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GRIMETON
Radio Station

Magnetic fields in vehicles generated by DC current ripple

Björn Bergqvist

Lennart Hasselgren

IEEE presentation at Grimeton meeting Security Class: Open

2022-05-17

Content

1. Background
2. Challenges in vehicles
3. Generation of requirements
4. Emission measurement methods
5. Corresponding immunity test

Magnetic fields in vehicles

Sources:

- Magnetic material
- Currents

Victims:

- Electronics
- Hall-effect sensors
- Humans

Need for requirements (1)

Sensitive components can be exposed.

Typically position and torque sensors.

Can be affected if close to magnetic material.

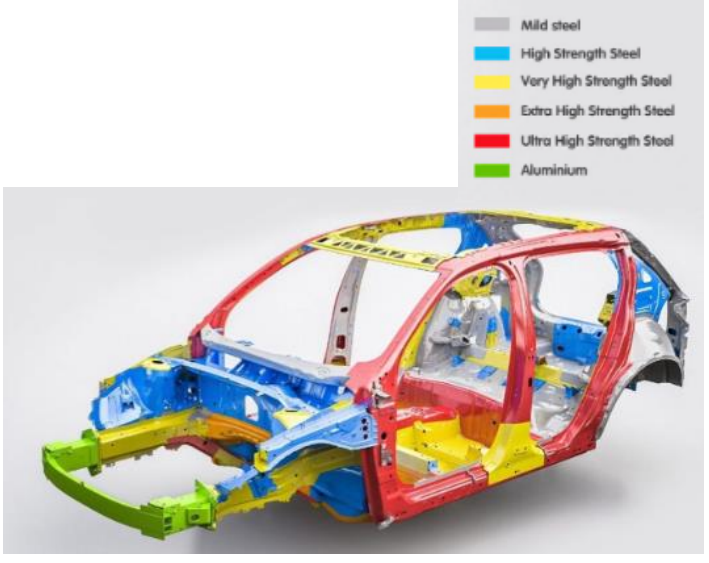
Factor to address:

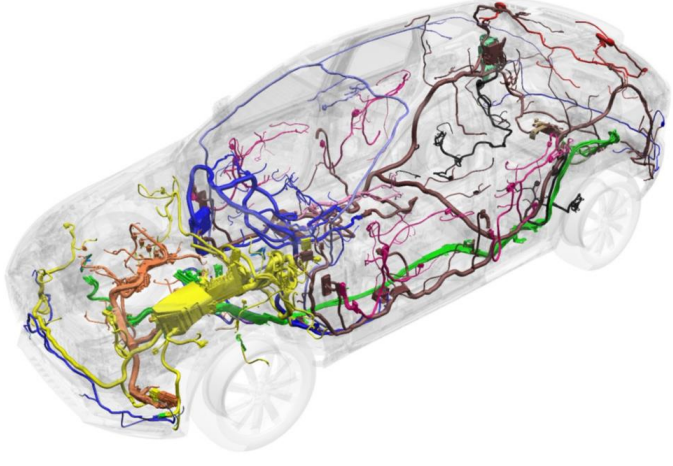
- Magnetization
- Distance

Can be affected if close to currents in cables or chassis.

Factors to address:

- Current amplitude
- Current frequency
- Distance (to cable and between leads)





Need for requirements (2)

Humans in the vehicle can be exposed if close to:

- Magnetic material (magnets).
- Point sources (transformers, radios …).
- Currents in cables or chassis.

ICNIRP review research and propose limits.

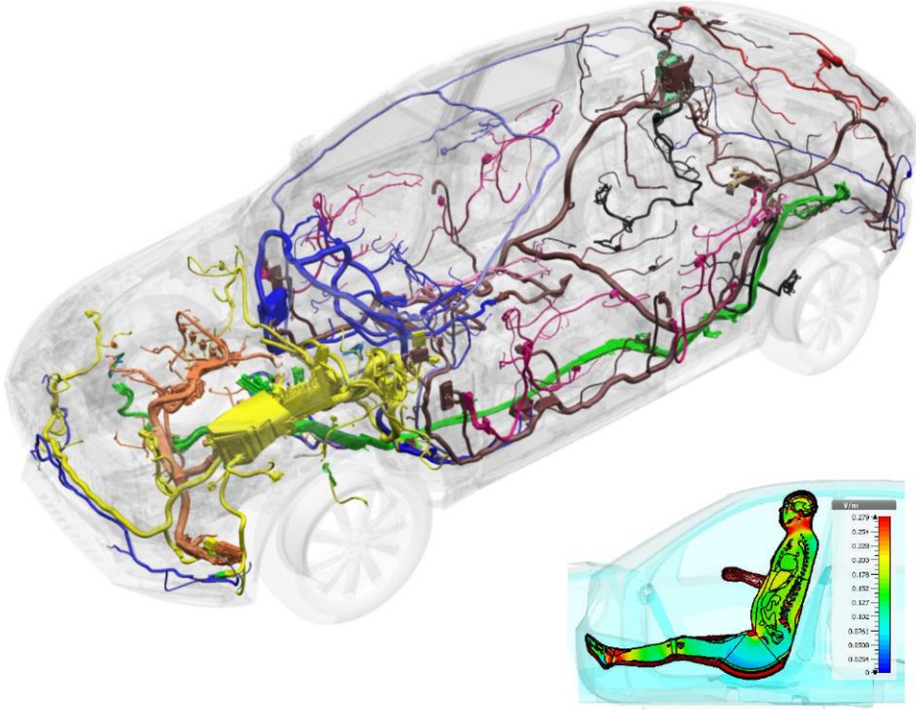
- ICNIRP reports 1998, 2010 and 2020

Authorities set legal requirements and recommendations.

- Directive 2013/35/EU, Council Recommendation 1999/519/EC
- GB 8702_2014 (Controlling limits for Elec. Mag. Env. China)

Precautionary principle.

- Possible long term effect of low level exposure.
- WHO(internat.), SSM (national), Customer satisfaction (e.g. China)



Example of Chinese rating systems: CCRT

- Measurements according to GB/T37130-2018
- Score based on margin to GB8702-2014

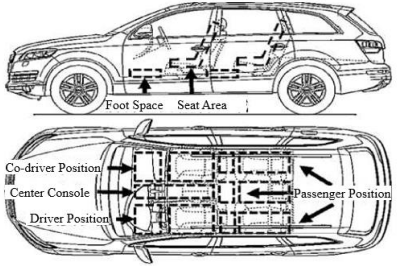


Figure 1 Example of Measuring Position of M-class Passenger Vehicle in Static Mode and Driving Mode

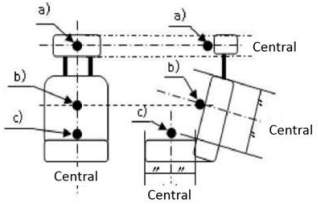
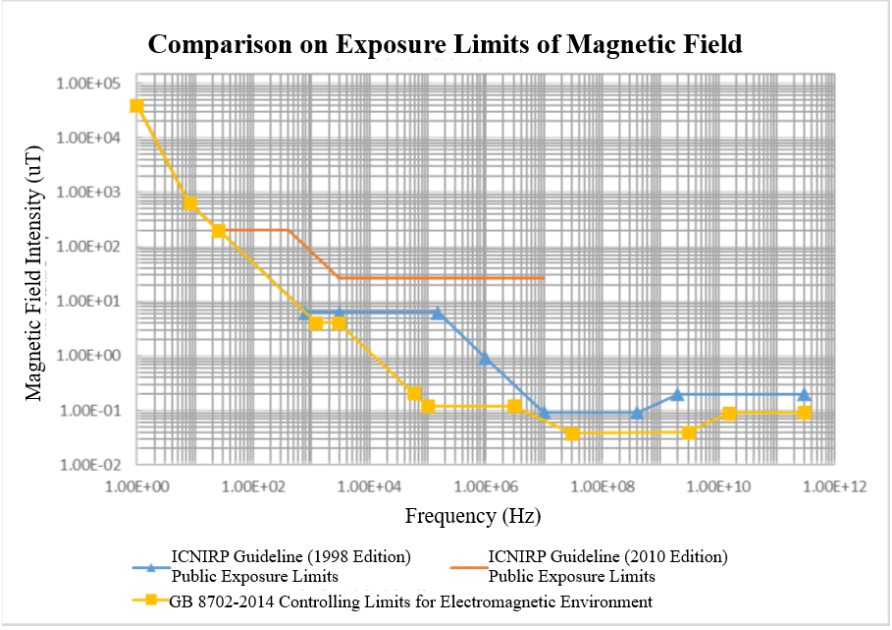


Figure 2 Example of Measuring Point of Seat Position

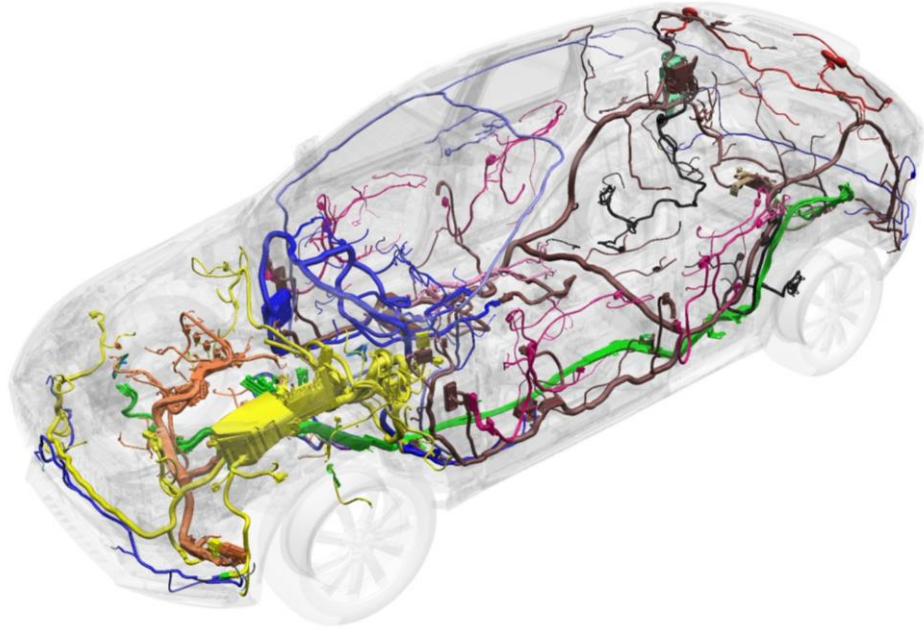


name	Margin (dB)	Score coefficient
	≥25	100
Human electromagnetic protection	15	60
	3	20
	<3	0

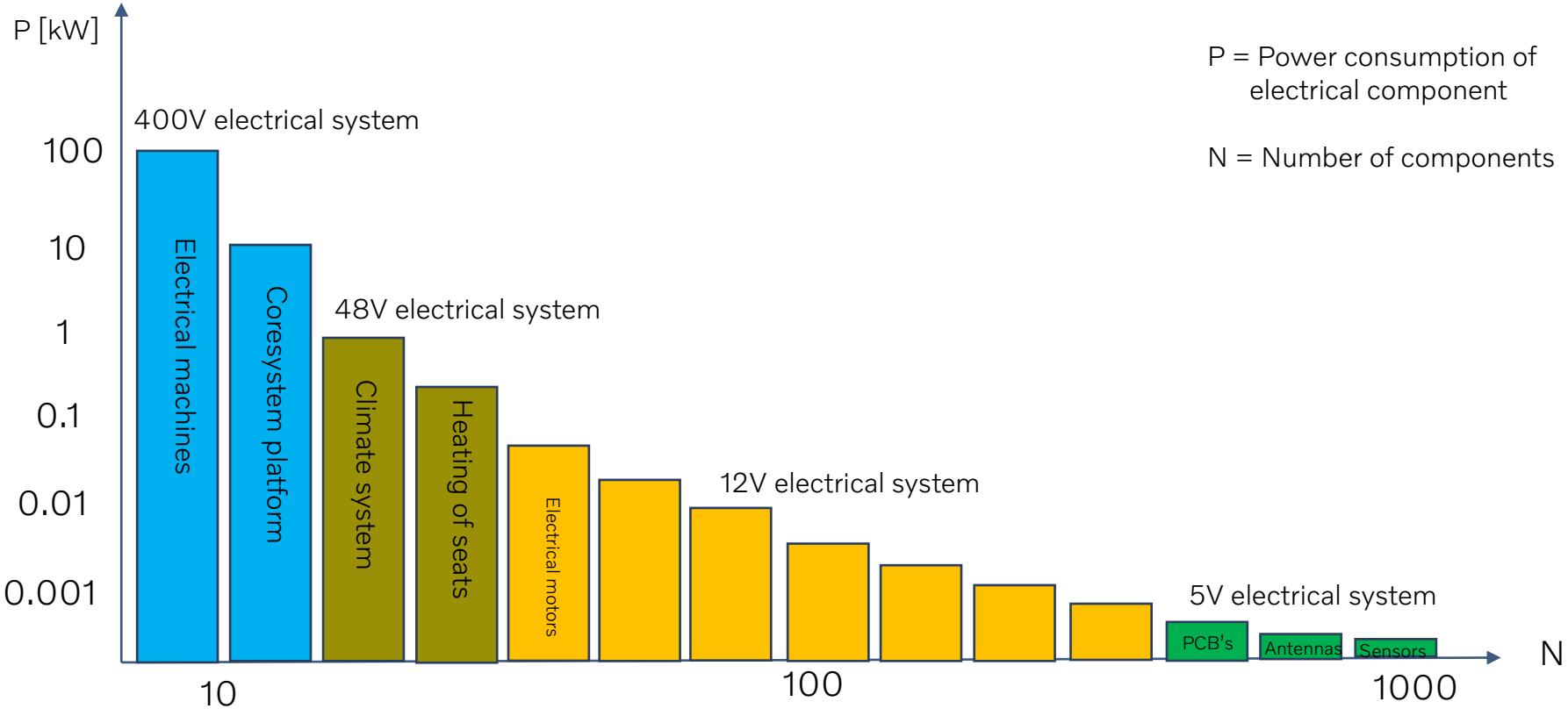
Challenges: EMF

The challenge in the vehicle I would say is the small distance between sources and victims.

- High power sources, up to 10^2 kW
- High currents up to 500A
- Transmitters 100 kHz to 80 GHz
- Power regulation using PWM

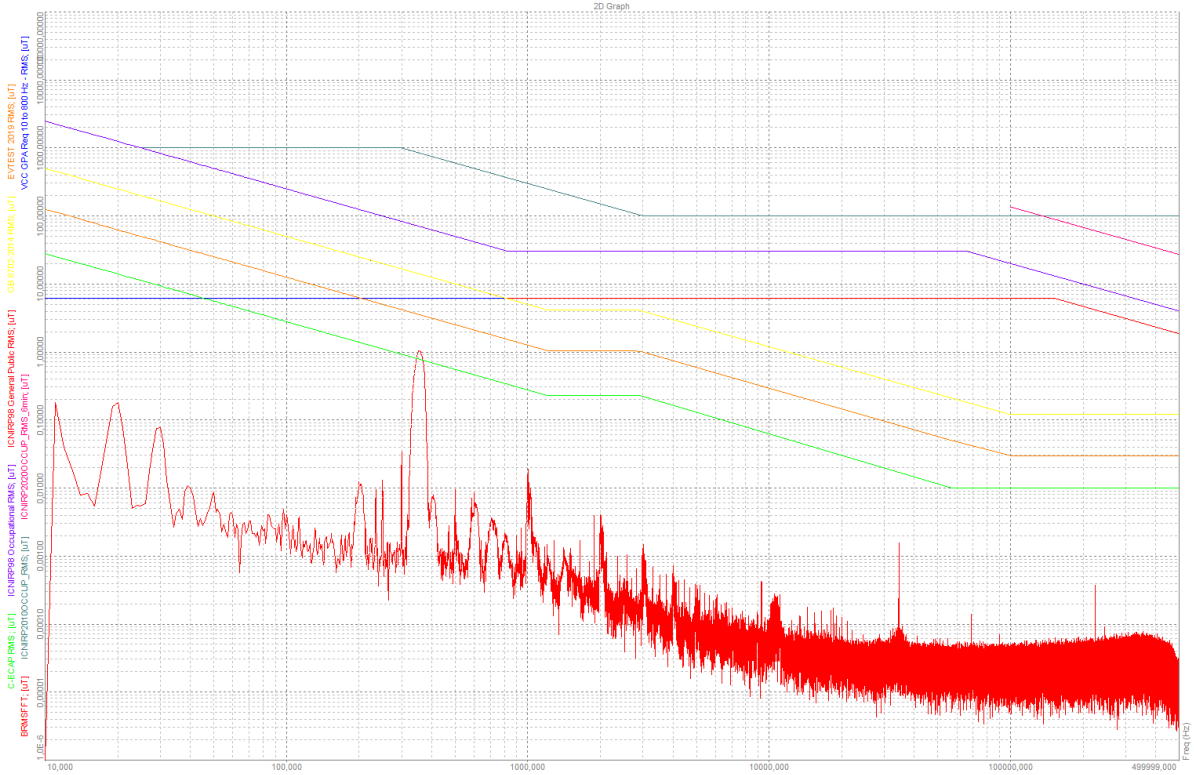


Challanges: Sources and victims – Comparison of power levels



Challanges: Example of magnetic field spectrum in vehicle

- Often many different sources
- Complicated spectrum
- Very different situation compared to other environments with one dominant source e.g. radio.

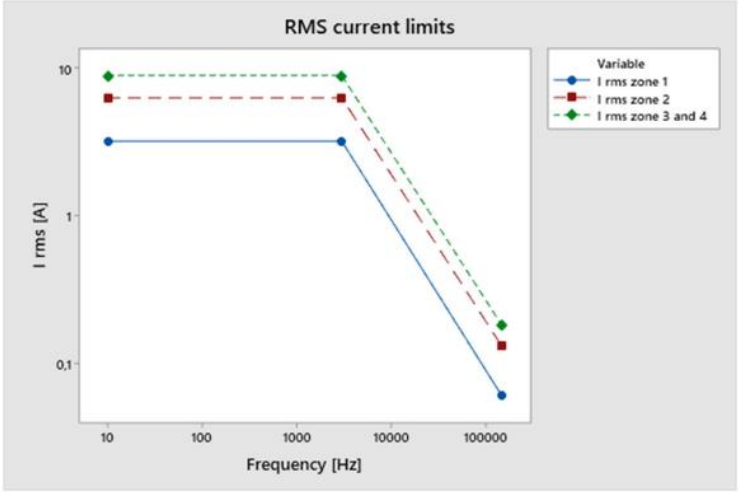


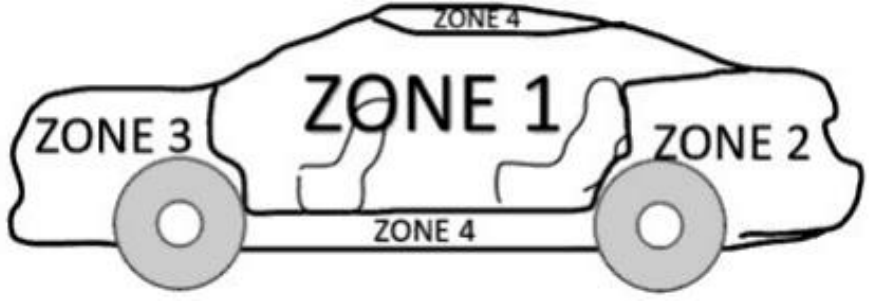
Factors to address in a ripple current requirement

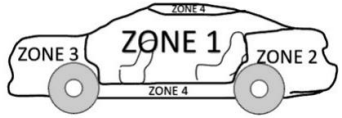
- Magnetic field at sensitive components.
- Magnetic field exposure of humans.
- Ripple current immunity on other components on the power bus.

Ripple Current Requirement: Here we have the answer.

Frequency [Hz]	Zone 1 I rms (A)	Zone 2 I rms (A)	Zone 3 I rms (A)	Zone 4 I rms (A)
10	3,20	6,30	8,9	8,9
3 k	3,20	6,30	8,9	8,9
150 k	0,06	0,13	0,18	0,18
	I peak (A)	**I peak (A)**	**I peak (A)**	**I peak (A)**
Peak amplitude in time domain	4,5	8,9	N/A	N/A



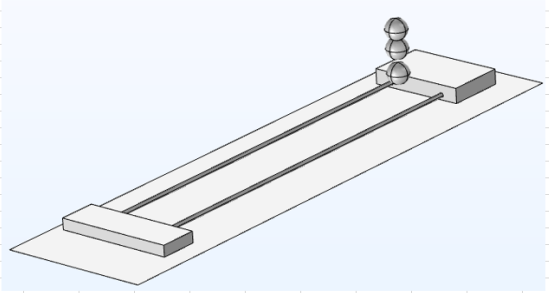




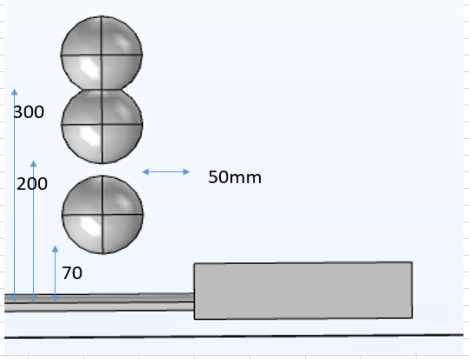
1. Allowed current calculated from EMF requirement in vehicle.

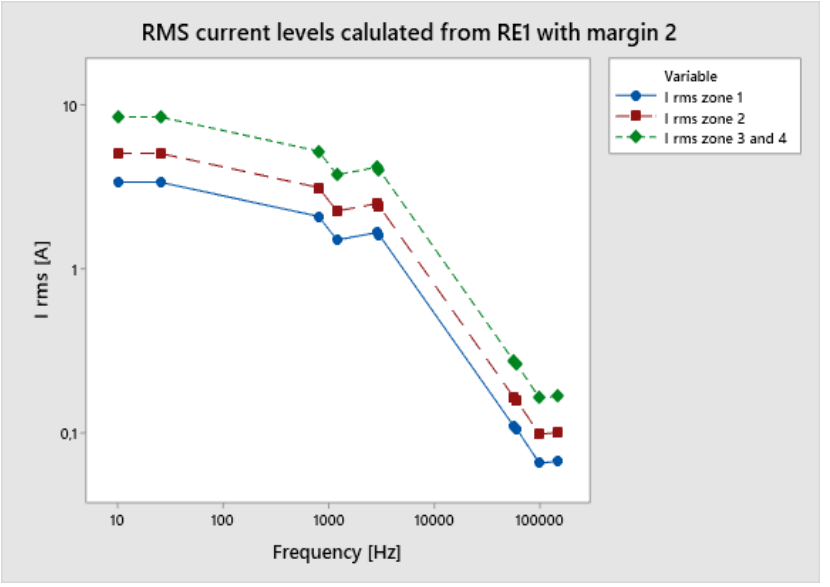
Material properties of ground plate:		
Permeability:	140	
Conductivity:	4MS/m	(Revised from previously used value according to information from Tata Steel)
Thickness:	0.7mm	

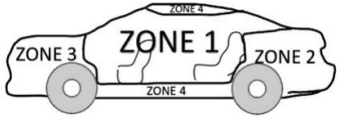
30cm distance between cable centers



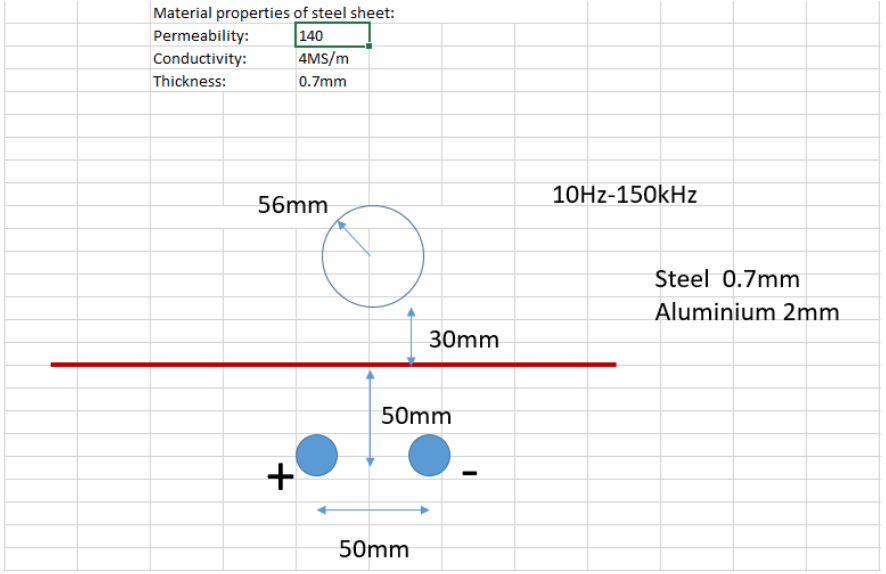
Positions for B field sensors

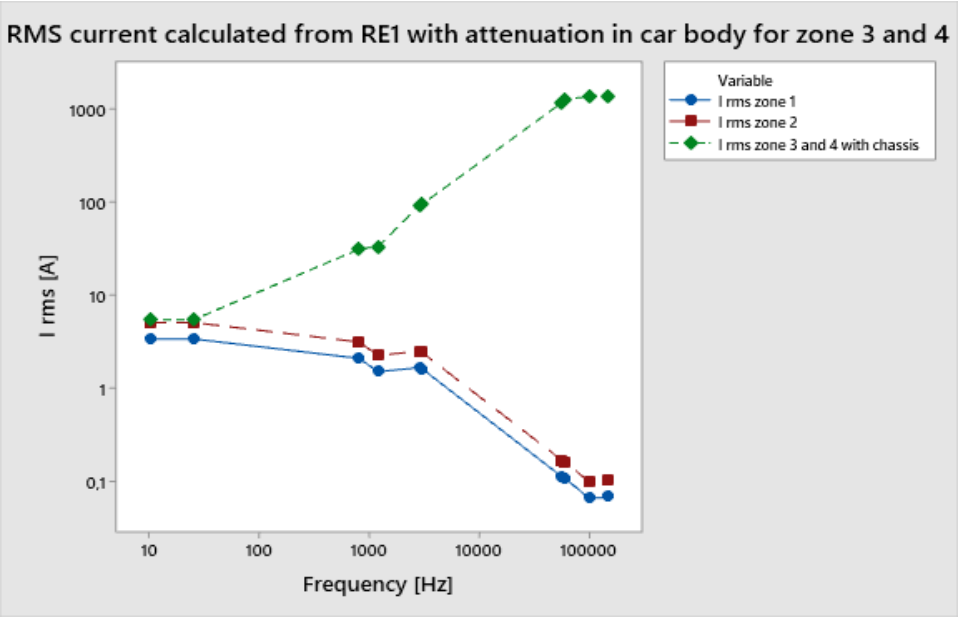


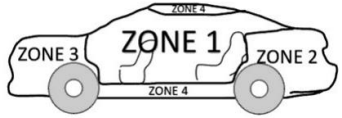




2. Allowed current calculated from EMF requirement in vehicle. Compensated for shielding effectivness in car body.





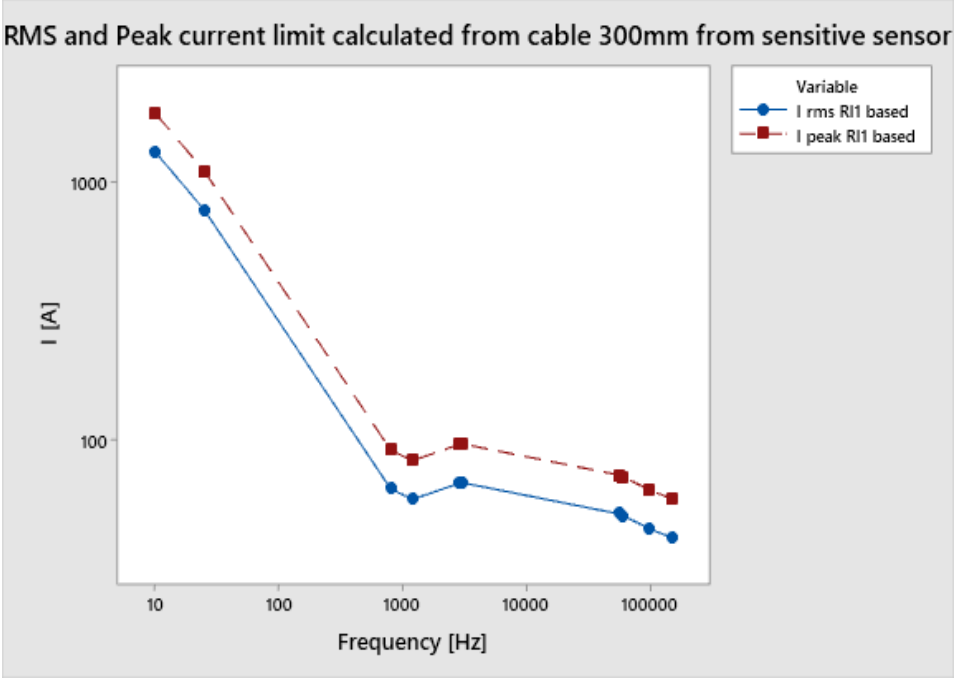


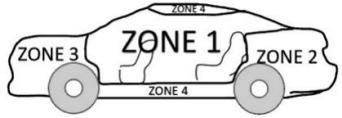
3. Allowed current calculated from magnetic field immunity of components.

Input:

- Packaging guideline for sensitive components.
- Magnetic field immunity requirement of component.

Calculation of allowed current vs. frequency from those.



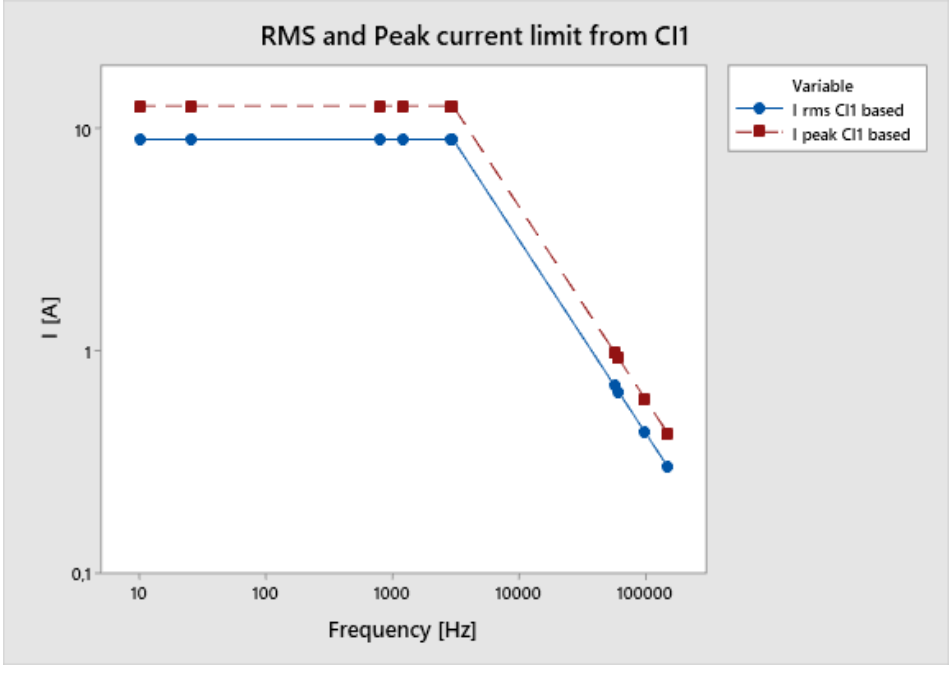


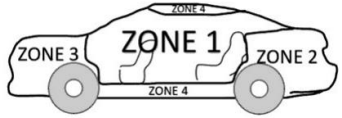
4. Allowed current calulated from Conducted immunity of components.

Input:

- Conducted immunity requirement of component. (Internal quality requirement)

Calculation of allowed current vs. frequency from those.



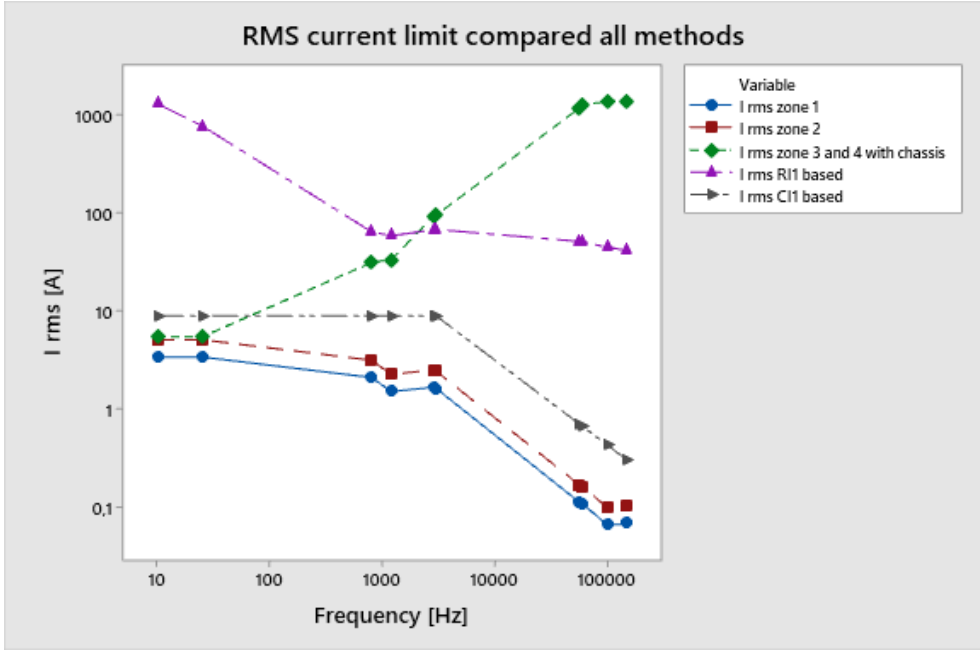


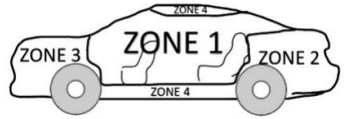
5. Adding them all together

All steps 1-4 added together.

In this plot we can find which factor that is the limiting factor in different zones and frequencies.

(EMF, Magnetic field immunity of components or Conducted ripple current immunity of components)





Ripple Current Requirement: This was our balanced compromise.

This was the result of the balancing of all the factors.

Aim is to:

- Handle the complete vehicle level.
- Make it as easy as possible for the suppliers.
- Get input to simulations (will be explained).
- Build data-base for future predictive modelling.

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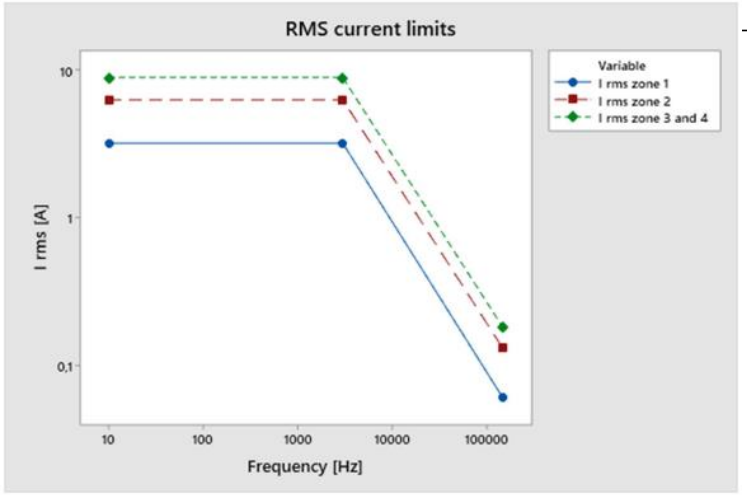

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Emission test methods

Measuring ripple effect – challenging ISO 21498

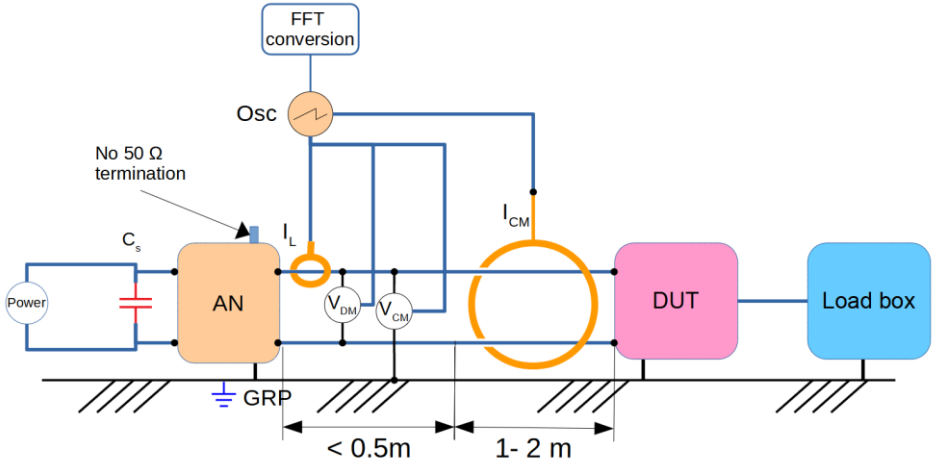
Method options. Ambition: try to find something existing

1. ISO 21498 (HV power quality)
   - Special equipment – difficult to build
   - Focused on HV systems
   - Focus on voltage ripple
     - But field of interest is magnetic (= currents shall be measured)
2. MIL STD 461, CE101 (LF conducted emission)
   - Existing method
   - Peak measurement
   - LISN impedance not relevant for HV systems
3. CISPR 25 (vehicle component emission)
   - Setup relevant for vehicle
   - Only above 150 kHz
   - Related to radio disturbances
4. EN 61000-3-2 (power harmonics)
   - Current harmonics measurement
   - Only up to 2 kHz
   - Related to thermal damages
   - AC power systems only

LF emission measurement – the selected choice: CISPR 25

Modified CISPR 25 as follows

- Keep main setup, available in most EMC labs
- 1 extra capacitor to be built
  - Large value and high voltage = big (but feasible)
- Measurement in time domain
  - Both current and voltage
  - Both CM and DM
- RMS values
  - Since it is related to both RadHaz and thermal risk
- Calibration data for AN + C_s requested
- Result report in both time and frequency domain



Advantages with the method

1. No special equipment – easy to create
   - Only HV capacitor to build
2. Setup relevant for vehicle
   - We do not need to rearrange the DUT compared to other emission tests
3. Challenge: to have a suitable measurement system for time domain data
4. System simulation possible
   - Synchronized measurement in time domain of current and voltage
   - Calibration data on LISN
   - = 2-port simulation DUT model feasible
5. From the models, system simulation is feasible
   - The system response is the prime target
6. Goal: combine component models and cable routing models to predict magnetic field in vehicle
   - Well before the complete vehicle build

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Immunity methods

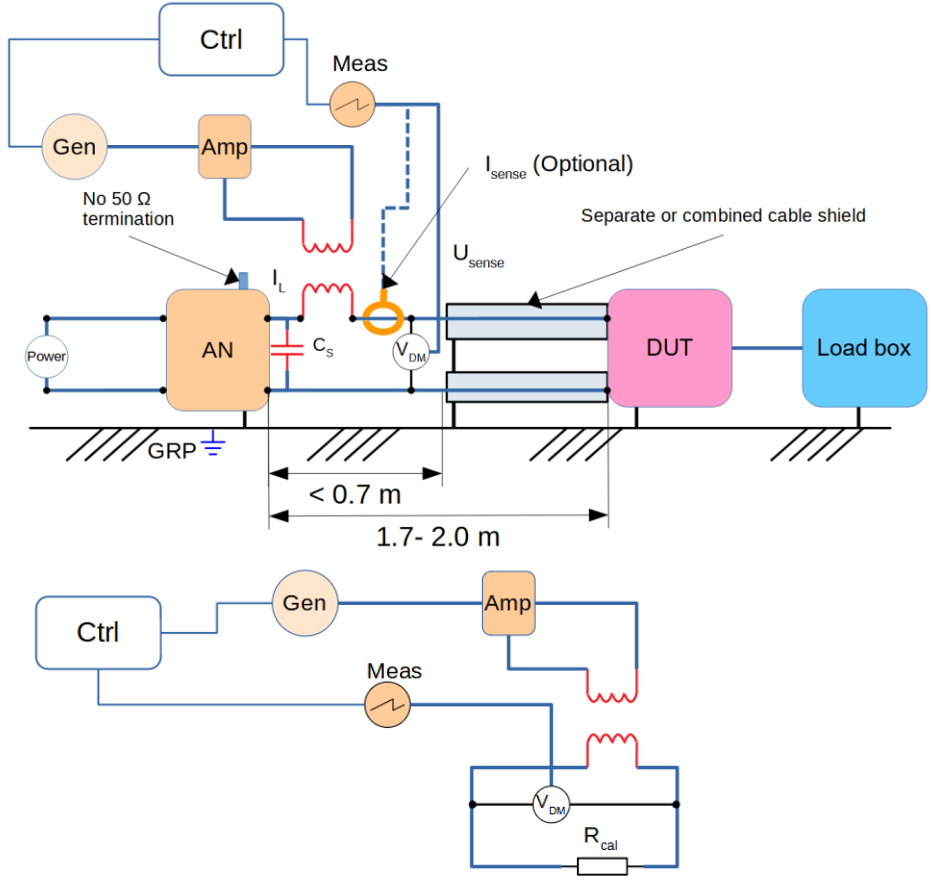
Measuring ripple impact – challenging ISO 21498

Method options . Ambition: try to find something existing

1. ISO 21498 (HV power quality)
   - Special equipment – difficult to build the Impedance Stabilization Network (ISN)
   - Focus on voltage ripple
     - But immunity problems are related to currents
2. MIL STD 461, CS101 (LF conducted immunity)
   - Existing method
   - Voltage regulation
   - Power limitation procedure
3. ISO 11452-4 (Bulk Current Injection, BCI)
   - Setup relevant for vehicle
   - Only above 100 kHz
   - Related to radio disturbances
4. ISO 16750-2 (LV vehicle power quality)
   - 12/24V power quality ripple
   - Only up to 20 kHz (but 150 kHz is feasible with ordinary equipment)
   - Focus on voltage only – no power limitation
   - LV power systems only
5. EN 61000-4-16 (LF conducted immunity)
   - Only CM ripple
   - Voltage method

LF immunity test – the selected choice: CS101

- MIL STD 461, CS101
  - available in most EMC labs
- NO extra equipment to be built
  - Reuse the same capacitor as in the emission measurement – just place it on the other side
- Modified settings
  - f = 10 Hz – 150 kHz
  - test level 3 dB offset from emission requirement, constant up to 20 kHz
  - Pmax = 160 W (calibrated in 0.5 ohm)
- Additional procedure:
  - Record the resonance frequencies
  - Repeat test at each resonance
    - 3 minute duration
    - Register malfunction or temperature increase. Challenge: how much increase is OK?



Result scenarios with different sense regulation (example)

Ohms law + power law: $U=RI$, $P=U^2/R = RI^2$

R_{cal} = 0.5 Ω, P_{max} = 80W -> I_{max}=9A, U_{max}=9V

R_{DUT}	I_{sense} method	U_{sense} method
1 Ω	I=9A (current limit) -> U=9V P_{out}=80W	U=9V (voltage limit) -> I=9A P_{out}=80W
0.5 Ω	I=9A (current limit) -> U=4.5V P_{out}=40W	U= $\sqrt{Pmax \times R}$ = 6.3V (power limit) -> I=12.6A P_{out}=80W
4 Ω	I= $\sqrt{\frac{Pmax}{R}}$ =4.5A (power limit) -> U=18V P_{out}=80W	U=9V (voltage limit) -> I=2.25A P_{out}=20W

Immunity response on system level

- The ripple test is intended to simulate the effect of high ripple current into the test object
  - Thermal effect
  - Disturbance on sensor signals
- Worst case in the system happens when the major part of the ripple current is concentrated into one of the components.
- This happens when that component has a *low impedance* resonance at a certain frequency
- The overheating is caused by the combination of the regular DC power loss – and the additional ripple power dissipation
- Focus shall be put on stressing the test object at these possible resonances
- But: the *actual* resonance effect is not shown until we build the complete system

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Thank you!