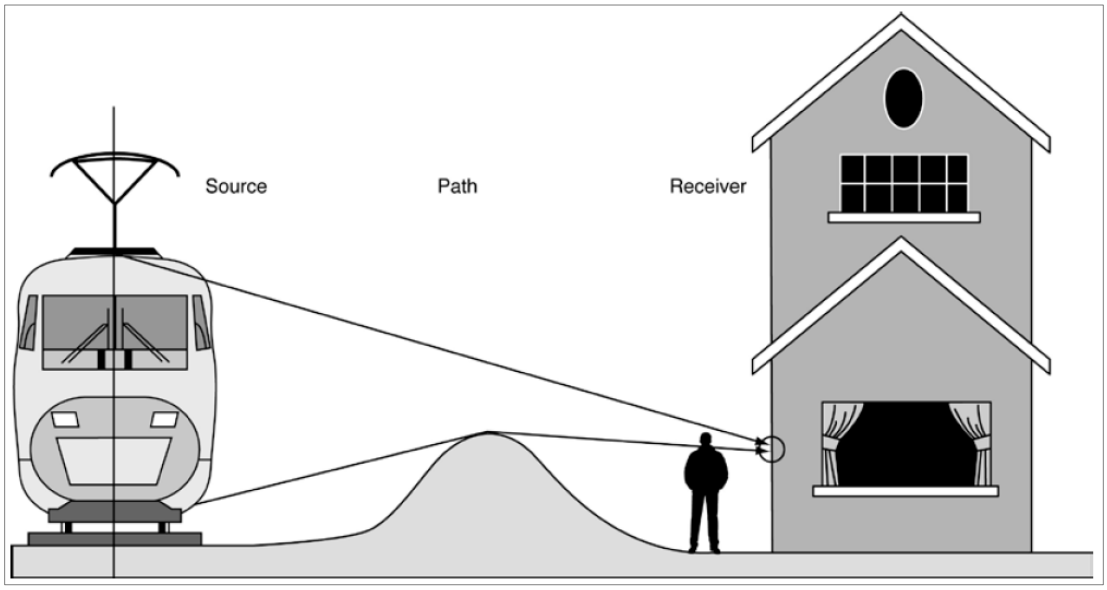
APPENDIX A: FUNDAMENTAL CONCEPTS OF NOISE AND VIBRATION FOR HIGH-SPEED TRAINS

A1 Basics of Noise for High-Speed Trains

Noise from high-speed trains can be evaluated in terms of a Source-Path-Receiver framework, as illustrated on Figure A-1, in which the source of noise is a train moving on its tracks. The path describes the intervening course between the source and the receiver, wherein the noise levels are reduced by distance, topographical and built obstacles, reflections from surfaces, atmospheric effects, and other factors. At each receiver, the noise from all sources and source paths combines and composes the noise environment at that location.



Source: FRA 2012

Figure A-1 Source-Path-Receiver Framework

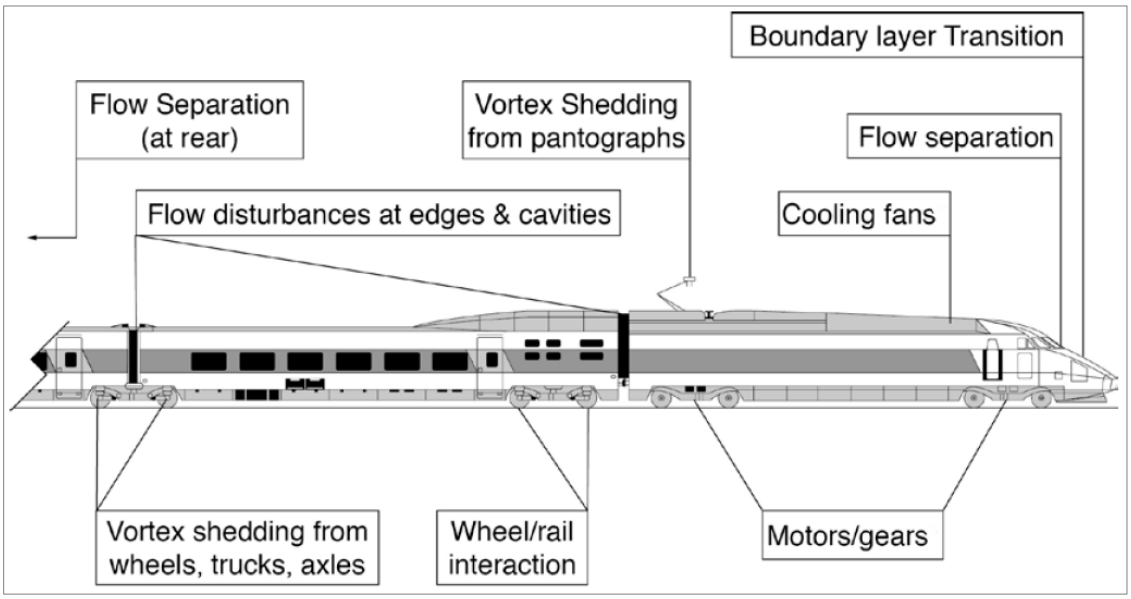
The noise from a train moving on its tracks is produced by several individual noise-generating mechanisms, each with its own characteristics (in terms of location, intensity, frequency content, directivity, and speed dependence) that depend on the train type. The most common train types include freight, commuter rail, light rail, and high-speed rail. Conventional train noise sources include locomotives, wheel/rail interaction, and audible warning devices at grade crossings, including train horns and warning bells.

For high-speed rail, train noise characteristics are speed dependent. For speeds below about 40 miles per hour (mph) (64 kilometers per hour [kph]), referred to as Regime I by Federal Railroad Administration guidance, noise emissions are dominated by the propulsion units, cooling fans, and under-car and top-of-car auxiliary equipment, such as compressors and air conditioning units.

In the speed range from 60 mph to about 150 mph (98 kph to 241 kph), referred to as Regime II, mechanical noise, resulting from wheel/rail interaction and structural vibrations, dominates the noise emission from trains. In the resource study area, existing trains seldom exceed 79 mph (127 kph); therefore, this speed range is the top end of noise characteristics for trains with which most people are familiar.

The aerodynamic noise component begins to be an important factor when the train speed exceeds about 160 mph (referred to as Regime III). Aerodynamic noise is generated from high-velocity airflow over the train. For a conventional steel-wheeled train, the components of

aerodynamic noise are generated by unsteady flow separations at the front and rear of the train and on structural elements of the train (mainly in the regions encompassing the trucks, the pantograph, inter-coach gaps, and discontinuities along the surface), and a turbulent boundary layer generated over the entire surface of the train. The distribution of noise sources on a typical high-speed train is depicted on Figure A-2.



Source: FRA 2012

Figure A-2 High-Speed Train Noise Sources

Noise from trains also depends on the type and configuration of the track structure. Typical noise levels refer to conventional rail operations at grade on ballast and tie track. For trains on elevated structures, train noise is increased, partially because of the loss of sound absorption by the ground and partially because of extra sound radiation from the bridge structure. Moreover, the sound from trains on elevated structures spreads about twice as far as it does from at-grade operations of the same train, because the sound source is higher above the ground and, therefore, is less affected by ground attenuation and shielding.

Horns are an example of a train noise source that is dominant at any train speed. Audible warning devices at grade crossings, including train horns and warning bells, are a common feature of conventional trains and a vital safety component of railroad operations. People living near railroad tracks often find horns to be annoying.

Another source of potential annoyance is wheel squeal that is produced by wheel-rail interaction, particularly on a curve where the radius of curvature is smaller than 100 times the truck length. According to the predecessor to the Federal Transit Administration, a typical truck length for freight trains of about 5.5 feet (1.7 meters) and radius of curvature greater than 560 feet (170 meters) would not be expected to produce wheel squeal. Wheel squeal is normally an issue with transit systems where small-radius curves often occur. Freight trains and modern high-speed train tracks are typically designed to minimize this occurrence by limiting track curvature and incorporating design features such as canting at the curve to reduce wheel flange contact with the rail.

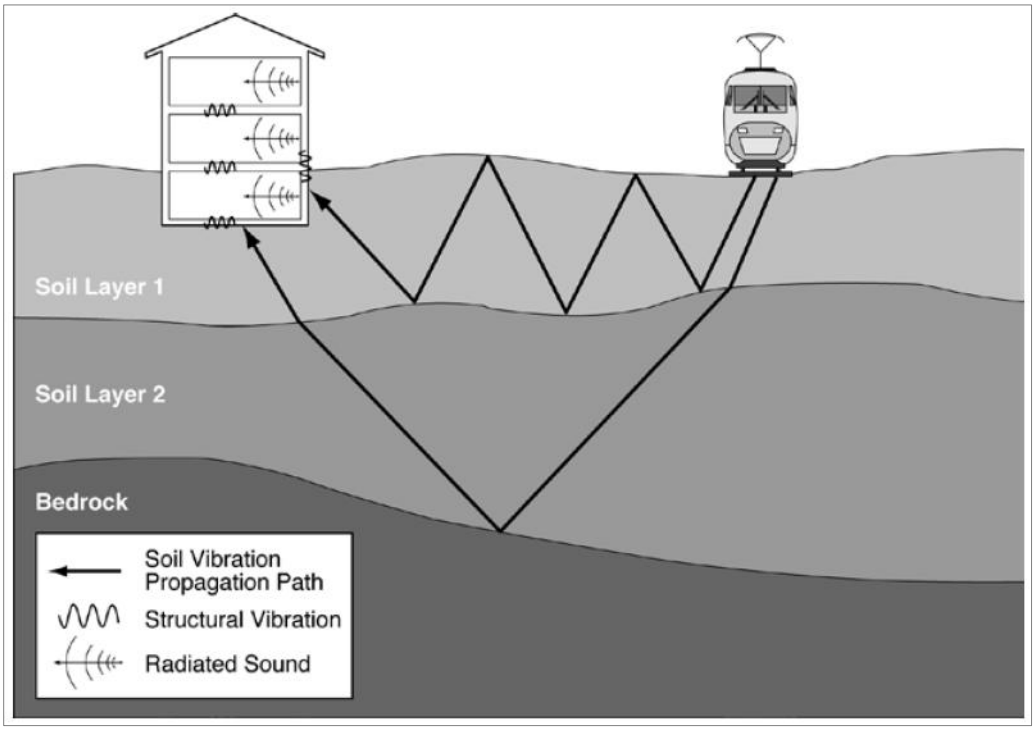
A2 Basics of Vibration for High-Speed Trains

The interaction of steel wheels rolling on steel rails causes vibration that is transmitted through the ground and into nearby buildings. Of concern to many building occupants is that the resulting building vibration could damage the building structure. In fact, the vibration from steel wheel/steel

rail systems is almost always well below the vibration thresholds used to protect even fragile historic buildings from minor cosmetic damage. However, there are several different ways in which the building vibration may be intrusive and annoying to building occupants. First, the vibratory motion of room surfaces may be felt. Second, the vibration may cause rattling of dishes and bric-a-brac on shelves, items hanging on walls, or windows. Third, the surfaces put into motion by ground-borne vibration will radiate sound that may be audible as a low-frequency rumbling noise that sometimes is akin to distant thunder.

The amount of energy generated by the wheels rolling on the track and then transmitted into the ground depends on factors such as the smoothness of the wheels and rails, the vehicle suspension system, and the track support system. The same speed-dependent vibration generation mechanisms are common to conventional and high-speed trains. Vibration levels increase with speed although the rate of the increase varies. A common assumption for high-speed trains is that the vibration levels are proportional to 20 times the logarithm of speed. For example, when train speed increases from 75 mph (120 kph) to 125 mph (200 kph), the expected increase in ground-borne vibration is 4.4 vibration decibels if all other conditions are the same.

As with noise, a Source-Path-Receiver relationship exists for vibration. Vibration experienced at the receiver is a function of the magnitude of the source and the path that the vibration takes to get to the receiver, as depicted on Figure A-3. High-frequency vibration decays more rapidly than low-frequency vibration as the vibrational energy passes through the ground. Soil conditions have a strong influence on the attenuation of ground-borne vibration. For the purposes of high-speed rail assessments, vibration is reported in terms of vibration velocity level or vibration decibels, which is the maximum root mean square vibration velocity level using a decibel reference of 1 micro-inch per second (1×10−6 inch per second).



Source: FRA 2012

Figure A-3 Typical Vibration Propagation Paths

References

Federal Railroad Administration (FRA). 2012. *High-Speed Ground Transportation Noise and Vibration Impact Assessment*. Final Report DOT/FRA/ORD-12/15. September. www.fra.dot.gov/eLib/Details/L04090 (accessed August 2016).