Passive and Active Noise Control For Next Generation Locomotive Cabs

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Noise Control for Next Generation Locomotive Cabs

- Background
- Acoustic Environment of Diesel-Electric Locomotive Cabs
- Passive Noise Control
- Active Noise Control
- Conclusions

FRA Final Rule on Noise Exposure in Locomotive Cabs

- Regulates noise limits for railroad employees in locomotive cabs:
  - An 8-hour time-weighted average (TWA) limit of **90 dBA**.
  - **Hearing protection** required if exceeded or option for railroads to introduce operational controls
- New requirements:
  - Railroads must conduct in cab **noise monitoring**
  - Railroads must implement a **hearing conservation program** for employees exposed to an 8-hour TWA of 85 dBA or greater
  - FRA will establish **design, build** and **maintenance standards** for new locomotives
- Primary concern is minimizing noise-induced hearing loss (NIHL) but other concerns include:
  - **Fatigue, speech interference, comfort, health effects**

U.S. Federal Railroad Administration updated 49 CFR Parts 227 and 229 - Occupational Noise Exposure for Railroad Operating Employees; Final Rule October 27, 2006

FRA Next Generation Locomotive Cab Project

- **FRA-sponsored project conducted by QinetiQ North America to research and develop the Next Generation Locomotive Cab**
- **Project Goals: demonstrate various safety, ergonomic, and employee health-related upgrades to locomotive cabs**
- **Conducted noise measurements in Alaska Railroad EMD SD70MAC locomotive**
- **Retrofit an EMD SD70MAC locomotive cab shell with:**
  - New interior that simulates improvements in ergonomics and advanced display systems
  - Isolated floor to reduce undesirable vibrations
  - Passive noise control treatments
  - Active noise control system

Test Locomotive Cab

Noise Levels in Locomotive Cabs

- Acoustic environment in locomotive cabs is complex

Noise Levels in Locomotive Cabs

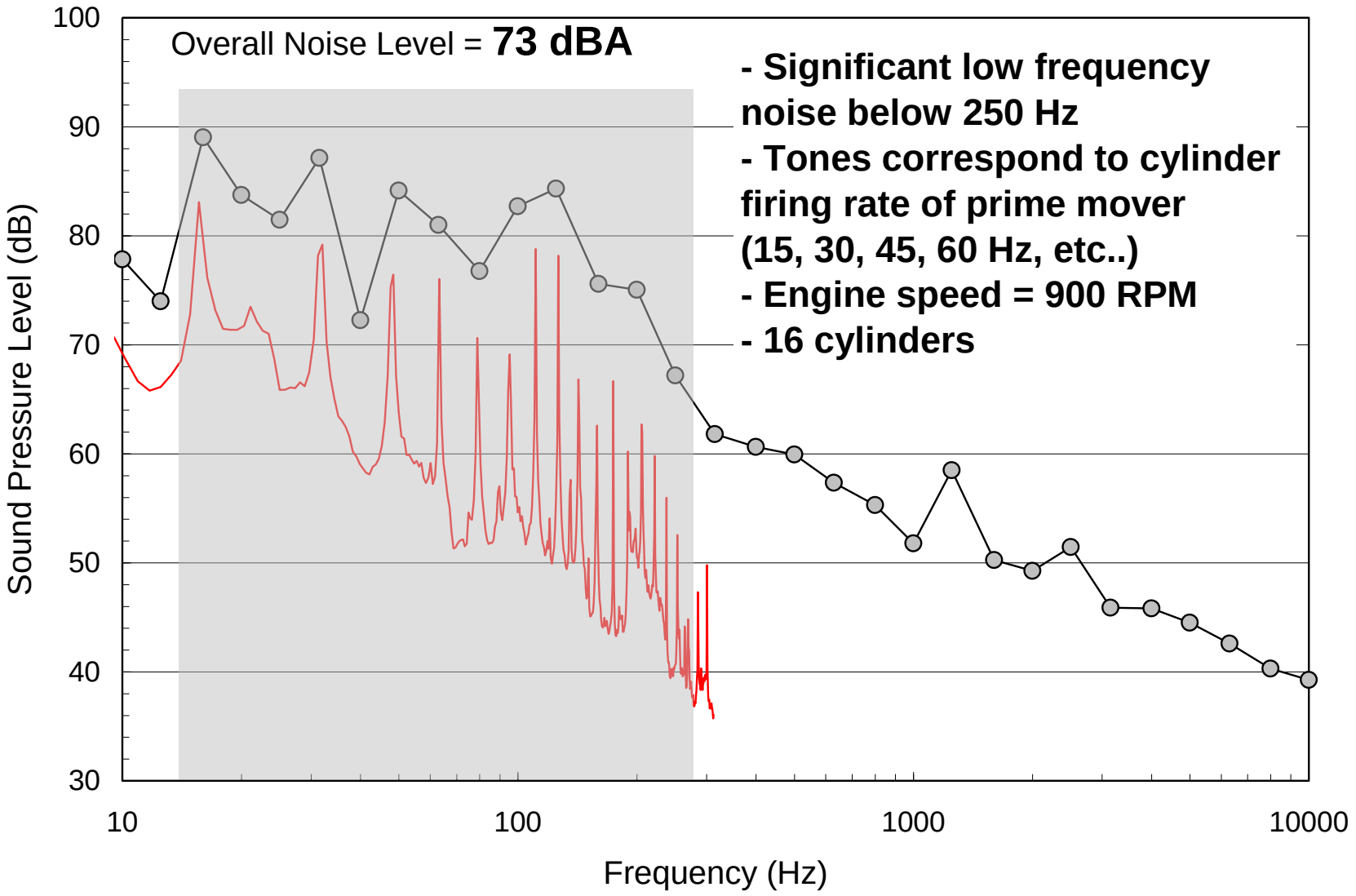
- **Noise sources**
  - Constant noise and vibration sources (prime mover, wheel/rail)
  - Short-term noise sources (train whistle, radio, special trackwork)

- **Character of the noise**
  - Significant low frequency content (typically below 200 Hz)
  - Tonal primarily due to diesel engine exhaust

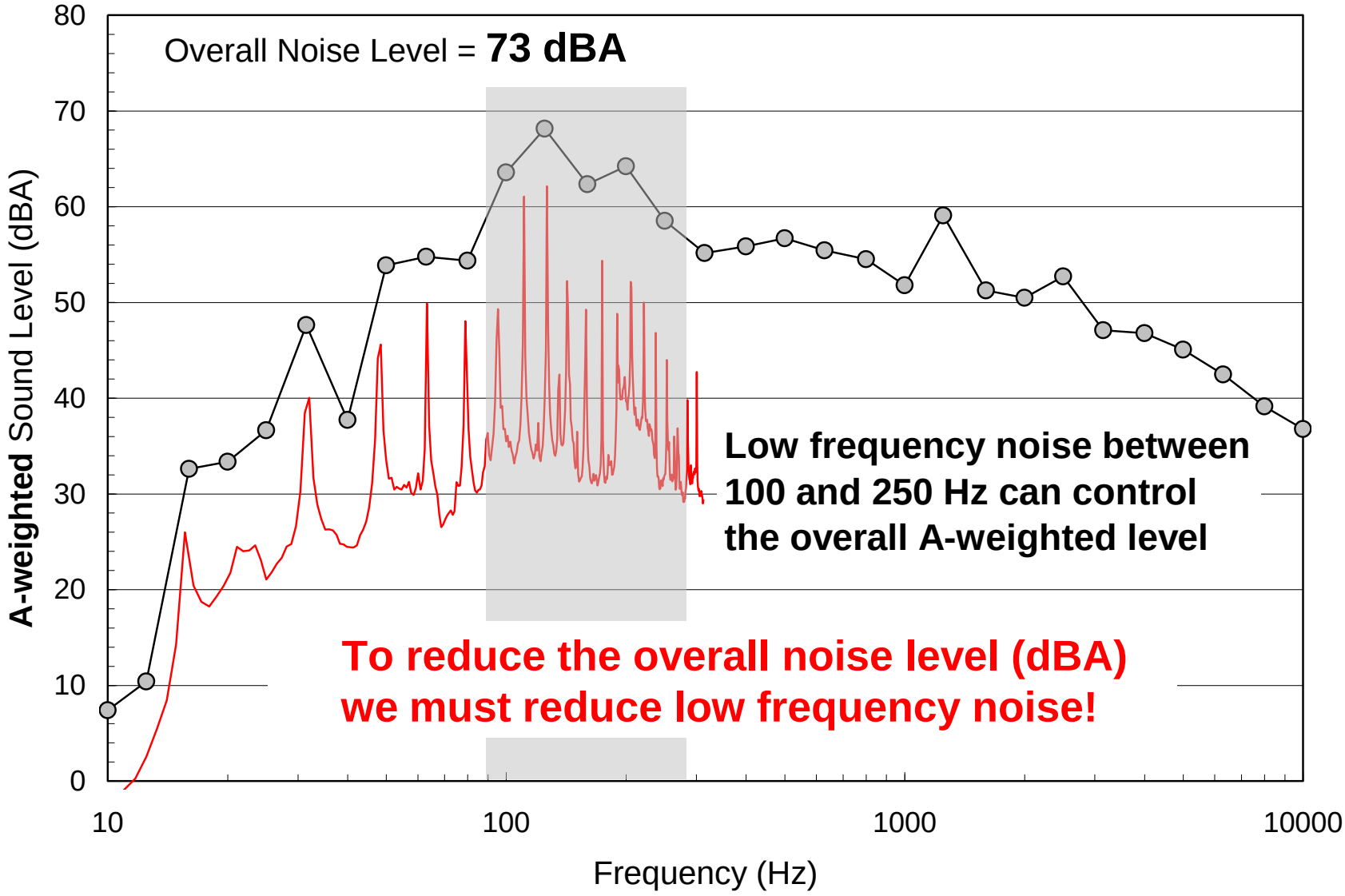
- **Other factors affecting environment**
  - **Open windows**
  - **Radio** must be louder than other noise sources
  - **Vibration of cab interior panels** radiate noise
  - **Aerodynamic noise**

What do locomotive cabs sound like?

Noise Levels Inside Locomotive Cab



Noise Levels Inside Locomotive Cab

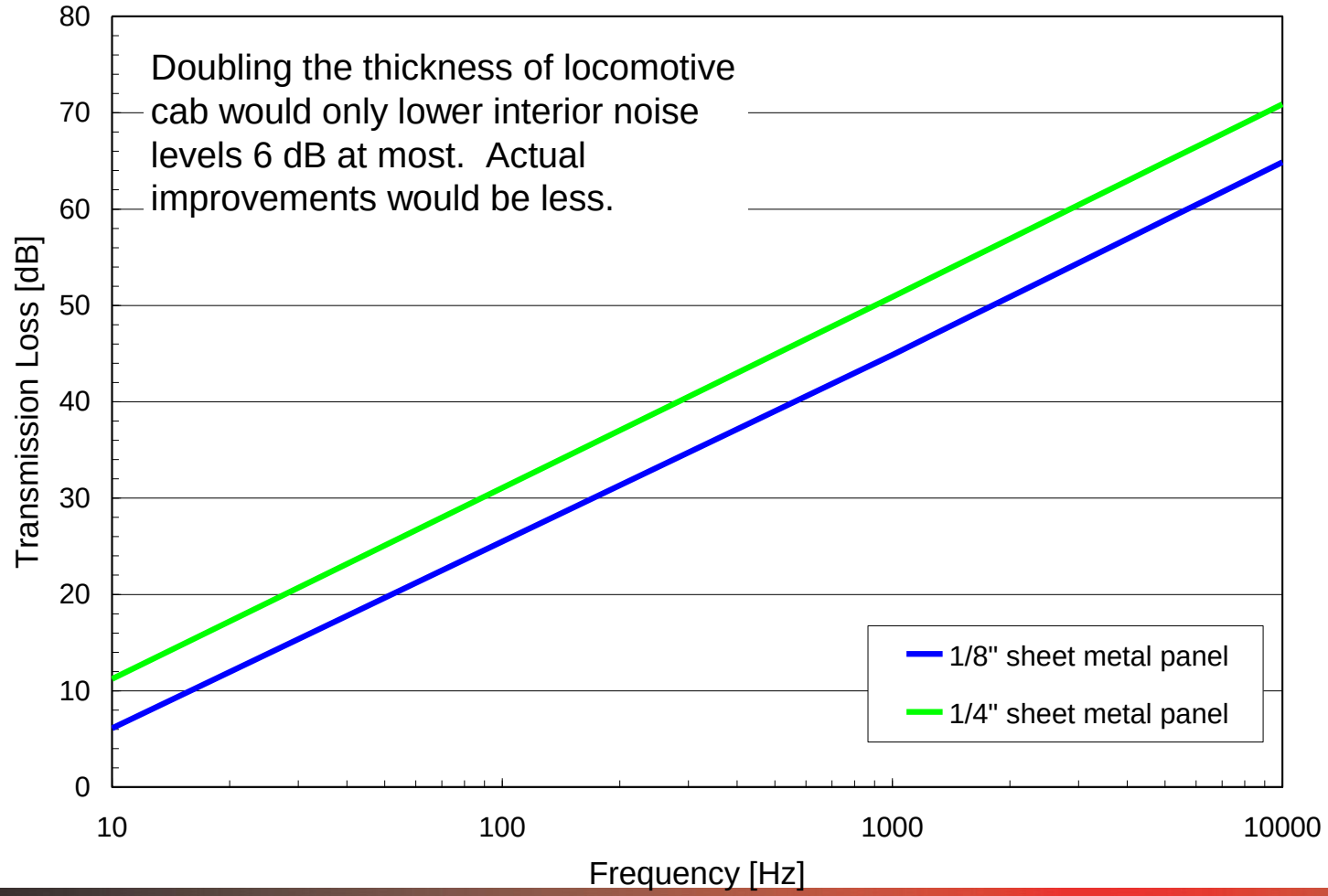


Passive Noise Control

- What can be done to reduce interior noise levels?
- Design, build and maintenance considerations:
  - Air gaps need to be closed
  - Windows and doors need good seals
    - A one inch hole in the side of a locomotive cab can increase noise levels 20 dB or more

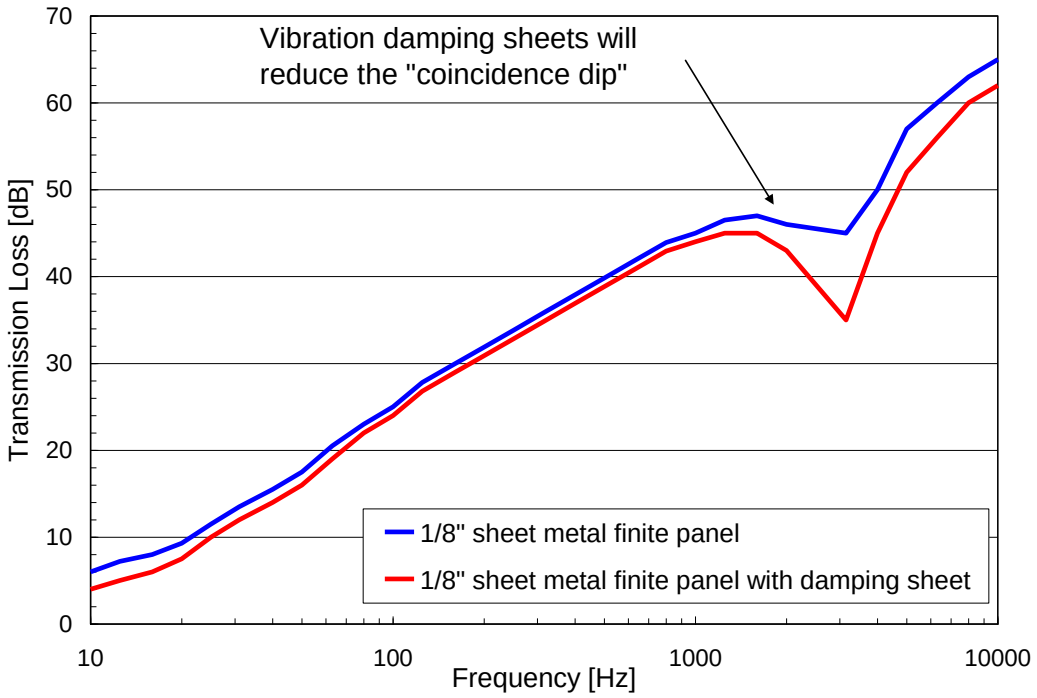
Passive Noise Control

- **Transmission loss (TL) of cab is inherently poor at low frequencies**
- **Improving transmission loss of cab structure is difficult**



Passive Noise Control

- **Vibration damping sheets applied to inside of panels can improve TL**
  - Increase the internal loss mechanisms (turns vibration into heat not sound)
  - Increase mass of panels
  - Useful as a retrofit to existing locomotives
  - Reduces “coincidence dip”



Passive Noise Control

- **The cab can be mounted on springs or rubber pads** to reduce structure-borne noise caused by vibration generated at the wheel/rail interface and the prime mover
  - EMD SD70MAC “Whisper Cab” has vibration isolation but this feature has since been discontinued

- Once noise gets into the cab, it reverberates around the cab
- **Increasing the acoustic absorption inside the cab** will reduce reverberant noise
  - Material must be thick and porous
  - Effectiveness depends on surface area applied
  - Requires perforated sheet metal faces

Test Locomotive Cab Passive Materials

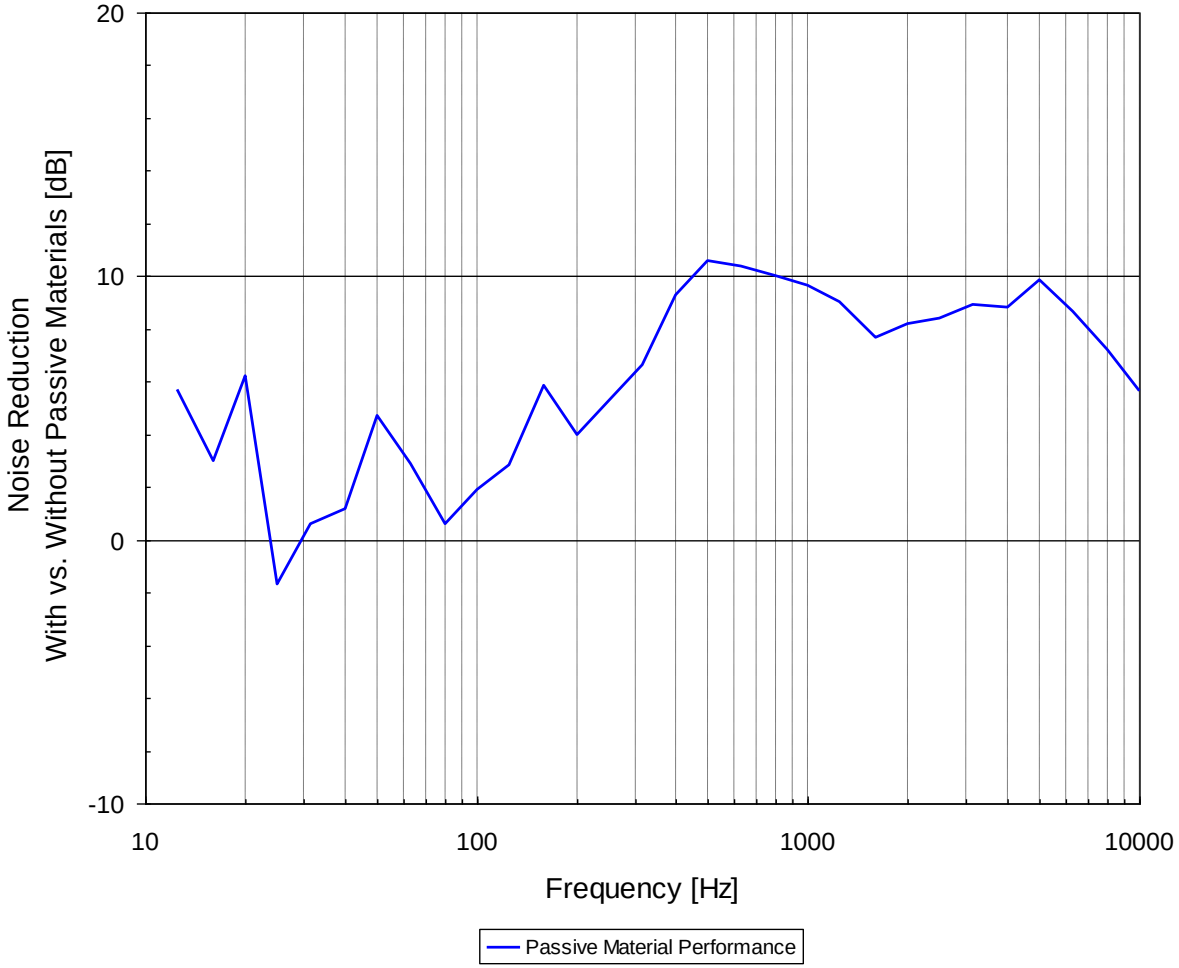
Unfinished Cab

Damping Panels and Absorption

Finished Cab with Perforated Sheet Metal Faces

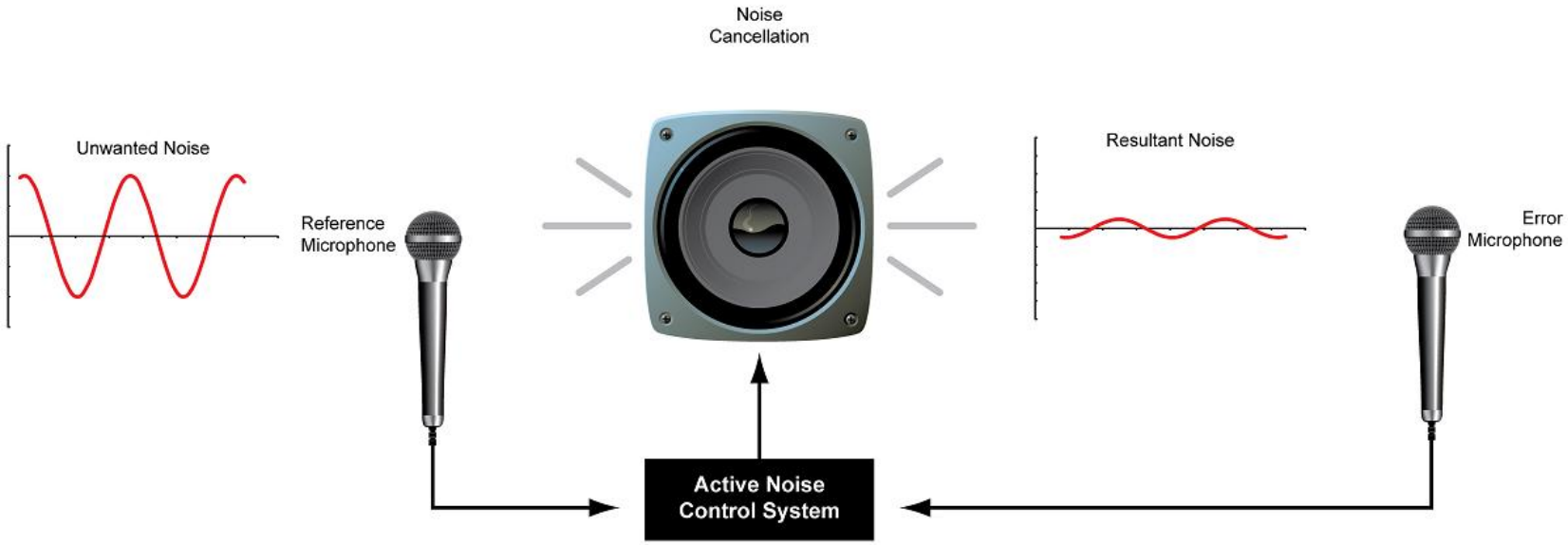
Measured Noise Reduction of Passive Treatment in Cab

- Damping panels and absorption improve noise reduction up to 10 dB
- No real benefits below 250 Hz



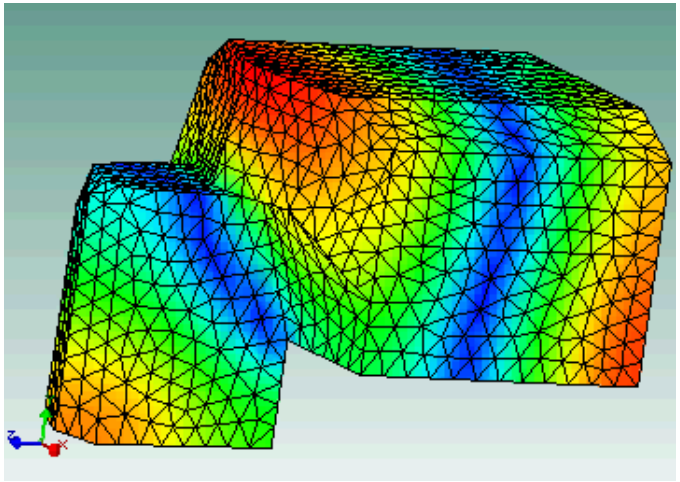
Active Noise Control Background

- How can we reduce low frequency noise?
- Active noise control!
  - **Unwanted sound** is the prime mover exhaust noise
  - **Reference microphones**/sensors measure the unwanted sound
  - **Active control system** calculates signal to cancel the noise
  - **Control speaker** reproduces the sound 180° out of phase
  - **Error microphones** measure the result and adjust the control system



Active Noise Control Background

- **Key elements to active noise control**
- **Control speaker needs to reproduce sound precisely in time to be 180° out of phase**
  - Repetitive/**tonal sounds are easiest to cancel**
- **Noise reduction is a function of the listeners proximity to the control speaker and the wavelengths of unwanted sound**
  - **Active control is <u>more</u> effective at low frequencies** than high frequencies
- **Active noise control can be either:**
  - "global"- effective throughout the cab
  - "local" - effective only in specific areas near the control speaker
  - Global reduction is generally achieved only at specific frequencies which are acoustic modes of the cab



- **The goal of the demonstration was to achieve localized noise reduction near the engineer's ears**

ANC System Demonstration Setup

- Diesel engine noise simulated by subwoofer loudspeaker positioned outside of locomotive cab
- Reference microphone located outside of cab near source

Active Noise Control Equipment

- **Feed-forward active noise control system**
  - EZANC II active noise controller manufactured by Causal Systems
    - Up to 10 reference and error signals
      - microphones, accelerometers, tachometer
    - Up to 10 control outputs (control speakers)

Photo property of Causal Systems Pty. Ltd. ®

ANC System Demonstration

- Control source loudspeaker located above the engineer's seat
- Speaker must be compact yet generate a lot of low frequency sound

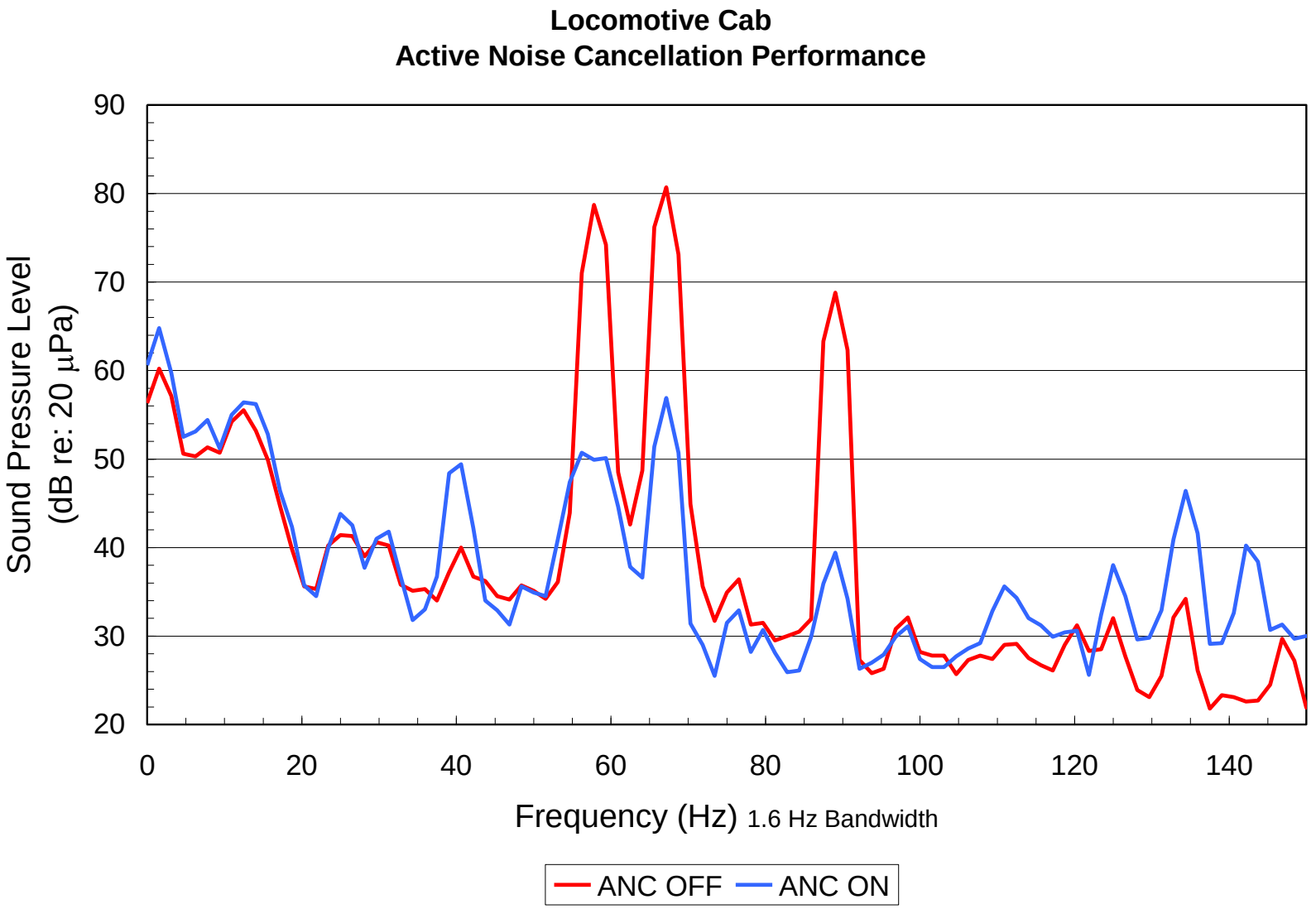
ANC System Demonstration

- Error microphones mounted to engineer's seat headrest (final location recessed into seat)

ANC System Demonstration Results

- The ANC demonstration focused on reducing the level of several tones simultaneously
- With the ANC system on, a strong noticeable quiet zone around the head of the train conductor was achieved
- The level of all tones were successfully reduced by 20-30 dB

Active Noise Control Performance in Cab



Other results typical of ANC systems

- **These proof-of-principle tests represent idealized performance**
- **Examples of other ANC systems in operating cabs:**
  - Noise reduction of 5 to 15 dB at low frequencies (tones between 60 Hz to 140 Hz) in a Class 1 locomotive cab has been attained by Cooper-Standard
  - Noise reduction of 3 to 4 dBA in an electric locomotive cab (which has more difficult to cancel high-frequency tones) has been achieved by SNCF (French National Railway)
  - Noise reduction up to 12 dB (at frequencies up to 150 Hz) have been achieved with a hybrid active/passive noise control system installed on the locomotive exhaust (FRA/Paul Remington)

Summary of Noise Control Treatments and Estimated Performance

Noise Control Treatment	Estimated Noise Reduction	Effective 1/3 O.B. Frequency Range
Rubber isolating pads	3 dB	4 Hz – 100 Hz
Vibration damping panels	3 dB	200 Hz – 10, 000 Hz
Acoustical absorption on ceilings and walls	5 dB	250 Hz – 500 Hz
	10 dB	5,000 Hz – 10,000 Hz
Active Noise Control	7 dB	31.5 Hz – 200 Hz

Conclusions

- FRA Final Rule on Occupational Noise Exposure for Locomotive Engineers brings awareness and action to improving the locomotive cab environment
- Acoustic environment in locomotive cabs has significant low-frequency, tonal sound from prime mover
- Passive noise control effective at high frequencies
- Active noise control needed for low frequencies which are critical to the overall acoustic environment in the cab

Thank You

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