shift below resonance.

The response of this microphone is shown in Figure 13. The capacitance of the microphone is approximately 500 micromicrofarads. The response shown in Figure 13 was measured with a 2-megohm load and a 150-micromicrofarad connecting cable. The response expected with a 5 megohm-load is also shown.

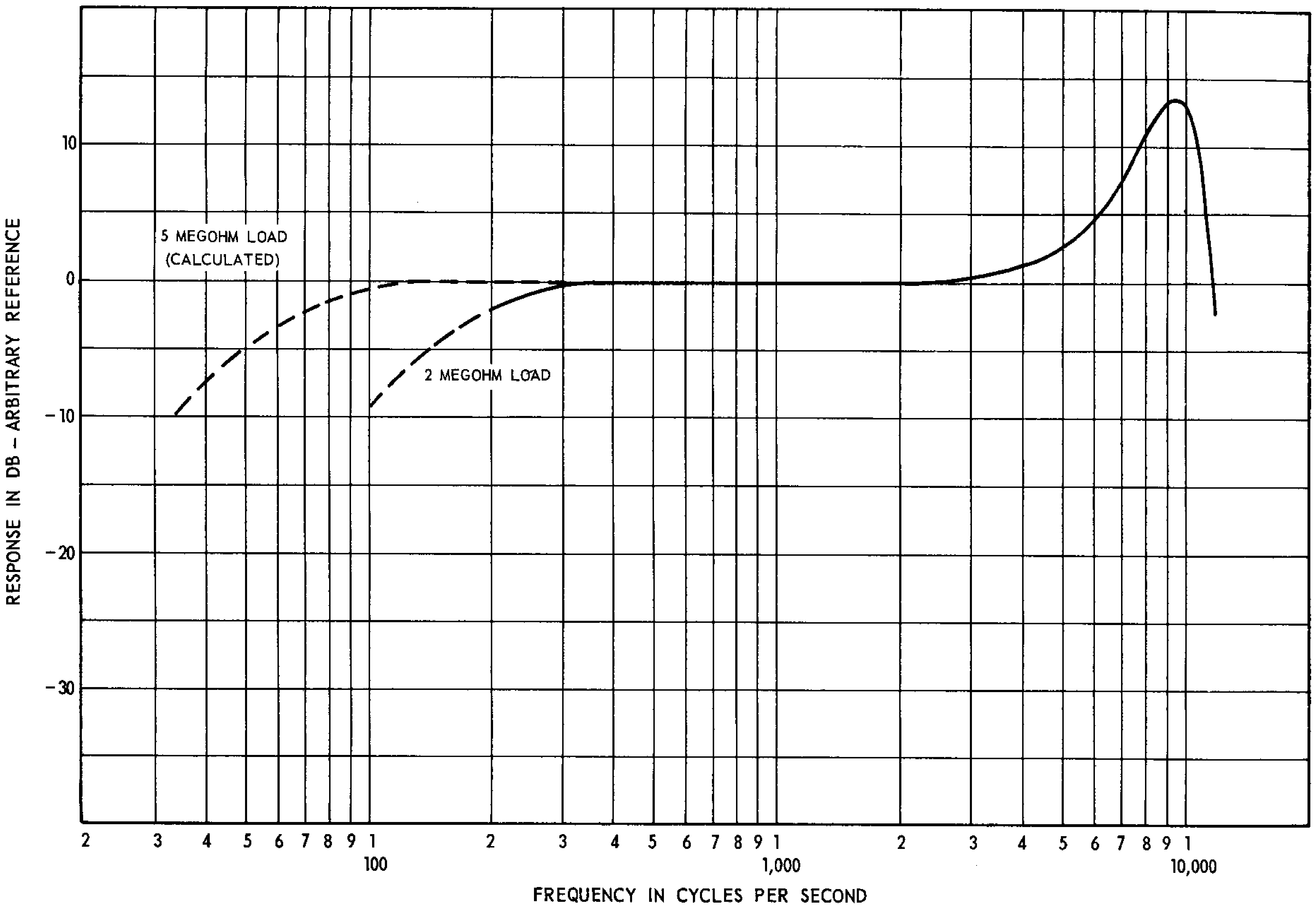

Figure 13. Response of Miniature Microphone

While the frequency of resonance was slightly lower than desired, it was thought that some electrical equalization would be feasible, and that the microphone would be useable.

C. EARPHONES

While the earphone requirements are not uniquely determined by the over-all objectives for noise reduction, the characteristics sought are detailed in the following:

(1) Power handling capacity. The earphone must be capable of producing peak pressures equal to the peak noise pressure existing under the ear-cushion when the active portion of the active ear defender is disabled. Since the earphones used were capable of producing such sound pressures, or very nearly so depending upon the arrangement, no effort was spent in the direction of improvement in power handling capacity. This would logically be reviewed after the objectives for noise reduction had been met.

(2) Response. The frequency response should be essentially flat throughout the frequency band in which noise reduction is desired, and should fall off at high and low frequencies at a sufficiently slow rate that the over-all response and phase requirements can be met. The response should be stable on an individual and should vary as little as possible from individual to individual, in order to minimize network adjustments.

(3) Phase Characteristic. The earphone should contribute as little excess phase shift as possible to the over-all phase characteristic.

The approach taken was to attempt to modify existing earphones to have substantially flat frequency response in the 100-1000 cps range, and to fall off smoothly above and below this range at a rate not exceeding 12 db per octave.

IV. TRANSDUCER ARRANGEMENTS

The need for keeping the microphone-earphone coupling volume and spacing to a minimum led to two different transducer arrangements. The first might be called a "T" arrangement and is intended for use with a semi-insert tip; it appears to offer the most noise reduction and would be better suited for use with portable battery operated amplifiers. The second arrangement, which we will call a "coaxial" arrangement corresponds more nearly to a conventional headset. The two arrangements are described in detail below.

A. "T" ARRANGEMENT

The "T" arrangement is shown in Figure 14. This arrangement is intended for use with an insert or semi-insert tip leading to the ear canal. The earphone and microphone are placed face-to-face and are thus coupled together by a very small volume (approximately 1 cc) which is, in turn, coupled to the ear canal with a short tube. This arrangement greatly reduces the enclosed volume. For that reason it should be limited less by excess phase shift than other arrangements. It would also be more suitable for use with battery operated amplifiers since the small volume is favorable to the earphone sensitivity.

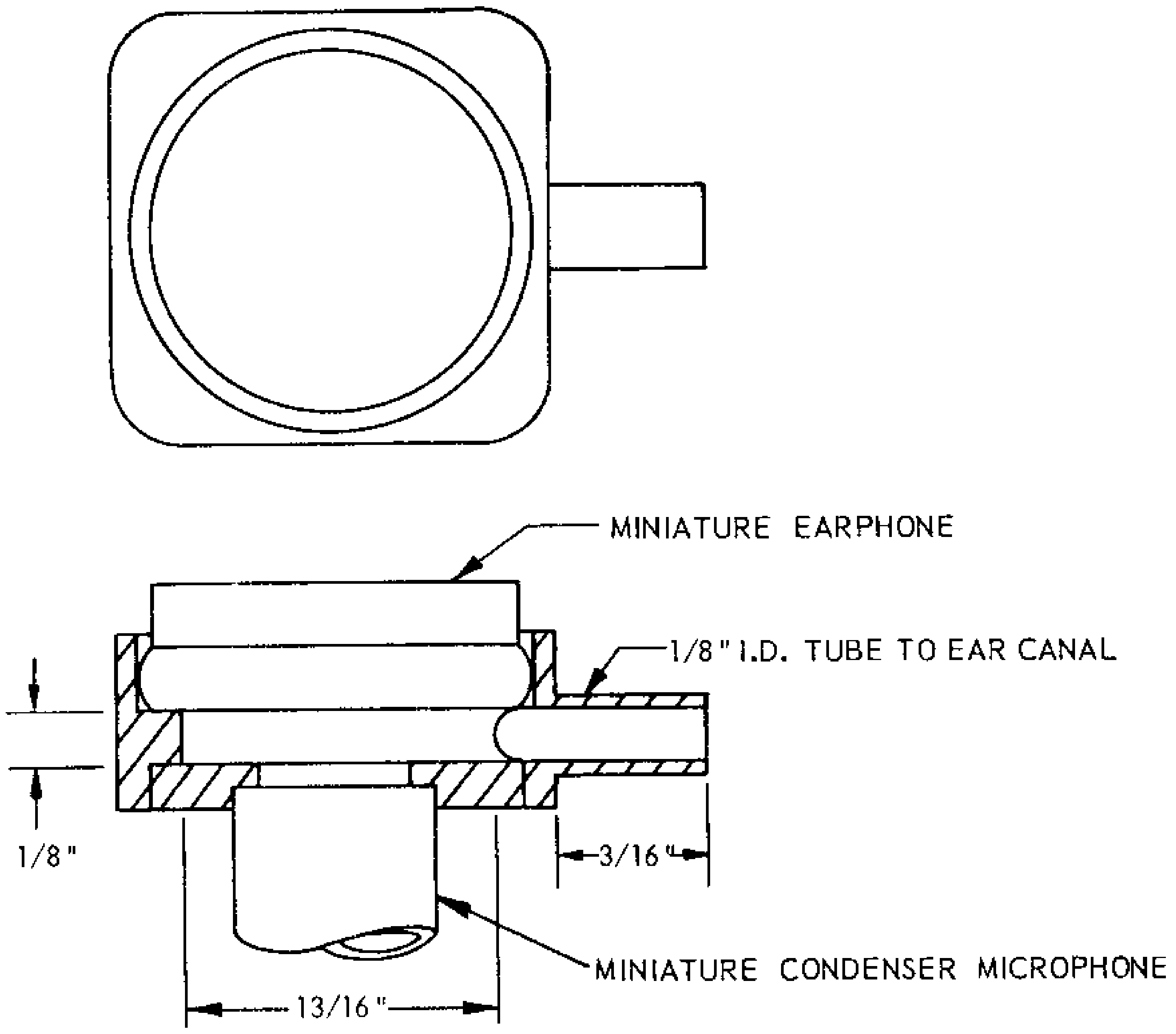

Figure 14. Diagram Showing the Manner in which the Earphone, Microphone and Coupler are Assembled in the Semi-Insert Arrangement

Figure 15 shows the response of the microphone used. It was a miniature condenser microphone normally used for laboratory measurements. It is similar in construction to the Western Electric 640AA but was smaller and had a correspondingly higher frequency response. The same preamplifier used with the WE 640AA for laboratory measurements was used. The resulting arrangement was, of course, too bulky for any practical model but very useful in determining something of the potential of this approach.

The earphone was a modification of a miniature earphone developed for the government by RCA. The principal modification was the omission of the front acoustical elements. The response of the miniature earphone measured separately on a 6 cc coupler is shown in Figure 16.

The over-all response and phase characteristics of the "T" arrangement of Figure 14 are shown in Figure 17. It was necessary to place acoustical damping material in the coupling cavity to reduce the effect of standing waves at high frequencies.

Determination of the amount of noise reduction attainable is most conveniently done by graphical methods. A cutoff frequency is first selected and a rate of cutoff assumed. The phase characteristic introduced by this characteristic is then determined and added to the original phase characteristic. The altered response characteristic is then inspected and a gain scale established which meets the criteria for noise reduction, noise amplification and stability. The characteristics are then reviewed to determine if further alterations could be made to give improved performance.

In the case of the characteristics shown in Figure 17, the cutoff frequency (top of the band in which noise reduction is obtained) was set at 500 cps. A 12 db per octave cutoff slope was assumed. In addition, it was assumed that equalization of the high frequency response was feasible, to the extent of the gain provided for noise reduction. The assumed amplifier and correcting network characteristics are then as shown in Figure 18. When these characteristics are combined with the original characteristic, the over-all characteristics shown in Figure 19 are obtained. We see that the phase shift does not exceed 90^{o} below 500 cps. With the gain below 500 cps set at 20 db, the phase shift does not exceed 140^{o} at 0 db gain, and at 180^{o} the gain is -10 db. Thus 20 db of noise reduction to 500 cps is indicated.

It is of interest to estimate the excess phase shift encountered in this arrangement. This has been done by approximating the high frequency cutoff by a straight line starting at 4000 cps and having a slope of -12 db per octave as shown in Figure 20. The phase shift associated with this characteristic is also shown in Figure 20. Subtracting the calculated phase shift characteristic from the measured phase shift characteristic we obtain an estimate of the excess phase shift. This is plotted in Figure 21. Figure 21 also shows the phase shift which would be produced by a 0.67-inch microphone-earphone separation. The effective separation is thus approximately 0.67 inch although the actual separation is approximately 0.125 inch.

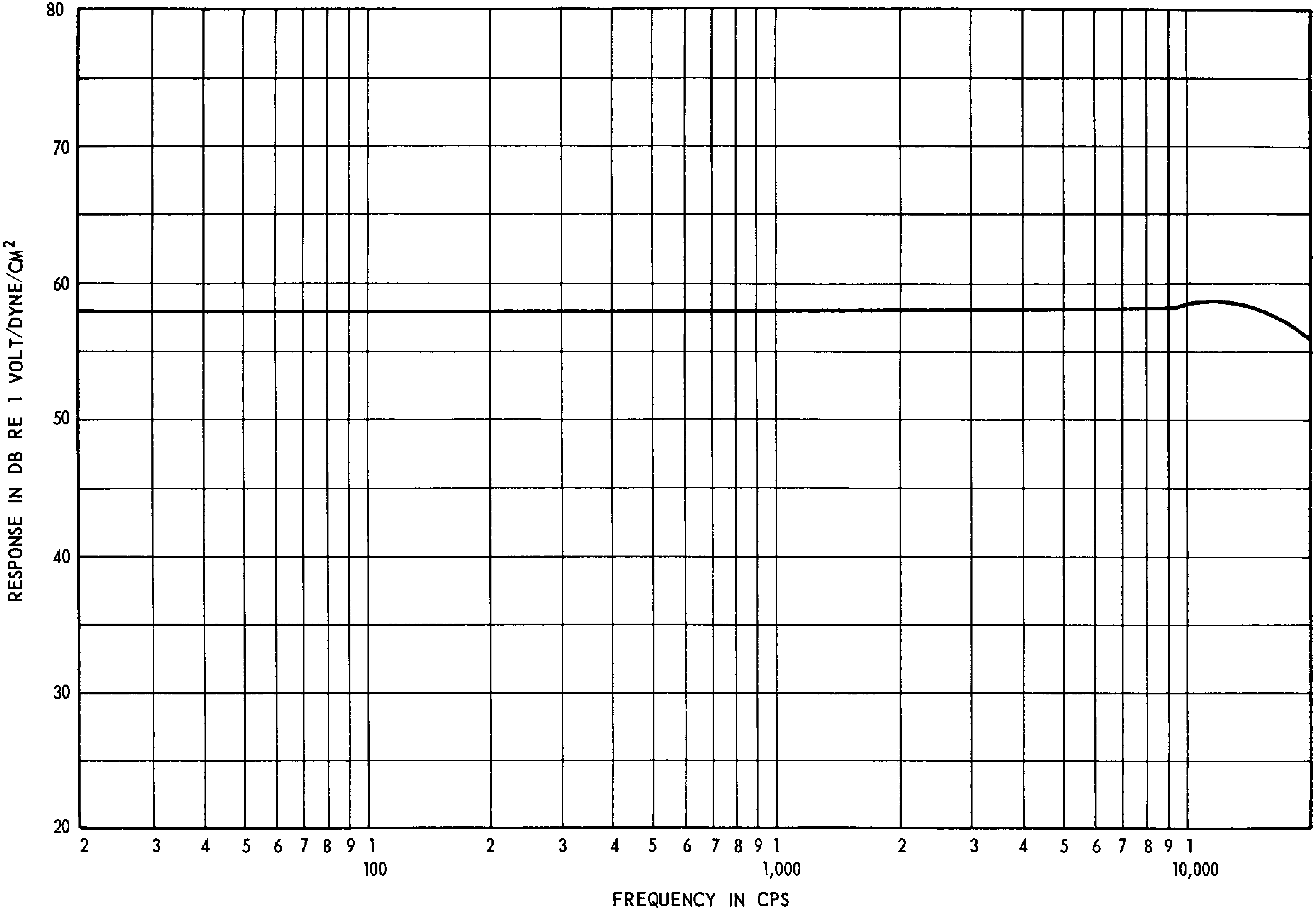

Figure 15. Pressure Response of Miniature Condenser Microphone Used in Semi-Insert Arrangement

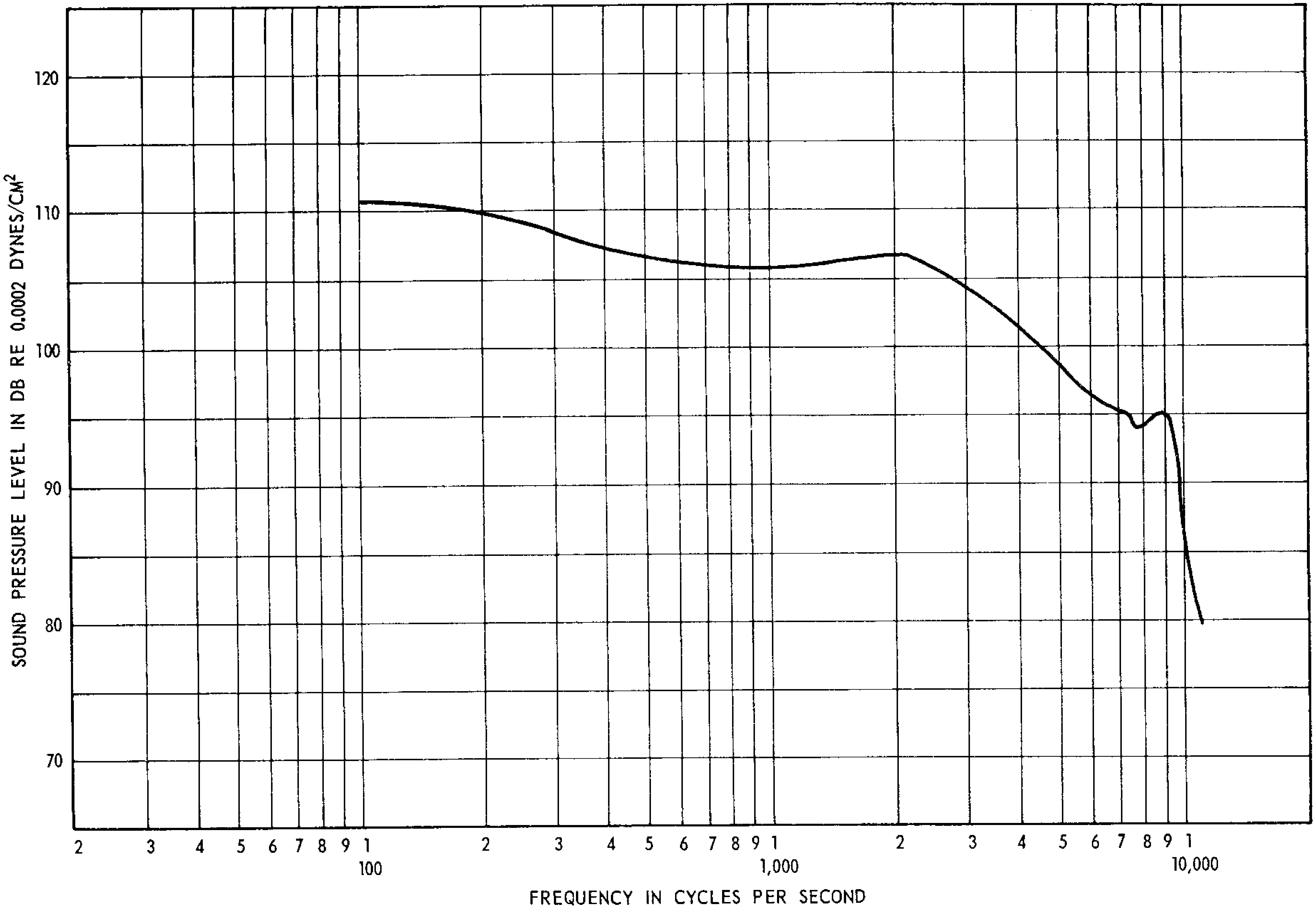

Figure 16. Response of Miniature Earphone in 6 cc. Coupler for mw. Input

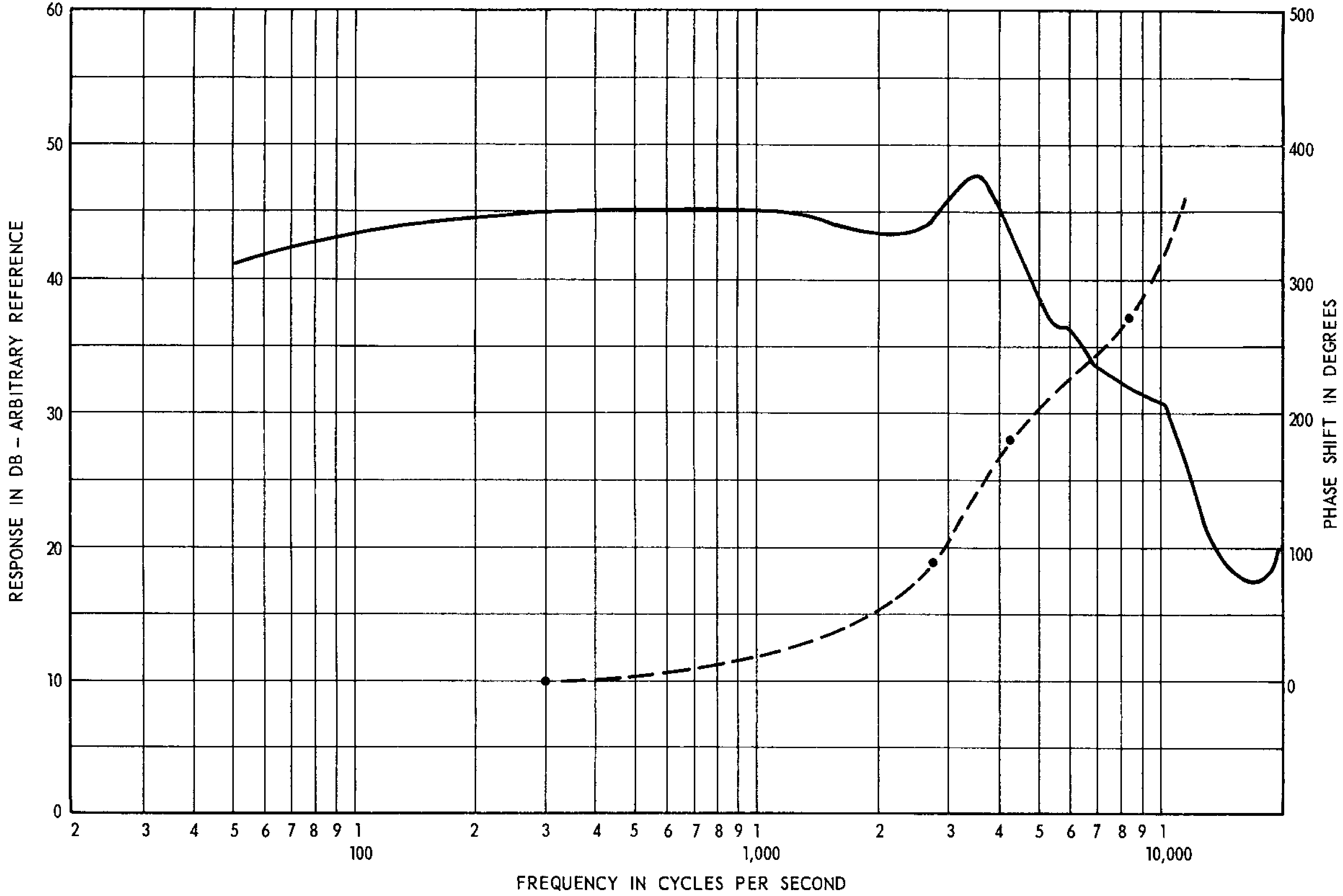

Figure 17. Overall Response and Phase Shift for Miniature Earphone and Miniature Condenser Microphone in the Semi-Insert Coupling Arrangement of Figure 14

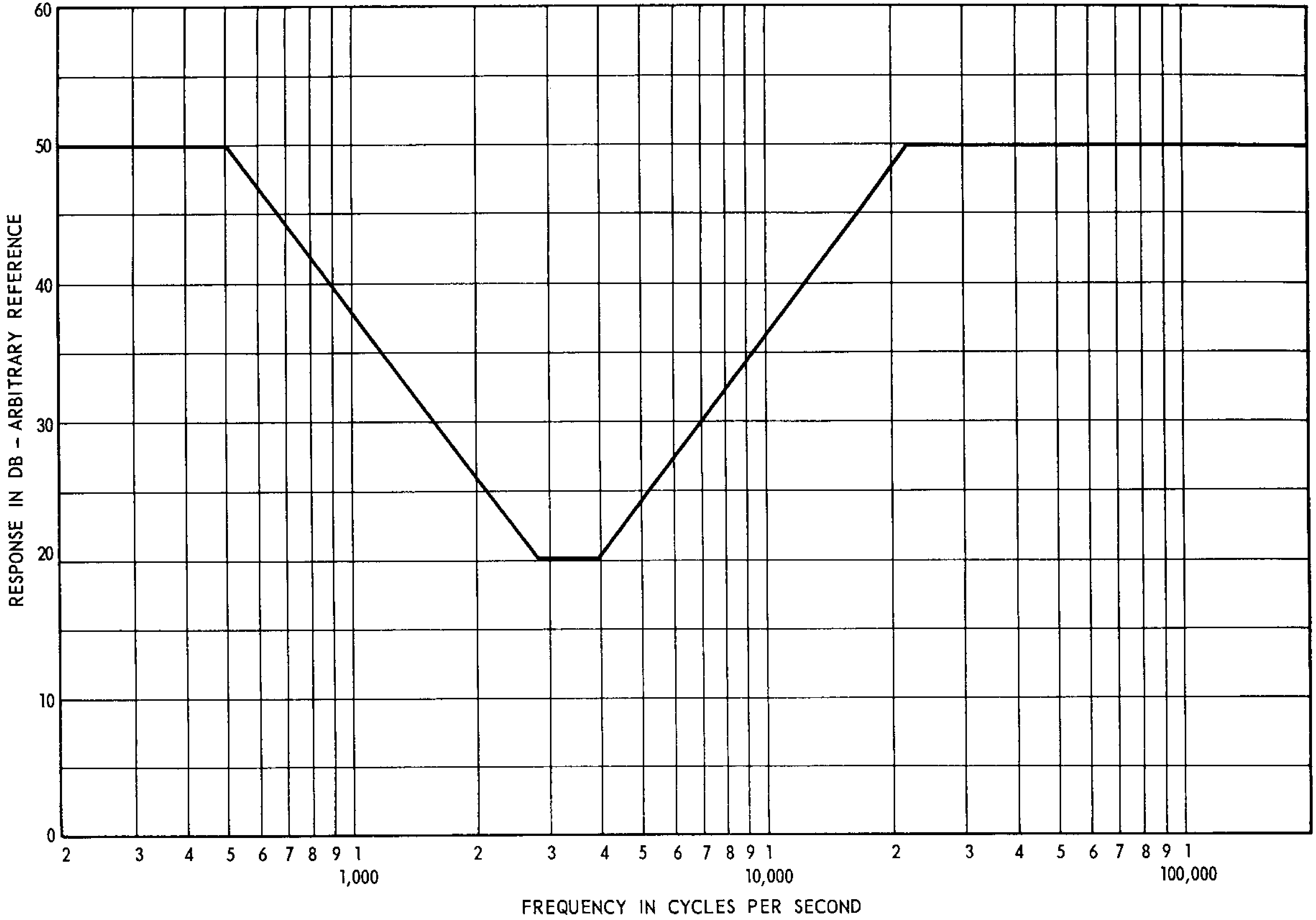

Figure 18. ***Response of Amplifier and Correcting Networks***

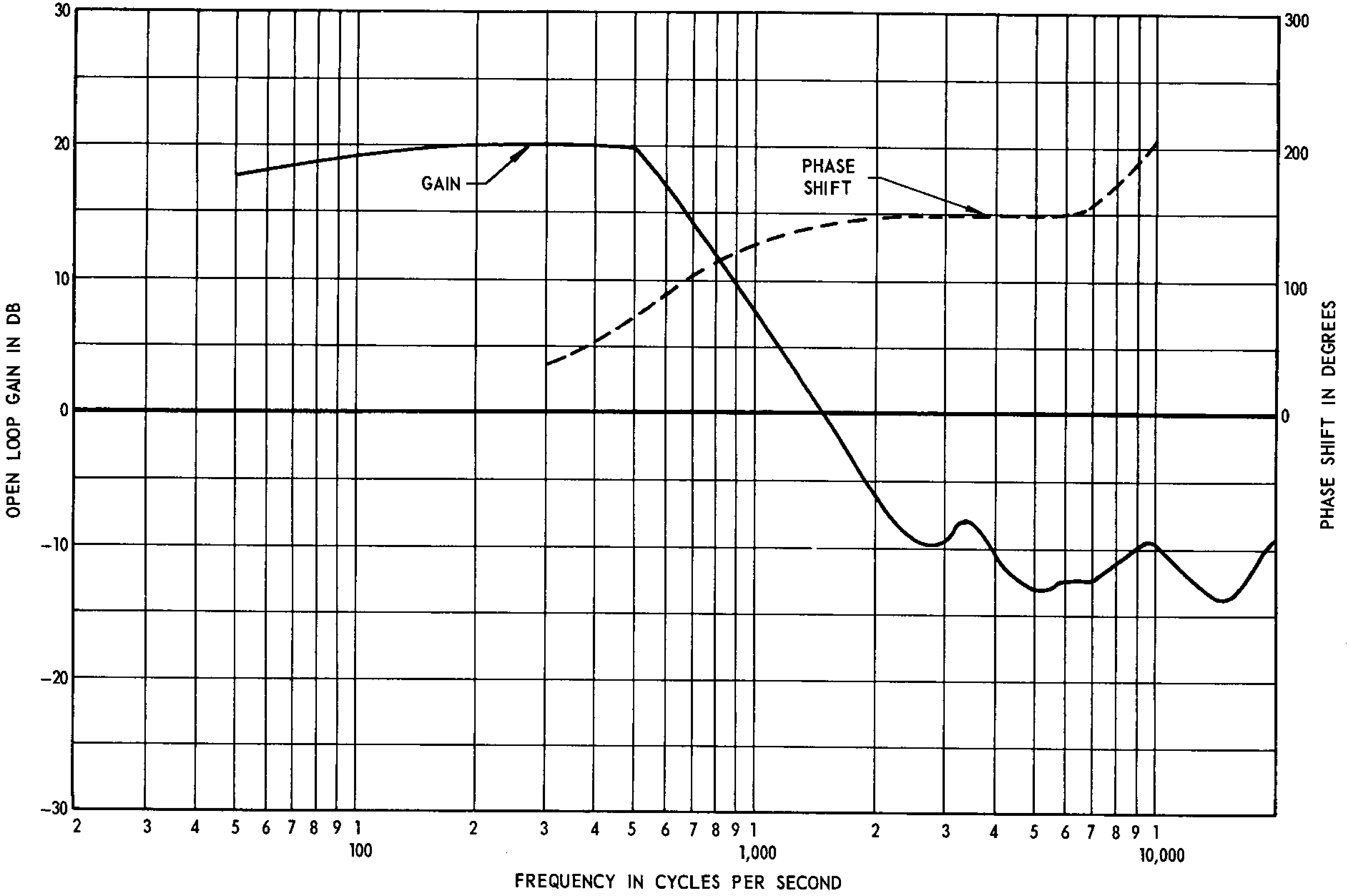

Figure 19. Overall Corrected Response and Phase Shift

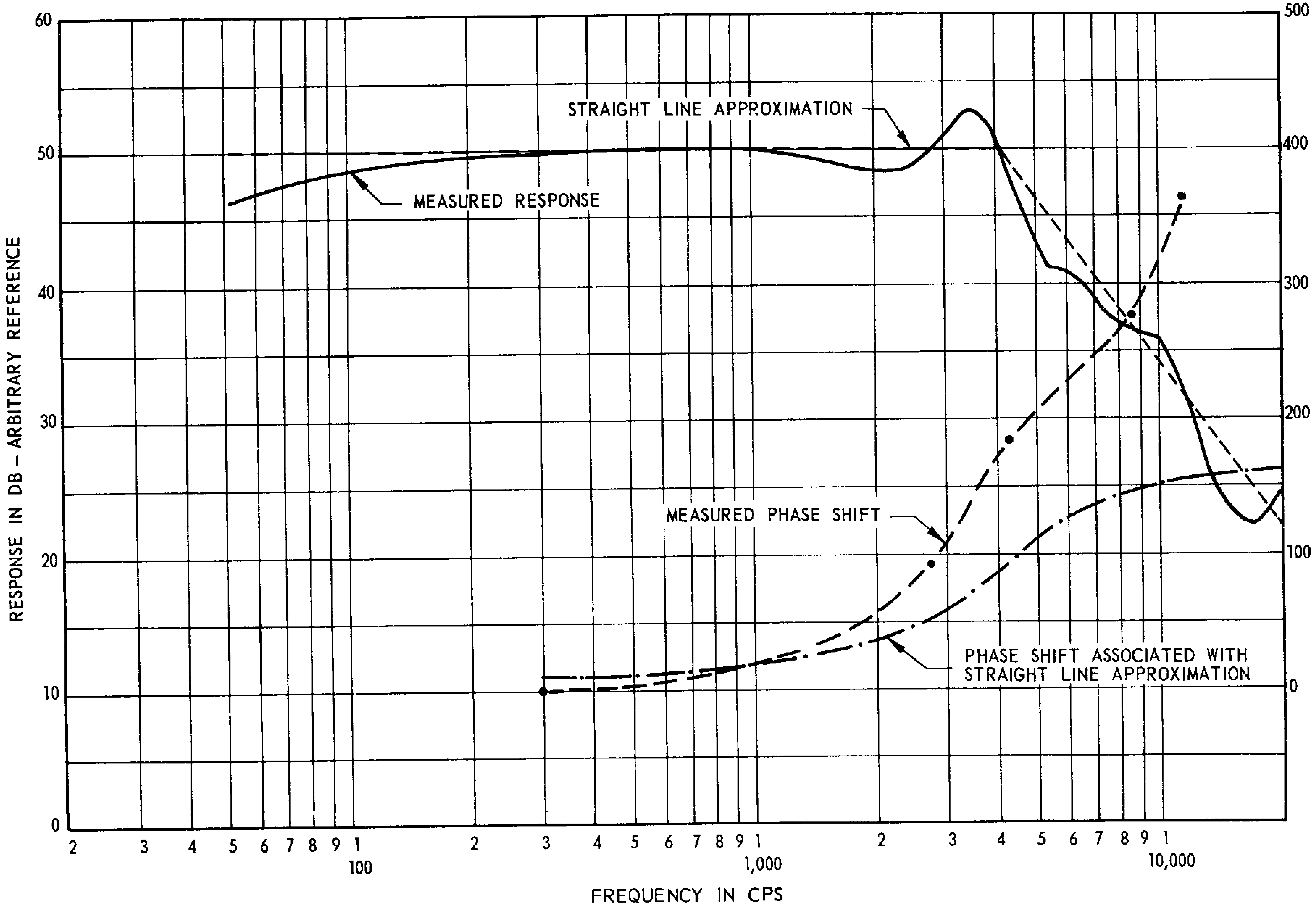

Figure 20. *Straight Line Approximation for Estimation of Excess Phase Shift*

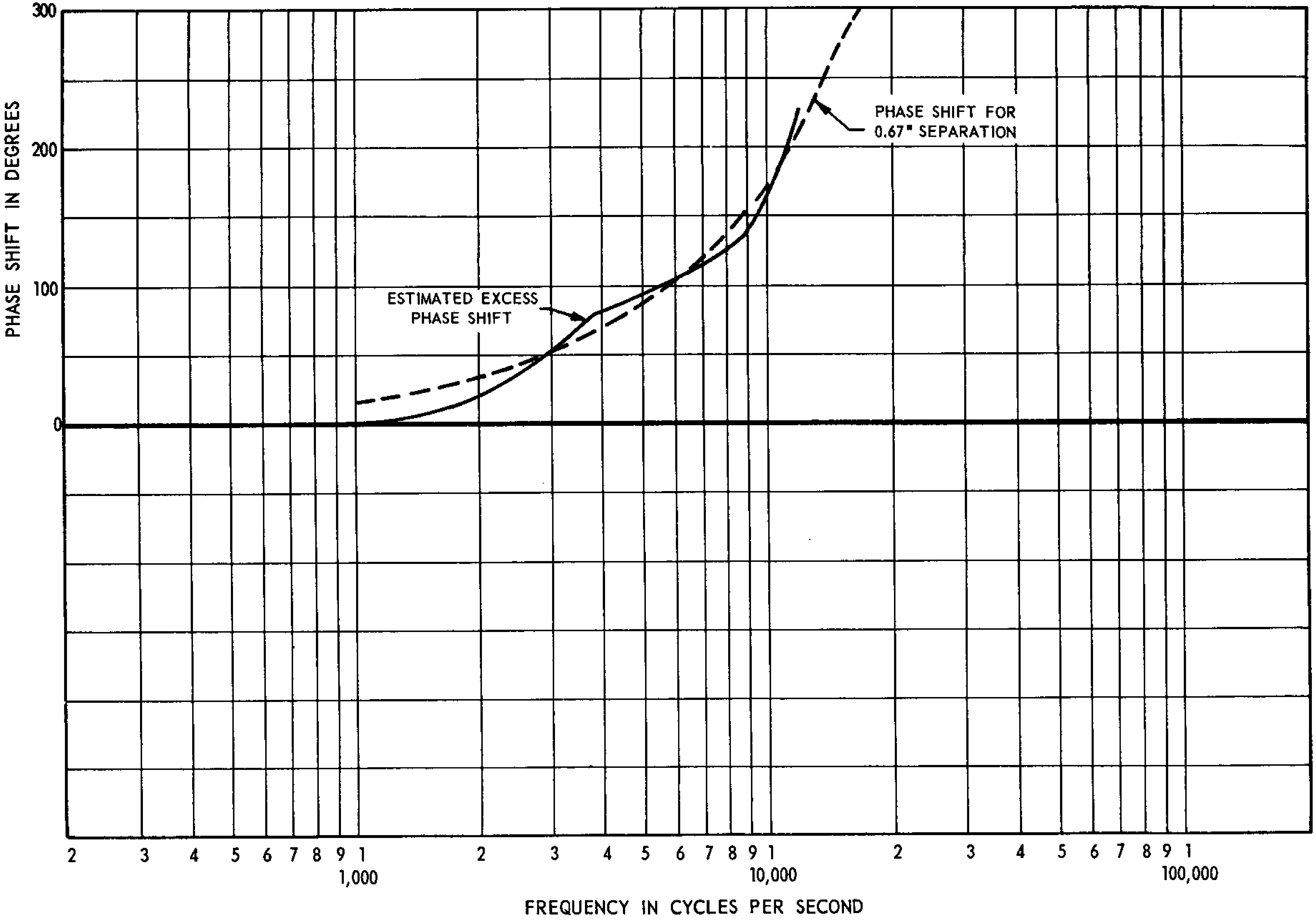

Figure 21. Estimated Excess Phase Shift

It should be noted that in the determination of attainable noise reduction, no allowance has been made for the phase shift which would be introduced by the high frequency cutoff of the amplifier. This means that it should not introduce appreciable phase shift below about 2000 cps. This is a severe requirement and will be discussed later.

Also, the low frequency region has not been considered. It is believed that there is no basic difficulty here. However, if noise reduction is to continue to 50 cps it will be necessary to consider the characteristic of the transducers and amplifiers at very low frequencies, perhaps 0.1 cps or lower.

An electrical network approximating the desired characteristics was determined. This network is shown in Figure 22. Using this network with laboratory amplifiers, as shown in Figure 23, the amount of noise reduction obtained was determined by introducing an electrical signal from an oscillator as shown. With the oscillator set at 400 cps, the gain was adjusted to reduce the voltage "V_1" to a minimum without any evidence of instability. The rise in voltage "V_1" when the earphone was disconnected then corresponded to the noise reduction obtained. This was done for other frequencies. The noise reduction obtained is shown in Figure 24. It is to be noted that while nearly 20 db of noise reduction was obtained in the vicinity of 400 cps, there was considerable noise amplification at about 1400 cps. This was caused by additional phase shift introduced by the amplifiers. At low frequencies, the rate of cutoff was controlled by condenser "C"; slightly more noise reduction in the 100 cps region could no doubt have been obtained by use of an RLC network. These measurements were made with the tube plugged with clay, which would normally connect to the ear canal; earlier measurements indicated that essentially the same results would be obtained if the unit sealed to the ear canal. Development of a universal insert or semi-insert tip was considered beyond the scope of the present work.

When the miniature PZT microphone was completed, it was coupled in a "T" arrangement using the same miniature earphone used in the above arrangement. An Altec preamplifier, normally used with the Altec BR-150 condenser microphone, was used with PZT microphone. The over-all response and phase characteristics obtained with this arrangement are shown in Figure 25. This arrangement gave more phase shift than the arrangement described earlier using a miniature condenser microphone. A part of the difference can be accounted for by the lower frequency of resonance of the PZT microphone. This additional phase shift introduces considerable difficulty in obtaining a substantial amount of noise reduction and indicates that a microphone with a higher frequency of resonance would be desirable.

Figure 26 shows the response and phase characteristic of a network which will permit approximately 20 db of noise reduction to 400 cps, assuming no additional phase shift is produced by the amplifiers in the critical region around 1500 cps. Figure 27 shows the resulting over-all response when the characteristics from Figures 25 and 26 are combined. The peak at 5700 cps in Figure 26 is intended to equalize the dip in the response at this frequency; actually it is not required from the standpoint of response equalization but since it produces leading phase shift below 5700 cps it does improve the phase shift characteristic. Even with this equalization and the 24 db per

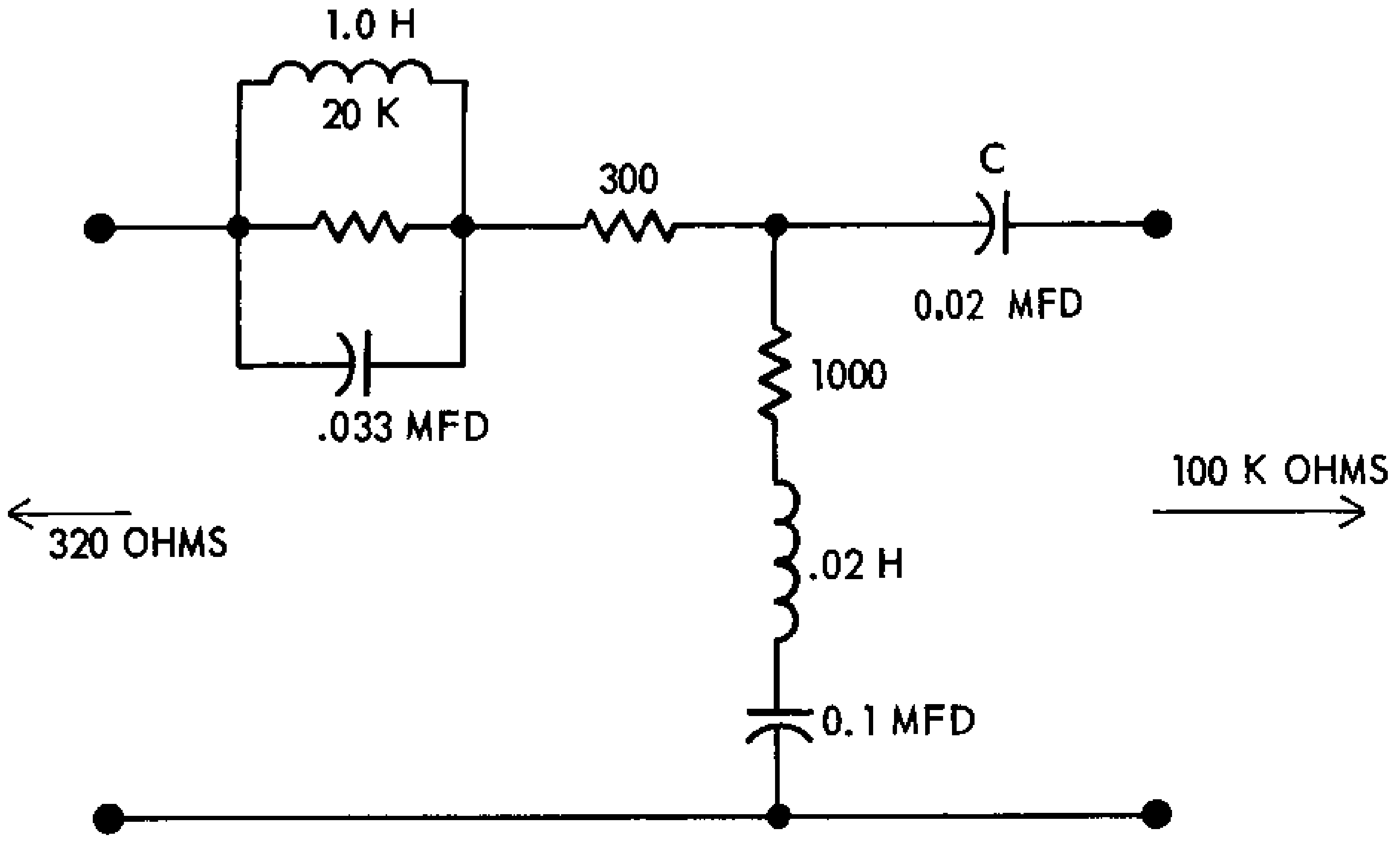

Figure 22. Diagram of Correcting Network

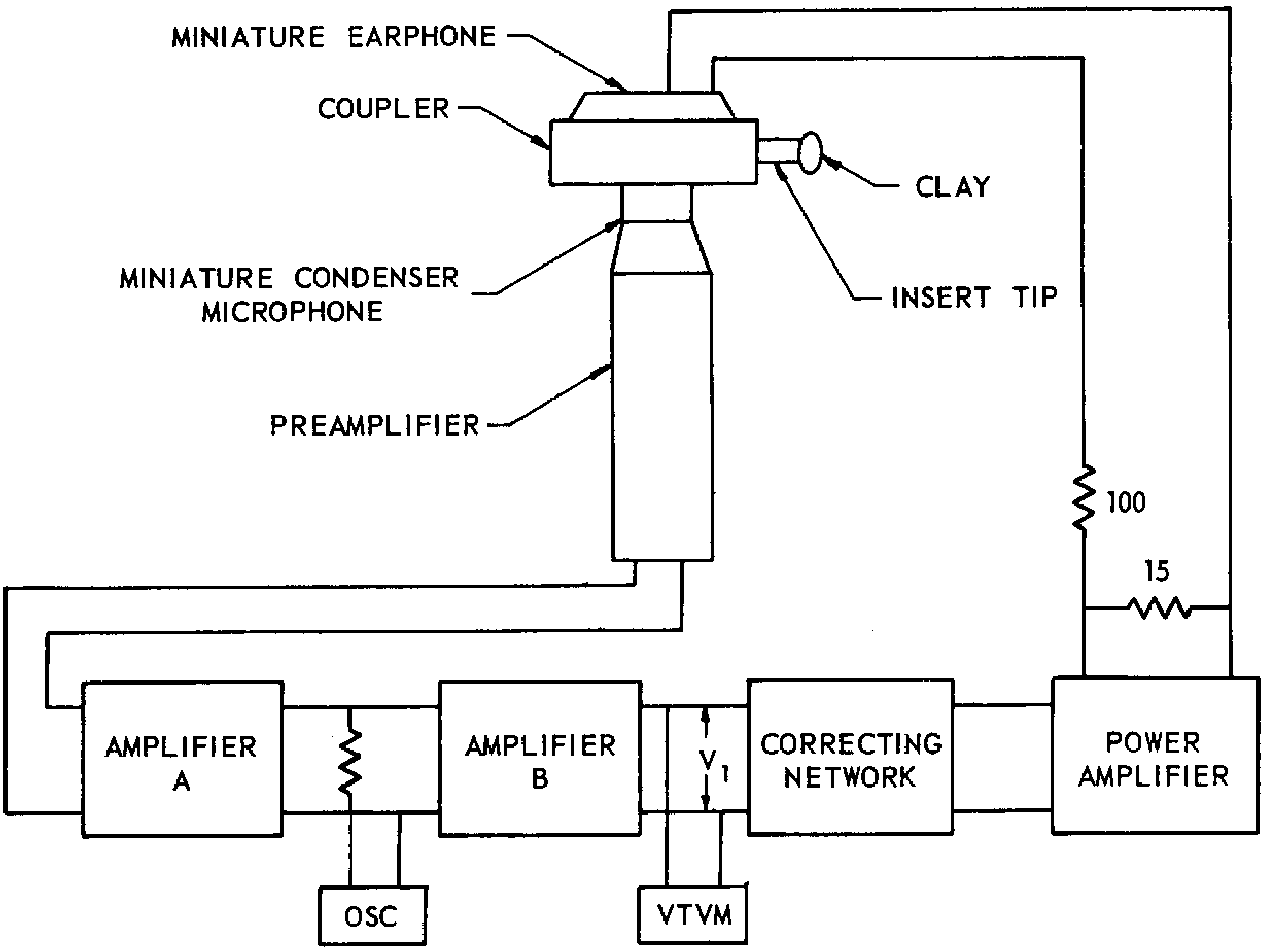

Figure 23. Diagram of Circuit Used for Preliminary Trial of the Semi-Insert Arrangement

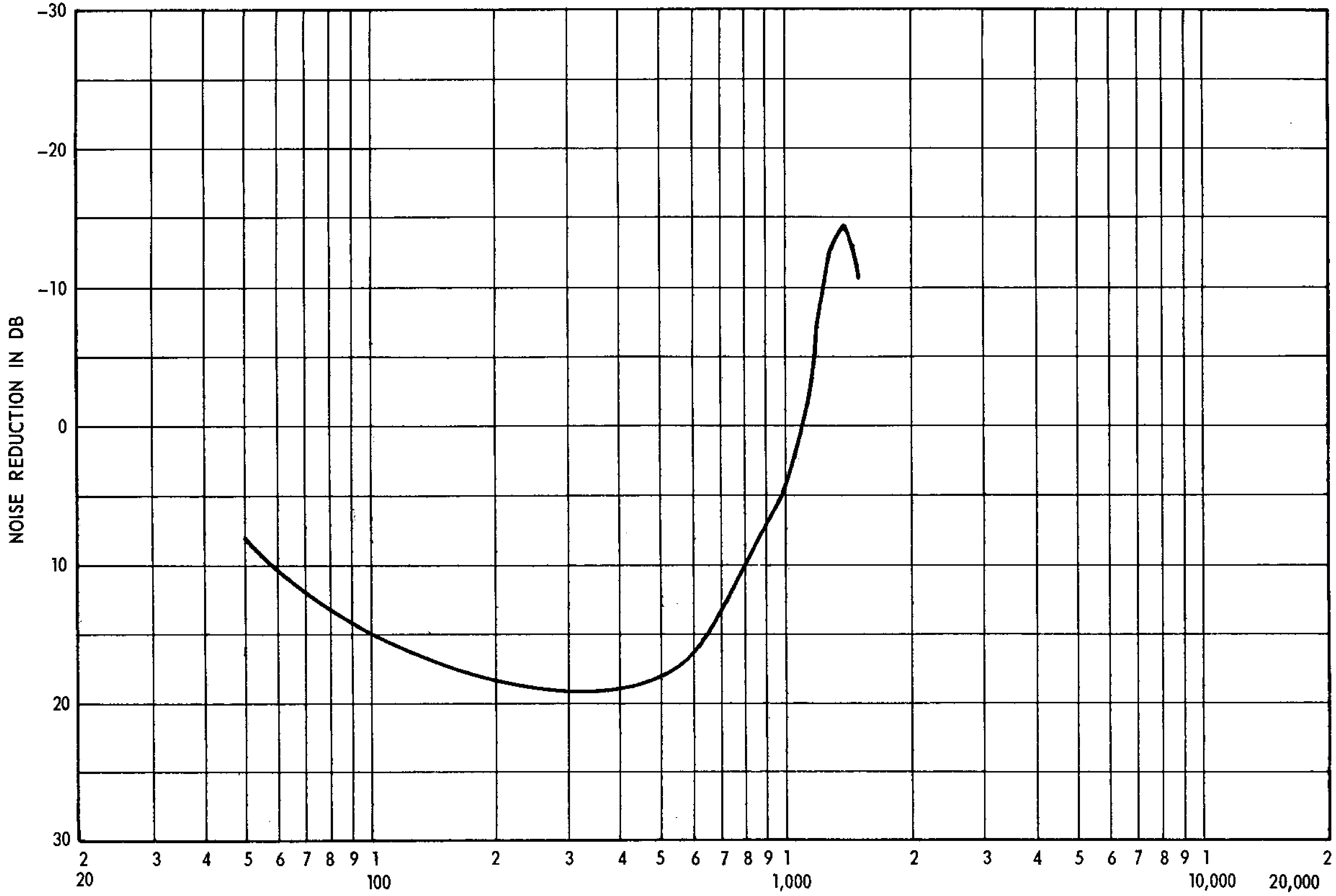

Figure 24. Noise Reduction Obtained with Semi-Insert Arrangement

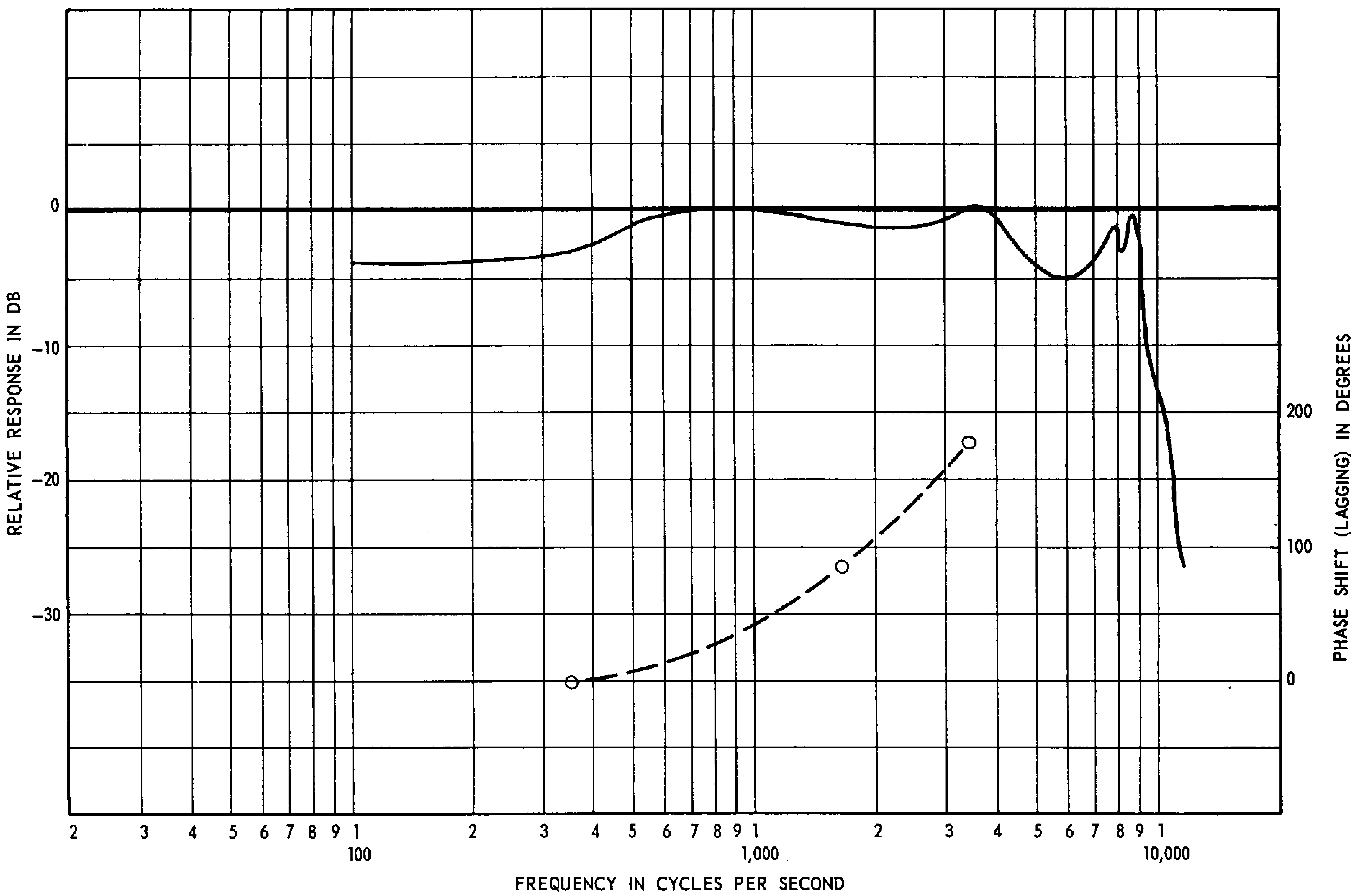

Figure 25. Over-all Response of "T" Arrangement Using Miniature PZT Microphone (On Ear)

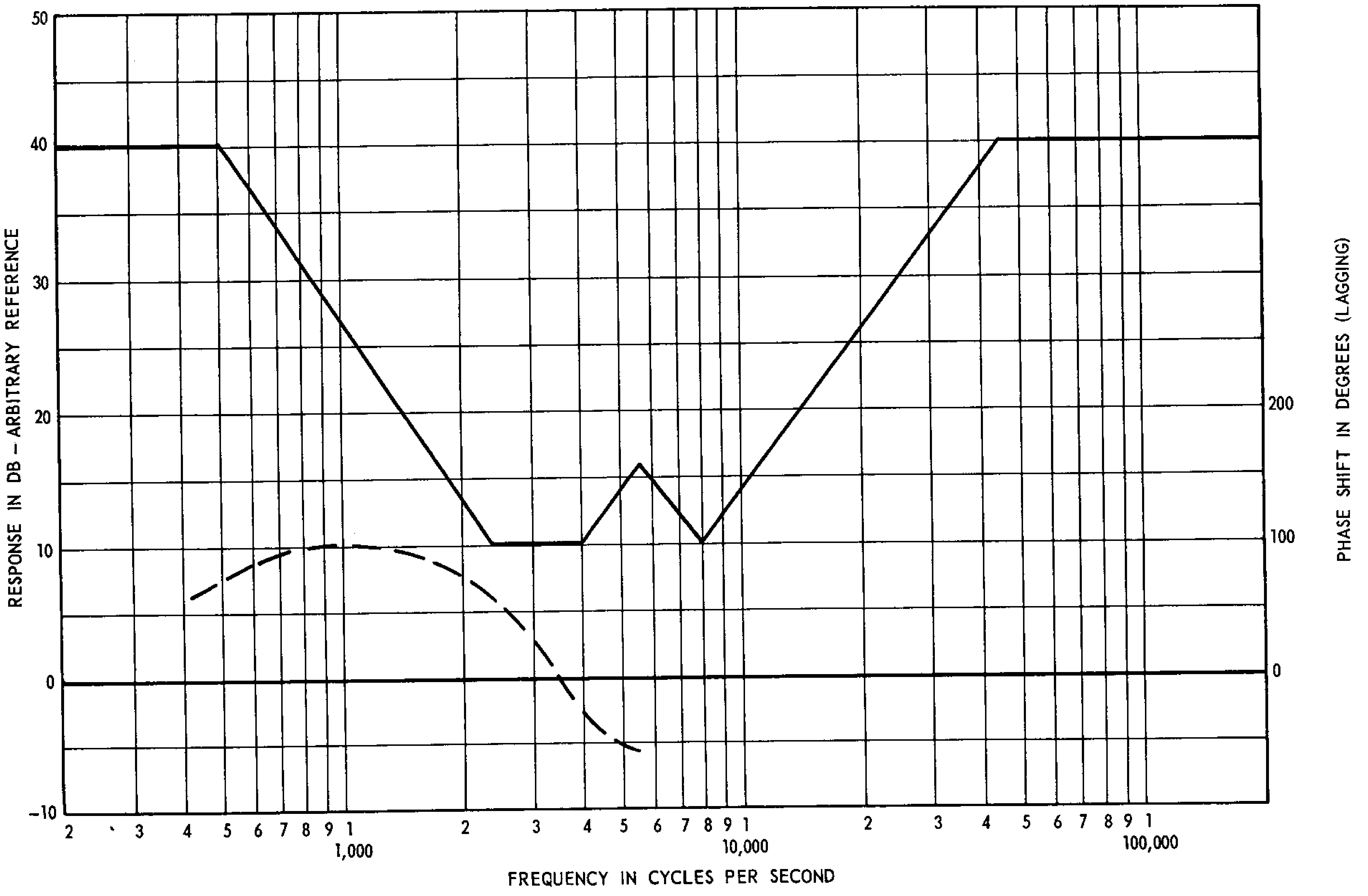

Figure 26. Characteristics of Network for Transducers of Figure 24

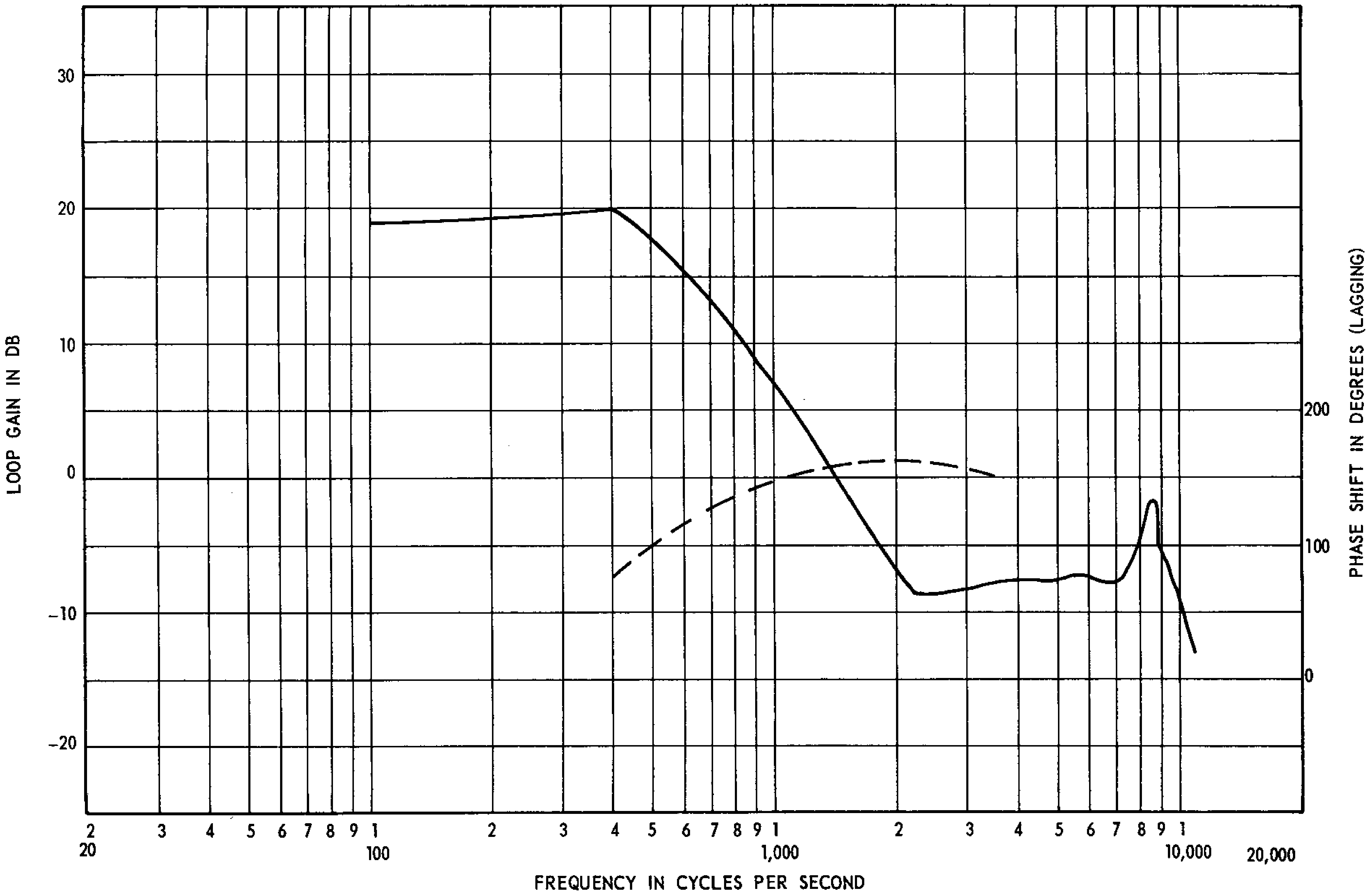

Figure 27. Over-all Corrected Response and Phase Shift for "T" Arrangement with Miniature PZT Microphone

octave equalization of the high frequency cutoff, we have approximately 155° phase shift at 0 db gain rather than 138°. As a result, we would have about 7.5 db of noise amplification in this region (from Figure 27 of (Part I)). In order that this amount of noise reduction be obtained, it would be necessary that the amplifier in the loop introduce no additional phase shift in the region around 1400 cps. While this problem has not been explored, it seems probable that more effort should be expended in extending the microphone frequency response so that somewhat less restriction on amplifier phase shift would be required. A compromise between microphone bandwidth and sensitivity and amplifier gain and phase shift is necessary and the optimum compromise is not readily determined.

B. COAXIAL ARRANGEMENT

The transducer arrangement termed here "coaxial" is shown in Figure 28. An H-143/AIC earphone was used without a front cover. The miniature PZT microphone described earlier was used. Initial measurements of the over-all response of this arrangement showed large resonances in the high frequency region. Figure 29 shows over-all response typical of this arrangement. In an effort to reduce these irregularities in response, damping was applied to the diaphragm; a mixture of fine sand and petroleum jelly was found to be quite effective. In addition acoustical damping material was placed in the enclosed volume. By these techniques, response and phase characteristics as shown in Figure 30 were obtained. Examination of these characteristics indicates that 20 db of noise reduction might be obtained to about 300 cps. However, this phase of the work was somewhat limited and these data should be regarded as indicative only.

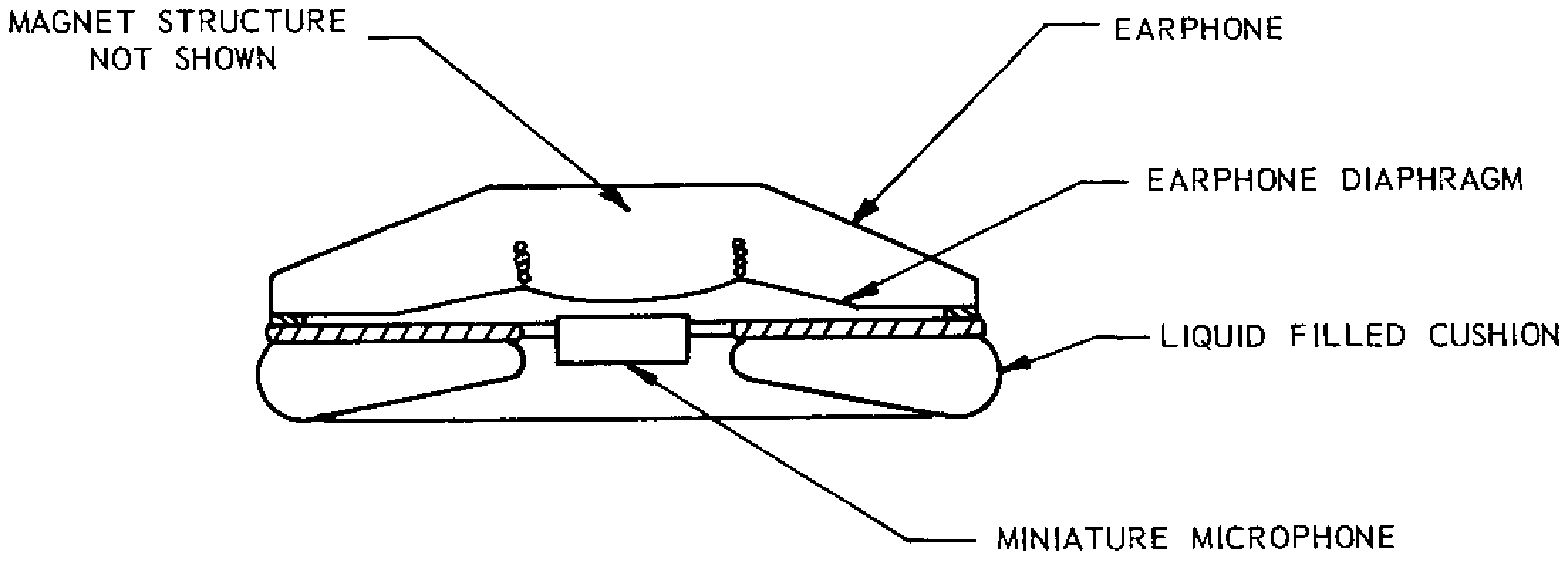

Figure 28. Diagram Illustrating Small Volume Earcushion Arrangement.

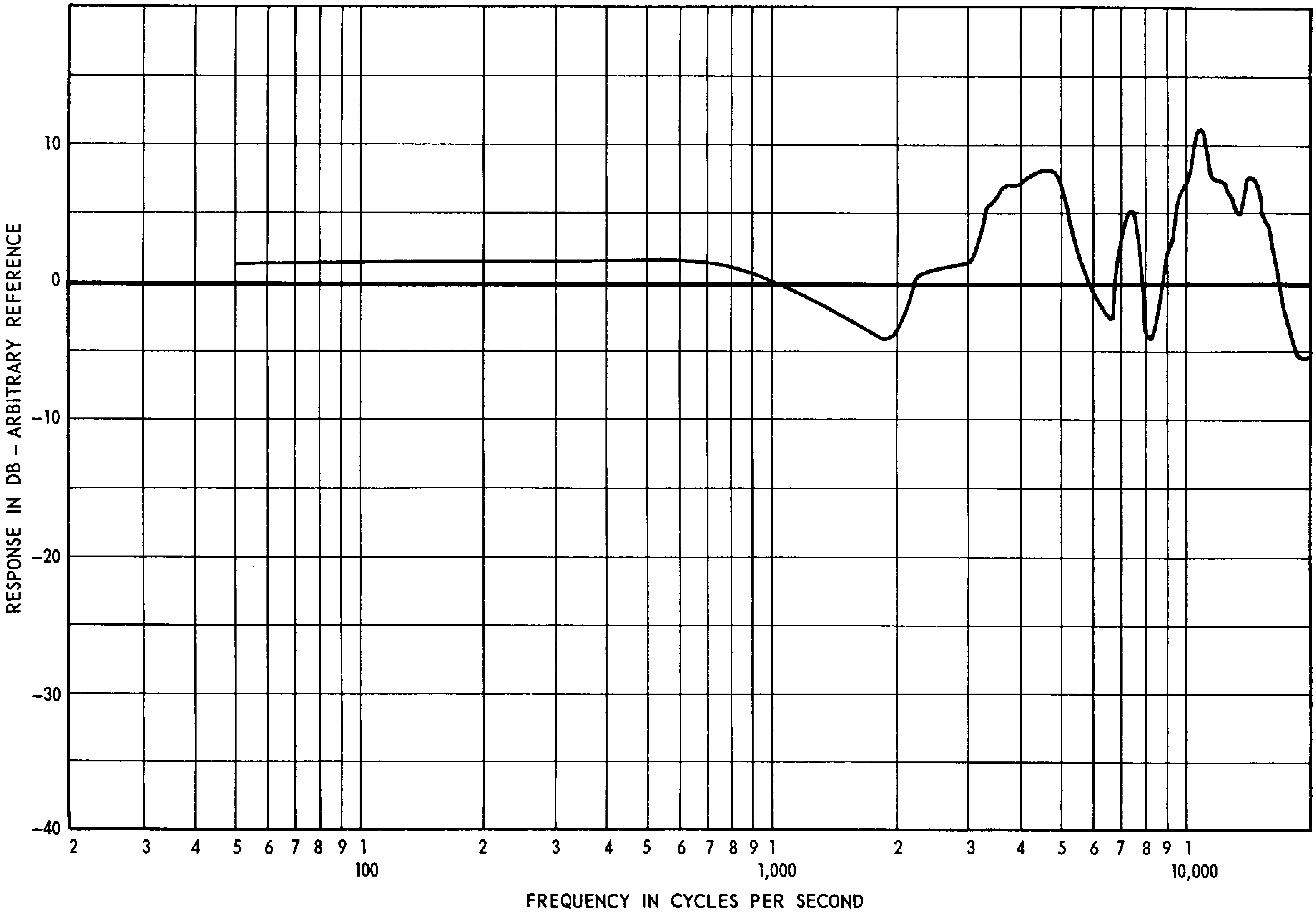

Figure 29. Over-all Response of Experimental Coaxial Arrangement Without Damping

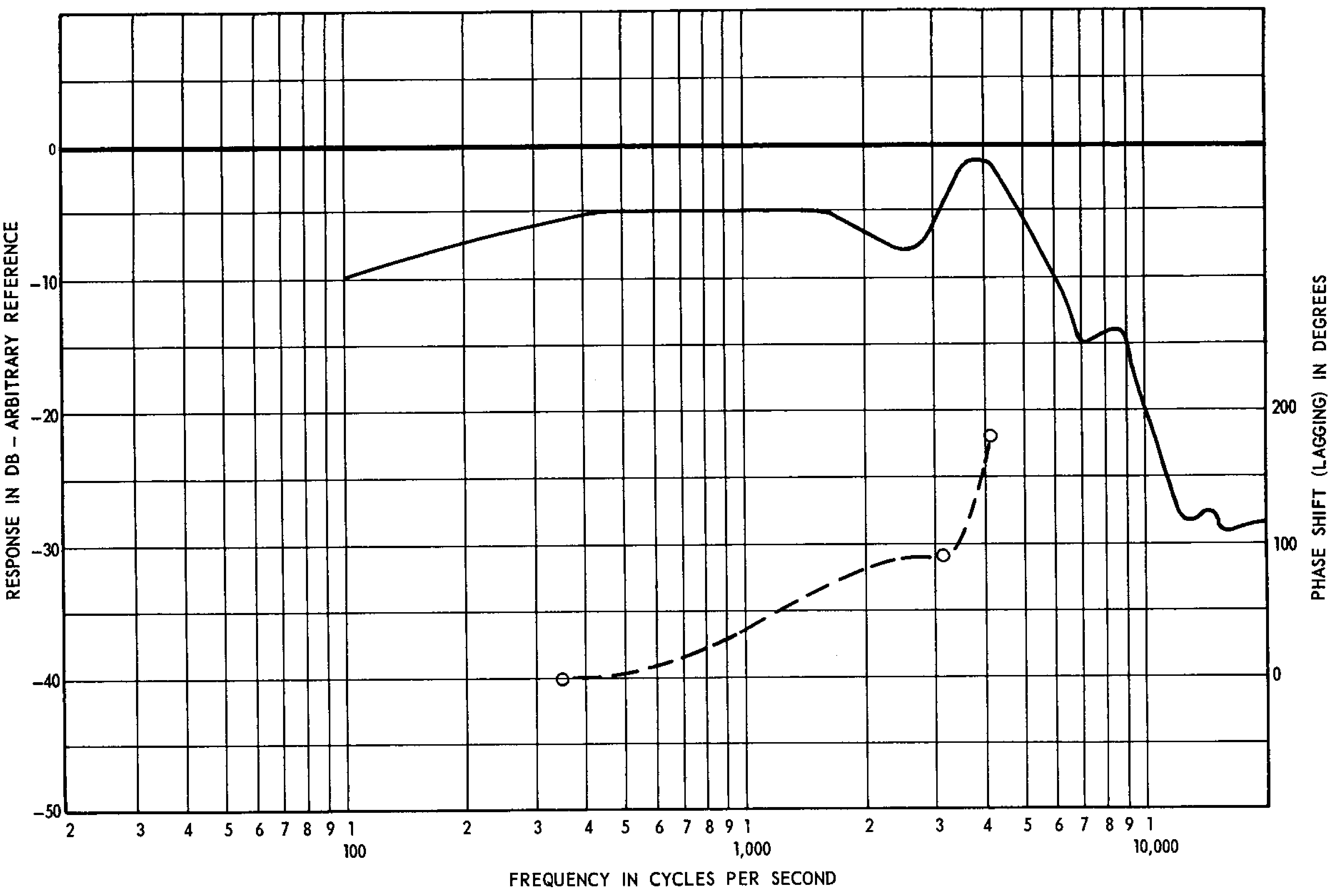

Figure 30. Over-all Characteristics for Experimental Coaxial Transducer Arrangement With Damping

V. DISCUSSION

Improvement in the noise reduction attained by active ear defenders has proved a more difficult problem than anticipated. It is difficult to fully appreciate the very large range over which response must be controlled in order to obtain desired phase characteristics. Measurements needed to study characteristics such as microphone phase shift are not readily made. The elements which introduce excess phase shift are not well known.

Nevertheless, significant noise reduction by electronic means has been demonstrated and the frequency range over which an active ear defender is effective can certainly be increased with additional effort. Technically, it would seem desirable to pursue the goal of improved performance. An active ear defender with substantially improved performance should be a useful laboratory tool in studies of limits of hearing by bone conduction and the manner in which ear protectors are, or fail to be, additive when used simultaneously. For general use, an active ear defender must compete economically with the very effective passive devices which are presently available.

VI. SUMMARY AND CONCLUSIONS

1. A laboratory model active ear defender providing approximately 15 db of noise reduction from 100 to 200 cps was constructed.

2. A miniature piezoelectric (lead zirconium titanate) microphone for use either under an earcushion or in an insert or semi-insert arrangement was developed. The microphone is 0.550 inch in diameter and 0.165 inch thick with a sensitivity of approximately -70 db re 1 volt/dyne/cm^2.

3. The transducers for an insert or semi-insert type of active ear defender were constructed. Their over-all characteristics indicate that 20 db of noise reduction from 100 to 400 cps should be attainable with this arrangement.

4. An experimental transducer arrangement similar to that of the model in (1) above indicated that 20 db noise reduction from 100 to 300 cps should be attainable with this arrangement.

5. In order to obtain substantially more noise reduction or noise reduction over a wider band extension of the microphone, response to a greater bandwidth is necessary. Very wideband amplifiers will also be required.

6. The use of the active ear defender in conjunction with a communication system appears feasible. A substantial increase in the amount of noise reduction or increased noise reduction over a wider range would probably reduce the effect of ambient noise or intelligibility.

BIBLIOGRAPHY

1. W. F. Meeker, "Active Ear Defender Systems: Component Considerations and Theory", Wright Air Development Center Technical Report 57-368 (I), 1958.

2. H. F. Olson and E. G. May, "Electronic Sound Absorber". Journal Acoustical Society of America, Vol. 25, November, 1953, P. 1130.

3. J. P. Dolch "An Investigation of Some Phase and Intensity Relationships in the Interference of Bone and Air-Conducted Sound" (Supplementary Report No. 2, U. S. Signal Corps, Contract DA-039-sc-42562, 1953).

4. E. D. Simshauser and M. E. Hawley, "The Noise-Cancelling Headset - An Active Ear Defender", Journal Acoustical Society of America, Vol. 27, January, 1955, P. 207 (Abstract).

5. M. E. Hawley, "Acoustic Interference for Noise Control", Noise Control, Vol. 2, March, 1956, P. 61.

6. E. D. Simshauser, W. F. Meeker and A. V. Balakrishnan, "The Noise-Cancelling Headset - An Active Ear Defender", Journal Acoustical Society of America, Vol. 28, July, 1956, P. 773 (Abstract).

7. H. W. Bode, Network Analysis and Feedback Amplifier Design (D. Van Nostrand Co. Inc., New York, 1945).

8. H. E. Von Gierke and D. R. Warren, "Protection of the Ear from Noise: Limiting Factors" (Chap. VII, Benox Report, Univ. of Chicago, 1 December, 1953).

9. E. A. G. Shaw and G. J. Thiessen, "An Improved Ear Defender Cushion" (National Research Council of Canada, Report No. PS-342, 21 July, 1954).