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Analog AM Band Interference in Electric Vehicles

Technical Solutions & Cost of Mitigating Electromagnetic Interference

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CENTER FOR AUTOMOTIVE RESEARCH

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CAR's mission is to inform and advise through independent research, education, and dialogue, enabling a more viable and sustainable automotive ecosystem.

Executive Summary

There is an effort in the US Congress to require automakers to maintain AM radio in all vehicles, including new electric vehicles (EVs). However, the nature of EVs and their operating conditions, including acceleration and deceleration, pose a challenge to ensuring electromagnetic compatibility (EMC) with the analog AM band radio. This study, conducted by the Center for Automotive Research (CAR), shows that mitigating electromagnetic interference (EMI) in an EV is challenging and could lead to added costs for vehicle manufacturers. The cost of mitigation depends upon the electrical architecture of the vehicle and entails several design and engineering tradeoffs. Automakers may mitigate some EMI through vehicle engineering choices, including shielding, filtering, active noise cancellation, and strategic placement of components. These mitigation techniques can improve analog AM band reception. However, a total vehicle system EMC requirement would need to be included from the beginning of any future EV redesign, if not already considered by the automakers, to eliminate the need for piecemeal late-stage mitigations. These costs can be avoided by deleting analog AM radio from vehicles and providing consumers with alternative products for in-vehicle audio content.

Introduction

The AM band has been integral to the automobile experience since "car radio" was first introduced in the US. Since then, advancements in broadcast communication technology have given broadcasters more options to deliver in-vehicle audio content to drivers and passengers; however, analog AM broadcast radio remains ubiquitous in the US. The effort in the US Congress to maintain AM Radio in all vehicles, including new EV models, resulted in a Senate inquiry. [1]Automaker responses to a Senate inquiry on the topic are included in Table 1.

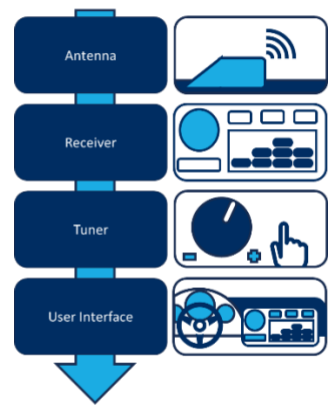
The presence of intermittent noise in the AM band is well understood technically and tolerated mainly by car radio listeners familiar with weakening signals and increasing noise as they drive away from the source broadcast station, pass a large truck on the highway or under a high-voltage power line. However, EVs bring new noise sources stemming from the electromotive nature of their propulsion systems.

[1] See Reference: 1

The key electromotive components of EVs are one or more high-power electric motors, associated electronic systems (such as inverters), and high-voltage batteries. Within an EV, these components, by design, generate electromotive forces that turn the rotor in the electric motor and cause the axles to turn the wheels. Given the high-power nature of these forces, there is an inherent high-current transmission between the high-voltage battery, the inverter, and the motors. While electromotive forces are propulsion sources in EVs, they are also the basis of noise sources causing interference in the AM band.[2]

AM Radio & Electromagnetic Interference

Figure 1. AM Radio Components



The analog AM band radio ("AM radio") captures and processes radio frequency (RF) signals in the 540 kHz – 1700 kHz range of the electromagnetic spectrum and, through a series of steps, using electronic components (Figure 1), generates audible AM radio content. The antenna receives RF signals across the AM band. It conducts the transduced electrical signals to the receiver that demodulates these signals (extracting the content about the audio content) and amplifies these signals. The tuner, via an interface, allows the user to select a desired radio station, adjust the radio volume, and access station information.[3]

EMI is an electronic device or system disturbance caused by an electromagnetic interaction with an external source. EMI can cause electronics to operate poorly, malfunction, or stop working altogether. It can arise due to both natural and human-made sources.[4]

Some examples of EMI include:

- Wi-Fi communications are disrupted by noise from LED lighting.
- Mobile radio transmissions are heard over the speakers in a home entertainment system.
- Radio signals from a passing aircraft open an automatic garage door.

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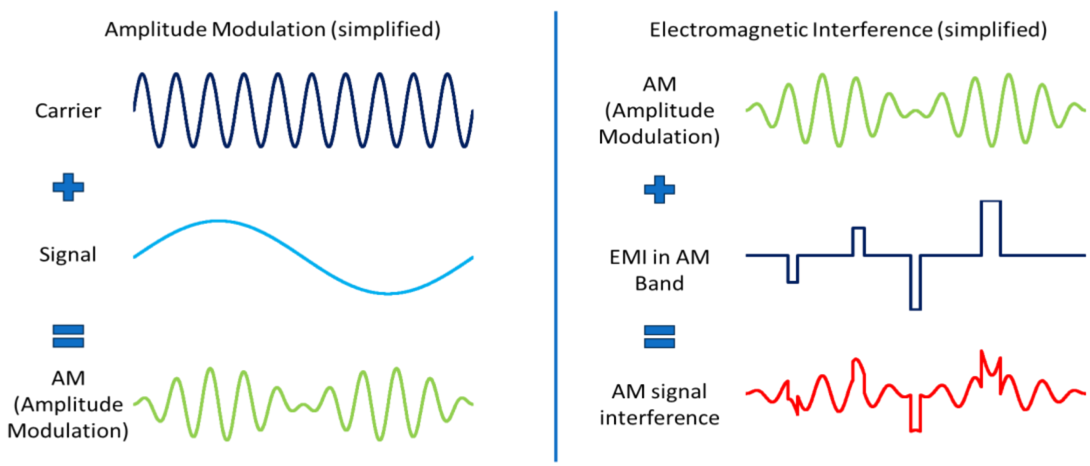
[2] See References: 2-25
[3] See Reference: 26
[4] See References: 2-25

- A lightning strike caused a power outage.

When unmanaged, EMI can pose significant operational problems. Electronic products and related services are regulated to ensure electromagnetic compatibility with other products and services sharing the same working environment. Addressing EMI poses a design and cost challenge to automakers, especially as they scale the manufacturing of EVs.

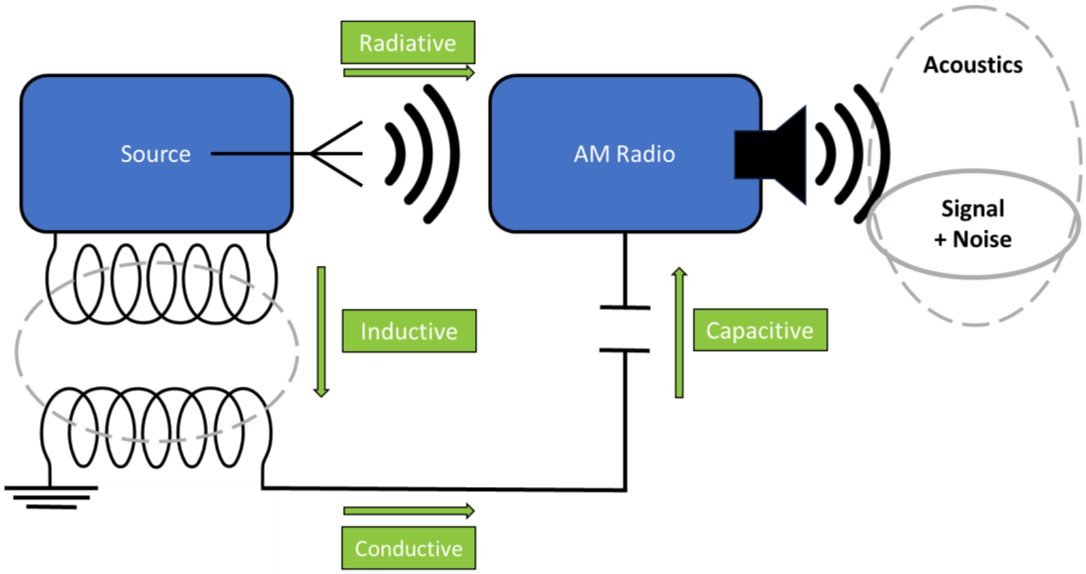
A simple illustration of EMI in AM bands is shown in Figure 2. As its name suggests, AM radio uses amplitude modulation to transmit a signal, with information transmitted by the signal modulating the amplitude of the carrier wave (as seen on the left side). In contrast, an electromagnetic spike causes interference on the right side, resulting in the distorted AM signal experienced in EVs. As AM radio is transmitted by modulating the signal's amplitude, these EMI spikes, which can be many times the amplitude of the AM signal, significantly impact the listener's experience.

Figure 2. AM Radio Signal and EMI Illustration (Simplified)



Steps can be taken to reduce EMI to AM radio in EVs, such as shielding sensitive components and using filters to block unwanted signals to maintain the fidelity of a vehicle's electronic components. EMI can be classified into four main types: inductive, radiative, capacitive, and conductive, as depicted in Figure 3. Radiative EMI requires no physical medium to be transmitted. At the same time, other types of interference (inductive, conductive, and capacitive) occur when an undesired electrical signal travels via an electrical path (i.e., wiring).

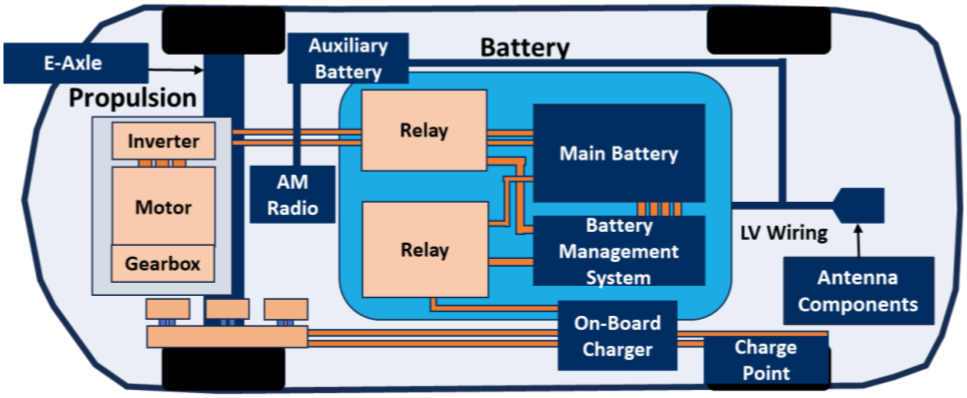
Figure 3. Four Pathways of EMI



Electromagnetic Interference in Automobiles

EVs are dependent on and powered by high-voltage electrical components that draw high currents. Through high-voltage cables, this current is carried between critical components within the car, such as the battery, electric motor, and inverter. This is depicted in Figure 4. The rapid current switching within the high-voltage cables and components generates an electromagnetic field capable of interfering with AM band signals. These fields can hinder the clear reception of AM radio signals, resulting in static and audio distortion for listeners. In essence, the operation of an EV inherently produces disturbances capable of causing varying levels of EMI.

Figure 4. Sources of EMI in EVs



Another factor contributing to EMI in EVs, traditional internal combustion engines (ICE) vehicles, and hybrid-electric vehicles (HEVs) is the growing complexity of onboard electronics. Modern vehicles have numerous electronic systems for functional requirements (such as the powertrain and chassis functions) and to support a wide range of vehicle attributes (such as safety and security). These include all the electronic sensors, actuators, and control modules associated with chassis controls (e.g., brake-by-wire, steer-by-wire systems), adaptive driver assistance systems or ADAS (with radars, camera, and ultrasonic sensors), vehicle body (e.g., door and mirror controls and climate controls) functions, infotainment, and connectivity functions, and in the case of HEVs, regenerative braking, battery management functions. These electronic components, modules, and systems can produce electromagnetic radiation, and their proximity to AM radio receivers can result in EMI.

AM Noise Mitigation: Technical Solutions

For regulatory and customer satisfaction reasons, the need to take steps to reduce or mitigate EMI is well-recognized by auto manufacturers. The approaches taken toward mitigation vary considerably. Automakers that manufacture EVs exclusively, most notably Tesla, have addressed the AM interference issue by simply deleting analog AM radio in their vehicles. Others have implemented techniques combining shielding and filtering to mitigate AM band interference. Some manufacturers have adopted different physical designs, packaging, and component placement approaches to mitigate EMI problems or have explored improving analog AM reception by adding a second AM antenna. Finally, like the techniques used in acoustic noisecanceling headphones, several emerging technologies exist for active noise cancellation in the AM band.

While shielding, filtering, component placement, receiver improvement, and active noise cancellation offer mitigation means, these measures add material and development costs. A longer-term approach may call for consideration of solutions to address the root causes of EMI through vehicle design and a rethinking of the engineering process. The costs associated with AM radio interference mitigation are challenging to compute as the components are integrated into the rest of the vehicle systems, including power and signal distribution and packaging. These costs are shared across functional systems and attributes. There is further discussion on potential costs in the AM Noise Mitigation: Cost and Weight Considerations section.

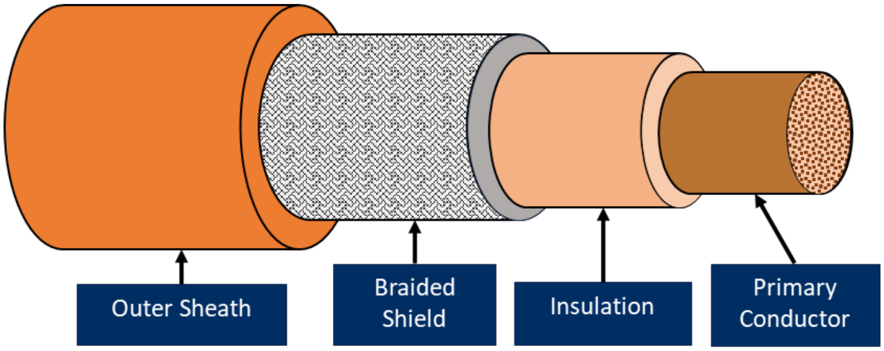
This section explores several technical solutions found in the automaker's toolkit: shielding, filtering, component placement, active noise cancellation, AM receiver improvement, and considering a long-term redesign. Each of these solutions comes with unique costs for implementation. A summary of these mitigation techniques can be seen in Figure 7.

Shielding

The shielding of cables and electrical systems is widely used to mitigate EMI, including in EVs. Cabling designed with a sheath of conductive mesh surrounding single or multiple power- or signal-carrying wires can form an effective shield when adequately grounded and mitigates some EMI (Figure 5). Having one shield around numerous wires can be more efficient than wrapping them individually.[5] Electronic systems, including power electronic circuit boards, inverters, and electric motor assemblies, can be enclosed in conductive metal cases and grounded. This helps to mitigate EMI, particularly the capacitive EMI, reduce the possibility of electric shock, and protect against the elements to which these components are exposed during their operating life in an automobile.

[5] See Reference: 27

Figure 5. Typical High-Voltage Cable Construction



By preventing unwanted EMI from infiltrating the signal path, shielded cables can help maintain the integrity of AM radio signals as they traverse the vehicle's electrical system. This ensures that drivers and passengers can have better AM radio broadcast reception.

Filtering

Filtering is another commonly used mitigation technique, beneficial for mitigation against conductive EMI. EMI filters are electronic components designed to attenuate or suppress unwanted EMI within a given frequency range. This concept is illustrated in Figure 6. In EVs, EMI filters are strategically integrated into the vehicle's electrical system to address interference issues affecting AM radio reception.

Figure 6. Filtering as a Means of EMI Mitigation

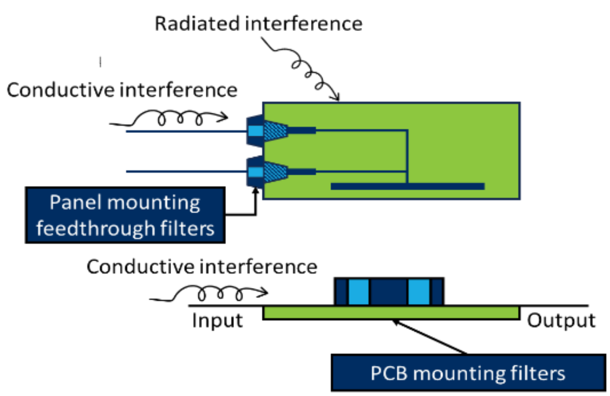


Image adapted from: Knowles Precision Devices Blog

Several considerations regarding EMI filters in EVs are worth noting. First, concerning frequency range, low-pass EMI filters can be specifically designed to reduce noise in the AM radio frequency band (530 kHz to 1700 kHz), allowing low-frequency signals to pass while attenuating higher-frequency noise. Second, filters can be integrated into various parts of the EV's electrical system, such as the power distribution unit, inverter, and charging infrastructure. High-performance filters with excellent attenuation characteristics and higher cost are typically desired to ensure minimal signal degradation.

Active Noise Cancellation

High-voltage power inverters create noise in the AM band that can be mitigated using active noise-cancellation techniques.[6] Active noise cancellation works by monitoring the noise generated within an inverter and generating an opposing signal that cancels it.

Placement

The placement of components essential to EV propulsion and AM radio reception is pivotal in EMI management. The physical arrangement of components like motor controllers, inverters, and battery management systems can minimize EMI. This is heavily dependent on the physical and electrical architecture of the vehicle in question. Some OEMs locate the inverter near the battery rather than near the motor. This results in long high-power alternating current (AC) cables and EMI.

Improvements to AM Radio Receivers

In most automobiles, AM radio receivers tend to be relatively simple compared to other radio receivers (e.g., GNSS, cellular, satellite). AM car antennas are typically short, tuned whip antennas that pick up only the electric field in the AM band. On the other hand, handheld AM radio receivers usually pick up the magnetic field. Combining the signals from two or more antennas of different types or locations on a vehicle makes it possible to reject noise from nearby sources and pick up only the signal from the distant AM transmitting tower.[7] It is important to note that these tuner-based approaches do not address the root causes of EMI in EVs but offer an additional option, with cost, to make the AM band less susceptible to EMI noise.

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[6] See Reference: 28

[7] See Reference: 27

Long-Term Redesign

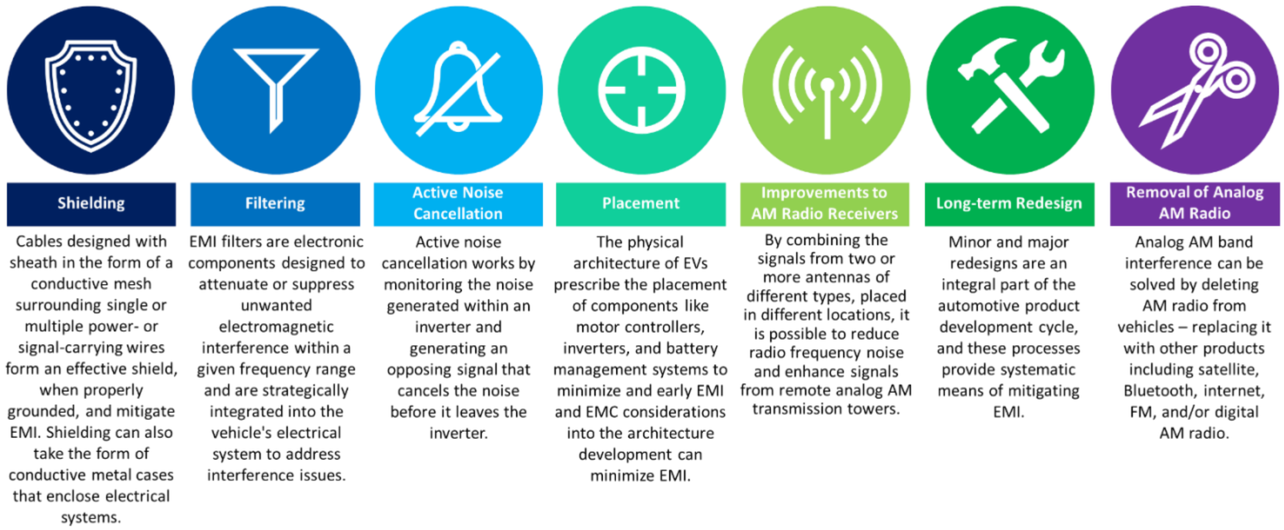
Automakers with internal combustion engines (ICE) and EV programs can mitigate additional AM band interference issues through vehicle-level redesign. This redesign will likely be optimized over several iterations, which could take three to five years. In the initial release, given the pressures of reducing go-to-market time, automakers focus on the significant changes in the powertrain systems to transition from ICE to EVs. Typically, only "as-needed" changes in chassis and body systems are made, notwithstanding the nearly independent changes in the "fast-cycle" infotainment or connected vehicle systems. As a result, it is not surprising that AM radios in first-generation EVs might be exposed to new sources of EMI. The next generation of EVs will likely incorporate the requisite chassis and body changes, with updates to powertrain technology (noting that changes driven by improved battery chemistry will continue). This second generation could be a fully redesigned vehicle with a better tolerance to EMI. However, the solution involves a third-generation version of a fully redesigned vehicle, where a component and system-level EMC are carefully planned. At that point, AM radios will not face the same level of EMI as the first-generation EVs. EMI can never entirely be eliminated in the AM band, given the sensitive nature of amplitude modulation to all signals that pass through the AM band. However, in future redesigned vehicles, AM radio mitigation will likely not have the material and test costs nor the added incremental weight burden it poses to the current production EVs.[8]

Removal of Analog AM Radio

Analog AM band mitigation costs, both material and potentially substantial engineering costs through development and testing, can be avoided by deleting analog AM radio from the vehicle. Many EV manufacturers have pursued this method to solve the poor AM band reception by providing alternative audio product options to their customers. These include FM, satellite, Bluetooth, and phone connectivity, allowing consumers to curate their in-car audio experience. Additionally, AM radio content can be accessed through digital AM radio if the broadcast is available, which has less noise and includes more text information for the user interface, or in-car streaming services stream AM station content.

[8] See Reference: 29 and 30

Figure 7. Potential Mitigation Solutions for AM Radio Interference in EVs



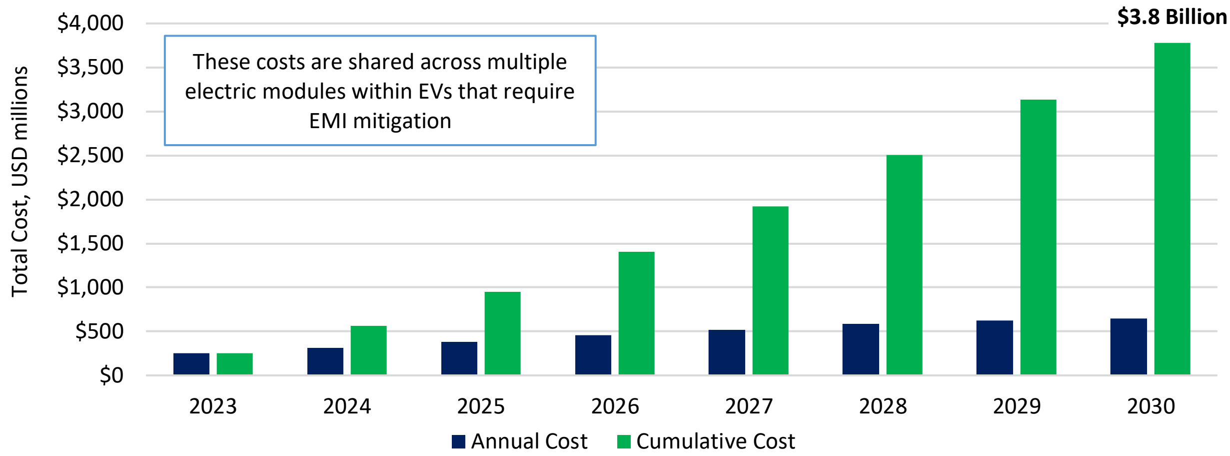
AM Noise Mitigation: Cost and Weight Considerations

EMI and EMC design expertise today is mainly in the supply base, not with the legacy ICE automakers who are now rapidly scaling their EV business. This results from more than a century-old requirements associated with the ICE vehicle design and associated automaker and supplier roles. The automakers typically design and manufacture major propulsion components (e.g., engines and transmissions). In contrast, the components in most non-powertrain systems, delivering chassis, body, and infotainment or connectivity functions, are primarily designed or manufactured by the supply base. Not surprisingly, the EMI and EMC expertise within the automakers has focused mainly on compliance requirements of modules or components, vehicle-level testing, and late-stage EMI mitigations where necessitated.

With the large-scale investments in EVs, automakers who control the design and manufacturing of the underlying propulsion systems have recognized the need to build in-house capabilities in electromagnetics and related design and development skills. These capabilities exceed the in-house EMI and EMC skills in typical ICE-focused engineering organizations. This OEM capability development is needed because the propulsion system components of EVs (that OEMs design and often manufacture) include high-power motors and inverters, all of which are sources of EMI. The automakers have recognized the need to design and engineer these components from the beginning to minimize EMI and to ensure EMC with all other vehicle electronic systems. The collateral benefit of this early-stage vehicle-level design consideration being given to EMI and EMC is that other vehicle electronic systems (serving the chassis, body, infotainment, and connectivity functions), including the AM band radio, will be relatively free of EMI from other vehicle systems. That said, analog AM band radio will never be interference-free as intermittent extra-vehicular sources of interference, as found in analog AM band radios in ICE vehicles, will persist in the driving environment.

In CAR's discussions with independent subject matter experts (SMEs) active in standards bodies and education, it has become clear that in-house electromagnetic design capabilities will give the legacy automakers an early-stage systemic design advantage, which will help avoid late-stage EMI mitigation costs. In the interim, there will be EMI mitigation costs between the first and second generations of EVs, where most legacy automakers are today. These costs will depend on several variables: the system architecture of the EV, the class and type of vehicle, and the chosen mitigation techniques. CAR's SME discussions revealed that the material cost of addressing AM band interference in EVs is relatively low because mitigation measures are often necessary and implemented to support other electronic systems susceptible to EMI. CAR's interview with one automaker revealed approximate shielding costs of $35 to $50 and filtering costs of $15 to $20 per vehicle. The shielding and filters can help mitigate interference with the functioning of electronic modules or components supporting attributes such as vehicle safety, durability, thermal conduction, and functional purposes of chassis, body, infotainment, and all the associated power distribution needs. They may be useful countermeasures, regardless of the presence of AM radio. CAR's analysis in Figure 8 shows how much EMI mitigation costs through shielding and filtering in forecasted EV production. Countermeasures or EMI mitigation actions are taken in the late stages of product development. They can prove more expensive than those in the early stages of the vehicle design and development process.

*Figure 8. Cost of EMI Mitigation Through Shielding and Filtering in Forecasted EV Production**



**The cost burden is shared by a number of other electronic modules in EVs that also have EMI mitigation needs, including AM radio. These aggregate numbers are based on the $70 unit costs of shielding and filtering, which is there for EMI migration and for other key-life purposes (e.g., durability). These numbers assume the 2023 state of a legacy automaker design assumptions, and these are assumed to stay unchanged (for purposes of this analysis) through the period of the cost analysis*
Source: CAR Analysis, GlobalData: North American Light Vehicle Powertrain Fitment Forecast

Even if the material costs are low, the intangible costs of EMI mitigation are substantial. A verifiable specification is required for every additional engineering requirement; a prime example of such a requirement could be ensuring that the electromagnetic interference (EMI) in the analog AM band of electric vehicles (EVs) doesn't introduce any more audible noise than that in traditional internal combustion engine (ICE) vehicles. This entails allocating valuable engineering expertise to developing detailed specifications, often spanning hundreds of pages, to align with the analog AM band interference mitigation requirements for EVs.

Furthermore, dedicated teams must be assigned to test these specifications and source components designed explicitly for mitigating analog AM band interference. Since this added requirement intersects with multiple functional groups, such as the chassis team, the "body" engineering team, and the electrical and electronic systems team, often operating under different leadership within the company, there is a significant opportunity cost associated with these efforts. Consequently, organizational efficiency is compromised, which is particularly challenging for traditional automakers that must excel in efficiency compared to all EV companies. This heightened efficiency is necessary for conventional automakers to attain the profit margins required to fund their EV programs while meeting annual EV production commitments in compliance with US Government regulations.

AM band interference mitigation actions using shields and filters also add incremental weight. For example, CAR's interviews with automakers and SMEs have indicated that a ferrite core filter weighs approximately 1000 grams (about 2.2 lb.) This burden is a lot, as reducing vehicle weight is a big concern for automakers, and they pay a premium to save every pound of weight in the car. This imposes an extra cost burden on the automakers and has the consumer-facing functional impact of reducing the driving range of an EV.

Conclusion

The compatibility of EVs with AM radio reception poses a significant challenge due to EMI generated by the inherent properties of their high-voltage electrical systems and onboard electronics. This interference distorts AM radio signals, affecting the listening experience for drivers and passengers.

Several mitigation techniques are available that help address this issue, including shielded cables, EMI filters, strategic component placement, active noise cancellation, and AM receiver improvements. These solutions offer EMI mitigation, reducing AM band interference and enhancing reception within EVs. However, these mitigation measures have associated costs, depending on the techniques adopted to mitigate EMI and the underlying vehicle architectures. For instance, shielded cabling can increase the cost of the connection system by an estimated 30-40% over the baseline. At the same time, the mitigation techniques do not eliminate unwanted noise in analog AM radio for EVs completely.

Returning to the central question of this research, the cost implications of implementing near-term EMI mitigation measures can pose a significant burden on automakers today. Some automakers have avoided “mitigation” costs by choosing not to offer analog AM radio in their products. Other automakers have faced increased charges in implementing EMI mitigation measures to provide analog AM radios in EVs. These costs have typically resulted from late-stage changes in the product development cycle.

Table 1. AM Radio Availability & Alternatives between EV-Producing Automakers

Automaker	AM Availability?	Replacement/Alternative Offered?
BMW	No	Offers Apple CarPlay, Android Audio, or Bluetooth options.
Ford*	No/Yes*	Software updates for EVs without capabilities will all be in the future.
Mazda	No	Offers Apple CarPlay, Android Audio, Bluetooth, FM, and AM radio.
Polestar	No	Offers TuneIn (app offering AM digital streaming) and Bluetooth.
Rivian	No	Offers Bluetooth capability.
Tesla	No	Owner responsible: Offers Bluetooth, FM radio, satellite radio (when configured), Android Audio, and other Bluetooth options. Premium Connectivity includes in-car music streaming, including TuneIn.
Volkswagen	No	Offers Apple CarPlay, Android Audio, other Bluetooth options, and SiriusXM.
Volvo	No	It offers Apple CarPlay, other Bluetooth options, and SiriusXM.
Honda	Yes	N/A: AM radio present.
Hyundai	Yes	N/A: AM radio present
Jaguar	Yes	N/A: AM radio present.
Kia	Yes	N/A: AM radio present.
Lucid	Yes	N/A: AM radio present.
Mitsubishi	Yes	N/A: AM radio present.
Nissan	Yes	N/A: AM radio present.
Stellantis	Yes	N/A: AM radio present.
Subaru	Yes	N/A: AM radio present.
Toyota	Yes	N/A: AM radio present.
GM	Defer to Alliance	Defers to Alliance
Mercedes-Benz	Defer to Alliance	Defers to Alliance

*Ford CEO **Jim Farley** announced that the company has reversed its decision to release new vehicles without AM radios: all **2024 Ford and Lincoln models** will be equipped with AM radio.

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