Sound emissions from a plug-in electric vehicle

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Some plug-in hybrid electric vehicles operate in all electric mode for their entire speed range, and only switch to gasoline after the batteries have drained. These vehicles, along with electric vehicles, can make a significant improvement in an urban soundscape, where vehicle speeds are limited. This paper presents exterior sound measurements of a plug-in hybrid vehicle from idle to 70 mph, along with estimated Reference Energy Mean Emission Level (REMEL) coefficients. Measurements are made in both all electric and all gasoline operations. We then model a city street using the FHWA Traffic Noise Model assuming all automobiles have similar sound emissions and compare this to a street with an existing mix of gasoline powered automobiles. Implications for changes to the urban soundscape are discussed.

1 INTRODUCTION

Modern hybrid electric vehicles have been mass produced since the late 1990's, starting with the introduction of the hybrid Toyota Prius and Honda Insight. Many of these hybrid vehicles operate in electric only mode when fully stopped and at slow speeds. More recently, all electric vehicles have been introduced which operate on electricity at all vehicle speeds, such as the Nissan Leaf. In 2010, Chevrolet introduced the Volt which operates on all electric for a rated 35 miles, then switches to a gasoline generator. Other gasoline vehicles have been introduced which are "start-stop". These vehicles automatically shut their engines off when idling.

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At idle and in all-electric mode, at least a low speeds, these vehicles are quieter than their gasoline or diesel counterparts. Some concern has been expressed by the visually impaired that these vehicles may be too quiet. However, another counterpoint, perhaps, is that the vast majority of internal combustion engine powered motor vehicles are too loud, and thus mask the sound that these vehicles make.

In the U.S., the standard method to evaluate traffic noise is the Federal Highway Administration's (FHWA's) Traffic Noise Model "TNM". At the heart of the model is a set of "Reference Energy Mean Emissions Levels (REMEL) or standardized sound emissions for automobiles, trucks, buses, and motorcycles by 1/3 octave band, vehicle speed, and throttle mode (cruise and full throttle). These REMEL curves are then used to estimate the sound power of the vehicle fleet on any road, which in turn is used in sound propagation modeling.

Because the FHWA presents a standardized approach to estimating vehicle emissions that can be used in the TNM, we set out to estimate the REMEL coefficients for an electric vehicle. In this case, we used the Chevrolet Volt in all-electric mode, and tested vehicle sound emissions. Then, to estimate the potential impact vehicles like these could have on noise levels in cities, we made a first-order estimate of fleet sound power using a typical vehicle mix found on a New York City arterial, assuming all automobiles are either equivalent to the standard REMEL automobile, or all are equivalent to the measured Chevrolet Volt electric vehicle.

2 METHODOLOGY

2.1 Vehicle testing

Two test locations were identified. The first was on US Route 5, in Bradford Vermont. US 5 is a two-lane road posted at 50 mph. It has a paved width of 28 feet (two 12 foot lanes with 2 foot shoulders). Two microphones were set up. They were set up at 25 feet and 50 feet from the center of the road. FHWA recommends a microphone at 50 feet and 100 feet, but because the sound emissions were so low, the 25 foot location was needed. The ground between the microphones and road was flat and covered with low-cut grass.

The second location was on Main Street in Union Village, a small rural village in Norwich, Vermont. The road has a 22 foot paved width and is posted at 30 mph. Again, microphones were set up at 25 feet and 50 feet from the roadway centerline, and the ground between microphone and road was flat and covered with low-cut grass.

Both microphone locations were set up with Larson Davis LD 831 sound level meters which are ANSI/IEC Type 1. The sound level meters logged 1-second equivalent average 1/3 octave bands for each passby.

A 2012 Chevrolet Volt was used for testing. The vehicle had about 8,000 miles on its odometer, but the tires were new Goodyear Assurance tires, the same that came factory installed on the vehicle.

Three runs were conducted to check vehicle speed. Calibrated police radar was set at a fixed position next to the road, and the vehicle was run at 20, 40, and 60 mph. In each run, the actual vehicle speed was within 1 mph of that shown on the vehicle digital dashboard.

The vehicle was then tested at 5 mph to 70 mph in 5 mph increments in both cruise and full-throttle modes. The maximum passby level was determined for each event. In some cases, especially at low-speeds, several runs were done because of excessive background noise. In all, at least two passbys of each speed and mode were conducted.

2.2 Sound Modeling

The sum of traffic sound on a roadway is a function of vehicle classification, vehicle volume, vehicle speed, the number of vehicles under different modes (acceleration, idle, full throttle), and environmental factors. In this case, we are taking a somewhat simplified approach to the modeling of traffic noise, by simply estimating the overall vehicle sound power under specified conditions on a New York City street.

We chose for this analysis a traffic count location at Park Avenue between 55^{th} and 56^{th} Streets. The data at this location showed hourly vehicle classification and count for a weekday in June 2010. The results varied by time of day, but generally ranged from 94 percent automobiles during the AM peak hour to 99% automobiles during the late night. The remainder were medium trucks (0 to 3%), heavy trucks (0 to 2%), buses (0 to 1%), and motorcycles (<0.5%).

We used this count to create weighted average vehicle sound emissions by time of day, given traffic mix and volume, based on the FHWA REMEL cruise coefficients for each category at 9 mph. The 9 mph is based on the average taxi speed in the central business district for 2010.

3 RESULTS

3.1 Measurement Results

Figure 1 shows the measured data and calculated REMEL curve for the Chevrolet Volt under cruise conditions compared to the FHWA REMEL curve for "automobiles." The Volt's curve shows lower sound emissions than the standard curve for speeds up to 15 mph. Between 15 and 40 mph the curves are very similar and above 40 mph the curves begin to diverge again with the standard curve louder than the electric vehicle curve.

Figure 2 shows the same two REMEL curves, but under full throttle. This shows a similar relationship with the Volt remaining quieter below 25 mph and the two vehicles remaining similar in sound level between 25 and 60 mph.

The data was further analyzed for spectral differences between the standard FHWA REMEL automobile and the Volt. Figures 3 through 5 compare 1/3 octave bands at three cruise speeds. Aside from the obvious overall lower sound levels at 5 mph, the electric engine exhibits much lower low frequency sound than the gasoline engine at all speeds. The same trend is shown under full throttle in Figures 6 through 8. Again, electric vehicles exhibit much lower low frequency sound, especially below 500 Hz.

3.1 Modeling Results

The weighted average vehicle sound emissions were calculated based on two scenarios. In the first scenario, we assumed a normal vehicle mix. In the second scenario, we assumed all automobiles were replaced with electric vehicles similar to that measured here.

A comparison of the weighted average vehicle sound emission (in sound pressure level at 50 feet) is shown in Figure 9. As shown, the replacement of automobiles with all-electric vehicles would have little impact during the morning peak hour, despite the fact that 94% of the vehicles would be replaced. This is due to the remaining 6% of trucks and buses which dominate the soundscape. However, at night, when the traffic volume is low and truck/bus percentages are low, the weighted average vehicle sound level decreases by about 2.5 dB.

4 DISCUSSION

The sound levels measured here clearly show the potential for lowered overall roadway traffic noise levels. The level of impact will be a function of the following, roughly in order of importance:

- Proportion of non-electric heavy vehicles (trucks and buses)
- Average speed
- Proportion of time spent idling, accelerating, and at cruise

If there are a number of non-electric heavy vehicles, then these will dominate the overall traffic noise level, no matter what the proportion of electric vehicles in the mix. Therefore, for dense urban cores, traffic noise improvements will heavily depend on replacing diesel engines with electric or other low-noise technologies.

Since the biggest improvement with electric vehicles come at low speeds, the most impact is expected in neighborhoods which include traffic calming, heavy congestion, or other factors that reduce vehicle speeds. Some traffic calming devices can increase vehicles noise, due to increased start-stop. However, with electric vehicles, this impact is reduced due to the proportionally lower full-throttle noise levels.

Finally, it is important to note the spectral differences in electric vehicles at all speeds. Because there is no internal combustion engine, the electric vehicles showed noticeably lower lower-frequency sound emissions. While the overall sound levels about 20 mph may be similar between gas and electric, the lower low-frequency sound will result in greater sound attenuation due to atmospheric absorption, structural absorption, and building attenuation. Therefore, in places like national parks, where anthropogenic sound can travel a long distance, electric vehicles may have a larger impact. This effect could also be significant in large cities where sound levels are increased due to reverberation between tall buildings. Due to the large path distances of the reflected sound waves, relatively higher rates of atmospheric attenuation at high frequencies could also cause an overall decrease of sound levels.

5 CONCLUSIONS

Electric vehicle sound emissions were measured from a Cheverlet Volt, following standardized FHWA procedures. Measurements were made at cruise and full throttle from vehicle speeds ranging from 5 mph to 70 mph at 5 mph increments.

When compared to the FHWA reference automobile sound emissions, the Volt showed lower sound levels below 15 mph under cruise conditions and 25 mph under full throttle. Above these speeds, the Volt tire noise brought emissions on par with gasoline automobiles until speeds increased enough. However, at both low and high speeds, the Volt sound emissions were measurably lower below about 500 Hz, which would indicate the potential for improvements in traffic noise levels at large distances, where atmospheric attenuation impacts the higher frequencies, and inside buildings, whose structures attenuate the higher frequencies to a greater extent.

Modeling of the weighted average sound emissions, based on a traffic count on Park Avenue in New York City, show that the impact of electric vehicles is highly dependent on the proportion of trucks and buses. Even if all automobiles were replaced with electric vehicles, the weighted average vehicle sound level would only be reduced by about 1 dB during the day and 2.5 dB at night.

Concern has been expressed, especially by the visually impaired, that electric vehicles may be too quiet. However, if steps can be taken to improve the soundscape of cities by reducing traffic noise, the audibility of all vehicles will improve. It is clear that the next step in this process would be to focus efforts on heavy vehicle noise.

6 FIGURES

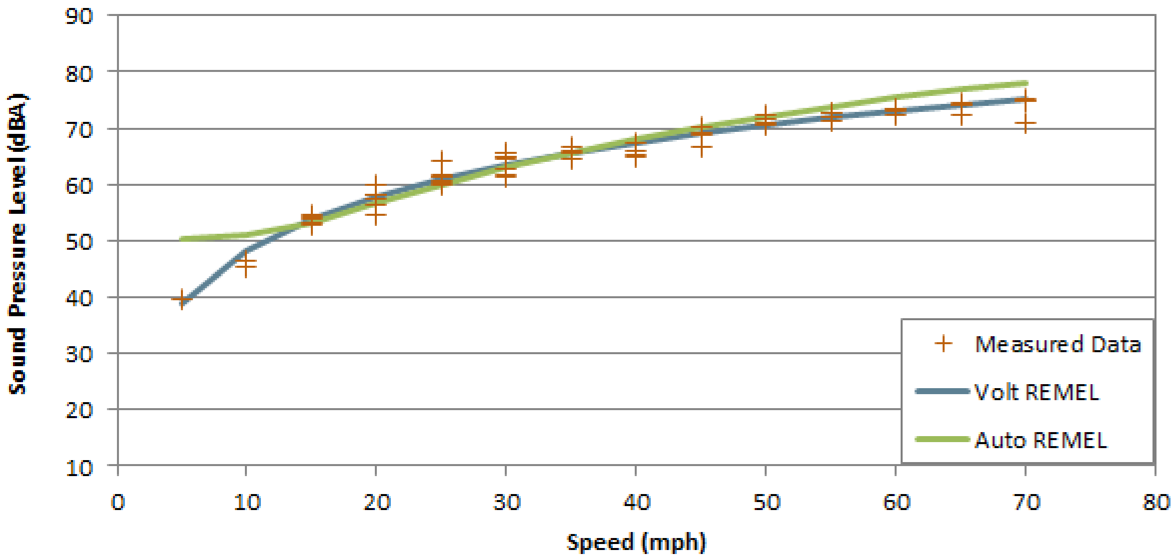

Fig. 1 - REMEL Curve Comparison at Steady Throttle

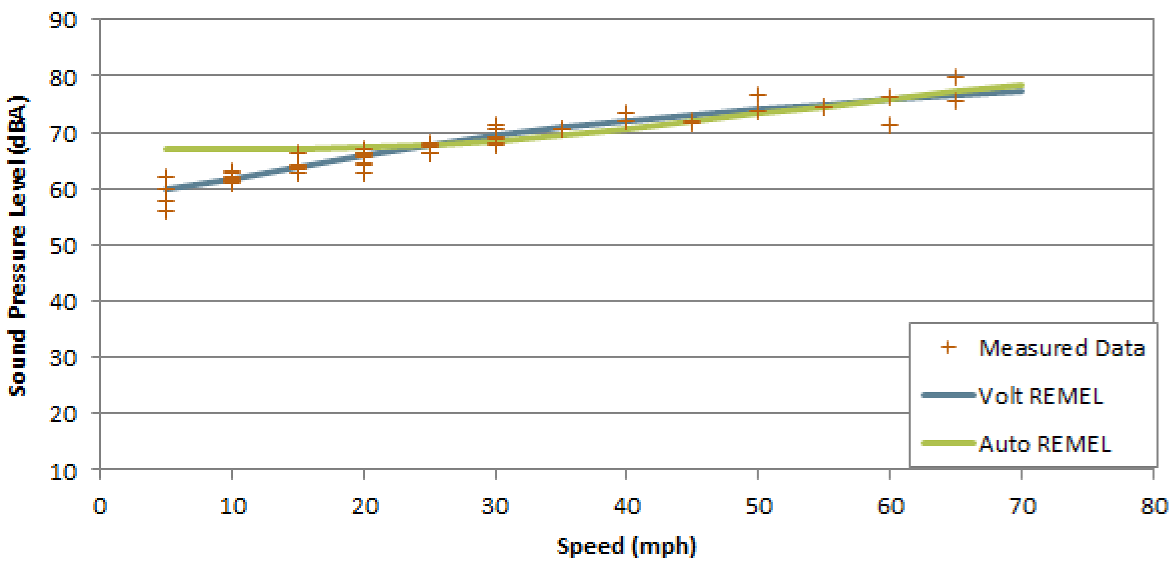

Fig. 2 - REMEL Curve Comparison at Full Acceleration

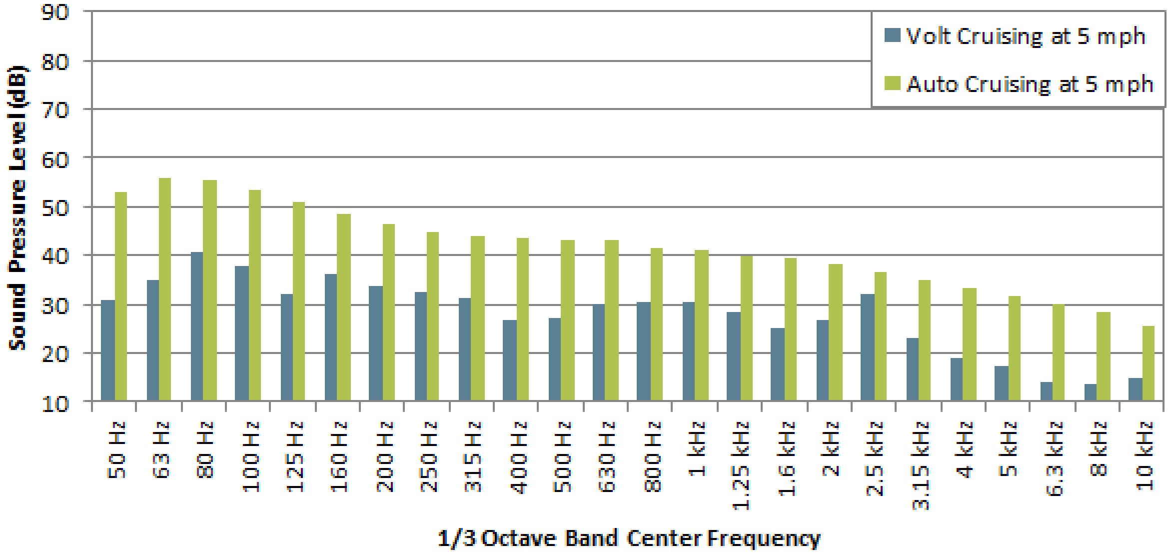

Fig. 3 - Spectrum Comparison at 5 mph Steady Throttle

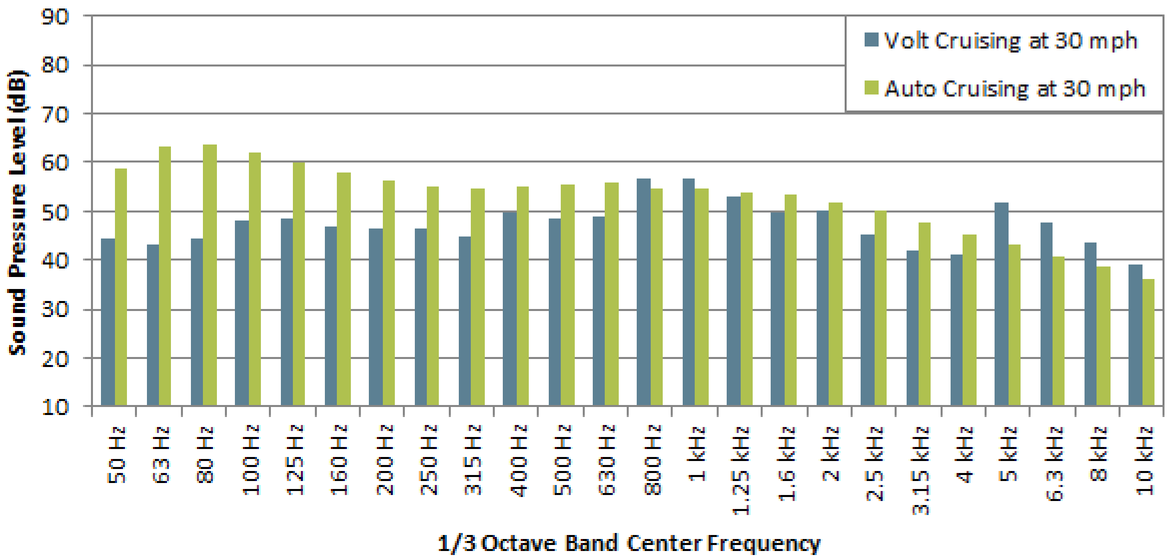

Fig. 4 - Spectrum Comparison at 30 mph Steady Throttle

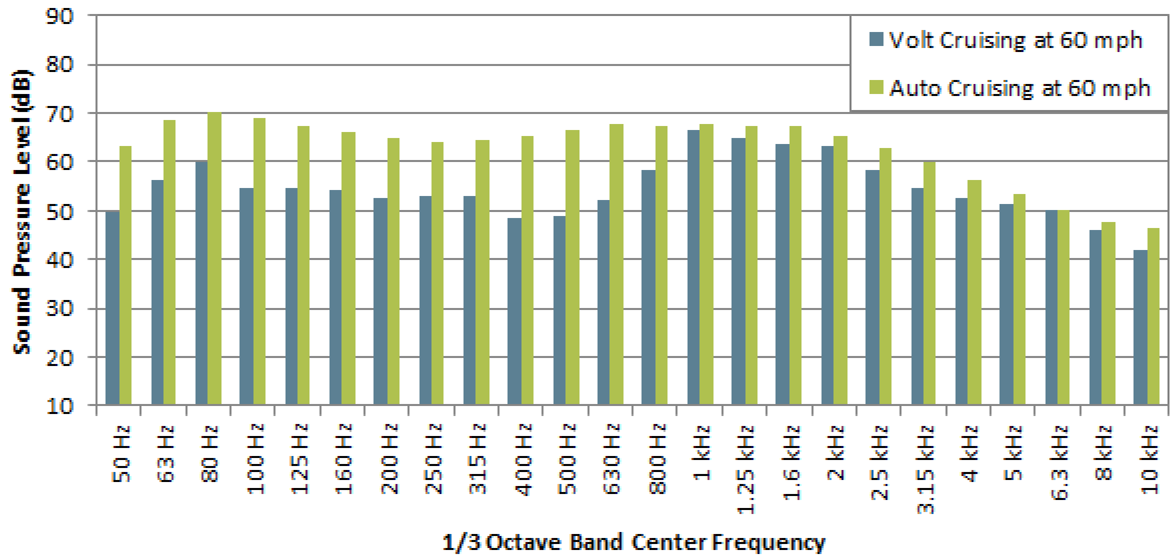

Fig. 5 - Spectrum Comparison at 60 mph - Steady Throttle

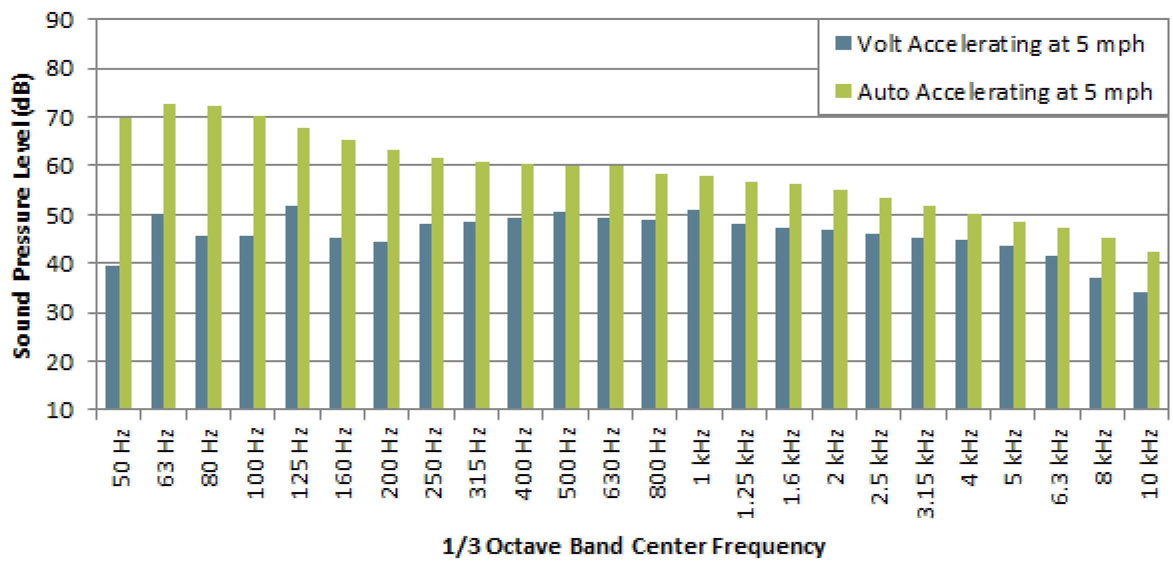

Fig. 6 - Spectrum Comparison at 5 mph - Full Throttle

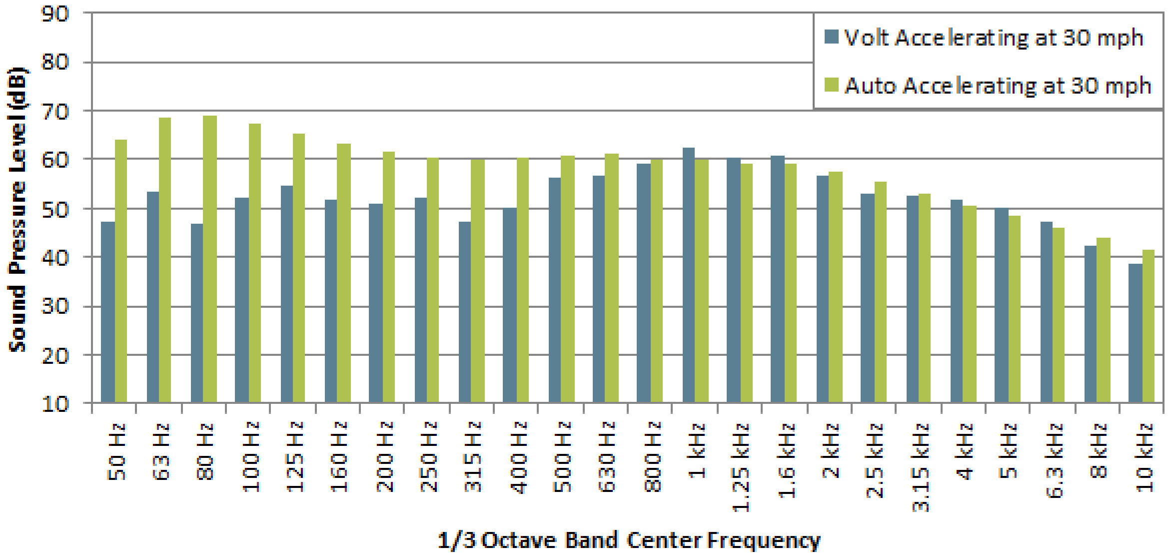

Fig. 7 - Spectrum Comparison at 30 mph - Full Throttle

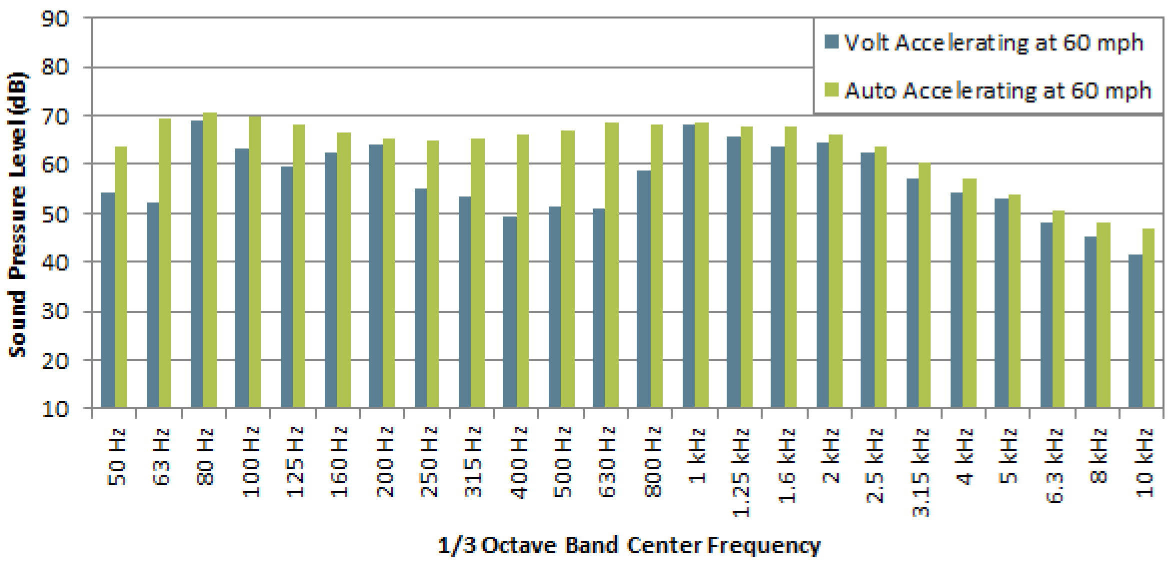

Fig. 8 - Spectrum Comparison at 60 mph - Full Throttle

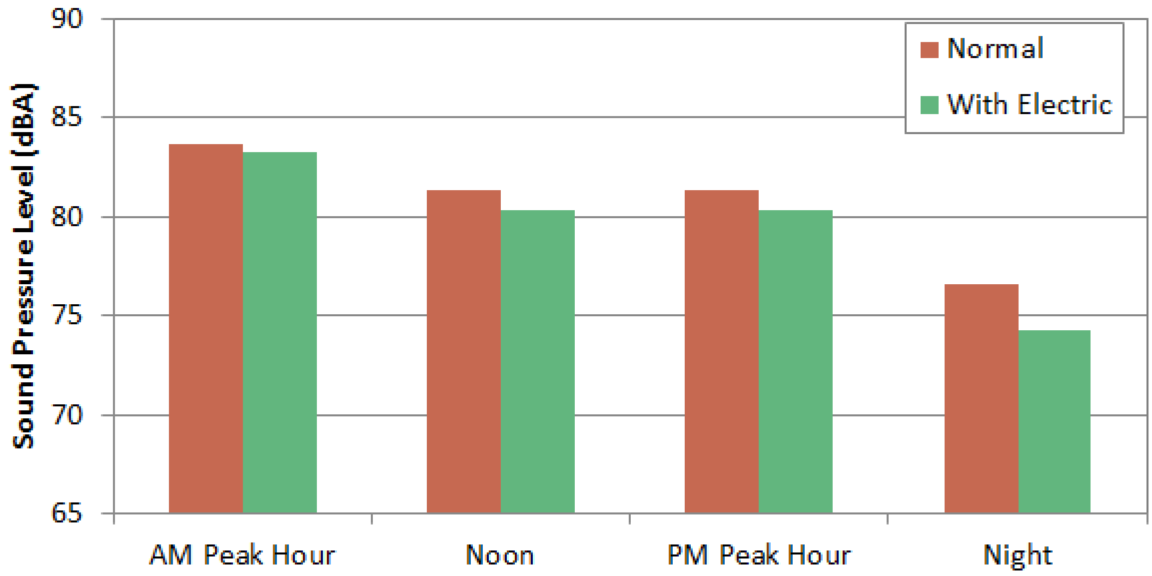

Fig. 9 – Traffic-Caused Sound Levels by Time of Day for Normal and Electric Vehicle Mixes

7 REFERENCES

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