Validation of implemented loudness algorithms

Loudness Toolbox

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Contents

1 Document purpose

In this day and age, various models allow the loudness computation of stationary sounds, non-stationary sounds and impulsive sounds. On the occasion of the celebration of its 10 year anniversary, GENESIS provides in free download a Matlab toolbox allowing the loudness computation according to most of the models described in literature. This document details the procedures used for the validation of implementations. The test sounds used and the results obtained are provided with the toolbox.

2 Loudness models

The following table gives the correspondences between the Matlab functions in the toolbox, the associated loudness models, and the validity domains of these models:

Matlab function name	Model / standard	Stationary sound	Time-varying sound	Impulsive sound
Loudness_ISO532B	ISO 532B DIN 45631	x		
Loudness_ANSI_S34_2007	ANSI S3.4-2007	x		
Loudness_NonStationnary_Zwicker	Fastl and Zwicker loudness model for time-varying sounds		x	
Loudness_NonStationnary_Moore	Moore and Glasberg loudness model for time-varying sounds		x	
Loudness_LMIS	Impulsive sounds loudness model from Boullet et al			x

Table 1: loudness models implemented in the toolbox

3 Loudness toolbox for Matlab

In this section, the results of the validation procedure applied to the implemented algorithms are presented. Moreover, a database of loudness values calculated by the different algorithms of the toolbox is given.

3.1 Validation of implementations (stationary sounds)

3.1.1 Pure tones

In example A-1.1 of the annex of norm ANSI S3.4-2007, loudness and equal loudness level are given for stationary pure tones at 1 kHz and 3 kHz in the first table.

1 kHz pure tone	10 dBSPL	40 dBSPL	50 dBSPL	60 dBSPL	80 dBSPL
ANSI S3.4-2007	0.03 Sone 10 Phons	1 Sones 40 Phons	2.1 Sones 50 Phons	4.2 Sones 60 Phons	16 Sones 80 Phons
Genesis (Moore)	0.03 Sone 10.2 Phons	0.98 Sone 39.8 Phons	2.06 Sones 49.7 Phons	4.07 Sones 59.6 Phons	15.5 Sones 79.5 Phons
Genesis (Zwicker)	0.02 Sones 9.41 Phons	1.01 Sone 40.2 Phons	2.04 Sones 50.2 Phons	4.07 Sones 60.2 Phons	16.4 Sones 80.4 Phons
ISO 532B (Zwicker, 1991)	0.02 Sone 10.2 Phons	1 Sone 40 Phons	2 Sones 50.1 Phons	4.01 Sones 60 Phons	16.07 Sones 80.1 Phons

Table 2: Data published by authors and calculated with the algorithms provided by GENESIS for a 1 kHz stationary pure tone.

Values obtained with the algorithm corresponding to Moore's model (1997) are the same as those of ANSI norm within 0.5 phons for levels higher than 40 dB SPL (see Table 2)
The algorithm corresponding to Zwicker's model (1997) gives the same values as the norm and the data published by Fastl (2009) within 0.2 phons (for levels higher than 40 dB SPL).
The implementations for a 3 kHz pure tone at 40, 60, and 80 dB SPL give the results shown in Table 3.

3 kHz pure tone	40 dBSPL	60 dBSPL	80 dBSPL
ANSI S3.4-2007	1.8 Sones 48 Phons	7.1 Sones 68 Phons	27.5 Sones 87.5 Phons
Genesis (Moore)	1.79 Sones 47.8 Phons	6.9 Sones 67.4 Phons	26.5 Sones 86.7 Phons
Genesis (Zwicker)	1.64 Sones 47.1 Phons	6.4 Sones 66.8 Phons	25.4 Sones 86.7 Phons

Table 3: Data published by authors and calculated with the algorithms provided by GENESIS for a 3 kHz stationary pure tone.

Values obtained with the algorithm corresponding to Moore's model (1997) are those of the norm within 1 phon.
Values obtained with the algorithm corresponding to Zwicker's model (1997) are slightly lower (about 1.5 phons) than those of the norm. Yet, let us remind that these values are coming from two different models, and thus are not directly comparable.

3.1.2 Pink noise band

In norm ANSI S3.4-2007, some values of loudness calculations are given for certain sounds, particularly for pink noises. In example A-2.3 of the annex of norm ANSI S3.4-2007, loudness and equal level loudness are given for 3 pink noise bands (50-15000 Hz), which given level is that of 1 kHz (0, 20, and 40 dB respectively)

Pink noise band (50-15000 Hz)	0 dBSPL at 1 kHz	20 dBSPL à at kHz	40 dBSPL at 1 kHz
ANSI S3.4-2007 (Moore, 1997)	3.62 Sones 57.9 Phons	16 Sones 80 Phons	49.28 Sones 95.3 Phons
Genesis (Moore)	3.62 Sones 57.7 Phons	15.66 Sones 79.7 Phons	47.34 Sones 94.7 Phons
Genesis (Zwicker)	2.25 Sones 51.7 Phons	11.2 Sones 74.9 Phons	40.4 Sones 93.3 Phons

Table 4: Data published and calculated by the algorithms implemented by GENESIS for a pink noise band at different levels at 1 kHz

Data obtained with the algorithm corresponding to Moore's model (1997) are that given by the norm within a few tenths of phon (see Table 4).
Fastl published data concerning his model (Fastl et al, 2009) and compared them to those provided with norm ANSI S3.4-2007. He gets significantly lower values (about 6 phons) than those given by Moore for a pink noise. Let us precise that input levels are given here by third octave bands (same value in each band).

Loudness calculations with Zwicker's model for the same signals are given (Table 2). Values are 5 to 8 phons lower. The difference with ANSI reference is all the more high as the signal level is low.

Thus for stationary sounds, the algorithms developed by GENESIS give the same results (within 1 phon) as those published by authors in norms.

3.2 Validation of implementations (non-stationary sounds)

In this section, data obtained with GENESIS algorithms are compared to data published by the authors of time-varying loudness models.

Zwicker published in 1984 data on temporal masking, especially on temporal waveform of pure tones. Tested sounds are tone bursts of 10 and 100 ms. However he does not specify the frequency and level. So as to do the comparison, two impulses with different duration, at frequency of 5 kHz and at a sound level of 86.5 dB were chosen (in reference to Zwicker et Fastl, 1999). The results of the algorithm developed by GENESIS are on Figure 1. These signals are considered as recorded with a microphone in free field.

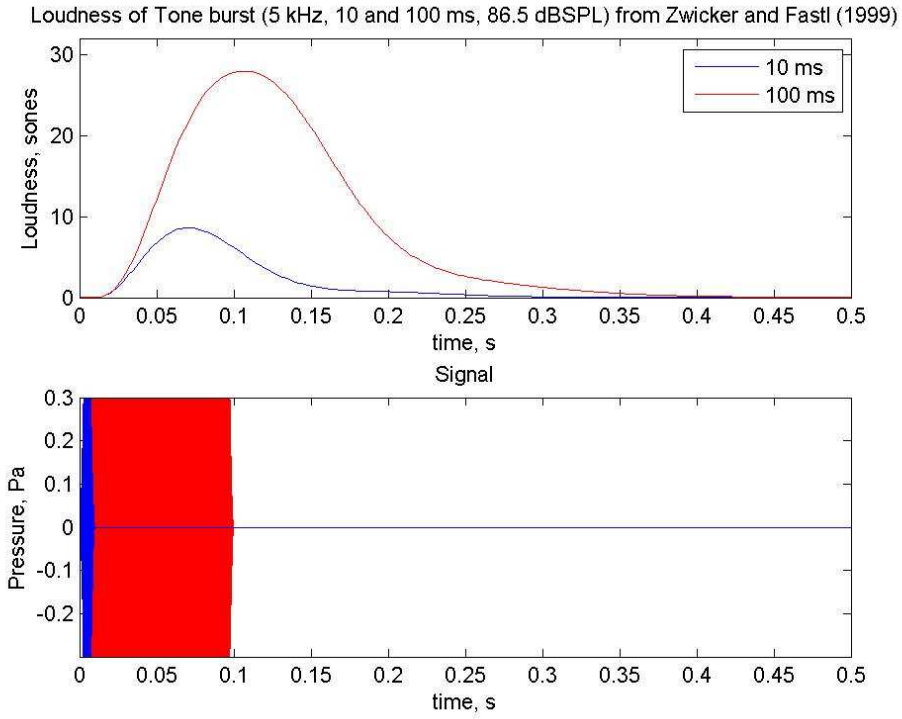

Figure 1: Loudness as function of time for tone bursts of 10 and 100 ms (5 kHz at 86.5 dB SPL). The lower figure presents the temporal signals

The temporal evolution of loudness is similar to that published by Zwicker and Fastl (1999).

In 2002, Glasberg and Moore published data relative to the calculation outputs of their model for instantaneous loudness, short-term loudness and long-term loudness. The sounds used are 4 kHz tone bursts at 60 dB with a duration of 200

ms. The results obtained with the GENESIS algorithm are shown in Figure 2. These signals are considered as recorded with a microphone in free field.

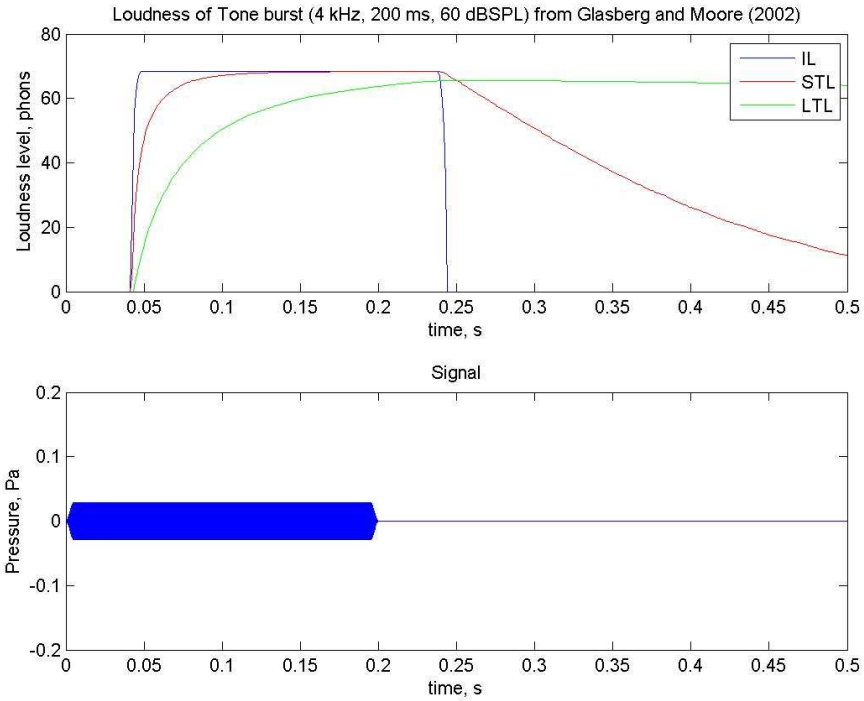

Figure 2 : Output of Glasberg and Moore's model (2002) in response to a tone burst : 4 kHz, 200 ms et 60 dB SPL (instantaneous loudness (blue), short-term loudness (red) and long-term loudness (green)). The lower figure shows the temporal signal.

The results given by the algorithms developed by GENESIS are similar to those obtained by Moore.

Glasberg and Moore also give values for various maxima of short-term loudness for 1 kHz and 4 kHz tone bursts (with a duration from 16 to 200 ms, and presented at 60 dB SPL).

The values calculated by the algorithm developed by GENESIS and presented in Figure 3 are similar to those given by authors.

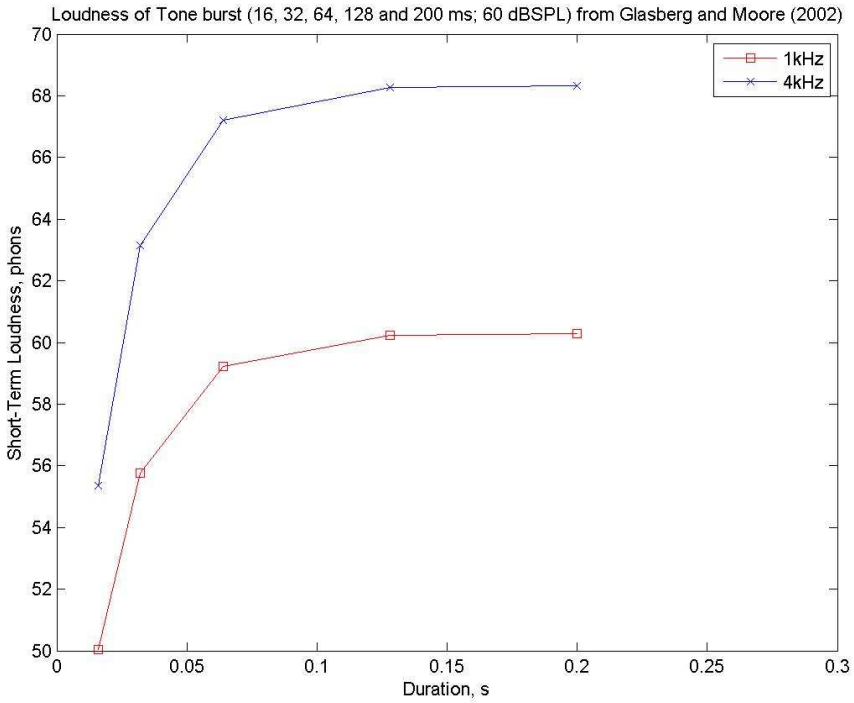

Figure 3 : Maximum short-term loudness as a function of tone burst duration for 1 kHz and 4 kHz tone bursts.

3.3 Data relative to N5 and STLmax indicators for time varying sounds

Data allowing the comparison of values given by loudness indicators such as N5 or STLmax could not be found in literature.

To serve as a reference, the time varying loudness, N5, and STLmax calculations were carried out using the toolbox algorithms on 10 second sounds (bus passing, moped passing and road traffic). Results are shown in Figure 4 (for Zwicker and Fastl, 1999) and Figure 5 (for Glasberg and Moore, 2002);

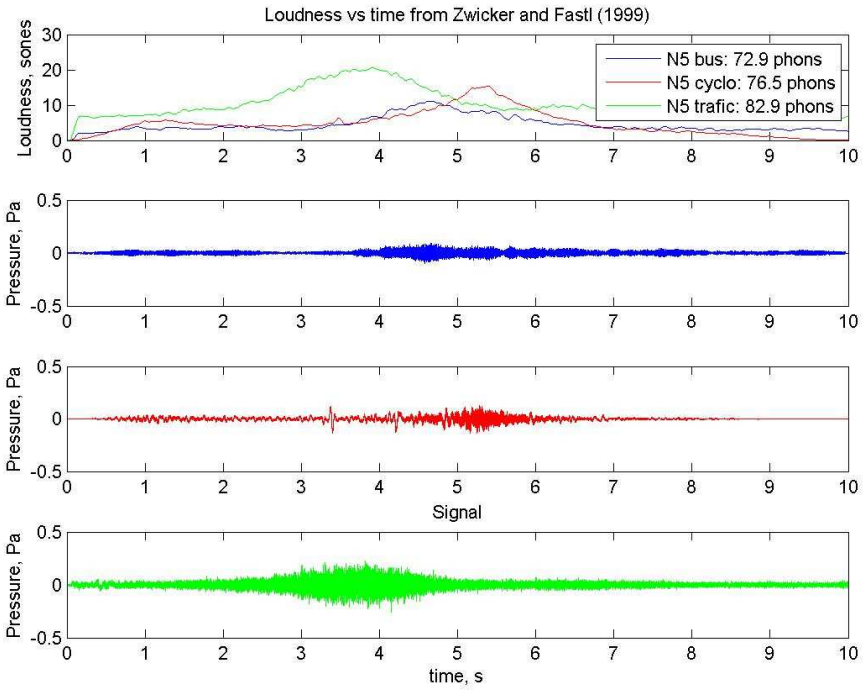

Figure 4 : Loudness as a function of time (with Zwicker and Fastl's model) for environment sounds (bus passing, moped passing and road traffic). The 3 lower figures show the temporal waveforms.

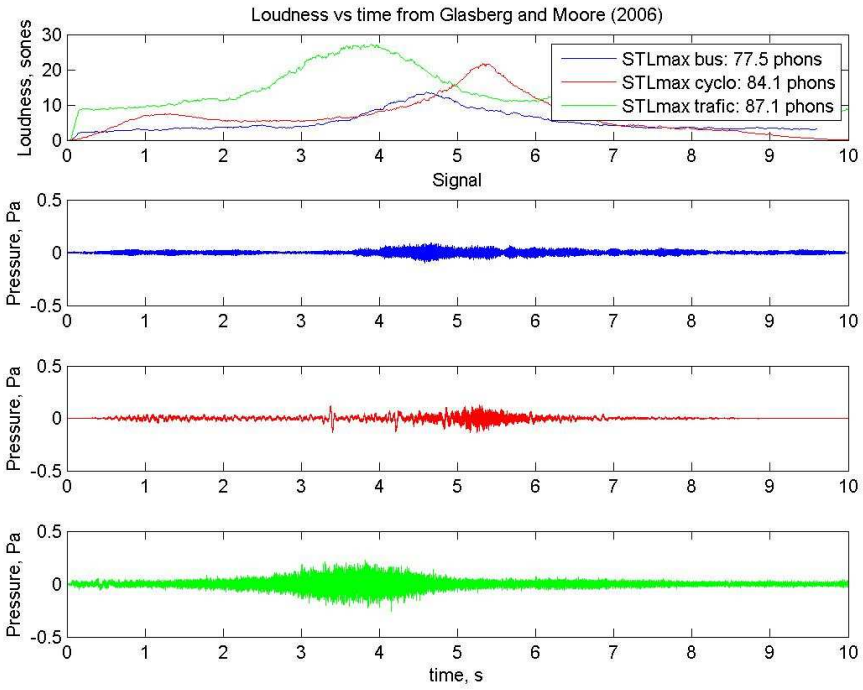

Figure 5 : Loudness as a function of time (with Glasberg and Moore's model) for environment sounds (bus passing, moped passing and road traffic). The 3 lower figures show the temporal waveforms.

It appears on these signals that STLmax is higher than N5 by about 6 phons. The same difference was noted on former calculations with both models on stationary pink noises.

3.4 Data relative to the loudness model for impulsive sounds (LMIS)

Boullet et coll. (2006) validated their loudness model for impulsive sounds using psychoacoustic tests. Furthermore, LMIS values were compared to those given by N5 and STLmax, which are preconized for the estimation of overall loudness of non-stationary sounds. It emerges from this study that LMIS gives more precise results (by 4 to 5 phons) than the other two indicators for this type of sounds. Some loudness values calculated with the LMIS algorithm are provided in Annex 1.

- § -

ANNEX 1 : Matlab code – values calculated on a set of sounds

This annex presents the loudness values obtained with GENESIS loudness toolbox on the set of sounds in the directory "WAV".

```
----------
stationary (ISO 532B)
----------

File: WAV\PinkNoise_0dBpHz@1000Hz.wav
Loudness: 2.25 sones
Loudness level: 51.70 phons
---------
File: WAV\PinkNoise_20dBpHz@1000Hz.wav
Loudness: 11.24 sones
Loudness level: 74.91 phons
---------
File: WAV\PinkNoise_40dBpHz@1000Hz.wav
Loudness: 40.44 sones
Loudness level: 93.38 phons
---------
File: WAV\sinus_1000Hz_10dBSPL.wav
Loudness: 0.02 sones
Loudness level: 9.41 phons
---------
File: WAV\sinus_1000Hz_40dBSPL.wav
Loudness: 1.01 sones
Loudness level: 40.19 phons
---------
File: WAV\sinus_1000Hz_50dBSPL.wav
Loudness: 2.04 sones
Loudness level: 50.25 phons
---------
File: WAV\sinus_1000Hz_60dBSPL.wav
Loudness: 4.07 sones
Loudness level: 60.24 phons
---------
File: WAV\sinus_1000Hz_80dBSPL.wav
Loudness: 16.43 sones
Loudness level: 80.38 phons
---------
File: WAV\sinus_100Hz_10dBSPL.wav
Loudness: 0.00 sones
Loudness level: 0.00 phons
---------
File: WAV\sinus_100Hz_40dBSPL.wav
Loudness: 0.25 sones
Loudness level: 24.45 phons
---------
File: WAV\sinus_100Hz_50dBSPL.wav
Loudness: 0.77 sones
Loudness level: 36.54 phons
```

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---------
File: WAV\sinus_100Hz_60dBSPL.wav
Loudness: 1.79 sones
Loudness level: 48.42 phons
---------
File: WAV\sinus_100Hz_80dBSPL.wav
Loudness: 10.03 sones
Loudness level: 73.26 phons
---------
File: WAV\sinus_3000Hz_10dBSPL.wav
Loudness: 0.07 sones
Loudness level: 15.77 phons
---------
File: WAV\sinus_3000Hz_40dBSPL.wav
Loudness: 1.64 sones
Loudness level: 47.13 phons
---------
File: WAV\sinus_3000Hz_50dBSPL.wav
Loudness: 3.24 sones
Loudness level: 56.95 phons
---------
File: WAV\sinus_3000Hz_60dBSPL.wav
Loudness: 6.40 sones
Loudness level: 66.79 phons
---------
File: WAV\sinus_3000Hz_80dBSPL.wav
Loudness: 25.46 sones
Loudness level: 86.70 phons
---------


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stationary (ANSI S3.4 2007)
----------

File: WAV\PinkNoise_0dBpHz@1000Hz.wav
Loudness: 3.62 sones
Loudness level: 57.72 phons
---------
File: WAV\PinkNoise_20dBpHz@1000Hz.wav
Loudness: 15.66 sones
Loudness level: 79.65 phons
---------
File: WAV\PinkNoise_40dBpHz@1000Hz.wav
Loudness: 47.34 sones
Loudness level: 94.70 phons
---------
File: WAV\sinus_1000Hz_10dBSPL.wav
Loudness: 0.03 sones
Loudness level: 10.19 phons
---------
File: WAV\sinus_1000Hz_40dBSPL.wav
Loudness: 0.98 sones
Loudness level: 39.80 phons
---------
File: WAV\sinus_1000Hz_50dBSPL.wav
Loudness: 2.06 sones
Loudness level: 49.69 phons
---------
File: WAV\sinus_1000Hz_60dBSPL.wav
```

```
Loudness: 4.07 sones
Loudness level: 59.61 phons
---------
File: WAV\sinus_1000Hz_80dBSPL.wav
Loudness: 15.52 sones
Loudness level: 79.50 phons
---------
File: WAV\sinus_100Hz_10dBSPL.wav
Loudness: 0.00 sones
Loudness level: 0.00 phons
---------
File: WAV\sinus_100Hz_40dBSPL.wav
Loudness: 0.08 sones
Loudness level: 16.00 phons
---------
File: WAV\sinus_100Hz_50dBSPL.wav
Loudness: 0.31 sones
Loudness level: 26.56 phons
---------
File: WAV\sinus_100Hz_60dBSPL.wav
Loudness: 0.81 sones
Loudness level: 37.27 phons
---------
File: WAV\sinus_100Hz_80dBSPL.wav
Loudness: 4.02 sones
Loudness level: 59.39 phons
---------
File: WAV\sinus_3000Hz_10dBSPL.wav
Loudness: 0.11 sones
Loudness level: 17.94 phons
---------
File: WAV\sinus_3000Hz_40dBSPL.wav
Loudness: 1.79 sones
Loudness level: 47.56 phons
---------
File: WAV\sinus_3000Hz_50dBSPL.wav
Loudness: 3.56 sones
Loudness level: 57.45 phons
---------
File: WAV\sinus_3000Hz_60dBSPL.wav
Loudness: 6.91 sones
Loudness level: 67.39 phons
---------
File: WAV\sinus_3000Hz_80dBSPL.wav
Loudness: 26.50 sones
Loudness level: 86.73 phons
---------


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NON stationary (Zwicker and Fastl)
----------

File: WAV\ToneBurst_1000Hz_60dBSPL_16ms.wav
Loudness N5: 1.25 sones
Loudness level N5: 43.25 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_32ms.wav
Loudness N5: 1.87 sones
Loudness level N5: 49.07 phons
```

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---------
File: WAV\ToneBurst_1000Hz_60dBSPL_64ms.wav
Loudness N5: 2.83 sones
Loudness level N5: 54.99 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_128ms.wav
Loudness N5: 4.01 sones
Loudness level N5: 60.03 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_200ms.wav
Loudness N5: 4.05 sones
Loudness level N5: 60.19 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_16ms.wav
Loudness N5: 1.49 sones
Loudness level N5: 45.80 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_32ms.wav
Loudness N5: 2.31 sones
Loudness level N5: 52.08 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_64ms.wav
Loudness N5: 3.56 sones
Loudness level N5: 58.32 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_128ms.wav
Loudness N5: 5.05 sones
Loudness level N5: 63.35 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_200ms.wav
Loudness N5: 5.10 sones
Loudness level N5: 63.51 phons
---------
File: WAV\ToneBurst_5000Hz_86.5dBSPL_10ms.wav
Loudness N5: 5.12 sones
Loudness level N5: 63.55 phons
---------
File: WAV\ToneBurst_5000Hz_86.5dBSPL_100ms.wav
Loudness N5: 23.20 sones
Loudness level N5: 85.36 phons
---------
File: WAV\bus.wav
Loudness N5: 9.77 sones
Loudness level N5: 72.88 phons
---------
File: WAV\cyclo.wav
Loudness N5: 12.51 sones
Loudness level N5: 76.45 phons
---------
File: WAV\trafic.wav
Loudness N5: 19.56 sones
Loudness level N5: 82.90 phons
---------


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NON stationary (Glasberg and Moore)
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File: WAV\ToneBurst_1000Hz_60dBSPL_16ms.wav
```

```
Loudness STLmax: 2.11 sones
Loudness level STLmax: 50.05 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_32ms.wav
Loudness STLmax: 3.15 sones
Loudness level STLmax: 55.76 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_64ms.wav
Loudness STLmax: 3.98 sones
Loudness level STLmax: 59.22 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_128ms.wav
Loudness STLmax: 4.24 sones
Loudness level STLmax: 60.23 phons
---------
File: WAV\ToneBurst_1000Hz_60dBSPL_200ms.wav
Loudness STLmax: 4.26 sones
Loudness level STLmax: 60.27 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_16ms.wav
Loudness STLmax: 3.05 sones
Loudness level STLmax: 55.34 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_32ms.wav
Loudness STLmax: 5.21 sones
Loudness level STLmax: 63.16 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_64ms.wav
Loudness STLmax: 6.82 sones
Loudness level STLmax: 67.21 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_128ms.wav
Loudness STLmax: 7.31 sones
Loudness level STLmax: 68.26 phons
---------
File: WAV\ToneBurst_4000Hz_60dBSPL_200ms.wav
Loudness STLmax: 7.33 sones
Loudness level STLmax: 68.32 phons
---------
File: WAV\ToneBurst_5000Hz_86.5dBSPL_10ms.wav
Loudness STLmax: 7.30 sones
Loudness level STLmax: 68.25 phons
---------
File: WAV\ToneBurst_5000Hz_86.5dBSPL_100ms.wav
Loudness STLmax: 29.92 sones
Loudness level STLmax: 88.40 phons
---------
File: WAV\bus.wav
Loudness STLmax: 13.67 sones
Loudness level STLmax: 77.52 phons
---------
File: WAV\cyclo.wav
Loudness STLmax: 21.71 sones
Loudness level STLmax: 84.13 phons
---------
File: WAV\trafic.wav
Loudness STLmax: 27.32 sones
Loudness level STLmax: 87.14 phons
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```

```
----------
IMPULSIVE SOUNDS (LMIS)
----------

File: WAV\son02.wav
Loudness : 3.40 sones
Loudness level : 57.65 phons
---------
File: WAV\son10.wav
Loudness : 23.81 sones
Loudness level : 85.73 phons
---------
File: WAV\son22.wav
Loudness : 2.58 sones
Loudness level : 53.67 phons
---------
```