

Passive and Active Noise Control For Next Generation Locomotive Cabs

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Noise Control for Next Generation Locomotive Cabs

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

FRA Final Rule on Noise Exposure in Locomotive Cabs

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- 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

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- 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

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Noise Levels in Locomotive Cabs

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- Acoustic environment in locomotive cabs is complex



Noise Levels in Locomotive Cabs

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- **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**

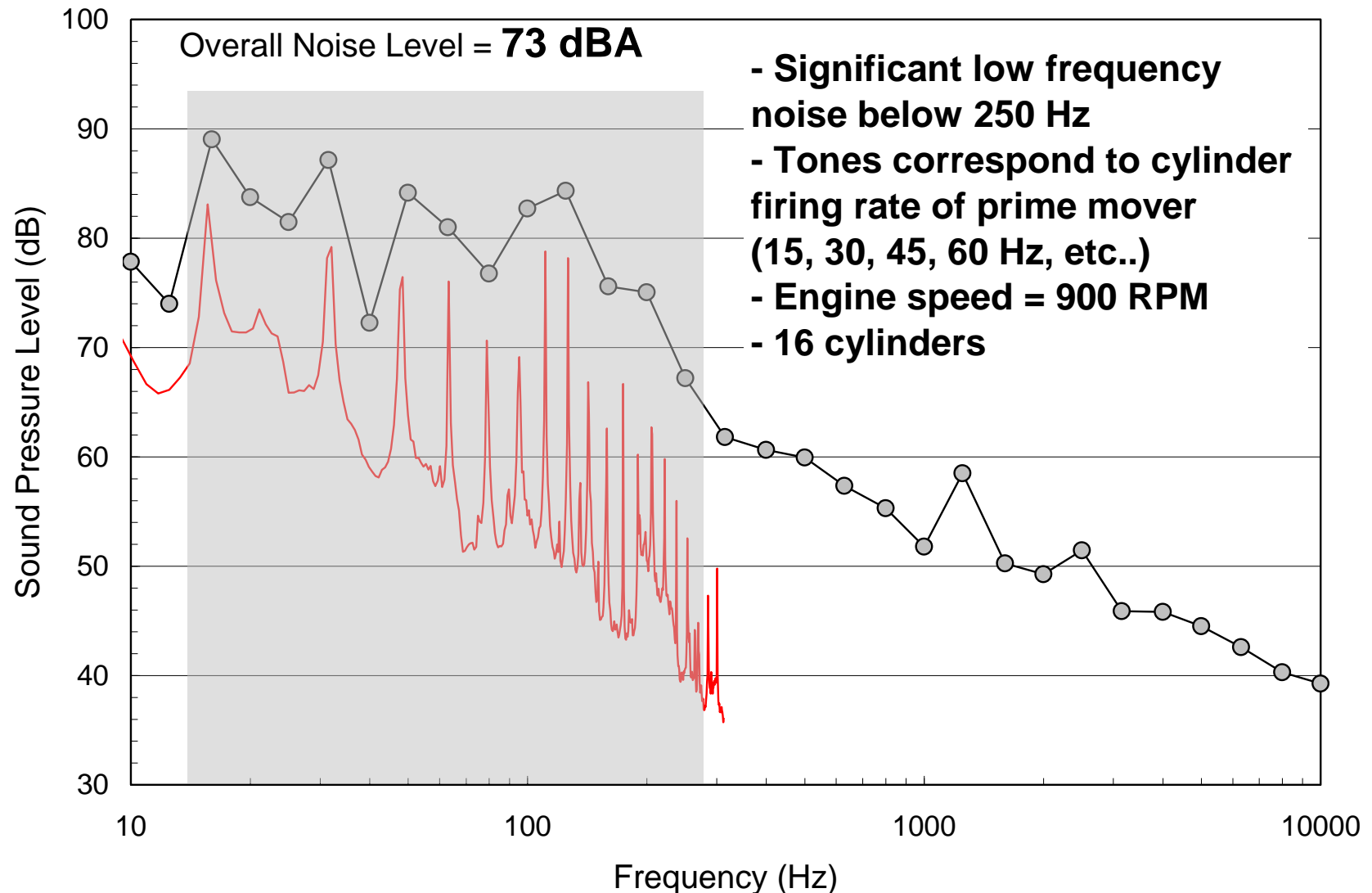
What do locomotive cabs sound like?

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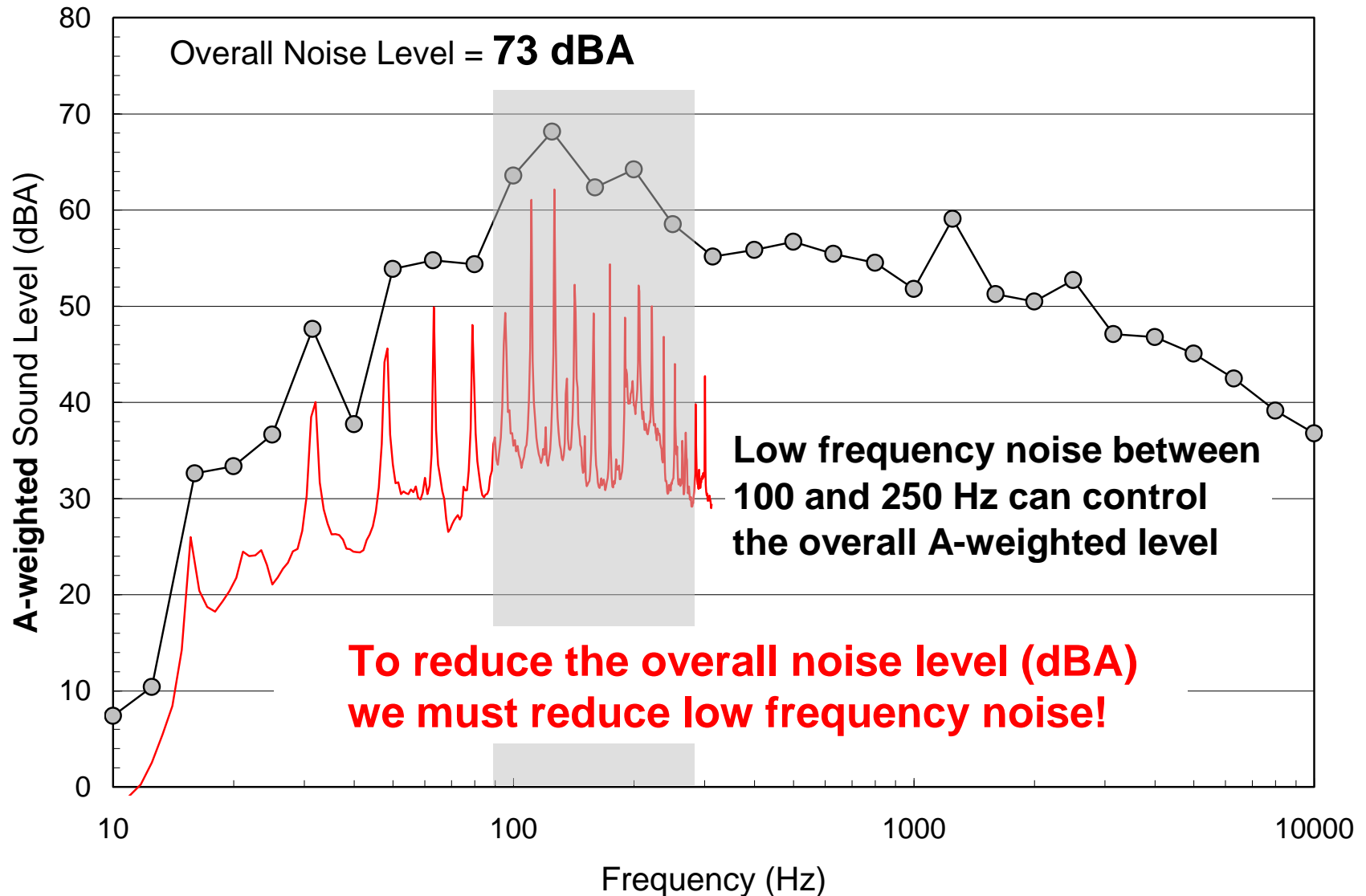
Noise Levels Inside Locomotive Cab

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Noise Levels Inside Locomotive Cab

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Passive Noise Control

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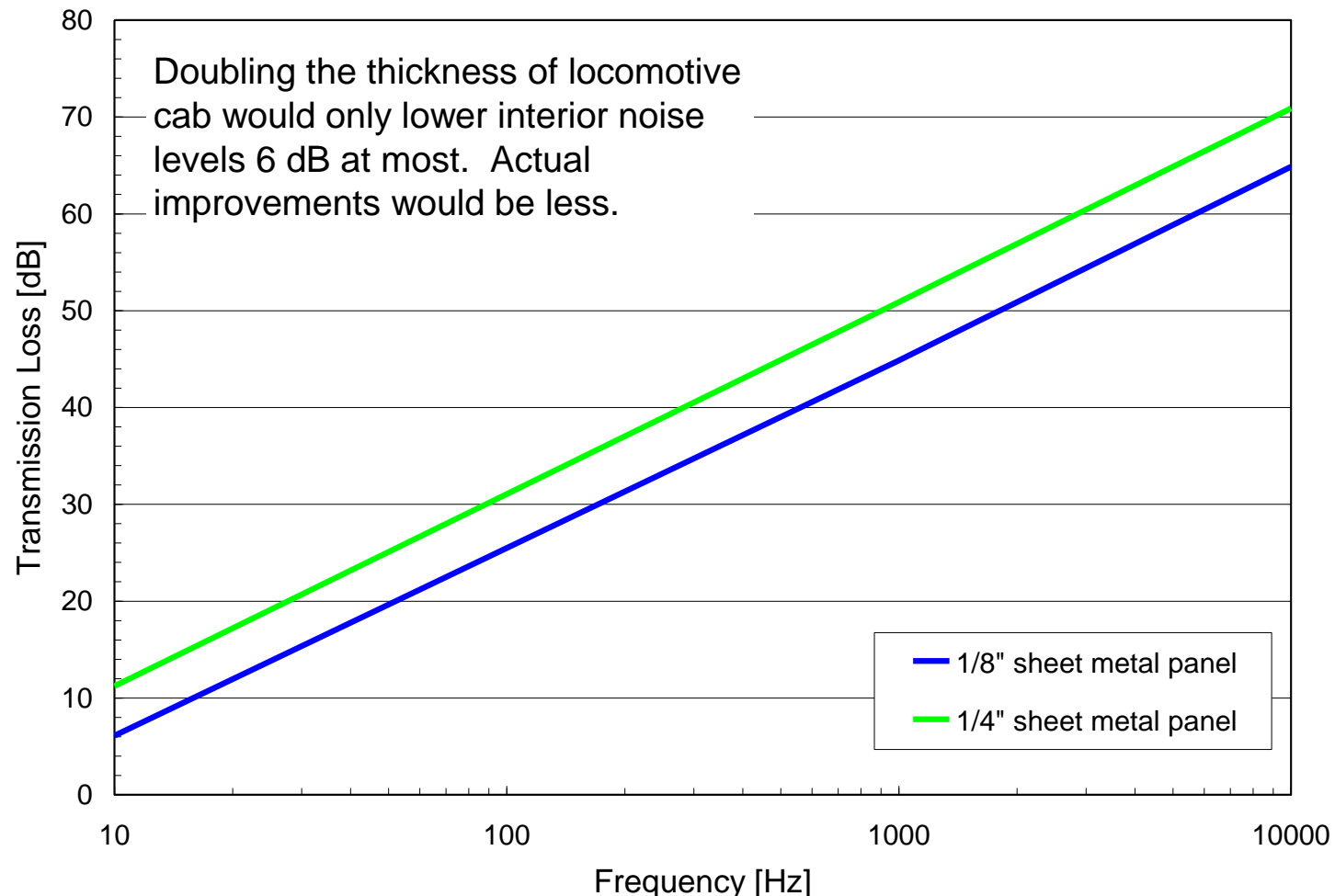
- What can be done to reduce interior noise levels?
- Design, build and maintenance considerations:
 - **Air gaps need to be closed**
 - **Windows and doors need good seals**
 - A one inch hole in the side of a locomotive cab can increase noise levels 20 dB or more



Passive Noise Control

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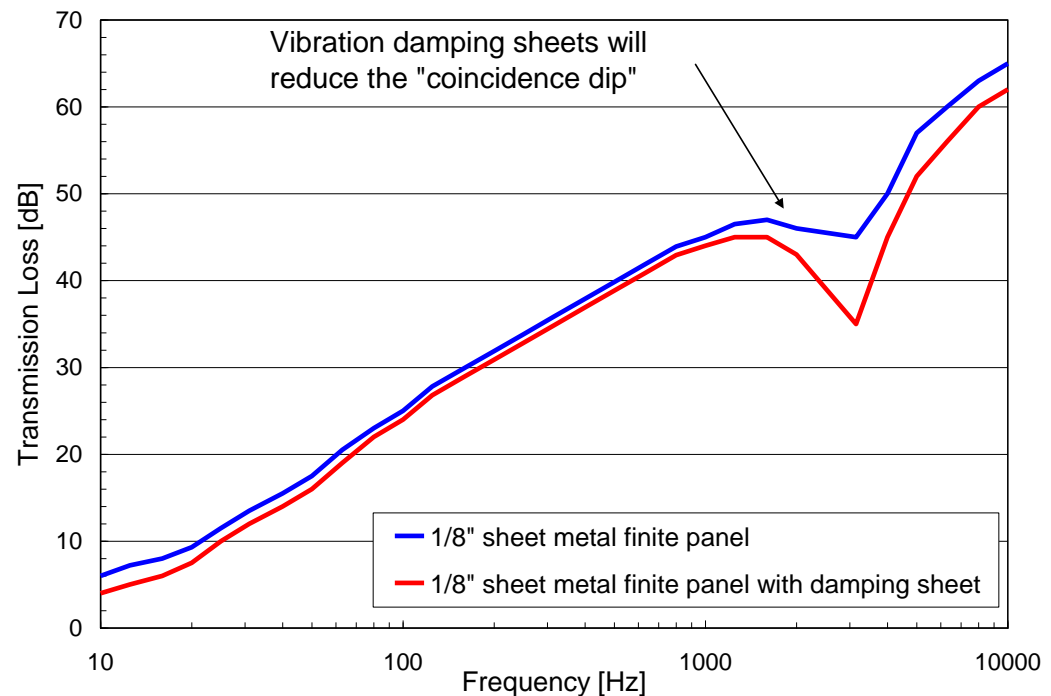
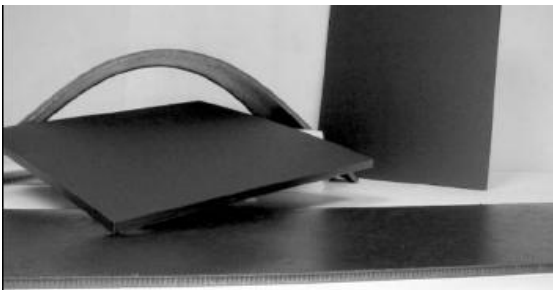
- Transmission loss (TL) of cab is inherently poor at low frequencies
- Improving transmission loss of cab structure is difficult



Passive Noise Control

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- **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

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- **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

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Unfinished Cab



Damping Panels and Absorption



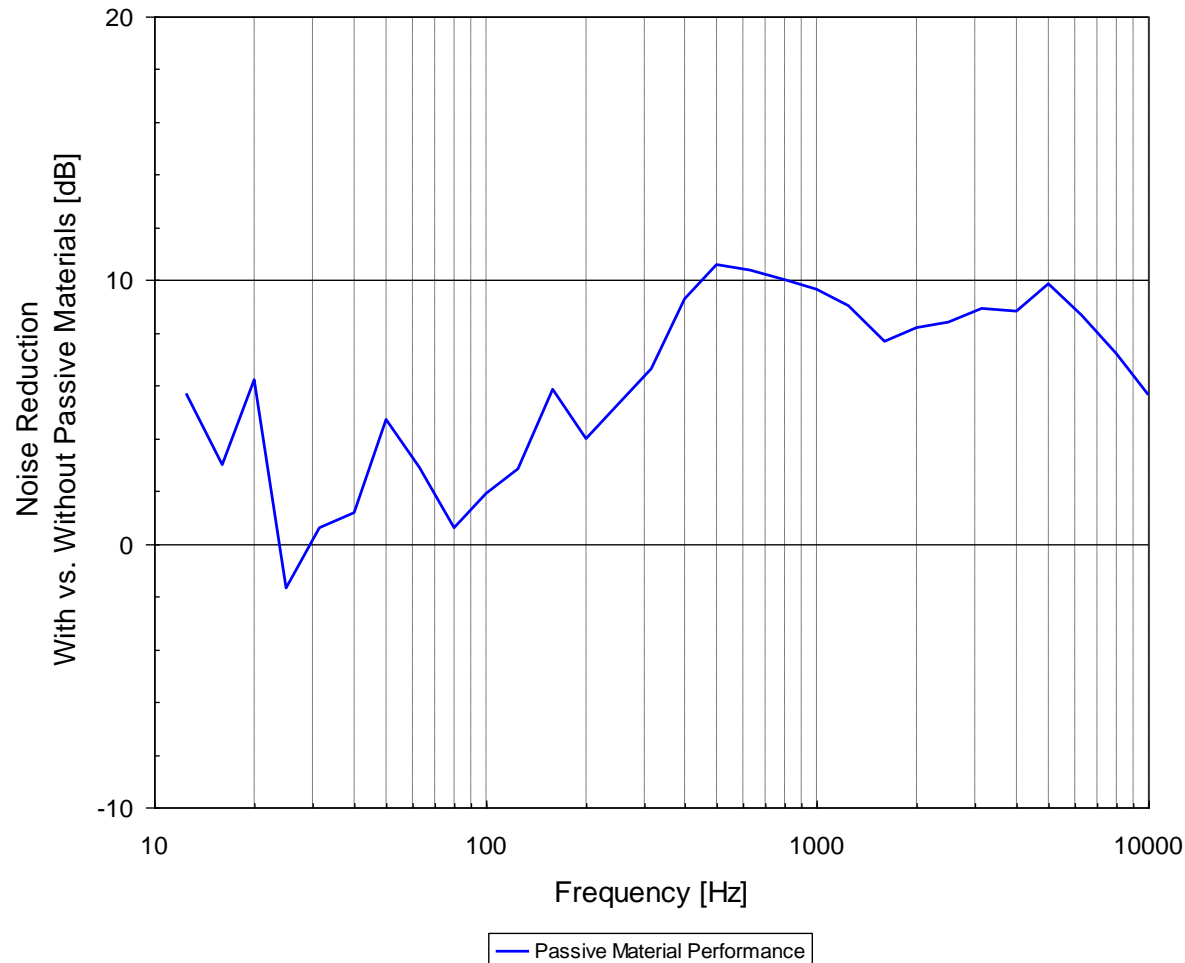
Finished Cab with Perforated Sheet Metal Faces



Measured Noise Reduction of Passive Treatment in Cab

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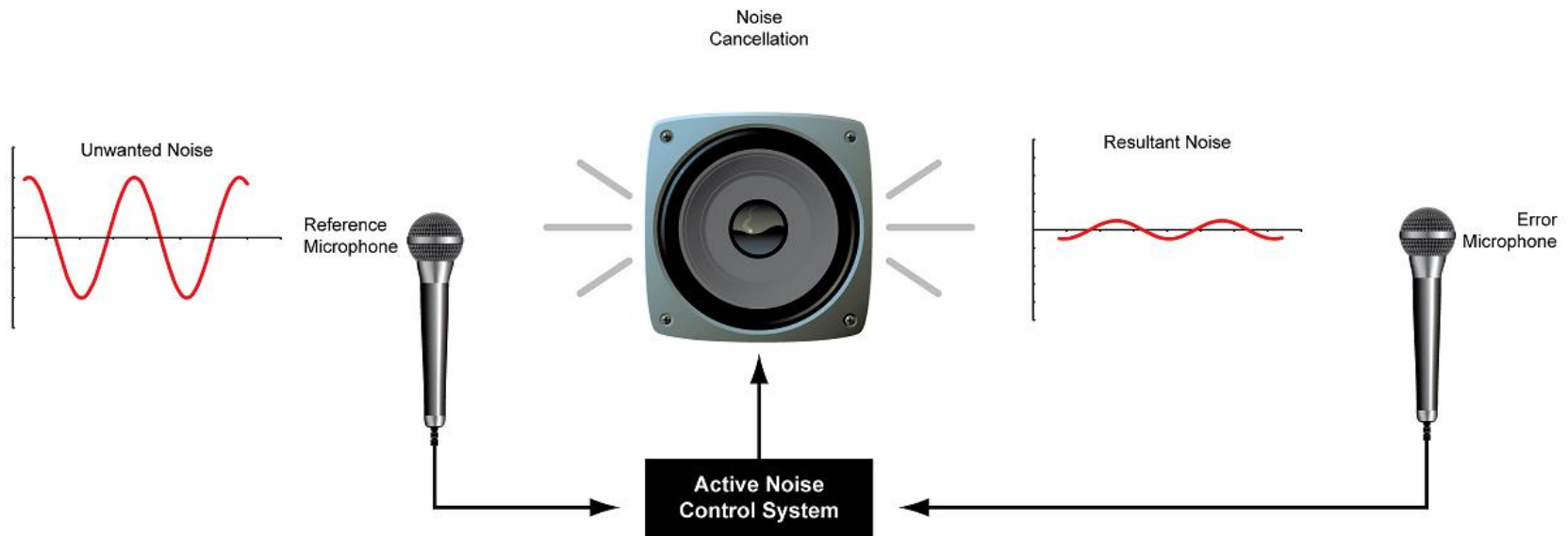
- Damping panels and absorption improve noise reduction up to 10 dB
- No real benefits below 250 Hz



Active Noise Control Background

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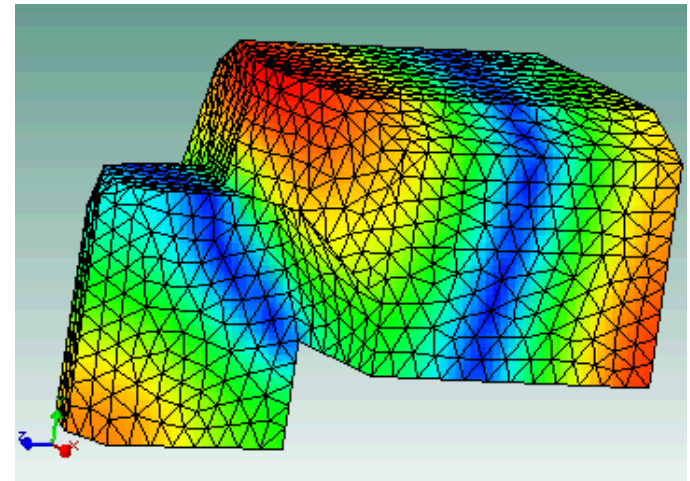
- How can we reduce low frequency noise?
- Active noise control!
 - **Unwanted sound** is the prime mover exhaust noise
 - **Reference microphones/sensors** measure the unwanted sound
 - **Active control system** calculates signal to cancel the noise
 - **Control speaker** reproduces the sound 180° out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



Active Noise Control Background

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- 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 more 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

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



Active Noise Control Equipment

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- **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
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ANC System Demonstration

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



ANC System Demonstration

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



ANC System Demonstration Results

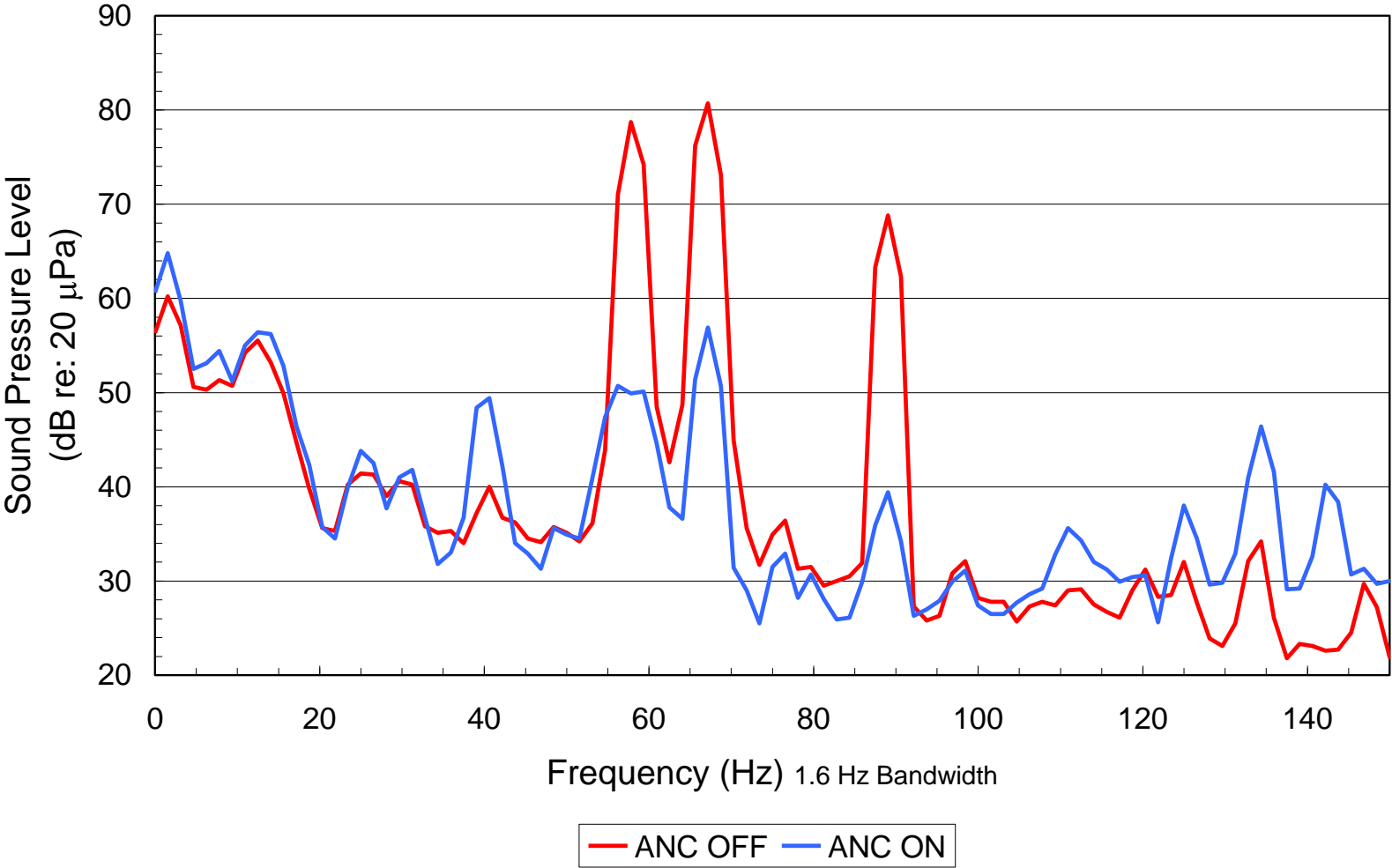
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- **The ANC demonstration focused on reducing the level of several tones simultaneously**
- **With the ANC system on, a strong noticeable quiet zone around the head of the train conductor was achieved**
- **The level of all tones were successfully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

Active Noise Control Performance in Cab

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Locomotive Cab
Active Noise Cancellation Performance



Other results typical of ANC systems

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- 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

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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

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- **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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