Analog Devices: Trinamics – Ideal control for solenoids to motors.

BP&M / ADI – Juliano K. Cioffi (FAE)

WE Tour 2026

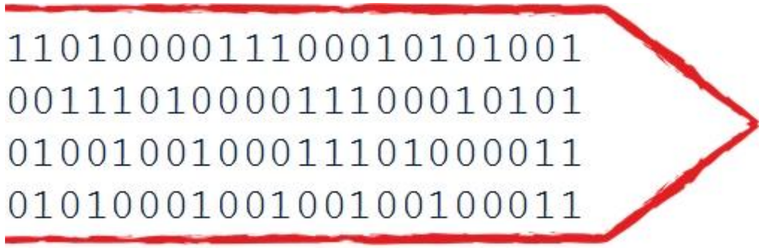
analog.com

Trinamics - Agenda

- Trinamics Overview
  - History and Concept
  - Wide view Portfolio
- Motor control solutions (HW)
  - Advantages and unique features
  - Ecosystem Picture
  - Highlighted Part Numbers
- Solenoid and contactors control solutions (HW)
  - Advantages and unique features
  - BDC control feature
  - Highlighted Part Numbers
- Software Platform
  - SW tool overview (MAX22216)
  - SW tool overview (BLDC)
  - Useful links

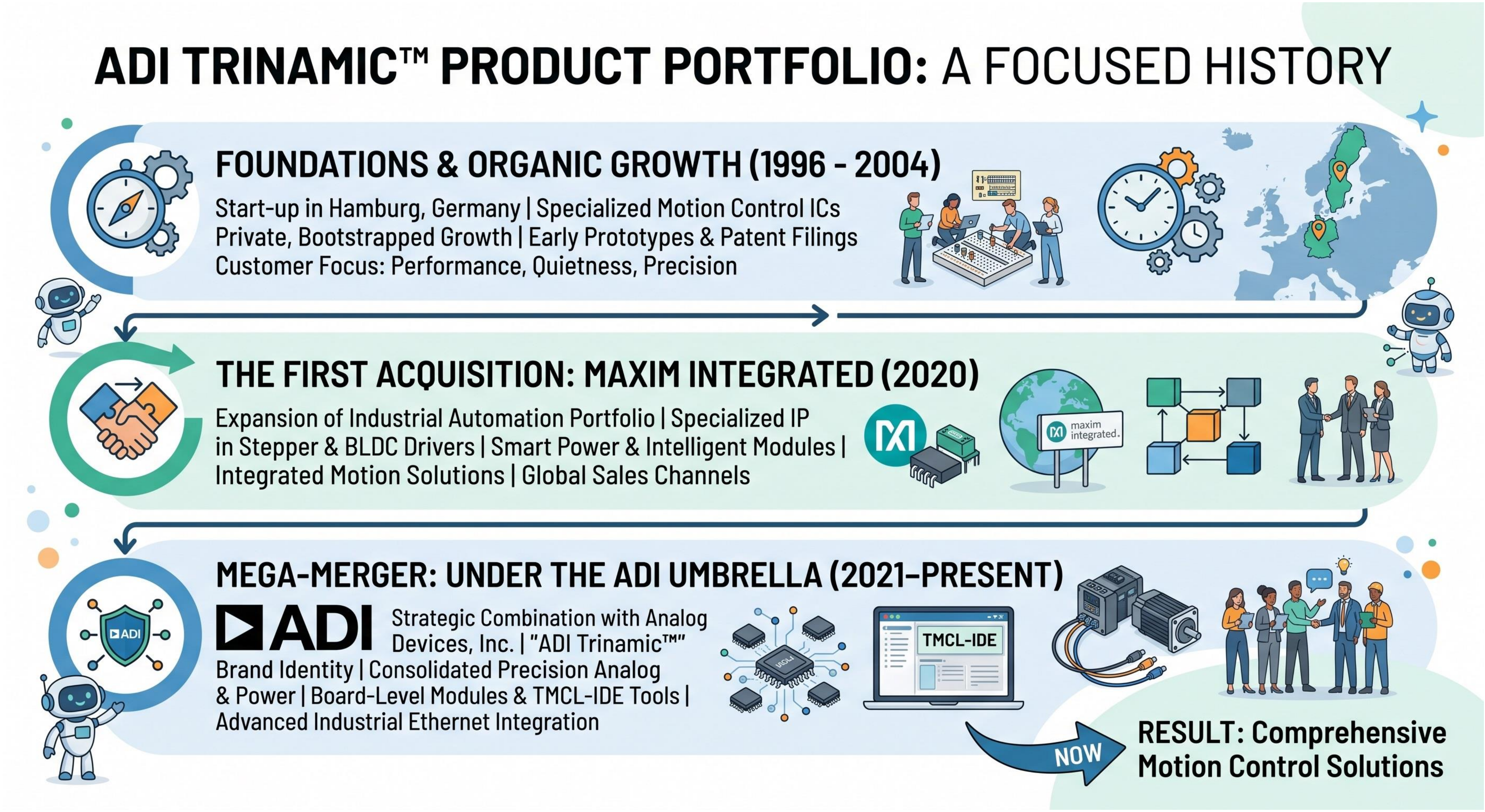
Trinamics Overview

Trinamics Overview – History and Concept



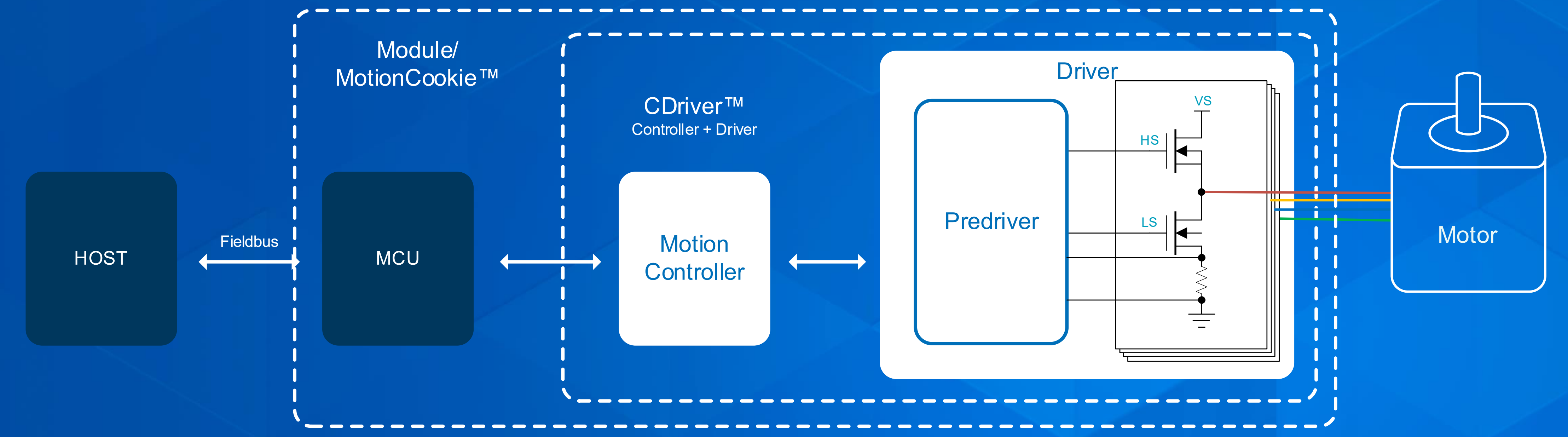
We Transform
Digital Information
Into **Physical Motion.**

Trinamics Overview – History and Concept

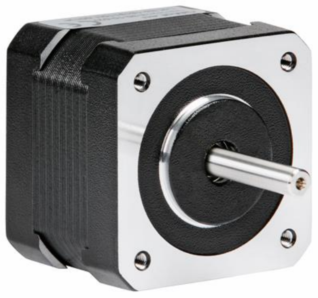


Trinamics Overview – History and Concept

- How does a typical System look like?

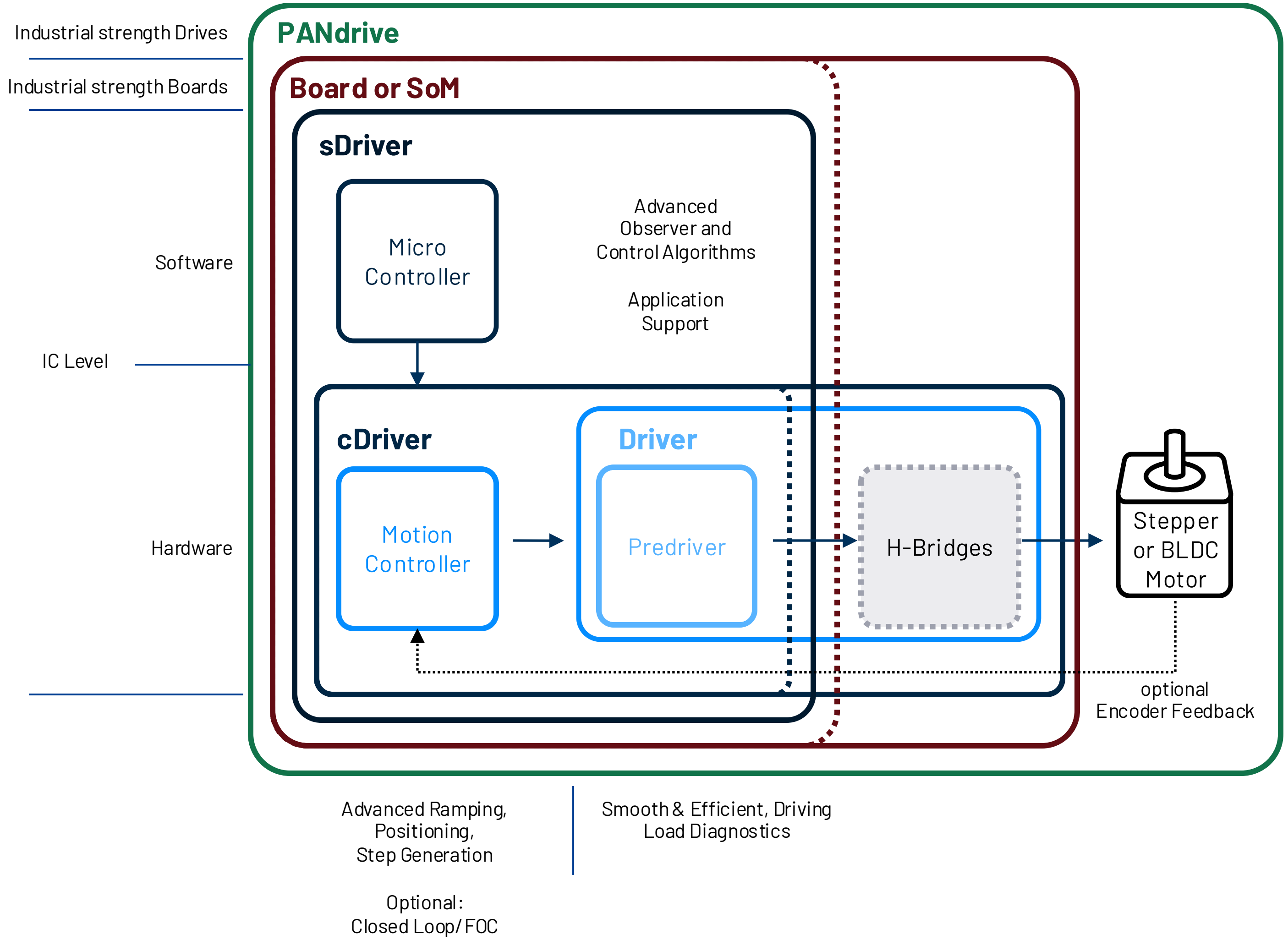


- Motor Types: Stepper, BLDC, Brushed DC
- Motor Sizes: mW … 1kW / 0.1A … 100A
- Voltage Range: 1.8…80V



Trinamics Overview – History and Concept

Solution	Description
PANdrive	Ready to go smart motor with ADI Trinamic motor driver & controller solutions, advanced software algorithms and industrial bus stacks, e.g. CANopen, CoE, TMCL for smallest time-to-market.
Board	Ready to go ADI Trinamic board-level single or multi-axes product with ready to go ADI Trinamic motor driver & controller solutions, advanced software algorithms and industrial bus stacks, e.g. CANopen, CoE, TMCL for smallest time-to-market.
SoM	System On a Module with ready to go ADI Trinamic motor driver & controller solutions, advanced software algorithms and industrial bus stacks, e.g. CANopen, CoE, TMCL for smallest time-to-market.
sDriver	Dedicated IC that integrates ADI Trinamic motor driver and controller hardware IP building blocks and a microcontroller for software algorithm and application support.
cDriver	Dedicated single IC that integrates ADI Trinamic motion control and driver hardware IP for smooth, reliable, efficient and fast positioning, ramping, as well as closed loop/FOC control.
Motion Controller	Dedicated single IC that integrates ADI Trinamic motion control IP to be used with ADI Trinamic or standard drivers, e.g. for positioning, ramp generation, FOC
Driver	Dedicated single IC that integrates ADI Trinamic driver IP and H-bridges for smoothest and most efficient motor control.
Pre-Driver	Dedicated single IC that integrates ADI Trinamic driver IP, with or without current controller and sequencer for smoothest and most efficient motor control to use with external MOSFETS.



Trinamics Overview – History and Concept

- Product Families - 3 Levels of Integration

Solution proposition, up the stack

PANdrive™

ASP

$125 to $600

1 – 1k+ pcs/Project

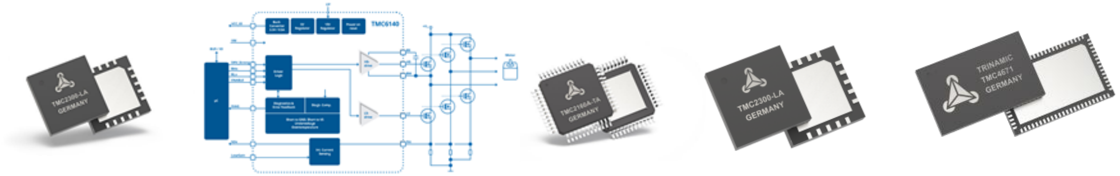
Boards

ASP

$50 to $400

1 – 5k+ pcs/Project

ICs



ASP

$1 to $10

10k – 1M+ pcs/Project

Trinamics Overview – History and Concept

- TMCL-IDE

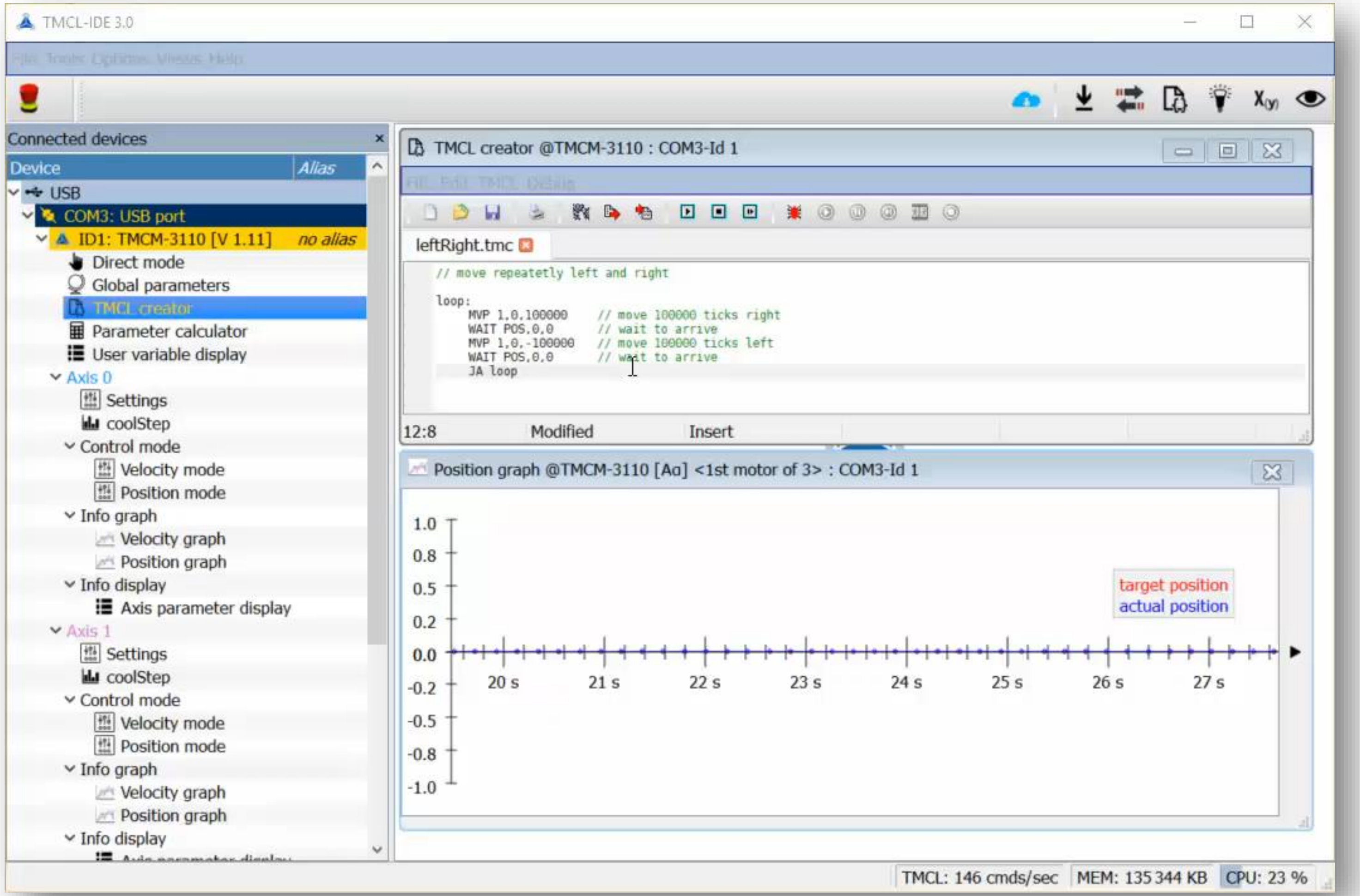
Connect & get Started

Parametrize & Program

Analyze & Debug

Intuitive

It's free to download & use!

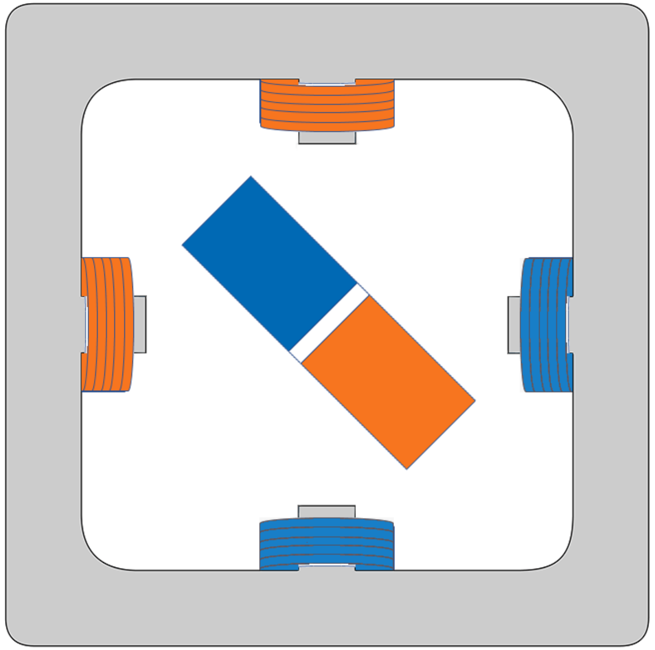


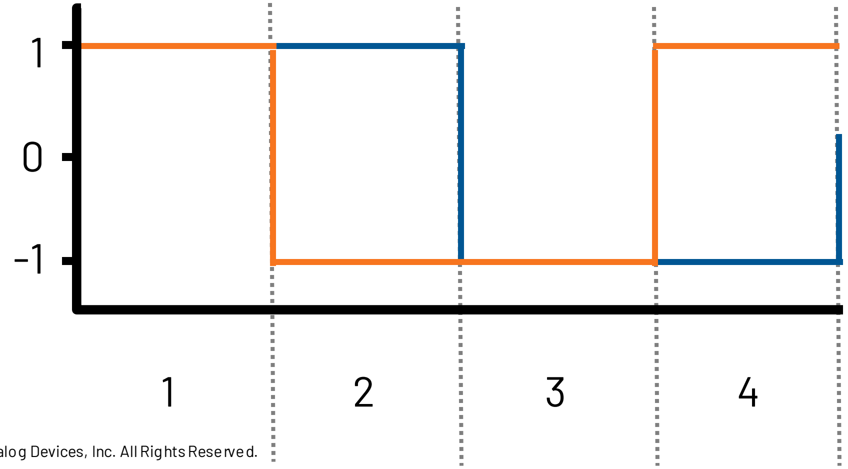
Motor Control solutions (HW)

Seamless Movement

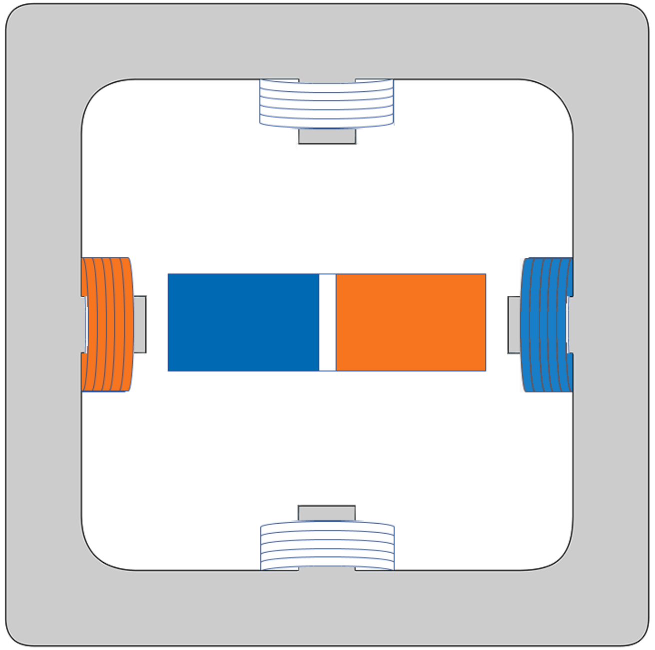
- Microstepping

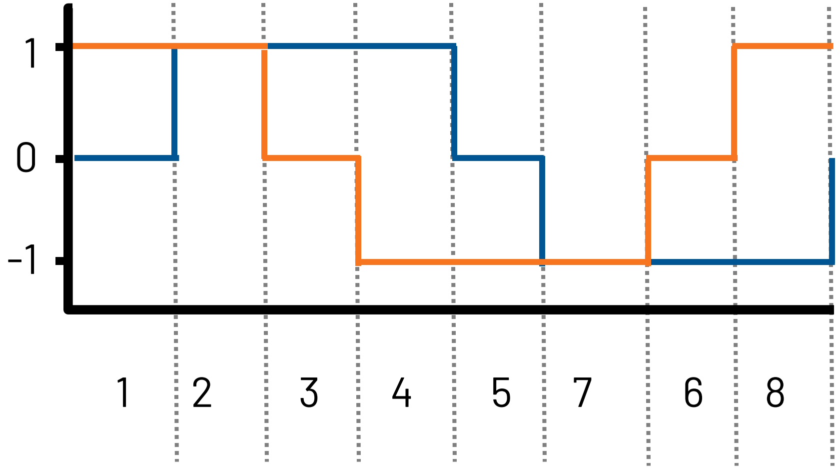
Fullstep





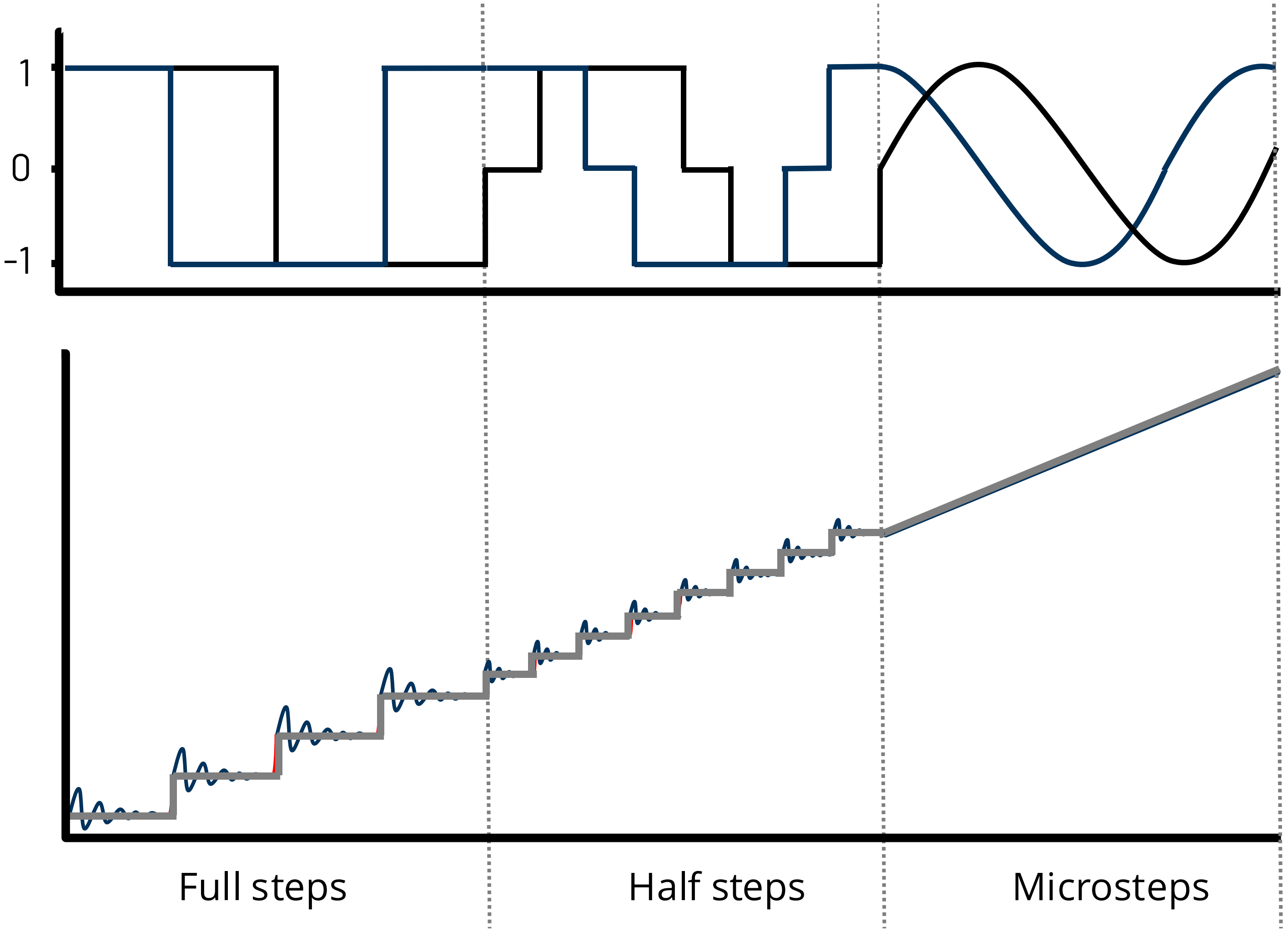
Halfstep





Seamless Movement

- Microstepping

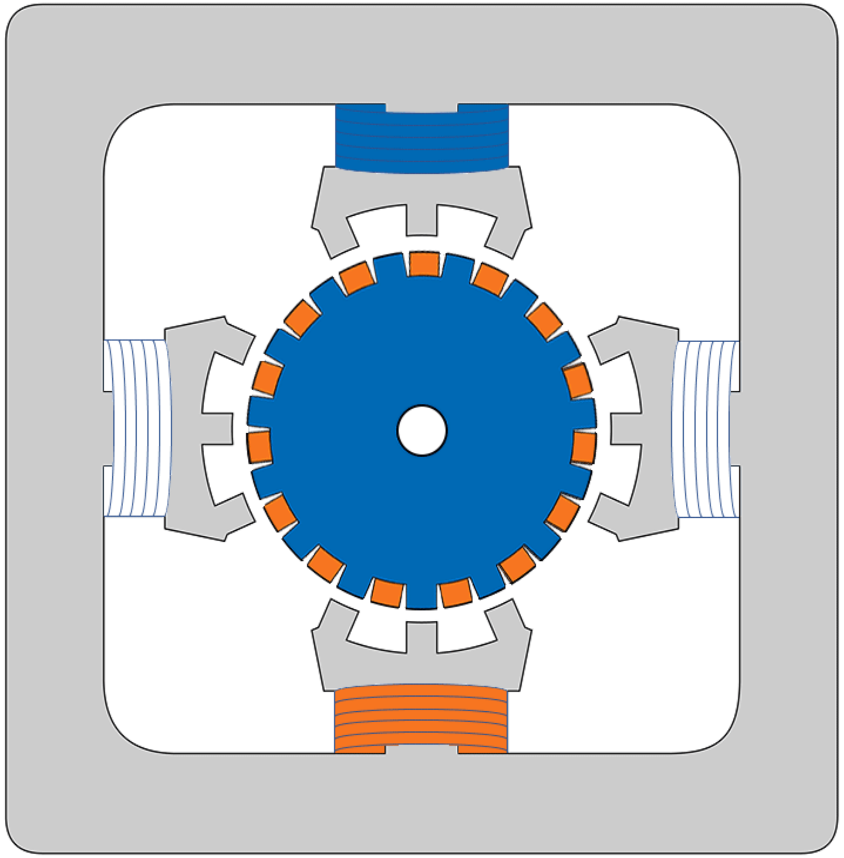


A Motion Controller generates pulses to move the motor forward.

256 times micro-stepping enables a sinusoidal current wave form.

Trinamic Motion Controllers can take care of the step pulse generation as well as advanced ramping of the step frequency.

MicroPlyer™



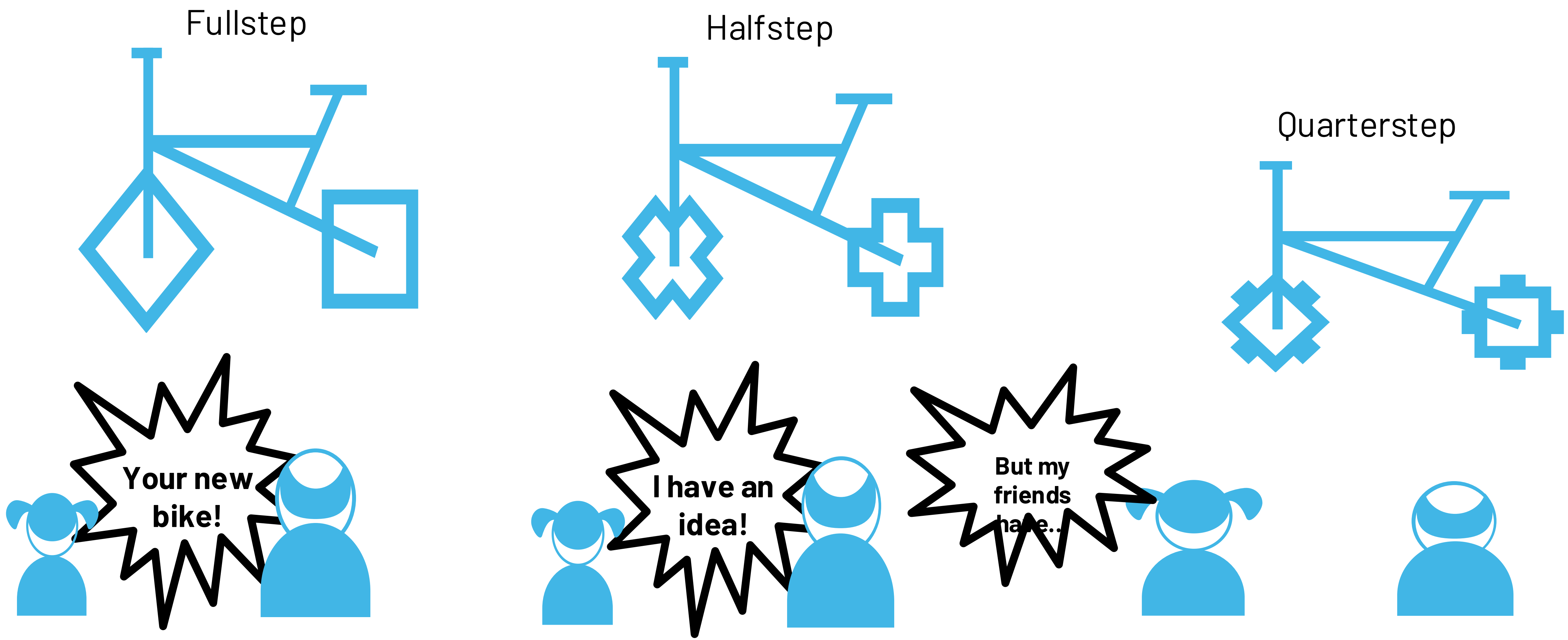
Hybrid Stepper Motor

MicroPlyer™ adds equidistant steps between micro steps to interpolate to 256 micro steps on the motor.

MicroPlyer™ reduces required processing power for smooth motion.

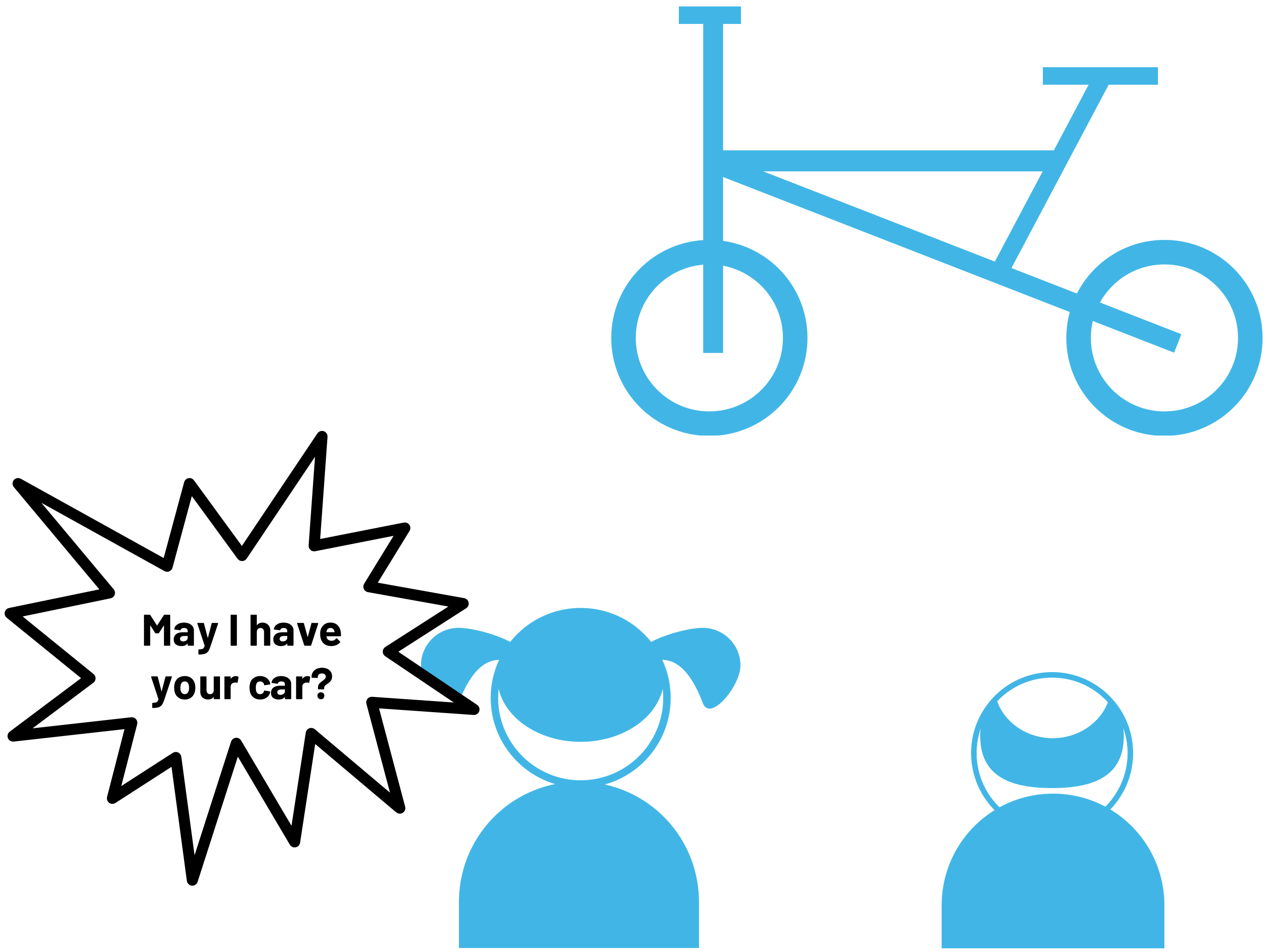
MicroPlyer™ works seamlessly. There are no software adaptions required

Microstepping



Microstepping

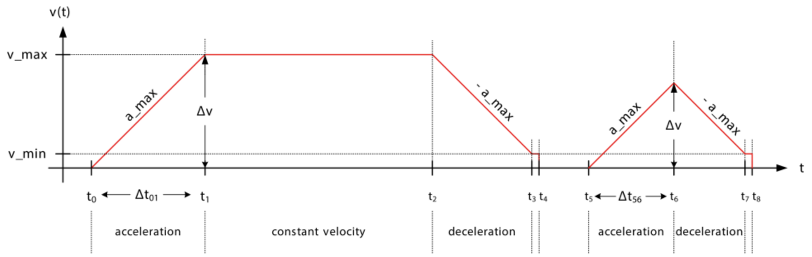
256 Microstep



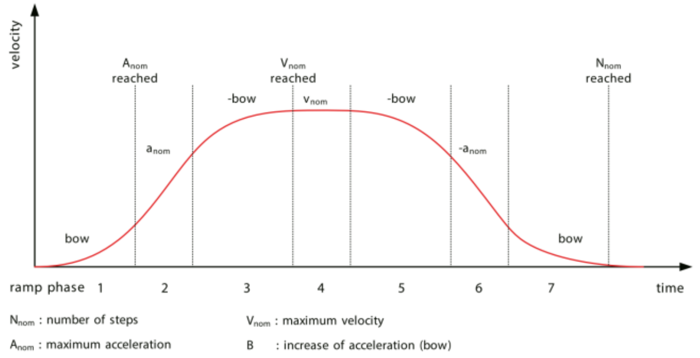
Micro-stepping adds equidistant steps between each native full step of a stepper motor.

This enables a way smoother motor run and higher torque output at low speed.

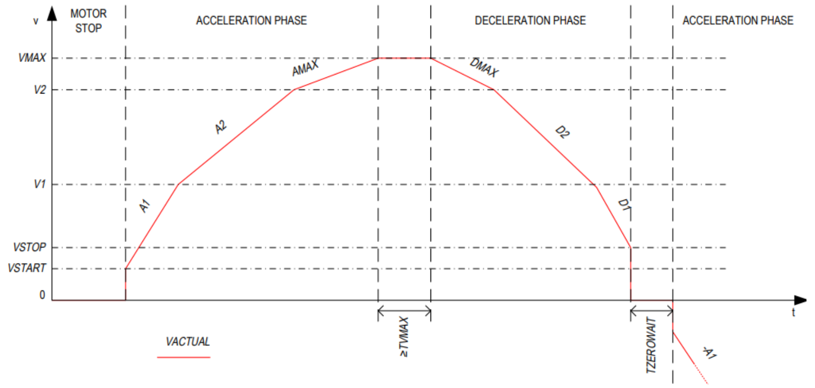
Advanced Ramping



- 1st generation Motion Controller – TMC429 / TMC4210



- 2nd generation motion controller – TMC457 / TMC4361



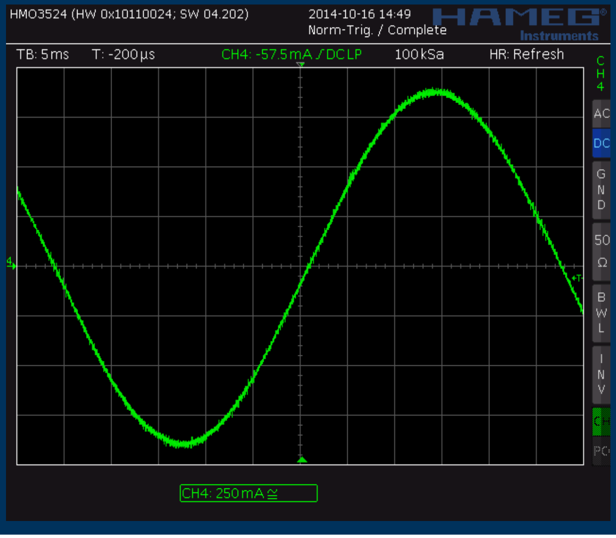
- 3rd gen. motion controller – multi point
- TMC5240, TMC5130 … all cDrivers

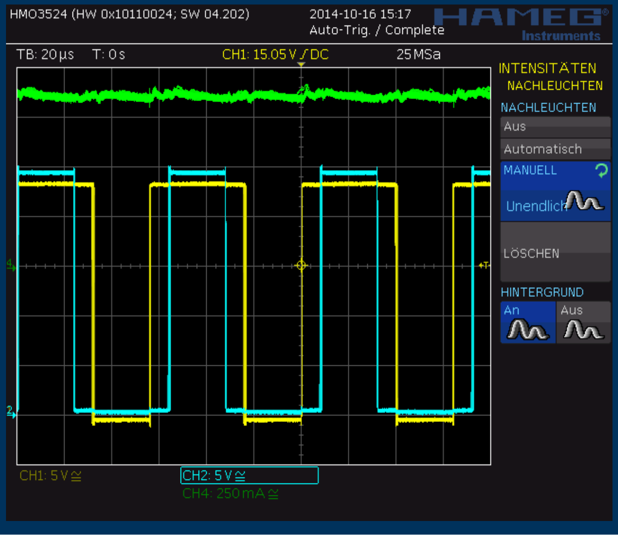
Advantages:

- Proven Hardware Blocks
- Offloading the Processor
- Parameter Change on the Fly
- Reference Switch input (Hard- /Soft-Stop)

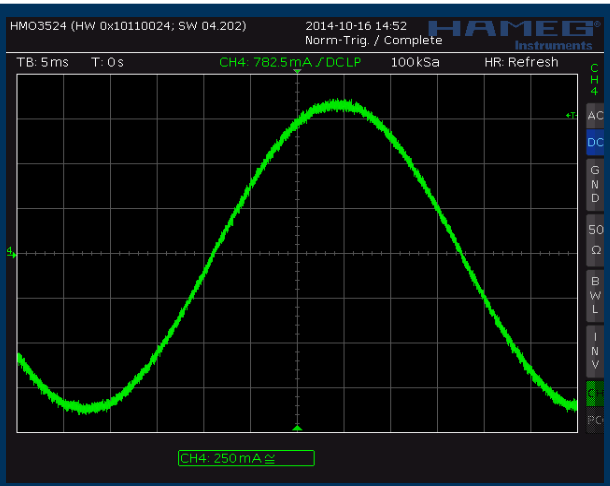
Current Control

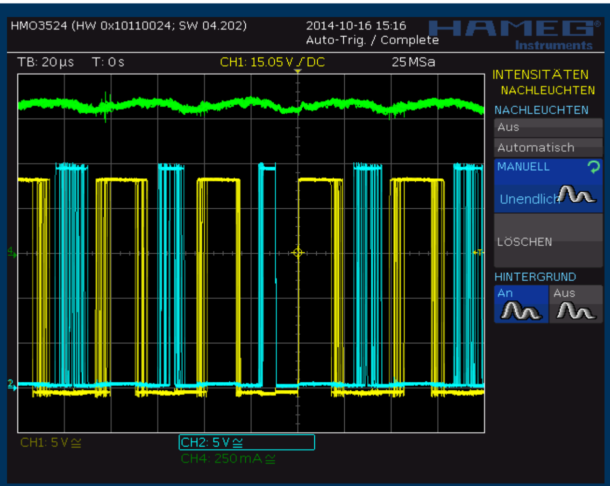
- Current Controller - SpreadCycle™ vs. StealthChop™
  - StealthChop™ = Silent, smooth motion at lower/medium speeds.
  - SpreadCycle™ = High torque, dynamic responsiveness, and fast acceleration at higher speeds.





StealthChop™





SpreadCycle™

Current Control

- Current Controller - SpreadCycle™ vs. StealthChop™
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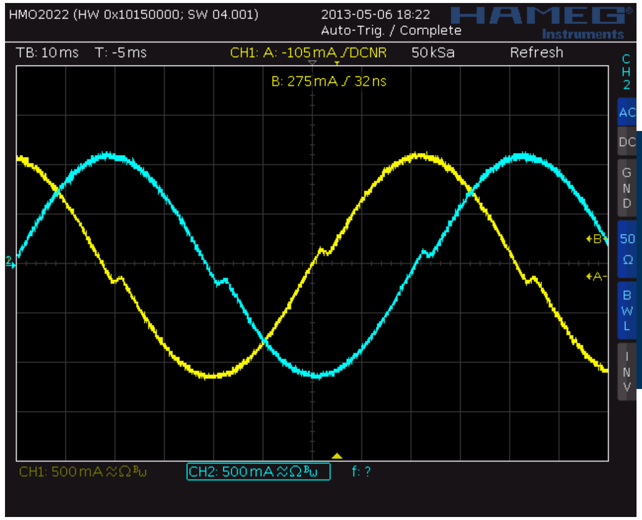
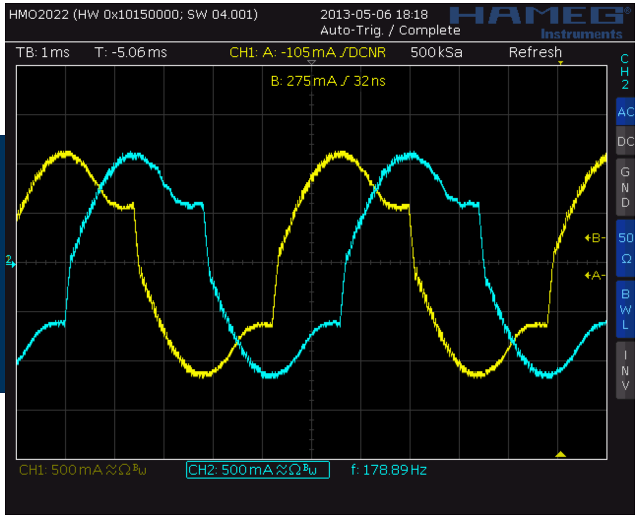
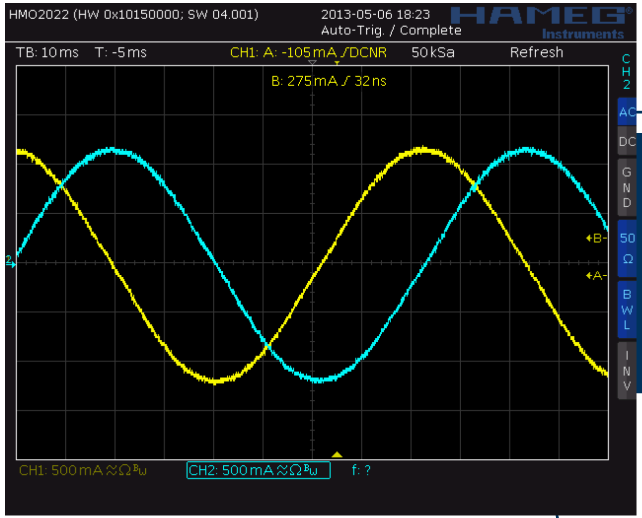


Conventional constant t_{off}

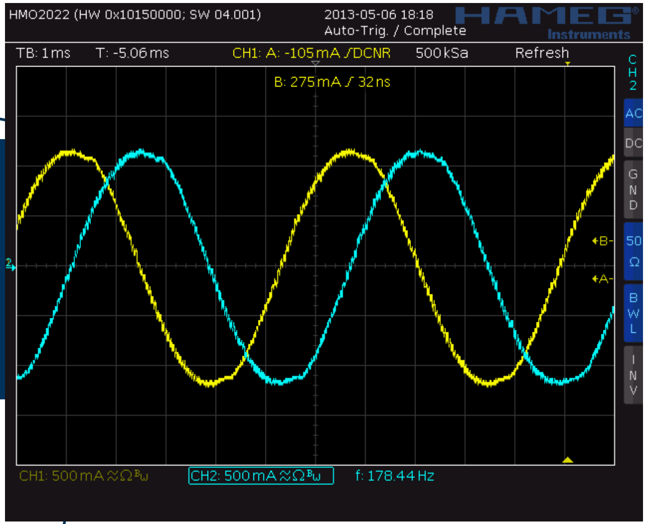


← Low Speed

High Speed →



TRINAMIC SpreadCycle™



Sinusoidal current waveform enables maximum torque and smooth motor run

Referencing

- Real World Position

ANALOG DEVICES

- After the system is powered off, there is no information of the motor position.
- The motor position might be manipulated.
- The absolute maximum travel distance might differ due to mechanical tolerances.

Trinamic offers StallGuard for sensor-free load detection.

Reference search algorithms aligns motor step positions to real world positions.

Using StallGuard...

...for sensorless homing

Instead of using limit switches, the mechanical hard stops can be used.

By adjusting the StallGuard values, it only kicks in when the normal load is exceeded.

If the load angle value is exceeded, the system knows it reached the end of the axis.

Bonus

Unexpected hard stops will make the system stop as well, adding a level of security.

Using CoolStep...

...for cooler motors

Originally designed for medical and lab automation, CoolStep keeps the motor cool using only the minimum current needed.

This safeguards sensitive tissue samples leading to more reliable test results.

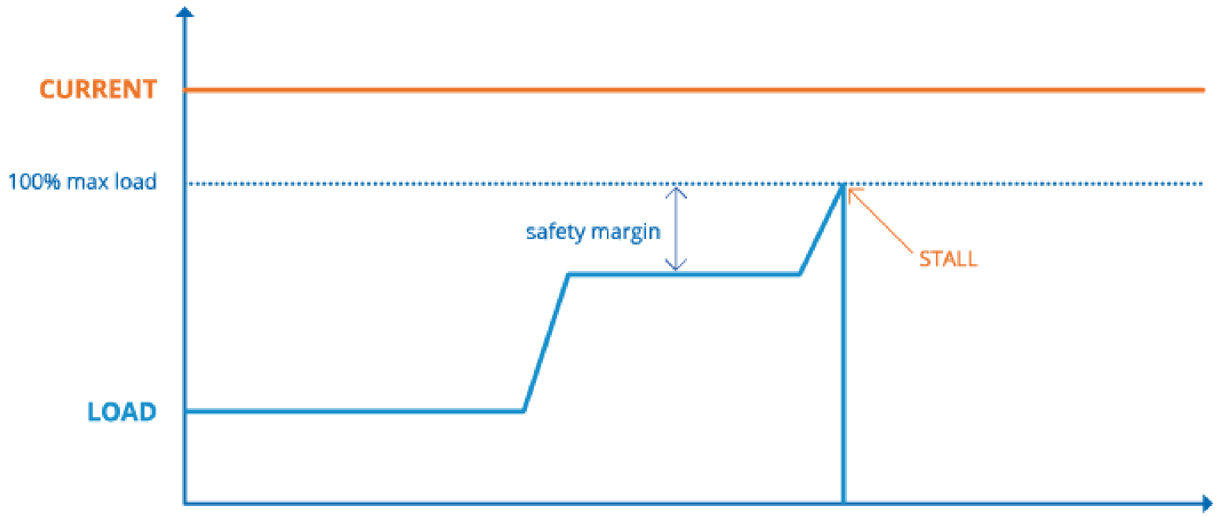
Running the motor at a lower temperature allows for temporary boosts.

Bonus

It also saves up to 75% energy.

Enables smaller motors.

StallGuard & CoolStep



StallGuard™

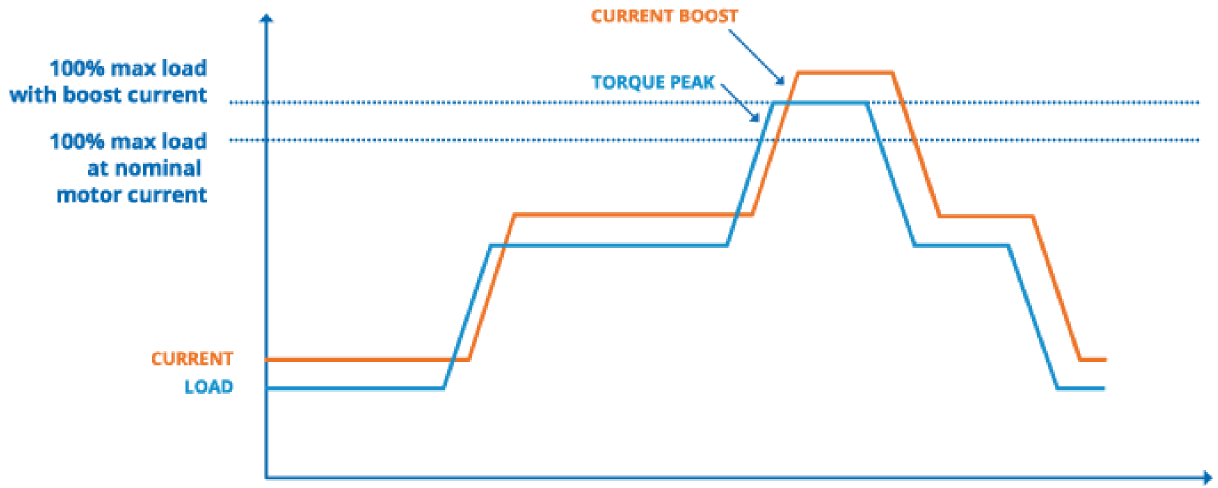
Sensorless Load Angle Detection

- Blocking Detection
- Referencing
- System Check

CoolStep™

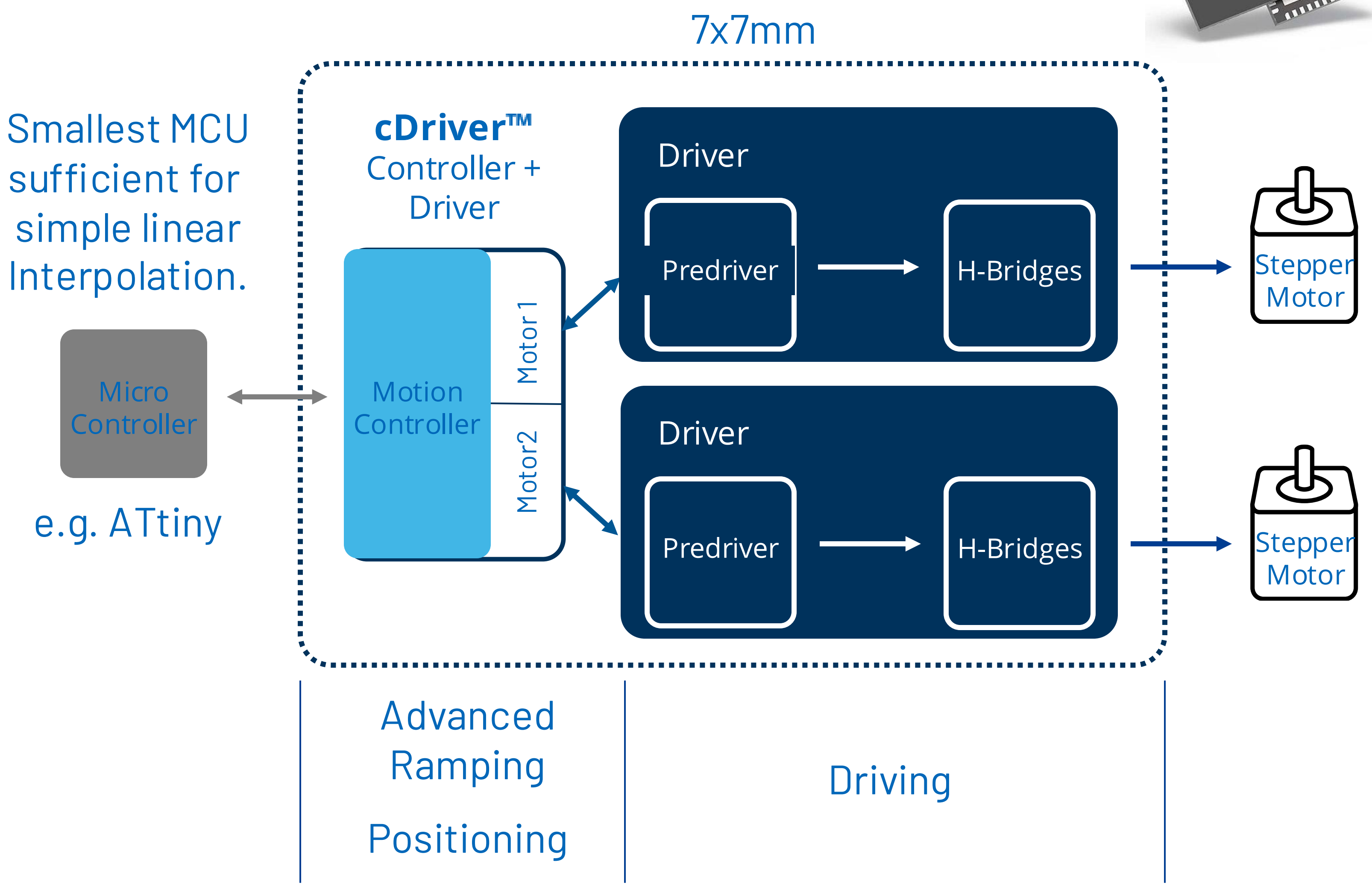
Load dependent Current Control

Saves up to 75% Energy



Development Time

- Solutions in Silicon



Why?

Reduce time to market trough integrated Motion Controller

Reduce size & part count

Meet expected quality on motor and motion control

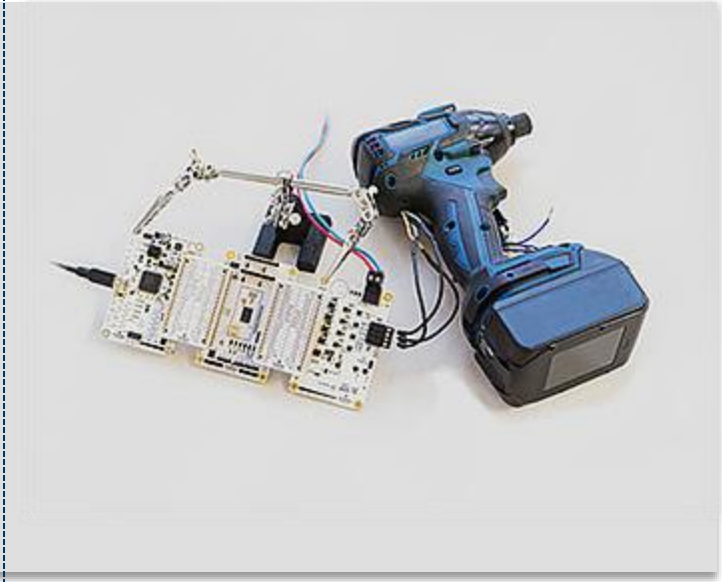
Development Time

Start with the Landungsbrücke

Depending on your Evaluation Kit, the Landungsbrücke or Startrampe interface board forms the bridge between your PC and Trinamic’s powerful ICs.

Connect the evaluation board

Connect the preferred eval board with the interface board using the Eselsbrücke connector board. You can even link a few together.



Discover powerful technologies

Explore the full potential of Trinamic's solutions using the free TMCL-IDE software. This allows for easy programming with ready-to-use code libraries.

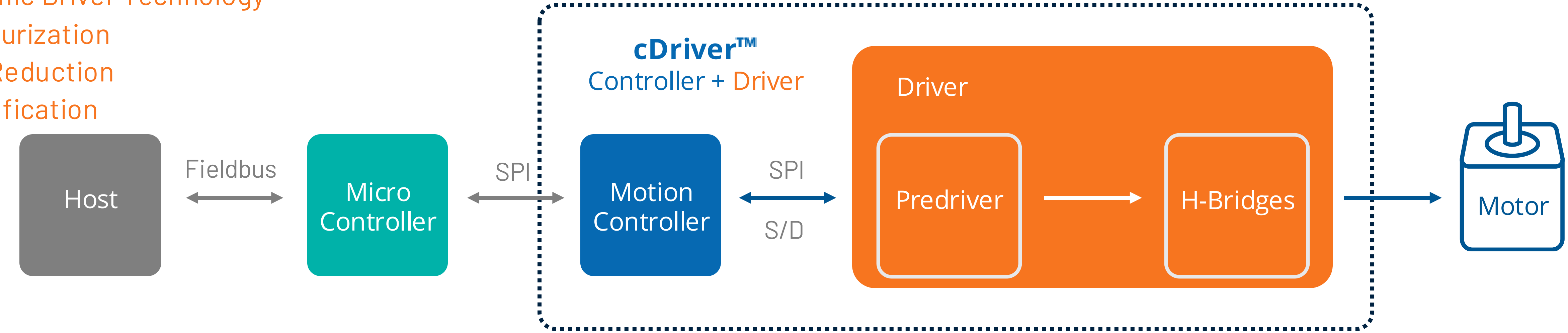
Driver Eco System

- **Pumps**
- **Medical equipment**
- **POS Printer**
- **White goods**
- **3D Printer**

Product	Motor Type	Interface	Product Type	Motor Supply	Phase Current (RMS)	Package
TMC2240	2-Phase Stepper Motor	S/D, SPI	Smart Driver	4,75 – 36 V	2.1A (int I sense)	TQFN32
TMC2130	2-Phase Stepper Motor	S/D, SPI	Smart Driver	4.75 – 46 V	1.4A	eTQFP48
TMC2209	2-Phase Stepper Motor	S/D, SPI / Pin	Smart Driver	4.75 – 29 V	2A	QFN28
TMC2300	2-Phase Stepper Motor	S/D, SPI / Pin	Smart Driver	1.8 – 11 V	1.2A	QFN20
TMC2160	2-Phase Stepper Motor	S/D, SPI / Pin	Smart Gate Driver	8 – 60 V	Ext. MOSFETs	eTQFP48

TMC2209: Stepper Driver IC

- Trinamic Driver Technology
- Miniaturization
- BOM Reduction
- Simplification



Predriver Eco System

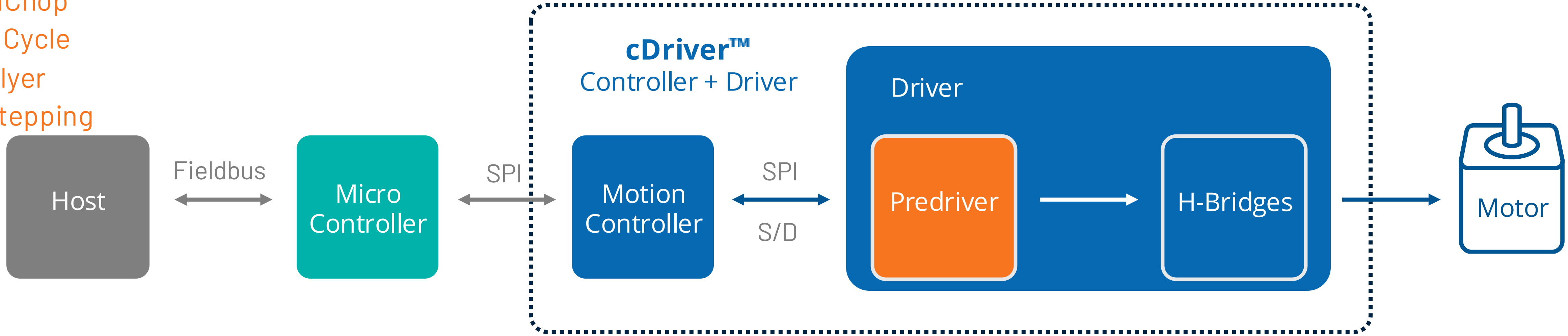
- Pumps
- Medical equipment
- POS Printer
- White goods
- 3D Printer

- **Packing machines**
- **Small industrial robots**
- **Semiconductor equipment**
- **Analyzers (Gas / Liquid)**

- Medical equipment
- CCTV/ conference cameras
- Textile machinery
- Dental milling

TMC2160: Predriver IC

- StallGuard
- CoolStep
- StealthChop
- SpreadCycle
- MicroPlyer
- Microstepping



cPredriver Eco System

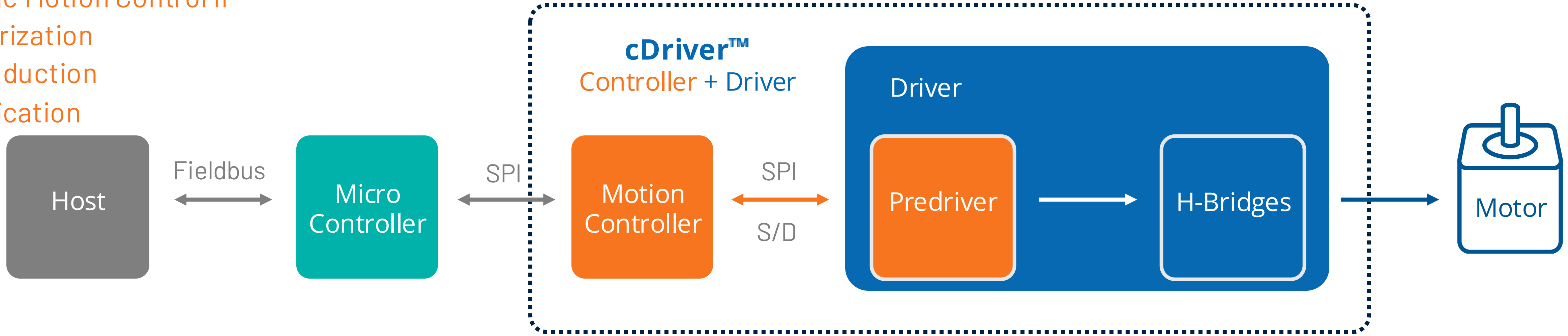
- Pumps
- Medical equipment
- POS Printer
- White goods
- 3D Printer

- **Packing machines**
- **Small industrial robots**
- **Semiconductor equipment**
- **Analyzers (Gas / Liquid)**

- Medical equipment
- CCTV/ conference cameras
- Textile machinery
- Dental milling

TMC5160: cPredriver IC

- Trinamic Driver Technology
- Trinamic Motion Control IP
- Miniaturization
- BOM Reduction
- Simplification



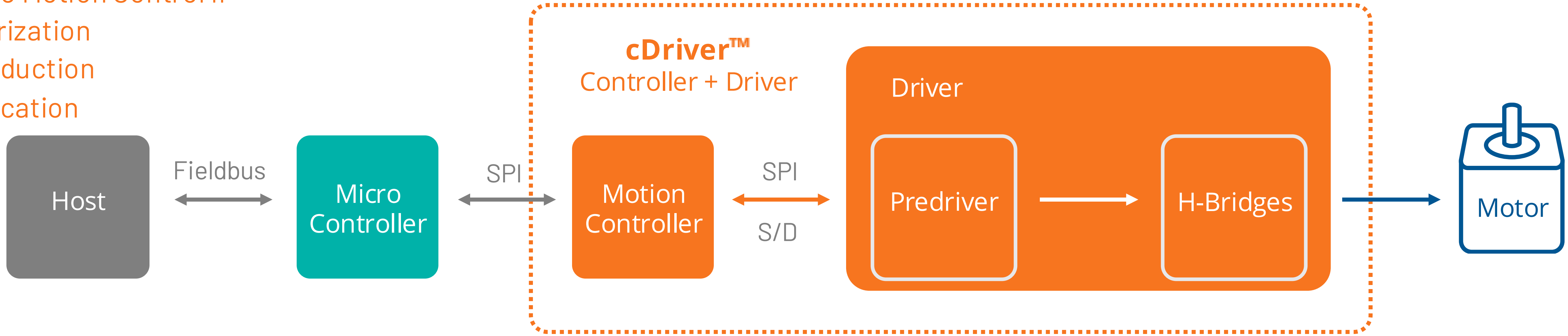
cDriver Eco System

Product	Motor Type / Feature	Product Type	Motor Supply	Phase Current (RMS)	Package
TMC5240	2-Phase Stepper Motor	cDriver™	4,75 – 36 V	2.1 A	TQFN32
TMC5130A	2-Phase Stepper Motor	cDriver™	4.75 – 46 V	1.4 A	eTQFP48
TMC5160	2-Phase Stepper Motor	cDriver™	8 – 60 V	Ext. MOSFETs	eTQFP48 / QFN56
TMC4361	S-Shaped Ramping / Closed loop	Motion Controller	digital	-	QFN40

- **Medical equipment**
- **CCTV/ conference camer**
- **Textile machinery**
- **Dental milling**

TMC5130: cDriver IC

- Trinamic Driver Technology
- Trinamic Motion Control IP
- Miniaturization
- BOM Reduction
- Simplification

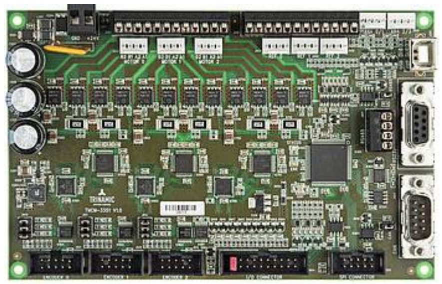


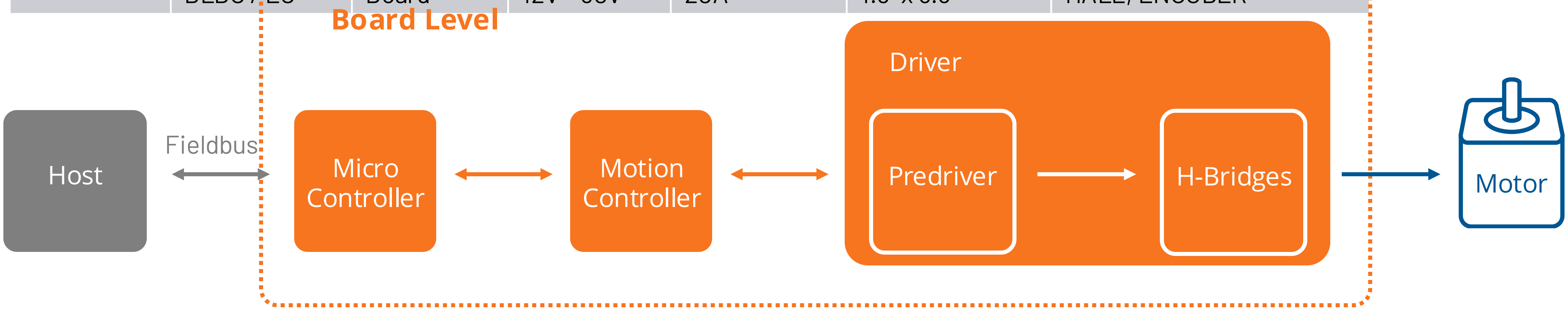
Board Level Turnkey Solutions

Product	Motor Type	Product Type	Motor Supply	Phase Current (RMS)	Size	Interface
TMCM-1260	2-Phase Stepper Motor	Single Axis Open Loop	12 – 48V	6A	60mm x 60mm 2.36” x 2.36”	CAN, RS485, USB, GPIO, Encoder
TMCM-3351	2-Phase Stepper Motor	3 Axis S-Ramps Closed loop	12V – 24V max 28V	3A	160mm x 100mm 6.2” x 3.9”	CAN, RS485, RS232, USB, GPIO, Encoder
TMCM-1640	3-Phase BLDC / EC	Single Axis Board	12V – 24V	5A	42mm x 42mm 1.7” x 1.7”	RS485, USB, HALL, Encoder
TMCM-1636	3-Phase BLDC / EC	Single Axis Board	12V - 24V 12V – 60V	30A 20A	45mm x 90mm 1.8” x 3.5”	CAN, HALL, ENCODER

Why Boardlevel?

- Short Time to Market
- Hardware Design Resouces / Expertise
  - Same for Firmware
- Small / Medium Demand



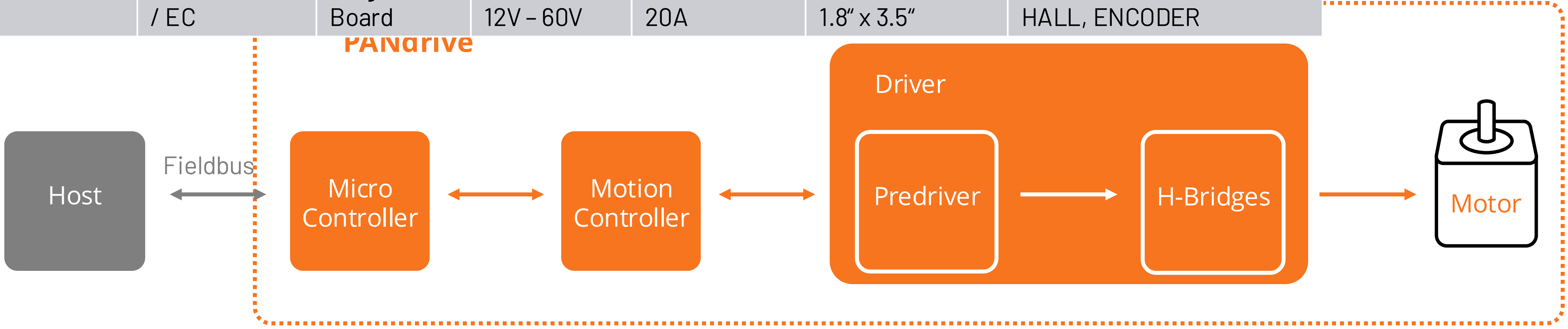


Smart Motor Turnkey Solutions

Product	Motor Type	Product Type	Motor Supply	Phase Current (RMS)	Size	Interface
TMCM-1260	2-Phase Stepper Motor	Single Axis Open Loop	12 – 48V	6A	60mm x 60mm 2.36“ x 2.36“	CAN, RS485, USB, GPIO, Encoder
TMCM-3351	2-Phase Stepper Motor	3 Axis S-Ramps Closed loop	12V – 24V max 28V	3A	160mm x 100mm 6.2“ x 3.9“	CAN, RS485, RS232, USB, GPIO, Encoder
TMCM-1640	3-Phase BLDC / EC	Single Axis Board	12V – 24V	5A	42mm x 42mm 1.7“ x 1.7“	RS485, USB, HALL, Encoder
TMCM-1636	3-Phase BLDC / EC	Single Axis Board	12V - 24V 12V – 60V	30A 20A	45mm x 90mm 1.8“ x 3.5“	CAN, HALL, ENCODER

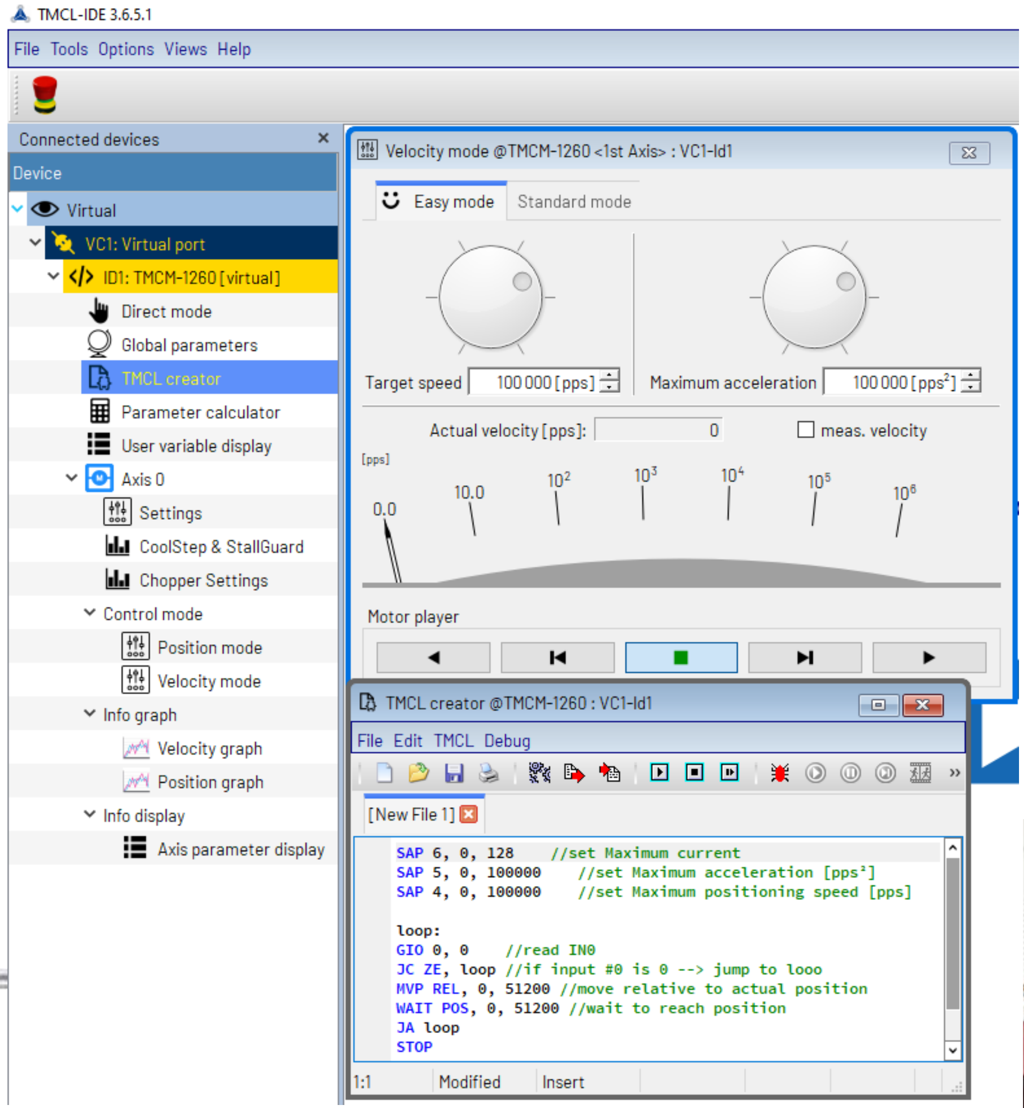
Why PANdrives? (and what is the PAN?

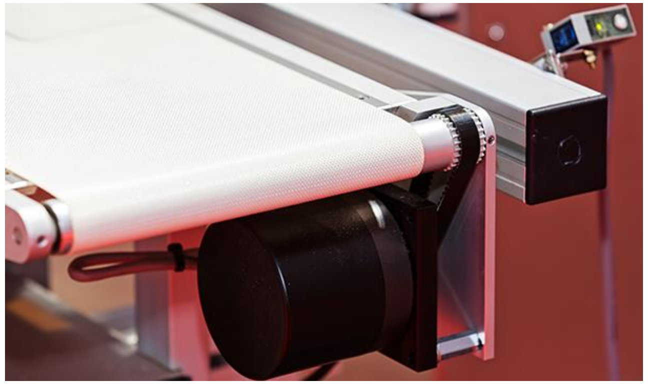
- One-Stop Solution
- Matching Motor + Electronics
- Short Time to Market
- Wide Range of Solutions



Smart Motor Turnkey Solutions

- ▶ Fully Integrated Mechatronic
- ▶ SensOstep Encoder
- ▶ Serial interface
- ▶ I/Os
- ▶ Easy to built in
- ▶ NEMA 8 – NEMA 34
- ▶ Stand Alone Mode
- ▶ TMCL Firmware





TMC5271: 20V / 1.6A RMS Stepper Motor Driver and Motion Controller

Features and Specs

Supply voltage: 2.1 to 20V

Motor current: 1.6A RMS

Fully Integrated Lossless Current Sensing

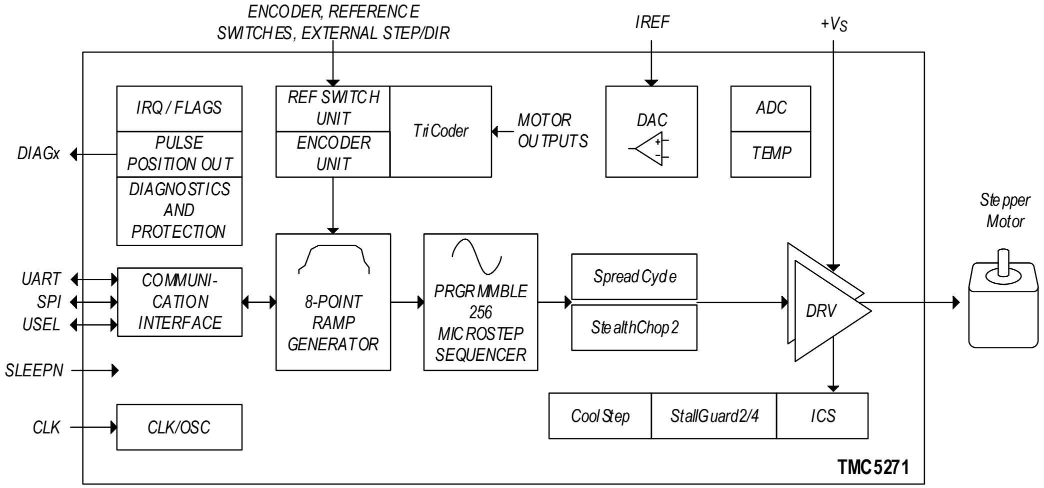
TriCoder Sensorless Standstill Steploss Detection and Full Step Encoder

EightPoint Motion Controller

256 microsteps per fullstep

Smooth and silent stepper motor motion with StealthChop™ and SpreadCycle™

Sensor less load & stall detection with StallGuard2/4™



Competitive Positioning

More efficiency than the competition

- 155 mΩ vs 400 mΩ RDSON

Advanced control optimizes power delivery to the motor

Up to 50% PCB space over integrated competition

- $9mm^2$ vs ($9mm^2$ + external sense resistors)

Integrated best in class diagnostic functions

TMC5271: 20V / 1.6A RMS
Stepper Motor Driver and Motion Controller

ANALOG DEVICES

Product Features	Customer Benefit	TMC5271	Comp1	Comp2
Integrated Motion Controller in HW	Offload calculation power from Micro Controller, reduce time to market, easier qualification of end product	Yes	No	No
Integrated Current Sensing	Saves power dissipation and board space	Yes	No	No
RDSON	Saves power dissipation and enables higher continuous motor current.	155mΩ	310mΩ	1000mΩ
TriCoder Standstill Movement Detect	Detect Movement in Standstill without Encoder or Sensory	Yes	No	No
Motor Temperature Estimation	Get an estimation of the motor temperature in standstill	Yes	No	No
StallGuard2&4™	Omits reference switches and allows for continuous monitoring of the load situation.	Yes	No	No
CoolStep™	Helps to save up to 75% power losses in the motor.	Yes	No	No
SpreadCycle™	Enables fastest silent movement	Yes	No	No
StealthChop™	Enables non audible movement at slow speed.	Yes, StealthChop4	**Yes,** but fixed duty cycle only	No
Package	Saves Board Space	3.2 x 3mm² WLCSP36	3x3mm² VFQFPN*	3x3mm² WQFN*

Wrap Up / Problems we are solving

ANALOG DEVICES

Pulsation in movement / vibrations High-resolution microstepping	SpreadCycle™
Dynamic load changes / overload and pot. position loss Sensorless load monitoring	StallGuard2/4™
Energy consumption / heat and power dissipation Current control based on sensorless StallGuard™ values	CoolStep™
Audible noise / mechanical resonances **Advanced current control**	StealthChop™
Jerky motion / position overshoot Advanced multi-segment / jerk-limiting acceleration ramps	EightPoint™

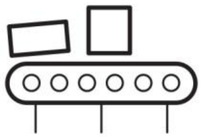
Solenoid and contactors control solutions (HW)

Markets and Applications

Industrial Automation

Hydraulics, Power and Control systems

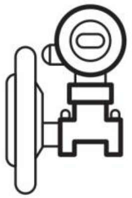
Valve Manifolds
DC Motor Drive
Proportional Valves
Electromechanical Brakes
Relays / Contactors
Heat Pumps



Broad Market

Consumer Products

Vending Macines
Coffee Machines
Electronic Faucet
Smart Door Locks



Healthcare

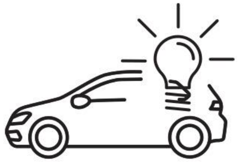
Medical Equipment

Dialysis Machines
Oxygen Concentrators
Ventilators

Automotive (MAX22216V)

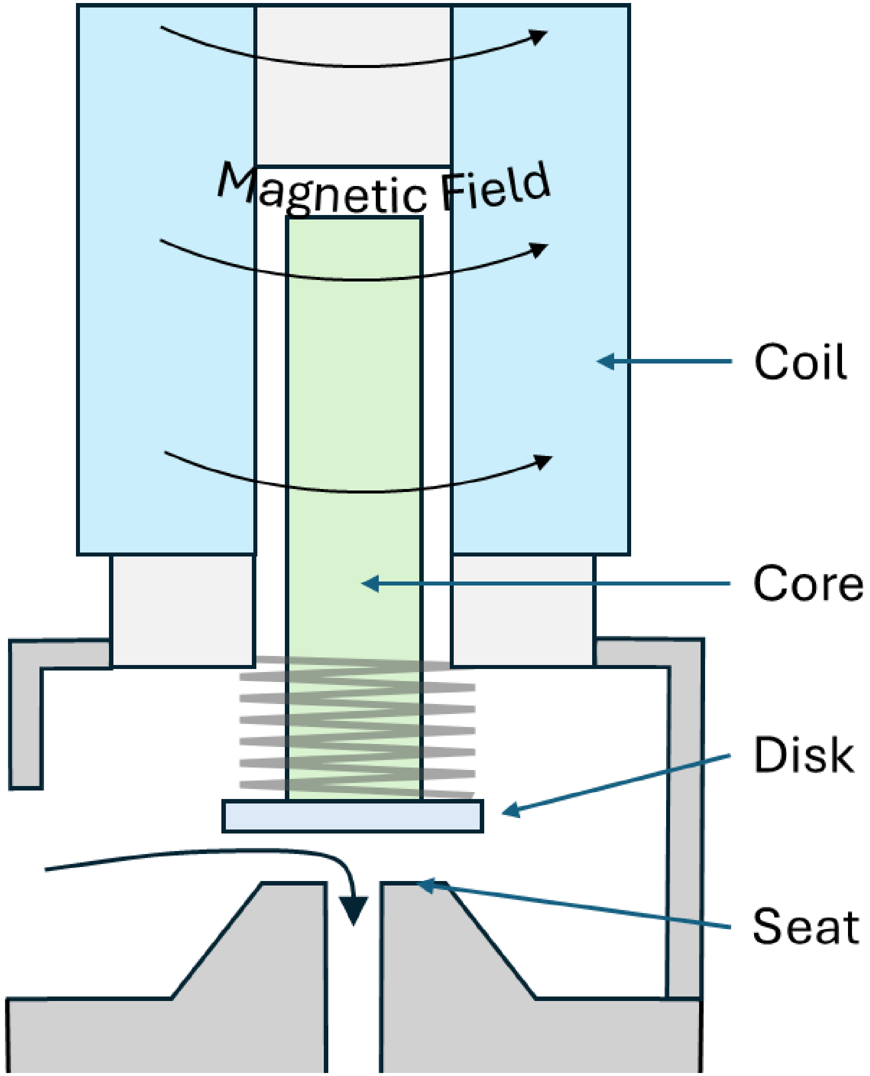
Subsystems

Suspension Systems Valves
Heating Systems
Battery charging
Fuel Pumps



Basic Introduction to Solenoid Actuators

- Solenoids consist of an insulated copper wire wound around a ferromagnetic core
- By applying a voltage, a current flows through the coil, generating a magnetic field:
  - A solenoid actuator's plunger then moves to the other state (OFF/ON)
  - A spring pushes the plunger back to its original position when the voltage is removed
- A lower current is typically sufficient to hold the plunger in the ON position
- The state of the solenoid is unknown without feedback

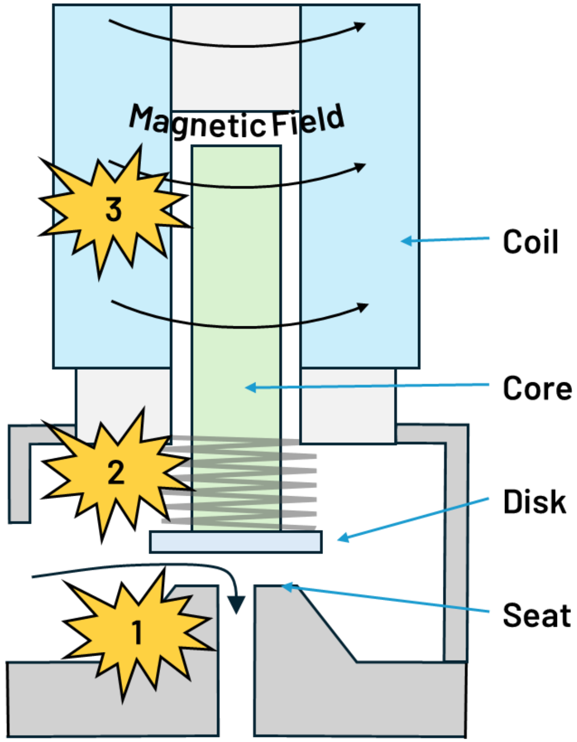


How Valves Fail

GRADUALLY, AND THEN SUDDENLY

Faults build slowly at first, without detectable signatures. Then the valve crosses the tipping point!

1. Seal abrasion
2. Fouling
3. Coil burnout



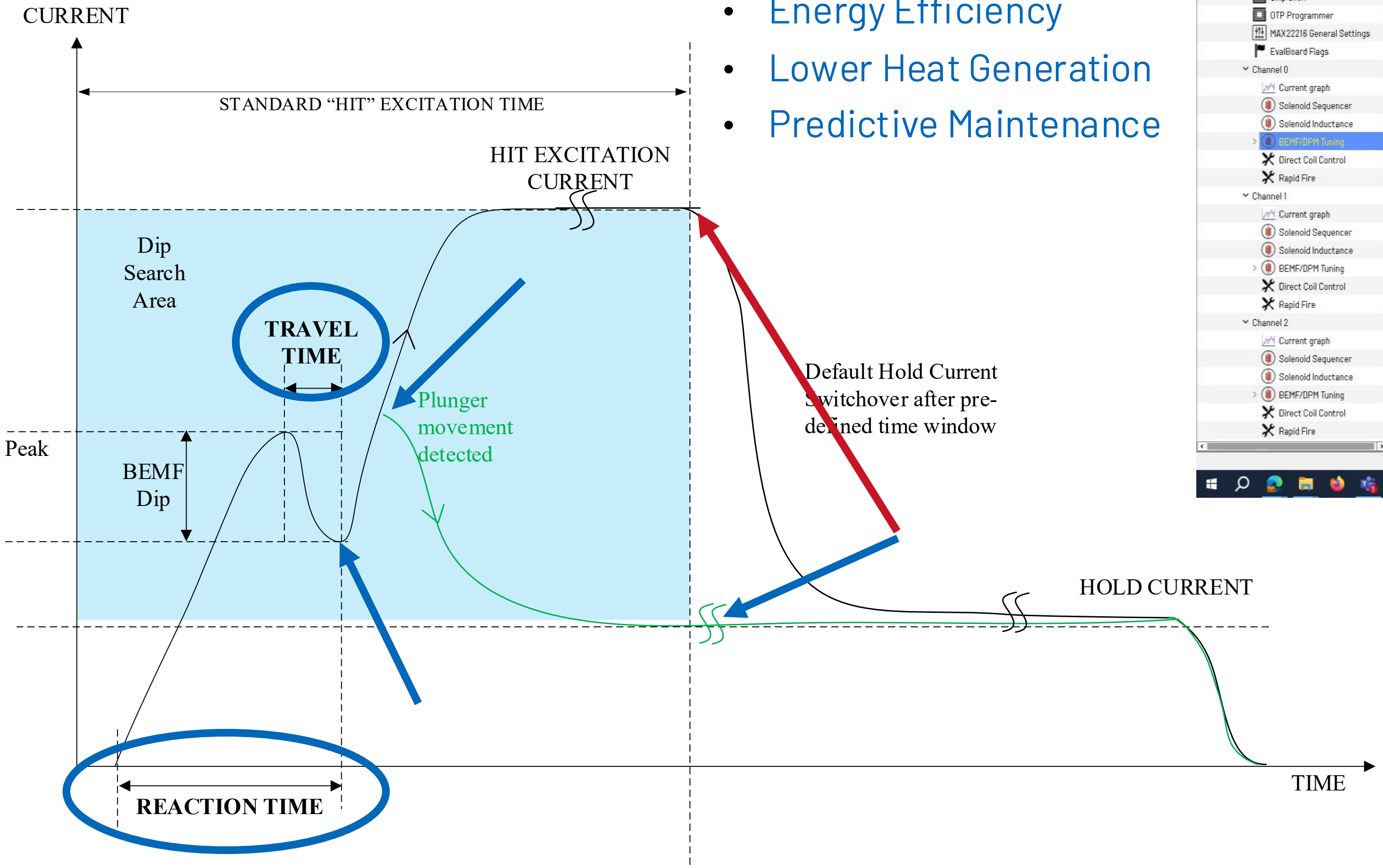
How to Detect Valve Failure

EXTERNAL MONITORING HAS A COST

Periodic manual inspections can be effective but maintaining the paper trail while ensuring quality adds complexity. As the number of valve points increases, so does the challenge.

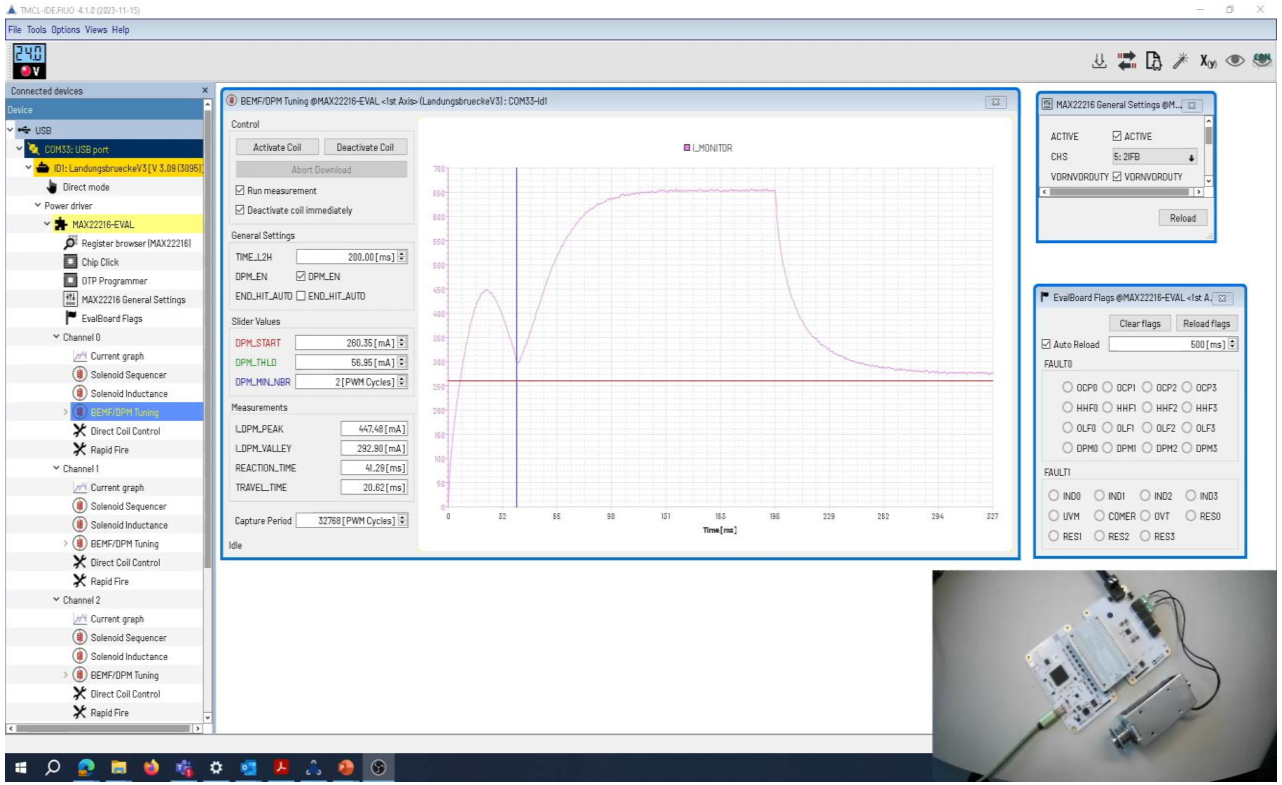
Designers can add various sensors (pressure/temperature/ flow meters) but they must balance the benefit of extra data with the cost of installation.

Analog Device's Solution Overview



Enables...

- Detection of Plunger Movements
- Energy Efficiency
- Lower Heat Generation
- Predictive Maintenance



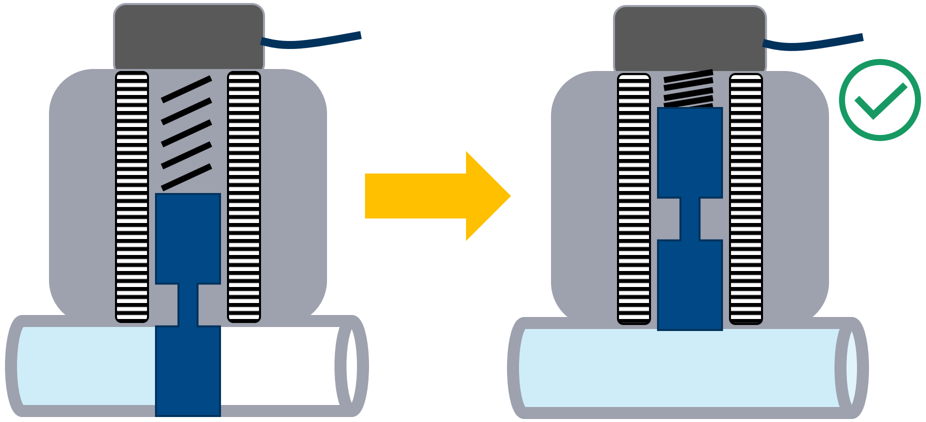
ADI SOLUTION

- No external encoders
- Reduce current to **minimum needed**
- Alert on slowing or stuck core
- Reduce coil temperature by **50°C**

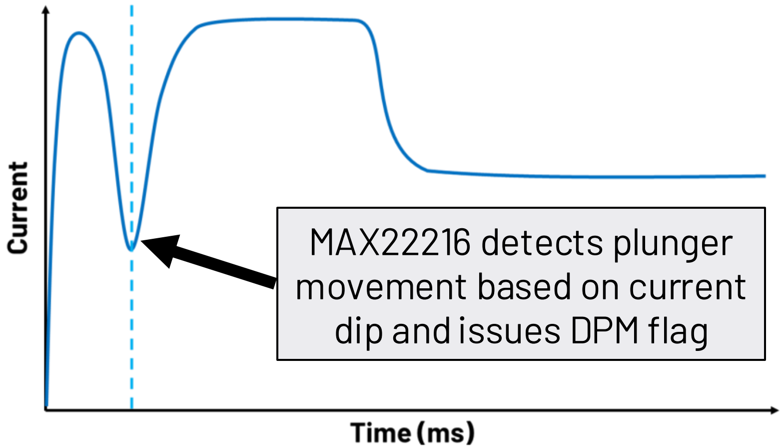
Detection of Plunger Movement in Solenoid Valves

OFF POSITION | ON POSITION | CURRENT SIGNATURE

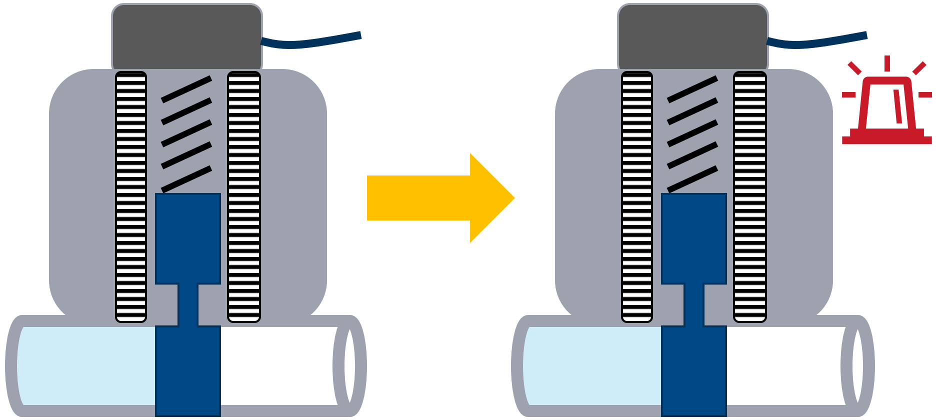
Properly Working Solenoid Valve



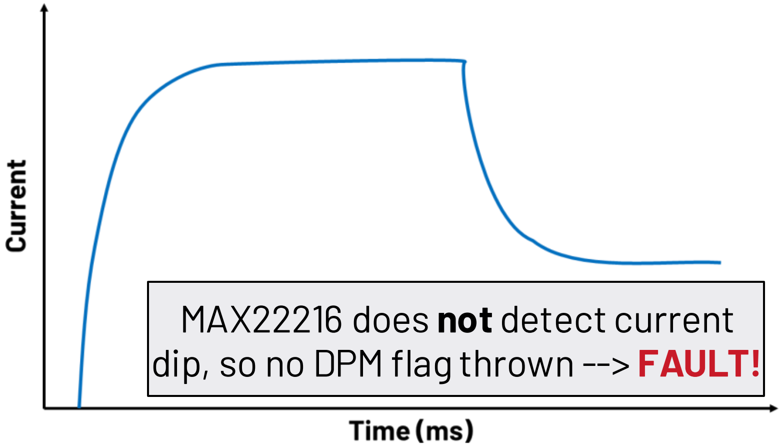
Solenoid actuates correctly and liquid can pass through.



Faulty Solenoid Valve

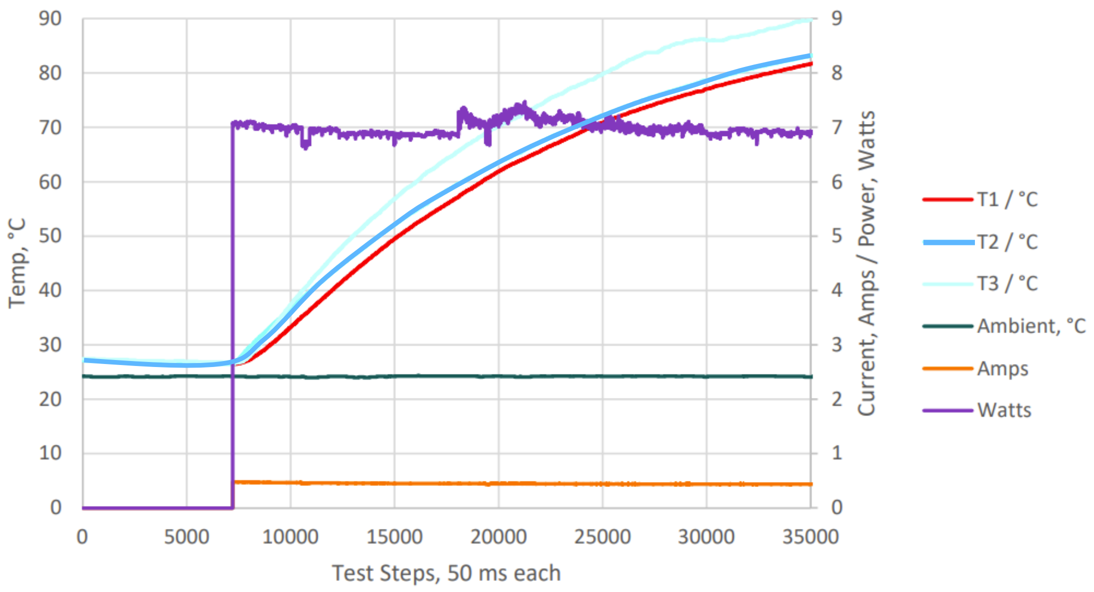


Solenoid does not actuate and liquid is blocked. System issues alarm.



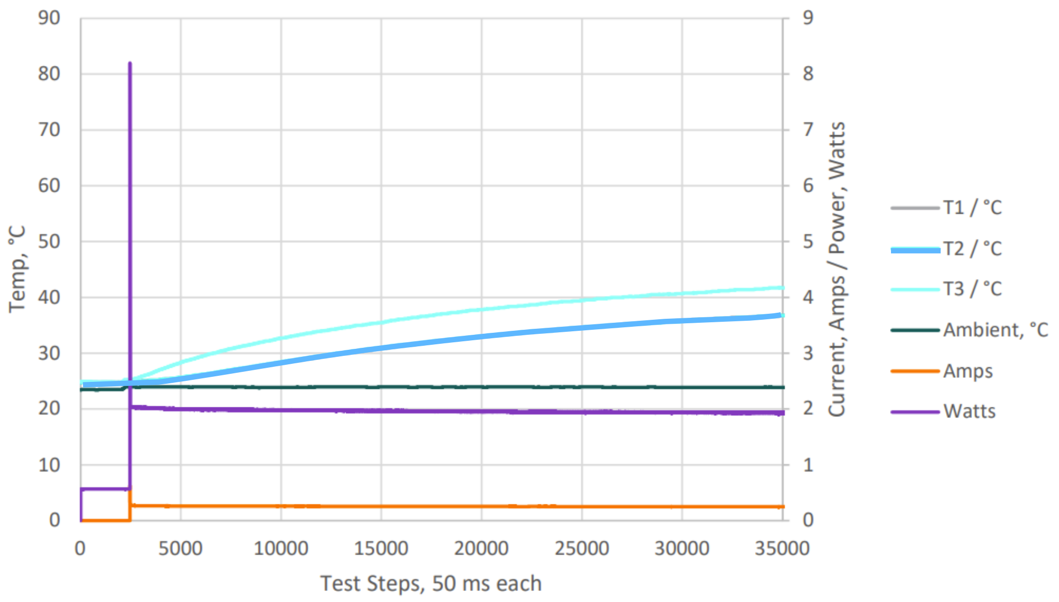
Detection of Plunger Movement in Solenoid Valves

24 VAC—SIMPLE RELAY CONTROL



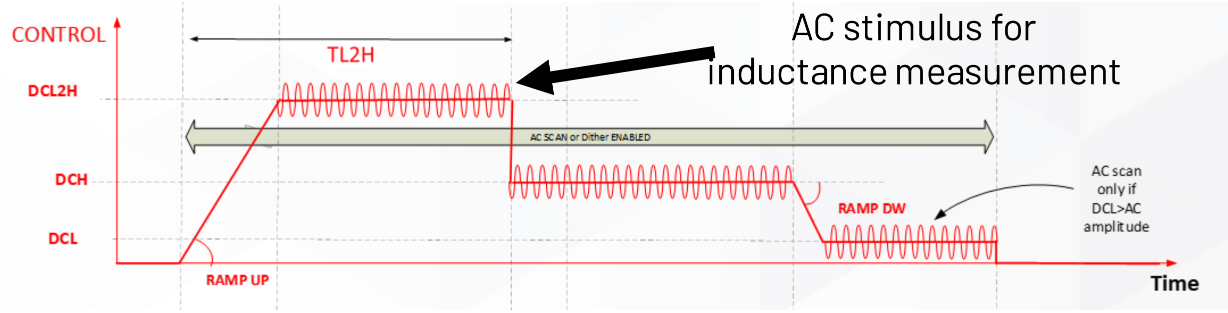
Basic relay control

TUNED SOLENOID DRIVE WITH MAX22216



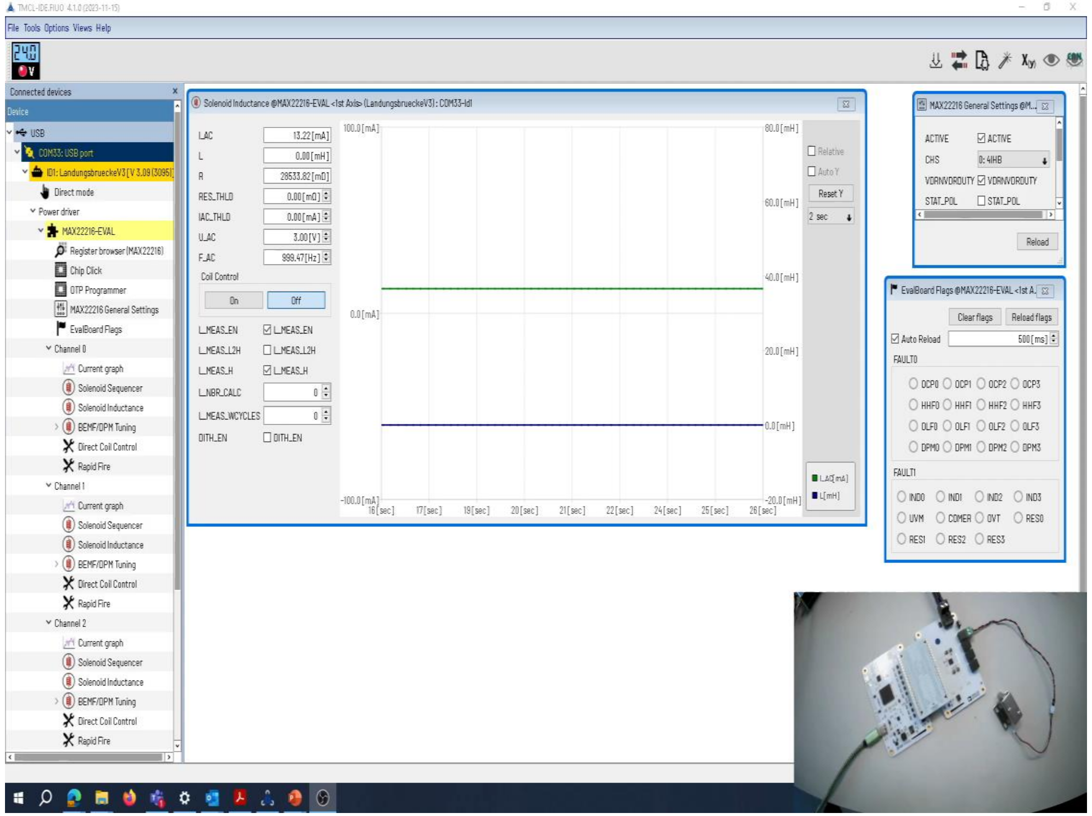
"Just enough" current with MAX22216

MAX22216 Inductance + Resistance Measurement



MAX22216 includes onboard circuitry for measuring solenoid **inductance** and **resistance**

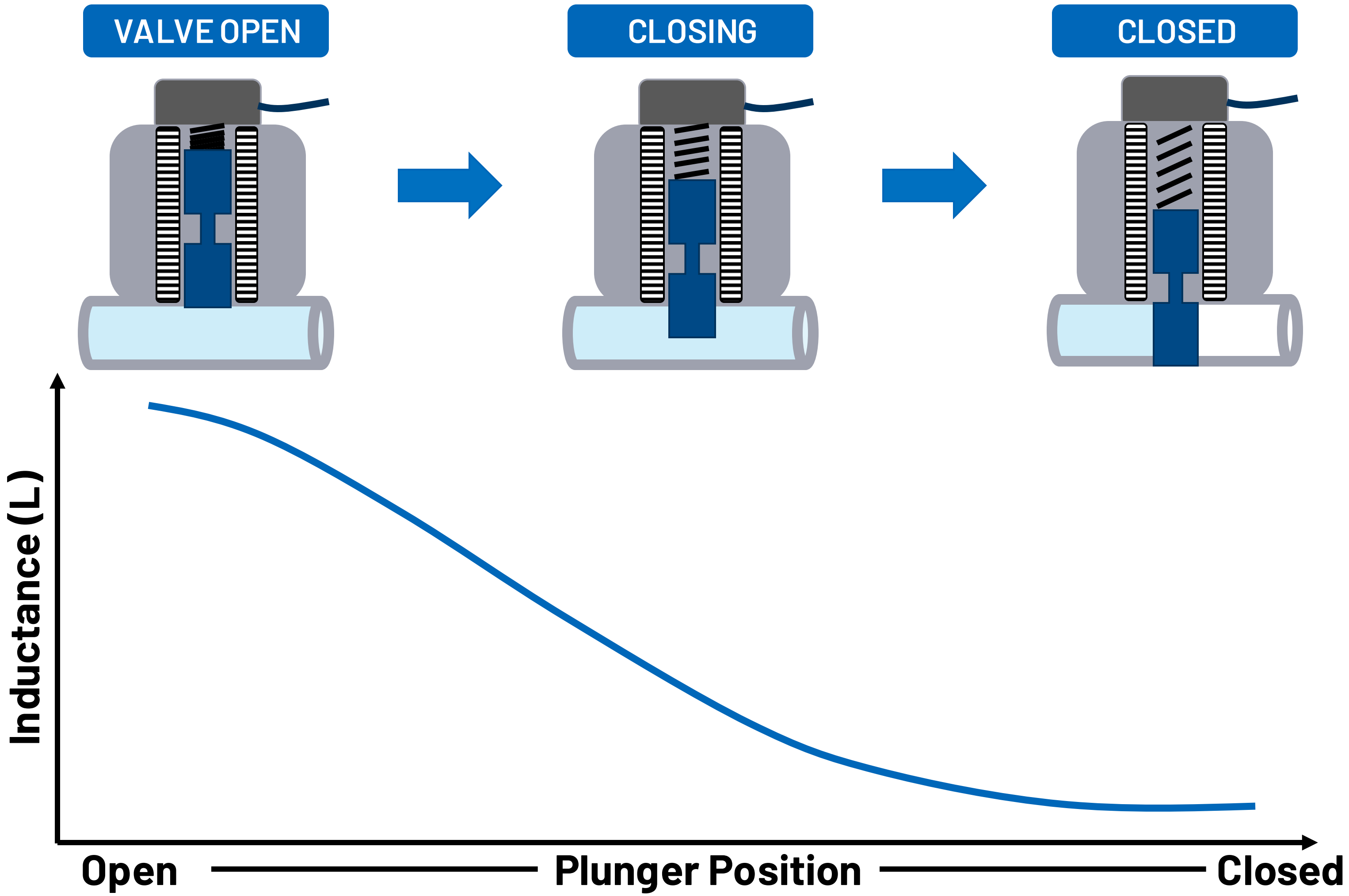
What's the benefit?



<u>Insights Into Solenoid State & Health!</u>

- **Inductance** can be used to estimate **plunger position** and **coil health**
- **Resistance** can be used to estimate **coil temperature** and **coil health**

Estimating Plunger Position via Inductance Measurements



Sensorless position feedback

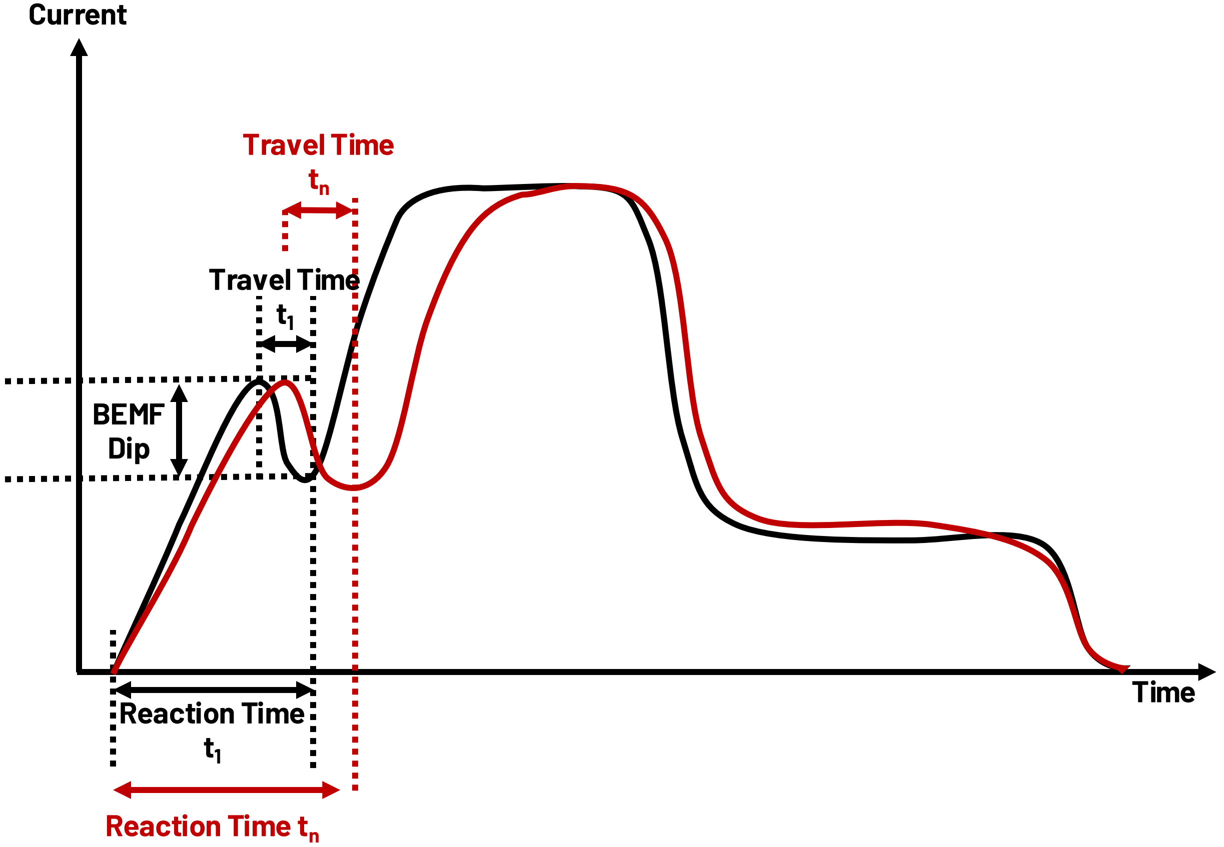
Inductance measurements verify plunger movement in real time, supporting accurate dosing and dependable assay performance

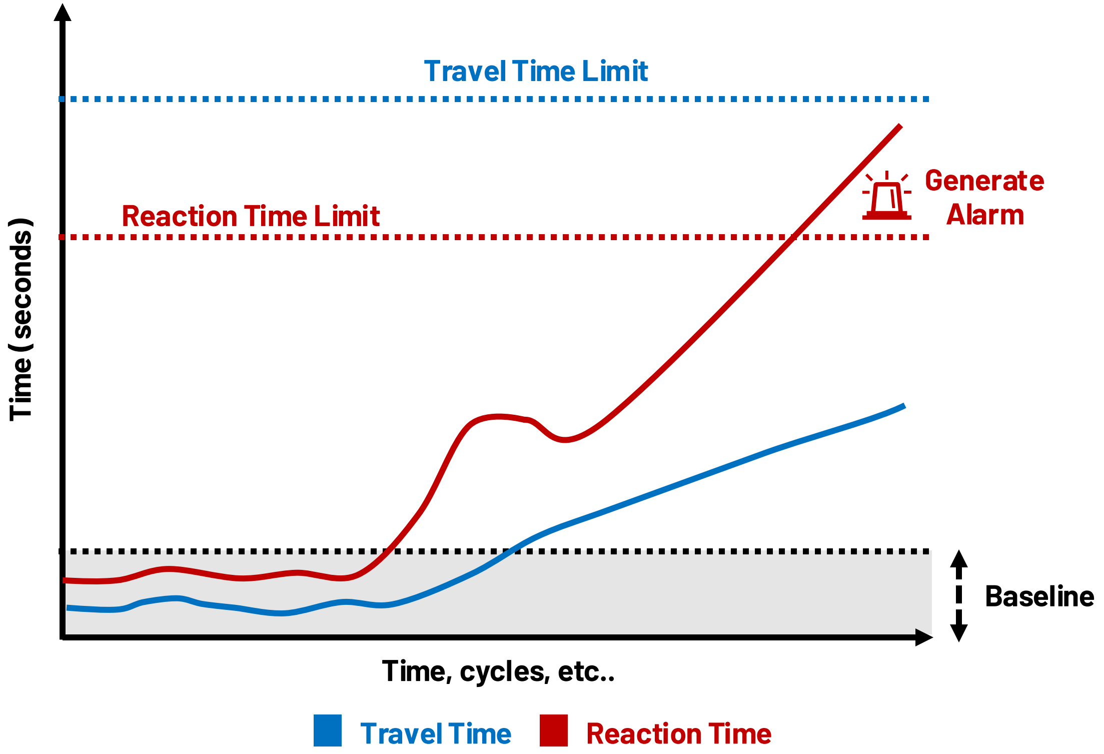
Benefits:

This real-time validation helps prevent dosing errors, reduces calibration drift, and increases confidence across high-throughput and point-of-care diagnostic platforms.

Predictive Maintenance

- Monitoring Reaction and Travel Time over the Lifetime of a Solenoid





Internal wear, friction, and contamination can cause slower valve response

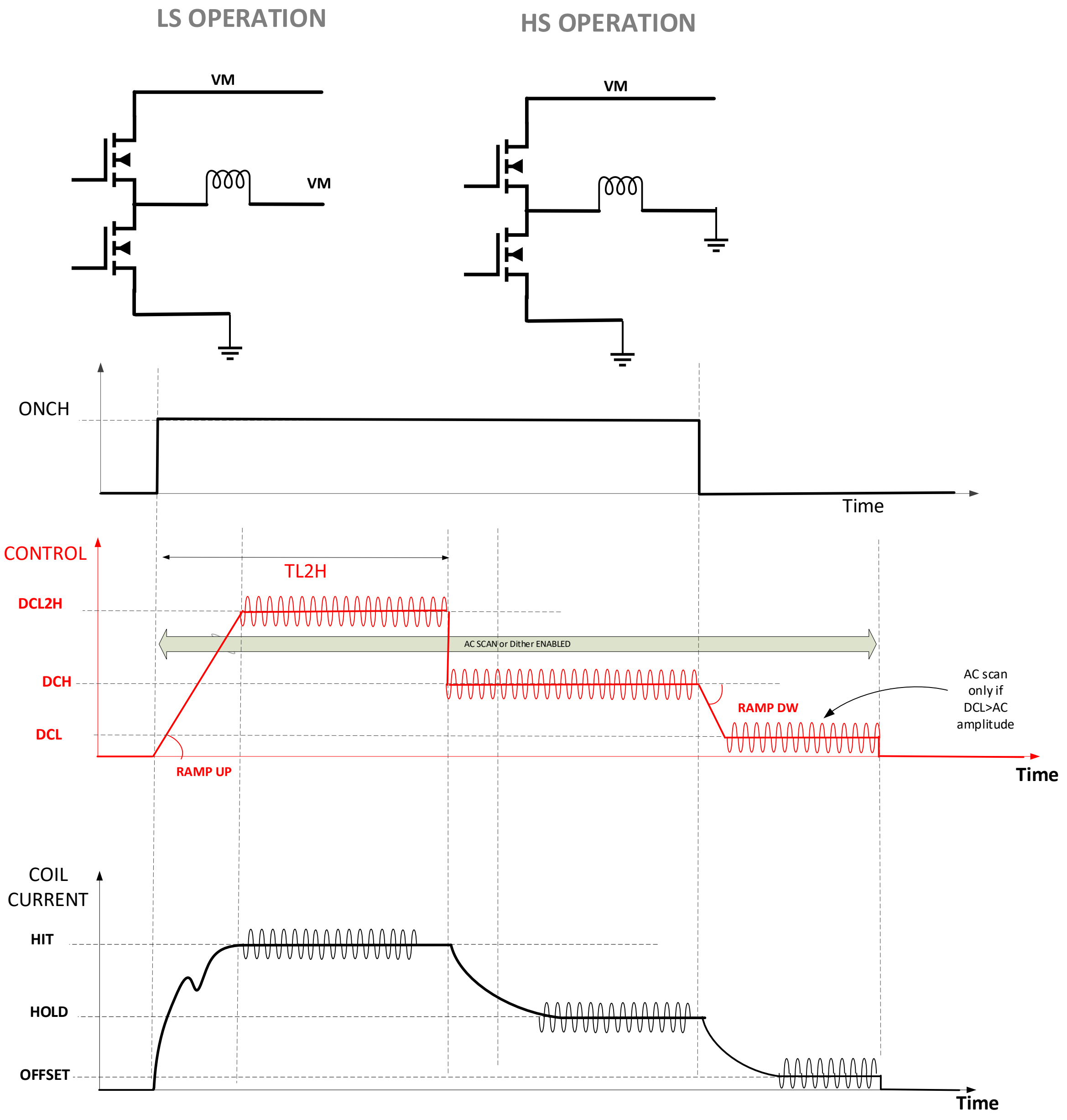
Early detection would allow proactive maintenance before valve failure occurs

Drifting **reaction time** and **travel time** indicate gradual degradation

Exceeding defined drift thresholds trigger maintenance events before functional failure occurs.

MAX22216-17 – Single Ended Operation

- Energy Efficient 2-Level Sequencer
  - Configurable Excitation, Hold and Low Levels
  - Configurable Excitation Time
- Level Transition RAMP Control
  - Reduces mechanical acoustic noise
- PWM Control
  - Globally Configurable 2.5 to 100 KHz
  - Channel Independent Divider up to 1/8
  - PWM Slew Rate Control to reduce EMI
- Sine Wave Generator
  - Dithering (get rid of static friction issues / Drive of Proportional Valves)
  - Inductance measurement (ON/OFF Status Detection and Coil Health, only in VDR)

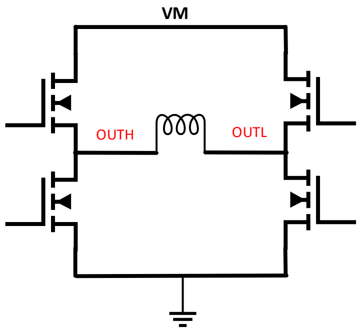


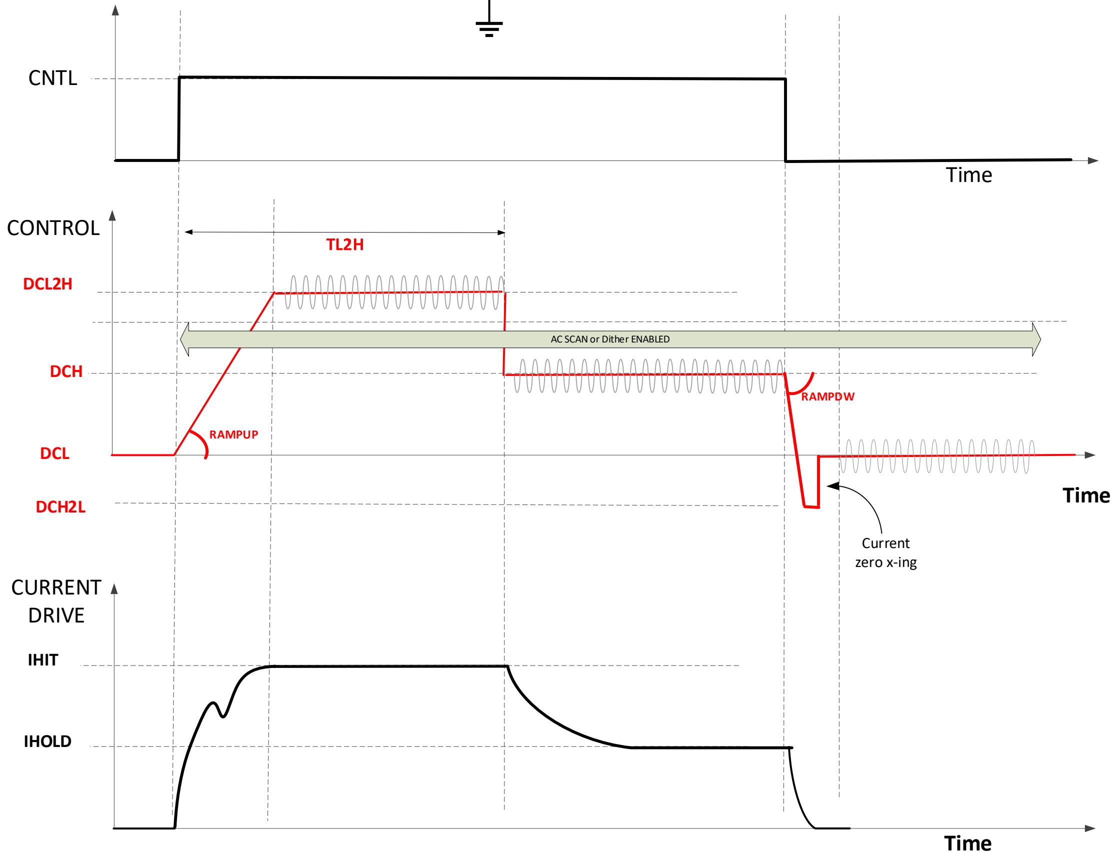
MAX22216-17 – Full Bridge Operation

- Everything Single-Ended operation can do…
  And more!

- Center-Aligned PWM
  - The effective PWM Frequency is doubled
  - Better HEAT distribution trough the IC

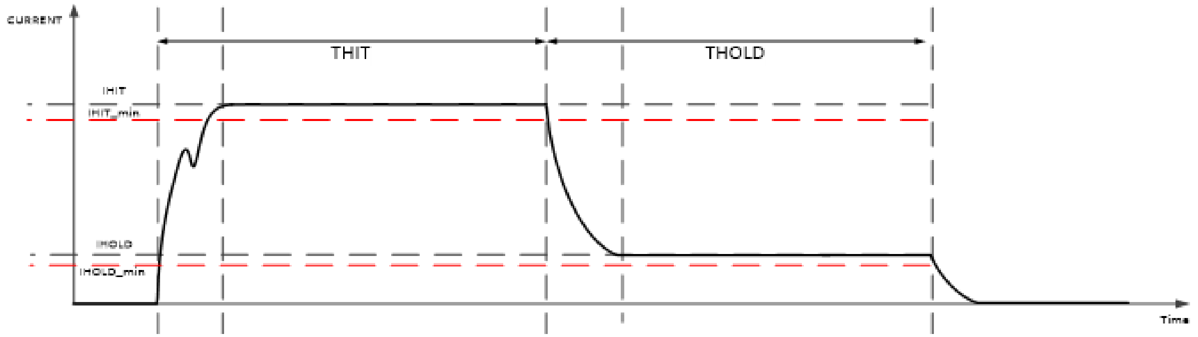
- Fast Demagnetization (zero x-ing)
  - To shorten solenoid on-off cycles

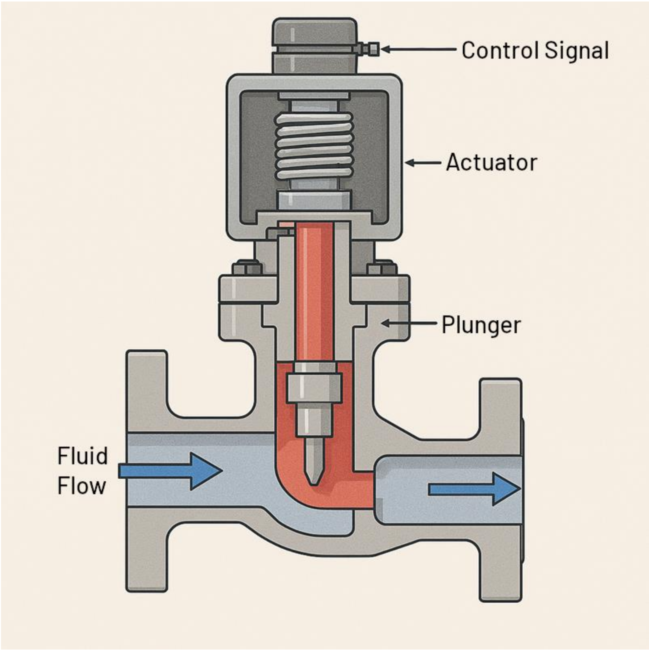




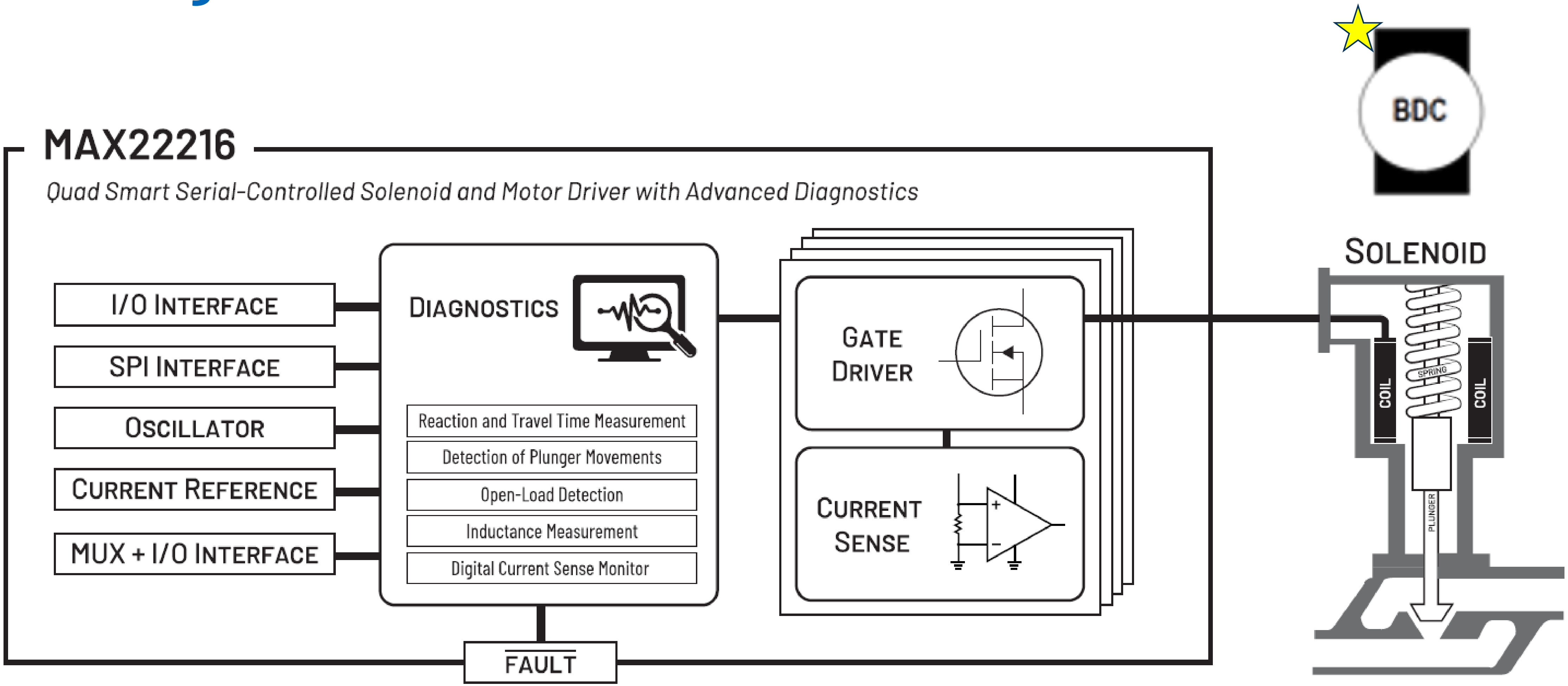
Driving Proportional Solenoid Valves

- Current Drive Regulation Mode (CDR):
  - The driver regulates the output current using internal sensing and feedback
  - You can configure **P**roportional and **I**ntegral gains to fine-tune the response for the whole position range
- Dithering Feature:
  - With configurable frequency the plunger "vibrates" to avoid getting stuck
- Real Time Current Feedback:
  - You can read the coil current via SPI which translates to the position





Block Diagram



Target Applications

- Valve Manifolds/Hydraulic Systems

CHALLENGE	MAX22216 SOLUTION
Miniaturization	Control up to 4 Channels + Integrated Current Sense and Shunts
Heat (Coil deterioration)	Resistance Measurement
Stuck plunger	Detection of Plunger Movements (DPM)
Plunger deformation	Current/Voltage Ramp Control
Acoustic noise	
Long on-off cycles	Fast Demagnetization to Shorten On-Off Cycles
Predictive maintenance	Impedance measurement + Detection of Plunger Movements
Energy efficiency	Two Level Current/Voltage Control
	Automatic HIT to HOLD Transition
EMI	Configurable Slope Control

Additional Benefits

- Fault/Protections—Robustness

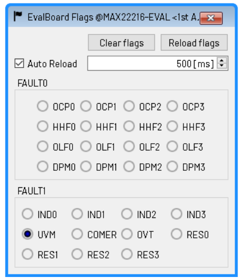
General Protections/Alarms

Undervoltage lockout (UVM)

Overtemperature protection (OVT)

Communication error (COMER)

Channel Faults/Alarms



Open-load detection (OL)

Overcurrent protection (OCP)

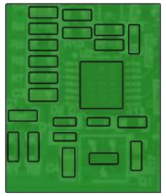
Hit current not reached alarm (HHF) - CDR

Detection of plunger movement error (DPM)

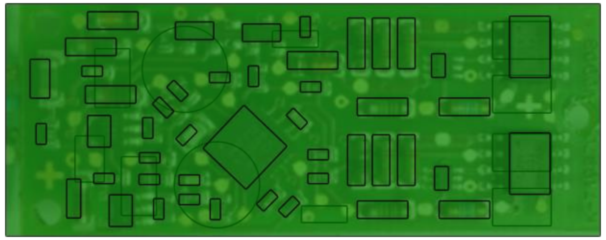
Resistance/inductance alarms (RES/IND)

C

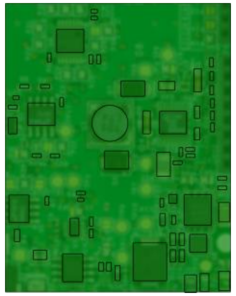
Miniaturization with Analog Device's Solutions



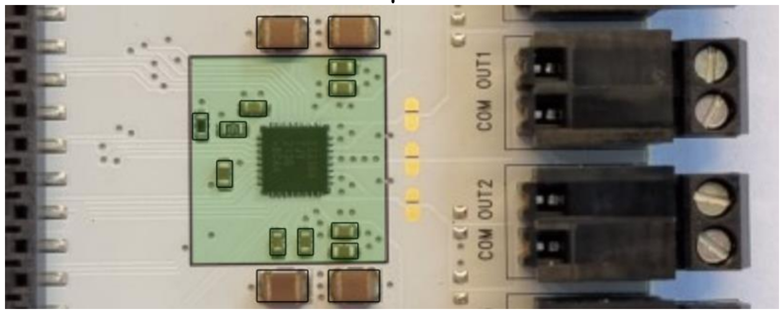
$13 \times 16 mm^2$
Single Actuator
DPM Example



$46 \times 18 mm^2$
Single Actuator
Fast Demagnetization Example



$34 \times 43 mm^2$
Current Control (Including Current Sensing) Example



$15 \times 16 mm^2$, up to 4 Actuators
ADI Trinamic Solution—MAX22216

OTP and Standalone Mode

Customer OTP via SPI Interface

All writable registers!

STANDALONE CONFIGURATION

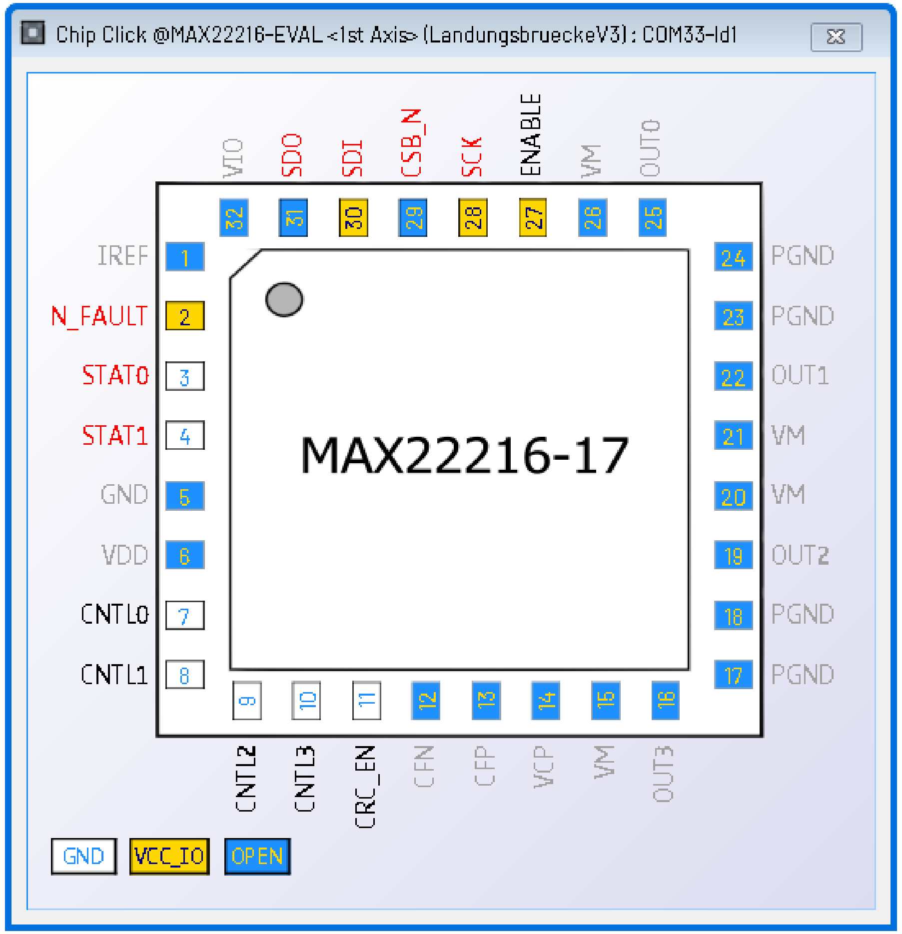
2 Stat Output Pins w Multiple Alarms

CNTL Pin (OR config with registers)

UVM Control with Hysteresis

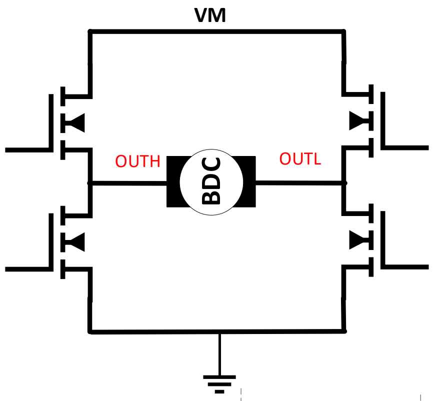
Internal Voltage Regulator (3.3 or 5V)

nFault Pin + fault Stretching + Fault masking



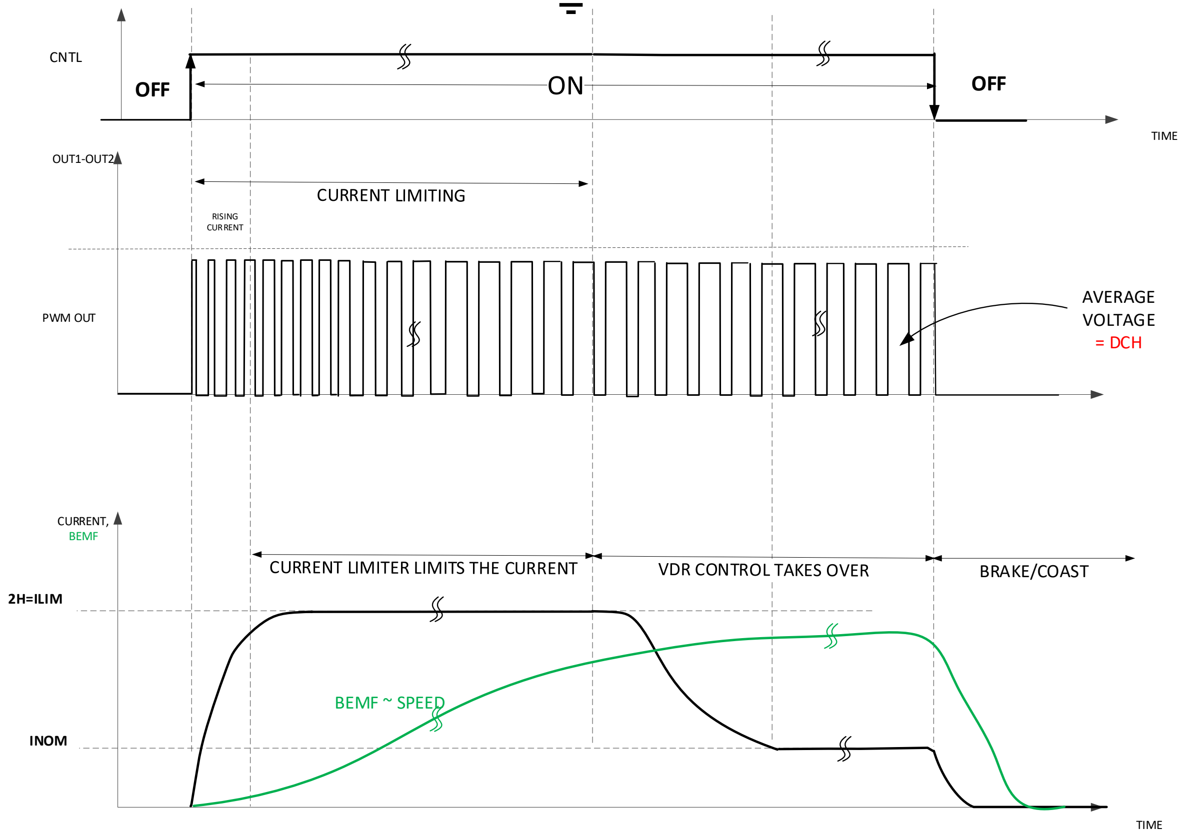
MAX22216-17 – DC Motor Drive Operation

- Programmable VDR (Speed) and CDR (Torque) Control
- SAME coil diagnostics as solenoids
- Special Motor Drive Mode
  - Current Control then Voltage Controlled
  - Limits the Start Inrush Current
  - Brake Function



KEY MOTOR CONTROL FEATURES IN MAX22216:

Feature	Details
VDR Mode	Voltage Drive Control for Speed Regulation
CDR Mode	Current Drive Control for Torque Regulation (12-bit PI Controller)
Motor Drive Mode	Current Control → Voltage Controlled, Limits Start Inrush
Brake Function	Integrated brake capability
Diagnostics	Plunger Movement Detection, Open Load Detection, Temperature Approximation
Current Sensing	Integrated Current Sense with Scaling
Package	5x5mm² TQFN



Design Resources and Evaluation System

ANALOG DEVICES

Product Home Page:

- [MAX22216]

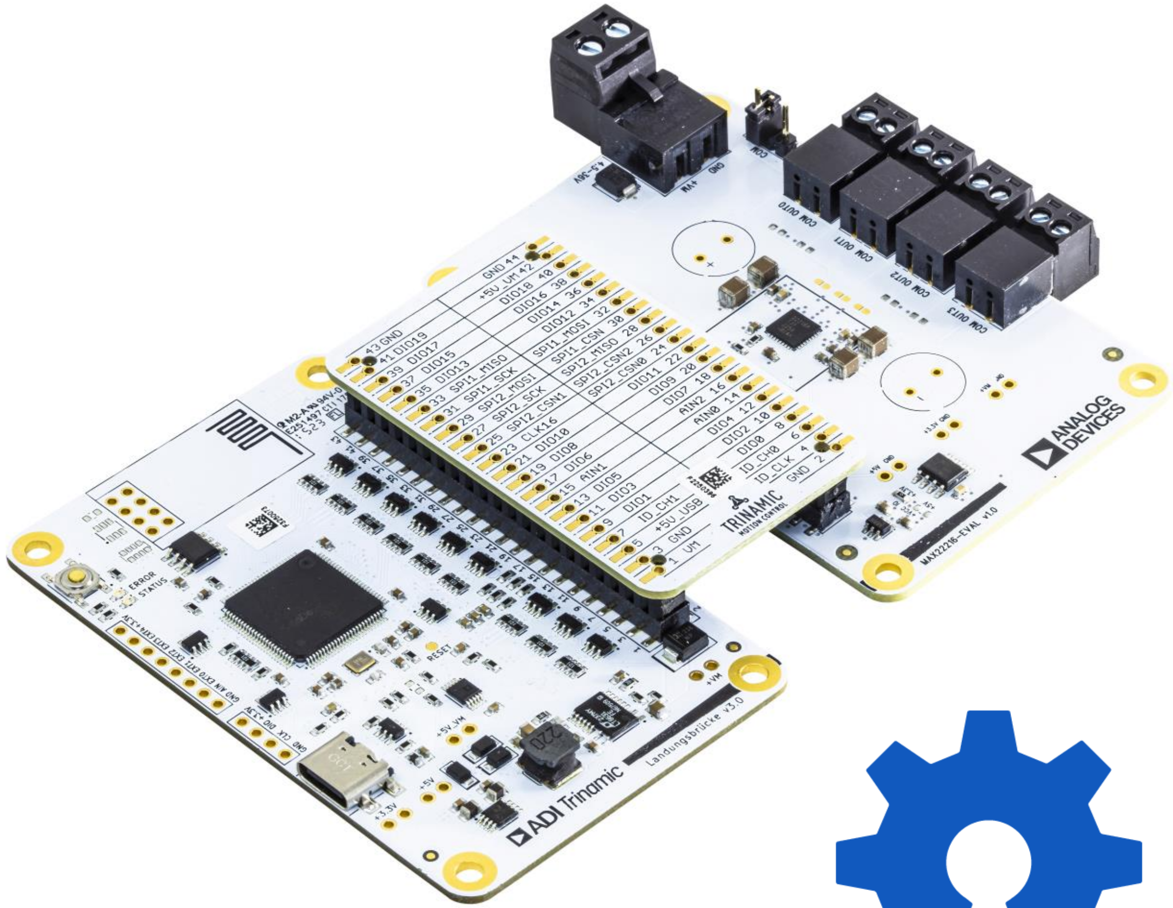
Evaluation Board:
[MAX22216-EVAL-KIT]

Software:

- [TMCL-IDE]

Landungsbrücke FW:

- [TMC-EvalSystem]



Open Source

MAX22216/17: Internal Positioning and Comparison

Product	MAX22200	MAX22216	MAX22217
Independent Half Bridges	8	4	
Current Capability (Channel)	1 A	1.7 A	0.55 A
Channel Configurations	Pairs of channels	All possible combinations	
Voltage Mode	YES: only DUTY	YES: DUTY + VM Comp	
Current Mode	YES: Peak Detection	YES: PI Control	
DPM	YES: Current	YES: Currents + Timing	
Ramp generator	NO	YES	
Inductance Measurement	NO	YES	
Current Monitor	NO	YES	
DC-Motor Drive	NO	YES	
BTL Mode - Fast Demag	YES: w/o zero x-ing	YES: with zero x-ing	
Dither	NO	YES	
Temp Grade	Industrial (-40°C, 85°C)	Auto (-40°C, 125°C)	

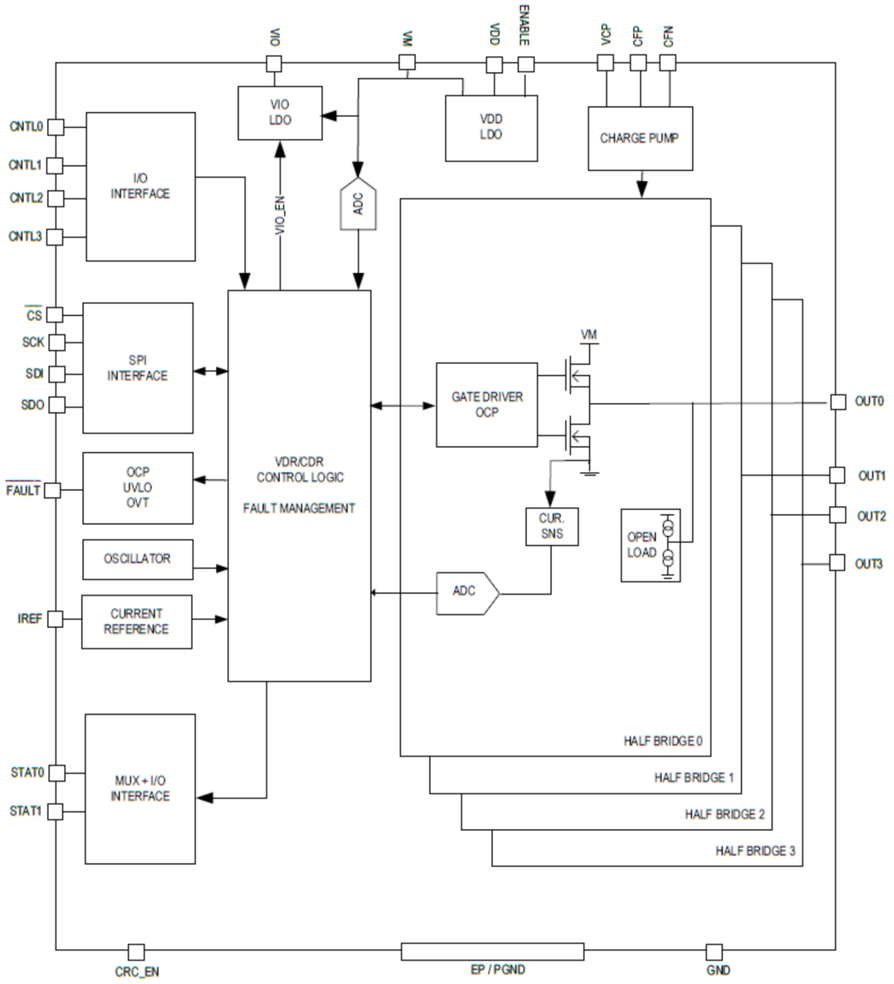
MAX22216/MAX22216V: Competition

Product	MAX22216V/MAX22216V	Comp1	Comp2
Operating Voltage (V)	36	40	40
Maximum Current (A RMS) (per channel)	1.7	2	1.6
Nr Channels	4	4	3
Internal Current Sensing	YES	YES	YES
Current Drive Regulation	YES, PI Control	NO	YES, Current Limitter
Interface	SPI, I/O	SPI	SPI, I/O
DPM	YES	NO	NO
Open-Load Detection	YES	YES	YES
Dithering	YES	NO	YES
Motor Temp Estimate	YES	NO	NO
Position Estimation (Inductance Measurement)	YES	NO	NO
RDSon (Ω)	0.17	0.5	0.25
Package Size	5x5mm²	5x4.4mm²	15.9 x 14.2 mm²

MAX22216/MAX22217 and MAX22216V

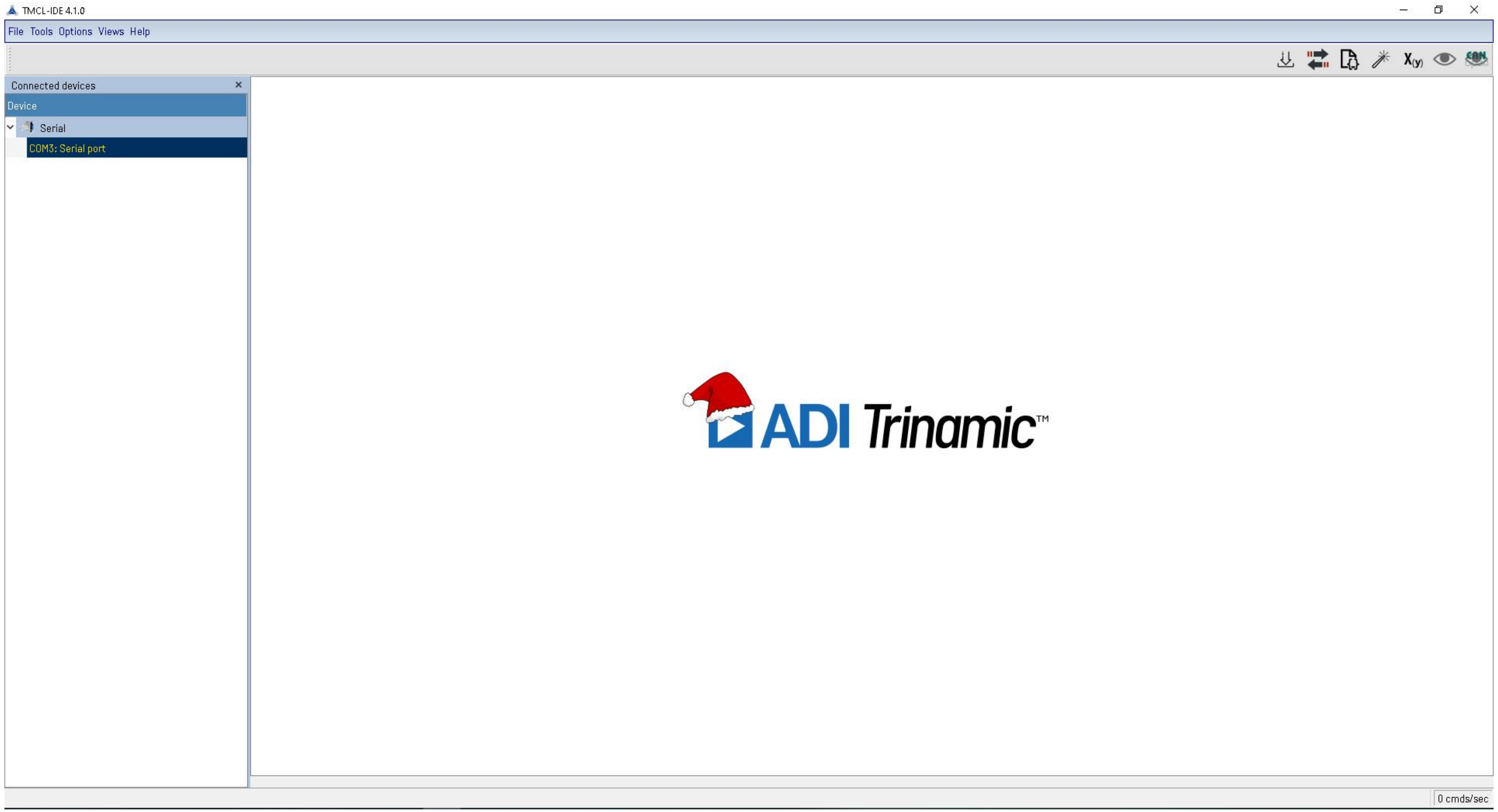
- Value Proposition
  - Low on-resistance (170 mΩ) provides high efficiency solution
  - Independent channel configuration settings programmable via SPI or OTP
  - Intelligent diagnostics include detection of plunger movement (PDM), plunger displacement sensing (PDS), and reaction time measurement (RTM)
  - MAX22216V version automotive qualified (AECQ100)
  - Easier system-level SIL/ASIL certification with MAX22216V

- Key Benefits
  - Reduced heat in module allows for more compact form factors
  - Advanced diagnostics and controls provide improved system reliability and enable predictive maintenance
  - Highly configurable solutions dynamically fits wide variety of applications



Software Platform (MAX22216)

TMCL IDE



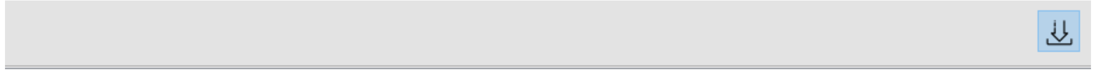
Software:

- [TMCL-IDE]
- Install & RUN

Landungsbrücke FW Update

Landungsbrücke FW:

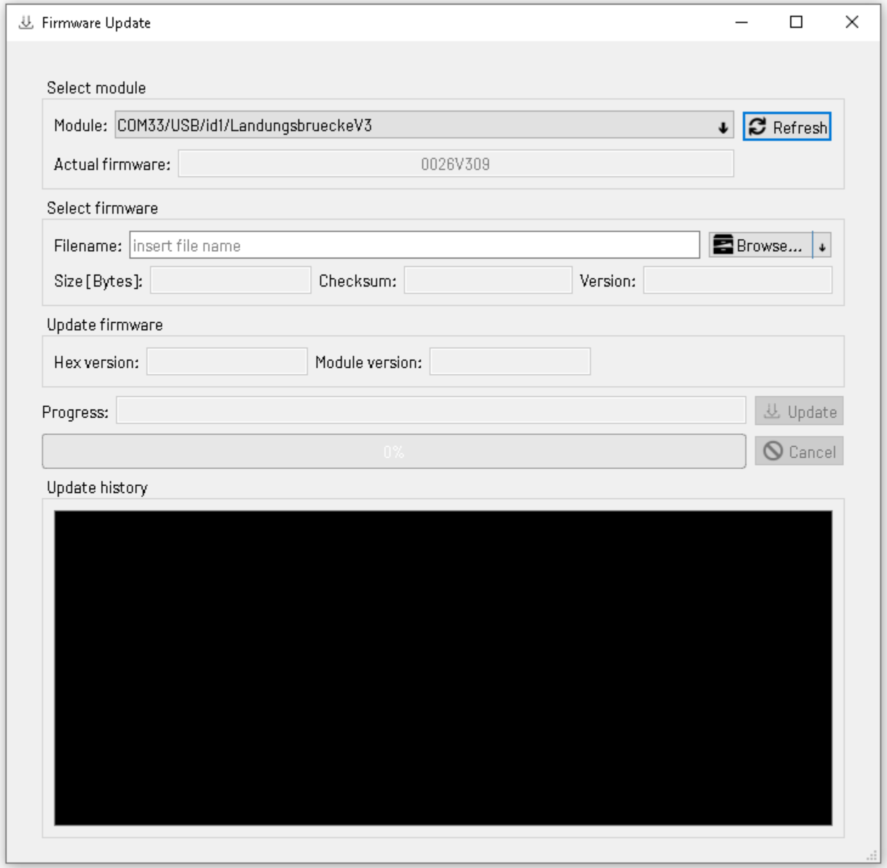
- [TMC-EvalSystem]



Inside the IDE, click on the ICON

Inside the tool, select the firware file

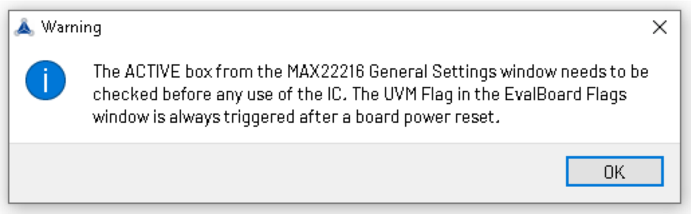
Press Updatec

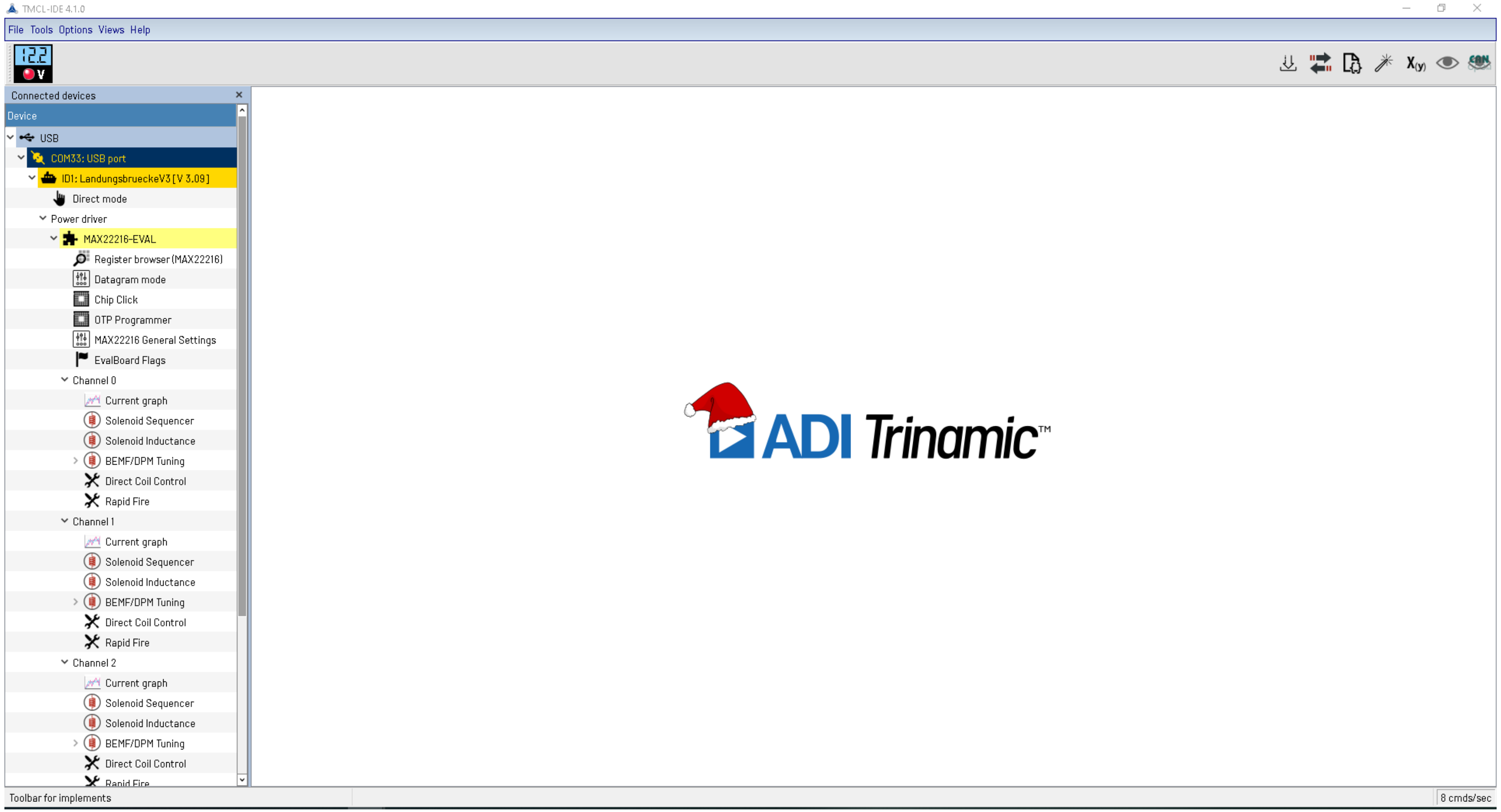


MAX22216-EVAL in the TMCL IDE

ANALOG DEVICES

- Connect power to the MAX22216-EVAL-KIT
- Connect the MAX22216-EVAL-KIT to your PC





MAX22216 General Settings

➢ Turn on the IC

- ENABLE PIN HIGH and ACTIVE Register HIGH

➢ Select the channel configuration

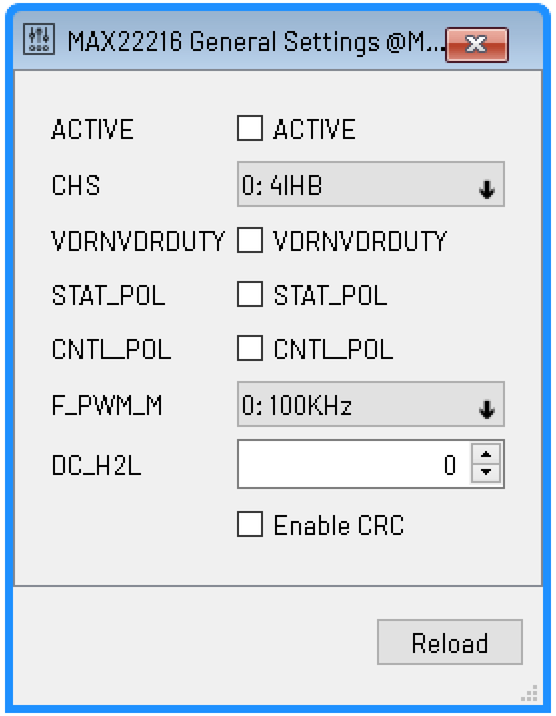
- CHS (I:Independent, P:Parallel, HB:Half-Bridge, FB:Full-Bridge)
- Please set it to CHS 6:1FB_2IHB

➢ DUTY or Internally Compansated VDR

- VDRnVDRDUTY – affects only channels using VDR

➢ Set Global PWM Frequency

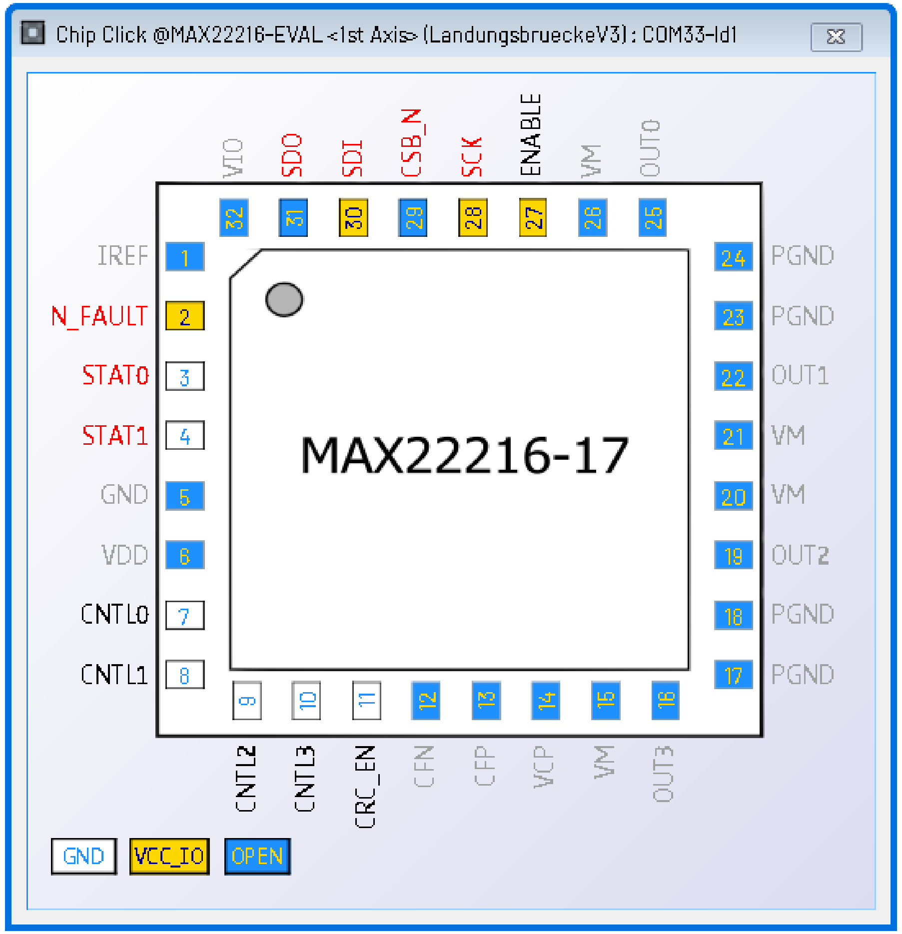
- F_PWM_M (2.5 to 100 KHz) – can be divided further for each channel



Chip Click

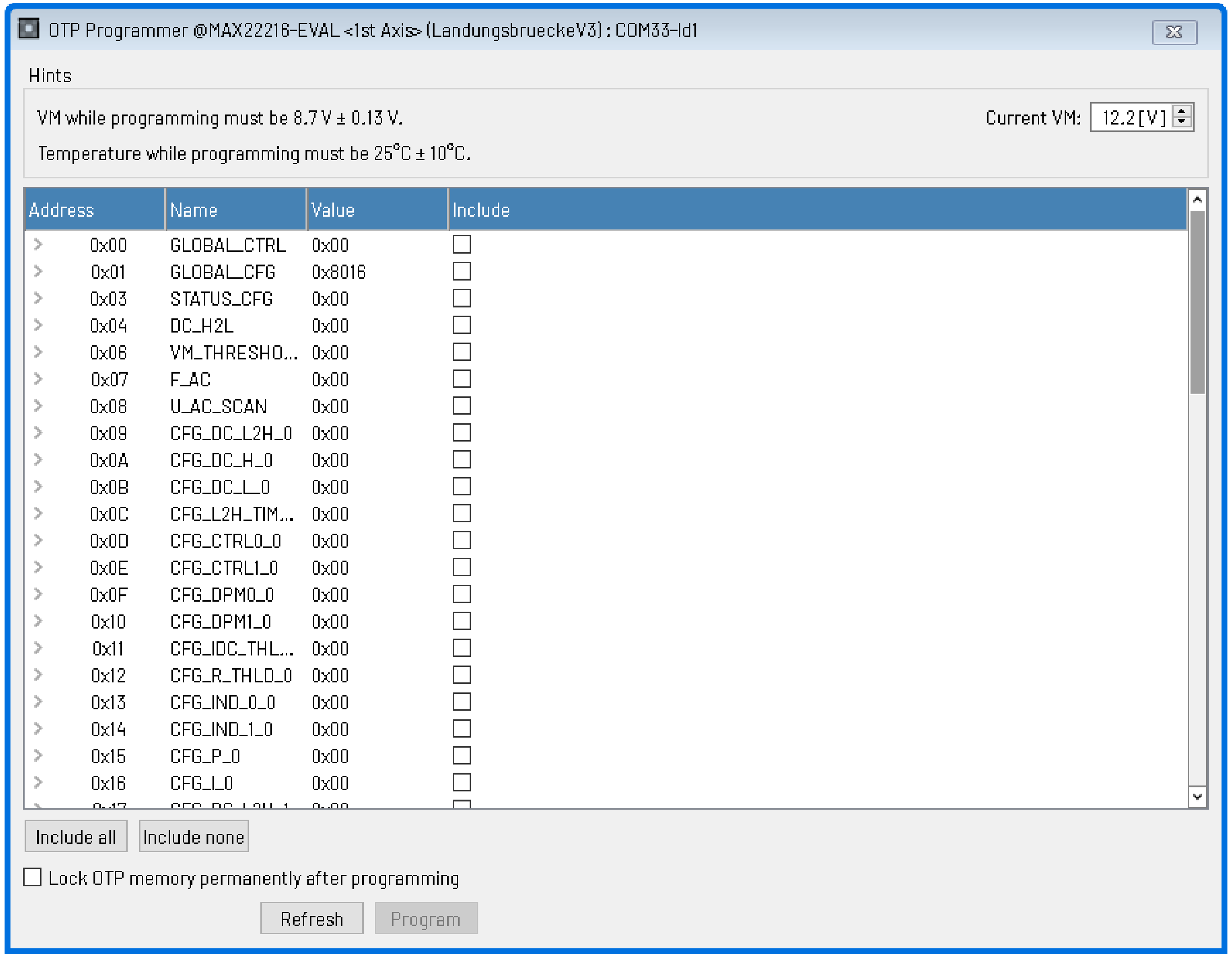
➢ **Can control/read pin status**

- ENABLE Pin must be HIGH (HIGH by default in the MAX22216-EVAL-KIT)
- CNTL Pins are on OR configuration with the CNTL Registers
- CRC_EN starts the CRC on the SPI



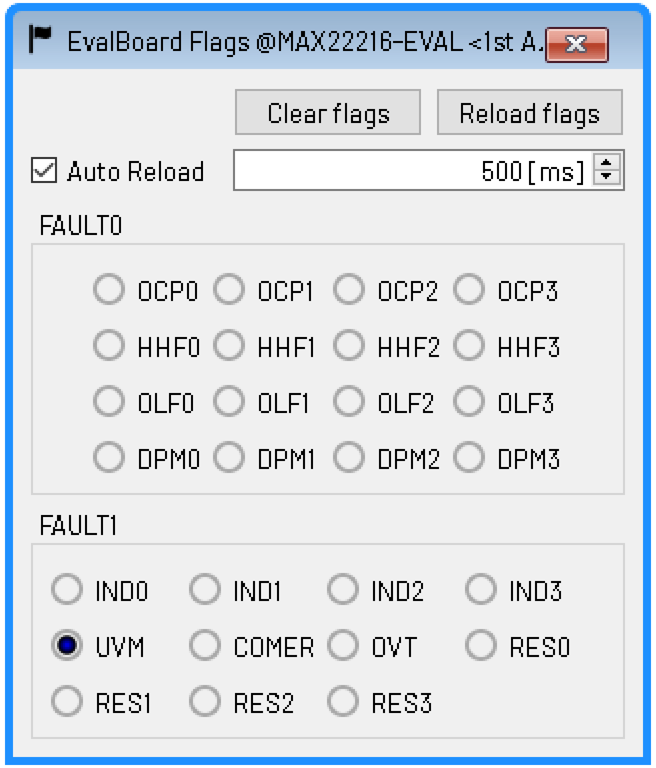
OTP Programmer

- All writable registers can be OTPd by the customer
- You can also start the internal 5V or 3.3V regulator
- You can also control the UVM and Mask Flags



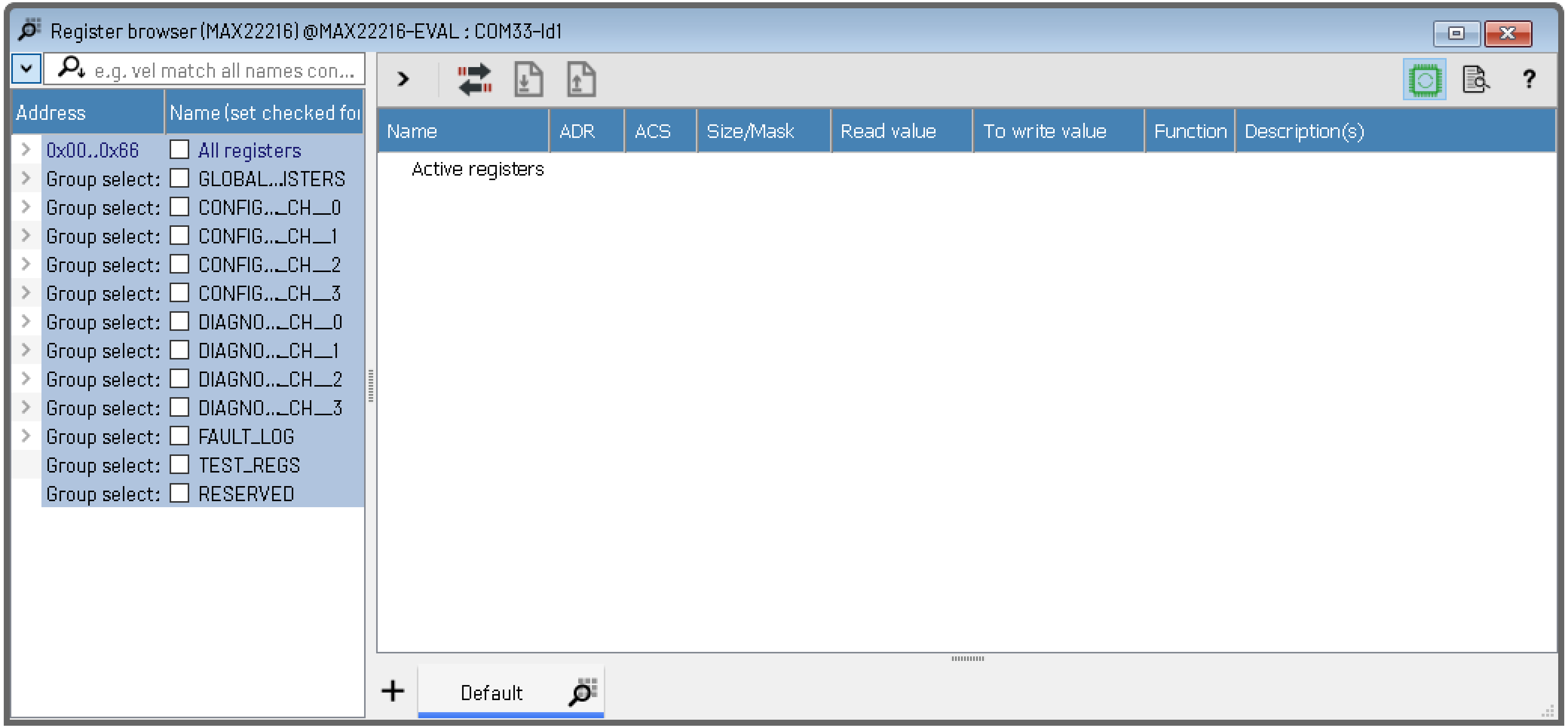
EvalBoard Flags

- Easy Overview of the FAULT Registers
- Can be set to automatically reload for near real-time Flag updates
- Always clear the UVM Flag at the start of the IC

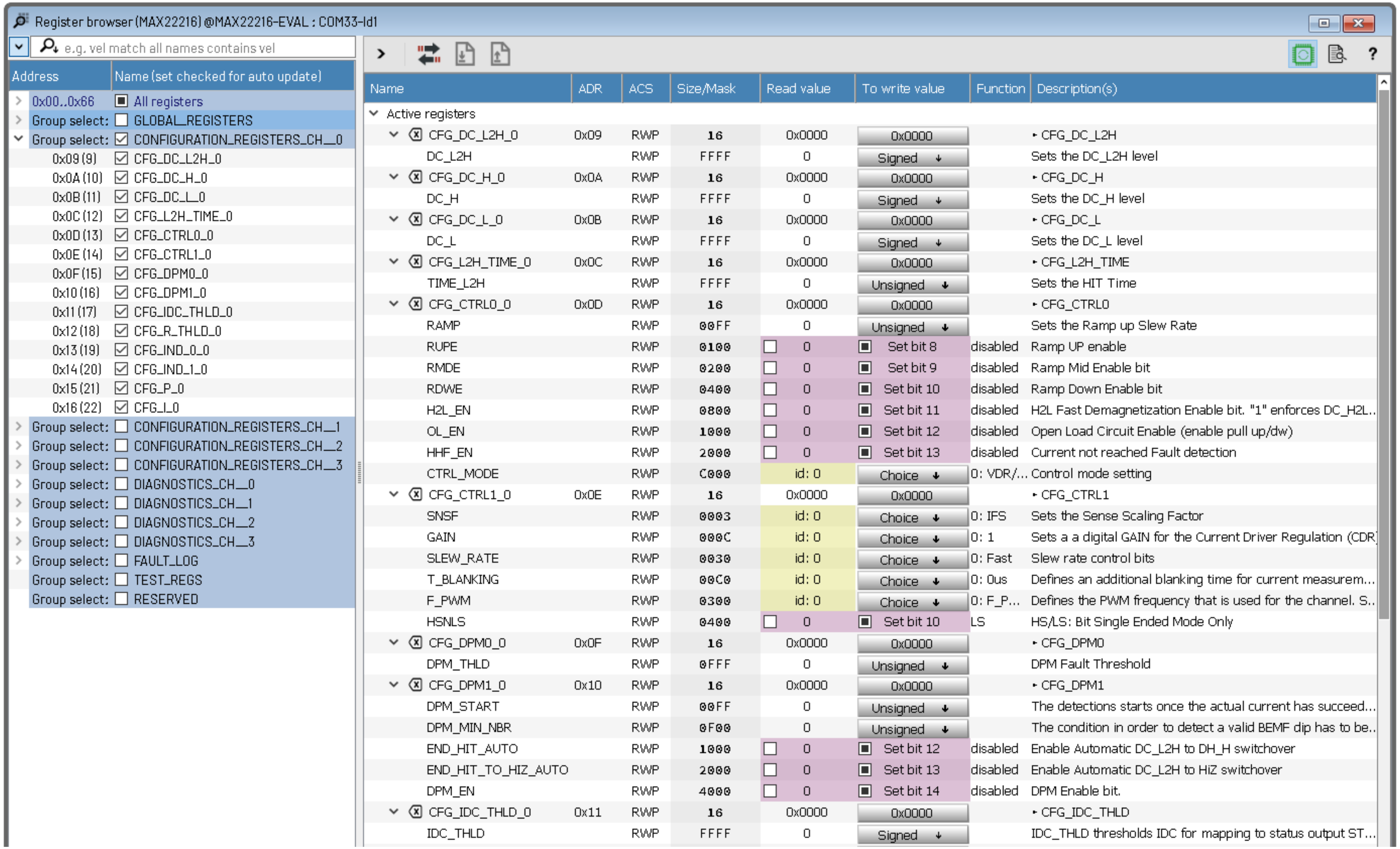


Register Browser

- Easy overview and control of all the registers
- Can export settings as C Code



Channel Configuration – Settings + DPM

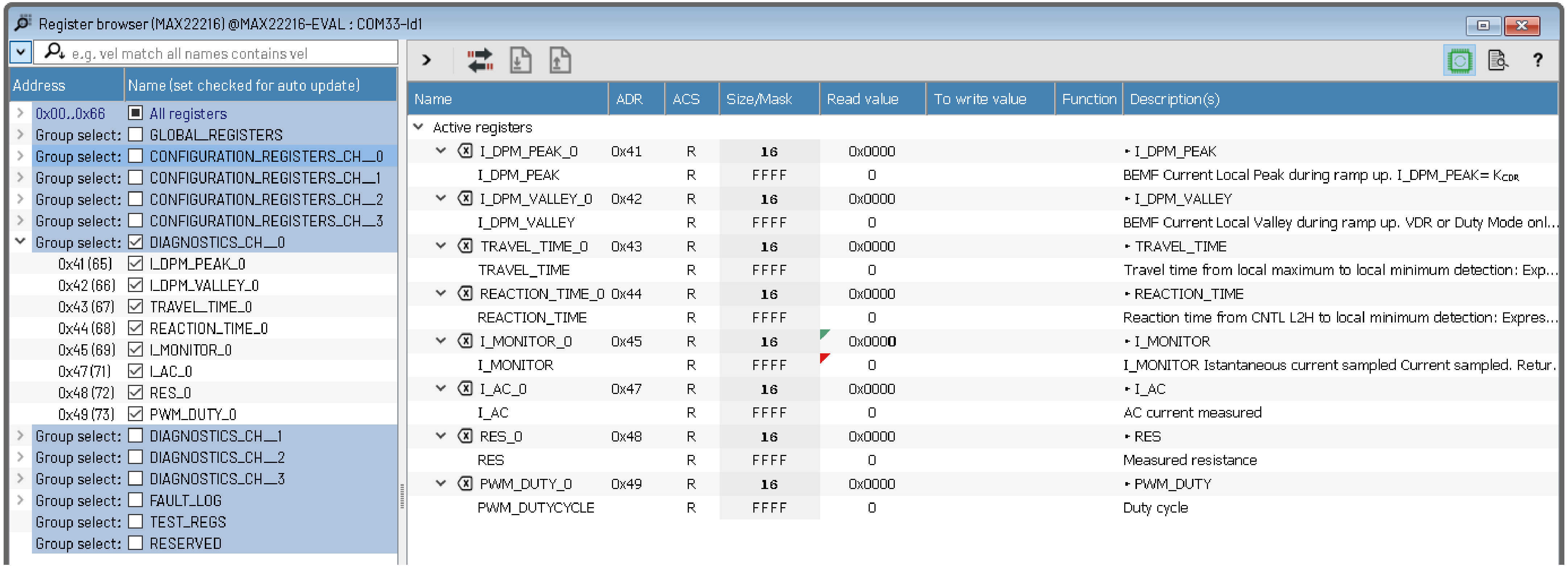


Channel Configuration – Inductance + PI Settings

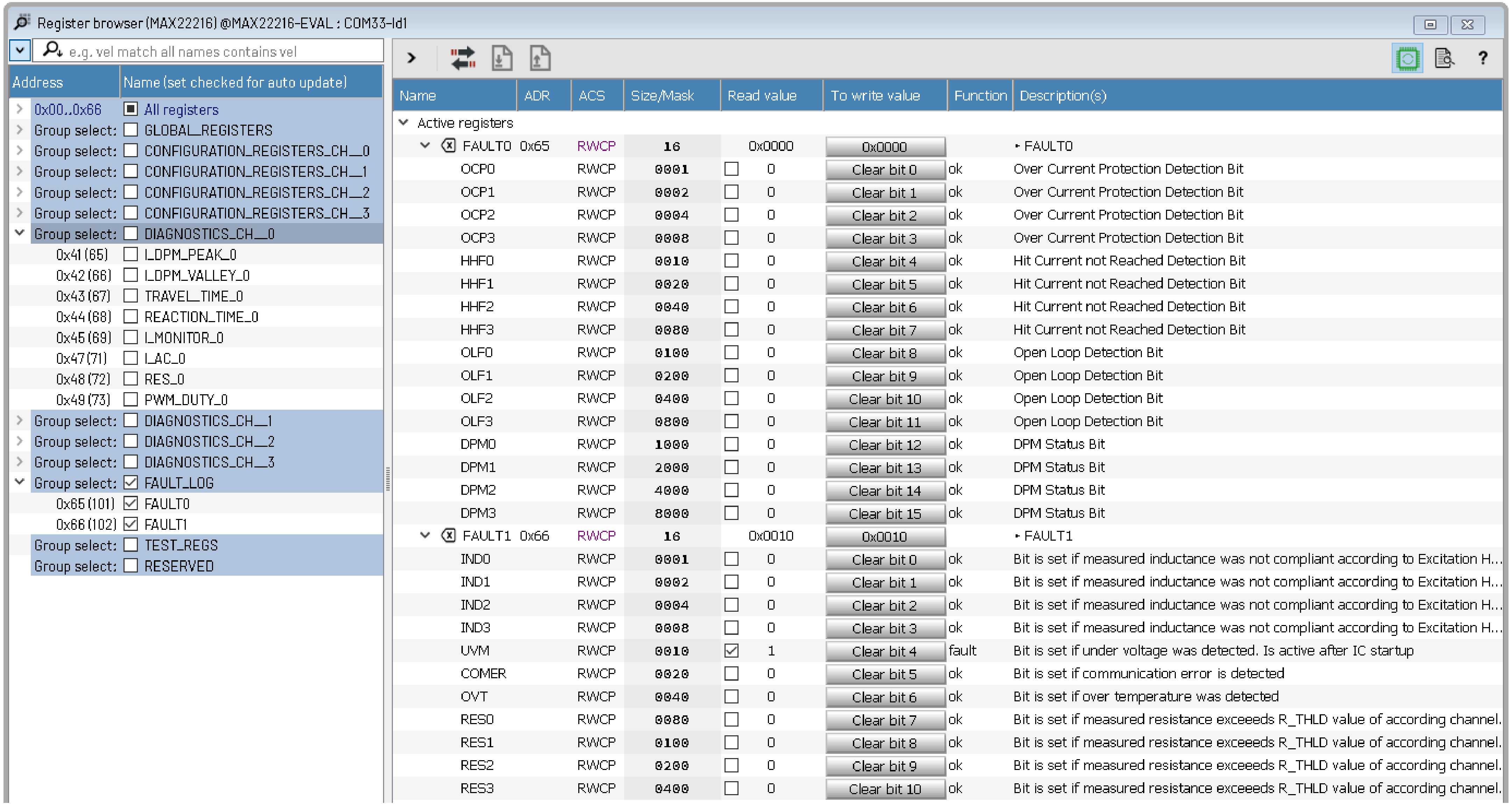
CFG_IDC_THLD_0	0x11	RWP	16	0x0000	0x0000		▸ CFG_IDC_THLD
IDC_THLD		RWP	FFFF	0	Signed		IDC_THLD thresholds IDC for mapping to status output ST...
CFG_R_THLD_0	0x12	RWP	16	0x0000	0x0000		▸ CFG_R_THLD
RES_THLD		RWP	FFFF	0	Unsigned		Threshold of measured resistance that triggers the corres...
CFG_IND_0_0	0x13	RWP	16	0x0000	0x0000		▸ CFG_IND_0
L_NBR_CALC		RWP	000F	0	Unsigned		Number of AC scan periods used to calculate the inductan...
L_MEAS_WCYCLES		RWP	00F0	0	Unsigned		Number of AC scan periods (Tscan/1/F_AC) starting from ..
L_MEAS_H		RWP	0100	0	Set bit 8	disabled	Used to enable inductance measurement during hold time.
L_MEAS_L2H		RWP	0200	0	Set bit 9	disabled	Used to enable inductance measurement during L2H excita..
L_MEAS_EN		RWP	0400	0	Set bit 10	disabled	U_AC_SCAN is superimposed onto DC_L2H, DC_H, DC L if ...
DITH_EN		RWP	0800	0	Set bit 11	disabled	Used to enable dithering function.
CFG_IND_1_0	0x14	RWP	16	0x0000	0x0000		▸ CFG_IND_1
IAC_THLD		RWP	0FFF	0	Unsigned		IAC_TLHD thresholds I_AC for mapping to status output S...
CFG_P_0	0x15	RWP	16	0x0000	0x0000		▸ CFG_P
CFG_P		RWP	FFFF	0	Unsigned		Set P parameter of PI controller
CFG_I_0	0x16	RWP	16	0x0000	0x0000		▸ CFG_I
CFG_I		RWP	FFFF	0	Unsigned		Set I parameter of PI controller

Default

Channel Diagnostics



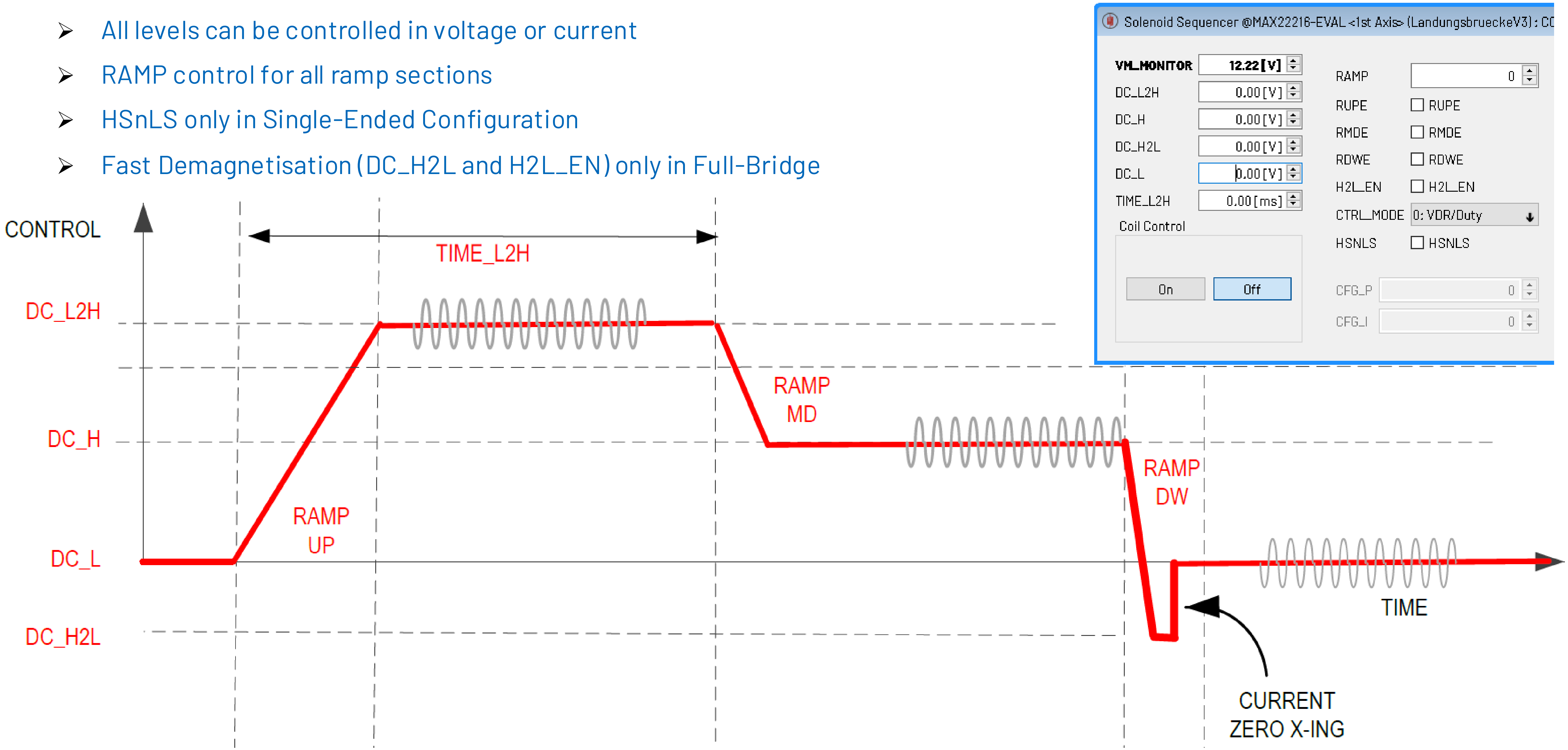
FAULT Logs



Register browser (MAX22216) @MAX22216-EVAL : COM33-Id1
e.g. vel match all names contains vel
Address
Name (set checked for auto update)
0x00..0x66 All registers
Group select: GLOBAL_REGISTERS
Group select: CONFIGURATION_REGISTERS_CH_0
Group select: CONFIGURATION_REGISTERS_CH_1
Group select: CONFIGURATION_REGISTERS_CH_2
Group select: CONFIGURATION_REGISTERS_CH_3
Group select: DIAGNOSTICS_CH_0
0x41 (65) LDPM_PEAK_0
0x42 (66) LDPM_VALLEY_0
0x43 (67) TRAVEL_TIME_0
0x44 (68) REACTION_TIME_0
0x45 (69) I_MONITOR_0
0x47 (71) LAC_0
0x48 (72) RES_0
0x49 (73) PWM_DUTY_0
Group select: DIAGNOSTICS_CH_1
Group select: DIAGNOSTICS_CH_2
Group select: DIAGNOSTICS_CH_3
Group select: FAULT_LOG
0x65 (101) FAULT0
0x66 (102) FAULT1
Group select: TEST_REGS
Group select: RESERVED
Name | ADR | ACS | Size/Mask | Read value | To write value | Function | Description(s)
Active registers
FAULT0 0x65 RWCP 16 0x0000 0x0000 ▸ FAULT0
OCP0 RWCP 0001 0 Clear bit 0 ok Over Current Protection Detection Bit
OCP1 RWCP 0002 0 Clear bit 1 ok Over Current Protection Detection Bit
OCP2 RWCP 0004 0 Clear bit 2 ok Over Current Protection Detection Bit
OCP3 RWCP 0008 0 Clear bit 3 ok Over Current Protection Detection Bit
HHF0 RWCP 0010 0 Clear bit 4 ok Hit Current not Reached Detection Bit
HHF1 RWCP 0020 0 Clear bit 5 ok Hit Current not Reached Detection Bit
HHF2 RWCP 0040 0 Clear bit 6 ok Hit Current not Reached Detection Bit
HHF3 RWCP 0080 0 Clear bit 7 ok Hit Current not Reached Detection Bit
OLF0 RWCP 0100 0 Clear bit 8 ok Open Loop Detection Bit
OLF1 RWCP 0200 0 Clear bit 9 ok Open Loop Detection Bit
OLF2 RWCP 0400 0 Clear bit 10 ok Open Loop Detection Bit
OLF3 RWCP 0800 0 Clear bit 11 ok Open Loop Detection Bit
DPM0 RWCP 1000 0 Clear bit 12 ok DPM Status Bit
DPM1 RWCP 2000 0 Clear bit 13 ok DPM Status Bit
DPM2 RWCP 4000 0 Clear bit 14 ok DPM Status Bit
DPM3 RWCP 8000 0 Clear bit 15 ok DPM Status Bit
FAULT1 0x66 RWCP 16 0x0010 0x0010 ▸ FAULT1
IND0 RWCP 0001 0 Clear bit 0 ok Bit is set if measured inductance was not compliant according to Excitation H...
IND1 RWCP 0002 0 Clear bit 1 ok Bit is set if measured inductance was not compliant according to Excitation H...
IND2 RWCP 0004 0 Clear bit 2 ok Bit is set if measured inductance was not compliant according to Excitation H...
IND3 RWCP 0008 0 Clear bit 3 ok Bit is set if measured inductance was not compliant according to Excitation H...
UVM RWCP 0010 1 Clear bit 4 fault Bit is set if under voltage was detected. Is active after IC startup
COMER RWCP 0020 0 Clear bit 5 ok Bit is set if communication error is detected
OVT RWCP 0040 0 Clear bit 6 ok Bit is set if over temperature was detected
RES0 RWCP 0080 0 Clear bit 7 ok Bit is set if measured resistance exceeeds R_THLD value of according channel.
RES1 RWCP 0100 0 Clear bit 8 ok Bit is set if measured resistance exceeeds R_THLD value of according channel.
RES2 RWCP 0200 0 Clear bit 9 ok Bit is set if measured resistance exceeeds R_THLD value of according channel.
RES3 RWCP 0400 0 Clear bit 10 ok Bit is set if measured resistance exceeeds R_THLD value of according channel.

Solenoid Sequencer

- All levels can be controlled in voltage or current
- RAMP control for all ramp sections
- HSnLS only in Single-Ended Configuration
- Fast Demagnetisation (DC_H2L and H2L_EN) only in Full-Bridge



Current and PWM Channel Configuration

ANALOG DEVICES

- I_MONITOR – Channel Current
- SNSF and GAIN – Current Scaling

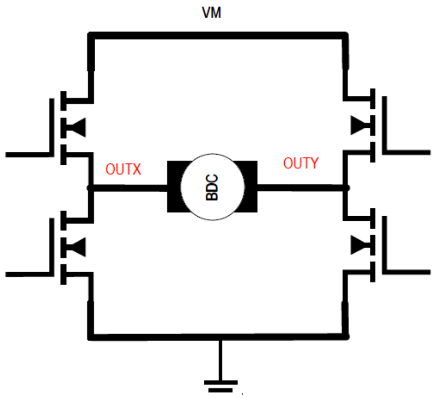
- F_PWM – Channel PWM Divider (up to 1/8)
- PWM_DUTYCYCLE – Ouput Dutycycle

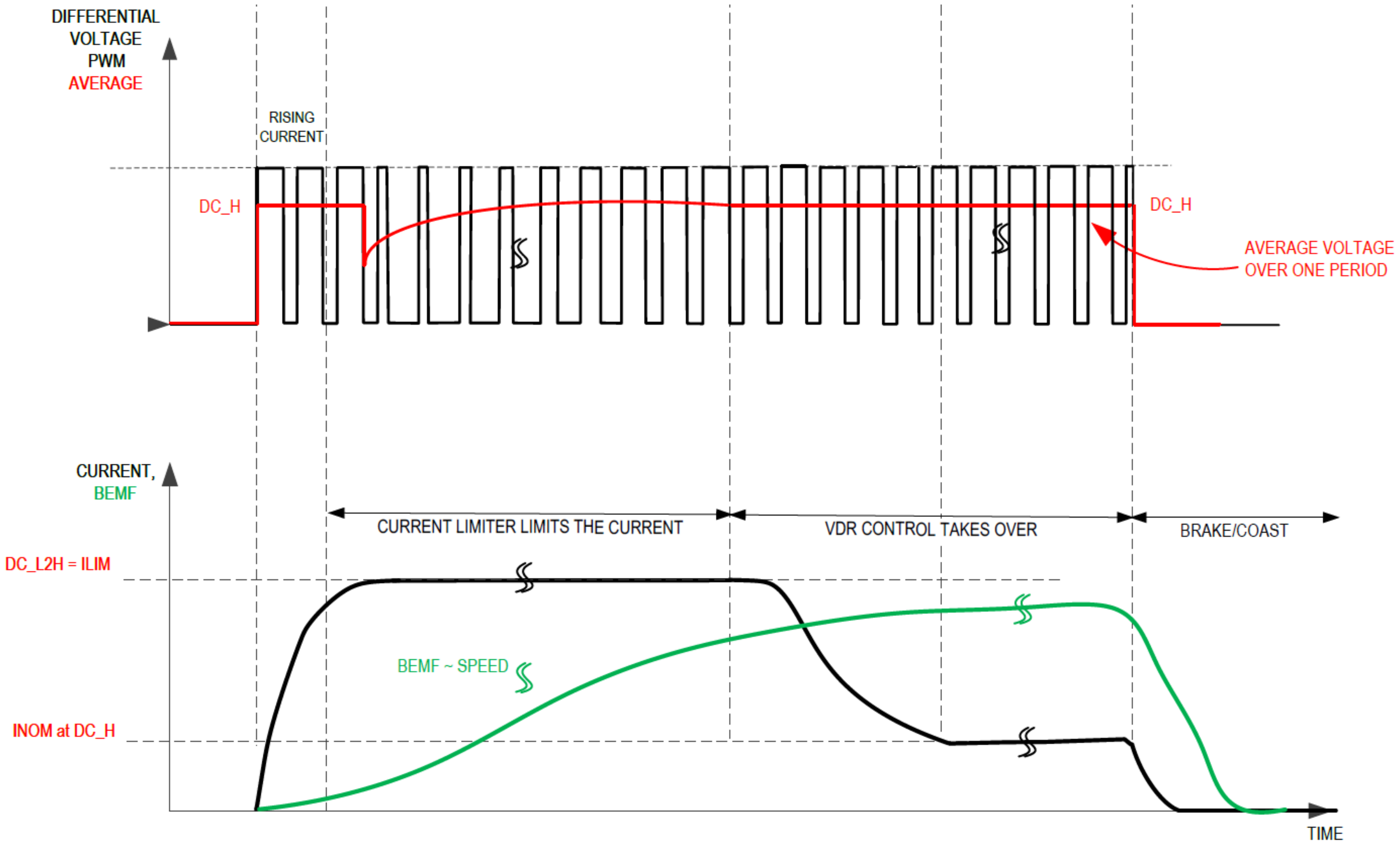
Full Scale and Sense Scale

GAIN [1:0]	GAIN	SNSF [1:0]	SNSF	TYP. LS R_{ON} (Ω)	TOTAL FACTOR	MULTIPLIER	MAX CURRENT (A)
00	1	00	1	0.17	1	1.00	4.165
01	1/2				1/2	0.5	2.082
10	1/3				1/3	0.333	1.388
11	1/4				1/4	0.25	1.041
00	1	01	2/3	0.23	2/3	0.667	2.776
01	1/2				2/6	0.333	1.388
10	1/3				2/9	0.222	0.925
11	1/4				2/12	0.167	0.694
00	1	10	1/3	0.43	1/3	0.333	1.388
01	1/2				1/6	0.167	0.694
10	1/3				1/9	0.111	0.463
11	1/4				1/12	0.083	0.347

CFG_CTRL1_0 0x0E	RWP	16	0x0000	0x0000		‣ CFG_CTRL1
SNSF	RWP	0003	id: 0	Choice	0: IFS	Sets the Sense Scaling Factor
GAIN	RWP	000C	id: 0	Choice	0: 1	Sets a a digital GAIN for the Current Driver Regulation (CDR)
SLEW_RATE	RWP	0030	id: 0	Choice	0: Fast	Slew rate control bits
T_BLANKING	RWP	00C0	id: 0	Choice	0: 0us	Defines an additional blanking time for current measurement.
F_PWM	RWP	0300	id: 0	Choice	0: F_P...	Defines the PWM frequency that is used for the channel. See Table 5
HSNLS	RWP	0400	0	Set bit 10	LS	HS/LS: Bit Single Ended Mode Only
I_MONITOR_0 0x45	R	16	0xFFFF			‣ I_MONITOR
I_MONITOR	R	FFFF	-1			I_MONITOR Istantaneous current sampled Current sampled. Returnes ...

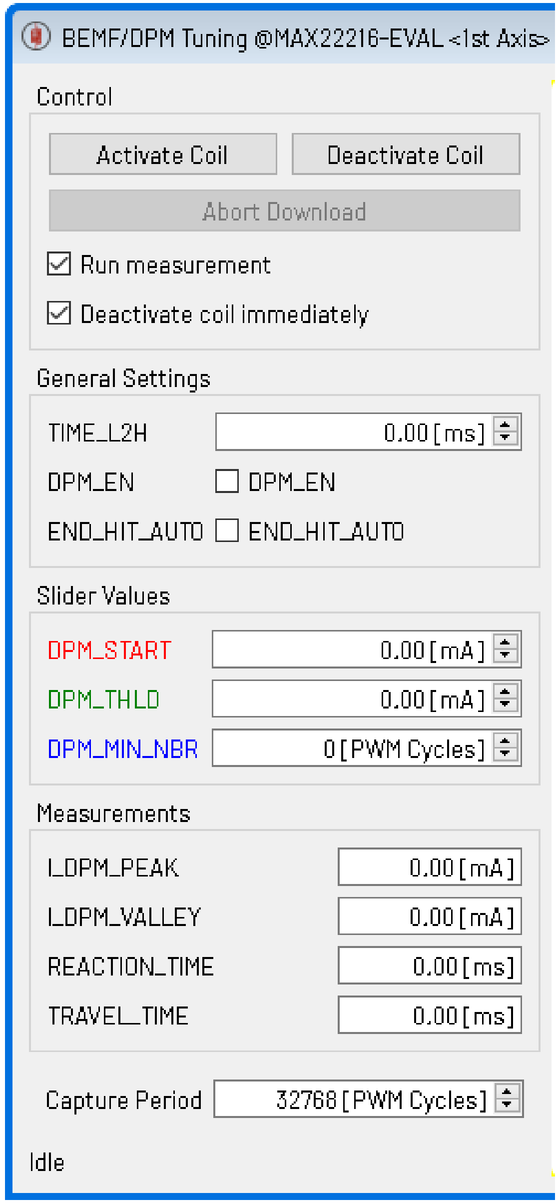
DC Motor Drive

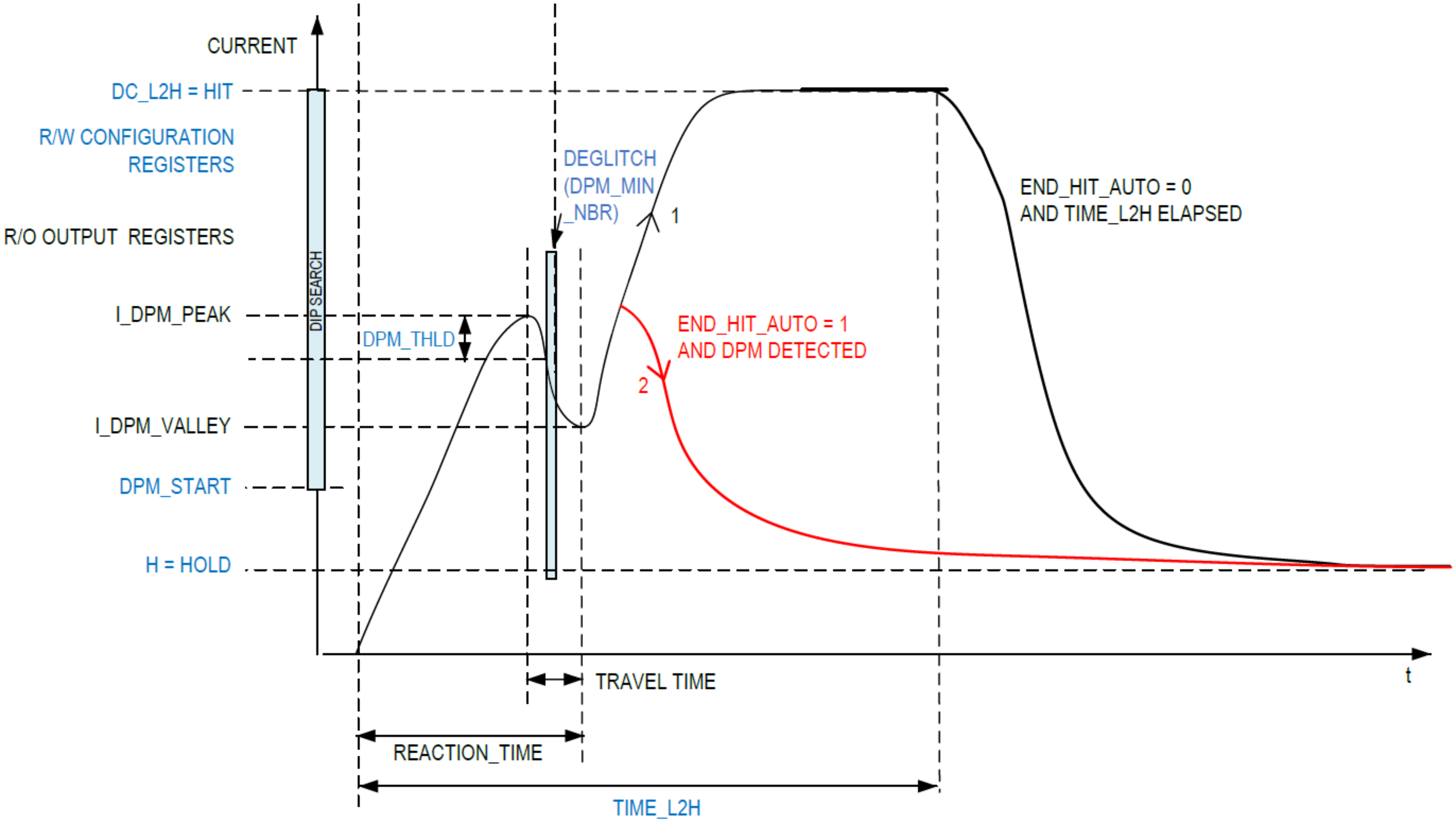




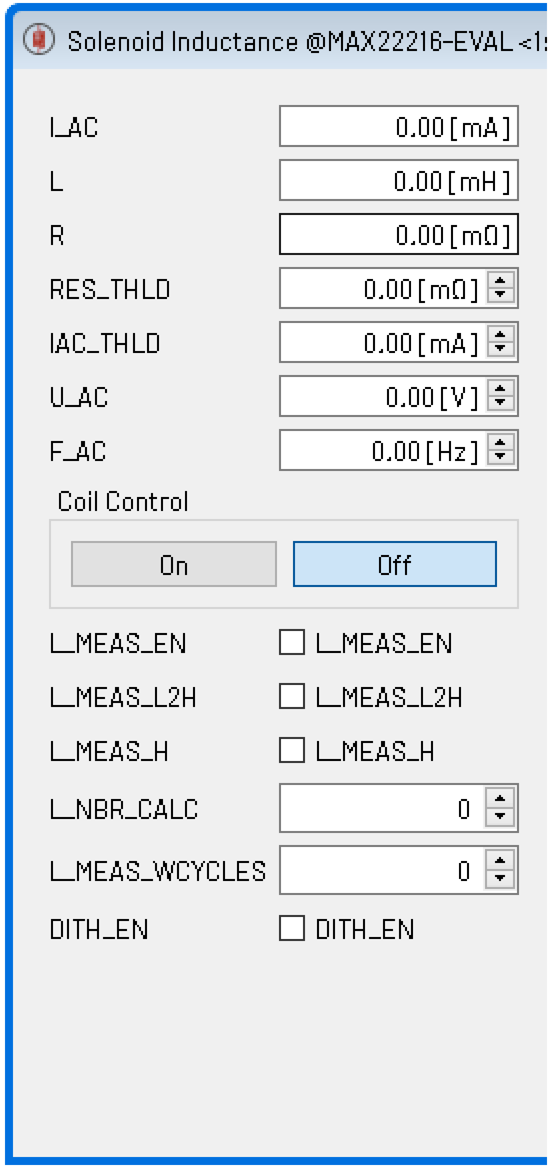
- CDR to limit inrush current
- VDR for easy control
- TIME_L2H is a BRAKE

BEMF/DPM Tuning – Detection of Plunger Movement

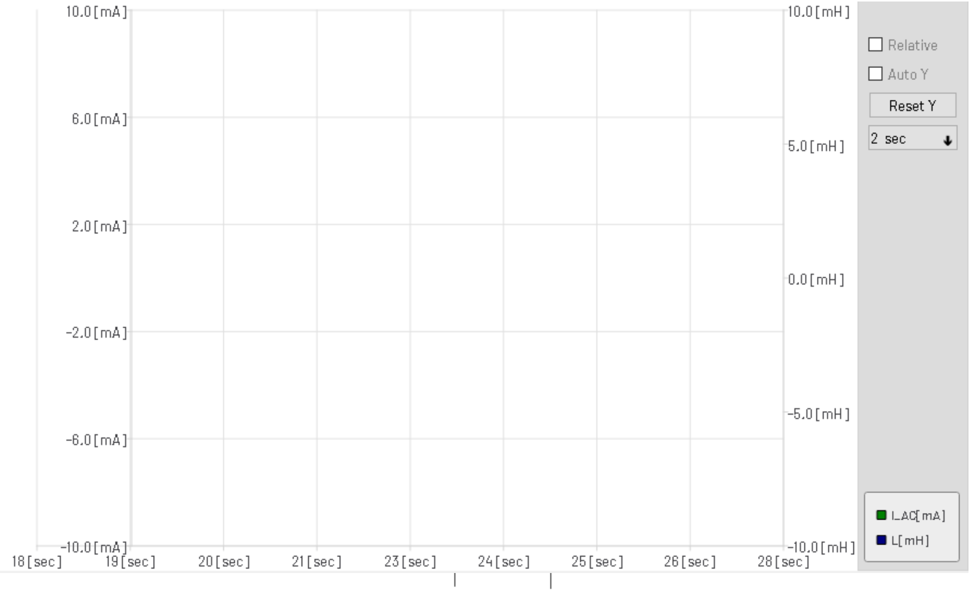


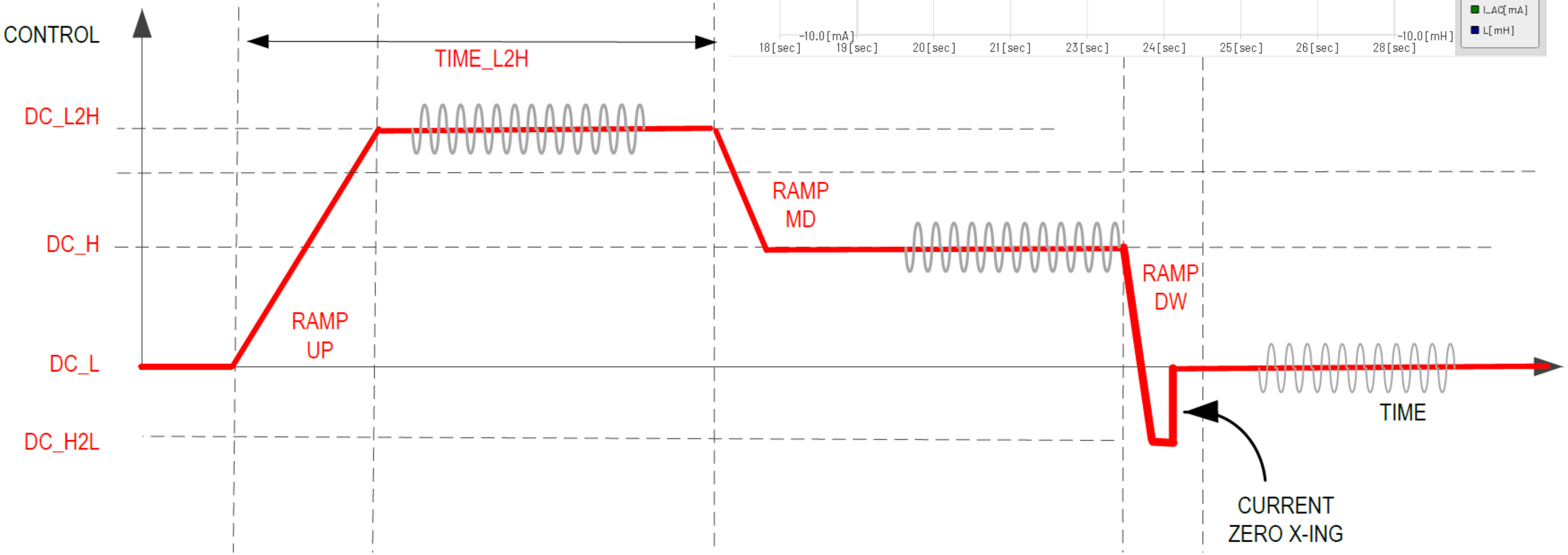


Solenoid Inductance



- I_AC is used to calculate L
- L – Solenoid Position
- R – Coil Temperature
- RESc_THLD and IAC_THLD can be set as alarms





Settable Faults

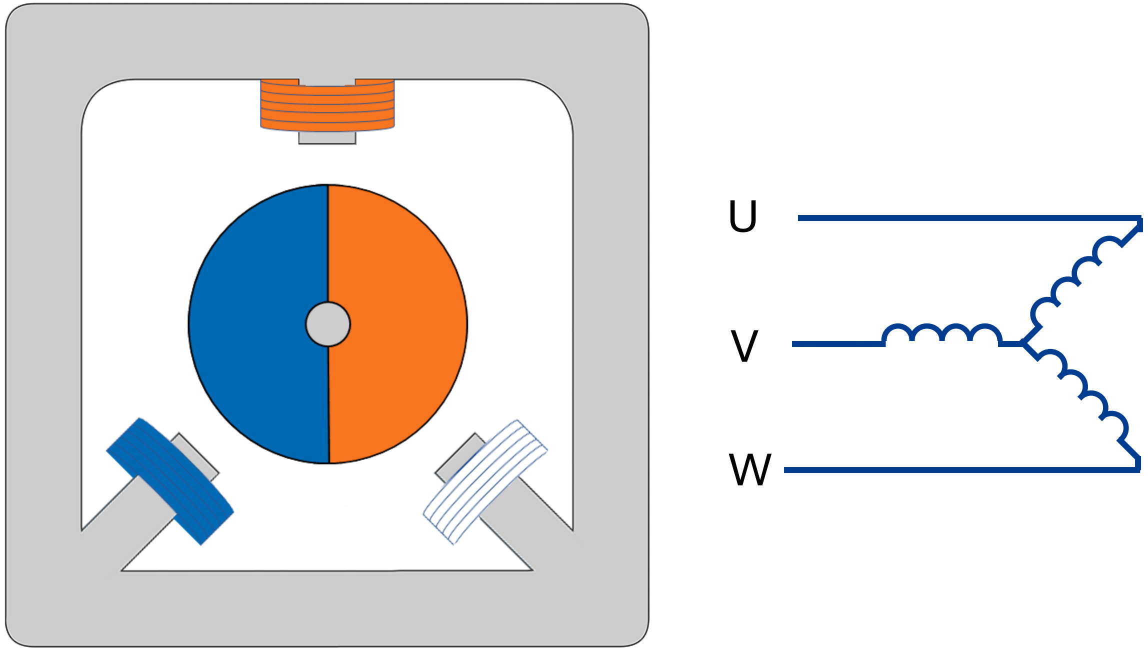
- Open-Load Detection (OL)
- Hit current not reached Alarm (HHF) - CDRc

Active registers						
CFG_CTRL0_0 0x0D	RWP	16	0x0000	0x0000		▸ CFG_CTRL0
RAMP	RWP	00FF	0	Unsigned		Sets the Ramp up Slew Rate
RUPE	RWP	0100	☐ 0	▣ Set bit 8	disabled	Ramp UP enable
RMDE	RWP	0200	☐ 0	▣ Set bit 9	disabled	Ramp Mid Enable bit
RDWE	RWP	0400	☐ 0	▣ Set bit 10	disabled	Ramp Down Enable bit
H2L_EN	RWP	0800	☐ 0	▣ Set bit 11	disabled	H2L Fast Demagnetization Enable bit. "1" enforces DC_H2L after CNTL H2L ...
OL_EN	RWP	1000	☐ 0	▣ Set bit 12	disabled	Open Load Circuit Enable (enable pull up/dw)
HHF_EN	RWP	2000	☐ 0	▣ Set bit 13	disabled	Current not reached Fault detection
CTRL_MODE	RWP	C000	id: 0	Choice	0: VDR/...	Control mode setting
I_MONITOR_0 0x45	R	16	0x0001			▸ I_MONITOR
I_MONITOR	R	FFFF	1			I_MONITOR Istantaneous current sampled Current sampled. Returnes Late...

Software Platform (BLDC)

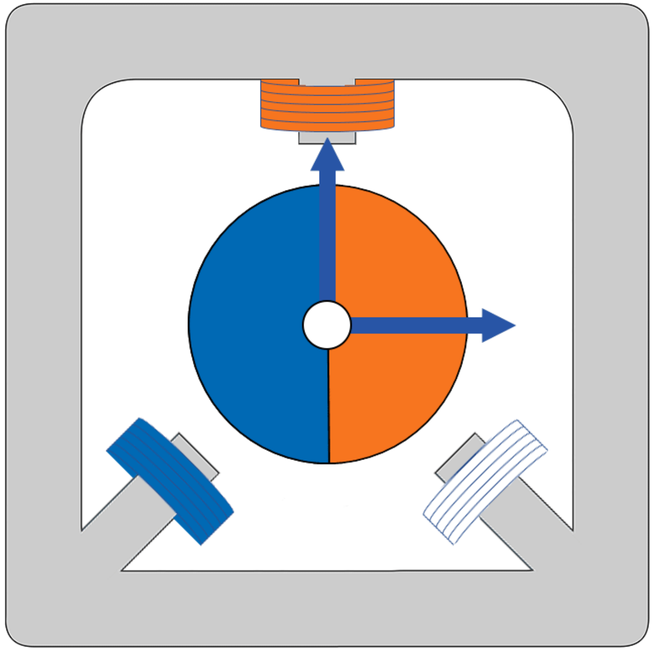
3-phase BLDC Motor

- **Basics:**
  - Three motor phases : U, V, W
- Sequential energizing:
  - Coils need to be energized in a specific sequence
- **Benefits**:
  - High velocity
  - Precise RPM control



Field Oriented Control (FOC)

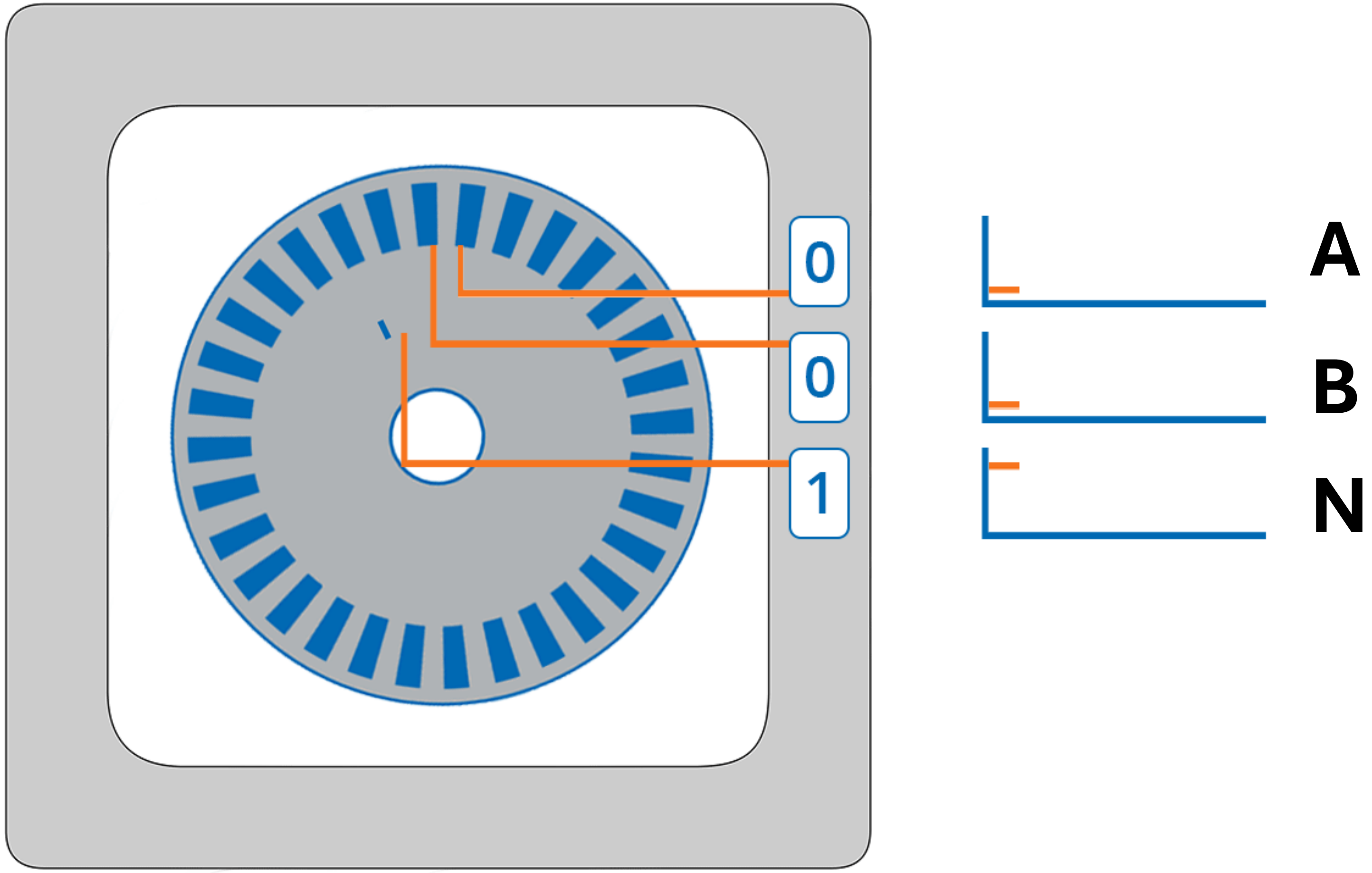
- **What is FOC:**
  - A method to apply the optimal current to the coils.
- **What is needed for FOC:**
  - We need to know the rotor position. Feedback required.
- **What is a Torque (Current):**
  - A coil current that pulls the motor into the turning direction.
- **What is a Flux (Current):**
  - A coil current that pulls the motor into the current angle position.



ABN - ENCODER

When to use:

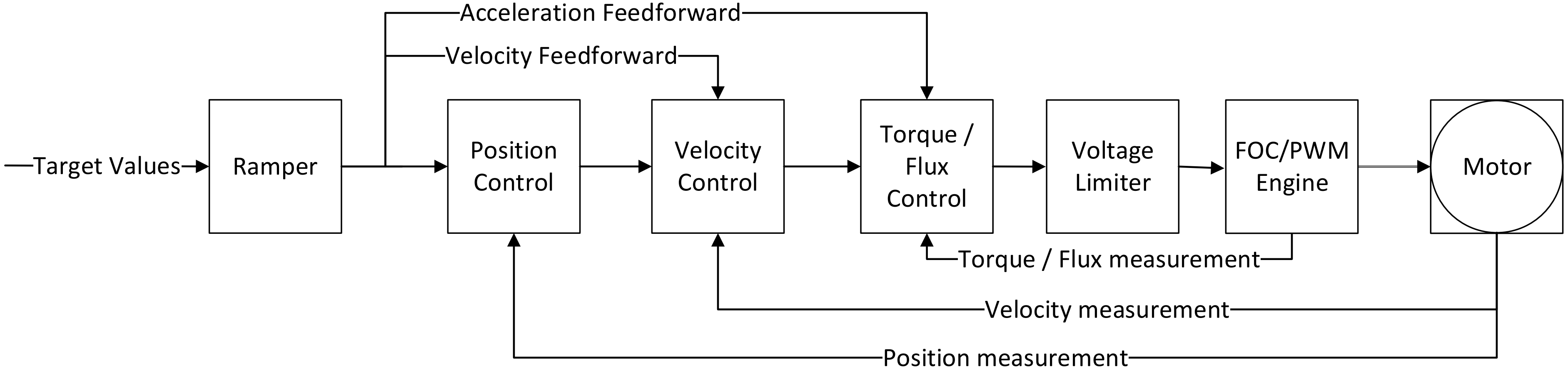
- High resolution
- Every motor type
- Initialization required



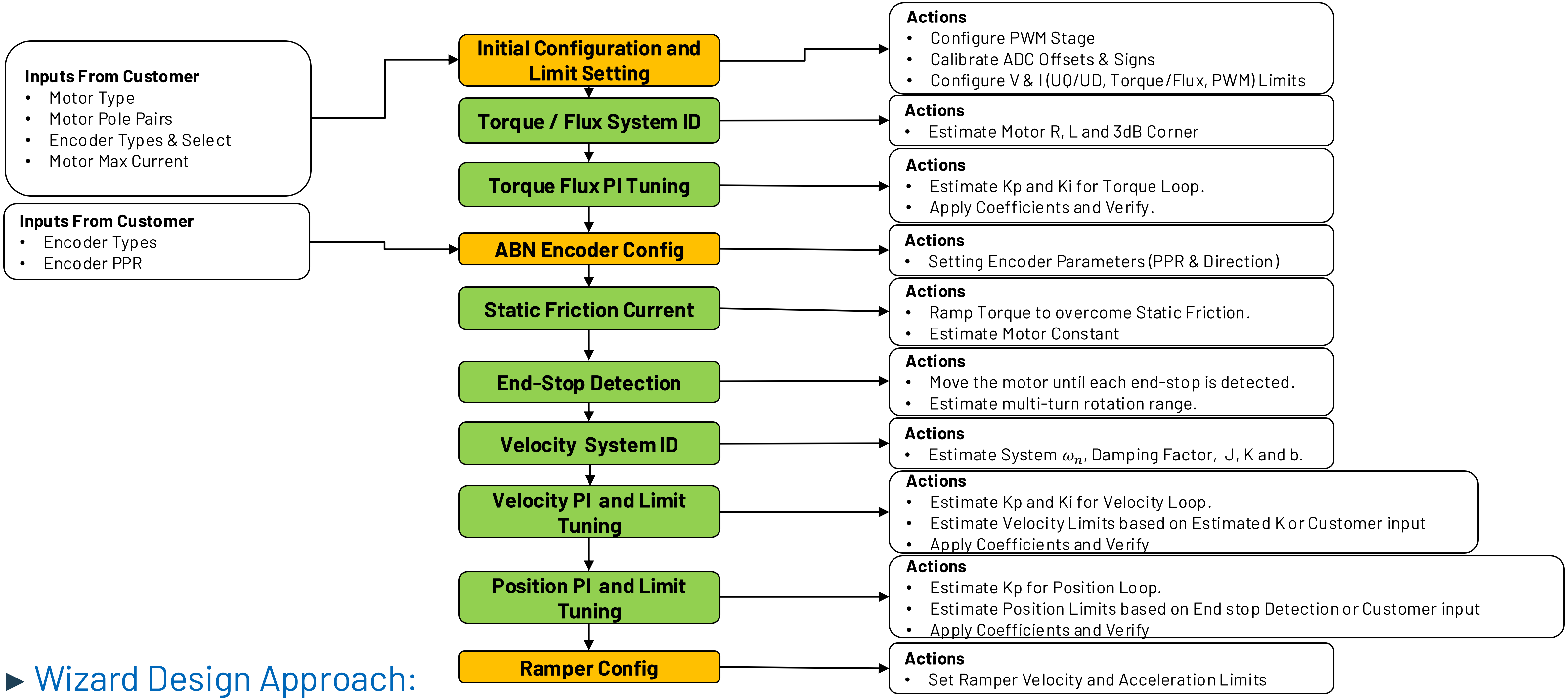
TMC9660: Motor Control Structure

Control Structure Includes:

- Cascaded control system
  - Torque / Flux Controller
  - Velocity Controller
  - Position Controller
- Further Info:
  - TMC9660 Parameter Mode Reference Manual

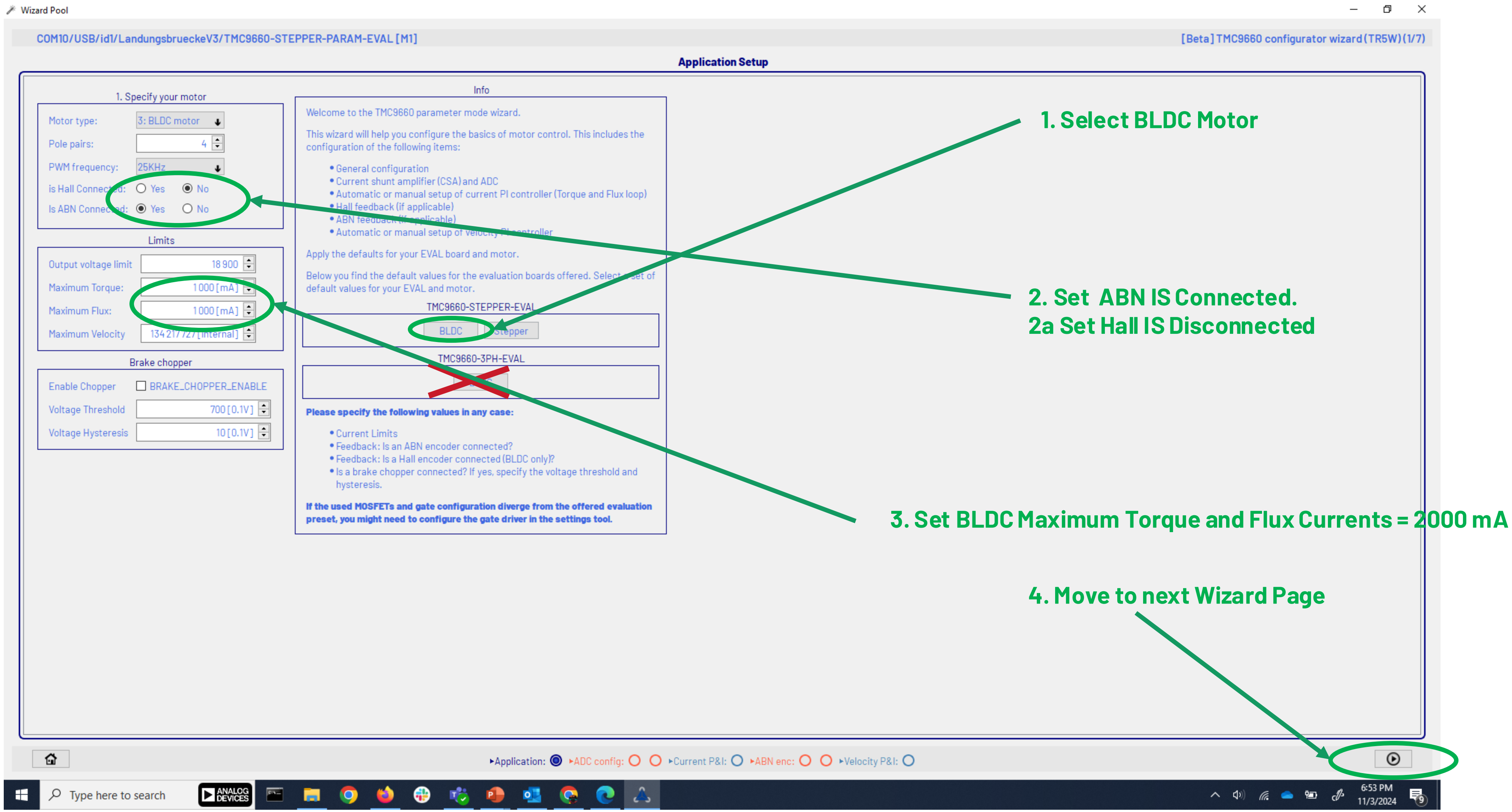


TMCL-IDE Brushless Motor Control Auto Tuning Flow

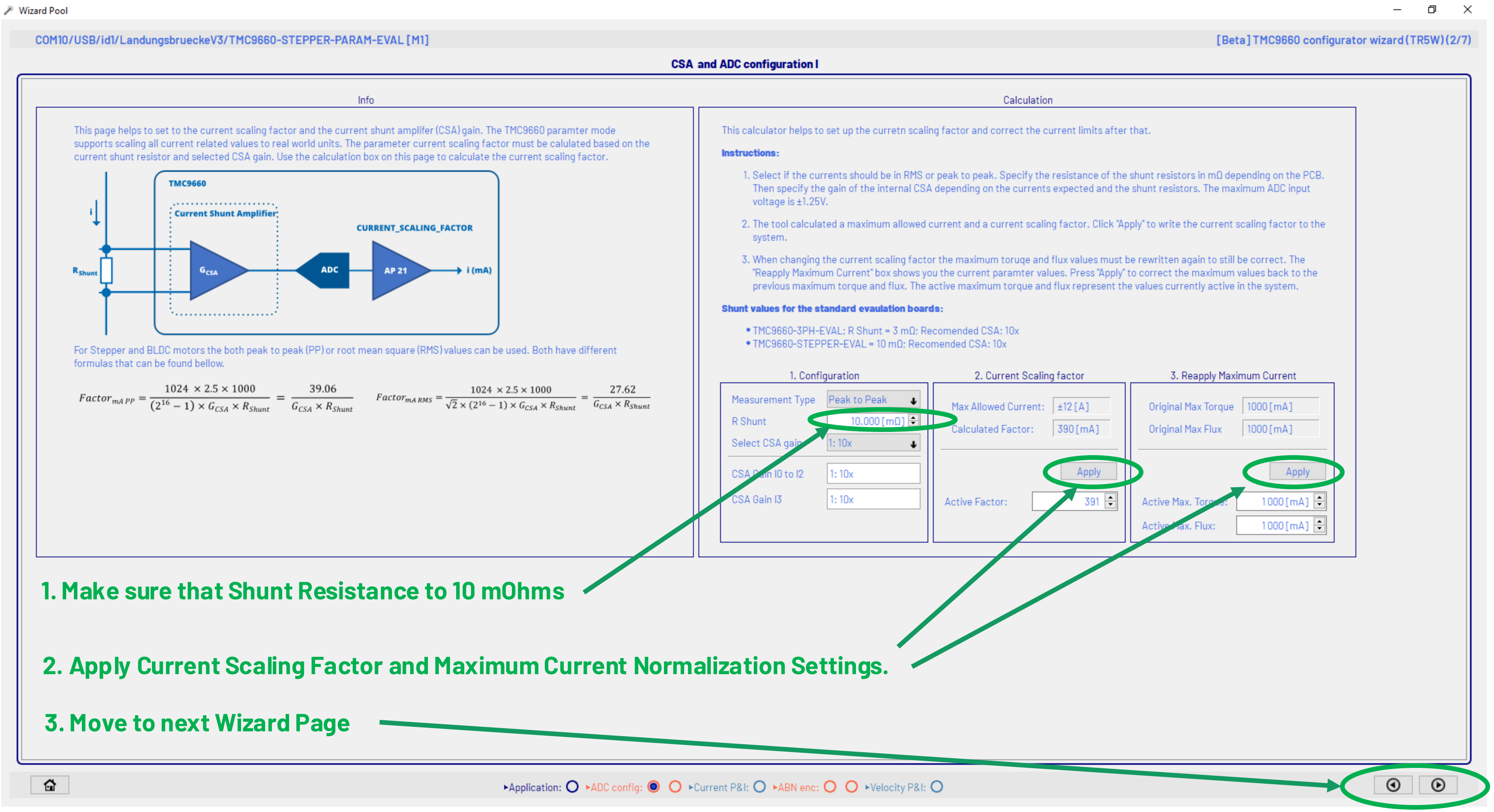


- Wizard Design Approach:
  - Assume Minimal Customer Input – System does most of the work.
  - At each step in the process, the system learns more about the Motor and Mechanical System.
  - Customers can repeat and iterate on individual steps as required.

Setup TMC9660 for BLDC Motors



Shunt and Current Sense Amplifier (CSA) Configuration.



$$Factor_{mA\,PP} = \frac{1024 \times 2.5 \times 1000}{(2^{16}-1) \times G_{CSA} \times R_{Shunt}} = \frac{39.06}{G_{CSA} \times R_{Shunt}}$$

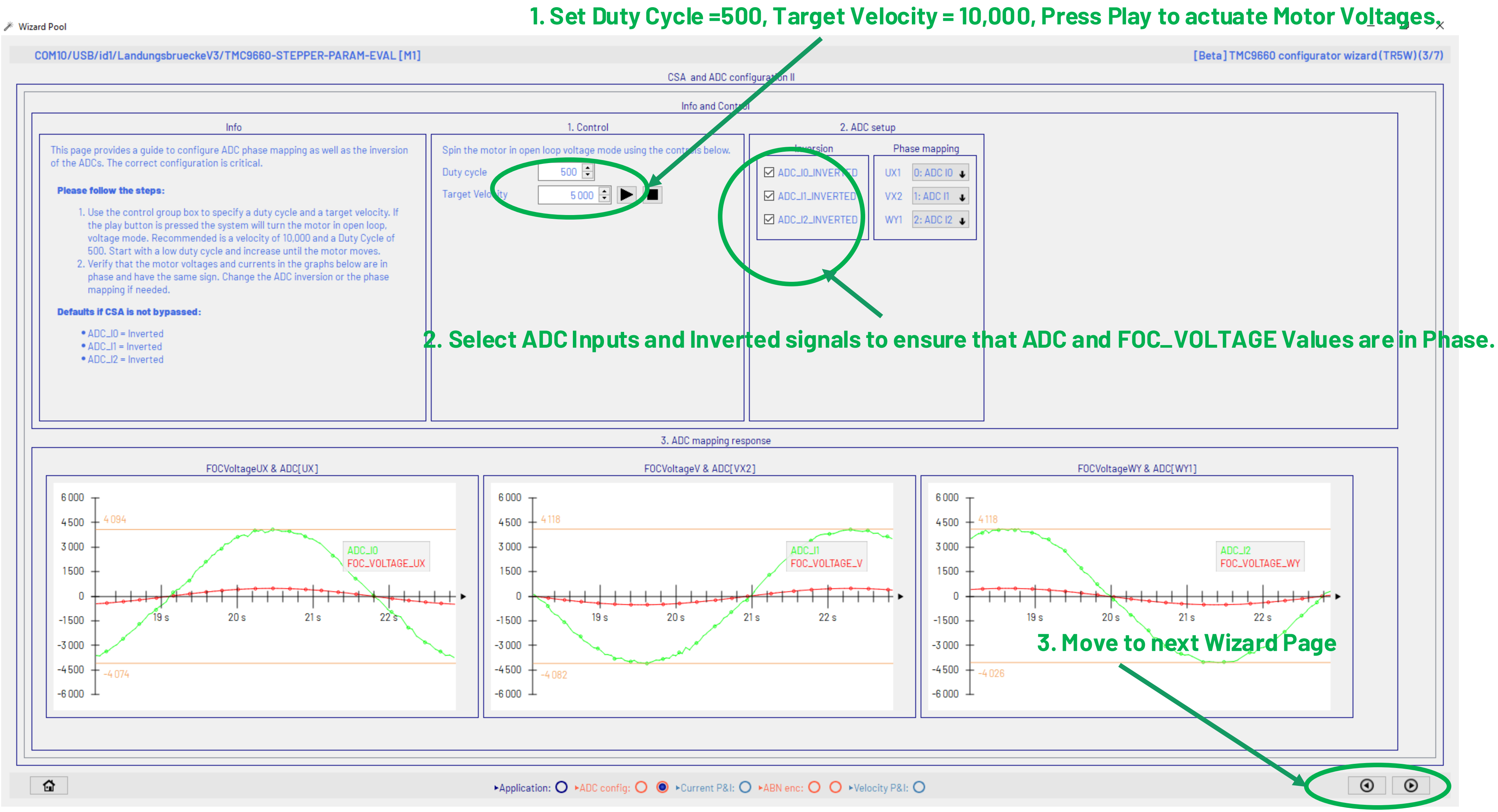
$$Factor_{mA\,RMS} = \frac{1024 \times 2.5 \times 1000}{\sqrt{2} \times (2^{16}-1) \times G_{CSA} \times R_{Shunt}} = \frac{27.62}{G_{CSA} \times R_{Shunt}}$$

1. Make sure that Shunt Resistance to 10 mOhms

2. Apply Current Scaling Factor and Maximum Current Normalization Settings.

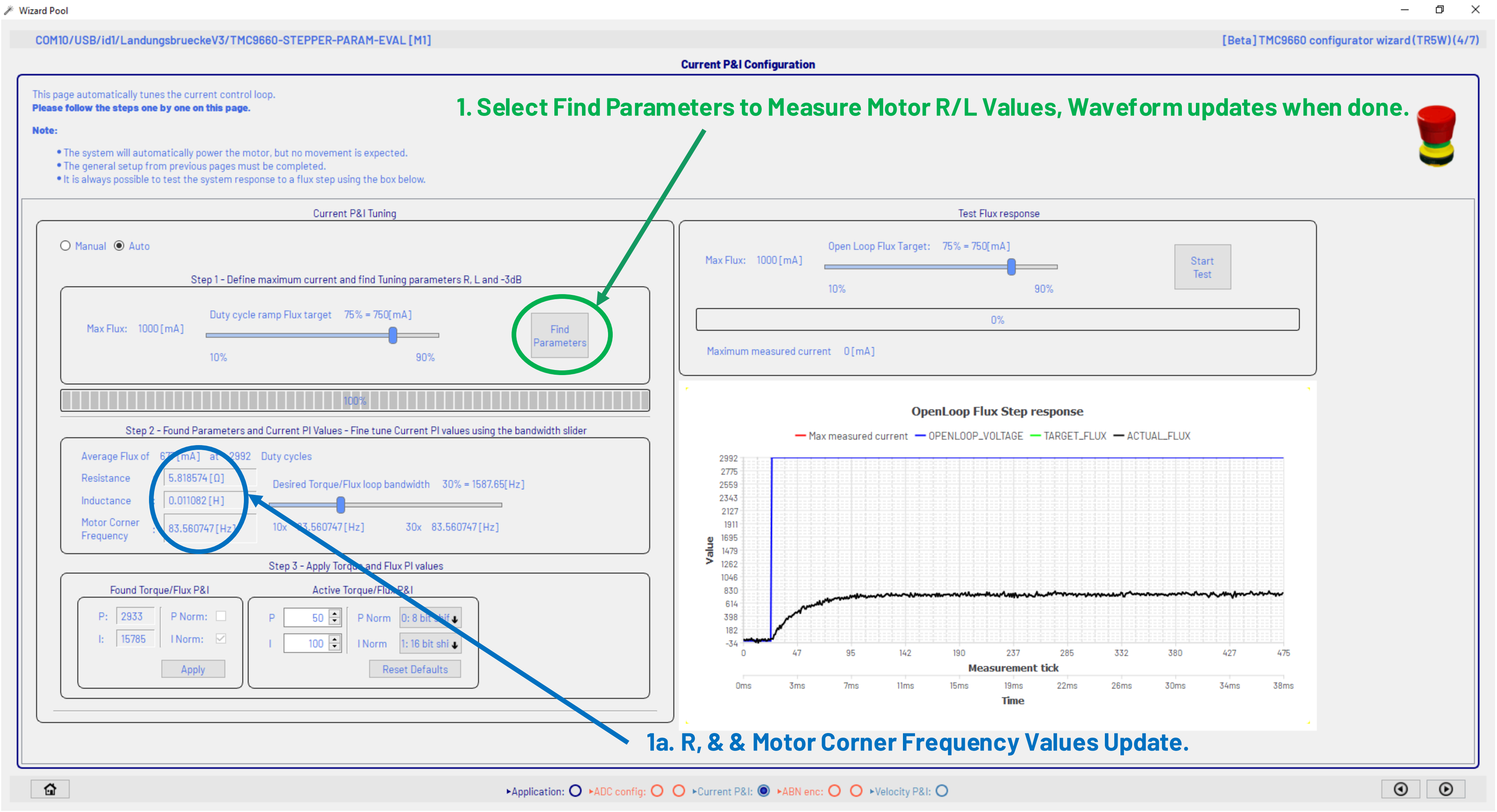
3. Move to next Wizard Page

ADC Inversion Configuration & Test - BLDC Motor

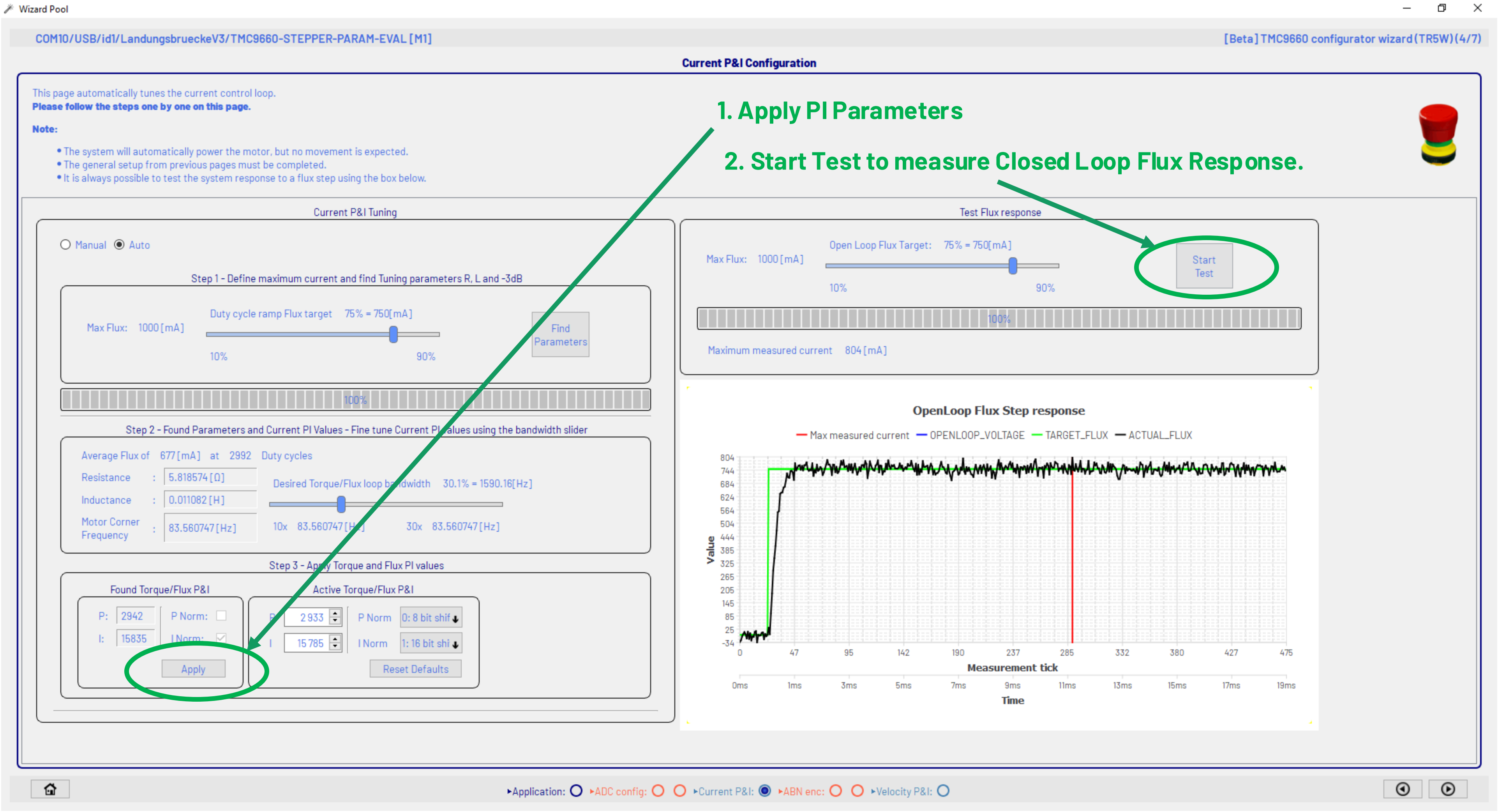


Current Loop System Identification and Tuning

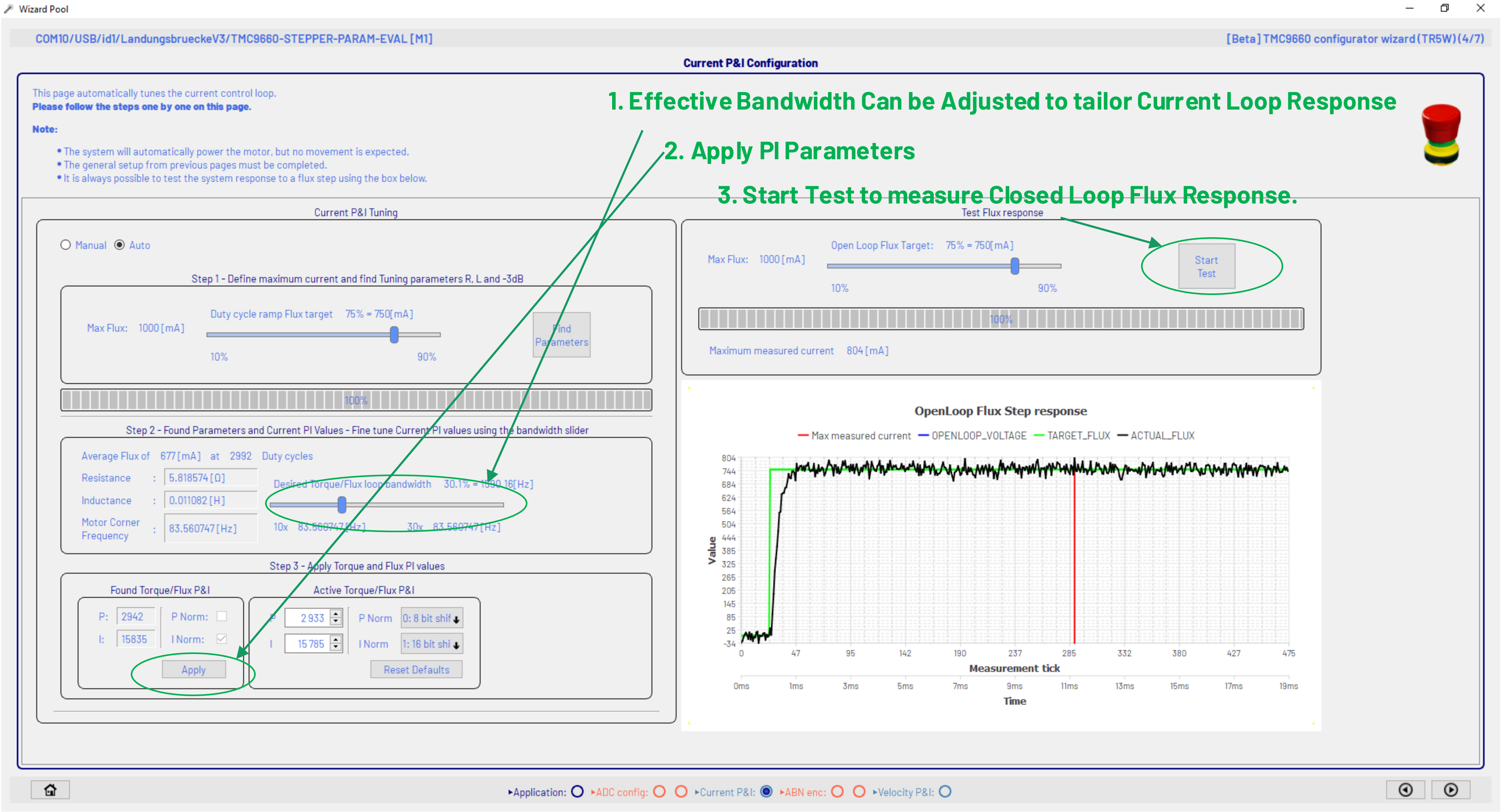
- Perform Motor R, L System Identification



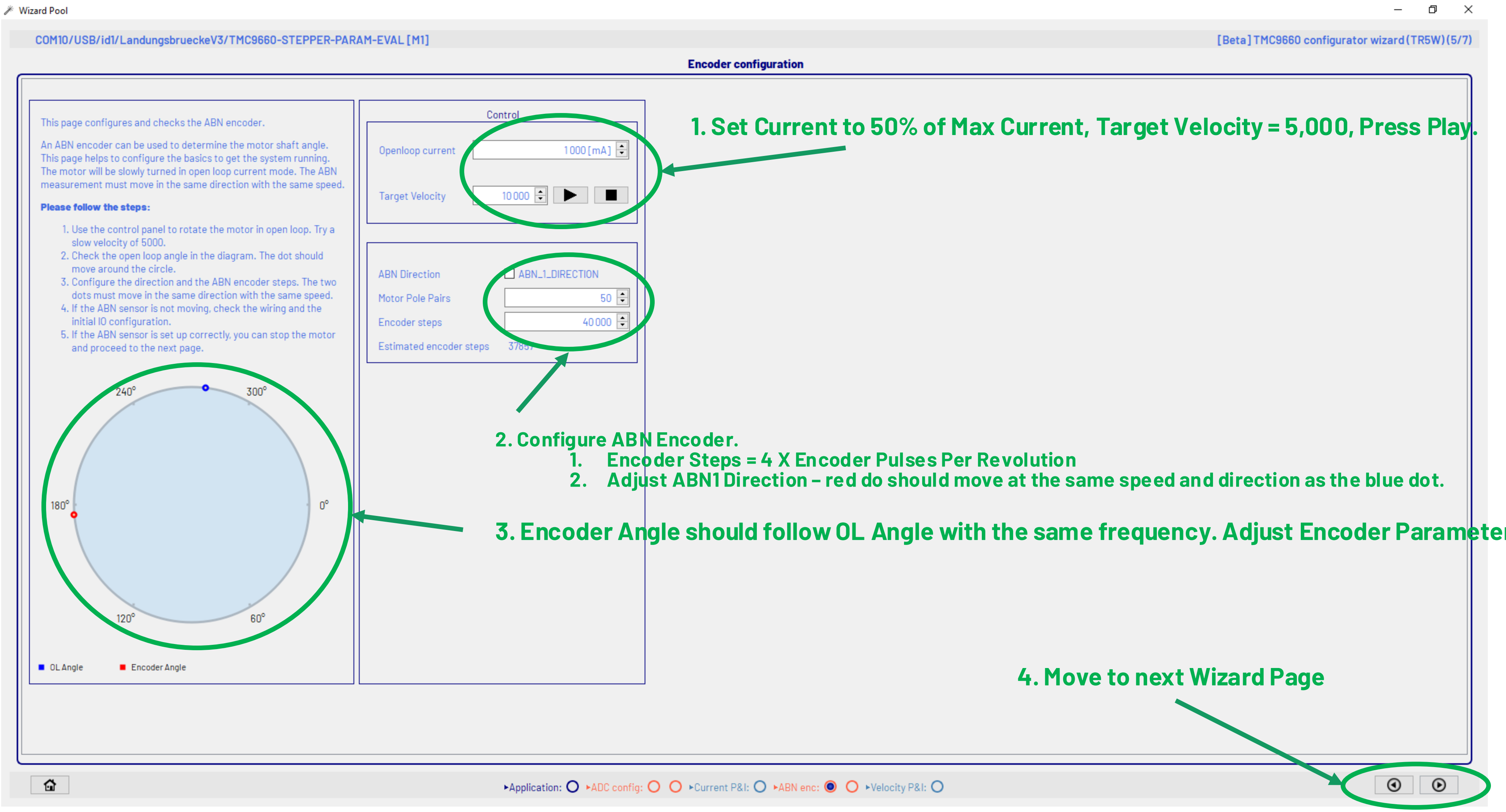
Apply PI (Proportional-Integral) Tuning Values and Test Flux Current Loop



Optional: Adjust Current Loop Bandwidth



Configure and Test ABN Encoder Setup



1. Set Current to 50% of Max Current, Target Velocity = 5,000, Press Play.

2. Configure ABN Encoder.
   1. Encoder Steps = 4 X Encoder Pulses Per Revolution
   2. Adjust ABN1 Direction – red do should move at the same speed and direction as the blue dot.

3. Encoder Angle should follow OL Angle with the same frequency. Adjust Encoder Parameters if Needed.

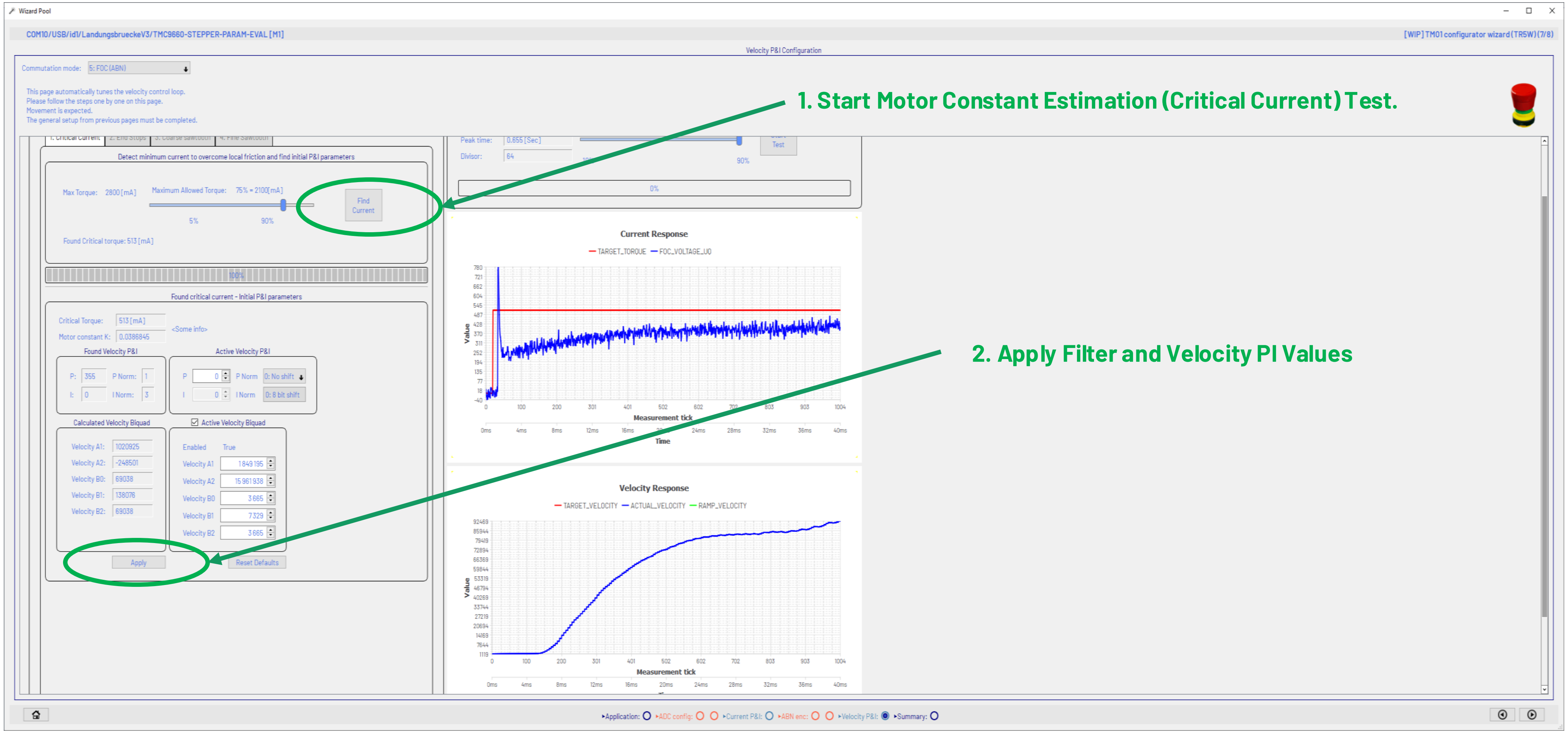
4. Move to next Wizard Page

Test Closed Loop Torque Loop

NOTE: Do not do this with an End-Stopped System.

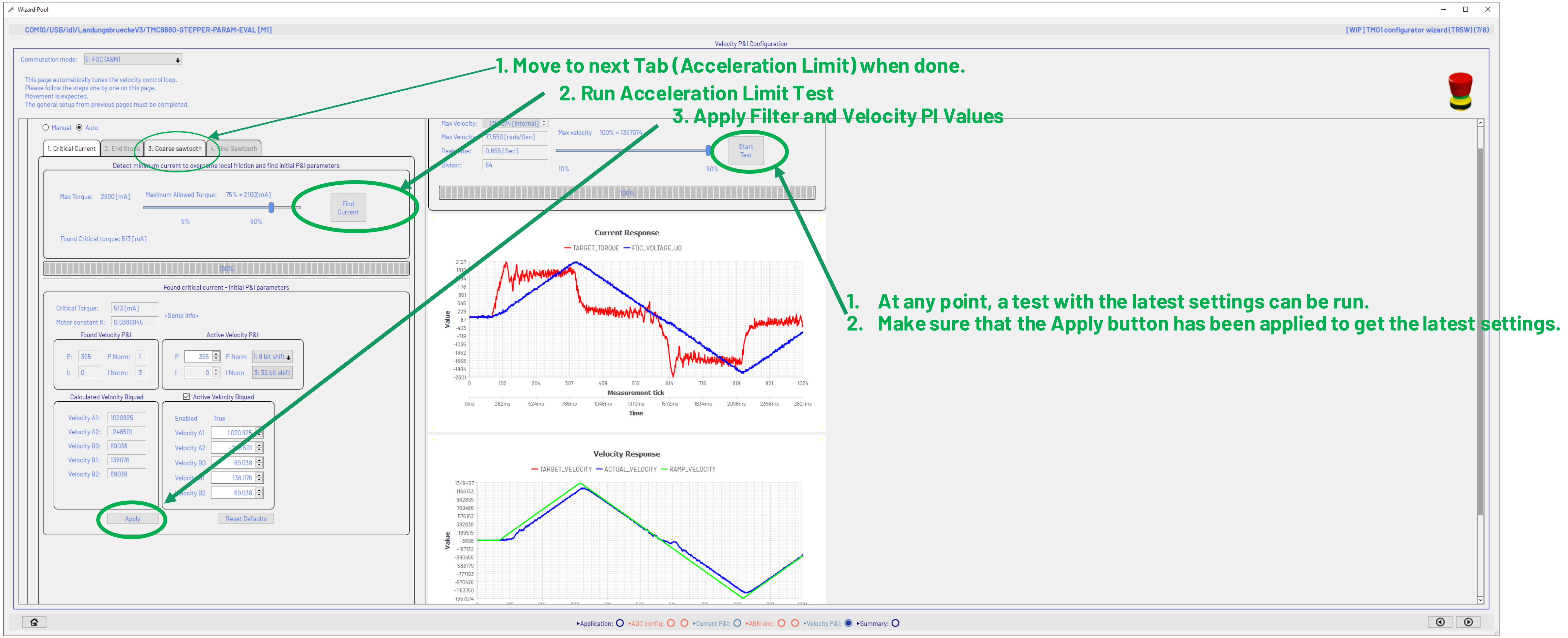
Velocity & Position Loop System Identification & PI Tuning

Step #1: Detect Static Friction Current and Initial Motor Constant Estimation.

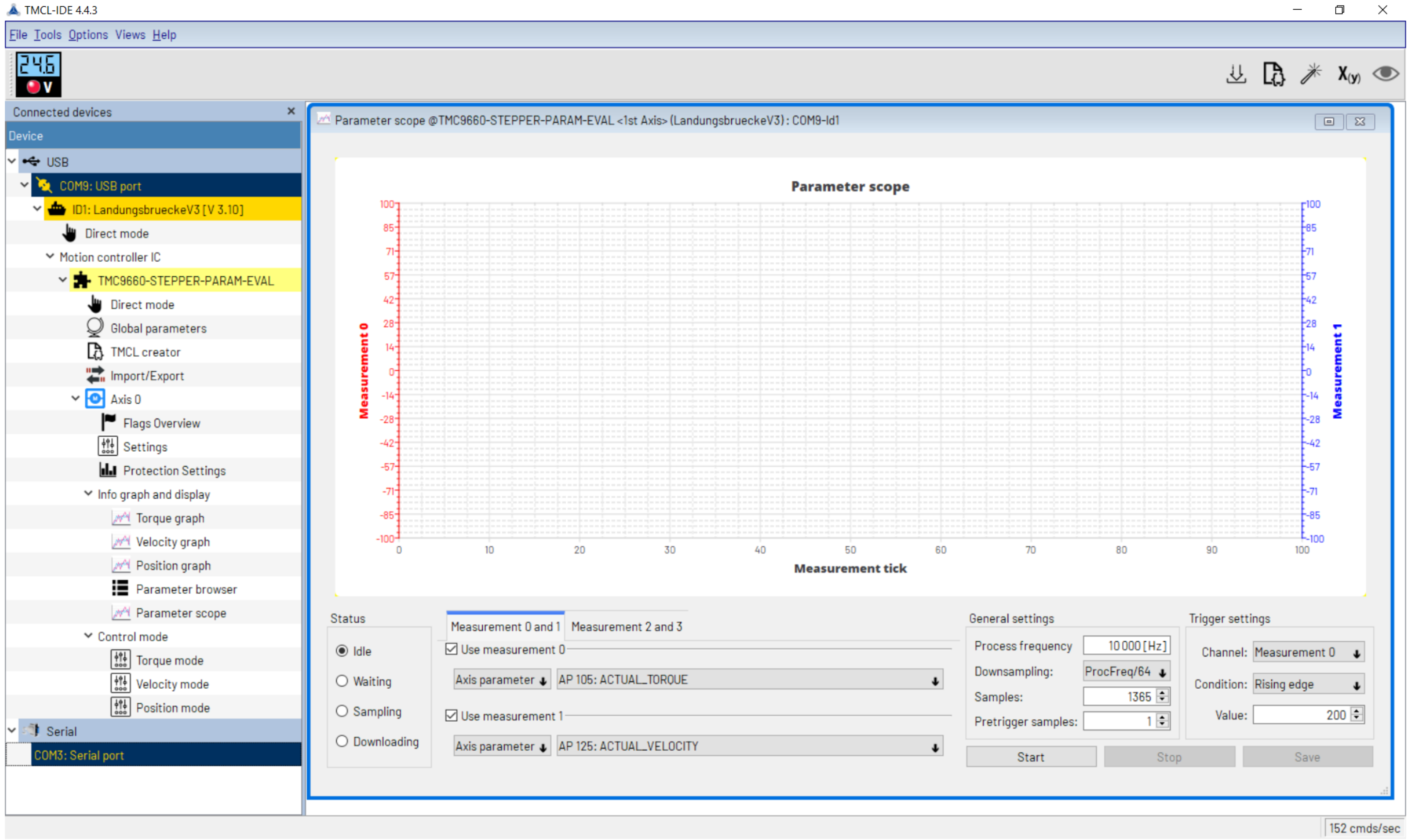


Velocity & Position Loop System Identification & PI Tuning

Step #2: Acceleration Limit Estimation – Matches Target Velocity Acceleration Profile to Load Response.

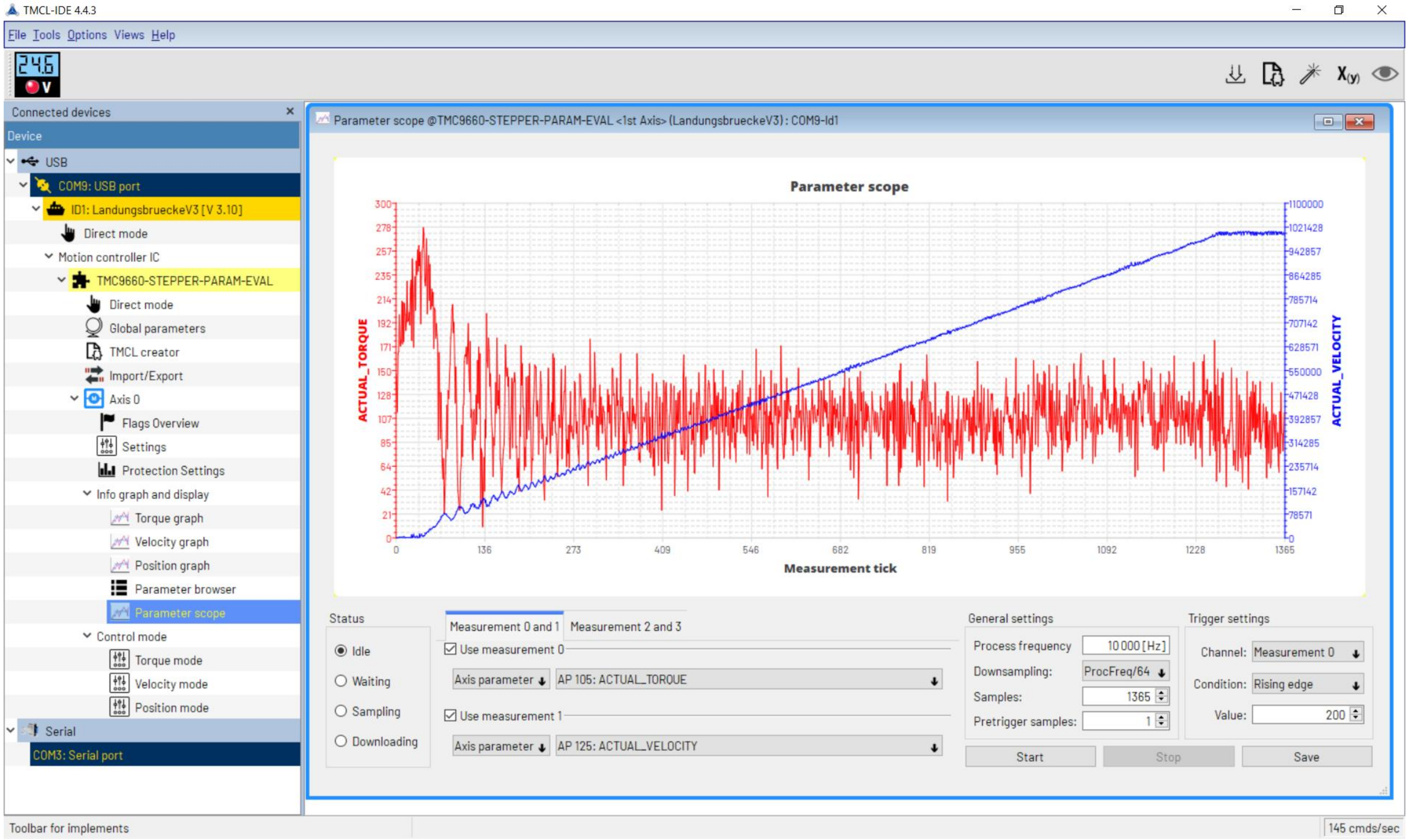


RAMDebug: TMCL-IDE tool



- Measurement mechanism available in various ADI Trinamic products
- On-chip data acquisition
- 4 measurement channels
- Up to 25 kHz sampling frequency
- Edge-based trigger mechanism
- TMC9660: Up to 8192 total samples

RAMDebug: Measurement result



AHEAD OF WHAT'S POSSIBLE

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Presentation Feedback