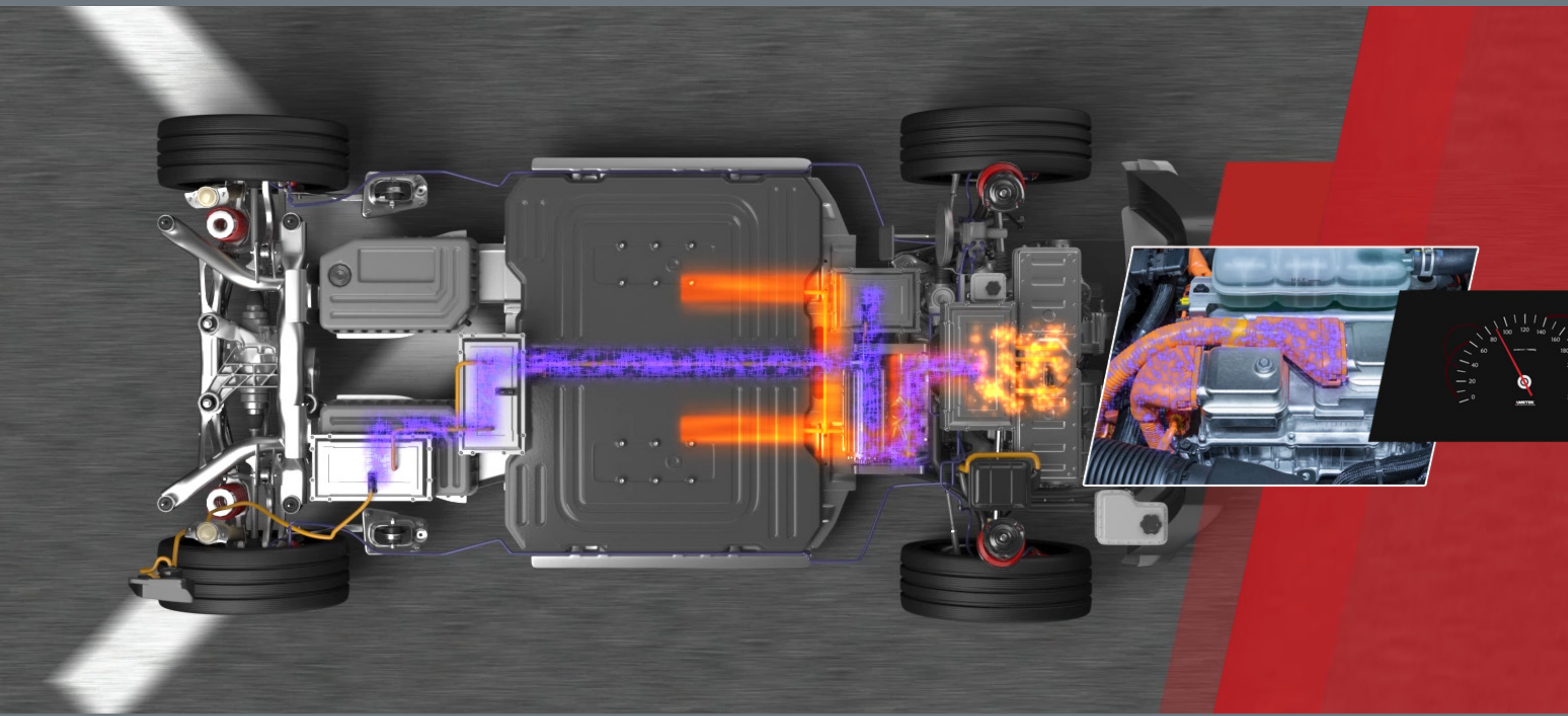
Insights and best practice

EMC COMPLIANCE KNOW-HOW



TECHNICAL NOTE 0116

ELECTRIC VEHICLE
RIPPLE DISTURBANCES

Overview

A ripple is a disturbance signal that is superimposed on the DC power supply. This ripple comes, for example, from periodic switching operations of semiconductor components.

In electric vehicles the electric drive system, especially the inverter part, represents the greatest potential source of ripple-voltages.

The ripple immunity test is required by international standards such as ISO 21498-2 and ISO 7637-4 or manufacturer standards such as MBN 11123, VW 80300 and PSA B21 7712, and is becoming increasingly important due to the constantly developing automotive industry.

The ripple test is carried out on different E-vehicle components, which partly requires powerful test equipment due to the normative requirements and the component characteristics.

In the following, the origin and dangers of ripple, requirements on test equipment, normative requirements and the solution from AMETEK CTS are discussed.

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AMETEK® COMPLIANCE TEST SOLUTIONS

Ripple origins

Acceleration processes and the resulting increase of power during driving lead to ripple voltages that are superimposed on the supply voltage.

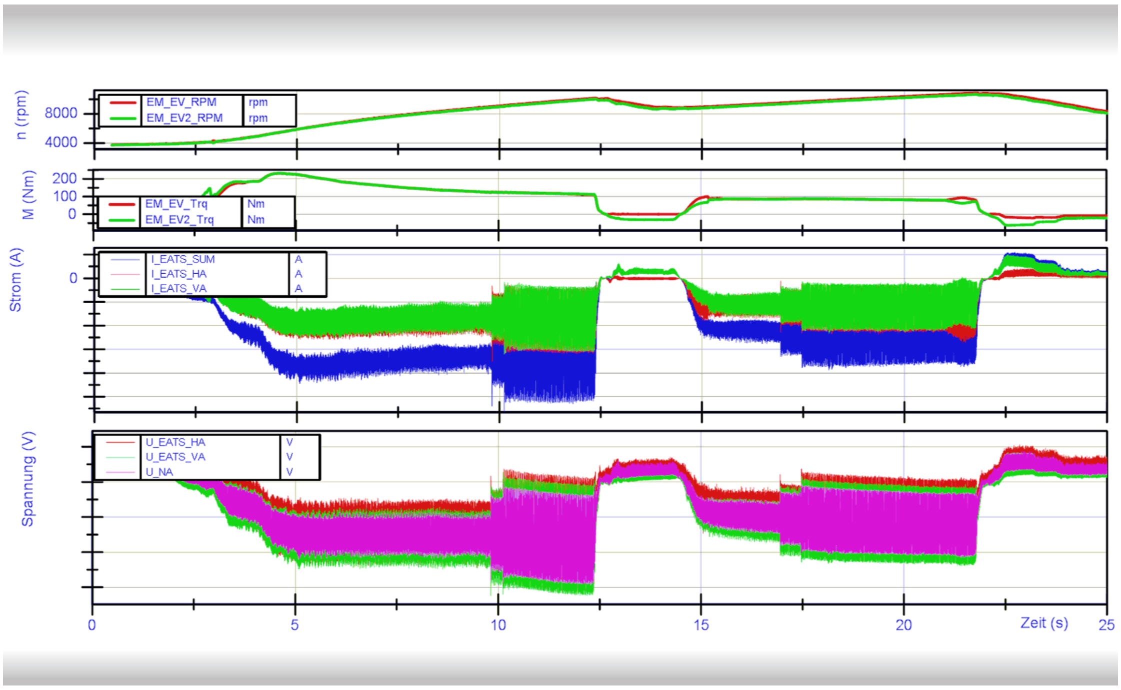


Figure 1

Current and voltage in dependence of rotation speed and torque

Figure 1 shows the changes of rotation speed and torque during operation in the two diagrams on top. The bottom two curves show the recorded voltage and current. It can be seen, that both are not smooth or constant but are superimposed by a ripple which is caused by the inverter part of the electric drive system.

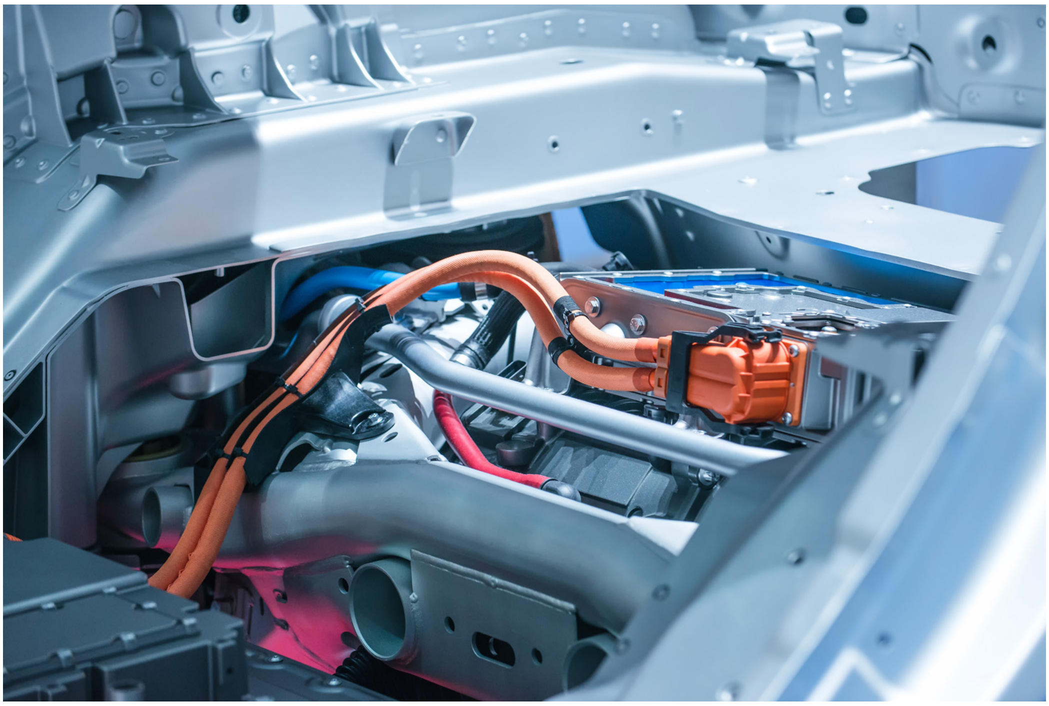
The voltage ripple leads to voltage differences on the supply voltage of up to 15 Vp which in turn results in a ripple in the current curve of up to 325 Ap.

These high currents occur among other things because of low-impedance components such as HV batteries and HV inverters, which will be discussed in more detail in the following sections.

Ripple – Dangers

The occurrence of a ripple on the DC power supply can lead to malfunctions of the components.

A vivid example is a ripple that couples to the supply of the HV battery. The measuring frequency of the battery management system (BMS) is typically around 30 kHz. The ripple can lead to a malfunction of the BMS at the appropriate frequency and this malfunction can trigger the battery contactor. The result is a complete power loss of the vehicle. This phenomenon can also occur on other components such as DC-DC converters and lead to an undesirable malfunction of the component.



Ripple currents will be transmitted to sensitive components connected to the HV network

Furthermore components can be destroyed because of very high ripple voltages. An example is a ripple superimposed on the supply voltage of the DC-DC converter which can lead to damage to the input filters due to high voltage amplitudes.

Therefore it is important to perform ripple tests on HV components to ensure sufficient immunity to voltage ripples.

Challenge - DUT Impedance
HV batteries and HV inverters often have a low DUT impedance over the frequency range, which is why these two components are considered more intensively.

HV battery:
The following example shows the impedance curve of an HV battery depending on the frequency:

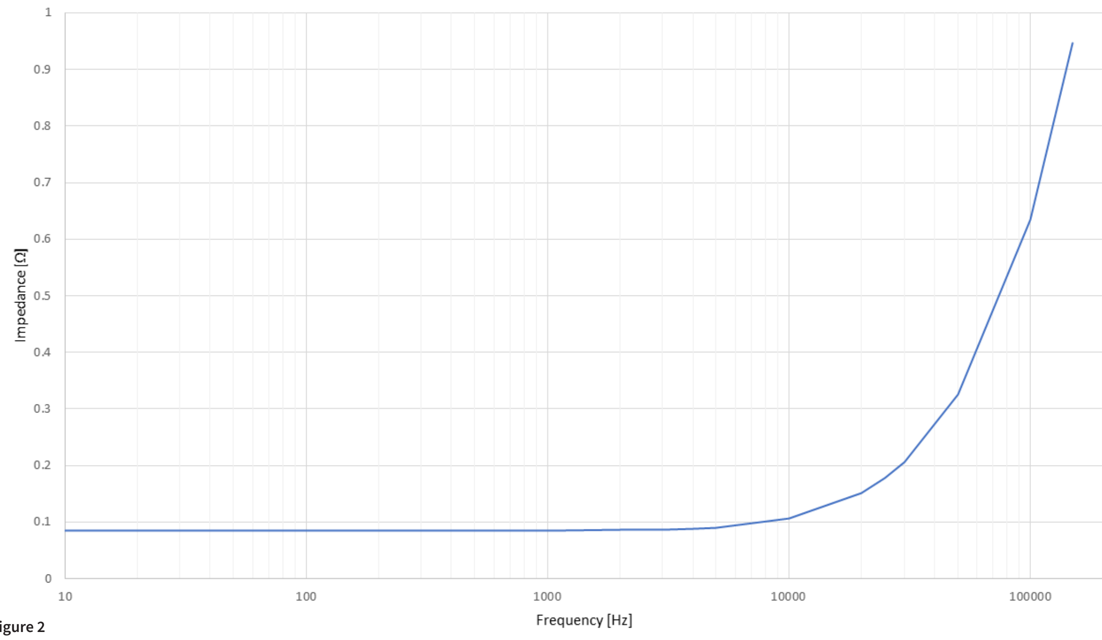


Figure 2
Impedance curve of a HV battery

As can be seen in the impedance curve from Figure 2 the low effective resistance of the impedance is dominant in the lower frequency range until the reactance rises above the higher frequencies whereby the value of the total impedance also rises.

With the help of Ohm's law the required Ripple current and the required ripple power can be calculated from the DUT impedance and the required test voltages:

Frequency	Impedance	Ripple Voltage	Ripple Current	Ripple Power
100 Hz	85 mΩ	12 Vp	141 Ap (100 Arms)	0.85 kVA
1 kHz	85.2 mΩ	24 Vp	282 Ap (200 Arms)	3.38 kVA
10 kHz	106 mΩ	24 Vp	230 Ap (161 Arms)	2.72 kVA
100 kHz	634 mΩ	8 Vp	13 Ap (9 Arms)	0.05 kVA

Table 1
Example calculation HV battery

In the following illustration the influence of the DUT impedance on the required ripple current becomes clear.

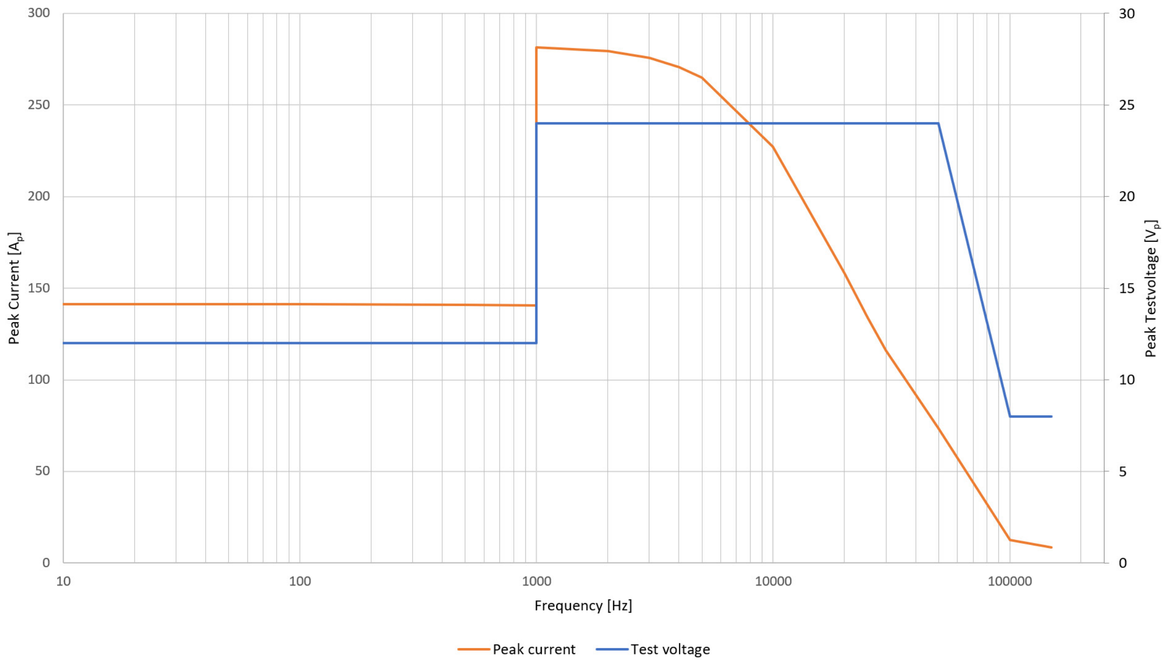


Figure 3

:Peak current as a function of test voltage and DUT impedance

The peak current shown in Figure 3 was calculated from the required test voltages included in ISO 21498-2 and the impedance curve of the HV battery from Figure 2. The current curve (orange) shows that the Ripple generator must provide a maximum peak current of about 280 Ap to test this low impedance DUT, which is only possible with very powerful test equipment.

HV inverter

In addition to the influences of the low-impedance HV battery, ripple testing of HV inverters is worth mentioning.

HV inverters have a very low DUT impedance at the resonance point. In the example from Figure 4 the impedance at a resonance frequency of 6.5 kHz only consists of the effective resistance of about 5 mΩ.

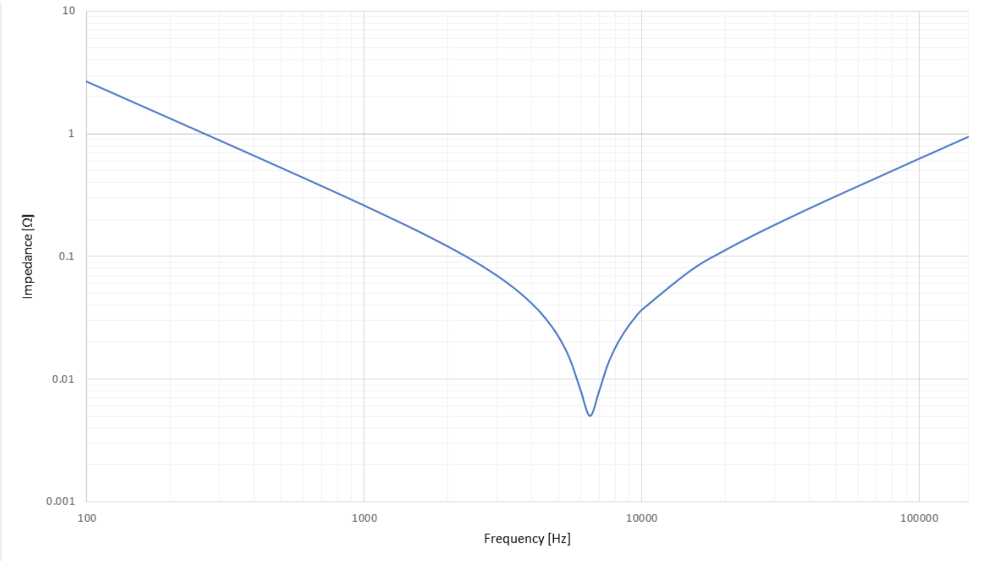


Figure 4

Impedance curve of an HV inverter

At a frequency of 6.5 kHz a test voltage of 24 Vp is required according to the requirements of ISO 21498 -2. That circumstance leads to a peak current of about 4800 Ap. This current would normally cause damage to the component which is not the goal of the test.

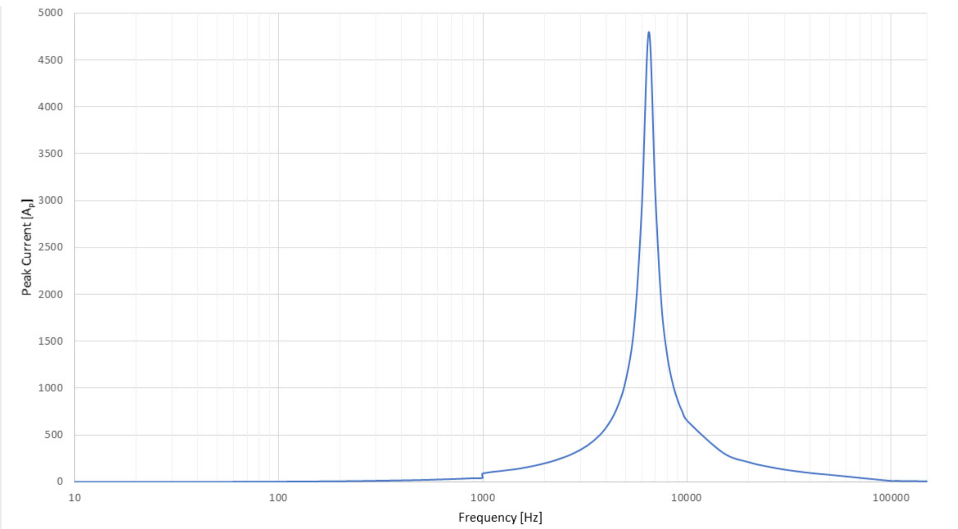


Figure 5

Current curve calculated from impedance and test voltage according to ISO 21498-2

It is important to determine what the realistic maximum peak current of the HV battery is and what current can be drawn by the DUT.

Figure 6 shows the maximum peak current in blue and the maximum current that can be supplied by the battery and absorbed by the component in orange. Assumed are 200 Ap.

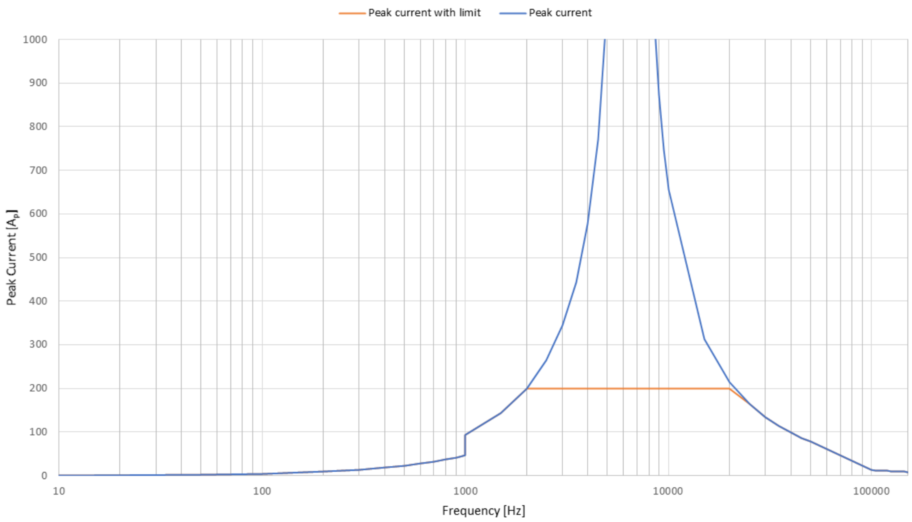


Figure 6

Current curve determined from impedance and test voltage compared to the current limit

By limiting the peak current, the test voltage can be adjusted accordingly in order to be able to carry out the test with the previously defined current limit.

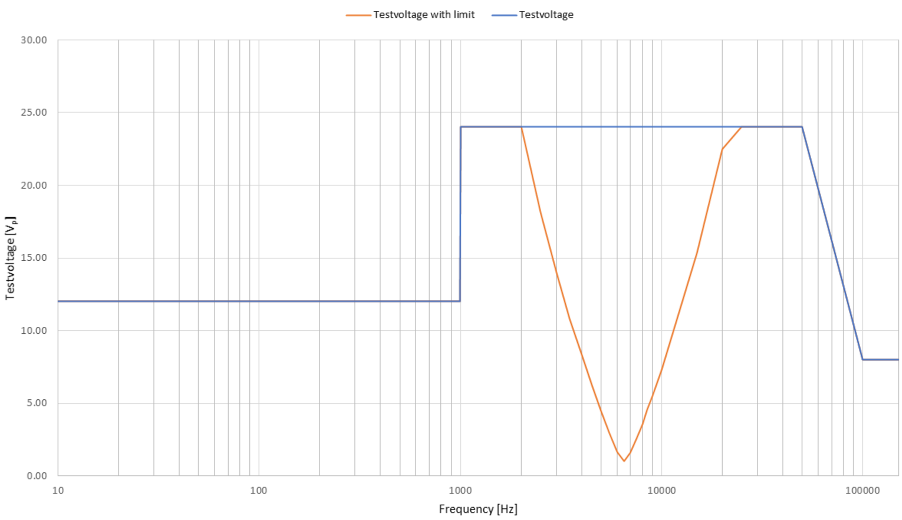


Figure 7

Test voltage adapted to DUT impedance

Depending on the current limit, the test voltage is adjusted and is shown as the orange curve from Figure 7. In comparison the test voltage specified by ISO 21498-2 is shown in blue.

$$U_{limit} = I_{limit} \times Z_{total} = 200\ A_p \times 5\ m\Omega\ (@\ 6{,}5\ kHz) = 1\ V_p$$

Formula 1

Example calculation to limit the test voltage depending on the DUT impedance

In this way, it is also possible to test components with very low impedances over the frequency range. To do so it is necessary to use a ripple generator that can provide enough power. Furthermore, the ripple generator must be able to supply a test voltage adapted to the impedance curve depending on the component-specific current.

Standards

The Ripple test, as already mentioned at the beginning is, required in different international and manufacturer standards:

- International standards are, for example, ISO 21498-2 and ISO TS 7637-4
- Manufacturer standards are, for example, the VW 80300, MBN 11123, PSA B21 7110, BMW GS 95023, GWT A D05-02, Nissan 28400 NDS91, Renault 36-00-811 and others

The specified voltage amplitudes and frequency ranges differ from standard to standard. In general, frequencies are in the range of 10 Hz to 300 kHz and voltage amplitudes up to 40 Vp are required.

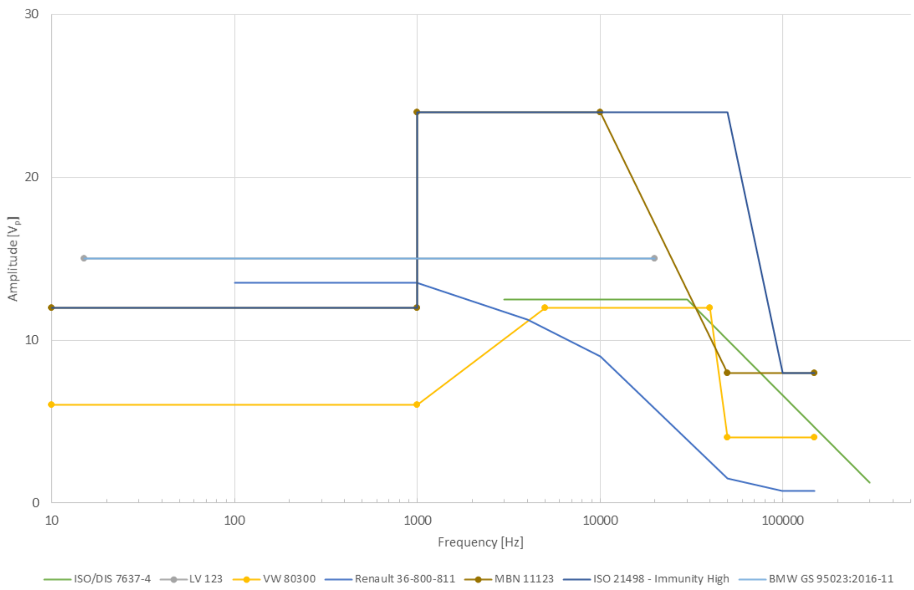


Figure 8
Overview of voltage amplitudes from different standards2

The different test levels of a standard are based on the expected ripple in the specified frequency ranges. Since the switching frequency of most HV inverters is in the range of 5 kHz to 60 kHz the highest test levels are defined for this frequency range as shown in Figure 8.

The first standard that required ripple testing was ISO TS 7637-4. Relatively low amplitudes of 12.5 Vp over a frequency range of 3 kHz to 300 kHz were defined. ISO TS 7637-4 was published as a technical specification in 2021. That standard is used all over the world, but it is less relevant than ISO 21498-2.

ISO 21498-2 was published in 2021. It is based on the experience of LV 123 and other manufacturer standards. This standard includes various tests such as voltage variations, emission measurements and ripple tests. Today, ISO 21498-2 is the decisive standard for testing high-voltage components.

As shown in Figure 8 the ISO 21498-2 specifies the highest test level which requires the corresponding test equipment.

Test setup

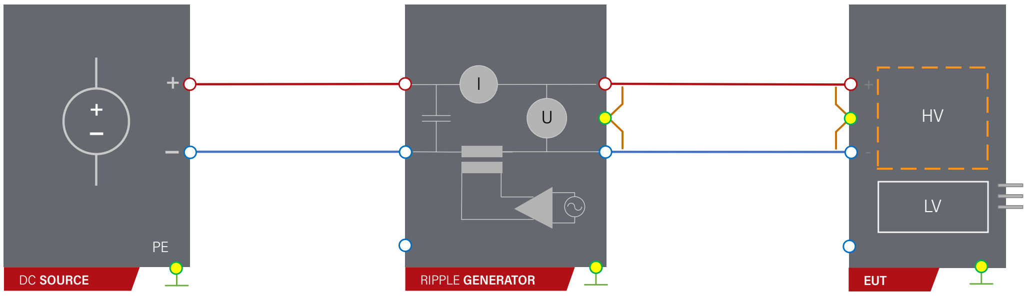


Figure 9
Simplified test setup

The DC source is used to supply the DUT. At low frequencies, the DC source can usually deliver the test signal consisting of supply voltage and superimposed ripple directly. The ripple generator basically consists of a signal generator and an amplifier which generate the ripple voltage. The generated ripple voltage is then coupled to the DC power supply.

To apply a DC voltage with a ripple, there are various coupling methods exist such as direct, capacitive or inductive coupling.

The preferred coupling method is coupling via transformers, which provides galvanic isolation between the DC and AC voltage side.

Compared to coupling via transformers, direct coupling represents a potential danger. If a malfunction of the DUT during a test (e.g. a voltage peak) occurs, the entire current can flow to ground over the AC amplifier if the direct coupling method is used. Among other things, the test equipment can be damaged and it comes to an uncertain operating state.

In Figure 9 the voltage amplitude is measured and ensured at the output of the ripple generator. Shielded cables are used to connect the DUT to the ripple generator. The shield is connected to ground on side of the test equipment.

The capacitor shown in the simplified test setup is used to decouple the DC source and guides the ripple current in the direction of the DUT. Without that capacitor the ripple current can flow towards the DC source which can cause issues in the test equipment.
Ripple tests can be complicated because of different DUT influences. Especially low-impedance DUTs require very powerful test equipment, which also provides the possibility to measure the DUT impedance and adjusts the test voltage according to the customer-specific limits.

Summary

The Electric Vehicle continues to evolve and with increasing battery voltages and increases in available power, Choosing a suitable ripple generator can be a challenge. With many questions that will need to be answered

The questions below are designed as checklist of the most important criteria that should be considered when specifying a tipple test solution.

1. **Maximum DC voltage**
...is defined by the DC bus voltage of the HV components. It defines the DC source as well as the maximum insulation voltage of the coupling unit (transformer). Typical voltages are in the range of 400 to 1000V.

2. **Maximum DC current**
...depends heavily on the power consumption and HV DC voltage of the component. Batteries and inverter are high power component where currents in the range of 500 – 1000 A are common. Auxiliary devices required less current, typically below 100A. The DC current defines the required power of DC source. It also gives an indication about the possible impedance of the component.

3. **Ripple voltage test levels in Vpp**
...are defined by the standard and/or the component test specifications. Typical values are between 10Vpp to 80Vpp. A big variety in required test levels exist and the ripple generator must cover them. The voltage levels must be reached at the terminals of the EUT.

4. **Impedance of the component**
...is a very important parameter to determine the required ripple current and power. The impedance can be estimated (DC resistance), simulated or measured. It is critical to know the impedance not only at DC but up to the maximum ripple frequency (i.e. 150 kHz for ISO 21498). Typical values are around 50 mΩ for HV batteries, 100 mΩ for inverters and 1 Ω for auxiliary systems (DC-DC converters, chargers, etc.).

5. **Ripple current in App**
...is given by the ripple voltage test levels and the impedance. Important is to calculate the ripple current over the complete frequency range. A fast current limiter is helpful to prevent that the tested component is destroyed.

6. **Accessibility of the EUT**
Some components might be required to be placed in a protected environment or climate chamber where the accessibility is difficult. Longer cables and remote voltage measurement might be required that ensure the ripple test is performed according the specifications.

7. **Integration into test stand**
Ripple tests are time lengthy tests that can take several days or weeks. HV batteries need to be tested at different SoC (state of charge), which makes it necessary to charge and discharge them during ripple testing. An automated test is helpful.

8. **Safety for personnel**
Ripple is a high voltage test and a potential danger to test engineers. Therefore, the ripple test system must be safe and have the possibility to be integrated into existing safety systems. Preferably is a galvanic insulation between DC and AC as offered by the transformer coupling method.

9. **Upgradeability**
EV is a very dynamic market where technologies and therefore testing evolve quickly. DC voltages go to higher levels to reduce losses and (cable-) weight. Faster charging is the key to customer acceptance which means increased DC current (and lower impedance). The ripple generator must cover the testing requirements of today and tomorrow – so upgradability is the key. This is true for the hardware and – even more importantly – for the software to include changes in standards.

10. **Ease of use**
Building and operating a ripple test system for HV components used to be a task for test specialists. Today compact and fully integrated ripple test systems are available that offer features and functionalities that allows everyone to perform the test.

About AMETEK CTS

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AMETEK CTS is a global leader in EMC compliance testing and RF power amplifiers. AMETEK has been designing and manufacturing precision instruments for more than 30 years. Under the brand names of EM Test, Teseq, IFI and Milmega the company produce a wide range of specialist solutions aligned to the individual needs of equipment manufacturers across a variety of industries. These include:

Automotive
Aerospace and Defense
Consumer electronics
Household appliances
Medical devices
Renewable energy

From its design and manufacturing facilities in Switzerland, Germany, the United States and the UK, AMETEK CTS provides customers with innovative solutions to the complex requirements of EMC compliance standards.

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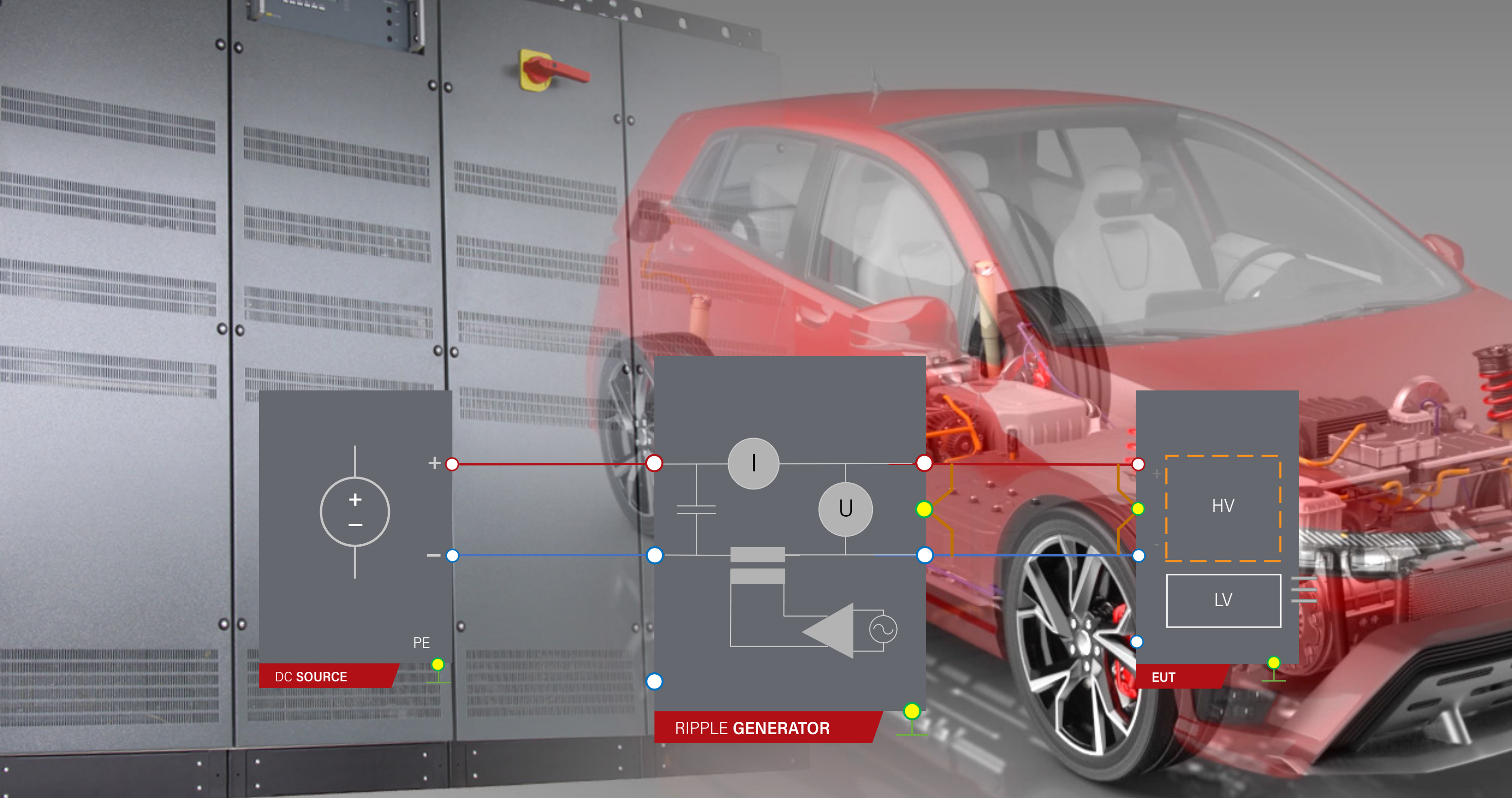
IMMUNITY TO RIPPLE



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	AMP 200N2 & CN 200N	Ripple NX300-1000-2.5	Ripple NX600-1000-5	Ripple NX1000-1000-10
EUT supply	1500 VDC / 300A	1000 VDC / 300A	1000 VDC / 600 A	1000 VDC / 1000 A
Ripple power	800 VA	2.5kVA	5 kVA	10 kVA
Bandwidth	200 Hz – 300kHz	200 Hz – 300 kHz	200 Hz – 300 kHz	200 Hz – 300 kHz
Outputs	1	1	2	2
Capacitor bank	C-Box 10/100-1000	Yes	Yes	yes

NEW high power ripple generator for EV component testing

Batteries, inverters, DC-DC converters, OBC and more

- Ripple tests according ISO 21498-2, ISO 7637-4, LV123, VW 80300, etc.
- High power ripple generator to test low impedance HV components
- Fully integrated system incl. amplifier, coupler and measuring device
- Safety features: interlock, capacitor pre-/discharge, overcurrent
- Remote control through CAN/Ethernet/OptoLink
- Integration in existing test bench or control via net.control

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