Welcome to the webinar
‘‘Efficiency Testing on Electrical Drive Trains’’

LIVE power calculations

….and….

continuous and **synchronous** acquisition of electrical and mechanical signals for verification and analysis

The webinar starts at 10 a.m.

Organizational information

- All participants' **microphones** are **muted** during the webinar.
- Please do not forget to **activate** your PC **speakers** to enable **audio** or connect **headphones** to your PC.
- Please use the '**Questions and answers**' window, if you have any questions. We will answer questions at the end of the presentation.

- We will email the presentation to you after the webinar.
- The webinar is recorded and will soon be made available on our website.

Speaker

- Klaus Lang, Focus Sales Manager T&M
  HBM Test and Measurement
- Degree in electrical engineering
- 30 years experience in
  fast electrical data acquisition
- 10 years product manager for
  GOULD digital storage oscilloscopes
- 10 years marketing manager for
  NICOLET transient recorders
- Since the acquisition of NICOLET by HBM in 2009, responsible as Focus Sales Manager for „eDrive“, which is defined as "testing of inverters and inverter driven electrical machines“

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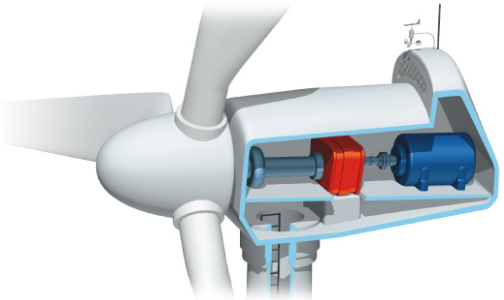
Electrical drives: Various application examples

Industrial VF inverter



Wind energy generator

Electrical or hybrid car

Electrical ship motor

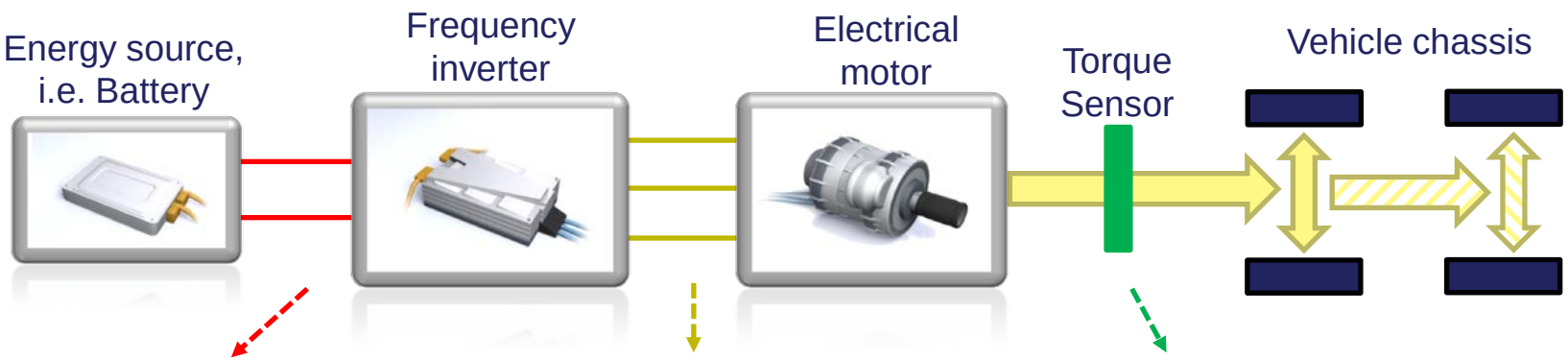
Electrical
Folklifter

3ph AC
industrial motor

Electrical drive in A320

High Speed train

eDrive: DAQ requirements on electrical (hybrid) drive train



Battery voltage and current

* Voltages up to 1000 V DC
* Currents up to 300 A DC
* Battery / cell temperatures

*** Electrical power up to 100 kW**

Frequency inverter output voltages and currents

* Voltages up to +/-500 V AC, n phases, modulated
* Currents up to 500 A AC
* Inverter temperature

*** Electrical power up to 100 kW**

Electrical motor output

* Torque
* RPM
* Rotor position
* Motor temperature

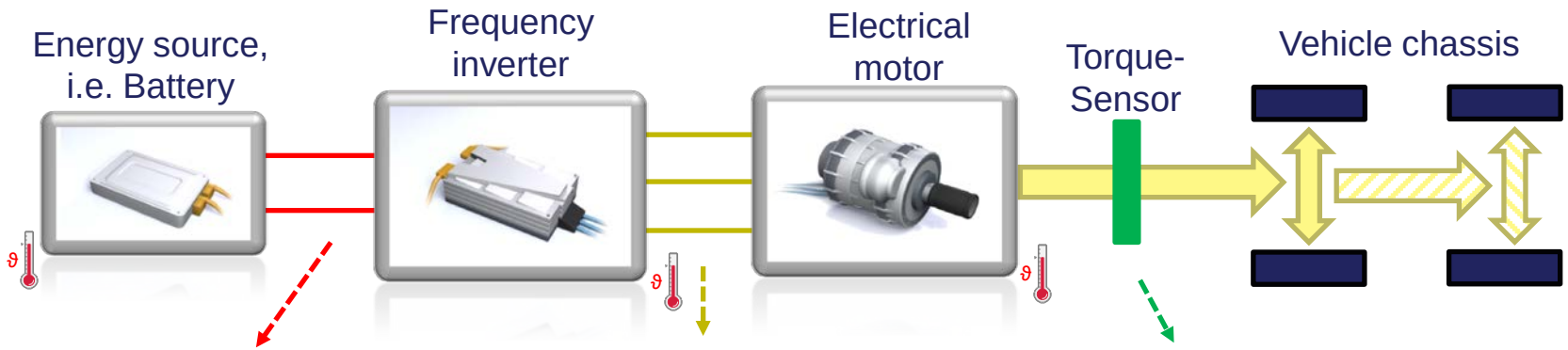
*** Mechanical power up to 100 kW**

Efficiency frequency inverter

Efficiency electrical motor

Efficiency electrical drive

eDrive: Measuring efficiency – the typical method



Battery voltage and current
Various slow speed measurement types,
i.e. just using DMM´s

Frequency inverter output
n-phase power meter
(plus extra oscilloscope)

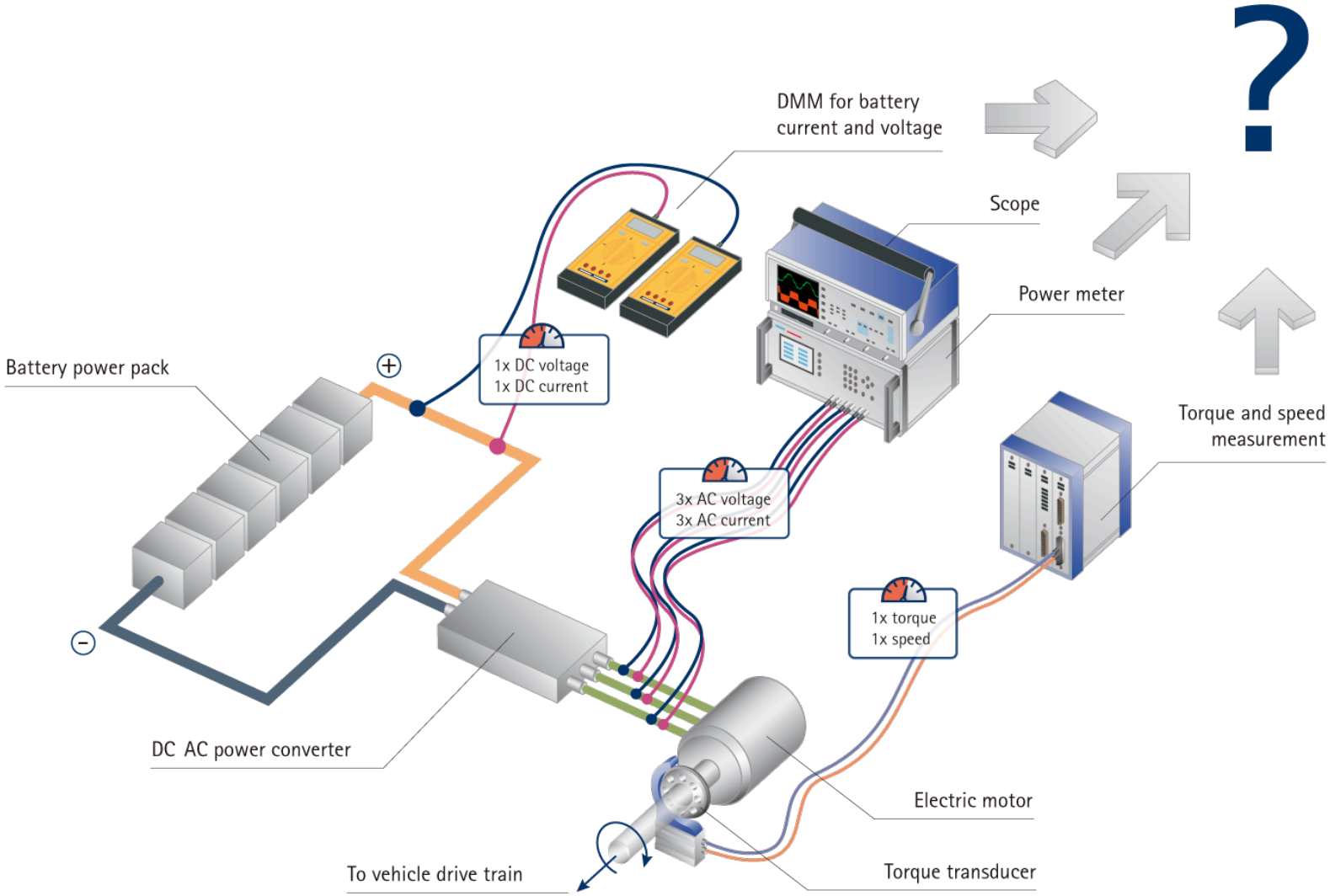
Electrial motor output
Torque transducer and DAQ system
for torque and speed

Problems:

1. Difficult time synchronization between different systems
2. Data storage in different systems & different formats
3. No continuous raw data available for verification or analysis
4. Slow calculation cycles of power meters
   and questionable results in dynamic load changes
5. No documentated algorithms for power analysis, no verification possible

User comment:
„Sometimes we measure efficiency larger 1. We can´t believe that, but we can´t analyse further as we have no raw data.

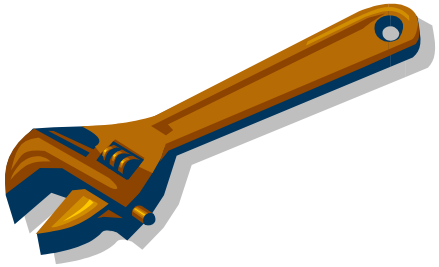
eDrive: Measuring efficiency – the typical method



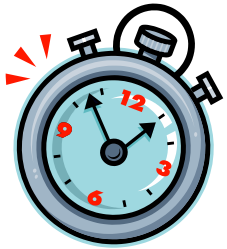
Note: For simplification, temperatures not shown

eDrive: Enhanced requirements on data acquisition

- Simple system configuration
  - One system for all different signals
    - Voltage, current, torque, speed
    - Position, temperatures, vibration….
  - Easy setup

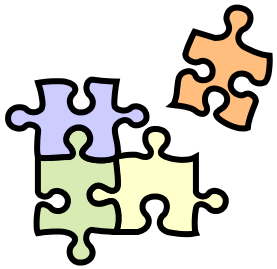


- Reliable acquisition
  - Simultaneous sampling of electrical and mechanical power
    - No phase shift caused by different data acquisition systems
  - Continuous storage to hard disc
  - One data format for all acquired data

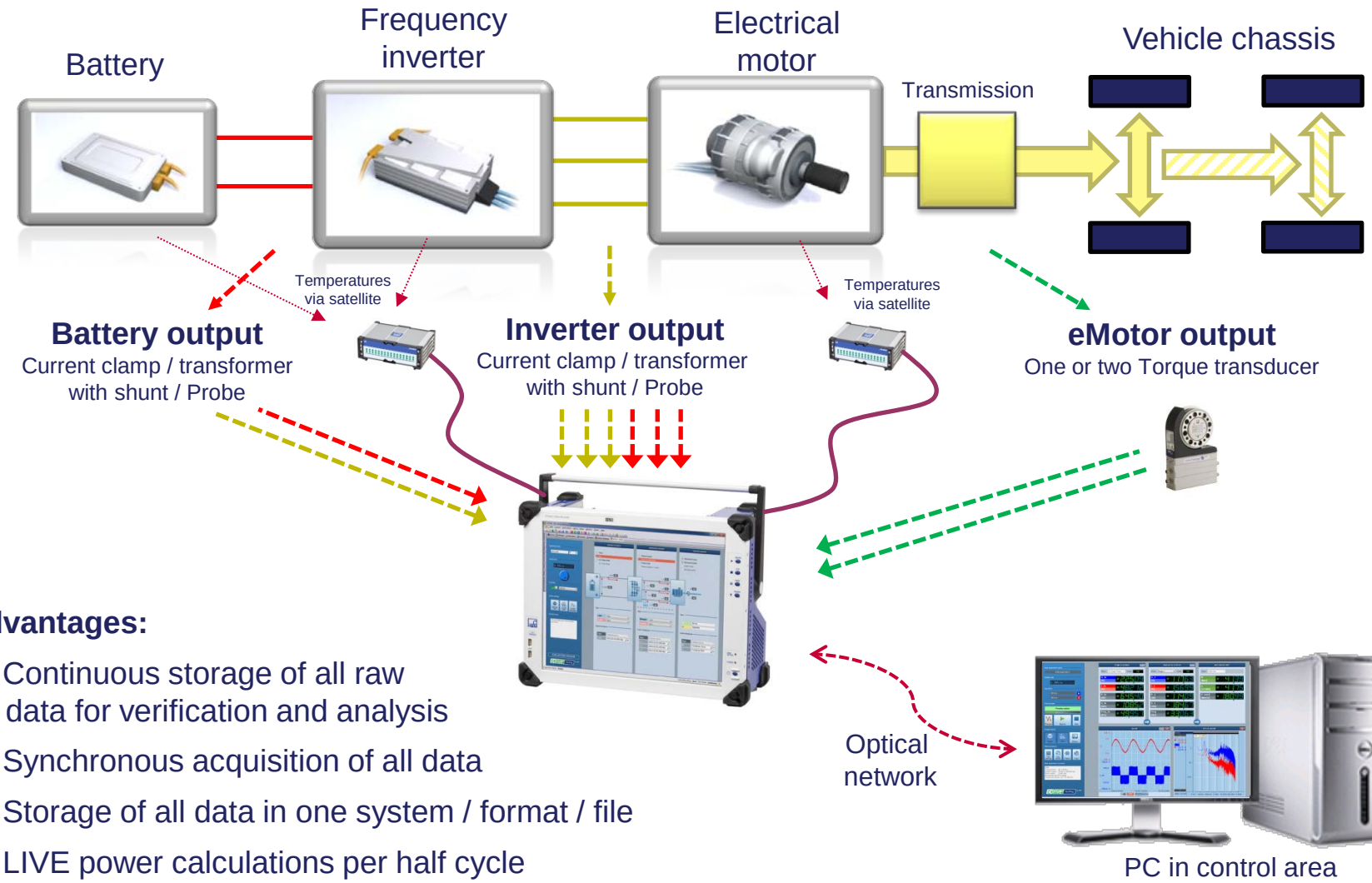


- Faster, better results
  - Analysis per half cycle with documented, traceable algorithms
  - Verification of results
  - Advanced analysis based on raw data

- Easier system integration
  - Open data format
  - Modern software interfaces



eDrive: HBM´s testing concept



Advantages:

1. Continuous storage of all raw data for verification and analysis
2. Synchronous acquisition of all data
3. Storage of all data in one system / format / file
4. LIVE power calculations per half cycle
5. LIVE scope and FFT displays

eDrive: Voltage measurement at e-motor input with GEN DAQ

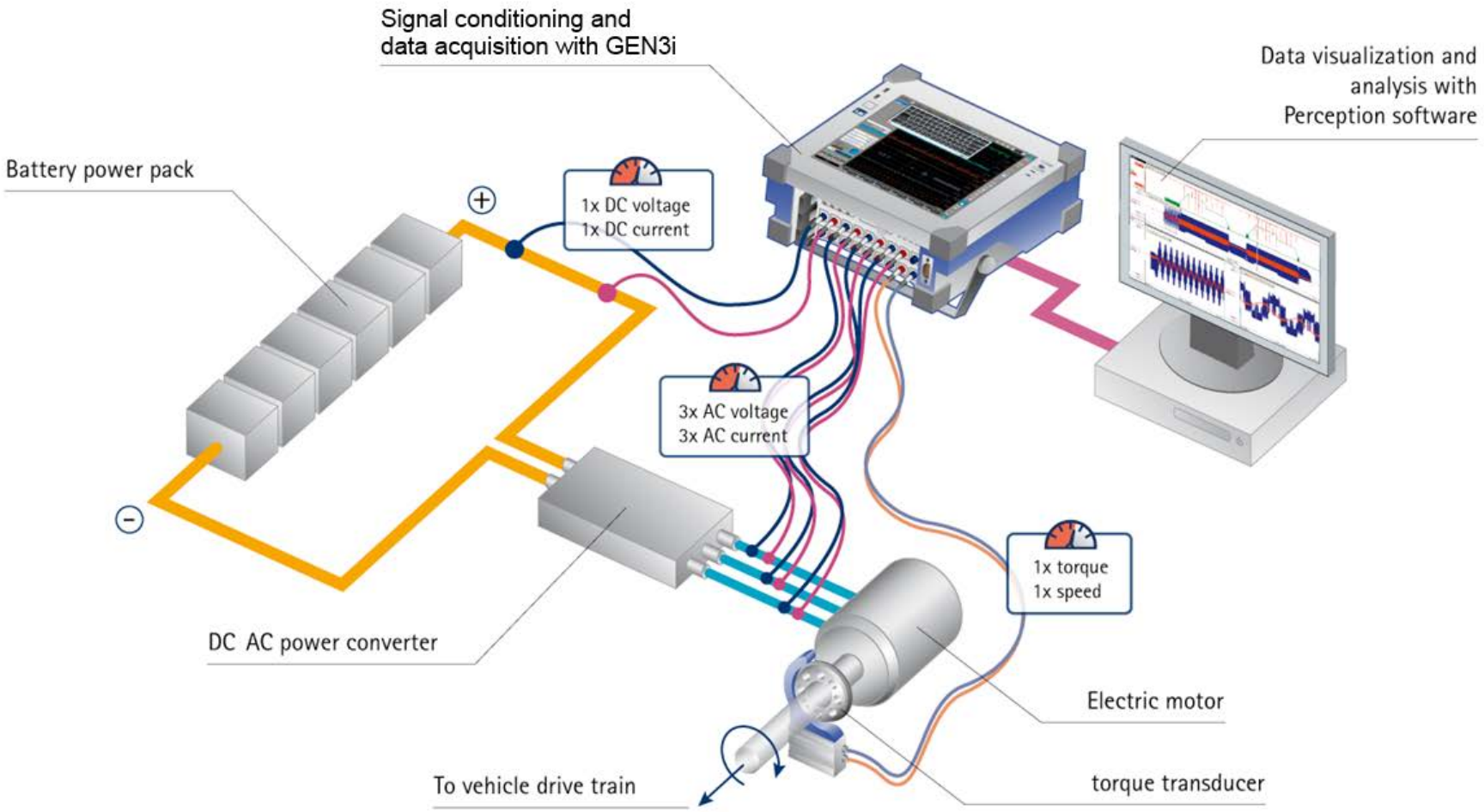
- GEN3i mainframe (or GEN3t)
  - 3 slots for acquisition modules
  - 200 MB/s streaming to 500 GB SSD
  - Build in Win7 64 bit PC (GEN3i only)

- Isolated 1 kV input card
  - 6 isolated channels, ±20 mV to ±1000 V
    - Direct connection to HV signals witout probes
  - Sample rate 2 MS/s @ 18 bit per channel
  - Isolation voltage 1,000 Vrms
  - Accuracy 0.1%
  - One torque & speed channel per board

- Plug-on artificial star module
  - Creates artificial star point for 3 phase measurements
  - Plugs directly into the card to minimize cabling

- Optional, remote temperature satellite
  - 16 channels type K or T
  - Keeps TC cables short for signal fidelity

eDrive: HBM´s testing concept

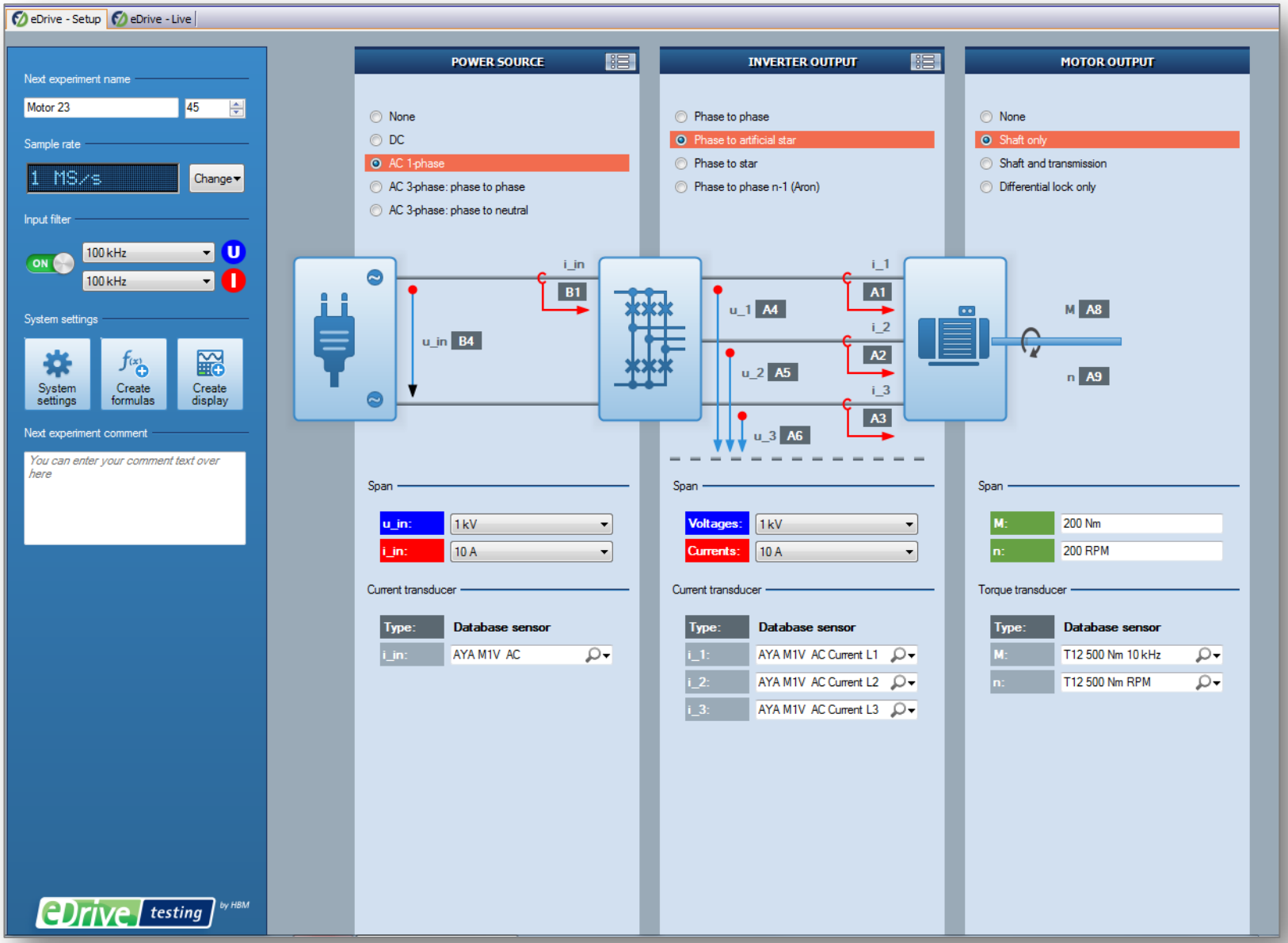


Note: For simplification, temperature satellite not shown

eDrive: HBM´s complete system for efficiency testing

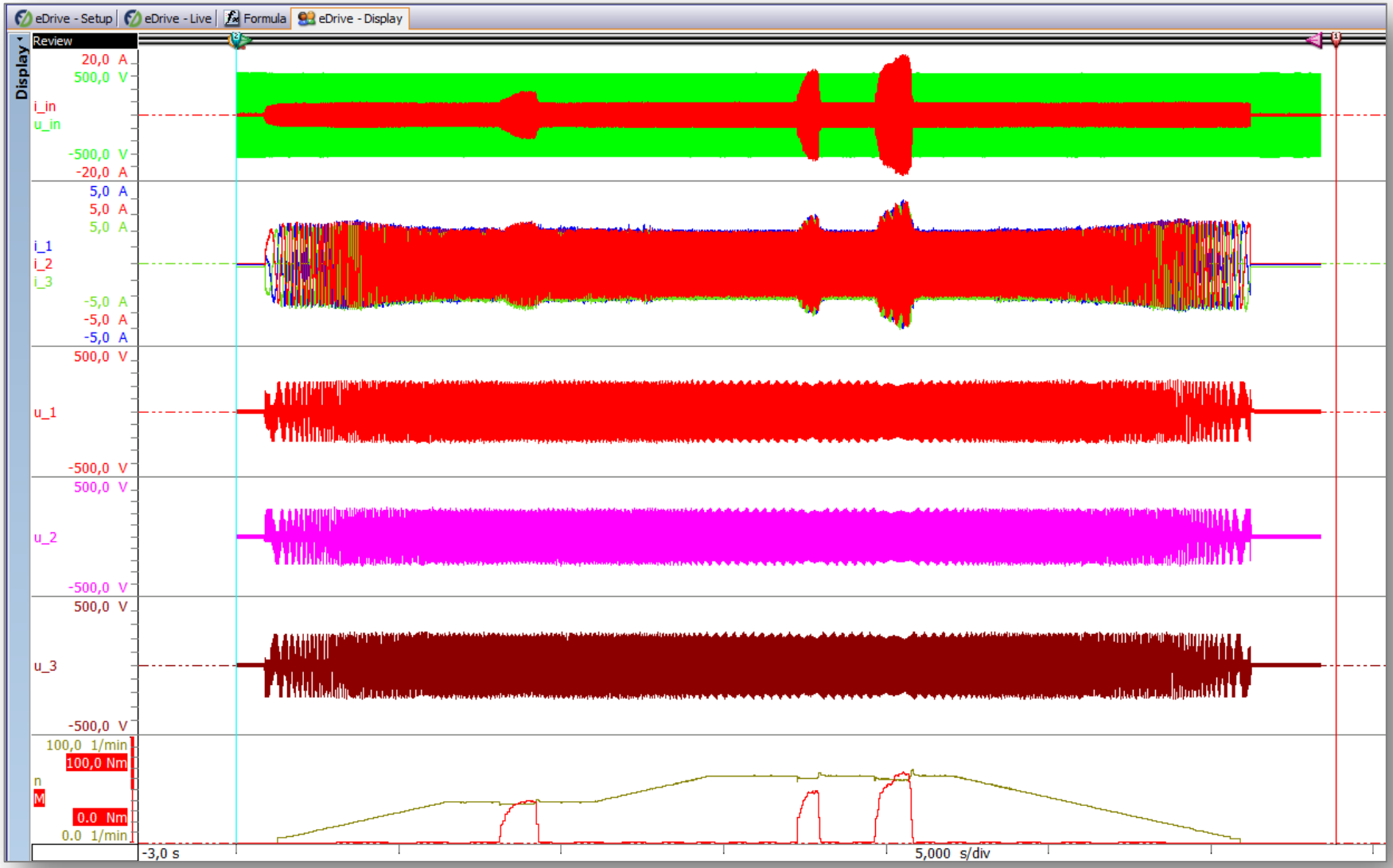
Optional: 16ch temperature satellite

eDrive SETUP: Setting up the test in one single, simple menu



eDrive LIVE: Numerical results and scope and FFT

eDrive REVIEW: Typical signals, continuously acquired for 1 minute



eDrive ANALYSIS: Some basic math (simplified)

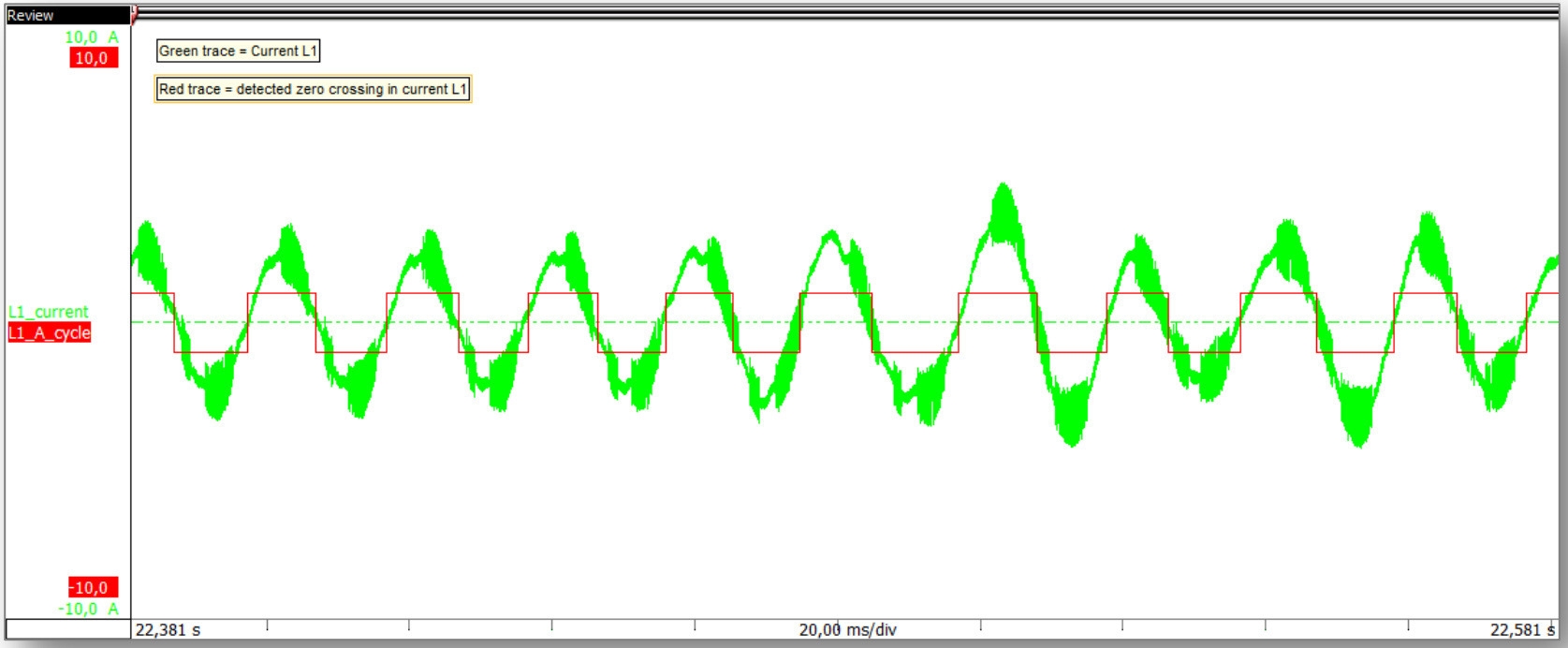
- Input signals (to be measured)
  - Voltage = u
  - Current = i
  - Torque = M
  - Speed = n

- Power calculations (simplified)
  - True power P = $MEAN_{cycle}$ (u x i)
  - Apparent power S = (RMS_{cycle} u) x (RMS_{cycle} i)
  - Mechanical power P_{mech} = $MEAN_{cycle}$ (2 x **π** x n x M)

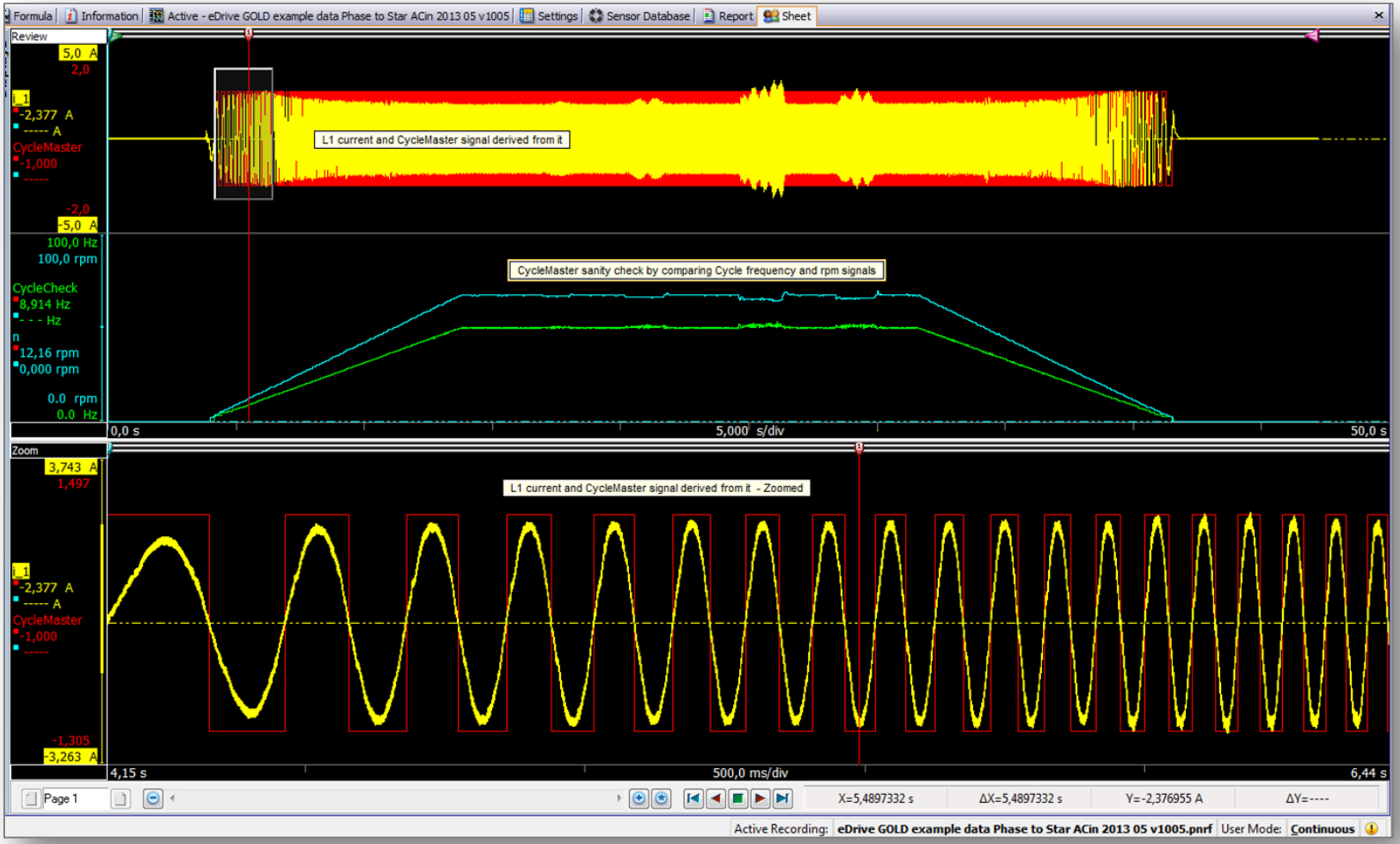
- Efficiency calculation
  - Efficiency electrical motor η (Eta) = P_{mech} / P

Anaylsis - Cycle detection in current signal

- To compute the TrueRMS the real “cycles” of the signals are needed
- Detecting the zero crossing is difficult due to noise
- Perception detects the zero crossings using advanced algorithms
  - Result can be shown for verification



Verification of detected cycles



- The “cycle detect” integrity can be checked by computing the cycle frequency to compare it with the rpm trace
  - Must be the same “waveshape”
  - Cycle Frequency must not have peaks or drops (= double / missing cycles)

Analysis using a formula database

- RMS per phase and cycle
  - Cycle detection in current i_1
  - RMS value of current per phase and per „cycle“
  - RMS value of voltage per phase and per „cycle“ of the current
- True power
  - Multiplication of u and i gives the instantaneous power per phase
  - Doing a MEAN over a cycle gives true power per phase
  - Summing up phases gives total P
- Mechanical power
  - Multiplication of torque and speed
- Motor efficiency
  - Ratio of mechanical to real power

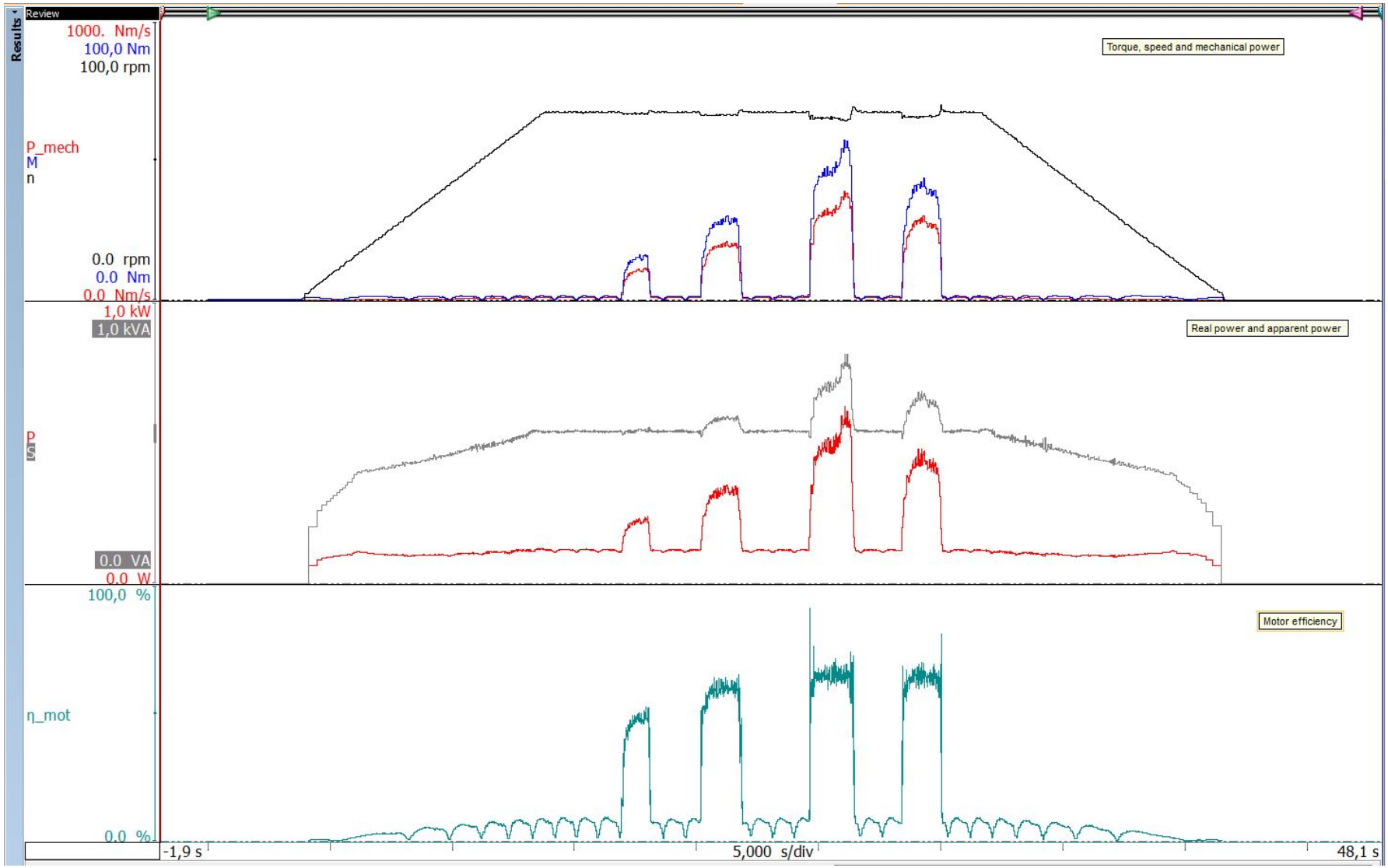
56	CycleMaster	@CycleDetect (Formula.i_1;0;1)
57		
58	I_1	@CycleRMS (Formula.i_1; 1; Formula.CycleMaster)
59	I_2	@CycleRMS (Formula.i_2; 1; Formula.CycleMaster)
60	I_3	@CycleRMS (Formula.i_3; 1; Formula.CycleMaster)
61		
62	U_1	@CycleRMS (Formula.u_12; 1; Formula.CycleMaster)
63	U_2	@CycleRMS (Formula.u_23; 1; Formula.CycleMaster)
64	U_3	@CycleRMS (Formula.u_31; 1; Formula.CycleMaster)

73	p_1	Formula.u_1 * Formula.i_1
74	p_2	Formula.u_2 * Formula.i_2
75	p_3	Formula.u_3 * Formula.i_3
76		
77	P_1	@CycleMean (Formula.p_1; 1;Formula.CycleMaster)
78	P_2	@CycleMean (Formula.p_2; 1;Formula.CycleMaster)
79	P_3	@CycleMean (Formula.p_3; 1;Formula.CycleMaster)
80		
81	P	Formula.P_1 + Formula.P_2 + Formula.P_3

119	P_mech	2 * System.Constants.Pi * Formula.n / 60 * Formula.M	Nm/s

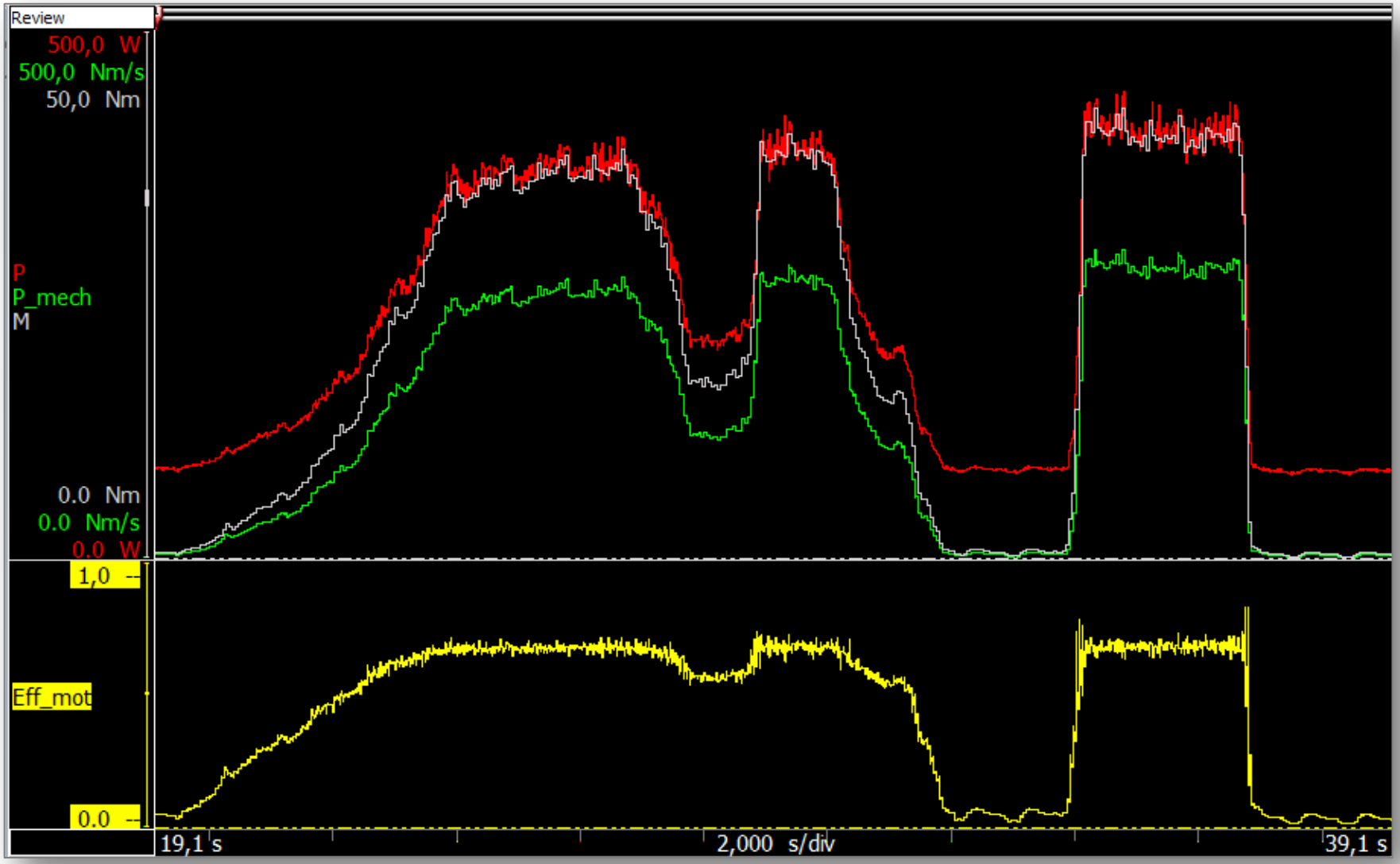
131	η_mot	(Formula.P_mech / Formula.P) * 100	%

Some computed results as shown in Perception software



Top to bottom: Mechanical power, electrical power (P, S), motor efficiency

eDrive example: Power values and motor efficiency

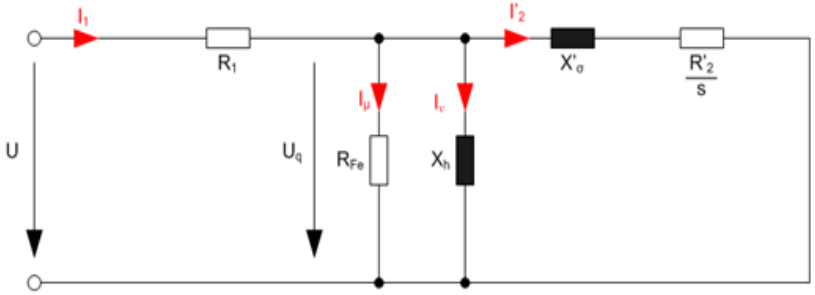


Torque, mechanical power and true power on top, motor efficiency underneath

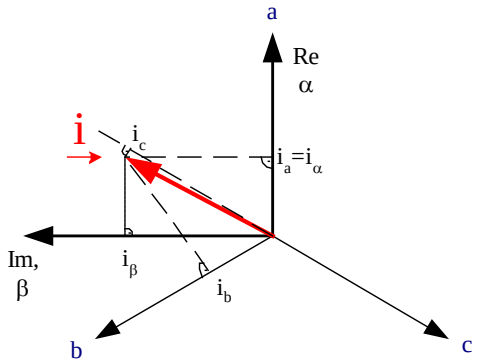
eDrive: Other analysis possibilities

- As all RAW data is stored, advanced analysis of motor and inverter data is possible using Perceptions formula database

- Potential Motor analysis
  - Equivalent circuit diagram
  - Iron losses
  - Main inductance
  - Starting currents
  - Armature currents
  - Airgap torque
  - Torque ripple
  - Cogging torque
  - Saturation effects

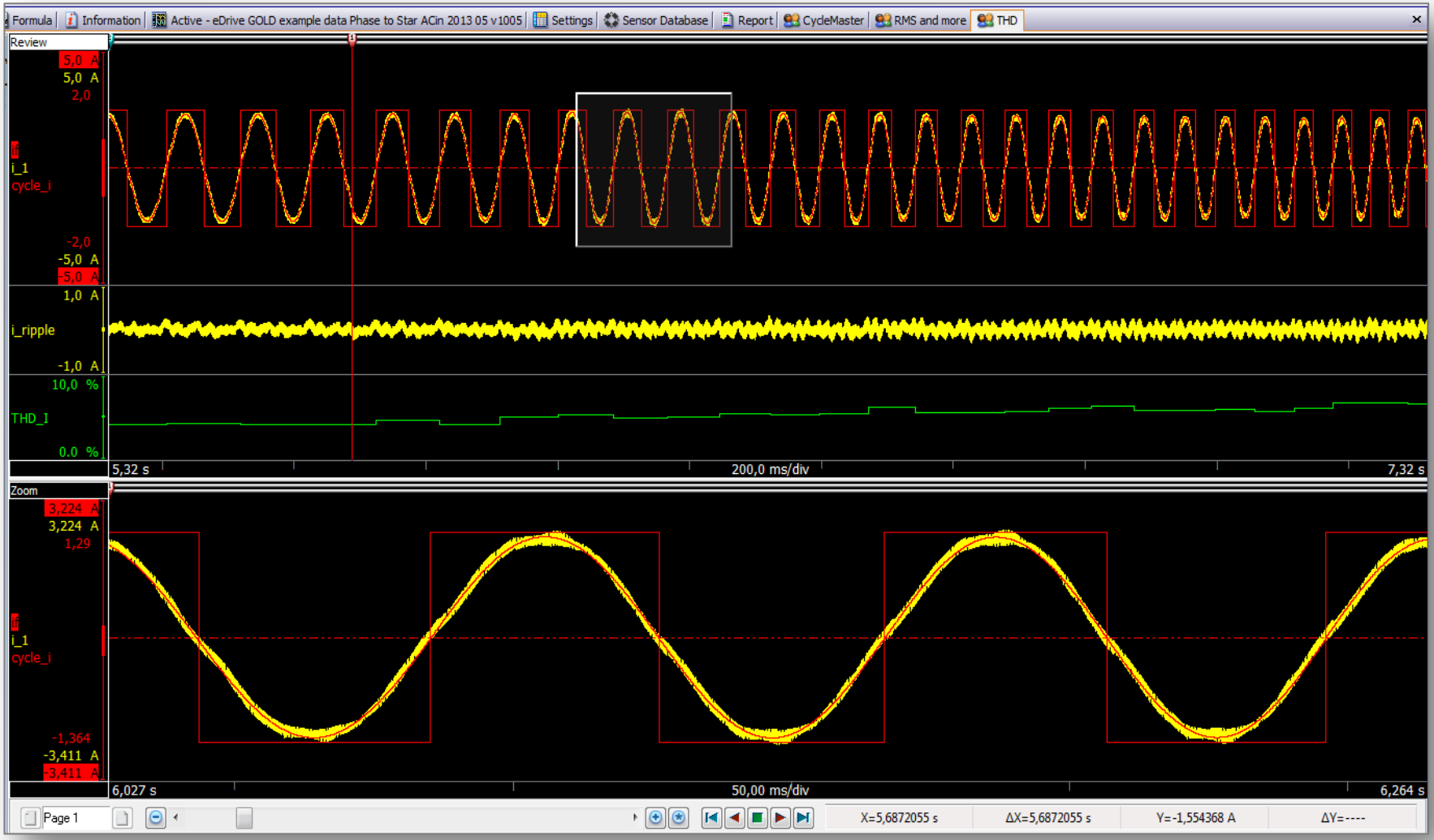


- Potential Inverter analysis
  - Space vector / DQ0 transformation
  - Inverter control behaviour
  - Modulation method
  - Frequency & amplitude of fundamental
  - THD of voltage and current
  - Switching frequency



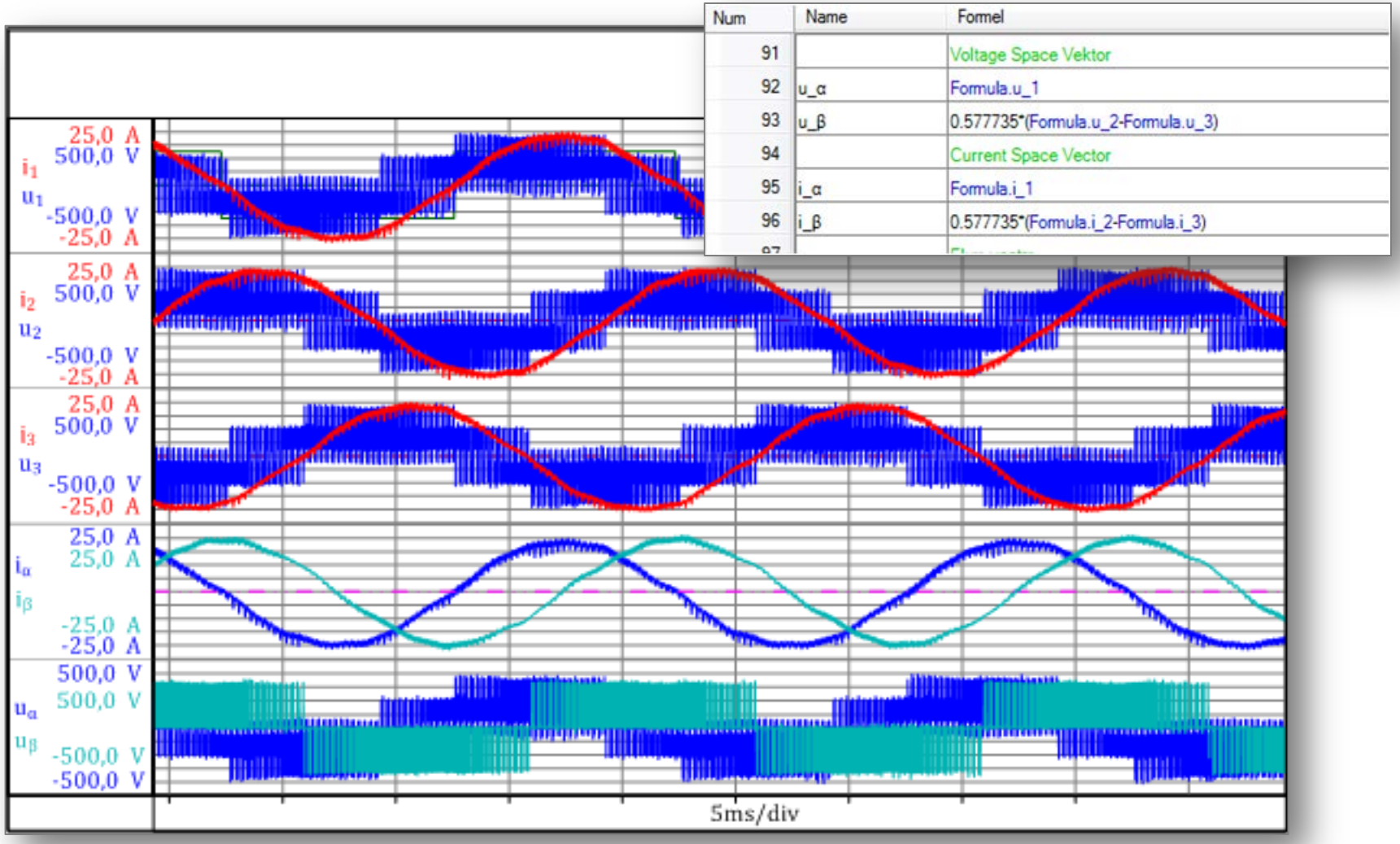
$$\vec{i} = i_\alpha + j i_\beta = \frac{2}{3}(i_a + a \cdot i_b + a^2 \cdot i_c)$$

eDrive: Fundamental of current, ripple current, THD computation



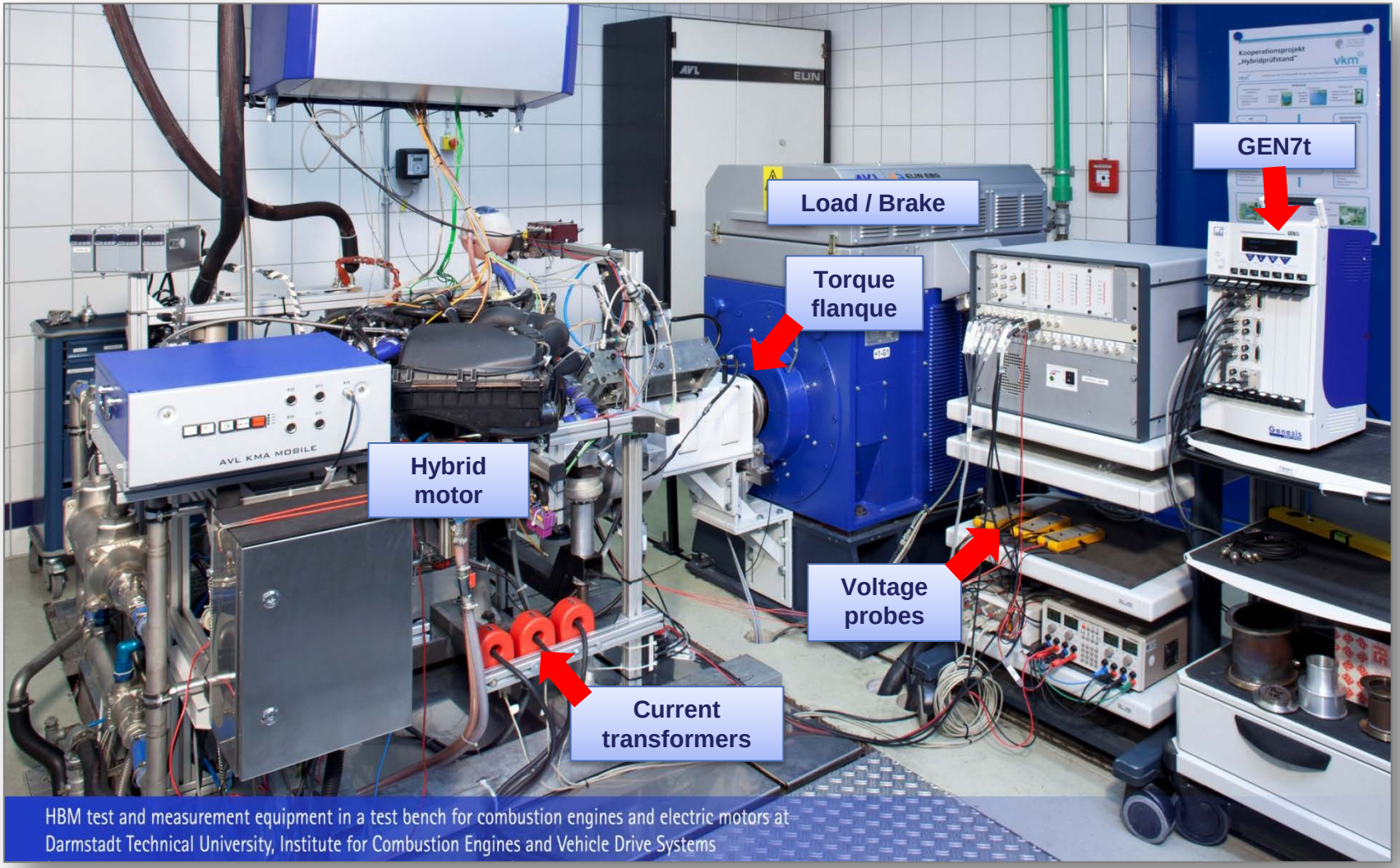
Current (lower yellow), fundamental of current (lower red sinewave), ripple current (mid yellow), THD (green)

eDrive: Space vector transformation



From the known signals u_1, u_2, u_3 and i_1, i_2, i_3
the space vectors u_α, u_β and i_α, i_β are calculated

Hybrid motor test cell equipped with T10 and GEN7t from HBM



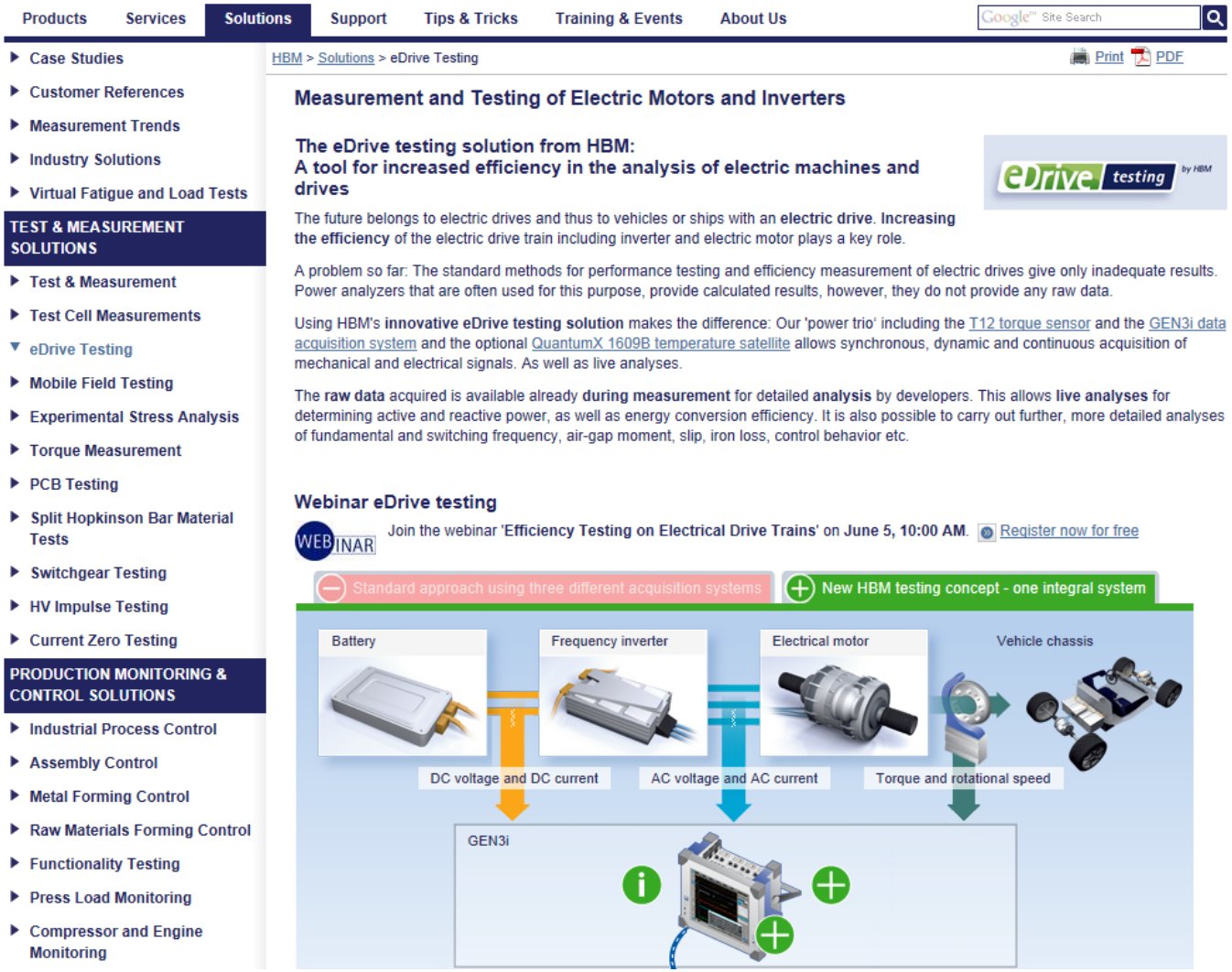
HBM test and measurement equipment in a test bench for combustion engines and electric motors at Darmstadt Technical University, Institute for Combustion Engines and Vehicle Drive Systems

eDrive: HBM concept for e-motor/inverter testing - Summary

- HBM GEN DAQ is able to **connect to all signals** being high voltage, currents, torque, speed, temperatures, vibration…..
- All signals are sampled **simultaneously** and displayed live
- Sampling is done with **high sample rate** and high resolution
- **Continuous raw data storage** allows verification and analysis
- Setting up the measurement is done in **one simple menu**
- Power calculations are done **LIVE and per half cycle**
- Perception´s formula database offers all tools for further, detailed **motor and inverter analysis**
- **So we offer an integrated tool not only to measure efficiency, but also to understand how to improve efficiency**

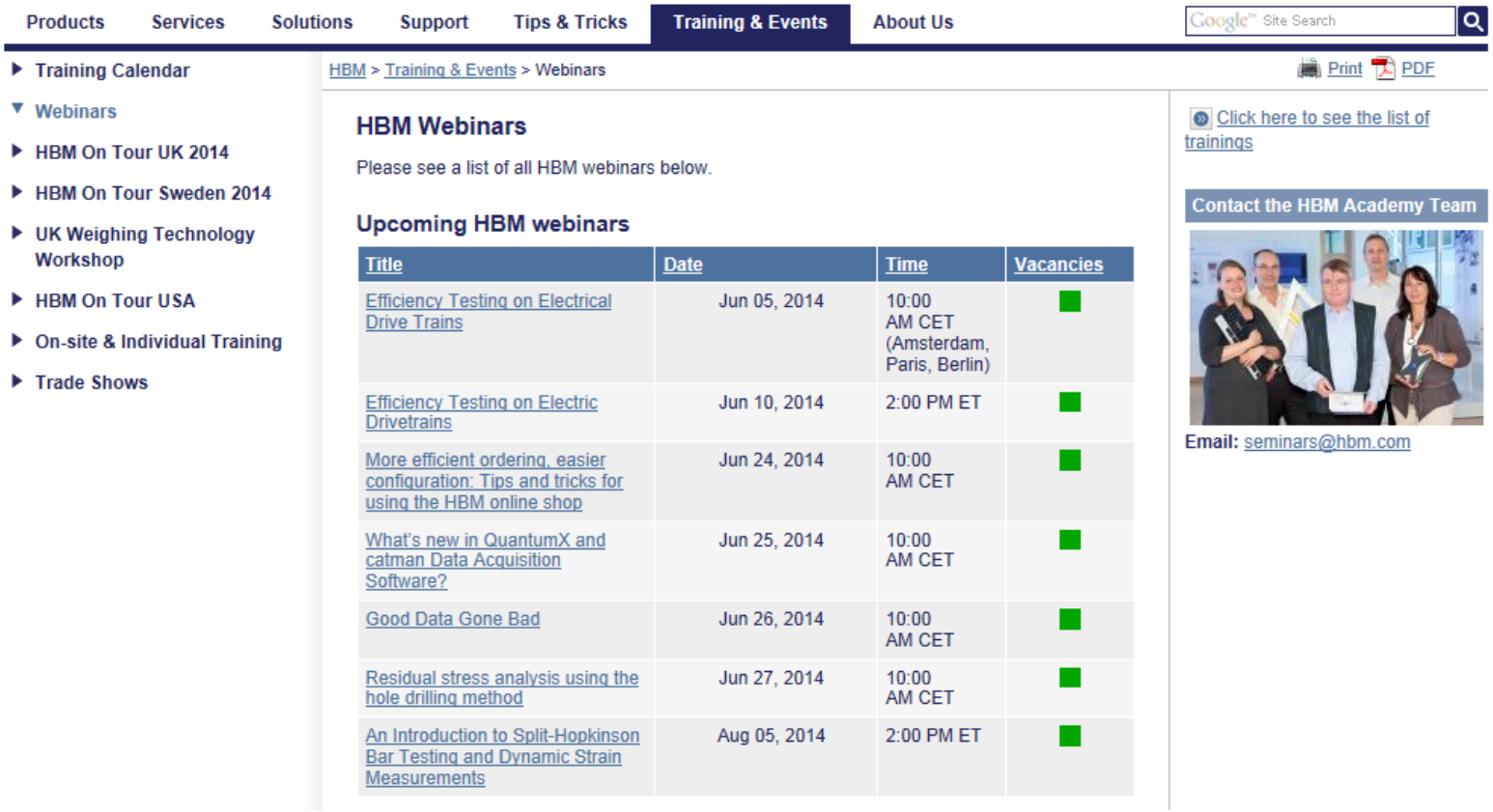
More detailed information

- www.hbm.com/edrive



More detailed information

- www.hbm.com/webinars



Any questions?

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- Or email the speaker directly: klaus.lang@hbm.com

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