CSM High-Voltage Measurement Systems
Safe measurements on high-voltage components
Safe Measurements on High-Voltage Components

E-mobility: enhancing efficiency, extending the range

In order to get more electric vehicles on the roads, a nationwide charging infrastructure is needed, alongside an increased range of vehicles. New product developments, the optimization of electric and hybrid vehicles and the necessary charging technology will play a key role in this process.

High-performance measurement systems are needed meeting the increased safety requirements of high-voltage environments. These measurement systems must allow high-voltage work to be carried out safely in the vehicle and on the test bench from the sensor up to data acquisition. They should also be compact and easy to install. Last but not least, they must deliver precise and reliable measurement results, as well.

Typical high-voltage measurement tasks

Typical measurement tasks associated with automotive high-voltage systems are:

- High-voltage and current measurements
- Temperature measurements
- Measurement of vibrations, moisture and cell voltages

CSM’s high-voltage-safe measurement systems allow you to take measurements:

- mobile in vehicles
- stationary on test benches

High-voltage measurement modules are provided with appropriate high-voltage-safe signal cables:

- as MiniModules
- in 19” housings
- … and are available for CAN and EtherCAT® systems

High voltages and currents can be safely and easily tapped and synchronously measured with:

- 1-/3-phase Breakout Modules
  - equipped with integrated temperature-compensated shunt modules
  - available for CAN and EtherCAT® systems

or, alternatively, via:

- CAN or EtherCAT® measurement modules for the measurement of high voltages
- high-precision Hall sensors for current measurements along with CSM standard measurement technology
CSM HV modules provide certified safety according to EN 61010

Thanks to the safety concept, CSM systems can be used to set up high-voltage-safe measurement chains from the sensor up to data acquisition.

A type approval test of the entire system of measurement modules and signal cables, according to EN 61010 by an accredited laboratory, is part of that concept. Unlike standard measurement modules, every high-voltage module and every signal cable undergoes a routine test consisting of a high-voltage isolation test before shipping.

The signal cables are 8-wire, double-insulated multi-connector cables. Each multi-connector cable can safely connect up to four points of measurement to a measurement module. This reduces cabling efforts and costs in comparison to individual cables.

Breakout Modules are directly looped into the vehicle’s live high-voltage wires. Alternatively, these wires can be replaced by appropriate cabling, including plugs.

Benefits of CSM High-Voltage Measurement Systems

CSM provides a complete product range of high-voltage-safe measurement technology for the development of electric and hybrid vehicles from a single source!

These products can be combined with CSM’s standard measurement technology and used with the same software tools.

Thanks to their compact design with IP67 protection class and an operating temperature range from -40 °C to +100 °C, HV MiniModules can be directly installed in the engine compartment close to the points of measurement and in other places where there is limited space for installation. This reduces disturbances, thus increasing measurement precision. By installing the modules close to the points of measurement, safety can be further increased as this reduces the risk of sensor cables being chafed through to high-voltage potential.

Due to their robust design, the wide operating temperature range and the very low temperature drift, these modules are ideal for test bench applications as well as for the installation in vehicles (e.g. in the car boot) and in climatic test benches. This allows high-voltage components to be measured with the same measurement technology, first on the test bench and then in the vehicle.

The high-voltage Breakout Modules are designed for high-precision and high-performance measurements of current, voltage and power. The high-voltage cables are routed into the housing through PG cable glands. The cables are connected to the installed units with suitable connectors at the other cable end. This allows a convenient and safe plug-and-play mounting. There are no live high-voltage measurement cables. The measurement results for voltage, current and power are provided digitally via EtherCAT® and in parallel via CAN bus.

CSM HV modules provide a complete product range of high-voltage-safe measurement technology for the development of electric and hybrid vehicles from a single source!

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Even the 19” HV modules are very compact. These devices are well suited for multi-channel applications such as precise measurement of temperatures in individual cells of high-voltage batteries.
Temperature Measurements on High-Voltage Components

High-voltage temperature measurement modules with thermocouples

**HV THMM 4**

MiniModule HV THMM 4 was especially developed for safe temperature measurements using K-type thermocouples on high-voltage components. It is suited for mobile use, even if only limited space is available for installation.

- 4 NiCr-Ni temperature inputs (K-type), galvanically isolated
- Reinforced insulation up to 846 V
- Internal cold junction compensation per channel
- Operating temperature range: −40 °C to +100 °C
- Robust and extremely compact aluminium housing, IP67

**HV TH-TBM 8**

Measurement module HV TH-TBM 8 was especially developed for safe temperature measurements with K-type thermocouples on high-voltage components. Designed as a 19” slide-in module, it is suited for use in test benches as well as vehicles, for example in the car boot.

- 8 NiCr-Ni temperature inputs (K-type), galvanically isolated
- Reinforced insulation up to 846 V
- Internal cold junction compensation per channel
- Operating temperature range: −40 °C to +85 °C
- Robust aluminium housing (19”/3 U/12 HP), IP65
High-voltage temperature measurement modules with PT sensors

**HV PTMM 2**

MiniModule HV PTMM 2 is equipped with two measurement inputs in 4-wire-connection for PT100 and PT1000 sensors. It was designed for high-precision temperature measurements in high-voltage environments.

Individual PT coefficients can be stored in the module to compensate for the temperature dependence of PT sensors.

- 2 measurement inputs in 4-wire-connection for PT100 and PT1000 sensors
- Reinforced insulation up to 846 V
- Operating temperature range: −40 °C to +100 °C
- Robust and extremely compact aluminium housing, IP67

**HV PT-TBM 8**

Measurement module HV PT-TBM 8 is equipped with eight measurement inputs in 4-wire-connection for PT100 and PT1000 sensors. It has also been especially designed for high-precision temperature measurements in high-voltage environments.

HV PT-TBM 8 is excellend for the optimization of high-voltage batteries (energy storage and sizing). PT sensors are available as extremely thin and robust foils and are therefore well suited for mounting between individual battery cells.

- 8 measurement inputs in 4-wire-connection for PT100 and PT1000 sensors
- Reinforced insulation up to 846 V
- Operating temperature range: −40 °C to +85 °C
- Robust aluminium housing (19”/3 U/19 HP), IP65
# Measurement of very high Voltages and Currents

## HV Breakout Modules

### HV Breakout Module 1.1 / 1.2

HV Breakout Modules (BM) 1.1 and 1.2 were designed for single-phase measurement applications on live high-voltage cables.

The voltage is measured directly. The current measurement is carried out via a shunt module. This shunt module contains a differential amplifier as well as a temperature sensor and memory to store calibration data for automatic online temperature compensation.

- 1-phase measurement of voltage (U) and current (I) in high-voltage applications
- Voltages up to ±1,000 V, transient overvoltages up to ±2,000 V
- Currents up to ±800 A (nominal value), ±1,400 A (peak)
- Online power calculation with 1 MHz calculation rate, 100 % synchronous
- Simultaneous EtherCAT® / CAN bus communication
- Output of voltage, current and power with measurement data rates up to 1 MHz

HV BM 1.1 is compact and ideally suited for measurement at auxiliaries powered via a single live high-voltage cable.

HV BM 1.2 is ideally suited for measurement at large consumers such as electric motors powered via separate cables for HV+ and HV−.

### HV Breakout Module 3.1 (preliminary information)

HV Breakout Module (BM) 3.1 was designed for 3-phase measurements of voltage, current and power on live high-voltage cables with currents up to 32 A, as, for example, supplied by public battery charging stations. The box is looped into the conventional 5-wire high-voltage cable by feeding the cable through PG cable glands into the module and connecting it there.

This 3-phase measurement solution in a single box offers considerable benefits in terms of cost reduction and space saving.

- 3-phase measurement of voltage (U) and current (I) in high-voltage applications
- Voltages up to ±1,000 V
- Currents up to ±32 A (nominal value), ±50 A (peak)
- Online power calculation with 500 kHz calculation rate, 100 % synchronous
- Simultaneous EtherCAT® / CAN bus communication
- Output of voltage, current and power with measurement data rates up to 500 kHz

HV BM 3.1 is ideally suited for 3-phase measurements of voltage, current and power on 5-pole high-voltage cables with currents up to 32 A.
HV AD modules with 1,000 Volt measurement range

**HV AD4 XW1000**

Measurement module HV AD4 XW1000 was designed for the fast and synchronous measurement of high voltages up to 1,000 V. Transient overvoltages of up to 2,000 V can be detected.

This module offers a maximum measurement data rate of up to 1 MHz per channel and is ideally suited for mobile use.

- 4 analog inputs with reinforced insulation
- Measurement data rate up to 1 MHz per channel via EtherCAT®
- Measurement range up to ±1,000 V (transient overvoltages up to ±2,000 V), adjustable per channel
- Precise synchronization (modules and channels), important for power calculation etc.
- Operating temperature range: −40 °C to +100 °C, IP67

**HV AD4 XW20**

Measurement module HV AD4 XW20 was designed for safe high-voltage measurements in high-voltage environments. This measurement module is excellently suited for use in test benches as well as in vehicles (e.g. in the car boot).

- 4 analog inputs with reinforced insulation
- Measurement data rate up to 20 kHz via CAN (max. 2 channels)
- Measurement range up to ±1,000 V, adjustable per channel
- Operating temperature range: −40 °C to +85 °C
- Robust aluminium housing (19”/3 U/12 HP), IP65

The maximum measurement range of the HV AD4 XW20 module is ±1,000 V.
Current Measurements with Hall Sensors

When combined with the CSM standard modules AD4 ECAT, the CSM LEM sensor packages are ideally suited for safe and accurate measurements of typical currents in high-voltage applications. The high sampling rate and excellent synchronicity of the CSM measurement modules for measuring high voltage and current enable precise power calculations.

- For high-precision measurements of currents up to ±1,000 A (700 A RMS permanent)
- For signal frequencies up to 200 kHz
- Measurement data rates up to 1 MHz
- Synchronicity for evaluation and power calculation better than 1 µs

Measurements with IEPE Sensors

HV IEPE3 FL1000

The HV IEPE3 FL1000 is equipped with three analog inputs and provides a modified sensor excitation for the connection of IEPE sensors. If combined with special sensor cables, standard IEPE sensors, which are typically used in the field of low-voltage applications, can be safely operated even in high-voltage environments.

- 3 analog inputs with reinforced insulation
- Safe measurement of acceleration, force and pressure with IEPE sensors in high-voltage environments
- High-voltage safe sensor excitation
- Measurement data rate up to 1 MHz per channel
- Precise synchronization (modules & channels)

The HV IEPE3 FL1000 has been specifically designed for measuring analog voltages with IEPE sensors, e.g. triaxial accelerometers, in high-voltage environments.
Measurement of Vibrations, Moisture, Cell Voltages etc.

HV AD modules with 20 Volt measurement range and sensor excitation for standard sensors

HV AD modules with high-voltage safe galvanically isolated sensor excitation used with high-voltage safe signal cables enable the use of standard sensors in high-voltage environments.

Low-voltage range sensors (<60 V) for the measurement of vibration, acceleration, strain, moisture, pressure, etc. can thus be applied in high-voltage environments (>>60 V).

A prerequisite for this is that the sensor in question is completely located within the high-voltage environment and is connected with a high-voltage-safe signal cable.

HV ADMM 2LI+

MiniModule HV ADMM 2LI+ has two measurement inputs, each with a galvanically isolated sensor excitation. This device is therefore suitable for installation in a vehicle and for the connection and supply of standard sensors.

- 2 analog inputs with measurement ranges up to 20 V and reinforced insulation up to 846 V
- Galvanically isolated sensor excitation with reinforced insulation up to 846 V
- Measurement data rate up to 20 kHz via CAN
- For use with standard sensors in high-voltage environments: measurement of moisture, pressure, acceleration, etc.
- Operating temperature range: −40 °C to +100 °C
- Robust and extremely compact aluminium housing, IP67

Integrated sensor excitation offers more measurement options:

HV AD modules with 20 Volt measurement range and sensor excitation for standard sensors

Can be used with standard sensors in high-voltage environments.

HV AD-TBM 4LI+

The 19” measurement module HV AD-TBM 4LI+ has four measurement inputs, each with a galvanically isolated sensor excitation. This makes the device excellently suited for the use in test benches and in vehicles for operating standard sensors in high-voltage environments.

- 4 analog inputs with measurement ranges up to 20 V and reinforced insulation up to 846 V
- Galvanically isolated sensor excitation with reinforced insulation up to 846 V
- Measurement data rate up to 20 kHz via CAN
- For use with standard sensors in high-voltage environments: measurement of moisture, pressure, acceleration, etc.
- Operating temperature range: −40 °C to +85 °C
- Robust aluminium housing (19”/3 U/12 HP), IP65

Integrated sensor supply offers more measurement options:

HV AD-TBM 4LI+ modules allow the safe measurement of analog signals from standard sensors in high-voltage environments.
HV AD modules with 90 Volt measurement range

HV AD modules with 90 V measurement range are suitable for applications in which lower voltages have to be measured safely in a high-voltage environment with high resolution.

HV AD-TBM 8LI

The 19" measurement module HV AD-TBM 8LI with eight measurement inputs is used, among other things, for high-voltage-safe cell voltage measurements in high-voltage batteries.

- 8 analog inputs with reinforced insulation up to 846 V
- Measurement data rates up to 20 kHz via CAN
- Measurement range up to ±90 V, adjustable per channel
- Robust aluminium housing (19"/3 U/12 HP), IP65

HV ADMM 4LI

MiniModule HV ADMM 4LI is equipped with four measurement inputs and allows the measurement of analog voltages up to 90 V in high-voltage environments.

- 4 analog inputs with reinforced insulation up to 846 V
- Measurement data rates up to 20 kHz via CAN
- Measurement range up to ±90 V, adjustable per channel
- Robust and extremely compact aluminium housing, IP67

HV AD4 OW1000

Module HV AD4 OW1000 from the MiniModule series HV AD4 ECAT with 4 inputs was designed for very fast, high-voltage-safe measurements of analog voltages up to 90 V.

In this way, the module supports the analysis of disturbances such as transient overvoltages when working with relatively low signal voltages in a contaminated high-voltage environment in the vehicle and in the test bench.

- 4 analog inputs with reinforced insulation up to 846 V
- Measurement data rates up to 1 MHz per channel
- Measurement range up to ±90 V, adjustable per channel
- Precise synchronization of all channels and further modules
- Operating temperature range: -40 °C to +100 °C, IP67
CSM Safety Concept

CSM measurement systems meet high safety requirements. Our safety concept includes type approval testing of the entire system, consisting of measurement modules and signal cables, by an accredited test laboratory. In addition, each measurement module is subjected to a routine test in accordance with safety standard EN 61010-1:2010 prior to shipment. A corresponding test report will be issued.

This concept comprises the following standard-compliant tests:

- Type approval test according to safety standard EN 61010-1:2010 by an accredited test laboratory
- Routine test of measurement modules according to safety standard EN 61010-1:2010
- EMC test (CE)
- Shock and vibration test
- Protection class testing (IP65/IP67)

Safety Features of the Measurement System*

- High-voltage-safe measurement modules and Breakout Modules
- Multi-connector cables with safe plug-in system for the sensor-to-module connection.
- Galvanically isolated, reinforced insulation according to EN 61010-1:2010 between:
  - individual measurement channels
  - measurement channels and power supply
  - measurement channels and CAN or EtherCAT®
  - measurement channels and housing
- Galvanically isolated sensor excitation with reinforced insulation according to EN 61010-1:2010, adjustable per channel
- Approved for use in environments with pollution degree 4 (HV MiniModules and Breakout Modules)
- Module components are partially potted, which means that these modules can be repaired.
- Additional ground terminal for connection to the ground of the car body; monitored by the ground leakage monitor of the vehicle
- The use of sensors and specifically developed, high-voltage-safe multi-connector cables with integrated, fully isolated, connector.

Typical measurement setup in a high-voltage environment using a CSM measurement system.

*See also technical information “Fields of Application for CSM HV Measurement Modules” (available on request)
**High-Voltage-Safe Multi-Connector Cables**

Specially developed multi-connector cables for up to four points of measurement are designed to pair with CSM measurement modules. They are protected against accidental touch (if isolated sensors are used) and feature a rugged design. Thanks to their small cross sections, they are ideally suited for space-saving applications. Because cables can suffer from chafing on body components, these multi-connector cables have a blue inner sheath. If the blue sheath becomes visible it indicates that the cable is no longer safe for operation. Cables are available for AD, PT and TH measurement modules.

**All advantages at a glance**

- Only one cable for up to four points of measurement: reduction of error sources and enhanced safety (abrasion, cable break, etc.)
- Reduced cabling efforts reduces costs in comparison to the use of single-channel cables
- Double insulation up to 1,000 V: protection against accidental touch and enhanced electrical and mechanical safety
- Individually designed multi-connector concept with fully isolated plastic connectors, suitable for CSM measurement modules: fire protection class V0, protection class IP67

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**Thermocouple cables**

**K940**
SC, R2P 8p, STC
Surface thermocouple cable for use in high-voltage environments with HV-TH modules; 4 × high-voltage sensor, type K, non-insulated measuring tips

**Connectors**
A NiCr-Ni multi-connector LEMO Redel 2P 8-pole code B
B 4 × non-insulated measuring tip

ART5810100 K940-0240 Length: 2.4 m

**K941**
SC, R2P 8p, STC, I10
Surface thermocouple cable for use in high-voltage environments with HV-TH modules; 4 × high-voltage sensor, type K, insulated measuring tips with heat-shrink sleeve protection

**Connectors**
A NiCr-Ni multi-connector LEMO Redel 2P 8-pole code B
B 4 × insulated measuring tip

ART5810105 K941-0240 Length: 2.4 m

**K950**
SC, R2P 8p, PT100
Signal cable for HV-PT measurement modules with 2 × HV PT100 sensor

**Connectors**
A multi-connector LEMO Redel 2P 8-pole code C
B 2 × PT100 sensor

ART5810200 K950-0250 Length: 2.5 m
Analog sensor cables

**K901**
SC, R2P 8p, open
Signal cable for HV AD measurement modules with measurement voltages up to 90 V, shielding per channel for suppressing interferences

**Connectors**
- A multi-connector LEMO Redel 2P 8-pole code B
- B 4 × open cable end, 2 wires and shield each

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**K910**
SC, R2P 8p, open
Signal cable for HV AD measurement modules with measurement voltages up to 1,000 V, shielding per channel for suppressing interferences

**Connectors**
- A multi-connector LEMO Redel 2P 8-pole code D
- B 4 × open cable end, 2 wires and shield each

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**K920**
SC, R2P 8p, open
Signal cable for HV AD measurement modules with sensor excitation for 2 sensors

**Connectors**
- A multi-connector LEMO Redel 2P 8-pole code C
- B 2 × open cable end, 4 wires each

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**K960**
SC, R2P 8p, open
Connection cable between a measurement module HV IEPE3 FL1000 and an IEPE sensor (triaxial, uniaxial)

**Connectors**
- A multi-connector LEMO Redel 2P 8-pole code C
- B open cable end, 4 wires and shield

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Please consult our CAN and ECAT Accessories catalogues for a full range of connection cables, connectors and mounting materials.
Fast Measurements in High-Voltage Environments

**Fields of application, special features, requirements**

Modern electric vehicle technology sets high standards for a high-voltage on-board system and the components connected to it. The inverter technology applied in the powertrain uses very fast switching frequencies and it is their impact on the on-board power supply that needs to be analyzed.

The voltage and current flows prevailing in high-voltage environments are decisive for dimensioning the electric components. Transient voltages and current peaks can occur during operation, usually with a duration of only a few milli- or microseconds. Despite their short duration, these voltage and current peaks may seriously damage electric components since they are often significantly higher than the permanently applied voltages and currents. It is thus essential that measurements allow the visualization of those peaks. Only sampling with high frequencies enables their detection.

Measuring the actual voltage flows of all three phases at the inverter during test drives is a critical measurement task. The optimization of electric motors and inverters is another field of application for fast measurements.

Besides the detection of transients in the voltage curve, the RMS value of the modulated sinusoidal voltage as well as the effective power and the power factor $\lambda$ are of particular interest, i.e. the ratio of the amount of the effective power $P$ to the apparent power $S$. The inverter operates with frequencies in the two-digit kHz range and generates a chopped voltage curve. The conversion into an RMS value therefore requires a high oversampling rate.

Synchronous high-speed data acquisition via Ethernet (EtherCAT® protocol) with robust distributed measurement technology opens up completely new options for analysis during test drives. Due to the synchronicity of the measurement data, the individual points of measurement (voltages and currents) are exactly on the same time axis. The sampling of voltage and current with 1 µs (at highest resolution) ensures a very precise power calculation.

Measurements on high-voltage components outside the vehicle, e.g. at charging stations and converters, are also of considerable interest due to the interactions between aggregates and the vehicle’s on-board power supply. This raises the question of the extent to which disturbances in the power grid affect the on-board power supply - and vice versa.

In the vehicle itself, measurements are carried out on high-voltage consumers such as air conditioning, steering and brakes. In the future, more and more components will be electrified and an increasing number of applications will be available.

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*Application example: fast measurement of voltage and current between electric motor and inverter with HV AD4 XW1000 and AD4 OG100 measurement modules and Hall sensors installed in a box.*
of consumers will be supplied via the high-voltage on-board power supply. Here too, influences on the on-board power supply need to be validated.

As a rule, the power consumers are clocked, i.e. controlled and regulated via pulse width modulation (PWM). Displaying the effective power is also relevant here, often in parallel and synchronous to other physical quantities, such as brake pressures, yaw rates, etc. To visualize these processes, measurement data rates in the three-digit kHz range are required. Sampling at lower frequencies is no longer sufficient.

The measurement-related challenge now is to find the suitable devices for data acquisition. CSM GmbH offers a wide portfolio of measurement modules for use in high-voltage environments. The bandwidth of the proven CAN measurement technology is no longer sufficient for recording the phenomena and measurement tasks described here.

CSM ECAT measurement modules for high-voltage applications allow measurement data rates of up to 1 MHz per measurement channel. For this purpose CSM offers the measurement module HV AD4 XW1000 for continuous voltage measurement up to 1,000 V. In order to detect transient overvoltages, the measurement ranges of the analog inputs have been dimensioned to ±2,000 V.

The recording of the current curve needs to be performed with a suitable sensor. Hall effect-based sensors are ideal here, as these current transformers enable high threshold frequencies. In addition, the galvanic isolation between test setup and measurement equipment is ensured when using these sensors. CSM has developed the LEM sensor packages for this measurement task. The LEM sensor packages are adapted to the ECAT measurement modules and are delivered ready to be operated.

Due to small housing dimensions, the CSM LEM sensor packages can be applied directly in the engine compartment (here: LEM LF 310-5). Note: For shielded high-voltage cables, the shield must be disconnected and the Hall sensor installed in order to ensure high-voltage-safety.

High-Voltage Isolation Testing Station

Testing the operational safety of high-voltage measurement modules

The high risk potential for measurements in high-voltage environments requires increased safety awareness. Here, safety for life and health of the user has to come first. CSM therefore recommends regularly checking the high-voltage isolation of all measurement modules in order to ensure operational safety at all times, especially if the modules are exposed to strong external influences during measurement operation.

CSM has developed the CSM High-Voltage Isolation Testing Station for this purpose. This station consists of a PC-based isolation testing software, the isolation tester, an “HV ISO self-test adapter” and further accessories. The CSM High-Voltage Isolation Testing Station enables the high-voltage isolation of CSM modules to be tested directly on the user’s premises.

This saves costs and increases availability, as the high-voltage measurement modules no longer have to be sent in for testing. During a high-voltage isolation test, the isolation of a measurement input is tested against all other measurement inputs, as well as against the housing, the power supply and the communication bus.
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