

TECH NOTE :: QuantumX Real-Time Processing and Outputs

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Intro

QuantumX is a modular distributable data acquisition solution from HBM for measurement and testing solving demanding engineering tasks for quicker innovation. The data acquisition modules offer highly accurate inputs acquiring physical quantities in the wide field of **mechanical, hydraulics, thermal and electrical or mixed systems** with data rates from 0.1 to 100 kS/sec and channel. QuantumX acquires sensor or transducer inputs measuring **force, strain, torque, pressure, temperature, displacement, speed, position, acceleration, flow, voltage, current and many more**. QuantumX offers superb A/D inputs supporting **voltage, current, bridge based inputs for strain gage or inductive transducers, LVDT, resistive, thermocouple, digital pulses** and signals from data busses like **CAN bus** parallel and time synchronous to all other inputs.

Some modules have output capability and work as signal converter (input to output), signal generator, real-time reaction (analog, digital) or gateway to other digital busses then Ethernet or FireWire like CAN bus or EtherCAT bus.

Abstract

This TECH NOTE shows in principle how to work with real-time processing and signal outputs in the QuantumX series.

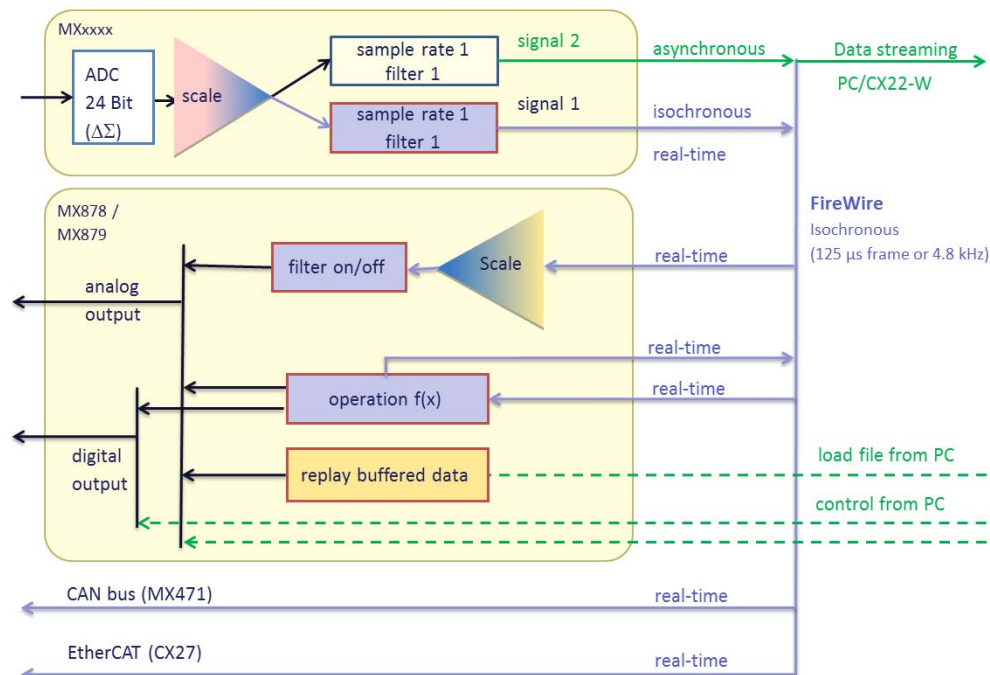
First of all it's good to understand the principle philosophy of the QuantumX **signal data path**.

Every QuantumX module has got two bus interfaces – Ethernet and FireWire

FireWire can be used for

- 1) asynchronous data transfer** from a source (input) to a sink (PC or Data Recorder)
- 2) isochronous real-time data transfer** routing signals to real-time processing units or outputs
- 3) automatic time synchronisation** of all modules and channels
- 4) power distribution from module to module or hub** with a maximum of 1.5 Ampere from node to node (rule of thumb: 3 modules over FireWire than new power supply with same voltage level or same source).

The following graphic shows in principle the complete data flow from input to output:



All inputs or in general “signal sources” can be split into two signals for different purposes:

- **Standard Signal:** with max datarate and filter for pure measurement and online PC based analysis
- **Reference or 2nd Signal:** up to 4.8 kHz/ch datarate for isochronous real-time data transfer over FireWire for real-time operation, analysis and output.

Parameterization can be done with the software QuantumX Assistant, LabVIEW or from your own application which includes the QuantumX application programming interface (.NET API).

QuantumX Assistant is a for free non programming application you can find on the QuantumX System CD or for download. This tool can easily parameterize:

- inputs to outputs (analog / digital / CAN → analog / digital / CAN / EtherCAT)
- signal generator as analog voltage output (harmonic pre-defined signal or file based free creation)
- real-time operation

A signal source can be a measurement input or a result of a math operation. Some QuantumX modules support mathematics, analysis or output functionality in real-time. Some outputs can be controlled via PC which brings us to the differentiation between real-time and online.

Real-Time: deterministic, fix time latency, no time jitter, fast response in some micro or milliseconds

Example for Real-Time: force sensor on MX840A channel no 1 -> asynchronous 1st signal with 19.2 kS/sec 2 kHz filter to PC for data acquisition / isochronous 2nd signal with max. 4.8 kHz and a respective filter for example 200 Hz -> MX879 picks up isochronous signal and is parameterized to do a limit switch math operation (200 Newton, active LOW, hysteresis - 10 N) -> MX879 digital output 1 switches to HIGH (24 V) when 200 N limit is reached, falls back if lower than 90 N. Time latency between input and output is approximately 2 ms.

Online: PC based, response in some milliseconds, varying time latency

Example for Online: force sensor on MX840A channel no 1 -> 1st signal asynchronous data transfer over Ethernet to PC -> catmanEASY / LabVIEW / .NET application parameterized to do a limit switch math operation (200 Newton, active LOW, hysteresis - 10 N) -> asynchronous data transfer to MX879 digital output 1 switches to HIGH (24 V) when 200 N limit is reached, falls back if lower than 90 N. Time latency between input and output is ~ 50 ms.

QuantumX Real-time Operation and Output

The following modules offer outputs:

- MX410/B: real-time operation (RMS, PEAK) and direct analog voltage output
- MX878: real-time math operation and analog voltage output
- MX879: real-time math operation and output (digital 5 or 24 V, analog voltage)
- MX471: send signals to CAN bus
- CX27: send any signal to EtherCAT bus

The modules MX878 (8 analog voltage output) and MX879 (8 analog voltage outputs and 32 digital IO) offer also real-time operation:

- PID control
- Cross calculation Add / Mul with the formula:

$$y = a_0 + a_1 * Signal_1 + a_2 * Signal_2 + a_3 * Signal_1 * Signal_2$$
Simple Addition: $a_0 = 0, a_1 = 1, a_2 = 1, a_3 = 0$
Simple Multiplication: $a_0 = 0, a_1 = 0, a_2 = 0, a_3 = 1$
- Matrix calculation 6 x 6 for example to compensate cross-talk of 6 DOF load cells with the formula

$$\begin{pmatrix} Fx \\ Fy \\ Fz \\ Mx \\ My \\ Mz \end{pmatrix} = \begin{bmatrix} & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \\ & & & & & \end{bmatrix} * \begin{pmatrix} Fx \\ Fy \\ Fz \\ Mx \\ My \\ Mz \end{pmatrix}$$

- PEAK detection over time or cycle
- Root Mean Square (RMS) calculation over time
- Signal Generator (standard, arbitrary)
- MX879 only: Limit Switch Function / Alarm: Switch on digital output on certain level of *Signal*

The module MX460 (4 channel digital input focusing on speed and torque) offers in addition real-time torsional vibration and angle difference for angle based analysis of shafts or combustion engines.

The outputs of the following modules can be controlled via PC online:

- Example: algebra or logic calculation in catmanEASY activating a digital output on MX879 or an analog output on MX878 / MX879 (timing ~ 50 ms)
- Analog output of MX878 or MX879
- Digital output on CX22-W Data Recorder, CX27 Ethernet / EtherCAT interface or MX879 Multi IO module
- MX440A, MX840A: digital output on every port (pin 15, timing ~ 200 ms)

QuantumX covers use cases like:

- A) Pure mapping of any input to analog voltage output (MX410/B, MX878, MX879)
 - On MX410 drag and drop universal input to direct analog voltage output.
Example: MX410 with direct voltage out (~ 200 µs time latency)
 - Output signals from any module in the FireWire network to **MX878** or **MX879**, scaled to ± 10 V, with additional low pass filter if necessary.
Example: all MX840A inputs send to MX879 analog out to be integrated into an existing test stand, MX879 also activates digital outputs when limit is reached in real-time (i.e. over 1 kN)
 - Drag and drop CAN signals from MX471 / MX840A to MX878 / MX879, scaled to ± 10 V, additional filter if necessary.
Example: MX471 CAN bus signals send to MX878 as analog voltage output

- B) Sending any signal to CAN bus (digital gateway)
 - Any signal in the FireWire network can be send via MX471 module as CAN message.
 - Example: analog sensor inputs of MX1615B and MX1601/B, MX410/B input as RMS value and CAN signals of MX471 itself and real-time torsional vibration of MX460 can be send as separate CAN signals via MX471
 - Inputs 2 to 8 on module MX840A can be sent as separate CAN signals on port 1 with 100 Hz datarate per signal.
 - To simply integration on the other side QuantumX Assistant can generate of CAN description file (*.dbc)
- C) sending any input signal to EtherCAT and integrate QuantumX universal inputs in large scale real-time test stands and in parallel over Ethernet to a standard PC with catmanEasy for signal analysis
 - Any input or calculated signal can be sent to EtherCAT bus in real-time via CX27 EtherCAT slave
 - Example: MX840A (input of load cell, displacement inputs), MX1609 (temperature signals), MX471 (CAN signal input, CCP signal input) send to => CX27 EtherCAT Gateway in real-time and to EtherCAT.
 - To simplify integration QuantumX Assistant can generate an EtherCAT parameter file (*.esi)
- D) using real-time processing functionality for small scale system test stands
 - Modules like MX878 / MX879 provide real-time processing power which can be easily parameterized
 - Example: MX840A inputs send to MX878 or MX879 working as PID controller with voltage output as control interface
- E) signal generation with MX878 / MX979
 - Standard Waveforms: constant value, sine, rectangle and triangle with variable frequency / amplitude
 - Arbitrary mode: load any signal into buffer and replay (up to 10.000 signals)
- F) Analog or Digital Output activation with catmanAP / EASYscript
 - Any input signal cross calculated -> limit switch / alarm monitorin -> digital output activation
 - Any input signal cross calculated -> analog output activation

Important to know: All configurations are stored permanently in the modules. After power down and power up all configurations are active!

A1) Mapping any signal to analog voltage output

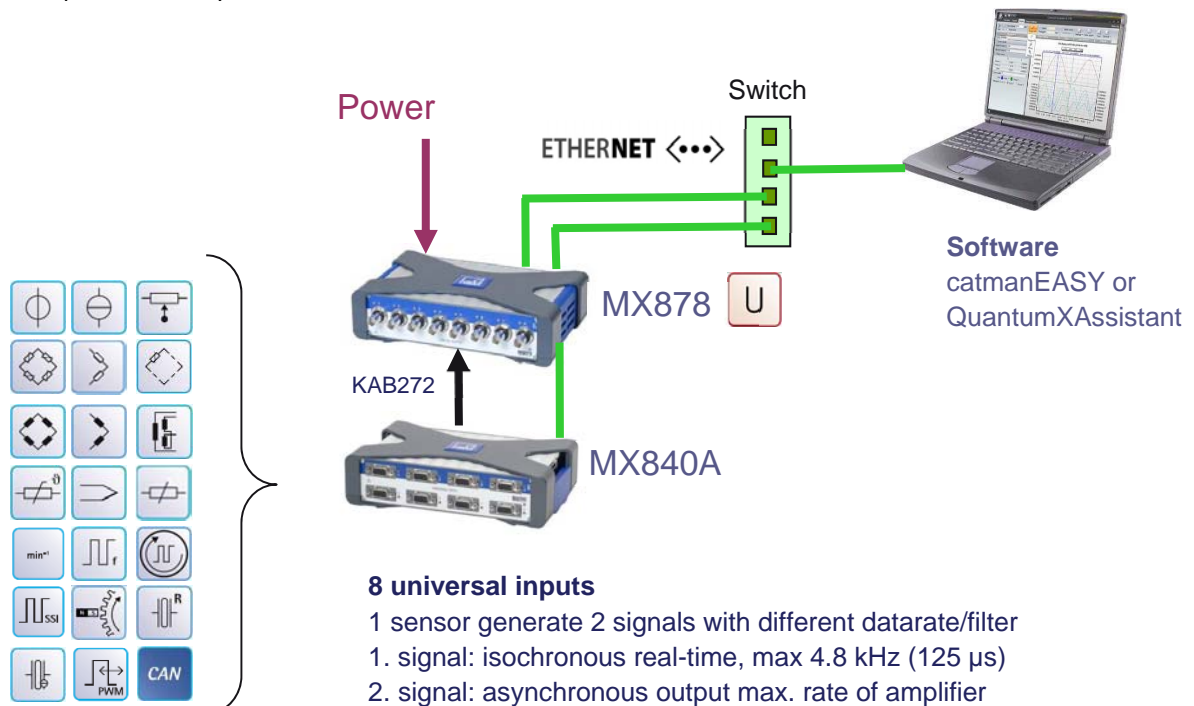
Any type of input (analog, digital, CAN) or signal (real-time calculated signal) within the QuantumX system can be mapped to an analog voltage output on MX878 or MX879 and will work right after power up. The PC is only necessary for parameterization.



Step by Step instruction on how to map inputs to outputs with the software QuantumX Assistant

The workflow to map any input to an output is shown in example. All other variants follow the same workflow.

1. Set up the overall system



2. Wire up the input and outputs

For this example the following cables are required: 2 x BNC to SubHD 15 pin voltage pinning



A signal generator delivers a 400 Hz sine signal with 1 V amplitude.

Connect the signal generator to **input 1 of MX840A** and parameterize it as 10 V voltage input via sensor database.

Input 1 signal 1 shall be parameterized with **4.8 kS/sec sample rate, no filter and isochronous**

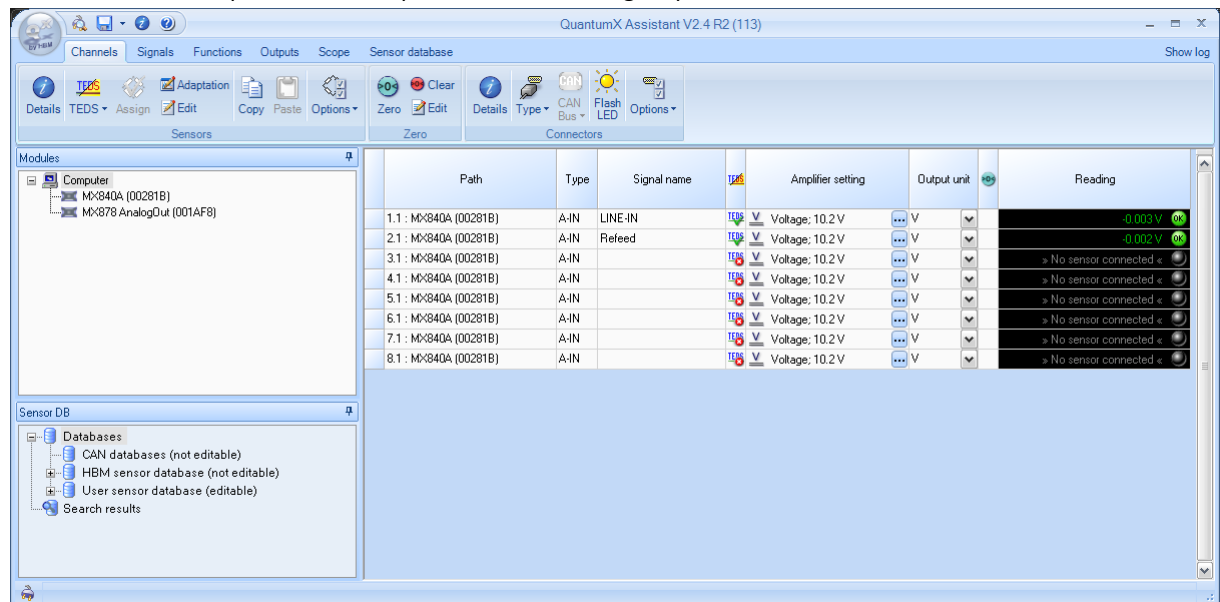
Input 1 signal 2 shall be parameterized with a datarate of 19.2 kS/sec, filter = OFF.

Connect output 1 of MX878 to input 2 of MX840A as reference for latency measurement

Parameterize port 1 of MX878 as 0 ... 10 V input = 0 ... 10 V output, filter = OFF

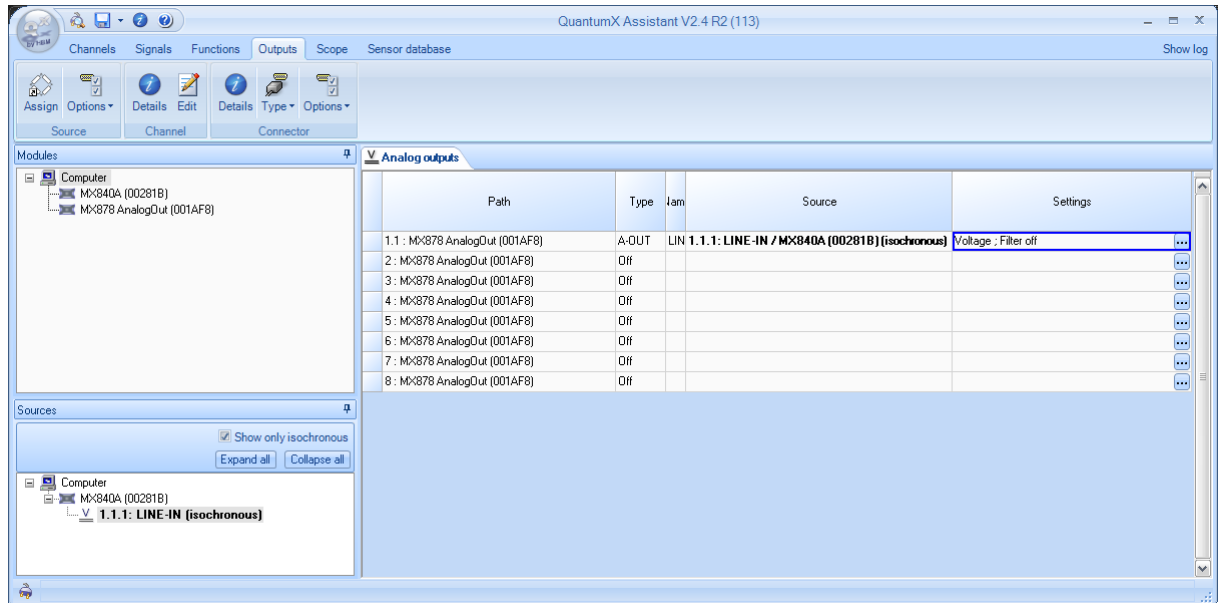
Parameterize MX840A port 2 as 10 V voltage input via sensor database. Datarate shall be 19.2 kHz, filter = OFF.

3. Go to *Channels* tab: parameterize inputs 1 and 2 as voltage input via Sensor Database

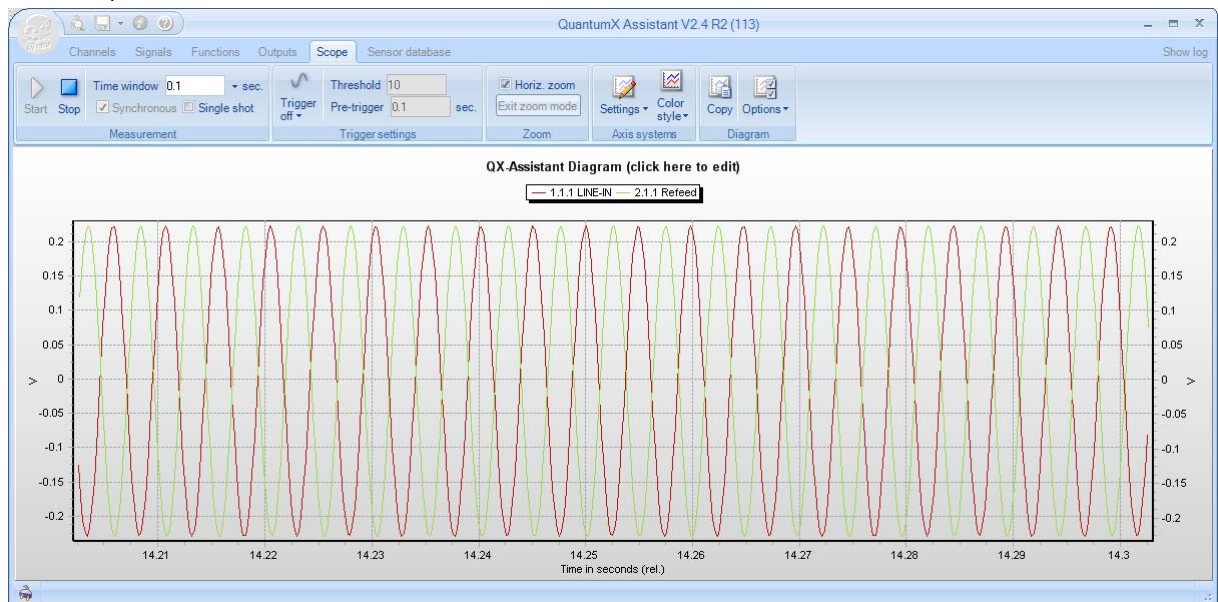


4. Go to *Signals* tab: configure datarate, filter and activate **isochronous** data transfer

5. Go to *Outputs* tab: drag & drop **isochronous** signal to port 1

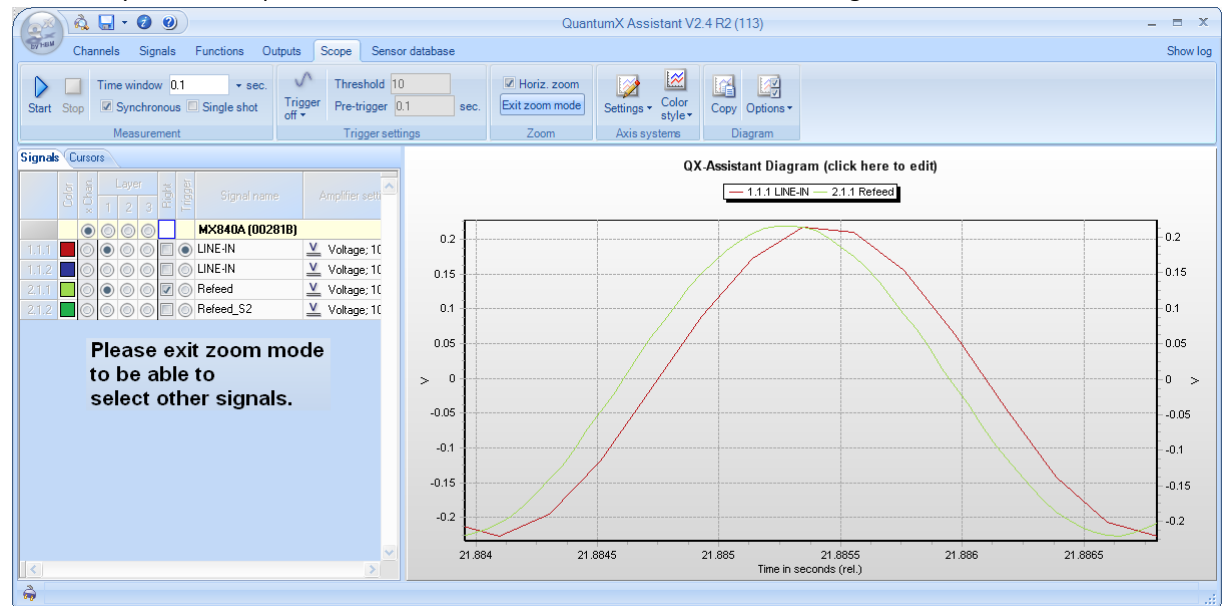


6. Go to *Scope* tab: Start measurement



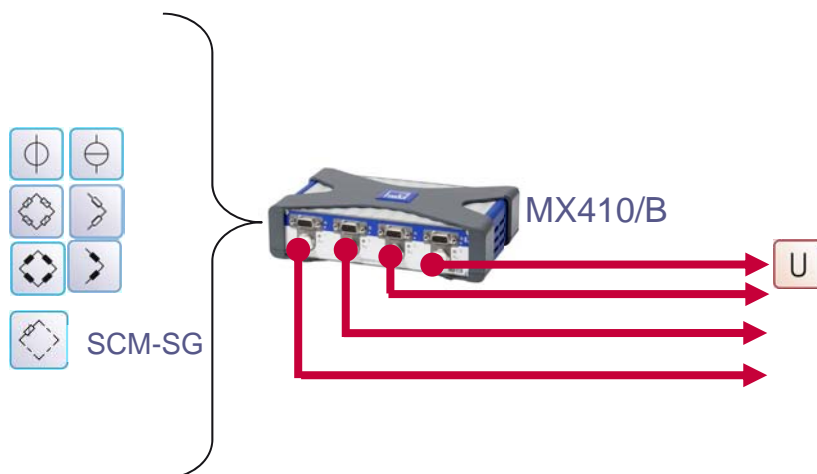
7. Stop measurement and measure time latency.

For latency calculation please refer to modules datasheet and the filter settings.



A2) MX410/B - universal analog inputs to analog voltage output

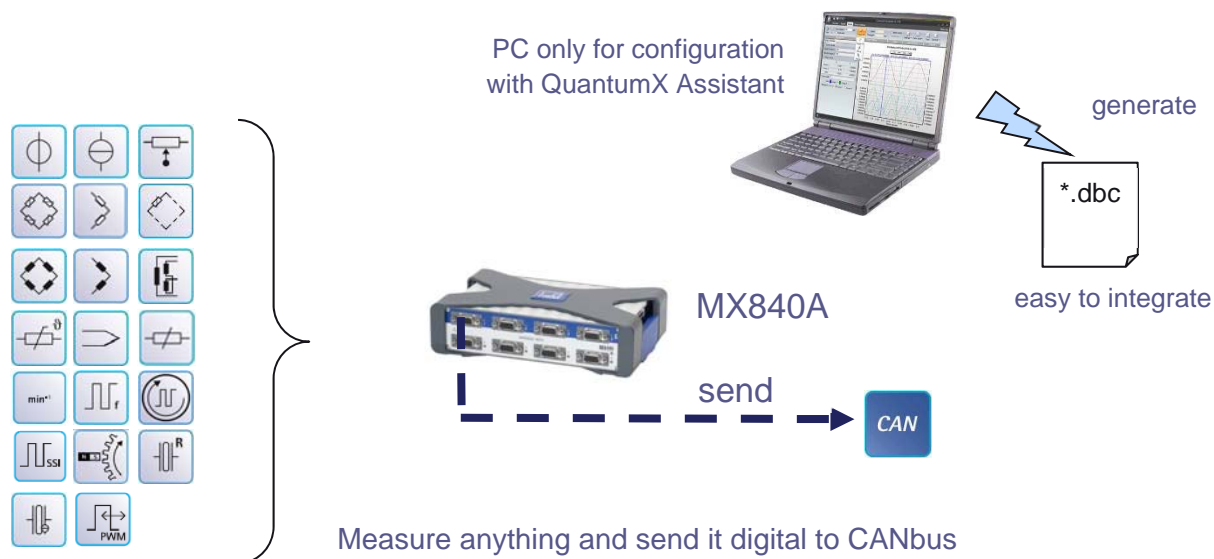
MX410/B offers direct analog output to every input of the module. Time latency from input to output is min. 250 μ s for max. data rate and filter = OFF.



B1) MX840A – 7 inputs send to CAN bus output (port 1)

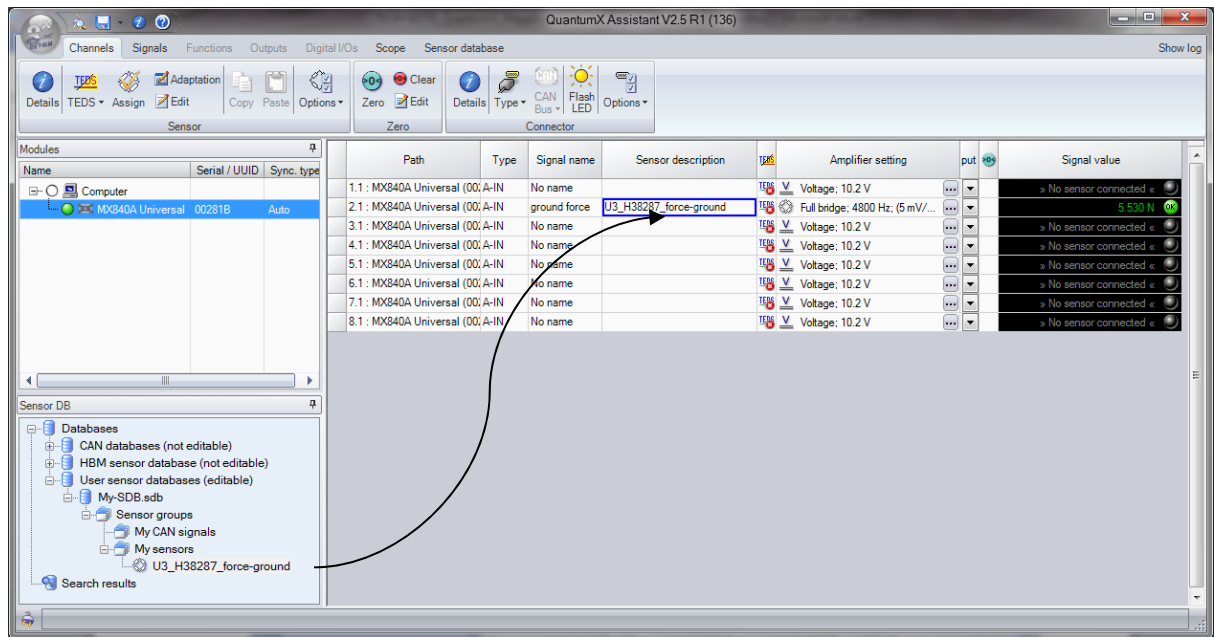
MX840A port 1 can be configured as CAN output. The procedure is almost the same like above. Isochronous data mode of the signal is not necessary as they don't go to FireWire. All 7 universal inputs of the module can be sent to CAN bus. It is not possible to send out inputs from other modules via port 1 of MX840A.

QuantumX Assistant is the best tool to map an input signal to a CAN message. The software can also generate a CAN configuration file (*.dbc) which makes integration very easy.



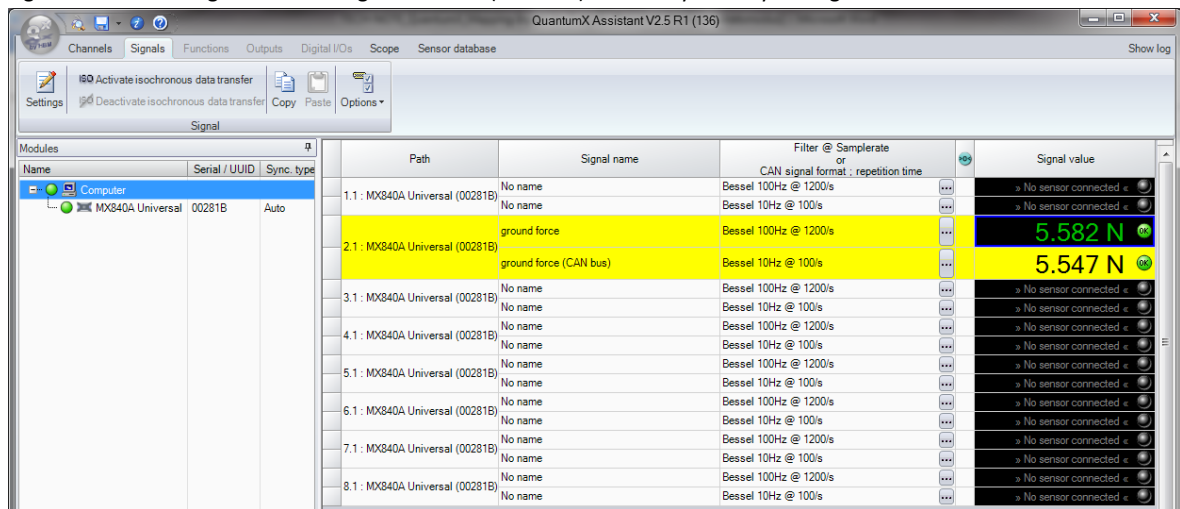
How to parameterize a CAN output?

1. Start the software QuantumX Assistant.
2. Go to *Channels* tab: parameterize sensor inputs via Sensor Database (drag & drop)
Remember: TEDS simplifies this step – everything is configured automatically right after sensor is plugged in.

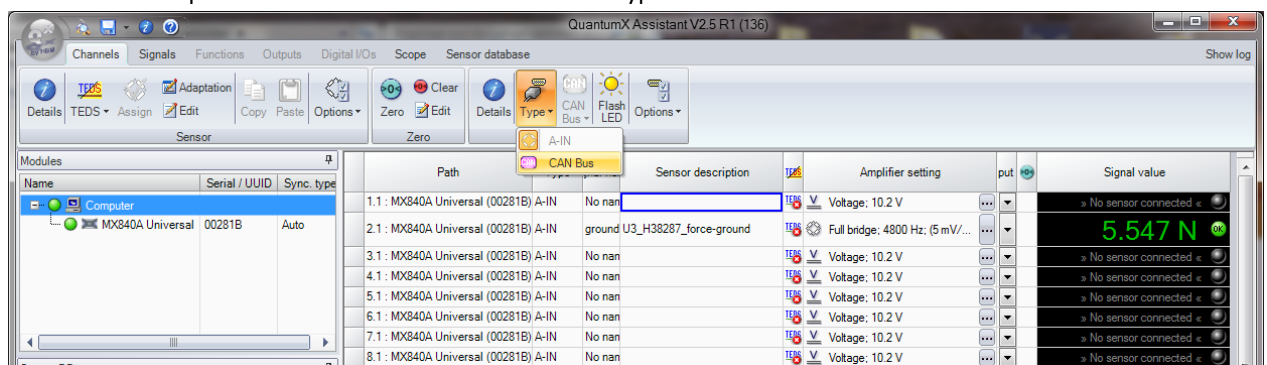


3. Go to *Signals* tab: configure datarate and filter and name of the signal

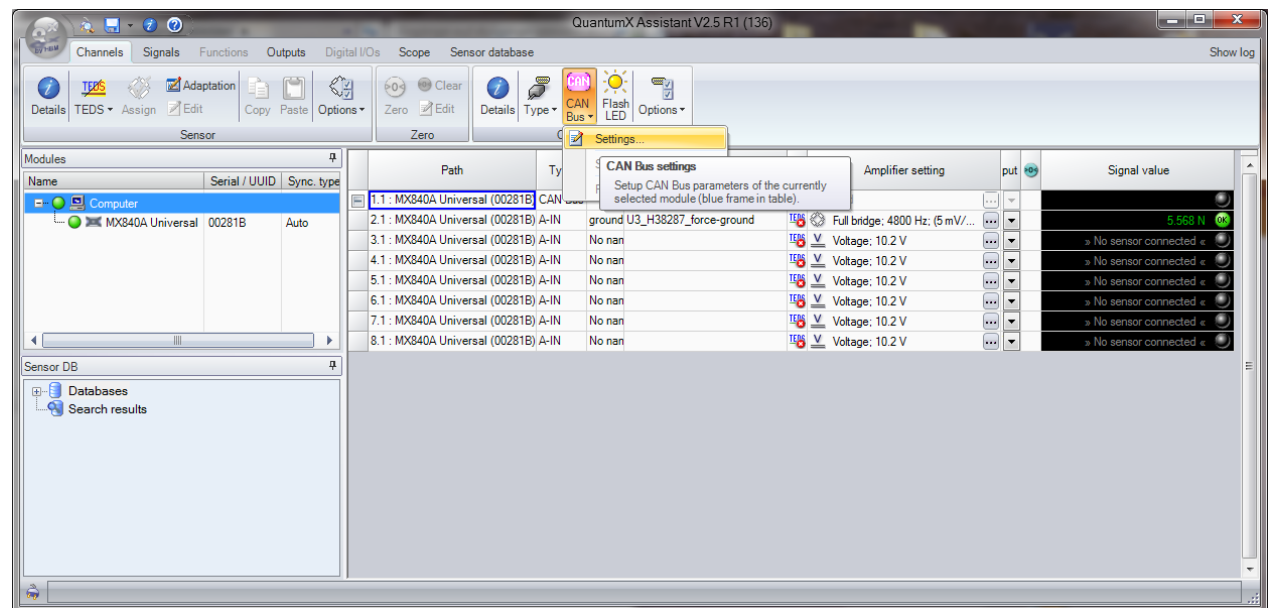
Remember: QuantumX can split a single source into two signals – one for example for analysis and another one for real-time purposes with certain limitations. Sending CAN messages over port 1 of MX840A is limited to 100 Hz max datarate per signal. The second signal is named “ground force (CAN bus)” to clearly identify the signal which shall be sent to CAN bus.



4. In *Channels* tab: parameterize channel 1 as CAN node – Type: CAN Bus



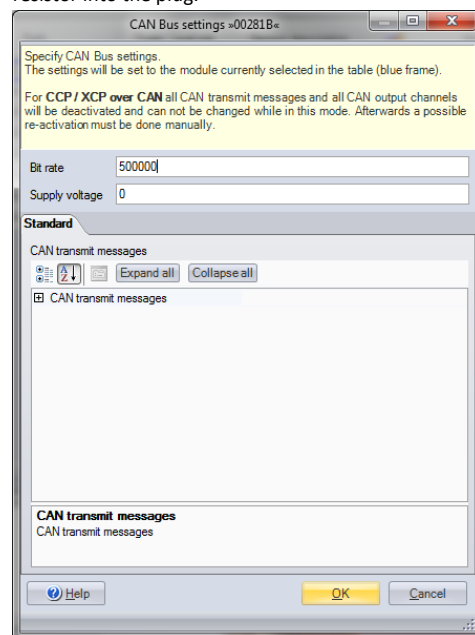
Parameterize CAN bus settings



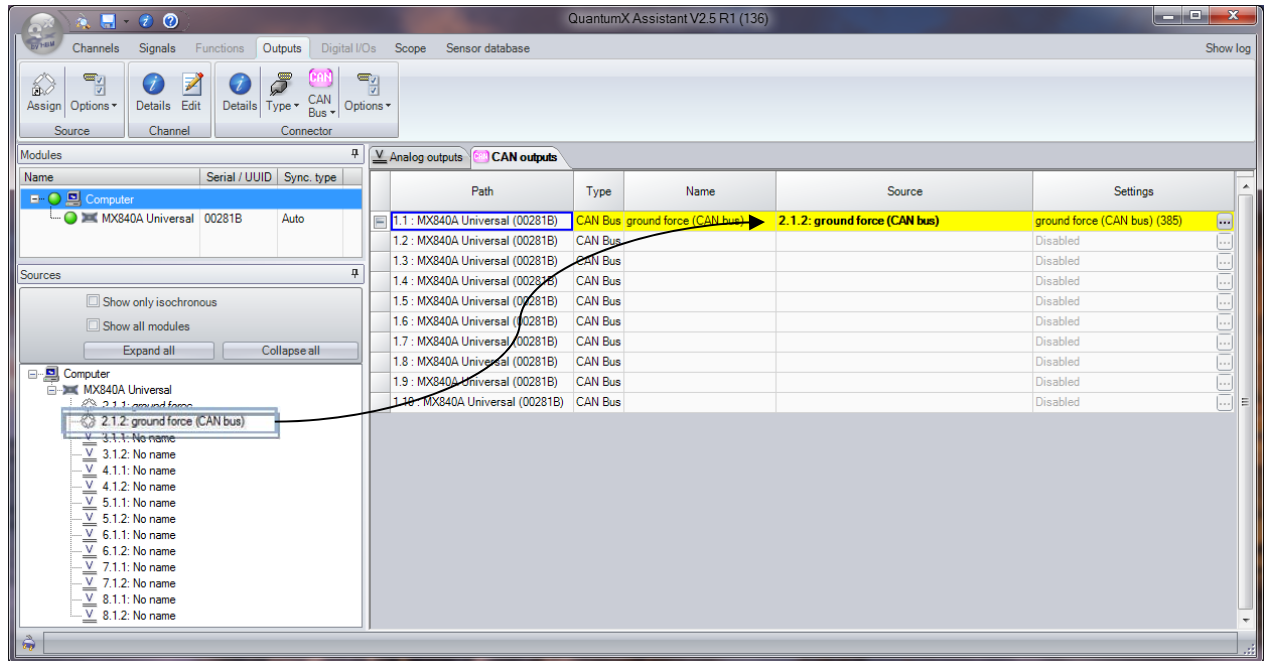
Modify the parameters according to your needs:

Example: Bit rate: 500.000 bit/sec

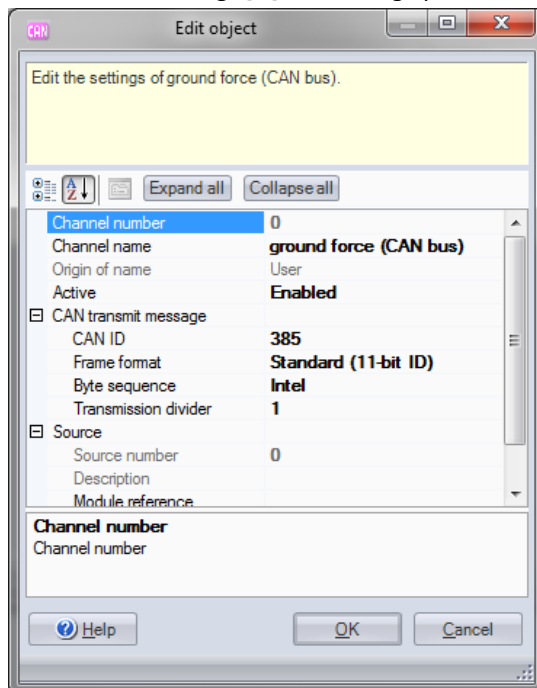
Remember: CAN bus has to be physically terminated on both ends of the bus with 120 Ohm. If needed you can solder a termination resistor into the plug.



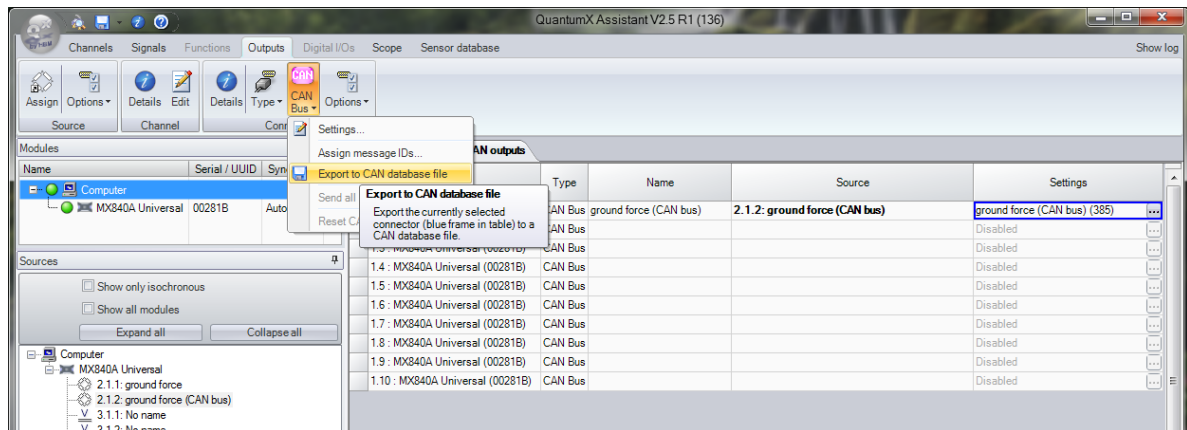
- Go to *Outputs* tab: drag and drop signal to “CAN outputs” field



Now click on Settings [...] for message parameterization

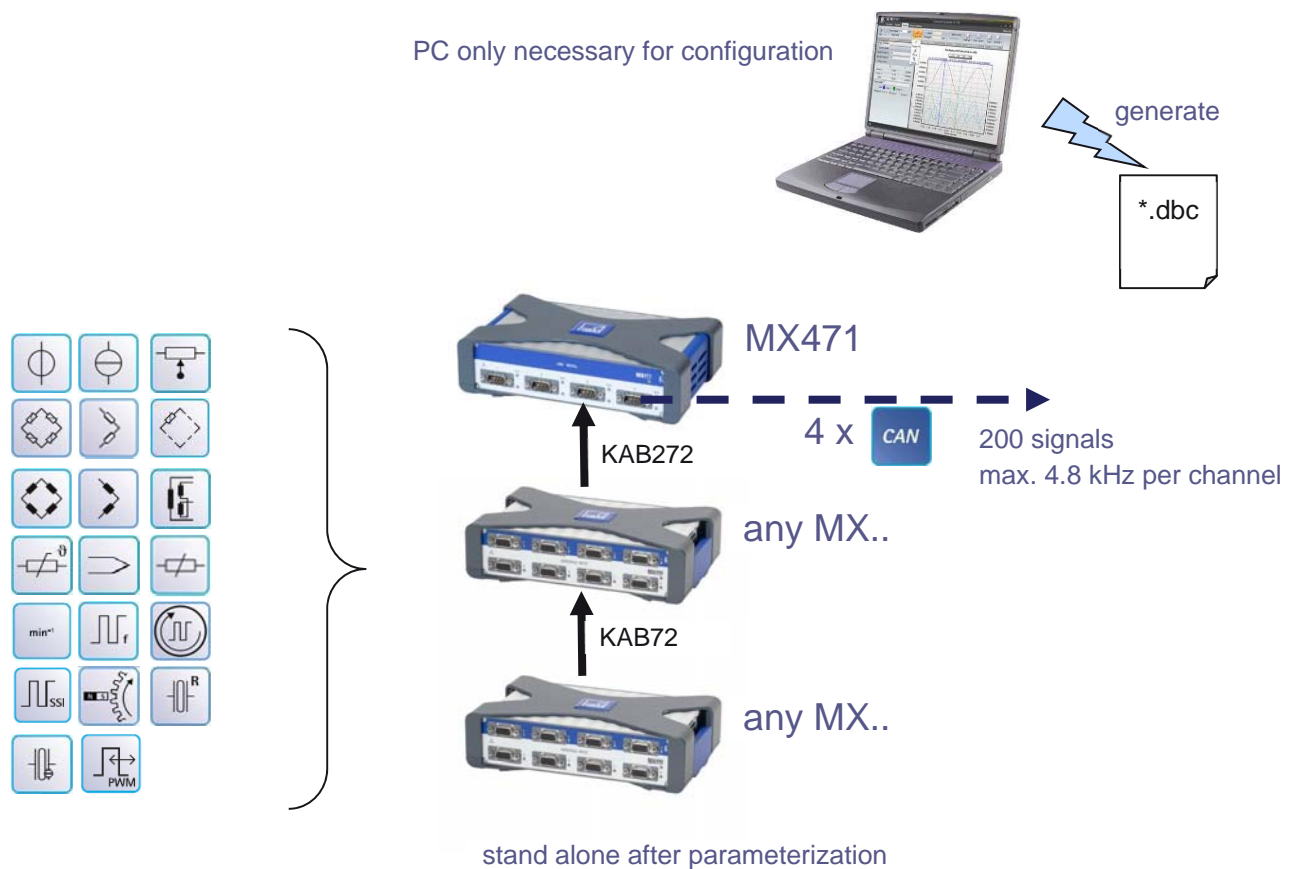


- Optional: generate CAN configuration file (dbc) like shown in the picture – “Export to CAN database file”. Remember: this file simplifies integration or parameterization of the receiver.



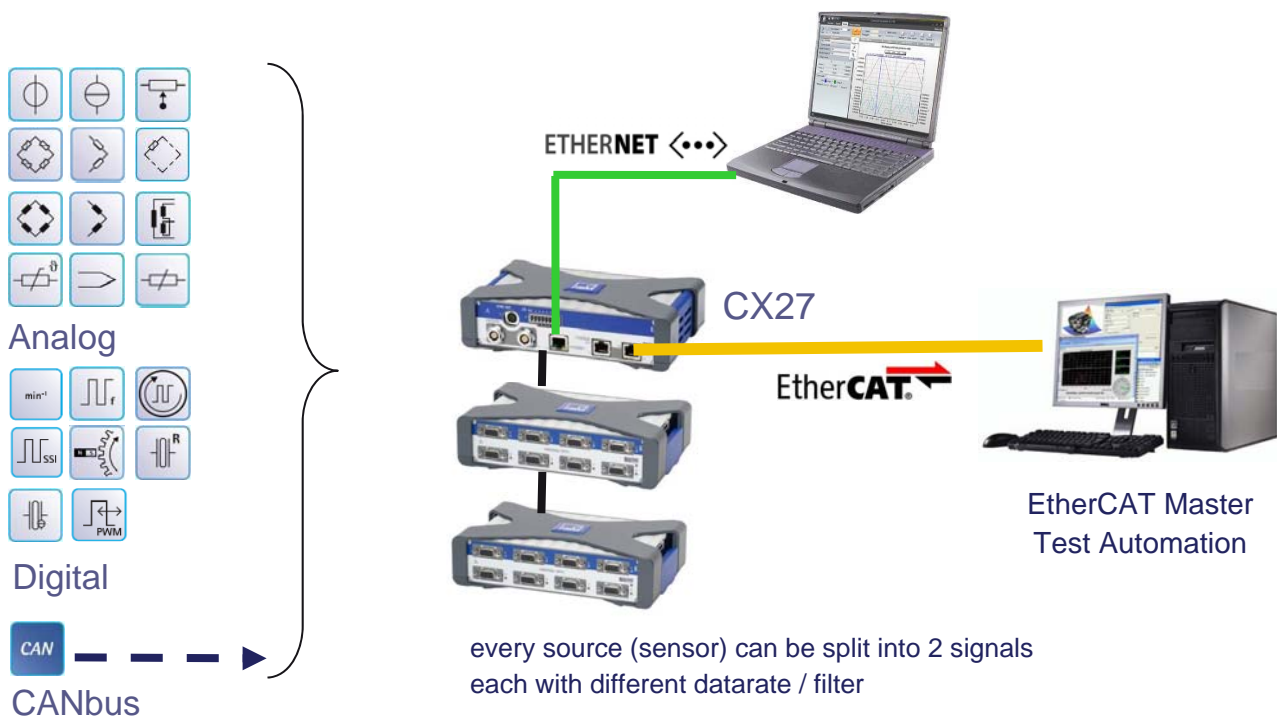
B2) MX471 – mapping all kind of signals to CAN bus output

MX471 is a module which can be used as gateway module sending any measurement input or real-time signal to CAN. MX471 is not a CAN-2-CAN gateway. All CAN signals acquired from MX471 are stored in Float data format.



C) Integrate QuantumX in real-time signal to EtherCAT bus

CX27 is the QuantumX EtherCAT / Ethernet gateway. Mapping of inputs to EtherCAT is the same like described above. In parallel a Data Logger can acquire high-speed data over Ethernet or FireWire.



D) PID control with QuantumX

MX878 / MX879 offer 4 PID controller which can be parameterized with the software QuantumX Assistant or in your own software based on QuantumX .NET / COM API.

The PID control algorithm comprises **three elements**:

- Proportional - also known as Gain
- Integral
- Derivative

PID controllers are typically parameterized in the following **combinations**:

- Proportional only
- Proportional and Integral (most common)
- Proportional, Integral, and Derivative
- Proportional and Derivative

Initial Conditions: setting up initial conditions is relevant for highly dynamic systems.

Coping with Limits: It is prudent to limit the output to a certain range. There can be good reasons for more restrictive limits: amplifiers that are unipolar and can't respond to negative values, systems that respond dangerously fast if driven too hard, etc. Therefore two additional configuration parameters are available forcing outputs to be limited to a specified range.

Avoiding Windup: After limits are applied linear PID controls become nonlinear, and this has some side effects. Consider what happens when a controller starts at a zero state and is commanded to start regulating at a high level. While the controller is driving hard toward the new level, the system is still far away from the target set point, so the integral accumulates rapidly. Eventually, even though the desired output level is reached, and passed, the integral effects by themselves are enough to continue driving ahead at maximum. This behaviour is known as windup, and the extended transient time required to correct the integrator imbalance is known as unwinding. Various strategies to counter windup effects are known collectively as anti-windup.

Functional PID description

Function	<p>Quasi-linear PID controller with parallel structure and anti-windup</p> $Kp * (1 + \frac{1}{Ti * s} + \frac{Td * s}{Tp * s + 1})$ <p>Tp is the parasitic time constant, see below</p>
Max amount of function blocks per module	4 from in total 4 Math Units running on MX878 / MX879
Max. turnaround time / Output rate	1200 Hz / ~ 1 ms (ATTENTION: input datarate and ouput datarate + filter are additional tuning factors which are still flexible.
Inputs	<ul style="list-style-type: none"> - Input in0 set point value - Input in1 actual value (process value, feedback) - Logical Enable input (digital, PC side: ON / OFF, output goes to steady state and needs default value parameter)
Outputs	Controller output out0, can be named Actuator and be mapped to analog voltage output or / and send in real-time to FireWire bus and then to CAN or EtherCAT
Parameters	<p>Gain Kp, P component</p> <p>Reset time Ti [seconds], I component</p> <p>Rate time Td [seconds], D component</p> <p>Upper limit of the controller output ymax</p> <p>Lower limit of the controller output ymin</p> <p>Additional value input: as fix output value</p> <p>Default output: default is output when Enable input = low</p>
Segmentation Selection	Set by actual value in certain range
Activation / Deactivation	<p>Set by control (any digital input, software control):</p> <ul style="list-style-type: none"> • PID is then in halt position and does not integrate any further. • Output is freezed to default value
Default	Kp = 0.0

	$T_i = 1e38 \text{ s}$ $T_d = 0.0 \text{ s}$ $y_{\max} = 1e20$ $y_{\min} = -1e20$ enabled = constant High, i.e. permanently active default = 0.0
Exception handling	If at least one of the inputs is invalid (Invalid bit), <ul style="list-style-type: none"> - the output is frozen and also marked as invalid - the controller is stopped
Integrated Plant Model	Integrated PT1 and PT2 models which can be used as test control plant

The controller cannot be used as mere P controller because of recursive calculation. An I component should always be present.

Parasitic time constant $T_p = \frac{1}{\text{calculation rate}}$

$$T_p = \frac{1}{19200} \text{ s} = 52 \mu\text{s} \text{ Default}$$

Segmented parameterization

A “segmented parameterization” corresponds to a set of P, I, D parameters, which will be auto selected from the PID controller’s measurement feedback sensor if not tied here. A segmented allows for higher level test scripts or cycles or PLC’s to force the selection of the P, I, D parameters independently from the PID controllers measurement feedback sensor.

Example:

- From -inf to 0:
 - P will be 0,05
 - I will be 0,8
 - D will be 0
- From 0 to +_:
 - P will be 0,1
 - I will be 1
 - D will be 0

The “beginning” and “end” parameters are the segment boundaries (same as “span” in the segment table).

The “range input” parameter is currently not used.

You can create any number of segments. If not forced by the segment selection input on the previous window, then the segment selection will be automatic, decided from the PID regulator’s measurement feedback sensor. This feature is extremely valuable, because it allows for fast rough cut approach to the

target set point, then soft landing. The “saturation” parameters allow clipping the PID regulator’s actuator outputs (in absolute range; in the physical unit of the set point, so in bars in our example).

Stabilization

The “stabilization” parameters allow defining the % range around the target set point, where the PID controller is considered stable. In the case above, the PID will be considered stable when the measurement feedback is between 95 and 105% of the set point. A time period parameter is lacking here: we will shortly add this, in order to consider the PID stable only after it has stayed in the stable range for x amount of time.

As the stabilization parameters are defined in % of set point, around zero they have no meaning (because

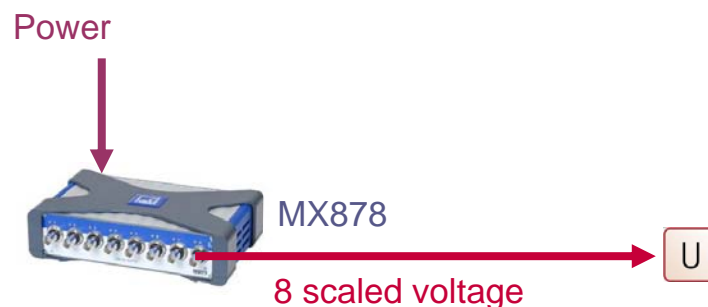
95% of zero = 105% of zero = zero). So the “dead band” parameters allow defining an absolute stabilization criterion, in the form of a dead-band around zero, in absolute range; in the physical unit of the set point, so in bars in the example above. If the “fixed command” parameter is checked, then the PID will not modify its actuator output when it is stable.

E1) MX878 or MX879 working as signal generator with analog voltage output

Analog voltage outputs of MX878 or MX879 can be parameterized as signal generator with the following signal types

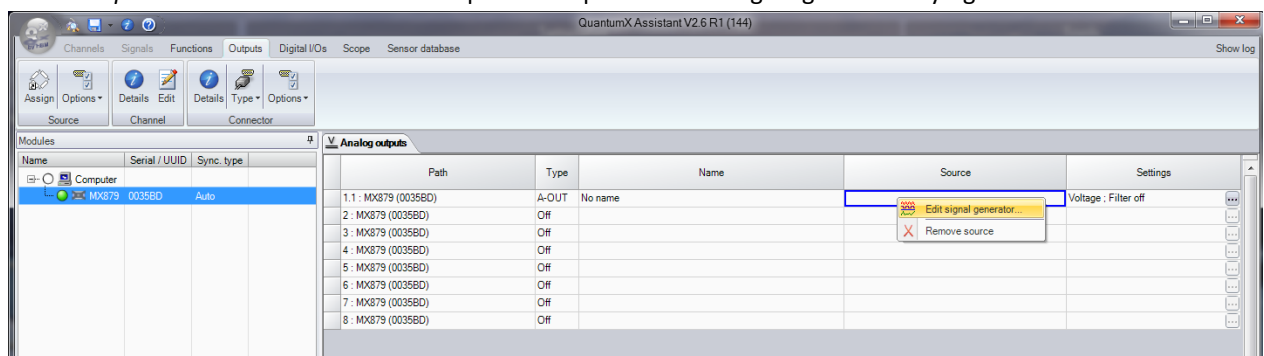
- Constant: i.e. 5 V, this value can also interactively loaded from the PC software side
- Periodic: rectangular, sine, ramp with a certain amplitude and frequency
- Arbitrary: loaded profile in ASCII format from PC side into buffer and replay (up to 10.000 signals)
Please go to chapter D2 below for more details.

Parameterized outputs will work right after power up and don't need PC connected.

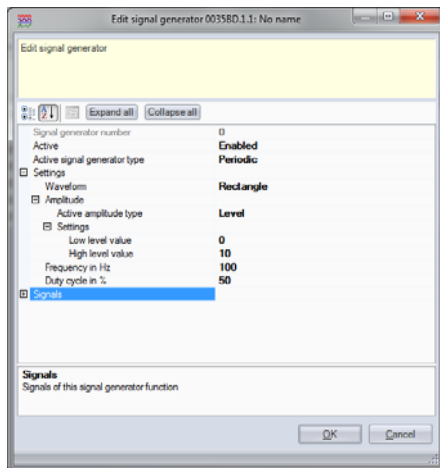


Step by Step parameterization with QuantumX Assistant

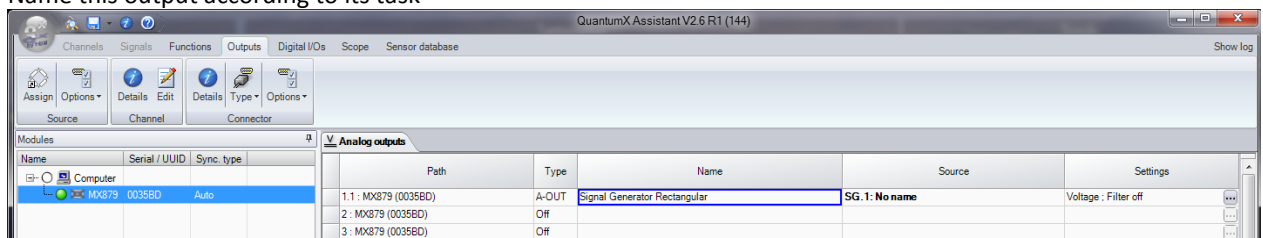
1. Start the software QuantumX Assistant. Search and configure modules (automatic: DHCP/APIPA)
2. Go to *Outputs* tab of MX878 or MX879 amplifier and parameterize signal generator by right mouse click



3. **Enable** signal generator, select **Periodic** type, waveform, frequency, amplitude level (here 10 V), duty cycle and activate or deactivate isochronous data transfer (i.e. sending generated signals out on CAN bus over MX471)



4. Name this output according to its task



E2) MX878 or MX879 working as profile generator with analog voltage output in arbitrary mode

All analog output channels of MX878 or MX879 can generate any signal when working in arbitrary mode. In this mode a file in ASCII format hosting maximum of 10.000 samples is loaded from the PC side to the channel. So it is possible to **replay acquired data** or any designed profile like sweeps or steps to stimulate the system under test.

Every analog voltage output has two buffers this size and can be parameterized with amplitude, frequency, repetition, start, stop, playback, time and switch to second buffer.

Parameterization is done in the same way like D1 above. Just select **Arbitration** type if you want to **load a specific signal** to an output for example to replay a measured input signal.

DEMO EXAMPLES

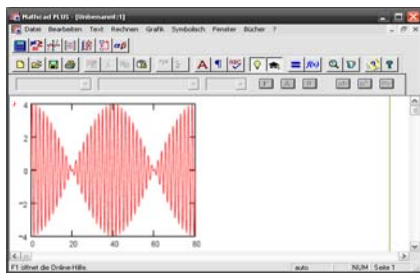
Files can be loaded over two ways and both are available as demo:

- 1) Microsoft Excel with macro based on QuantumX ActiveX / COM API
- 2) C#.NET demo with QuantumX .NET API.

Both demos are part of the QuantumX System CD:

<http://www.hbm.com/en/menu/support/software-firmware-downloads/data-acquisition-systems/quantumx/>

Parameterized outputs will work right after power up and don't need PC connection.



Profile in ASCII format

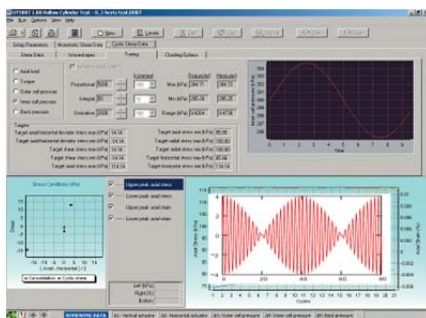
Example: Measurement data working as real-time replay

Source: any load profile

Hint: you can tune signal profiles in catmanEASY analysis mode



Store data
Load profile



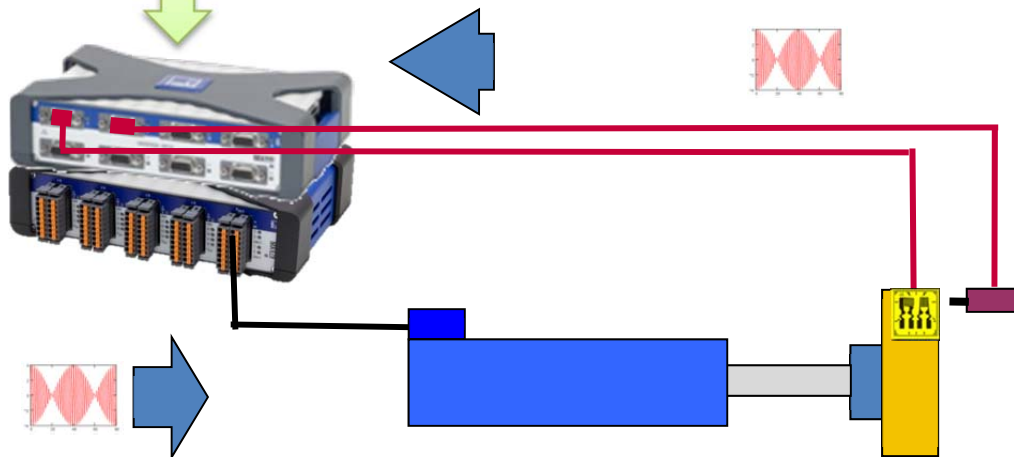
Software: your own software (.NET based)

LabVIEW with integrated .NET based API

catmanEasy: not available yet - please request



Load profile to device and channel
Get measurement data



F) Evaluating inputs in the PC software, cross calculating signals and activating outputs

catmanEasy is a PC based software running on Microsoft Windows and can take over non real-time critical jobs with update rates up to ~ 50 ms. We speak about online instead of real-time!

MX879 offers 8 analog outputs and 32 digital input / outputs.

catmanAP is a professional DAQ software from HBM which allows:

- general online scientific math
 - basic algebra
 - statistics: class counting, min / max, mean, RMS
 - integral, differential
 - filter box / phase correction
 - trigonometric function, logic, ,
- structural durability testing math
 - rosette calculation: resulting strain, angle
 - cycle counter
 - vibration analysis in frequency domain
- powertrain / drivetrain math
 - angle based statistics: min, max, peak-to-peak

Examples using catmanEasy to activate outputs:

- Logical combination of digital inputs activating digital outputs (AND, OR, NOR, NOT combination) on MX879
- Generating a voltage output signal with MX878 / MX879 by a script (Easy Script license necessary)
- Cross calculating analog inputs to each other (algebra), evaluate certain limits and switch on a digital output on MX879.
- Many more...

Please use the online help of catmanEasy/AP for any further information.