

Leading the Charge – The Future of Electric Vehicle Noise Control

Greg Goetchius, Contributing Editor

In the next few years, more electric hybrids, range-extended hybrids and full electric vehicles will be coming to the consumer market. There are a growing number of noise control engineers who are working on the new set of challenges that these vehicles create. Can we imagine with a little bit of experience and a lot of speculation what these challenges might be?

Of course . . . speculation is free, as they say. So in the next few paragraphs, I will attempt to frame the problem and outline some of the major NVH challenges that electric vehicles (EVs) will present, and which will need to be solved if EVs are to be accepted by the buying public. I will limit my coverage to full electric vehicles, since I believe in the long term this is where the industry is headed. However, much of what I will outline applies also to hybrids, more specifically range-extended hybrids that will operate a significant amount of their lives in full electric mode.

In general terms, it is likely that EVs will make judicious use of lightweight materials to achieve the highest levels of efficiency and range. Most of us in noise control recognize that more often than not, mass is our friend. Newton's second law clearly applies here, and whether it's sound transmission mass-law, resonance behavior, or forced vibration response, these lighter weight structures will most certainly exhibit higher vibration levels (noise) for a given set of sources. The good news, though, is that EVs will have significantly lower forcing functions as a result of eliminating the internal combustion (IC) engine.

In fact, eliminating the IC engine from an EV completely changes the source side of the "source-path-receiver" equation often used in NVH engineering. Consider this: An EV requires no engine, no multispeed transmission, no transfer case, no fuel tank, no air intake or exhaust systems, no long driveshafts or center bearings. In their place, there is much more space to accommodate the electric motor(s) and battery pack, with lots of room left over for creative interior occupant packaging. More importantly, the sources of noise and vibration in EVs are:

- Reduced in Number
- Potentially located in different, often more beneficial areas of the vehicle compared with an IC engine car.
- Greatly simplified – which also reduces the complexity of the various noise paths and the probability of cross-coupling and system interaction.

These are all good things for the EV NVH engineer, and so it would seem that the task of engineering would be easy. Not so! There is still a tremendous challenge for EV noise control, but it's just a bit different from what we're used to. Most importantly, we'll need

to understand that the elimination of the IC engine will expose many of the noise behaviors of a vehicle that were previously acceptable but will now seem plainly audible and perhaps annoying. I'll call this the "draining of the swamp."

Certainly the newly exposed boulders and tree stumps in our drained swamp will require our focus, but consider this: if the water level in the swamp represents the overall noise level in the car, then what we are really saying here is that there are enormous opportunities with EVs to achieve much lower levels of interior noise than we ever thought possible. The task at hand will be to judiciously engineer solutions for these remaining boulders and tree stumps, which include:

- Electric motor noise
- Wind noise
- Tire/road noise
- Ancillary system noise
- Other noise and vibration phenomenon of which we may not even be aware

Electric Motor Noise. Let's start with the most obvious – the electric motor itself. It would be wrong to assume that electric motors are completely quiet. Quite the contrary is true, in fact. Depending on the design of the motor, the electromagnetic (EM) pulses and corresponding torque pulses from the motor can be very strong. These can be radiated as noise directly from the motor housing and can also be transmitted structurally to the support structure through the motor mounts.

The good news is that the EM forces are generally lower than the combustion and reciprocating mass forces of an IC engine, and significantly, they are at a much higher frequency. As a result, the rubber isolation systems used to mount the electric motor to the body can be tuned more efficiently and achieve a much higher level of isolation than with an IC engine. Also, the noise radiated directly from the motor is generally quite high in frequency (>1000 Hz), which means that conventional acoustical materials are highly effective at blocking and absorbing this airborne noise energy. So while it is true that electric motors present a lesser challenge for noise control engineers as compared to IC engines, strategies for mechanical and acoustic isolation of the motor must still be effectively executed, which is not a trivial task.

In addition to the motor itself, other parts of the electromotive system create noise, in particular, the gearbox and the power electronics unit. With respect to the gearbox, most EVs use direct-drive, single-speed gear sets. The standard knowledge base on gear design (e.g. helical versus straight cut gears), and more importantly gear finishing, applies to EV gearboxes. The goal should

be to create a system that generates high-frequency gear whine no greater than the noise generated by the motor itself. The power electronics unit provides the high-voltage, high-current energy to the motor. This is a sophisticated computer-controlled switch that has variable or fixed switching frequencies almost always above 10,000 Hz. This high-energy switching can generate quite a bit of radiated noise at the base switching frequency and at higher harmonics. For both gearbox and power electronic unit systems, the radiated noise spectrum is very high in frequency, so conventional acoustical materials are highly effective at minimizing this noise.

So far, so good. It seems like we've got things well under control with the electric drive system. As for the rest of the vehicle, let's not forget that an all-electric vehicle still rides on the same pneumatic tires, drives on the same roads, and pushes through the same air as its IC engine cousin. So it should come as no surprise that the noise generated by the tires and wind are the two largest boulders in the swamp that must be aggressively dealt with. Normal levels of wind noise and tire/road noise will suddenly become unacceptable due to the absence of engine noise, especially at low to moderate speeds (less than 50 MPH). This means that achieving a new balance between electric motor noise, wind noise and tire/road noise will be the fundamental job at hand for EVs.

Wind Noise. Let's explore the challenges associated with wind noise. The good news here is that most EV manufacturers place a tremendous emphasis on reducing aerodynamic drag, since the energy losses associated with drag have a profound impact on driving range. As a result, EVs will tend to have more "slippery" exterior shapes and, in some cases, smooth or completely flat underbodies.

Aerodynamicists and exterior designers will focus on smooth flow transitions, especially in areas where flow separation can create abrupt pressure changes and turbulence. In addition, it is now well understood that much of the aero-acoustic energy generated at low frequencies inside the vehicle (<250 Hz) comes from the highly turbulent airflow underneath the vehicle and its dynamic coupling to the structure of the underbody panels. This underbody turbulence is also a significant factor in aerodynamic drag; so many EV designers will place more emphasis on a smooth, if not completely flat, underbody. All of these efforts will certainly be helpful but not entirely sufficient in minimizing wind noise.

That's the good news. The bad news is that low drag does not automatically mean low wind noise. In fact, if detailed attention

is not given to the flow separation around the A-pillar, exterior mirror and front side glass (efforts that do not generally affect drag), wind noise is almost certainly guaranteed to be a problem. Much of the high-frequency aero-acoustic energy present inside the vehicle is generated at the interface of the A-pillar and exterior mirrors.

The turbulent wake created by these airflow interruptions can impinge on the door side glass and quite efficiently re-radiate noise inside the vehicle. Detailed CFD (computational fluid dynamics) and wind tunnel work must be carried out to manage the airflow in this region, where the smallest of shape changes can generate enormous changes in acoustic response. This requires a highly collaborative approach between the aerodynamicist, the exterior designer and the packaging engineer, among others. In reality, this process is no different than in conventional IC engine cars, but the stakes will be higher for EVs, since the need to reduce wind noise will be greater due to the absence of engine noise.

Incidentally, we could achieve lower levels of wind noise if we could eliminate the exterior mirrors altogether from the vehicle. The technology to replace mirrors with cameras and viewing screens is available and (mostly) affordable. Moreover, removing the exterior mirrors can result in up to a 7% reduction in aerodynamic drag depending on the vehicle. This is a significant reduction and would have a measurably positive effect on EV driving range. However, there are significant regulatory obstacles here. For the time being, U.S. regulations prohibit this approach, where European regulations are a little more accommodating. EV manufacturers would see significant benefits if the regulations could be made to accommodate this approach.

Tire/Road Noise. And now the more onerous of the two main noise sources – tire/road noise. I expect that much of the NVH development effort for EVs will be focused on this area more than any other. By comparison, for a conventional IC engine vehicle, I would estimate that the amount of engineering effort spent on powertrain noise is roughly 40-50% of the total NVH effort on a vehicle. This is because the vibration and noise levels generated by an IC engine and its drivetrain are highly complex, crossing over many subsystems of the vehicle. Moreover, the energy levels are very high due to the combustion and reciprocating forces generated by an IC engine.

Tire/road noise is arguably a little less complex and involves somewhat lower energy levels but is still no walk in the park to resolve. Nonetheless, I predict that for EVs, tire/road noise will become the new “powertrain noise” and will require the highest level of effort.

Why is this? A speed-versus-time histogram of a typical vehicle over its normal life would show that most of its life is spent between 25 and 50 MPH. This is a very interesting speed range for an EV, since wind noise is still minimal, and motor/gear whine

will be mostly masked by road noise, leaving tire/road noise as the dominant player. So the single most dominant noise experienced by the occupants of an EV over most of its life will be tire/road noise. Also, many EVs will use low rolling resistance tires that have historically shown to increase the force transmissibility from the tire patch to the spindle for a given road surface.

Increased forces from the tire combined with the NVH handicap of lighter weight structures in the rest of the vehicle will significantly increase the difficulty in mitigating tire/road noise. EV NVH Engineers must hit this head on with an intense focus on tire technology, mechanical isolation in the suspension, body structure stiffness and innovative noise control materials both inside and outside the car. And they must do this without adding weight and cost back into the vehicle. Clearly, this is where much of the engineering effort will be for most EVs.

Ancillary System Noise. Assuming our EV NVH team is successful in creating that perfect balance between road, wind and motor noise, there is (not surprisingly) still more work to do, as many of the smaller boulders and stumps are subsequently exposed. An all-electric vehicle must still have an air conditioning and heating system, properly functioning brakes, ABS/ESP systems and other various mechanical systems. Without the engine to drive these systems, a whole host of electrically driven ancillary devices will be needed to provide this functionality. The vibration and acoustic challenges presented by these ancillary devices are by themselves perhaps relatively minor but as a whole could become significant. These include, but are not limited to:

- Vacuum pump to power brake booster
- Heat exchanger cooling fan(s) for motor and/or battery cooling
- Fluid pumps for EV system cooling (if using water-to-air heat exchangers)
- A/C compressor for cabin cooling
- ABS module/pump
- Electric steering rack

Some EVs will have more and some will have fewer of the systems, depending on their design. Nonetheless, all EVs will most certainly have some kind of ancillary system noise to overcome. Due to the wonders of acoustic masking, most of these sounds will drop into background noise once the vehicle is underway at sufficient speed. However, at full stop (say at a traffic light) where the background noise levels are very low (often in the 35-40 dBA range), one can imagine all of these systems buzzing, gurgling, and howling away and drawing the ire of vehicle occupants.

Worse, the sounds that these ancillary devices make will be mostly independent of vehicle operating conditions such as vehicle speed. Imagine, for example, the sound of an automotive repair shop air compressor cycling on and off as the demands of the shop deplete air supply. While not inherently annoying, it's the kind of acoustic

event that if it were in an EV, might seem disconnected from the operation of the vehicle as it randomly cycles on and off. As such, it may in fact be perceived as an annoying condition by the vehicle occupants. Incidentally, for range-extended hybrids where the IC engine is used only to charge a depleting battery, one could actually think of the IC engine as an ancillary device (albeit a very large one).

In all these ancillary device cases, the strategy must be to make them nearly imperceptible to occupants. This is potentially a tall order given the number of such devices and their vibration and acoustic output characteristics, and the inherently low ambient noise of the vehicle interior, especially at a full stop.

To summarize the main efforts for EV NVH, I boldly offer my prediction of how this effort will be ranked in terms of overall effort:

1. Tire/road noise – 40%
2. Wind noise — 30%
3. Motor/gearbox noise – 15%
4. Ancillary device noise – 15%
5. Unknown noises – 10%

Note that this distribution adds up to 110% and that the “unknown” category is what puts it over the top. This is my way of suggesting that this task may be more difficult than originally imagined and that additional resources may be needed once we start to learn what it is that we don't know.

Before concluding, I should mention two more aspects of EV NVH that bear some discussion: The evil “BSR” conundrum (buzz, squeak and rattle), and sound quality.


BSRs. Like any vehicle in the market today, there must be a zero tolerance for BSRs in EVs. Experience has shown, however, that BSR problems often remain elusive and show up in the most bizarre and frustrating ways. As with the other NVH attributes, the absence of an IC engine in EVs will potentially unmask many of these gremlins, and so a great deal of focus and attention must be paid to this area to prevent the overall perception of an otherwise quiet vehicle to be shattered. This is true for any vehicle, but even more so for EVs.

Sound Quality. Given the potential for much lower interior noise levels in EVs, I believe that the need for engineering the *quality* of sounds the vehicle makes will be even greater for EVs. This is due as much to the lower noise levels as it is to the expectations of the people who buy EVs. My sense is that most people view EVs as “high-tech” machines, so the sound field that surrounds vehicle occupants must live up to that image. I predict a greater use of sound quality tools that will allow the EV NVH engineer to “sculpt” the sound so that the high-tech image can be reinforced. Would you like a little bit more 24th order in your motor noise spectrum to give it some “bite?” No problem, here you go. As is always true with sound quality, however, it is one thing to determine how you want the noise to sound, and quite yet another to get the system in question to behave that way.

Final Thoughts. So what is the point of all this? Two things, really. Number one, for the casual observer I thought it might be interesting to see what adventures may lie ahead for EV NVH Engineering. Two, I'd like to say to those of you who are worried that EVs will make automotive NVH engineers obsolete: "Fuggedaboutit!" When it comes to EV NVH, I believe that we're so early in the life of these types of vehicles

that we don't even know yet what we *don't* know. It would be amusing to me, and not too surprising, if one day in the not-too-distant future, you and I are sitting across the table from each other laughing at how fundamentally wrong I was about some or all of what I have written here!

Finally, please understand that most of what you have read here is speculation on my part based on "a few" years of automo-

tive NVH experience and a little bit of exposure to EVs. I expect that the next few years will open the eyes of many of us, and create new and unimagined "opportunities" in automotive noise control. As always, I welcome additional insights and contrary opinions. 

The author can be reached at: ggoetchius@teslamotors.com.