



OFFICE OF RESEARCH & DEVELOPMENT

2012 **R&D**
REVIEW

Feasibility of a Variable-Directivity Locomotive Horn

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U.S. Department
of Transportation

**Federal Railroad
Administration**

Program Area & Risk Matrix

Feasibility of a Variable-Directivity Locomotive Horn

Program Areas	Risk Factors	Trespass	Grade Crossing	Derailment	Train Collision	All Other Safety Hazards
Railroad Systems Issues						
Human Factors						
Track & Structures						
Track & Train Interaction						
Facilities & Equipment						
Rolling Stock & Components						
Hazardous Materials						
Train Occupant Protection	X	X				
Train Control & Communications						
Grade Crossings & Trespass						

Background

- It is estimated that up to 9.3 million persons in the U.S. may be impacted by locomotive horn noise
- In 2009, there were over 1,900 incidents, over 700 injuries and over 240 fatalities at highway-rail grade crossings
- The National Academy of Engineering Committee on Technology for a Quieter America has indicated that the public would benefit if train horns were more directional
- An ideal train horn optimized for directivity could both improve safety and reduce environmental noise impact

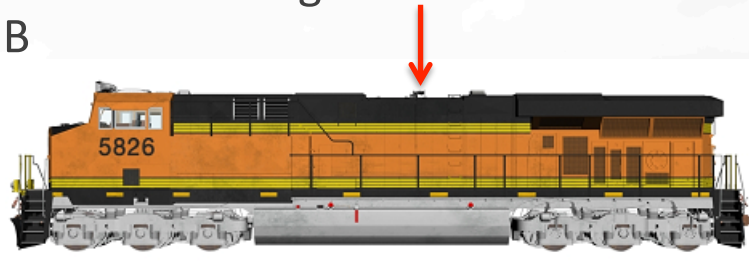
Objectives

This Federal Railroad Administration-sponsored study:

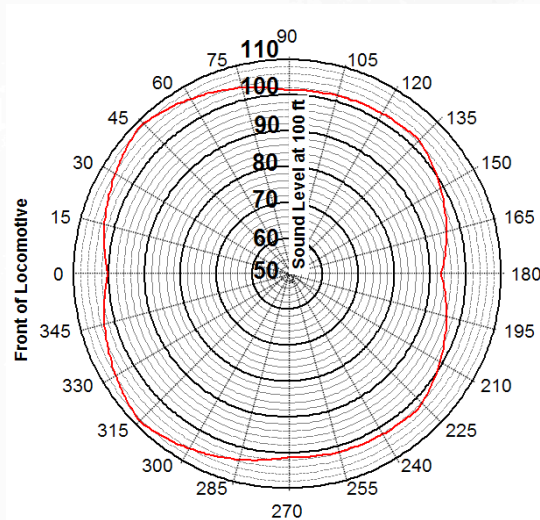
- Specifies the acoustical parameters for an ideal on-board locomotive “acoustical warning device” with variable-directivity
- Compares this ideal optimized device to standard horns for:
- Audibility/detectability
- Environmental noise exposure
- Occupational noise exposure
- An initial prototype has been developed
- Implementation and cost issues have been considered

Standard Train Horn Systems

- Typically mounted on the center of locomotive or on the cab roof
 - Moving horns to the center of long hood has been shown to reduce in-cab noise levels by 10 dB



- Horns generally produce sound equally in all directions around the train



Center-mounted horns have slightly lower amplitudes directly forward of the locomotive due to shielding from the locomotive body

Typical directivity pattern of standard horn

Train Horn Sounding Requirements

- **FRA 49 CFR Parts 222 and 229 Final Rule on Use of Locomotive Horns at Highway-Rail Grade Crossings (2006)**
 - Regulates horn levels to between 96 and 110 dBA at 100 ft forward of locomotive (+/- 20 degrees)
 - Engineer typically sounds horn for 15 to 20 seconds with a maximum of 25 seconds
 - Depending on train speed, horns are typically sounded for 1400 feet beginning 1/4-mile from the crossing until the first locomotive is entirely through the crossing
 - Horns are typically sounded using a long-long-short-long pattern

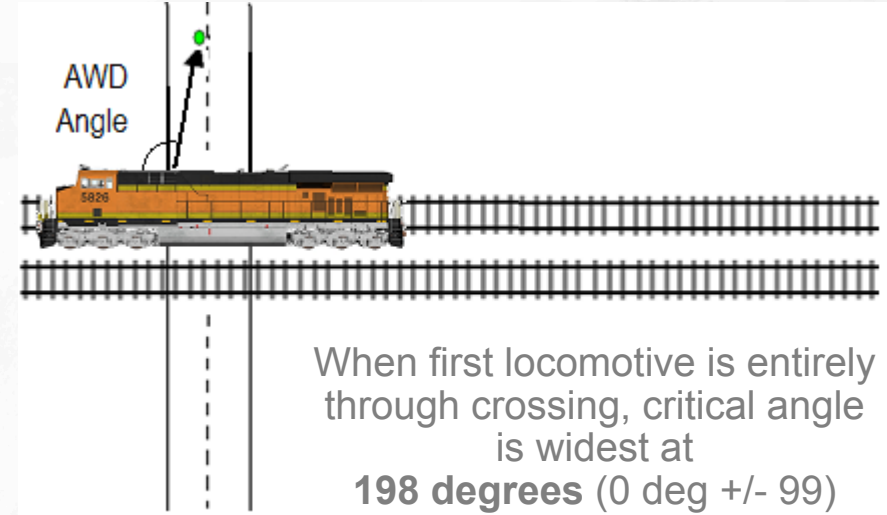
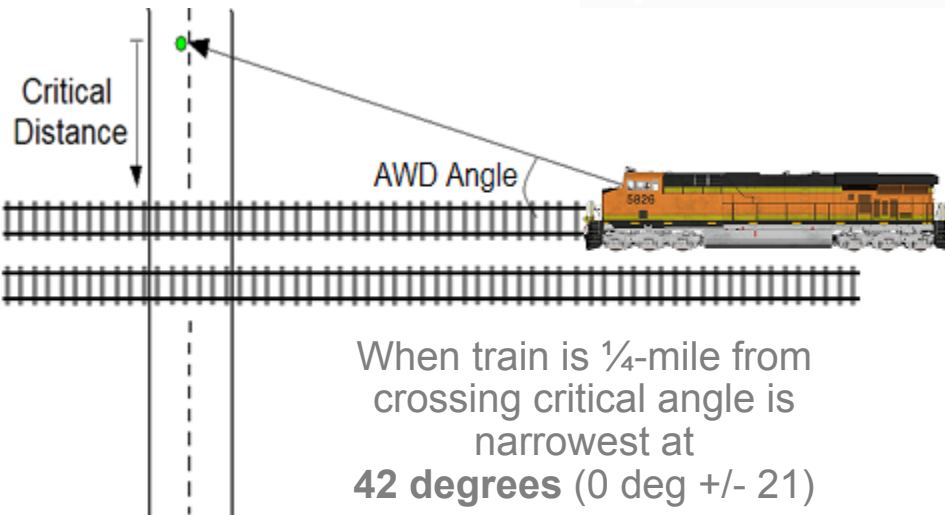
Optimized Acoustical Warning Device (AWD)

General Information

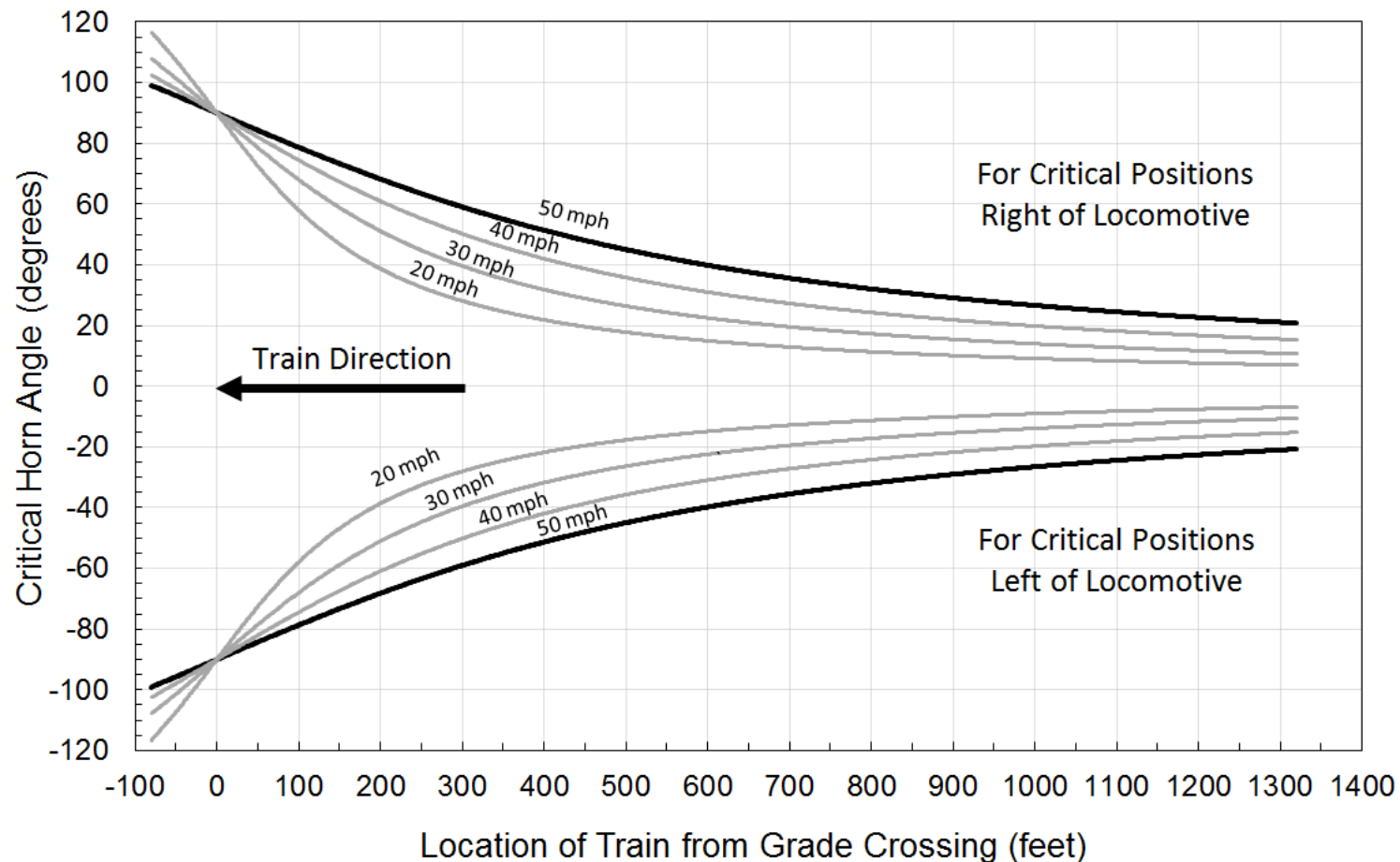
- AWD would meet current FRA regulations for use of locomotive horns at highway-rail grade crossings
- Sounds the same as a typical standard horn
- Keeping the sound signature is critical to maintaining association of sound to a train event
- Allows for a secondary emergency signal to be generated, even voice commands could be sounded
- AWD will have a variable-directivity pattern that changes based on the location of the train to the grade-crossing
- This is necessary to significantly reduce environmental noise impact

Optimized Acoustical Warning Device (AWD)

- The variable directivity pattern focuses sound to “critical positions” needed for detectability to motorists and pedestrians and minimizes sound to the wayside
- The directivity of the AWD depends on:
 - Location of train relative to the crossing
 - “critical distance” for cars to stop prior to crossing (i.e. for a car traveling at 50 mph, the critical distance for it to stop prior to a crossing is ~500 feet)

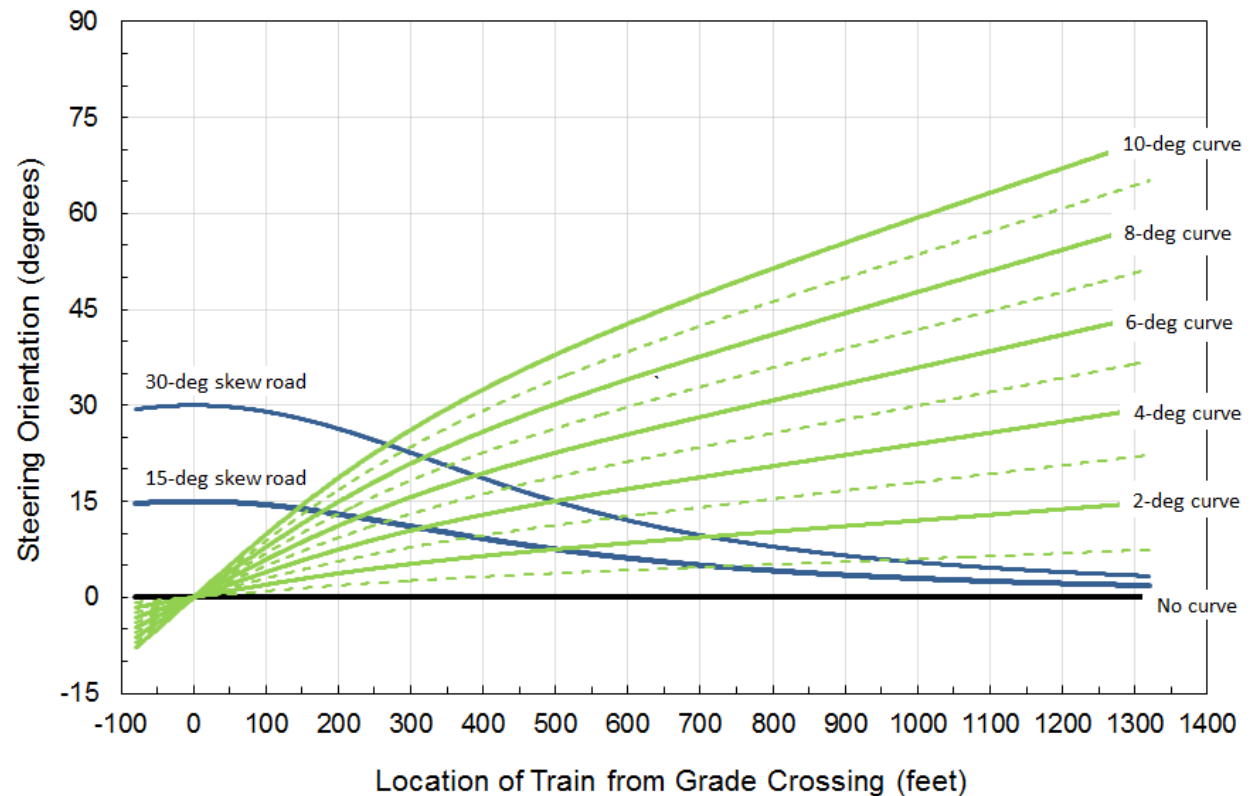
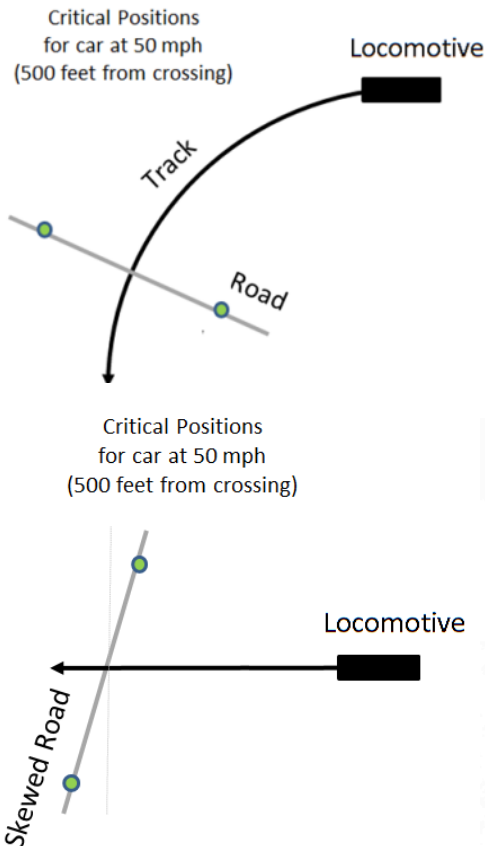


Critical Angles for Tangent Track



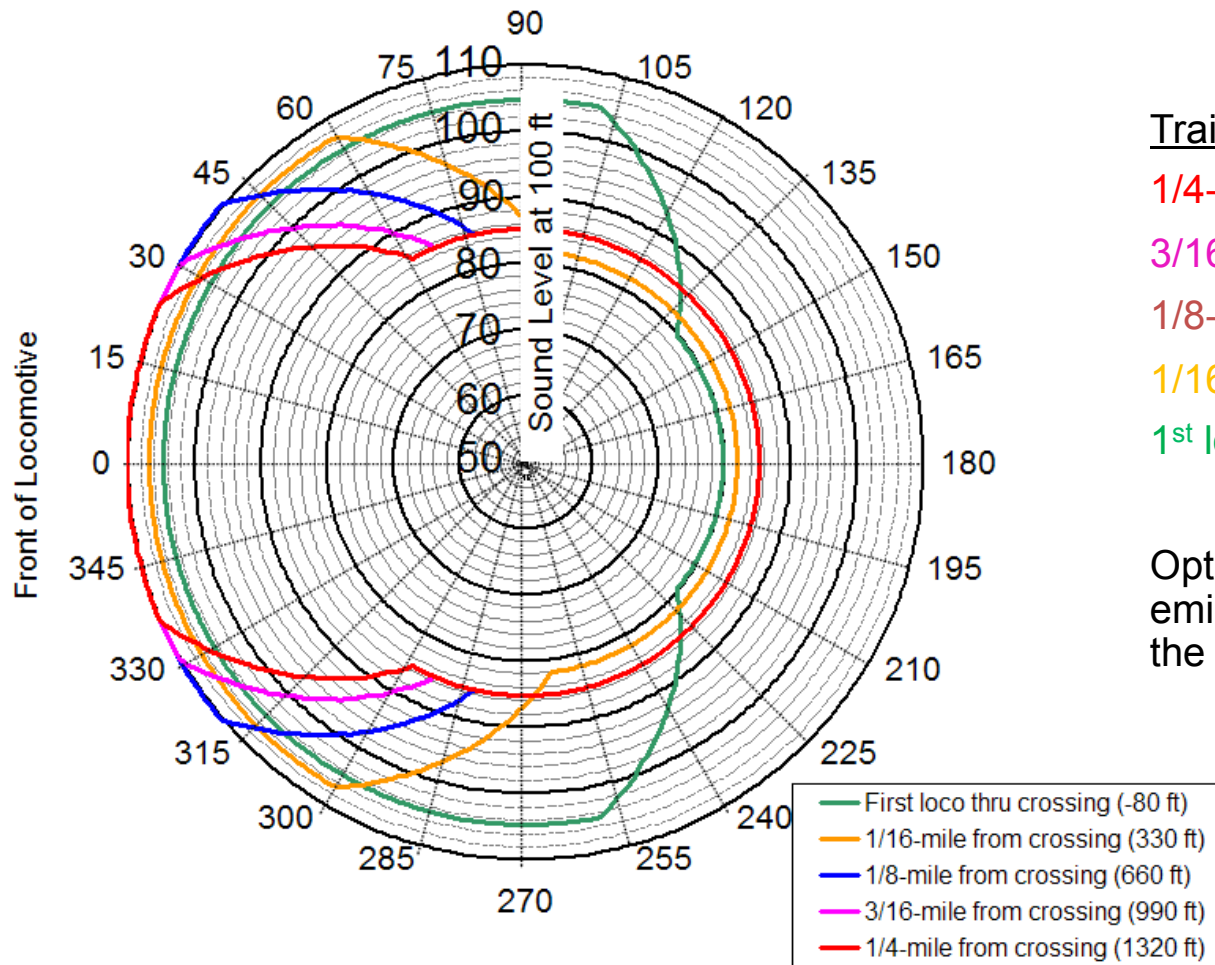
Curved Track and Skewed Road Conditions

The ideal AWD will need to steer its beam and/or widen its beam for curved track and skewed road conditions



Optimized Acoustical Warning Device (AWD)

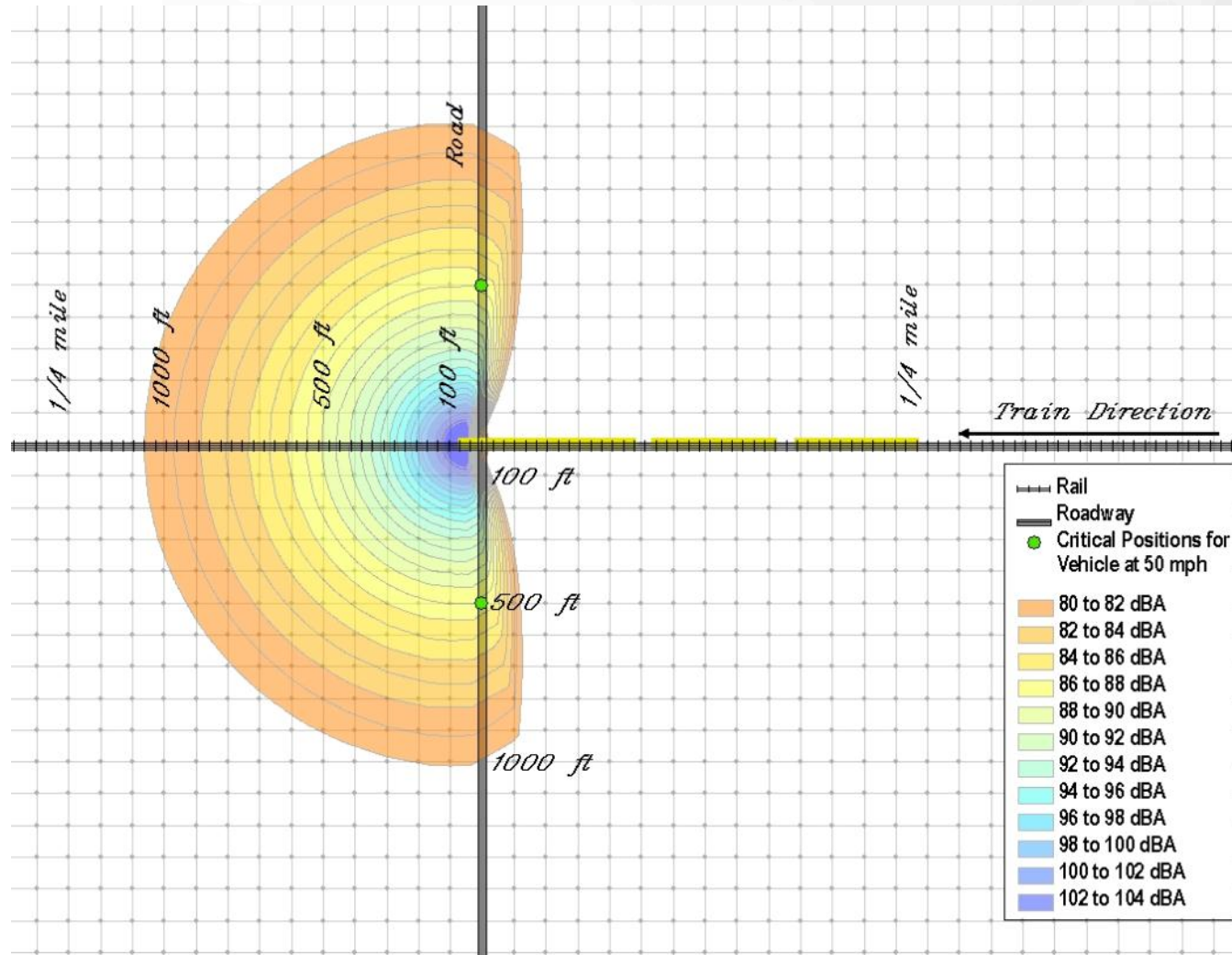
Directivity pattern continuously varies as function of train position



<u>Train Position</u>	<u>Critical Horn Angle</u>
1/4-mile	42 deg (0 deg +/- 21)
3/16-mile	60 deg (0 deg +/- 30)
1/8-mile	84 deg (0 deg +/- 42)
1/16-mile	120 deg (0 deg +/- 60)
1 st loco thru	198 deg (0 deg +/- 99)

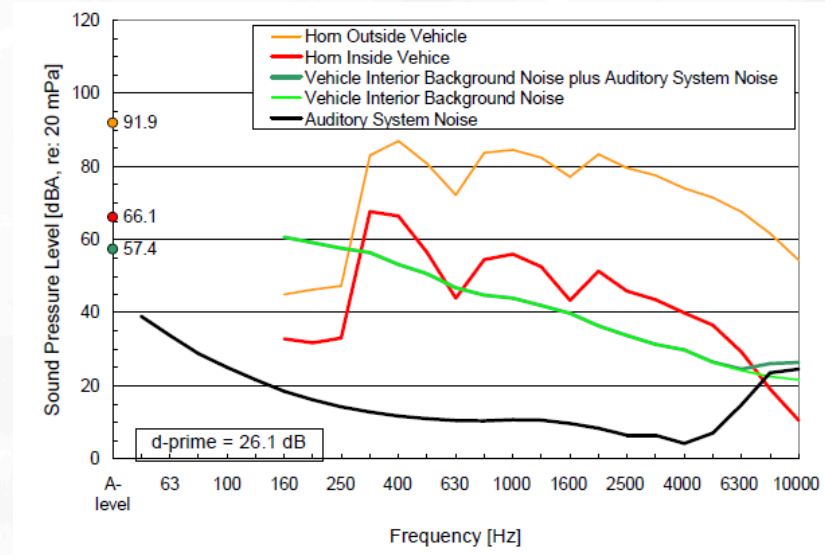
Optimized device will minimize sound emissions as much as possible beyond the critical horn angle

Optimized Acoustical Warning Device (AWD)



Detectability / Safety

- The detectability of a trains' horn for approaching motorists depends on several factors such as:
 - How loud the horn is
 - Frequencies generated by the horn
 - The directivity pattern of the horn
 - How much a car reduces sound with windows closed
 - What the background noise is inside the car
 - Human threshold of hearing
- 3 different levels of detectability:
 - **Audible** – can be detected by person who is attentively listening
 - **Noticeable** – can be detected by person not actively listening
 - **95% Likelihood of Noticeability** – greatest chance of being detected

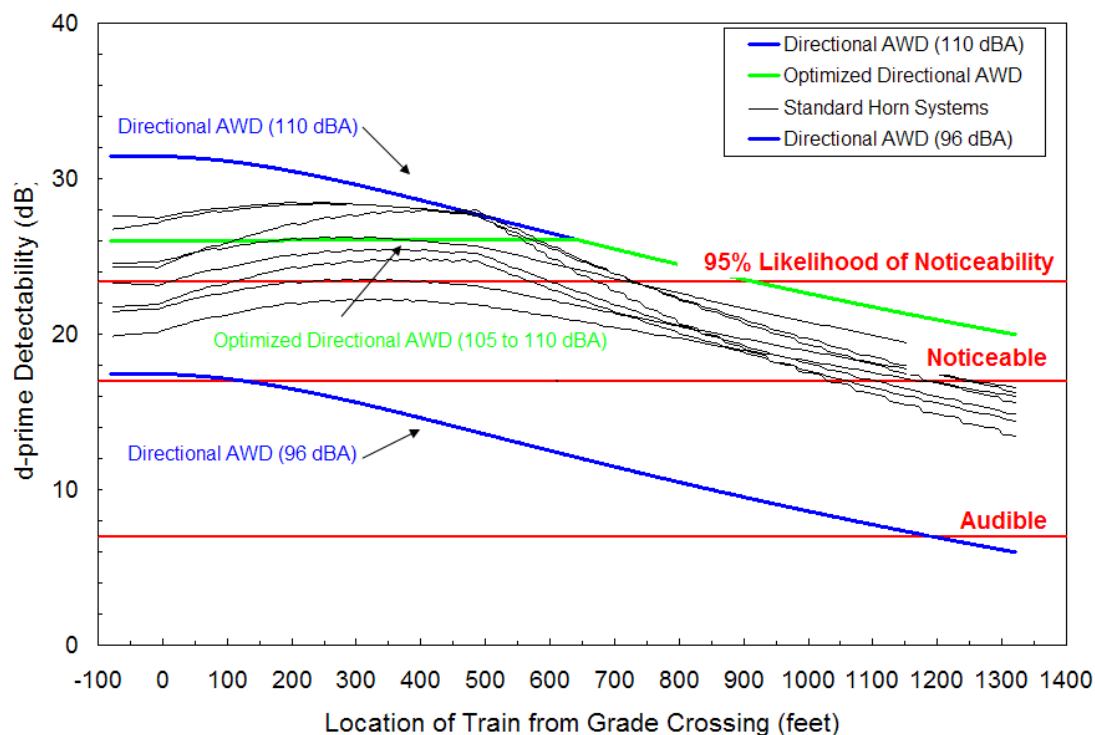


Horns / AWDs Analyzed

- 8 typical “**standard horn**” systems (measured by Volpe Acoustics)
- A “**modified horn**” which is representative of a standard center-mounted horn with a static directivity pattern sufficient to direct sound to the widest critical angle (0 degrees +/- 99 degrees) and minimized at wider angles
- A variably-directive AWD designed for “**maximum safety**” with constant amplitude of 110 dBA at 100 feet.
- A variably-directive AWD “**optimized**” for both safety and noise. The amplitude is 110 dBA from the beginning of the sounding event until the train is ~1/8-mile from the crossing to maximize detectability. Between 1/8-mile and the crossing, the amplitude gradually decreases from 110 to 105 dBA.
- A variably-directive AWD designed for “**maximum noise reduction**” with constant amplitude of 96 dBA at 100 feet.

Detectability

- Detectability is computed for all locations of the train within ¼-mile
- Optimized AWD would be detectable for longer distances (duration) than most standard horns



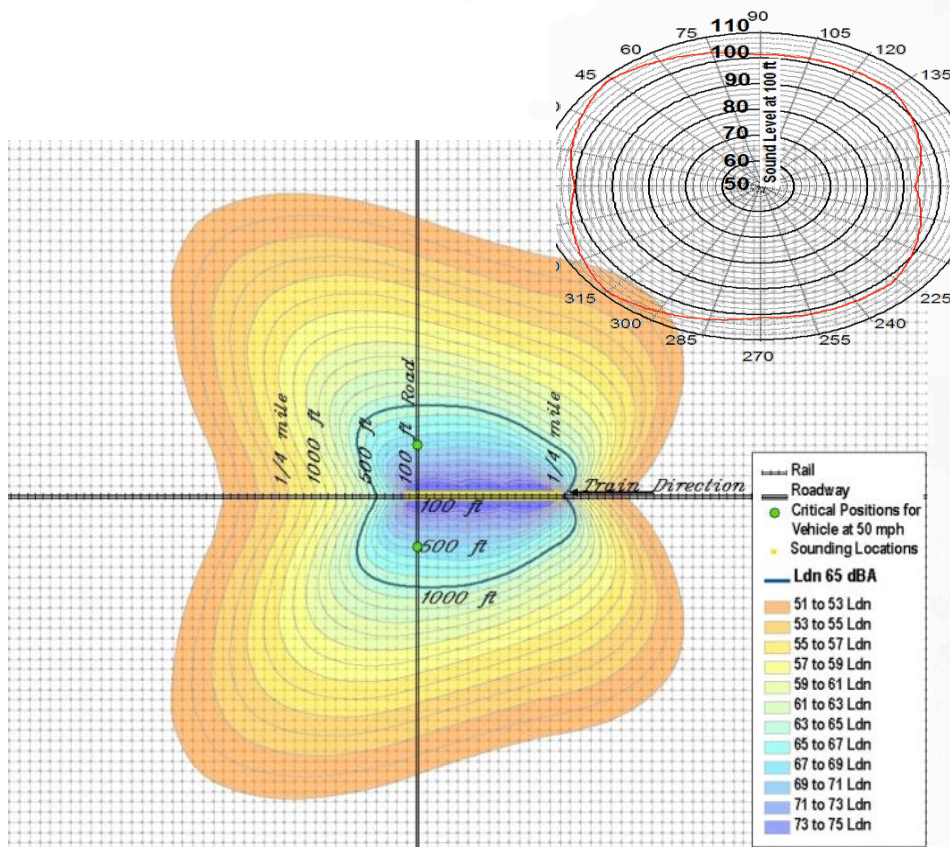
Audible Warning Device	Total Distance Meeting Detectability for Motorists at 50 mph (feet)		
	Audible	Noticeable	95% Likelihood of Noticeability
Average of Standard Horns	1400	1263	533
Modified Horn	1400	1260	810
Directional AWD Designed for Maximum Safety (110 dBA)	1400	1400	1028
Directional AWD Optimized for Safety and Noise (105 to 110 dBA)	1400	1400	1028
Directional AWD Designed for Maximum Noise Reduction (96 dBA)	1275	210	0

Environmental Noise Benefit

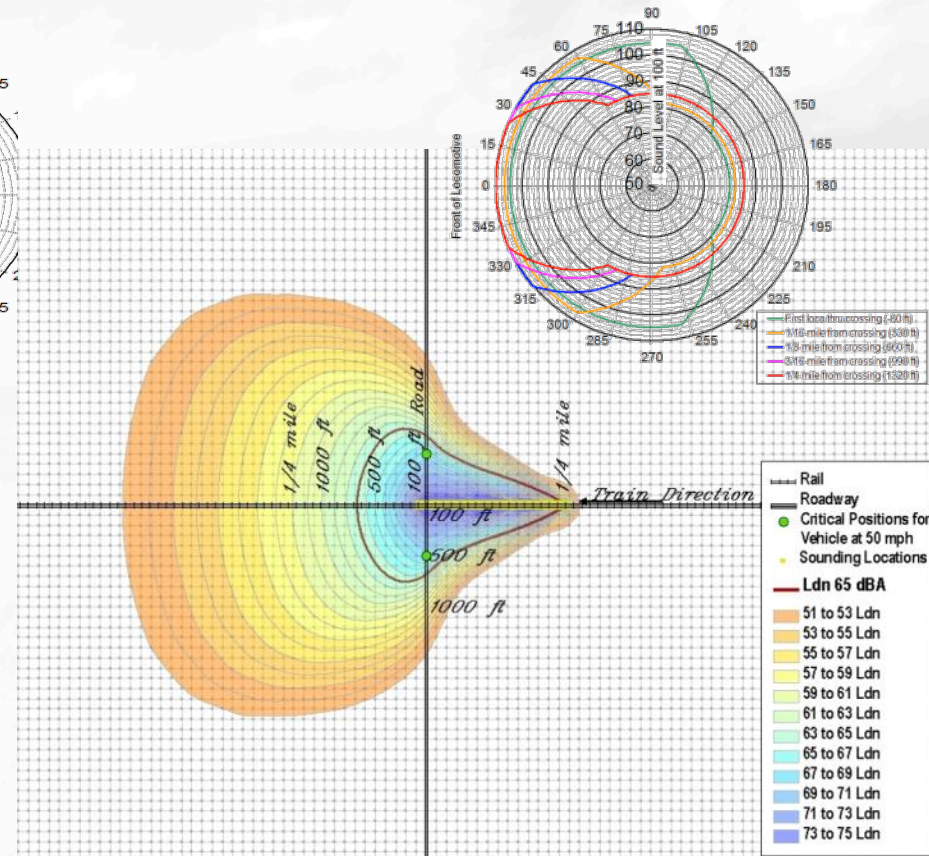
- Noise impact has been defined as the area with a day-night sound level, **Ldn of 65 dBA**
 - Ldn is a 24-hour cumulative noise metric that takes into account
 - How loud the horns are
 - How long the horns are sounded
 - The number of times they are sounded per day and night
- Modeling assumptions
 - Assumed one train pass every hour (~ national average)
 - Train activity in only one direction and activity in two directions
 - Trains traveling at 60 mph

Environmental Noise Benefit

Noise impact from pass-bys in *one* direction



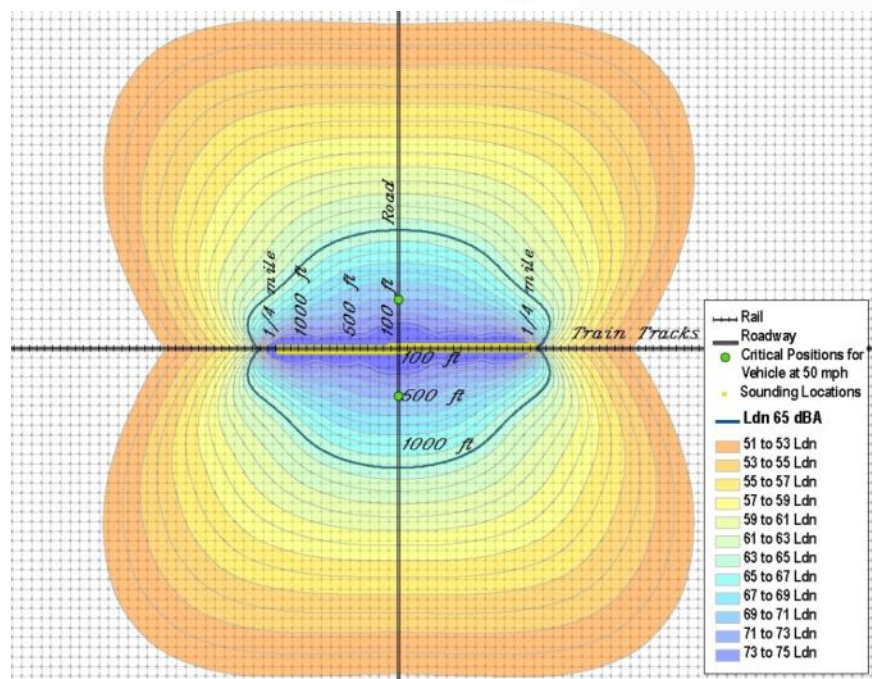
Standard Horn



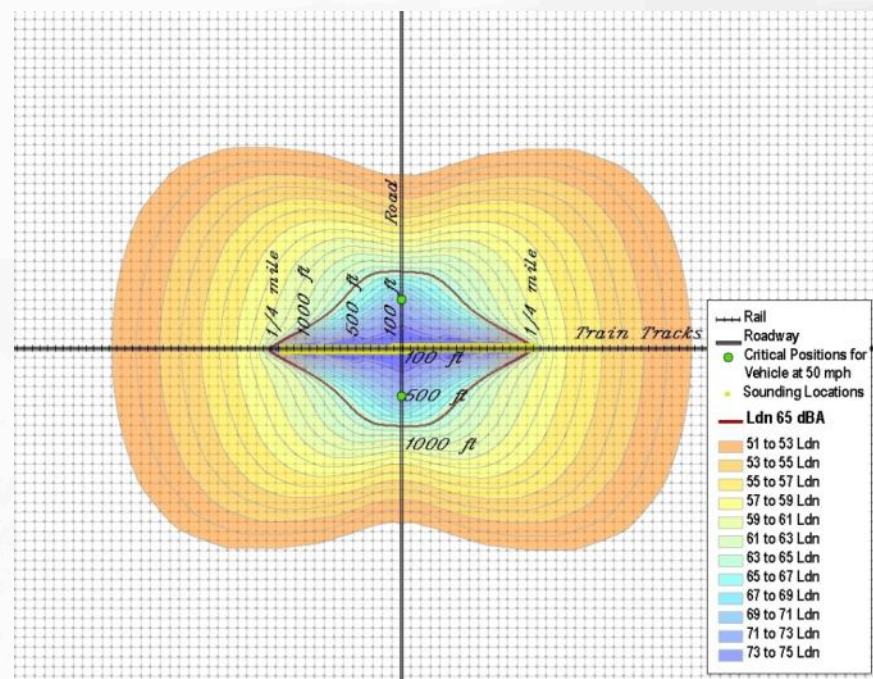
Optimized AWD

Environmental Noise Benefit

Noise impact from pass-bys in *both* direction



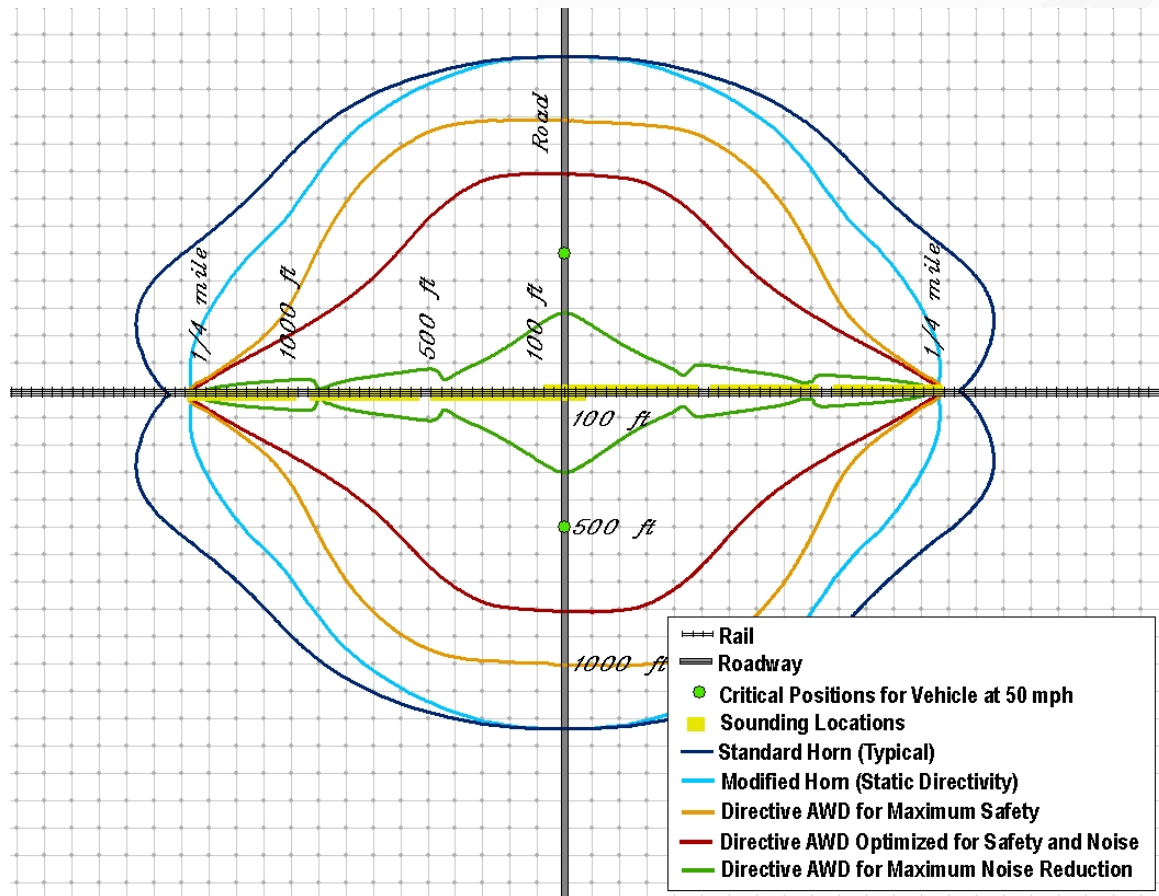
Standard Horn



Optimized AWD

Environmental Noise Benefit

Impact area would be reduced 57% with optimized horn!



Audible Warning Device	Reduction in Noise Impact Area (relative to standard horn)
Standard Horn (Avg)	--
Horn with Static Directivity	15%
Directional AWD for Maximum Safety (110 dBA)	38%
Directional AWD Optimized for Safety and Noise (105 to 110 dBA)	57%
Directional AWD for Maximum Noise Reduction (96 dBA)	91%

Modified horn with static directivity only reduces impact by 15%

AWD must have variable directivity to significantly reduce impact

Occupational Noise Exposure Benefit

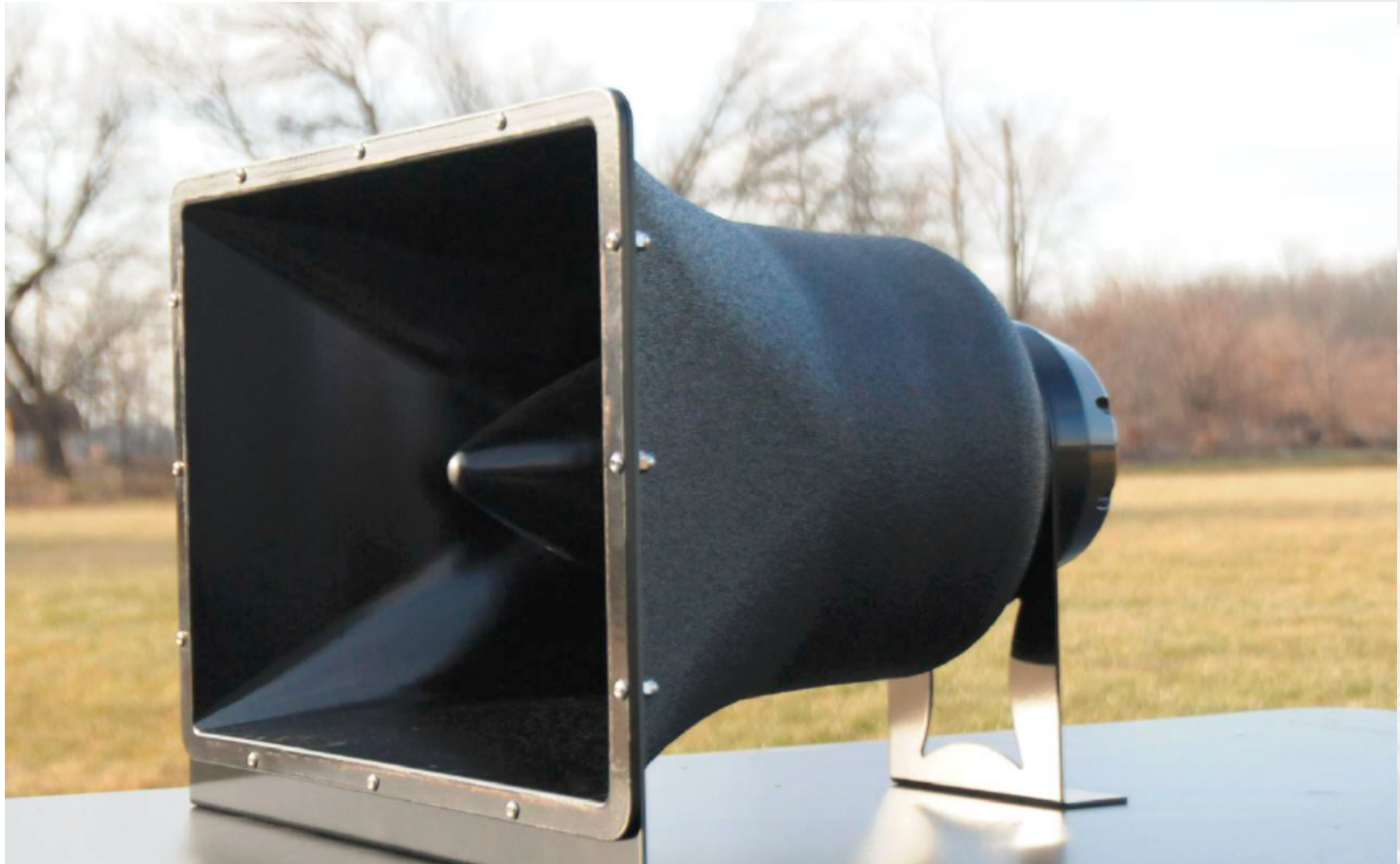
In-cab noise levels depend on AWD mounting location:

- **Mounted forward of the cab roof**
 - In-cab noise levels could be reduced significantly due to the significant rear radiation of the optimized AWD
- *In-cab noise levels may be quieter with optimized AWD than moving a standard horn from the cab roof to the center of the locomotive (10 dB reduction)*
- **Mounted on top of cab roof**
 - Optimized AWD would provide a few decibels of reduction or more when cab windows are open
- **Mounted in the center of the locomotive**
 - Optimized AWD would not reduce in-cab noise since amplitude forward of the locomotive is not reduced

Acoustical Warning Device (AWD) Prototype

- Based on ideal acoustical specification, we have worked together with UE/USSI, a manufacturer of acoustic devices, to develop an initial prototype
- The prototype is based on technology commonly used in military applications to focus verbal commands or warning signals at high amplitudes over long distances
- It is robust and can withstand the railroad environment
- Preliminary tests have shown that the initial prototype can meet the narrowest directivity pattern goal
- An advanced prototype with 2-4 acoustic elements can improve low frequency directivity, increase amplitude and provide beam steering capabilities
- As an electronic noise source, it can generate secondary emergency signals or voice

Acoustical Warning Device (AWD) Prototype



Optimized AWD

QinetiQ
North America



HARRIS MILLER MILLER & HANSON INC.

Acoustical Warning Device

Break | Nearby Food Options

(all within 5-7 minutes walking distance)



- Au Bon Pain: 601 Indiana Ave NW # 1 Washington, DC 20004
- Burger King: 501 G Street NW, Washington, DC 20001
- Chipotle: 601 F Street NW, Washington, DC 20005
- Cosi: 601 Pennsylvania Ave NW # 2 Washington, DC 20004
- Dunkin Donuts: 601 F Street NW, Washington, DC 20004
- Firehook Bakery & Coffee House: 441 4th Street NW, Washington, DC 20001
- Jack's Famous Deli: 501 3rd St NW # 2, Washington, DC 20001
- Quiznos Sandwiches: 772 5th St NW, Washington, DC 20001
- Starbucks: 443 7th St. NW, Washington, DC 20004
- Subway: 501 D Street NW, Washington, DC 20001