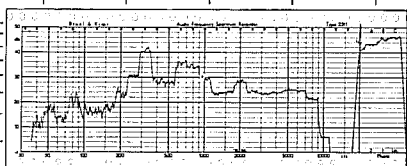
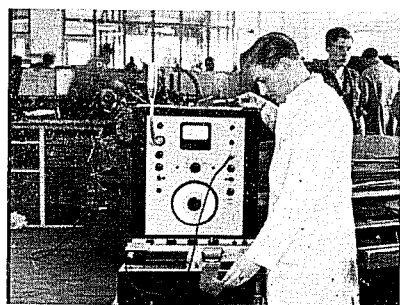


Technical Review

Teletechnical, Acoustical and Medical Research



Noise Measurements
and Analyses



Some Notes on the Practical Aspects of Noise Measurement and Analysis Using B & K Equipment

It is found when noise measurements and analysis are carried out using the indicating meter of instruments such as a Microphone Amplifier or Analyzer that the results apparently differ from those obtained with the Level Recorder. This difference is dependent on the type of rectifying circuit employed in the instruments and the effect is most noticeable when measurements are taken of a random noise after both instruments have been calibrated with a sine wave.

Experiments have shown that calibration of the instruments with a random noise voltage in most cases reduces the difference in indication to only 1—2 db. This may be of importance when the measuring results of one laboratory are compared with results obtained by another laboratory, and the correlation that may be expected between the different types of readings will be discussed in this article. It is based on experiments carried out in one of our laboratories, and is meant as a practical guide for the comparison of noise measurements and analysis.

In order that it be clearly understood why it should be possible to obtain two apparently different measurements on two different instruments which have been calibrated with the same reference signal, the measuring circuits employed and the waveform of the signal to be measured must be considered.

An indicating meter must be fed by a D.C. current, the deflection of the meter being proportional to the current (or to the square of the current). A rectifying circuit must therefore be incorporated before an A.C. voltage can be measured.

Depending upon the properties of the rectifying circuit different deflections are obtained on the meter.

The "value" of an A. C. voltage may be expressed as *the average value* of the voltage, normally defined by the expression:

$$E_{av.} = \frac{1}{T} \int_0^T |e(t)| dt$$

where T is the time interval between two successively following moments of equal phase, see fig. 1.

A second method of expressing the value of the voltage is by means of its *root mean square* (or effective) value, defined by:

$$E_{r.m.s.} = \sqrt{\frac{1}{T} \int_0^T [e(t)]^2 dt}$$

Finally, it is often wanted to know the max. value that the voltage may reach within a certain time interval (a period), and this value is known as the *peak value* of the voltage.

Fig. 1 indicates the significance of the above definitions with regard to a periodic signal of period T .

The rectifying circuit of an instrument can be designed to give a D.C. output voltage proportional to anyone of the three different definitions of the A.C. input voltage given above. Furthermore the rectifier might be designed as a half wave rectifier, i.e. only the positive (or negative) half period of the A.C. voltage is present at its output, or it might be a full wave rectifier. This is illustrated in fig. 2.

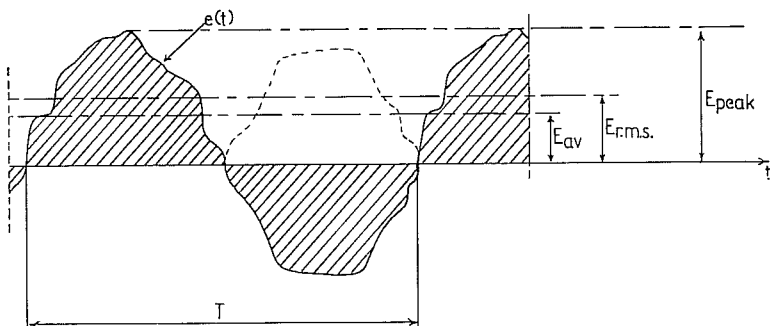


Fig. 1. Example of a periodic signal with indication of the peak, r. m. s. and average value of the voltage.

It is thus obvious that the deflection on the instrument meter will depend upon which type of rectifying circuit is employed.

Normally a rectifier giving a D.C. output voltage proportional to the average value of the A.C. input voltage measured is incorporated in audio frequency measuring instruments.

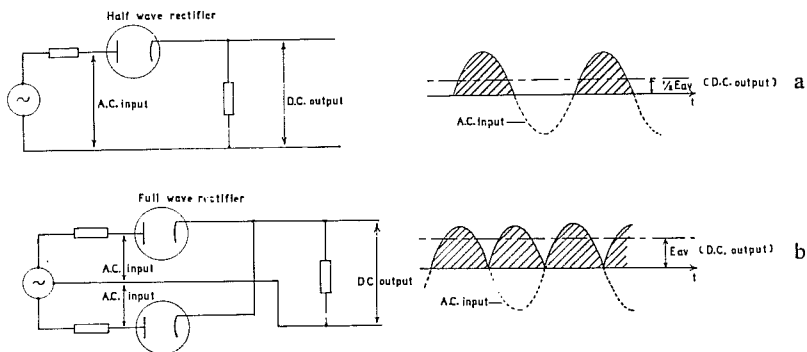


Fig. 2. Basic diagram of a rectifying circuit the output voltage of which is proportional to the average value of the input signal.

a) Half wave rectifier.

b) Full wave rectifier.

When calibrated with a sinusoidal signal the meter scale may be graduated in average, peak or r. m. s. values without any loss of generality, as in this case only a mathematical transformation of the different expressions for the A. C. voltage is necessary. However, when the input A. C. signal is not a sine wave, instruments calibrated with a sine wave voltage will give different readings, depending upon the type of rectifier circuit employed.

Both Microphone Amplifier Type 2602, Audio Frequency Spectrometer Type 2109 and the A. F. voltmeters produced by B & K are supplied with rectifiers, the output voltage of which is proportional to the average value of the A. C. input voltage. The instrument meters are normally calibrated in r. m. s. values of a sinusoidal input signal.

However, the Level Recorder Type 2304 employs a peak value rectifying circuit.

Due to the complicated nature of a noise signal the measured result obtained from the Level Recorder will differ from that obtained by reading off the scale of the instrument meter, both instruments having been originally calibrated by means of a sinusoidal reference signal.

Experimental results have shown that when a random noise signal is used for calibration the difference in measured results obtained from the two types of indications are largely reduced, and some of these experiments will now be discussed.

A number of tests have been carried out and data returned to our laboratory examined in order to determine the degree of correlation that could be expected over a wide range of conditions.

The occasions for comparing these data have almost invariably been a comparison of band type analyses, either octave band or third octave band, read either on a meter or graphically recorded, and therefore the data will be presented in each instance as read both linearly and through a series of filters. These tests were all made on the Audio Frequency Spectrum Recorder Type 2311. The instrument comprises a $\frac{1}{3}$ octave band filter system and associated amplifiers with the standard ASA approved average reading meter in the output. The output of this third octave filter system can likewise be applied to the Level Recorder which is combined with it. It is, therefore, possible to compare the output from the third octave filter system both on the average reading meter and on the Level Recorder. The detection circuit in the average reading meter utilizes a full wave average rectifier and in the case of the Level Recorder the detection circuit is a half wave diode rectifier network.

The objective was to make the following comparisons:

1. To compare the meter reading and the graphic level recording of two different types of signals; random noise and jet engine noise when both instruments had been calibrated with the same signal either random noise or sine wave.
2. To compare the readings on the two different instruments when the calibration has been made on the Level Recorder by taking the overall

reading of the sound level meter as the overall reading for the Level Recorder, arbitrarily selecting a deflection to represent this value.

Many of the natural noises have a Gaussian distribution of amplitude; examples of these are white random noise, noise from jet engines, and other similar broad band noises. For this type of signal, even when both instruments have been calibrated with a sine wave signal, the maximum deviation encountered between the meter reading and the Level Recorder paper indication for any filter setting as well as on "linear" was 3 to 4 db. In Table I, shown below, is an illustration of the readings obtained when white random noise was used to calibrate both instruments and then a 1000 cycle sine wave and 60 cycle sine wave were applied with the same average level. The resulting readings indicate the normal deviation that can be expected for the two different types of signals. The difference in the level obtained for 1000 cycle sine wave calibration and 60 cycle sine wave calibration is attributable to the amplifier gain of the Level Recorder dropping slightly at the 60 cycle point with respect to 1000 cycle.

Table I.

Calibration Signal Comparison on Average Reading Sound Level Meter Type 2109 and Peak Responding Level Recorder Type 2304.

Calibration Signal:	S.L.M. Reading:	Level Recorder Indication:
*) White Noise	100 db	100 db
1000 cycles	100 db	98 db
60 cycles	100 db	97 db

*) Vacuum Tube Noise Amplified.

This shows the type of conditions that might be encountered and illustrates the difference in sound level readings that could be expected. In order to obtain the highest degree of correlation, the recommended procedure is to use the signal to be analysed and take an overall reading from the Sound Level Meter, which will be an average reading, and use this reading to set a corresponding calibration on the Level Recorder. The calibrations now hold for this particular type of signal whatever it may be.

The factors which could introduce inaccuracy when the total noise reading on the Sound Level Meter is used to calibrate the over-all reading of the Level Recorder will now be considered. In those instances where random noise constitutes the background noise of the signal and there are one or more pronounced single resonant frequencies of a more sinusoidal character which are 10 to 30 db higher than the overall white noise background, a difference of up to 2 db can be encountered in the two readings of the level for any single $1/3$ octave band as read on the instrument meter and on the Level Recorder. (For random noise with a frequency drop-off of the order of 6 to 12 db per octave the Level Recorder will read approx. 2 db higher than the meter reading for the filter bands in the upper frequency

range). The filter bands containing the predominant sinusoidal waves will show a reading of approx. 1 db lower on the Level Recorder. These effects are produced primarily by the digression of the wave form of the signals, within any individual pass band, from the overall characteristics of the total signal which is used for the calibration.

In Table II, tape recorded jet engine noise was fed into the Audio Frequency Spectrum Recorder Type 2311 and the sequential filter analysis performed with data being tabulated directly from the average reading meter in the analyzer section and simultaneously recording the level on the peak responding Level Recorder. The instrument meter section and the Level Recorder were both calibrated such that they gave the same overall reading for the jet engine noise. It will be noted that a rather close correlation throughout the entire spectrum has been maintained. Some difficulty was encountered in reading the lower filters because of considerable fluctuation in the readings and a degree of inaccuracy may be attributed to this. A check was made of the difference when the Level Recorder was calibrated with a sine wave signal. The readings differed by as much as 2 to 3 db as would be expected from the previous test.

Table II.

EXAMPLES OF CORRELATION OBTAINABLE

When the Signal for Analysis is Used to Give the Same Overall Reading on Both Average and Peak Responding Instruments.

Filter Frequency	Sound Level Meter Reading	Lev. Rec. Indication	Filter Frequency	Sound Level Meter Reading	Lev. Rec. Indication
linear	110	110	1.600	98	98
16.000	91	91	1.250	98.5	98.5
12.500	96	96	1.000	98	98
10.000	94	94	800	98	97.5
8.000	92.5	92.5	640	98.5	98
6.400	92.5	93	500	97	96
5.000	93.5	94	400	96.5	96
4.000	94.5	94.5	320	97	96
3.200	95.5	95.5	250	96.5	95
2.500	96.5	97	200	95	93
2.000	97.5	98	160	89	88
			125	86	85
			100	86	85
			80	85	84
			64	83	81
			50	89	85
			40	82	82

Readings Difficult Due
to Level Fluctuation

{

Noise Type — Jet Engine Exhaust. N A C A Data.

The greatest degree of deviation between the two types of readings will be encountered in a random type noise with a steep decay slope in the upper spectrum. Such a signal has been utilized in Table III in the form of random noise produced by the first amplifier stage of an instrument.

Fig. 3 shows the total spectrum of the noise as recorded on the Automatic Spectrum Recorder Type 2311 after calibration of the recording paper with the aid of a sine wave reference signal of 60 c/s. The recording was taken with gear wheel D inserted and a paper speed 0.3 mm/sec, allowing a time of 16 sec. for each separate filter. This rather long measuring time is advisable due to the fluctuating nature of the noise with time. A good estimation of the average noise level is thus obtained.

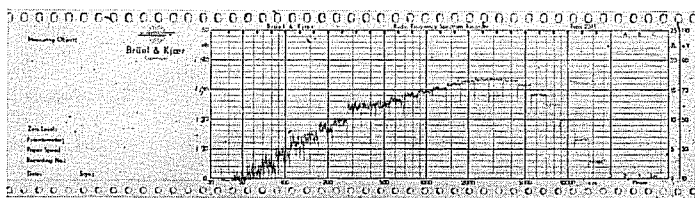


Fig. 3. Spectrogram of the noise produced by the first amplifier stage of an instrument.

Table III.

Comparison of $\frac{1}{3}$ octave meter readings and level recorder chart paper indications after calibration with 60 c/s reference tone, as well as with over all sound level.

Filter Frequency in c/s	S.L.M. Reading	Level Recorder Reading 60 c/s Calibration	Level Recorder Reading; Overall Level Calibration
100	110	118	113 $\frac{1}{2}$
160	118	124	119 $\frac{1}{2}$
250	122	129	124 $\frac{1}{2}$
400	131	135	130 $\frac{1}{2}$
640	132	136 $\frac{1}{2}$	132
1.000	135	139	134 $\frac{1}{2}$
1.600	137	142	137 $\frac{1}{2}$
2.500	138	143 $\frac{1}{2}$	139
4.000	138	143	138 $\frac{1}{2}$
6.400	133	138 $\frac{1}{2}$	134
10.000	123	130	125 $\frac{1}{2}$
16.000	108	115 $\frac{1}{2}$	111
lin.	147	151 $\frac{1}{2}$	147

It is noted that in the "flat" part of the spectrum between 900 and 6400 c/s the difference in S. L. M. reading and Level Recorder indication is rather small

when the overall sound level is used for calibration. Both for the lower and higher frequencies deviations between meter and paper reading is greater. At the lower frequencies the accuracy of the fluctuating meter reading plays a role, but at the higher frequencies the spectrum slope within one filter range is apparently the only reason for the discrepancy. The peak value of the greatest component within one $1/3$ octave filter band contributes more to the peak responding Level Recorder indication than to the average value of the total noise signal as indicated by the Spectrometer meter.

From the described experiments, and other measured results, it is thus found that a calibration of the instruments by means of the overall noise level might be practical in many cases where noise voltages are measured or analyzed. In case the meter reading is too inaccurate for calibration, due to the fluctuations in the noise, a random noise generator can be successfully employed.

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Willem Brand.

ACKNOWLEDGMENT

*Thanks are due to Mr. James W. Day of Brush Electronics Company
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NOISE MEASUREMENTS AND ESTIMATION OF TOTAL LOUDNESS IN SONES BY SPECTRUM ANALYSES

by

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and

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The evaluation of noise from measurements of sound pressure level taken in different frequency bands is of considerable practical interest for all noise reduction work.

Different types of analysis are employed for this evaluation, dividing the noise spectrum into several contiguous frequency bands. A common type of analysis is performed by dividing the spectrum into a number of octave bands. However, bandwidths of $\frac{1}{2}$ octave or $\frac{1}{3}$ octave may also be used, the conversion factors for the evaluation of the loudness in sones are then different from those employed for full octave band analysis.

In most cases an evaluation of the noise level based on $\frac{1}{3}$ octave bandwidth will give far more valuable information with regard to the character of the noise than will be achieved with a $\frac{1}{2}$ octave or octave band analysis.

This article discusses the use of $\frac{1}{3}$ octave bandwidths for noise measurements and indicates how the Audio Frequency Spectrometer Type 2109 (or the Audio Frequency Spectrum Recorder Type 2311) can be applied. The treatment is based on investigations recently made by professor Stevens of the Psycho-Acoustic Laboratory at Harvard University, and a comparison is made between octave band analysis and $\frac{1}{3}$ octave band analysis.

Loudness is a subjective quantity and cannot be measured exactly with any instrument. It is defined as that aspect of auditory sensation in terms of which sound may be gradated on a scale running from "soft" to "loud". It is chiefly a function of the sound pressure level, but it is also dependent on the frequencies and the composition of the sound. The loudness of sound is related to the total wave energy produced by the sound in the ear, whence it is sent to the brain.

To establish a scale of loudness as a function of the sound pressure level in decibels subjective measurements are made with a pure tone. Normally the frequency of this tone is 1000 c/s and a reference level is chosen at 40 db re 2×10^{-4} μ bar = 1 sone. A loudness of 10 sones is then twice as loud as 5 sones and 10 times as loud as 1 sone. Furthermore 1 sone = 1000 millisones. Fig. 1 shows the relationship between loudness in millisones and loudness level in phons. At 1000 c/s the loudness level in phons corresponds to the sound pressure level in db re 2×10^{-4} μ bar.

However, the loudness of a sound of a given sound pressure level at one frequency may be quite different from the loudness of a sound of the same sound pressure level at a different frequency. By subjective measurements listeners can adjust the loudness of one tone to match the loudness of another tone. The results obtained from such experiments can be plotted in a fre-

quency-decibel chart and are referred to as equal loudness contours. Equal loudness contours for pure tones are shown in fig. 2.

It is also possible to determine equal loudness contours for other sounds than pure tones e.g. a random type noise. The normal procedure is then, by means of filters, to cut out certain frequency bands of the noise under consideration and compare the loudness of these bands with that of a 1000 c/s pure tone. The shape of the equal loudness contours will then depend upon the bandwidth of the filters employed for the measurements.

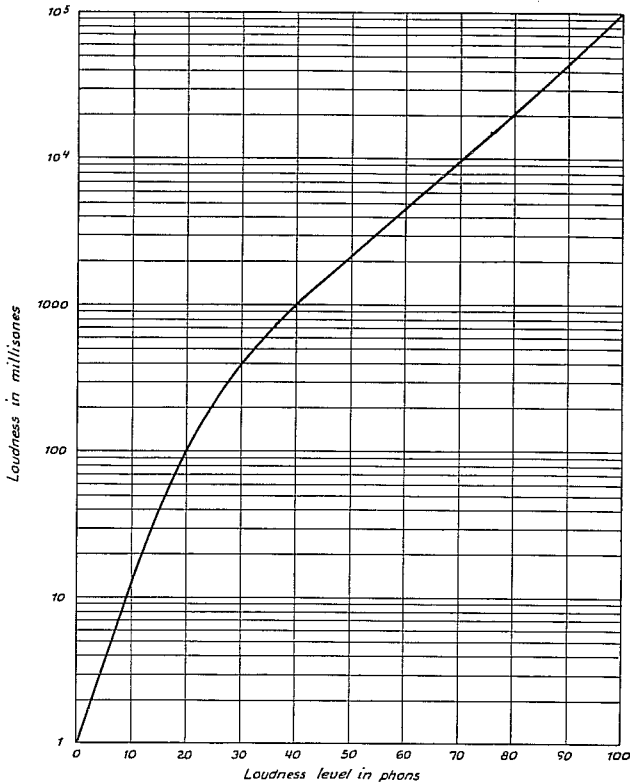


Fig. 1. Loudness in sones as a function of the loudness level in phons.

Because of the introduction of phons which indicate the dependency of loudness upon frequency (see fig. 2) the curve of fig. 1 applies to sound of any frequency, or combination of frequencies. If the loudness level of a sound is 40 phons, it will have a loudness of 1000 millisoness, if the loudness level is 70 phons, it will have a loudness of 10,000 millisoness. A reduction of the loudness level from 70 to 40 phons then corresponds to a tenfold change in loudness.

In equivalent tone methods of noise loudness calculation the following procedure has been employed up to now:

1. The noise is divided into several contiguous frequency bands.
2. The sound pressure level of each band is measured.
3. The measured sound pressure level in each band is treated as if it was concentrated at a frequency in the middle of the band, and a value of loudness in sones is then calculated for each mid-frequency.
4. The values from 3 are added arithmetically, whereby the total loudness is determined.

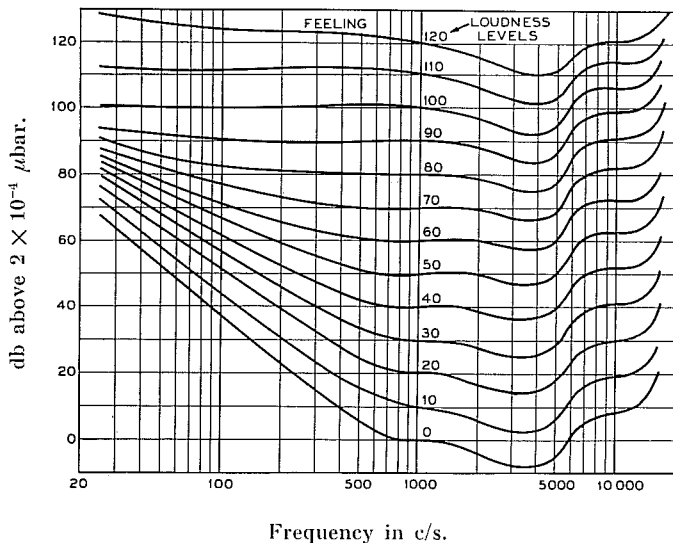


Fig. 2. Sensitivity curves of the human ear (Fletcher - Munson).

For practical noise measurements with the Spectrometer Type 2109 or Audio Frequency Spectrum Recorder Type 2311 the division into frequency bands according to point 1. is fixed. The total spectrum is divided in 27 contiguous $\frac{1}{3}$ octave bands ranging from 35.5 — 45 — 56 — 71 — 90 — 112 — 140 — 180 — 224 — 280 — 355 . . . 14000 — 18000 c/s.

Point 2 concerns the actual measurement of the noise level within each $\frac{1}{3}$ octave band. When using Spectrometer Type 2109 the value read off the meter indicates the r.m.s. value of a pure sinusoidal voltage. However, the meter itself is of the average type and for random noise the reading will be approx. 1 db lower than the actual r.m.s. value of this type of signal. (see Beranek: Acoustic Measurements, p. 453). The rectifier and meter system in Type 2109 correspond exactly to the new proposed standards which will be approved officially by A. S. A. very shortly.

In case the Level Recorder of the Audio Frequency Spectrum Recorder Type 2311 is used as indicating instrument care should be taken regarding the calibration of the instrument because the detector circuit employed in the Level Recorder gives an output voltage corresponding to the peak value of the input signal.

A useful method of calibration is described in the preceding article, and shows that it might be carried out by means of an overall reading of the total noise level, the Spectrometer filter switch being in position "Linear".

Point 3 in the procedure to be followed when loudness calculations are made gives rise to some difficulties. In principle the problem does not look complicated at all. However, different methods are unfortunately employed for the estimation of the sone value corresponding to the sound pressure level measured for each separate frequency band. Large discrepancies are thus found in practice when different measurements are compared, even if the measurements are taken with one and the same noise source.

The largest discrepancy can be expected where the loudness of the noise, based on an octave band analysis, is compared to the loudness calculated from measurements with frequency bands of $1/3$ octave.

As previously mentioned, the conversion chart for evaluation of loudness in sones is based on a family of curves of equal loudness expressed in phons.

When phon curves are established for all kinds of noises and bandwidths the determination of loudness in sones follows immediately.

However, for $1/3$ octave bands of white random noise there still exists no equal loudness contours based on sufficient subjective measurements.

IBM has therefore, for routine measurements, established conversion tables based on fig. 1 and fig. 2. Table I illustrates the use of these tables, showing how the measured sound pressure levels are converted into their respective sone values.

Table I.

1000 c/s $1/3$ octave band	200 c/s $1/3$ octave band
20 db = 0.10 sone	40 db = 20 phon = 0.10 sone
30 db = 0.34 sone	46 db = 30 phon = 0.34 sone
40 db = 1.00 sone	53 db = 40 phon = 1.00 sone
50 db = 2.15 sone	59 db = 50 phon = 2.15 sone
60 db = 4.64 sone	66 db = 60 phon = 4.65 sone
70 db = 10.00 sone	73 db = 70 phon = 10.00 sone
80 db = 21.60 sone	81 db = 80 phon = 21.60 sone
90 db = 47.00 sone	90 db = 90 phon = 47.00 sone
100 db = 100.00 sone	100 db = 100 phon = 100.00 sone

A similar type of conversion table is given in the Handbook of Noise Measurements published by General Radio Co.²⁾ The data given in the hand-

book are valid for octave band analysis, and are no more based on fig. 2 but on the equal loudness contours shown in fig. 3.

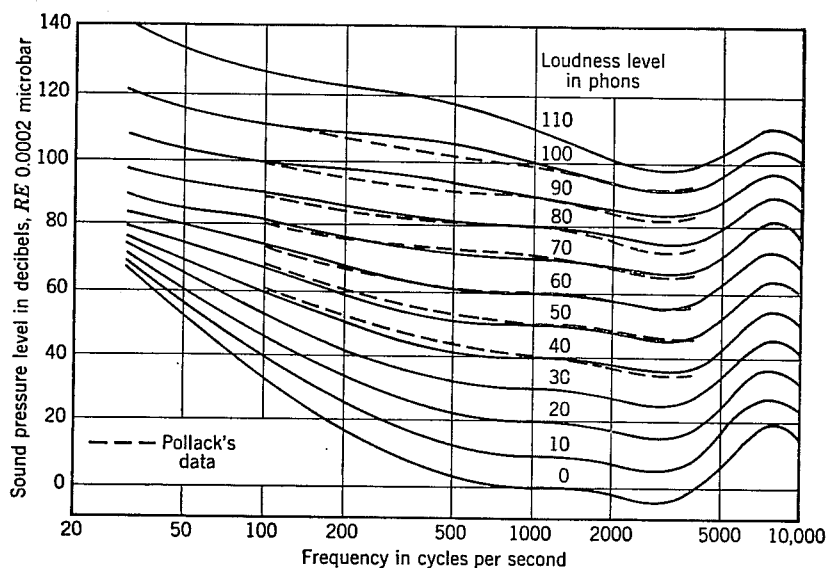


Fig. 3. Equal loudness contours for pure tones by Curcher-King and for a 250-mel band of noise by Pollack.

It should be noted that the frequency bands used to obtain these equal loudness contours were not actually 1 octave wide, but had subjectively felt equal widths for the average listener, expressed in mels. As equal bands of mels do not correspond to octave bands, the application of these data is open to discussion.⁹⁾

Table II.

600—1200 c/s octave band		150—300 c/s octave band (fig. 3)		212 c/s (according to fig. 2)	
20 db	0.10 sones	38 db	0.26 sones	38 db =	20 phon = 0.10 sones
30 db	0.36 sones	44 db	0.58 sones	44 db =	30 phon = 0.36 sones
40 db	1.00 sones	51 db	1.20 sones	51 db =	40 phon = 1.00 sones
50 db	2.15 sones	59 db	2.40 sones	59 db =	50 phon = 2.15 sones
60 db	4.60 sones	65 db	4.10 sones	65 db =	60 phon = 4.60 sones
70 db	10.00 sones	72 db	7.80 sones	72 db =	70 phon = 16.00 sones
80 db	22.00 sones	80 db	14.50 sones	80 db =	80 phon = 22.00 sones
90 db	47.00 sones	90 db	30.00 sones	90 db =	90 phon = 47.00 sones
100 db	100.00 sones	100 db	58.00 sones	100 db =	100 phon = 100.00 sones

From table II is seen that for the 600—1200 c/s octave band the sone values (or transfer values as they are called in the Handbook) correspond di-

rectly with fig. 1. For the 150—300 c/s band, however, (mean frequency 212 c/s) the difference in sone values when derived from fig. 2 or fig. 3 are quite evident.

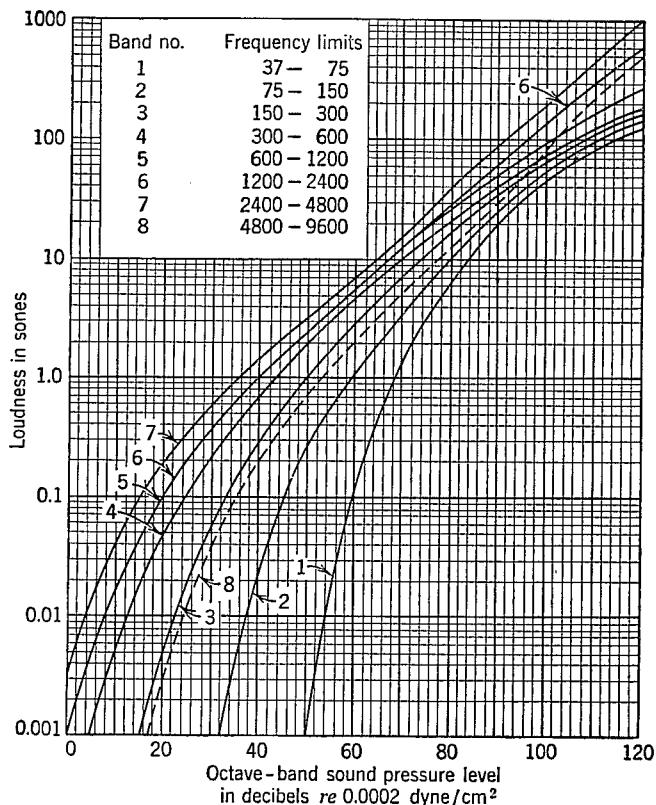


Fig. 4. Chart for converting from octave-band levels in decibels to loudness in sones. The chart is strictly accurate only for continuous spectrum noises. The total loudness of a wide-band continuous spectrum noise is determined by adding together the loudness for each band. (After Beranek and Peterson).

Fig. 4 shows a graph from which the sone value can be directly found when the sound pressure level is measured in db re 2×10^{-4} μ bar, without employing fig. 3. The graph is based on octave band analysis, and a somewhat similar chart has been published in the manual for the Spectrometer Type 2109, which might be used when a bandwidth of $1/3$ octave is employed.

At the meeting of the Acoustical Society of America in December 1955 Professor Stevens of the Psycho-Acoustic Laboratory at Harvard University proposed a new method of calculating the total loudness in sones. According to results obtained from subjective tests the assumption that loudness bands

should be added to yield the total loudness value is, in his opinion, wrong. The tests show that the loudness of each separate band can be combined according to the formula

$$S_t = S_m + F (\Sigma s - S_m)$$

S_t is the loudness in sones of the total noise, S_m the loudness of the loudest band, Σs the sum of the loudness of all bands together, and F a factor which varies with the conditions under which measurements are taken. For octave band measurements F has a value around 0.27, and for $1/3$ octave measurements F should lie between 0.11—0.16.

Employing the formula given by Professor Stevens combined with the data prepared by IBM, discrepancies between calculations based on octave band analysis and those based on the use of $1/3$ octave bands can be almost eliminated.

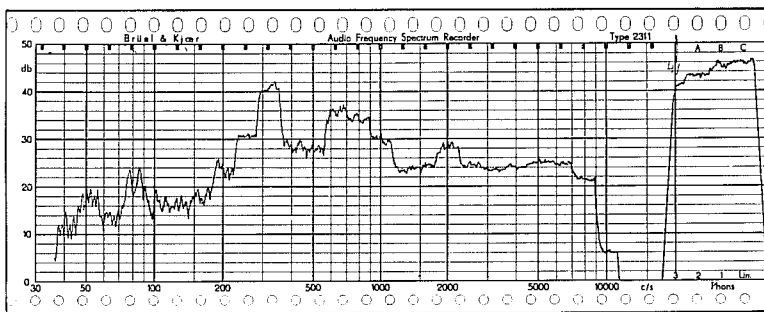


Fig. 5. Spectrogram of a small lathe.

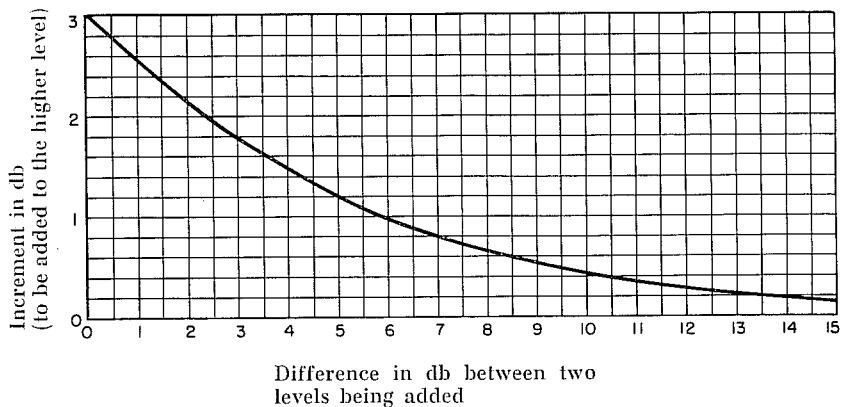


Fig. 6. Chart for combining noise levels (G.R. Handbook of noise measurement).

Fig. 5 shows the spectrogram of the noise from a small lathe, and in table III the calculations of the total loudness in sones are given. Using the IBM-tables for conversion of sound pressure levels in db into loudness values in sones, and applying the above formula an exactly equal total loudness is found.

The factor $F = 0.15$ is chosen to show how the results of these two different types of analysis can be brought into complete agreement.

Even if a factor $F = 0.13$ is chosen (average value of the interval 0.11—0.16 given by Stevens), the result is still quite satisfactory.

Table III.

Mid-frequency of $\frac{1}{2}$ octave filter c/s	Sound pressure level in db (measured with 2311)	Loudness value according to IBM-tables (sones)	Equivalent octave band	Equivalent S.P.L. in db for octave band	Loudness value according to IBM tables (sones)
40	32	0	35.5— 71	40	0
50	38	0			
63	33	0			
80	41	0			
100	37	0	71— 140	43	0
125	36	0			
160	38	0			
200	44	0.23	140— 280	52	0.86
250	51	1.11			
315	61	3.92 (1.55)			
400	48	1.47	280— 560	61	4.80
500	48	1.67			
630	56	3.42 (1.59)			
800	54	2.93	560—1120	59	4.30
1000	50	2.15			
1250	44	1.36			
1600	44	1.36	1120—2240	51	2.33
2000	49	2.01			
2500	45	1.63			
3150	44	1.63	2240—4480	49	2.51
4000	44	1.75			
5000	45	1.47			
6400	45	0.83	4480—8960	49	1.15
8000	41	0.98			
10000	26	0			
$\Sigma = 29.92$ sones			$\Sigma = 15.95$ sones		

Total loudness:
(Bandwidths of $\frac{1}{3}$ octave)
 $S_t = S_m + 0.15 (\Sigma s - S_m)$
 $S = 3.9 + 0.15 \times 26 =$
 7.8 sones

Total loudness:
(Bandwidths of 1 octave)
 $S_t = S_m + 0.27 (\Sigma s - S_m)$
 $4.8 + 0.278 \times 11.15 =$
 7.8 sones

For the sake of comparison the important methods known until now concerning the conversion of spectrum measurements into a total loudness value, are listed below.

The different methods are then applied to the noise spectrum of the small lathe, as shown in fig. 5 and the discrepancies are clearly noticed.

1. The sound pressure levels in db re 2×10^{-4} μ bar for different octave bands are converted into their respective sone values with the aid of fig. 4 and added arithmetically (Octave band analysis).
2. The sound pressure levels in db for different $1/3$ octave bands are converted into their respective sone values with the aid of fig. 7. The curves shown in fig. 7 are the same as the curves originally published in the manual for Type 2109. ($1/3$ Octave band analysis).
3. The sound pressure levels in db for different octave bands are converted into their respective sone values with the aid of the IBM tables, and Stevens' formula for octave band analysis applied to obtain the total loudness.
4. The sound pressure levels in db as measured with the Spectrometer Type 2109 are converted into their respective sone values with the aid of the IBM tables, and Stevens' formula for $1/3$ octave analysis applied to obtain the total loudness.

The evaluation according to method 1) is shown in table IV. The total loudness in sones is then 16,0 sones which corresponds to a weighted total sound pressure level of approx. 77 phons (see also fig. 1).

Table IV.

Octave band	S. P. L. in db re 2×10^{-4} μ bar	Loudness in sones
35.5 — 71 c/s	40	0
71 — 140 c/s	43	0.06
140 — 280 c/s	52	1.2
280 — 560 c/s	61	4.4
560 — 1120 c/s	59	5
1120 — 2240 c/s	51	2.7
2240 — 4480 c/s	49	2
4480 — 8960 c/s	49	0.6
		Total loudness: 16.0

By employing method 2), a total loudness in sones of 10.1 sones is found, which corresponds to a weighted total sound pressure level of approx. 71 phons. See also table V.

The evaluation of the total loudness according to method 3 is given previously (Table III, p. 15), resulting in a total loudness of 7,8 sones, which corresponds to a weighted total sound pressure level of 67 phons.

Table V.

$\frac{1}{3}$ octave Band (Center Frequency, c/s)	S. P. L. in db re 2×10^{-4} μ bar	Loudness in sones
40	32	0
50	38	0
63	33	0
80	41	0.001
100	37	0.003
125	36	0.009
160	38	0.042
200	44	0.18
250	51	0.4
315	61	1.2
400	48	0.5
500	48	0.55
630	56	1.55
800	54	1.1
1000	50	0.8
1250	44	0.47
1600	44	0.47
2000	49	0.75
2500	45	0.62
3150	44	0.61
4000	44	0.56
5000	45	0.55
6400	45	0.13
8000	41	0.004
10000	26	0
Total loudness:		10.099

However, employing the IBM tables for octave band analysis, the conversion from decibels to sones should be performed at the following frequencies:

<i>Band Limits:</i>	<i>Frequency:</i>
37.5— 75 c/s	50 c/s
75 — 150 c/s	100 c/s
150 — 300 c/s	200 c/s
300 — 600 c/s	400 c/s
600 —1200 c/s	800 c/s
1200 —2400 c/s	1600 c/s
2400 —4800 c/s	3150 c/s
4800 —9600 c/s	6300 c/s

Exactly the same result is obtained when employing method 4 for the evaluation and choosing the value 0.15 for F .

The reading on the meter (or rather on the recording) for the weighted sound pressure level also gives 67 phons.

To obtain an idea of the inaccuracy of the loudness evaluation due to the choice of a "wrong" F -factor in Stevens' formula for $1/3$ octave analysis, the lower limit for this factor ($F = 0.11$) gives for the noise Spectrum of fig. 5:

Total loudness:	6.76 sones
Total weighted S.P.L.:	approx. 63 phon

Until a reliable set of equal loudness contours for $1/3$ octave and one octave white random noise measurements is published, it is difficult to advise any specific method of evaluation. It seems however, that the method proposed by Stevens, when properly used, will give quite satisfactory results.

The advantage of $1/3$ octave type of sound-spectra analyses, compared with one octave measurements, lays not so much in the establishment of an overall subjective loudness value of any particular noise, but in the details it gives to the noise abatement engineer, trying to ascertain in which direction his endeavours to silence the noise source under consideration should be directed. The spectrum shown in fig. 5 indicates clearly that certain parts of this machinery radiate a considerable amount of sound energy in the narrow frequency range 280—350 c/s. The second harmonic, possibly generated through a 1:2 gear connection, is also prominent.

From table III it follows that, reducing the noise 10 db in these two bands only, e.g. by appropriate sound insulation of the gear box, the sone values are more than halved (figures within brackets). The total loudness will then be $S_t = 2.93 + 0.15 \times 25.72 = 6.8$ sones.

The octave band analysis shows a constant level of approx. 60 db over the total range of two whole octaves from 280—1120 c/s, and does not give sufficient information as to where a successful noise reduction technique should be applied.

It is interesting to see how the new addition rule, given by Professor Stevens, even more than before, emphasizes the importance of the loudest part of the considered noise spectrum.

An analysis based on $1/3$ octave bands will therefore be of more value to the abatement engineer than will an analysis based on 1 octave bands.

The evaluation of the measurements as described in this article has been based on the assumption of ideal filters, i.e. filters having zero insertion loss in the passband and infinite attenuation outside this band.

No practical filters have such characteristics, and a method of correcting the results taking the finite slope of the actual filter curve into account is given in General Electric Report No. R53 GL 119—1.⁴) For the Audio Frequency Spectrometer Type 2109 this correction factor will be of the order of 0.2 to 0.6 db for white random noise and should be subtracted from the measured noise level before using the IBM conversion tables.

References:

- 1) Lecture given by Professor Stevens at the december meeting of the Acoustical Society of America in Providence 1955.
- 2) G. R. Handbook of Noise Measurements, p. 73. General Radio Company, 1953.
- 3) J. A. S. A. Vol. 23, 1951, p. 261—269.
- 4) General Electric Report No. R53 GL 119—1, p. 32—50.

Acknowledgment.

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APPENDIX I.

LOUDNESS CONVERSION TABLES

(I. B. M.)

SOUND PRESSURE LEVEL IN DECIBELS TO LOUDNESS IN SONES

DB	40~	DB	50~	DB	63~	DB	80~	DB	100~	DB	125~	DB	160~
40		40		40		40		40		40		40	
41		41		41		41		41		41		41	
42		42		42		42		42		42		42	
43		43		43		43		43		43		43	0.10
44		44		44		44		44		44		44	0.12
45		45		45		45		45		45		45	0.15
46		46		46		46		46		46		46	0.18
47		47		47		47		47		47	0.10	47	0.23
48		48		48		48		48		48	0.12	48	0.28
49		49		49		49		49		49	0.15	49	0.34
50		50		50		50		50		50	0.18	50	0.40
51		51		51		51		51	0.10	51	0.23	51	0.47
52		52		52		52		52	0.12	52	0.28	52	0.54
53		53		53		53		53	0.15	53	0.34	53	0.63
54		54		54		54		54	0.18	54	0.41	54	0.73
55		55		55		55	0.10	55	0.23	55	0.49	55	0.86
56		56		56		56	0.13	56	0.28	56	0.58	56	1.00
57		57		57		57	0.16	57	0.34	57	0.70	57	1.17
58		58		58		58	0.21	58	0.42	58	0.84	58	1.36
59		59		59		59	0.27	59	0.52	59	1.00	59	1.59
60		60		60	0.10	60	0.34	60	0.65	60	1.17	60	1.85
61		61		61	0.14	61	0.42	61	0.81	61	1.36	61	2.15
62		62		62	0.18	62	0.52	62	1.00	62	1.59	62	2.40
63		63		63	0.25	63	0.65	63	1.17	63	1.85	63	2.70
64		64	0.10	64	0.34	64	0.81	64	1.36	64	2.15	64	3.00
65		65	0.14	65	0.42	65	1.00	65	1.59	65	2.45	65	3.34
66		66	0.18	66	0.52	66	1.21	66	1.85	66	2.78	66	3.72
67		67	0.25	67	0.65	67	1.47	67	2.15	67	3.16	67	4.16
68	0.10	68	0.34	68	0.81	68	1.78	68	2.51	68	3.61	68	4.64
69	0.12	69	0.45	69	1.00	69	2.15	69	2.93	69	4.07	69	5.17
70	0.18	70	0.58	70	1.29	70	2.51	70	3.42	70	4.64	70	5.79
71	0.25	71	0.77	71	1.67	71	2.93	71	3.98	71	5.29	71	6.46
72	0.34	72	1.00	72	2.15	72	3.42	72	4.64	72	5.99	72	7.20
73	0.49	73	1.29	73	2.61	73	3.98	73	5.40	73	6.81	73	8.02
74	0.70	74	1.67	74	3.16	74	4.64	74	6.30	74	7.77	74	9.00
75	1.00	75	2.15	75	3.83	75	5.40	75	7.35	75	8.79	75	10.00
76	1.29	76	2.78	76	4.64	76	6.30	76	8.60	76	10.00	76	11.47
77	1.67	77	3.61	77	5.62	77	7.35	77	10.00	77	11.47	77	12.90
78	2.15	78	4.64	78	6.81	78	8.60	78	11.47	78	12.90	78	14.80
79	2.78	79	5.62	79	8.26	79	10.00	79	12.90	79	14.80	79	16.80
80	3.61	80	6.81	80	10.00	80	11.70	80	14.80	80	16.80	80	19.05
81	4.64	81	8.26	81	11.47	81	13.70	81	16.80	81	19.05	81	21.60
82	5.99	82	10.00	82	12.90	82	16.00	82	19.05	82	21.60	82	23.60
83	7.77	83	11.70	83	14.80	83	18.60	83	21.60	83	24.00	83	25.70
84	10.00	84	13.70	84	16.80	84	21.60	84	24.20	84	26.30	84	28.06
85	12.20	85	16.00	85	19.05	85	24.20	85	27.18	85	29.10	85	30.54
86	14.80	86	18.60	86	21.60	86	27.18	86	30.28	86	31.90	86	33.28
87	17.95	87	21.60	87	24.76	87	30.28	87	33.56	87	35.24	87	36.32
88	21.60	88	25.30	88	28.06	88	33.56	88	37.38	88	38.50	88	39.52
89	25.30	89	29.50	89	31.90	89	37.38	89	41.92	89	42.56	89	42.88
90	29.50	90	34.40	90	36.32	90	41.92	90	47.00	90	47.00	90	47.00
91	34.40	91	40.20	91	41.04	91	47.00	91	51.00	91	51.00	91	51.00
92	40.20	92	47.00	92	47.00	92	51.30	92	55.00	92	55.00	92	55.00
93	47.00	93	51.90	93	51.90	93	55.72	93	59.00	93	59.00	93	59.00
94	52.20	94	56.80	94	56.80	94	60.20	94	64.00	94	64.00	94	64.00
95	58.56	95	62.80	95	62.80	95	65.60	95	68.00	95	68.00	95	68.00
96	65.20	96	68.00	96	68.00	96	72.20	96	74.00	96	74.00	96	74.00
97	72.90	97	75.80	97	75.80	97	78.20	97	80.00	97	80.00	97	80.00
98	80.60	98	83.00	98	83.00	98	84.80	98	86.00	98	86.00	98	86.00
99	90.60	99	91.80	99	91.80	99	92.40	99	93.00	99	93.00	99	93.00
100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00

DB	200~	DB	250~	DB	315~	DB	400~	DB	500~	DB	630~	DB	800~
20		20		20		20		20		20		20	0.10
21		21		21		21		21		21		21	0.11
22		22		22		22		22		22	0.10	22	0.13
23		23		23		23		23		23	0.11	23	0.14
24		24		24		24		24		24	0.13	24	0.16
25		25		25		25		25	0.10	25	0.15	25	0.18
26		26		26		26		26	0.11	26	0.17	26	0.21
27		27		27		27		27	0.13	27	0.20	27	0.24
28		28		28		28	0.10	28	0.15	28	0.23	28	0.27
29		29		29		29	0.12	29	0.17	29	0.26	29	0.30
30		30		30		30	0.14	30	0.20	30	0.30	30	0.34
31		31		31		31	0.16	31	0.23	31	0.34	31	0.38
32		32		32	0.10	32	0.18	32	0.26	32	0.38	32	0.42
33		33		33	0.12	33	0.22	33	0.30	33	0.43	33	0.47
34		34		34	0.14	34	0.25	34	0.34	34	0.49	34	0.52
35		35		35	0.17	35	0.29	35	0.39	35	0.55	35	0.58
36		36	0.10	36	0.20	36	0.34	36	0.45	36	0.62	36	0.65
37		37	0.12	37	0.24	37	0.39	37	0.51	37	0.70	37	0.72
38		38	0.14	38	0.29	38	0.45	38	0.58	38	0.79	38	0.81
39		39	0.17	39	0.34	39	0.51	39	0.67	39	0.89	39	0.90
40	0.10	40	0.20	40	0.39	40	0.58	40	0.77	40	1.00	40	1.00
41	0.12	41	0.24	41	0.45	41	0.67	41	0.88	41	1.08	41	1.08
42	0.15	42	0.29	42	0.51	42	0.77	42	1.00	42	1.17	42	1.17
43	0.18	43	0.34	43	0.58	43	0.88	43	1.09	43	1.26	43	1.26
44	0.23	44	0.40	44	0.67	44	1.00	44	1.18	44	1.36	44	1.36
45	0.28	45	0.47	45	0.77	45	1.10	45	1.29	45	1.47	45	1.47
46	0.34	46	0.54	46	0.88	46	1.21	46	1.40	46	1.59	46	1.59
47	0.40	47	0.63	47	1.00	47	1.34	47	1.54	47	1.71	47	1.71
48	0.47	48	0.73	48	1.11	48	1.47	48	1.67	48	1.85	48	1.85
49	0.54	49	0.86	49	1.25	49	1.62	49	1.82	49	2.00	49	2.00
50	0.63	50	1.00	50	1.39	50	1.78	50	1.98	50	2.15	50	2.15
51	0.73	51	1.11	51	1.55	51	1.97	51	2.15	51	2.33	51	2.33
52	0.86	52	1.25	52	1.72	52	2.15	52	2.34	52	2.51	52	2.51
53	1.00	53	1.39	53	1.94	53	2.34	53	2.55	53	2.72	53	2.72
54	1.14	54	1.55	54	2.15	54	2.55	54	2.78	54	2.93	54	2.93
55	1.29	55	1.72	55	2.34	55	2.78	55	3.02	55	3.16	55	3.16
56	1.47	56	1.94	56	2.55	56	3.02	56	3.31	56	3.42	56	3.42
57	1.67	57	2.15	57	2.78	57	3.31	57	3.61	57	3.69	57	3.69
58	1.89	58	2.38	58	3.02	58	3.61	58	3.92	58	3.98	58	3.98
59	2.15	59	2.61	59	3.31	59	3.92	59	4.26	59	4.30	59	4.30
60	2.40	60	2.88	60	3.61	60	4.26	60	4.60	60	4.64	60	4.64
61	2.70	61	3.16	61	3.92	61	4.64	61	5.00	61	5.00	61	5.00
62	3.00	62	3.50	62	4.26	62	5.00	62	5.40	62	5.40	62	5.40
63	3.34	63	3.83	63	4.64	63	5.40	63	5.83	63	5.83	63	5.83
64	3.72	64	4.23	64	5.13	64	5.83	64	6.30	64	6.30	64	6.30
65	4.16	65	4.64	65	5.62	65	6.30	65	6.81	65	6.81	65	6.81
66	4.64	66	5.17	66	6.21	66	6.81	66	7.35	66	7.35	66	7.35
67	5.17	67	5.79	67	6.81	67	7.35	67	7.95	67	7.95	67	7.95
68	5.79	68	6.46	68	7.54	68	7.95	68	8.60	68	8.60	68	8.60
69	6.46	69	7.20	69	8.26	69	8.60	69	9.30	69	9.30	69	9.30
70	7.20	70	8.02	70	9.11	70	9.30	70	10.00	70	10.00	70	10.00
71	8.02	71	9.00	71	10.00	71	10.00	71	10.90	71	10.90	71	10.90
72	9.00	72	10.00	72	10.95	72	10.95	72	11.70	72	11.70	72	11.70
73	10.00	73	11.10	73	11.90	73	11.90	73	12.60	73	12.60	73	12.60
74	11.10	74	12.20	74	12.90	74	12.90	74	13.70	74	13.70	74	13.70
75	12.20	75	13.50	75	14.10	75	14.10	75	14.80	75	14.80	75	14.80
76	13.50	76	14.80	76	15.60	76	15.60	76	16.00	76	16.00	76	16.00
77	14.80	77	16.35	77	16.80	77	16.80	77	17.20	77	17.20	77	17.20
78	16.35	78	17.95	78	18.40	78	18.40	78	18.60	78	18.60	78	18.60
79	17.95	79	19.80	79	19.90	79	19.90	79	20.00	79	20.00	79	20.00
80	19.80	80	21.60	80	21.60	80	21.60	80	21.60	80	21.60	80	21.60
81	21.60	81	23.40	81	23.40	81	23.40	81	23.40	81	23.40	81	23.40
82	23.60	82	25.30	82	25.30	82	25.30	82	25.30	82	25.30	82	25.30
83	25.70	83	27.40	83	27.40	83	27.40	83	27.40	83	27.40	83	27.40
84	28.06	84	29.50	84	29.50	84	29.50	84	29.50	84	29.50	84	29.50
85	30.54	85	31.90	85	31.90	85	31.90	85	31.90	85	31.90	85	31.90
86	33.28	86	34.40	86	34.40	86	34.40	86	34.40	86	34.40	86	34.40
87	36.32	87	37.10	87	37.10	87	37.10	87	37.10	87	37.10	87	37.10
88	39.52	88	40.20	88	40.20	88	40.20	88	40.20	88	40.20	88	40.20
89	42.88	89	43.20	89	43.20	89	43.20	89	43.20	89	43.20	89	43.20
90	47.00	90	47.00	90	47.00	90	47.00	90	47.00	90	47.00	90	47.00
91	51.00	91	51.00	91	51.00	91	51.00	91	51.00	91	51.00	91	51.00
92	55.00	92	55.00	92	55.00	92	55.00	92	55.00	92	55.00	92	55.00
93	59.00	93	59.00	93	59.00	93	59.00	93	59.00	93	59.00	93	59.00
94	64.00	94	64.00	94	64.00	94	64.00	94	64.00	94	64.00	94	64.00
95	68.00	95	68.00	95	68.00	95	68.00	95	68.00	95	68.00	95	68.00
96	74.00	96	74.00	96	74.00	96	74.00	96	74.00	96	74.00	96	74.00
97	80.00	97	80.00	97	80.00	97	80.00	97	80.00	97	80.00	97	80.00
98	86.00	98	86.00	98	86.00	98	86.00	98	86.00	98	86.00	98	86.00
99	93.00	99	93.00	99	93.00	99	93.00	99	93.00	99	93.00	99	93.00
100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00	100	100.00

SOUND PRESSURE LEVEL IN DECIBELS TO LOUDNESS IN SONES

DB	1000~	DB	1250~	DB	1600~	DB	2000~	DB	2500~	DB	3150~	DB	4000~
20	0.10	20	0.10	20	0.11	20	0.14	20	0.17	20	0.20	20	0.18
21	0.11	21	0.11	21	0.12	21	0.16	21	0.20	21	0.22	21	0.21
22	0.13	22	0.13	22	0.14	22	0.17	22	0.22	22	0.24	22	0.24
23	0.14	23	0.14	23	0.16	23	0.20	23	0.24	23	0.27	23	0.27
24	0.16	24	0.16	24	0.17	24	0.22	24	0.27	24	0.30	24	0.30
25	0.18	25	0.18	25	0.20	25	0.24	25	0.30	25	0.34	25	0.34
26	0.21	26	0.21	26	0.22	26	0.27	26	0.34	26	0.37	26	0.37
27	0.24	27	0.24	27	0.24	27	0.30	27	0.37	27	0.41	27	0.41
28	0.27	28	0.27	28	0.27	28	0.34	28	0.41	28	0.46	28	0.46
29	0.30	29	0.30	29	0.30	29	0.37	29	0.45	29	0.50	29	0.50
30	0.34	30	0.34	30	0.34	30	0.41	30	0.49	30	0.55	30	0.55
31	0.38	31	0.38	31	0.38	31	0.46	31	0.54	31	0.62	31	0.62
32	0.42	32	0.42	32	0.42	32	0.50	32	0.58	32	0.68	32	0.68
33	0.47	33	0.47	33	0.47	33	0.55	33	0.64	33	0.75	33	0.75
34	0.52	34	0.52	34	0.52	34	0.62	34	0.70	34	0.83	34	0.83
35	0.58	35	0.58	35	0.58	35	0.68	35	0.77	35	0.91	35	0.91
36	0.65	36	0.65	36	0.65	36	0.75	36	0.84	36	1.00	36	1.00
37	0.72	37	0.72	37	0.72	37	0.83	37	0.92	37	1.07	37	1.07
38	0.81	38	0.81	38	0.81	38	0.91	38	1.00	38	1.15	38	1.15
39	0.90	39	0.90	39	0.90	39	1.00	39	1.07	39	1.23	39	1.23
40	1.00	40	1.00	40	1.00	40	1.07	40	1.15	40	1.32	40	1.32
41	1.08	41	1.08	41	1.08	41	1.15	41	1.23	41	1.41	41	1.41
42	1.17	42	1.17	42	1.17	42	1.23	42	1.32	42	1.53	42	1.53
43	1.26	43	1.26	43	1.26	43	1.32	43	1.41	43	1.63	43	1.63
44	1.36	44	1.36	44	1.36	44	1.41	44	1.53	44	1.75	44	1.75
45	1.47	45	1.47	45	1.47	45	1.53	45	1.63	45	1.87	45	1.87
46	1.59	46	1.59	46	1.59	46	1.63	46	1.75	46	2.01	46	2.01
47	1.71	47	1.71	47	1.71	47	1.75	47	1.87	47	2.15	47	2.15
48	1.85	48	1.85	48	1.85	48	1.87	48	2.01	48	2.33	48	2.33
49	2.00	49	2.00	49	2.00	49	2.01	49	2.15	49	2.51	49	2.51
50	2.15	50	2.15	50	2.15	50	2.15	50	2.33	50	2.72	50	2.72
51	2.33	51	2.33	51	2.33	51	2.33	51	2.51	51	2.93	51	2.93
52	2.51	52	2.51	52	2.51	52	2.51	52	2.72	52	3.16	52	3.16
53	2.72	53	2.72	53	2.72	53	2.72	53	2.93	53	3.42	53	3.42
54	2.93	54	2.93	54	2.93	54	2.93	54	3.16	54	3.69	54	3.69
55	3.16	55	3.16	55	3.16	55	3.16	55	3.42	55	3.98	55	3.98
56	3.42	56	3.42	56	3.42	56	3.42	56	3.69	56	4.30	56	4.30
57	3.69	57	3.69	57	3.69	57	3.69	57	3.98	57	4.64	57	4.64
58	3.98	58	3.98	58	3.98	58	3.98	58	4.30	58	5.00	58	5.00
59	4.30	59	4.30	59	4.30	59	4.30	59	4.64	59	5.40	59	5.40
60	4.64	60	4.64	60	4.64	60	4.64	60	5.00	60	5.83	60	5.83
61	5.00	61	5.00	61	5.00	61	5.05	61	5.50	61	6.30	61	6.30
62	5.40	62	5.40	62	5.40	62	5.50	62	5.99	62	6.81	62	6.81
63	5.83	63	5.83	63	5.83	63	5.99	63	6.50	63	7.35	63	7.35
64	6.30	64	6.30	64	6.30	64	6.50	64	7.14	64	7.95	64	7.95
65	6.81	65	6.81	65	6.81	65	7.14	65	7.77	65	8.60	65	8.60
66	7.35	66	7.35	66	7.35	66	7.70	66	8.48	66	9.30	66	9.30
67	7.95	67	7.95	67	7.95	67	8.48	67	9.21	67	10.00	67	10.00
68	8.60	68	8.60	68	8.60	68	9.21	68	10.00	68	10.95	68	10.95
69	9.30	69	9.30	69	9.30	69	10.00	69	10.90	69	11.90	69	11.90
70	10.00	70	10.00	70	10.00	70	10.90	70	11.70	70	12.90	70	12.90
71	10.90	71	10.90	71	10.90	71	11.70	71	12.60	71	14.10	71	14.10
72	11.70	72	11.70	72	11.70	72	12.60	72	13.70	72	15.60	72	15.60
73	12.60	73	12.60	73	12.60	73	13.70	73	14.80	73	16.80	73	16.80
74	13.70	74	13.70	74	13.70	74	14.80	74	16.00	74	18.40	74	18.40
75	14.80	75	14.80	75	14.80	75	16.00	75	17.20	75	19.90	75	19.90
76	16.00	76	16.00	76	16.00	76	17.20	76	18.60	76	21.60	76	21.60
77	17.20	77	17.20	77	17.20	77	18.60	77	20.00	77	24.00	77	24.00
78	18.60	78	18.60	78	18.60	78	20.00	78	21.60	78	26.30	78	26.30
79	20.00	79	20.00	79	20.00	79	21.60	79	24.00	79	29.10	79	29.10
80	21.60	80	21.60	80	21.60	80	23.60	80	26.30	80	31.90	80	31.90
81	23.40	81	23.40	81	23.60	81	25.70	81	29.10	81	35.24	81	35.24
82	25.30	82	25.30	82	25.70	82	28.06	82	31.90	82	38.50	82	38.50
83	27.40	83	27.40	83	28.06	83	30.54	83	35.24	83	42.56	83	42.56
84	29.50	84	29.50	84	30.54	84	33.28	84	38.50	84	47.00	84	47.00
85	31.90	85	31.90	85	33.28	85	36.32	85	42.56	85	51.90	85	51.90
86	34.40	86	34.40	86	36.32	86	39.52	86	47.00	86	56.80	86	56.80
87	37.10	87	37.10	87	39.52	87	42.88	87	51.30	87	62.80	87	62.80
88	40.20	88	40.20	88	42.88	88	47.00	88	55.72	88	68.00	88	68.00
89	43.20	89	43.20	89	47.00	89	51.30	89	60.20	89	75.80	89	75.80
90	47.00	90	47.00	90	51.00	90	55.72	90	65.60	90	83.00	90	83.00
91	51.00	91	51.00	91	55.00	91	60.20	91	72.20	91	91.80	91	91.80
92	55.00	92	55.00	92	59.00	92	65.60	92	78.20	92	100.00	92	100.00
93	59.00	93	59.00	93	64.00	93	72.20	93	84.80	93	108.20	93	109.00
94	64.00	94	64.00	94	68.00	94	78.20	94	92.40	94	115.40	94	117.00
95	68.00	95	68.00	95	74.00	95	84.80	95	100.00	95	124.00	95	127.00
96	74.00	96	74.00	96	80.00	96	92.40	96	109.00	96	133.00	96	137.00
97	80.00	97	80.00	97	86.00	97	100.00	97	117.00	97	142.00	97	148.00
98	86.00	98	86.00	98	93.00	98	109.00	98	127.00	98	154.00	98	160.00
99	93.00	99	93.00	99	100.00	99	117.00	99	137.00	99	164.80	99	172.00
100	100.00	100	100.00	100	109.80	100	127.00	100	148.00	100	176.20	100	187.00

DB	5000~	DB	6300~	DB	8000~	DB	10,000~	DB	12,500~	DB	16,000~
20	0.12	20		20		20		20		20	
21	0.14	21		21		21		21		21	
22	0.16	22		22		22		22		22	
23	0.17	23	0.10	23		23		23		23	
24	0.20	24	0.11	24		24		23		24	
25	0.22	25	0.12	25		25		25		25	
26	0.24	26	0.13	26		26		26		26	
27	0.27	27	0.15	27		27		27		27	
28	0.30	28	0.16	28		28		28		28	
29	0.34	29	0.18	29	0.10	29		29		29	
30	0.37	30	0.19	30	0.11	30	0.10	30		30	
31	0.41	31	0.21	31	0.12	31	0.11	31	0.10	31	
32	0.46	32	0.23	32	0.14	32	0.12	32	0.11	32	
33	0.50	33	0.26	33	0.16	33	0.14	33	0.12	33	
34	0.55	34	0.28	34	0.17	34	0.16	34	0.14	34	
35	0.62	35	0.31	35	0.20	35	0.17	35	0.16	35	
36	0.68	36	0.34	36	0.22	36	0.20	36	0.17	36	
37	0.75	37	0.37	37	0.24	37	0.22	37	0.20	37	
38	0.83	38	0.41	38	0.27	38	0.24	38	0.22	38	
39	0.91	39	0.46	39	0.30	39	0.27	39	0.24	39	
40	1.00	40	0.50	40	0.34	40	0.30	40	0.27	40	0.10
41	1.08	41	0.55	41	0.38	41	0.34	41	0.30	41	0.11
42	1.17	42	0.62	42	0.42	42	0.38	42	0.34	42	0.13
43	1.26	43	0.68	43	0.47	43	0.42	43	0.37	43	0.14
44	1.36	44	0.75	44	0.52	44	0.47	44	0.41	44	0.16
45	1.47	45	0.83	45	0.58	45	0.52	45	0.46	45	0.18
46	1.59	46	0.91	46	0.65	46	0.58	46	0.50	46	0.21
47	1.71	47	1.00	47	0.72	47	0.65	47	0.55	47	0.24
48	1.85	48	1.07	48	0.81	48	0.72	48	0.62	48	0.27
49	2.00	49	1.15	49	0.90	49	0.81	49	0.68	49	0.30
50	2.15	50	1.23	50	1.00	50	0.90	50	0.75	50	0.34
51	2.31	51	1.32	51	1.07	51	1.00	51	0.83	51	0.38
52	2.47	52	1.41	52	1.15	52	1.07	52	0.91	52	0.42
53	2.65	53	1.53	53	1.23	53	1.15	53	1.00	53	0.47
54	2.84	54	1.63	54	1.32	54	1.23	54	1.06	54	0.52
55	3.04	55	1.75	55	1.41	55	1.32	55	1.14	55	0.58
56	3.28	56	1.87	56	1.53	56	1.41	56	1.21	56	0.65
57	3.52	57	2.01	57	1.63	57	1.53	57	1.29	57	0.72
58	3.77	58	2.15	58	1.75	58	1.63	58	1.38	58	0.81
59	4.04	59	2.31	59	1.87	59	1.75	59	1.47	59	0.90
60	4.33	60	2.47	60	2.01	60	1.87	60	1.56	60	1.00
61	4.64	61	2.65	61	2.15	61	2.01	61	1.67	61	1.07
62	5.05	62	2.84	62	2.33	62	2.15	62	1.78	62	1.16
63	5.50	63	3.04	63	2.51	63	2.33	63	1.89	63	1.23
64	5.99	64	3.28	64	2.72	64	2.51	64	2.03	64	1.32
65	6.50	65	3.52	65	2.93	65	2.72	65	2.15	65	1.41
66	7.14	66	3.77	66	3.16	66	2.93	66	2.38	66	1.53
67	7.77	67	4.04	67	3.42	67	3.16	67	2.61	67	1.63
68	8.48	68	4.33	68	3.68	68	3.42	68	2.88	68	1.75
69	9.21	69	4.64	69	3.98	69	3.69	69	3.16	69	1.87
70	10.00	70	5.05	70	4.30	70	3.98	70	3.50	70	2.01
71	10.95	71	5.50	71	4.64	71	4.30	71	3.83	71	2.15
72	11.90	72	5.99	72	5.05	72	4.64	72	4.23	72	2.38
73	12.90	73	6.50	73	5.50	73	5.05	73	4.64	73	2.61
74	14.10	74	7.14	74	5.99	74	5.50	74	4.97	74	2.88
75	15.60	75	7.77	75	6.50	75	5.99	75	5.34	75	3.16
76	16.80	76	8.48	76	7.14	76	6.50	76	5.70	76	3.50
77	18.40	77	9.21	77	7.77	77	7.14	77	6.12	77	3.83
78	19.90	78	10.00	78	8.48	78	7.77	78	6.55	78	4.23
79	21.60	79	10.95	79	9.21	79	8.48	79	7.05	79	4.64
80	23.60	80	11.90	80	10.00	80	9.21	80	7.60	80	4.94
81	25.70	81	12.90	81	10.95	81	10.00	81	8.14	81	5.20
82	28.06	82	14.10	82	11.90	82	10.90	82	8.72	82	5.54
83	30.54	83	15.60	83	12.90	83	11.70	83	9.35	83	5.89
84	33.28	84	16.80	84	14.10	84	12.60	84	10.00	84	6.21
85	36.32	85	18.40	85	15.60	85	13.70	85	10.95	85	6.60
86	39.52	86	19.90	86	16.80	86	14.80	86	11.90	86	7.04
87	42.88	87	21.60	87	18.40	87	16.00	87	12.90	87	7.48
88	47.00	88	24.00	88	19.90	88	17.20	88	14.10	88	7.90
89	51.90	89	26.30	89	21.60	89	18.60	89	15.60	89	8.40
90	56.80	90	29.10	90	23.60	90	20.00	90	16.80	90	8.93
91	62.80	91	31.90	91	25.70	91	21.60	91	18.40	91	9.40
92	68.00	92	35.24	92	28.06	92	24.00	92	19.90	92	10.00
93	75.80	93	38.50	93	30.54	93	26.30	93	21.60	93	11.10
94	83.00	94	42.56	94	32.28	94	29.10	94	24.20	94	12.20
95	91.80	95	47.00	95	36.32	95	31.90	95	27.18	95	13.50
96	100.00	96	52.20	96	39.52	96	35.24	96	30.28	96	14.80
97	109.80	97	58.56	97	42.88	97	38.50	97	33.50	97	16.35
98	119.00	98	65.20	98	47.00	98	42.56	98	37.38	98	17.95
99	130.00	99	72.90	99	52.20	99	47.00	99	41.92	99	19.80
100	141.00	100	80.60	100	58.56	100	52.20	100	47.00	100	21.60

Aktieselskabet
Brüel & Kjær

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