November 3, 1972

REPORT No. 20022-1

ZWISLOCKI COUPLER EVALUATION

with

INSERT EARPHONES

by
R. M. Sachs and M. D. Burkhard

PROJECT 20022

FOR
KNOWLES ELECTRONICS, INC.
2100 N. MANNHEIM ROAD
FRANKLIN PARK, ILLINOIS 60131

INDUSTRIAL RESEARCH PRODUCTS, INC.
Elk Grove Village, Illinois 60007

TABLE OF CONTENTS

F I G U R E S

F I G U R E S

1. INTRODUCTION

This report discusses the fabrication and acoustical evaluation of the Zwislocki Insert Earphone Coupler (Zwislocki, 1970, 1971). The evaluation is based on the use of insert and "button" type earphones used with a standard earmold. While the entire coupler can be used for calibration of circum- and supra-aural earphones, this application was not within the scope of the study. The coupler has been proposed for calibration of either vented or "high-frequency emphasis" earmolds (open canal earmolds). The evaluation for this mode of operation will be the subject of another report.

The Zwislocki coupler was designed to approximate for earphone calibration purposes the dimensional and acoustic characteristics of the average human ear. As such, the coupler has a simplified concha and ear canal. The concha and part of the ear canal can be removed leaving a bottom portion (the insert earphone coupler) which simulates the ear canal between an earmold tip and eardrum (Fig. 1). The eardrum impedance is simulated by four "resonator" branches, designated R1, R2, R3, and R4. Each branch consists of a tube leading from the "canal" to a cavity and three of them contain combinations of Feltmetal* discs and spacer washers to increase damping. A 1/2" condenser microphone** is threaded into the bottom of the coupler to sense pressure at the effective eardrum.

The report begins with a discussion of the coupler fabrication. Next, a comparison of the Zwislocki coupler, a sample of 11 human ears, and the 2cc coupler is made using the criteria of insert earphone pressure response. Then, an evaluation is presented in terms of "eardrum" impedance and earphone response variability.

In addition to an evaluation of the Zwislocki coupler, several modifications in design are suggested, including increase of resistance in one branch and incorporation of a capillary tube for static pressure release. In an effort to reduce earphone response variability, a recommendation is given to specify measured branch resistance values rather than combinations of sintered metal discs and spacer washers for use in the branch cavities. The effect of deviations from preferred resistance values on earphone response is given, and a simple method is described to measure acoustic resistance of the coupler branches _in situ_.

2. COUPLER CONSTRUCTION

2.1 General Considerations

Six Zwislocki couplers were fabricated of brass using the construction drawing from Zwislocki (1971, p. 40). Required tooling included special drills for each branch and various punches for the sintered metal disc and washer assemblies used in branches R2, R3, and R4. The coupler body was machined into the form of a rectangular block. This shape provided well defined reference planes for further machine operations. All critical dimensions were held to within ±0.001" as specified by Zwislocki (1971). The drawings were quite complete, with the exception noted in the next paragraph.

---

*Feltmetal, a brand of sintered metal, is a trademark of Huyck Corporation, Milford, Conn.

**Bruel & Kjaer Model 4134

2.2 Damping Disc Assemblies

Branches R2, R3, and R4 employ combinations of sintered metal discs and branch cavity entrance holes. No diameters of the discs were given in the construction drawing (Zwislocki, 1971), the only instruction being, "Press into place and avoid compressing Feltmetal discs". The original punched discs, as fabricated for this evaluation, were several thousandths of an inch undersized relative to the cavity diameters, to avoid compressing the discs in a loading operation. However, Mr. Klock of Zwislocki's laboratory indicated it was their intent that the discs be slightly oversized. Suitable disc diameter size relative to cavity diameter is +0.0005, -0.0000". These discs were punched and then inserted in their cavities with a piece of plastic tubing, pressure being applied only along the edges of the discs.

2.3 Tooling Variations

If the coupler is to be duplicated in individual laboratories, attention should be given to tooling requirements. Inherent tooling precision limits provide a source of uncontrolled coupler dimensional variation.

3. ACOUSTICAL EVALUATION

3.1 Coupler - Real Ear Earphone Response

Sound pressure measured in 11 human ears and converted to eardrum pressure was compared to that measured in a 2cc coupler cavity (ANSI S3.3-1960) and the Zwislocki insert earphone coupler under identical excitation conditions. The results of these measurements (Sachs and Burkhard, 1971) are summarized in Fig. 2. While the earphone response using the 2cc coupler differs noticeably from that in the real ear, the response using the Zwislocki coupler matches the mean response of ears within 2 dB up to 7.0 KHz. The Zwislocki coupler, as originally constructed, produced a response curve with some irregularity in the 600 to 1000 Hz region. This irregularity resulted from low acoustic resistance in branch R1. When the resistance was increased, as will be discussed in section 4.2, there was closer agreement between ear and coupler responses in this frequency range.

3.2 Coupler - Real Ear Impedance

A Zwislocki acoustic bridge was used to evaluate the "eardrum" impedance of one of the six Zwislocki couplers (XD-960-S1). Figs. 3 and 4 show impedance measurements for this coupler and a coupler constructed in Zwislocki's laboratory (LSC-MKV), and the median eardrum impedance of 22 subjects, 10 male and 12 female (Zwislocki, 1971, pp. 13-15). All measurements were performed in the laboratory of Sensory Communication on the same acoustic bridge. Coupler XD-960-S1 was made with slightly undersized damping discs in branch R2, R3 and R4, to avoid compressing these discs during the loading operation. The impedance of this first attempt at coupler duplication is shown as squares and the impedance of the same coupler loaded with the preferred oversized discs as triangles. The principal effects of increasing disc diameter are: (1) an increase in resistance at most frequencies (Fig. 4) and (2) a decrease in the frequency of zero reactance from 4700 Hz to 4200 Hz (Fig. 3). Note that the LSC-MKV coupler exhibits zero reactance at an even lower frequency (3700 Hz) and the real ear median crosses at a lower frequency still (3000 Hz). A match of the frequency of zero reactance between coupler and ear is considered by Prof. Zwislocki to be an important parameter for coupler acceptability. At 2500 Hz and below the reactance of the couplers XD-960-S1 and LSC-MKV match the ear reactance equally well.

3.3 Earphone Response Sensitivity to Disc Placement

Using a single insert earphone, response repeatability was examined on a second coupler, XD-960-S2. Repeatability was tested by replacing the Feltmetal material in branches R2, R3, and R4 with new discs. The range of responses encountered is indicated in Fig. 5. There is a 2 dB spread in response around 1200 Hz and around 4 KHz. Above 5 KHz, where the earphone response is no longer controlled by the impedance of the side branches, the variations are much smaller.

By subsequently varying and measuring the resistance in the branches, it was inferred that the spread of earphone response in the 1.2 and 4 KHz regions was a result of resistance variations in branches R2, R3, and R4. Specifically, the variations were attributed to disc location uncertainty in the cavities and/or lack of resistance uniformity in the Feltmetal material.

4. MODIFICATIONS

4.1 General Construction

It is recommended that the outside surface of the coupler body be machined into the form of a rectangular block before branch cavities are drilled. This shape, shown by dashed lines in Fig. 1, provides well defined reference planes for further machining operations, in addition to leaving more threads in the branch cavities of the coupler body in which the branch screw plugs are inserted. Acoustical performance is unaffected by this modification.

4.2 Branch R1 Damping Change

It is recommended that the damping in Branch R1 be increased by narrowing and shortening the entrance tube. Fig. 6 shows the revised design. The portion of the R1 entrance tube contained in the main coupler body remains unaltered. With this change, the original design value of 750 cgs acoustic ohms is increased to about 1200 ohms. Comparison of pressure response measurements, on a number of real ears and the Zwislocki coupler, demonstrated that the larger resistance is required for a better match. Fig. 2 shows the effect on earphone response of modifying branch R1.

4.3 Pressure Equalization and Earmold Leak

The Zwislocki insert earphone coupler, as designed, does not provide for static pressure equalization. It is recommended that the coupler body incorporate a high resistance leak using the technique described in ANSI-Z24.9-1949. A 0.024" diameter hole should be drilled along a diagonal of the recommended rectangular shaped body resulting in a hole 0.4" long (see Fig. 1). A 0.020" bent wire should be inserted into this hole. Because of extreme variability in earmold fit, it is recommended that an intentional acoustic leak to simulate the leak between an insert earmold and the human ear canal, should not be incorporated. Rather, the coupler should simulate the conditions of the best (i.e., "perfect") acoustic fit in earmolds. Any desired leak may then be introduced to study the effect of such a leak.

4.4 Branch Hole Centering

The original design (Zwislocki, 1971) specified branch holes located off-center relative to the branch cavities axes to keep these holes as close to the 1/2" microphone diaphragm as practical. From discussions with Prof. Zwislocki, it was concluded that a coupler employing branch holes that are centered on the axis of each branch cavity would simplify and improve uniformity in machining operations and, at the same time, might not alter the acoustic characteristics. Some evaluation of this alternative design has been carried out, but more data are needed before it can be specified.

4.5 Acoustic Resistance Specification

Since much of the earphone response variability is due to variations in branch resistances, it is desirable to specify preferred resistance values in the finished coupler rather than simply the number of discs and washers required. Such a specification would enable any laboratory to use whatever branch or type of damping element that would yield these resistances (assuming, of course, that the total branch inertance and compliance are not altered).

It should be recalled that the design parameters were tentatively derived from an electrical network analog (Zwislocki, 1971, p. 72). The final specification of discs and washers was empirically adjusted to provide a "best fit" to eardrum impedance and ear canal pressure distribution. The following table lists resistance values for each branch. These values, as measured on coupler XD-960-S2, were chosen so that the coupler gave a best match to the mean human ear as judged by earphone response measurements.

Branch		Resistance
R1	Original	750 ohms
	Modified	1200 ohms
R2		650 ohms
R3		970 ohms
R4		340 ohms

The effect on response of varying the branch resistance around their preferred value was studied with an electric analog. The reason for investigating this resistance variation follows from observations in Figs. 7 through 10. They show the effect of changing the damping disc and washer combinations in branches R1 through R4, respectively. As an example, when the R2 branch resistance (Fig. 8) is changed according to the disc and washer loading shown, the greatest change in the earphone response curve occurs at frequencies below the resonance frequency f_0. No discs in branch R2 produces curve B with a response deviation of -2.6 dB at 1400 Hz, showing the effect of too little resistance. Two discs and one washer in R2, as in curve C, produces a maximum deviation of about +0.7 dB at 1200 Hz, showing the effect of too much resistance. The maximum deviation in earphone response from nominal value (regardless of frequency) was measured in a network analog (Fig. 11).

It can be seen that the accuracy of the earphone response is directly related to the precision of the resistance in the branches. For example, Fig. 11 shows that a 20% deviation in the resistance of branch R2 causes as much as a 0.4 dB change in earphone response. Accurate branch resistance of the material, as well as the size, location, and shape of the discs should be well controlled. When Feltmetal discs were replaced with new ones in branch R2 (the only criterion being the proper number of discs and washers), resistance was sometimes as much as two times the nominal (650 ohms) value.

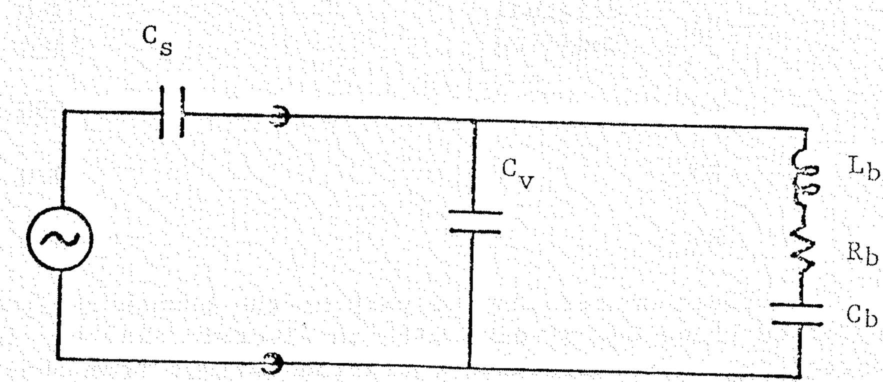
A means for deciding if the coupler is damped correctly within predetermined tolerance limits for earphone response is desirable. The plots of response variation vs. branch resistance in Fig. 11, together with the technique of measuring branch acoustic resistance *in situ*, given in section 5, provide the basis for determining the resistance characteristics of the coupler quantitatively.

4.6 Earphone Adapters for Zwislocki Coupler

A set of four adapters that are threaded on to the Zwislocki insert earphone coupler were designed and constructed. These adapters are for use with button type and regular insert type earphones, or with regular earmolds, and simulate HA-1, HA-2, and HA-3 type connections. Drawings for these adapters, designated XD-951, 952, 953 and 961, are given in Figs. 12 through 15.

5. ACOUSTIC RESISTANCE MEASUREMENT

Several methods exist for measuring the amount of resistance in each branch. One method is given below, based on the following low frequency analog of the central or main cavity and one branch of the coupler:



An earphone with low effective compliance and good low frequency response is used to excite the coupler. C_v and C_s are the low frequency compliance of the main coupler cavity and the earphone, respectively, R_b is the branch resistance, L_b is the branch inertance, and C_b is the branch compliance. Two measurements are performed for each branch:

Measurement #1:

Seal off all four resonators from the main cavity and produce a response curve.

Measurement #2:

Seal off all resonators except the branch "b". Remove the screw-on cap making $C_b = \infty$ and exposing the branch resistance, R_b, and the inertance, L_b, to the atmosphere. The Feltmetal disc assembly must still be held in its normal position. Record a second response curve on the same chart paper.

The two response curves cross at a frequency, f_1, independent of resistance, given by

$$f_1 = \frac{1}{2\pi\sqrt{2C_vL_b}}$$

The maximum difference, DB_{max}, at a frequency above f_1 is noted which is simply related to $2\pi f_1 R_b C_v$. For convenience, the conversion function is plotted in Fig. 16. R_b can then be computed from the values read from Fig. 16, and the value C_v computed from cavity dimensions.

An example of the measurement is shown in Fig. 17, for branch R2, using three combinations of "Feltmetal" discs. All curves pass through the common frequency f_1 = 550 Hz. Calculation of branch resistance for the three conditions and C_v corresponding to 0.47 cc is as follows:

Curve	DB_{max}	$2\pi f_1 R_b C_v$	R_b
B	1.9	1.1	950 ohms
C	4.5	0.56	480 ohms
D	8.0	0.31	270 ohms

An easy method of sealing off the resonators is to insert a thin sleeve into the cavity whose outside diameter closely matches inside diameter of the main coupler cavity. Fig. 18 shows a design for the sleeve. A large notch on one end enables the sleeve to be placed so that any one branch entrance hole is exposed for measurement #2 by rotating the sleeve. If the sleeve is replaced up side down in the coupler, all branches are sealed for measurement #1. With the sleeve in place, the net volume for the main cavity is 0.47 cc. This technique of sealing off branches enables each branch Feltmetal disc assembly resistance to be evaluated "in situ" and to remain untouched after the measurement is completed.

At first glance, one would think that L_b, the branch inertance, can also be obtained from this method knowing f_1 and C_v. A word of caution: The L_b so measured includes the inertance produced by the open ended branch cavity. This extra inertance can be quite significant; in fact, it is about equal to the normal branch inertance in the fourth branch.

6. SUMMARY

Six Zwislocki earphone couplers were fabricated according to the construction drawing in Zwislocki (1971). After some initial experimentation and discussion with Prof. Zwislocki, it was determined that the damping disc diameters in three of the four coupler branch elements should be slightly oversized compared to the cavity diameters in which they are inserted to provide an interference fit without disc deformation. An evaluation of the coupler's acoustic "eardrum" impedance showed it was in fair agreement with published impedance curves (Zwislocki, 1971, pp. 13-15). The insert earphone response on the Zwislocki coupler agreed with that on the mean (N = 11) human ear within ±2 dB up to 7 KHz. Earphone response variability depends critically on the damping constants of the coupling branches. This variation is approximately 2 dB (total spread) in the vicinity of 1200 Hz and 4000 Hz. This degree of uncertainty may be acceptable in areas of research where a device that simulates the ear is needed. The variability, however, is larger than would be acceptable for an acoustical standard.

Several minor modifications appear to be desirable. First, the damping should be increased in branch R1 to obtain earphone responses on the coupler which more closely match those on the average human ear. This change will have relatively small effect on the complete coupler's performance for supra- and circum-aural and other full ear earphone calibrations. Second, it is recommended that a high resistance static pressure equalization "leak" be employed in the coupler body.

If the uncertainty of earphone response determination is to be reduced below the range of 2 dB, actual branch resistance values need to be measured and adjusted *in situ*. A parametric study of resistance changes in a circuit analog of the Zwislocki coupler showed that a 20% change in one branch resistance could cause as much as a 0.4 dB change in earphone response. Acoustic resistance of each branch *in situ* can be measured with response plotting instruments.

7. ACKNOWLEDGMENT

Professor Jozef Zwislocki and Mr. Bernard Klock of the Laboratory of Sensory Communication have provided much assistance and consultation during the evaluation reported here. Some of the data in Figs. 3 and 4 were taken at the laboratory specifically for the study. This contribution is gratefully acknowledged.

REFERENCES

ANSI "Methods for Measurement of Electroacoustical Characteristics of Hearing Aids" S3.3-1960.

ANSI "American Standard Method for the Coupler Calibration of Earphones" Z24.9-1949.

Sachs, R. M. and Burkhard, M. D. "Earphone Pressure Response in Ears and Couplers" Report No. 20021-2, Industrial Research Products, Inc., June 1971.

Zwislocki, J. J. "An Acoustic Coupler for Earphone Calibration" Report LSC-S-7, Laboratory of Sensory Communication, Syracuse University, Sept. 1970.

Zwislocki, J. J. "An Ear-like Coupler for Earphone Calibration" Report LSC-S-9, Laboratory of Sensory Communication, Syracuse University, April, 1971.

8. APPENDIX: EARPHONE RESPONSE CURVES

Response curves are attached to this report to show the effects of the 2cc and Zwislocki couplers on typical hearing aid type earphones. The earphones shown are as follows:

Knowles Electronics BK-1615	Figs. A-2, A-3
Knowles Electronics BP-1712	Figs. A-4, A-5
Audivox 9-C	Figs. A-6, A-7
Oticon CF-D-8	Figs. A-8, A-9

All earphones were driven by both constant current and constant voltage. Each earphone was attached to the coupler cavities in two of three ways, as shown in Fig. A-1. The condition where the earphone was connected directly to the cavity with no intervening tube is designated HA-3, 0 mm, and this condition was used with all earphones. The button type earphone (Audivox 9-C and Oticon CF-D-8) also employed the HA-2 condition, in which an 18mm long x 3mm diameter tube is inserted between earphone and cavity. Finally, the insert earphones (Knowles Electronics BK-1615 and BP-1712) were connected to the coupler cavity by a series of three tubes: HA-2 plus 25mm of 2mm diameter plus 32mm of 1.5mm diameter. In this last method of attachment, the effect is shown of adding a damping element (770 cgs acoustic ohms) in the acoustic transmission path, at the junction of the 3mm and 2mm diameter tubes.

In all of these response curves, the increased pressure in the Zwislocki coupler, relative to that in the 2cc coupler, is evident. At low frequencies, the pressure difference is principally due to the total volume difference, the Zwislocki coupler containing 1.2cc. As frequency increases, the effective volume of the Zwislocki coupler decreases, providing a further increase in the pressure difference between the two couplers. Small differences in the frequency and "Q" of resonance peaks also appear when the responses on the two couplers are compared.

Frequency shifts of the response peaks are 2.5% with the BP-1712 on the long tube connection (Fig. A-5) and 8% with the Audivox 9-C on an HA-2 coupler (Fig. A-7). At the frequency of resonance, the impedance of the source (looking into the earphone tube from the coupler) is no longer high relative to the coupler. This peak frequency is determined principally by the source inertance and the series combination of source and coupler compliance. Since the coupler compliance is smaller with the Zwislocki coupler, the resonance frequency will, in general, be higher, as observed.

For the BP-1712 with tube, the Q of the lowest resonance peak is 6.0 on the 2cc coupler and 4.3 on the Zwislocki coupler (Fig. A-5). Similarly reduced Q's are evident in the BK-1615 and Audivox 9-C response curves. The Q of these peaks is inversely proportional to both the total resistance (including the source and series equivalent coupler resistance) and the combined source and coupler compliance. The Q decreases apparent in the responses on the Zwislocki coupler relative to the 2cc coupler are predicted quite well by the added equivalent series resistance and reduction in compliance of the Zwislocki coupler. When the damper is present in the Knowles Electronics earphone tubing (Fig. A-3, A-5), the Q is further reduced as discussed in Knowles Electronics Technical Bulletin E-6.

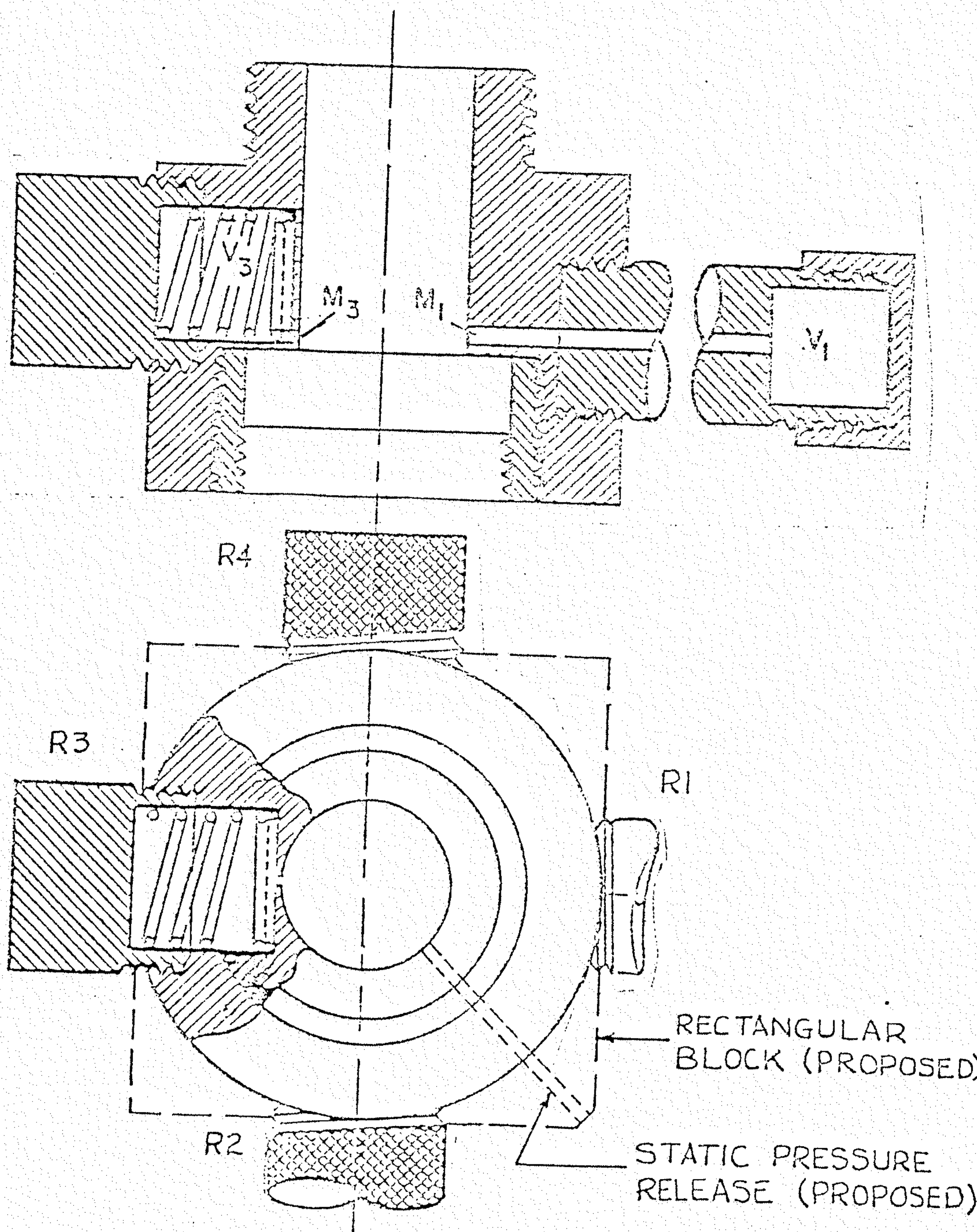
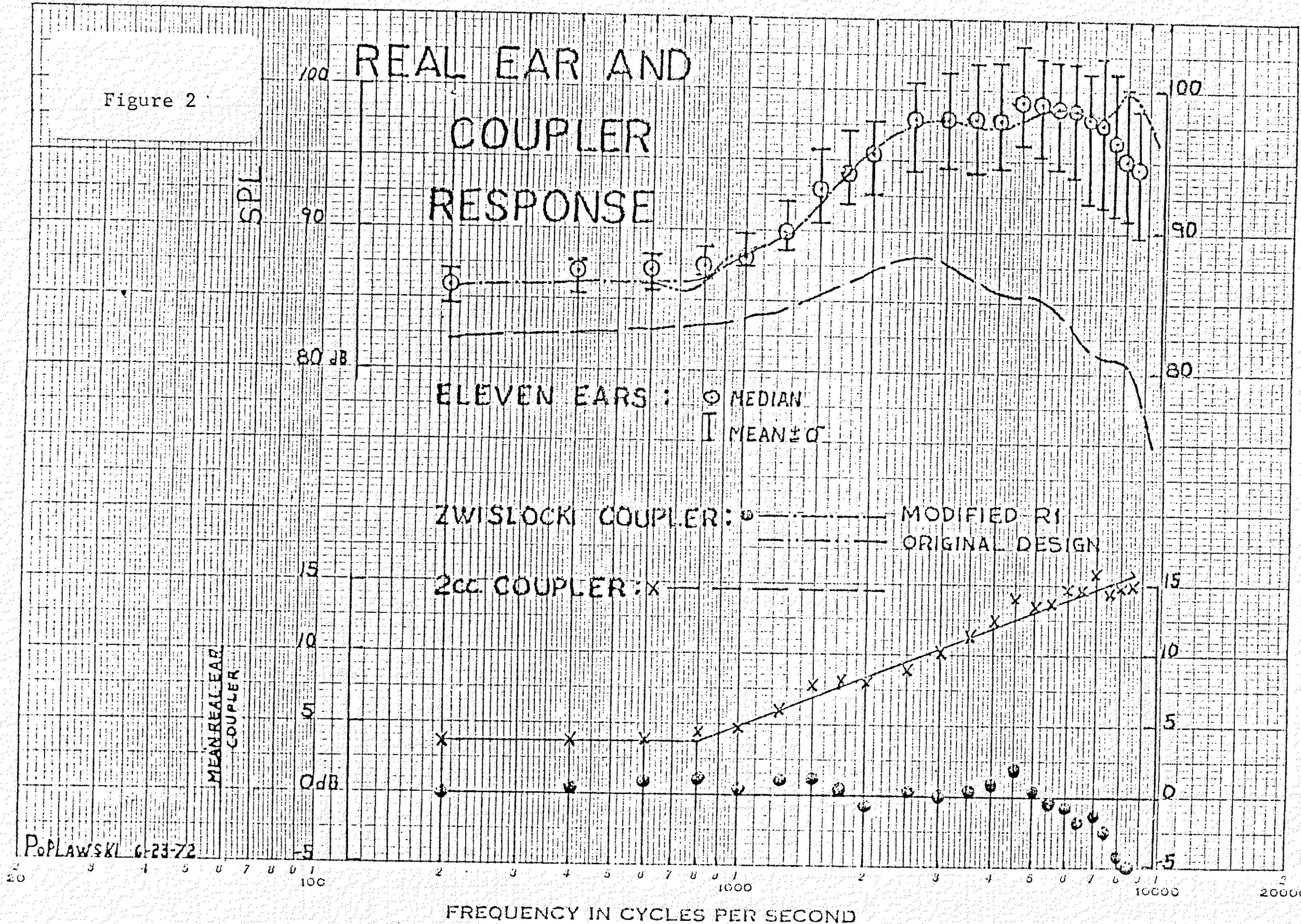
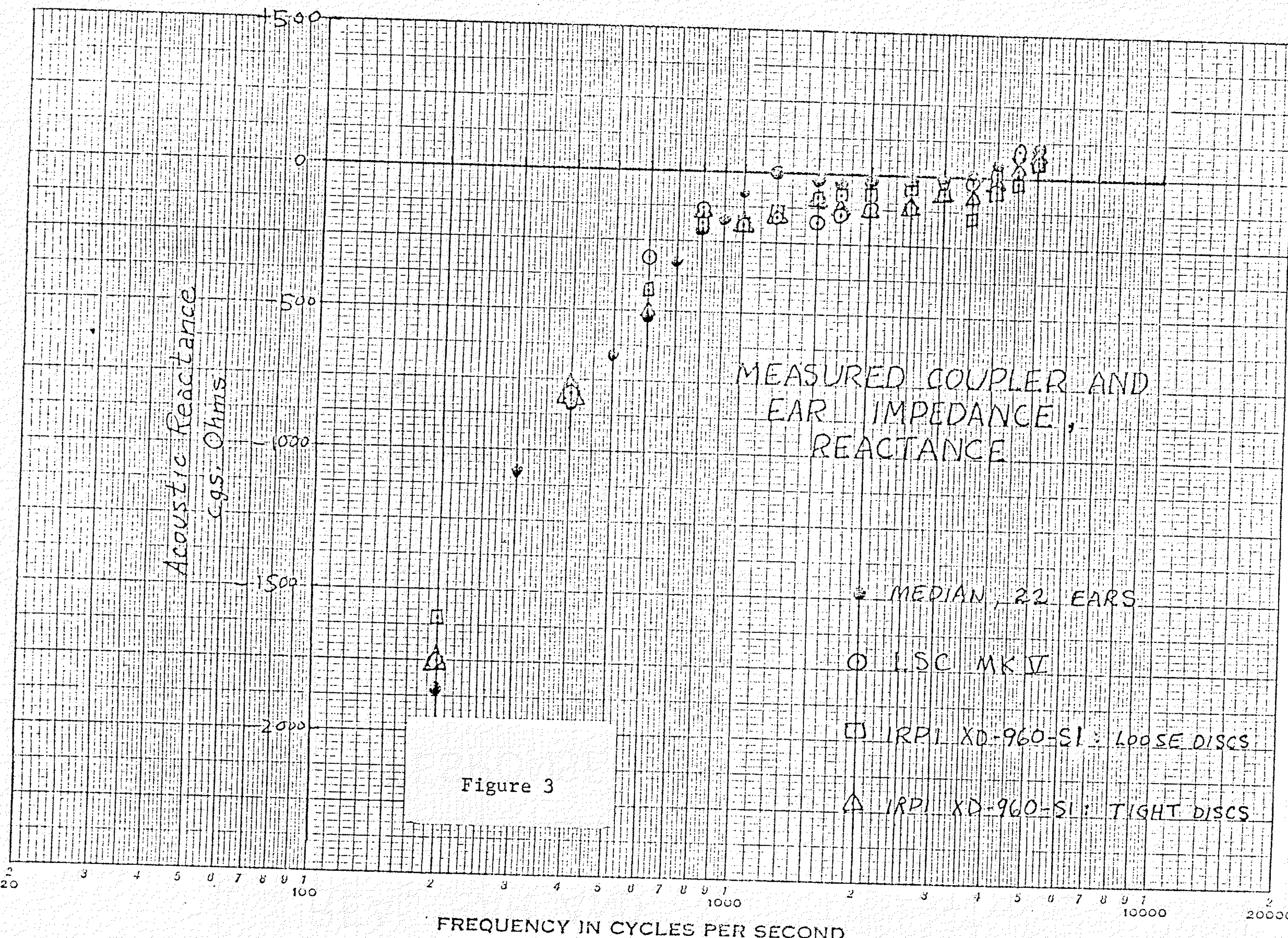


Figure 1 Zwislocki Insert Earphone Coupler

Figure 2



REAL EAR AND
COUPLER
RESPONSE
SPL
100
90
80 dB
ELEVEN EARS : MEDIAN
MEAN ± σ
ZWISLOCKI COUPLER: MODIFIED R1
ORIGINAL DESIGN
2cc COUPLER: X
15
10
5
0 dB
-5
MEAN REAL EAR - COUPLER
POPLAWSKI 6-23-72
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND



+500
0
-500
-1000
-1500
-2000
Acoustic Reactance
c.g.s. Ohms
MEASURED COUPLER AND
EAR IMPEDANCE,
REACTANCE
MEDIAN, 22 EARS
LSC MK V
IRPI XD-960-SI : LOOSE DISCS
IRPI XD-960-SI : TIGHT DISCS
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure 3

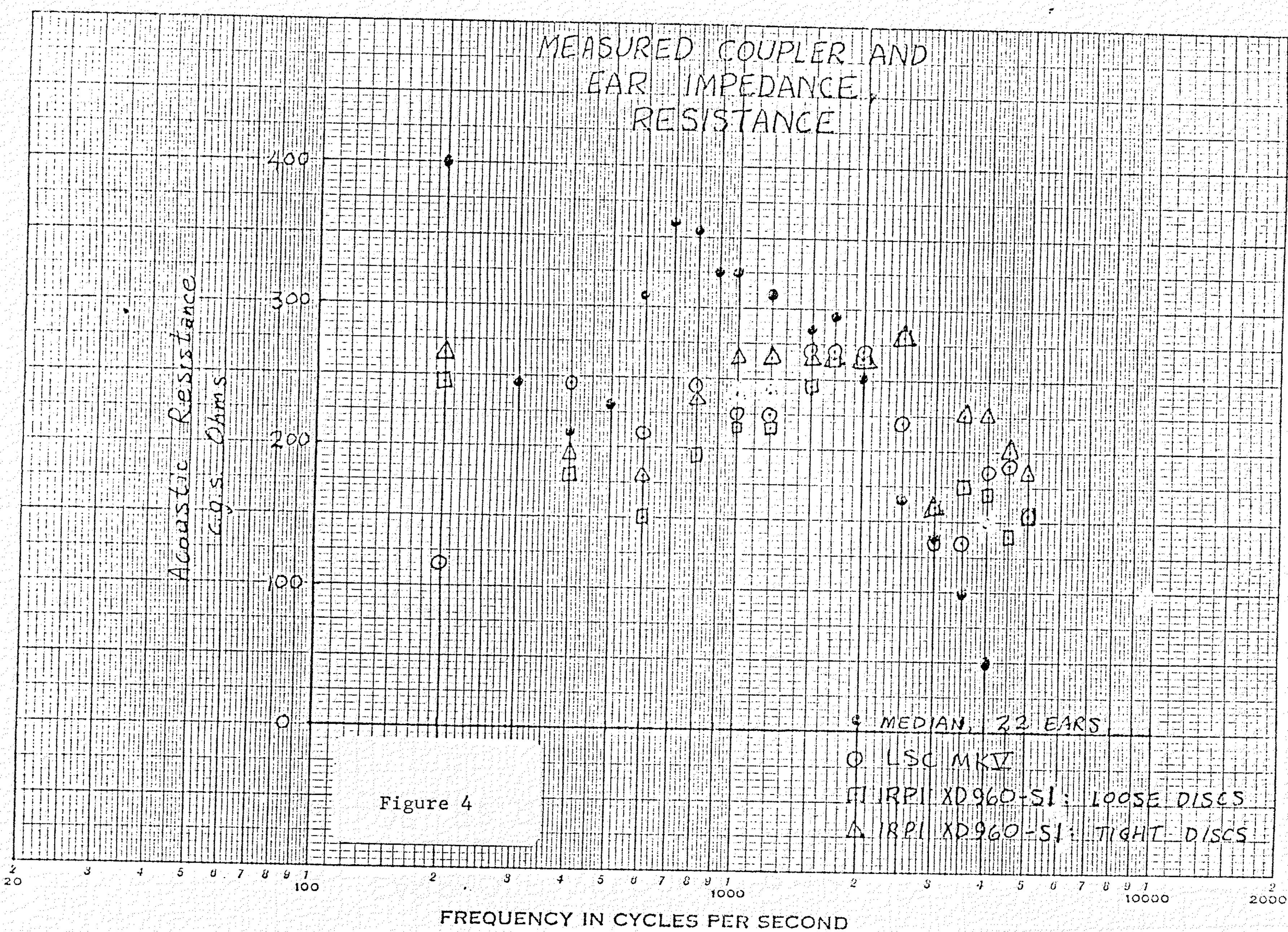

MEASURED COUPLER AND
EAR IMPEDANCE,
RESISTANCE
Acoustic Resistance
c.g.s. Ohms
400
300
200
100
0
MEDIAN, 22 EARS
LSC MKV
IRPI XD960-S1: LOOSE DISCS
IRPI XD960-S1: TIGHT DISCS
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure 4

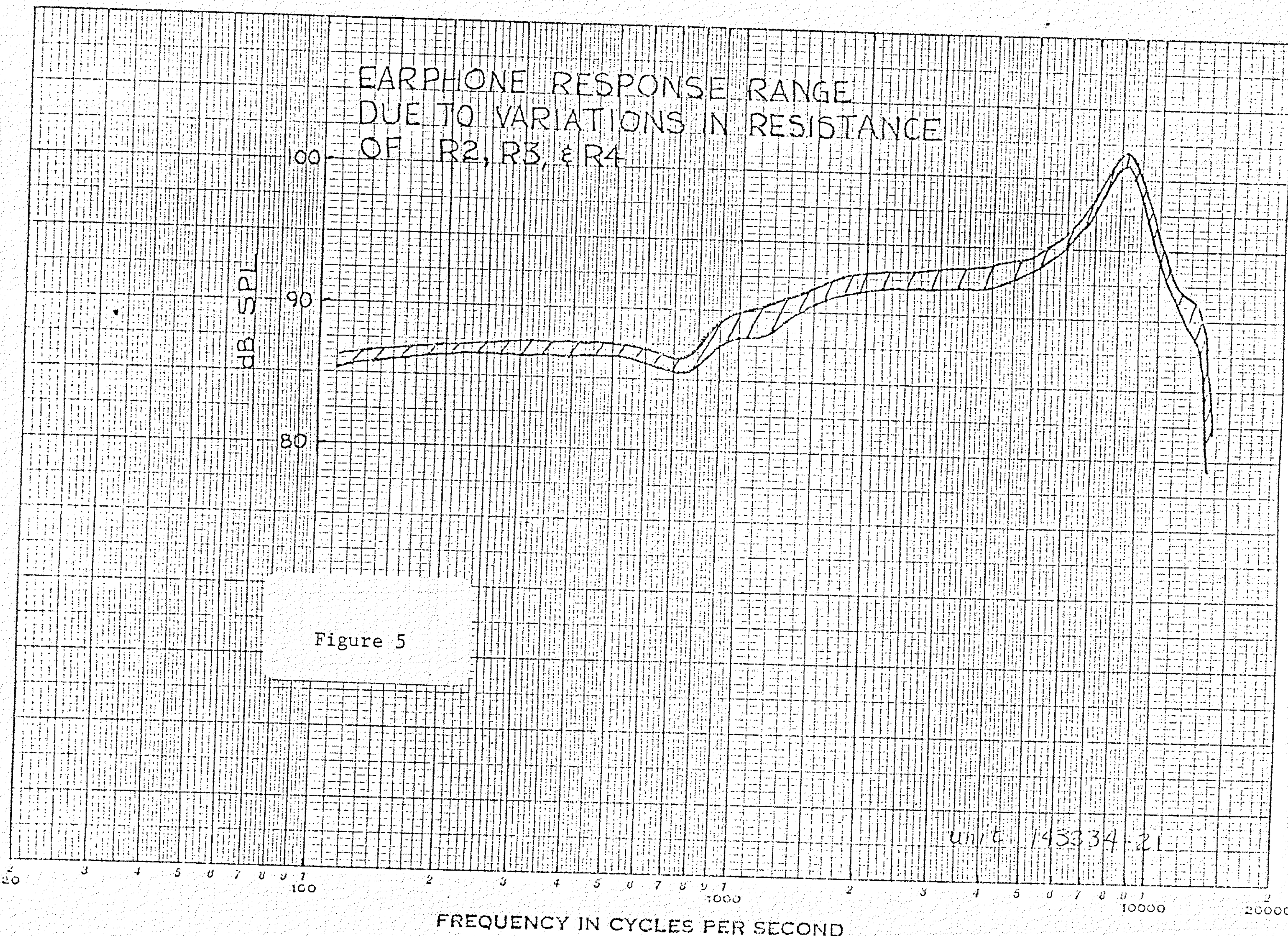
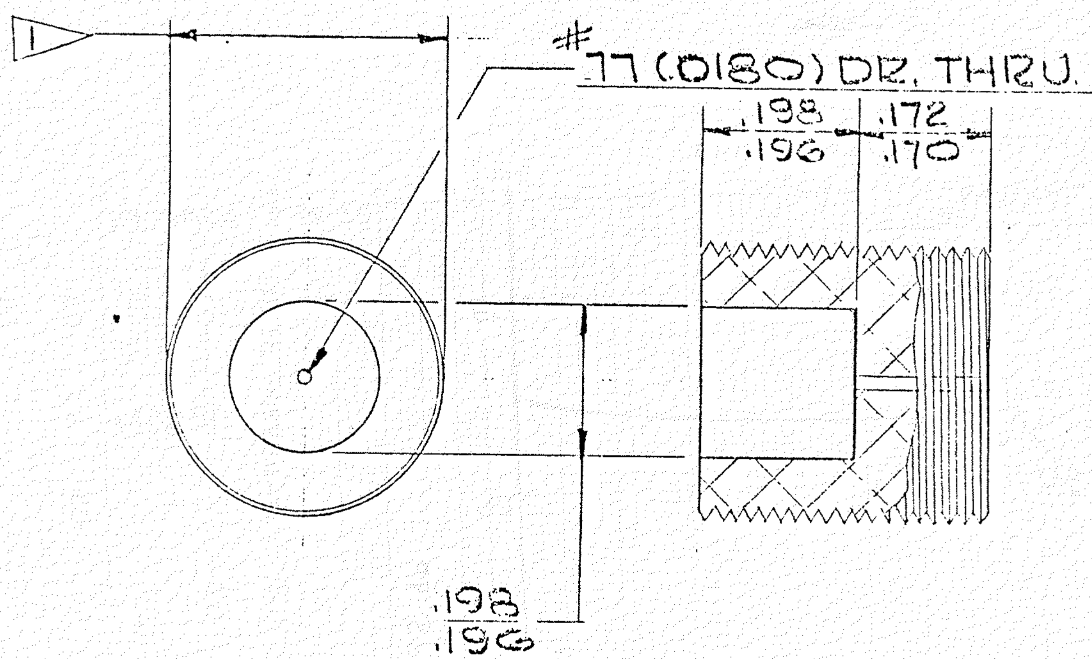

EARPHONE RESPONSE RANGE
DUE TO VARIATIONS IN RESISTANCE
OF R2, R3, & R4
100
90
80
dB SPL
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND
unit 145334-21

Figure 5

XD·960·2-3

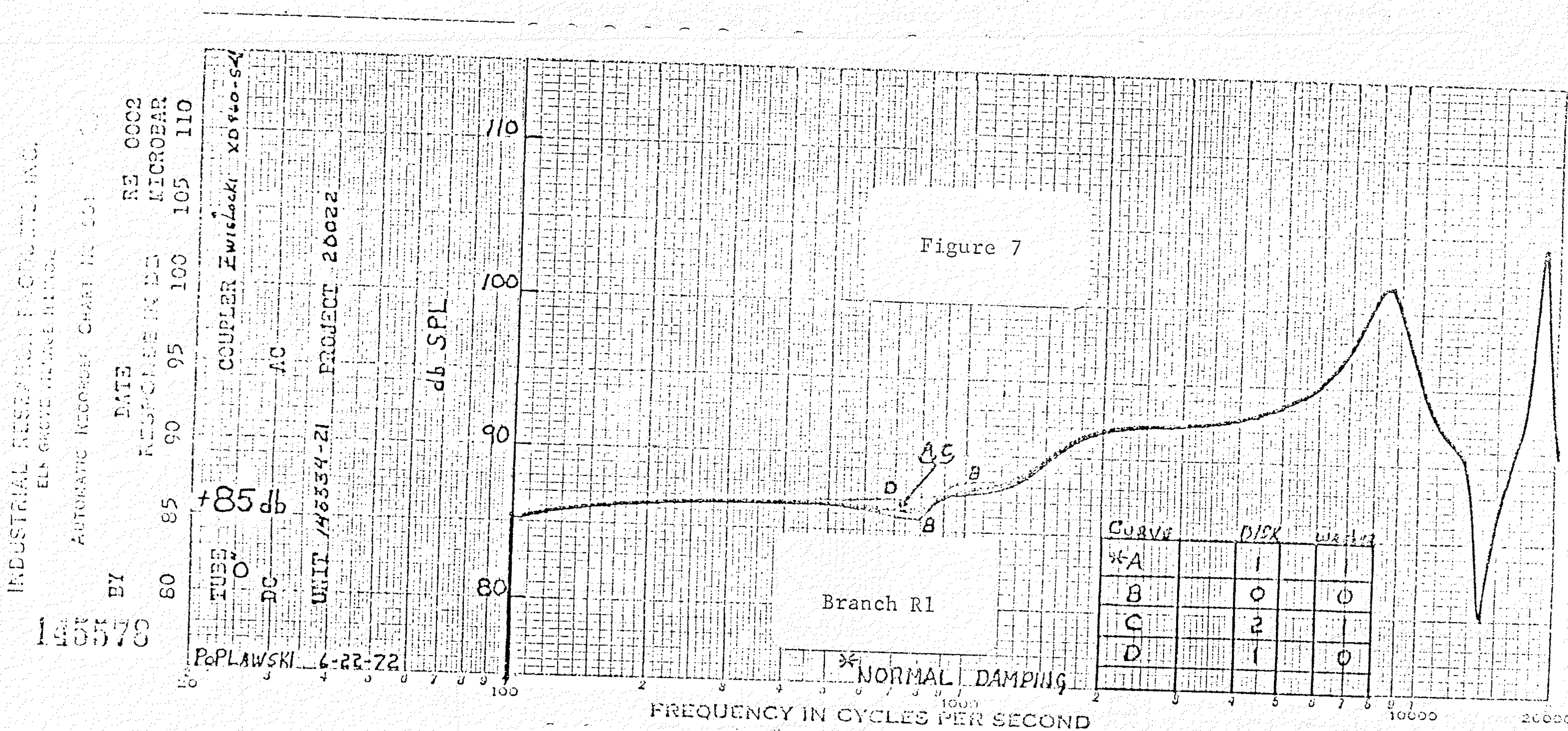


NOTE:

1 BRANCH R1 THREAD TO MATE WITH R1 CAP AND R1 HOLE OF ZWISLOCKI-COUPLER BODY.

CONTRACT OR JOB NO. 20022	SCALE: 4:1	DO NOT SCALE DRAWING	ISSUE
MATERIAL- BRASS		DR. BY JW	DATE 8472
FINISH-		CH. BY	DATE
INDUSTRIAL RESEARCH PRODUCTS, INC. ELK GROVE VILLAGE, ILLINOIS		APP. BY	DATE
TITLE:			

Figure 6


INDUSTRIAL RESEARCH PRODUCTS, INC.
ELK GROVE VILLAGE, ILLINOIS
AUTOMATIC RECORDER CHART NO. 501
BY
DATE
RESPONSE IN DB RE 0002 MICROBAR
80 85 90 95 100 105 110
COUPLER Zwislocki XD940-54
TUBE 0
+85 db
AC
DC
UNIT 146334-21
PROJECT 20022
db SPL
PoPLAWSKI 6-22-72
110
100
90
80
Figure 7
Branch R1
A,C
B
D
Curve
Disk
Washer
*A
1
1
B
0
0
C
2
1
D
1
0
* NORMAL DAMPING
FREQUENCY IN CYCLES PER SECOND
100
1000
10000
20000
155578

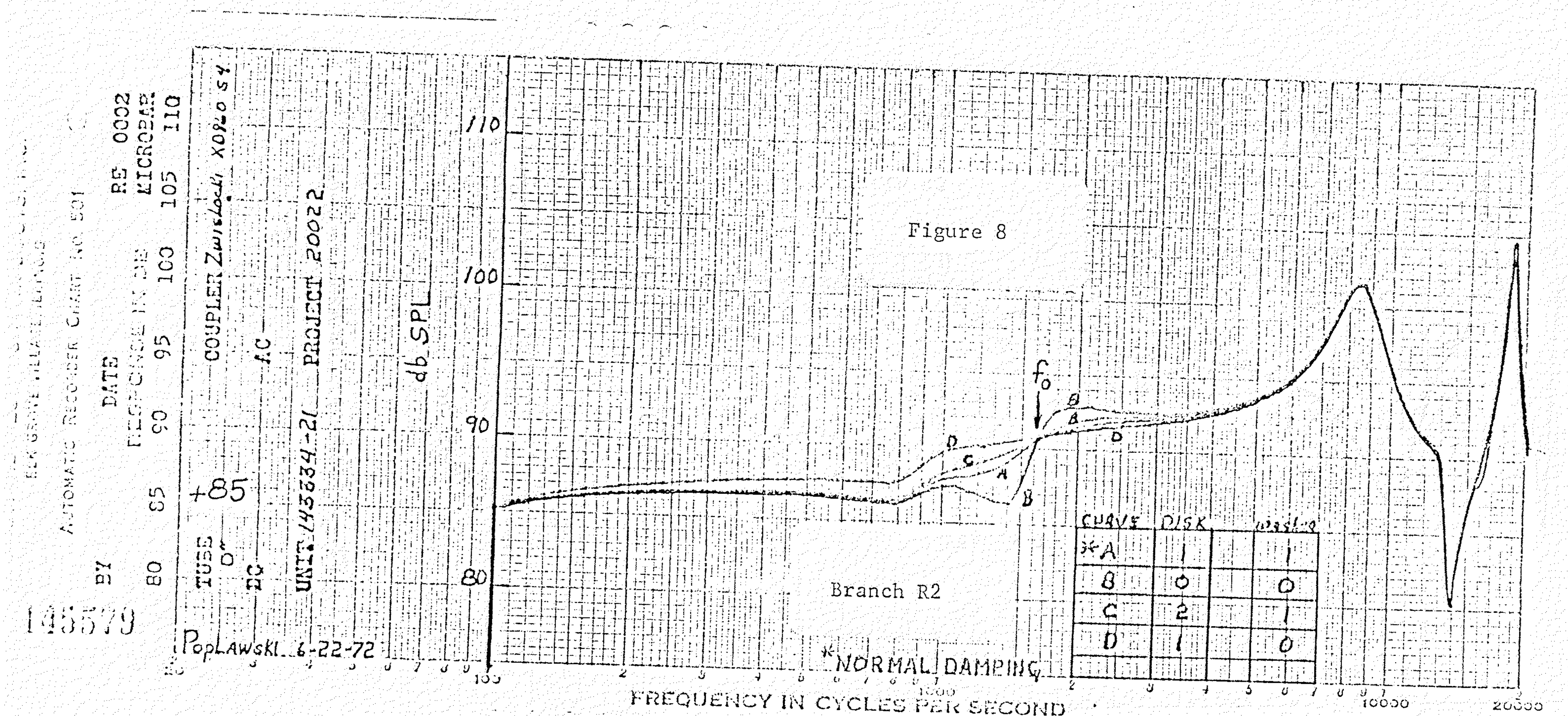
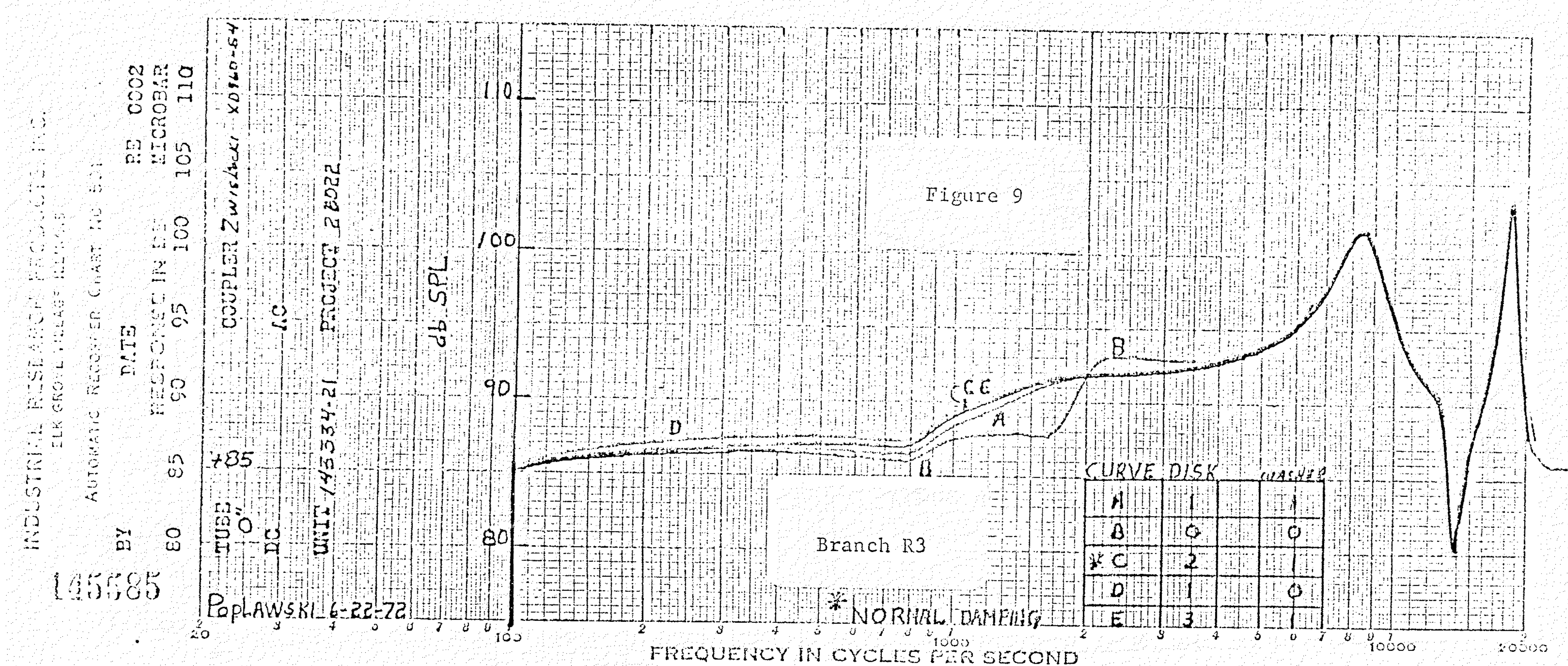
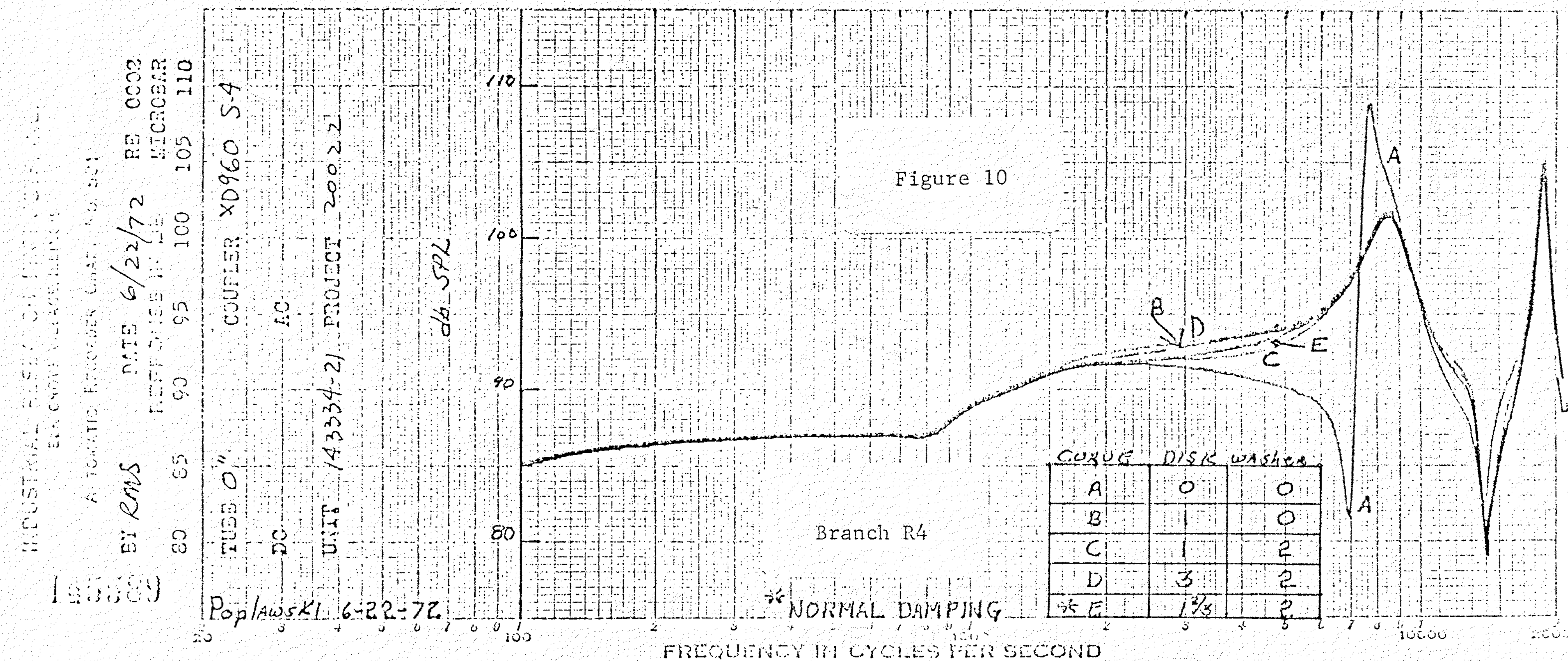


Figure 8
Branch R2
COUPLER Zwislocki X0920 54
UNIT 143534-21 PROJECT 20022
Poplawski 6-22-72
+85
TUBE
AC
DC
db SPL
110
100
90
80
f0
A
B
C
D
CURVE DISK
*A 1 1
B 0 0
C 2 1
D 1 0
*NORMAL DAMPING
FREQUENCY IN CYCLES PER SECOND
1000
10000
20000
RESPONSE IN DB
RE 0002 MICROBAR
DATE
BY
AUTOMATIC RECORDER CHART NO. 501
145579

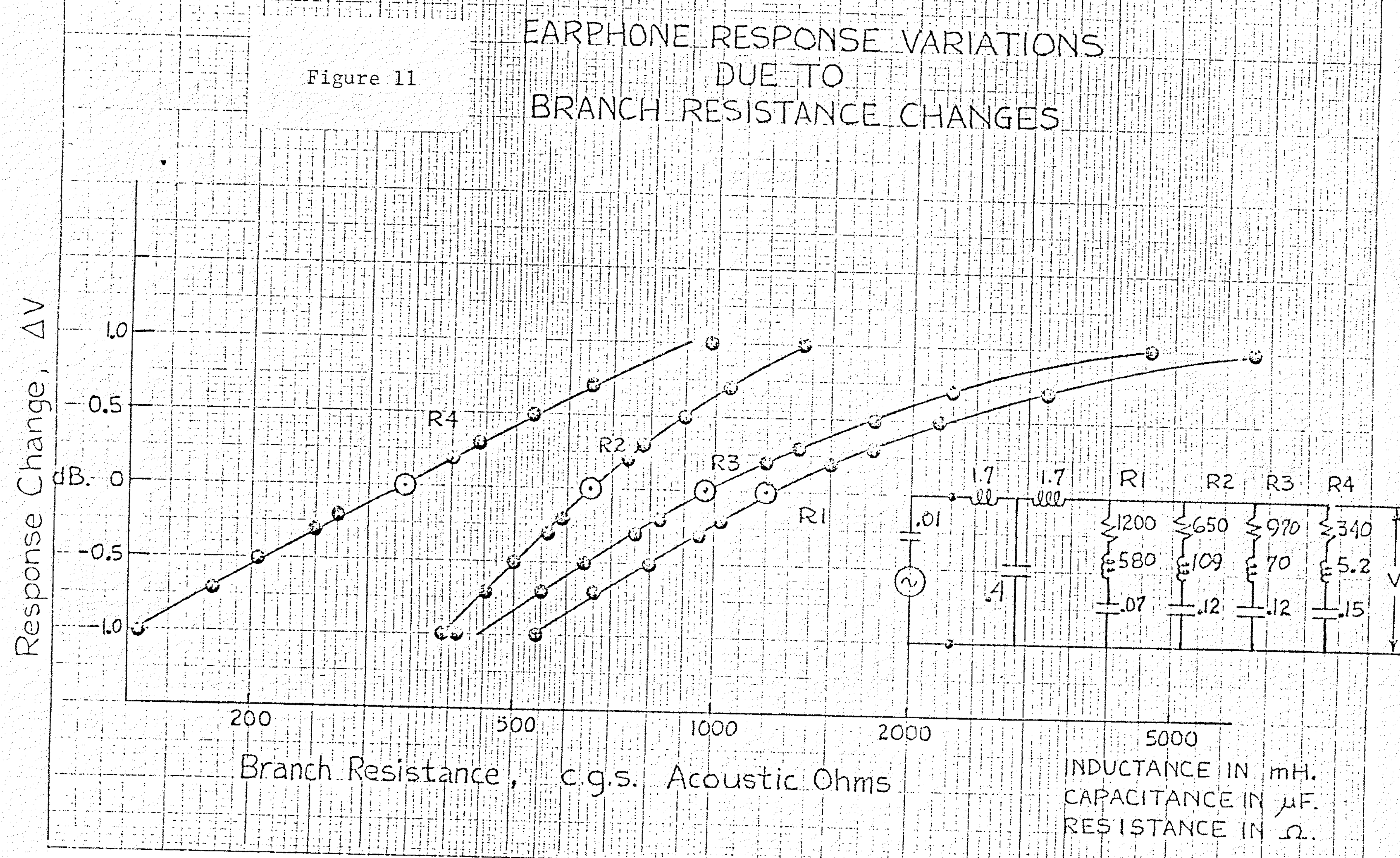


INDUSTRIAL RESEARCH PRODUCTS INC.
ELK GROVE VILLAGE ILLINOIS
AUTOMATIC RECORDER CHART NO 501
BY
DATE
RE 0002 MICROBAR
RESPONSE IN DB
80 85 90 95 100 105 110
145685
TUBE "O"
+85
DC
AC
UNIT 145334-21
PROJECT 28022
COUPLER Zwislocki XD960-54
Poplawski 6-22-72
db SPL
110
100
90
80
Figure 9
Branch R3
* NORMAL DAMPING
CURVE DISK WASHER
A 1 1
B 0 0
*C 2 1
D 1 0
E 3 1
A
B
C E
D
FREQUENCY IN CYCLES PER SECOND
100
1000
10000
20000



INDUSTRIAL RESEARCH PRODUCTS, INC.
AUTOMATIC RECORDER CHART NO. 501
BY RMS
DATE 6/22/72
RE 0002 MICROBAR
80 85 90 95 100 105 110
TUBE 0"
COUPLER XD960 S-4
DC
AC
UNIT 143334-21 PROJECT 20022
db SPL
110
100
90
80
Figure 10
Branch R4
Poplawski 6-22-72
* NORMAL DAMPING
FREQUENCY IN CYCLES PER SECOND
A
B
C
D
E
CURVE | DISK | WASHER
A | 0 | 0
B | 1 | 0
C | 1 | 2
D | 3 | 2
* E | 1 1/3 | 2

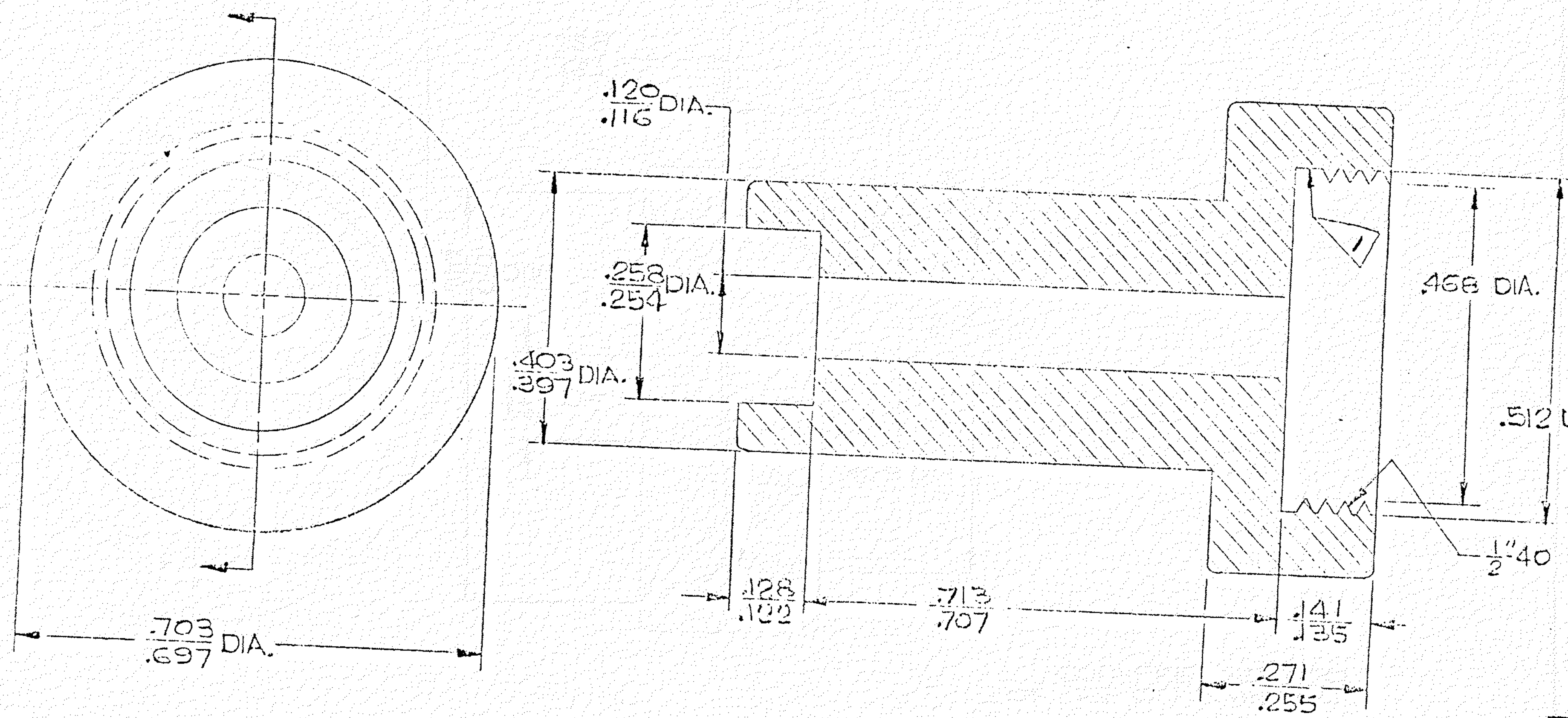
Figure 11


EARPHONE RESPONSE VARIATIONS
DUE TO
BRANCH RESISTANCE CHANGES
Response Change, ΔV
dB.
1.0
0.5
0
-0.5
-1.0
R4
R2
R3
R1
200
500
1000
2000
5000
Branch Resistance, c.g.s. Acoustic Ohms
.01
1.7
1.7
.4
R1
R2
R3
R4
1200
580
.07
650
109
.12
970
70
.12
340
5.2
.15
V
INDUCTANCE IN mH.
CAPACITANCE IN μF.
RESISTANCE IN Ω.

XD-952

NOTES-

1) UNDERCUT 1/2"40 THREAD
2) ROUND ALL OUTSIDE EDGES
3) FOR USE ON ZWISLOCKI COUPLER, XD-900



CONTRACT OR JOB NO. 20022	SCALE: 4×1	DO NOT SCALE DRAWING	ISSUE B
NO. REQ.	MATERIAL- BRASS		DR. BY TEK DATE 1-10-72
ASSEM.	FINISH-		CH. BY DATE
	INDUSTRIAL RESEARCH PRODUCTS, INC. ELK GROVE VILLAGE, ILLINOIS		APP. BY DATE
	TITLE:		

Figure 13

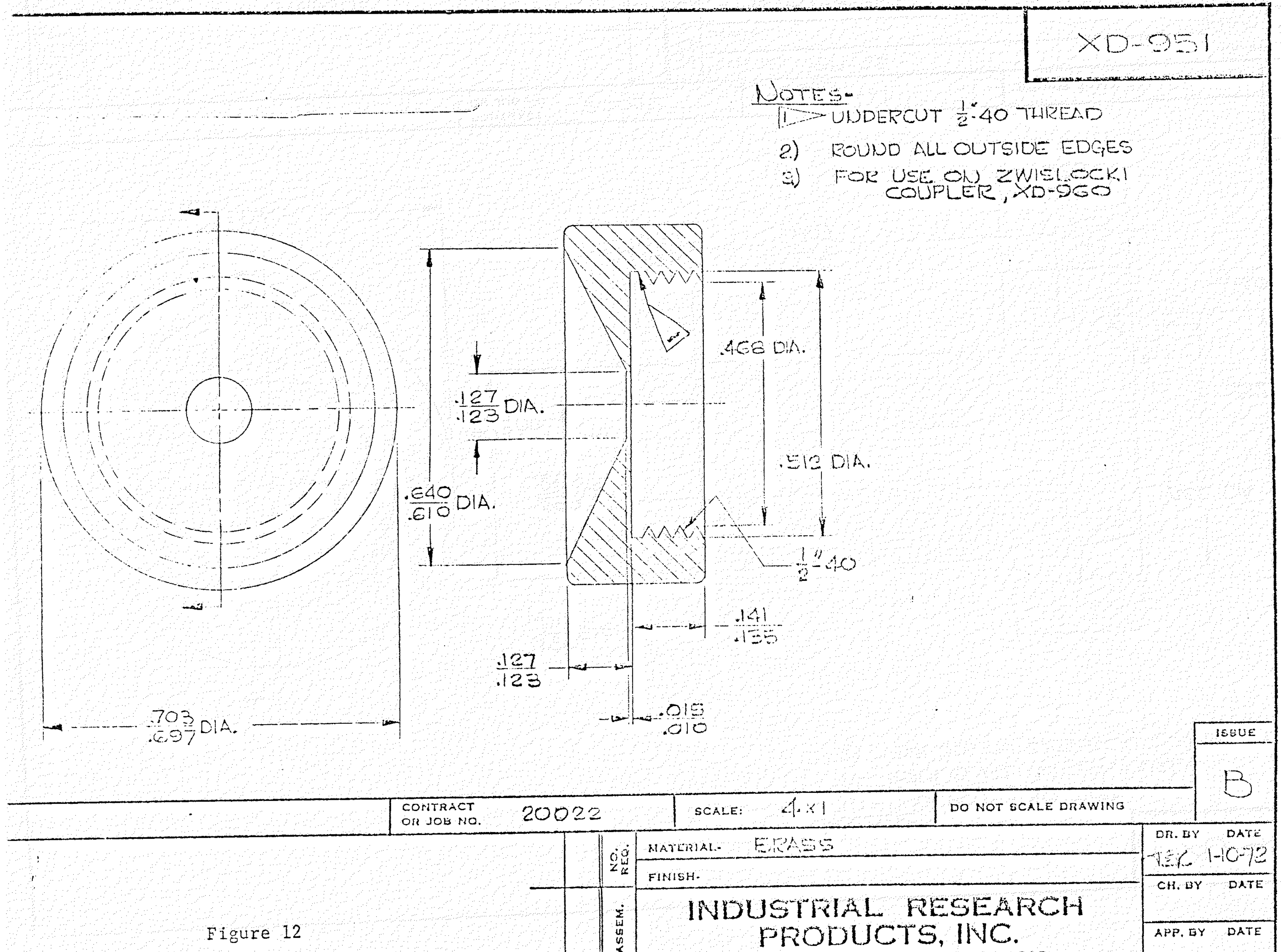
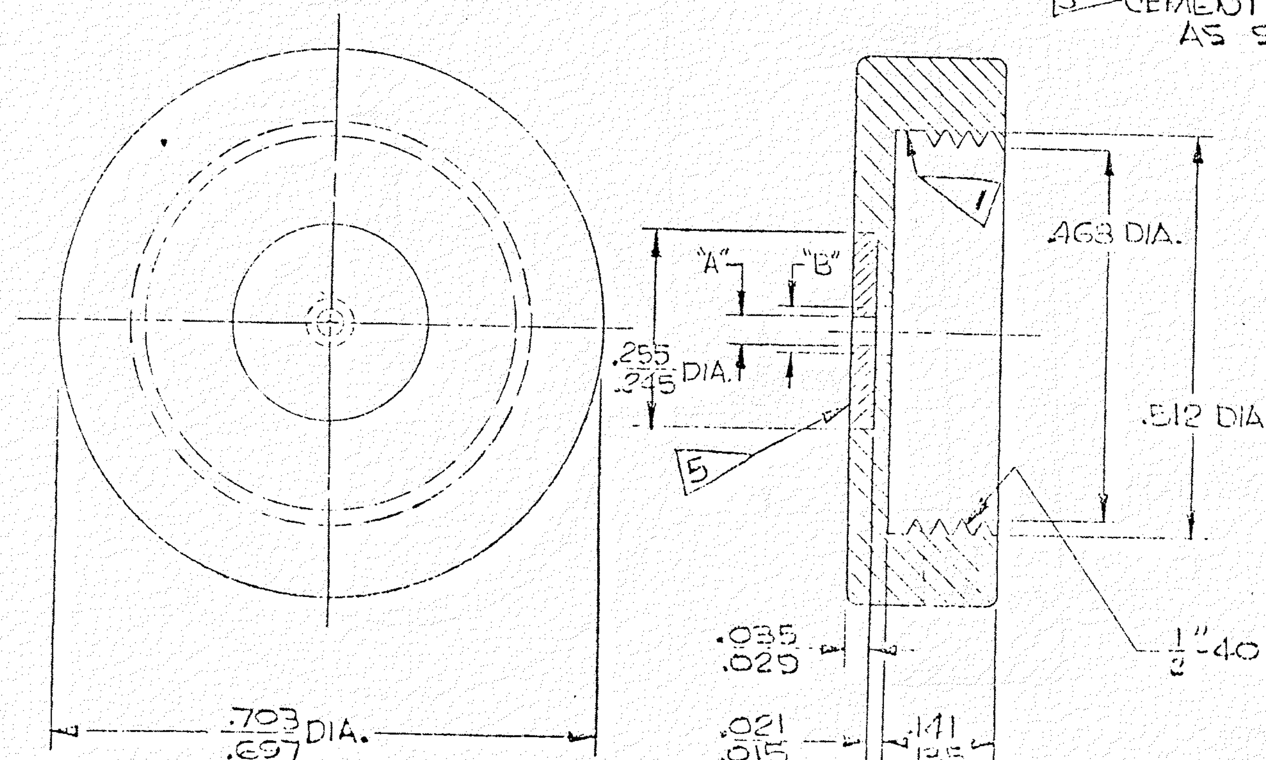

XD-951
NOTES-
1 UNDERCUT 1/2"-40 THREAD
2) ROUND ALL OUTSIDE EDGES
3) FOR USE ON ZWISLOCKI COUPLER, XD-960
.468 DIA.
.512 DIA.
.127/.123 DIA.
.640/.610 DIA.
1/2"-40
.141/.135
.127/.123
.015/.010
.703/.697 DIA.
ISSUE
B
CONTRACT OR JOB NO. 20022
SCALE: 4:1
DO NOT SCALE DRAWING
DR. BY DATE
1-10-72
MATERIAL- BRASS
NO. REQ.
FINISH-
CH. BY DATE
ASSEM.
INDUSTRIAL RESEARCH PRODUCTS, INC.
APP. BY DATE

Figure 12

XD-953-(SEE NO. BLOCK)

NOTES-

1. UNDERCUT $\frac{1}{2}$"40 THREAD
2. ROUND ALL OUTSIDE EDGES
3. FOR USE ON ZWISLOCKI COUPLER, XD-960
4. FOR DIRECT COUPLING WITH INSERT EARPHONE
5. CEMENT RUBBER INSERT IN POSITION AS SHOWN.



NUMBER BLOCK		
NO.	DIM. "A"	DIM. "B"
-1	.036 / .032 DIA.	.067 / .061 DIA.
-2	.064 / .060 DIA.	.130 / .124 DIA.

ISSUE: A

CONTRACT OR JOB NO. 20022 | SCALE: 4×1 | DO NOT SCALE DRAWING

NO. REQ. | ASSEM.

MATERIAL- BRASS

FINISH-

INDUSTRIAL RESEARCH PRODUCTS, INC.
ELK GROVE VILLAGE, ILLINOIS

DR. BY TEK DATE 11-0-72

CH. BY DATE

APP. BY DATE

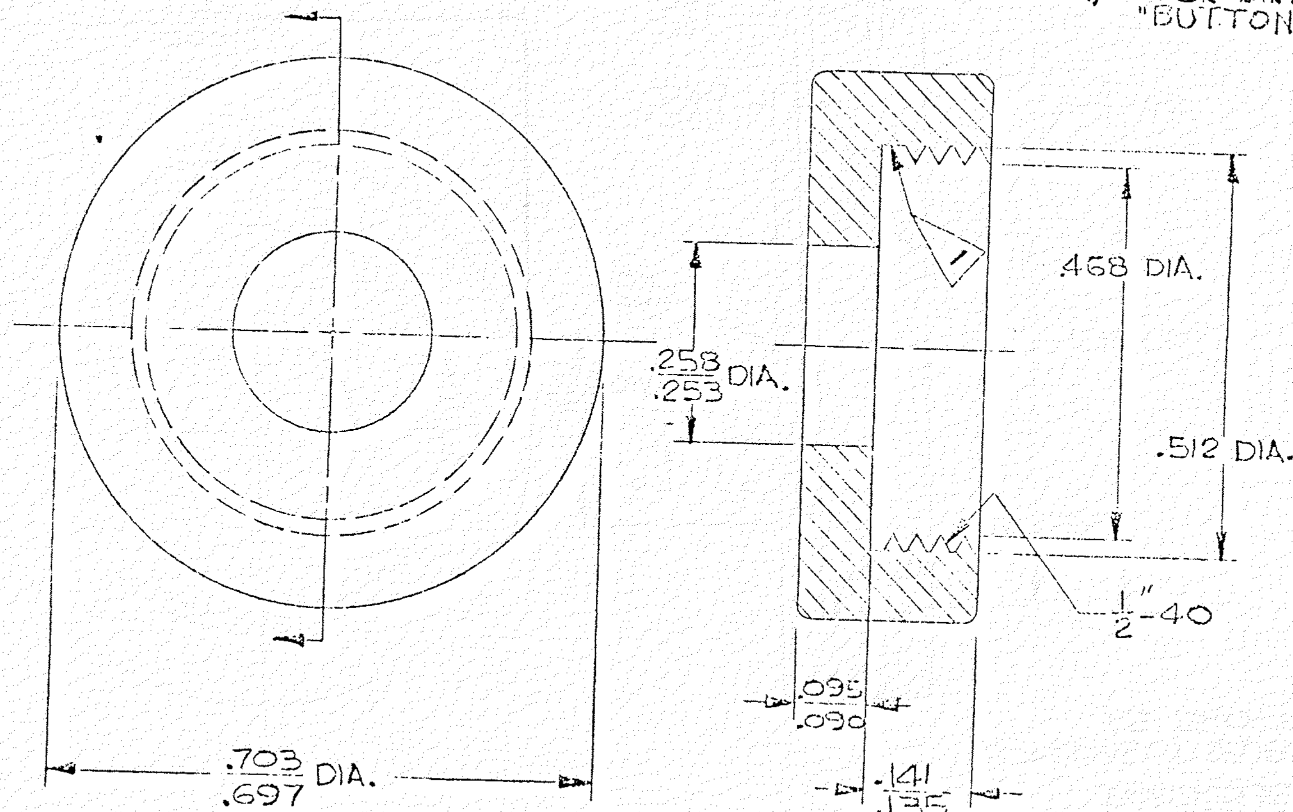
Figure 14

TITLE:

XD-961

NOTE–

1. UNDERCUT 1/2"40 THREAD
2.) ROUND ALL OUTSIDE EDGES
3.) FOR USE ON ZWISLOCKI COUPLER, XD-960.
4.) FOR DIRECT COUPLING WITH "BUTTON" EARPHONE NUB.



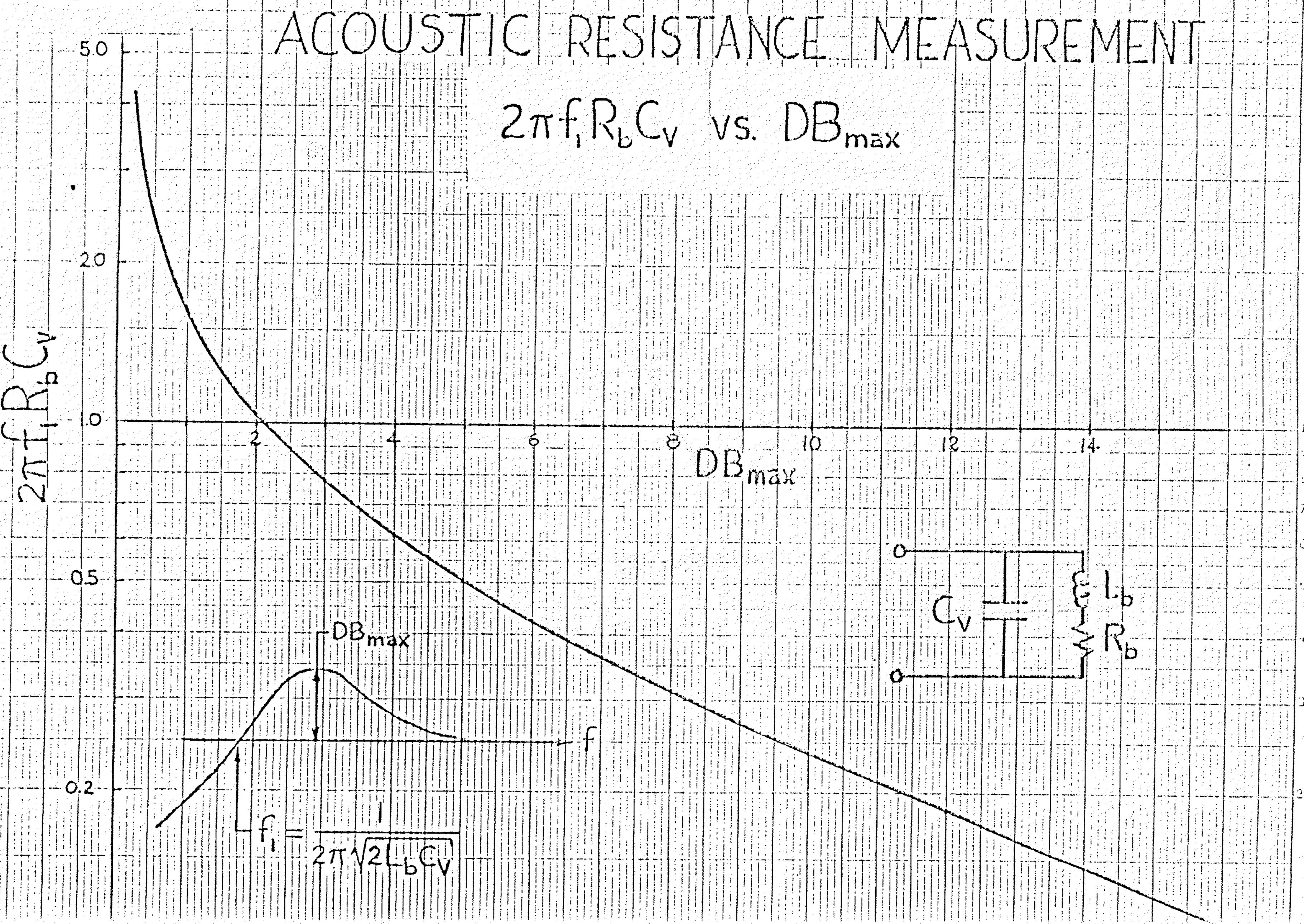
CONTRACT OR JOB NO. 20022	SCALE: 4×1	DO NOT SCALE DRAWING	ISSUE	A
MATERIAL- BRASS			DR. BY TEK	DATE 1-10-72
FINISH-			CH. BY	DATE
INDUSTRIAL RESEARCH PRODUCTS, INC. ELK GROVE VILLAGE, ILLINOIS			APP. BY	DATE
TITLE:				

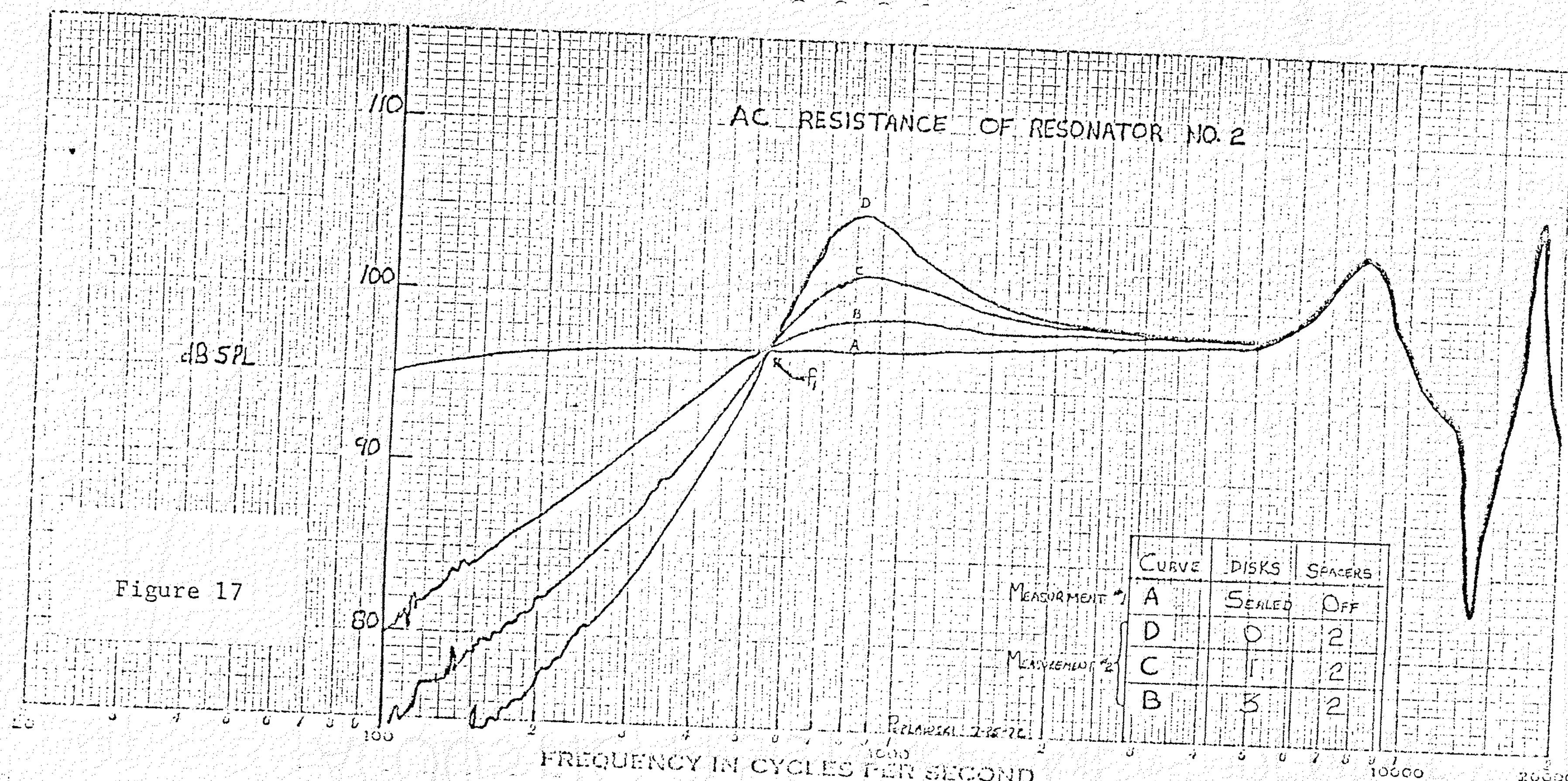
NO. REQ.

ASSEM.

Figure 15

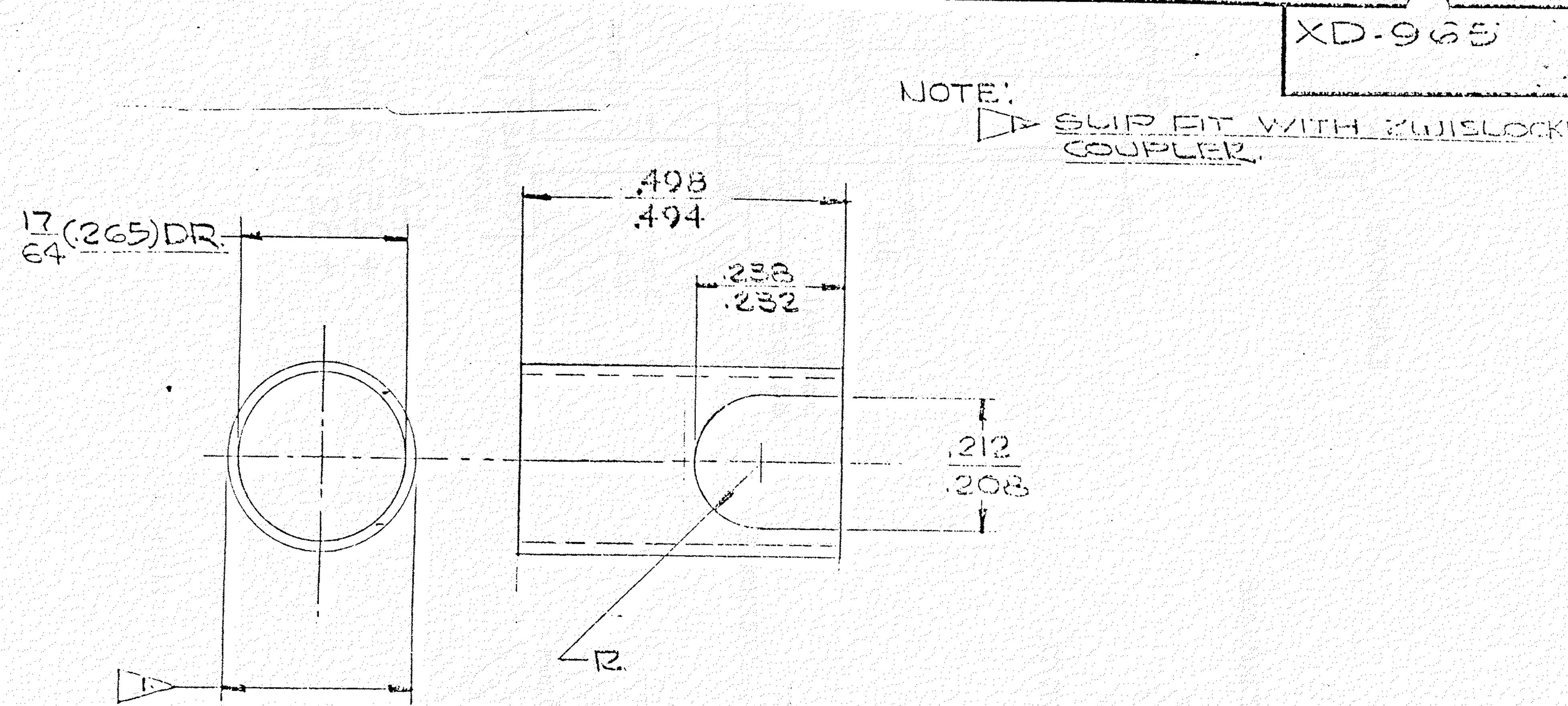
Figure 16


ACOUSTIC RESISTANCE MEASUREMENT
$2\pi f_1 R_b C_v$ vs. DB_{max}
$2\pi f_1 R_b C_v$
5.0
2.0
1.0
0.5
0.2
2
4
6
8
10
12
14
DB_{max}
DB_{max}
f
$f_1 = \frac{1}{2\pi\sqrt{2 L_b C_v}}$
C_v
L_b
R_b



AC RESISTANCE OF RESONATOR NO. 2
dB SPL
110
100
90
80
D
C
B
A
f_1
FREQUENCY IN CYCLES PER SECOND
100
1000
10000
20000
Measurment #1
Measurement #2
Curve | Disks | Spacers
A | Sealed | Off
D | 0 | 2
C | 1 | 2
B | 3 | 2

Figure 17



CONTRACT OR JOB NO. 20022	SCALE: 4-1	DO NOT SCALE DRAWING	ISSUE A
MATERIAL- BRASS		DR. BY JCU	DATE 7/24/7
FINISH-		CH. BY	DATE
INDUSTRIAL RESEARCH PRODUCTS, INC. ELK GROVE VILLAGE, ILLINOIS		APP. BY	DATE
TITLE: SLEEVE		XD 965	

Figure 18

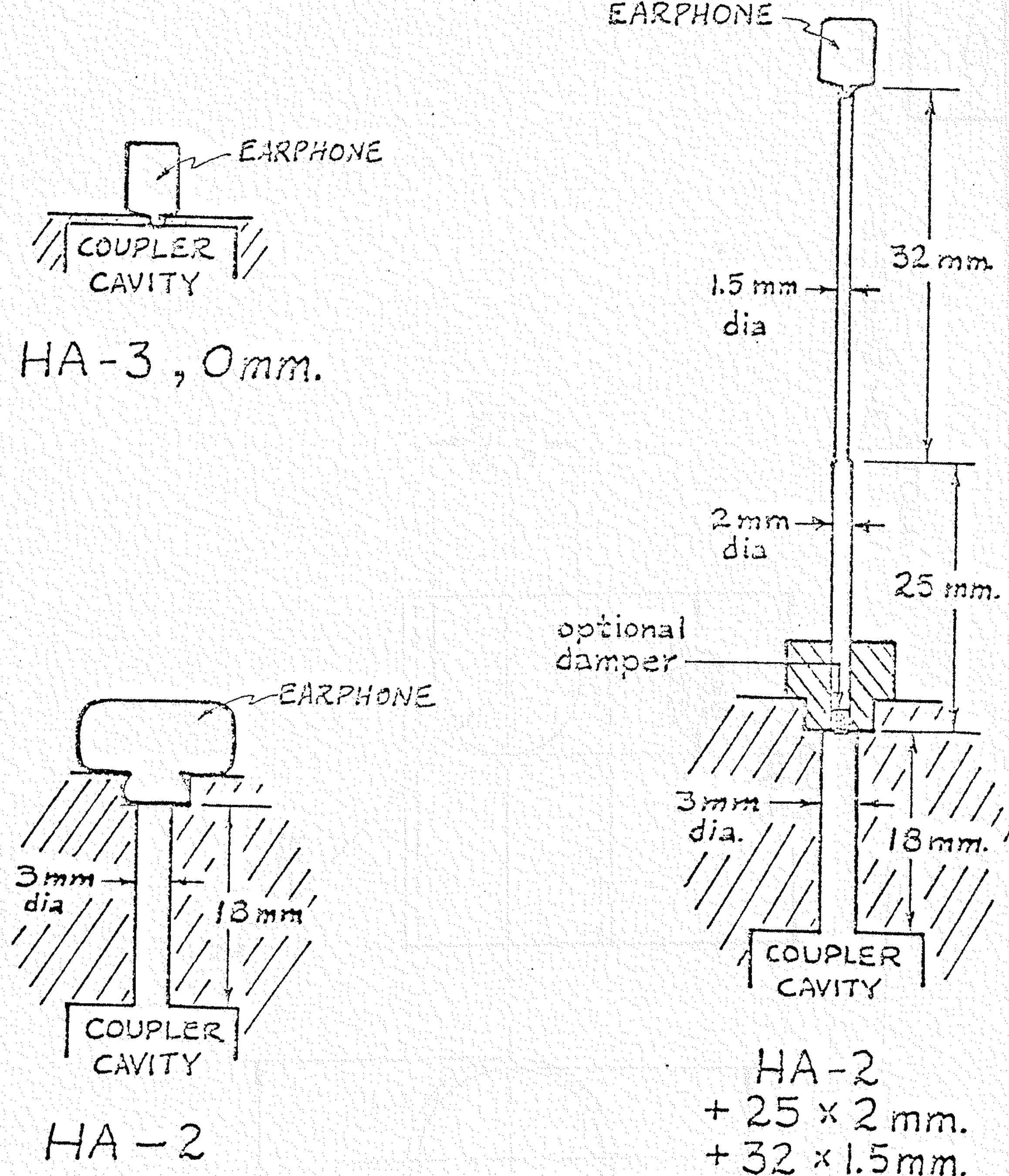
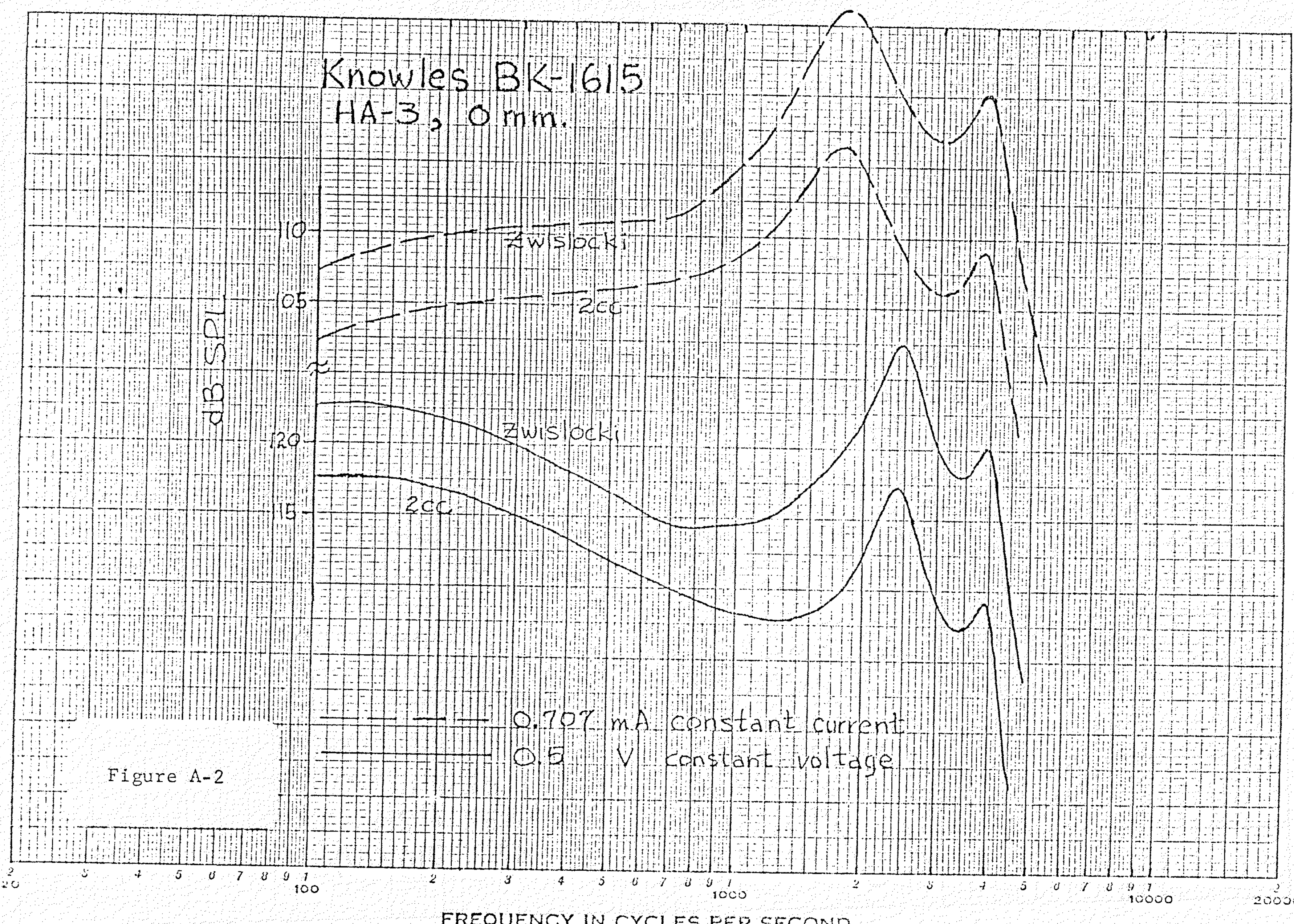

EARPHONE
COUPLER
CAVITY
HA-3 , 0mm.
EARPHONE
3mm
dia
18mm
COUPLER
CAVITY
HA-2
EARPHONE
1.5 mm
dia
32 mm.
2mm
dia
25 mm.
optional
damper
3mm
dia.
18mm.
COUPLER
CAVITY
HA-2
+ 25 × 2 mm.
+ 32 × 1.5mm.

Figure A-1


Knowles BK-1615
HA-3, 0 mm.
dB SPL
10
05
120
15
Zwislocki
2cc
Zwislocki
2cc
0.707 mA constant current
0.5 V constant voltage
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND
Figure A-2

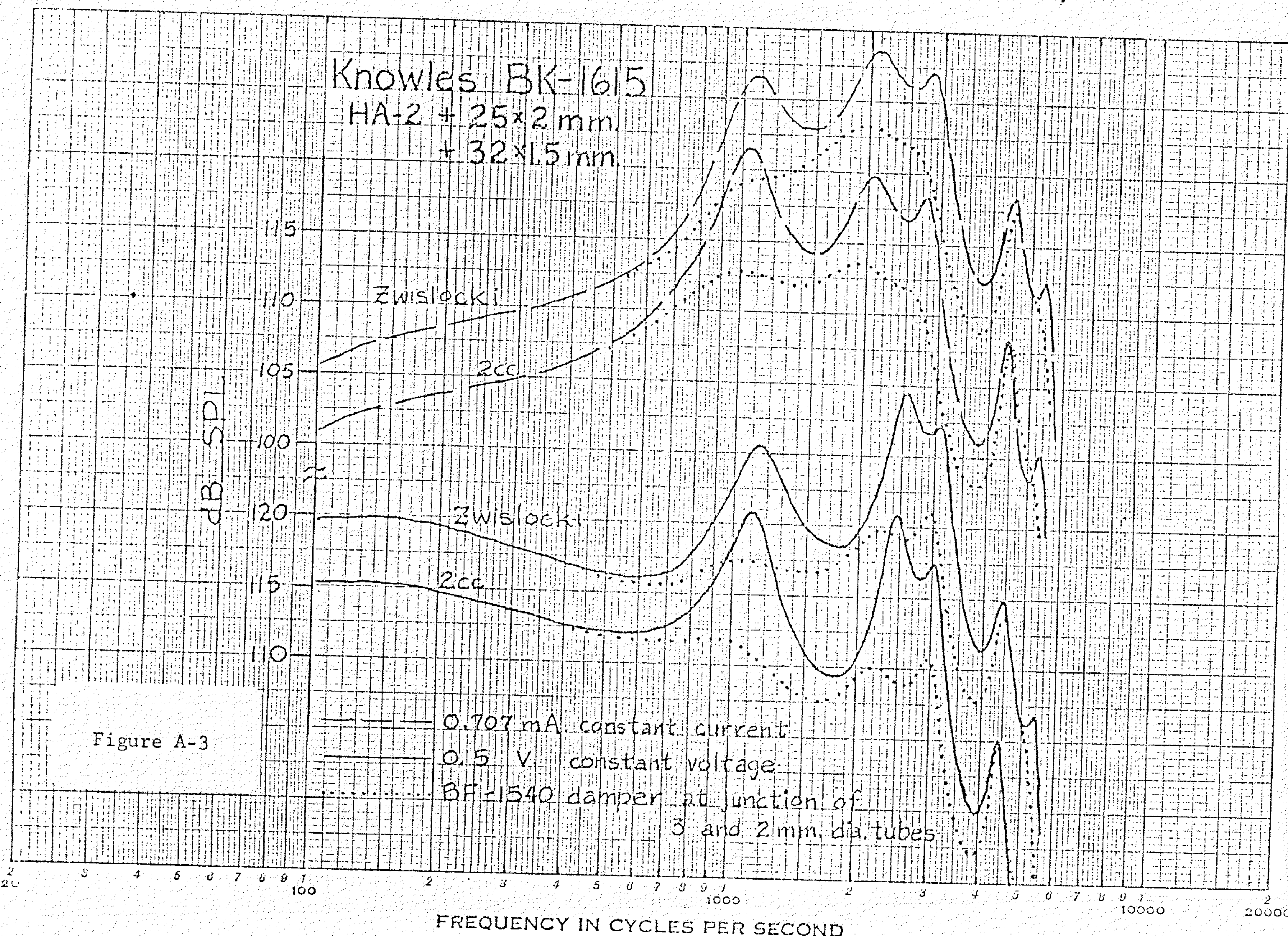

Knowles BK-1615
HA-2 + 25×2 mm
+ 32×1.5 mm
dB SPL
115
110
105
100
120
115
110
Zwislocki
2cc
Zwislocki
2cc
0.707 mA constant current
0.5 V constant voltage
BF-1540 damper at junction of
3 and 2 mm dia. tubes
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-3

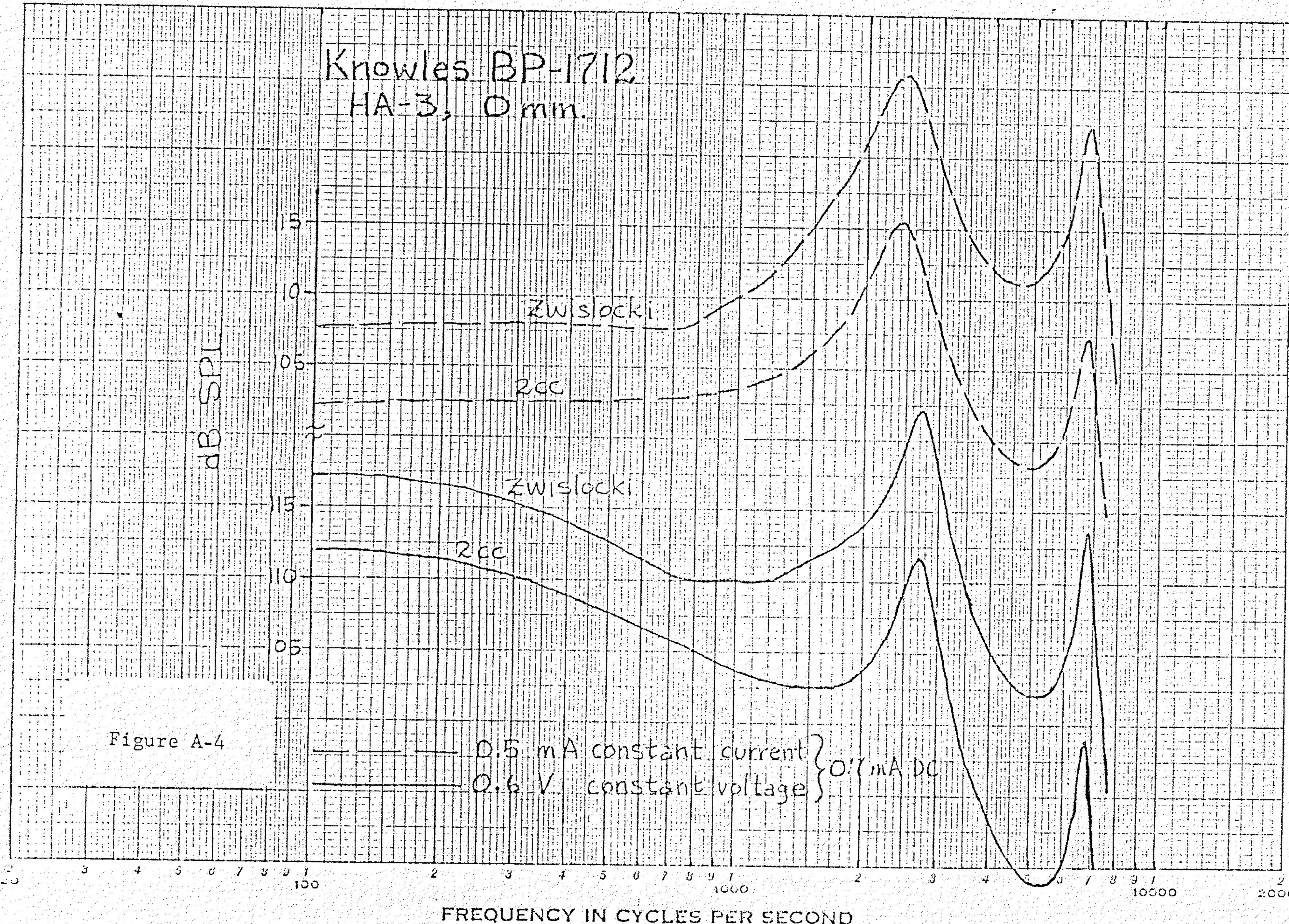

Knowles BP-1712
HA-3, 0 mm.
dB SPL
15
10
05
15
10
05
Zwislocki
2cc
Zwislocki
2cc
0.5 mA constant current
0.6 V constant voltage
0.7 mA DC
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-4

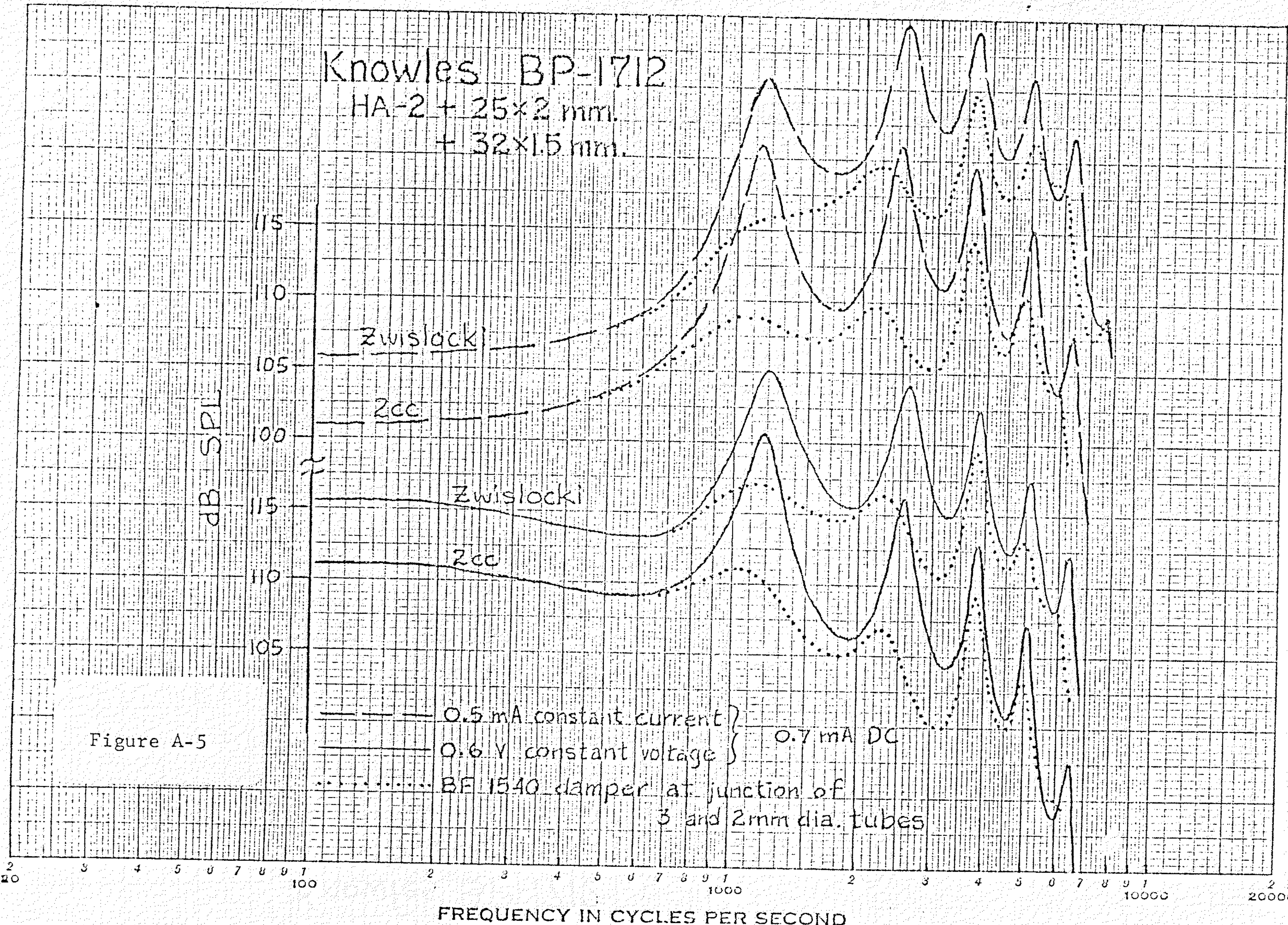
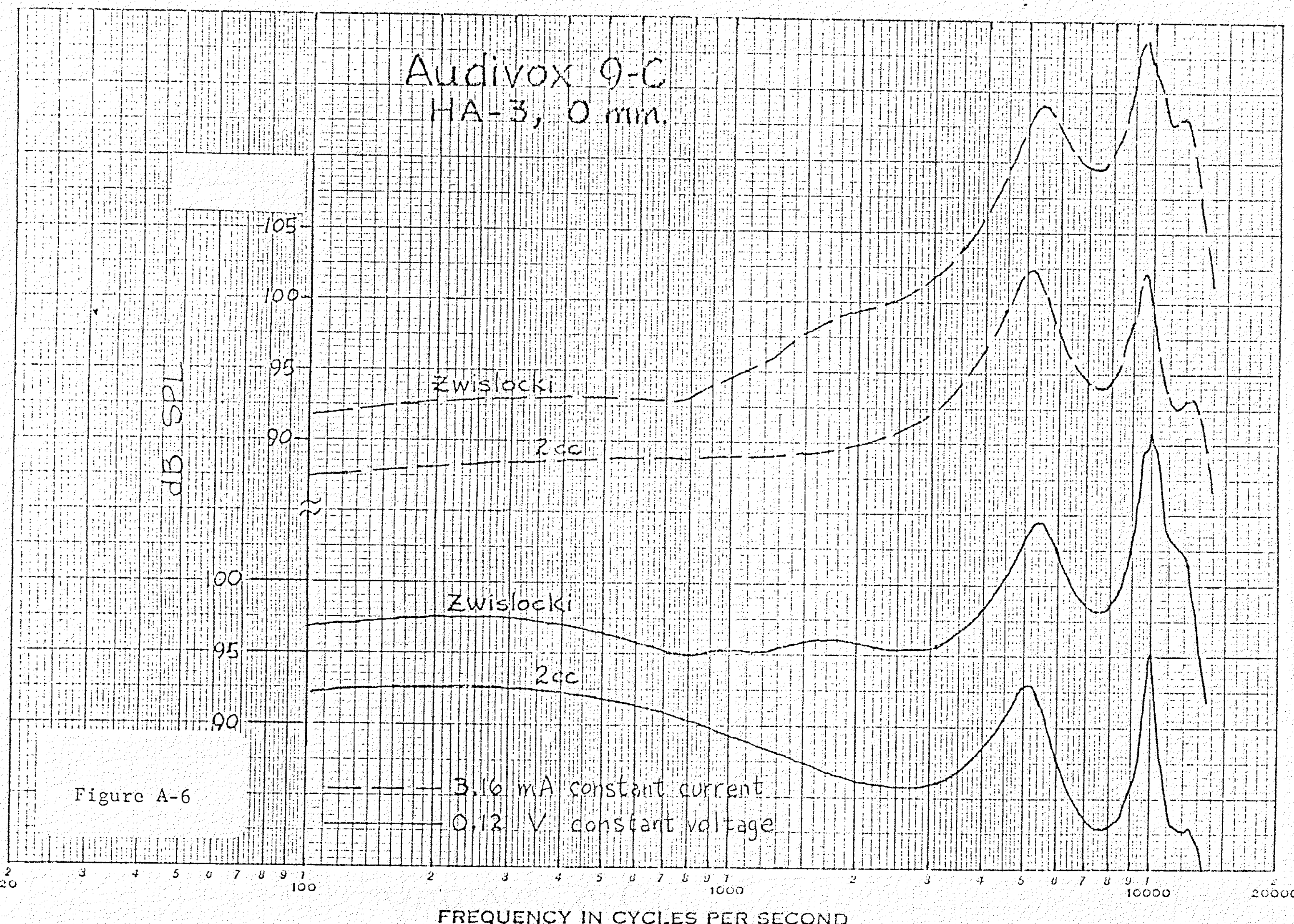
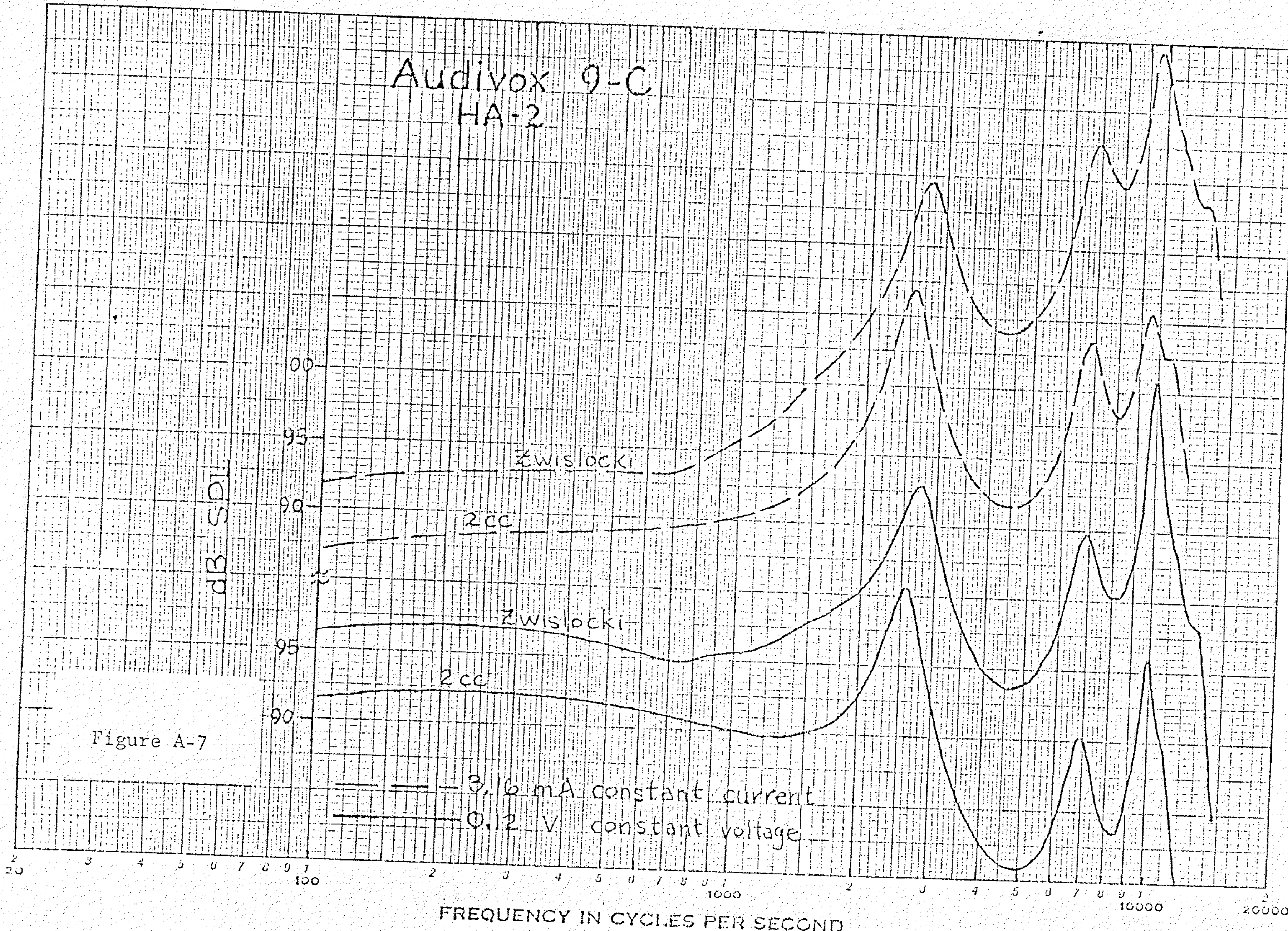

Knowles BP-1712
HA-2 + 25×2 mm.
+ 32×1.5 mm.
dB SPL
115
110
105
100
115
110
105
Zwislock
2cc
Zwislocki
2cc
0.5 mA constant current
0.6 V constant voltage
0.7 mA DC
BF 1540 damper at junction of
3 and 2mm dia. tubes
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-5



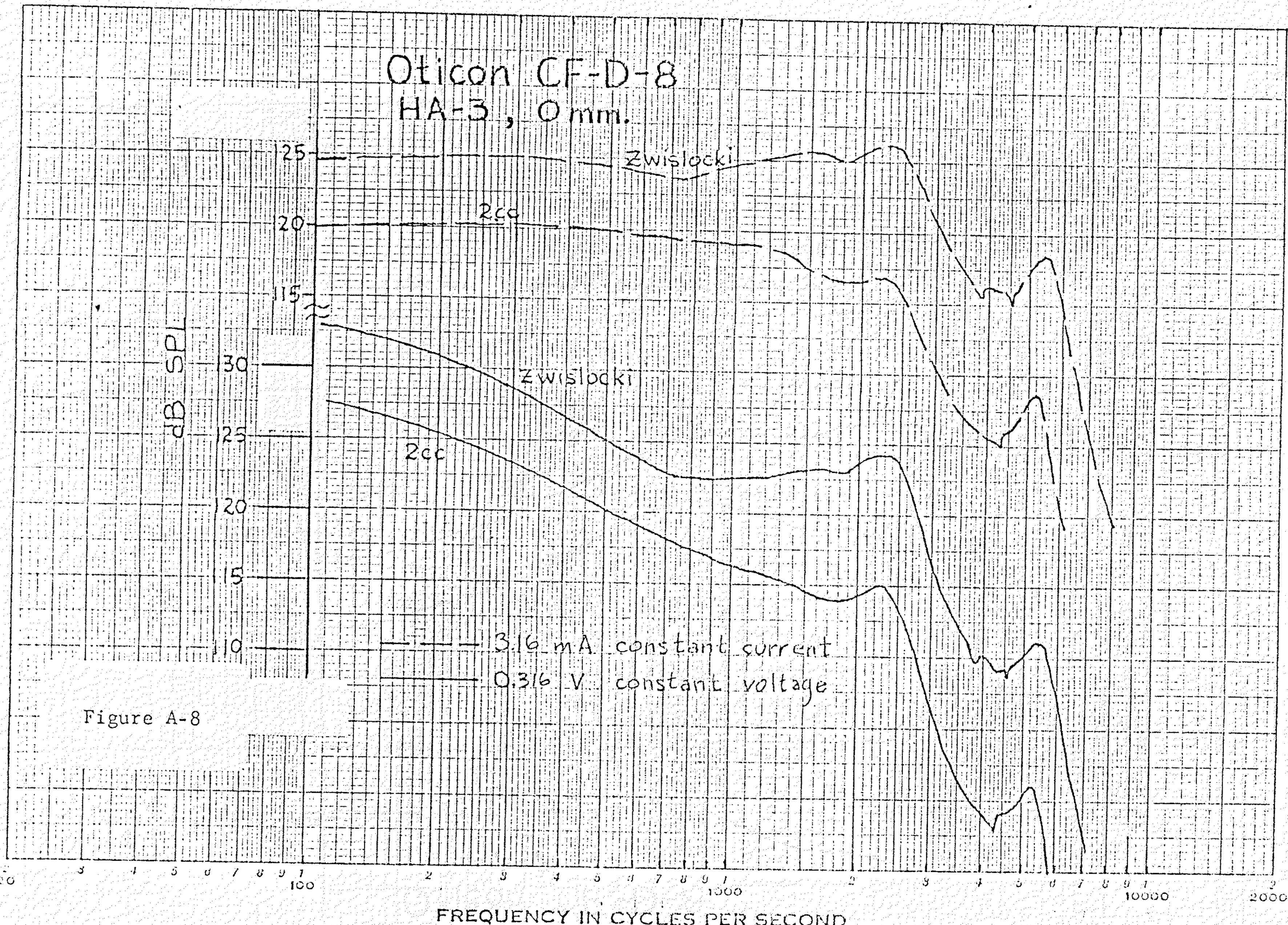
Audivox 9-C
HA-3, 0 min.
dB SPL
105
100
95
90
100
95
90
Zwislocki
2cc
Zwislocki
2cc
3.16 mA constant current
0.12 V constant voltage
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-6



Audivox 9-C
HA-2
dB SPL
100
95
90
95
90
Zwislocki
2cc
Zwislocki
2cc
3.16 mA constant current
0.12 V constant voltage
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-7



Oticon CF-D-8
HA-3 , 0 mm.
Zwislocki
2cc
Zwislocki
2cc
dB SPL
25
20
15
30
25
20
15
10
3.16 mA constant current
0.316 V constant voltage
FREQUENCY IN CYCLES PER SECOND
100
1000
10000
20000

Figure A-8

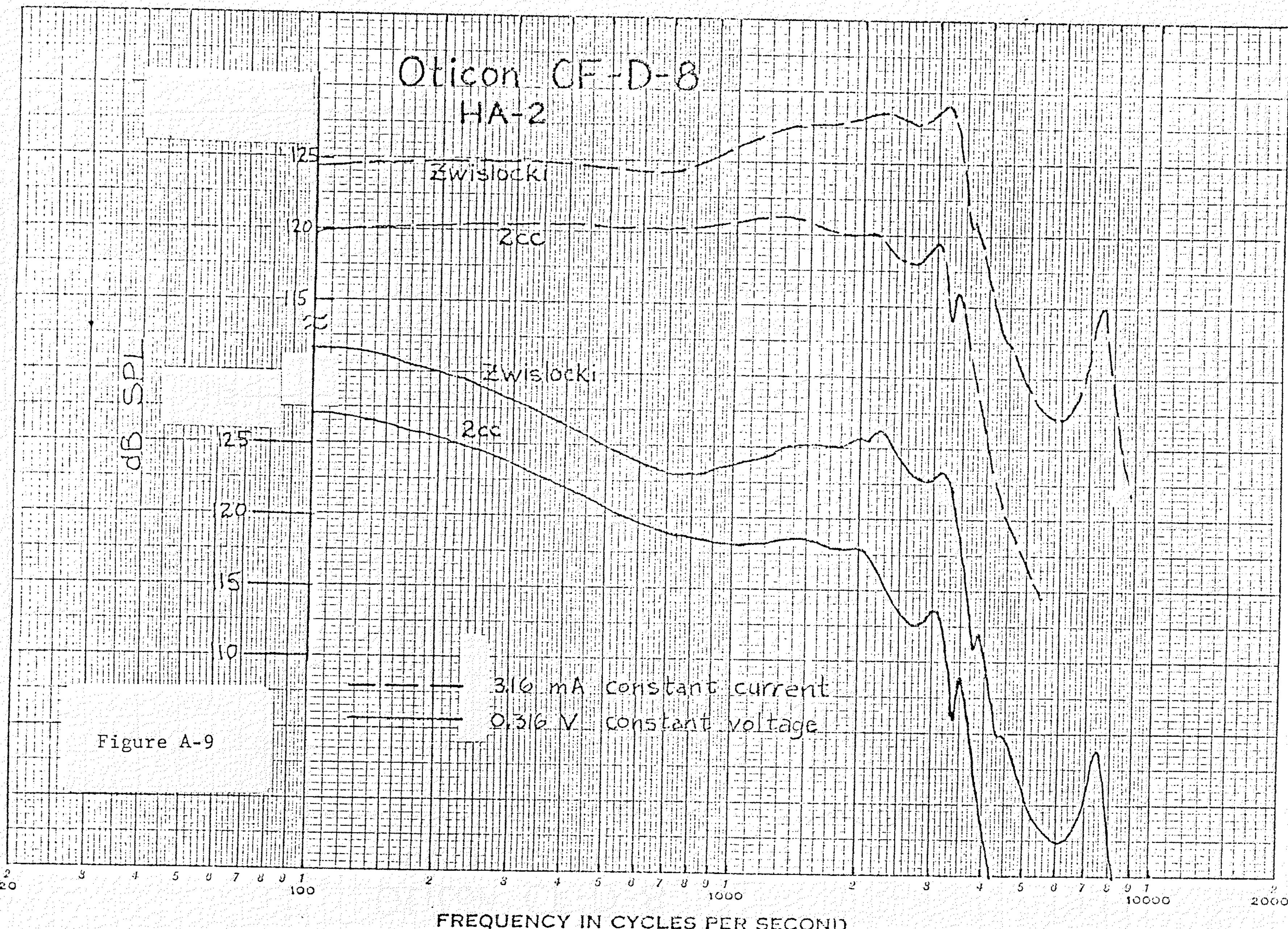

Oticon CF-D-8
HA-2
Zwislocki
2cc
Zwislocki
2cc
dB SPL
125
120
115
25
20
15
10
3.16 mA constant current
0.316 V constant voltage
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

Figure A-9