Emerging Topics in Automotive EMC

Mark Emery – EMC Technical Manager

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Synopsis

Presenters: Mark Emery & Alastair Ruddle

Title: Emerging Topics in Automotive EMC: Standardisation Developments and Risk-Based Systems Engineering

Summary: The range and complexity of technologies that are now being deployed in modern vehicles are increasing at an unprecedented rate. These developments are driving changes in automotive EMC standardisation and legislation, as well as in related engineering approaches.

This session will outline the current status and planned developments of the relevant automotive CISPR & ISO standards, along with the impact the recent introduction of UNECE Regulation 10.06 has upon component sub-system and vehicle manufactures.

In addition, the benefits of a more robust systems engineering practice and a risk-based approach for meeting the challenges of future automotive EMC engineering will be discussed.

Emerging Topics in Automotive EMC: Standardisation & Legislation Developments

Mark Emery – EMC Technical Manager

IEC CISPR: International Special Committee on Radio Interference

- CISPR A - Radio-interference measurements and statistical methods
- CISPR B - Interference relating to industrial, scientific and medical radio-frequency apparatus, to other (heavy) industrial equipment, to overhead power lines, to high voltage equipment and to electric traction
- **CISPR D - Electromagnetic disturbances related to electric/electronic equipment on vehicles and internal combustion engine powered devices**
- CISPR F - Interference relating to household appliances tools, lighting equipment and similar apparatus
- CISPR H - Limits for the protection of radio services
- CISPR I - Electromagnetic compatibility of information technology equipment, multimedia equipment and receivers
- CISPR S – Steering Committee

International Standardisation Organisation

- **ISO/TC22** – Road Vehicles
- **ISO/TC22/SC32/WG3 - Electrical and electronic components and general system aspects, EMC**

IEC CISPR/D

- CISPR 12
- CISPR 25
- CISPR 36

ISO/TC22/SC32/WG3

- ISO 11451-x
- ISO 11452-x
- ISO 7637-x
- ISO 10605

UNITED NATIONS
ECONOMIC COMMISSION
FOR EUROPE

Automotive EMC Legislation for Vehicle and Component Subsystem

- UNECE Regulation 10

EMC AUTOMOTIVE STANDARDIZATION

IEC CISPR/D

IEC CISPR 12 6th Edition: 2007 + AMD1 2009 – Vehicles, boats and internal combustion engines - Radio disturbance characteristics – Limits and methods of measurement for the protection of Off-Board Receivers

- Standard covers not only motor vehicles, but many products with an internal combustion engine i.e. boats, chainsaws, snow mobiles etc
- Electric vehicle test methods are included but only in a driven mode at 40 km/h
- Frequency spectrum limited to 30 MHz - 1000 MHz
- No height scanning of the measurement antenna
- No rotation of the test vehicle or product


IEC
CISPR 12
Edition 6.1 2009-03

INTERNATIONAL STANDARD
NORME INTERNATIONALE

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE
COMITÉ INTERNATIONAL SPÉCIAL DES PERTURBATIONS RADIOÉLECTRIQUES

Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers

Véhicules, bateaux et moteurs à combustion interne – Caractéristiques de perturbation radioélectrique – Limites et méthodes de mesure pour la protection des récepteurs extérieurs

INTERNATIONAL ELECTROTECHNICAL COMMISSION

COMMISSION ELECTROTECHNIQUE INTERNATIONALE

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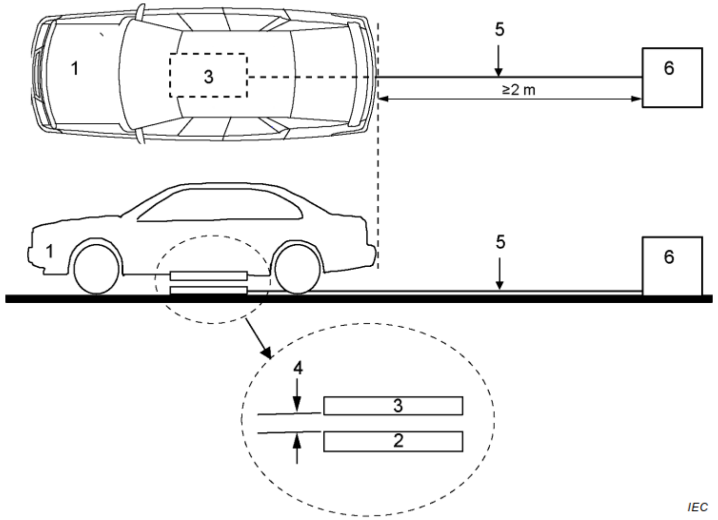
IEC CISPR 12 7th Edition: CD– Vehicles, boats and internal combustion engines - Radio disturbance characteristics – Limits and methods of measurement for the protection of Off-Board Receiver

The 7th edition of CISPR 12 is currently at CD stage following the failure of the FDIS in 2018, with a forecasted release date of 2021. A number of changes are planned from the 6th edition as follows

- Measurement antenna 3dB beamwidth to cover the product under test
- New Annex G for AN's, AMN's, AAN's and new DC-Charging AN
- Removal of Annex B for maintenance of antennas / coaxial cable
- Inclusion of electric vehicles (EV) and plug-in electric vehicles (PHEV) charging Modes 1, 2, 3 and 4 taken from IEC 61851-1
- Wireless Power Transfer test condition based upon parameters from IEC 61890

Wireless Power Transfer



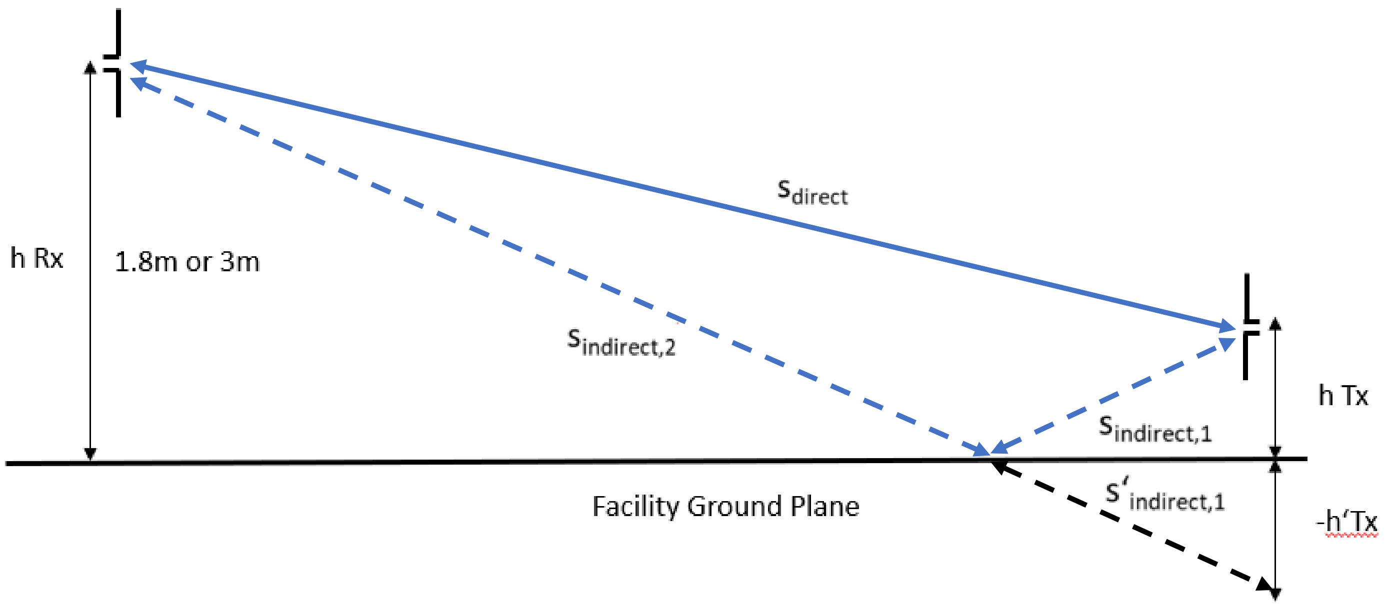
CISPR 12 – NSA Special Task Force

- IEC CISPR 16-1-4 and ANSI C64.4 site characterisation measurements employ height scanning of the measurement antenna which is not representative of the CISPR 12 test method
- Taskforce established to determine the validation method of an OTS, OATS and ALSE test facilities

CISPR 12 – PK/QP Special Task Force

- CISPR 12 currently allows a relaxation of the broadband Quasi-Peak limit by 20 dB
- Objective to justify / determine the value for today’s road vehicles and associated EV test methods

Fixed Height CISPR 12 Measurements



IEC CISPR 25 4th Edition 2016 – Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers


CISPR 25
Edition 4.0 2016-10

INTERNATIONAL STANDARD

NORME INTERNATIONALE

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Significant changes from 3rd Edition

- Inclusion of charging mode for electric vehicles (EV) and plug-in electric vehicles (PHEV)
- Methods for chamber validation included
- Test methods for shielded power supply systems / high voltages for electric and hybrid electric vehicles
- Corrigendum of October 2017 was issued to correct a number of technical discrepancies

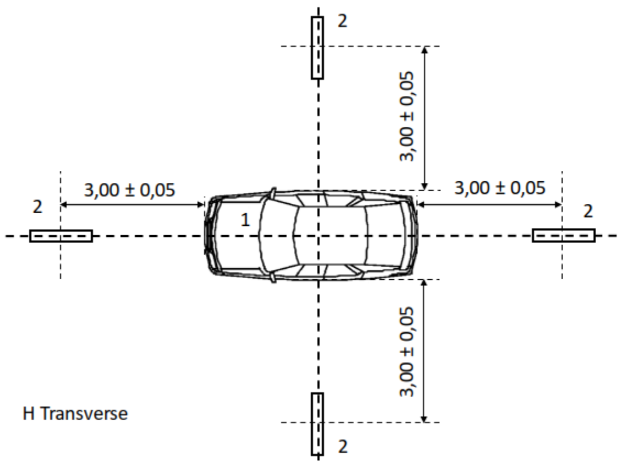
IEC CISPR 25 5th Edition – CD – Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers

- Frequency spectrum extended up to 5850 MHz
- Update to electric vehicle charging Modes 1, 2 , 3 and 4 in line with the proposed CISPR 12 modifications
- Updates to Annex E (Artificial networks) to include DC Charging AN
- New Annex for measurement uncertainties
- Addition of BDS GNSS band for the Chinese market
- Digital service band limits and test parameters, with all digital services proposed to use a 1 MHz RBW.
- Updates to Annex I (EV test Methods) with greater clarity on the test setups
- Expected release date 2021

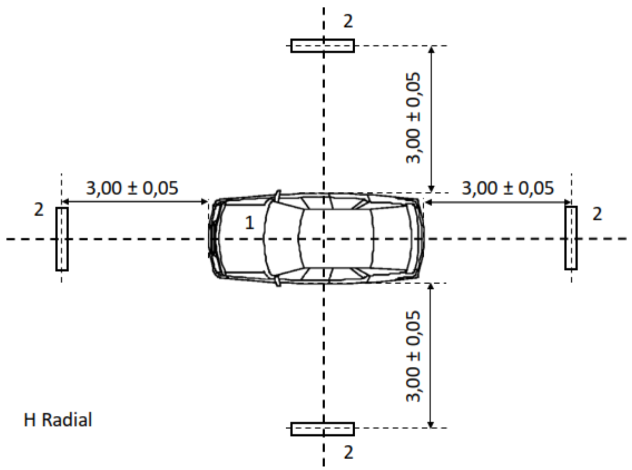
IEC CISPR 36 – Electric and hybrid road vehicles – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers below 30 MHz

- Standard developed in line Chinese Standard GBT/18387 and SAE J551-5
- Frequency Range 150 kHz to 30 MHz
- Requirement only for EV & HEV vehicles in a driven 40 km/h mode
- Two measurement antenna planes at a 3m distance from the vehicles edge
- 4 positions, 1m above reference ground plane
- Positive CDV late 2019
- Expected release date mid 2020

Mag Loop - Transverse



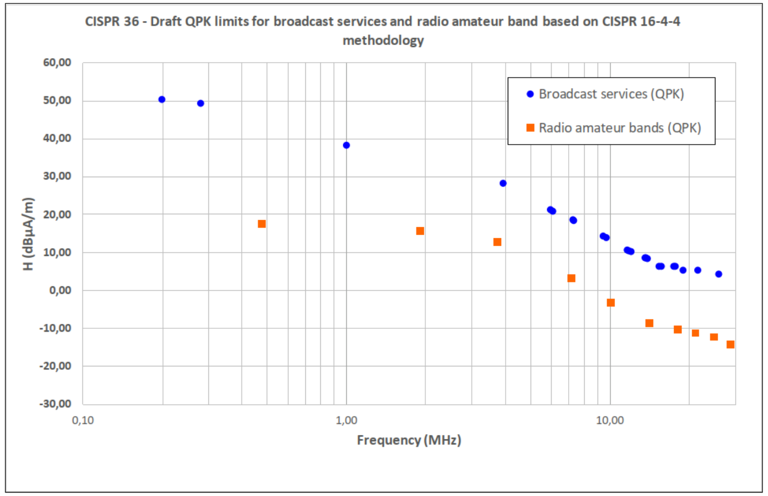
Mag Loop - Radial



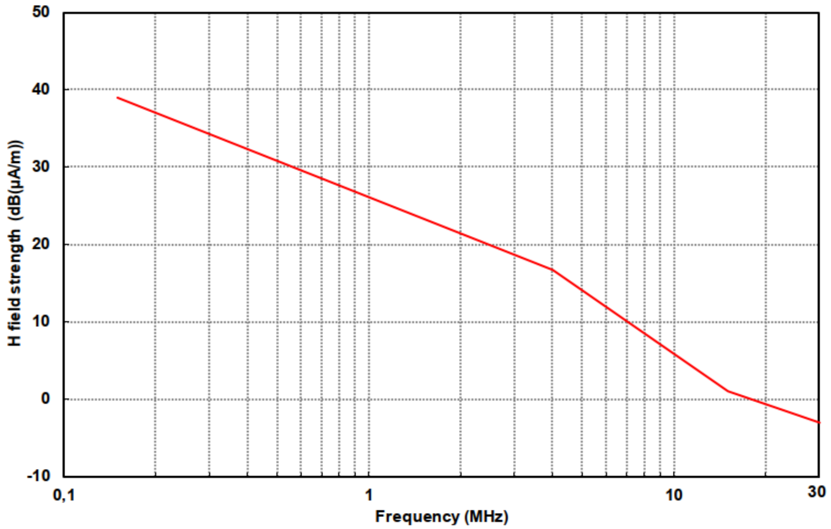
IEC CISPR 36 Special Task Force – Limit Justification

- CISPR 16-4-4 describes calculation of limits for disturbance field strengths along with recommendations on how to deal with statistics of radio complaints.
- 10 probability or influence factors included in the calculation which include; minimum value of the wanted field strength, radiation pattern of the disturbance source, typical gain of victim source, expected mean value building attenuation and the distance the source is likely to be from the victim.

CISPR 16-4-4 Limit Calculation



CISPR 36 Proposed CDV Limit



EMC AUTOMOTIVE STANDARDIZATION

ISO TC22/SC32/WG3

ISO/TC22/SC32/WG3

Vehicle Standard Status

- ISO 11451-1:2015 - General principles and terminology, Published 4th Edition – No on-going work
- ISO 11451-2: 2015 - Off-vehicle radiation sources, Published 4th Edition – No on-going work
- ISO 11451-3: 2015 - On-board transmitter simulation, Published 3rd Edition – No on-going work
- **ISO 11451-4:2013 – Bulk Current Injection (BCI), Published 3rd Edition**
- **ISO 11451-5 – New Standard Development - Reverberation Chamber**
- **ISO 10605: 2008 – Test methods for electrical disturbances from Electro Static Discharge, Published 2nd Edition**

ISO 11451-4: 2013 Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 4: Bulk current injection (BCI)

- Proposal to extend frequency spectrum to 3 GHz, include EV test conditions and Tubular Wave Coupler test method
- WD to be led by Japan and Germany with an anticipated International Standard in 2022

ISO/AWI 11451-5: Road vehicles — Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 5: Reverberation chamber

- As vehicle technologies advance the extrapolation of ECU's is considerable requiring a multi antenna position approach
- Ability to significantly decrease test times with full vehicle testing
- AWI being drafted by the German delegation
- Frequency spectrum likely to cover 100 kHz to 18 GHz
- Planned International Standard for 2023

Vehicle Reverberation – Daimler 2019

ISO/TC22/SC32/WG3
Component Standard Status

- ISO11452-1:2015 - General principles and terminology, Published 4th Edition – No on-going work
- ISO 11452-2: 2019 - Absorber-lined shielded enclosure, Published 3rd Edition – No on-going work
- ISO 11452-3: 2016 - Transverse electromagnetic (TEM) cell, Published 3rd Edition - – No on-going work
- **ISO 11452-4: 2011 – Harness excitation methods, Published 4th Edition**
- ISO 11452-5: 2002 - Stripline, Published 2nd Edition - No on-going work
- ISO 11452-8: 2015 - Immunity to magnetic fields, Published 2nd Edition – No on-going work
- **ISO 11452-9: 2012 – Portable transmitters, Published 1st Edition**
- ISO 11452-11: 2010 - Reverberation chamber, Published 1st Edition – No on-going work
- ISO 7637-1: 2015 - Definitions and general considerations, Published 3rd Edition – No on-going work
- **ISO 7637-2: 2011 – Electrical transient conduction along supply lines, Published 3rd Edition**
- ISO 7637-3: 2016 - Electrical transient transmission by capacitive and inductive coupling, Published 3rd Edition – No on-going work
- **ISO 7637-4: - New Standard Development - Electrical transient conduction along shielded high voltage lines only**
- **ISO 10605: 2008 – Test methods for electrical disturbances from Electro Static Discharge, Published 2nd Edition**

Component Standards

ISO 11452-4 & 11452-9 Future Development

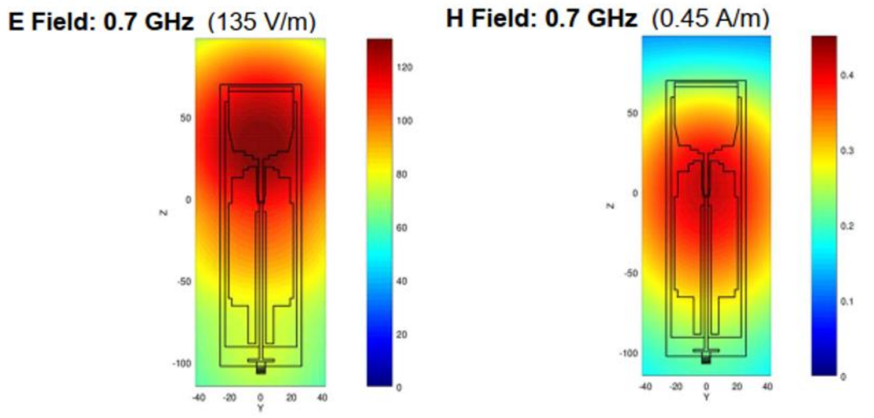
ISO 11452-4: 2011 Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 4: Harness excitation methods

- HV system test methods included along with updated Annex for associated Artificial Networks
- Currently at FDIS stage with a planned International Standard in June 2020

ISO 11452-9: 2012 Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 9: Portable transmitters

- New field characterisation procedure used to determine the required net power test level.
- Test methods for HV systems and Artificial Networks
- Inclusion of new broad band sleeve antenna with E&H field patterns
- Currently at 2nd CD Stage, with a planned International Standard in 2021

Broadband Sleeve Antenna E&H Field (50mm)



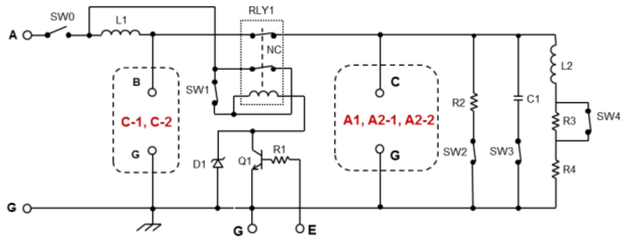
Component Standards

ISO 7637-2 Future Development

ISO 7637-2: 2011 Road vehicles — Electrical disturbances from conduction and coupling — Part 2: Electrical transient conduction along supply lines only

- New pulses A1, A2 and C moved from informative Annex into main body of the standard and are similar in origin to Pulses 1, 2a, 3a / 3b
- These pulses are not simulations however and are more representative of pseudo random vehicle applications due to the presence of reactive loads
- Plan to include 48V pulses 48a and 48b in new informative annex
- Currently at CD ballot stage
- Planned International Standard in 2021

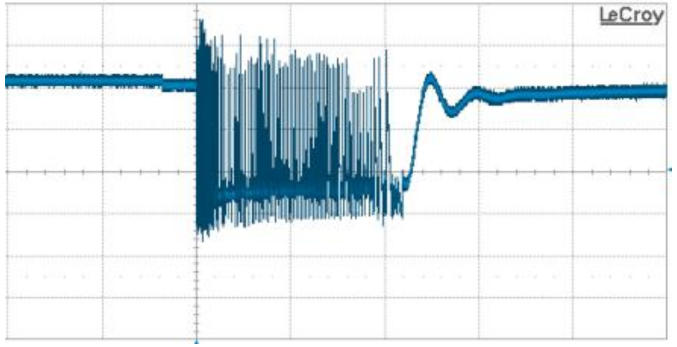
Pulse A1, A2 and C Generator



Key

R1: 51 Ω, 0.25 W	D1: Zener Diode, 39 V, 5 W
R2: 220 Ω ± 5%, 2 W	Q1: NPN transistor
R3: 33 Ω ± 5%, 10 W	SW0 – SW4: Single Throw Switch (10 contact rating)
R4: 6 Ω ± 5%, 50 W	RLY1: Relay Actuating System: AC Contact Arrangement: ≥ 2 PDT
C1: 100 nF PETP polyester film capacitor, 400 V	

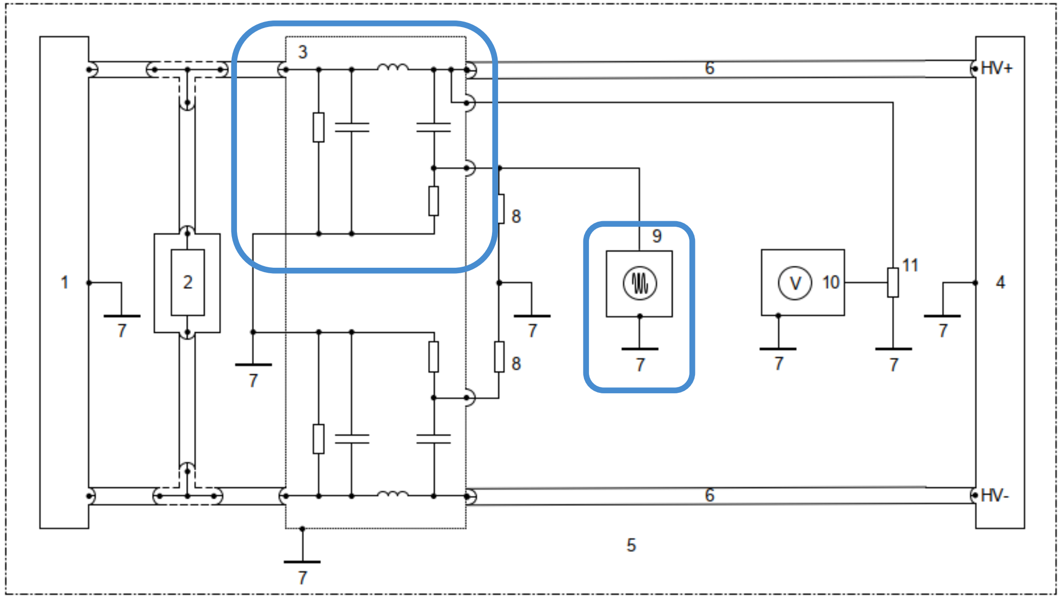
Pulse A2-1



ISO/DTS 7637-4: Road Vehicles — Electrical disturbance by conduction and coupling — Part 4: Electrical transient conduction along shielded high voltage supply lines only

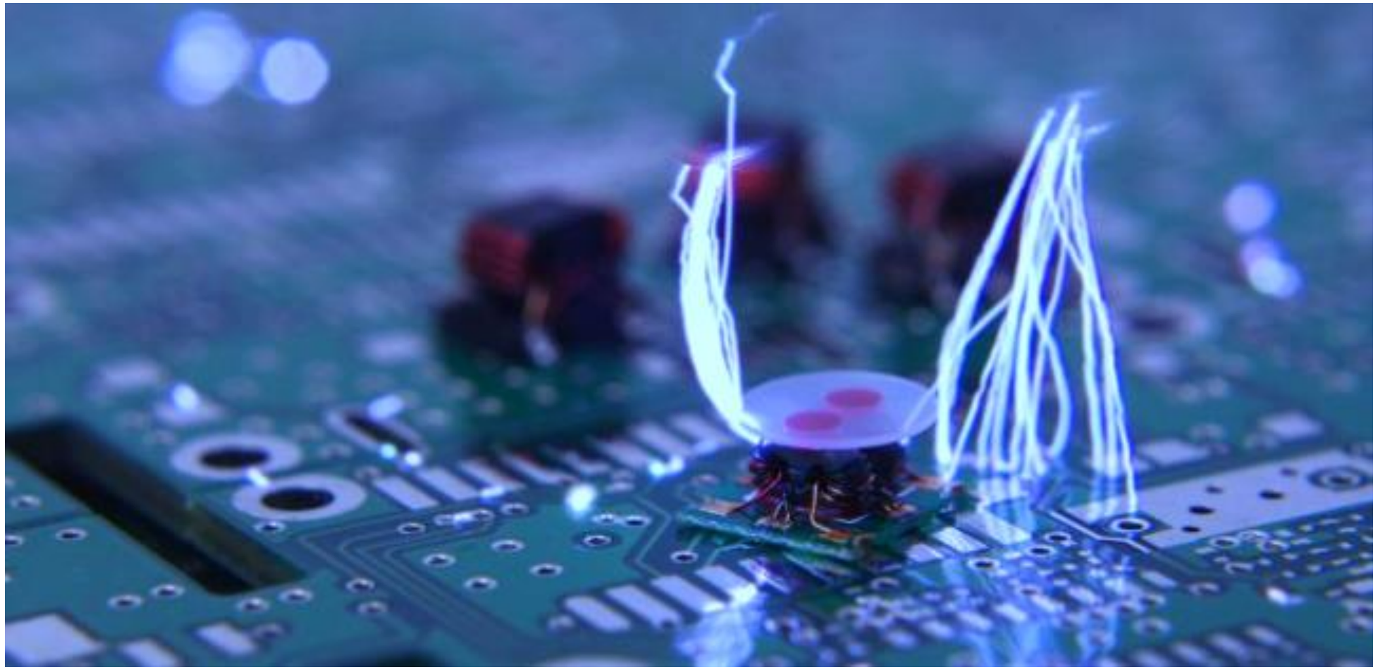
- Measurements performed line to line and HV to GND
- High Voltage transient emissions
- Pulse B represents ringing caused by switching operations of high voltage semiconductors at 1, 2, 5 and 10 MHz
- Pulse C represents sinusoidal waves generated by harmonics from the grid and revolutions from e.g. electric propulsion motors. Frequency range 3 kHz to 300 kHz
- Currently at DTS Stage, with planned Technical Specification in mid 2020

Typical Setup – Pulse B HV+ to GND



ISO 10605: 2008 Road vehicles — Test methods for electrical disturbances from electrostatic discharge

- WD being drafted by German and French delegations
- Possible inclusion of new Annex for measurement uncertainty and automated test methods
- Planned issue date TBC



ISO/TC22/SC32/WG3

Development Road Map

Reverberation Vehicle	ADAS & V2X	Functional Safety	Magnetic Field	Reference Immunity
Vehicle Reverberation Test Method	Development of reference standard for test methods of Advance Driver Assistance Systems (ADAS) and Vehicle to Everything (V2X) Equipment	Functional Safety ISO 26262 ASIL Levels	Creation of new standard for Magnetic Field tests at vehicle level	Reference standard for immunity testing

EMC AUTOMOTIVE STANDARDIZATION

UNECE Regulation 10.06

History of Automotive Legislation

UNECE Regulation 10

06 series of amendments to UN Regulation No. 10 (Electromagnetic compatibility) Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility.

- Automotive EMC Legislation 72/245/EEC (and subsequent amendments) was repealed on 1 November 2014 by EU regulation 661/2009
- The changes introduced through EU regulation 661/2009 as corrected and amended, designates UNECE regulation No. 10, Revision 3
- The EU Commission's aim with Directive 2007/46/EC was to establish a competitive legal framework for motor vehicles
- Directive 2007/46/EC will be repealed by Regulation 2018/858 on 1 September 2020
- UNECE Regulation 10.06 issued on 15 November 2019

E/ECE/324/Add.9/Rev.6–E/ECE/TRANS/505/Add.9/Rev.6

20 November 2019

Agreement

Concerning the Adoption of Harmonized Technical United Nations Regulations for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these United Nations Regulations*

(Revision 3, including the amendments which entered into force on 14 September 2017)

Addendum 9 – UN Regulation No. 10

Revision 6

06 series of amendments – Date of entry into force: 15 October 2019

Electromagnetic compatibility

This document is meant purely as documentation tool. The authentic and legal binding text is: ECE/TRANS/WP.29/2019/20.

UNITED NATIONS

* Former titles of the Agreement:
Agreement concerning the Adoption of Uniform Conditions of Approval and Reciprocal Recognition of Approval for Motor Vehicle Equipment and Parts, done at Geneva on 20 March 1958 (original version);
Agreement concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions, done at Geneva on 5 October 1995 (Revision 2).

UNECE Regulation 10.06

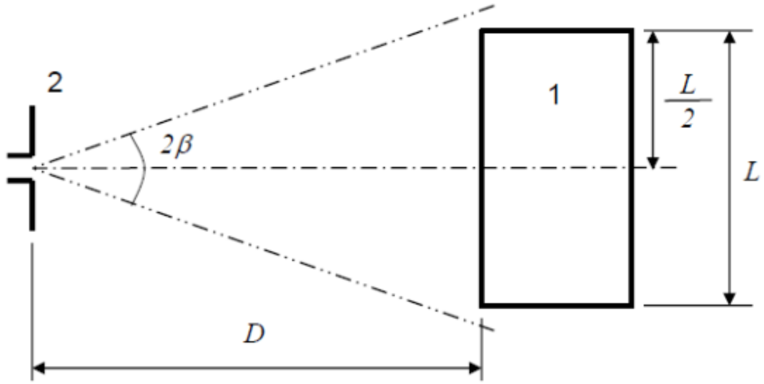
Technical Changes

- Addition of vehicle categories T, R and S for consistency with commission delegated regulation (EU) 2015/208
- Definition of "immunity related functions" updated to include indirect vision & blind spot systems and emergency calling. Note, the list is not exhaustive and shall be adapted for technical evolution of vehicles technologies
- Updates to charging mode descriptions for Mode 1, Mode 2, Mode 3 and Mode 4 in line with IEC 61851-1
- Pulse 4 has been removed for REESS LV lines as there is no starter / cranking motor for these applications.
- Transitional Provision section modified to include two bespoke sections for the 05 Series and 06 Series respectively, with transitions concerning 03 and 04 series removed. Transition will allow the use of 05 Series until 1 September 2022
- Reduction of DC charging current for Annex 4, 7, 13, 14, 19 and 20 from a nominal 80% to a value to be agreed with the Technical Service
- Electric or hybrid motor engines may be operated in their dynamic mode with transmission shafts, belts or chains disconnected to achieve the same operation condition for the propulsion test
- Change from facility to vehicle reference point for consistency with the latest revision of ISO 11451-2

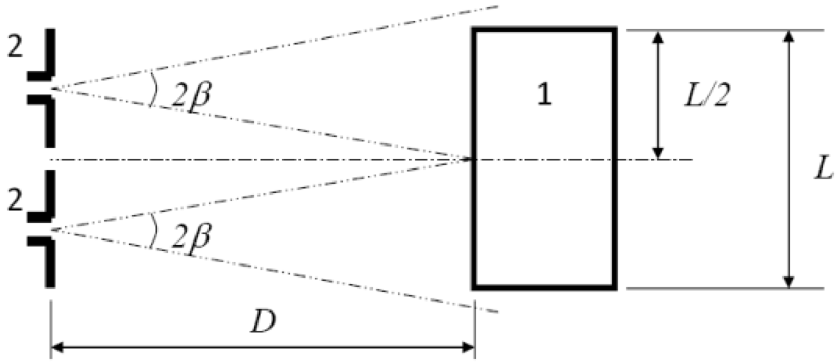
Annex 4 & 5 Antenna Position With Respect To The Vehicle

- Multiple antenna positions may be required for both 10m and 3m antenna distance
- If the length of the vehicle is smaller than the 3dB beam-width of the measurement antenna, only one antenna position is necessary and shall be aligned to the centre of the vehicles length
- If the length of the vehicle is greater than the 3dB beam-width of the antenna, multiple antennas will be necessary and be symmetric with regards the vehicles perpendicular axis

Single Antenna Approach



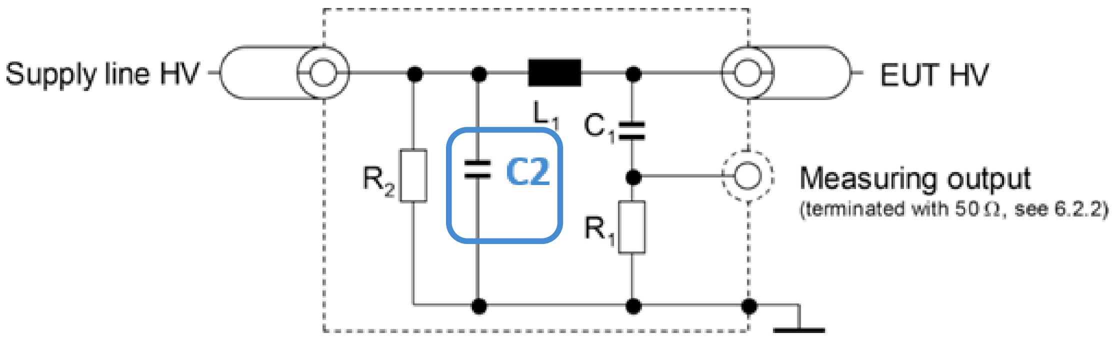
Multiple Antenna Approach



Appendix 8 – AN, HV-AN, DC-AN, AMN and AAN’s

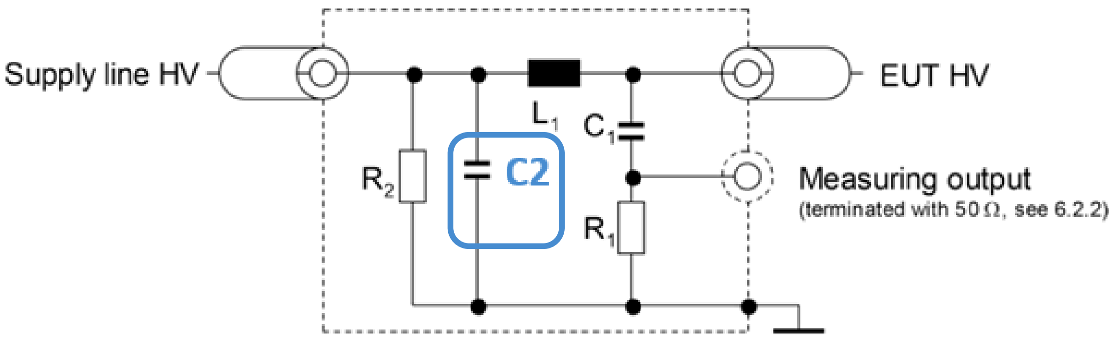
Appendix 8 updated with reference to Artificial Networks, commercial Artificial Mains Networks and Asymmetrical Artificial Networks along with new DC Charging AN

High Voltage Artificial Network



C2: 0.1µF

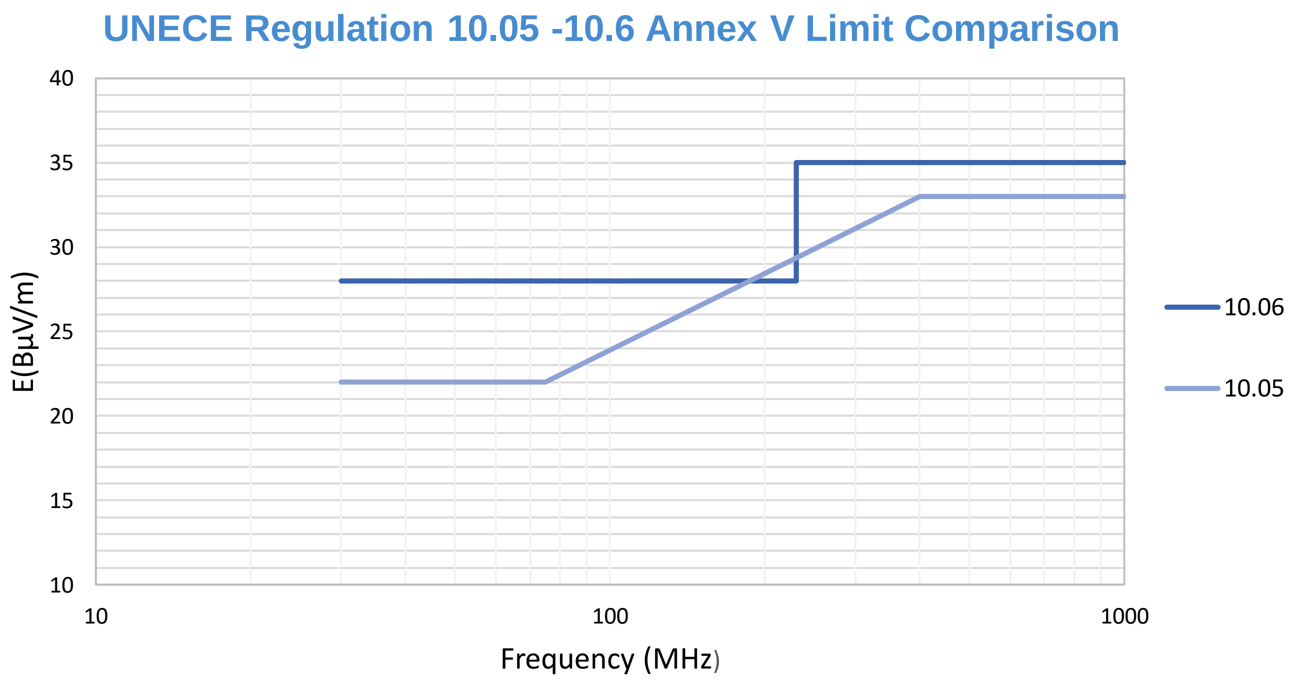
DC-Charging Artificial Network



C2: 1µF

UNECE Regulation 10.06 - Annex 5 Narrowband Average Limit Modification

- Annex V limits modified in line with IEC CISPR 12, but reduced by -2dB
- Limit changed to 28 dBµV/m in the 30 to 230MHz frequency band and 35dB dBµV/m in the 230 to 1GHz
- Results in a 6dB relaxation below 75 MHz and 2dB above 400 MHz



The automotive sector is going through unprecedented change, there's a strong and welcome desire for environmental change, safer roads , zero emissions and zero fatalities.

Emerging vehicles will be electrified with intelligent systems making all of us safer drivers and in time autonomous vehicles will bring independent mobility to us all.

This brings new challenges to the standards and directives we create and as such the responsibility in their development is now even more crucial than it once was.

Standardisation and legislation will always lag technology, but through collaboration with equipment providers such as Rohde & Schwarz, we will ensure we have the right toolsets available to enable the development and validation of our future road vehicles

Emerging Topics in Automotive EMC: Risk-Based Systems Engineering

Alastair Ruddle – Chief Scientist, Vehicle Resilience

Background

Why do we need to change?

- Vehicle EMC traditionally has heavy reliance on physical testing
  - Relatively late in development, when hardware becomes available
  - Demonstrating compliance with legislative requirements, developed for conventional (ICE) vehicles
  - Many manufacturers apply in-house requirements (generally based on standard tests e.g. higher immunity test levels)
- Modern vehicle complexity is rapidly out-growing capabilities of current development methods and tools
  - Sub-systems developed in isolation, with limited system knowledge, increasing risk of developing “brittle” systems
  - Emerging technologies bringing new threats e.g. cyber security
  - Standards struggle to keep pace with deployment of new technologies
- Major disasters such as Challenger and Columbia are considered to have resulted from a failure to map, manage and mitigate risks appropriately
- More robust EMC engineering methods are needed
  - Employing a risk–based approach
  - Based on more holistic systems thinking

Current Automotive Trends

Their features and EM-related threats

ELECTRIFICATION

High current, low frequency traction currents
Switching devices (inverters, converters)
Wireless power transfer (~85 kHz now, >100 kHz in future)

CONNECTIVITY

GSM, DAB, DTV, 3/4/5G, GNSS, WiFi, Bluetooth, SDARS, V2X
High volumes of data traffic (infotainment, situational)
Personal devices and integration

Low frequency magnetic fields (EMC and EMF)
Connection to electrical grid
Architectural flexibility

Antenna performance and integration issues
Impact of poor propagation environments
Higher speed data transfer

Human exposure to RF transmissions, EMC and cyber security (jamming, spoofing, tracking, eavesdropping , IEMI, unauthorised control)

Reduced EM shielding by structure
Possible antenna performance impacts
Novel interconnects (printed, reconfigurable)

Higher frequency EMC issues
Active EM Sensors (RADAR, LIDAR)
Potential for EMC issues in complex systems

Low permeability conductors
Non-conductors, poor conductors
Replacement of conventional wiring

LIGHT-WEIGHTING

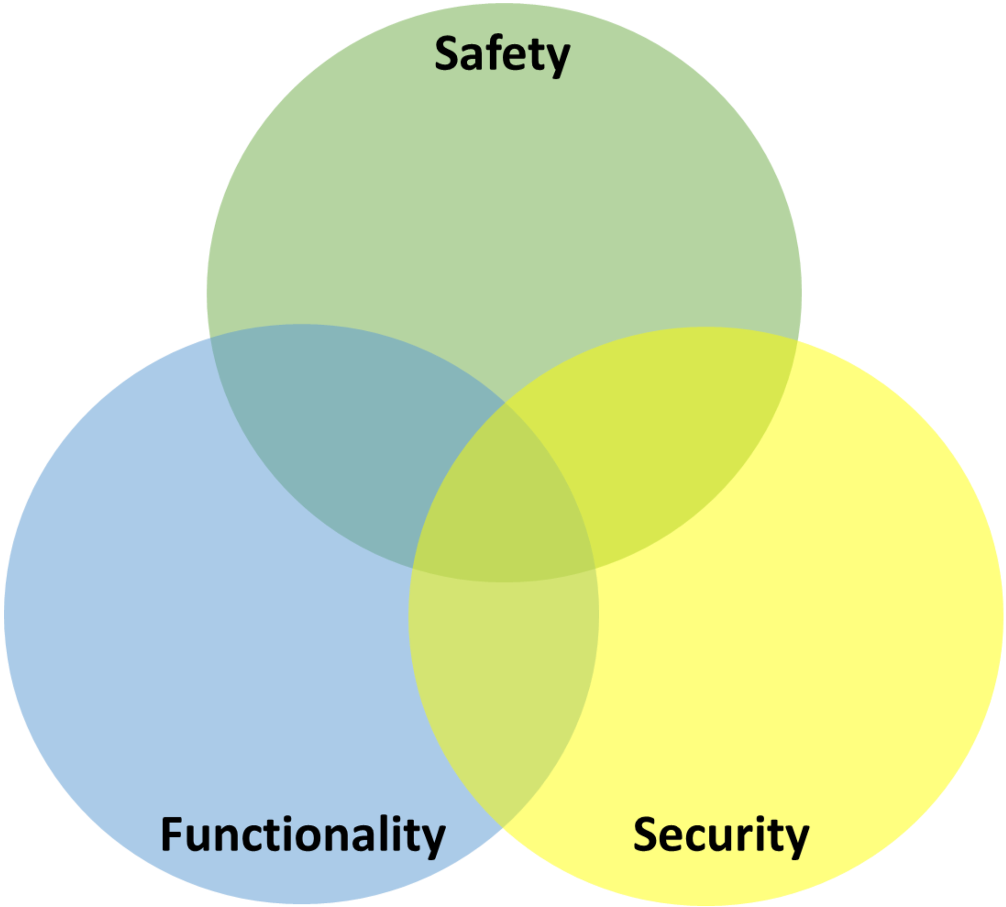
Automated Driving
Advanced Driver Assistance Systems (ADAS)
Very high system dependability requirements

AUTOMATION

Vehicle Resilience

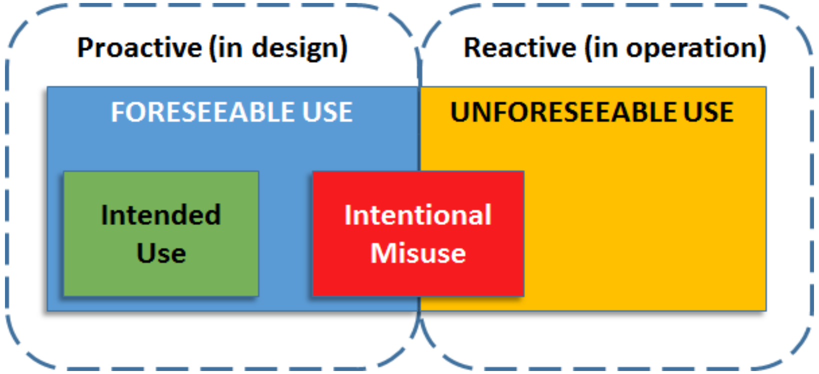
What does it mean?

- **Resilience**
  - The persistence of "dependability" in the face of change
- **Dependability**
  - Functionality – reliability, availability, maintainability and durability
  - Safety – functional safety and inherent safety of systems
  - Security – confidentiality, integrity and availability of data
- **Vehicle resilience**
  - Ability to ensure the continued execution, or timely resumption, of its essential functions, safely and securely
  - Accommodating/mitigating foreseeable safety hazards and other potential threats
  - Enabling a graceful degradation of performance otherwise



- Hazards and threats – may affect one or more, and even all, aspects of dependability

- Here, "use" includes the wider aspects of system behaviour and operating environment – not just what user controls
- Only considering the "intended use" scenarios is not sufficient to achieve resilience
  - Need to proactively consider "unintended uses" that a **reasonable** user might undertake or encounter
    - Driving a car onto grass – Yes, numerous valid reasons to go off-road
    - Exposure to EMI threats – Yes, feature of the operating environment
    - Driving a car into a lake – No, reckless behaviour
    - Driving to kill or injure – No, unlawful behaviour
  - Includes "intentional misuses" that may be foreseeable during design
    - Experience with computers and mobile phones makes cyber security attacks foreseeable for connected vehicles
    - Exposure to security threats is not due to reckless or unlawful user activity – but could lead to unauthorized external control
  - Not all unintended uses are foreseeable
    - These can only be addressed reactively as they emerge
    - Unforeseen use/misuse subsequently becomes foreseeable as "lessons learned"



Mission-critical Functionality

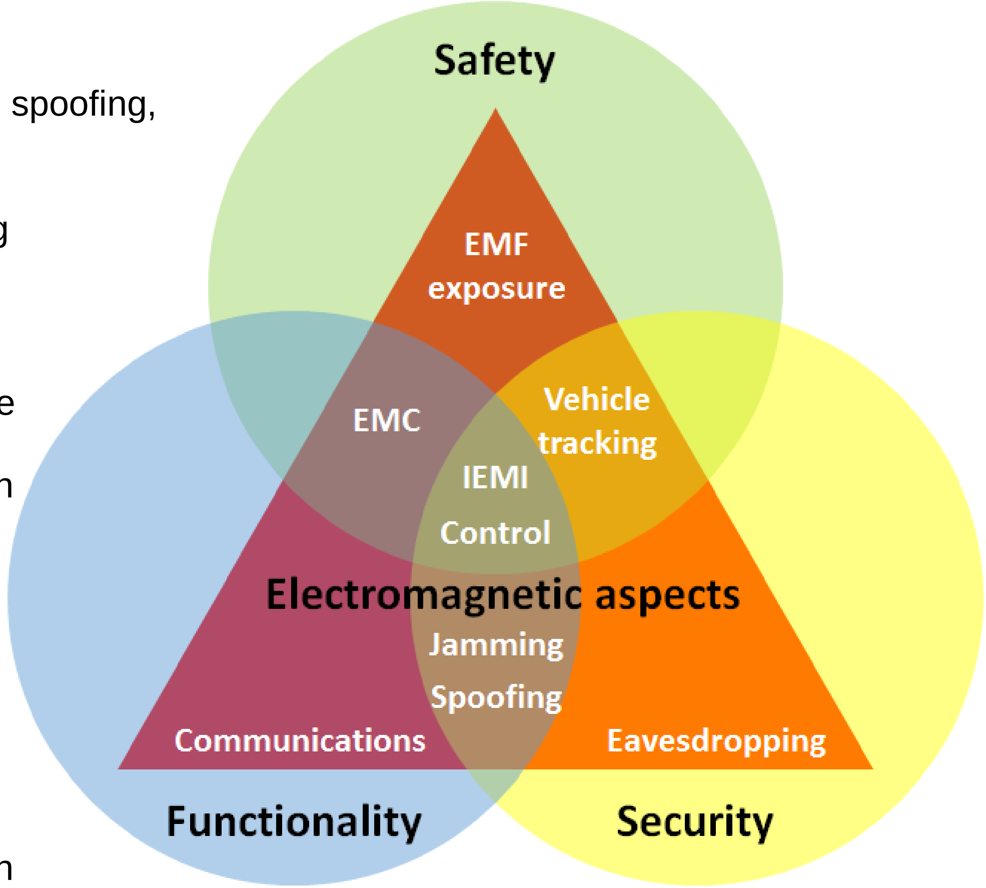
More than just safety-related functions

- Primary mission-critical function is clearly to provide safe transport for the user
- For the vehicle manufacturer, the mission involves more than that
    - Satisfying legislative requirements, ensuring customer satisfaction, building brand reputation
- Safety is clearly of great importance, but other aspects are not insignificant
    - Poor radio reception is amongst most common customer complaints
- Rising vehicle connectivity is making performance of wireless communications services increasingly important
    - Customer expectation in a “connected world”
    - May be critical for some driving automation functions
- Aircraft requirements (Design Assurance Levels) already mix safety and functionality aspects
- Rising vehicle connectivity is also making cyber security increasingly important in the automotive sector
    - Development also needs to take account of potential for misuse

Electromagnetic Resilience

More than EMC

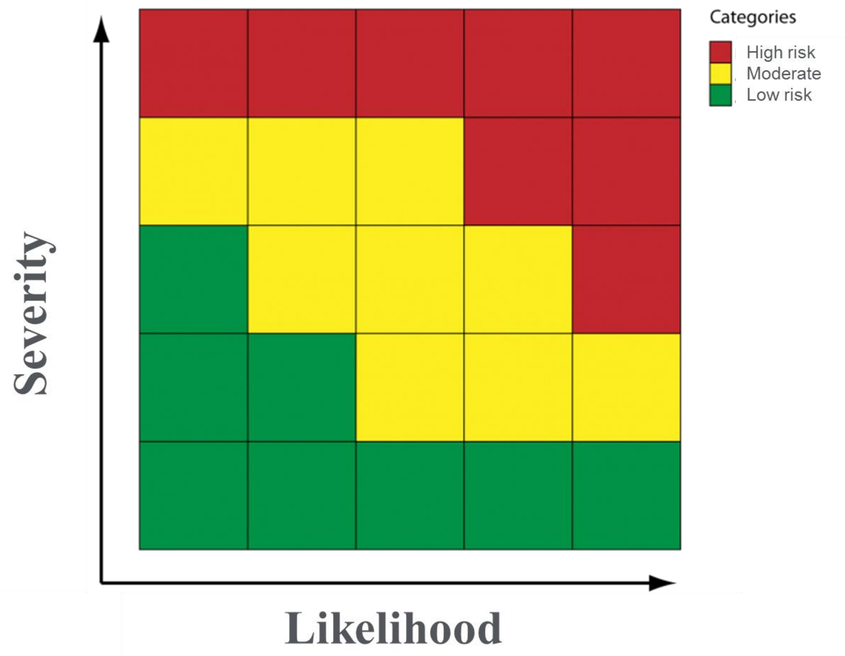
- Security (misuse) threats
    - Operational threats – IEME (intentional EMI), wireless jamming and spoofing, and unauthorised remote control
    - Privacy threats – unauthorised eavesdropping, vehicle/user tracking
- Safety
    - Operational threats – RF and low frequency magnetic field exposure
    - Environmental threats – off-board transmitters, poor RF propagation
    - Misuse threats – IEMI, jamming, spoofing, unauthorised eavesdropping, tracking or control may all compromise safety
- Mission-critical functionality
    - Operational threats – personal transmitters, intra-vehicle EMC
    - Environmental threats – off-board transmitters, poor RF propagation
    - Misuse threats – IEMI, jamming, spoofing, and unauthorised remote control may all compromise mission-critical functionality



Risk Assessment

Functional safety approach

- IEC 61508 (process industries), ISO/IEC 26262 (automotive specific)
  - Zero risk is unachievable
  - Safety must be considered from the outset
  - Where risks are considered unacceptable, measures must be employed to reduce the risks to a level that is considered to be “broadly acceptable”
  - Only concerned with potential safety impacts of functional failures in programmable electrical/electronic systems
- Safety risk parameters
  - **Hazard** – a specific situation that may result in harm
  - **Severity** – degree of harm associated with a specific hazard
  - **Likelihood** – probability of occurrence of a specific hazard
- Risk – in general, $Risk = f(Severity, Likelihood)$
  - ISO 26262 includes an additional “controllability” factor to reflect the potential for driver to influence outcome under hazardous conditions



Risk Mapping

Risk Assessment

Need for a systems approach

- **Severity** of outcome
    - Can only be determined at system level – impact on stakeholders (users, operators etc.)
- **Likelihood** of occurrence
    - For complex systems depends on chain of circumstances that lead to the undesired outcome
    - Likelihood depends on individual contributor likelihoods
- **Risk** is a system-level attribute
    - Depends on **severity** as well as **likelihood**
- Risk may have different components
    - Safety, Security and Functionality
    - Also need to consider overlapping areas and subsidiary risk aspects
- Functional safety already uses a risk-based systems engineering approach
    - Provides a basis for developing a unified approach with wider applicability

ISO 26262 Severity Classification

Safety, and its extension to wider cyber security issues

- Severity for functional safety
    - Based on order of magnitude change in levels of personal injury
    - Only those people directly involved in resulting accident are affected
- Key differences for cyber security
    - Safety is only one aspect that may be compromised by security threats
    - Security threats may also compromise other aspects of concern for stakeholders
        - Privacy, Financial, Operational
    - Some security threats may be deployed against entire classes of vehicles, potentially affecting very large numbers of vehicles and people
    - Threat agents and capabilities vary widely (hobby hacking to rogue government)
    - Security threats are constantly evolving, driven by human ingenuity

ISO 26262 Severity category	Physical harm to vehicle occupants and other road users
S0	No injuries.
S1	Light or moderate injuries.
S2	Severe and life-threatening injuries (survival probable).
S3	Life threatening (survival uncertain) or fatal injuries.

Severity for Automotive Cyber Security

Proposed in FP7 EVITA project

Severity category	Categories of harm to stakeholders			
	SAFETY (S_S)	PRIVACY (S_P)	FINANCIAL (S_F)	OPERATIONAL (S_O)
S0	No injuries.	No unauthorized access to data.	No financial loss.	No impact on operational performance.
S1	Light or moderate injuries.	Anonymous data only (no specific driver or vehicle data).	Low-level financial loss (~€10^1).	Operational impact not discernible to driver.
S2	Severe and life-threatening injuries (survival probable). Light/moderate injuries for multiple vehicles.	Identification of vehicle or driver. Anonymous data for multiple vehicles.	Moderate financial loss (~€10^2). Low losses for multiple vehicles.	Driver aware of performance degradation. Indiscernible operational impacts for multiple vehicles.
S3	Life threatening (survival uncertain) or fatal injuries. Severe injuries for multiple vehicles.	Driver or vehicle tracking. Identification of driver or vehicle, for multiple vehicles.	Heavy financial loss (~€10^3). Moderate losses for multiple vehicles.	Significant impact on operational performance. Noticeable operational impact for multiple vehicles.
S4	Life threatening or fatal injuries for multiple vehicles.	Driver or vehicle tracking for multiple vehicles.	Heavy financial losses for multiple vehicles.	Significant operational impact for multiple vehicles.

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S4	Life threatening or fatal injuries for multiple vehicles.	Driver or vehicle tracking for multiple vehicles.	Heavy financial losses for multiple vehicles.	Significant operational impact for multiple vehicles.

This is just a descriptive severity scale – it is not intended to imply equivalence of associated risks!

Severity for Mission-Critical Functionality

Based on “operational” element of EVITA severity categories

Severity category	Categories of harm to stakeholders			
	SAFETY (S_S)	PRIVACY (S_P)	FINANCIAL (S_F)	OPERATIONAL (S_O)
S0	No injuries.	No unauthorized access to data.	No financial loss.	No impact on operational performance.
S1	Light or moderate injuries.	Anonymous data only (no specific driver or vehicle data).	Low-level financial loss (~€10^1).	Operational impact not discernible to driver.
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S4	Life threatening or fatal injuries for multiple vehicles.	Driver or vehicle tracking for multiple vehicles.	Heavy financial losses for multiple vehicles.	Significant operational impact for multiple vehicles.

FUNCTIONALITY

“Operational” category is also relevant to mission-critical functionality issues

Safety Hazards of Correctly Functioning Equipment

Electromagnetic field exposure

- Functional safety only addresses those safety risks that are due to faults
- Some electronic systems have safety risks even in normal operation
    - Exposure to electromagnetic fields
- In-vehicle human exposure to intentional transmissions and stray electromagnetic fields
    - On-/off-board RF transmissions
    - Wireless power transfer (WPT) for traction batteries, personal devices
    - Low frequency magnetic fields due to traction current waveforms
- Bystanders and domestic animals are also potentially at risk from stationary WPT

- Several potential issues associated with EM field exposure
- Direct effects on biological tissues
    - Electro-stimulation: 1 Hz to 10 MHz
    - Tissue heating: 100 kHz to 10 GHz
    - Skin heating: 10–300 GHz
- Indirect effects on human body
    - Metallic implants – direct heating, field enhancement
    - Body-worn and active implanted medical devices (AIMD)
- Possible chronic exposure effects
    - Considered questionable, as causal mechanisms unclear
    - Already some related national legislation at power frequencies
    - Cancers, neurological effects etc.

Possible EMF Severity – 100 kHz to 10 MHz

Categories based on EU field criteria and functional safety injury criteria

- EU exposure limits
  - 1999/519 should protect all (general public) from acute effects, and lower levels also possible chronic effects
  - 2013/35/EU acute effects should be tolerable for healthy adults (workers)
- All direct and indirect effects are possible in this band
- Difficulties
  - Range of effects
  - Range of frequencies
  - Effects differ by frequency
  - Metrics differ by effect
  - Lack of data for some effects
- Insufficient information can be compensated for by increased (more conservative) severity

Field exposure relative to EU field reference levels	Severity categories for direct and indirect effects				
	Electro-stimulation	*Tissue heating*	*Metallic implant heating*	*AIMD EMC*	*Possible chronic effects*
<E>, <H>, |E|, |H| << 1999/519/EC	S0	S0	S0	S0	S0
|E|, |H| ≤ 1999/519/EC	S0	S0	S1	S1	S1
<E>, <H> ≤ 1999/519/EC	S0	S0	S1	S2	S1
1999/519/EC < |E|, |H| < 2013/35/EU	S1	S1	S2	S3	S2
1999/519/EC < <E>, <H> < 2013/35/EU	S2	S2	S3	S3	S2
<E>, <H>, |E|, |H| > 2013/35/EU	S3	S3	S3	S3	S3

Risk Assessment for Vehicle Resilience

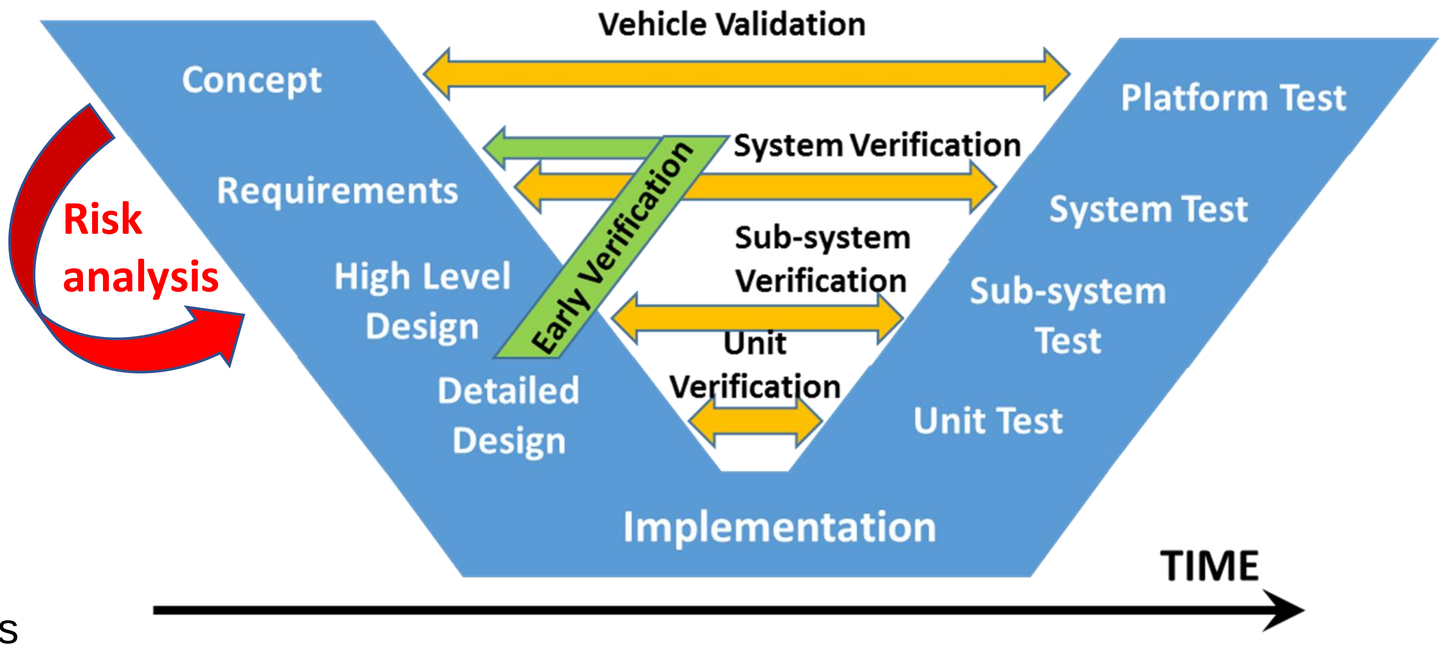
Classification options

Risk Aspect	System Safety	Cyber Security	Mission-Critical Functionality
Severity	ISO 26262 Severity (functional safety hazards) EVITA Severity (security related safety hazards) Bespoke for specific issues (e.g. EMF hazards)	EVITA Severity (privacy and financial threats)	Mission-Critical Functionality Severity (functional failures, environmental threats etc.) EVITA Operational Severity (security related operational threats)
Likelihood	ISO 26262 Exposure (functional safety and SOTIF, e.g. EMF) EVITA Probability (security related safety hazards)	EVITA Probability (security related threats)	ISO 26262 Exposure (non-safety/security threats) EVITA Probability (security related threats)
Controllability	ISO 26262 Controllability (functional safety hazards)	ISO 26262 Controllability (safety related security threats only)	*Not applicable*
Risk mapping	ISO 26262 Risk Graph (functional safety hazards) IEC 61508 or MISRA Risk Graph (Bespoke for electromagnetic hazards) EVITA Risk Graph (security related safety hazards)	EVITA Risk Graph (privacy and financial threats)	IEC 61508 or MISRA Risk Graph (non-safety/security threats) EVITA Risk Graph (security related operational threats)

Risk-based Electromagnetic Engineering

Integration with current development processes

- Threat and risk analysis should be initiated as early as possible
- Significant risks should be identified and investigated by "early verification"
- Early verification tools could include
  - Theoretical analysis
  - Representative simulations
  - Representative experiments
- Early verification results will indicate whether risks may be tolerable or must be mitigated with additional design constraints and requirements
- Risk-based approach should reduce the need for difficult and costly rework in the later stages of the "V" cycle



Risk-based vs. Rules-based Approaches

Pros and cons

Rules-based approach

Pros

- Applying EMC design rules/guidelines and standard tests should limit potential for EMC issues (“belt and braces” approach)

Cons

- Often not possible to apply guidelines in all cases: then what – how does one prioritize?
- Does not guarantee necessary performance
- May result in costly over-engineering
- Standard tests may not be relevant to technology
- Unexpected issues do not become apparent until late in development, or even during operation

Risk-based approach

Pros

- Aims to ensure that EMC measures are proportionate to foreseeable threats, thus optimising effort and costs
- Encompasses wider EM aspects beyond EMC
- Risks associated with new/emerging technologies are considered and specific measures/tests defined
- Should reduce to potential need for difficult and costly rework late in development when prototypes become available for test

Cons

- Requires additional effort in early stages of design and development

Risk-based electromagnetic engineering

Summary

- Rapidly changing automotive technology and increasing system complexity indicate a need for new approaches to automotive EMC and related electromagnetic engineering issues
- Reliance on EMC standards will not be sufficient to achieve the resilience and dependability required for future vehicles
- Holistic risk management approach promotes overall resilience of vehicle electronic systems to foreseeable hazards and threats (including human and environmental)
- Systems approach is essential to assess implications of sub-system behaviour for user experience
- Risk-based approach of automotive functional safety can be adapted to wider aspects of vehicle resilience
    - Cyber security
    - Mission-critical functionality
    - Safety issues for correctly functioning equipment (EM field exposure)
- Unified approach offers potential for reuse in overlapping areas, promoting greater efficiency in development
- EM aspects are significant for all these areas, although functional safety does not yet address EMC adequately
- Development of these approaches is on-going

The automotive industry is embarking on a journey that will create some of the most intricate and complex super-systems on the planet.

Major disasters, such as Challenger and Columbia, are considered to have resulted from a failure to map, manage and mitigate risks appropriately.

The adoption of more robust, risk-based systems engineering practices will be key to meeting the challenges of ensuring electromagnetic resilience in future vehicles.