INTERNATIONAL STANDARD 532

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION •МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Acoustics — Method for calculating loudness level

Acoustique — Méthode de calcul du niveau d'isosonie

First edition — 1975-07-15
Corrected and reprinted — 1977-04-15

UDC 534.61

Ref. No. ISO 532-1975 (E)

Descriptors : acoustics, acoustic measurement, sound pressure, loudness, computation.

ISO 532-1975 (E)

Price based on 18 pages

FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO Member Bodies). The work of developing International Standards is carried out through ISO Technical Committees. Every Member Body interested in a subject for which a Technical Committee has been set up has the right to be represented on that Committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the Technical Committees are circulated to the Member Bodies for approval before their acceptance as International Standards by the ISO Council.

Prior to 1972, the results of the work of the Technical Committees were published as ISO Recommendations; these documents are now in the process of being transformed into International Standards. As part of this process, Technical Committee ISO/TC 43 has reviewed ISO Recommendation R 532 and found it technically suitable for transformation. International Standard ISO 532 therefore replaces ISO Recommendation R 532-1966 to which it is technically identical.

ISO Recommendation R 532 was approved by the Member Bodies of the following countries :

Australia	Denmark	Netherlands
Austria	Finland	New Zealand
Belgium	Germany	Sweden
Brazil	Greece	Switzerland
Canada	Hungary	United Kingdom
Chile	India	U.S.A.
Colombia	Italy	U.S.S.R.
Czechoslovakia	Korea, Rep. of	Yugoslavia

The Member Body of the following country expressed disapproval of the Recommendation on technical grounds :

France

The Member Bodies of the following countries disapproved the transformation of ISO/R 532 into an International Standard :

Canada
U.S.A.

Acoustics – Method for calculating loudness level

0 INTRODUCTION

It is often desirable to seek a single number that corresponds to the loudness or to the loudness level of a given sound. Such a number can be calculated if there is available a spectrum analysis of the sound obtained by physical measurement. It has to be understood that the calculated number is a statistic, i.e. it conveys less information than the spectrum measurements from which it is derived.

Such analysis is often accomplished in terms of either octave bands or one-third octave bands. Sounds in which the spectra do not have discontinuities as a function of frequency can be represented adequately in terms of octave bands, but sounds which contain such discontinuities may require one-third octave-band analysis if they are to be described adequately.

This International Standard specifies two methods for calculating the loudness or loudness level of a complex sound, which differ not only in the method of analysis of the sound, but also in the principles of computation. The first, Method A, utilizes physical measurements obtained from spectrum analysis in terms of octave bands. The second, Method B, utilizes spectrum analysis in terms of one-third octave bands.

In addition to the different band widths involved in the basic physical measurements, the two methods differ in other respects, and the results obtained do not always agree. Method B generally gives slightly higher results than those obtained for the same sounds by Method A, the difference being possibly as much as 5 phons; but it would seem to take better into account those variations in sound spectra that occur within narrow ranges of frequency.

The quantities calculated by either method should be designated with specific reference to one or other method using the system of symbols and abbreviations given in table 1.

TABLE 1 – **Designations for calculating loudnesses and loudness levels**

Method	Quantity measured		Band width of analysis	Sound field
	loudness	loudness level		
A	sones (OD)	phons (OD)	octave	diffuse
B	sones (GD) sones (GF)	phons (GD) phons (GF)	1/3 octave	diffuse free

SECTION ONE

METHOD A FOR CALCULATING THE LOUDNESS OF A COMPLEX SOUND THAT HAS BEEN ANALYSED IN TERMS OF OCTAVE BANDS

1 GENERAL

This section of this International Standard specifies a procedure, Method A, for calculating the loudness of steady complex sounds for which octave-band analyses are appropriate. (Octave-band analyses may, of course, be reconstructed from more detailed analyses.) The level in each octave band is converted into a loudness index, and the total loudness in sones (OD) is then calculated by means of an empirical formula. The total loudness thus calculated may then be converted into a calculated loudness level in phons (OD) by means of the relation specified in ISO/R 131, *Expression of the physical and subjective magnitudes of sound or noise.*

Method A also yields a graph that provides a valuable guide for the further study of the sound, particularly if the loudness index is plotted as the ordinate (see note to 4.3).

Method A also contains extensions for analyses made in terms of bands of one-third octave and one-half octave. For calculating the loudness of noises that require one-third octave-band analysis, however, Method B is recommended.

This Method A has the advantage of simplicity and is specified for sounds for which octave-band analyses are appropriate. Many noises of practical interest fall in this class.

Since the purpose of this section is to provide a simple and convenient method by which complex sounds of diverse levels and spectra may be ordered on a scale of subjective magnitude, certain simplifying assumptions and linear approximations have been made. The procedure is derived from three relations :

1) A loudness function relating loudness in sones to loudness level in phons, which is identical to that in ISO/R 131.

2) An empirical set of equal-loudness contours for bands of noise in a diffuse sound field.

3) A rule relating the total loudness of a sound to the loudness indices of the frequency bands composing it.

On the basis of these empirical relations, the total loudness of a sound may be calculated with the aid of a table or a chart, together with a linear equation. Subject to certain restrictions specified below, the recommended method may be expected to assess loudness or loudness level with an accuracy that is sufficient for engineering purposes.

2 SCOPE AND FIELD OF APPLICATION

This section of this International Standard specifies a method for calculating the loudness experienced by a typical (median) listener under the following conditions :

2.1 Diffuse sound field

The sound is assumed to reach the listener's ears from all directions at the same intensity. This condition is approximated in an ordinary room.

2.2 Kind of spectrum

The method is designed specifically for the types of broad band spectra most commonly encountered. Errors may arise if it is applied to certain types of line spectra, or to spectra having two or more sharp maxima that are separated by more than an octave. The magnitude of the error that may result from an unusual spectrum can only be determined experimentally.

2.3 Steady state

The method is designed for noises that are steady rather than intermittent. Nevertheless, in a diffuse field, many noises of impulsive origin behave effectively as steady noises, because reverberation serves to diminish temporal discontinuities.

NOTES

1 The error that may result with intermittent noises is not necessarily attributable to the calculation procedure. It may also be affected by the averaging characteristics of the meter used to determine the sound pressure levels.

2 Since the loudness of a sound depends upon the nature of the enclosure in which it is heard, it is important that comparative evaluations of different noise sources should be based on measurements made in essentially similar enclosures.

3 The band levels in the diffuse field should be measured by means of an omni-directional microphone located in the unobstructed sound field at the position of the listener's head.

3 DEFINITIONS

For the purposes of this International Standard the following definitions apply (the definitions in 3.1 and 3.4 are common to both methods) :

3.1 sound pressure level (L) : Sound pressure level in decibels is $20 \log_{10} (p/p_0)$ dB, where p is the measured sound pressure and p_0 is a reference sound pressure having the value

$$2 \times 10^{-5} \text{N/m}^2 = 2 \times 10^{-4} \text{dyn/cm}^2 \text{ (see ISO/R 131).}$$

3.2 band pressure level : Sound pressure level corresponding to the part of the spectrum (octave) under measurement.

3.3 loudness (*S*) **in sones** : Numerical designation of the strength of a sound which is proportional to its subjective magnitude as estimated by normal observers. One sone is the loudness of a sound whose loudness level is 40 phons.

3.4 loudness-loudness level relation : Loudness level *P* in phons of a sound is related to the loudness *S* in sones by the relation :

$$S = 2^{(P-40)/10}$$

NOTE — When loudness levels are computed from calculated loudness values, the results may differ from those obtained by direct subjective judgement. It is important, therefore, to state whether the values have been calculated or have been measured by other means.

3.5 loudness index : Number determined by the geometric mean frequency and the band pressure level of the octave band, according to the curves of figure 1.

4 SPECIFICATION

4.1 Calculated loudness

The method for calculating loudness is embodied in a table and a formula. For convenience, table 2 is also presented graphically as a chart (figure 1). The table or chart provides a means for converting each band level to a loudness index, and the formula provides a rule for combining the loudness indices to obtain the calculated total loudness.

The procedure is as follows :

1) Enter the geometric mean frequency of each band in the table or in the abscissa of figure 1. Then, from the band level (the ordinate in figure 1), determine the loudness index of each band.

2) Compute the total loudness in sones (OD) S_t by means of the formula :

$$S_t = S_m + F\,(\Sigma S - S_m)$$

where S_m is the greatest of the loudness indices and ΣS is the sum of the loudness indices of all the bands. For octave bands the value of *F* is 0,3.

NOTE — Method A has also been applied to analyses made in terms of one-half octave and one-third octave bands, and may be so used in cases where the sound spectrum would fall under the restrictions of Method A. In such cases the value of F is as follows :

One-third octave 0,15

One-half octave 0,2

4.2 Calculated loudness level

The total loudness may be converted into calculated loudness level in phons (OD) by means of the formula :

$$S_t = 2^{(P-40)/10}$$

$$\text{or } P = 40 + 10 \log_2 S_t$$

A nomogram giving this relation is included in figure 1.

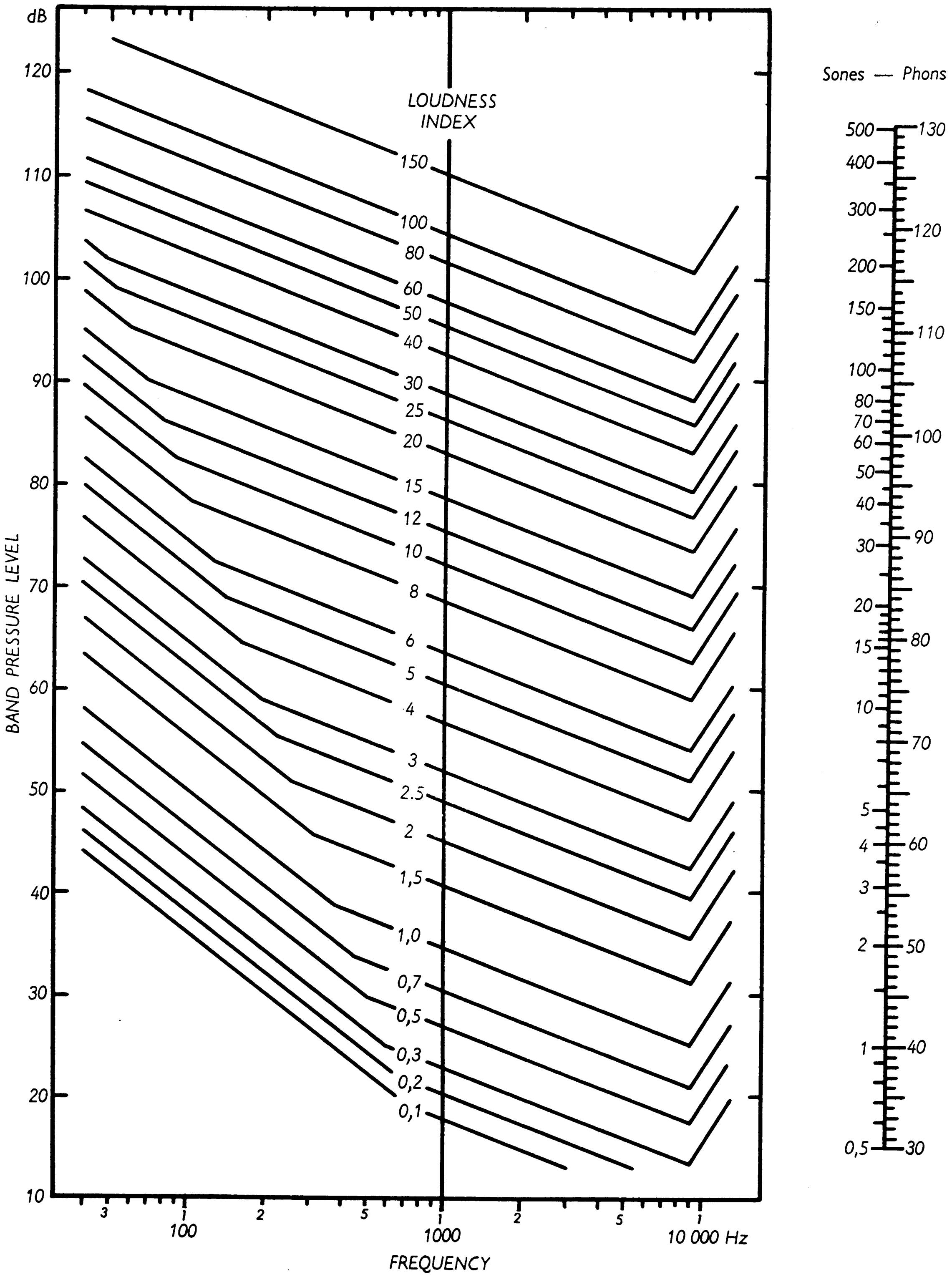
4.3 Table of loudness index

In table 2 values of the loudness index are tabulated for the frequency of 1 000 Hz. Values at other frequencies can be obtained by means of the following rules. The value of the loudness index is constant on the contour having a slope of − 3 dB/octave. Above 9 000 Hz the contour has a slope of 12 dB/octave. Below a certain frequency the contour has a slope of − 6 dB/octave. The frequency at which this change of slope occurs lies on a line having a slope of − 21 dB/octave. This line passes through the point determined by 1 000 Hz and 10 dB band pressure level.

NOTE — The chart of figure 1 shows one means of presenting the relation between loudness index, band pressure level and frequency. Here the loudness index is the parameter of the family. For certain purposes, it may be convenient to prepare charts for the band pressure level as a parameter, and the loudness index as an ordinate.

TABLE 2 — **Loudness index at 1 000 Hz**

Band pressure level dB	Loudness index	Band pressure level dB	Loudness index	Band pressure level dB	Loudness index
15		50	2,68	85	23,0
16		51	2,84	86	24,7
17		52	3,0	87	26,5
18	0,10	53	3,2	88	28,5
19	0,14	54	3,4	89	30,5
20	0,18	55	3,6	90	33,0
21	0,22	56	3,8	91	35,3
22	0,26	57	4,1	92	38,0
23	0,30	58	4,3	93	41,0
24	0,35	59	4,6	94	44,0
25	0,40	60	4,9	95	48
26	0,45	61	5,2	96	52
27	0,50	62	5,5	97	56
28	0,55	63	5,8	98	61
29	0,61	64	6,2	99	66
30	0,67	65	6,6	100	71
31	0,73	66	7,0	101	77
32	0,80	67	7,4	102	83
33	0,87	68	7,8	103	90
34	0,94	69	8,3	104	97
35	1,02	70	8,8	105	105
36	1,10	71	9,3	106	113
37	1,18	72	9,9	107	121
38	1,27	73	10,5	108	130
39	1,35	74	11,1	109	139
40	1,44	75	11,8	110	149
41	1,54	76	12,6	111	160
42	1,64	77	13,5	112	171
43	1,75	78	14,4	113	184
44	1,87	79	15,3	114	197
45	1,99	80	16,4	115	211
46	2,11	81	17,5	116	226
47	2,24	82	18,7	117	242
48	2,38	83	20,0	118	260
49	2,53	84	21,4	119	278
				120	298


dB
120
110
100
90
80
70
60
50
40
30
20
10
BAND PRESSURE LEVEL
LOUDNESS INDEX
150
100
80
60
50
40
30
25
20
15
12
10
8
6
5
4
3
2.5
2
1,5
1,0
0,7
0,5
0,3
0,2
0,1
3
1
100
2
5
1
1000
2
5
1
10 000 Hz
FREQUENCY
Sones — Phons
500
400
300
200
150
100
80
70
60
50
40
30
20
15
10
5
4
3
2
1
0,5
130
120
110
100
90
80
70
60
50
40
30

SECTION TWO

METHOD B FOR CALCULATING THE LOUDNESS OF A COMPLEX SOUND THAT HAS BEEN ANALYSED IN TERMS OF ONE-THIRD OCTAVE BANDS

5 GENERAL

This section of this International Standard specifies a procedure, Method B, for calculating the loudness of steady complex sounds for which one-third octave band analyses have been obtained. By means of graphs, the one-third octave band levels are transformed into parts of an area which correspond to parts of loudness. The loudness level in phons (GF or GD) is calculated from the total area and is read from a scale. The loudness level may then be converted into loudness in sones (GD or GF) by means of the relations specified in ISO/R 131.

Method B is applicable not only to sounds with smooth broadband spectra but to sounds with strong line spectra or irregular spectra for which octave-band analyses are not appropriate. Furthermore, the graph that it yields of the relation between the components of the loudness of a noise and its spectrum provides a valuable guide for the further study of the sound, for example with a view to noise reduction.

Since the purpose of this section is to provide a convenient method by which complex sounds of various levels and spectra may be ordered on a scale of subjective magnitude, certain simplifying assumptions have been made, especially linear approximations of critical bands (*Frequenzgruppen*) to one-third octave bands. The procedure is based on five empirical relations or concepts :

1) The widest frequency bands in which the loudness level depends only on the sound pressure level (critical bands) (*Frequenzgruppen*).

2) A rule relating the total loudness of a sound to the contributions from the critical bands (*Frequenzgruppen*) composing it.

3) A relation between the part of the loudness appropriate to each band and the centre frequency of that band.

4) The difference between the equal-loudness contours for frontal sound and for a diffuse sound field.

5) A loudness function relating loudness in sones to loudness level in phons, which is identical to that given in ISO/R 131.

On the basis of these concepts, the total loudness or the loudness level of a sound may be calculated with the aid of a set of graphs, either for a frontally-incident sound or for a diffuse sound field.

6 SCOPE AND FIELD OF APPLICATION

This section of this International Standard specifies a method for calculating the loudness experienced by a typical (median) listener under the following conditions :

6.1 Frontal sound

The sound is assumed to reach the listener's ears only from the direction straight ahead of him, in the open air or in a non-reflecting environment. In all enclosures, frontal sound is approximated when a small source is operating close to and directly ahead of the listener.

6.2 Diffuse field

The sound is assumed to reach the listener's ears from all directions at the same intensity. This condition is approximated in an ordinary room.

The method is applicable to all types of spectra.

The method is based on the assumption that the sound is steady rather than intermittent.

NOTES

1 The error that may result with intermittent noises is not necessarily attributable to the calculation procedure. It may also be affected by the averaging characteristics of the meter used to determine the sound pressure levels.

2 Since the loudness of a sound depends upon the nature of the enclosure in which it is heard, it is important that comparative evaluations of different noise sources should be based on measurements made in essentially similar enclosures.

3 The one-third octave band levels in the case of a diffuse field should be measured by means of an omni-directional microphone located in the unobstructed sound field at the position of the listener's head. In the case of frontal sound, the free field sound pressure levels should be measured.

7 DEFINITIONS

7.1 band pressure level : Sound pressure level corresponding to the part of the spectrum under measurement. Symbols L_{GF}, L_{GD} signify band pressure levels in a critical band (*Frequenzgruppen*), for frontal sound F and diffuse field D respectively.

7.2 critical bands (*Frequenzgruppen*) : Critical bands approximated by bands one third-octave wide above 280 Hz and by groups of one-third octave bands for lower frequencies.

7.3 calculated loudness level : Calculated loudness level expressed in phons (GF) or phons (GD), and obtained by the procedure specified in clause 4. The abbreviations GF and GD signify that the calculation is based on critical bands and refer to frontal sound and a diffuse field respectively. (Cf 3.1 and 3.4.)

NOTE — The term phon, without a qualifying abbreviation, should be reserved for the expression of loudness levels determined by direct subjective measurement.

8 SPECIFICATION

The procedure for the calculation of loudness level consists of three steps based on a set of graphs. These graphs (figures 2 to 11, according to the level range and the type of sound field) provide a means of combining and converting the one-third octave band levels to give the total loudness level. Figures 2 to 6 are used for frontal sound and figures 7 to 11 for a diffuse field.

Step 1

Each graph contains stepped curves designated by numbers related to the one-third octave band levels L_T. Select a graph which corresponds to the appropriate type of sound field and which includes the highest one-third octave band level measured. Draw the measured levels in the bands above 280 Hz as horizontal lines so that the cut-off frequencies of the one-third octave bands correspond to the abscissa of the graph and the measured levels correspond to the numbering of the stepped curves.

Because the critical bands are wider than one-third of an octave at the lower frequencies, it is necessary to group the low frequency bands as follows to obtain corresponding critical band levels L_1, L_2 and L_3 before entering them on the diagram.

1) Combine all bands up to the cut-off frequency of 90 Hz (L_1).

2) Combine the three bands from 90 to 180 Hz (L_2).

3) Combine the two bands from 180 to 280 Hz (L_3).

The rule of combination may be understood from the example :

$$L_2 = 10 \log_{10} (\text{antilog } L_{100}/10 + \text{antilog } L_{125}/10 + \text{antilog } L_{160}/10)$$

where L_{100}, etc., is the measured one-third octave band pressure level for the band with centre frequency 100 Hz.

Draw each of these combined levels as a horizontal line of the width of the combined band, so that the levels correspond to the numbering of the stepped curves.

NOTE — In combining levels in the very low frequency bands it may be appropriate, in the case of certain spectra, to weight the contributions of the one-third octave bands in accordance with equal loudness contours.

Step 2

Where the steps formed by these horizontal lines are rising with frequency the adjacent horizontal levels are connected by vertical lines at the common abscissa. When the level in the next highest frequency band is lower, the fall is drawn as a downward sloping curve interpolated between the dashed curves on the graph, starting from the right-hand end of the horizontal line. The area enclosed by the whole stepped figure so obtained corresponds to the total loudness.

Step 3

Transform the enclosed area into a rectangle of the same area and having a base equal to the width of the graph, either by eye or by means of a planimeter. The height of the rectangle gives directly the loudness level in phons (GF) or phons (GD) from the scales on either side of the graph. The corresponding loudness in sones (GF) or sones (GD) may be read from the second scale.

Method B described above is based on the publications mentioned in annex B.

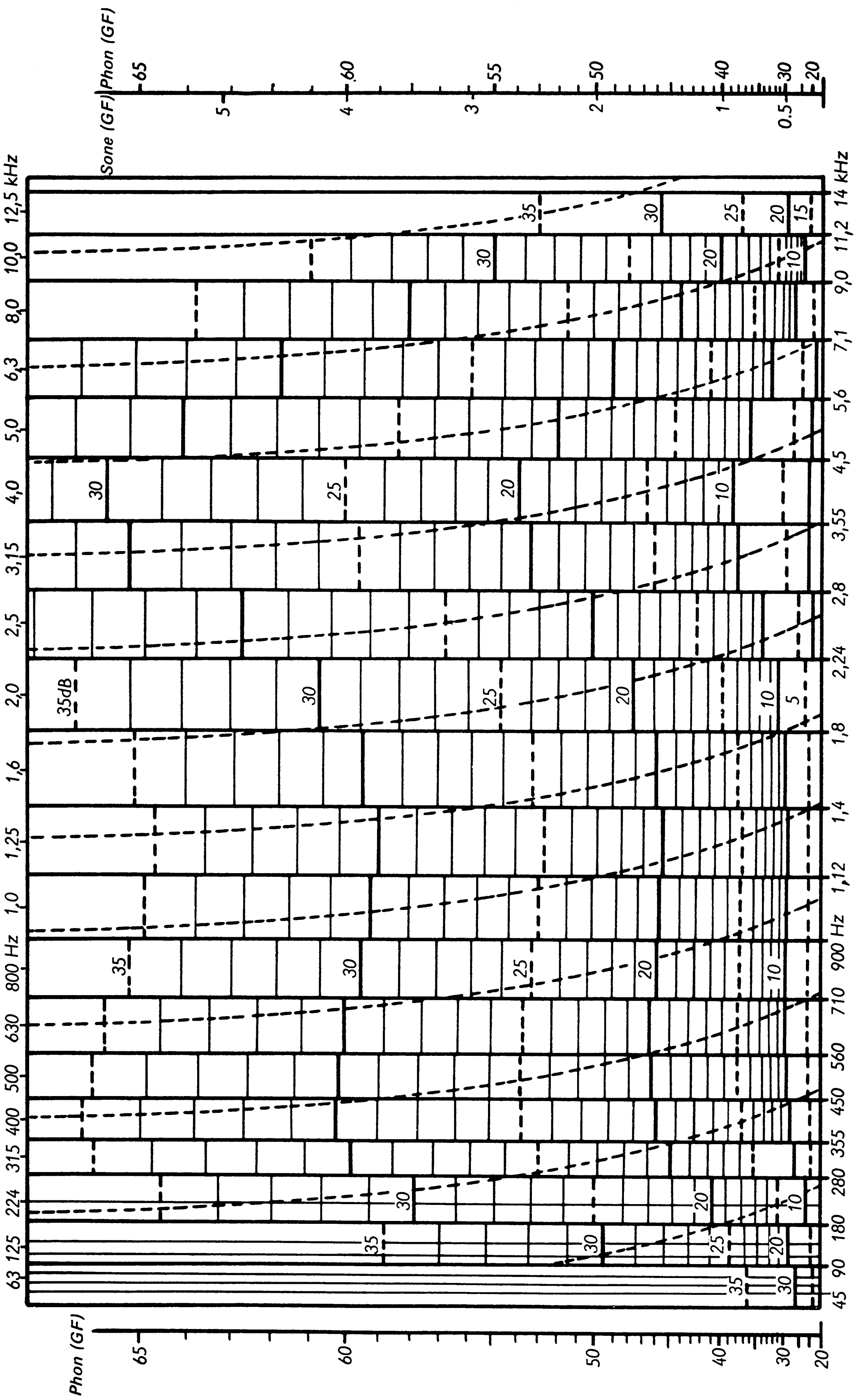

Sone (GF)
Phon (GF)
12,5 kHz
10,0
8,0
6,3
5,0
4,0
3,15
2,5
2,0
1,6
1,25
1,0
800 Hz
630
500
400
315
224
125
63
14 kHz
11,2
9,0
7,1
5,6
4,5
3,55
2,8
2,24
1,8
1,4
1,12
900 Hz
710
560
450
355
280
180
90
45
35dB
Phon (GF)

FIGURE 2

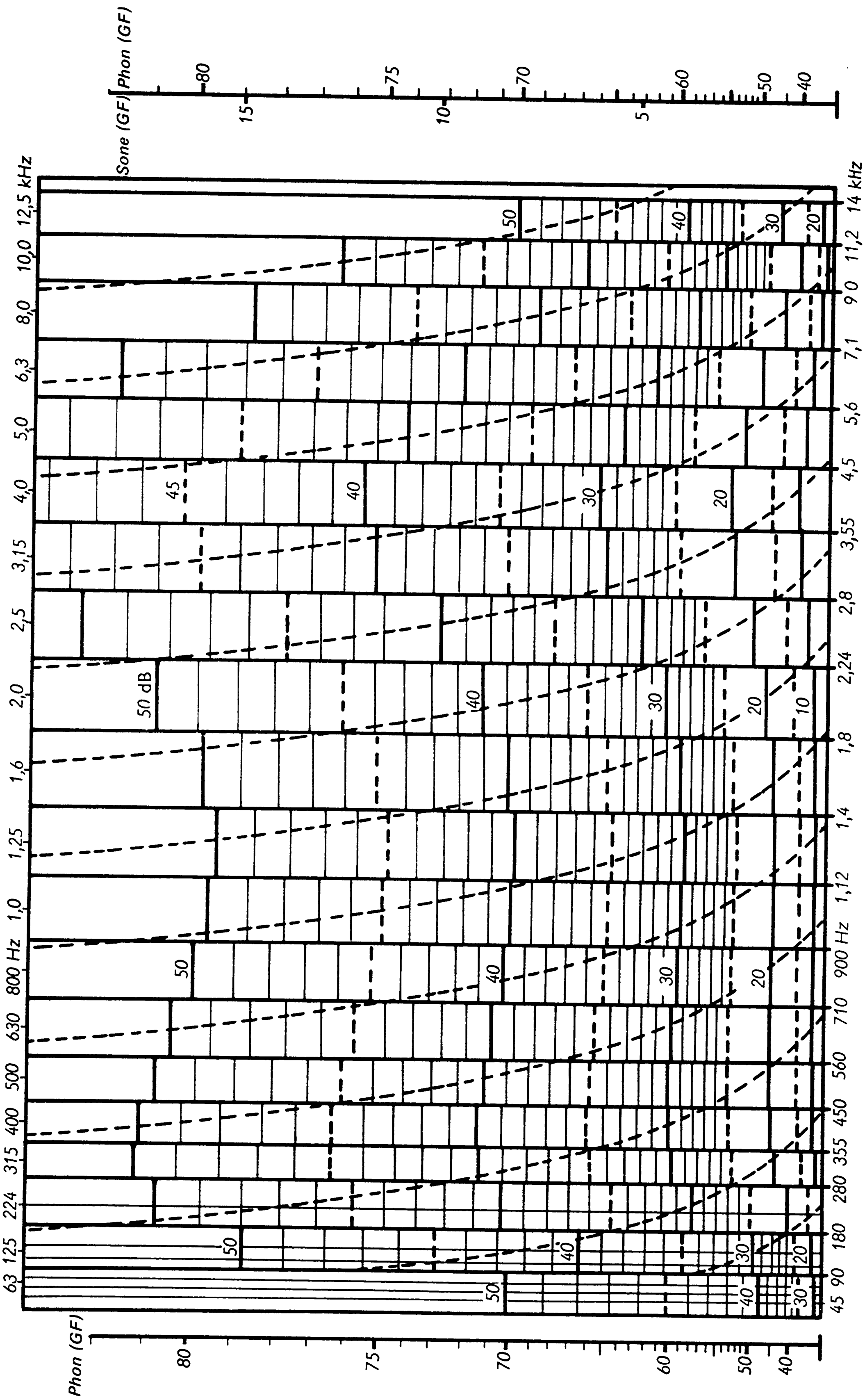


FIGURE 3

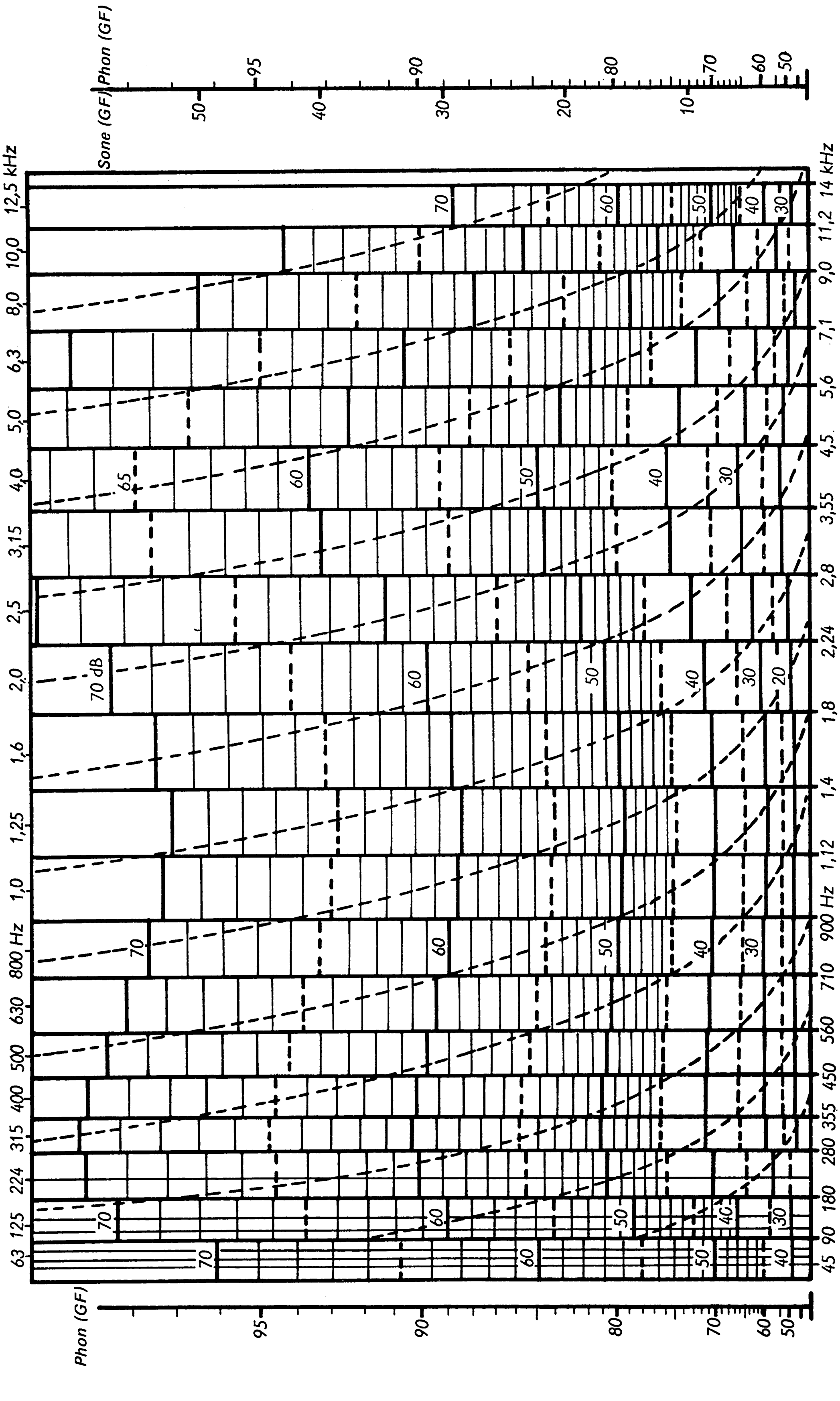

Sone (GF)
Phon (GF)
63
125
224
315
400
500
630
800 Hz
1,0
1,25
1,6
2,0
2,5
3,15
4,0
5,0
6,3
8,0
10,0
12,5 kHz
45
90
180
280
355
450
560
710
900 Hz
1,12
1,4
1,8
2,24
2,8
3,55
4,5
5,6
7,1
9,0
11,2
14 kHz
70 dB

FIGURE 4

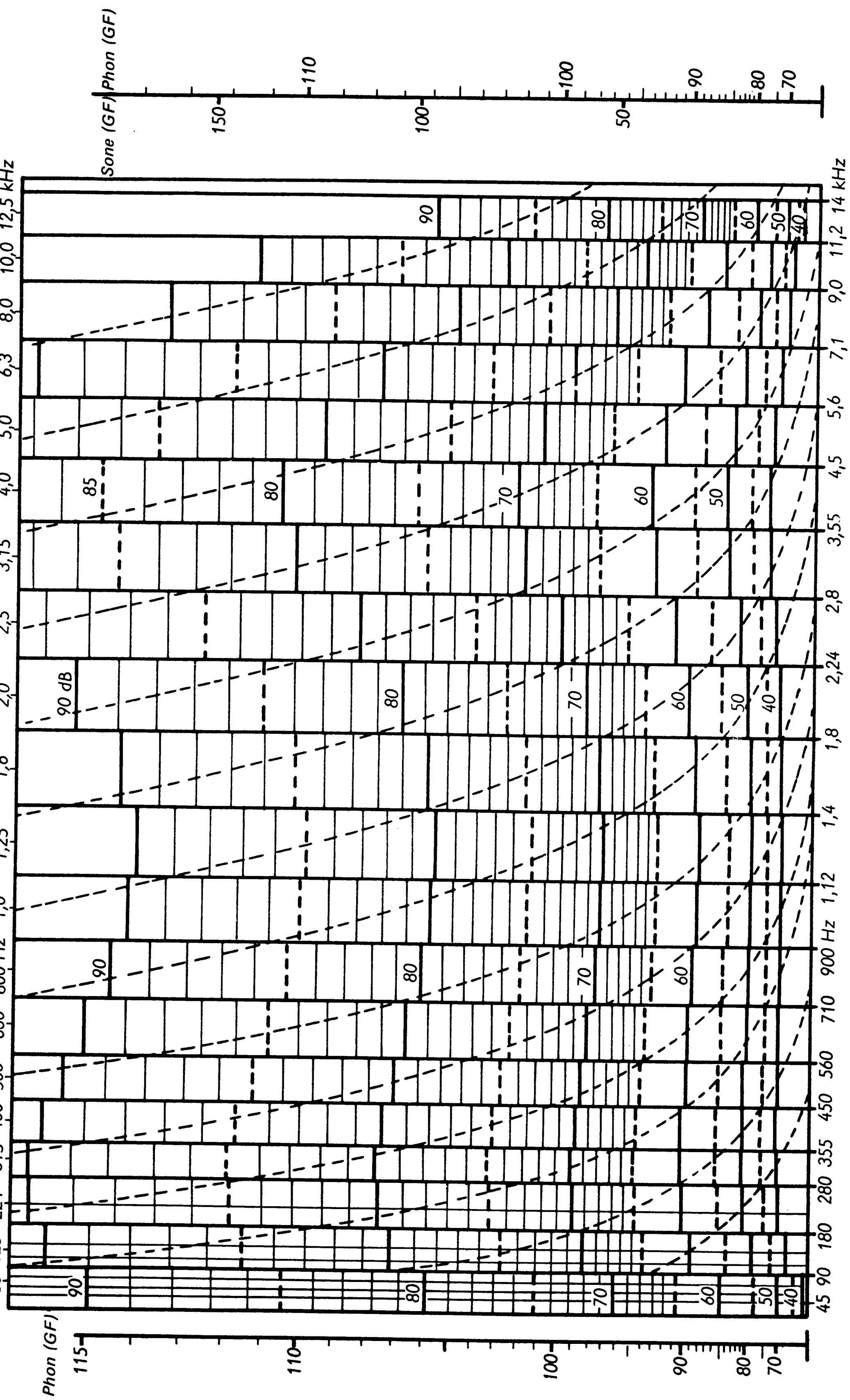

Sone (GF)
Phon (GF)
150
100
50
110
100
90
80
70
63 125 224 315 400 500 630 800 Hz 1,0 1,25 1,6 2,0 2,5 3,15 4,0 5,0 6,3 8,0 10,0 12,5 kHz
45 90 180 280 355 450 560 710 900 Hz 1,12 1,4 1,8 2,24 2,8 3,55 4,5 5,6 7,1 9,0 11,2 14 kHz
90 dB
85
Phon (GF)
115
110
100
90
80
70

FIGURE 5

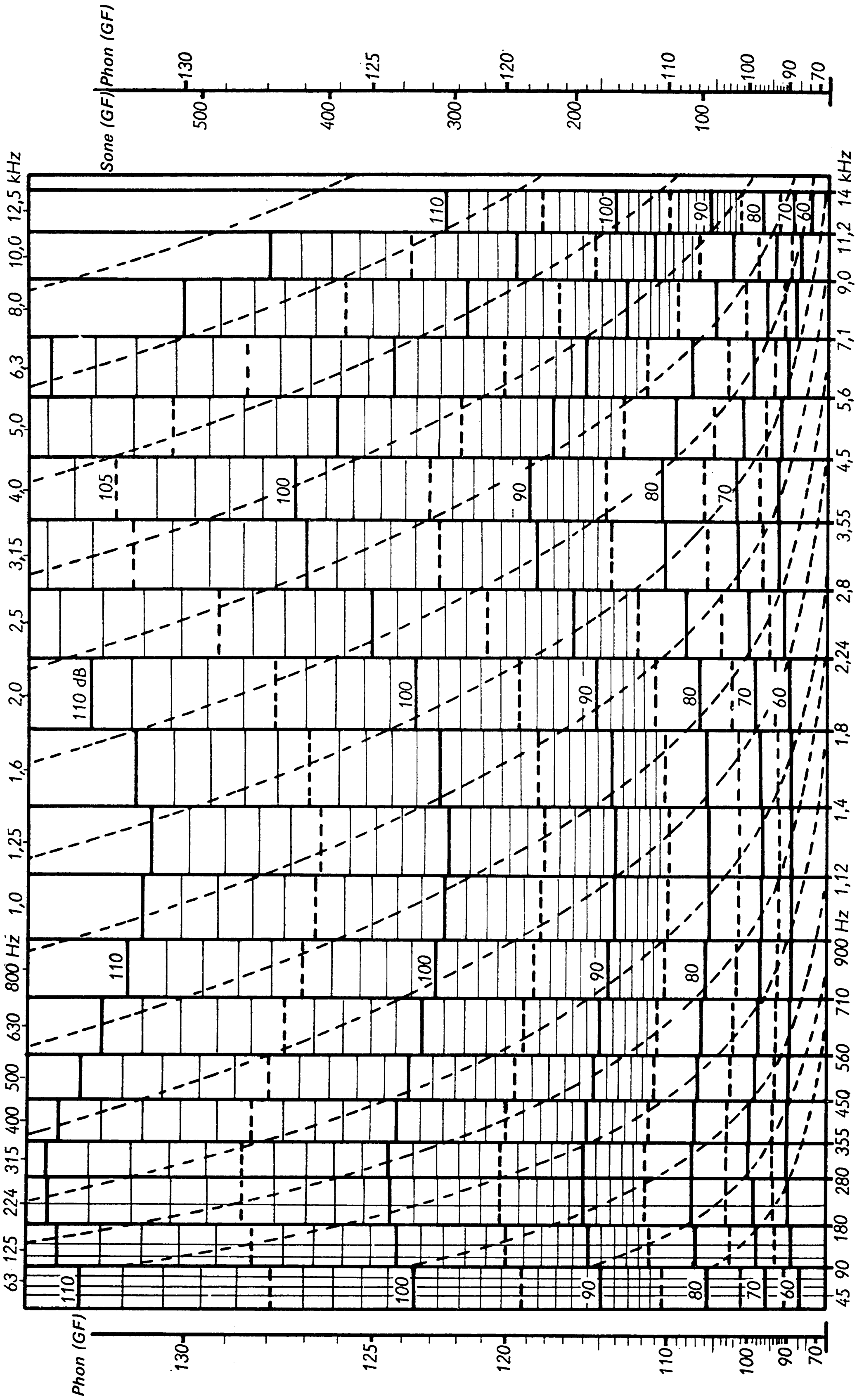

Sone (GF)
Phon (GF)
500
400
300
200
100
130
125
120
110
100
90
70
63 125 224 315 400 500 630 800 Hz 1,0 1,25 1,6 2,0 2,5 3,15 4,0 5,0 6,3 8,0 10,0 12,5 kHz
45 90 180 280 355 450 560 710 900 Hz 1,12 1,4 1,8 2,24 2,8 3,55 4,5 5,6 7,1 9,0 11,2 14 kHz
110 dB
105
80
60
Phon (GF)
130
125
120
110
100
90
70

FIGURE 6

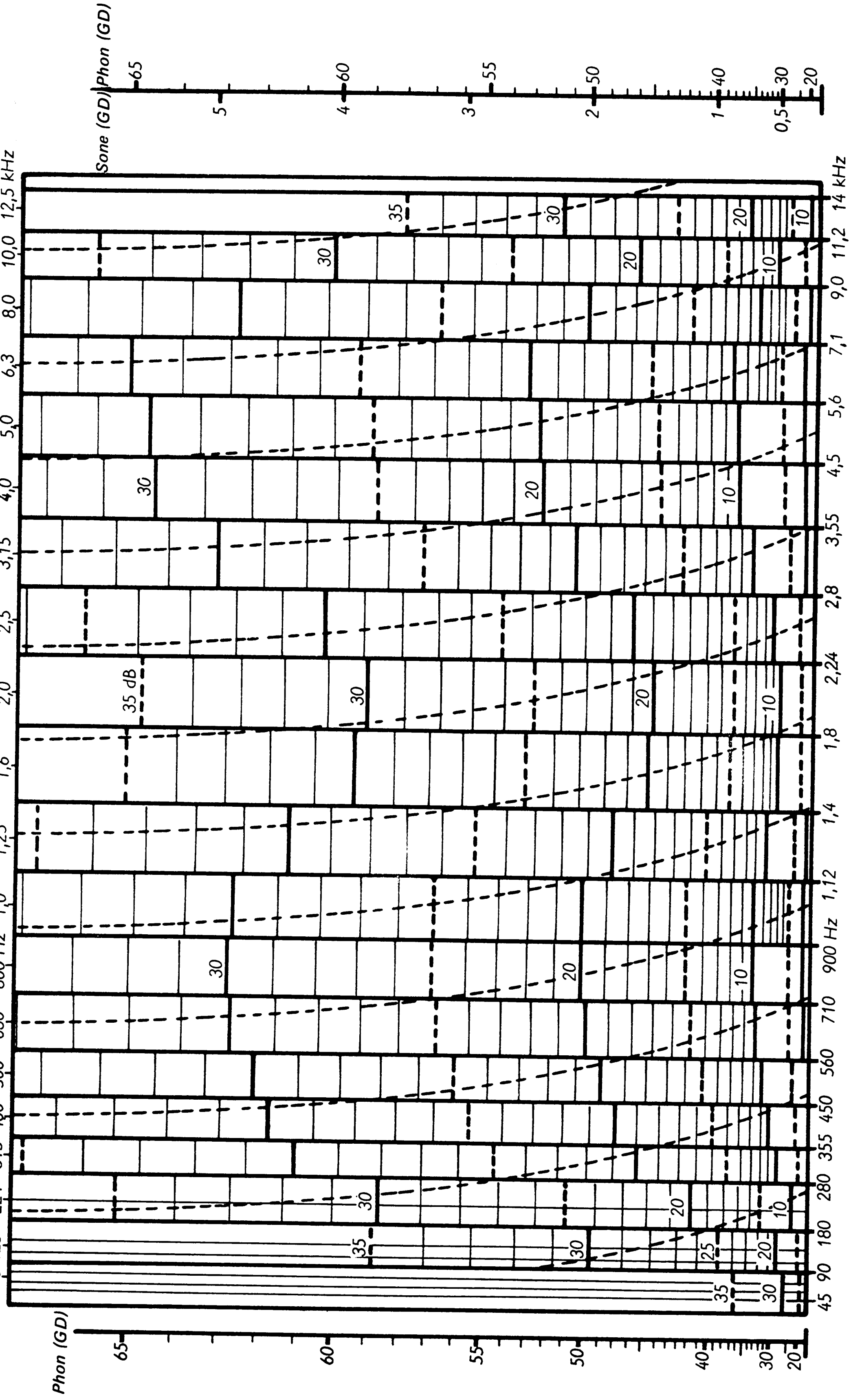

Sone (GD)
Phon (GD)
63 125 224 315 400 500 630 800 Hz 1,0 1,25 1,6 2,0 2,5 3,15 4,0 5,0 6,3 8,0 10,0 12,5 kHz
45 90 180 280 355 450 560 710 900 Hz 1,12 1,4 1,8 2,24 2,8 3,55 4,5 5,6 7,1 9,0 11,2 14 kHz
35 dB

FIGURE 7

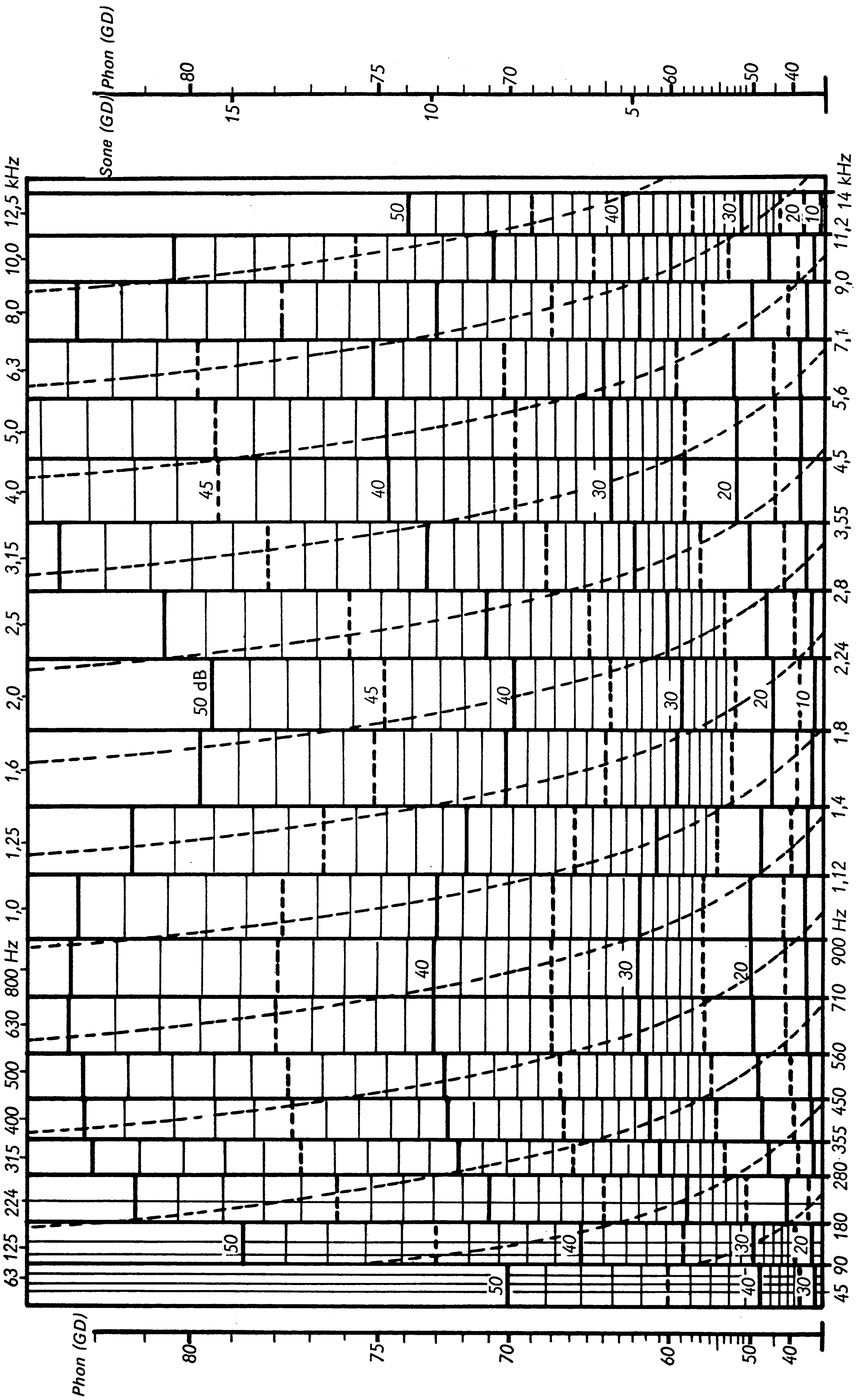
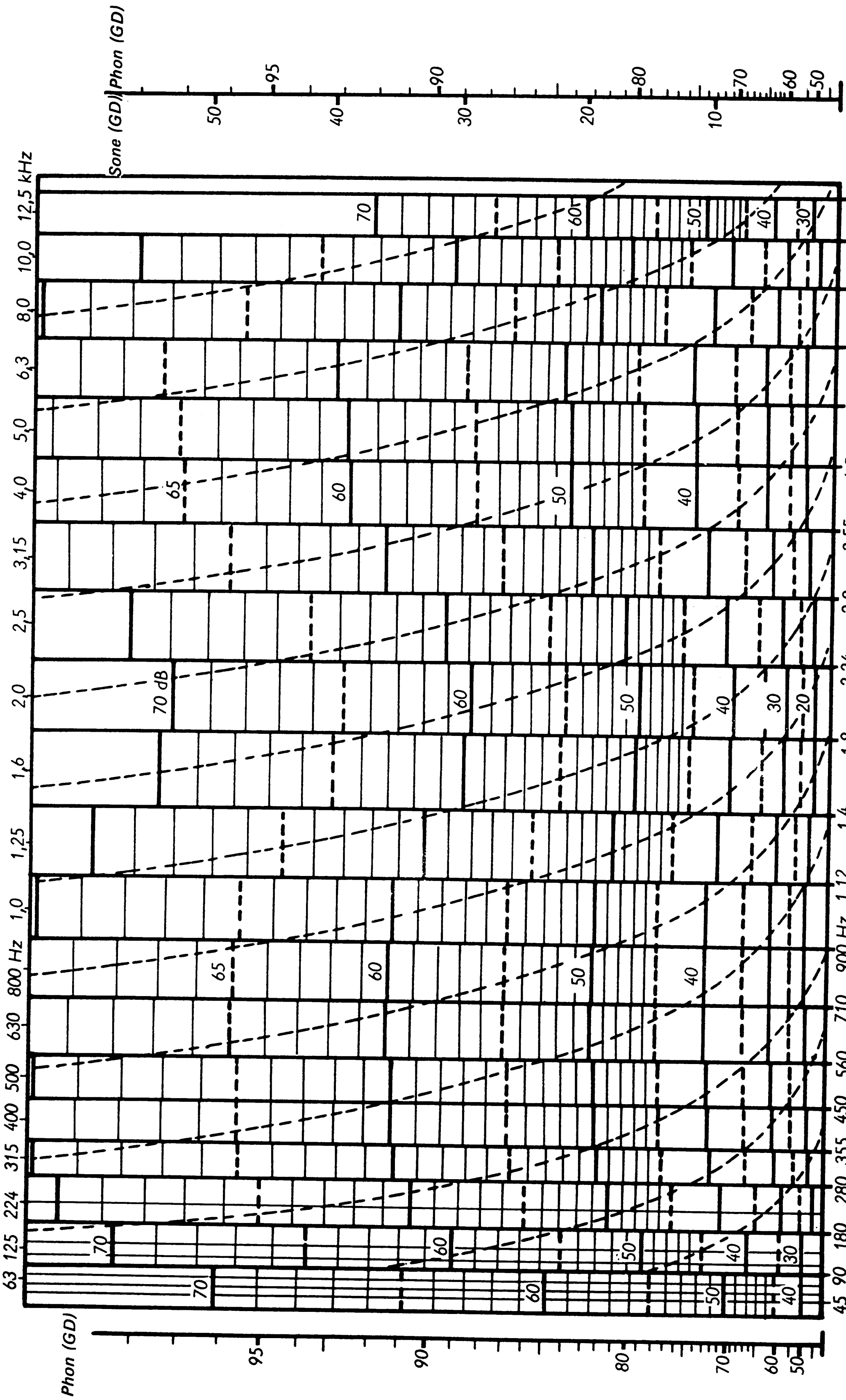

Sone (GD)
Phon (GD)
63 125 224 315 400 500 630 800 Hz 1,0 1,25 1,6 2,0 2,5 3,15 4,0 5,0 6,3 8,0 10,0 12,5 kHz
45 90 180 280 355 450 560 710 900 Hz 1,12 1,4 1,8 2,24 2,8 3,55 4,5 5,6 7,1 9,0 11,2 14 kHz
50 dB

FIGURE 8


Sone (GD)
Phon (GD)
63
125
224
315
400
500
630
800 Hz
1,0
1,25
1,6
2,0
2,5
3,15
4,0
5,0
6,3
8,0
10,0
12,5 kHz
45
90
180
280
355
450
560
710
900 Hz
1,12
1,4
1,8
2,24
2,8
3,55
4,5
5,6
7,1
9,0
11,2
14 kHz
70 dB

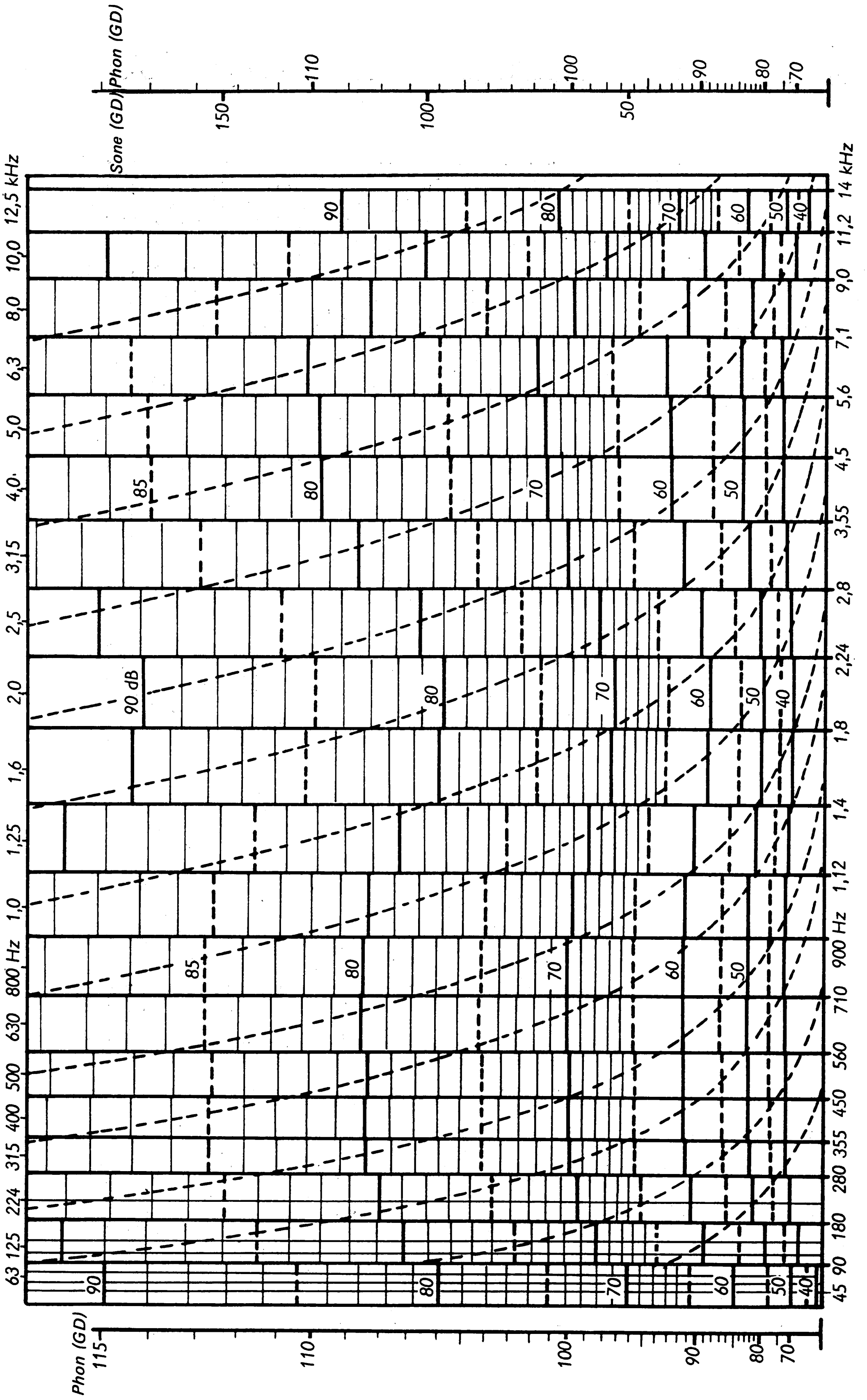

Sone (GD)
Phon (GD)
150
100
50
110
100
90
80
70
12,5 kHz
10,0
8,0
6,3
5,0
4,0
3,15
2,5
2,0
1,6
1,25
1,0
800 Hz
630
500
400
315
224
125
63
14 kHz
11,2
9,0
7,1
5,6
4,5
3,55
2,8
2,24
1,8
1,4
1,12
900 Hz
710
560
450
355
280
180
90
45
90 dB
85
80
70
60
50
40
Phon (GD)
115
110
100
90
80
70

FIGURE 10

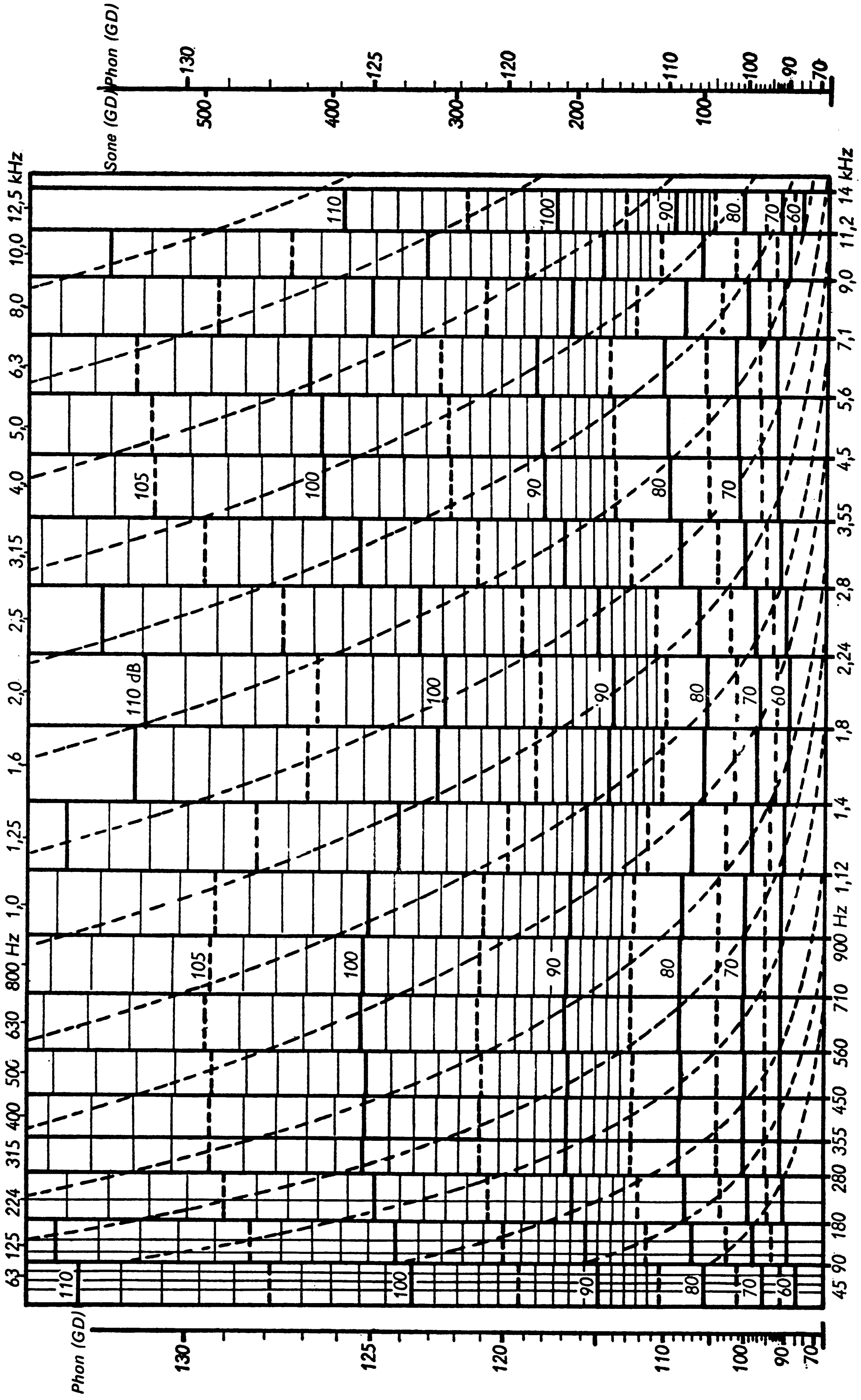


FIGURE 11

ANNEX A

BIBLIOGRAPHIC REFERENCES (Method A)

1) STEVENS, S. S., *Journal of the Acoustical Society of America*, **28**, 807 (1956).

3) STEVENS, S. S., *Journal of the Acoustical Society of America*, **33**, 1577 (1961).

3) CREMER, L., PLENGE, G., and SCHWARZE, D., *Acustica*, **9**, 65 (1959).

ANNEX B

BIBLIOGRAPHICAL REFERENCES (Method B)

1) ZWICKER, E., *Acustica*, **10**, 304 (1960).

2) ZWICKER, E., *Journal of the Acoustical Society of America*, **33**, 248 (1961).