Introduction to Psychoacoustics

David Herrin
University of Kentucky

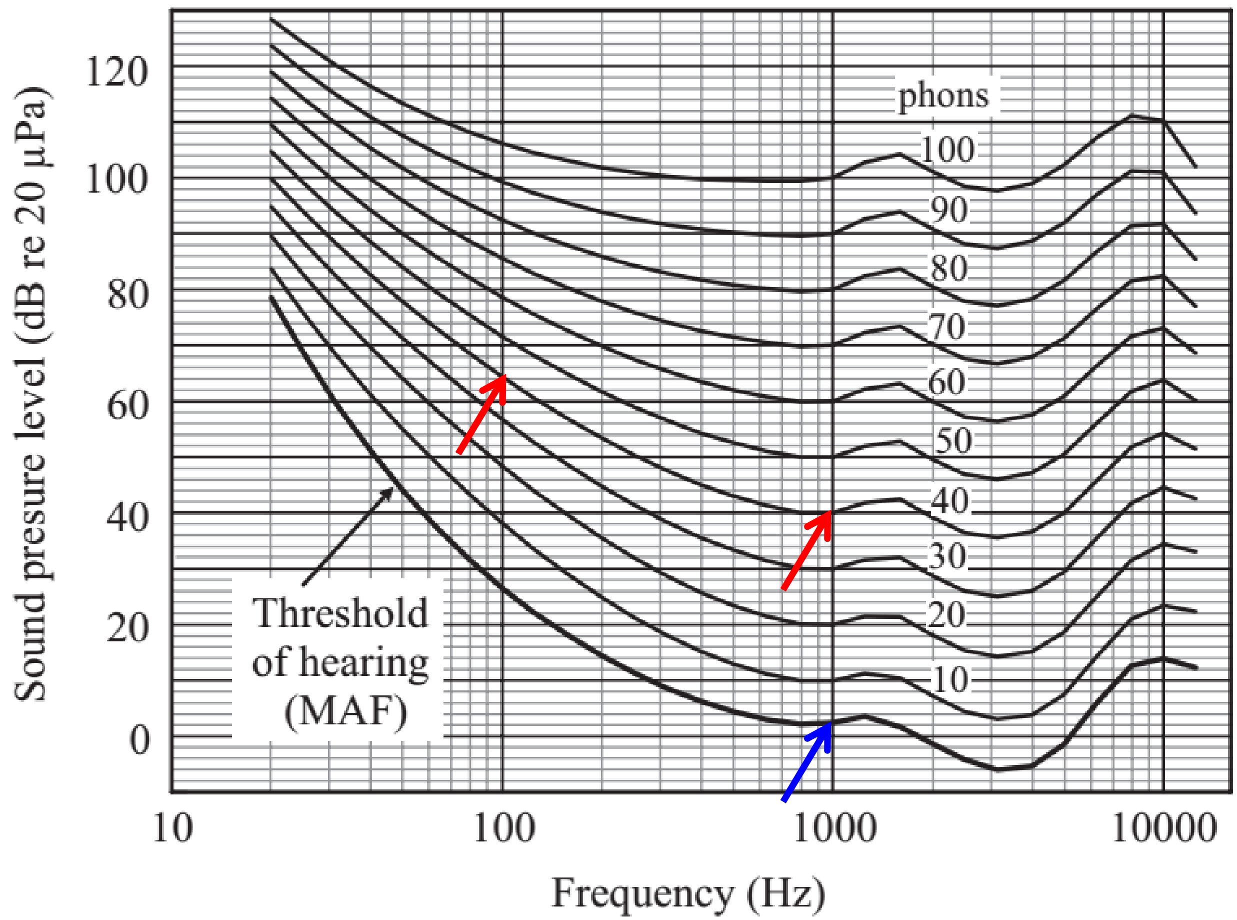
Overview

Psychoacoustics

- Loudness
- Pitch
- Timbre
- Sound Quality Metrics

Loudness Level (phons)

Psychoacoustics



A-Weighting Adjustment

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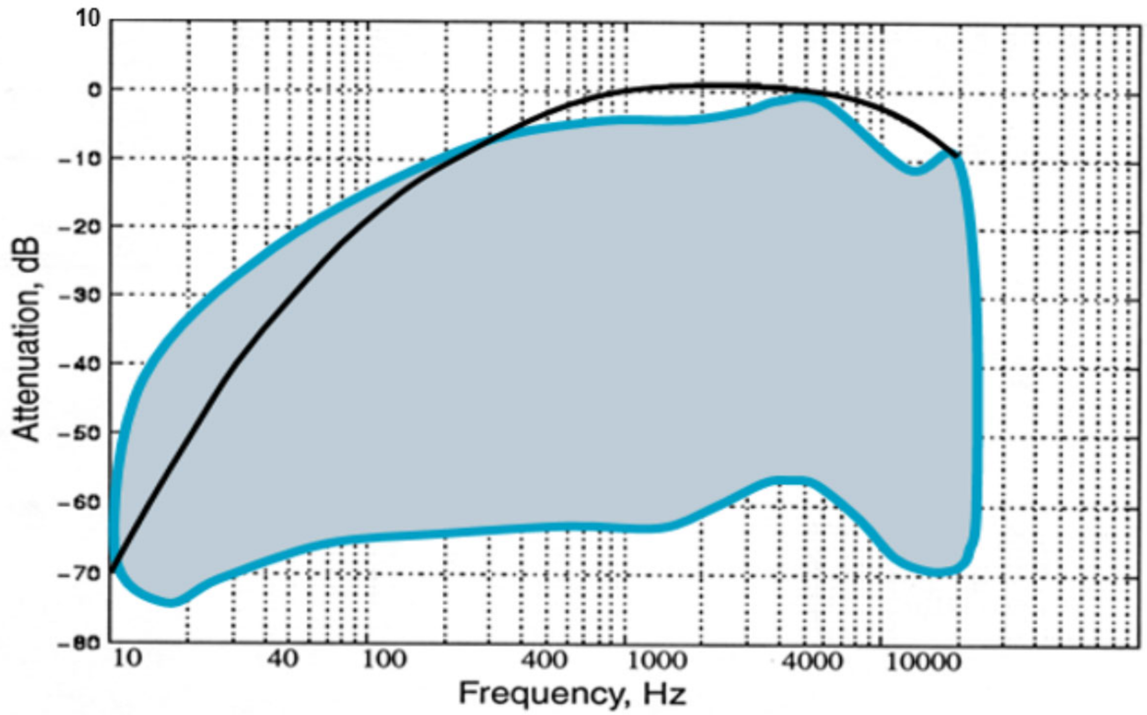

https://community.sw.siemens.com/s/article/sound-quality-metrics-loudness-and-sones

A- and C- Weighting

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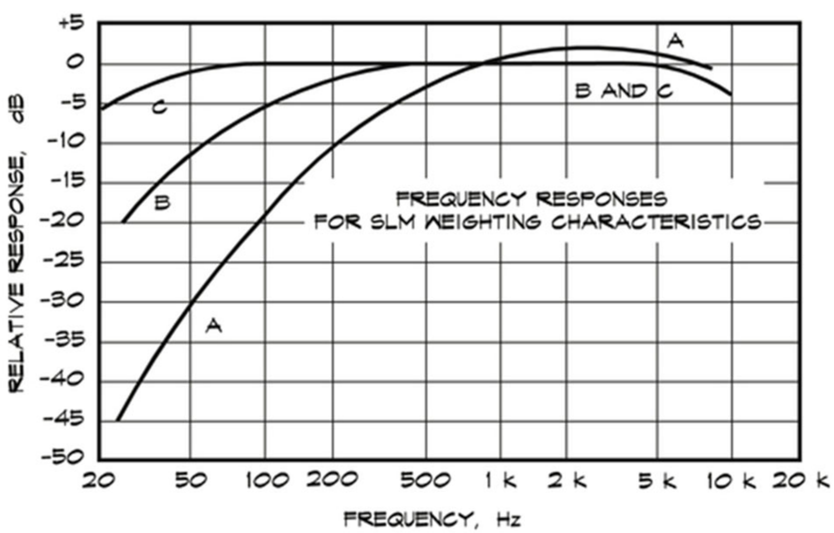

Center Frequency [Hz]	A-weighting [dB]	C-weighting [dB]
25	-44.7	-4.4
31.5	**-39.4**	**-3.0**
40	-34.6	-2.0
50	-30.2	-1.3
63	**-26.2**	**-0.8**
80	-22.5	-0.5
100	-19.1	-0.3
125	**-16.1**	**-0.2**
160	-13.4	-0.1
200	-10.9	0
250	**-8.6**	**0**
315	-6.6	0
400	-4.8	0
500	**-3.2**	**0**
630	-1.9	0
800	-0.8	0
1000	**0**	**0**
1250	+0.6	0
1600	+1.0	-0.1
2000	**+1.2**	**-0.2**
2500	+1.3	-0.3
3150	+1.2	-0.5
4000	**+1.0**	**-0.8**
5000	+0.5	-1.3
6300	-0.1	-2.0
8000	**-1.1**	**-3.0**
10000	-2.5	-4.4
12500	-4.3	-6.2
16000	**-6.6**	**-8.5**
20000	-9.3	-11.2

Example

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Octave Band Center Frequency (Hz)	dB Level	ΔA_n	dBA Level
125	90	-16.1	73.9
250	96	-8.6	87.4
500	92	-3.2	88.8
1000	90	0	90.0
2000	85	1.2	86.2
4000	85	1.0	87.0
8000	81	-1.1	79.7

$$L_A = 10\log_{10}\left(\sum_{n=1}^{N} 10^{(L_{pn}+\Delta A_n)/10}\right)$$

$$L_A = 10\log_{10}(10^{7.39} + 10^{8.74} + 10^{8.88} + 10^{9.0} + 10^{8.62} + 10^{8.7} + 10^{7.97}) \approx 95\ \text{dB(A)}$$

Relative Loudness (sones)

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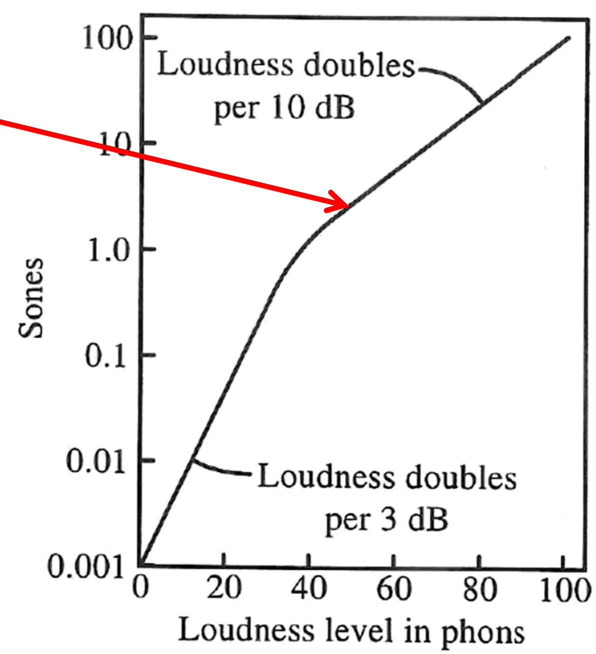
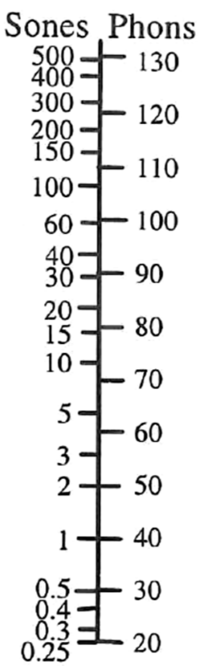
Loudness is considered on a linear scale where 2 sones is twice as loud as 1 sone.

$$S = 2^{\frac{P-40}{10}}$$

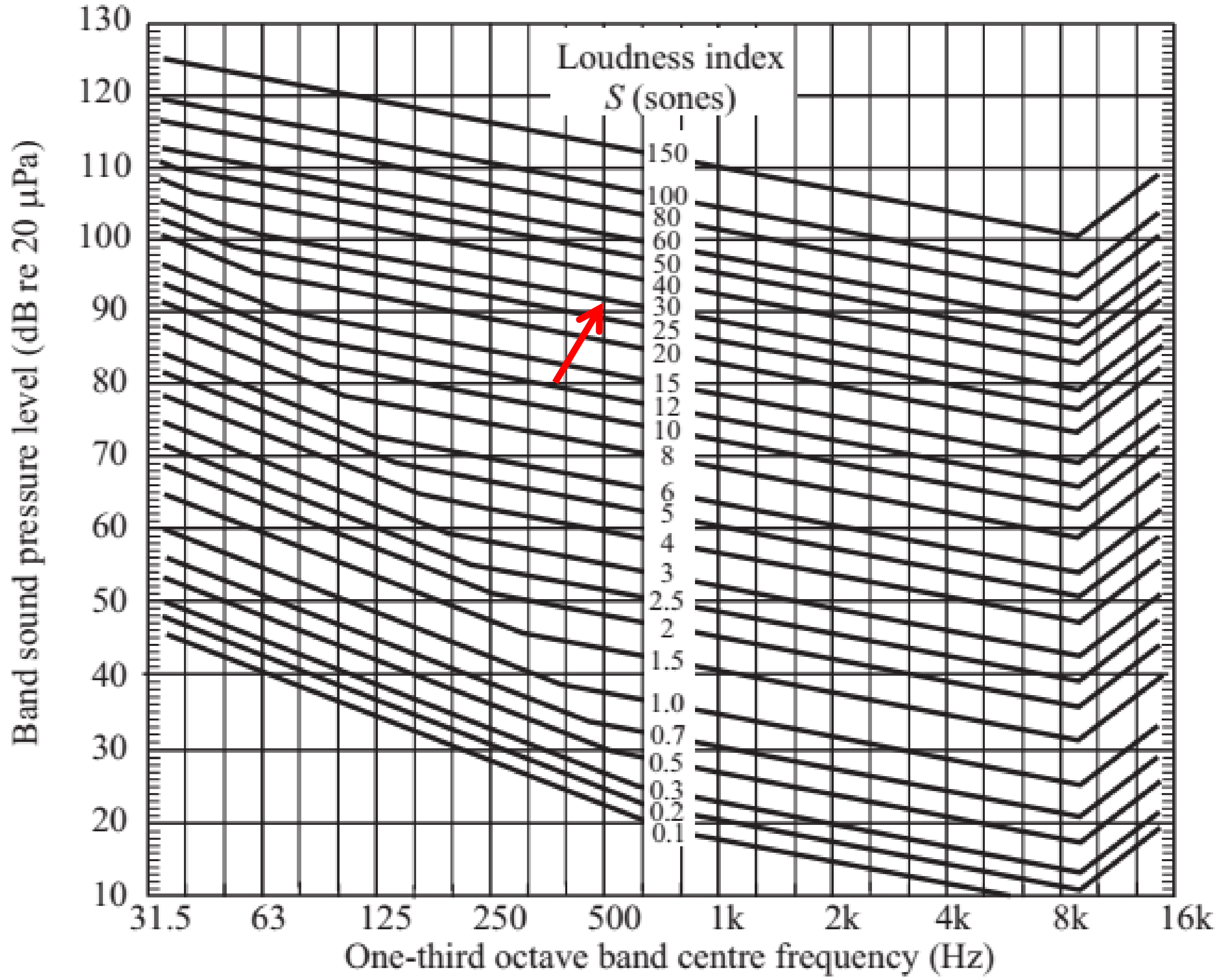
S ~ Sones

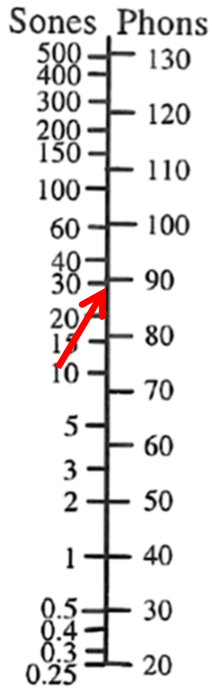
P ~ Phons





Sound Pressure Level and Sones





Example

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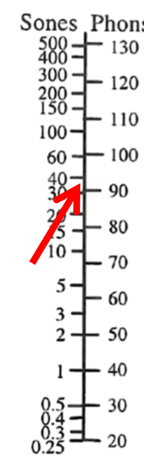
$$S_{total} = S_{max} + B\left(\sum_{i \neq max} S_i\right)$$

S_{total} ~ Overall Loudness Level (sones)
S_i ~ Loudness in Octave Bands (sones)
S_{max} ~ Highest Level (sones)
B ~ 0.3 for Octave, 0.15 for 1/3-Octave

	Octave Band Center Frequencies (Hz)								
	31.5	63	125	250	500	1000	2000	4000	8000
Band Level (dB)	57	58	60	65	75	80	75	70	65
Band Loudness (sones)	0.8	1.3	2.5	4.6	10	17	14	13	11

$S_{total} = 17 + 0.3(0.8 + 1.3 + 2.5 + 4.6 + 10 + 14 + 13 + 11) = 34.2$ sones (loudness)



34.2 sones is approximately 91 phons

Example Vacuum Cleaners

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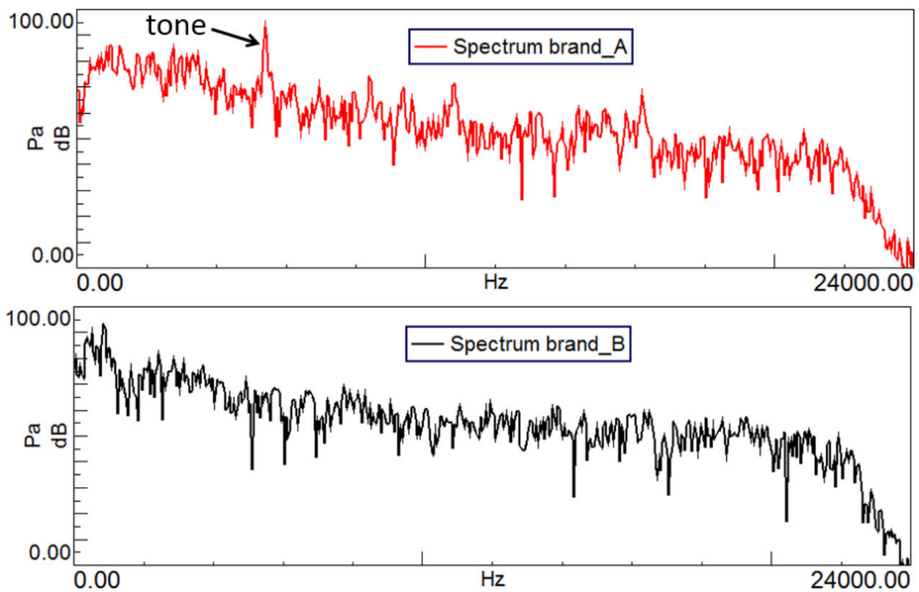


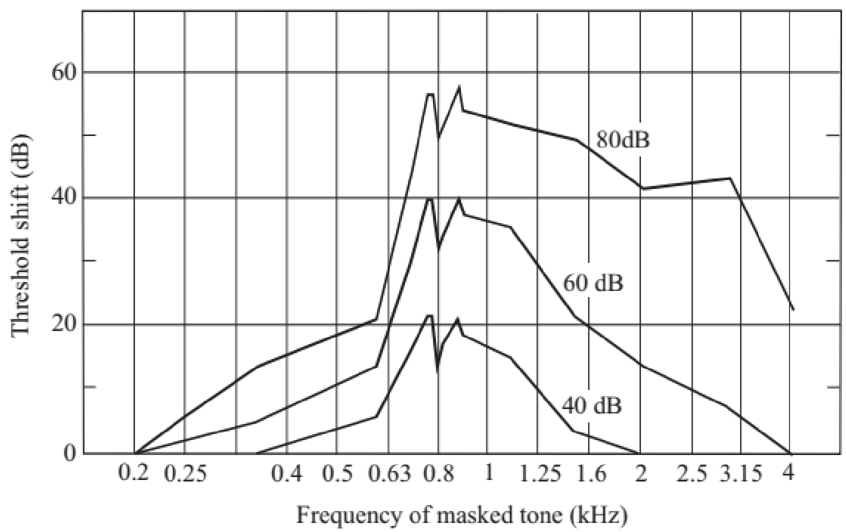
	Vacuum A	Vacuum B
dB	95.9	95.3
dB(A)	95.4	93.2
Sones	86.6	58.1

https://community.sw.siemens.com/s/article/sound-quality-metrics-loudness-and-sones

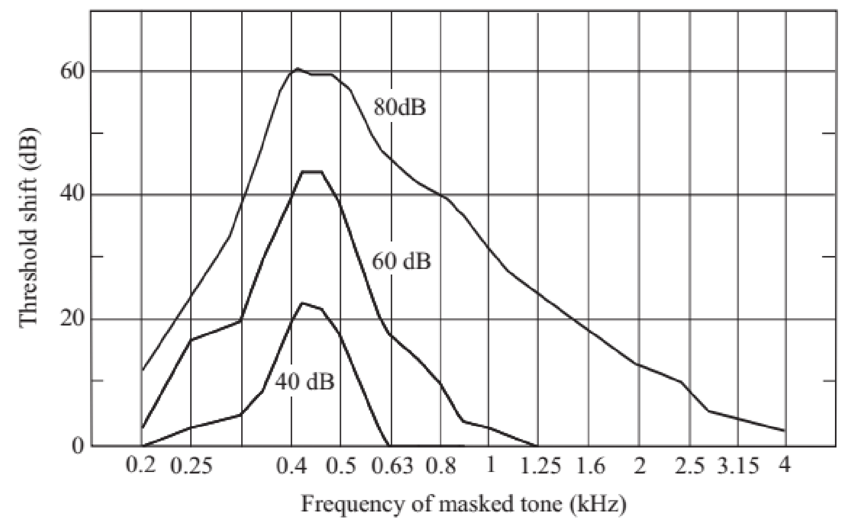
Masking

Psychoacoustics

800 Hz pure tone



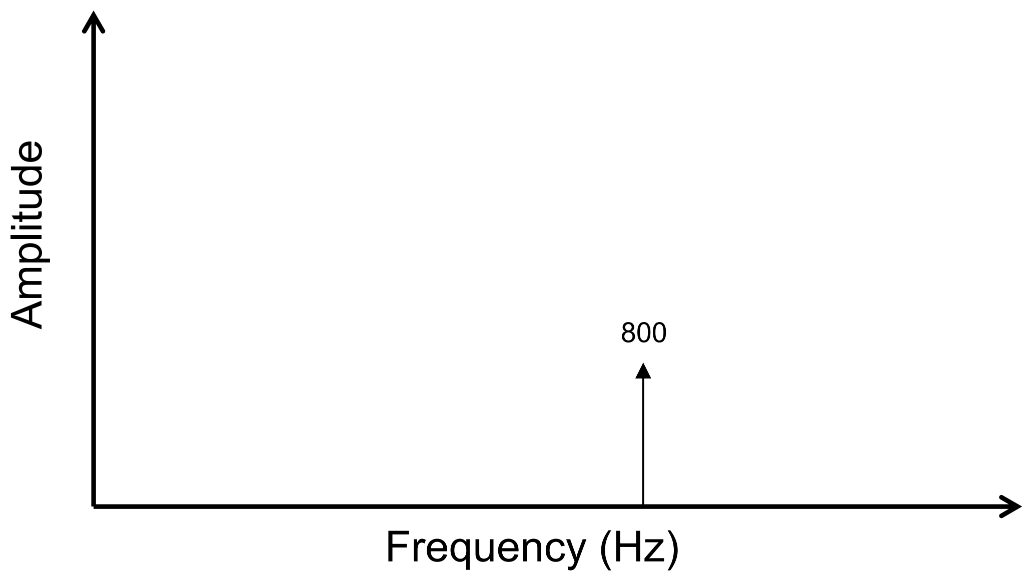
Narrow band of noise 90 Hz wide centered at 410 Hz



From Bies, Hansen, and Howard, 2009

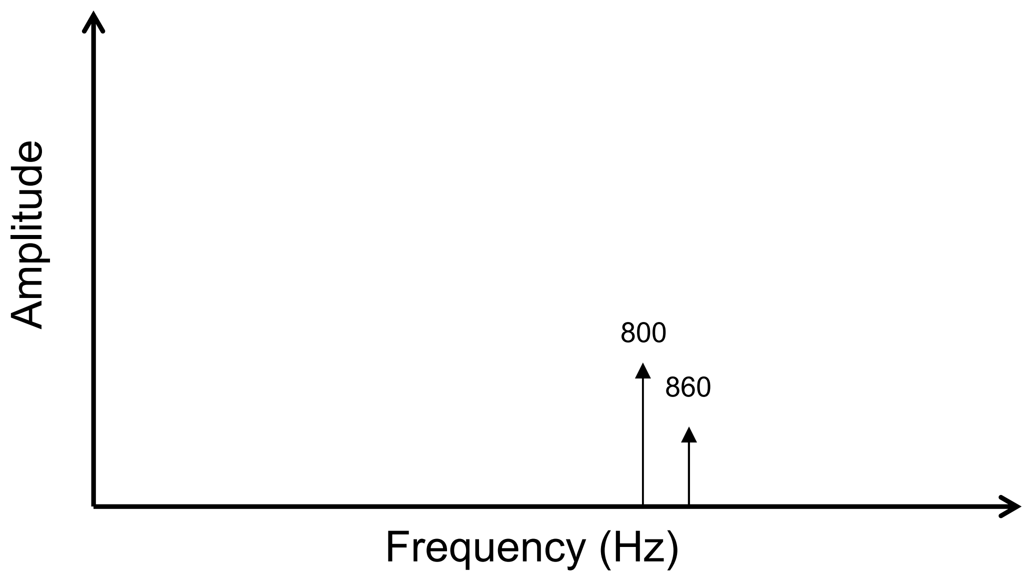
Masking 800 Hz Tone

Psychoacoustics



Masking 800 Hz and 860 Hz Tone

Psychoacoustics



Overview

Psychoacoustics

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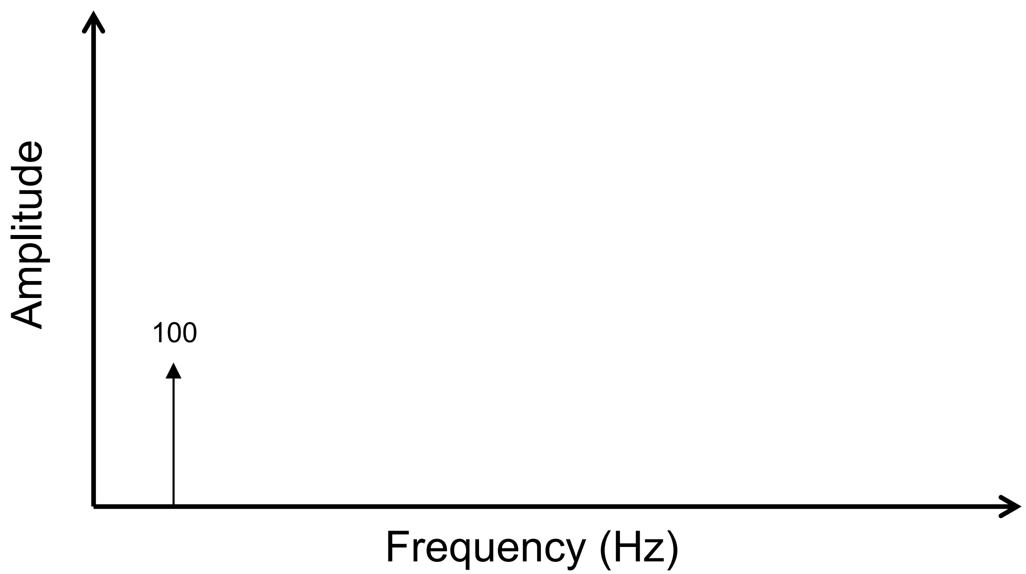
Pitch Not Partial

Psychoacoustics

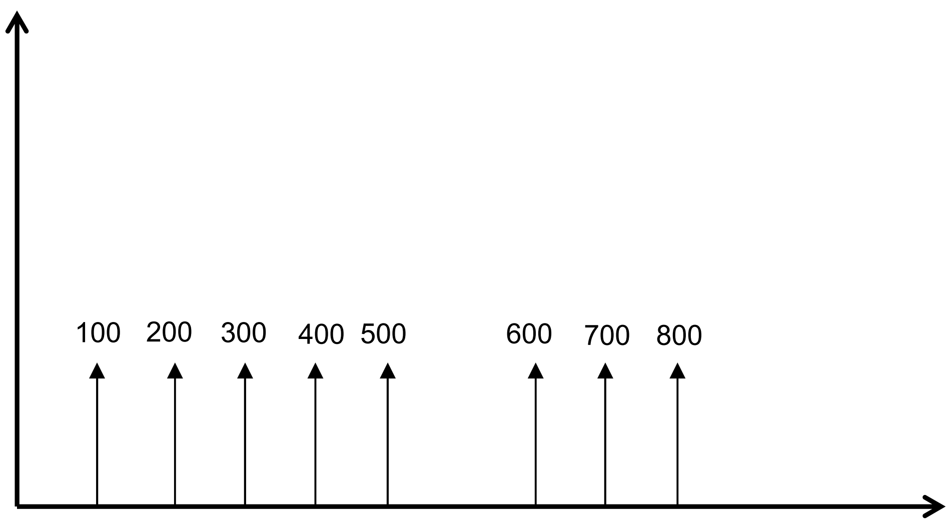
Tone at 100 Hz



Pitch Not Partial

Psychoacoustics

Tones at 100, 200, 300, 400, 600, 700, and 800 Hz.



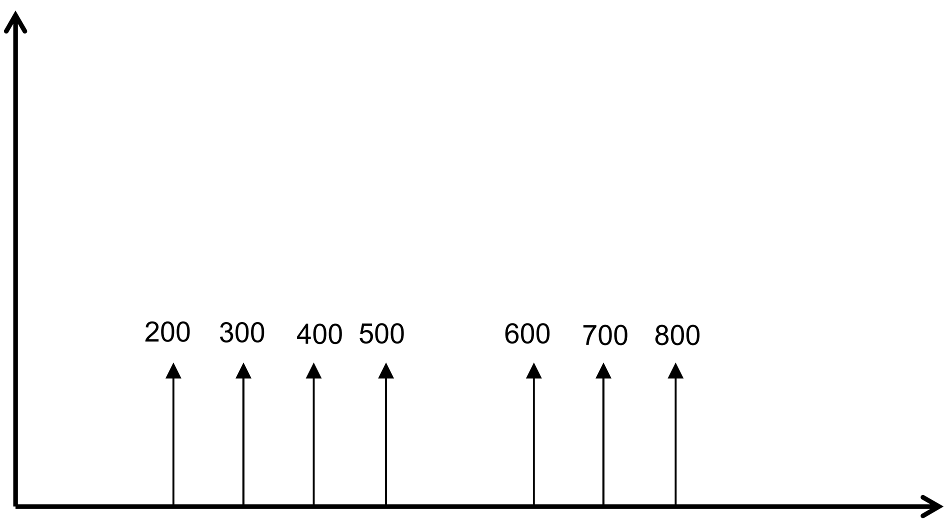
What is the perceived pitch?

100 Hz

Pitch Not Partial

Psychoacoustics

Tones at 200, 300, 400, 600, 700, and 800 Hz.



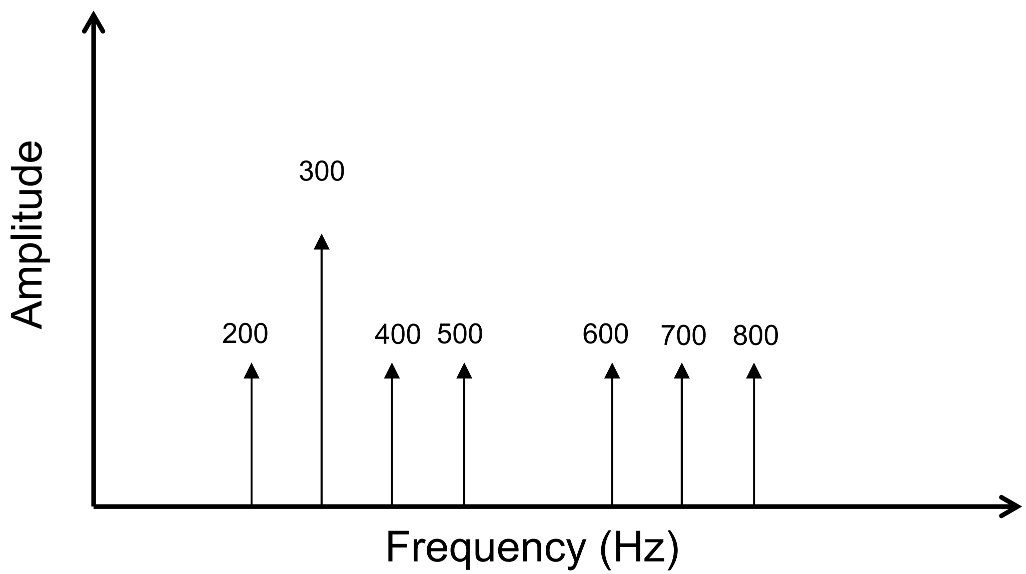
What is the perceived pitch?

100 Hz

Pitch Not Partial

Psychoacoustics

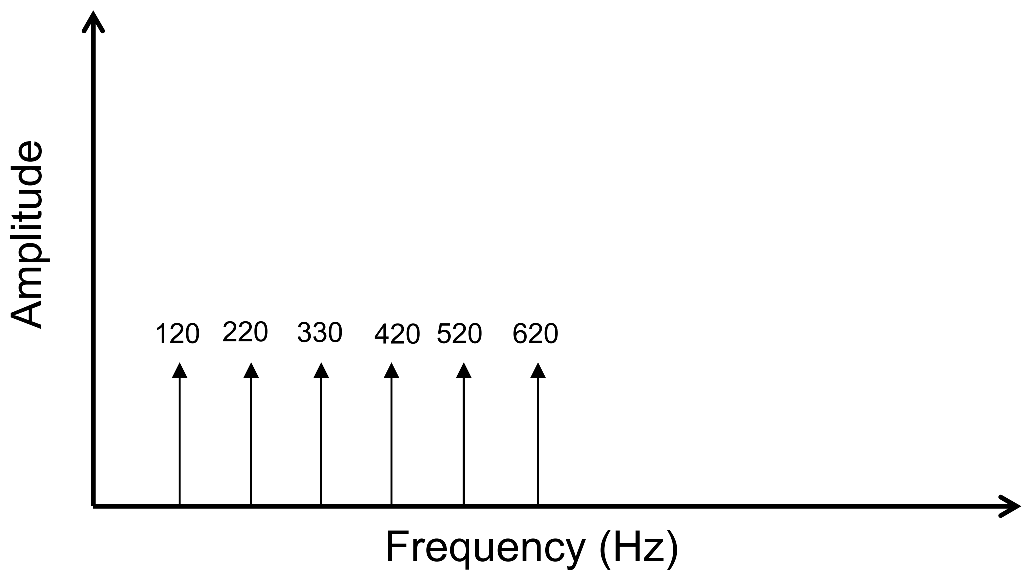
Tones at 200, 300, 400, 600, 700, and 800 Hz.



Pitch Not Periodic

Psychoacoustics

Tones at 120, 220, 320, 420, 520, and 620 Hz.



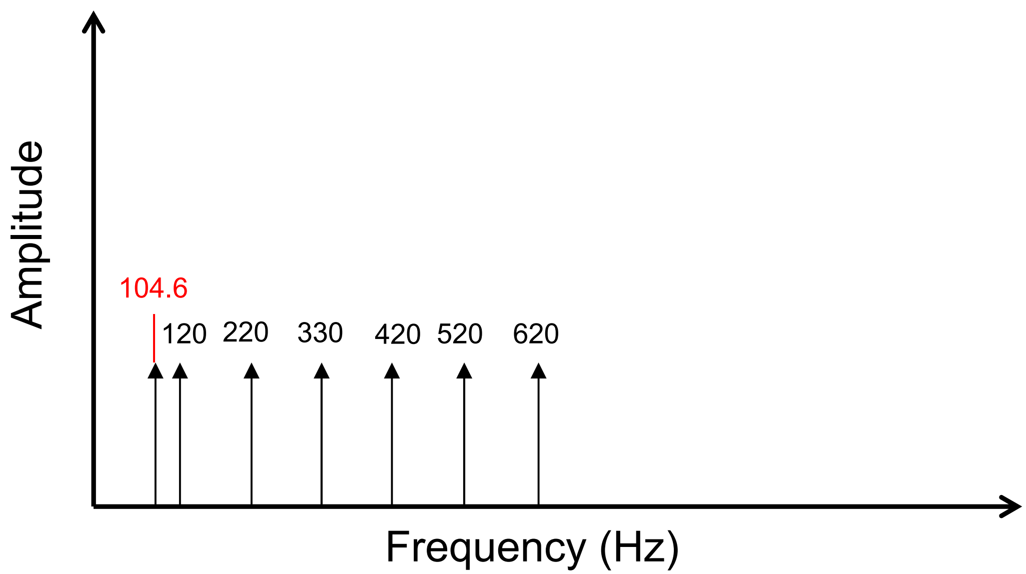
What is the perceived pitch?

104.6 Hz

Pitch Not Periodic

Psychoacoustics

Tones at 120, 220, 320, 420, 520, and 620 Hz.



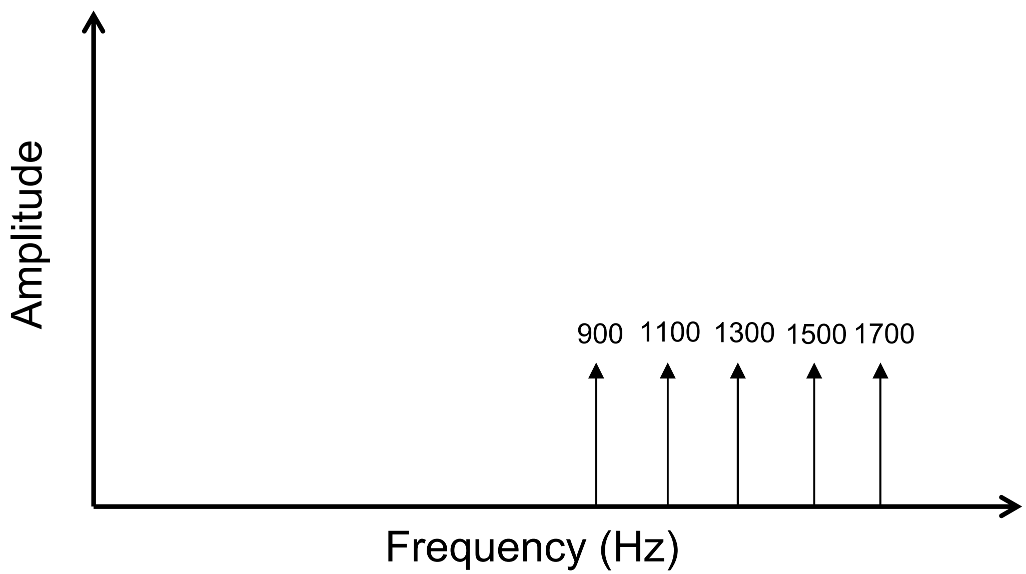
What is the perceived pitch?

104.6 Hz

Pitch Just Strange

Psychoacoustics

Tones at 900, 1100, 1300, 1500, and 1700 Hz.



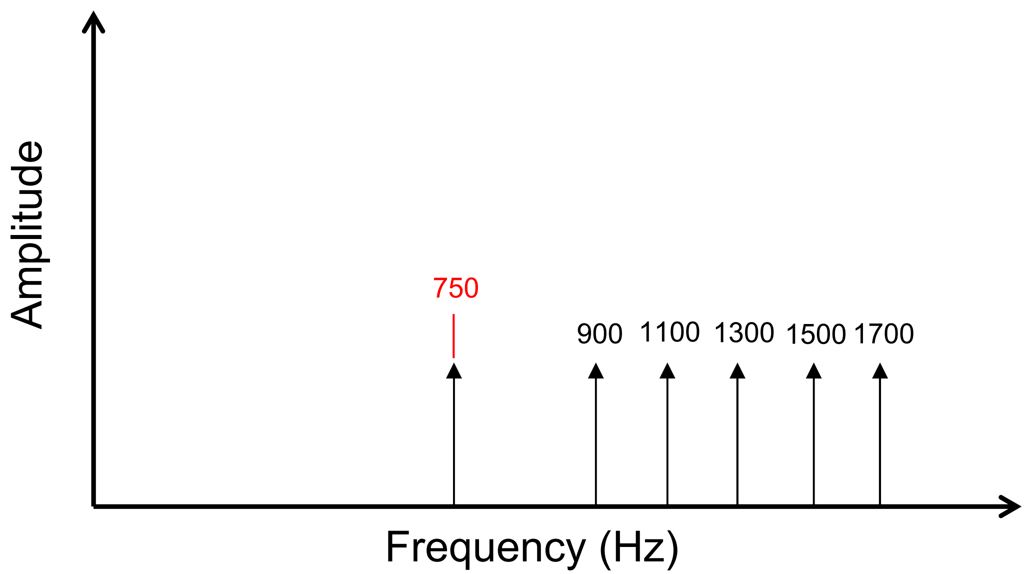
What is the perceived pitch?

216.6 or 185.9 Hz

Pitch Just Strange

Psychoacoustics

Tones at 900, 1100, 1300, 1500, and 1700 Hz.



What is the perceived pitch?

216.6 or 185.9 Hz

Equation for Residual Tone Identification

Psychoacoustics

$$f_{res} \approx \frac{\sum_n a_n^2 f_n^2}{\sum_n a_n^2 N_n f_n}$$

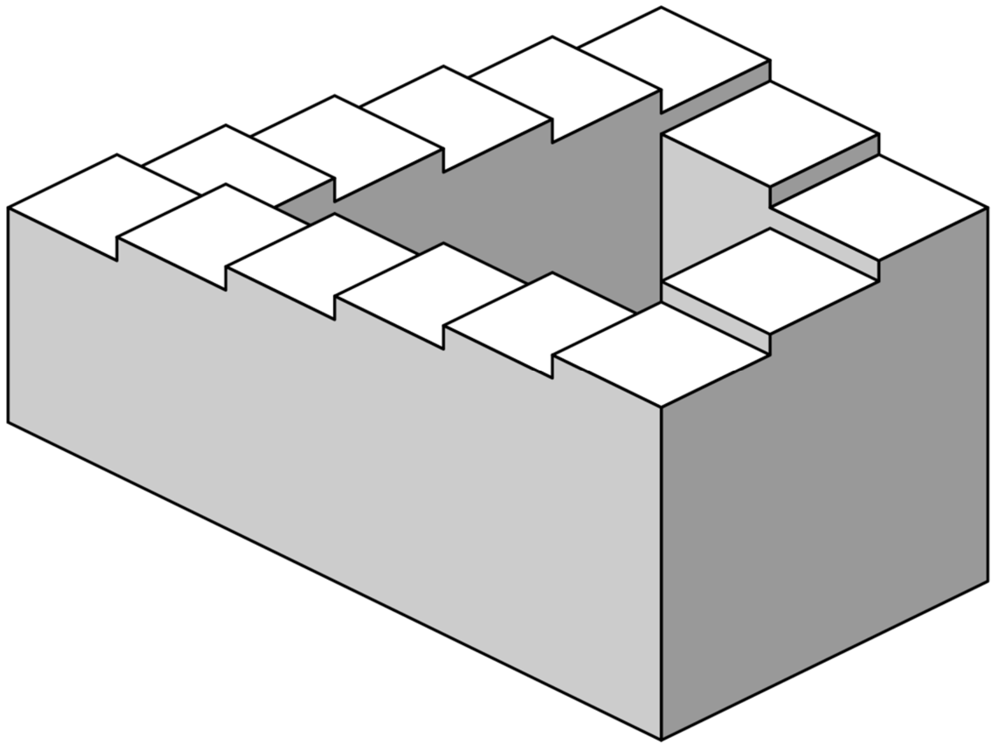
a_n^2 power (amplitude squared)
f_n frequencies
N_n integer combinations (i.e., 3,4,5,6,7 or 4,5,6,7,8 or others)

$$N_n = \frac{f_n}{f_{res}}$$

Shepard Tones

Psychoacoustics

Search on YouTube for “The sound illusion that makes Dunkirk so intense”



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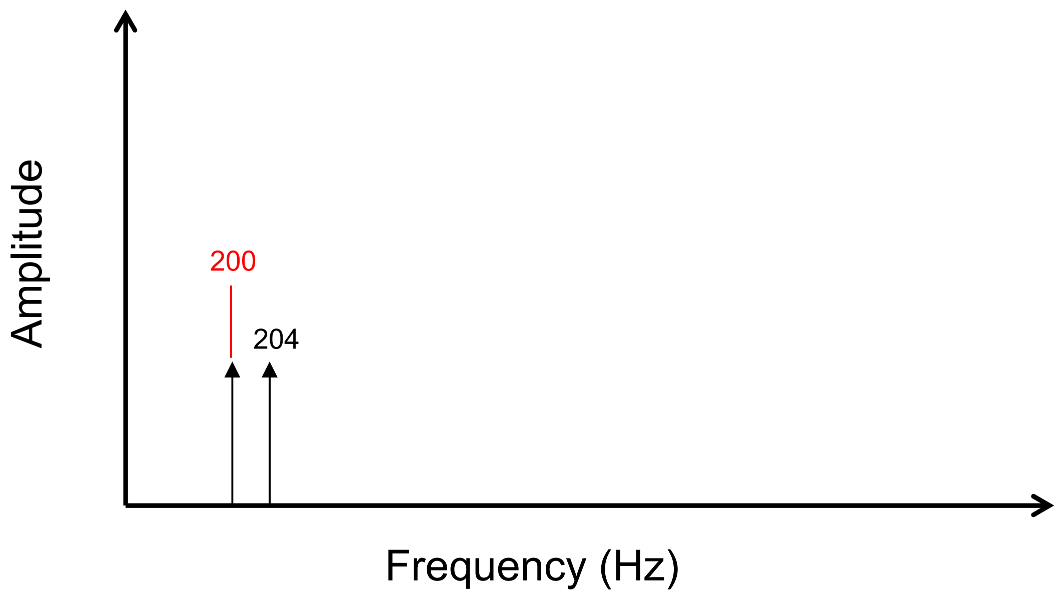
Timbre Beating

Psychoacoustics

Tones at 200 and 204 Hz.



What is the beat frequency?

4 Hz

Timbre Beating

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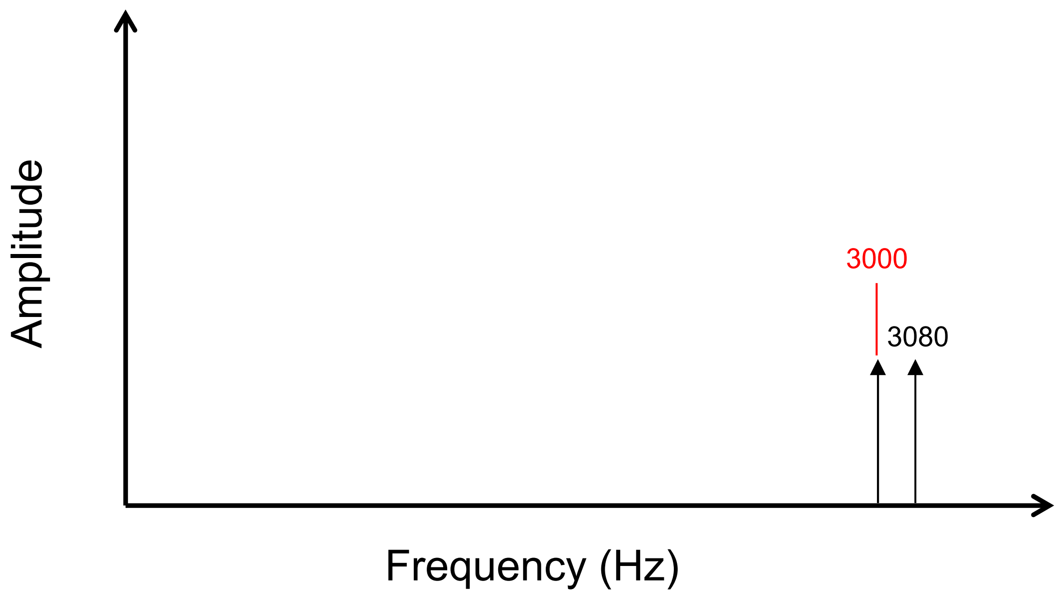
Tones at 3000 and 3080 Hz.



What is the beat frequency?

80 Hz

Timbre Beating

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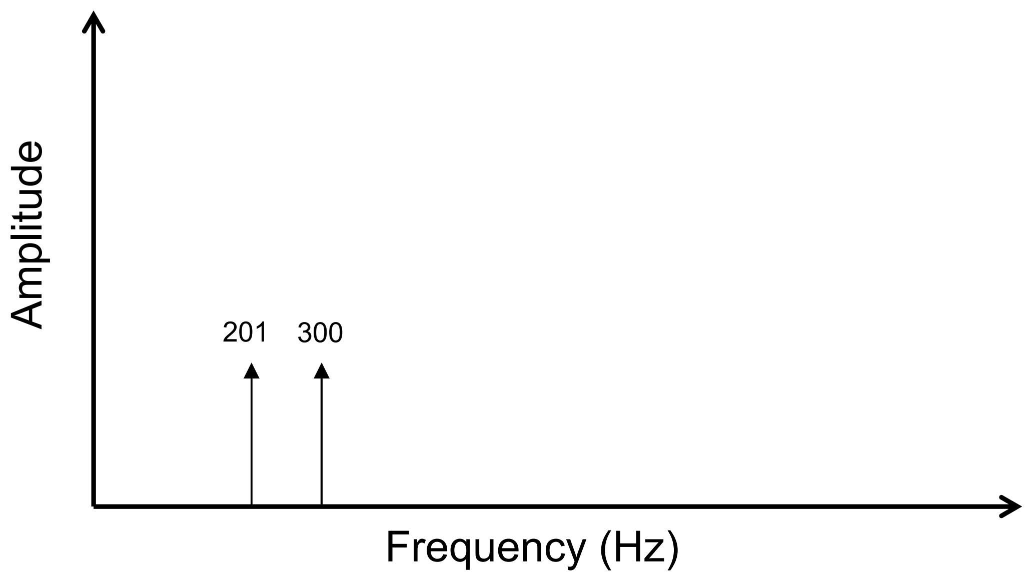
Tones at 201 and 300 Hz.



What is the beat frequency?

3 Hz

Timbre Bach Backwards

Psychoacoustics

- Bach
- Bach with notes reversed

Overview

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Metrics Tonality

Psychoacoustics

- Classic Tonality – provides a relative weight of the tonal components to the rest of the spectrum on a scale from 0 to 1. Delivers one number for entire frequency range. 1.0 is defined as a 60 dB sine tone at 1 kHz with no other noise present.
- Psychoacoustic Tonality – more sophisticated metric which incorporates features of human hearing. Results are delivered in frequency bands. Numbers increase with amplitude.
- Tone to Noise Ratio – compares the tone level to that of the masking noise in each band.
- Prominence Ratio – compares the level in a frequency band to surrounding bands.

Metrics Modulations or Transients

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- Fluctuation Strength – appropriate for modulations up to ~20 per second.
- Roughness – appropriate for modulations from ~20 to 300 per second.
- Kurtosis – statistic for identifying irregularities in the signal (i.e., clicking sounds).

"Turns out it was a marble in the ashtray"

Richard Lyon (2000)

Psychoacoustics

Some perceptual psychologists, among which psycho-acousticians are a subset, propose additional metrics that can be used to choose among product variations. In the area of sound, such metrics carry names like roughness, sharpness, and fluctuation strength. They are measured using combinations of frequency and temporal filtering, and instrumentation is available for computing these metrics.

These metrics undoubtedly shed some light on the correlation between features of sound and perception. But engineers design gear trains, motors, and structures, not spectra, so a correlation between component sounds and the acceptability of a product (which we have defined as sound quality) is of more direct value to the design engineer.

References

Psychoacoustics

- Eric Heller, Why You Hear What You Hear: An Experiential Approach to Sound, Music, and Psycho-Acoustics, Princeton University Press (2013).
- Richard Lyon, *Designing for Product Sound Quality*, Marcel Decker, Inc., New York (2000).
- Richard Lyon, “Product Sound Quality – from Perception to Design,” Sound and Vibration, March issue (2003).