

TECH NOTE: Using QuantumX and catmanAP for Noise Analysis

Version: 2016-08-09

Author: Christof Salcher, Product Manager Test & Measurement, HBM Germany

Status: public

Abstract

QuantumX is a powerful data acquisition system from HBM used in many industries for typical test & measurement tasks in mobile or lab based testing and for service or monitoring tasks. This TECH NOTE shows the possibilities and potential in using one single solution for your projects acquiring all crucial quantities - mechanical, thermal, electrical, noise, visual and position over to data storage, analysis and reporting using QuantumX and **catman®AP** software.

Introduction

HBM enjoys a global reputation for state-of-the-art test & measurement solutions providing a "seamless measurement chain" – from transducers for torque, rotational speed, force, pressure, strain and displacement, to data acquisition systems and powerful software packages.

QuantumX is a modular distributable data acquisition solution from HBM for measurement and testing, solving demanding engineering tasks for quicker innovation or high quality service. The data acquisition modules offer highly accurate inputs acquiring physical quantities in the wide field of **mechanical, hydraulics, thermal, electrical, noise or mixed systems** with data rates from 0.1 to 100 kS/sec per channel. QuantumX acquires sensor or transducer inputs measuring **force, strain, torque, pressure, temperature, displacement, speed, position, acceleration, flow, voltage, current, noise and many more**. QuantumX offers superb A/D inputs supporting **voltage, current, bridge based inputs** (resistive, strain gages or inductive), **IEPE, LVDT, PT100/PT1000, thermocouple** and many more. Also highly accurate **digital timer based pulse and frequency** inputs or **absolute encoders (SSI)** can be acquired in parallel. Signals from bus protocols like **CAN, CCP, xCP-on-CAN** can be acquired time synchronous to all inputs. Some modules offer embedded real-time computing like **alarms, math operation, signal generator** (standard signal, arbitrary / replay) or just work as gateway to digital field busses in real-time like EtherCAT. All modules can be connected to PC software over Ethernet.

The powerful data acquisition and analysis tools are mainly used in development, experimentation, simulation, test, service and maintenance.

Acoustic noise of machines or system components under investigation is becoming more and more important in development, experimentation, production sampling, service and maintenance. After all, the "extra quantity" of acoustics is often crucial for comfort, occupational health and safety, and brand image in the complete product life cycle. Additional measuring tools are often used when acoustics are involved. As a result, users have to battle with different devices, user interfaces, philosophies and data formats.

The QuantumX and catman®AP data acquisition solution from HBM not only acquires mechanical, thermal, electrical and digital bus signals such as CAN, as well as GPS or video, but now also acoustic signals. All the Information can be quickly and easily visualized, analyzed and saved in a file or a report – everything in one easy-to-use software.

The additional functions of sound level analysis in dB(A), with psychoacoustic evaluation according to loudness, and frequency analysis in the 2D spectrogram, make QuantumX and catman®AP the perfect test & measurement tool:

Measure, Test, Analyze and Report with one tool!

There are many advantages in using a single tool for parallel, synchronized acquisition of all the interesting measurands:

- + Time saving fast acquisition and analyses jobs with just a few clicks
- + Saving all data in one file and export to different other formats
- + Speedy comparison with earlier measurement results (trend analyses)
- + Compact and portable solution for service and maintenance

This TECH NOTE puts this forward as a starter kit:

- + QuantumX module MX410B with sample rates up to 100 kS/sec and a 40 kHz bandwidth per channel
 - o Connecting IEPE based microphones for noise analysis
 - o with resistive bridge inputs in full and half bridge configuration measuring strain, load cells, piezo-resistive acceleration, pressure
 - o and also inductive full and half bridge for displacement transducers
 - o and finally standardized voltage (± 10 V) and current (0/4 ... 20 mA) with active transducer supply for any active sensor
- + catman[®]AP software for powerful configuration, visualization, alarming, analysis and reporting
 - o Converting sound pressure to sound level in dB(A) in the time domain
 - o FFT frequency analysis, 2D spectrogram, frequency triggers
 - o Report generation, data export

Typical applications

Typical applications in development, experimentation, production and service:

- **Development** of drives, motors, gearboxes, clutches, bearings, linkage joints or mechatronic components
 - o Test: Function, run-up measurement, performance, durability, lifetime.
- **Production**
 - o Quality Inspection: Function with acoustic constraints, for example car interior, steering and so forth needs to be qualified before integrated into vehicles.
- **Condition Health Monitoring**
 - o Long-term analysis: structural health or machine monitoring and its influence to environment for example in railway monitoring (wheel ovality, acoustic emissions / ambient noise, etc.), its online analysis, alarming and data transfer (ftp, email, sms, digital output, ...)
- **Machinery Service**
 - o Diagnosis: routine inspection, calibration/adjustment, continuous monitoring, troubleshooting, fault investigation

Typical requirements

The following are known requirements in relation with noise analysis:

- Presentation over time, frequency, angle or other quantities such as displacement, rotational speed (tachometer)
- Presentation in a color spectrogram as power-spectral-density (PSD)
- Overall sound level characteristic in dB(A)
- Band-limited level characteristic in dB(A)

Categorizing Acoustical Noise

Acoustics is the science of sound. In an industrial environment, we mostly look at unwanted noise. The typical audible frequency range is between 20 and 20000 Hz. In German-speaking countries in particular, the terms *noise*, *vibration*, and *harshness*, or **NVH** for short, are widespread in the automotive market, and describe audible noise, or perceptible vibrations in vehicles or machines. *Harshness* is the subjective transition region between 20 and 100 Hz that is both audible and perceptible. The reason for *vibration* is the force introduced by a vibration source into vibration-transmitting structures, such as self-induced stick-slip effects, that are either the side-effects of desirable friction, or the unwanted result of friction between solids, that leads to the emission of **structure-borne noise** and ultimately, audible **air-borne noise**. Typical examples of NVH are stick-slipping windscreen wipers, transmission whine, a gripping clutch, or noisy vehicle air conditioning.

An elastic solid can take up shear stress, as well as normal stress. So in a solid that is unrestricted on all sides, two different kinds of structure-borne sound waves propagate, so-called longitudinal waves and transverse waves. These waves propagate independently of one another. In both cases, the sound velocity, as with air-borne noise, is not dependent on the frequency. The sound velocity is affected by density, the *modulus of rigidity* (transverse waves) and the *modulus of elasticity* (longitudinal waves).

The recording and analysis of structure-borne noise plays a major role in engineering. It is possible to analyze the noise properties of systems and/or the technical status of a machine, e.g. bearing wear. The development of cracks and material failure can also be recorded. The evaluation of the electrical signals obtained covers finding characteristic frequency components and sound amplitudes.

With NVH, it is a matter of avoiding vibrations that could reduce comfort.

Noise Source	Sound Pressure Level in dB(A)
Aircraft with jet engine, 25 m distance	140
Live rock concert	120
Heavy Truck	100
Office, noisy	80
Conversation	60
Living Room	40
Whispering	20
Hearing Threshold	0

Microphones

The function of a microphone is to convert pressure vibrations and the associated sound pressure into electrical signals. Typically, the amplitudes are analyzed in decibels (dB). Frequency ranges are analyzed in Hertz (Hz).

The types of microphone most frequently used include:

- Pre-polarized electret condenser microphone
- Externally polarized condenser microphone
- Piezoelectric microphone (acoustic pressure sensor)
- Fiber-optic microphone
- Carbon microphone
- Micro-electromechanical systems (MEMS)

The following factors are important in the choice of microphone:

- Sensitivity, typically between 10 and 220 dB
- Frequency range, e.g. 20 ... 20,000 Hz
- Dynamic range
- Robustness

Measurement, testing and calibration

Nationally and internationally, the ISO 9001 standard is the most widespread and significant standard in Quality Management (QM). It demands that the measuring devices and test equipment are calibrated with traceability to national standards – which can be done periodically or before each measurement task. A calibration can, for example, be performed on the basis of measurement standards that are subjected to regular test equipment monitoring. Mechanical, electrical and thermal measured quantities can be calibrated by HBM.

Measuring microphones should also be calibrated with traceability to national standards. IEC61094 and ANSI S1.40 are the standards to mention here. Standard IEC60942 on the other hand describes the **acoustic calibrators**. Of the three classes, the laboratory standard (LS) has the closest tolerances. Class 1 devices are intended for field applications. A class 1 sound level meter should be calibrated with a class 1 calibrator.

Standard IEC61672 defines the electro-acoustic performance standards for sound level meters. The sound level meters considered here have the following focus:

- The sound exposure level
- The time-average sound level
- The exponential time-weighted sound level

In our practical setup, a so-called "sound level calibrator" of the LARSON DAVIS CAL200 series is used for **calibration**. The calibrator is based on ANSI S1.40-2006 and IEC60942-2003 class 1. The calibrator can emit the two sound levels 94 dB and 114 dB at a frequency of 1000 Hz as a reference.

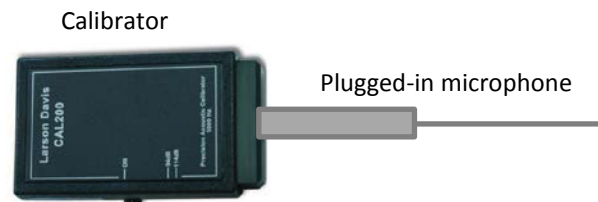


Image caption: Calibration

QuantumX Data Acquisition Solution

The data acquisition system QuantumX supports a broad range of different sensor technologies and is therefore capable of acquiring many physical quantities at the same time. The "Swiss army knife of measurement technology" is an expression that has taken hold throughout the industry among thousands of customers to describe QuantumX – the universal measuring tool. The product is widely used, especially in the research and development of vehicles, ships and aircraft and their system parts as well as machines and drives, but also in construction technology. Numerous other applications include inspection, troubleshooting and optimization of production. QuantumX is universal, compact, portable, freely scalable, sturdy and distributable, making it an ideal DAQ system for both mobile and stationary applications.

The main measurement quantities typically include mechanical, electrical and thermal quantities such as strain, displacement, torque, rotational speed, force, voltage and current, temperature, pressure, oscillation, vibration, speed, position, acceleration, as well as flow rate and many other physical quantities of a dynamic or static system. With connected microphones and technical software support in catman AP, noise is another quantity to include.

The number of acquired measured quantities is virtually unlimited. The distributable system concept offers advantages here as the measurement equipment can be placed close to the measuring point, thus allowing for the use of short ready-made sensor lines. That increases measurement quality for certain types of sensors, reduces installation costs and offers significantly greater flexibility for recurring tasks.

MX410B – the universal amplifier with maximum signal bandwidth

The MX410B **universal amplifier** is the flagship of the QuantumX series.

The module has an incredibly wide range of functions. Each of the 4 channels can be individually configured, and supports:

- Resistivity in full and half bridges for SGs or piezo-resistive transducers
- Current-fed piezoelectric transducers (IEPE / ICP®)
- Normalized voltage: +/- 10 V
- Normalized current: 0 / 4 20 mA
- Sample rate/filters
 - o 24-bit sigma-delta AD converter
 - o 100 kS/s per channel or in two-channel operation up to 200 kS/s, bandwidth to 40 kHz
 - o Digital Bessel or Butterworth filters
- Can be extended with clip-on adapters:
 - o 300 V CAT II: SCM-HV
 - o SG quarter bridge: SCM-SG120 or -SG350
- Analog output of the universal input: +/- 10 V, optional filter, 150 µs latency
- Internal module calculations of the root mean square value (RMS) or peak value (PEAK) are possible



Virtually any system expansion is possible. Synchronization mechanisms such as PTP, FireWire, NTP, IRIG-B or EtherCAT are available for this. The channels are electrically isolated from one another for supply and communication, which allows an extremely high signal-to-noise ratio (SNR) of approx. 120 dB.

Acquisition at a high sample rate is possible for any transducer type with MX410B. The high signal bandwidth is ideal for connecting microphones.

The high-resolution digital module MX460 is a good addition for **rotational analyses** of internal-combustion engines or rotating shafts in general. The module helps on all 4 channels:

- Digital frequency signal of HBM torque transducers, e.g. with a 60 kHz mid-frequency
- Digital rotary transducers/encoders with/without index, e.g. 2 tracks A and B, 2048 pulses per revolution, index pulse
- Inductive rotary transducers, pick-ups, e.g. crankshaft sensor
- Pulse-width modulated signals (PWM) for determining the pulse width as % or time
- Internal module calculations allow an analysis of torsional vibration or a peak value analysis (PEAK)

Of course, other amplifiers or modules of the series can also extend the overall system, such as for acquiring the quantities of voltage and current (MX403B), CAN-Bus (MX840B, MX471) or temperatures (MX1609KB).

The full description of the modules can be found on our website at hbm.com.

The catman[®]AP Software

The powerful catman[®]AP software from HBM can roughly be described as follows:

- Support for HBM DAQ systems such as QuantumX
- Support for additional devices such as GPS, video, odometers
- Parameterization of all channels and sources
- Offsetting input signals with one another
 - Algebra, logic, ...
- Intelligent triggers for recording measurement (start/stop)
 - In the time or frequency range, e.g. sound level
- Visualization of all signals in the following domains:
 - Time (x over t)
 - Channel (x over y), e.g. displacement, angle, rotational speed, velocity
 - Frequency (x over f), e.g. acoustics, vibrations
- Data storage in the desired data format
- Data analysis, modification and storage
 - Export: UFF58, MAT, ...
- Report generation (direct printing or via Microsoft Office, e.g. Word or PowerPoint)

The catman[®]AP software not only offers data acquisition, it also has an integrated math library for online, as well as post-process calculations. The mathematical functions extend from simple algebraic calculations, filters, statistics, classifications such as rainflow or time-at-level, to spectral analyses, to calculation of electrical power and efficiency through simple parameterization.

The Microphone

Our practical setup uses the Microtech Gefell **measuring microphone M370**. In the built-in converter type, there is an electret pressure receiver with a circular characteristic. Constant current from the QuantumX MX410B amplifier feeds the mic and the measured sound pressure is modulated to a voltage signal (IEPE). The measurable frequency range is between 20 and 20,000 Hz (class 1, open air use). The maximum sound pressure level is 130 dB A.

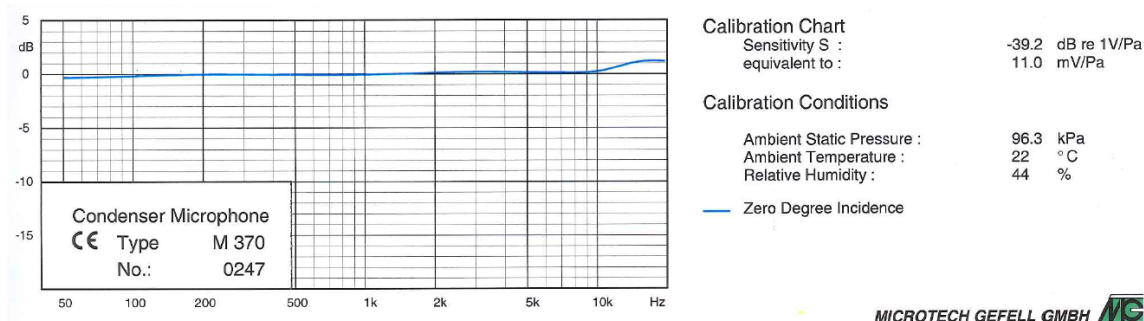


Image caption: MICROTECH GEFELL calibration certificate

The connection to the QuantumX MX410B module uses a BNC to 15-pin Sub HD adapter (HBM order no.: 1-SUBHD15-BNC).

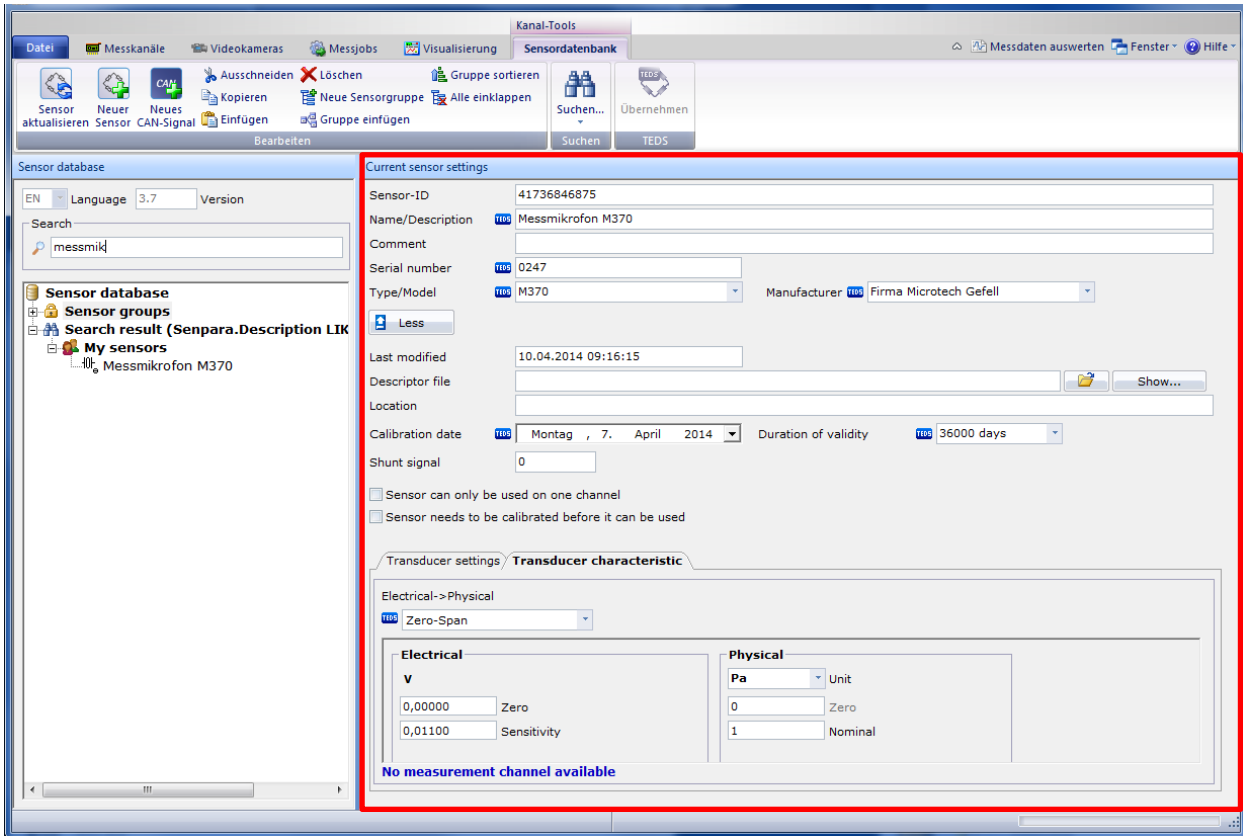
Measurement Setup

In catman[®]AP, a measurement channel is assigned parameters by the integrated sensor database or directly by the sensor, if this has its own electronic data sheet (TEDS).

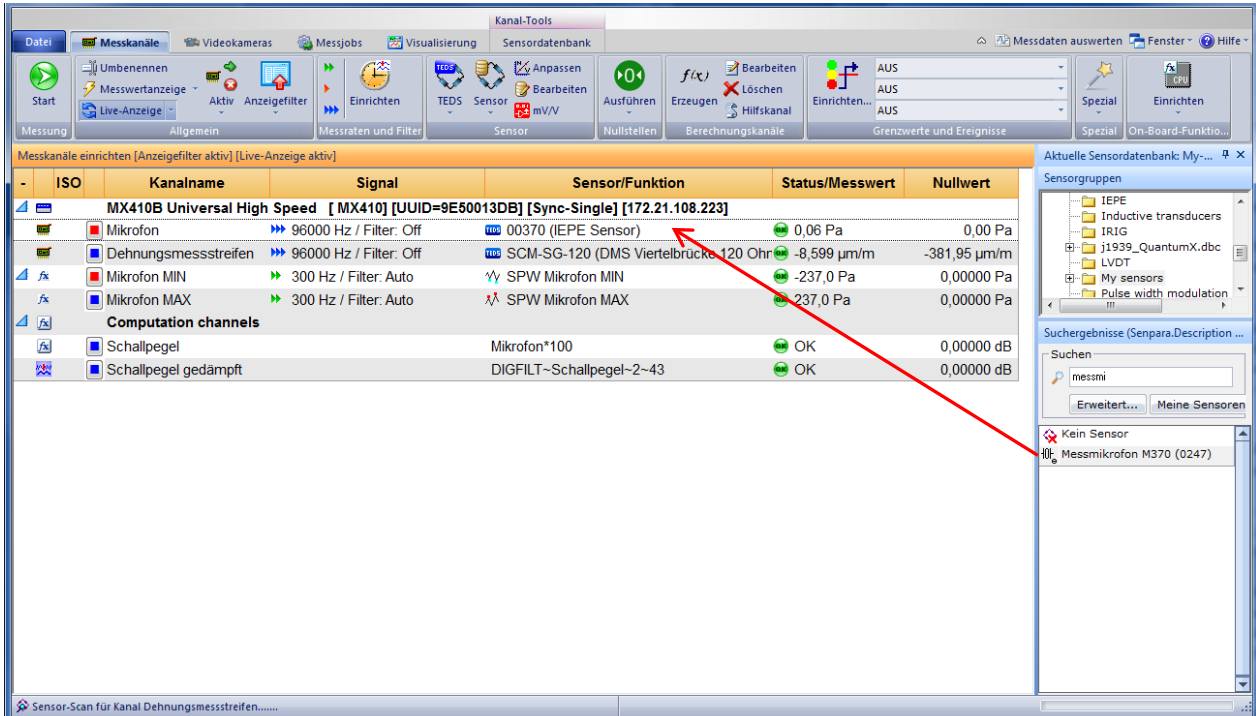
In our example, we are using the sensor database to parameterize the measurement channels. If the correct signal description cannot be found in the sensor database, you can create the relevant data sheet. Using the sensor data sheet makes it easier to set the parameters of each individual channel later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

The amplitude is the sound pressure expressed in Pascal (Pa). The sensitivity, as taken from the calibration report is 11 mV/Pa.

Digital data sheet of the measuring microphone in the sensor database:



Parameterize the particular channel from the sensor database by “drag & drop”



Initial test with a signal generator:

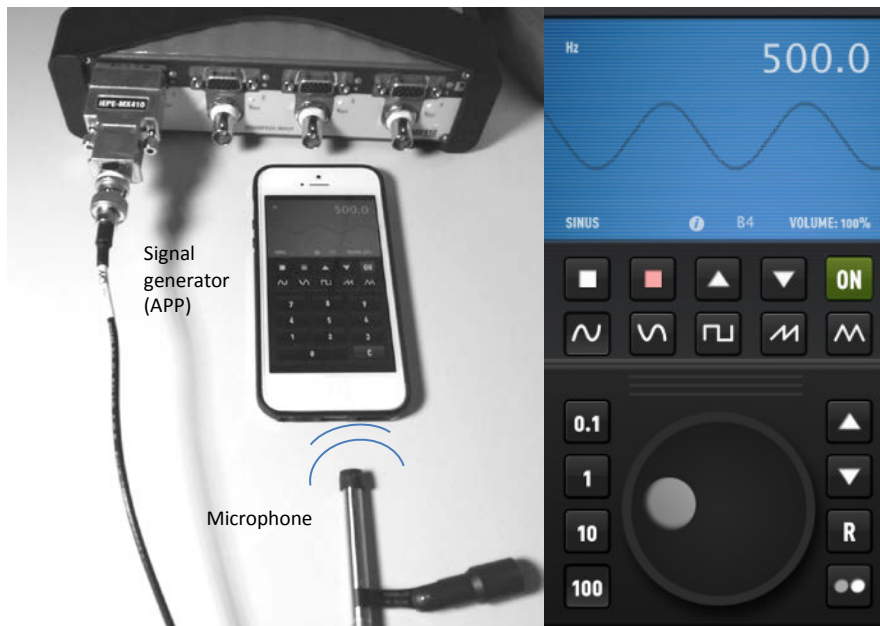


Image caption: A smartphone as a signal generator

Sound Pressure Level (SPL) Calculation

Our hearing perceives the sound of varying frequencies as being more or less loud. The sound pressure level or noise level is a psychoacoustic quantity. The signals are filtered for measurement, so that they imitate the properties of human hearing. The weighting curves of these filters are standardized. Weighting curve A, which is also displayed in the unit dB(A) or dBA, is the one mainly used for the analyses.

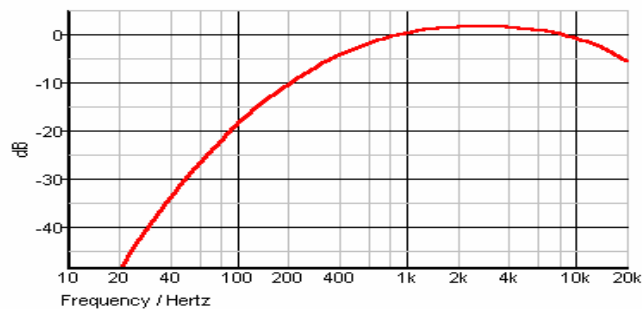
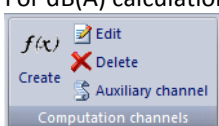


Image caption: A-weighting filter curve

Zero dB(A) corresponds to the threshold of audibility. The threshold of noise pain is just about 130 dB(A). It is very easy to convert sound pressure into the sound pressure level (SPL) by using the "computation channels".

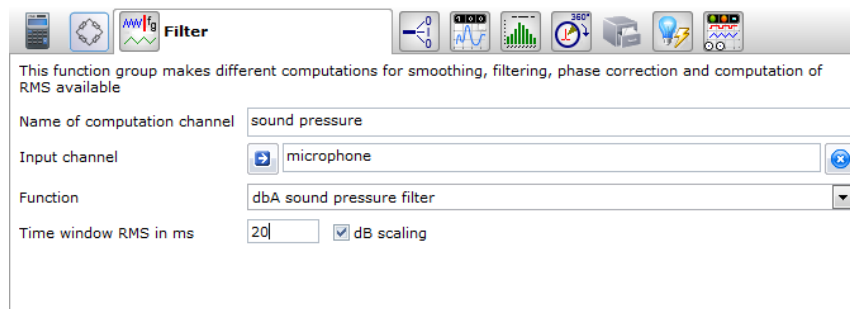
Important: The weighted sound level is neither a physiological nor a physical measurand! The good thing about it is that metrologically, we can also acquire, save and analyze the sound level and the weighted sound pressure level.

For dB(A) calculation we need to **Create a new Computation channel**



In the **Filter** dialog box we find the Function “dBa sound pressure filter”

- Name the newly calculated signal with for example “sound pressure”
- Drag and drop the channel with the connected microphone to “Input channel”
- Set a time window where root mean square value (RMS) value is calculated for the dBa weighing: e.g. 20 ms



The new computation channel appears in the "Computation channels" list and you can use it in visualization, store it in the data file and analyze it in post-process after your test.

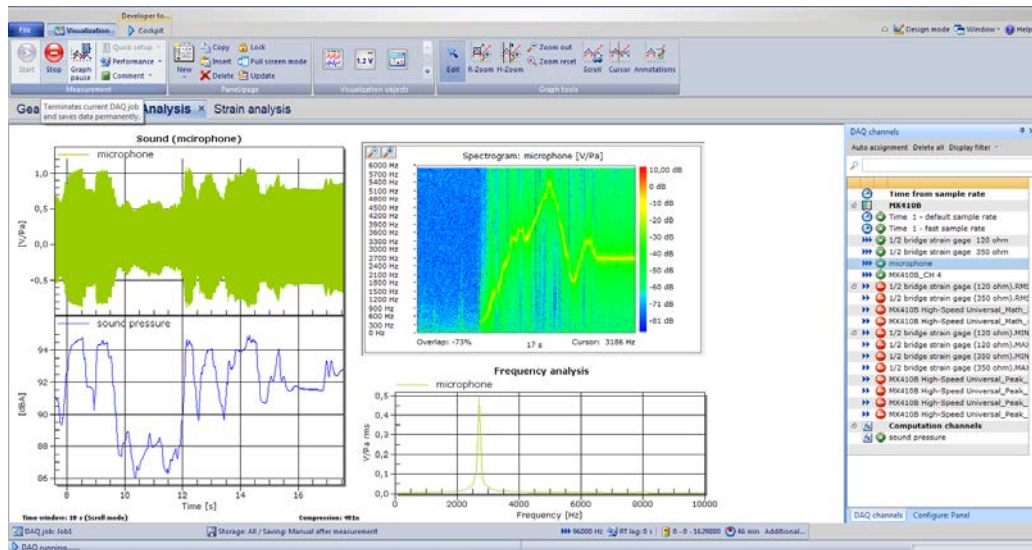
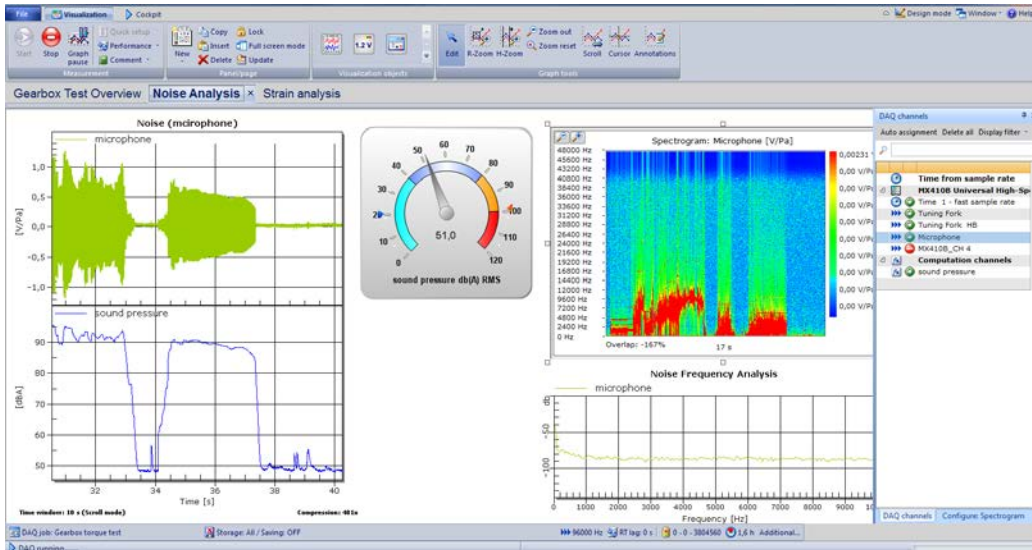
Visualization, Signal Analysis in Time and Frequency range

Instrument the signal “sound pressure in dBa” in a diagram over **time** (y-t) or over a second **measurand** (x-y) such as displacement. Also instrument the “microphone” input in a standard FFT diagram where amplitude is shown over frequency.

Although analyzing a signal in frequency-domain don’t show how the frequency content of a signal evolves over time. For this task you can use the spectrogram in catman. The **spectrogram** directly shows a **Joint-Time-Frequency-Analysis (JTFA)** by computing the frequencies contained in a signal with the associated color-coded amplitudes **over time**. The software catman uses the so called Short Time Fourier Transform (STFT) to calculate the JTFA and applies a Fast Fourier Transform (FFT) repeatedly to short segments of a signal over time. So in sum the JTFA of a spectrogram shows more details than a standard FFT: frequency content (y-axis) over time evolution (x-axis), shown in a so-called 2-D 1/2 visualization where amplitude or energy is mapped to a color code.

The JTFA needs to be parameterized, such as the number of measured values used to calculate the spectrum. Rule of thumb: the more measured values you include in the FFT, the more accurate the resolution in the frequency range. 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.

The time window is given automatically from the measurement time. The number of measured values is divided by the number of pixels for the width of the graph. In each case a column with FFTs is calculated and displayed over this number of values. Manually define the color scale for the amplitudes (Contour tab); only the frequency axis can be determined completely automatically.

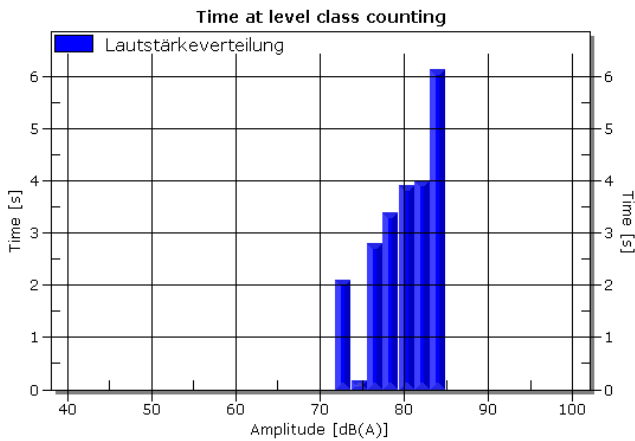


Parameterization Set

General JTF parameters, Layout of the spectrogram, Contour type and scaling and Office for automatic report generation by a tag or bookmark.

Configure: Spectrogram	Configure: Spectrogram	Configure: Spectrogram	Configure: Spectrogram
<p>General Layout Contour Office</p> <p>Name: Spectrogram</p> <p>Title: [Empty]</p> <p>FFT: 8192</p> <p>Window: No window</p> <p>Unit: Peak</p> <p>Time window: Auto</p> <p>Overlap: Auto</p> <p>Averaging: Off</p> <p><input checked="" type="checkbox"/> Peak detection</p> <p>Threshold: 2</p> <p>Width: 4</p>	<p>General Layout Contour Office</p> <p>Background: [Dropdown]</p> <p>Text: [Dropdown]</p> <p>Title font: Verdana, Bold, Italic</p> <p>Verdana: 10</p> <p>Axis font: Verdana, Bold, Italic</p> <p>Verdana: 8</p>	<p>General Layout Contour Office</p> <p>Color map: Spectra</p> <p>Color scale: <input checked="" type="checkbox"/> Automatic</p> <p>Max: 10,00</p> <p>Min: 0,00000</p> <p>Apply</p> <p>Frequency scale (Hz): <input checked="" type="checkbox"/> Automatic</p> <p>Max: 1000</p> <p>Min: 0</p> <p>Apply</p>	<p>General Layout Contour Office</p> <p>Specify a bookmark where the graph should be inserted on exporting to MS Word.</p> <p>[Text Box] Bookmark</p>

You can also **classify the sound pressure level** over the measurement period by using Time-at-Level calculation you can also find in the **Computation channel** dialogue.

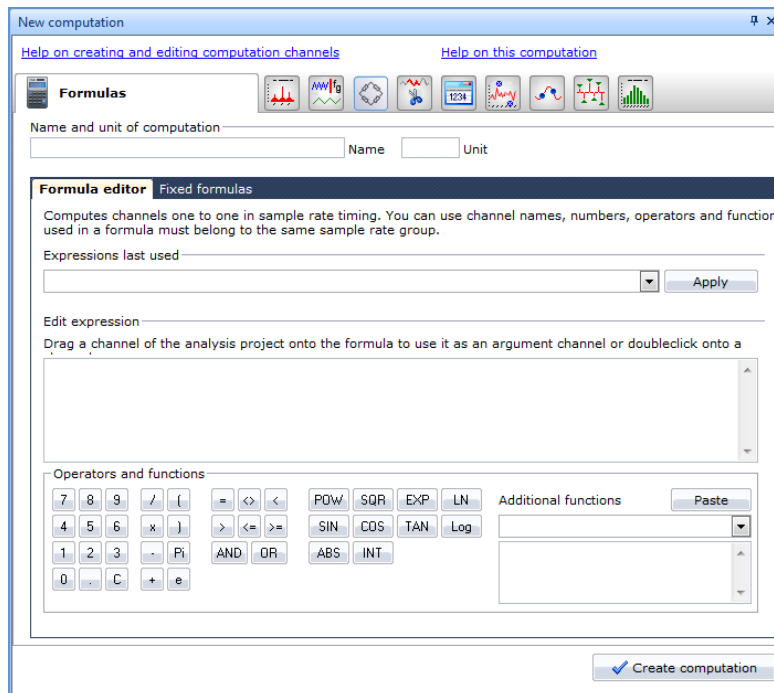


Data Analysis

Switch to data analysis mode (post-process).

In this mode you work on acquired data sets and can compare several tests with each other without a device connected to it. It allows you to deep dive into your data, analyzing and adapting it get an answer out of your DAQ job.

Post-process Computation



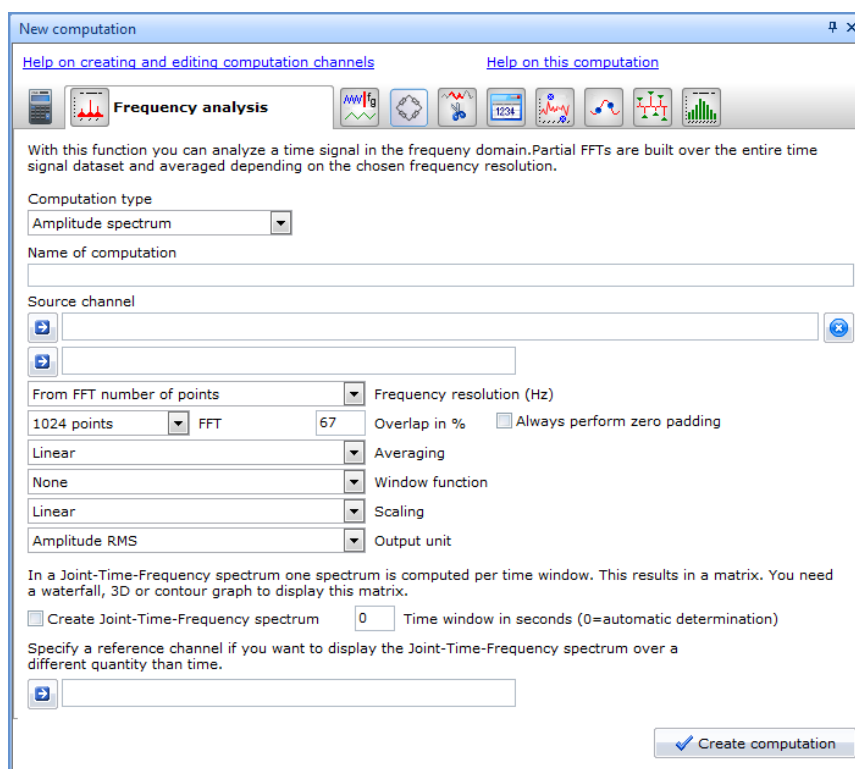
Post-process computations

Next to manual “scrolling” through the data or direct manipulation the following set of pre-defined computations are available:

- **Formula editor** you can cross calculate signals with each other
 - Including fixed formulas: Statistical analysis (min, max, mean), linearization table, removing offset
- **Frequency analysis** (see screenshot below)
- **Filter box**
 - Sliding mean
 - Savitzky-Golay smoothing
 - Mean over time window
 - RMS value over time window
 - Low-, high-, band- and band-rejection filters in Butterworth, Chebyshev and elliptic characteristics
 - Low-pass filter with Bessel characteristic

- Sound pressure filter in dBA
- **Strain gage rosette calculation**
- **Curve Operations**
 - *Form plot* function cuts out the specified section of a channel. Alternatively, you can also use the Section functions or the cursor functions.
 - *Shift plot* function moves all values of a channel in the positive or negative direction, for example to compensate a time delay (propagation time) of various filter characteristics.
 - *Outlier elimination* in case the signal level exceeds a certain value (threshold)
- **Interpolation**
 - converting to other sample rates (higher or lower) or x-y recalculation allowing an easier comparison of several data sets of the same test
 - *Accurate PEAK detection* using interpolation algorithm
- **Class Counting**
 - *Rainflow* (FromTo, RangeMean) counts the frequency of occurrence of certain amplitude values subdivided into sections, the so-called classes used for material fatigue tests.
 - *Time-At-Level* (TAL) counts how long a signal is located in a certain amplitude range, the so-called classes and shown in a so called histogram.
 - *Span Pairs* counts the frequency of occurrence of certain amplitudes.
 - Joint-Time-at-Level (2-dim) counts how long a signal is located in a certain amplitude range considering also the amplitude range of a second reference channel, for example for monitoring torque towards rotational speed.

The frequency analysis in post-process mode uses the acquired data 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 this purpose you need to create a computational channel.



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.

Data Export

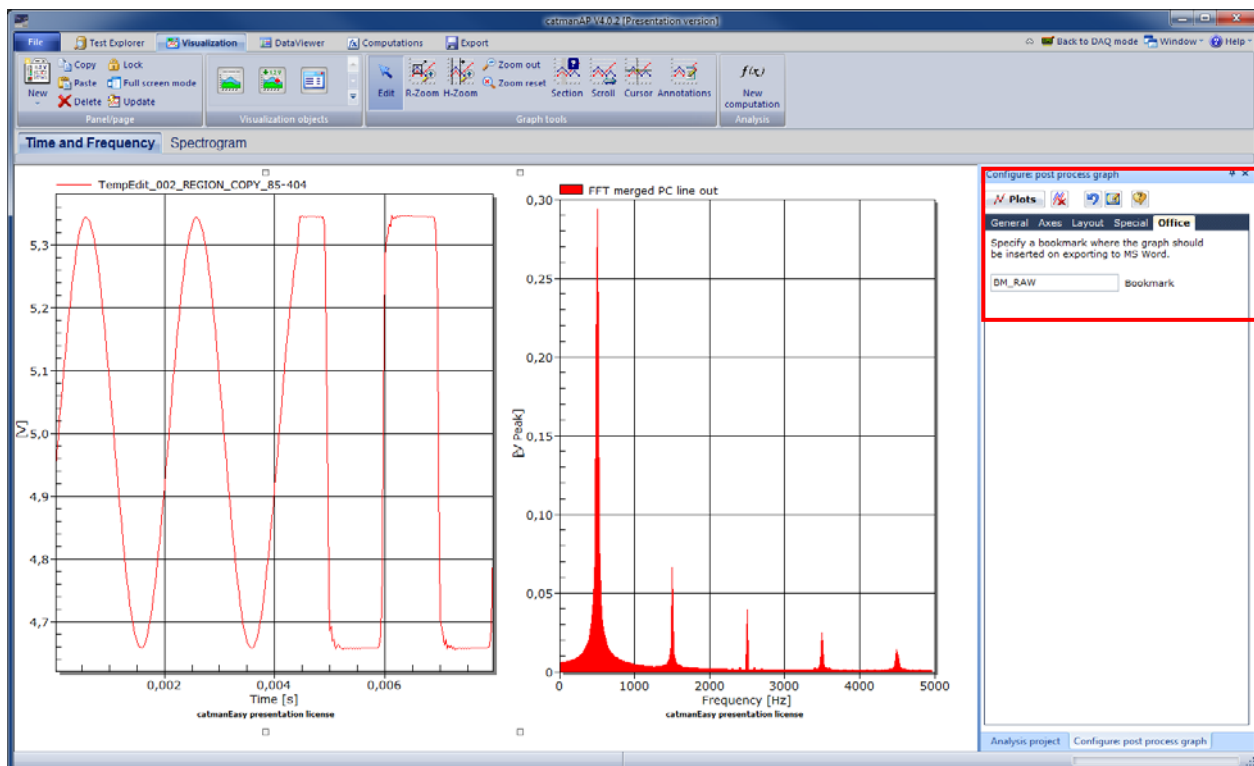
In principle we recommend to store all data in catman BINARY file (*.BIN) or HBM Fast Stream Format when you need to handle high data throughput. These file formats are highly robust and in case of an incident you only lose a fragment of the data and not the whole file. Nevertheless you can post-process your data in a lot of different formats:

- Catman BIN
- HBM nCode s3t - can be directly processed by the software HBM GlyphWorks and nCode DesignLife
- HBM Playback or Wave Form - can be read in and "played back" by catman in DAQ mode
- ASCII
- MS Excel 97-2003 – Microsoft Excel needs be installed
- MS Excel Office 2007 or Excel 2010 - Microsoft Excel needs be installed
- MATLAB 5.0
- Vector MDF 3
- ASAM MDF 4 or 4.1 - Measurement Data Format is standardized by ASAM
- RPC III by MTS – format for durability testing from MTS
- UFF58 (Universal File Format 58) - often used in modal analysis
- Audio WAV file - produces one file per channel in wave format (PCM coded with 16 bits) and can, for example, be played back by a media player.
- NI DIAdem (*.DAT) from National Instruments

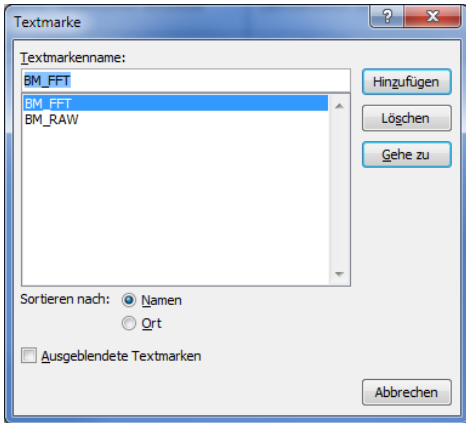
Report Generation

There is much freedom of expression for report generation in Microsoft Word or PPT. The graphic displays of a measurement or analysis project in catman®AP can automatically be copied to a test report in Word format at a pre-defined bookmark (e.g. tt1 in the Office tab). Right-click on a display and follow the "Export/Print" dialog.

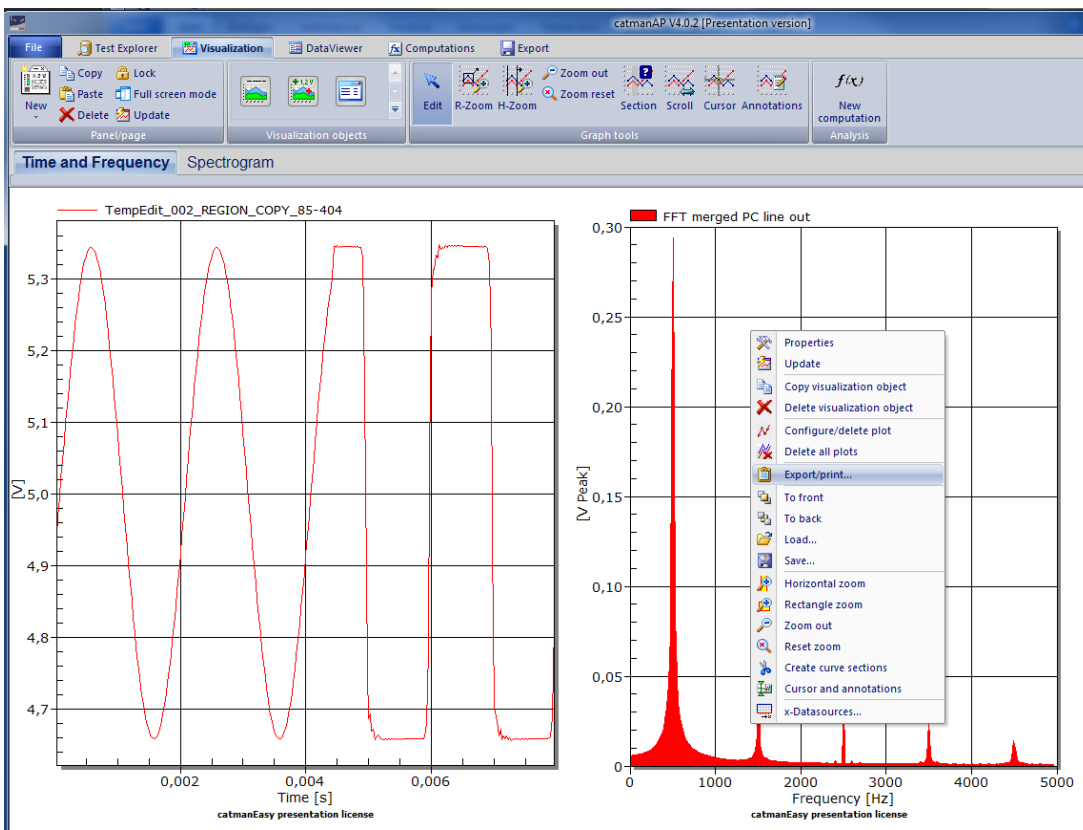
Enter corresponding bookmarks into the "Office" tab of each graph you would like to transfer:

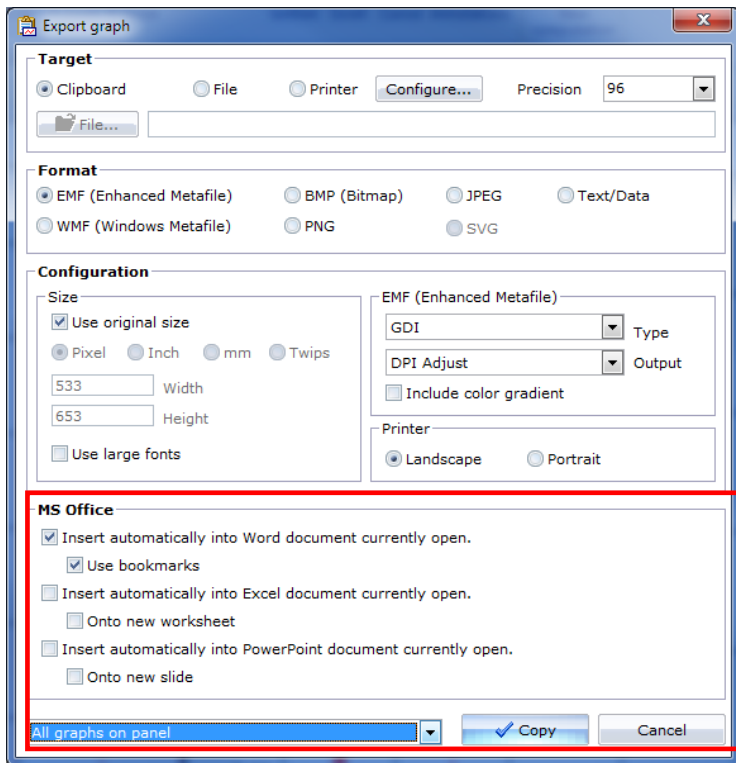


Now open up your Test report template in Microsoft Word and integrate the bookmarks:

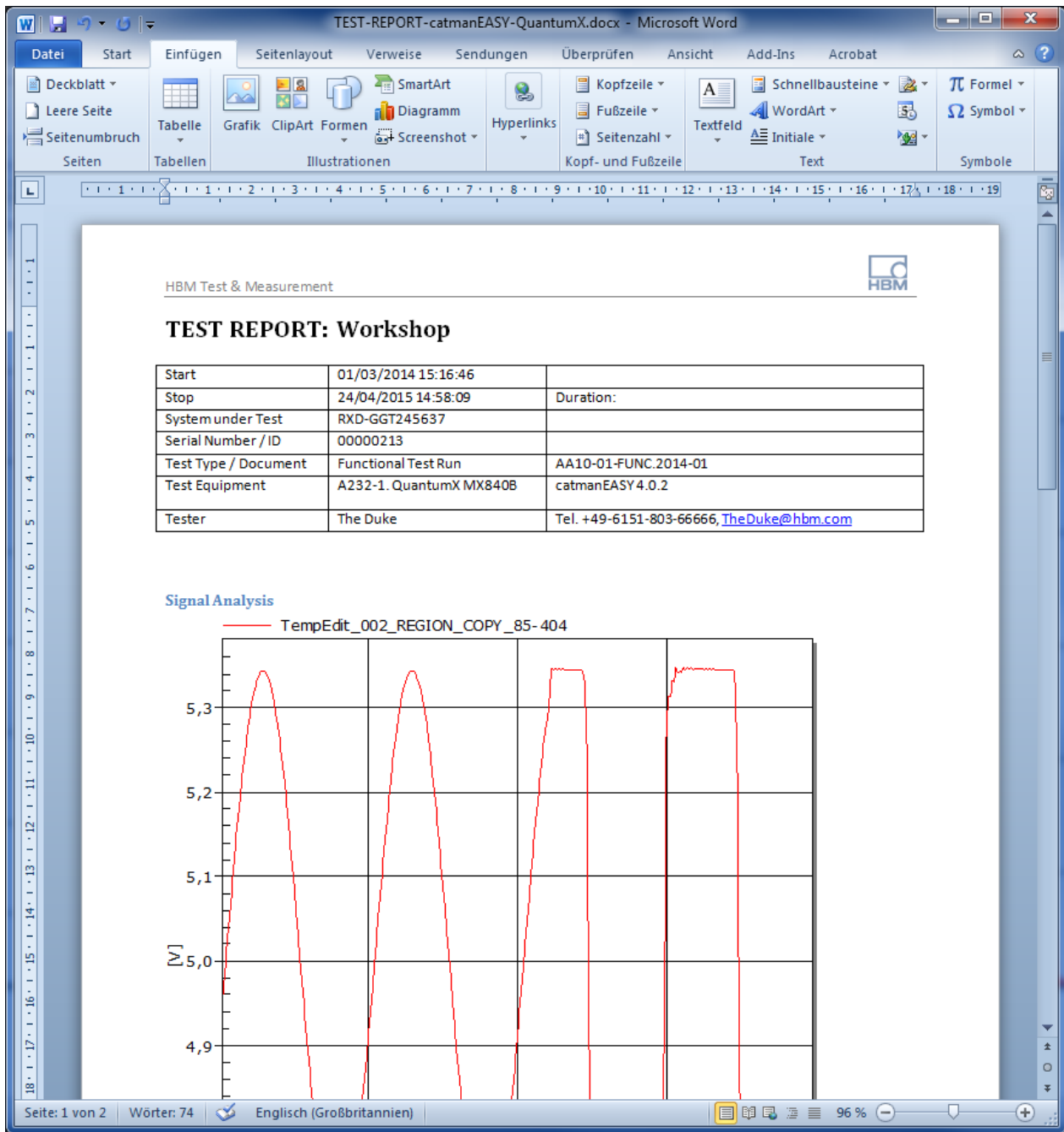


Back in catman you can export all graphs from your analysis project with one mouse click.





Result is that all objects are copied into your test report. For recurring tests with a pre-defined analysis project and a pre-defined test report this is a quick solution.



You can save your analysis project for upcoming projects.

Summary

In product development, testing, production, service and maintenance – in many Test & Measurement tasks finding one single data acquisition solution which covers a wide range of different sensors allowing the user to quickly test and analyze a single part of a machinery or a complete structure or vehicle is an efficient way to reliable results. Acoustic noise analysis is becoming more and more important in and allows an overall analysis concerning for example comfort issues. With QuantumX and catmanAP users have a team measuring all types of inputs in the mechanical, hydraulics, thermal, electrical and electronics world including noise analysis.

-- end

Legal Disclaimer: TECH NOTEs are designed to provide a quick overview. TECH NOTEs are continuously improved and so change frequently. HBM assumes no liability for the correctness and/or completeness of the descriptions. We reserve the right to make changes to the features and/or the descriptions at any time without prior notice.