Industrial & IoT Motor Control Overview

BL SCE

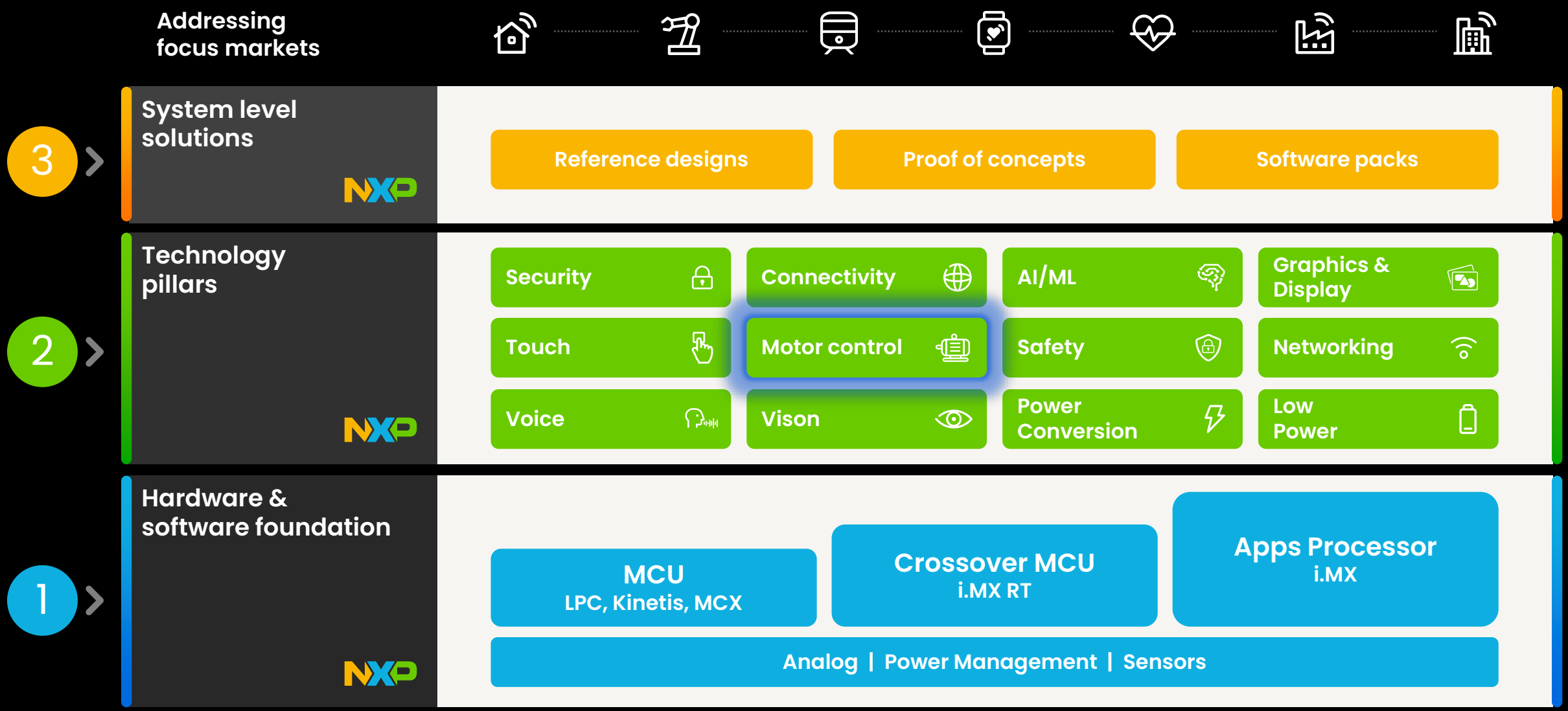
Consider the complexity factors

Then

Now

1. The hardware foundation
2. Technology requirements
3. Application level software development

Cut through complexity and scale with NXP technology pillars



Motor Control – horizontal technology covering various vertical markets

Addressing focus markets							
System level applications	Garage door	Servo robot	Drone	Construction tool	Medical pump	Washer / dryer	HVAC & Compressor
	Smart doorlock	AGV / AMR	Mobile robot	Handheld tool	Surgical robot	Refrigerator	Fan
	Window shade	AC drive	E-bike	Pump / Blower	Patient lift	Vacuum cleaner	Printer
Motor control	Brushed DC	Stepper	BLDC	PMSM	ACIM		

Efficient Drive
- Efficient control algorithm
- Emerging motor types

Low-power Systems
- Ultra-low voltage drives
- Battery-based systems

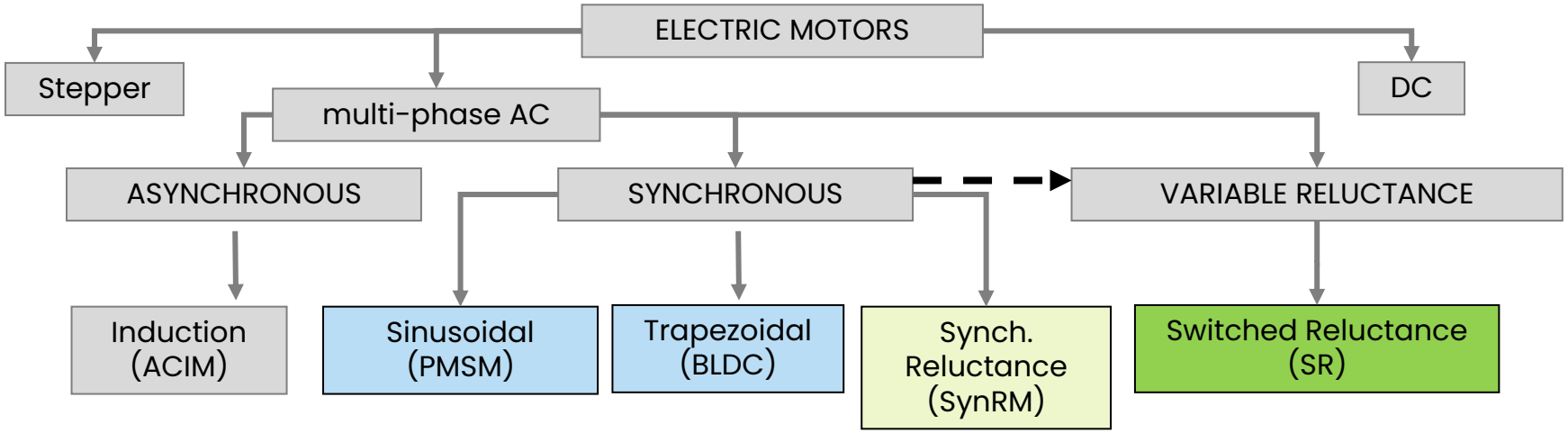
Synchronized Control
- Industrial networking
- Multi-axis motion control

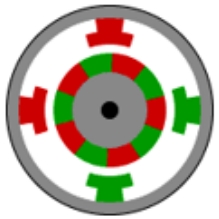
Safety & Security
- Functional safety
- Cyber security

Robustness
- Predictive maintenance
- Industrial qualified

Major motor types for industrial and IoT applications

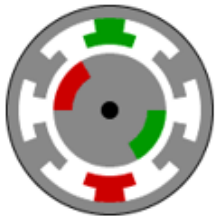
Electric Motor Type Classification





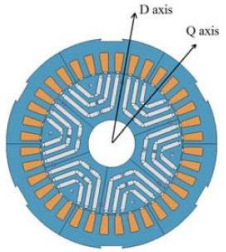
Stepper Motor

(ACIM)
AC Induction Motor



(BLDC)
Brushless DC Motor

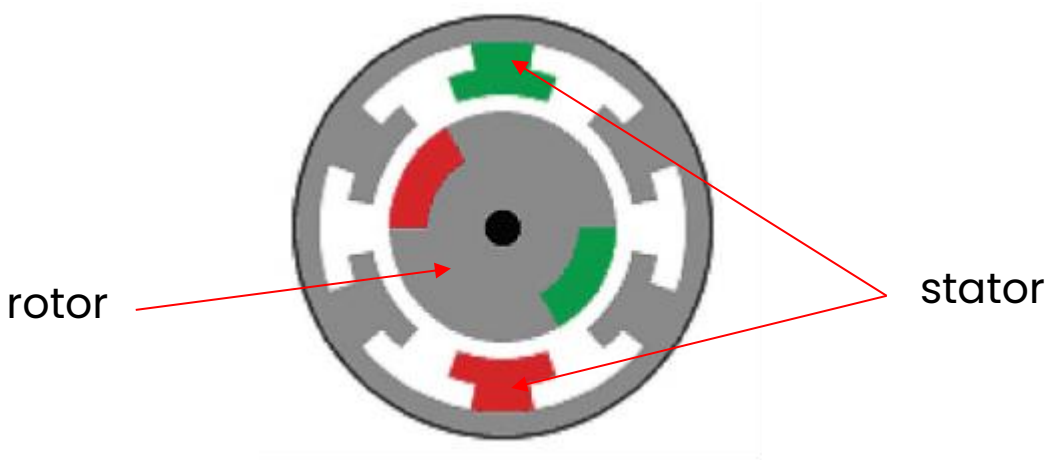
(PMSM)
Permanent Magnet
Synchronous Motor



(SynRM)
Synchronous
Reluctance Motor

(SR)
Switched
Reluctance Motor

Brushless DC (BLDC) Motor



BLDC motors consist of fixed stators containing stator windings, which surround a rotor with permanent magnets.

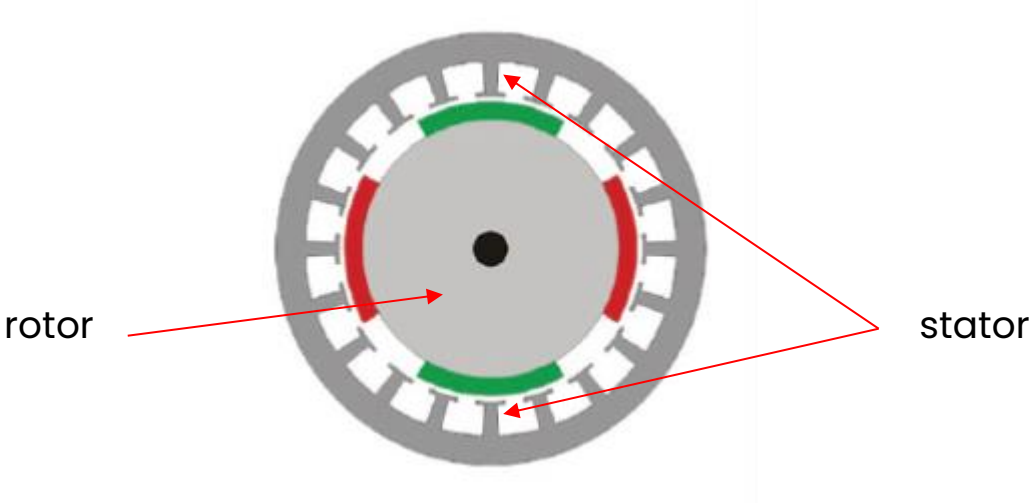
An electric current through the stator windings generates an EMF, which pushes and pulls the permanent magnet in the rotor, causing rotation.

Advantages
- Heat generated in stator is easy to dissipate
- High torque per frame size
- Reliability due to absence of brushes and commutator
- High efficiency
- High-speed performance
- Precise speed monitoring and control possible

Disadvantages
- Rotor position sensing required for commutation
- Torque ripple
- Position sensor or sensorless technique is required for motor operation
- Difficult to startup the motor for variable load using sensorless technique

Application examples
- Power tools
- Drones
- Compressors
- Vacuum cleaners
- Printers
- White goods
- Toys
- Fans
- Door openers
- Etc.

Permanent Magnet Synchronous Motor (PMSM)



Similar to BLDC motors, PMSM also consist of fixed stators containing stator windings which surround a rotor with surface-mounted permanent magnets.

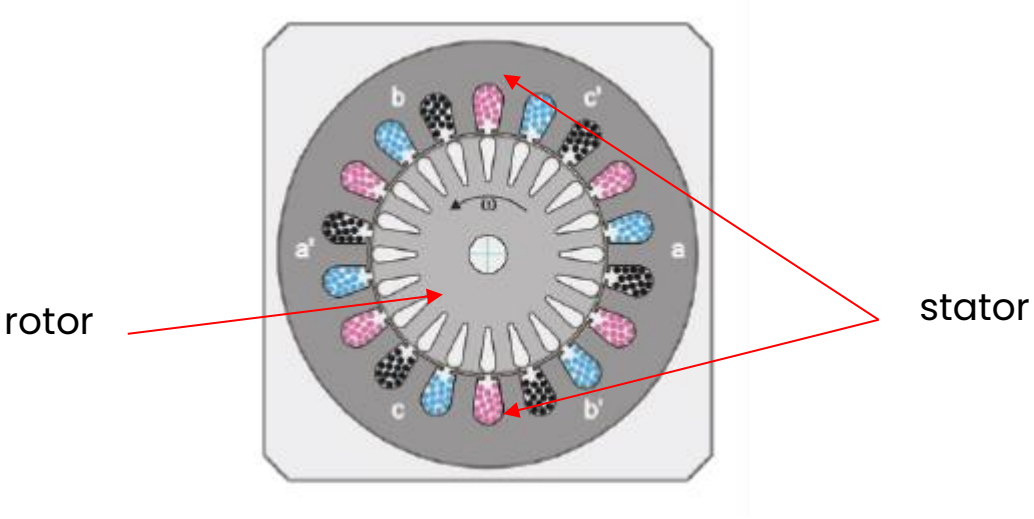
PMSM Motors require an AC current to generate torque in the rotor.

Advantages
- Heat generated in stator is easy to dissipate
- High torque per frame size
- Reliability due to absence of brushes and commutator
- High efficiency
- Synchronous operation makes field orientation easy
- High-speed performance
- Precise speed monitoring and control possible
- Smooth torque

Disadvantages
- Rotor position sensing required
- Position sensor or sensorless technique is required for motor operation
- Difficult to startup the motor using sensorless technique

Application examples
- Power tools
- White goods
- Servo drives
- Pumps
- Robots
- Electromobility
- E-Bikes/e-scooters
- Home appliances
- Compressors
- Etc.

AC Induction Motor (ACIM)



ACIMs have a classic three-phase stator and commonly have a “squirrel cage” rotor in which the conductors are shorted together at both ends.

The operation principle of ACIM is very similar to a transformer. A rotor current is induced in the rotor circuit from the stator windings. This current produces rotor flux, which interacts with the stator electromagnets to produce torque.

Advantages

- Low cost per horsepower (no permanent magnets)
- Inherent AC operation (direct connection to AC line)
- Very low maintenance (no brushes) and rugged construction
- Available in wide range of power ratings
- Low-cost speed control with tachogenerator
- Simple control (volt per hertz + PFC can handle 8-bit MCU)

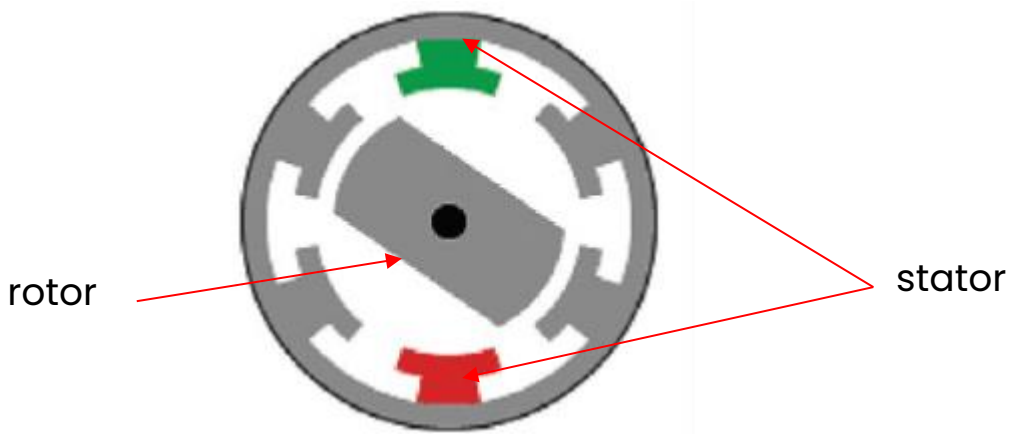
Disadvantages

- Inefficient at light loads
- Rotor temperature change complicates sensorless control
- Speed control requires varying stator frequency
- Position control difficult (field orientation required)

Application examples

- Industrial variable speed drives
- Power tools
- White goods
- Pumps
- Construction machinery
- Home appliances
- Etc.

Switched Reluctance Motor (SR)



SR motors do not contain magnets and are constructed such that both the stator and rotor have salient poles. The motor is driven by a sequence of current pulses applied at each phase, which requires control electronics for operation.

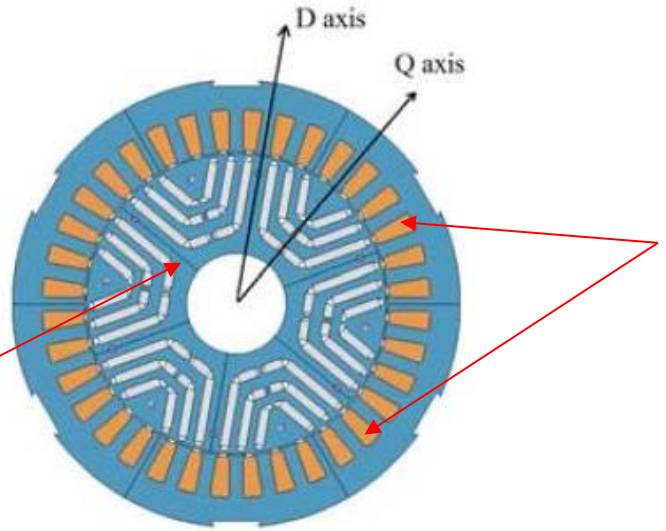
The SR motor works on the principle that the magnetic circuit tries to minimize the reluctance (air gap distance) of the magnetic circuit. The magnetic field creates a force on the rotor so that its poles line up with the poles of stator phase.

Advantages
- Low cost resulting from simple construction
- High reliability
- High fault tolerance
- Heat generated in stator is easy to dissipate
- High-speed operation possible

Disadvantages
- Torque ripple (acoustic noise)
- High vibration
- Magnetic non-linearities make smooth torque control difficult
- Dependent on electronic control for operation

Application examples
- Lawn movers
- Mixers
- Vacuum cleaners
- Electric vehicles
- Automotive applications
- Etc.

Synchronous Reluctance Motor (SynR)



SynR motor is magnet-free design and combines the performance of the permanent magnet motor with the simplicity of an induction motor.

When the stator windings of the SynR motor are excited a magnetic filed is generated and the rotor aligns its most magnetically conductive axis in order to minimize the reluctance in the magnetic circuit. Reluctance torque is generated

Advantages

- Simple and robust rotor construction
- No fundamental rotor losses (I^2R)
- Low heat on a rotor
- Rotor without permanent magnets
- Low moment of inertia of a rotor
- Cost efficiency
- Reliability
- Easy maintenance comparing to PM motors

Disadvantages

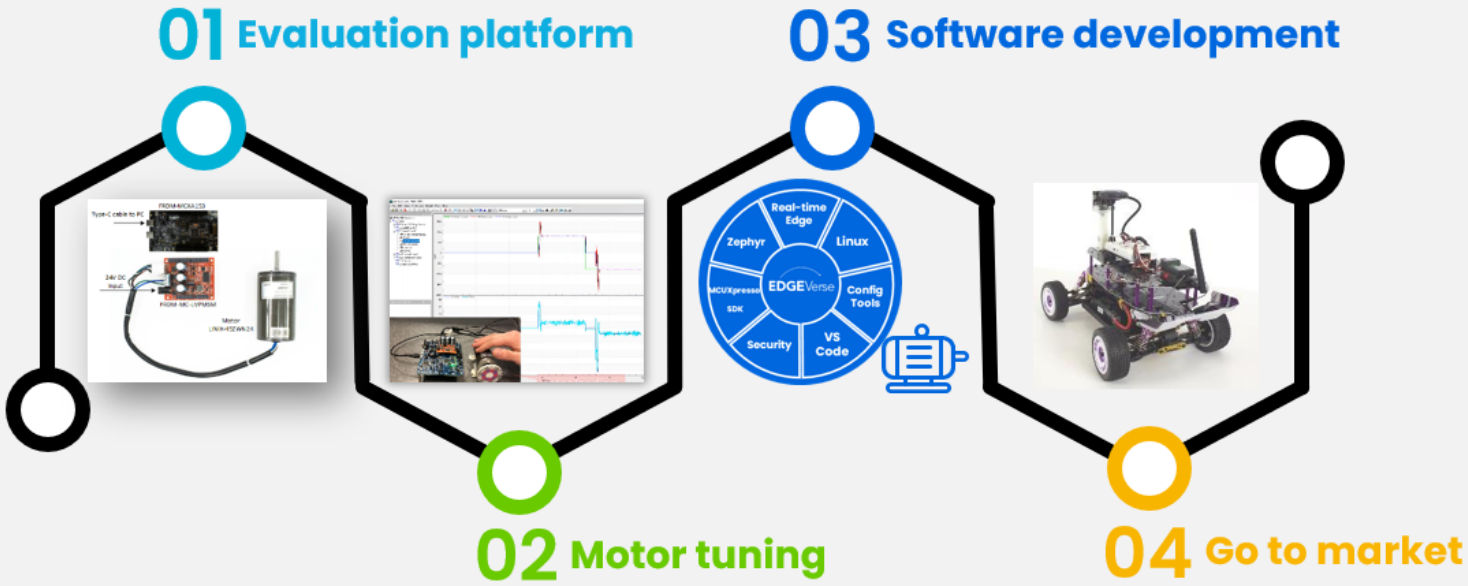
- Low power factor – magnetic flux is generated only by a reactive current
- Frequency control

Application examples

- White goods
- Home appliances
- Variable speed drives
- Industrial pumps
- Compressors
- Conveyors
- Etc.

NXP Motor Control Offering

Scalable processing portfolio + Streamlined user experience



Motor control highlights

- Highly dynamic control
- Optimized application cost
- Unified motor control IPs
- Use-case specific solutions
- AI/ML predictive maintenance
- Rapid time-to-market

NXP Motor Control Featured Product and Application Mapping

*Future product

Hero Product	**MCX Cx5x*** 96MHz CM23	**MCX A13x, 17x** 96/180MHz CM33	**MCX A34x** 180MHz CM33	**MCX N94x** 150MHz 2x CM33	**MCX E31x*** 160MHz CM7	**i.MX RT10xx, i.MX RT1170** 500Mhz - 1GHz CM7	**i.MX RT1180** 800MHz CM7 + CM33	**i.MX94*** 4x Cortex-A 2xCM7 + 2xCM33
Best for	Analog integration Low-cost	Cost-efficient CM33	Motor control math accelerator BOM saving w/ analog integration	Highly integrated AI accelerator	Industrial FuSa SIL2 100base Enet & TSN	Best DMIPs/dollar ~4x motor control PWM instances	Industrial Ethernet & EtherCAT Fastest MCU for industrial	Industrial Ethernet & EtherCAT Digital encoder interface Motion control
Focused Applications	Low-cost Appliance Fan control Lowe-cost Power tool Water pump	Appliance Fan control Power tool	Appliance HVAC / heat pump High-end Power tool Factory motor drive E-bike	Factory motor drive w/ Enet Motor control + AI E-bike	Factory motor drive w/ Enet Simple factory servo drive	Multi-motor drive Drone Simple robotics Factory motor drive w/ Enet E-bike	Factory servo drive w/ real-time Enet Robotics	Factory servo drive w/ real-time Enet Robotics Motion controller

NXP motor control for factory automation

- Industrial robot must be considered as a system. It includes **motion controller** and several motor controllers (depending of degrees of freedom).

- Common end user applications:
  - Assembly lines
  - Automated painting and spray coating
  - Soldering tasks
  - Others

- NXP's differentiators in smart factory:
  - Complete MCU + MPU portfolio for motor and motion control
  - TSN and real-time network capability for both MPU and MCU
  - Industrial cybersecurity for IEC62443
  - Predictive maintenance with AFE + ML at the edge

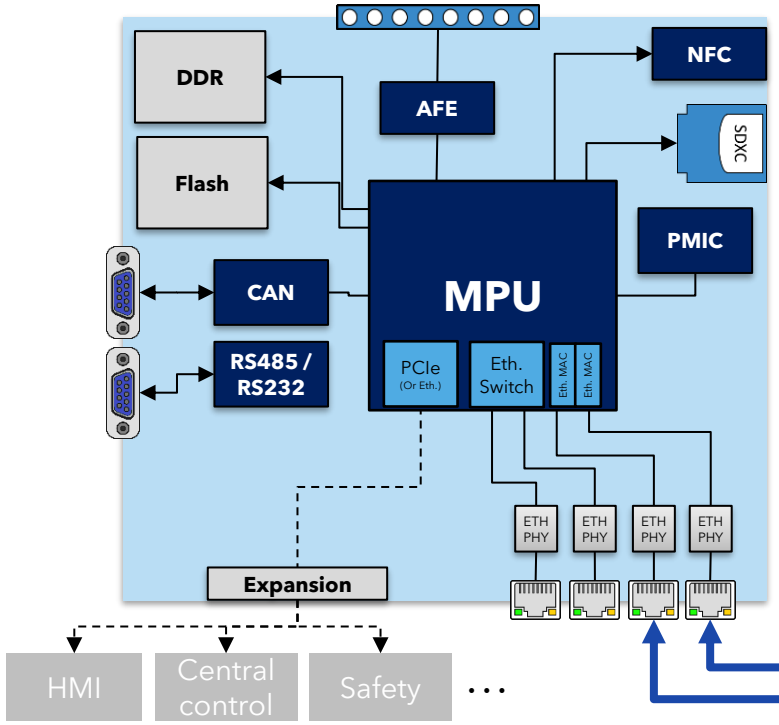
- Proposed motor controller portfolio:
  - **MCX A & E, i.MX RT MCUs, i.MX94x**
- Proposed motion controller portfolio:
  - **i.MX**

Robotic ARM: Generic application diagram

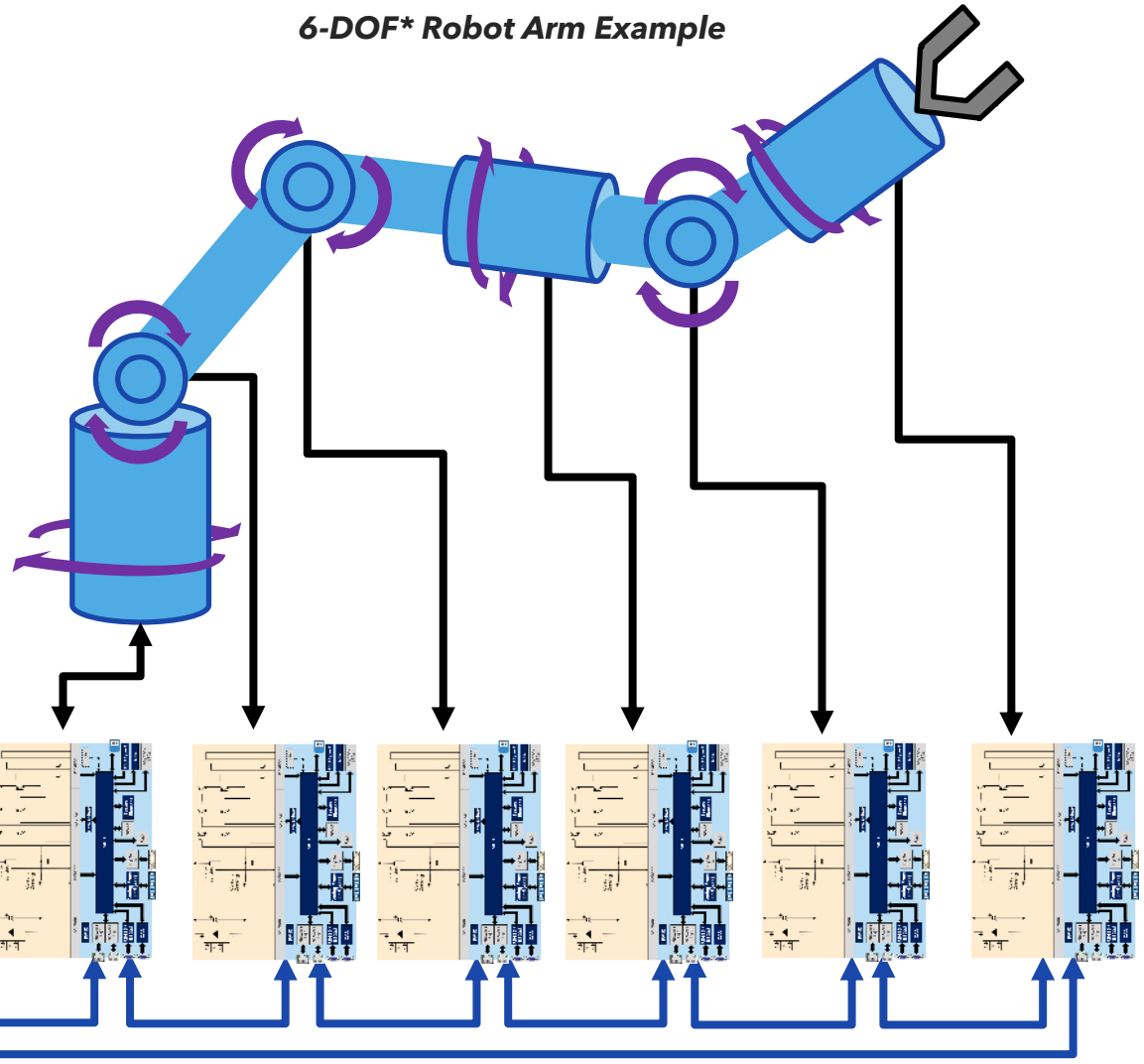
Key requirements:

- High performance real-time processing
- High precision
- Real-time Communication
- Robustness
- Security
- Safety

Motion Controller



6-DOF* Robot Arm Example

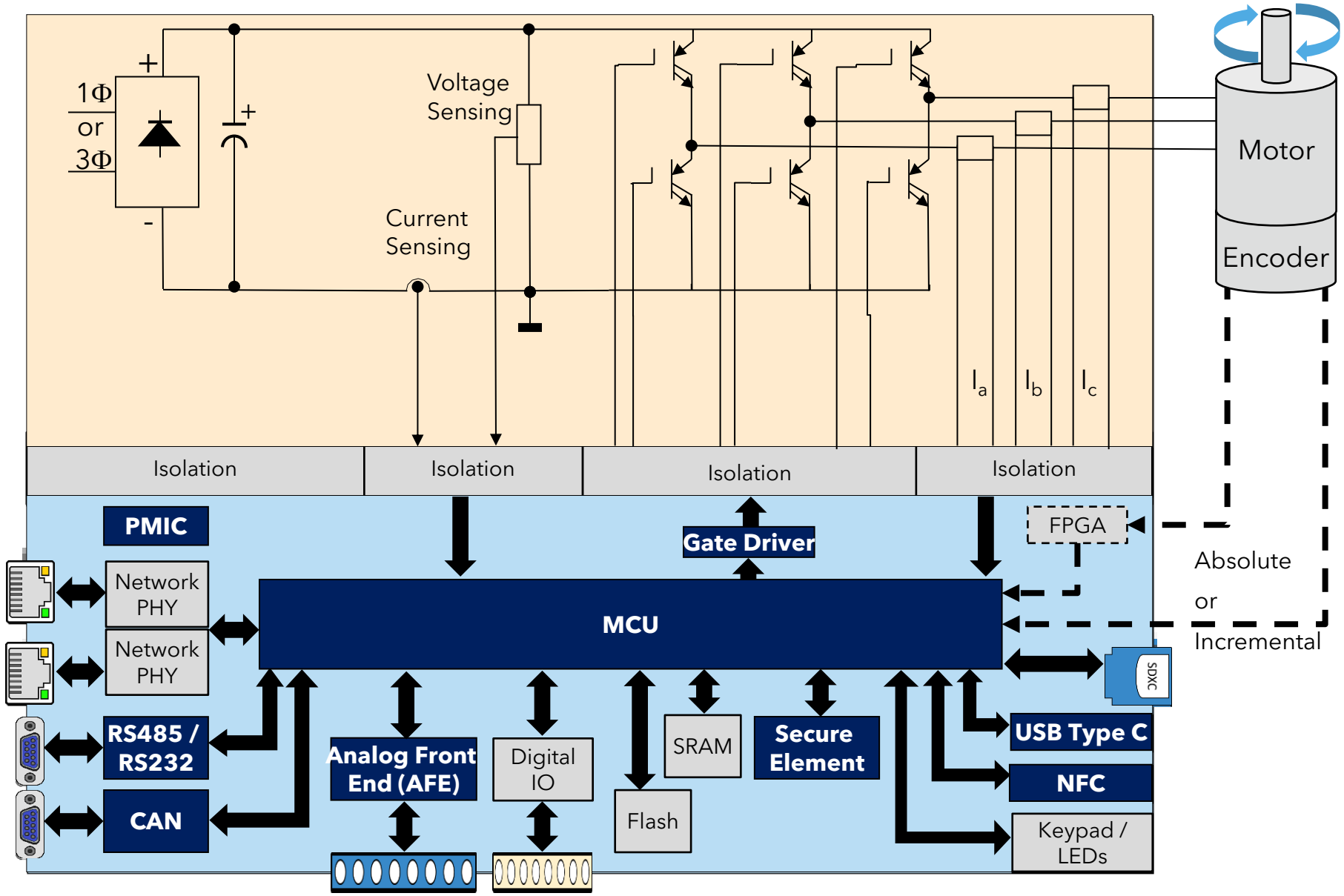


*DOF: Degrees of Freedom

Motor Controller for robotic arm

Key requirements:

- High precision
- Real-time Communication
- Robustness
- Temperature range
- Security
- Safety



NXP motor control for Smart home and appliances

- Wide range of applications that involve BLDC, PMSM and ACIM motor control

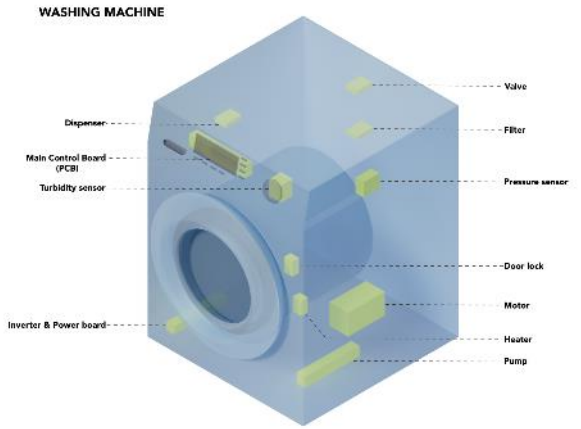
- Common end user applications:
  - Washing machine
  - Dryer
  - Dishwasher
  - Fridge
  - HVAC
  - Robot & stick vacuum cleaner
  - Coffee machines

- NXP differentiators in smart home and appliance
  - Extensive solution offering for motor control, system control and HMI
  - Robust 5V MCU – KE series for appliances
  - Integrated analog on MCUs to save space and BOM cost
  - Anomaly detection with ML at the edge

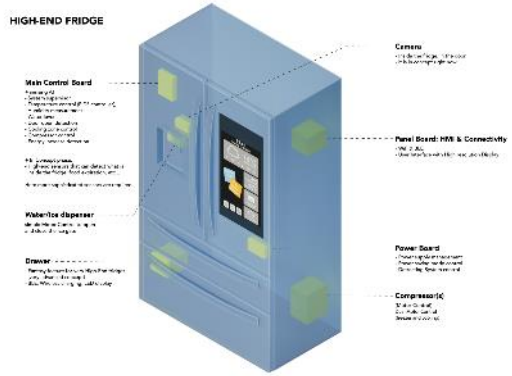
- Proposed motor controller portfolio:
  - **KE, MCX C, MCX A, DSC**

NXP Solutions and differentiators for Appliance Platforms

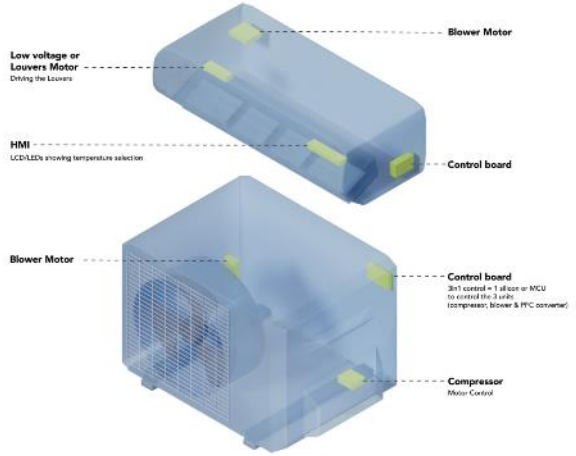
Washing Machine



Refrigerator



HVAC



Products

Washing Machine	Refrigerator	HVAC
KE (Main Ctrl and UI)	**MCX A17/A34 (Motor Ctrl)**	**MCX A1x / KE (Indoor unit)**
MCX A1x (Main Ctrl and UI)	i.MX 91 (UI - Entry Level)	**MCX A34 (3In1 for outdoor unit)**
MCX A17/A34 (Motor Ctrl)	i.MX 93 (UI – Mid Tier)	
MCX N5 & N9 (Main Ctrl, UI & Motor Ctrl)		
i.MX RT700 (Main Ctrl & UI, AI & Voice)		

Key Features

Washing Machine	Refrigerator	HVAC
Efficiently and safely drive the motor	**Efficiently drive the motor**	**Efficiently and safely drive the motor, fan and PFC**
Resistant User Interface	**Graphic reach User Interface**	**ML – AI applications**
ML – AI applications	**ML – AI applications**	

NXP in Mobile Robotics

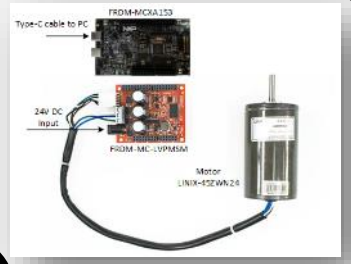
- NXP has decades of experience in semiconductors for automotive, aerospace, RF, security, functional safety, motor control, battery management systems and more.
- This broad technology portfolio of components and system solutions are applicable to the many needs of modern mobile robotics, including commercial drones and rovers.
- Additional information on more products can be found at www.nxp.com/uav

Motor Control Developer Journey & Our Enablement

01

Evaluation platform

FRDM motor driver board + motor for rapid prototyping



02

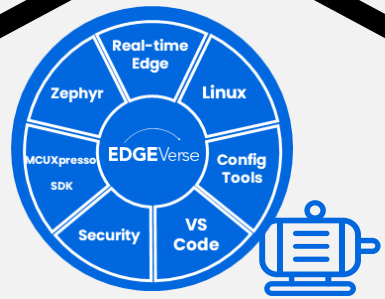
Motor tuning

FreeMaster real-time visualized debugging with Motor Control Application Tuning (**MCAT**) tool

03

Software development

MCUXpresso SDK code examples backed by Real-time Control Embedded Software Library (**RTCESL**)



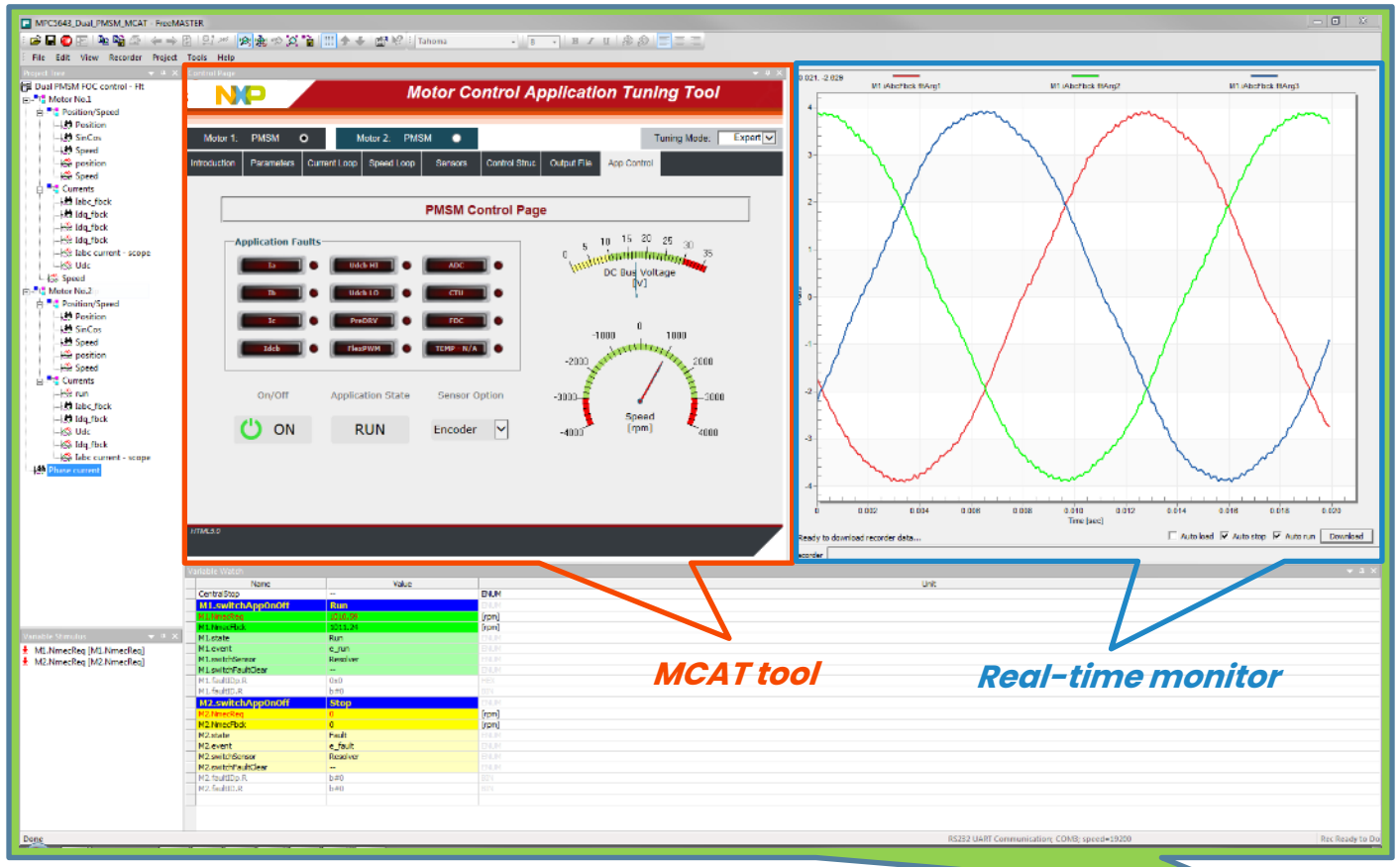
04

Go to market

Leverage NXP's motor control **solutions** and reference designs to go to market faster

MCAT – MOTOR CONTROL APPLICATION TUNING TOOL

- **MCAT** is a plug-in tool for **FreeMASTER** – NXP's real-time debug monitor and data visualization tool.
- MCAT tool in connection with FreeMASTER allows real-time monitoring, tuning and updating of the control parameters in motor control application.



MCAT features

- MCAT enables tuning of control parameters according to the target motor / application
- Dynamic tuning & update of control parameters
- Generation of header file with static configuration of the tuned parameters
- MCU independent
- Arithmetic independent (16-/32-bit, Fix/Flt

RTCESL – REAL-TIME CONTROL EMBEDDED SOFTWARE MOTOR CONTROL AND POWER CONVERSION LIBRARIES

Libraries of S/W Algorithms
- Math
- General
- Motor control
- Filters
- Advanced control
- Power conversion

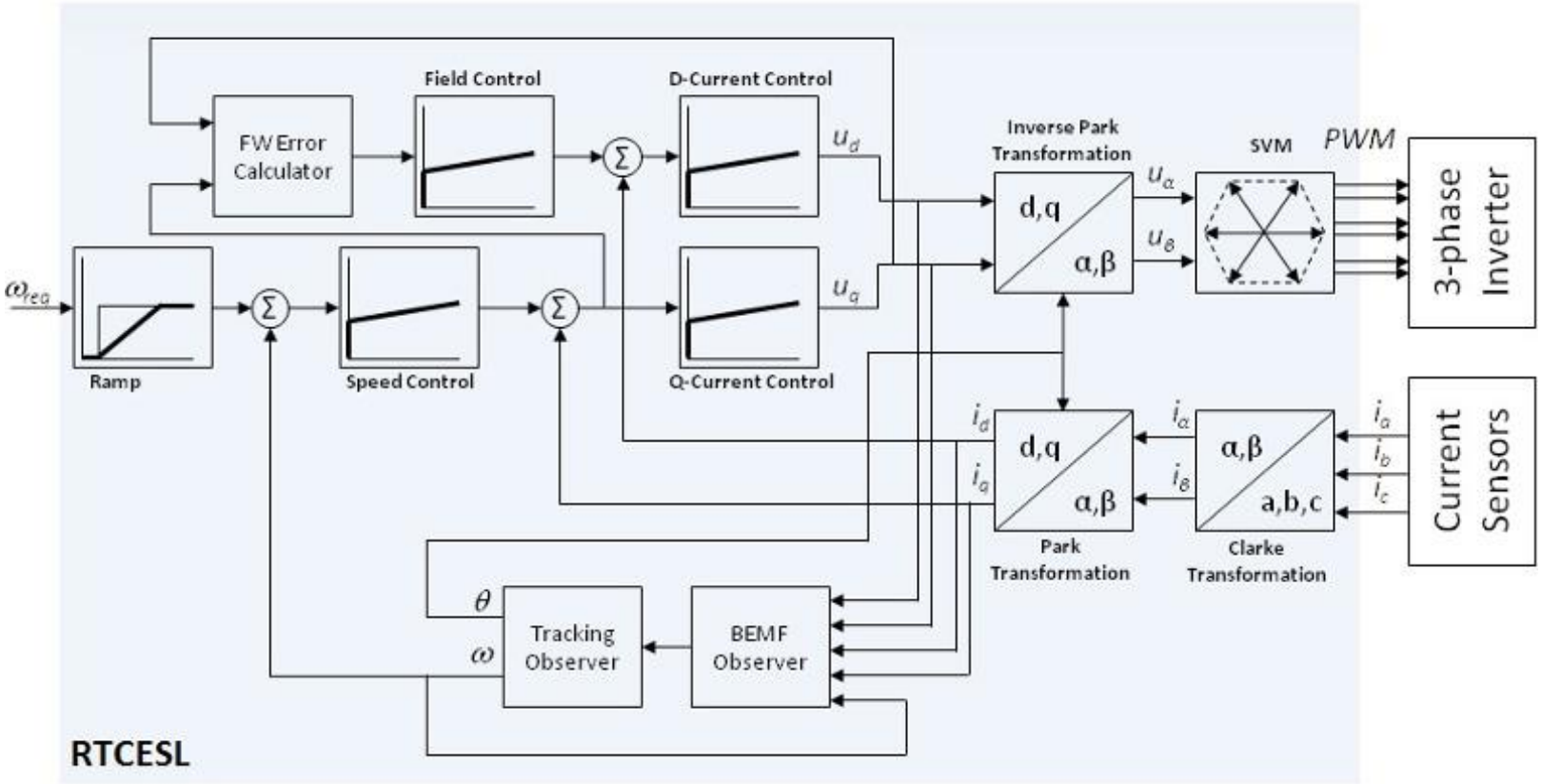
Deep Algorithm Testing
- Millions of patterns
- MATLAB reference models
- 64-bit double precision

Easy-to-use
- Unified API & types
- Detailed algorithms description
- Easy installation & inclusion

Compilers
- **Cortex-M MCUs:**
  - IAR
  - Keil
  - MCUXpresso
- **DSC:**
  - CodeWarrior

Arithmetic
- fixed point: 16, 32 and 64-bit
- floating point: 32-bit single precision

Library algorithms are **validated** against Matlab/Simulink models



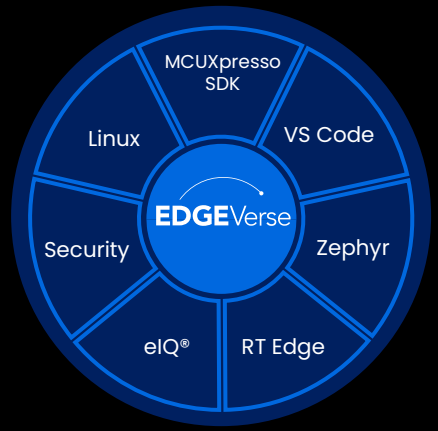
FRDM to innovate

Open-source developer ecosystem

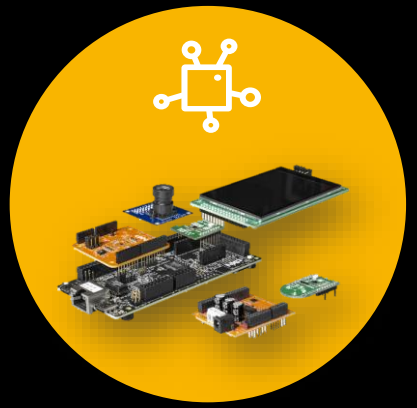
- Comprehensive software and tools for rapid development
- Modular, quick-start FRDM & expansion boards with open design files and schematics
- Access code snippets and tutorials through our Application Code Hub

Ease development for reduced time to market

Software tools



Modular hardware

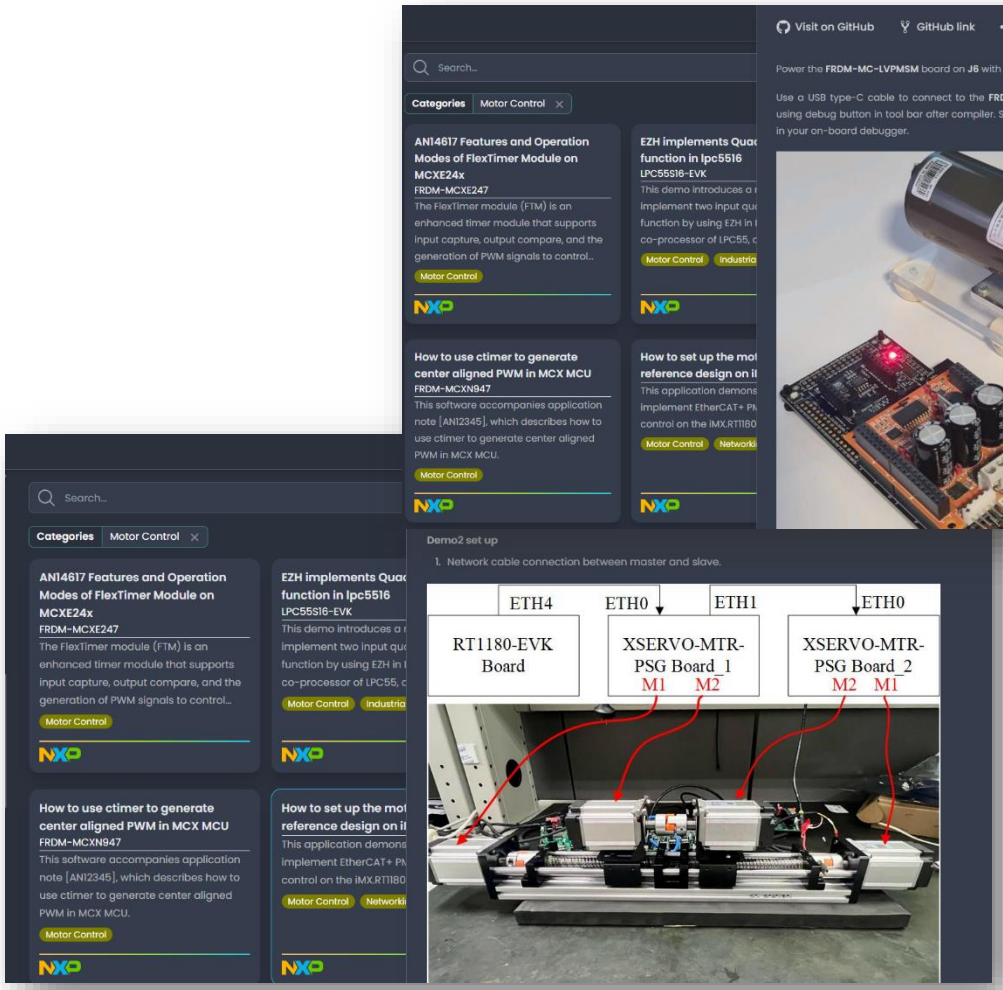


Application Code Hub

Rapid Prototyping with FRDM ecosystem and Application Code Hub

Exploring motor control demos and code examples

Look for the tag “motor control” on Application Code Hub.

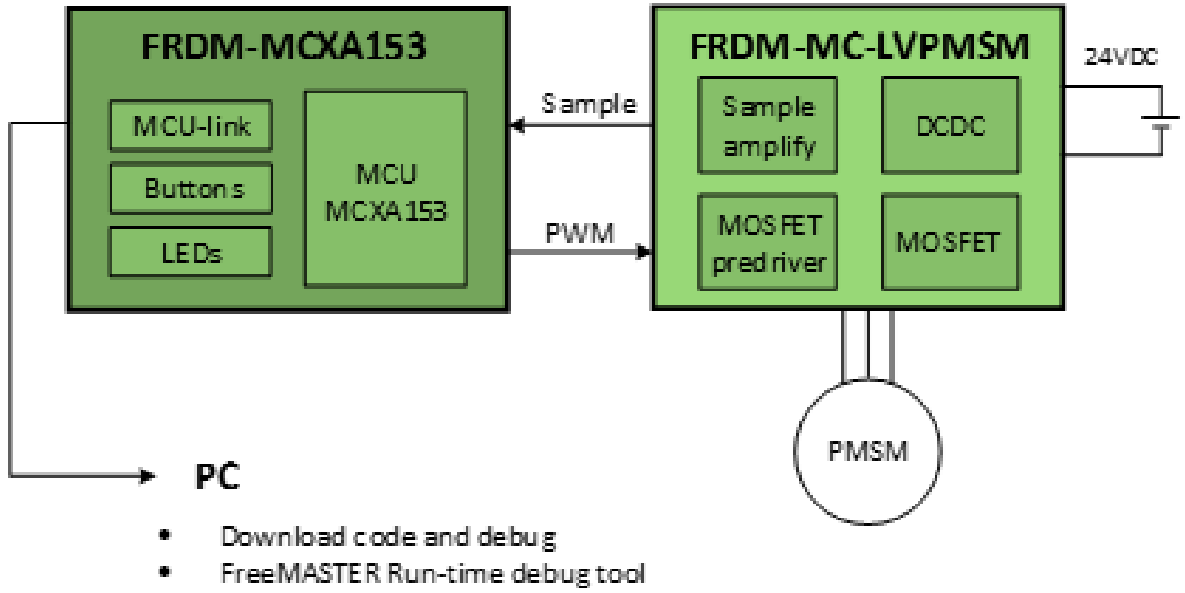


Eval. Platform

MCX A14x/15x Sensorless PMSM Control

NXP Offering:

- Motor control subsystem for fast and precise real-time control loop.
  - **4Msps** high-speed ADC with hardware averaging to multiple trigger sources for BOM cost saving and low-power operation
  - Quadrature Encoder/Decoder (Not used on sensorless example)
  - FlexPWM (FlexPWM peripheral can generate control signals for a three-phase half-bridge)
  - Temp sensor and Comparator
  - Synchronization mechanism between ADC and FlexPWM.
- Highly energy efficient compared to “equivalent” MCUs.
- Low cost
- Modeling, Debugging and tuning tool
- Advanced math and MC libraries.



Eval. Platform

FRDM-MCXA346 demos

- Motor Control applications

Dual PMSM control on MCXA34x

- Dual Sensorless PMSM Field-Oriented Control(FOC)
- NXP Real Time Control Embedded Software Motor Control and Power Conversion Libraries(RTCESL) 4.8.1
- BEMF observer algorithm for sensorless control
- 16KHz current control loop and 1KHz speed control loop for each motor
- 12.8us current loop process time and 1.8us speed loop process time for each motor, totally 41.3% CPU loading(12.8/62.5*2 + 1.8/1000*2)
- 1.5us saved in current loop process time if MAU enabled(to calculate sine, cosine, arctangent and square root)

Proof of Concept

Air conditioning OutDoor Unit

Dual motor + High-frequency PFC control solution

Application cost saving

- All 3 control objectives with **one** MCU device (72kHz PFC and sensorless PMSM FOC for fan up to 90W and compressor up to 2800W)
- **Compact PFC** converter drive with smaller filter value/size (inductors/capacitors)
- **Single-shunt** current sampling for compressor control
- Better **math acceleration** unit performance requires lower CPU usage

Efficient power conversion

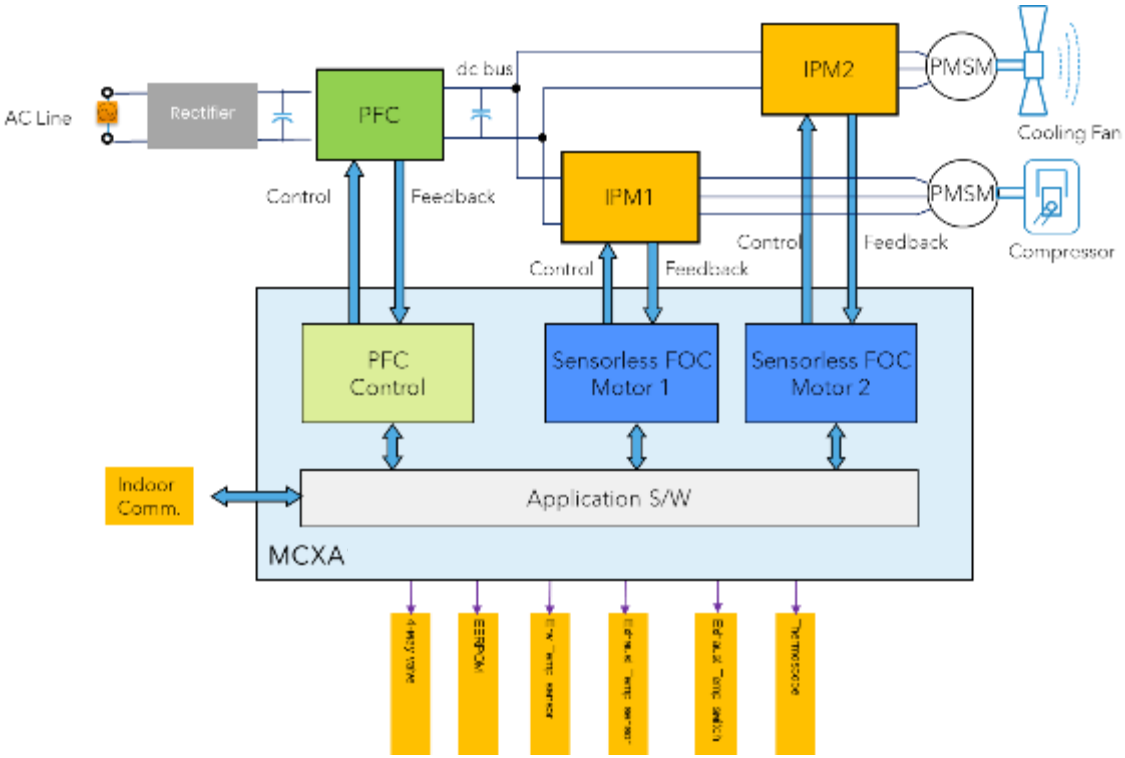
- High frequency PFC converter drive with high efficiency (>95%)
- Silicon Carbide used for PFC topology with better power dissipation

Advanced motor control

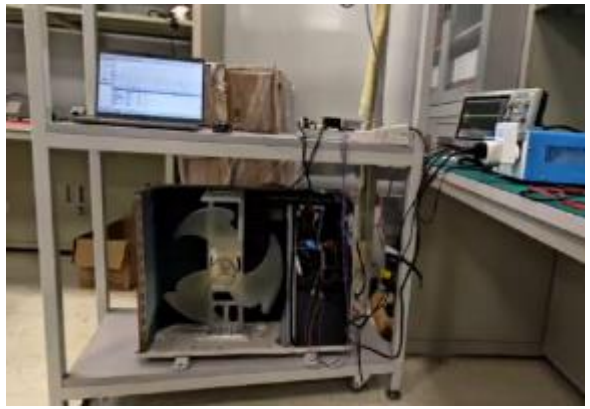
- **Anti-typhoon**, **on-the-fly startup** for fan, and on-line load **torque compensation** control for compressor to reduce vibration and noise
- **Fast reliable startup** performance and good low/high speed performance
- High-speed operation with patented **field-weakening** algorithm

Robust and easy path to development and production

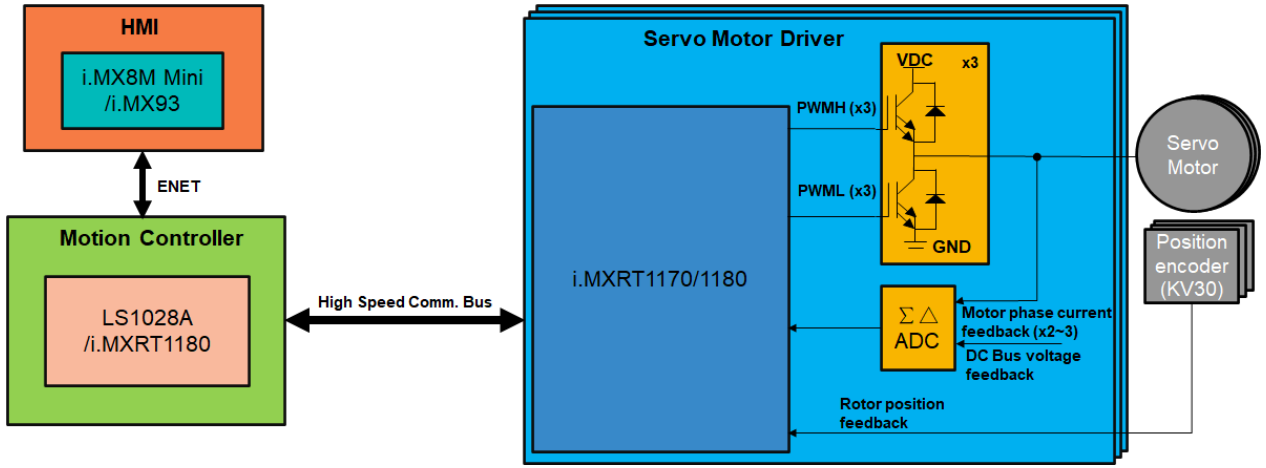
- Over/under-voltage, overcurrent, over-temperature, over-input power protection
- FreeMASTER online debug and monitor
- Function safety based on IEC 60730 Class B

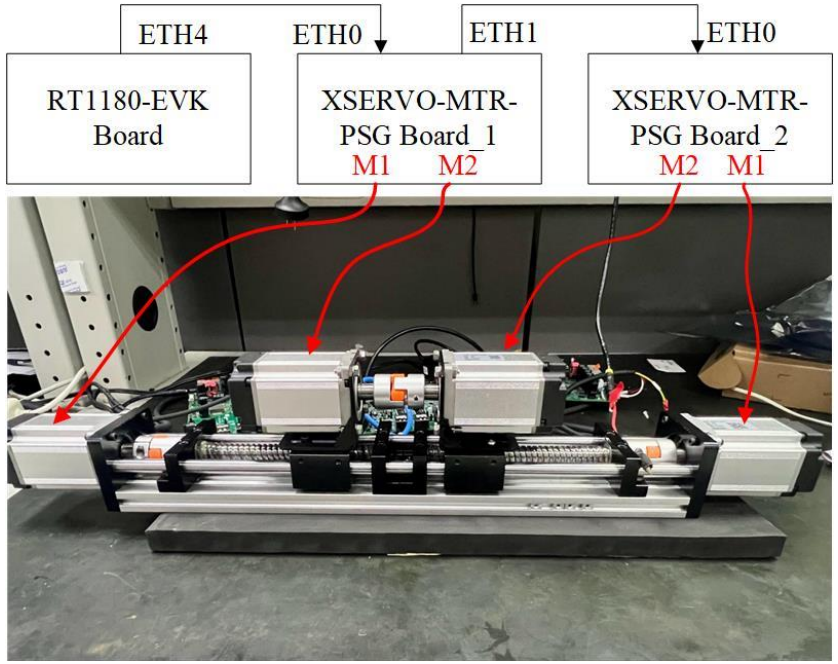


MCXA34x



Factory Motion/Servo Control Solution





Reference Design

Solution Highlights

- Typical motion control system architecture design with **decentralized control topology**, close to end customer products
- **TSN** communication between MCU platforms (TSN switch feature on RT1180, and endpoint feature on both RT1180 and RT1170)
- **EtherCAT** network enablement and performance test (both EtherCAT master and slave on RT1180)
- **Single chip solution** with dual-core to **remove the external FPGA requirement** (FOC loop + SD ADC demodulator + EtherCAT slave stack + position sensor protocol)

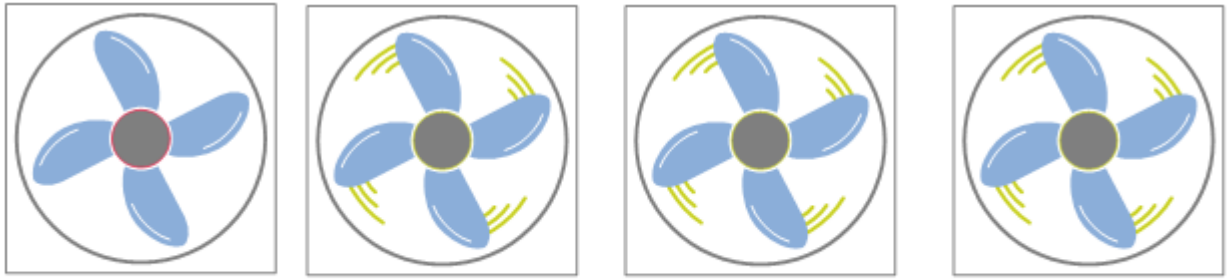
NXP Processors

- **Motion Controller:** i.MX / i.MX RT1180
- **Motor Controller:** i.MX RT1180 / i.MX RT1170
- **HMI:** i.MX 8M Mini / i.MX 93
- **Position Encoder:** MCXA34

Eval. Platform

AI/ML State Monitor Application Software Pack

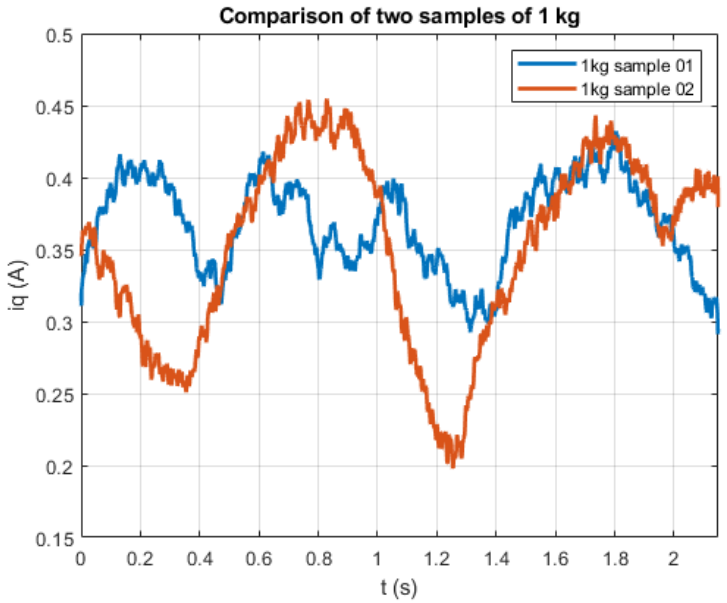
- Fan State Monitoring and State Identification
- Analyzes vibrations picked up by NXP FXLS8974CF accelerometer on ACCEL-4-CLICK
- Based on ML State Monitor Application Software Pack and adds LCD and Audio features

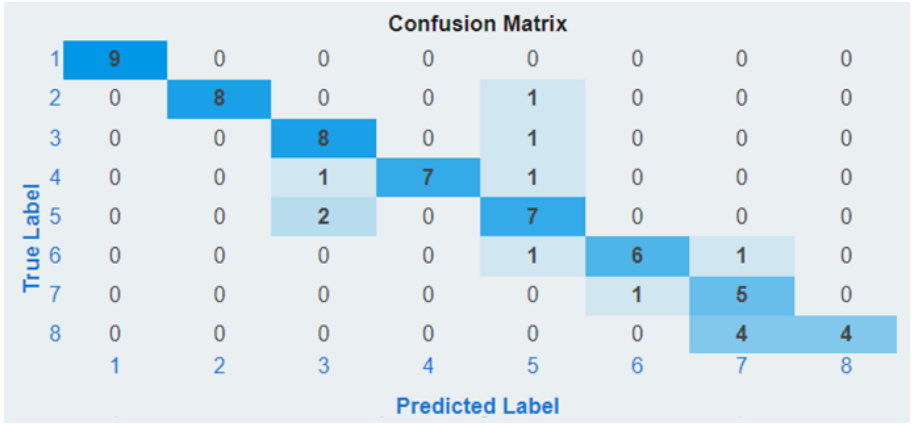


Proof of Concept

Sensor-less Weight Estimation Project Example

- AI accelerated weight estimation of washing machine load
- With our eIQ Neutron accelerator included in the MCX N94x MCU, it is possible to offload most of the calculations and leave the core available for other tasks
- Proof of concept implementation on small dataset indicates at least 80 % accuracy, with inaccurate predictions being usually off by one classification bin
- Optimized ML model with small memory footprint
- Inference runs directly on the MCU -> low cost and private solution





Resources

Motor control homepage:

- www.nxp.com/motorcontrol

MCUXpresso SDK for motor control:

- https://www.nxp.com/design/design-center/software/development-software/mcuxpresso-sdk-for-motor-control:MCUXPRESSO-SDK-MOTOR-CONTROL

Rapid Prototyping with Application Code Hub:

- https://mcuxpresso.nxp.com/appcodehub