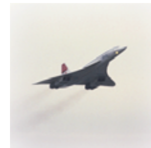
Introduction to Acoustics



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Agenda

- Introduction to Theory and Terminology
- The Decibel
- Frequency of Sound
- Measuring Sound
- Applications of Acoustics

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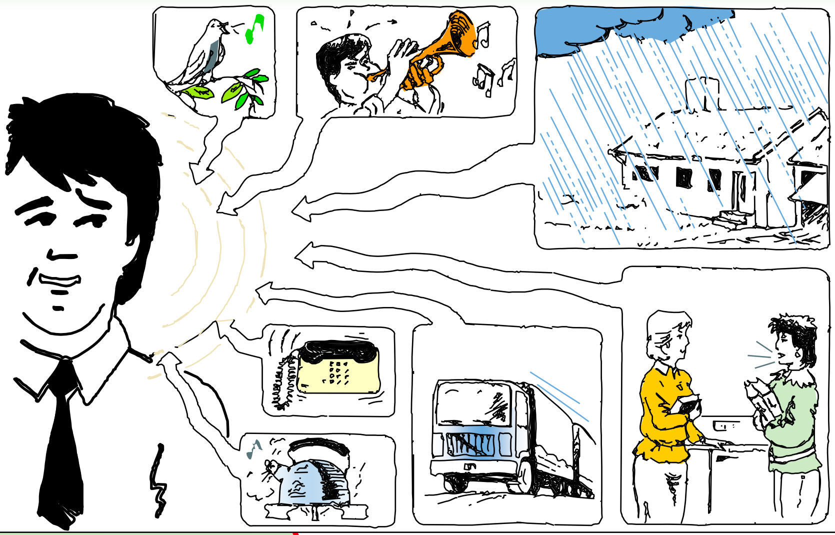
Sound



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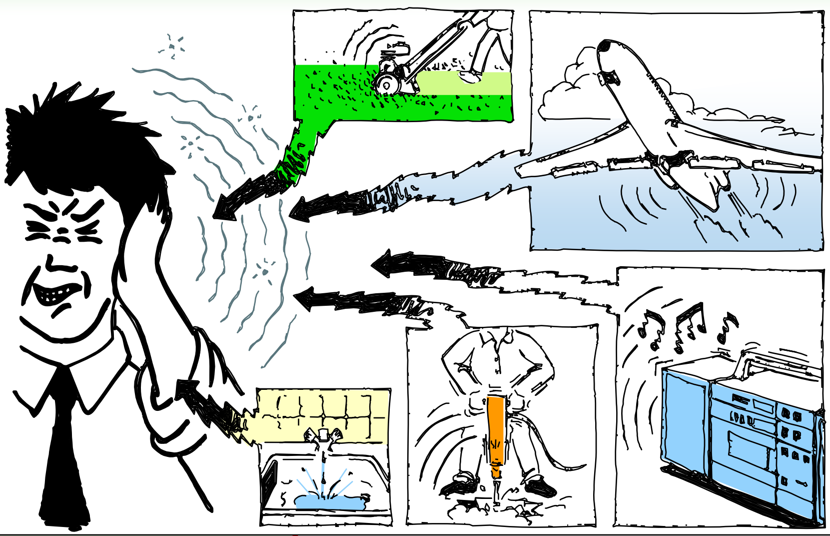
Sound and Noise



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Terminology of Sound

Active Intensity

RMS
Peak

Statistical analysis

Fast
Slow
Impulse

Free Field/Pressure Field

dB

Sound Pressure

Percentile level

Logarithmic scales

Weighting

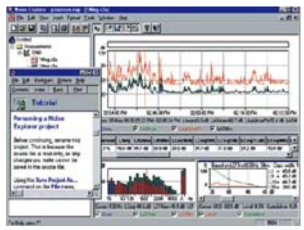
Pascal

L_{eq}

L_{10}

RMS

L_{90}



Constant percentage bandwidth

1/1 and 1/3 Octave Analysis

Noise Dose

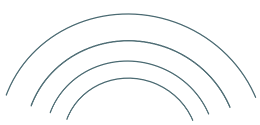
Basic Parameters of Sound (cont.)

Receiver ⟺ Sound Pressure Level

$$L_p = 10\log_{10}\frac{p^2}{p_o^2}$$

$$p_o = 2\times10^{-5}\,N/m^2$$

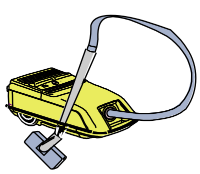
$$= 20\mu Pa$$



Path ⟺ Sound Intensity Level

$$L_i = 10\log_{10}\frac{I}{I_0}$$

$$I_o = 1pW/m^2$$

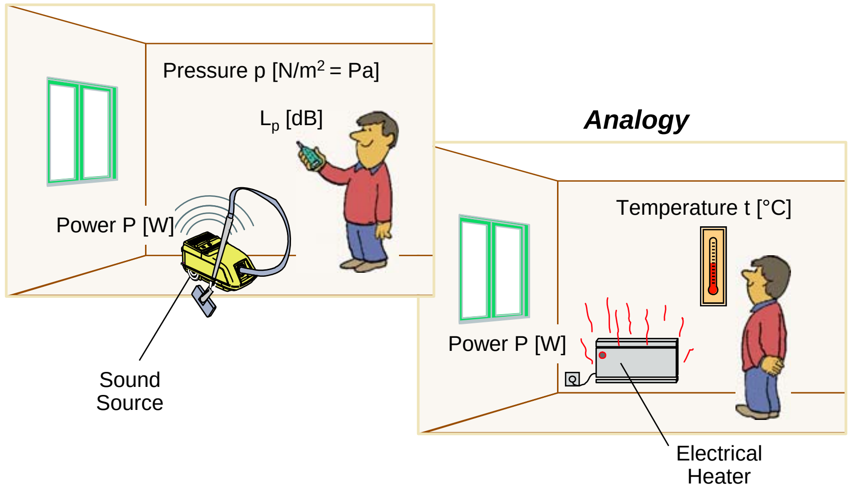


Source ⟺ Sound Power Level

$$L_w = 10\log_{10}\frac{W}{W_o}$$

$$W_o = 1pW$$

Pressure vs. Power



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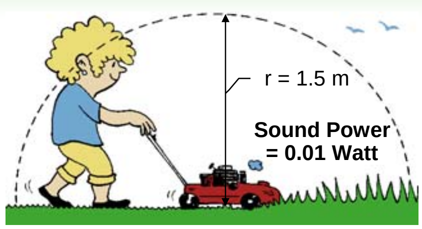
Sound Levels Under Free-field Conditions

Example:



$$I = \frac{W}{2\pi r^2} = \frac{p^2}{\rho c}$$

Where $2\pi r^2$ is the area of the hemisphere

Sound Power

W = 0.01 Watt

Sound Intensity

$$I = \frac{W}{2\pi r^2} = \frac{0.01}{2\pi \cdot 1.5^2} = 0.000707 \ {}^{W}\!/_{m^2}$$

Sound Pressure

$$p = \sqrt{I \cdot \rho c} = \sqrt{0.000707 \cdot 400} = 0.532 \text{ Pascal}$$

$$L_W = 10\log_{10}\frac{W}{W_0}\text{ dB} = 10\log_{10}\frac{0.01}{10^{-12}}\text{ dB}$$
$$L_W = 100 \text{ dB}$$

$$L_I = 10\log_{10}\frac{I}{I_0}\text{ dB} = 10\log_{10}\frac{7.07\cdot 10^{-4}}{10^{-12}}\text{ dB}$$
$$L_I = 88.5 \text{ dB}$$

$$L_p = 10\log_{10}\frac{p^2}{p_0^2}\text{ dB} = 10\log_{10}\frac{0.532^2}{(20\cdot 10^{-6})^2}\text{ dB}$$
$$L_p = 88.5 \text{ dB}$$

$L_I = L_p$ under free-field conditions

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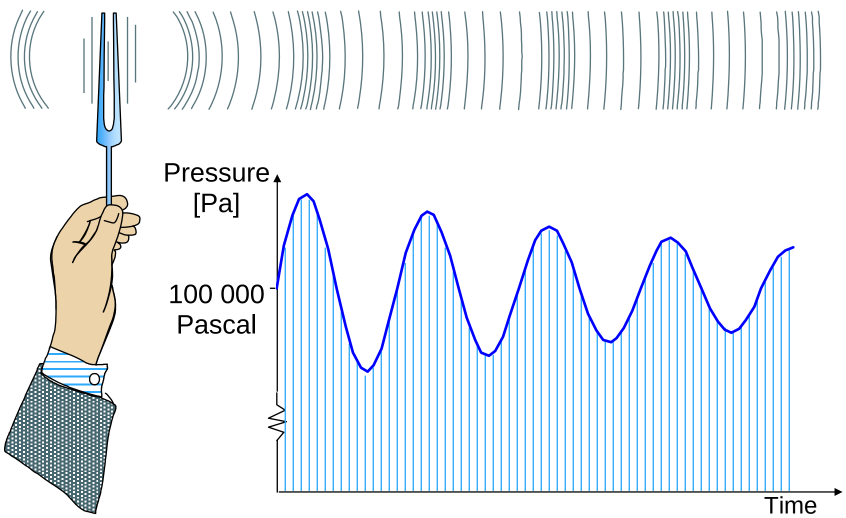
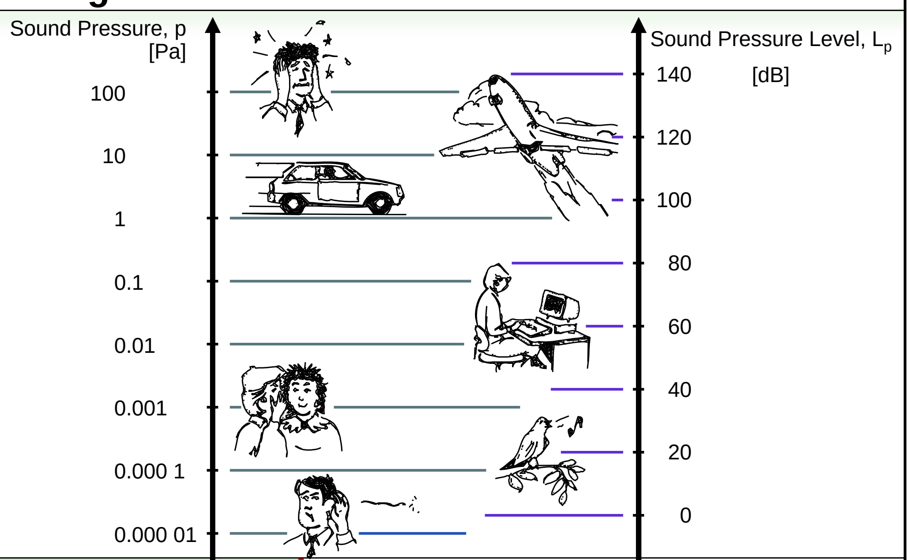
Sound Pressure Propagation



Range of Sound Pressure Levels



Converting Pascals to Decibels

$$L_p = 20 \log \left(\frac{p}{p_0}\right) \text{ dB re } 20\ \mu\text{Pa}$$

$$(p_0 = 20\ \mu\text{Pa} = 20 \times 10^{-6}\ \text{Pa})$$

Ex. 1: p = 1 Pa

$$L_p = 20 \log \frac{1}{20 \times 10^{-6}}$$

$= 20 \log 50\,000$

$= 94$ dB

Ex. 2: p = 31.7 Pa

$$L_p = 20 \log \frac{317}{20 \times 10^{-6}}$$

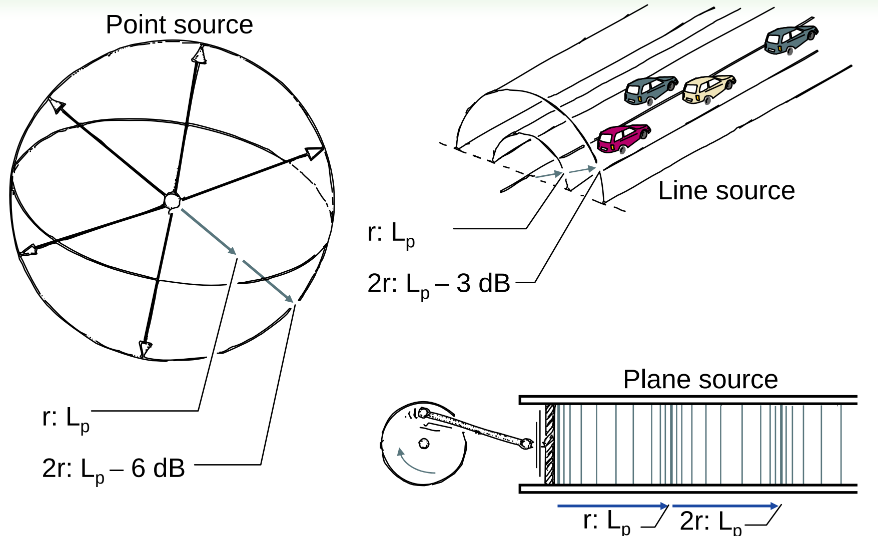
$= 20 \log 1.58 \times 10^6$

$= 124$ dB

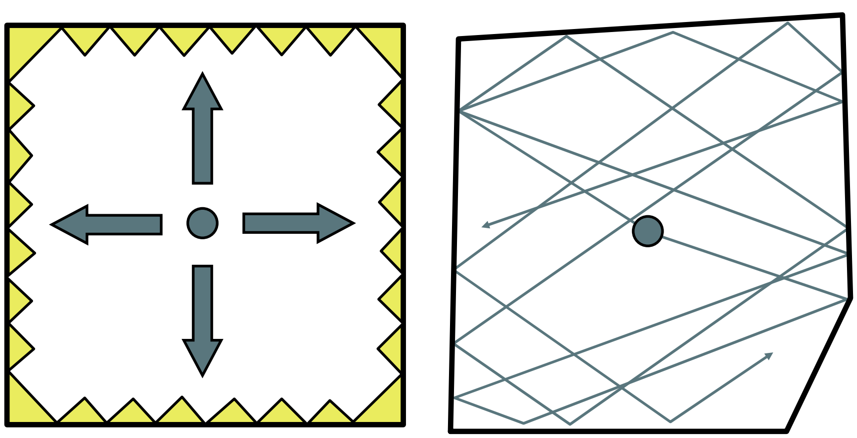
Human Perception of dBs

Change in Sound Level (dB)	Change in Perceived Loudness
3	Just perceptible
5	Noticeable difference
10	Twice (or 1/2) as loud
15	Large change
20	Four times (or 1/4) as loud

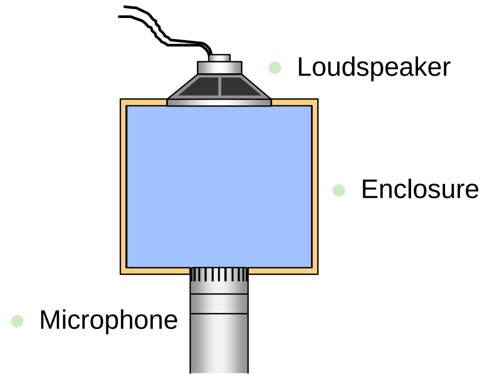
Types of Sound Sources

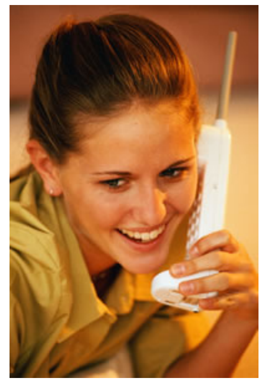


Anechoic and Reverberant Enclosures

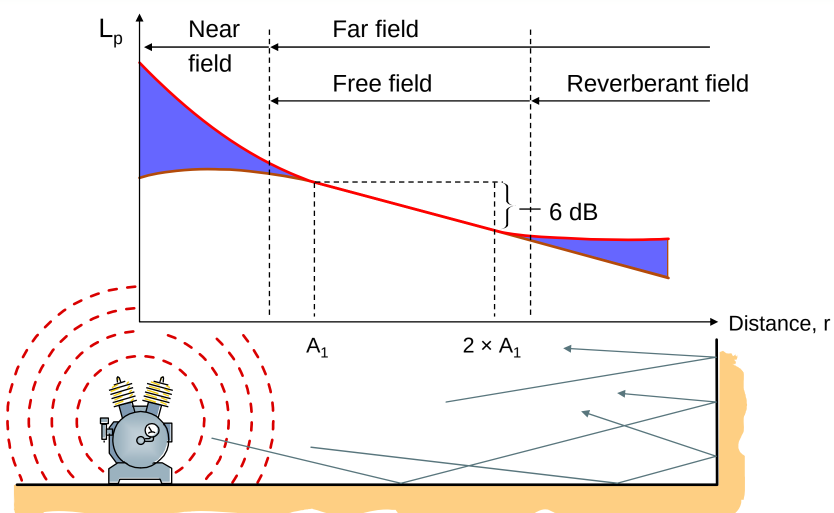


Pressure Field

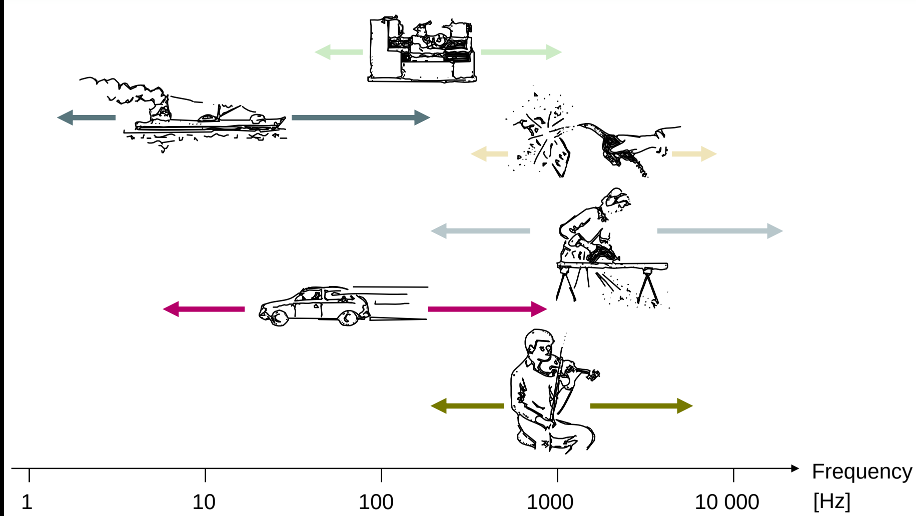




Sound Fields

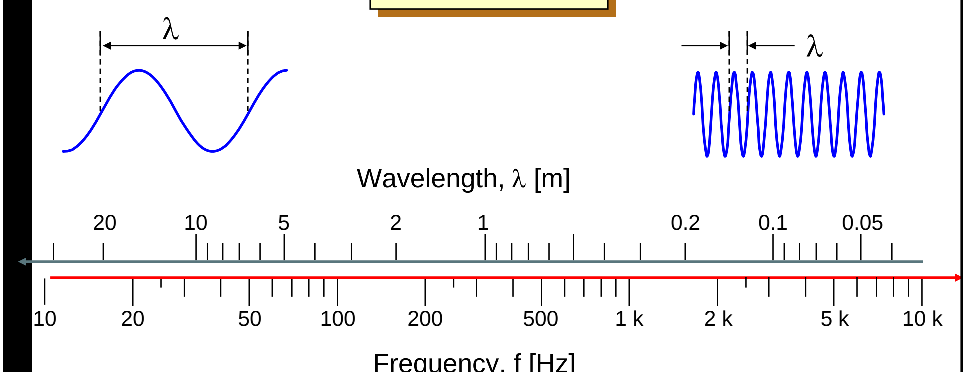


Frequency Range of Different Sound Sources

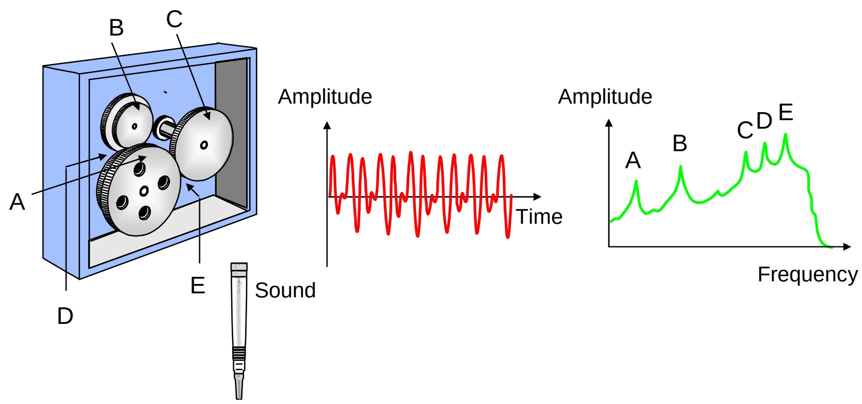


Wavelength and Frequency

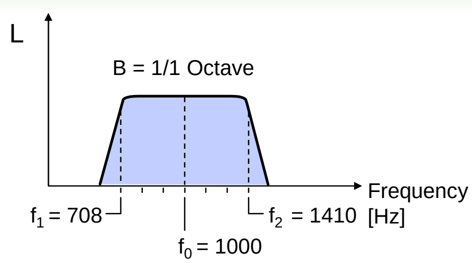
$$\lambda = \frac{c}{f}$$



Why Make a Frequency Analysis



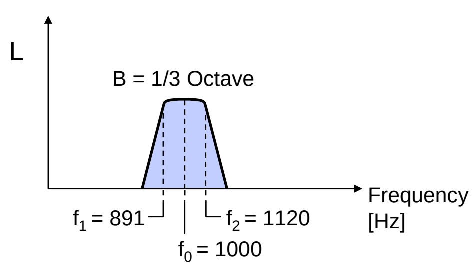
1/1 and 1/3 Octave Filters



1/1 Octave

$f_2 = 2 \times f_1$

$B = 0.7 \times f_0 \approx 70\%$

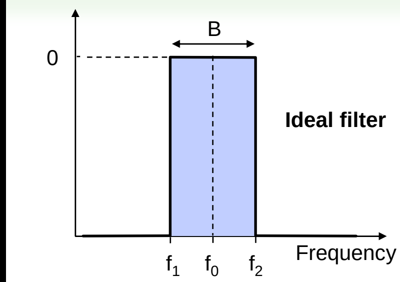


1/3 Octave

$f_2 = \sqrt[3]{2} \times f_1 = 125 \times f_1$

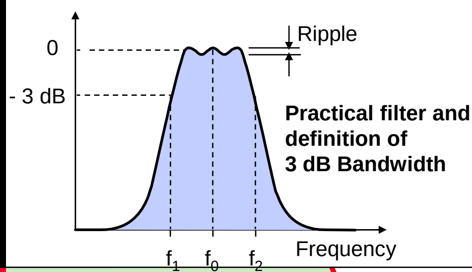
$B = 0.23 \times f_0 \approx 23\%$

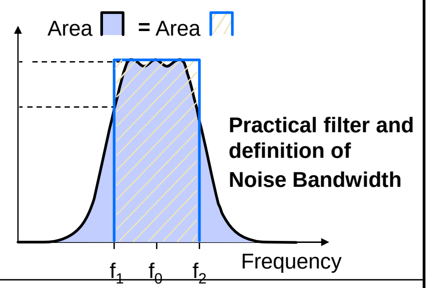
Bandpass Filters and Bandwidth



Bandwidth = $f_2 - f_1$

Centre Frequency = f_0

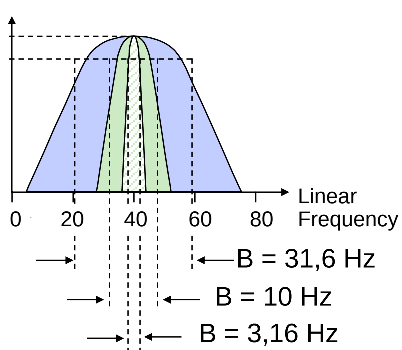




Filter Types

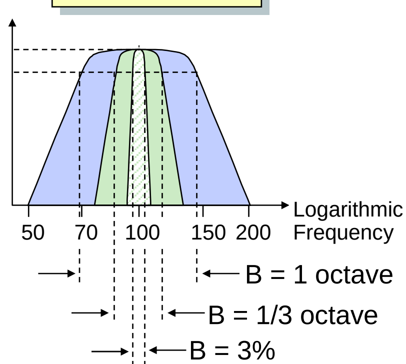
Constant Bandwidth

$B = x$ Hz

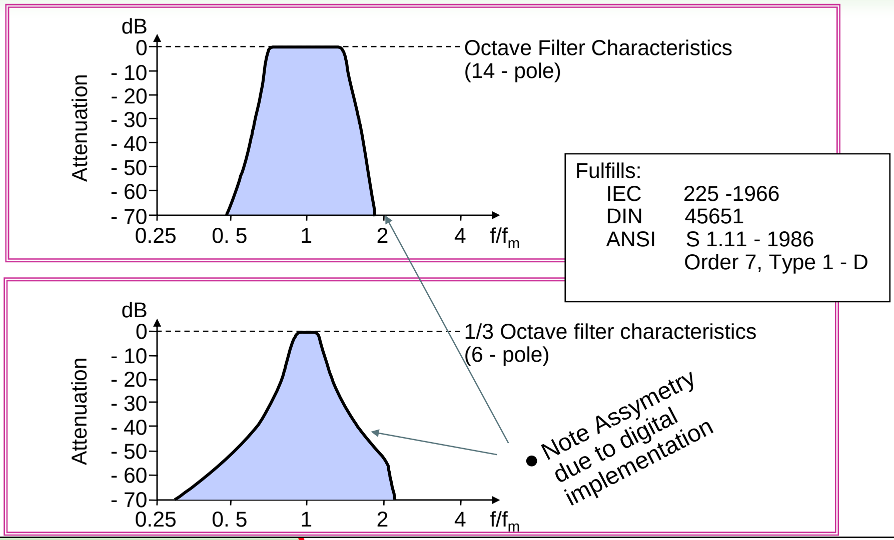


Constant Percentage Bandwidth (CPB)
or Relative Bandwidth

$$B = y\% = \frac{y \times f_0}{100}$$



Bandpass Filters



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Third-octave and Octave Passband

Band No.	Nominal Centre Frequency Hz	Third-octave Passband Hz	Octave Passband Hz
1	1.25	1.12 – 1.41	
2	1.6	1.41 – 1.78	
3	2	1.78 – 2.24	1.41 – 2.82
4	2.5	2.24 – 2.82	
5	3.15	2.82 – 3.55	
6	4	3.55 – 4.47	2.82 – 5.62
27	500	447 – 562	355 – 708
28	630	562 – 708	
29	800	708 – 891	
30	1000	891 – 1120	708 – 1410
31	1250	1120 – 1410	
32	1600	1410 – 1780	
40	10 K	8910 – 11200	
41	1.25 K	11.2 – 14.1	
42	16 K	14.1 – 17.8 K	11.2 – 22.4 K
43	20 K	17.8 – 22.4 K	

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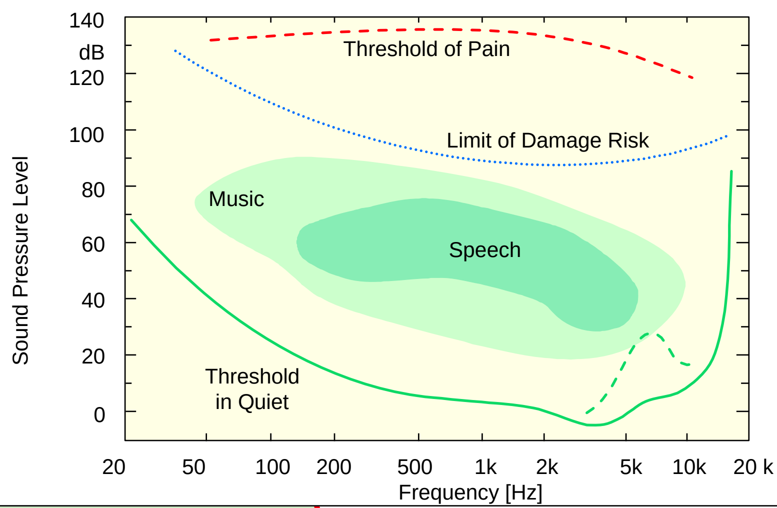
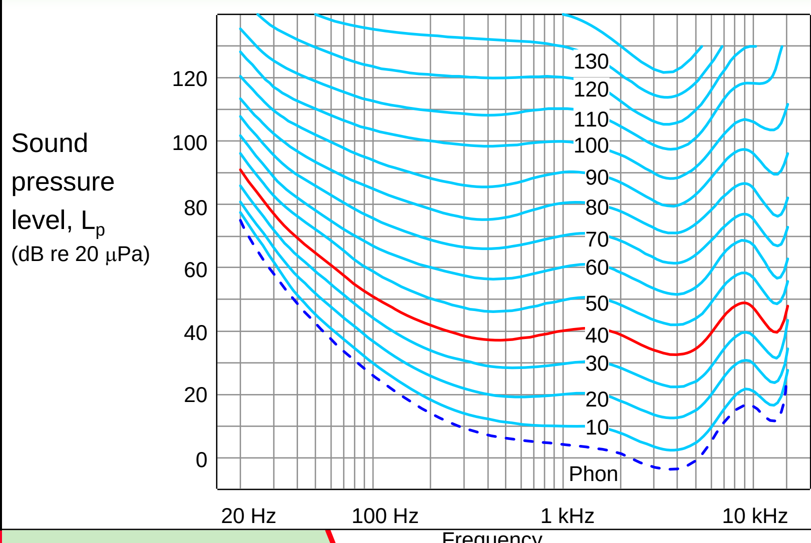
Auditory Field



Equal Loudness Contours for Pure Tones



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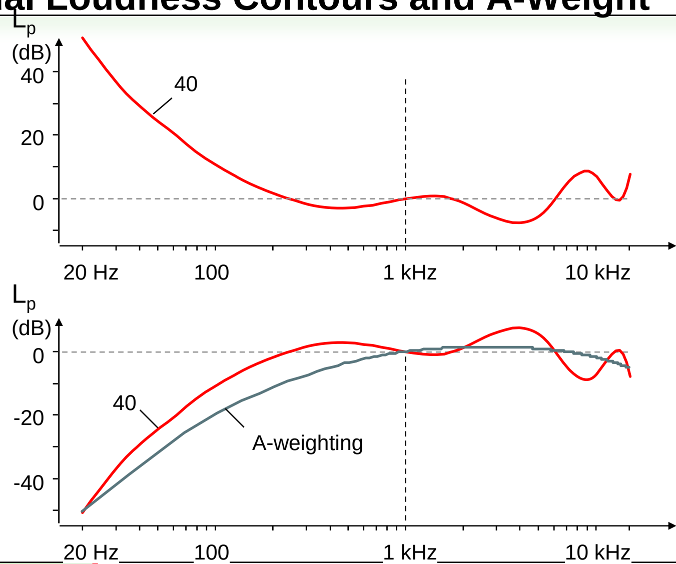
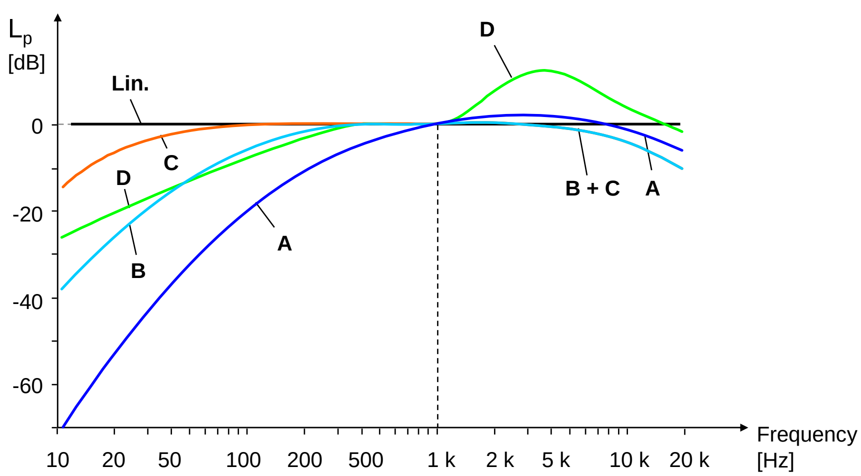
40 dB Equal Loudness Contours and A-Weight

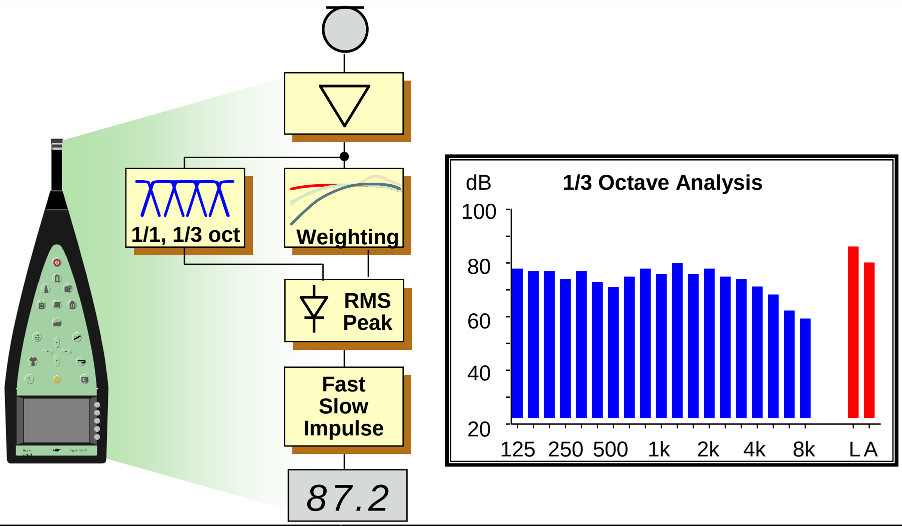
- 40 dB Equal Loudness Contour normalized to 0 dB at 1kHz
- 40 dB Equal Loudness Contour inverted and compared with A-weighting



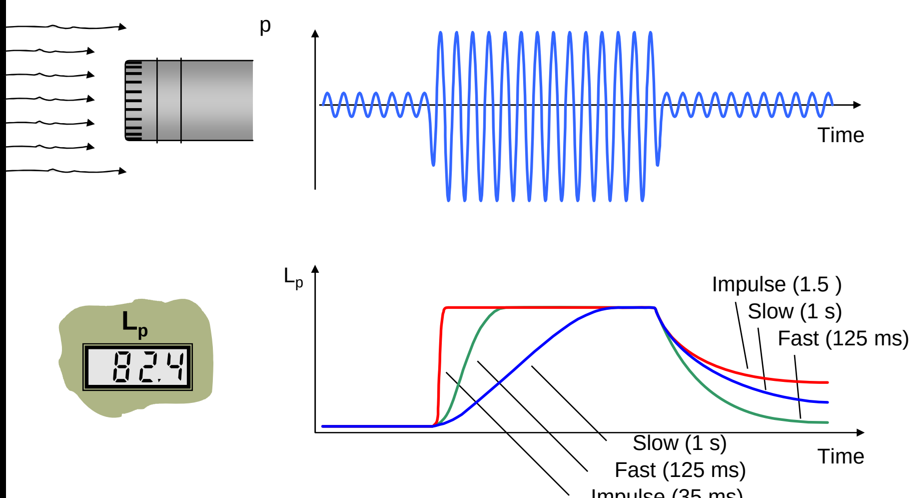
Frequency Weighting Curves



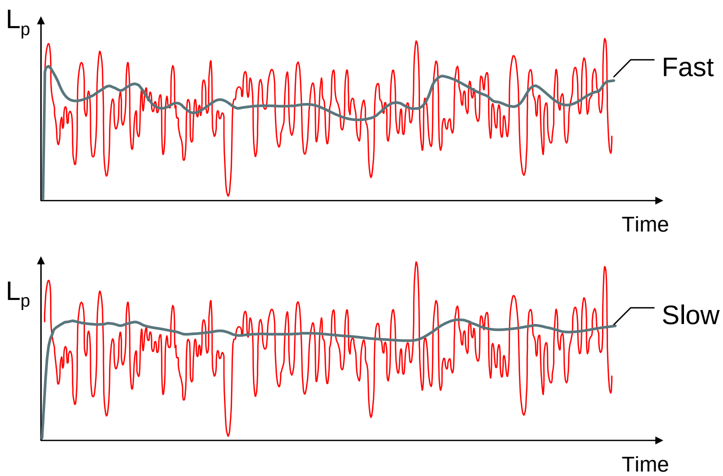
The Sound Level Analyzer



Time Weighting



Time Weighting



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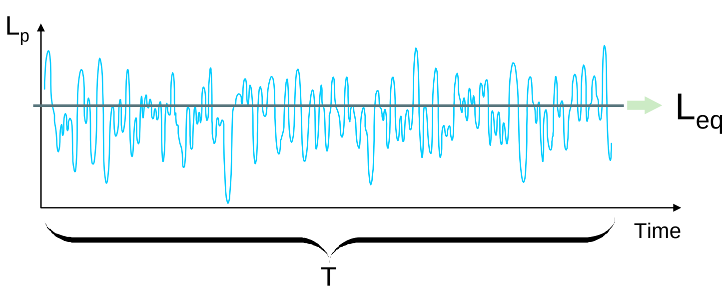
Equivalent Level, L_{eq}

$$L_{eq} = 10 \log_{10} \frac{1}{T} \int_0^T \left(\frac{p(t)}{p_0} \right)^2 dt$$



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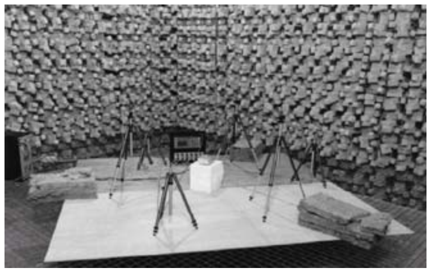
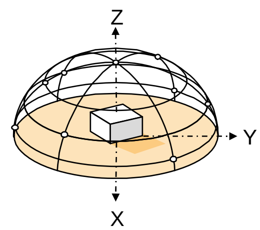
Sound Power

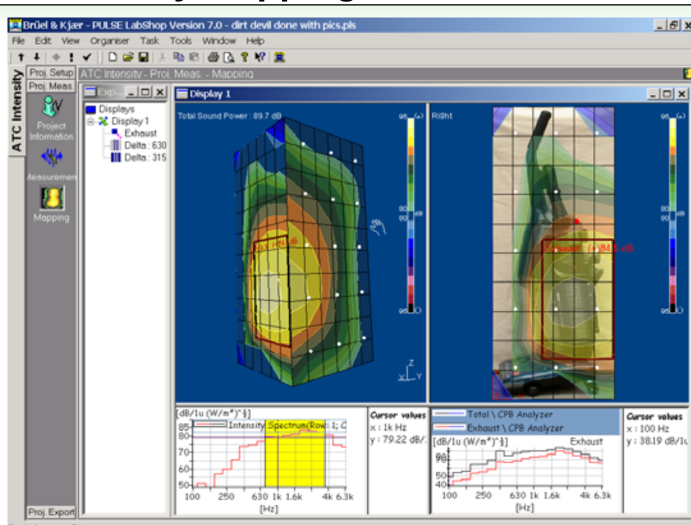


- Product noise labeling
- Government regulations
- 'Apples to Apples' comparison of noise
- Can predict SPL with knowledge of sound field

- Three ways to calculate sound power:
  - Free Field
  - Reverberant Field
  - Sound Intensity



Intensity Mapping

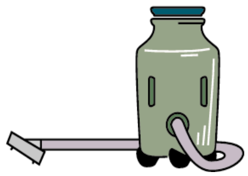


- Visually identify where sounds come from
- Rank sound power contribution of individual components
- Make modern art?

Sound Quality

L = 63 dBA

L = 63 dBA

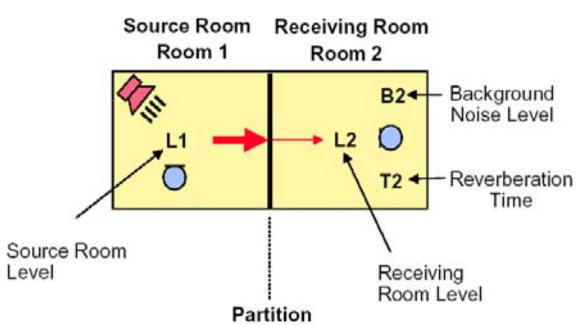


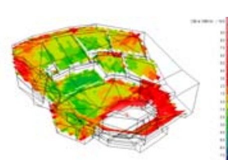
L = 63 dBA

- Sound Quality is a parameter that sells the product
- A-weighted noise levels and sound power are not sufficiently sensitive to fully characterize the “quality” of product sound
- Sound Quality is function of consumer expectations

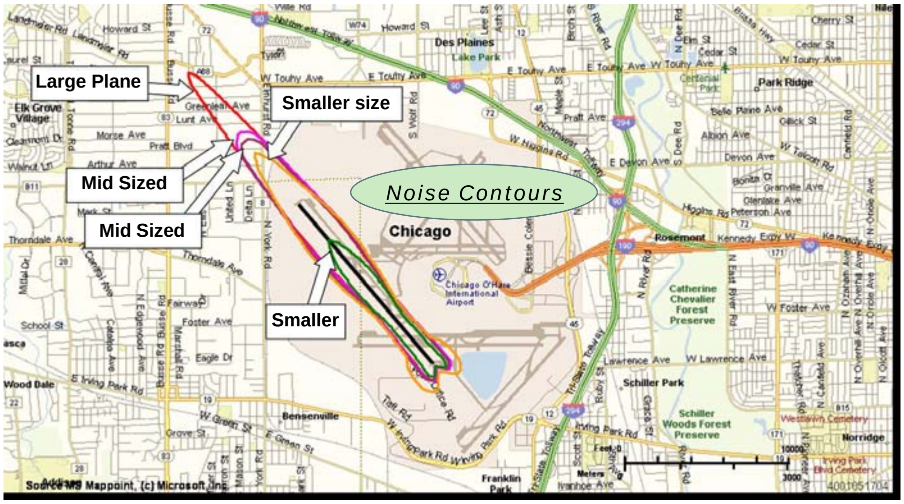
Building Acoustics

- Reverberation Time
- Transmission Loss
- Leakage between rooms
- Impact Isolation
- Speech Intelligibility





Environmental Noise Models



Conclusion

- Clear understanding of the three basic acoustic parameters: pressure, intensity, power
- What a decibel is and why we use it in acoustics
- Differences between Anechoic, Reverberant, and Pressure sound fields
- How wavelengths are calculated and the importance of frequency analysis in acoustics
- Introduction to some different acoustic applications

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Literature for Further Reading

References

- Acoustic Noise Measurements
  Brüel & Kjær (BT 0010-12)
- Noise Control - Principles and Practice
  Brüel & Kjær (188-81)
- *Noise and Vibration Control*
  L. L. Beranek, ed. INCE
- *Industrial Noise Control*
  Louis Bell, Dekker
- *The Science and Application of Acoustics*
  Daniel Raichel, AIP Press
- *Industrial Noise and Vibration Control*
  Irwin and Graf, Prentice Hall
- *Acoustics*
  L.L. Beranek, Acoustical Society of America
- *Acoustical Designing in Architecture*
  V. Knudsen, C. Harris Acoustical Society of America

Journals and Magazines

- Journal of the Acoustical Society of America
- Noise Control Engineering
- Sound and Vibration Magazine
- Bruel & Kjaer Magazine

Websites

- www.bkhome.com
- asa.aip.org
- www.inceusa.org
- www.nonoise.org

Questions

Jason Kunio
Application Engineer
678-250-7684
jason.kunio@bksv.com