Simplifying Field Oriented Control of Brushless Motors

Speeding Up Development of Applications Using Advanced Motor Control Algorithms and Simplified Development Hardware

Introduction

Electrical motors and their control have changed almost beyond recognition in the past decades. Advancements in magnetics and design, coupled with continued miniaturisation and integration in electronics, have delivered improved efficiency, higher speeds, lower audible noise, and higher dynamic response. Furthermore, the higher torque to weight ratio has made way for some impressive new applications, like drones. At the same time, the reduced mechanical wear, thanks to a lack of carbon brushes, delivers as much as six times longer lifespan over brushed DC motors.

What remains challenging is the control of such motors. The semiconductor industry has developed a range of solutions, from simple with limited configuration to advanced using a microcontroller with highly competent motor control peripherals. Therefore, it makes sense to regularly review the silicon landscape when starting or updating a design. To support developers, there are also a wealth of development boards and evaluation tools to ease the prototyping process and quickly discover the available capabilities.

Fast Motor Start-Up

The options for application prototyping have exploded in recent years, with a plethora of boards to simplify the integration of sensors, memories, and input controls. At the forefront of this development is MikroElektronika, the Serbian manufacturer of tools and software for embedded systems. Their Clicker 4 for TMPM4K targets brushless motor control, delivering a low-cost but versatile entry point board for prototyping based upon their well-established mikroBUS interface.

At the core of the Clicker 4 is the TMPM4KNFYAFG microcontroller from Toshiba featuring a 32-bit Arm® Cortex®-M4 core. The device targets brushless motor control applications with four dedicated peripherals (Figure 1). The first is the Advanced Vector Engine Plus (A-VE+), a vector control accelerator that can handle axis and coordinate transformation, perform space vector modulation, and provides hardware proportional-integral (PI) controllers. Once configured, this peripheral can execute vector motor control almost autonomously. This is made possible due to the high level of integration with the three other key peripherals. An Advanced Programmable Motor Control (A-PMD) provides an array of clever pulse modulation options that simplifies control and eases the deadtime configuration. It also offers a collection of abnormal function detection capabilities and an over-voltage detection input for system safety.

The Advanced Encoder Input Circuit (A-ENC32) supports both Hall and incremental encoders for six modes of operation in sensor-controlled applications. Finally, the 12-bit Analog to Digital Converter (ADC) supports current and voltage monitoring, autonomously triggering from the range of A-PMD module signals. Together, the four peripherals provide almost "set and forget" support for sensor-based and sensorless vector motor control.

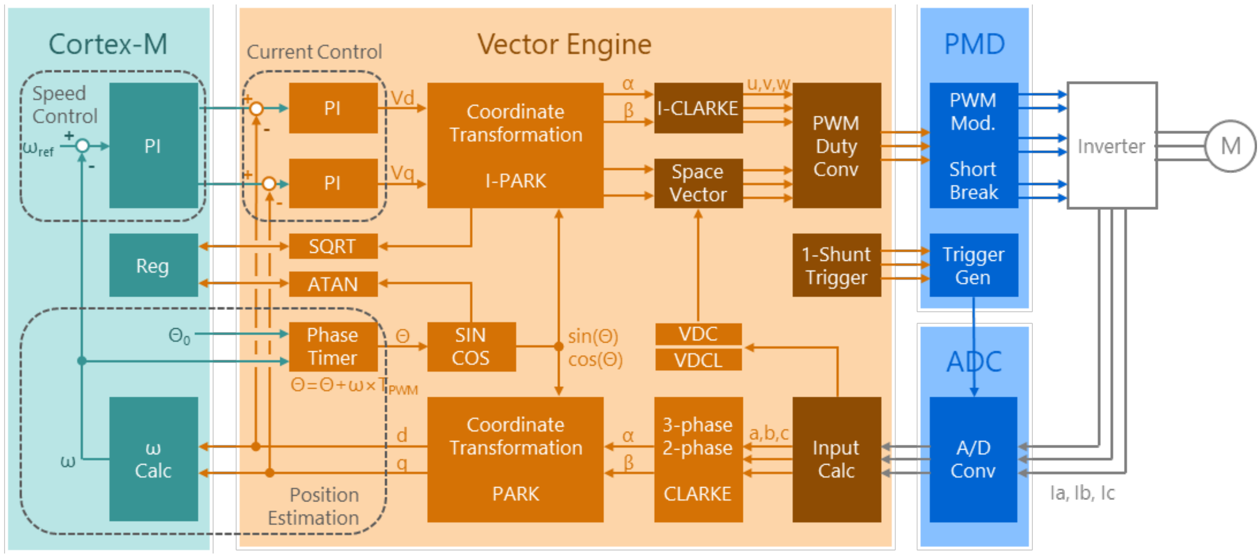

Figure 1: TMPM4KNFYAFG's dedicated peripherals for field-oriented BLDC motor control support high-precision encoders as well as sensorless systems when coupled with the firmware's accurate position control algorithms

Additionally, the TMPM4KNFYAFG has a complete collection of common microcontroller peripherals, from communication to analogue, along with 256 kB code flash, 32 kB data flash, and 24 kB of SRAM operating at up to 160 MHz. Self-diagnostics are also supported to meet functional-safety standards such as IEC 60730 class B.

The Clicker 4 evaluation board (Figure 2) features two different options for debugging. An onboard debug system provides a standard CMSIS-DAP interface that is supported by most of the popular integrated development environment (IDE) platforms. Alternatively, a JTAG/SWD interface is provided for use with an external debugger. A USB interface configured as a serial port is also provided, giving developers a method for outputting text messages from their application or an input for downloading control or configuration data.

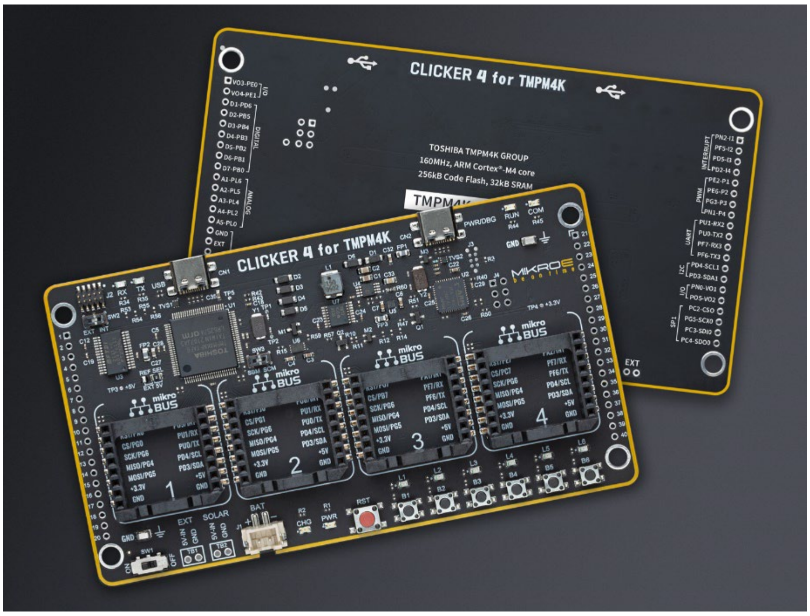

Figure 2: The Clicker 4 evaluation board for TMPM4K

To speed up prototyping, the board also provides four mikroBUS sockets. This standard, defined and maintained by MikroElektronika, offers default pinning for analogue, SPI, UART, I^2C, a reset signal, interrupt, PWM, and power. Currently, well over 400 boards support the standard, and more than 1300 Click boards comes with functionality ranging from sensor inputs and wireless connectivity to rotary encoders and external memory.

The board features six LEDs and push buttons, a reset button, and external power inputs for a power supply or battery. Many of the microcontroller's pins are routed to two 20-pin headers on either side of the board (Figure 3), making it easy to expand functionality, connect external circuitry, or monitor signals with test equipment.

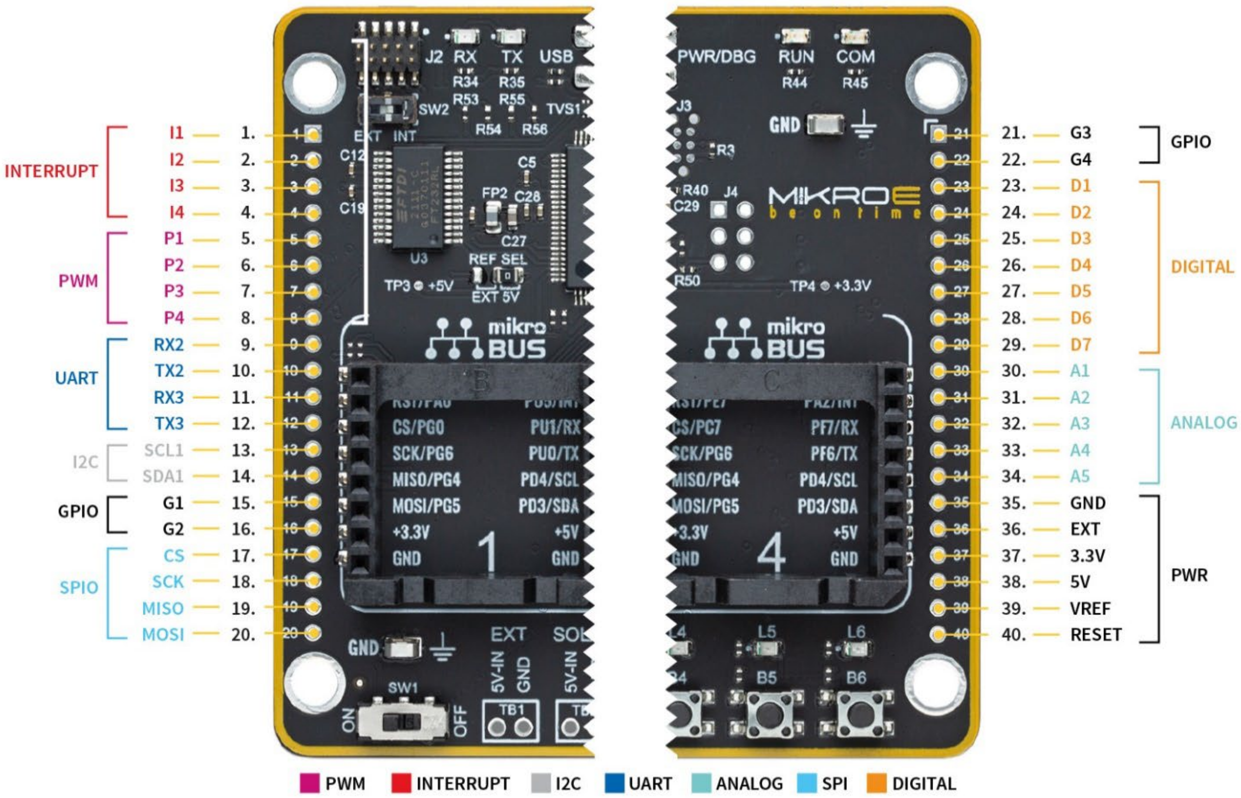

Figure 3: Microcontroller features are routed to both edges of the Clicker 4, simplifying attachment of prototyping circuits or monitoring of signals.

Speedy firmware development

The board is supported by Toshiba's MCU Motor Studio[1], a software package containing two components. The first is the motor control firmware for the TMPM4K family of microcontrollers. With solutions for sinewave commutation and vector-oriented control, it's suited to brushless DC (BLDC), permanent magnet synchronous (PMSM), switched reluctance and asynchronous AC motors. The firmware can support up to three motors from a single M4K microcontroller, but the Clicker 4 is designed to support a single motor. The second software component is the Motor Control PC Tool, providing parameter configuration, drive control, and real-time logging and diagnostics via the Clicker 4's high-speed UART/USB interface.

The firmware (Figure 4) offers three control schemes: speed, torque, and precise position. Each scheme defines the primary control point for the algorithm. In speed mode, the algorithm attempts to maintain the desired speed of the motor. In torque mode, the algorithm concentrates on maintaining the motor at the set torque, adjusting the speed as required. Finally, for precision position mode, the focus is on the rotor position, although torque and speed are adapted as needed. All three control schemes are available in conjunction with sensorless and sensor-based motor control.
Both one-shunt and three-shunt current detection schemes are supported. When coupled with the precision position control mode, high accuracy is possible. Compared to a Hall sensor (offering 60° detection points) measurements have confirmed that the Toshiba motor control algorithm shows better accuracy. The results are also close to those attained using a high-precision encoder. PWM frequencies are generally in the 16 to 20kHz range, although the combination of software and hardware supports up to 50kHz.

In the motor control services layer (Figure 4), various advanced and convenient functions are available, all abstracted from the board and hardware used. This simplifies porting to other hardware or microcontrollers within the M4K family. A Zero Current Point detector calibrates the ADC with no current applied to the motor, an essential part of the control algorithm. Stop Control supports gentle braking, short-braking through shorting the MOSFETs in the inverter, and self-inertia braking by leaving the inverter MOSFETs open circuit. Recovery from a magnetic field stall condition is available, along with load-dependent speed reduction. Sensor-based and sensorless precise control are also integrated into this software layer.

Fault protection mechanisms include over current and voltage, and under voltage, along with motor disconnection detection and over temperature monitoring. A digital storage oscilloscope (DSO) and high-speed DSO, along with statistics collection, are available to observe the internal operation of the control algorithm and sensor data. This is of significant benefit to software developers as the firmware cannot be halted using the debugger to examine the state of registers and memory. The available data, including target and actual speed, torque and current, are monitored with the Motor Control PC Tool (Figure 7).

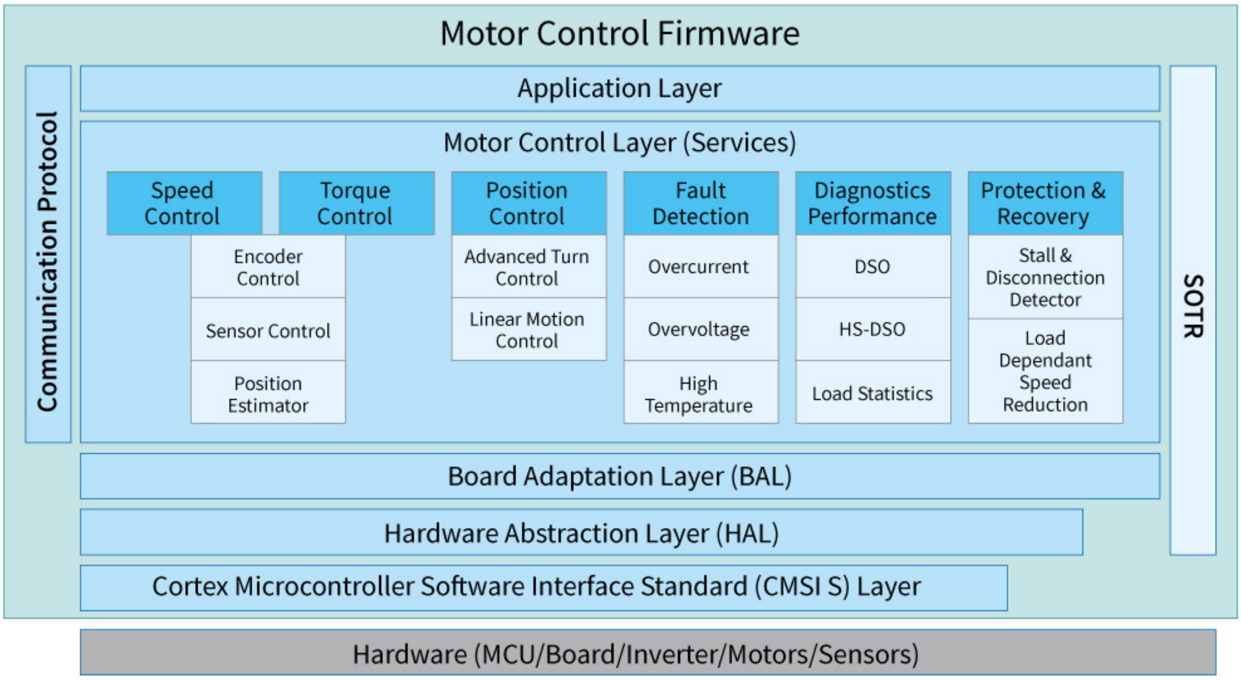

Figure 4: The layered structure of the motor control firmware.

Driving the motor

The Clicker 4 can be combined with the MikroElektronika Clicker 4 Inverter Shield (Figure 5) that provides the interface to the chosen motor and any sensor. The three-phase inverter is constructed from an SPI-based 60V gate driver coupled with Toshiba's low $R_{DS(ON)}$ SSM6K819R MOSFETs available in ultra-small 1 × 1mm packages. An analogue output temperature sensor provides feedback to the Clicker 4 MCU board on the operating temperature, while an incremental encoder interface supporting four differential receivers or two single-ended receivers handles RS-422, HTL, and TTL sensors.

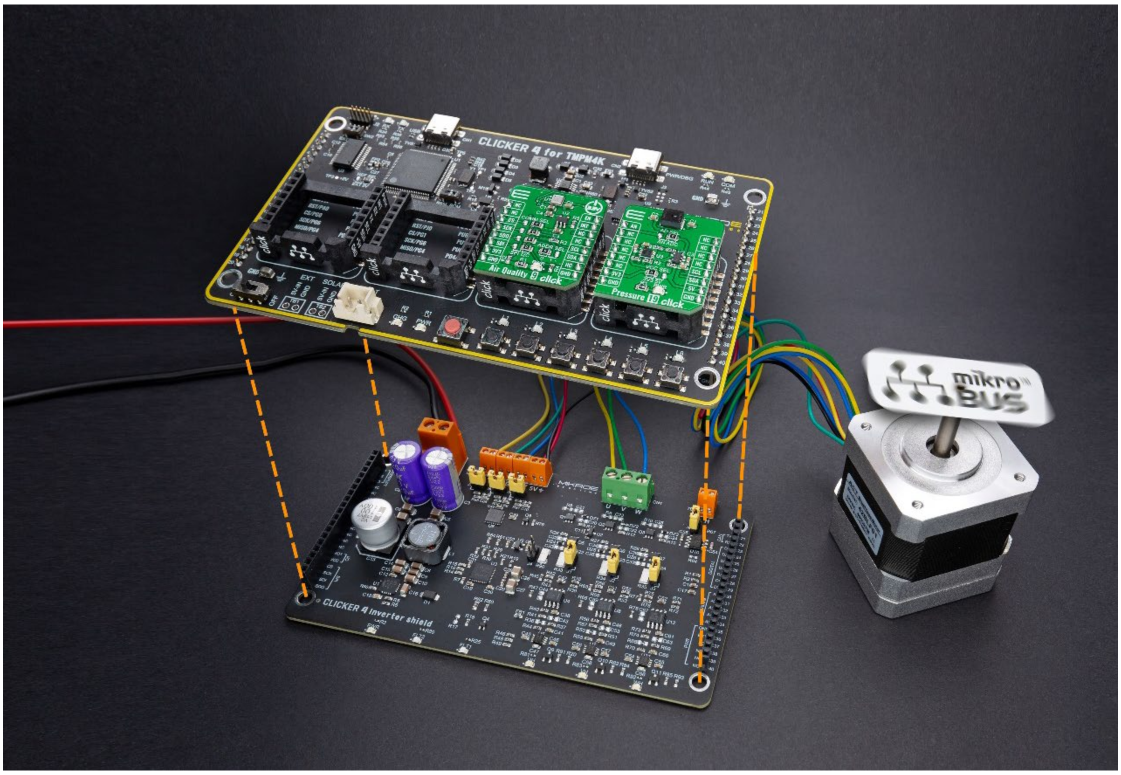

Figure 5: The Clicker 4 for TMPM4K combined with the 3-phase Clicker 4 Inverter Shield featuring Toshiba's low $R_{DS(ON)}$ SSM6K819R MOSFETs driving a BLDC motor

A CAN transceiver rounds off the design complete with a selectable 120Ω termination resistor. Many of the Inverter Shield features can be configured using a selection of jumpers delivered with the board. All key signals, interrupts, and the CAN interface are provided along two headers at the side of the board (Figure 6).

Motor configuration, control, monitoring, and diagnostics

Matching the firmware to the chosen motor is achieved with ease using the Motor Control PC Tool. With the chosen elements compiled into the firmware and downloaded to the microcontroller, the PC tool allows the developer to define the motor characteristics using its graphical user interface (GUI). Initial configuration options cover the number of pole pairs, direction, and resistance and inductance of the windings. In the event that the required details are not included in the datasheet for the motor, a range of calculators are included to help determine missing values.

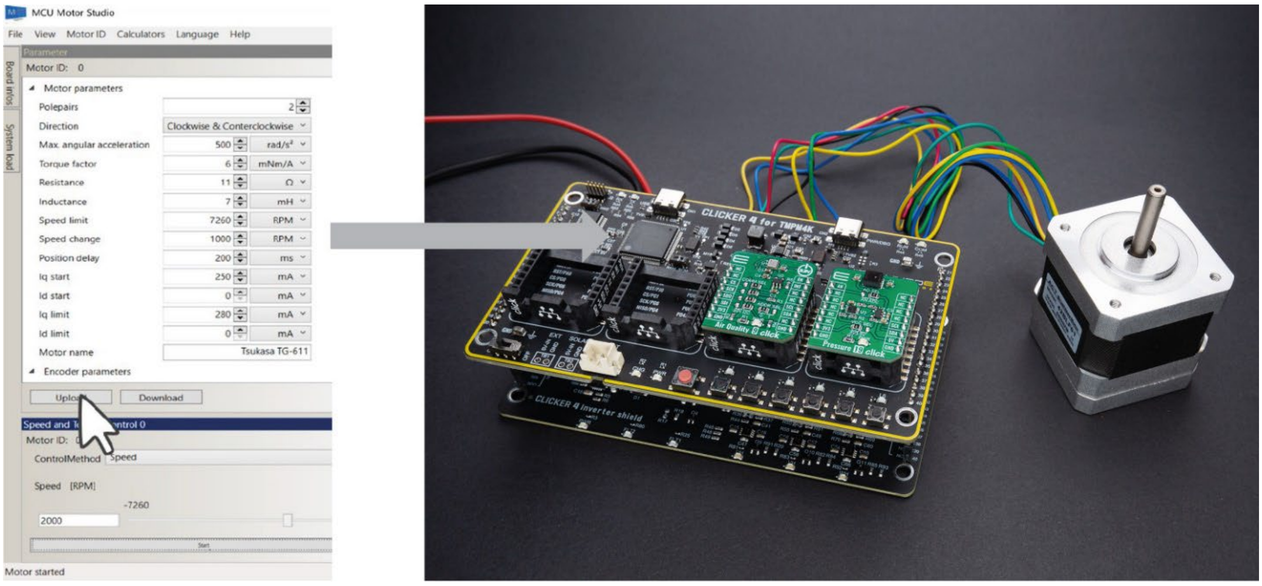

Figure 6: For a quick start the motor parameters can be easily configured and uploaded to the target by the Motor Studio PC Tool

The motor control firmware's PI controller is also configured using the GUI along with the PWM frequency. Some settings, such as the shunt, deadtime, and bootstrap delay, are configured in the firmware and only read out from the microcontroller for display. To check which features are compiled into the firmware, developers can access an information panel with a complete list.

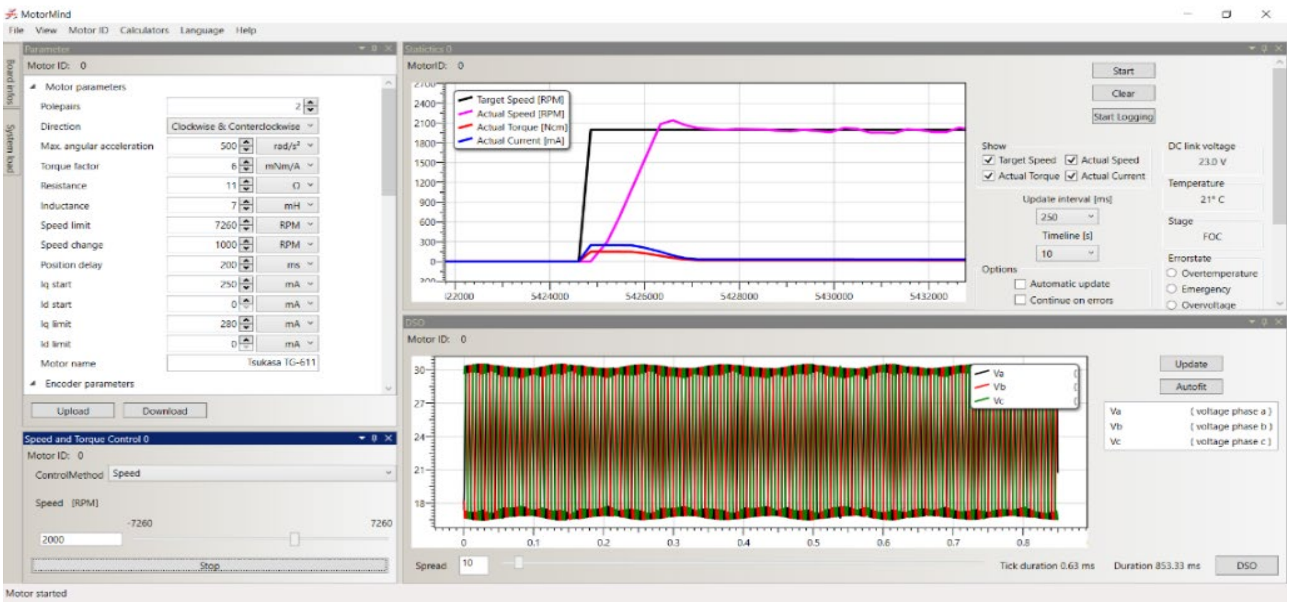

Figure 7: The GUI provides a means to configure the firmware to match the selected motor (left), monitor any errors that occur (top centre), and display real-time data using the integrated Digital Oscilloscope (bottom centre).

Settings within the GUI can be uploaded live to the Clicker 4 board. When the optimal settings are found, they can be exported as a new header file using the PC tool. Source code for the M4K microcontroller is provided that can be built with the leading development toolchains, e.g., IAR Embedded Workbench.

Summary

BLDC and PMSM motor control developers continually look for more efficient, compact, and higher-density solutions to build motor inverters. The Clicker 4 and the Inverter Shield provide them with a rapid, low-cost means of evaluating Toshiba's M4K family of microcontrollers, thanks to the integrated onboard debugger and power devices. Combined with the firmware as source code and a PC tool that delivers real-time statistics and DSO output, designers can rapidly prototype sensor-based and sensorless motor control using off-the-shelf development toolchains before moving to the design stage.

References

1. Software and firmware: https://toshiba.semicon-storage.com/eu/semiconductor/product/microcontrollers/motor-studio.html

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