TECH NOTE :: Recording electric voltage and current with QuantumX and calculating power with catmanEASY

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Subtitle

These TIPS FOR USE deal primarily with the acquisition of voltage and current as electrical quantities using QuantumX as well as power calculation and signal analysis in the time domain and frequency range with catmanEASY/AP.

Introduction

HBM is traditionally strong in the acquisition, visualization, storage and analysis of mechanical quantities in the time domain. For these purposes HBM offers first and foremost sensors for torque and rotational speed, force, pressure, displacement and strain. HBM also offers electronic measurement technology and software for data acquisition and evaluation in the area of analysis and testing for the development of components, systems and complete products with high standards of quality.

We can see the world around us becoming increasingly electrified. This is clearly evident in consumer goods, but also in public spaces, for example public transport in elevators, escalators and vehicles. Electrical actuators are rapidly replacing hydraulics, as seen in drives and valves. Physical processes of complex machines are turned on their head by electrification. It follows that the acquisition of "electrical quantities" such as voltage and current is also becoming increasingly more significant. QuantumX allows for acquisition of electrical quantities such as voltage and current as well as all other typical physical measurands in electrical, mechanical or mechatronic systems. Purely electrical quantities can be measured on electrical actuators, in energy storage devices such as batteries or in infrastructure.

The **QuantumX MX403B 4-channel measurement module**, which is now available, was developed especially for precise acquisition of electric voltages up to 1000 V. Small differential voltages can also be measured at a high electrical potential. The high safety level of the MX403B is ensured by consistent development based on the latest requirements of measuring device standards IEC 61010-1:2010 + corr. 2011 and for instruments IEC 61010-2-030:2010 + corr. 2011 and by certification and production monitoring by the VDE (German Electrotechnology Association).

Applications with QuantumX MX403B and benefits

The module is suitable for applications in labs, on test benches, as a portable data acquisition system or for mobile field applications.

Typical applications can be found in the following areas:

- Testing mechatronic components with electrically powered actuators
  - Function, performance, stress and durability
  - Measuring DC voltage, 1-phase alternating voltage up to 1000 V CAT II or 600 V CAT III, measuring current via shunt or current probe
- Dynamic testing of energy storage devices (batteries up to 1250 V, etc.)
  - Long-term testing / service life (charge/discharge cycles, self-discharge, fast charging, short circuit)
  - Loading / effects (temperatures, feedback, overload, short circuit, fault, overheating, application of force)
  - Single cell tests with high common-mode rejection
  - Battery management tests (overloading protection)
- Measurements in networks with transients
  - Low-voltage signals with aperiodic high peak voltages
  - Networks with induced voltage peaks (solenoid valves, relays, etc.)

The MX403B is designed in general for applications of measurement categories CAT II (from the socket) and CAT III (building distribution). Each measurement channel of the MX403B returns not only the raw values but also root mean square values and peak values.

Seamless integration into the established QuantumX series thus enables synchronous acquisition of mechanical, electrical and thermal measurands and CAN bus signals. QuantumX modules can be physically distributed and set up close to the measuring point. They can also be easily integrated in real time via outputs such as standardized voltage, EtherCAT or CAN.

Classification in measurement categories

Measurements of hazardous voltage (AC rms > 33 V, DC > 70 V) must only be performed by persons trained to do so. The measurement categories of IEC 61010 play an important role in selecting the measuring instruments – see also the section on safety at the end of the TIPS FOR USE.

The MX403B can be used in the following areas:

- 1000 V CAT II
- 600 V CAT III
- The module can also be used outside of the measurement categories (for example battery testing). A precise analysis of the operating voltage, peak voltage, loop impedance, occasional overvoltage and transient overvoltage of the circuits must be determined in advance through precise analysis. Note the following characteristics in this regard:
    - Peak voltage: maximum 1250 V
    - Loop impedance: at least 100 mV
    - Occasional overvoltage: none
    - Transient overvoltage: 3000 V

QuantumX MX403B for measuring electric voltages

The MX403B has four isolated differential measurement channels for direct measurements of voltages up to DC 1000 V or AC 1000 V (rms). The freely parameterizable measuring ranges of 10, 100 and 1000 V allow for acquisition of high voltages against reference ground as well as measurements of small differential voltages at a high potential against reference ground. Each channel is equipped with analog anti-aliasing filters, 24-bit AD converters and digital filters, and can be individually parameterized.

The module permits measuring rates up to 100 kHz per channel and bandwidths up to 40 kHz. It can be incorporated seamlessly into the established QuantumX data acquisition system, thereby making available the advantages of that successful solution. QuantumX thus allows acquisition of all physical measurands from the mechanical, electrical and thermal worlds completely synchronously and calculates the signals, thereby establishing itself as a comprehensive complete solution and a valuable tool in research and development. QuantumX modules can be physically distributed and connected within close optical range of the measuring point (optical Ethernet or optical FireWire) to ensure maximum reliability between the measuring point and the PC.

Acquisition of currents

The traditional methods for measuring current are based on the principles of the shunt (ohmic resistance) and current probe.

While the shunt allows for a precise, phase-synchronous measurement of small currents, current probes are especially suitable for quick current measurements without disconnecting the line. Different designs of current probes are available for different application purposes. The inductive measurement principle results in a phase shift between the current and the measured electrical signal voltage from the current probe. This phase shift must be compensated for to determine power. The easiest way to do this is to delay the measured electric voltage correspondingly. This process is described below.

Now that both electrical measurands have been discussed, we turn to the software.

catmanEASY software

HBM's catmanEASY software is ideally suited for the following steps:

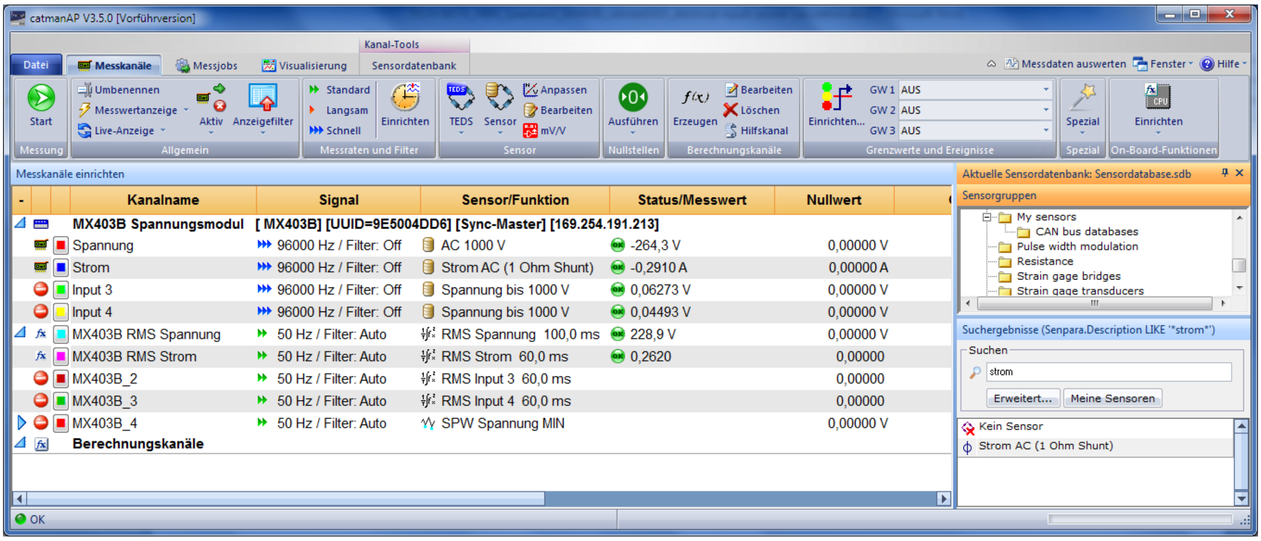
- Parameterization of channels (storage of channel settings or current probes in the sensor database)
- Optional phase compensation when using current probes
- Calculation of signals for the effective, apparent and reactive power as well as other factors
- Visualization of raw values and calculated values in individual displays
- Data storage in the desired data format
- Analyses during ongoing measurement
- Post-process analysis and creating a report

In addition to measurement acquisition, the catmanEASY software also offers an integrated mathematics library. The mathematical functions extend from simple algebraic calculations to statistical and spectral analyses and also include calculation of electrical power and efficiency with simple parameterization.

The RMS value of input quantities can also be calculated in the software.

Step-by step measurement, online calculation and analysis with catmanEASY

You can use the sensor database to help parameterize the measurement channels. If the correct signal description cannot be found in the sensor database, you can create the relevant data sheet. Using the sensor data sheet makes it easier to set the parameters of each individual channel later and it makes the process reproducible at any time.



Phase-synchronous analysis of signals with catmanEASY

Acquisition is synchronous for all channels of a QuantumX system. QuantumX offers a great many possible sensor and recorder technologies to convert physical quantities such as electric voltage, current, torque, rotational speed, temperature, acceleration, vibration, noise, bus signals for control device communication, etc. into digital signals.

Is there a phase delay between current and voltage?

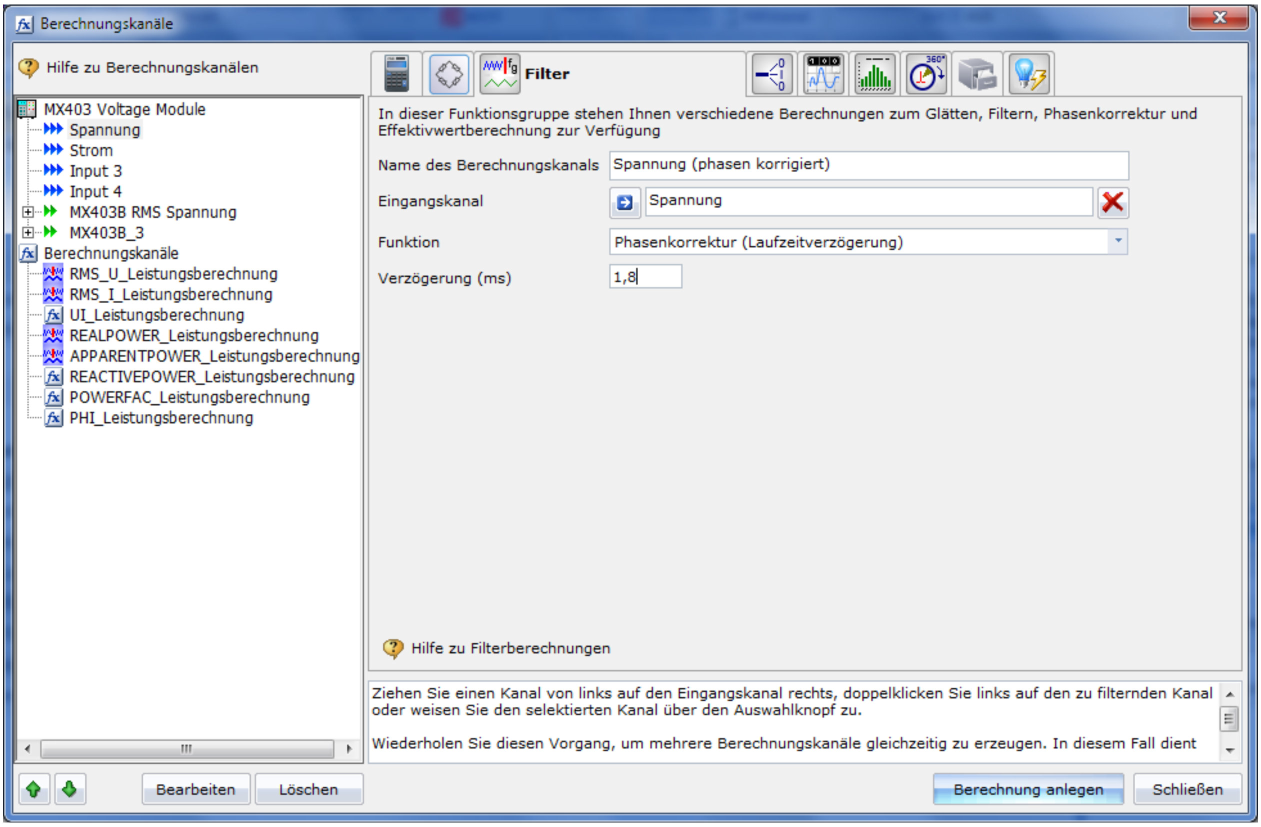
Shunts are often used to measure alternating and direct currents. The structure of shunts is purely resistive and they are therefore phase-exact. Due to their inductive measuring core, current probes have a phase delay. This means the phase of the converter's output signal is delayed relative to the current phase. If the phase delay of the converter is known, it can easily be gauged by measuring the current and voltage on a resistive consumer (for example a filament bulb) and correcting it with the catmanEASY software. The measured voltage can be delayed correspondingly.

For example, current probes can be connected to the MX403B using an adapter banana on the BNC.

Picture: Adapter banana for BNC

Of course the current probe can also be connected by using another measuring amplifier in a group, for example using an adapter BNC to SubHD on the MX840A universal amplifier. This amplifier is also able to record the following variables: torque, rotational speed, temperature, acceleration, vibration and CAN bus signals.

An example of a phase correction – Computing channels -> Filter -> Phase correction function:



In our example the current is measured by a shunt.

Online power calculation

In the power calculation we consider only low-frequency harmonic signals (< 100 Hz). The process does not involve any complex integration algorithms. The commonly used standard formulas are used.

The power calculation in catmanEasy incorporates a window-based process. The accuracy of the power calculation thus depends on the fundamental frequency of the signal and the width selected for the window.

Example: 50 Hz fundamental oscillation -> 20 ms per period -> 100 ms window -> 5 periods on average.
The calculated power will exhibit a slight residual ripple, even in a static system.

A complete calculation of all quantities in catmanEASY includes the root mean square value (RMS) and also the mean value (MEAN) over a time window. Neither one is formed in a straight forward averaging process with n values, as in the MX403B, for example. (This would require a buffer for n values, so max. time window would be limited!). Instead the process is a one-step Iteration that makes do with no buffer.

The formulas are as follows:

RMS (n) = sqrt((1-a)*measured value(n)*measured value(n) + a * RMS(n-1))

where a = exp(-1/(data rate * time window)). The MEAN is formed in a similar manner:

MEAN (n) = (1-a)*measured value(n) + a * MEAN(n-1))

The process is faster, requires practically no buffer, and can therefore implement time windows of any size. The result agrees closely with the on board calculated values of an MX410/B or MX403B. RMS and MEAN can also be filtered for smoothing. The other computing channels are calculated as follows:

REALPOWER = MEAN(U * I)

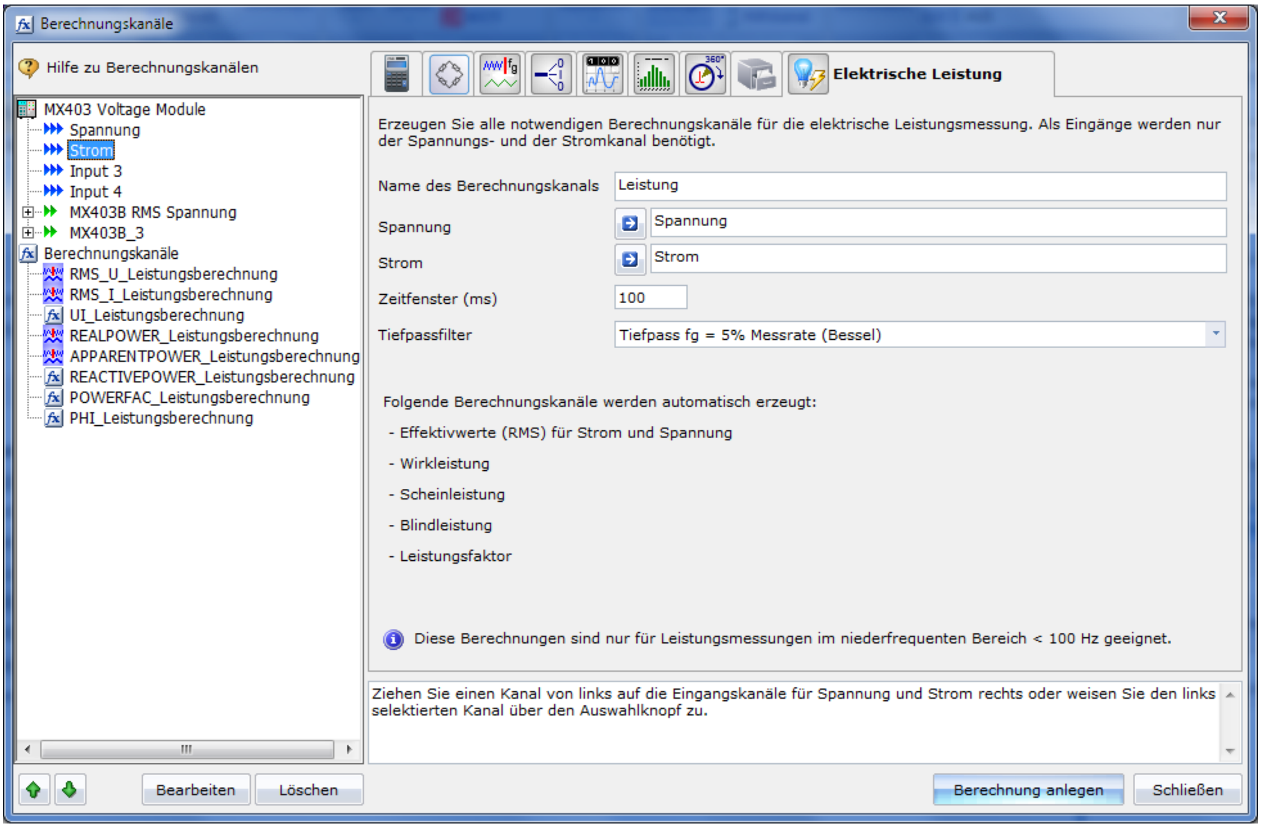
APPARENTPOWER = RMS(U) * RMS(I)

REACTIVEPOWER = sqrt(APPARENTPOWER*APPARENTPOWER – REALPOWER*REALPOWER)

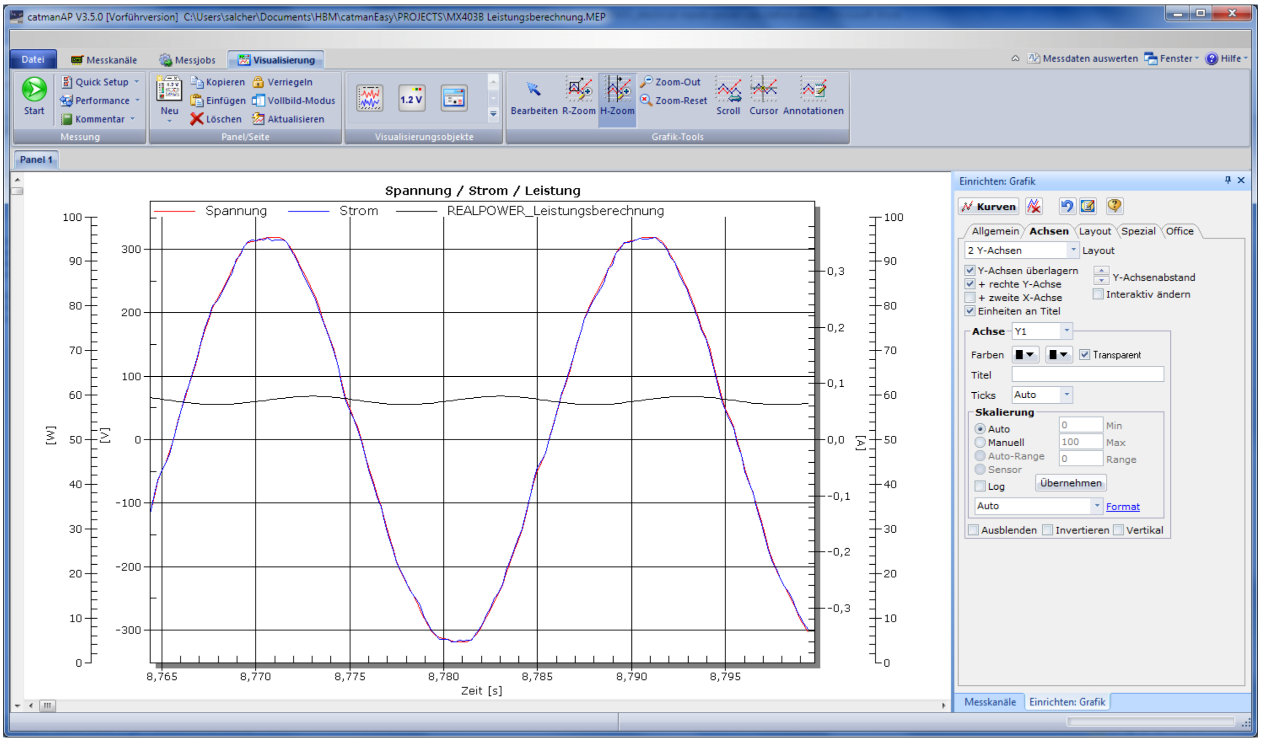
POWERFACTOR = REALPOWER/APPARENTPOWER

PHI = acos(POWERFACTOR) * 57.29 to go from rad to °

The process of parameterizing the power calculation is as follows:

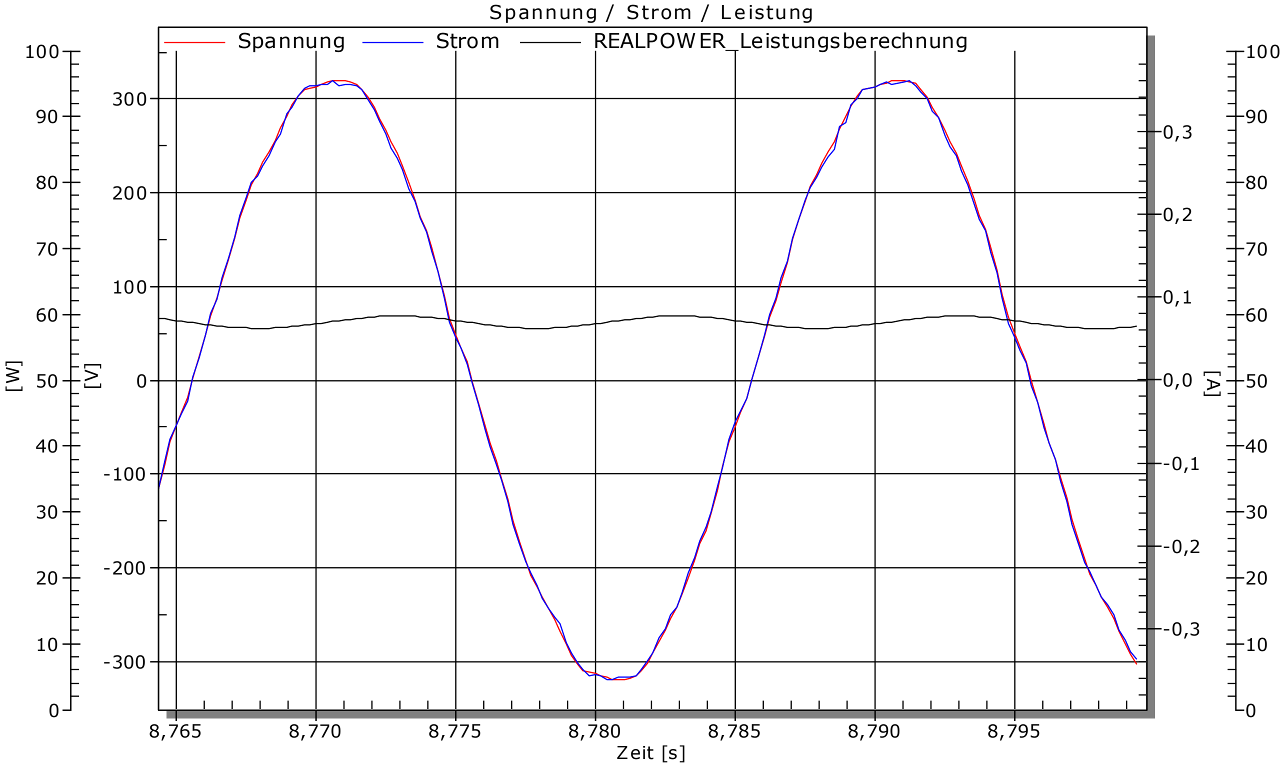


Perform a measurement with the quantities you have just obtained:

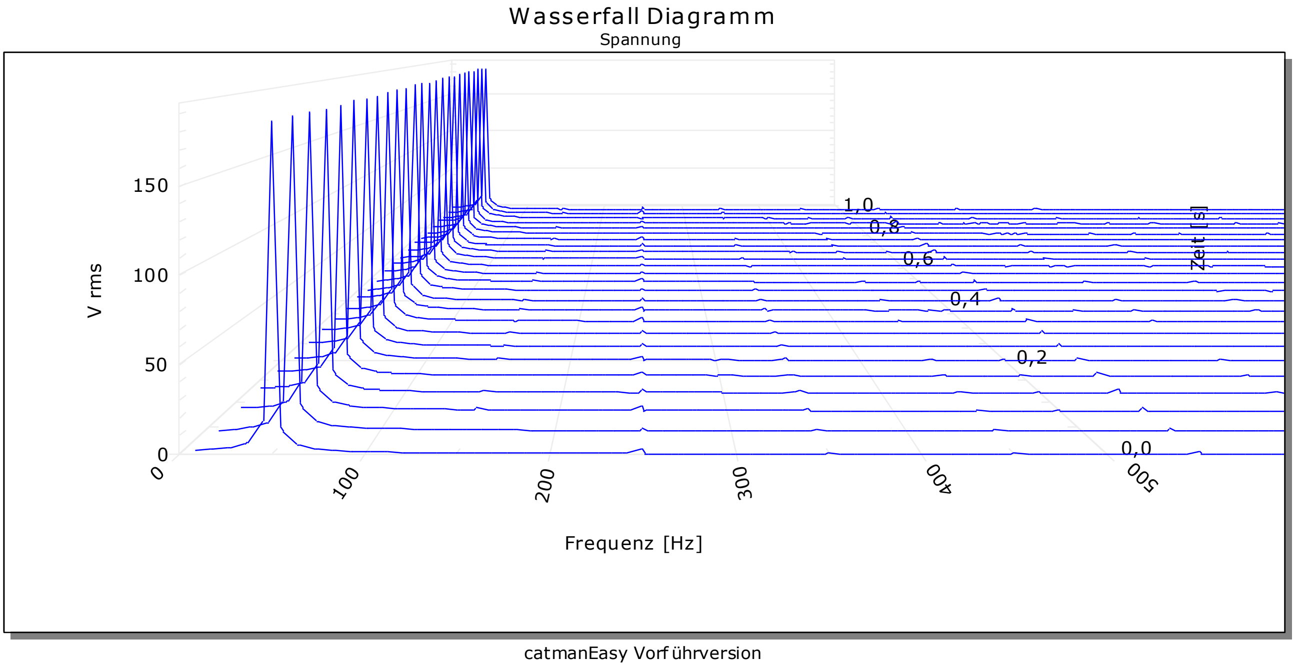


A 60-watt filament bulb will be used.

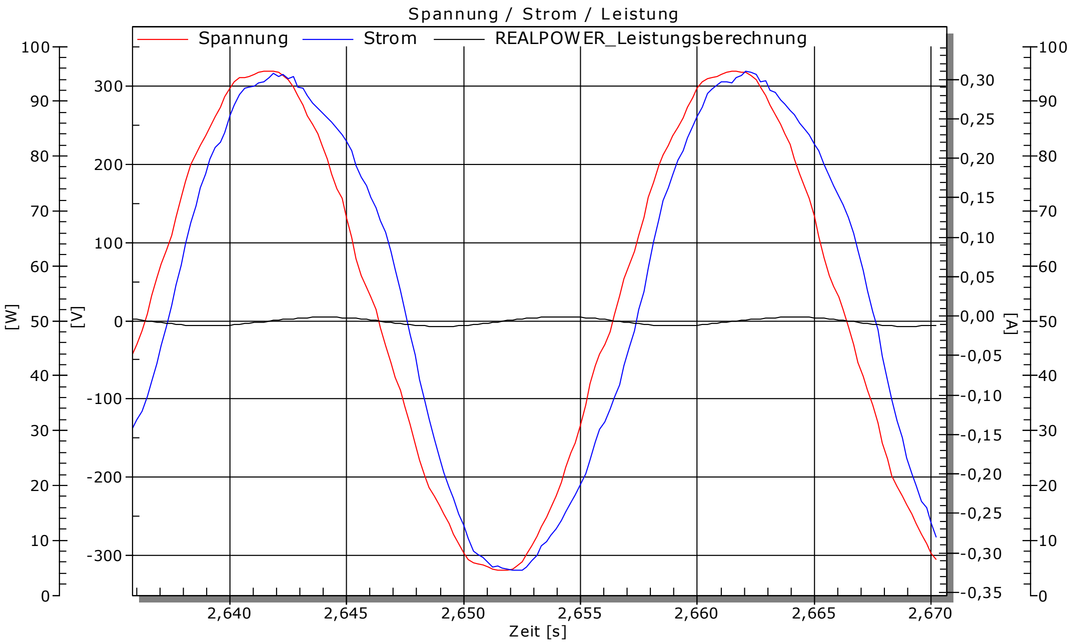
The graph can simply be exported to a measuring report in Microsoft Word with Text Markers (Office tab) .



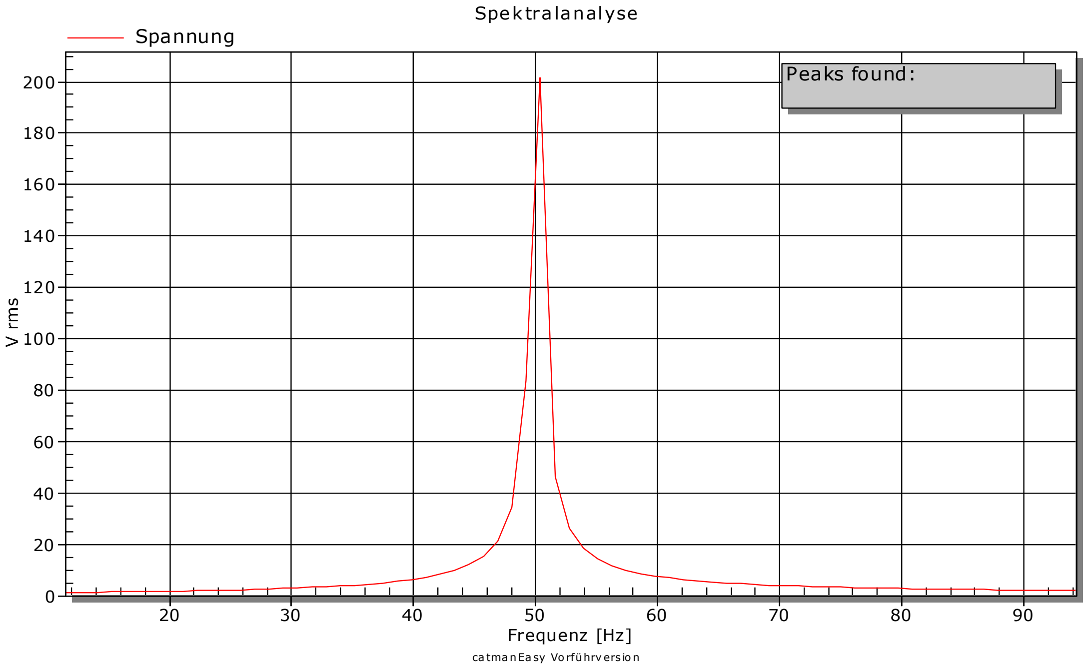
A frequency analysis can be performed in 2D and 3D. A waterfall diagram in this example:



Another graph shows a measurement of inductive loads, in this case a 50-watt soldering iron:



Perform a signal analysis in the frequency range. A signal analysis of this type is based on the Fast Fourier Transform (FFT). It facilitates the transition from time signals to the frequency range. catmanEASY can display and also analyze the frequency distribution of one or more signals. The required parameters are the number of measurands over which the amplitude spectrum will be calculated. As a general rule, the higher the number of measurands for the FFT, the more accurate the resolution. The window function is another parameter. It determines the weighting to be applied for sampling values derived from sampling a signal within a segment (window) when they are used in the calculation. If multiple channels are assigned to the graph, the spectra of the channels can also be displayed as the vector sum.



Displaying multiple spectra over time is especially important in dynamic operation. A "waterfall diagram" can be used for this purpose by successively displaying amplitude spectra tiered in three dimensions. The view can be freely rotated in all directions.

Analysis of recorded measurement data

Switch to data analysis mode (post-process). Frequency analysis in the post-process mode uses the FFT to calculate a spectrum (an amplitude, phase or power spectrum). The calculation may be performed multiple times over a part of the measurands in some circumstances depending on the frequency resolution. The advantage of this method is that the available measurands can be analyzed best if there is not a 2n number of measurands present. For frequency resolution either select Number of points from FFT and enter the number of values (points) under FFT or define the frequency resolution you want.

If you specify a frequency resolution, depending on the number of available measurands and the data rate you are using, either all measurands will be used for a calculation or several spectra may be calculated, each over part of the measurands. In this case the mean value will then be formed from all calculated spectra unless you activate the Joint Time Frequency Spectrum option.

You can activate Generate Frequency Data Set to have the frequency channel available for export as well. The channel is not needed for the display in an overview graphic.

Safety first !!!

Speaking generally, voltage cannot be perceived by the senses. Human beings have no way of sensing electrical current (only its effects are perceived). A flow of current requires voltage as its cause. A high voltage can quickly bridge and flow through conductive parts. Electrical current is lethal. The let-go threshold is 10 mA, while respiratory arrest can occur at 30 mA. Everything depends on the nature of the current, the duration of its effect, the frequency and perfusion.

What categories of voltage are there?

Low voltage	**≤ 1000 VAC / ≤ 1500 VDC**
Separated extra-low voltage (SELV)	≤ 25 VAC / ≤ 60 VDC
Extra-low voltage (ELV)	≤ 50 VAC / ≤ 120 VDC
Mains voltage	230 VAC, 400 VAC

The MX403B covers a range up to either 1000 V AC CAT II or 1250 V DC non CAT.

High voltage	**> 1000 VAC / > 1500 VDC**
Medium voltage	≤ 52kV
High voltage	60kV, 110kV
Extra high voltage	220kV, 380kV, …, 1150kV

The MX403B is therefore not an instrument for measuring high voltage!

Safety is a topic that encompasses many different areas related to testing and measurements.

How are the measuring instruments structured?

Test laboratories such as the **VDE** can certify a product and its manufacturing process. In the case at hand the product, QuantumX MX403B, was certified by the VDE. In addition to the module design, naming conventions and instructions in the documentation, the production location and personnel were all subjected to a comprehensive audit.

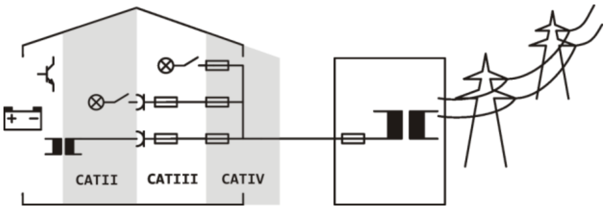
International standards such as **EN61010** play an important role in this. A standard describes the current state of the art, in other words what can reasonably be implemented in terms of design. EN61010 deals with safety requirements for electrical measurement, control, regulatory and laboratory equipment
Part 1: General requirements
Part 2: Special provisions for test and measuring circuits

The **EN61010** standard defines measures for minimizing hazards that can occur while measuring electrical quantities.

Hazards and structural countermeasures for:

- Electrical shock
    - Double insulation for conductive parts that can be touched
    - Reinforced insulation separates hazardous active circuits
    - Insulation from air and creepage distances or fixed
    - Energy and signals are transferred via certified converters
    - High-voltage quantities are energy-limited by protective impedances
- Mechanical hazards (housing)
    - No injuries
    - Stable and secure under loading
- Spreading of fire
    - A fire originating in the device must not be allowed to spread
    - No ventilation slots
    - All plastics, non-flammable

Measurement categories



Version 3 of EN 61010, the most recent, has been in effect since October 2013. Measurement category I is now history.
Both the SCM-HV voltage adapter and the MX403B have already been developed in compliance with version 3.

Measurement categories describe the **energy capacity** of a measuring place. Thus the **source impedances** and the **number of safety devices** differ from one category to another. In addition, the magnitude of transients that are expected increases with higher categories.

The voltage specified in connection with the CAT figure is referred to as the **operating voltage**. It applies **against reference ground** (L-N). The following supply network applies to phase-to-phase (Lm-Ln):
300V (L-N) ⇨ 400V (Ln-Lm). Thus phase-phase measurements are also permitted with SCM-HV!

CAT I implied that CAT II was a safe measuring place. The fallacy of this has become evident, however, at least now that high battery voltages can occur in electric vehicles. **Outside of the measurement categories**, the suitability of the measuring device for peak voltages and overvoltages that will occur, the loop impedance and expected transients must therefore be tested in addition to the electrical strength of the measuring device.

Operating voltage	**CAT II**	**CAT III**
300V DC / VAC	U_{TR} 2 500V, R_{LOOP} 100mΩ	U_{TR} 4 000V, R_{LOOP} 20mΩ
600V DC / VAC	U_{TR} 4 000V, R_{LOOP} 100mΩ	U_{TR} 6 000V, R_{LOOP} 20mΩ
1000V / VAC	U_{TR} 6 000V, R_{LOOP} 100mΩ	U_{TR} 8 000V, R_{LOOP} 20mΩ

Who is permitted to perform live working?

Live working refers to work carried out on energized electrical equipment with operating voltages above 50 V AC or 120 V DC. Live working requires specially trained employees (qualified electricians trained for live working) and special work equipment.
Only a qualified electrician is permitted to determine zero voltage in low voltage networks.
In Germany the term "qualified electrician" (Elektrofachkraft) is used to describe a person who is permitted to perform and monitor electrical engineering tasks.
EU law defines the matter in this manner: "A qualified electrician is someone whose technical training, know-how and experience, as well as knowledge of the relevant requirements, allows him/her to assess the work assigned to him/her and recognize potential risks." (Employers' Liability Insurance Regulations A 3 ; 2 Definitions of Terms No. 6)

HBM regularly qualifies selected personnel as part of training to become a qualified electrician.

To exclude the possibility of working on live parts, the following safety rules must be followed:

- Isolate
- Protect against being turned on again
- Determine zero voltage on all poles
- Ground and short-circuit
- Cover or block off adjacent live parts

Only a qualified electrician is permitted to determine zero voltage in low voltage networks.

What else requires attention?

"Live working" presupposes "live parts that can be touched." The **correct** accessories must therefore be used. Regarding accessories pay close attention to the measurement category and the specified voltage. Incorrect accessories nullify the structural safety of measuring devices!

How should I interpret the information on the data sheet?

Measuring range: Important in terms of figures related to the full scale value (accuracy class, linearity deviation and drift). The measuring range is also reused in the catmanEASY software, since a conventional designation (such as 1200 V) could result in prompting hazardous actions.

Measurement category (CAT): A certain maximum voltage is permitted within the specified category according to the standard. As non-sinusoidal voltages also occur with AC outside of the supply network, pay close attention to the maximum peak voltage here as well.

Transients: brief voltage peaks that occur rarely. Insulation is designed according to the various categories of transients that are expected.

Coverage: the maximum range for which acquisition is still possible. If we enter 2000 V here, for example, the measuring amplifier will return OVERFLOW at 2001 V.

No distinction is made for insulation between AC and DC. 1000 V CATII simply means that you are only permitted to apply 1000 V AC or 1000 V DC (transients up to 3000 V can occur and will be recorded up to 1200 V).

Yes, but then how high can the measurement signals be on the MX403B?
Answer: Downstream from a mains plug and therefore in the CATII area, maximum 1000 V DC or AC rms against ground potential and 1000 V AC RMS against other channels (phase-against-phase).
Upstream from a mains plug and therefore in the CATIII area, maximum 600 V DC or AC rms against ground potential and 600 V AC RMS against other channels (phase-against-phase).
Outside of the network or measurement category maximum 1250 V DC or AC RMS are OK.
Maximum additional transient overvoltages are protected up to ± 3000 V.

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