



**Aalto University**  
School of Electrical  
Engineering

# Communication acoustics

## Ch 10: Basic psychoacoustic quantities

**Ville Pulkki and Matti Karjalainen**

*Department of Signal Processing and Acoustics  
Aalto University, Finland*

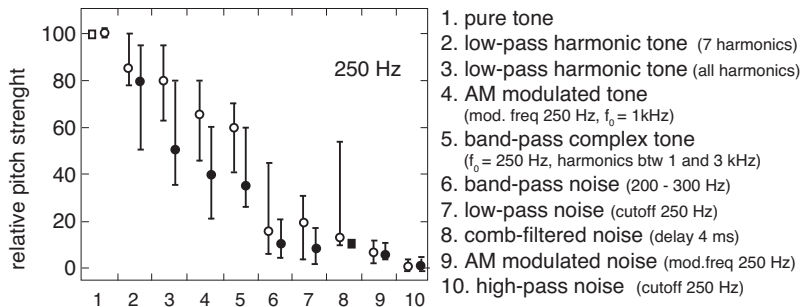
**September 19, 2017**

# This chapter

- Pitch
- Loudness
- Timbre
- Duration

# Pitch

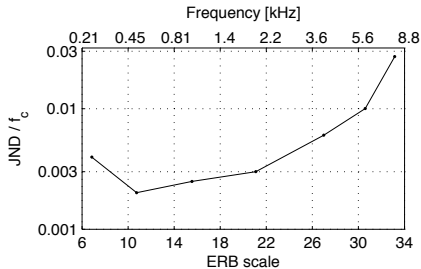
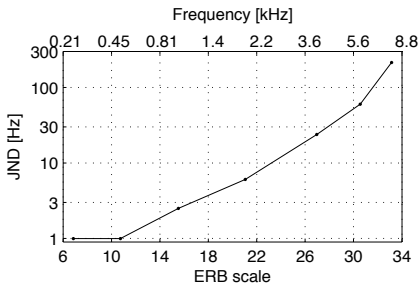
- 'that auditory attribute of sound according to which sounds can be ordered on a scale from low to high' ANSI
- Pitch strength



Adapted from Fastl and Stoll (1979)

# JND of pitch

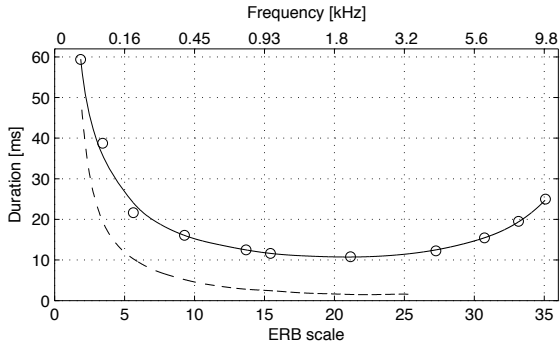
## ■ JND of frequency of two successive sinusoids



Adapted from Sek and Moore (1995)

# Pitch perception versus duration of sound

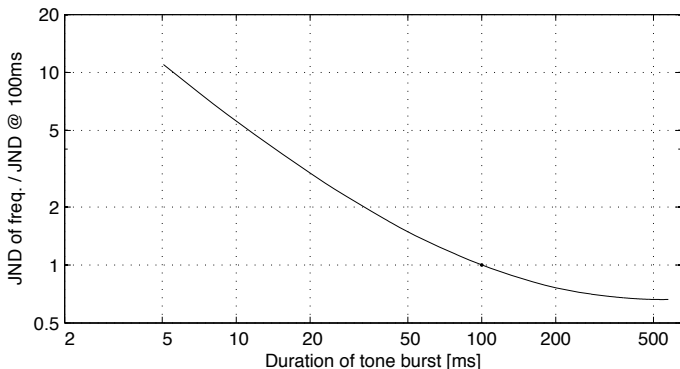
- Minimum length required for pitch perception
- Already very short tone bursts lead into perception of pitch



Adapted from Burck et al. (1935)

# Pitch perception versus duration of sound

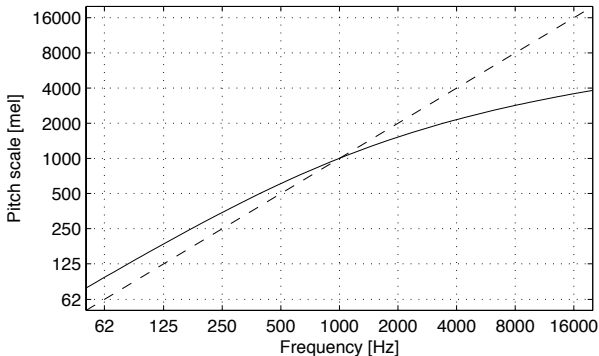
- The accuracy of pitch perception is enhanced during first 200 ms of sound



Adapted from Fastl and Zwicker (2007)

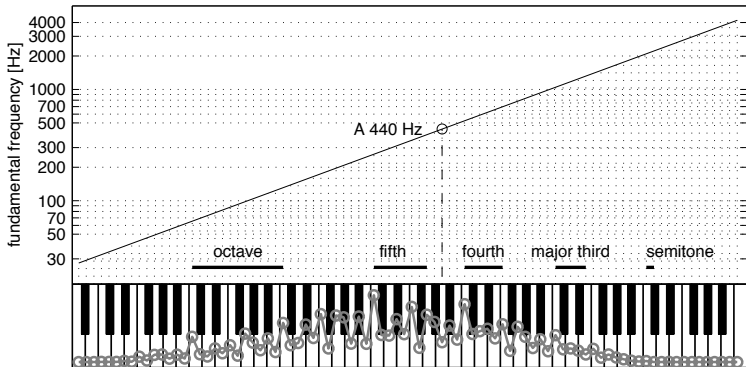
# Mel frequency scale

- 'adjust the pitch of the test tone to be two times higher than the reference tone'
- Mel scale derived



# Musical scale

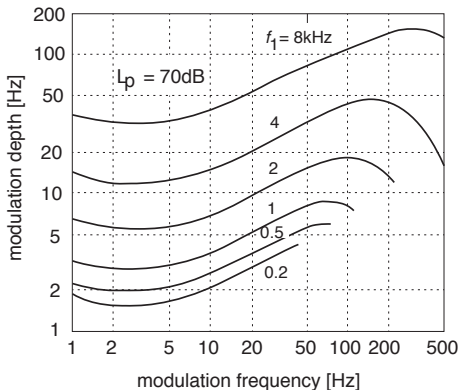
- Musical pitch scale is logarithmic
- (Approximate) frequency ratios: Octave = 2:1, Fifth = 3:2, Fourth 4:3, Third 5:4





# Detection of frequency modulation

- Curves have different carrier frequencies



Adapted from Demany and Semal (1989)

## Virtual pitch

- Although lowest harmonics are missing, a pitch is perceived to  $f_0$
- Compare: telephone band 300Hz + 4kHz, although male voice  $f_0 < 100\text{Hz}$

## Pitch theories

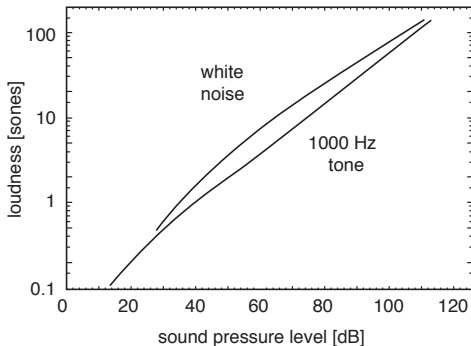
- Peak of activation at basilar membrane?
- Some kind of autocorrelation process after cochlea?
- Pitch theories have been debated for decades
- Neither theory explains fully perceptual phenomena

# Loudness

- 'that attribute of auditory sensation in terms of which sounds can be ordered on a scale extending from quiet to loud' ANSI
- One of fundamental quantities in psychoacoustics
- Approach loudness with simple tests, and continue to more complicated ones

# Loudness

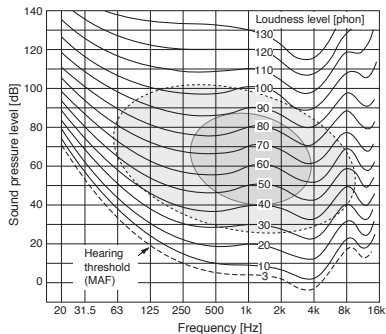
- Task: adjust sound to be 'twice as loud', lots of subjects, repetitions, and SPLs tested
- Define loudness scale with unit [sone]



Reprinted from Canteretta and Friedman (1978)

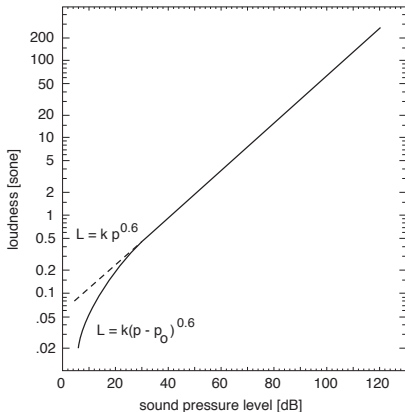
# Loudness level

- Loudness level defined with reference values located at 1 kHz with 10 dB spacing in the sound pressure level
- Unit: [phon]



# Connection between sound pressure, loudness and loudness level

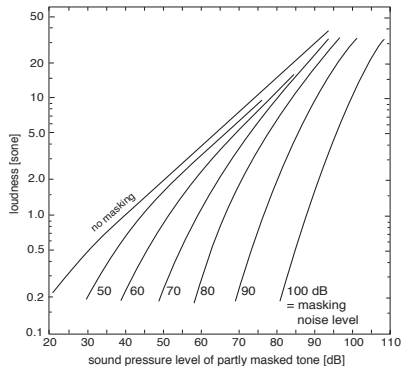
- $N$  = loudness [sone]
- $L_L$  = loudness level [phon]
- $N = 2^{(L_L - 40)/10}$
- $L_L = 40 + 10 \log_n(N)$
- $N = k \cdot (p - p_0)^{0.6}$
- Doubling loudness in sones means 10phon (= 10dB @ 1kHz) change in loudness level (or SPL)



Reprinted from Canteretta and Friedman (1978)

# Loudness of tone in presence of noise

- White noise as masker with different SPLs
- Loudness decreases fast when approaching the masking threshold

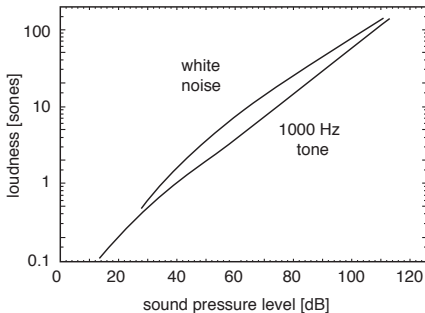


Reprinted from Canterretta and Friedman (1978)



# Loudness with broad-band signals

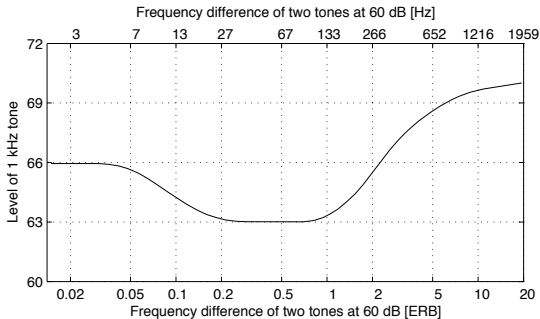
- Loudness is often affected, if the spectrum of sound changes and SPL is kept equal
- This was already seen in basic loudness listening test with sinusoids and noise



Reprinted from Canteretta and Friedman (1978)

# Loudness with two sinusoids

- The level of a reference tone adjusted to match the loudness with a pair of tones
- Frequency difference shown in x-axis



Adapted from Fastl and Zwicker (2007)

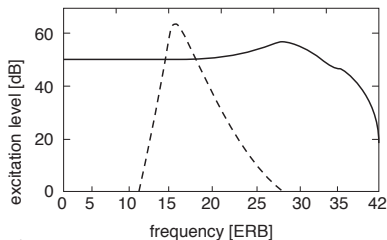
## A theoretic view of loudness process

- Input signal  $S(f)$  is warped to auditory frequency scale  $z$
- $S'(z) = S[f(z)] \frac{df}{dz}$
- Signal also spreads in frequency due to frequency masking,  $B(z)$  is spreading function
- $E(z) = S'(z) \star B(z)$
- Compute specific loudness  $N'(z)$ , kind of loudness function over frequency
- $N'(z) = c E(z)^{0.23}$
- Integrate over frequency for loudness  $N$
- $N = \int_0^M N'(z) dz$

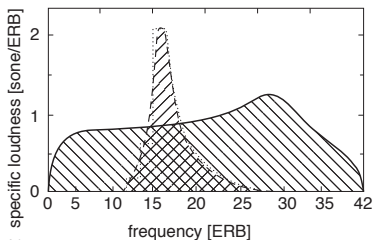
# Excitation pattern and specific loudness

■ a) excitation patterns. b) Specific loudness.

■ (dashed) sinusoid, (continuous) noise



a)

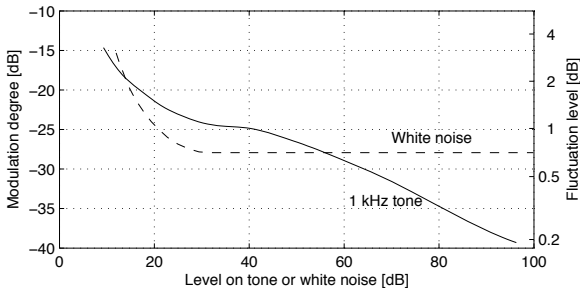


b)

Adapted from Fastl and Zwicker (2007)

# Difference threshold of loudness

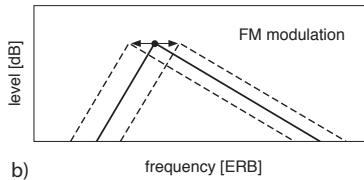
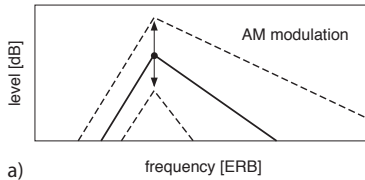
- The just noticeable level of amplitude modulation, about 1 dB with noise
- Why 1kHz value decreases continuously? Similar FM-tone JND result did not show this kind of result.



Adapted from Fastl and Zwicker (2007)

# Difference threshold of loudness

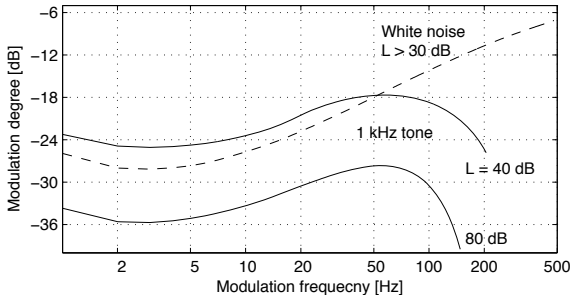
- AM causes periodic change of width of excitation pattern, especially at higher levels
- With FM this is not available
- Explains why larger level causes smaller difference thresholds



Adapted from Fastl and Zwicker (2007)

# JND threshold of amplitude modulation

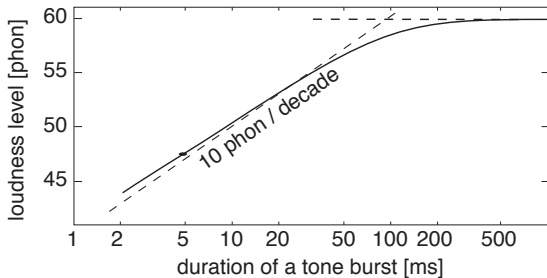
- Curves for tones with two levels and noise



Adapted from Fastl and Zwicker (2007)

# Loudness vs duration of sound

- The dependence of loudness level on duration
- Tone burst with frequency of 2kHz and a sound pressure level of 57dB



Adapted from Fastl and Zwicker (2007)

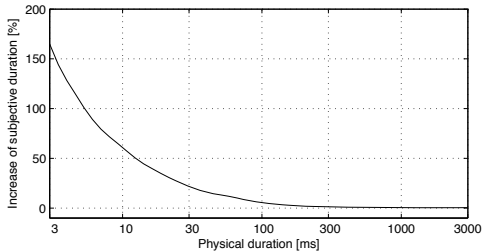


# Timbre

- When two sounds have the same pitch, loudness, and duration, timbre is what makes one particular sound different from another
- Humans recognize the sound source mostly with timbre
- Closest physical explanation is magnitude spectrum and its variation with time
- Also phase spectrum has an effect
- Complex phenomenon, not well understood or modeled
- Simple specific loudness models explain only steady noise-like sounds

# Perceived duration of sound

- 1-kHz tone at an SPL of 60 dB with duration shown in x-axis
- Adjust the duration to "twice" or "half"
- Subjective duration [dura]



Adapted from Fastl and Zwicker (2007)

# References

*These slides follow corresponding chapter in: Pulkki, V. and Karjalainen, M. Communication Acoustics: An Introduction to Speech, Audio and Psychoacoustics. John Wiley & Sons, 2015, where also a more complete list of references can be found.*

*References used in figures:*

Burck, W., Kotowski, P., and Lichte, H. (1935) Die horbarkeit von laufzeitdifferenzen. Elek. Nachr.-Techn., 12, 355–362.

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