A Cost and Size Optimized Motor Control Solution using Radiation Hardened AFE + Microcontroller Circuits

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

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SMART | CONNECTED | SECURE

Agenda

- Traditional motor control using LX7720
- Challenges on using LX7720 with a microcontroller
- MCU-friendly solution
- Prototype and results
- Conclusions and future work

Traditional Motor Control using LX7720

LX7720 Overview

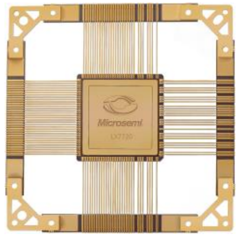
Power Driver with Rotation and Position Sensing

Features

- 4 half-bridge N-channel MOSFET drivers
- 4 floating differential current sensors for motor winding currents
- PWM driver for resolver or LVDT primary winding driver
- 3 differential sense inputs for resolver/LVDT measurement
- 6 threshold adjustable bi-level logic inputs
- Fault detection and automatic fault protections
- 132-pin CQFP, 24 mm x 24 mm
- Plastic QFP in space plastic screening

Radiation Tolerance and Approvals

- 100 krad TID, 50 krad ELDRS, SEL immune up to 60 MeV.cm²/mg
- In Production
- QML SMD 5962-2120201 (Q and V flows)



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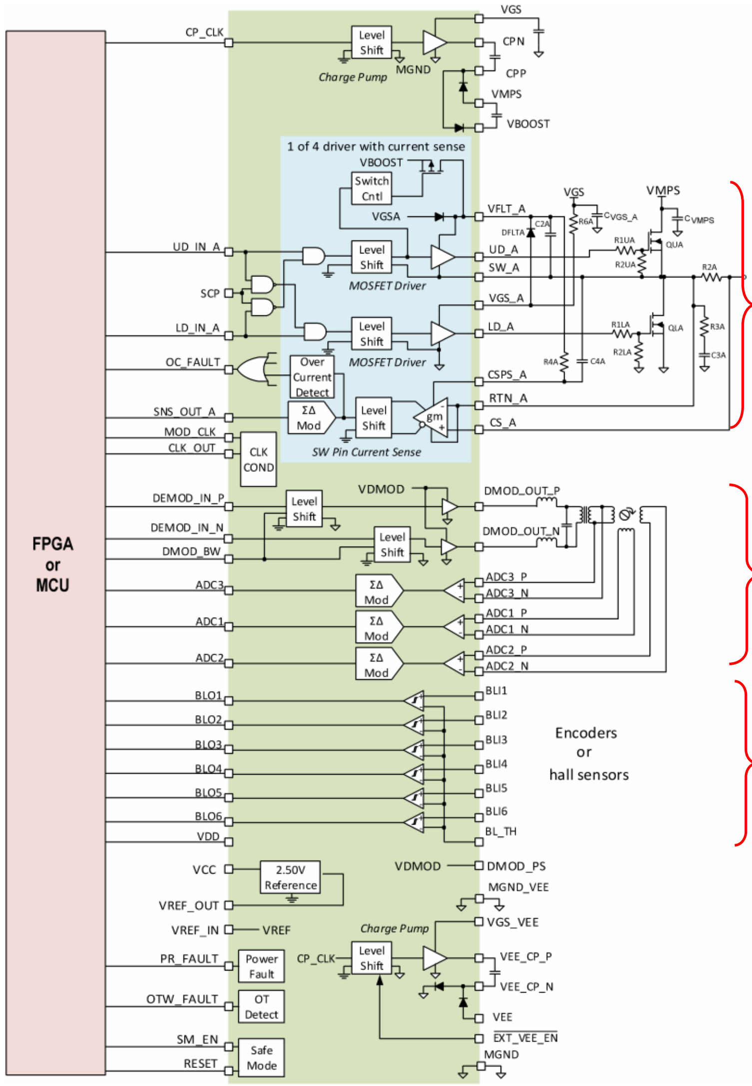
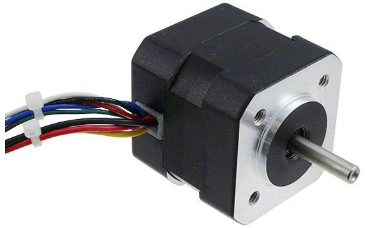


4 half-bridge motor winding drivers



Analog rotation sensor manager

Digital rotation sensors interface

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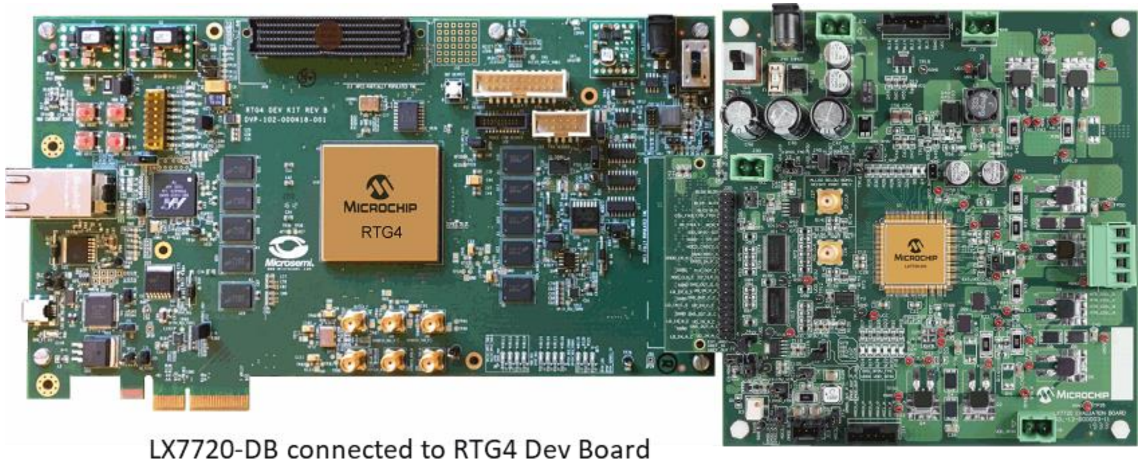
LX7720 for motor control

- **Traditionally LX7720 is used in conjunction with a Rad-Hard FPGA:**
  - LX7720 implements:
    - Current sense for the motor and possibly input DC currents
    - Resolver winding sense
    - Level shift for discrete inputs (typically used in MC to read Hall effect switches or similar)
  - FPGA covers:
    - Sigma delta modulators digital filters (to reconstruct data output for the acquisition channels of currents and resolver channels). Typically implemented as $SINC^3$ filters.
    - Field Oriented Control (FOC) processing that implements PID loops for torque is a rotor referenced system.
    - Interface to higher level control
- **While this is a high performance solution lending itself to high speed MC applications, there is also a need for a Rad-Hard, lower performance and lower cost solution.**



LX7720-DB connected to RTG4 Dev Board

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Issues in trying to run current sense DSP in SW

- **LX7720 current sense delta sigma modulators interface runs at 1 bit sample at 20-30Msps.**
  - The first stage of a typical SINC3 filter will have to execute three e.g. 16bit additions and update three 16-bit state variables = 6 ops.
  - This would require >180MIPS/channel only to sustain calculations.
  - Additionally servicing the interrupt and return from interrupt will require even more MIPS.

$\Rightarrow$**It is not feasible to implement this filter in SW. We need a better solution using an MCU**

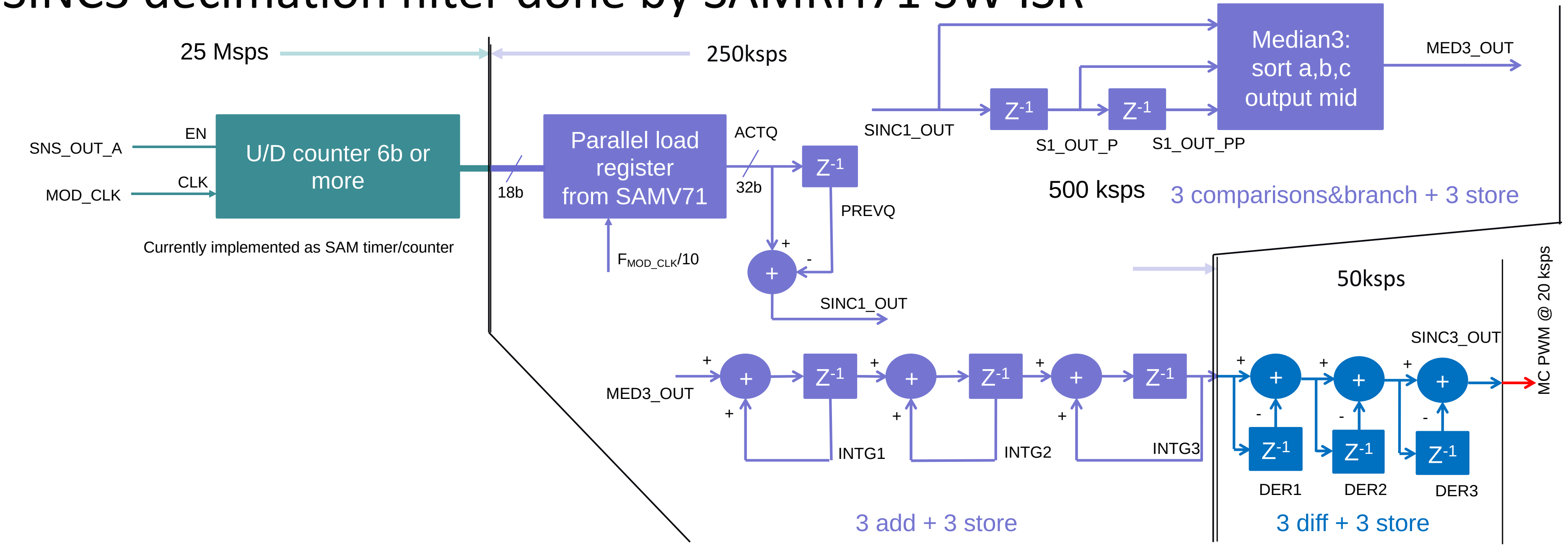
MCU friendly solution

Idea

- **Decimate the signal before it gets into the SW.**
- **Looking at a SINC[1] filter the first section is an integrator (counter). The contents of this counter is sampled at the decimated sampling rate.**
- **This counter could be implemented using a timer/counter resource of an MCU.**
- **Sizing the counter decimation factor:**
  - Ideally would want to have as small as possible decimation factor (some second order DSM noise spectrum will spill into the baseband if using a SINC1 filter)
  - For a given MCU we determine what is the maximum ISR frequency that can run the second part of the SINC1 and the following SINC3 and leave enough CPU room for the FOC and other.

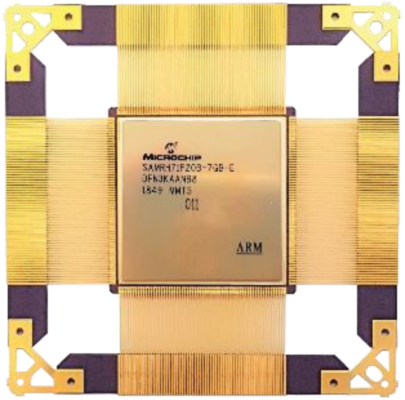
LX7720 current sense processing using SAMRH71

- **LX7720 current sense output is 1 bit Delta Sigma Modulator output at 24-32Msps.**
- **Processing is done by a cascade of digital filters:**
  - <u>one SAMRH71 timer/counter is used as an integrator</u>
  - Decimation + a median filter
  - SINC3 decimation filter done by SAMRH71 SW ISR



Implementation details

SAMRH71 Rad-Hard MCU



- ATMX150RHA space qualified, **100Mhz, >200DMIPS**
- **Temperature range -55°C / 125°C**
- **Radiation performance improved by design**
  - Latch up immune up to **62 MeV.cm²/mg**
  - **TID > 100Krad**
  - **SEU LET > 20 Mev** without system mitigation
  - Characterization TID & SEU for all functional blocks
- **Data integrity & Fault management**
  - ✓ **ECC on TCM interface**
  - ✓ ECC on Embedded SRAM & Flash Memories
  - ✓ **ECC on External Memories**
  - ✓ Embedded "Integrity Checker Monitor"
  - ✓ Hardening of the critical area of the design of the SoC
  - ✓ 16-regions (max) memory protection unit (MPU)

128KB Flash
1MB SRAM
(384KB TCM)
Ext Mem ECC

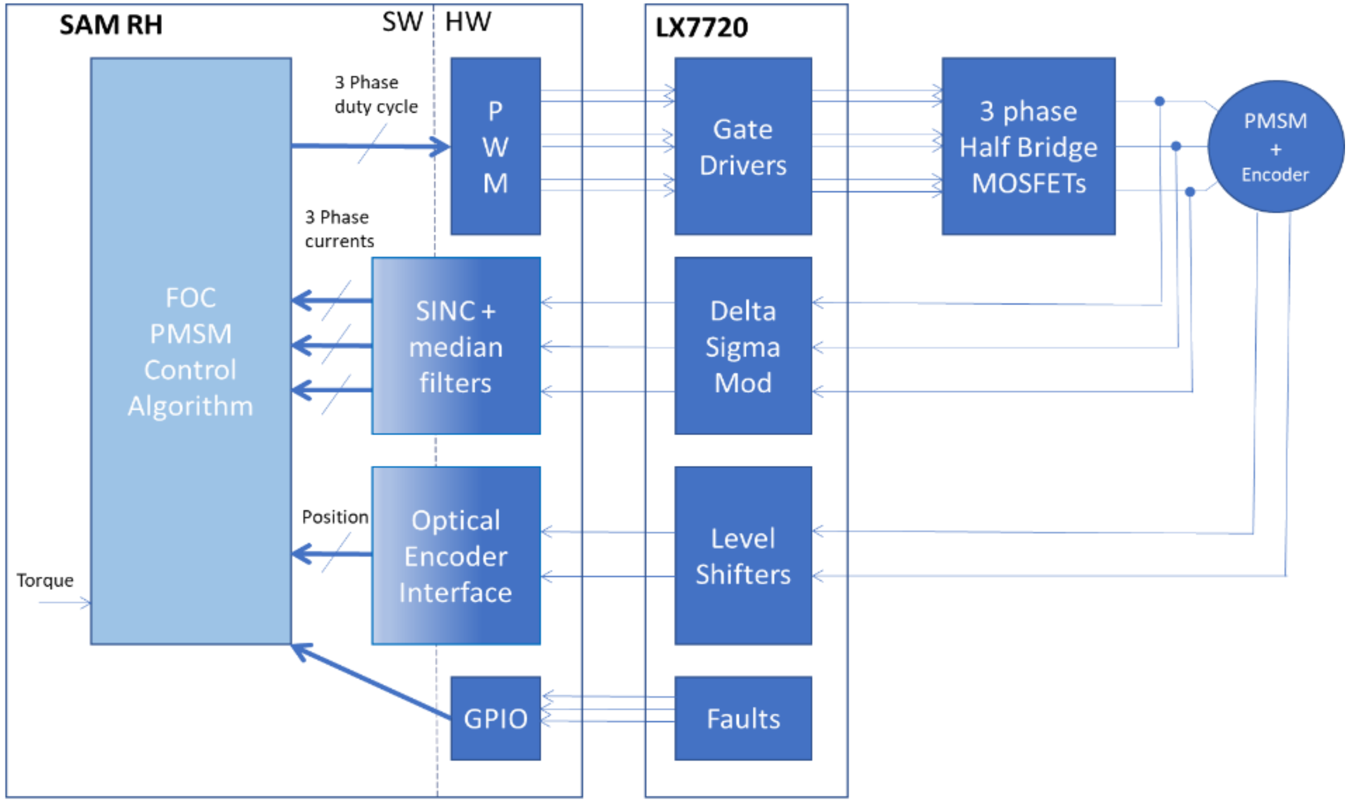
QFP256

Spacewire
1553 M/S
FPU/DSP
Dual CAN FD
Ethernet AVB

https://www.microchip.com/wwwproducts/en/SAMRH71

SAMRH71 – LX7720 interface

- LX7720 current sense DSM outputs drive SAMRH71 timer/counters
- LX7720 gate drivers inputs driven by SAMRH71 PWM
- LX7720 fault outputs drive SAMRH71 GPIOs
- Encoder drive LX7720 BLI inputs and corresponding BLO outputs drive SAMRH71 GPIOs
- SAMRH71 drives the DSM and charge pump clocks of LX7720
- LX7720 drives external MOSFETs and senses output currents
- SAMRH71 senses rotor position using and encoder interface



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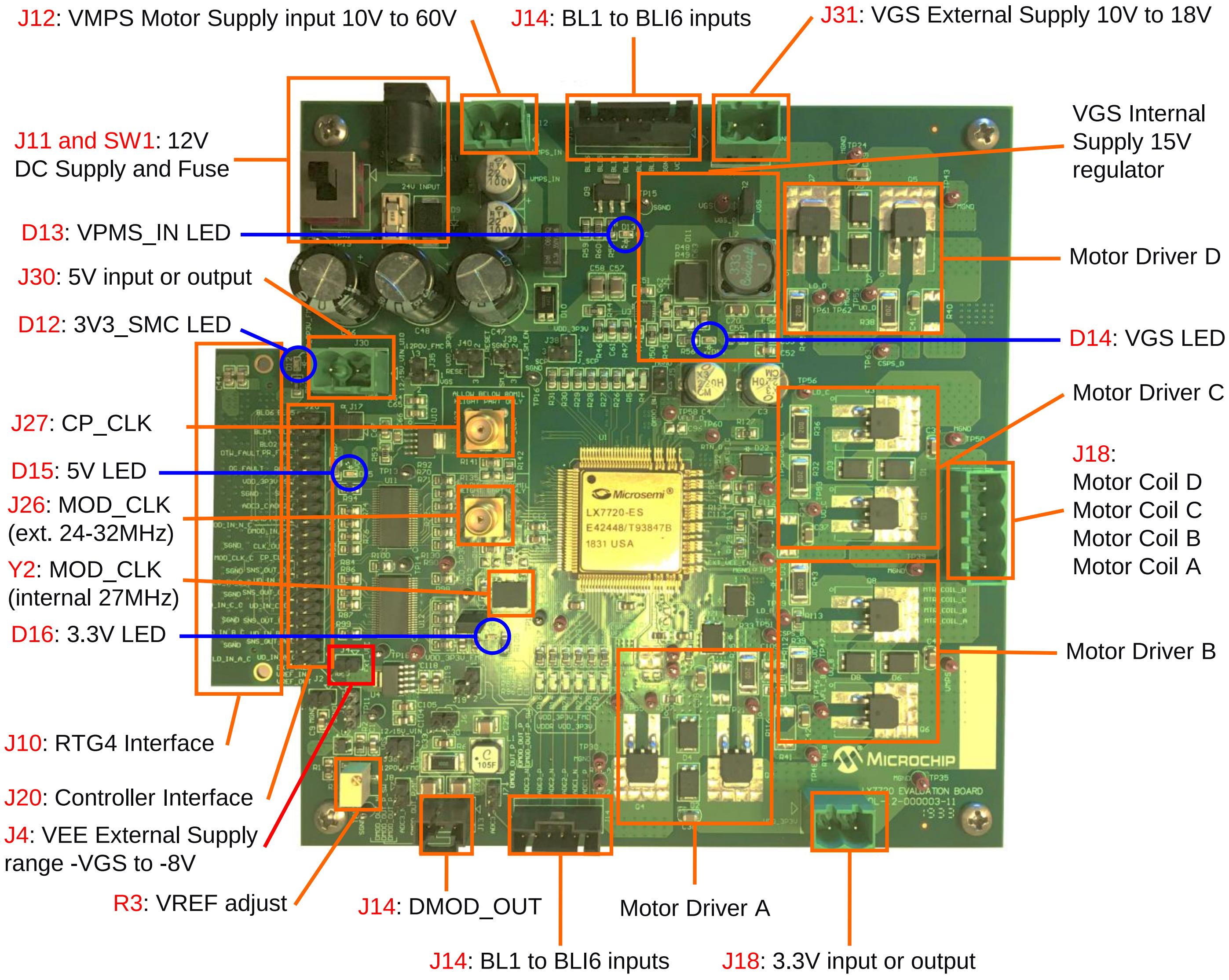
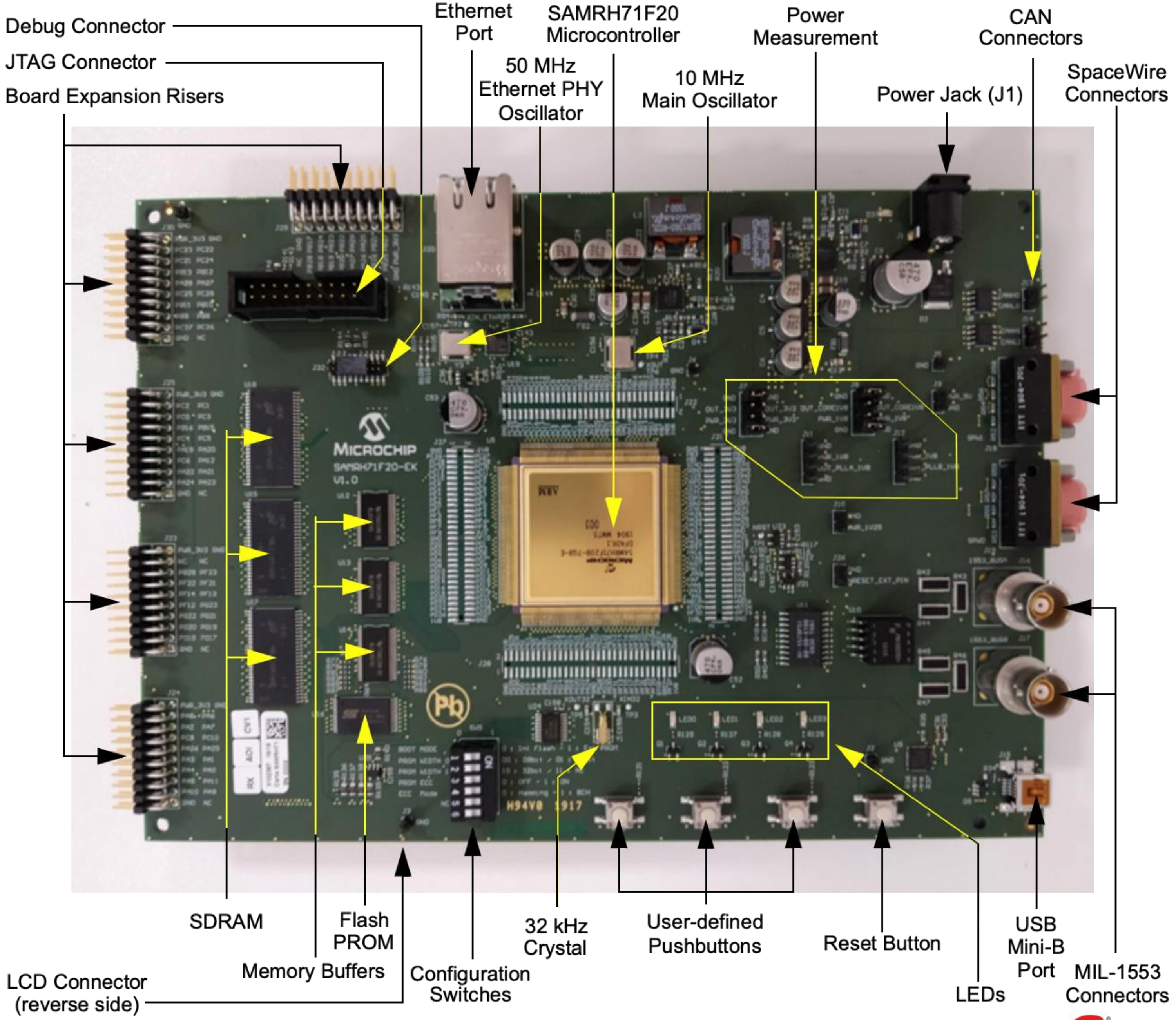
Prototype

LX7720 daughter board



https://www.microsemi.com/product-directory/space-system-managers/3708-position-motor-controller-ic#resources

SAMRH71 development kit

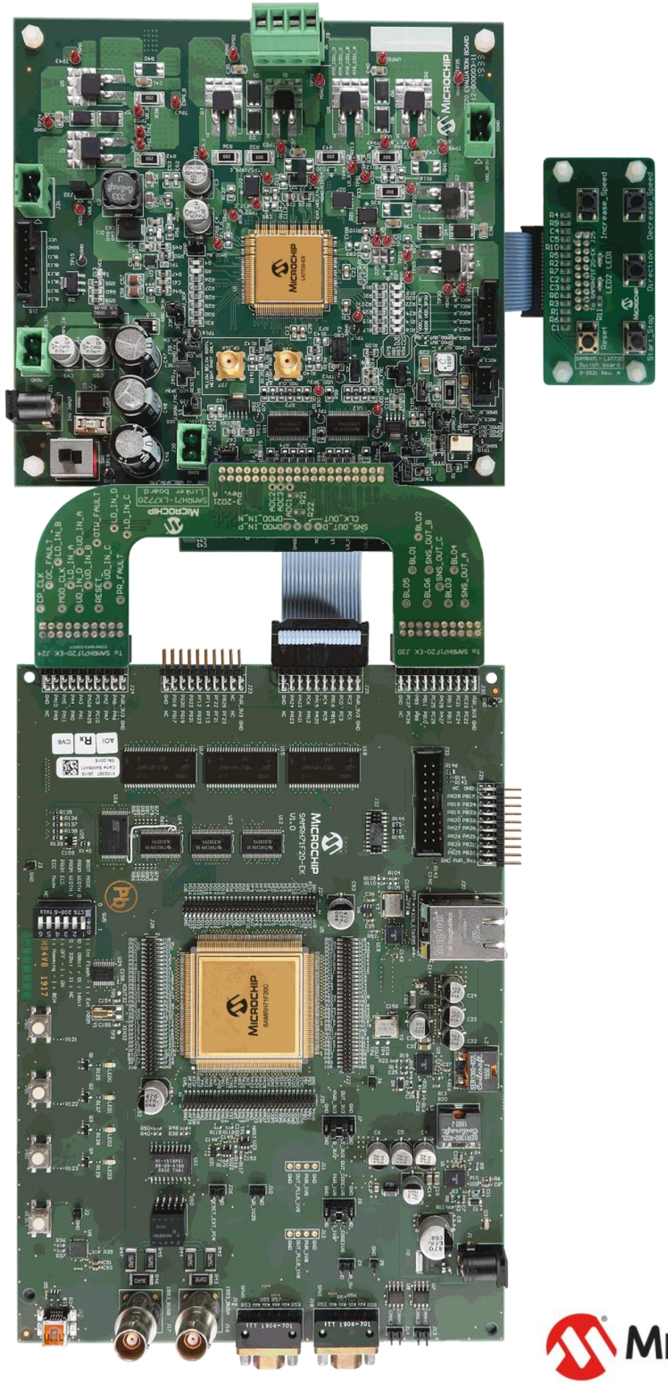


https://www.microchip.com/DevelopmentTools/ProductDetails/PartNO/SAMRH71F20-EK

MC platform Evaluation kit

SAMRH71F20-EK

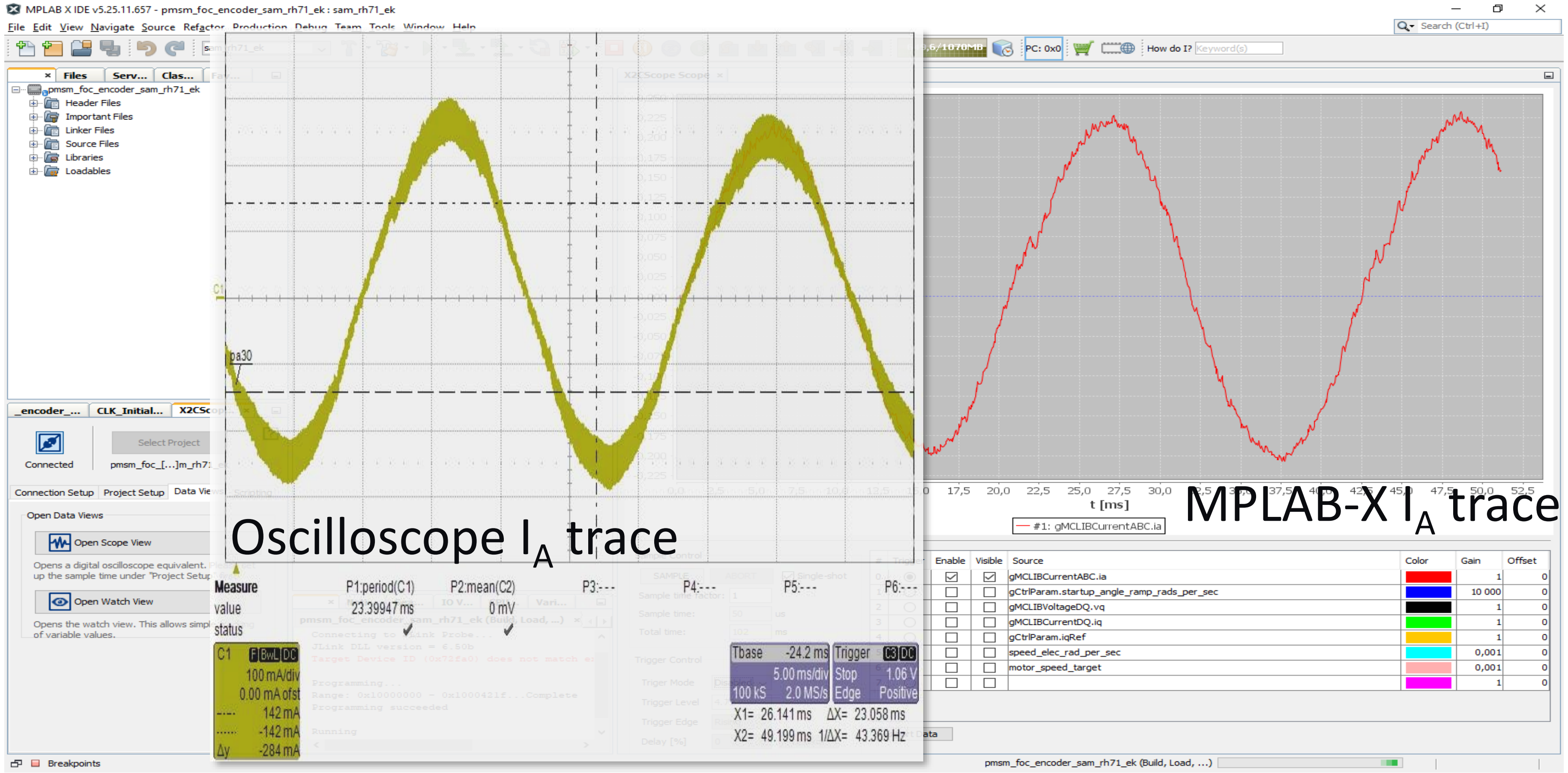
- Connector kit for evaluation of LX7720-DB with a SAMRH71F20-EK
- Current firmware supports field-oriented control of 3-phase Permanent Magnet Synchronous Machine (PMSM) using a 2-channel quadrature optical encoder for position feedback
- SW implements two D/Q space current PI loops and one external speed regulation loop.
- The current sense processing and the FOC algorithm sustaining a 20kHz PWM (fast) loop and 4kHz torque (slow) loop bring the SAMRH71 CPU to < 55% loading.
- Application SW is available in Harmony SW suite.



Measurement results

Capture from MPLAB-X and oscilloscope

- **Validate acquisition of current: compare external / internal measurement**



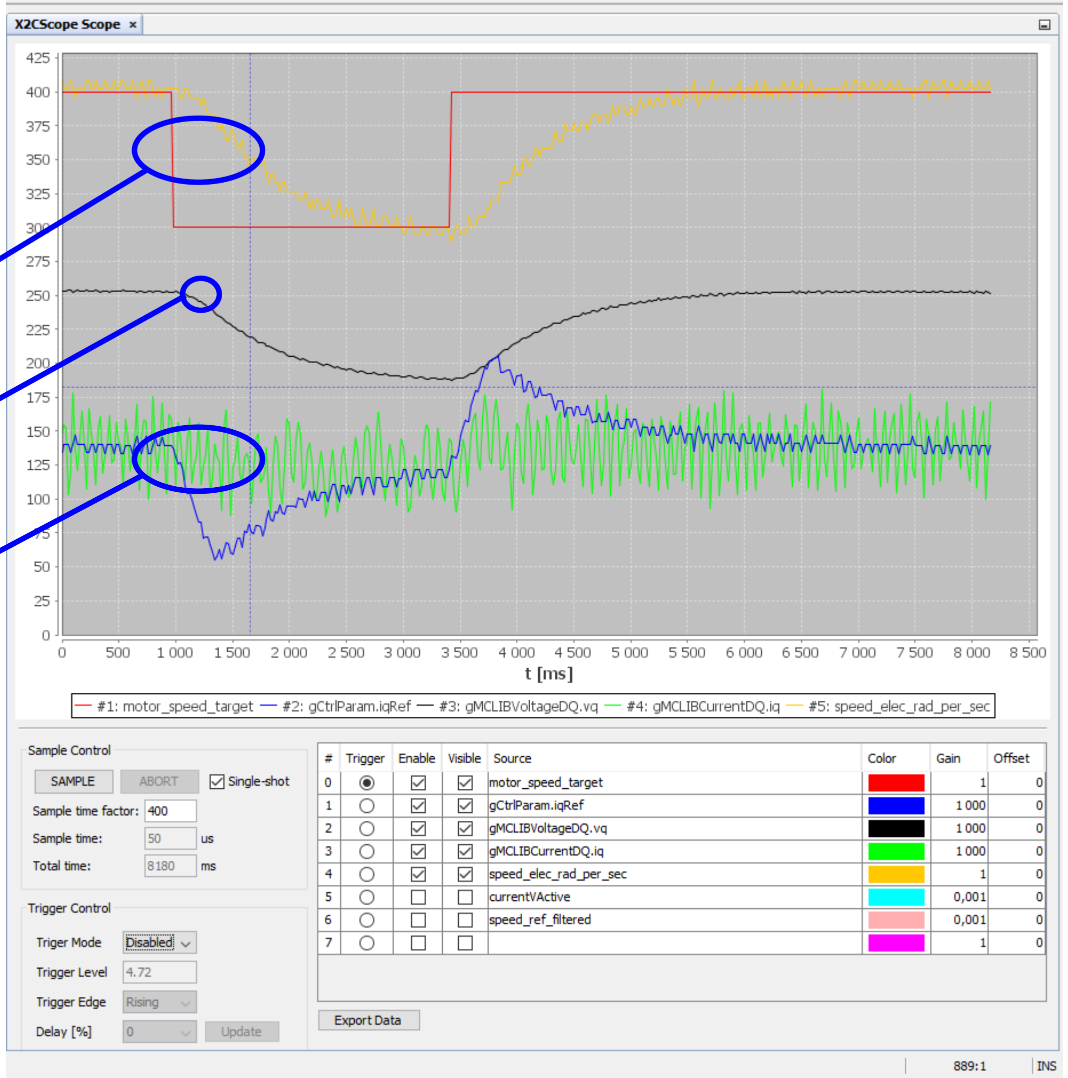
FOC control light load

- **Transition between two target speed values**

Speed target and feedback [rpm]

Vq (output voltage in rotor coord)[mV]

Iq (output current in rotor coord) target and feedback [mA]



Note: Ripple in the current target (green) is due to the asymmetric torque in the load.

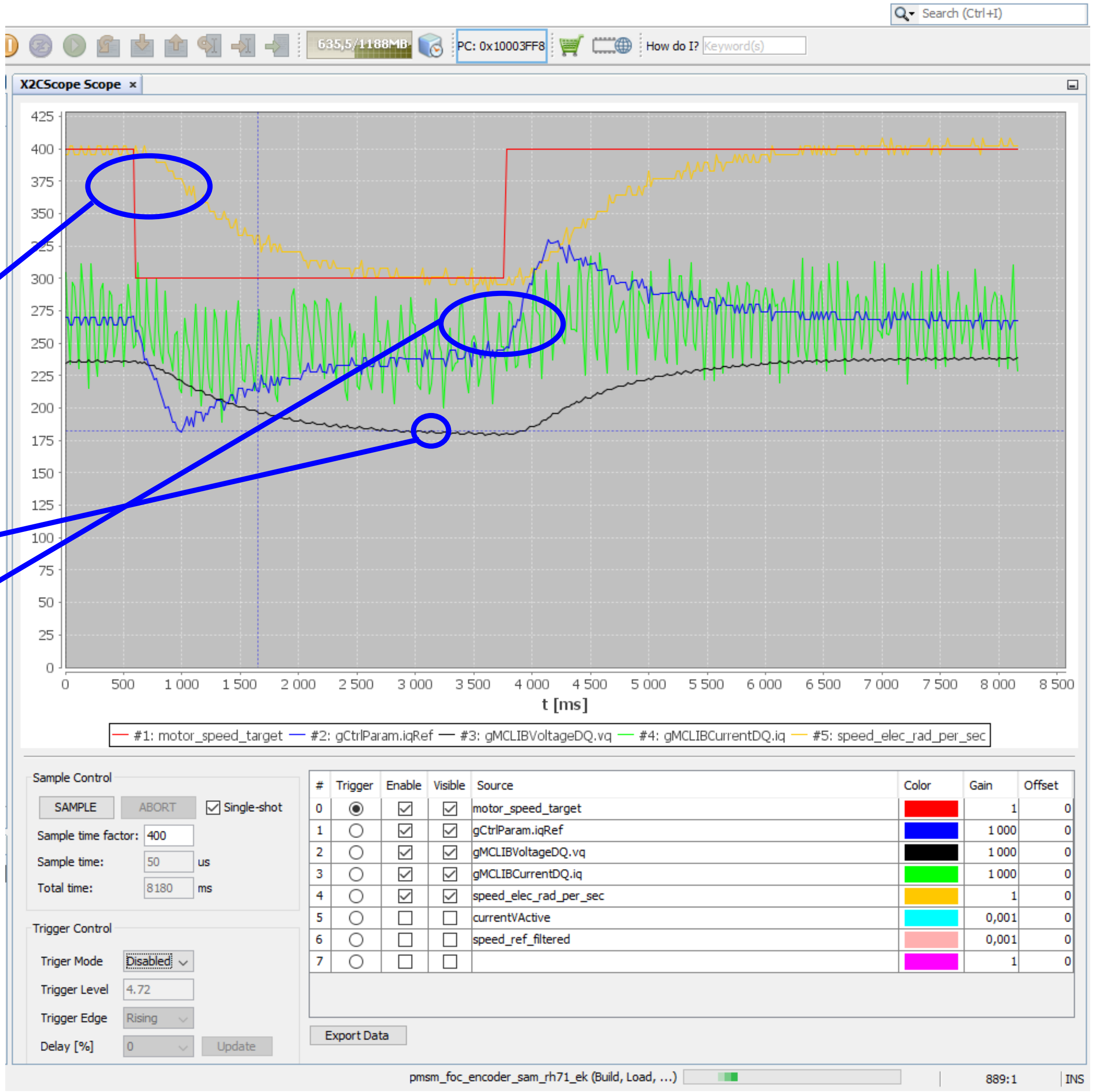
FOC control heavier load

- **Transition between two target speed values**

Speed target and feedback [rpm]

Vq (output voltage in rotor coord)[mV]

Iq (output current in rotor coord) target and feedback [mA]



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Conclusions and future work

- MCU-friendly decimation filters for use with LX7720 delta-sigma modulators were implemented
- The new design is used in a motor control application using SAMRH71 as the control engine.
- A demo kit and demo software is available
- Future development will target other decimation filter implementations even more MCU-friendly