Summer Youth Program 2016
Automotive
(Exhaust Noise)

Michigan Technological University

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Agenda

- Exhaust Noise
  - Source-Path-Receiver
  - Sound waves
  - Engine Types
    - 4 stroke
    - 2 stroke
  - Quarter Wavelength Resonator
  - Insertion Loss
  - Other Exhaust Types
  - **Demo**

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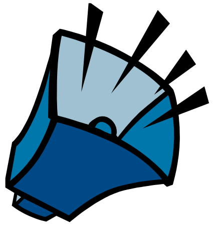
The source-path-receiver paradigm is very important for noise control engineering measurements.

Source



- Can be a system, sub-system, or component
- Has a power level and a direction

Path

- Any path the acoustic waves take between source and receiver
- Can be multiple paths
- Can be fluid-borne, structure-borne, or combination of both
- Consist of magnitude and direction

Receiver

- Anything that senses the acoustic wave
  - Ear
  - Structure
  - Sensor (microphone)

Engine -> **Exhaust** -> Ear or Microphone

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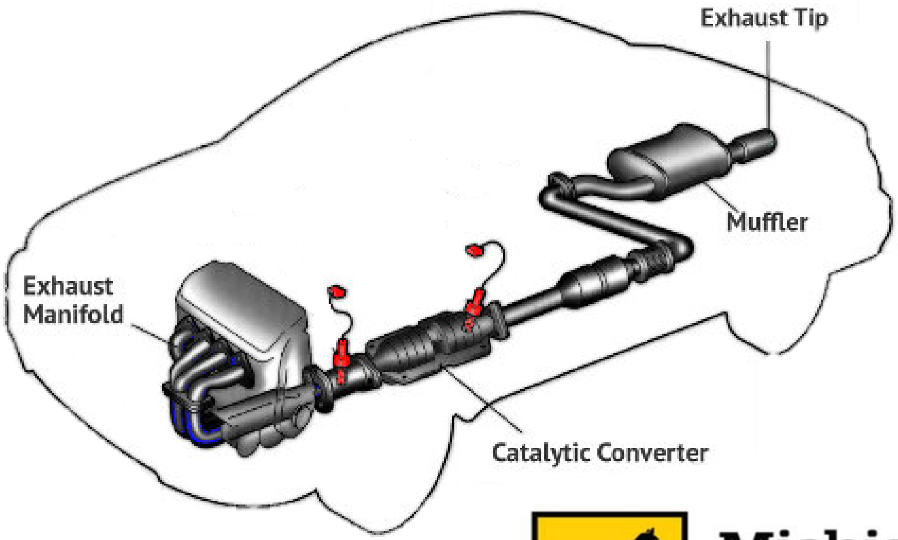
Sound and Exhaust Systems

- Engine making noise – Sound Source
- Want to reduce the sound level or change sound characteristics
  - Make quieter
  - Improve sound quality
  - Reduce detection distance (military)
- The exhaust system is one way of doing this



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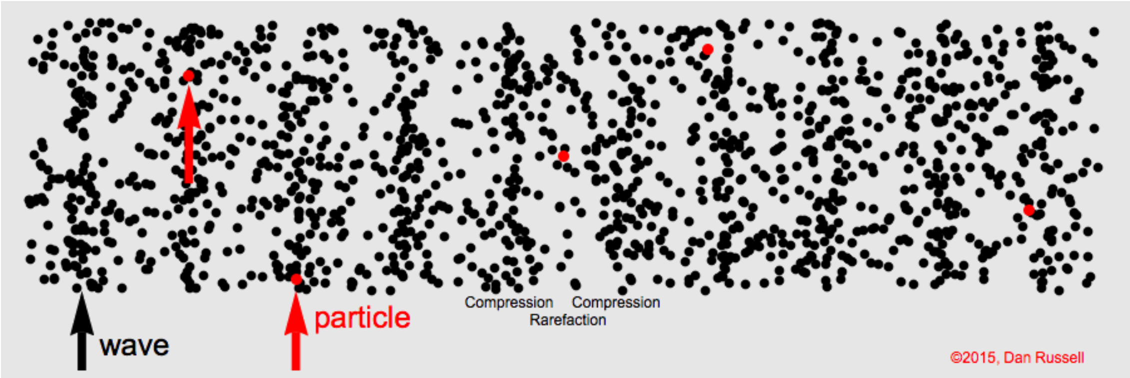
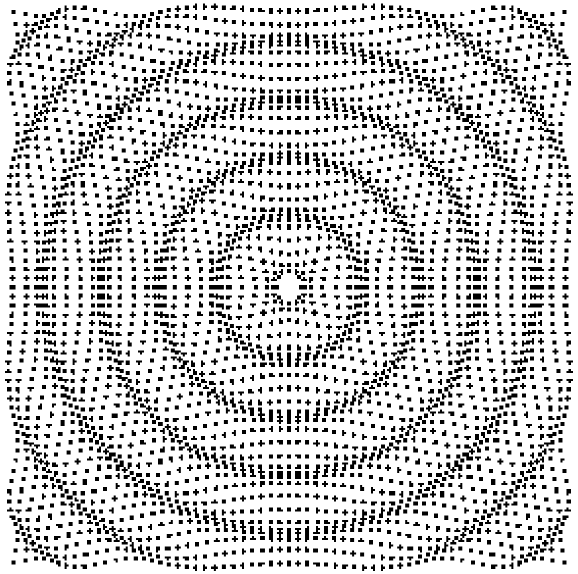
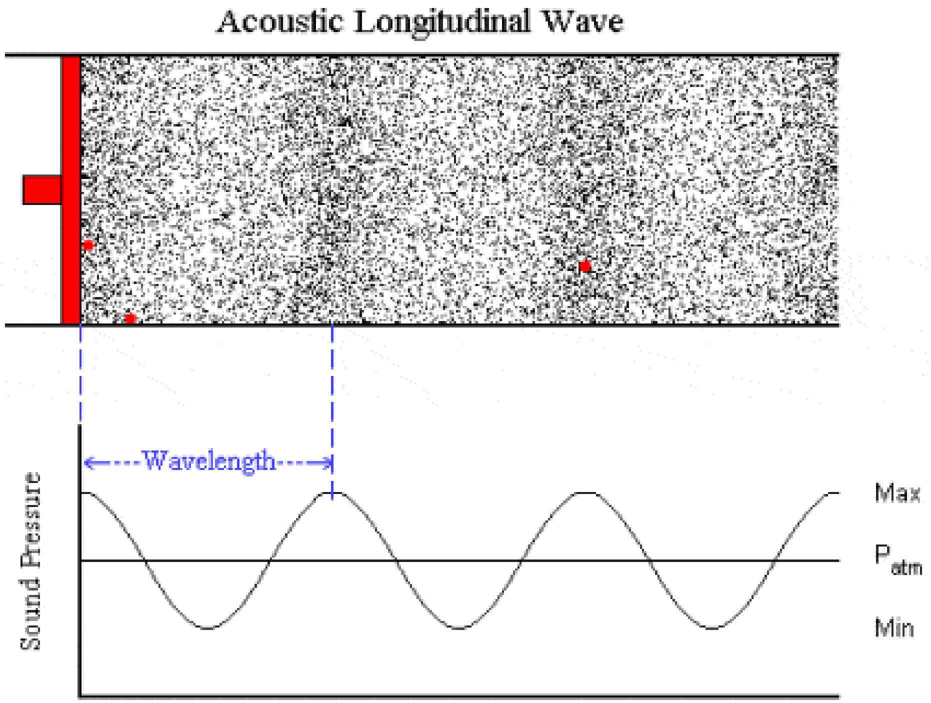
Sound is a pressure wave in air







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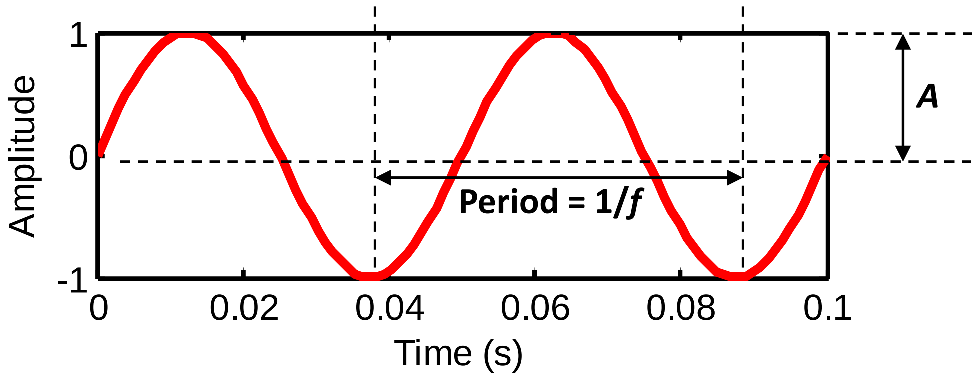
Equation of pressure wave

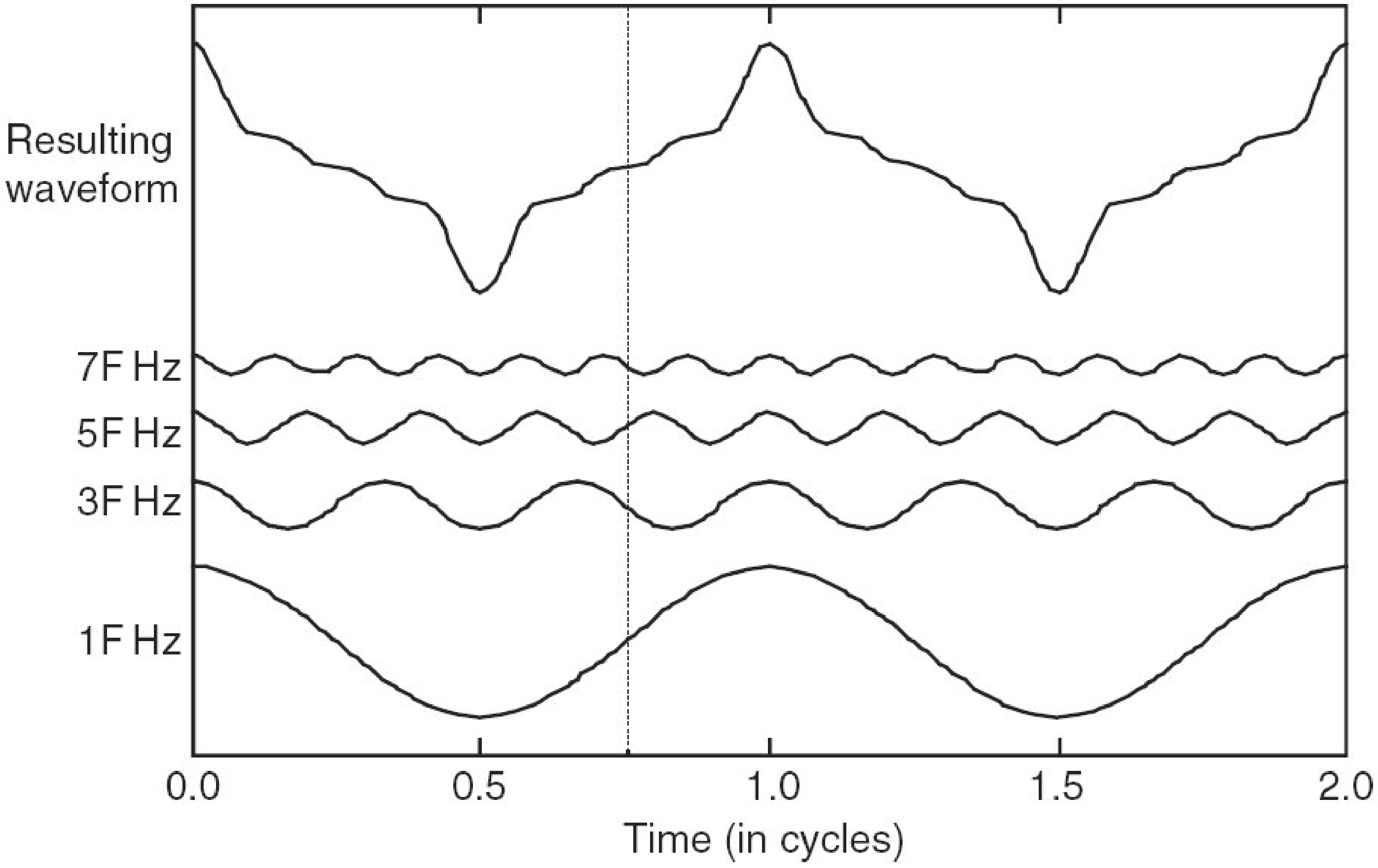
- $y(t) = A * \sin(\omega t + \varphi)$

- A: amplitude of the pressure wave (Pa)
- ω: angular frequency (rad/s) $= 2\pi f$ (Hz)
- φ: phase shift (rad). Represents how much time delay the waveform has with respect to time $t = 0\ sec$.

Example: 20 Hz wave



Multiple Frequencies Sum Together



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Frequency, Sound Speed, & Wavelength

- $f = \frac{c}{\lambda}$
- Speed of Sound depends on Temperature of Air
  - $c = \sqrt{\gamma RT} = 20.05\sqrt{T}$
    - T in Kelvin: $K = \ ^{\circ}C + 273$
  - At 20˚C, c=343m/s or 1126 ft/s
  - For small engines exhaust temp is roughly 150 ˚C. Correspond to c~=410m/s

Units are Important!

- Frequency units are $Hz\ \left(\frac{cycles}{s}\right)$
- Speed units are $\left(\frac{m}{s}\right)$
- Wavelength units are (m)

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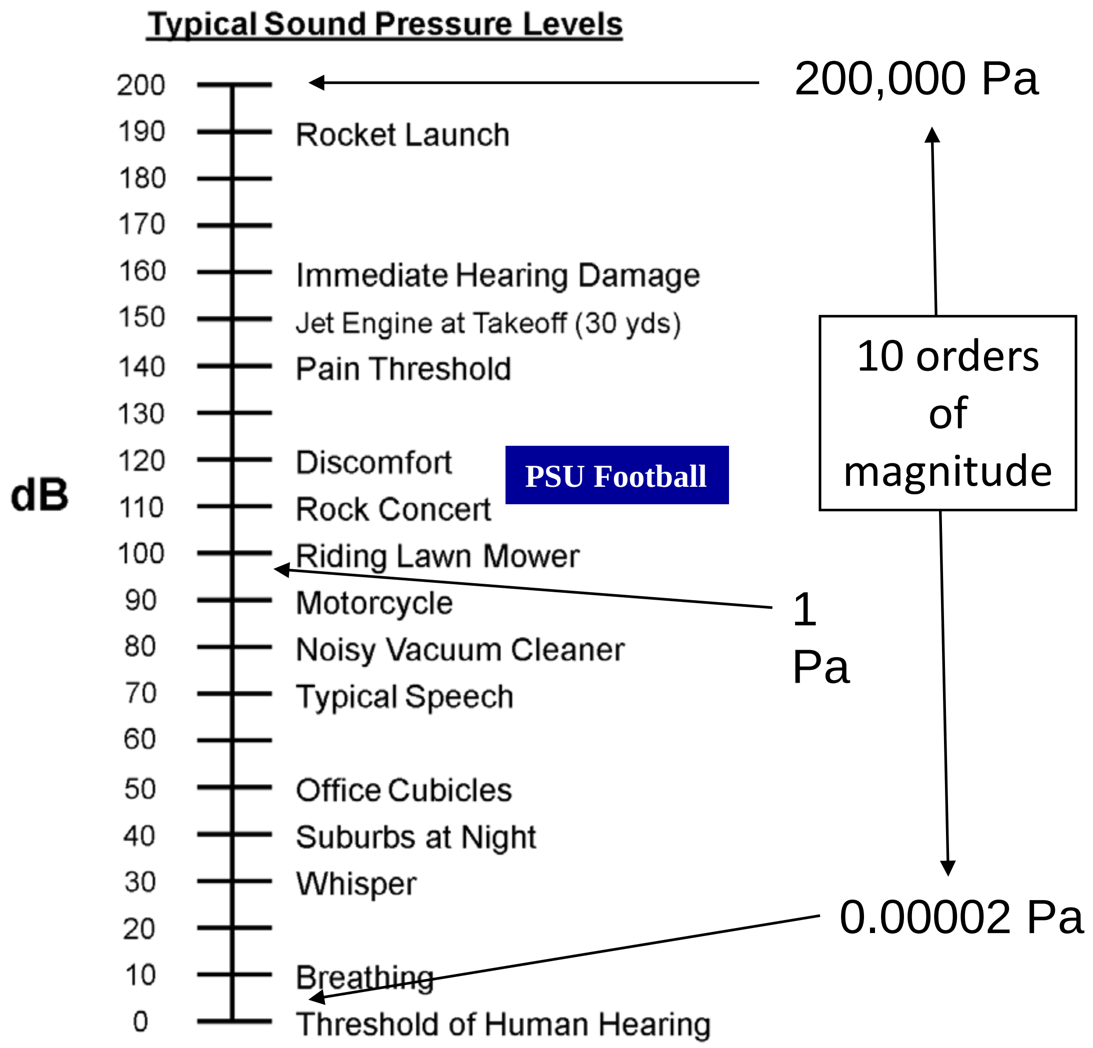
Sound Pressure Level

- $L_p = 20 * \log_{10}\left(\frac{p_{meas}}{p_{ref}}\right)$ dB
- $p_{ref} = 20\ \mu Pa$
  - Quietest sound humans can hear
- $1\ Pa = 1\frac{N}{m^2} = 1\frac{kg}{m{*}s^2}$



Sound pressure amplitude is usually measured as a level in decibels to compress its large range of values

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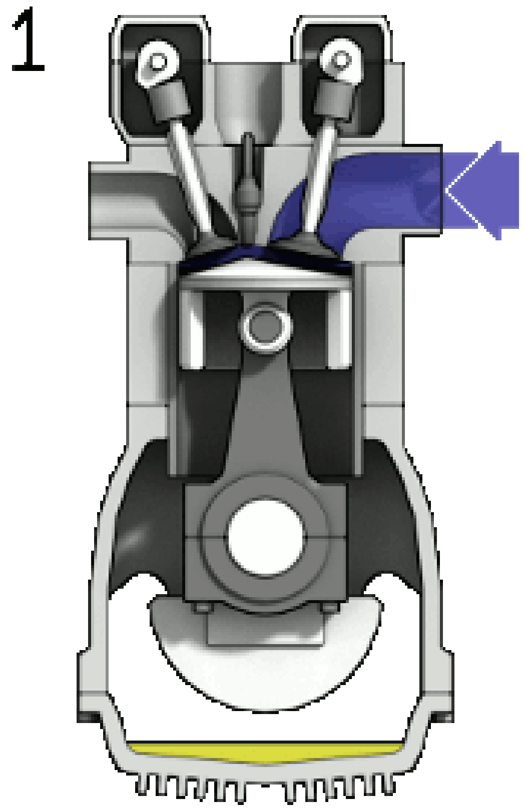
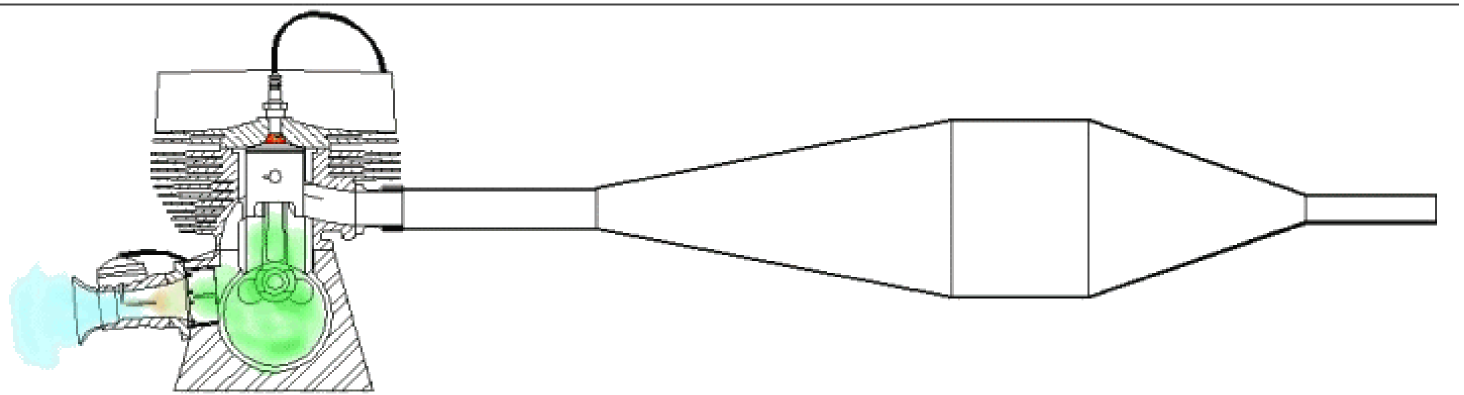
4-stroke engine cycle

- 1. Intake (Air/Fuel Mixture)
- 2. Compression
- 3. Combustion – power stroke
- 4. Exhaust



2-stroke engine cycle

- 1. Intake & Compression
- 2. Power Stroke & Exhaust
- Note. Exhaust pipe is designed to reflect the sound wave from the exhaust pulse – this pushes fuel/air mix back into the cylinder.



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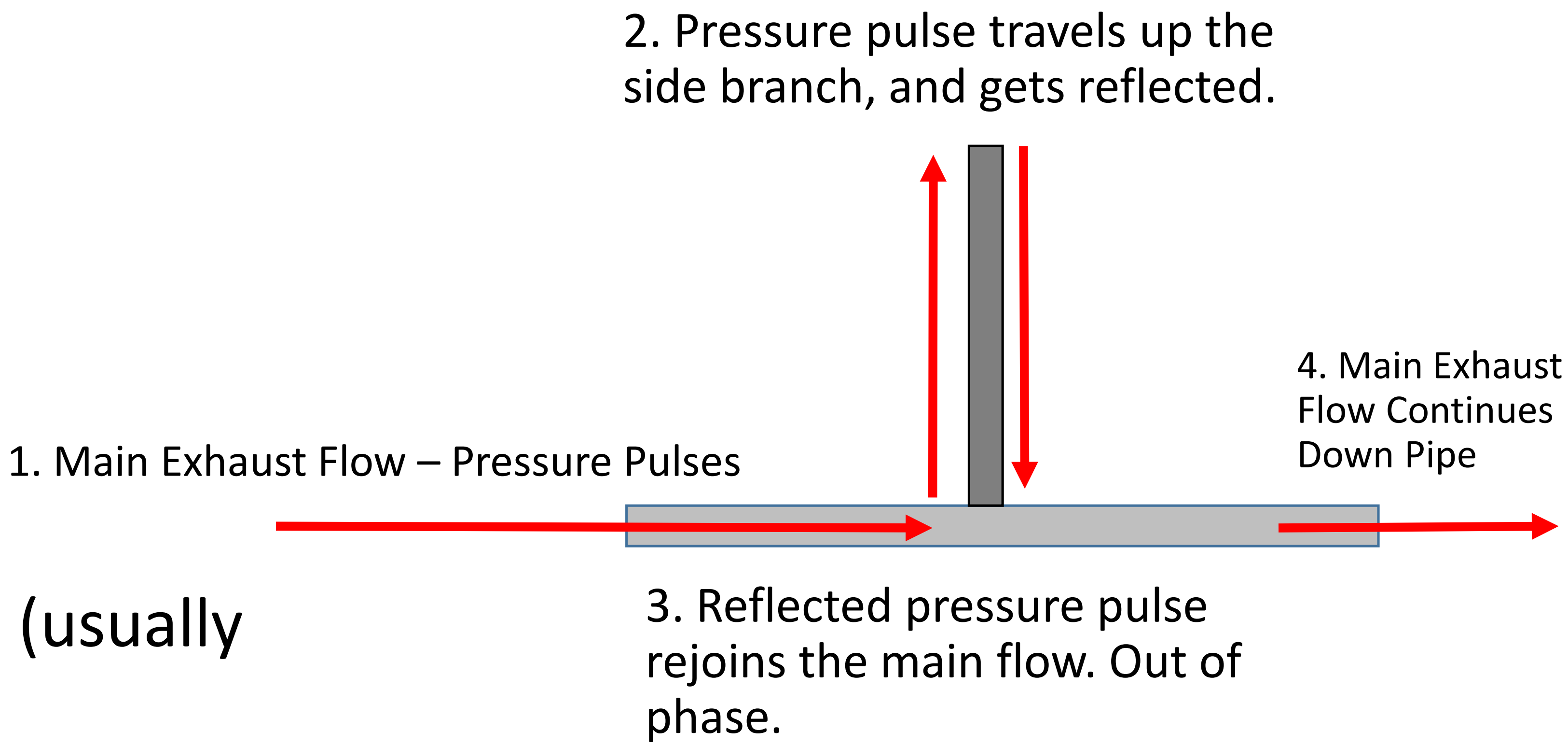
Quarter-Wavelength Resonator

$$f_n = \frac{(2n-1)c}{4L}$$



- n: Integer Harmonic (usually 1st harmonic)
- c: Speed of Sound
- L: Length of side branch

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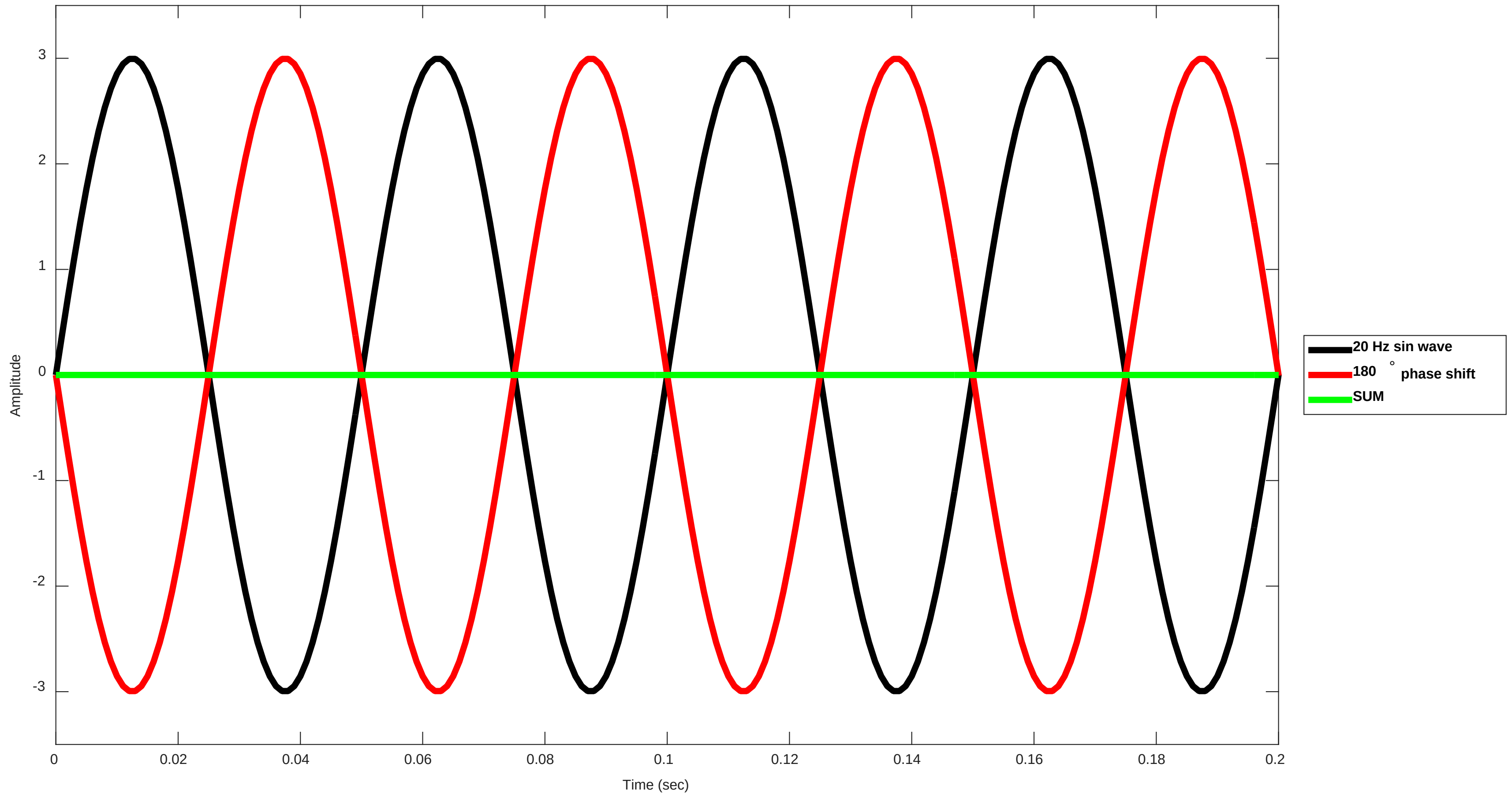
Phase Shift

- The original wave and the phase shifted wave (180) sum to zero amplitude.



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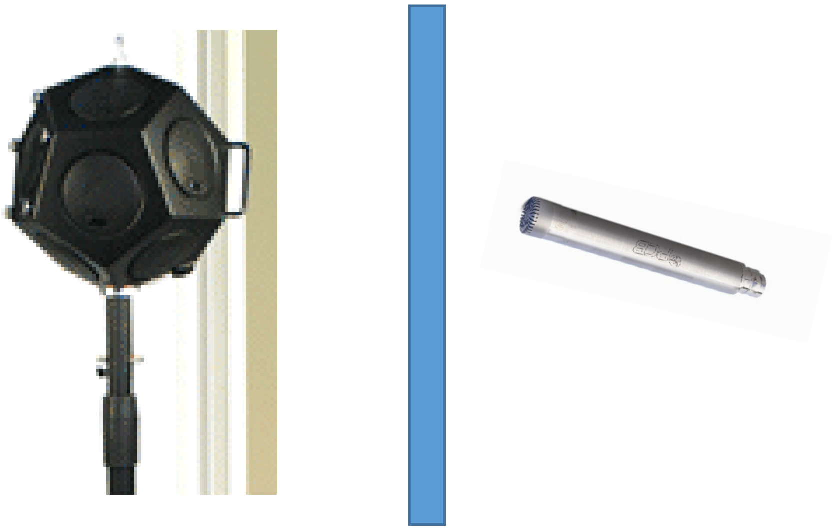
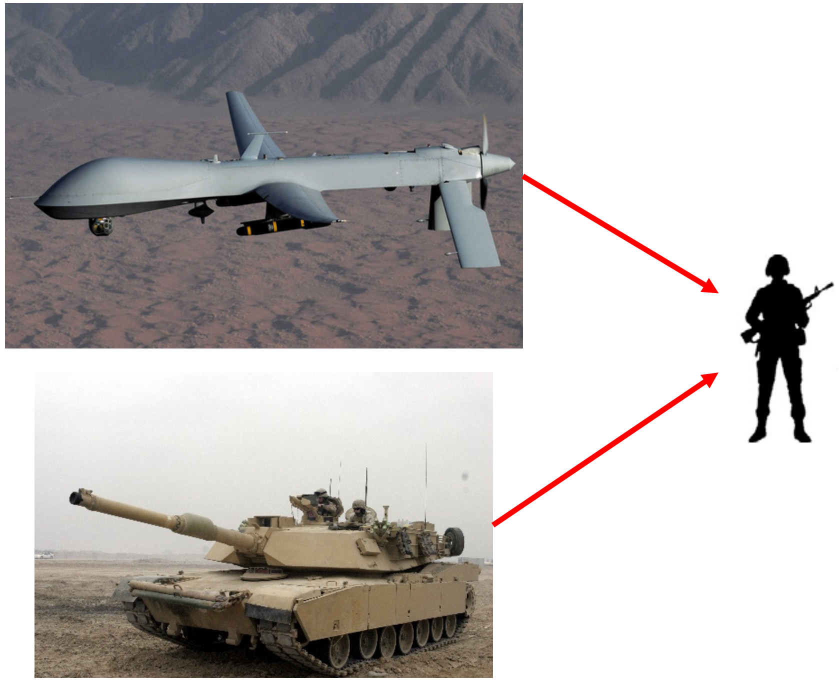
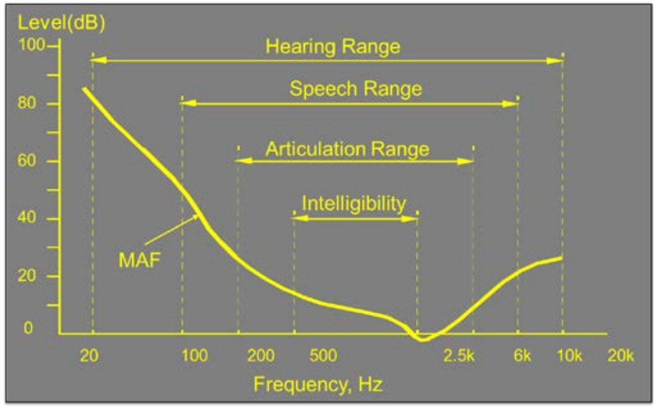
Insertion Loss



$$IL = 20\log_{10}\left(\frac{p_{\text{without barrier}}}{p_{\text{with barrier}}}\right) = L_{p_1} - L_{p_2}$$

- Low frequencies travel farther than high frequencies
  - Important to attenuate low frequency content to reduce detection distance for military applications
- Humans have difficulty hearing low frequencies
  - We communicate with frequencies between 200-2500 Hz therefore our ear are most adapt at perceiving these.





Human hearing is most sensitive at 1000 Hz

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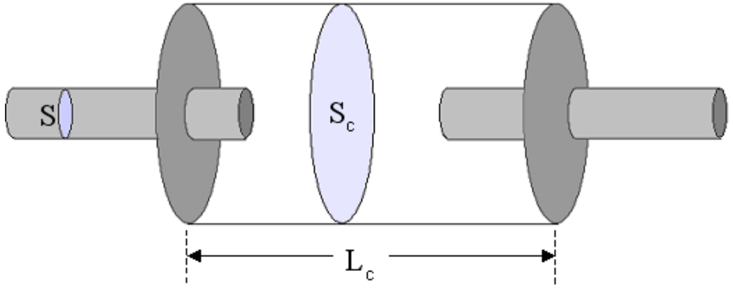
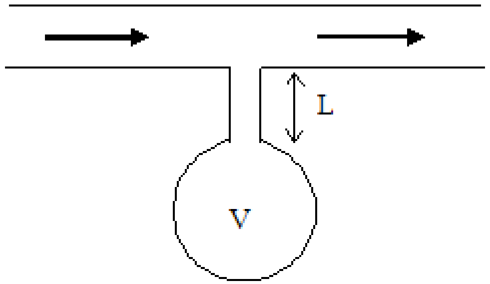
1885

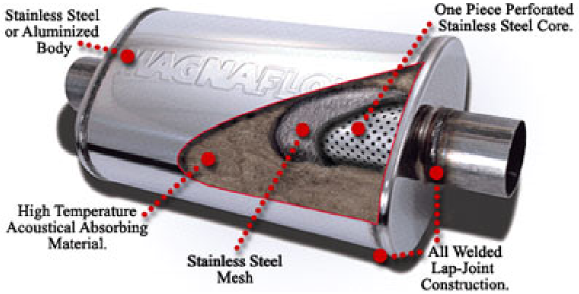
Quarter-wave resonators are not the only way exhaust noise is attenuated!



- Expansion Chamber
- Baffles
- Other resonator type: Helmholtz



- Absorption material (High Frequency)
- Perforated tubing inside



- Most exhaust systems (mufflers) combine several – or all – of these

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