Basic design consideration and layout recommendations for EMC robustness

TLE480x family

About this document

Scope and purpose

This document describes proposals for potential countermeasures for improvements for electromagnetic compatibility when using the TLE480x family in an environment with high EMC requirements.

Additional information for the correct sensor parameter setup is provided in the TLE480x data sheets and user manuals: Infineon-TLE4802-DS-vxx_xx-EN, Infineon-TLE4801-DS-vxx_xx-EN, Infineon-TLE4803-DS-vxx_xx-EN, Infineon-TLE4802-UM-vxx_xx-EN, Infineon-TLE4801-UM-vxx_xx-EN, Infineon-TLE4803-UM-vxx_xx-EN.

Intended audience

The intended audiences for this document are design engineers, technicians, and developers of electronic systems.

A technical guide for design engineers, technicians, and developers implementing inductive TLE480x sensors in demanding electromagnetic environments.

Table of contents

1 Overview

The below diagram shows an application set up using SENT configuration with passive components to cover EMC requirements on PCB level. Further details in the chapters below.

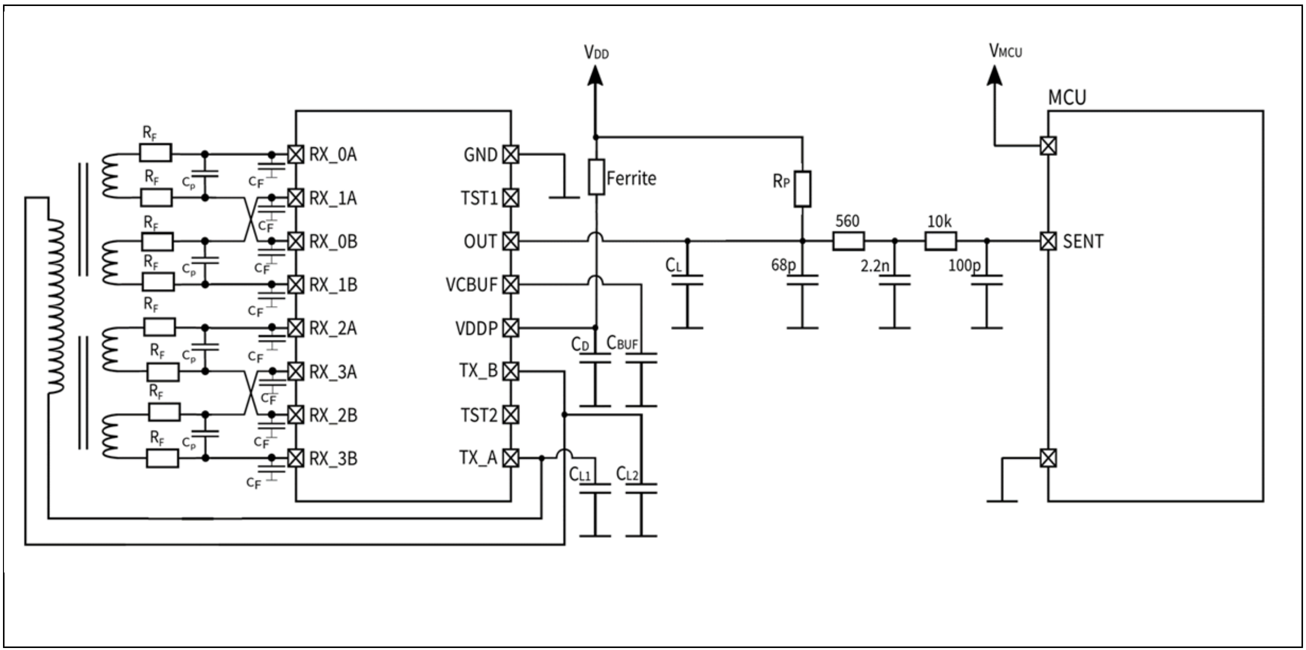

Figure 1 Overview application circuit example SENT

- The TLE480x family uses an inductive sensing principle, which involves a transmitter (TX) coil that generates magnetic fields and a set of receivers (RX) coils that pick-up signals modulated by a rotating metallic target (rotor). The system evaluates angular positions based on sine and cosine signals derived from the RX coils. However, the utilization of high-frequency magnetic fields, typically within the 3 - 5.5 MHz frequency spectrum, renders the system inherently susceptible to electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues, necessitating careful consideration of external noise sources and radiated emissions.
- Active Signal transmission:
  - SENT Interface: Transmits the angle and diagnostic data to the ECU using a pulse-width modulation protocol. This interface can be disturbed by high-frequency noise and requires appropriate filtering.
  - Passive Components:
    - Decoupling Capacitors (C_D and C_{BUF}) are placed close to power pins to stabilize the sensor's power supply and reduce high-frequency noise.
    - The Pull-Up Resistor (R_P) ensures proper signal integrity on the SENT line by matching the electrical timing requirements to the line capacitance.
    - Filter capacitors (C_F) help reduce electromagnetic interference (EMI) by filtering noise from RX coil signals, improving system immunity and accuracy."
    - Other components such as C_L capacitors and coil configurations are adjusted to meet application-specific requirements and frequency ranges. More details to the SENT line filters in the chapters regarding immunity.

- Design Implications
  - Proximity to Noise Sources: Placement of decoupling capacitors to the IC is crucial, as it reduces the loop area, thereby mitigating its potential to act as a parasitic antenna that could receive and couple noise into pins, thus preventing inductive interference and ensuring a more stable power supply.
  - Coil Configurations and Shielding: Coil placement and isolation are critical to minimize crosstalk and maximize the signal-to-noise ratio (SNR). To achieve this, careful consideration must be given to coil spacing and the strategic use of grounded guard rings, which serve as a shield to prevent electromagnetic coupling and ensure the best signal transmission.

2 Immunity

Immunity represents a critical aspect of PCB design for the sensor module performance, referring to its capacity to withstand and resist electromagnetic interference (EMI) from external sources. This section delves into the specific challenges and requirements outlined by ISO standards and provided design hints and countermeasures to effectively mitigate the adverse effects of EMI, ensuring reliable and accurate sensor operation in harsh electromagnetic environments.

2.1 EMC Test Standards

The document outlines several ISO-defined immunity tests to evaluate how the sensor performs when exposed to electromagnetic disturbances. Each test addresses a different type of interference:

- Bulk Current Injection (BCI, ISO 11452-4):
  - RF currents are injected into the wiring harness to simulate interference from nearby systems like radios, power lines, or motors. The primary concern is noise coupling (decoupling filters help to avoid those for the SENT output and the power supply line), which can propagate to the coil system disrupting angle measurements or communication.

- Radiated Immunity (ALSE, ISO 11452-2):
  - The Absorber-Lined Shielded Enclosure (ALSE) method evaluates how the sensor withstands radiated electromagnetic fields, such as those from antennas or other vehicle electronics operating in the 80 MHz–6 GHz range. The wiring harness and PCB traces can act as unintentional antennas, amplifying the effects of radiated fields.

- Radiated Immunity (Stripline, ISO 11452-5):
  - This test targets lower-frequency electromagnetic fields (10 kHz–400 MHz) using a strip line setup. Frequencies close to the sensor’s operating range (3-5.5 MHz) are particularly critical because they can directly interfere with the RX coil signals.

- Magnetic Field Immunity (ISO 11452-8):
  - Simulates low-frequency magnetic fields, such as those from nearby current-carrying conductors. While the sensor's design is inherently robust against low-frequency fields, coupling effects and crosstalk between coils can degrade performance.

- Transient Pulse Immunity (Fast/Slow Pulses, ISO 7637-3):
  - Simulates electrical disturbances caused by switching events in automotive electrical systems (e.g., relays or motors). Voltage spikes can propagate through power or signal lines, disrupting the IC or causing angle glitches.

2.2 Behaviour and Potential Issues

The document identifies key failure mechanisms during these tests, such as:

- Induced voltages and currents in PCB traces disrupting signal integrity.
- Ground plane noise affecting reference voltages for the analog and digital circuits.
- SENT signal corruption due to RF interference, leading to communication errors with the ECU.
- Crosstalk between closely spaced coil traces creating phase or amplitude distortion in the RX signals.

2.3 Countermeasures to improve Immunity

To ensure robust electromagnetic compatibility, several countermeasures can be implemented to mitigate electromagnetic interference (EMI) in the inductive torque angle sensor layout, specifically addressing the requirements of the specified immunity tests. These targeted measures focus on vulnerabilities in key areas, including:

- Sensor wiring: VDD, GND, and SENT lines
- PCB traces: optimized routing and layout to minimize EMI susceptibility
- IC: integrated circuit design and layout considerations to reduce EMI sensitivity
- Coil system: TX1/TX2 for the LC circuit and 8 Rx coil pins for sin/cos signals, with specific design features to minimize EMI coupling and maximize signal integrity

By implementing these countermeasures, the inductive torque angle sensor is well prepared to withstand electromagnetic interference and maintain accurate and reliable operation in harsh environments.

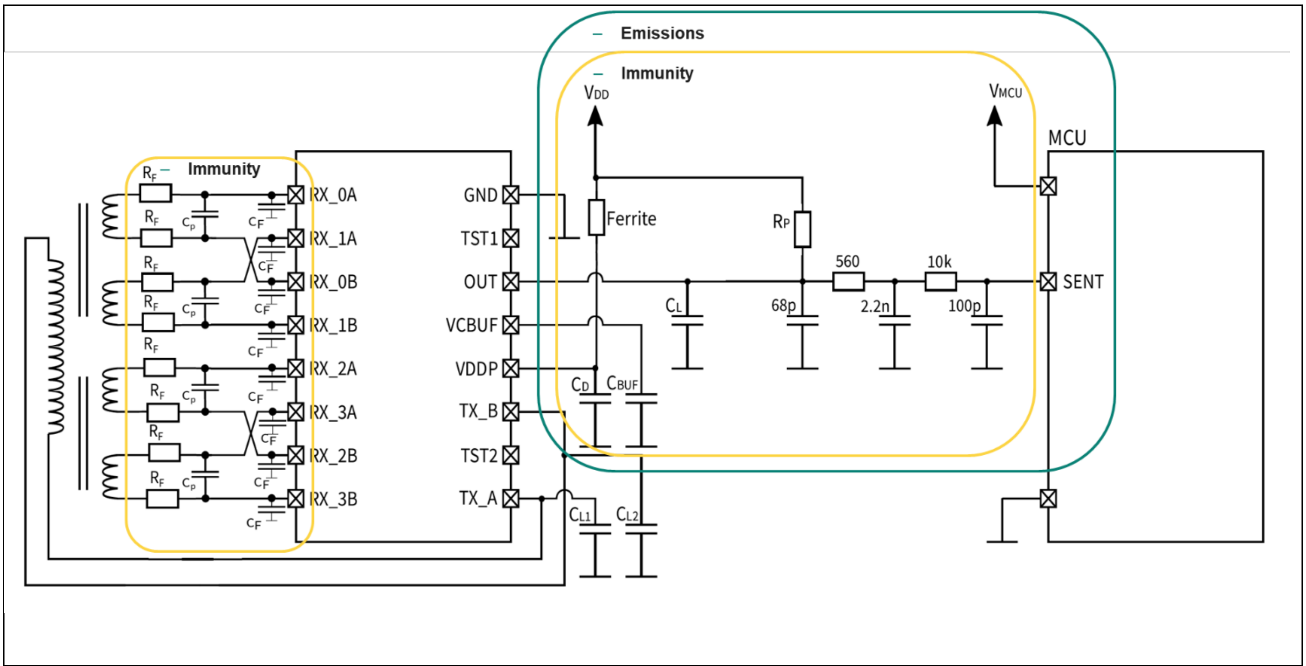

Figure 2 Application circuit example SENT with EMC countermeasures marked

1. **PCB-level filtering:** Low-pass filters (e.g.: Ferrite: 600 Ω at 100 MHz, and a C_D = 10 µF X7R ceramic capacitors to ground.) on power supply reduce high-frequency interference from external sources:

$$f_c = \frac{1}{2\pi RC} \rightarrow \frac{1}{2\pi * 600\Omega * 10\mu F} = f_c = \frac{1}{2\pi(600)(10\times10^{-6})}, f_c = \frac{1}{2\pi(6000\times10^{-6})}, f_c = \frac{1}{0.037699}, f_c \approx 26.52, Hz$$

Equation 1

2. **Decoupling:** Capacitors close to the IC shunt noise to ground, stabilizing the power supply and protecting sensitive circuits.
3. **Ground Plane Design:** A solid ground plane reduces ground impedance and stabilizes reference voltages across the PCB.
4. **Trace Optimization:** Differential routing and proper spacing of TX/RX traces minimize crosstalk and RF noise coupling.
5. **Coil Filtering**: Adding small resistors and capacitors to RX signals forms a low-pass filter, improving noise rejection:
    - R_F = 22 Ω in series and C_F = 470 pF to ground on each differential Rx coil connection (sin/cos), implemented symmetrically to form a low-pass filter with a ~15.44 MHz cutoff.

$$f_c = \frac{1}{2\pi RC}, C = 470\ pF, R = 22\,\Omega, f_c = \frac{1}{2\pi(22)(470\times10^{-12})} \approx 15.44, MHz$$

Equation 2

3 Emission

Emissions refer to the electromagnetic noise generated by the sensor itself, which may interfere with other vehicle systems. Compliance with CISPR 25 standards ensures that emissions remain within acceptable limits.

- CISPR 25 Radiated Emission (ALSE Method):
  - Measures electromagnetic fields emitted by the device and its wiring harness in a controlled environment, covering frequencies from 150 kHz to 2.5 GHz. This test ensures the sensor does not radiate excessive electromagnetic interference that could disrupt other automotive systems.
- CISPR 25 Conducted Emission (Voltage Method):
  - Measures electromagnetic noise conducted through the device's power and signal lines onto the wiring harness, covering frequencies from 150 kHz to 108 MHz This test ensures the sensor does not inject excessive noise into the vehicle's power network, which could affect other electronics.

3.1 Radiated Emissions

The primary sources of radiated emissions include:

- TX coil drive currents (3-5.5 MHz and harmonics).
- High-frequency noise generated by the IC.
- SENT signals with high slew rates generating high-frequency harmonics.

3.2 Conducted Emissions

Noise propagates through the power and ground lines, originating from:

- Oscillations in the TX coil.
- IC operational noise.
- SENT signal harmonics coupling into power lines.

3.3 Countermeasures

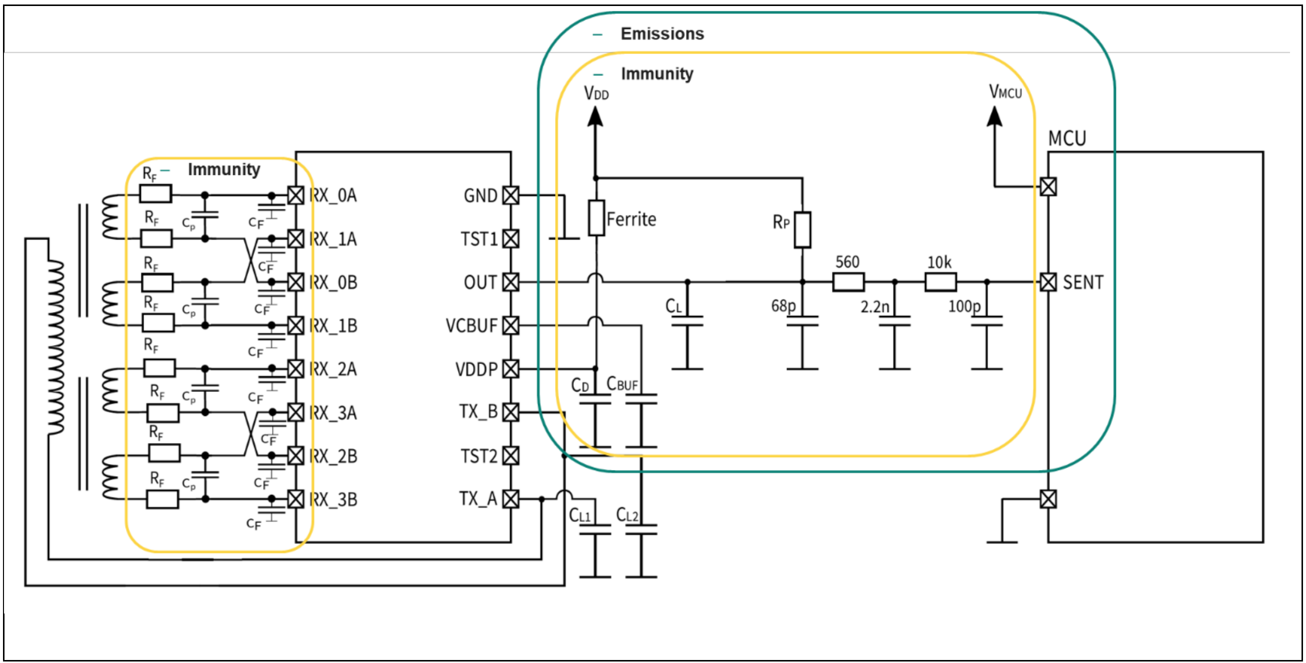

Figure 3 Overview application circuit example SENT with countermeasures against emissions marked

1. **Filtering (Supply and SENT Lines):** Add ferrite beads and RC filters to block high-frequency noise: Low-pass filters (e.g.: Ferrite: 600 Ω at 100 MHz, and a C_D = 10 µF X7R ceramic capacitors to ground.) on power supply reduce high-frequency interference from external sources:

$$f_c = \frac{1}{2\pi RC} \rightarrow \frac{1}{2\pi * 600\Omega * 10\mu F} = f_c = \frac{1}{2\pi(600)(10\times10^{-6})}, f_c = \frac{1}{2\pi(6000\times10^{-6})}, f_c = \frac{1}{0.037699}, f_c \approx 26.52, Hz$$

Equation 32

2. **SENT Line Smoothing:** Include capacitors and resistors to reduce harmonics: For the SENT line, implement a two-stage RC filter (100 Ω + 100 pF, followed by 100 Ω + 100 pF) to ensure the total RC time constant is below 2µs, preserving the 1.5 µs SENT tick time
3. **Shielding:** Ground planes and guard rings confine magnetic fields and reduce emissions: Use a solid ground plane in a multi-layer PCB (e.g., 4-layer), tied to the GND line via multiple vias. Route all signal traces (Tx, Rx, SENT) over the ground plane, adding stitching vias around Tx/Rx coil traces to enhance shielding.
4. **Trace Layout Optimization**:
    - Design short, wide, symmetrical Tx and Rx coil traces. Use differential routing for Rx signals (sin/cos pairs). Route SENT and supply traces on opposite PCB layers.

4 Further Measures for Harsh EMC Requirements

This chapter introduces two additional countermeasures to enhance the electromagnetic compatibility (EMC) of the inductive torque angle sensor:

- Isolating the rotor from GND in the application
- incorporating a capacitive shielding layer in the coil PCB.

These measures address both immunity and emission concerns, complementing the countermeasures in Chapters 2 and 3, and are designed to mitigate interference while maintaining the sensor's performance.

4.1 Rotor Isolation

- **Implementation**: Ensure the rotor in the sensor application is electrically isolated from the system's ground (GND) by using non-conductive mounting materials (e.g., plastic or ceramic spacers) or insulating coatings on the rotor's mounting interface. In the mechanical assembly, avoid direct electrical contact between the rotor and conductive components connected to the PCB's GND plane or vehicle chassis.
- **Mechanism**:
    - The rotor interacts with the Tx coil's magnetic field (3-5.5 MHz) to induce eddy currents, which modulate the Rx coil signals (sin/cos). Electrically connecting the rotor to GND, such as through a conductive shaft or chassis, can significantly increase the susceptibility of the system to conducted noise, including electromagnetic interference from sources like BCI or transient events. In addition, this connection could amplify emissions, potentially leading to EMC issues and compromising the overall performance and reliability of the system.
    - Isolation prevents the rotor from forming a low-impedance path to GND, thus the coupling of external disturbances (e.g., RF currents, transients) into the Rx coils is reduced to minimum.
- **Purpose**: Reduces the rotor's contribution to noise coupling for immunity tests and confines Tx coil emissions to prevent exceeding emission limits.

4.2 Capacitive Shielding

- **Implementation**: Incorporate a dedicated capacitive shielding layer in a multi-layer PCB (e.g., 4-layer or 6-layer), positioned as a middle layer (e.g., layer 2 or 3 in a 4-layer stack up, below the top layer with Tx/Rx coils and above the bottom layer with signal traces). The shielding layer is a copper plane with different cut outs or patterns connected to the PCB's GND or floating, covering the area underneath the Tx and Rx coils and sensitive traces (e.g., Rx signals). Ensure the layer is continuous, with cuts and shapes to incorporate it between RX and TX traces and connected to the main GND plane via multiple vias if required.
- **Mechanism:**
    - Unwanted Parasitic Capacitance: The Tx coil's high-frequency magnetic field (3-5.5 MHz) and Rx coil signals can couple capacitively to nearby traces, components, or the rotor, introducing unwanted parasitic capacitances. These capacitances can:
    - Amplify noise susceptibility in immunity tests (e.g., BCI, radiated fields) by coupling external RF or transients into Rx signals.
    - TX coil harmonics can increase radiated emissions by coupling to the wiring harness or radiating via PCB traces
    - Controlled Parasitic Capacitance: The shielding layer introduces a controlled parasitic capacitance between the Tx/Rx coils and GND. This capacitance:

   - Shunts high-frequency noise (from external fields or Tx harmonics) to GND, reducing its impact on Rx signals or emission paths.
   - Acts as a low-impedance path for parasitic currents, preventing them from coupling to sensitive traces or the wiring harness.
   - Counters unwanted parasitic capacitance by providing a dominant, predictable capacitance to GND, which is less sensitive to external disturbances due to its uniform structure.

- **Negative impacts**: Certain shielding layers could also have negative impact at certain frequency ranges. Therefore, carefully simulation and testing are recommended.

Example of a shielding layer:

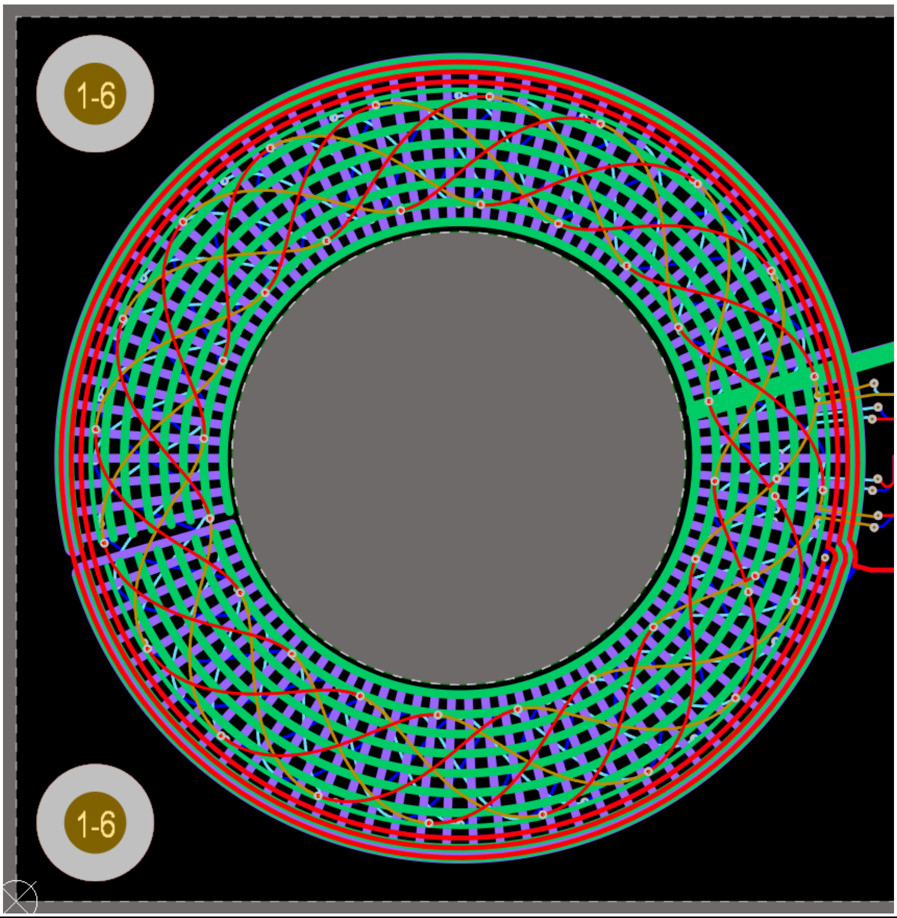

Figure 4 Example for a shielding layer

References

[1] International Organization for Standardization (ISO): ISO 11452-1:2015, Road vehicles - Electrical disturbances from conduction and coupling - Part 1: Definitions and general considerations; Geneva; ISO; 2015; www.iso.org

[2] International Organization for Standardization (ISO): ISO 7637-2:2011, Road vehicles - Electrical disturbances from conduction and coupling - Part 2: Electrical transient conduction along shielded high voltage supply lines only; Geneva; ISO; 2011; www.iso.org

[3] International Electrotechnical Commission (IEC): CISPR 25:2021, Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers; Geneva; IEC; 2021; www.iec.ch

Revision history

Document revision	Date	Description of changes
1.0	26.05.2025	Initial Release

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