An Open Source Software Package for ESS EtherCAT Motion Control Applications

Based on the open source EtherCAT master by IgH (etherlab)

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DENIM 2018, PSI, 19th September

www.europeanspallationsource.se

Outline

- EtherCAT fieldbus
- Previous work
- EtherCAT at ESS
- ECMC (EtherCAT Motion Control):
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  - Architecture
  - Axis class
  - Synchronization
- Hardware
  - Master
  - Slaves
- Safety
- Applications:
  - 2-Axis slit system
  - 2-Axis Wire Scanner
  - Data Acquisition
- Summary
- Acknowledgments
- References

EtherCAT Fieldbus

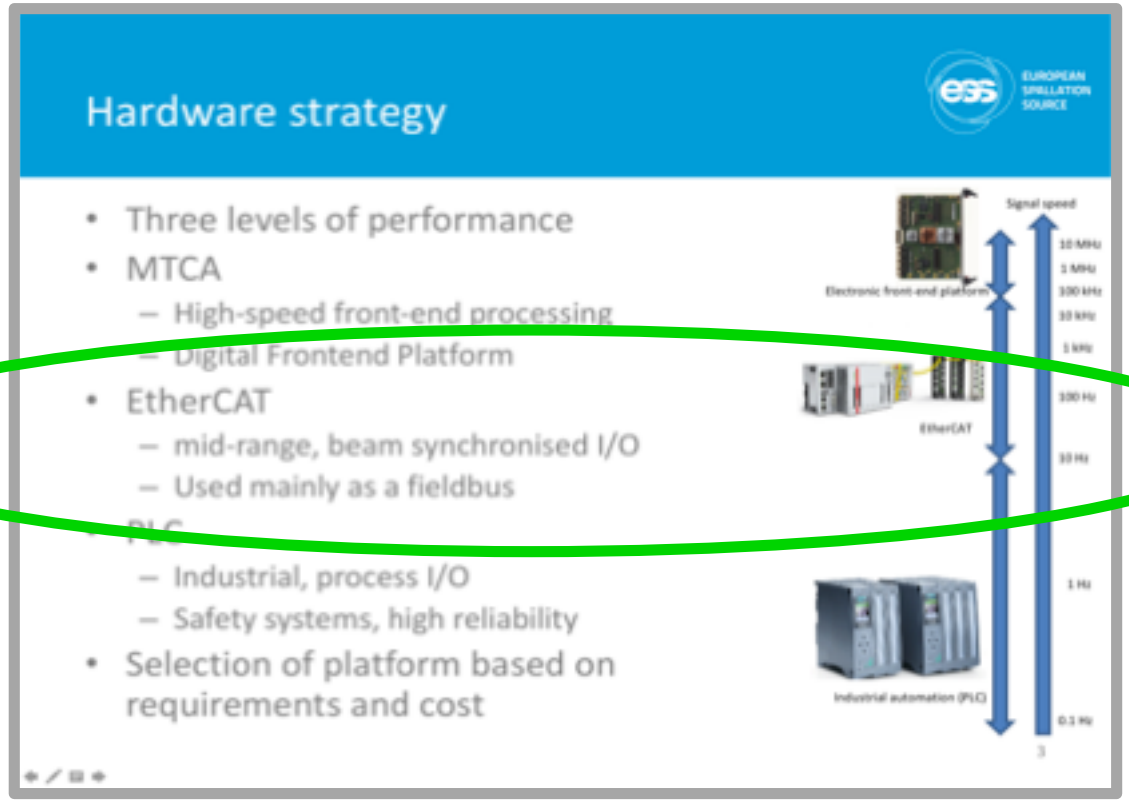
- EtherCAT
  = Ethernet for Control Automation Technology
- Open fieldbus standard originally developed by Beckhoff GmbH [1].
- Maintained by EtherCAT Technology Group [2].
- Hardware requirements:
  - Master: standard computer hardware (NIC)
  - Slaves: dedicated hardware, EtherCAT Slave Controller (ESC)
- Masters: Commercial (e.g. Beckhoff TwinCAT) and open source masters available.
- Slaves: Several 100 manufacturers of slaves (drives, I/O, sensors, robots).
- Topologies: Line, Star, Ring.
- Media: Cat 5 cable, plastic fiber, glass fiber.
- Bandwidth utilization: 80%-97% (100 Mbit/s , Ethernet, Full-Duplex) .
- Supports Distributed Clock (DC) in slaves with a max. of 100ns synch error.
- Cycle times > 50µs.
- Applications: Motion, large or long distance systems, synchronized systems.

Previous work

- Diamond Light source “dls-ethercat” driver [7, 8]:
  - Data acquisition and control
- Paul Scherrer Institute “ecat2” driver [9]:
  - Data acquisition and control
- Other facilities are using EtherCAT as well but based on commercial software / hardware platforms.

EtherCAT at ESS

- Chosen as a medium performance platform for data acquisition and control [3, 4].
- Chosen for motion control in accelerator applications



Source: [5]

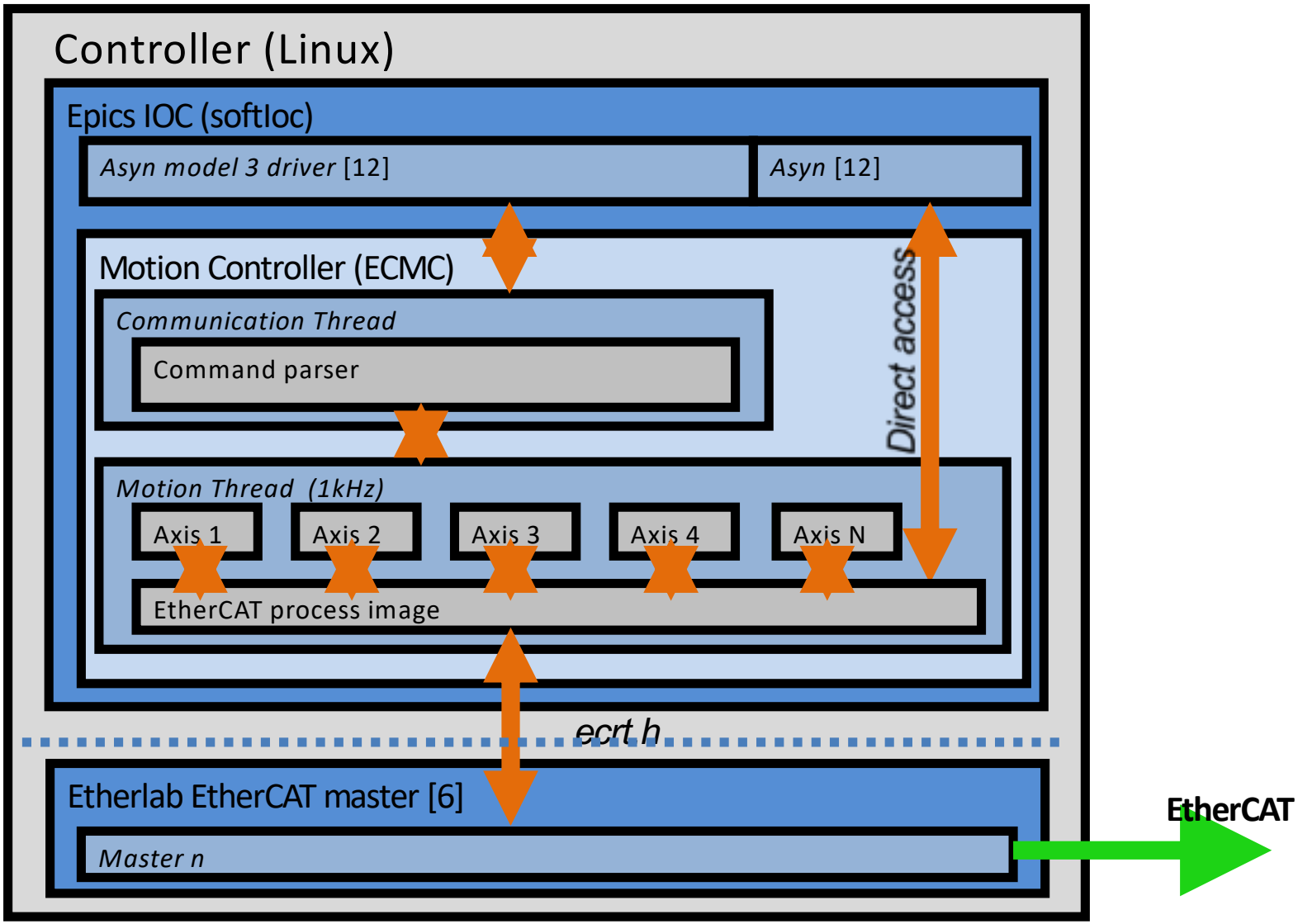
ECMC: EtherCAT Motion Control

ECMC is an open source motion control framework for EPICS environment [10].

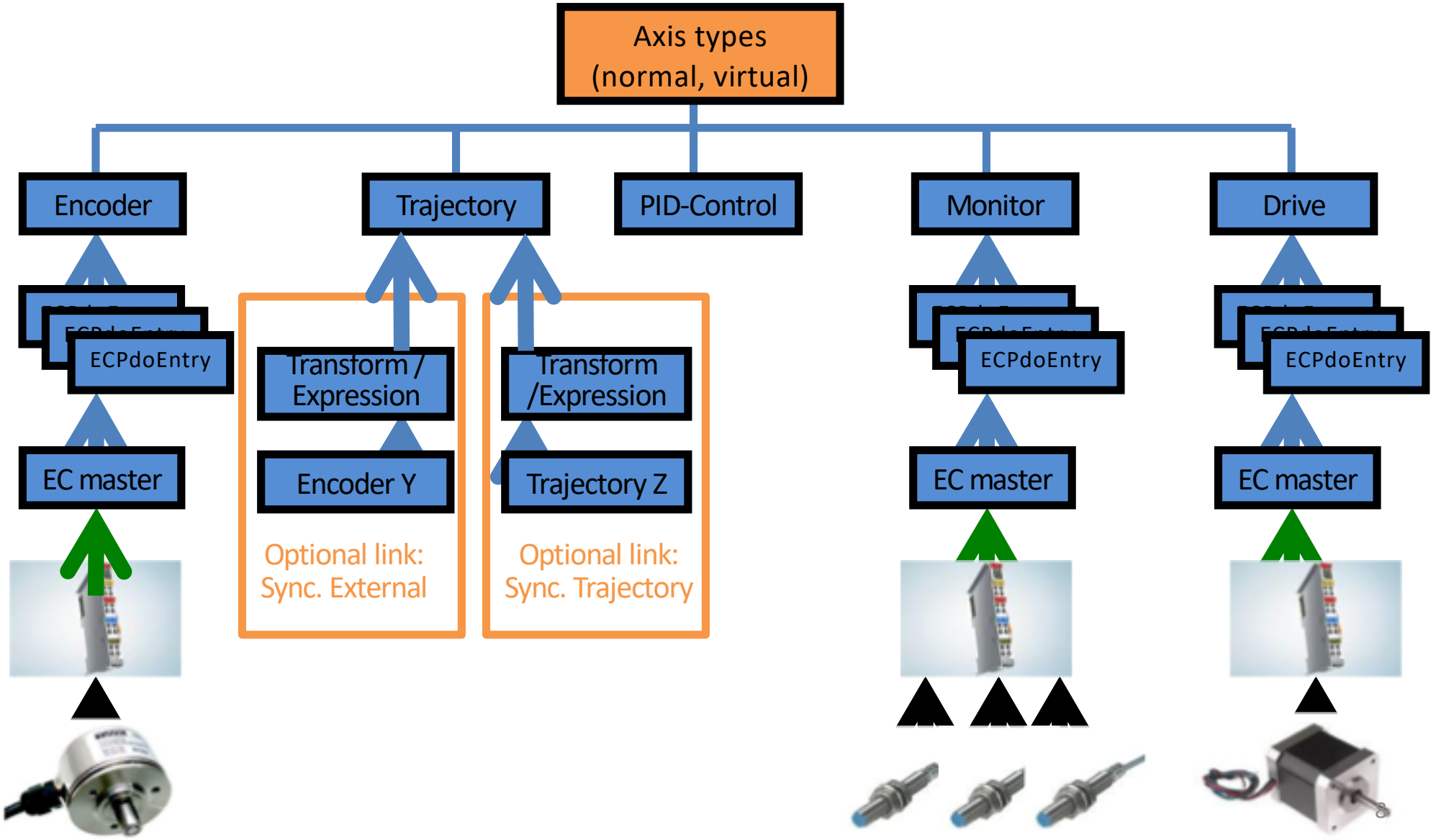
Functionalities:

- Motion (with EPICS Motor Record support):
  - Positioning (absolute, relative)
  - Constant speed
  - Referencing sequences
- Motion (extension to Motor Record)
  - Motion interlocks
  - Triggering, latching positions
  - Synchronization axis to axis
  - Synchronisation to external source (timing system,…)
- General
  - Data acquisition (analogue <100kHz, digital <1Mhz)
  - General I/O + low level control

ECMC: Architecture



ECMC: Axis class



ECMC: Synchronization

- Synchronization of axes by expressions (exprTk) [14].
  - setPosx = Trajectory generated setpoint for axis x
  - actPosx = Actual position of axis x
  - enx = Enable amplifier of axis x
  - ilx = Motion interlock of axis x (allowed to move if true)
- Update of expression at runtime possible (evaluated in 1kHz).

Examples:

Slaving:	setPos2:=actPos1;
Synchronization:	setPos2:=setPos1;
Gearing:	setPos2:=0.5*setPos1;
Phasing:	setPos3:=setPos1+setPos2;
Advanced:	setPos1:=10*sin(setPos2+actPos3);
Interlocks:	il1:=il2 and il5 and actPos4>actPos3;
Enable:	en2:=en1;

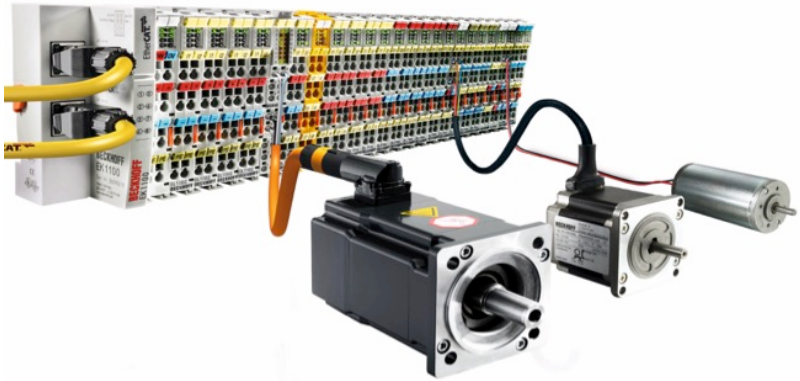
ECMC: Hardware Platforms

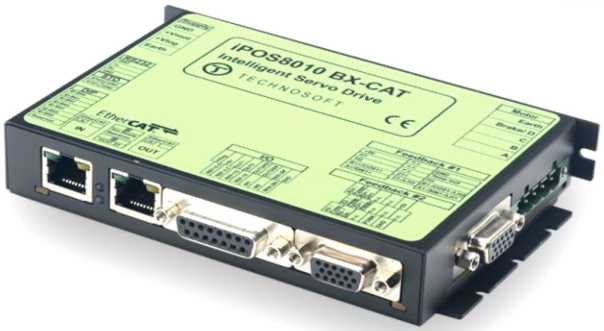
- Standard computer hardware (NIC needed for EtherCAT Master).
- Flexible hardware choice:
  - µTCA
  - Industrial computer
  - DIN rail computer

Supported EtherCAT Slaves

- Beckhoff I/O (analog and digital):
  - Normal and over-sampling
- Beckhoff position:
  - Absolute: SSI, Resolver
  - Incremental: AquadB, sin/cos 1Vpp
- Beckhoff drives:
  - Stepper, BLDC/PMSM, DC: I_{rms}< 3.5A
- Other Supplier drives:
  - Kuhnke (stepper, BLDC, DC): I_{rms}< 5A
  - Technosoft (stepper, BLDC,DC): I_{rms}< 14A

http://www.beckhoff.com/





https://kuhnke.kendrion.com/industrial/ics/en/

http://www.technosoftmotion.com/

Supported EtherCAT Slaves

Moition Terminals	
EL5002	2ch SSI encoder interfaces
EL5021	1ch SinCos encoder interface, 1 VPP
EL5101	Incremental encoder interface, diff, 32bit, 16bit mode
EL7031	Stepper motor terminal 24 V DC, 1.5 A
EL7037	Stepper motor terminal 24 V DC, 1.5 A, with incremental encoder, vector control
EL7041	Stepper motor terminal 50 V DC, 5 A, with incremental encoder
EL7047	Stepper motor terminal 50 V DC, 5 A, with incremental encoder, vector control
EL7201	Servomotor terminal for resolver, 50 V DC, 2.8 Arms
EL9576	Brake chopper terminal
FIODrive	Kuhnke Stepper drive, 72V DC, 5A
IPOS4808	Technosoft Stepper drive, 50V DC, 8A , STO
IPOS8020	Technosoft Stepper drive, 80V DC, 20A

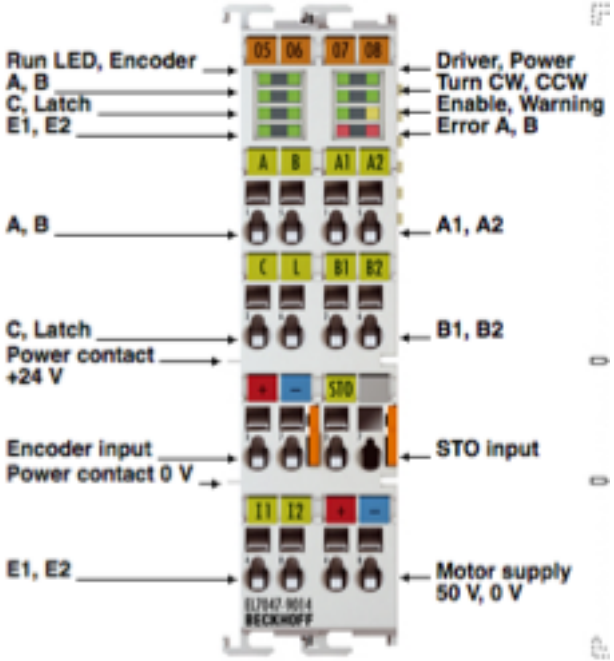
Digital Terminals	
EL1014	4-channel digital input terminal 24 V DC, 10 µs
EL1018	8-channel digital input terminal 24 V DC, 10 µs
EL1252	2-channel digital input terminal with timestamping
EL2004	4-channel digital output terminal 24 V DC, 0.5 A
EL2124	4-channel digital output terminal 5 V DC
EL2502	2-channel pulse width output terminal 24 V DC
EL2808	8-channel digital output 24 V DC, 0.5 A
EL2819	16-channel digital output 24 V DC, 0.5 A, with diagnostics

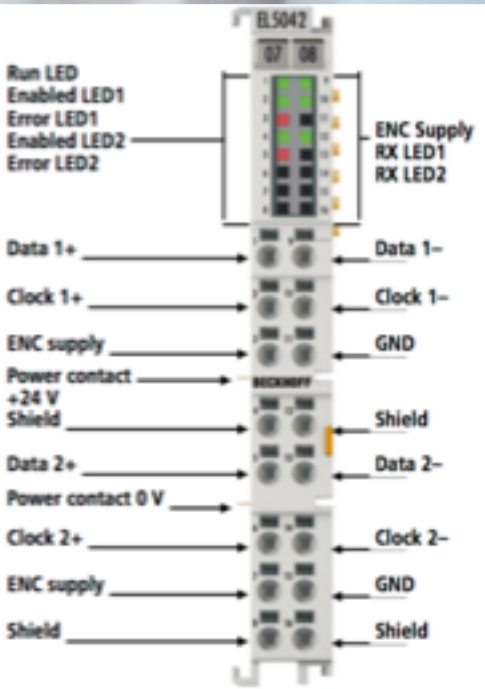
Misc. Terminals	
EK1100	Coupler
EK1110	Extension
EK1122	2-port EtherCAT junction
EL6080	Memory terminal 128 kbyte
EL9410	Power supply terminal for E-bus, with diagnostics
EL9505	Power supply terminal 5 V DC

Analog Terminals	
EL3002	2-channel analog input terminal -10…+10 V, single-ended, 12 bit
EL3004	4-channel analog input terminal -10…+10 V, single-ended, 12 bit
EL3162	2-channel analog input terminal 0…10 V, single-ended, 16 bit
EL3164	4-channel analog input terminal 0…10 V, single-ended, 16 bit
EL3202	2-channel input terminals PT100 (RTD) for 4-wire connection, high-precision
EL3204	4-channel input terminal PT100 (RTD)
EL3214	4-channel input terminal PT100 (RTD) for 3-wire connection
EL3255	5-channel input, potentiometer measurement with sensor supply
EL3602	2-channel analog input terminal ±10 V, ±5 V, ±2.5 V, ±1.25 V, differential input, 24 bit
EL3632	2-channel analog input terminal for Condition Monitoring (IEPE), 50KHz
EL3702	2-channel analog input terminal -10…+10 V, 100kHz
EL4004	4-channel analog output terminal 0…10 V, 12 bit
EL4032	2-channel analog output terminal -10…+10 V, 12 bit
EL4102	2-channel analog output terminal 0…10 V, 16 bit
EL4104	4-channel analog output terminal 0…10 V, 16 bit
EL4122	2-channel analog output terminal 4…20 mA, 16 bit
EL4134	4-channel analog output terminal -10…+10 V, 16 bit

Planned supported slaves

- AX5000 Servo drive
- EL5042 BISS-C
- EL7047-9014 (STO)





Safety:

- Beckhoff I/O:
  - Yellow modules NOT supported

- Beckhoff drives (STO input SIL3/PLd), not tested:
  - Stepper, EL7047-9014, (Q4,2018): I_{rms}< 3.5A
  - BLDC, EL7411-9014, (Q4,2018): I_{rms}< 4.5A
  - Servo drive, EL72*1-9014, (max 50VDC): I_{rms}< 8A
  - AX5000

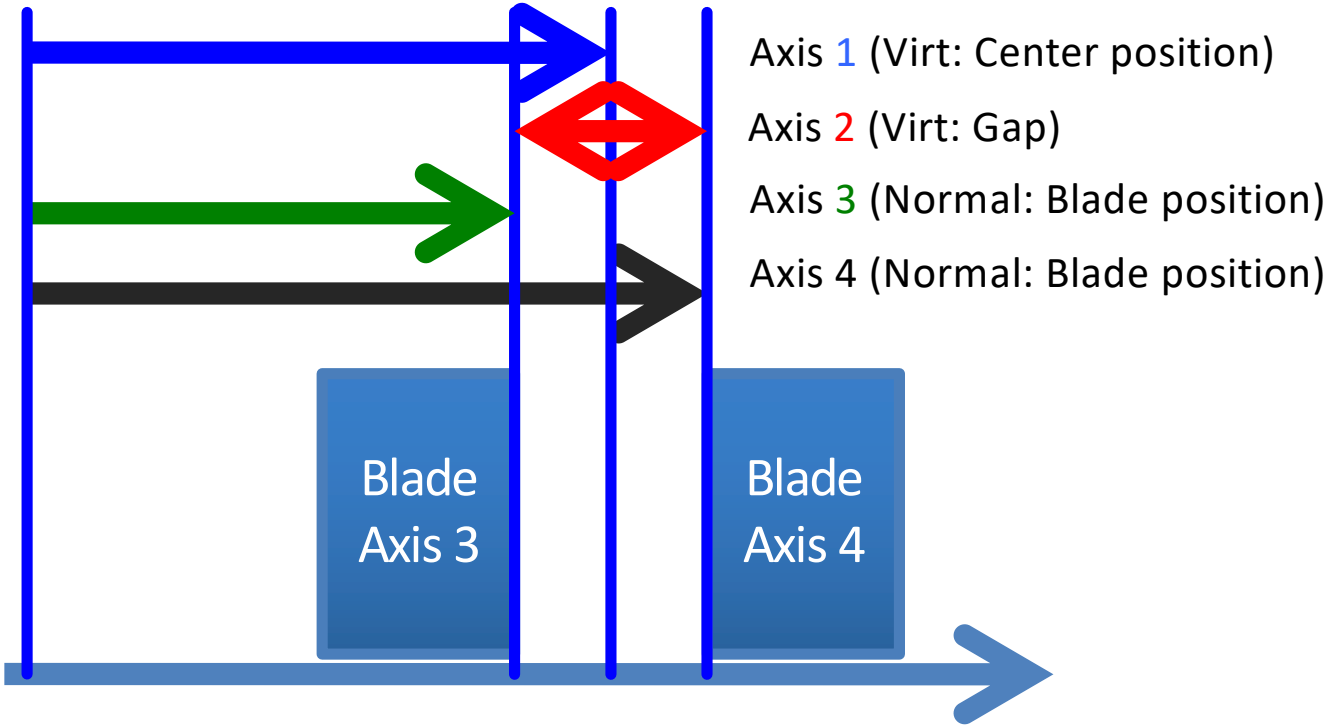
http://www.beckhoff.com/

- Technosoft (STO input SIL3/PLe), tested:
  - iPOS4808, Stepper, BLDC, DC: I_{rms}< 5.5A

http://www.technosoftmotion.com/

Application: 2-Axes Slit Set

- 2 virtual axes
  - Slit center position
  - Slit gap/opening
- 2 normal axes (blade positions)



Forward Kinematics:

setPos3:=setPos1-setPos2/2;
setPos4:=setPos1+setPos2/2;

Inverse Kinematics:

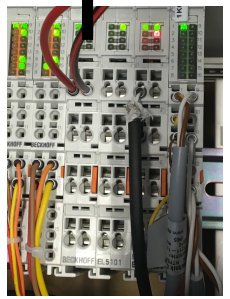
actPos1:=(actPos3+actPos4)/2;
actPos2:=(actPos4-actPos3);

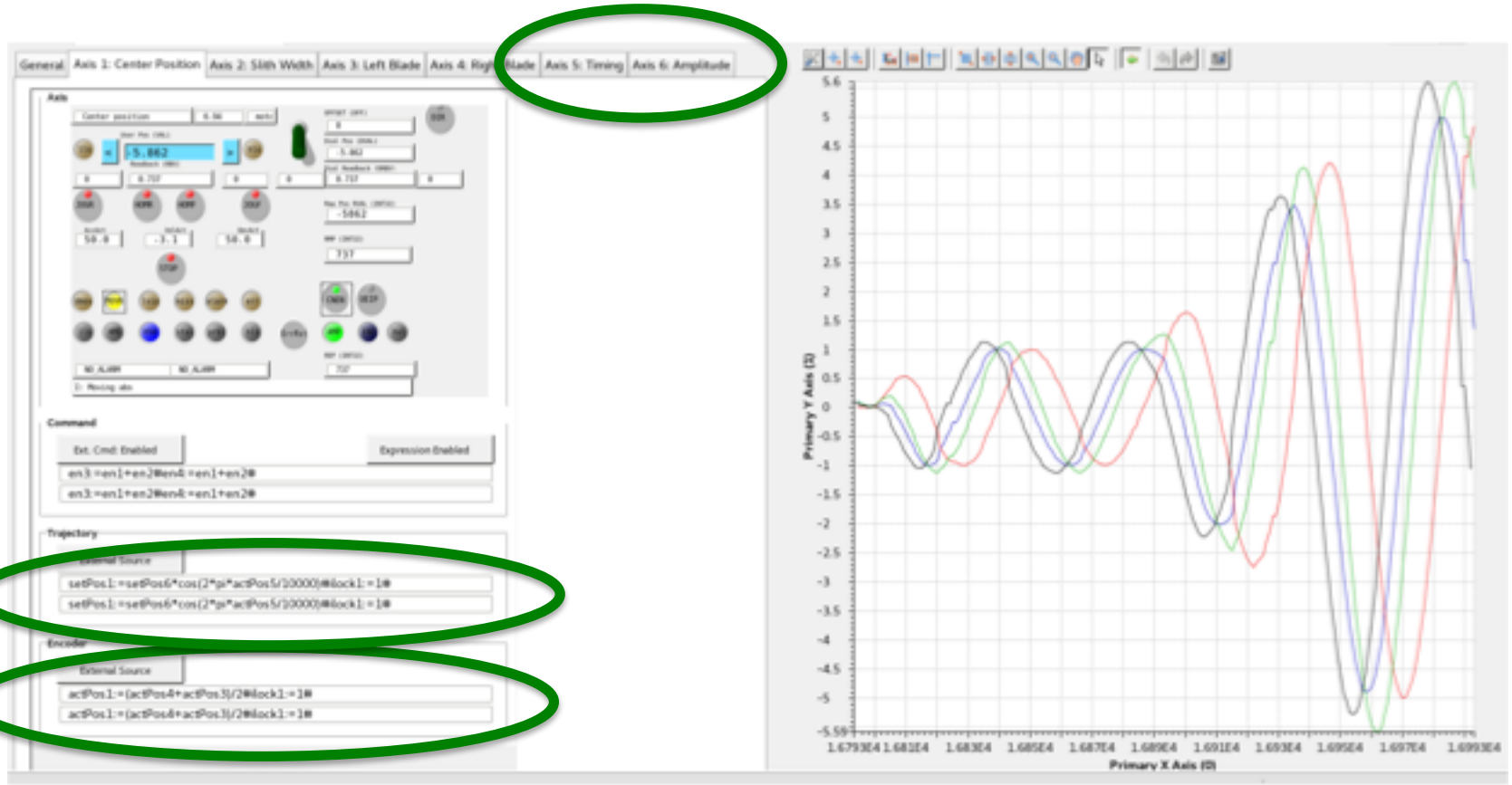
Amplifier enable:

En3:=En1 or En2;
En4:=En1 or En2;

Application: 2-Axes Slit Set, External Sync.

- Add 2 virtual axes
  - Timing system (Signal Generator connected to EL5101)
  - Amplitude





Axis 1 (Centre)

Axis 2 (Gap)

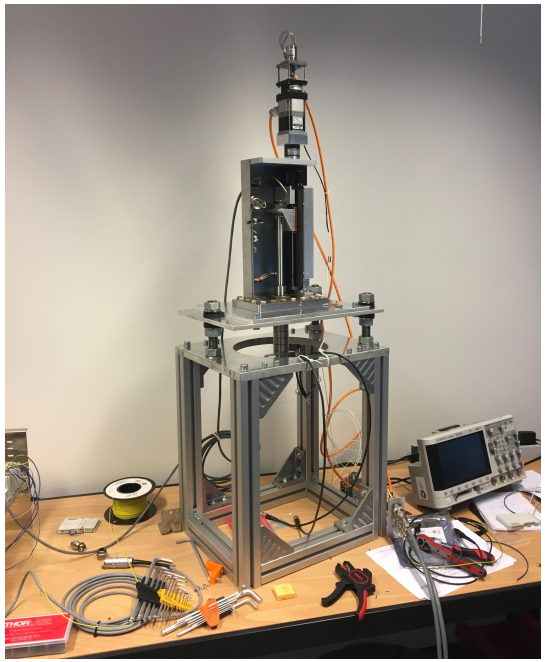
Axis 3 Left blade

Axis 4 Right blade

Application: 2 Axes Wire Scanner

Application:

- Beam profile measurement (two directional)



Requirements:

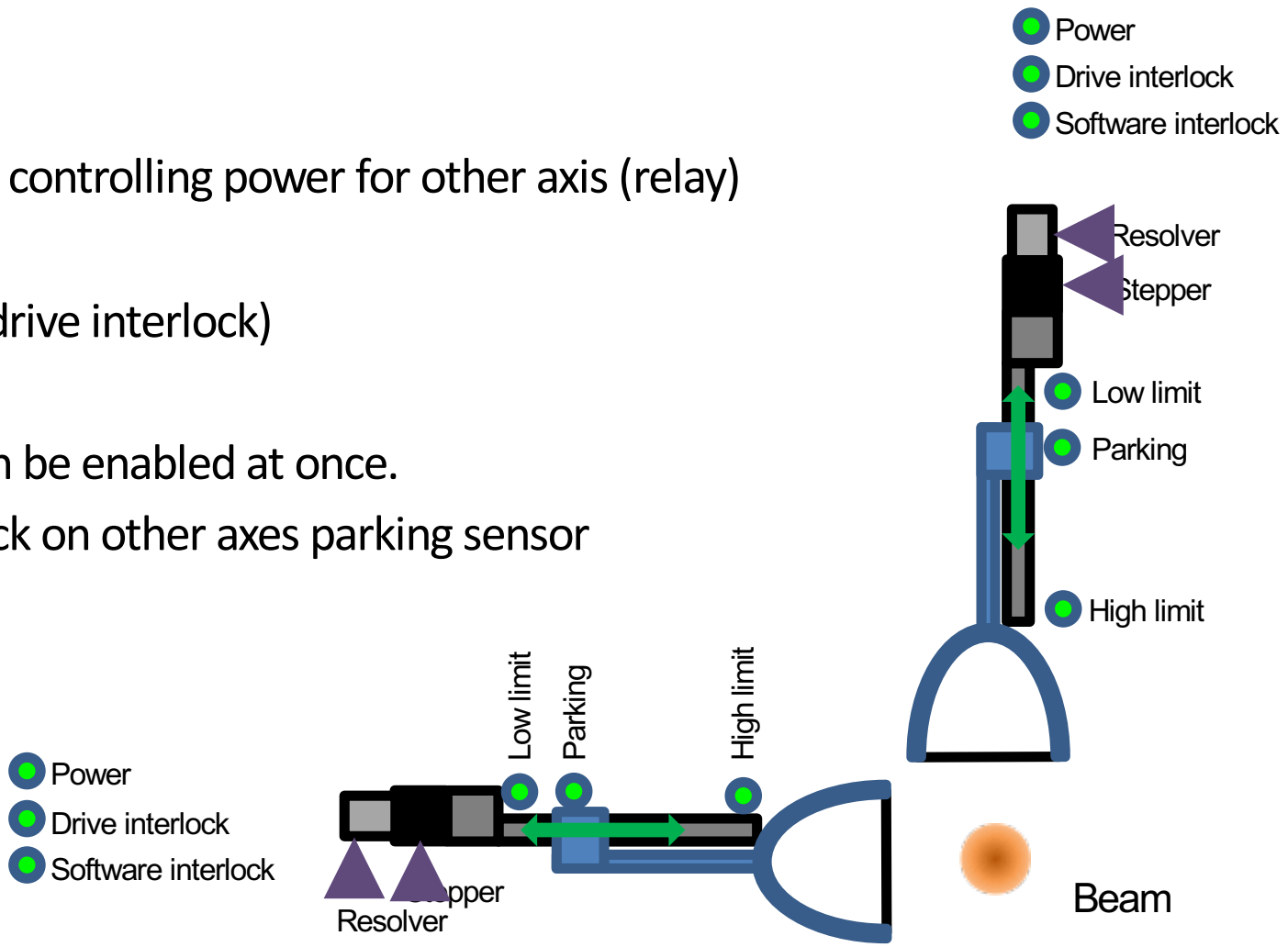
- Machine safety:
  - Collision avoidance
- Position sampling synchronized to timing system

- Hardware solution for prototype:
  - Actuators: Stepper motors, EL7037 drive
  - Feedback: Resolvers (radiation), EL7201 resolver interface
  - Controller: ECMC running on µTCA CPU

Wire Scanner: Collision Avoidance

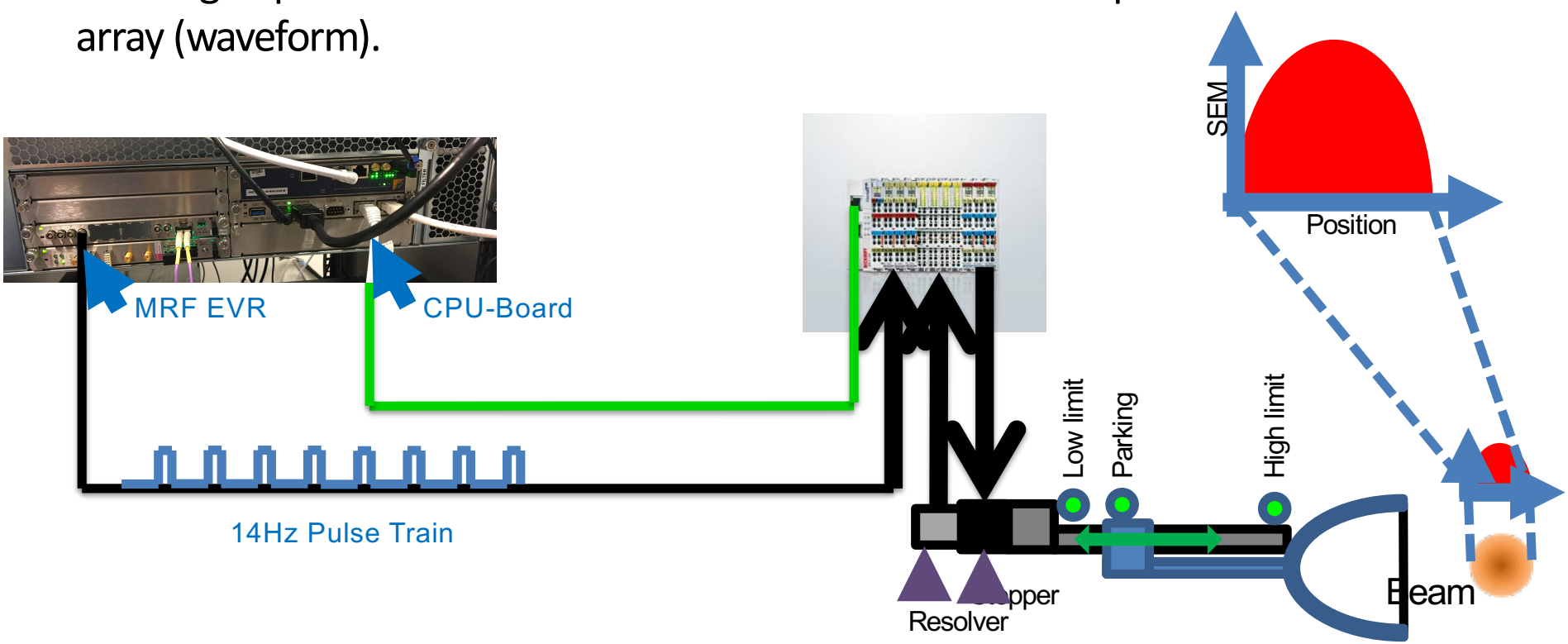
Three layers of interlocks:

1. Hardware:
   - Parking switches controlling power for other axis (relay)
2. “Semi hardware”:
   - Drive interlock (drive interlock)
3. Software:
   - Only one axis can be enabled at once.
   - Software interlock on other axes parking sensor



Wire Scanner: Latching of data

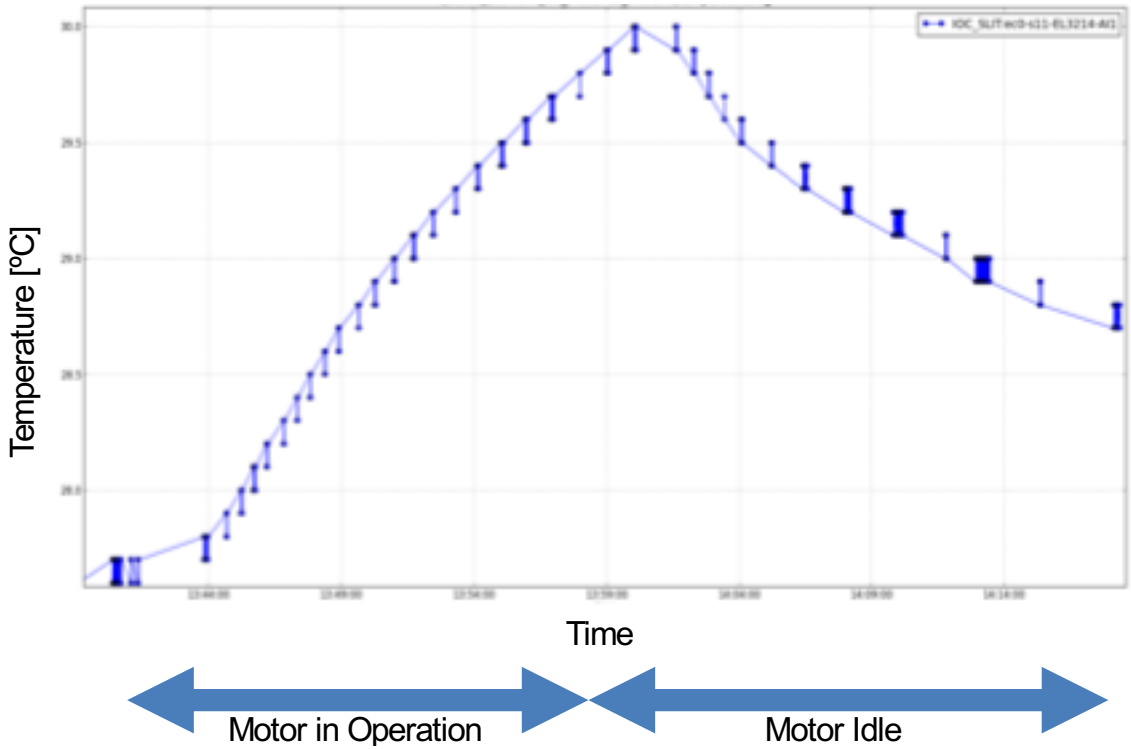
- Actuator position recorded synchronized to the ESS timing system (and thereby to analog wire readout of secondary emission current, SEM).
- Timing system Event Receiver (EVR) pulse train connected to 5V input.
- Latching of position is made and buffered in ECMC and then presented in EPICS as a array (waveform).

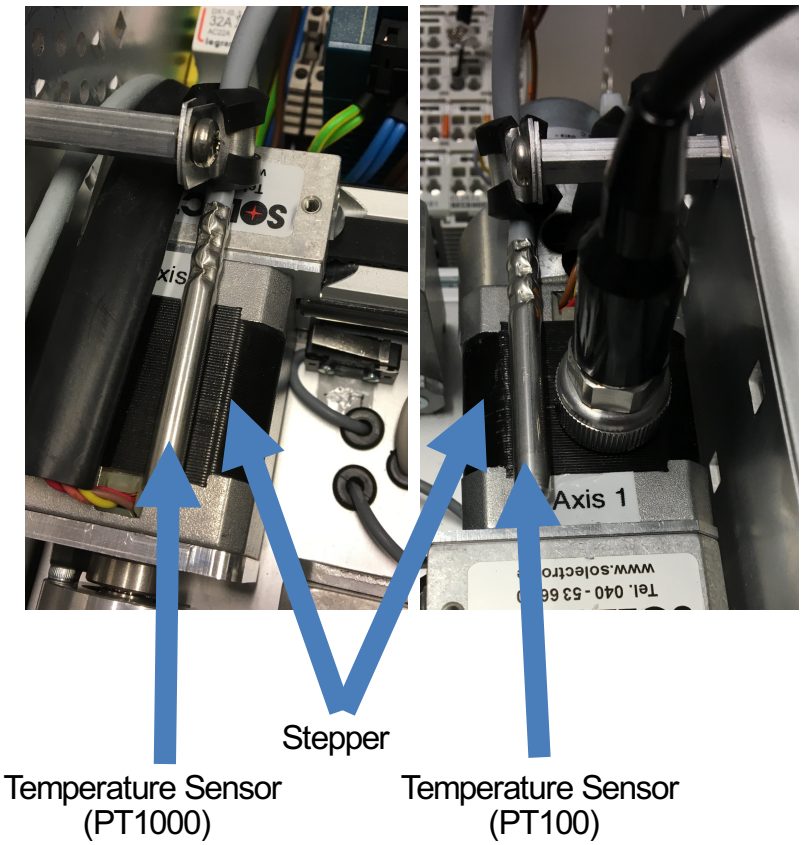


Data Acquisition: Temperature

Analog Data Acquisition:

- Example: Motor temperature (PT100 or similar)
- Data accessible through EPICS PV (AI record)
- Update EPICS PV on change
- Resolution 0,1°C (standard)

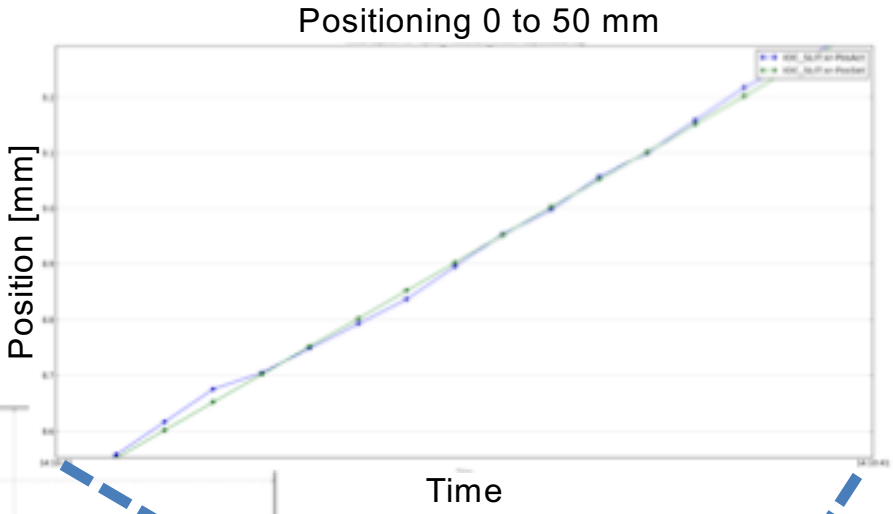


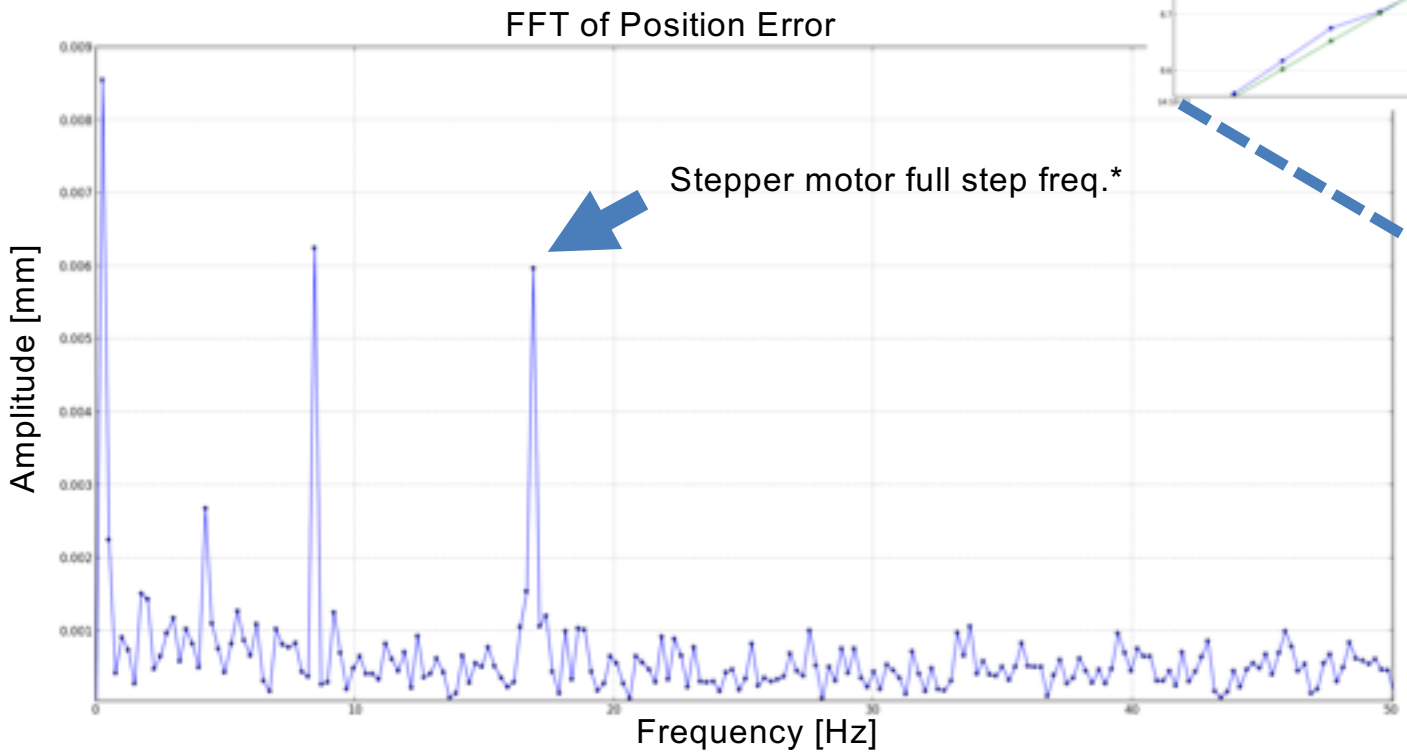


Data Acquisition: Position Data Analysis

Analysis of position error during move:

- Data accessible in EPICS PVs (AI records)
- Example: Positioning task from 0mm to 50mm



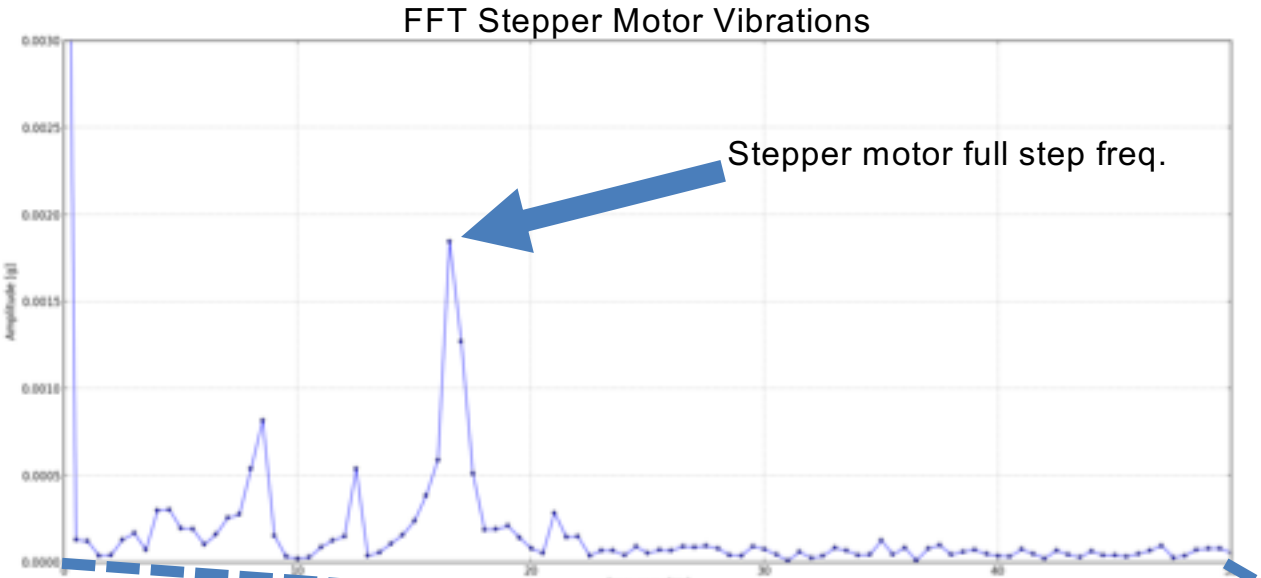


*5mm/s , 60mm/rev, 200 steps/rev=> 16.67Hz full step freq

Data Acquisition: Vibration Analysis

Vibration measurement:

- IEPE interface (or normal analog)
- Oversampling max 50kHz (other analog 100kHz)
- Data accessible through EPICS PV (waveform record)
- Condition monitoring (bearings…)



Analysis in Python (pyepics, scipy, numpy, and matplotlib)

Summary

- A motion control frame work for use within EPICS environment has been presented.
- The frame work utilizes the open source EtherCAT master from IgH Etherlab to configure and communicate with EtherCAT hardware.
- Basic motion functionalities as well as more advanced have been implemented.
- Framework can also be utilized for general control and data acquisition.
- Focus on accelerator applications.

Acknowledgments

- IgH open source EtherCAT master
- EPICS community (base, motor, asyn, stream device)
- Mathematical Expression Toolkit Library (ExprTk)
- ESS Motion Control & Automation Group:

  Paul Barron, Torsten Bögershausen, Thomas Gahl, Kristina Jurišić, Markus Larsson, Federico Rojas.

Questions?

References

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An Open Source Software Package for ESS EtherCAT Motion Control Applications

- Additional slides-

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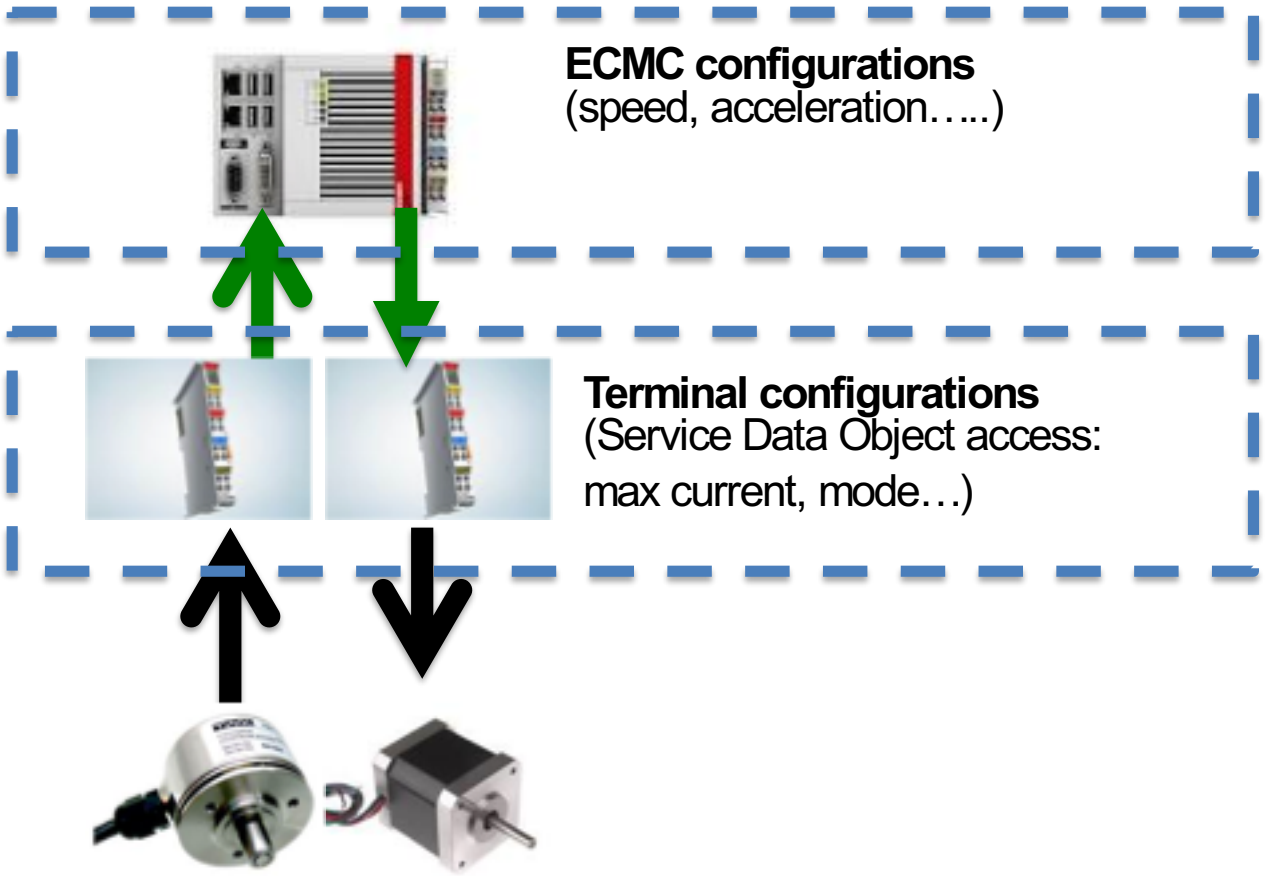
ECMC: Configuration

All configuration in EPICS startup file:



Control Loop Execution Options