“Noise 101” Workshop on Acoustics

AWMA/OS Noise Conference 2012

May 7, 2012

HGC Engineering
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Principal

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“Noise 101” Outline

- Why Care About Noise?
- The Science of Sound
- Logarithmic Math (just a bit!)
- Measures for Time-varying Sound
- Frequency and Pitch
- A-weighting & Octave Bands
- Sound Level Limits
- Typical Noise Control Methods
- Vibration
- Miller Time!

Why care about noise?

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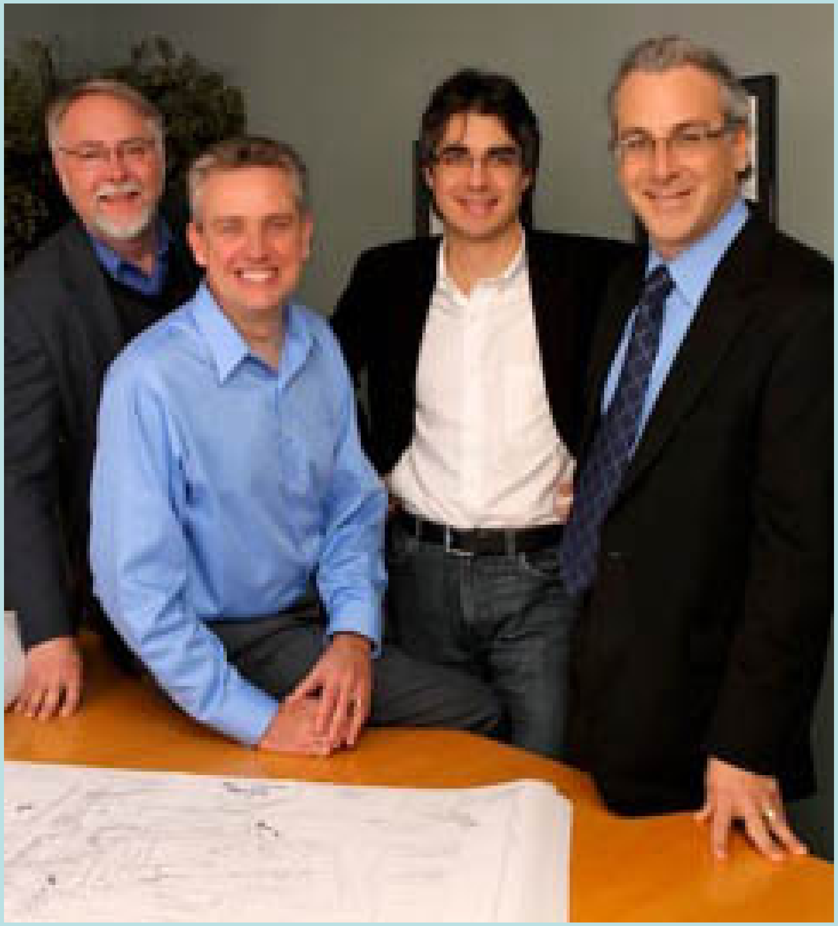

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Why Should you care about noise?

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Why Should you care about noise?

- Outdoors ("Environmental") – Avoid adverse impact: disturbance, annoyance, loss of enjoyment of property, interference with sleep

- Industrial Workplace – Avoid hearing damage, avoid interfering with communications

- Office Workplace – Productivity, comfort, acoustical privacy

It’s the Law! Section 9, EPA:

No person shall, except under and in accordance with an environmental compliance approval issued by the Director,

(a) construct, alter, extend or replace any plant, structure, equipment, apparatus, mechanism or thing that may discharge or from which may be discharged a contaminant into any part of the natural environment other than water; or

[underlining added]

Section 9, EPA (cont'd)

(b) alter a process or rate of production with the result that a contaminant may be discharged into any part of the natural environment other than water or the rate or manner of discharge of a contaminant into any part of the natural environment other than water may be altered. [underlining added]

R.S.O. 1990, c. E.19, s. 9 (1).

Section 9, EPA (cont'd)

"contaminant" means any solid, liquid, gas, odour, heat, sound, vibration, radiation or combination of any of them resulting directly or indirectly from human activities that may cause an adverse effect; [underlining added]

<u>It's the Law!</u> OHSA states:

(3) Every employer shall take all measures reasonably necessary in the circumstances to protect workers from exposure to hazardous sound levels. O. Reg. 565/06, s. 2.

(6) Without limiting the generality of subsections (3) and (4), every employer shall ensure that no worker is exposed to a sound level greater than an equivalent sound exposure level of 85 dBA, $L_{ex,8}$. O. Reg. 565/06, s. 2.

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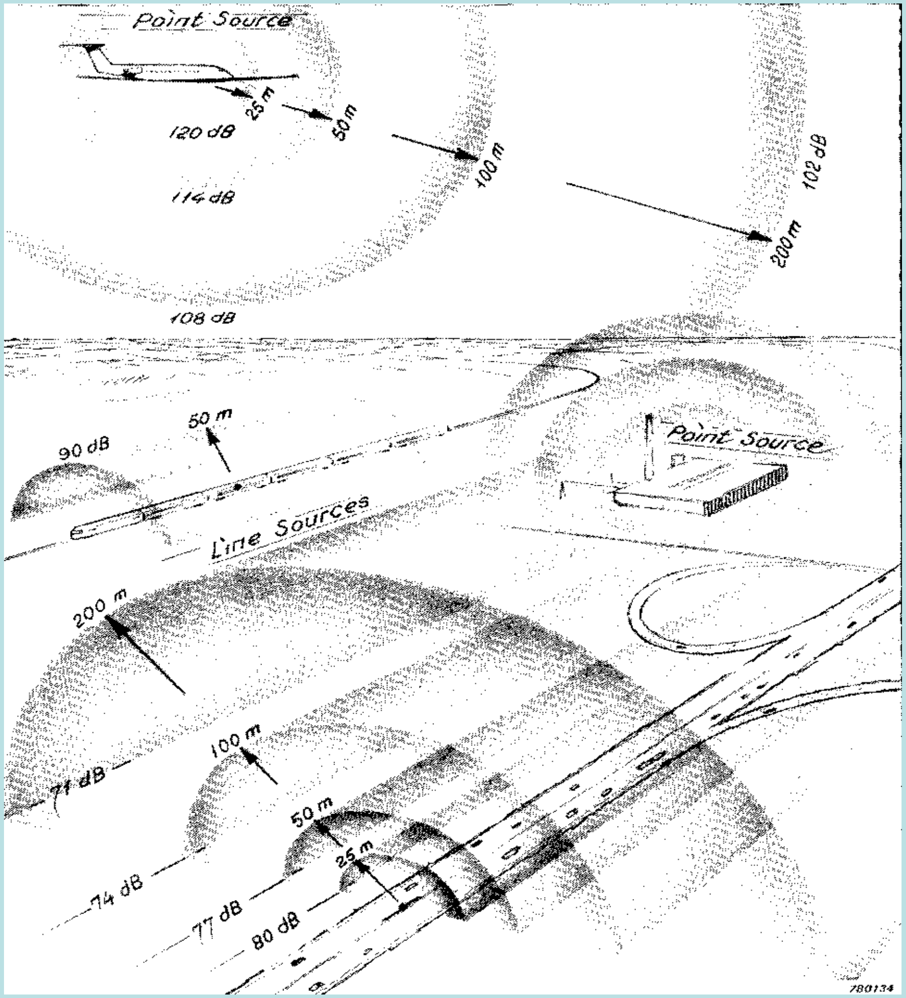
A bit about the science of sound…

Sound = Air pressure fluctuations

(in the range of 20 to 20,000 per second)



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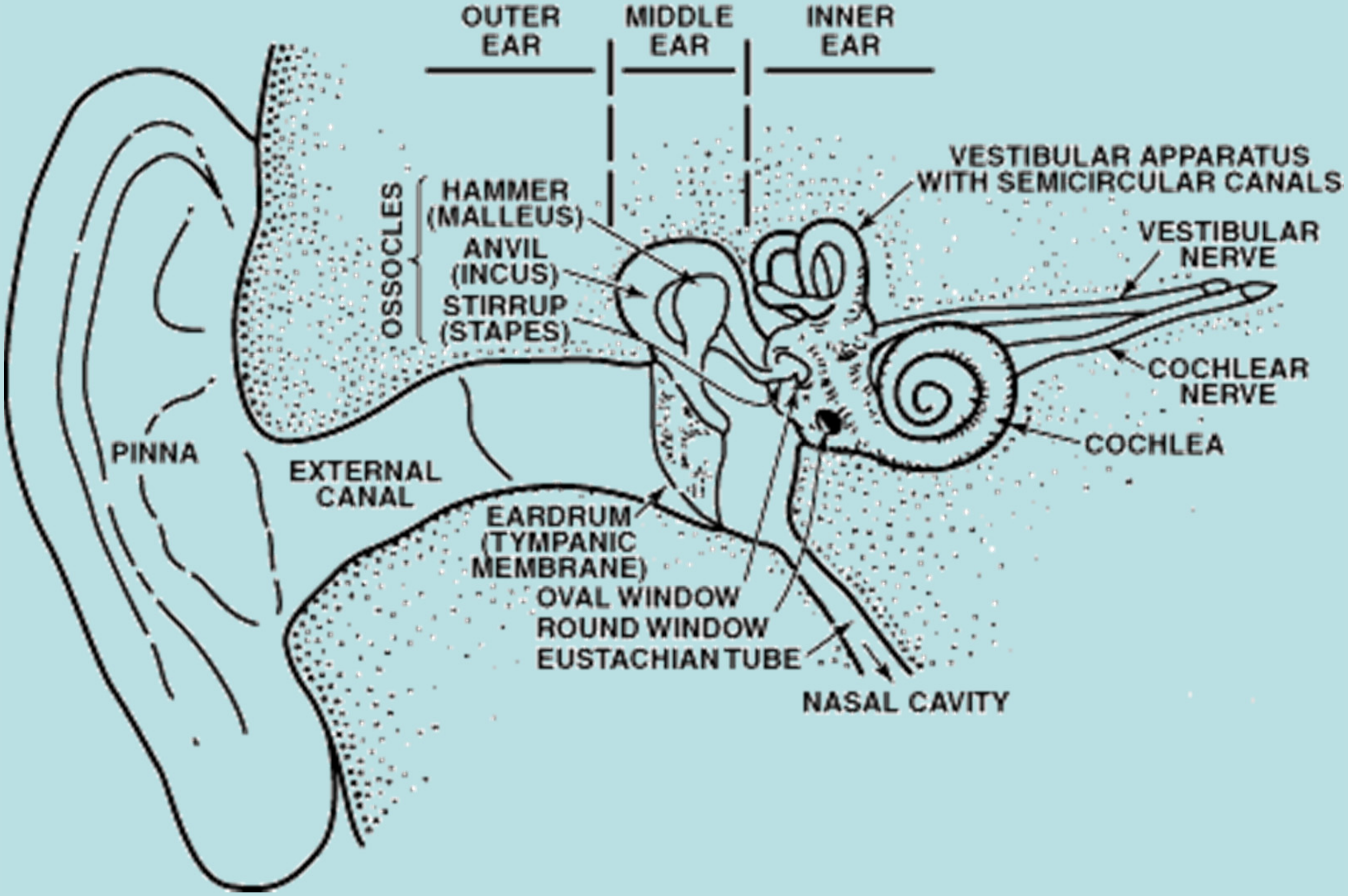
The Ear is Essentially a Microphone



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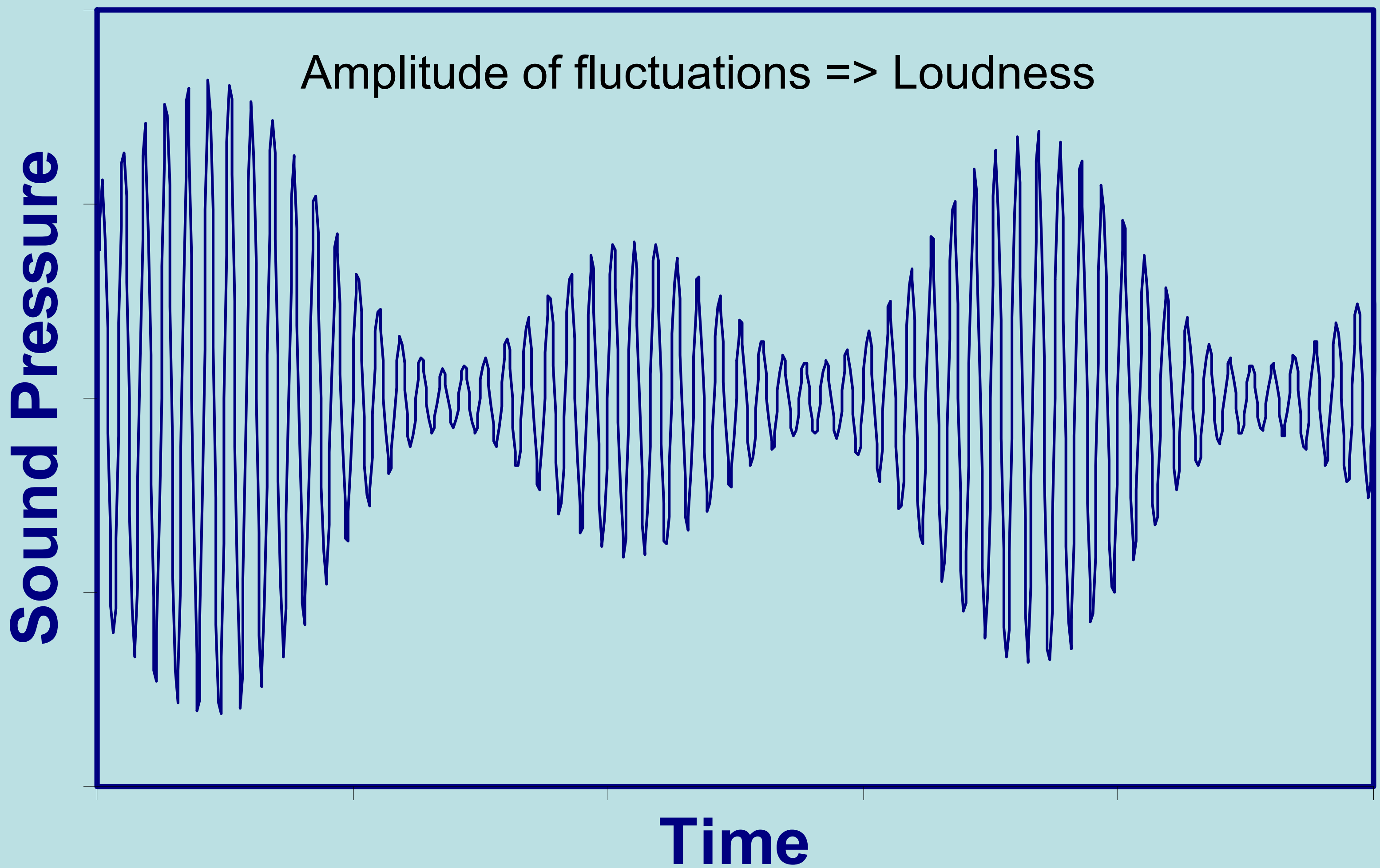

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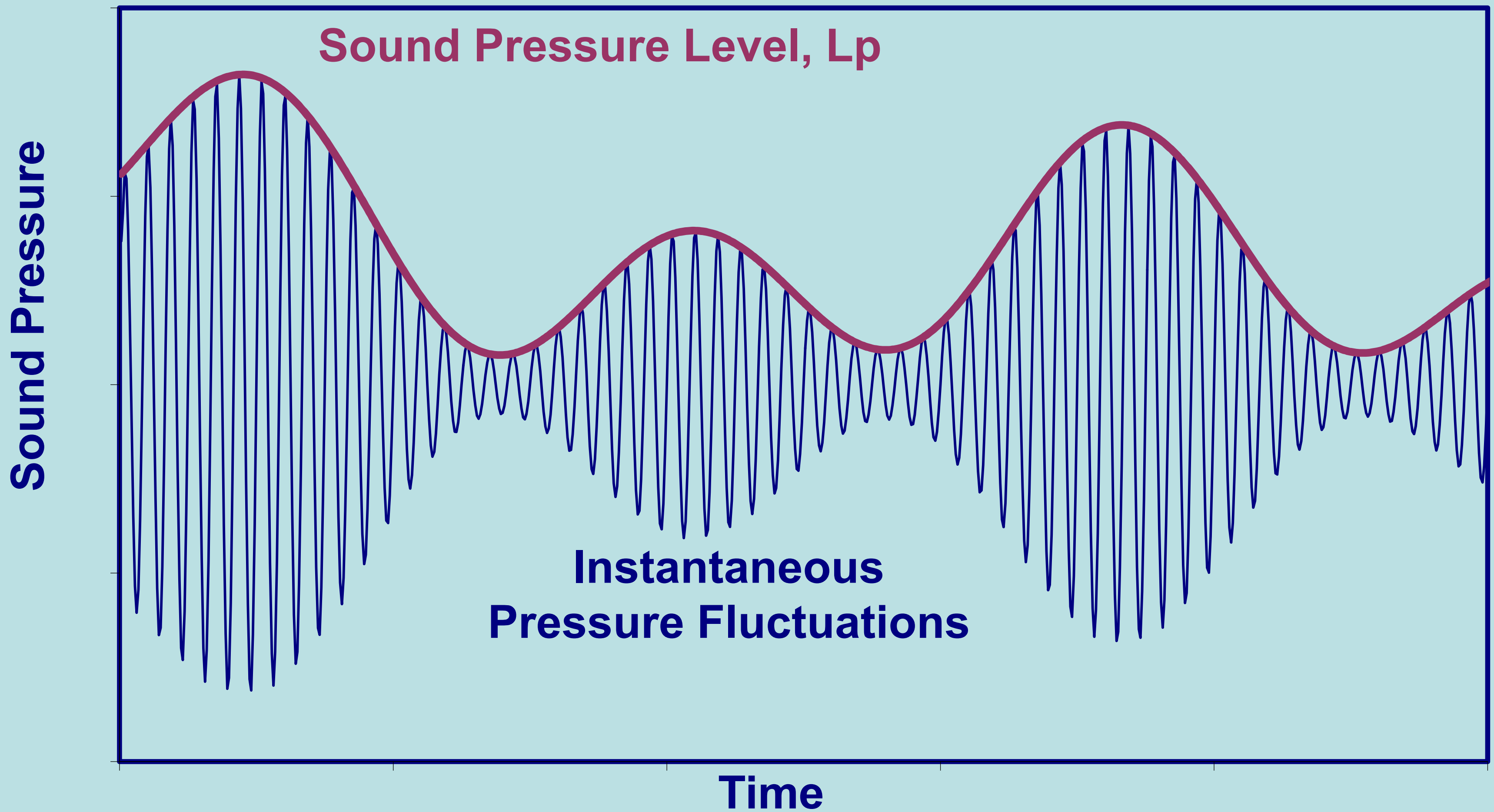


Sound Pressure Level, Decibels

Audible range of loudness is immense – more than a factor of one million, from

20 μPa to more than 20,000,000 μPa

So, we use a logarithmic scale, in units of *decibels*

Sound Pressure Level, Decibels

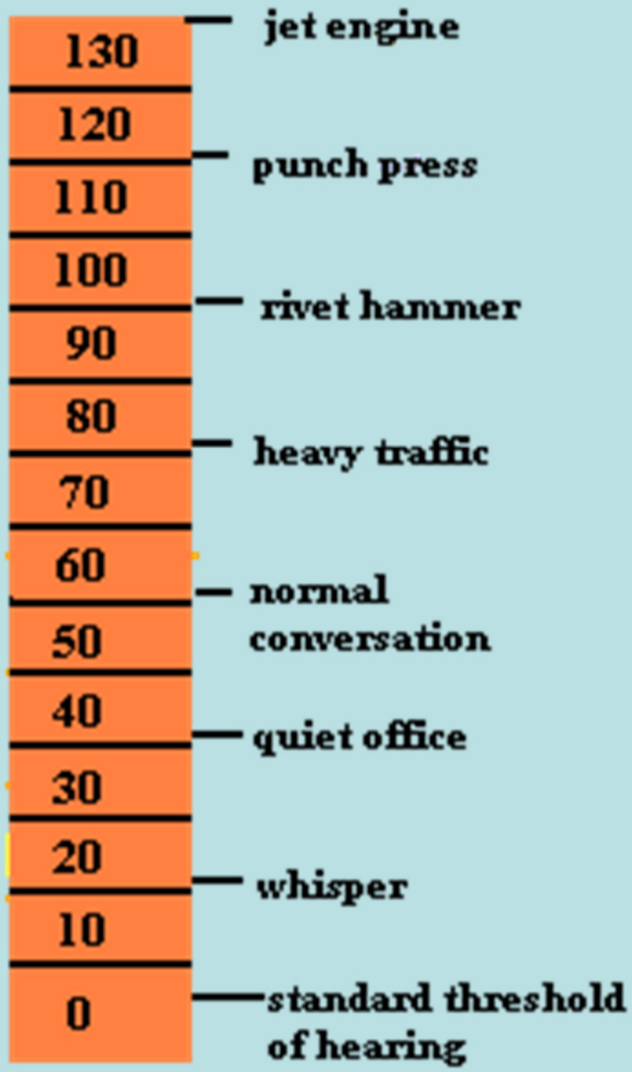
Sound pressure level “Lp” in decibels is defined as:

$$Lp = 20 \cdot \log(P/P_{REF})$$

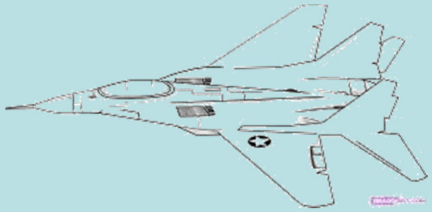
$$P_{REF} = 20\ \mu Pa = 0\ dB$$

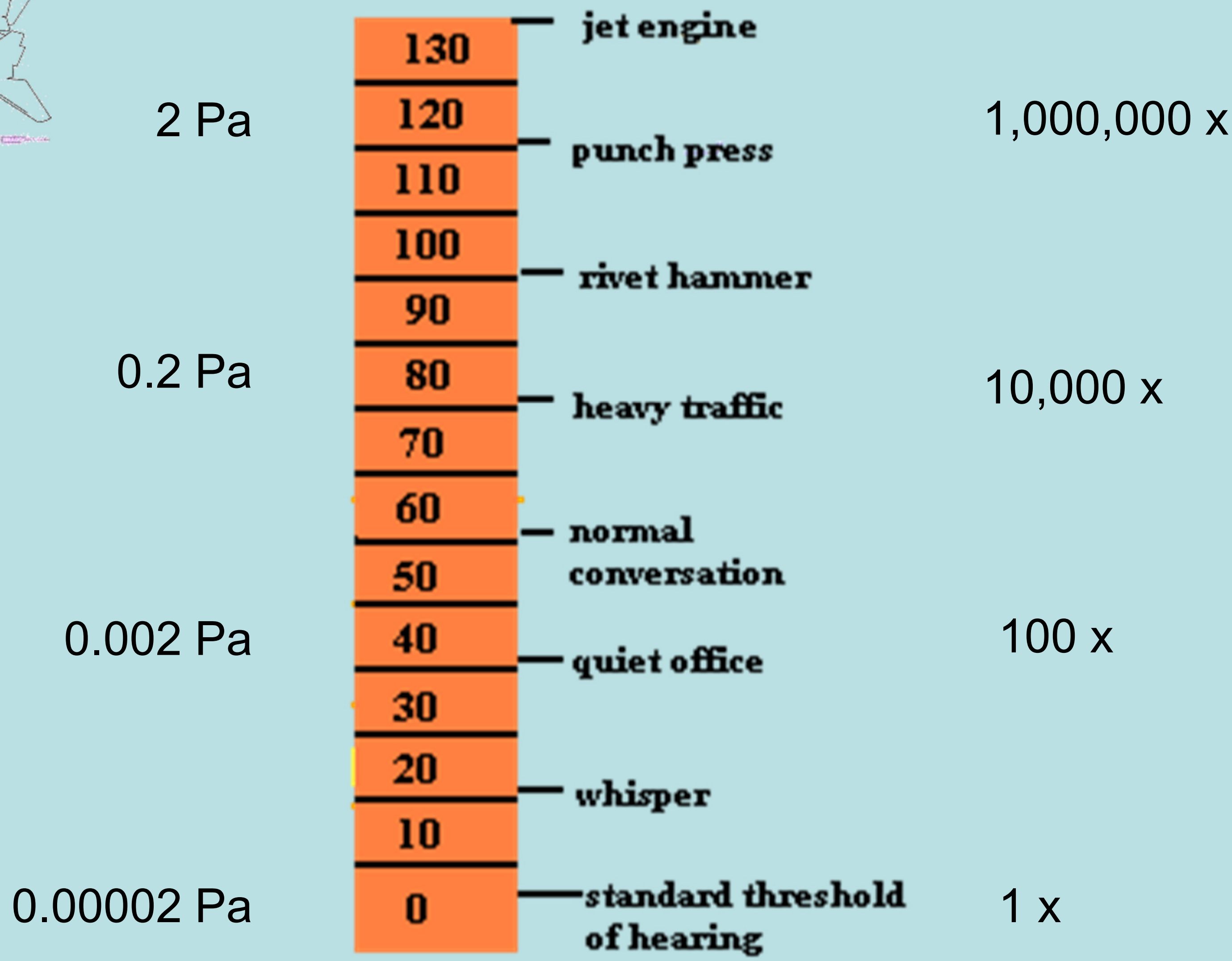
≈ Threshold of Hearing

Range of Human Hearing in Decibels



Range of Human Hearing in Decibels





Logarithmic Math
(2 + 2 = 5!)

Logarithmic Math

- Two sounds, each of 50 dBA do <u>not</u> sum to 100 dBA, but to 53 dBA

- Must use *logarithmic addition,* not arithmetic addition

- One common notation is:

  50 dB ++ 50 dB = 53 dB

- "++" implies log addition

Logarithmic Math
(It gets worse…)

- 50 dB ++ 40 dB = 50 dB
- When adding two dB values where one value is 10 dB greater than the other (or more), the lesser sound effectively does not increase the total
- Why?
- Actually, 50 dB ++ 40 dB = 50.4 dB

Logarithmic Math

- **The actual math behind the madness:**

$$X\ dB\ {++}\ Y\ dB =$$

$$10 \cdot \log(10^{X/10} + 10^{Y/10})$$

Logarithmic Math

DIFFERENCE BETWEEN TWO DECIBEL LEVELS TO BE ADDED (dB)	AMOUNT TO BE ADDED TO LARGER LEVEL TO OBTAIN DECIBEL SUM (dB)
0	3.0
1	2.6
2	2.1
3	1.8
4	1.4
5	1.2
6	1.0
7	0.8
8	0.6
9	0.5
10	0.4
11	0.3
12	0.2

Logarithmic Math

- Multiple sounds with the same level:

X dB ++ X dB ++ X dB ++ X dB ++ X dB…

$$Lp_{TOTAL} = Lp + 10 \cdot \log(N)$$

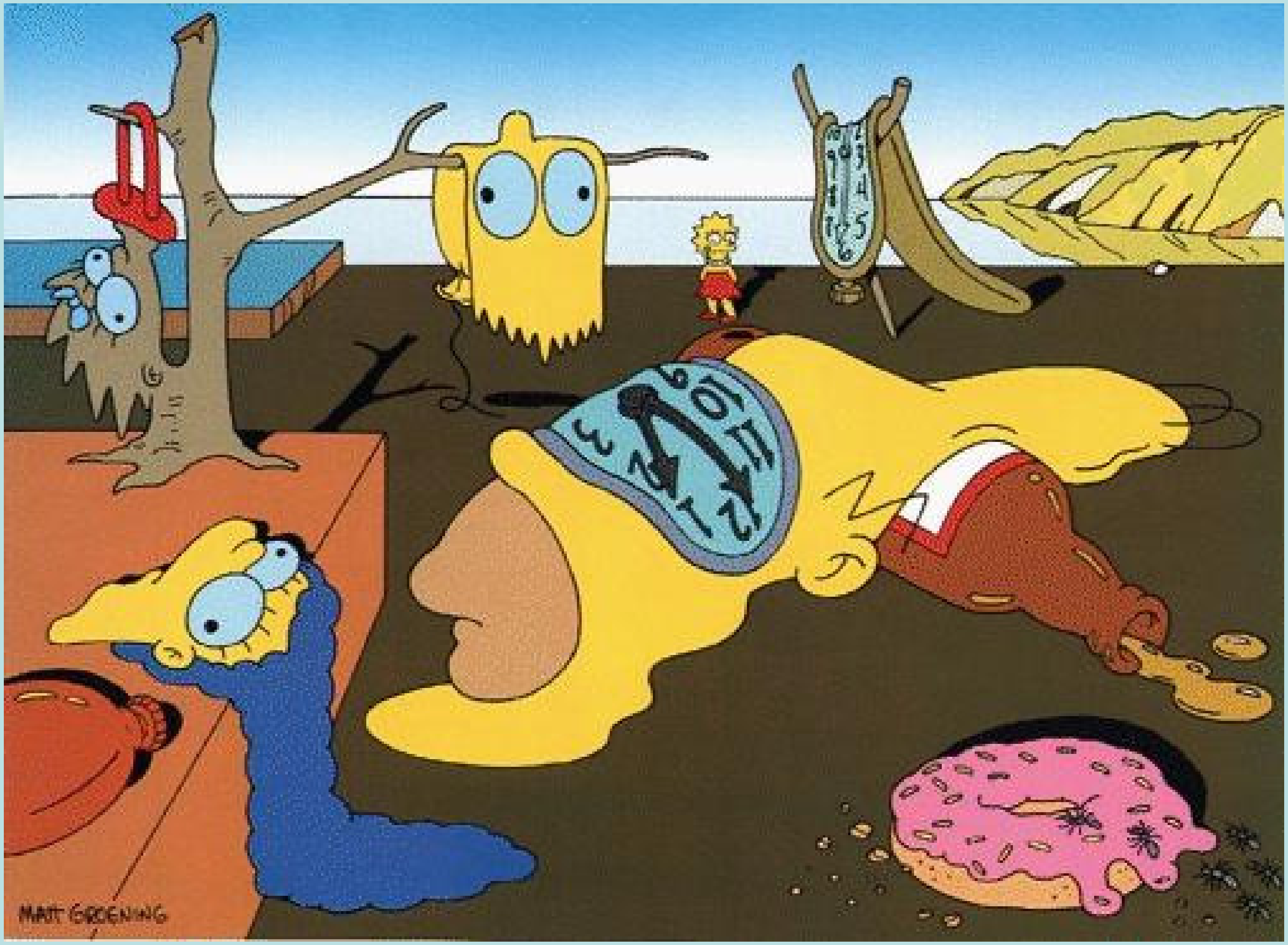
- E.g., if one car produces 65 dB, how loud would 50 cars be:

$$Lp = 65 + 10 \cdot \log(50) = 65 + 17 = 82 \text{ dB}$$

Logarithmic Math

Number of Sources	Level relative to One Source [dB]
1	0
2	3
3	5
4	6
5	7
6	8
7	8
8	9
9	10
10	10
20	13
50	17
100	20
200	23

Time-varying Sound



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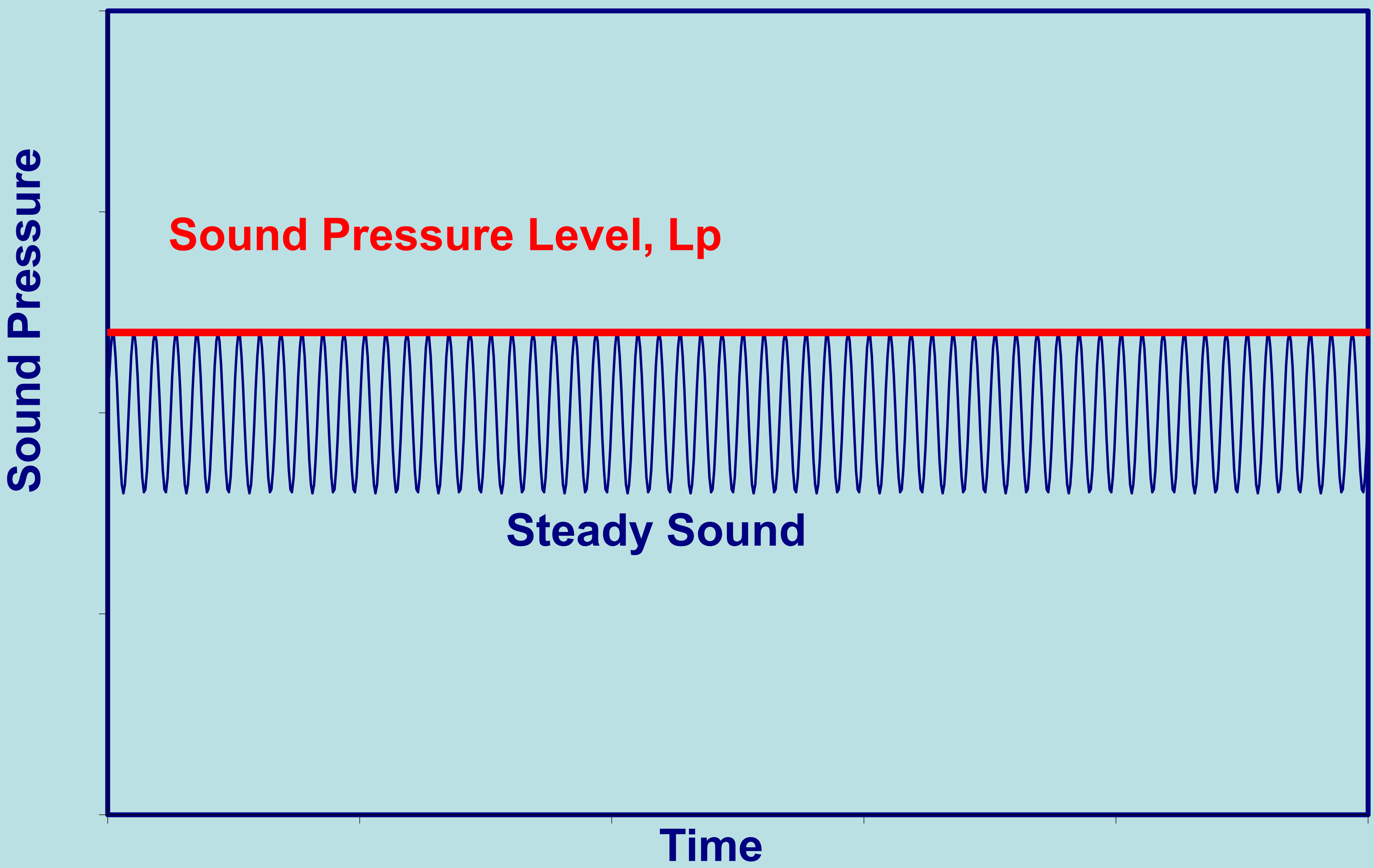
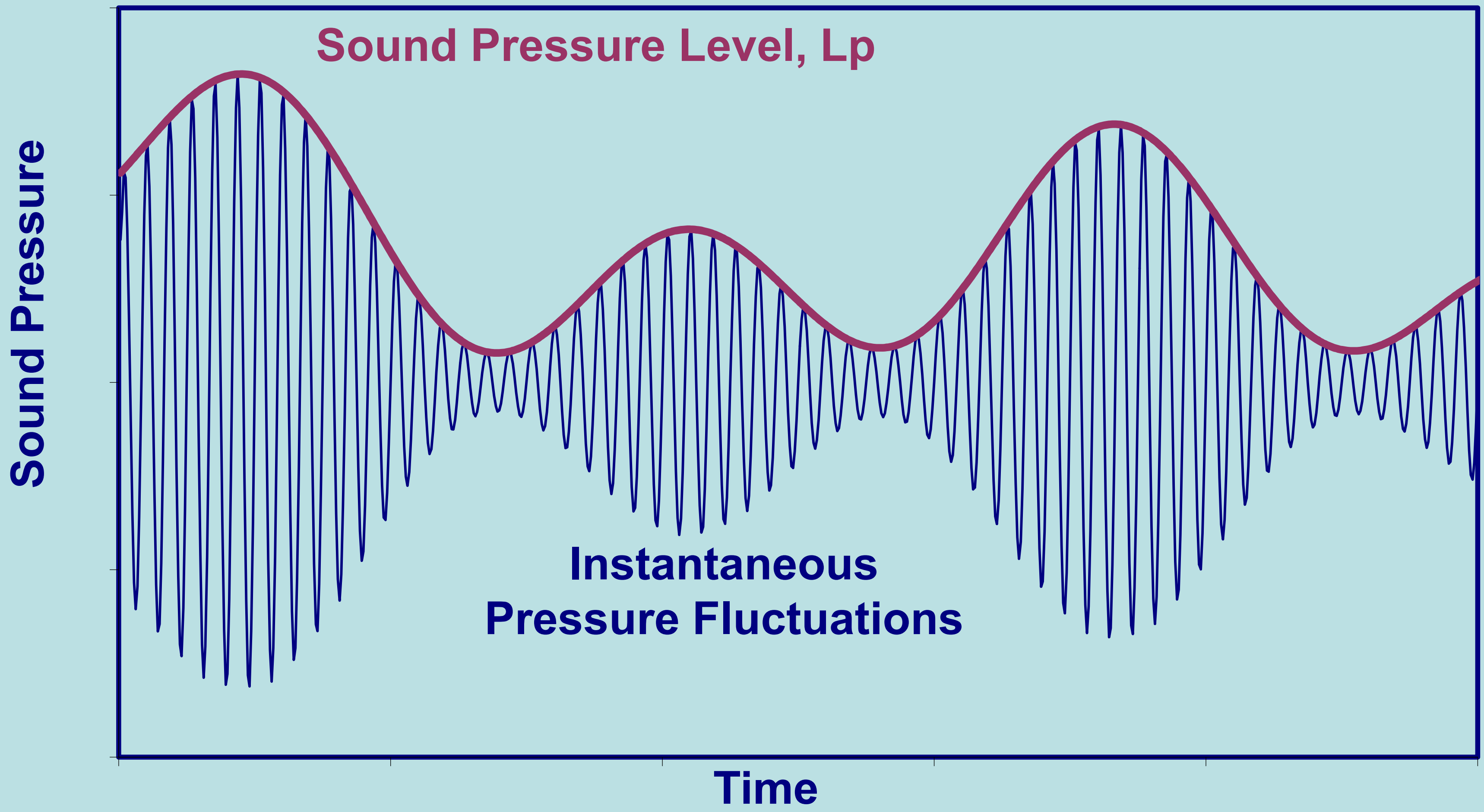
Steady sound, the level is obvious…



What is the level of this sound?



Two most common descriptors for time-varying sounds: L_{EQ} & L_{90}?

- L_{EQ} = Energy equivalent sound exposure level (over a given time period)

- Like an average, but a *logarithmic* average

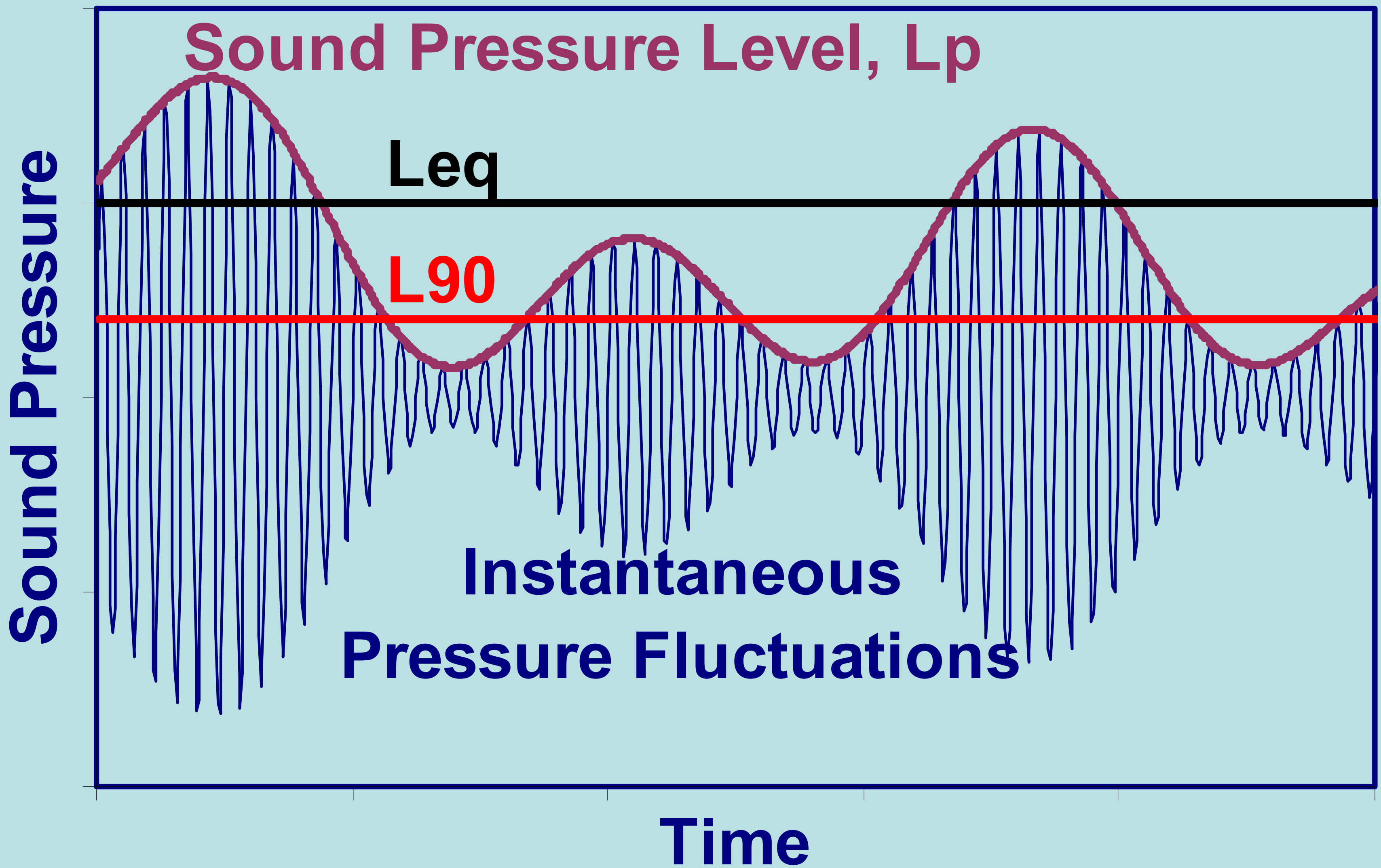
- Definition: L_{EQ} is that steady sound level that would contain the same energy in a given period of time as the actual time-varying sound

Two most common descriptors for time-varying sounds: L_{EQ} & L_{90}?

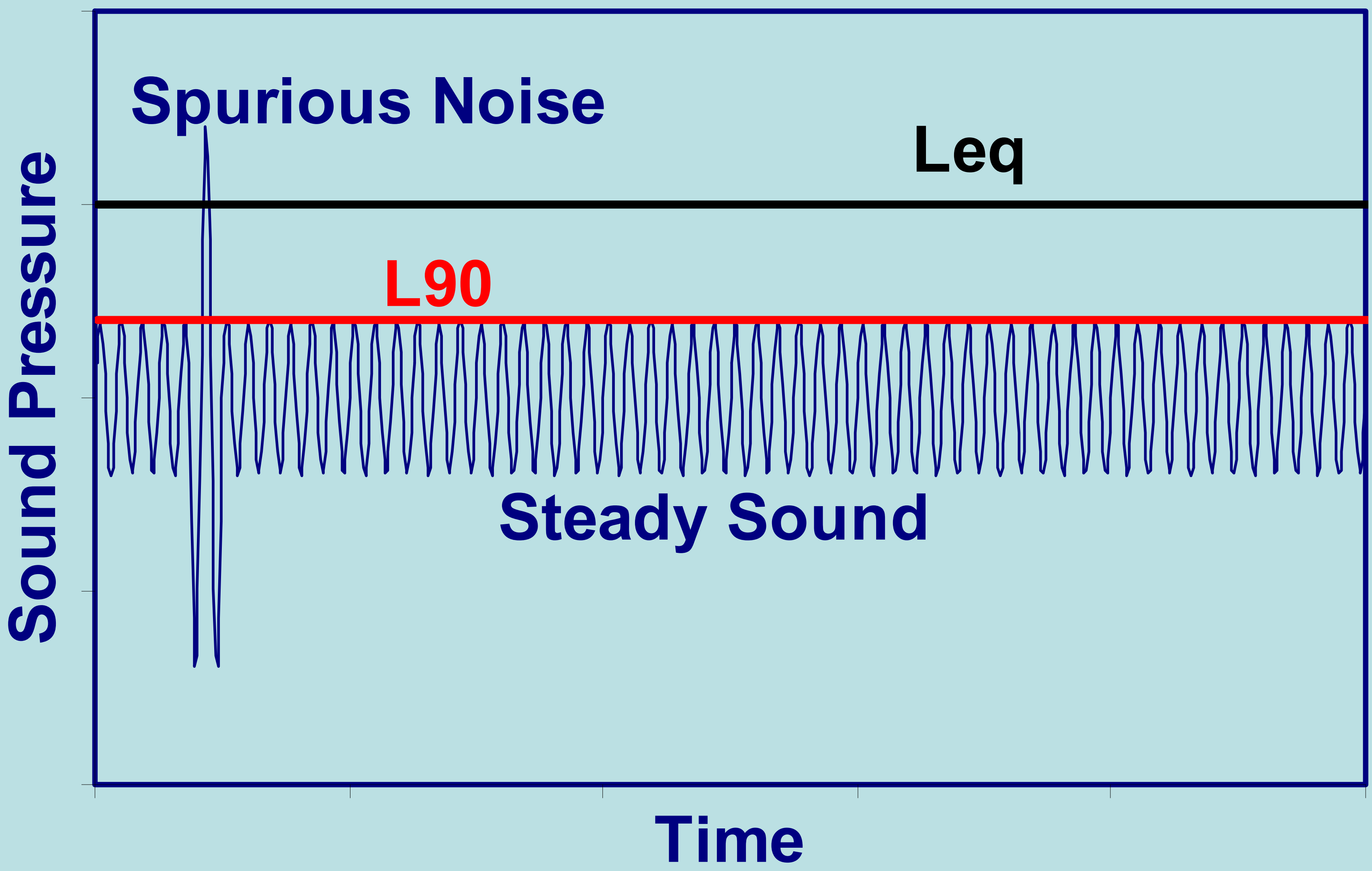
- L_{90} = "Ninetieth percentile" exceedance sound level

- The sound level that is exceeded 90% of the time in a given period

- Useful for capturing the *steady component* of the sound, and rejecting short term transient sounds



Sound Pressure Level, Lp
Leq
L90
Instantaneous
Pressure Fluctuations
Sound Pressure
Time


Spurious Noise
Leq
L90
Steady Sound
Sound Pressure
Time

Two most common descriptors for time-varying sounds: L_{EQ} & L_{90}?

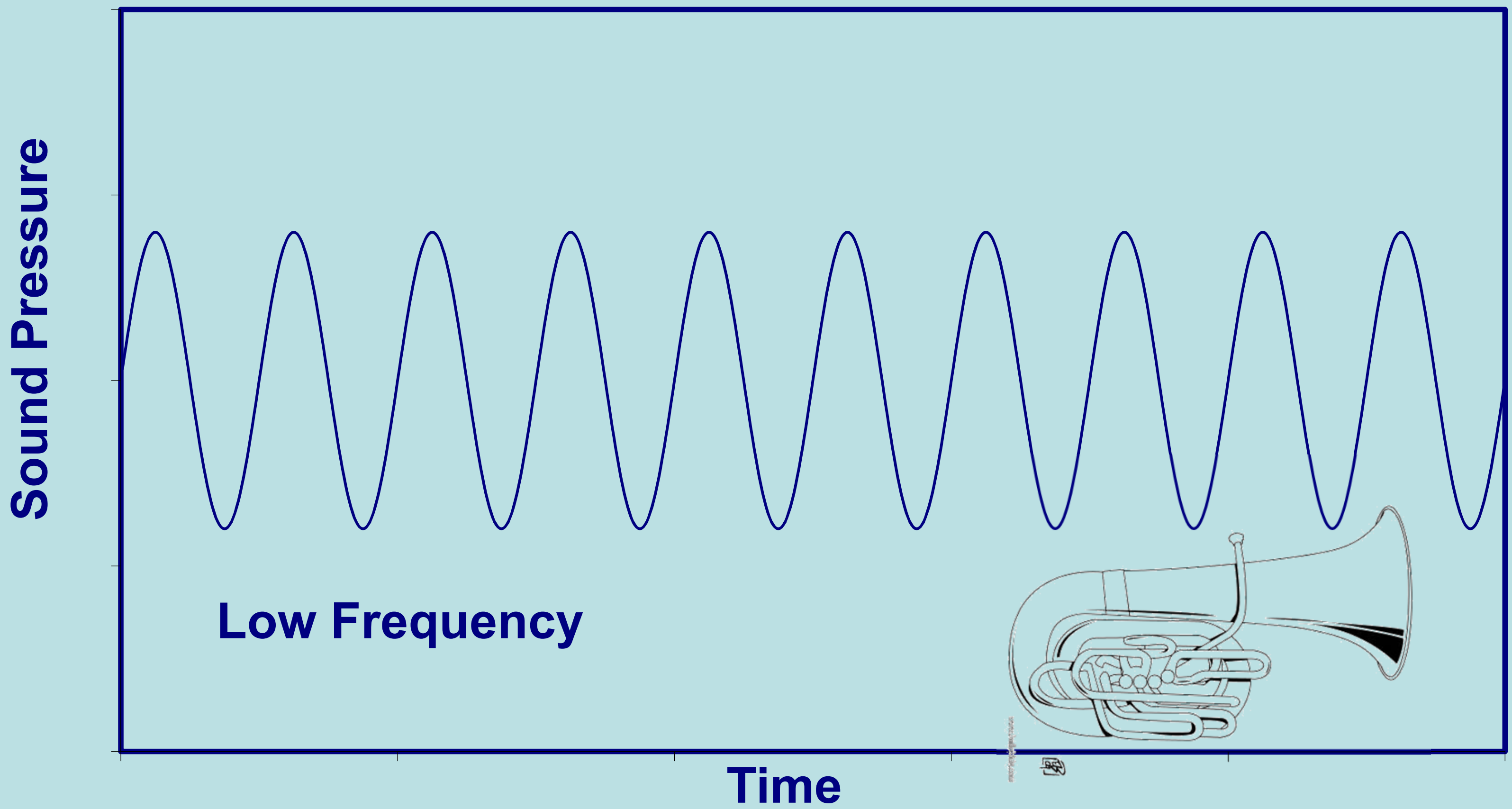
- L_{EQ} correlates well with potential of a sound to disturb residences and with risk of hearing damage
- L_{EQ} is the basis of most environmental and workplace noise legislation in Ontario (and elsewhere)
- L_{90} is useful to isolate the sound of a steady industry from transient background sounds e.g., traffic, birds

Frequency

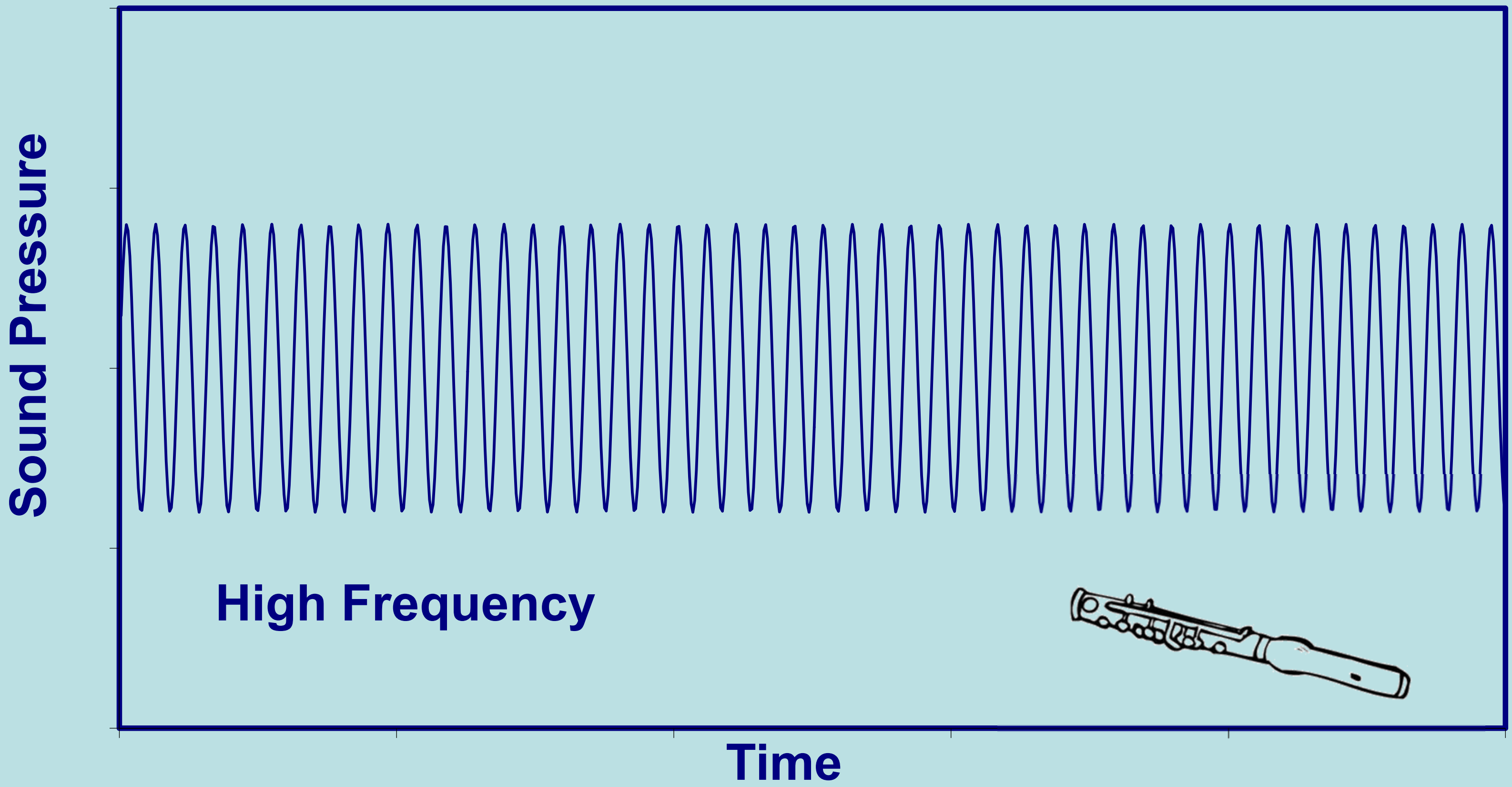
Frequency

- In addition to differences in level of sound, the ear can detect differences in frequency
- Frequency = rate of pressure oscillations
- Measured in Hz
- Hz = "cycles per second"

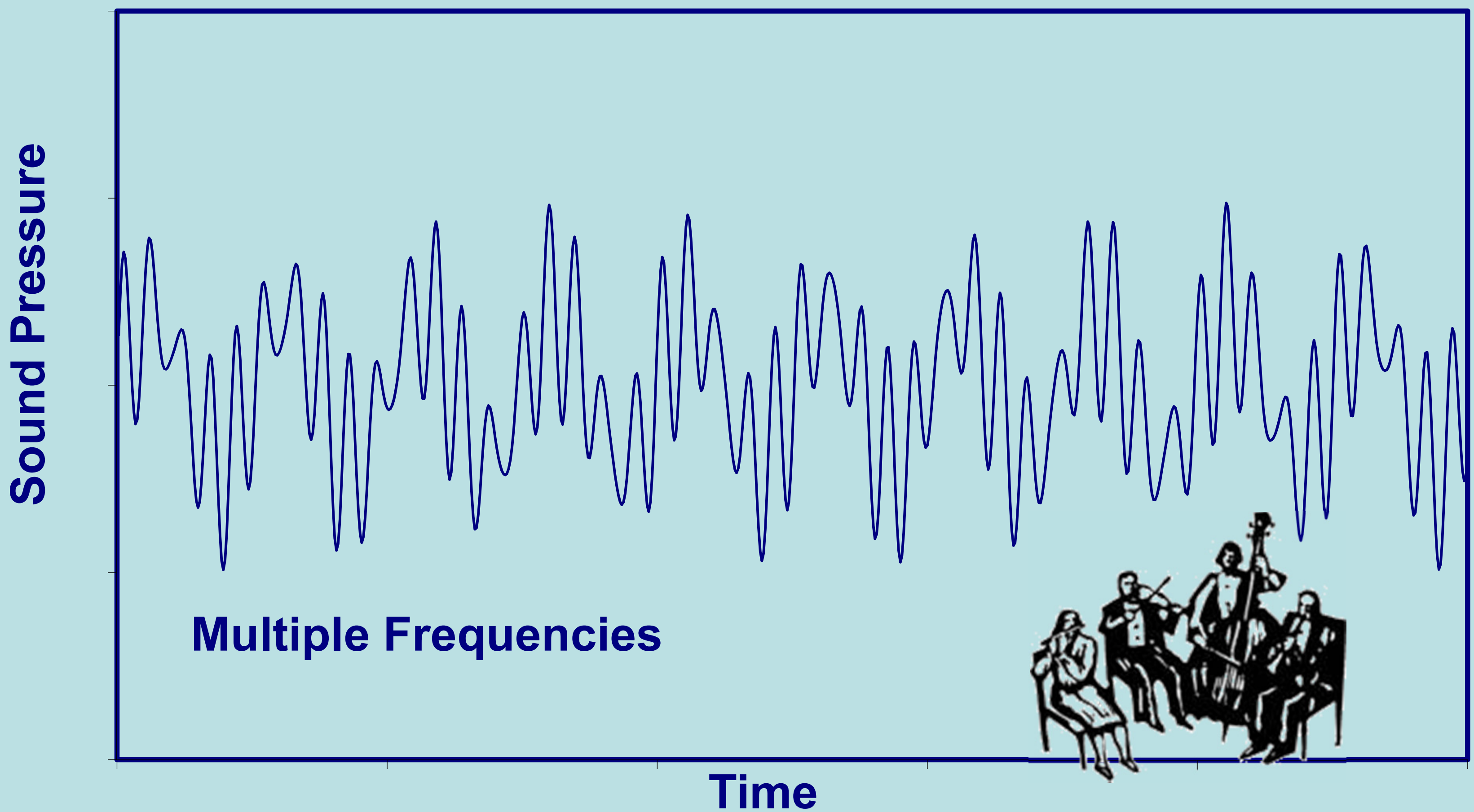
Frequency



Frequency



Frequency



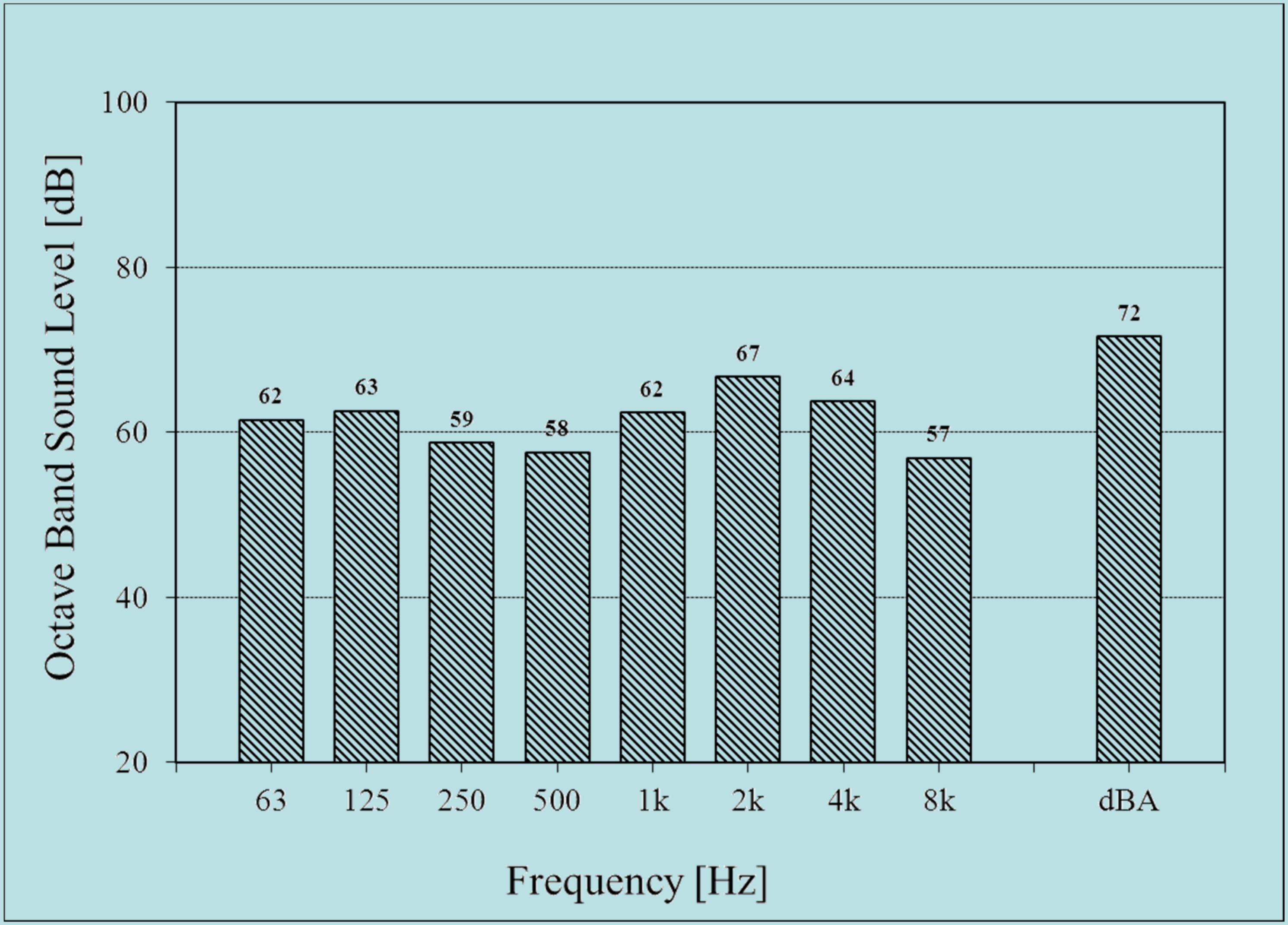
Frequency

- Many “noises” contain an irregular mixture of multiple frequencies

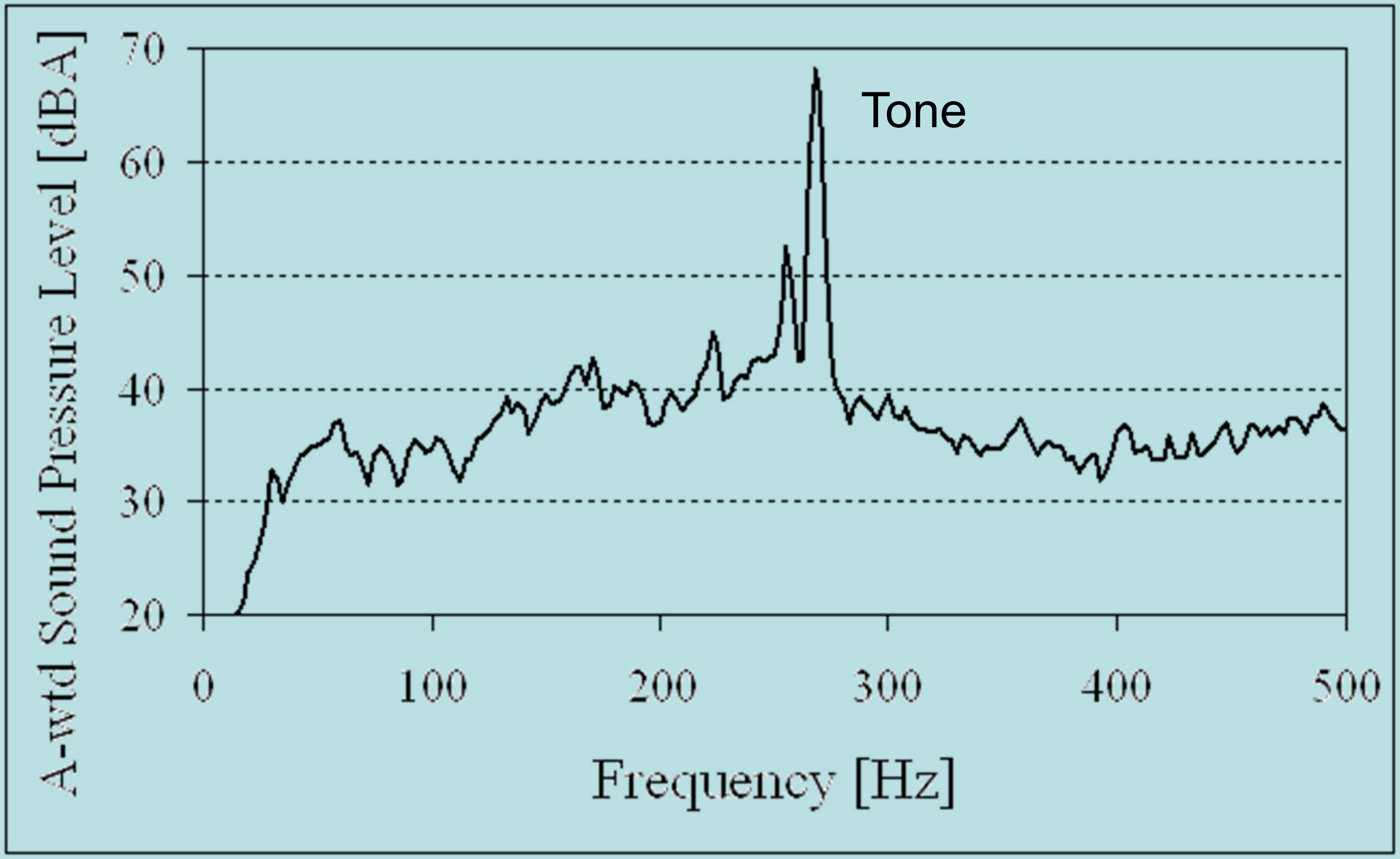
- (Whereas (most) music contains a harmonious mixture of multiple frequencies)

- How to handle the multitude of frequencies contained in a sound or noise, when measuring?

Frequency – Octave Bands



Frequency – Narrowband



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Frequency

- **Octave bands, fractional octave bands or narrowband levels can be inconvenient – a *spectrum* of levels…**
- **Also, a spectrum does not intuitively describe how *loud* the combined sound is**
- **To make simpler and more intuitive, we use the *A-weighted sum* (single number)**

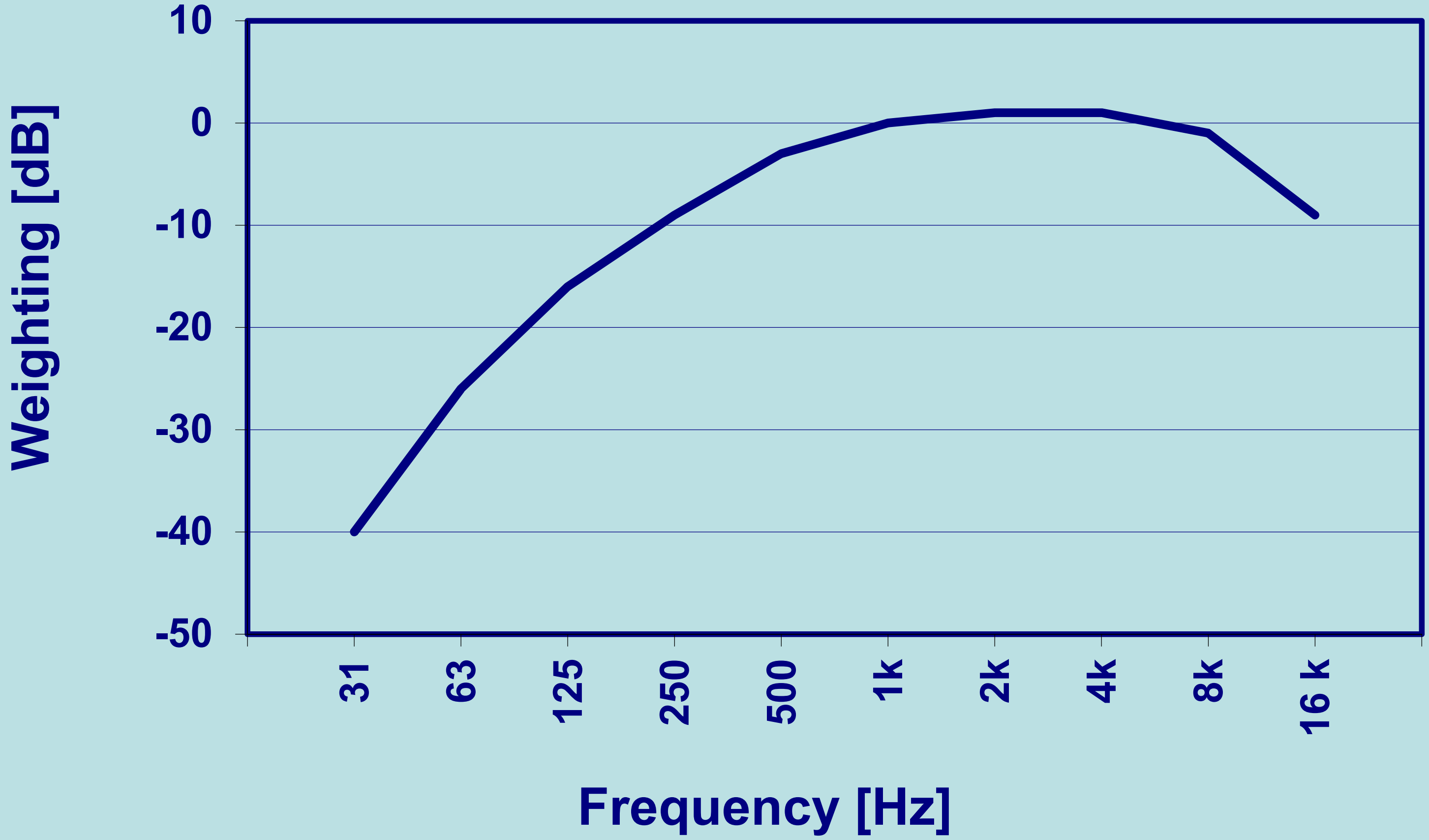
Frequency – A-weighting

- Human ear is not equally sensitive to sounds (or components of a sound) having different frequencies

- Frequency response of the human ear is referred to as the "A curve"

- We apply the A curve weightings to the levels at each frequency and sum the result into a single number

Frequency – A-weighting



Frequency – A-weighting

- An A-weighted sum (dBA) is a good single-number descriptor of the loudness of a sound
- Levels measured in dBA correlate well with the potential of a sound to cause disturbance and risk of hearing damage
- Thus, environmental and workplace noise limits are quoted in units of dBA
- However, for the more detailed purpose of acoustical modeling, analysis and noise control spectral levels (e.g., octave bands) are necessary

Sound Level Limits

Ministry of Environment Noise Assessment Guidelines

- **NPC-103 – Procedures (measurement)**
- **NPC-104 – Adjustments**
- **NPC-205 – Sound Level Limits (Urban)**
- **NPC-206 – Background sound levels (traffic)**
- **NPC-232 – Sound Level Limits (Rural)**
- **NPC-233 – Information to be submitted for approvals**
- **November 2003 Protocol for format of an Acoustic Assessment Report**

Ministry of Environment Sound Level Limits

- NPC-205/232
- Point of reception limits (e.g., residences)
- Based on background sound
- Background = “excluding sound from source under consideration”
- Background sound = minimum 1 hour Leq
- Exclusionary minimum limits – e.g., nighttime: 45 dBA Urban, 40 dBA Rural

MOE Exclusionary Minimum Sound Level Limits

- Urban: NPC-205
  - 50 dBA day; 47 dBA eve; 45 dBA night

- Semi-urban: NPC-205
  - 50 dBA day; 45 dBA evening & night

- Rural: NPC-232
  - 45 dBA day; 40 dBA evening & night

OR minimum 1 hour background L_{EQ} level

Sample: Background Sound vs Sound Level Limits (Night)

Acoustic Environment	Min 1-hr Background	MOE Limit
Urban	56 dBA	56 dBA
Urban	42 dBA	45 dBA
Rural	56 dBA	56 dBA
Rural	42 dBA	42 dBA
Rural	32 dBA	40 dBA

Occupational Noise Limits

- 85 dBA L_{EQ} average over an 8 hour shift
- Because of 8-hour reference for L_{EQ}, the limit becomes:
    - 83 dBA for a twelve hour shift
    - 88 dBA for a four hour shift (or exposure)
    - 91 dBA for two hour exposure, etc.

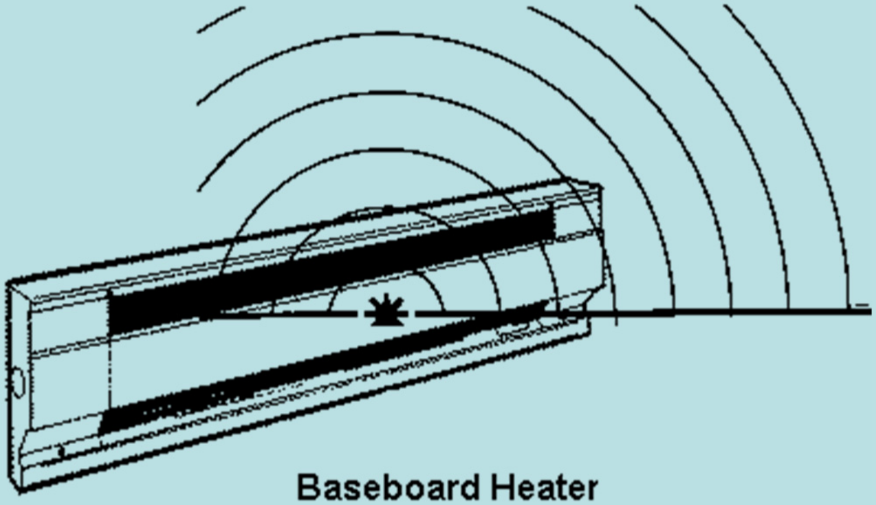
A bit more about sound…

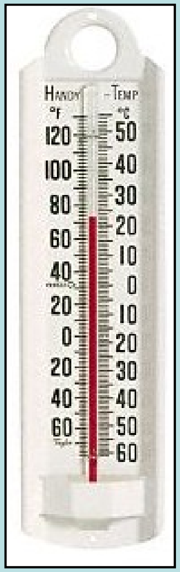
Sound Power vs Sound Pressure

Sound pressure level represents the magnitude of resulting air pressure fluctuations at some defined point in space.

Sound power level is the total rate at which a source emits sound energy into the surrounding environment.

Sound Power vs Sound Pressure
Thermal Analogy

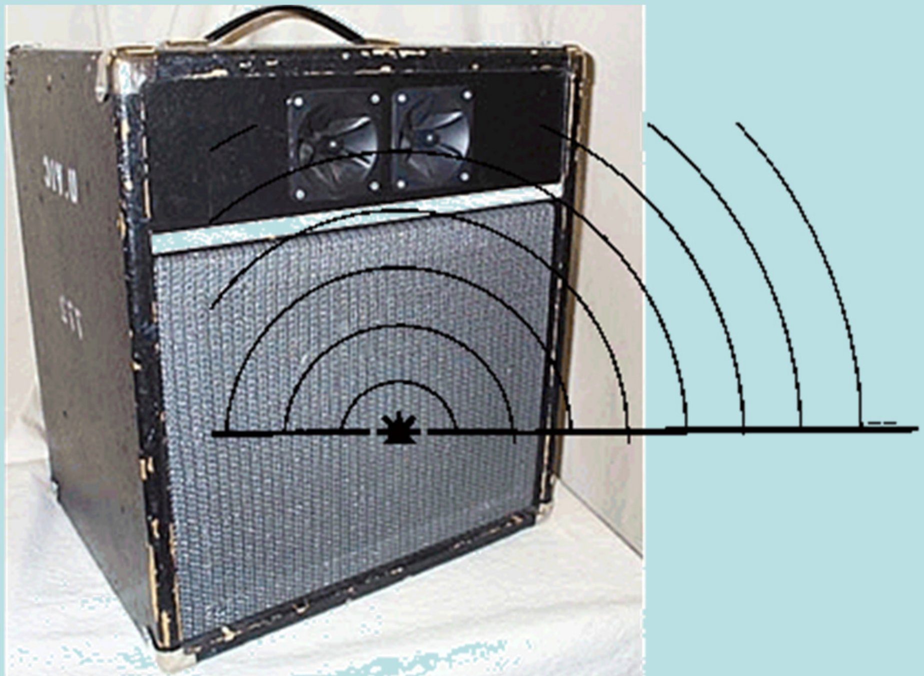




Thermal Power
[Watts]
√

Temperature
[Degrees]
?

Sound Power vs Sound Pressure



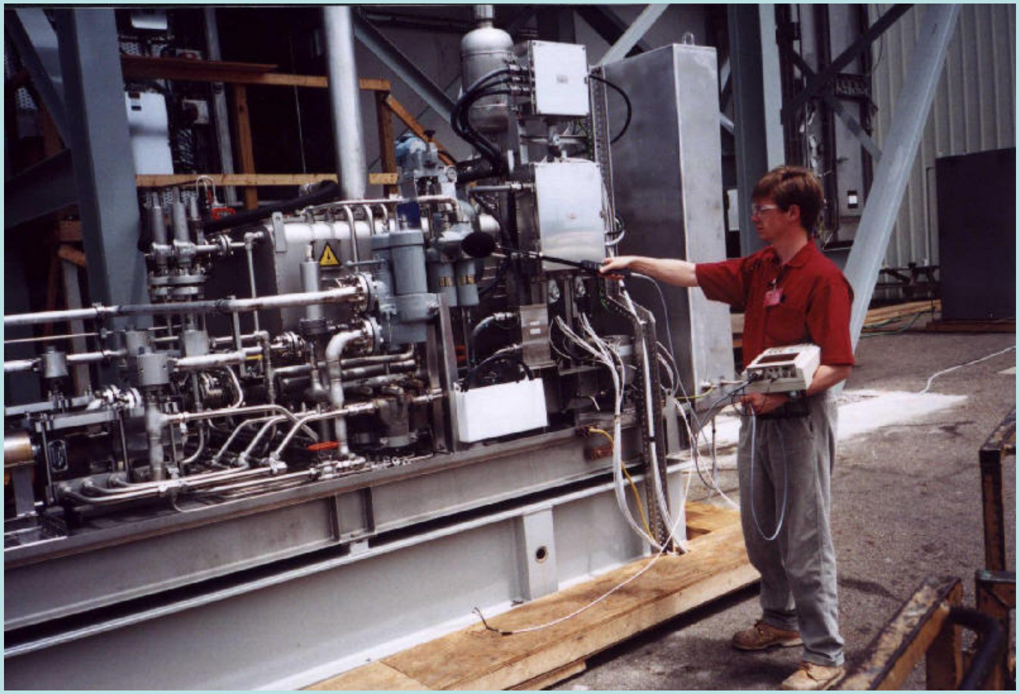
Sound Power Level
[dB re 10^{-12}W]
√

Sound Pressure Level
[dB re 20 μPa]
?

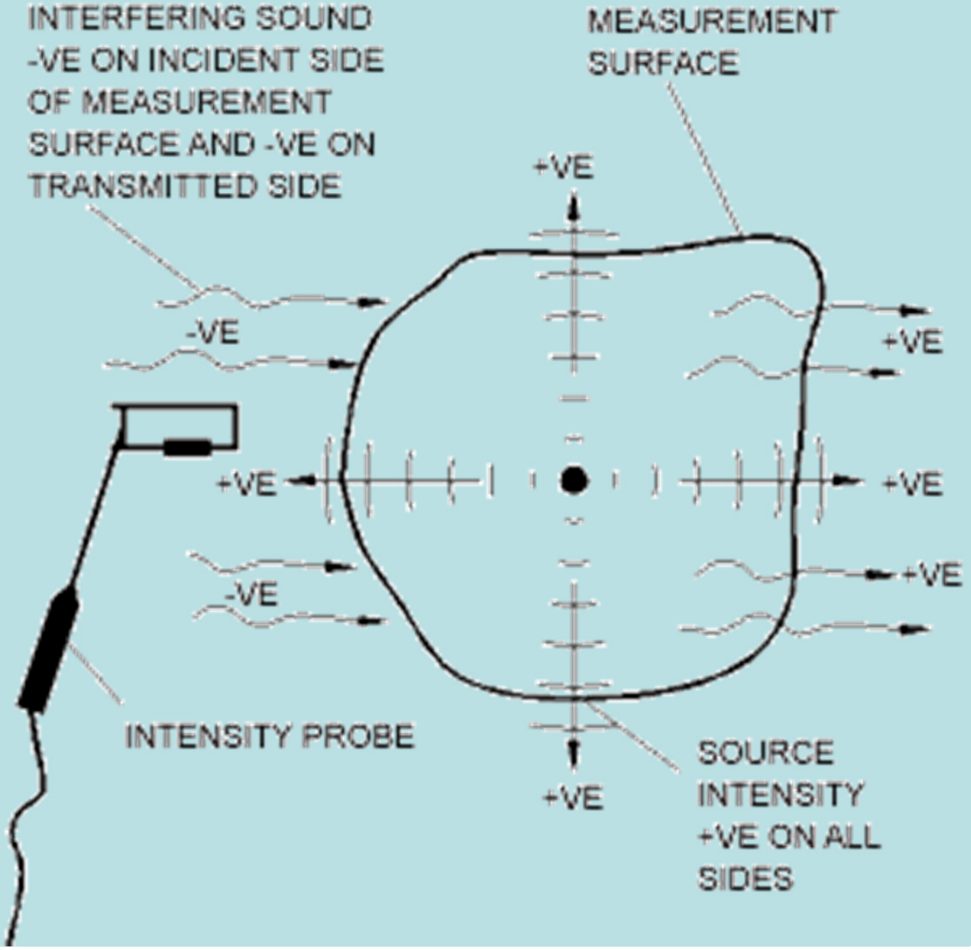
Estimate Sound Power Directly by Measuring Sound Pressure

Fine if there is no background sound or room reverberation

Measure Sound Power Directly Using Sound Intensity System



Sound Intensity Measurements
How Does it Work?



Rejects sounds originating from outside the measurement volume

Sound Power vs Sound Pressure

Sound pressure level depends upon:

- Source sound power level
- Source-receiver distance
- Reverberation/Reflections
- Background Sound

Sound power level is a fundamental quantity, independent of these environmental factors.

Sound Power vs Sound Pressure

Sound power levels needed for an Acoustic Assessment because:

- **MOE requires that sound power level of all sources be listed in a table**
- **Sound power level is the starting point for predictive *acoustical modeling***

Sound Power vs Sound Pressure

Sound power levels needed for an Acoustic Assessment because:

- **MOE requires that sound power level of all sources be listed in a table**
- **Sound power level is the starting point for predictive *acoustical modeling***

Why do acoustical modeling?

- New, proposed sources
- Proposed alteration to source (e.g., noise control)
- Determine which sources need abatement
- MOE requires inventory of individual sound pressure contributions of *each source*

Factors Considered in Model:

- Source sound power level
- Duty cycle, applicable penalties
- Propagation effects:
  - Geometrical spreading
  - Directivity
  - Atmospheric absorption
  - Absorption by soft ground
  - Shielding (barrier)
  - Foliage
  - Meteorology

Acoustical modeling

Show sample model

Noise Control Measures:

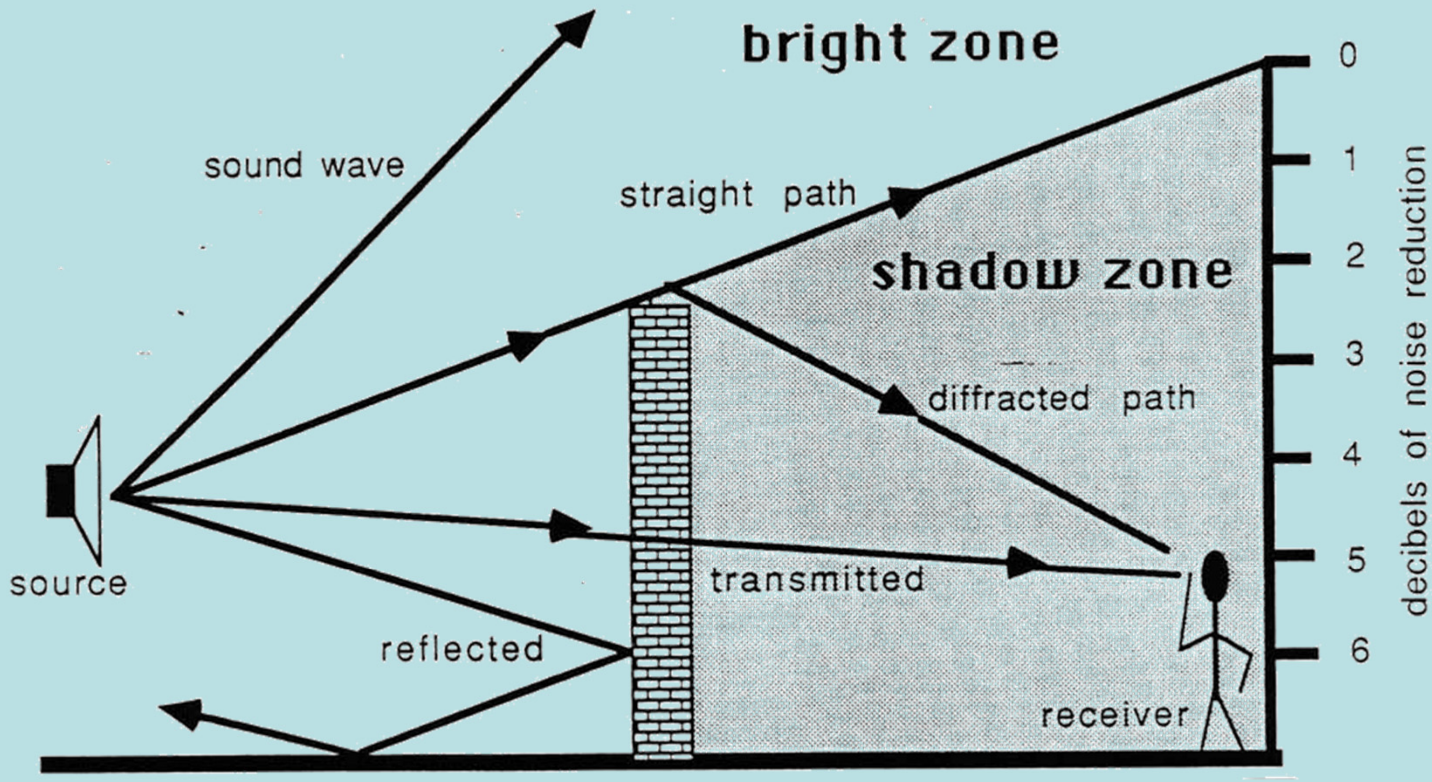
Noise Control Measures:

In decreasing order of preference:

- Site location, site layout
- Quiet Equipment
- Source Orientation
- Engineered Noise Controls:
  - Barriers
  - Silencers
  - Acoustical Louvres
  - Enclosures, etc.

Noise Control Measures:

Some Comments on Noise Barriers

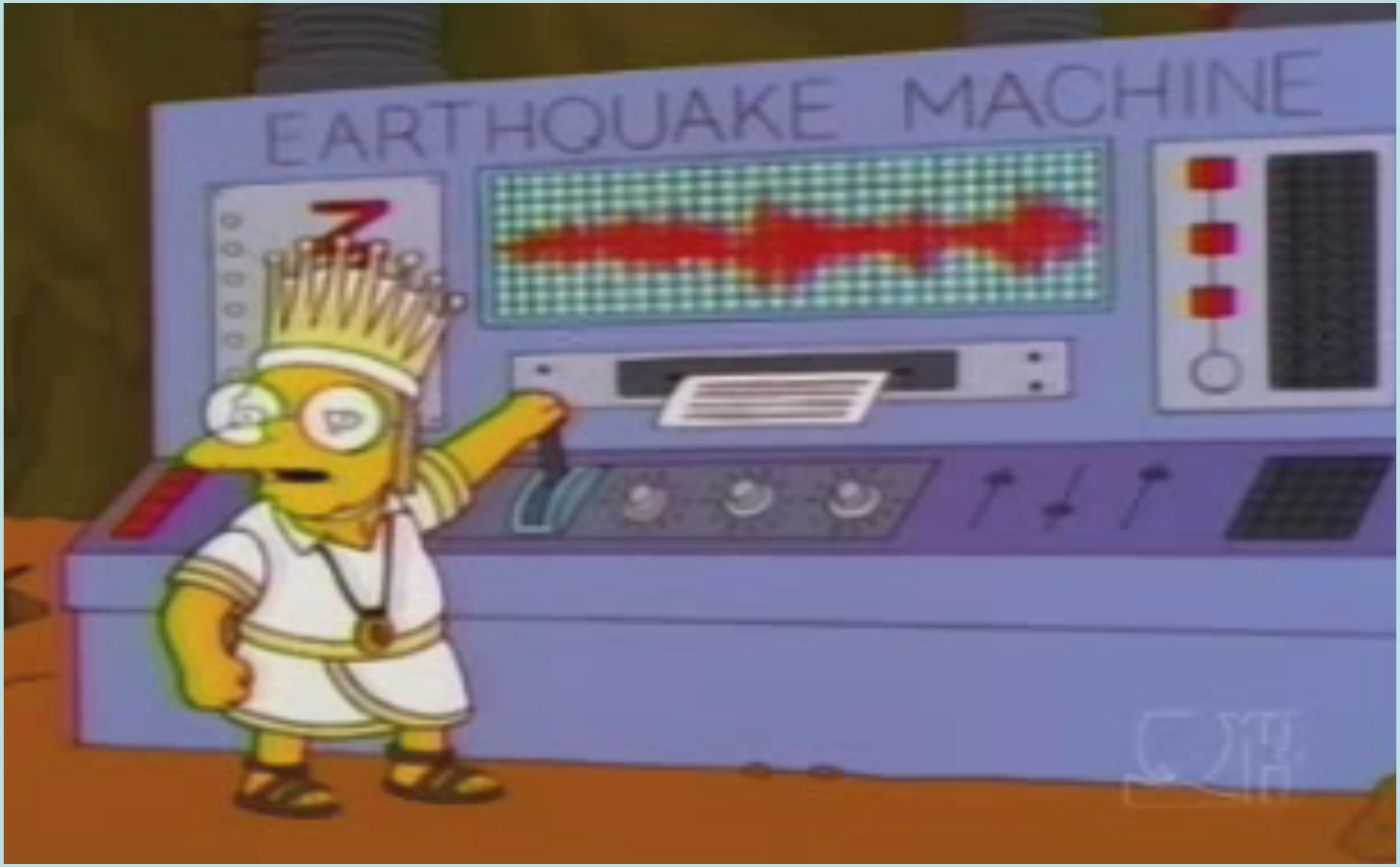


Noise Control Measures:

Some Comments on Noise Barriers

- Noise reduction only in “shadow zone” – no reduction if straight-path not interrupted
- Practical maximum reduction is ~15 dBA under ideal conditions
- Typical reduction is 5 to 10 dBA
- Best when located very close to source or to receiver (poorest performance at midpoint)

Vibration:



Vibrations:

- Typically refers to oscillations in solid material
- If frequency is within 20 Hz to 20 kHz, sometimes called structure-borne noise
- If amplitude is severe, can be perceptible to touch
- Can also cause re-radiated sound

Vibrations:

- Many of the principles of sound apply also to vibration
- E.g., sometimes use decibels, although dBV or dBG (relative to velocity or acceleration)
- Also measure in non-logarithmic units, e.g.,:
  - displacement mm or inches
  - Velocity (peak, peak to peak or rms)
  - Acceleration (peak, peak to peak or rms)

Vibrations:

- **Sound can induce vibrations in structures and vice versa**
- **Frequency range for perceptible vibration generally extends much lower in frequency than audible sound – as low as fractions of a Hz**

End of Prepared Material!
Open for questions…