# PMSM FOC using PSOC™ Control C3 MCU

## About this document

### Scope and purpose

This document describes the implementation of permanent magnet synchronous motor (PMSM) sensorless field-oriented control (FOC) using the Infineon's PSOC™ Control C3 MCU.

### Intended audience

This document is intended for customers who would like a configurable system for FOC control with sensorless feedback using the PSOC™ Control C3 MCU.

Please read the sections "Important notice" and "Warnings" at the end of this document

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# 1 Introduction

Sensorless FOC for brushless permanent magnet synchronous motors has been widely used as a control method in variable frequency drive applications. The system cost and energy efficiency are the two main factors driving the adoption of FOC-driven three-phase motors. For most applications, three shunt resistors located at the low side of inverter switches are used to measure three-phase motor currents for FOC. However, a single shunt is also widely used for cost-sensitive applications.

The PSOC™ Control C3 MCU is designed for real-time control applications such as motor control. The uses of various peripherals intended for motor control applications are described in this document.

## 1.1 Key features

**PSOC™ Control C3 key features**

- 32 bits, single-core Arm® Cortex®-M33 based MCU running up to 180 MHz clock frequency. It supports DSP, FPU, MPU, and state-of-the-art security features
- Supports up to 240 MHz peripheral clock
- 256 KB read-while-write flash with ECC
- 64 KB SRAM with ECC support
- 16 KB instruction cache (I-cache)
- Hardware CORDIC to accelerate calculation
- 12-bit, 12 Msps SAR ADC block, support 16 samplers for simultaneous sampling
- Sixteen 16-bit and four 32-bit timer/counter pulse-width modulator (TCPWM)
- Two DMA controllers with 16 channels each
- Smart I/O capable of logically combine the outputs of multiple channels
- Analog comparators with in-built DAC to generate the comparator reference

**FOC motor control features**

- Multiple motor control capabilities
  - Speed control
  - Current control
  - Torque control
  - Voltage control
- Adaptive sensorless observer that provides minimal phase distortion. It can observe rotor angle, speed, stator angle, stator flux magnitude, and load angle
- Start-up technique
  - Open-loop Volt/Hz
  - Rotor prealignment
  - Six-pulse injection
  - High-frequency injection
- Maximum torque per amp (MTPA)
- Maximum torque per volt (MTPV)
- Field weakening
- Active damping
- Motor I2T protection
- Various voltage modulation methods
- DSP math library

- Hardware and software fault detection for protection
- Floating point implementation of all control features
- Motor profiler to facilitate tuning when new motors are used
- High-sampling-rate oscilloscope support for signal monitoring

## 1.2 Abbreviations and acronyms

**Table 1** **Abbreviations and acronyms**

| | |
|---|---|
| API | Application programming interface |
| CORDIC | Coordinate rotation digital computer |
| DMA | Direct memory access |
| DSP | Digital signal processor |
| FOC | Field-oriented control |
| FPU | Floating point unit |
| HPPASS | High-performance programmable analog subsystem |
| I-PMSM | Interior permanent magnet synchronous motor |
| ISR | Interrupt service routine |
| MCU | Microcontroller unit |
| MPU | Memory protection unit |
| PMSM | Permanent magnet synchronous motor |
| PWM | Pulse width modulation |
| RFO | Rotor frame orientation |
| SFO | Stator frame orientation |
| SMPMSM | Surface-mounted permanent magnet synchronous motor |
| SVM | Space vector modulation |
| TBC | Trapezoidal block commutation |
| TCPWM | Timer/counter, and pulse-width modulator |

## 1.3 PSOC™ Control C3 resource allocation

PSOC™ Control C3 MCU peripherals allocated for the FOC sensorless solution are captured in Table 2.

**Table 2** **PSOC™ Control C3 resource allocation for FOC**

| PSOC™ Control C3 peripherals | Usage | Default resource allocation |
|---|---|---|
| TCPWM | PWM_U: PWM generation for phase U, 16-bit resolution | TCPWM0-G1-C0 |
| | PWM_V: PWM generation for phase V, 16-bit resolution | TCPWM0-G1-C1 |

**(table continues...)**

**Table 2** **(continued) PSOC™ Control C3 resource allocation for FOC**

| PSOC™ Control C3 peripherals | Usage | Default resource allocation |
|---|---|---|
| | PWM_W: PWM generation for phase W, 16-bit resolution | TCPWM0-G1-C2 |
| TCPWM | ADC0_ISR0:<br>• Trigger ADC group-0 for current sampling. End of group-0 conversion is connected to a fast control loop (ISR0)<br>• Trigger the PWM compare value swap | TCPWM0-G1-C3 |
| TCPWM | SYNC_ISR1:<br>• Overflow ISR connected to the slow control loop (ISR1)<br>• Trigger the ADC low priority group-1 | TCPWM0-G0-C0 |
| TCPWM | PWM_START: Start all the timer in sync. | TCPWM0-G1-C4 |
| ADC | ADC_SAMP_IU: Phase U current sensing | AN_A0 |
| | ADC_SAMP_IV: Phase V current sensing | AN_A1 |
| | ADC_SAMP_IW: Phase W current sensing | AN_A2 |
| | ADC_SAMP_VBUS: DC link voltage sensing | AN_A4 |
| | ADC_SAMP_VPOT: Potentiometer for onboard speed control | AN_B4 |
| | ADC_SAMP_TEMP: Power board temperature sensing | AN_B6 |
| Interrupt controller (NVIC) | ISR1: Timer interrupt | tcpwm_0_interrupts_0_IRQn |
| | ISR0: ADC conversion complete interrupt | pass_interrupt_sar_entry_done_0_IRQn |
| MATH | FPU | – |

## 1.4 PSOC™ Control C3 peripheral inter connectivity

The following figure shows the inter- connection between PSOC™ Control C3 peripherals using solution personality used for three-shunt sensorless FOC.

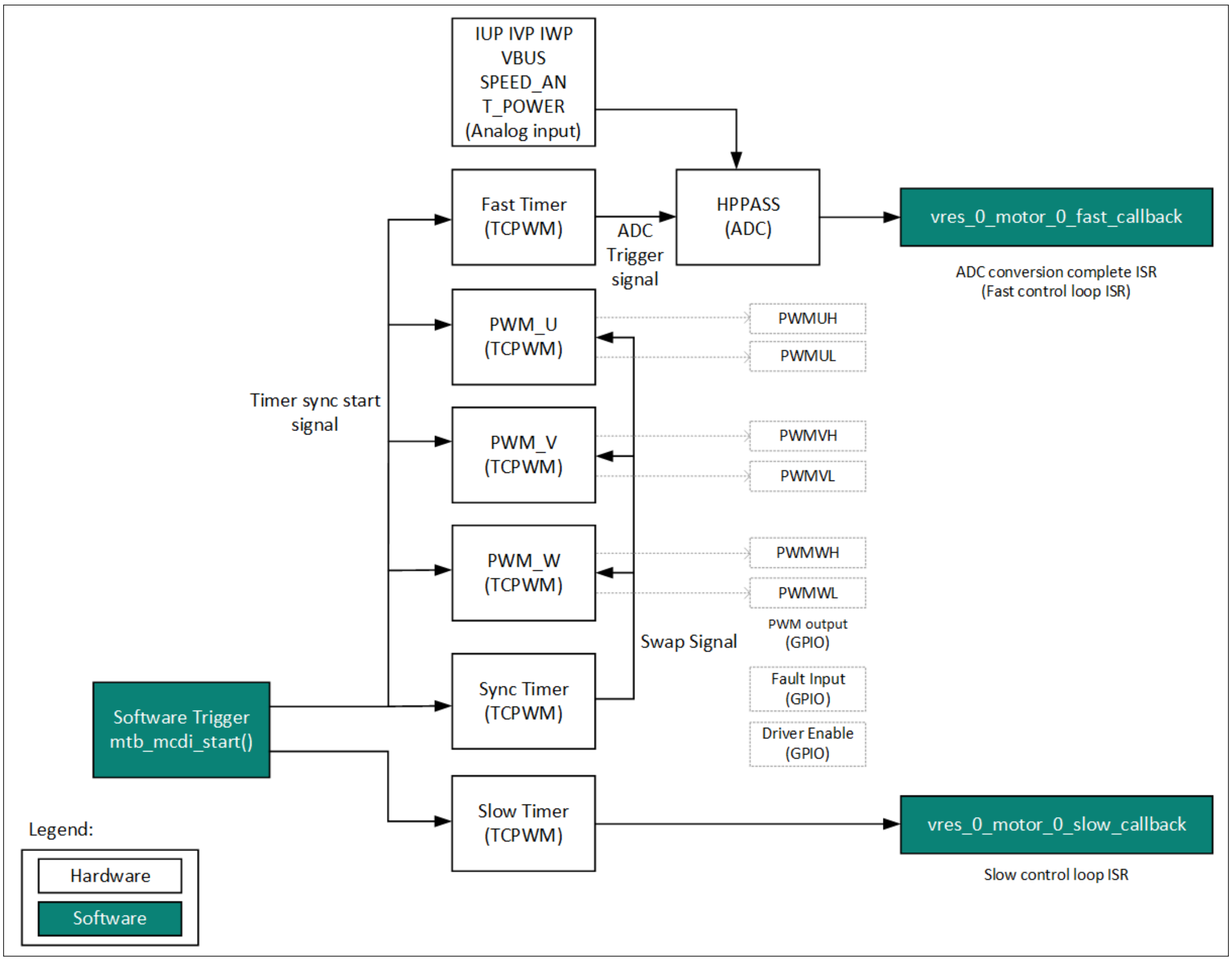
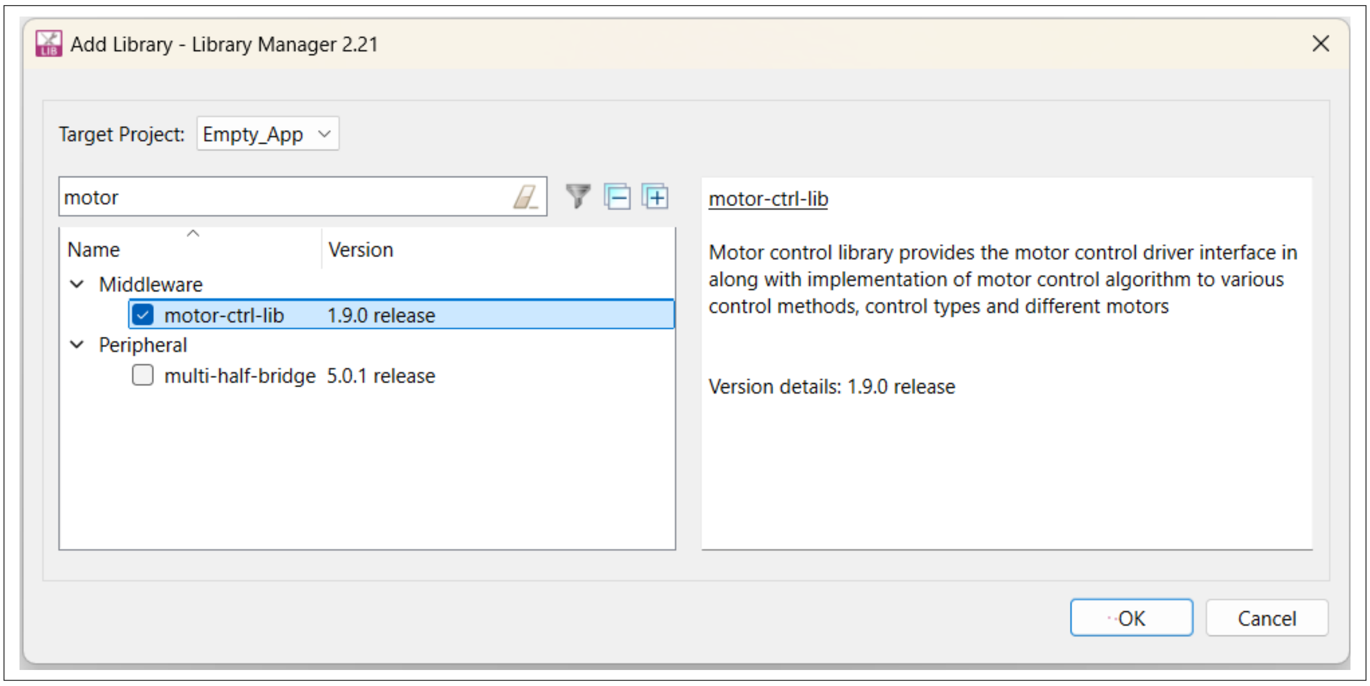


**Figure 1** **Peripheral inter-connectivity**

## 1.5 Motor control library

The motor control library is a ModusToolbox™ middleware asset. It can be integrated with a new application using Library Manager as shown in Figure 2.



Add Library - Library Manager 2.21

Target Project: Empty_App

motor

| Name | Version |
|---|---|
| Middleware | |
| [✓] motor-ctrl-lib | 1.9.0 release |
| Peripheral | |
| [ ] multi-half-bridge | 5.0.1 release |

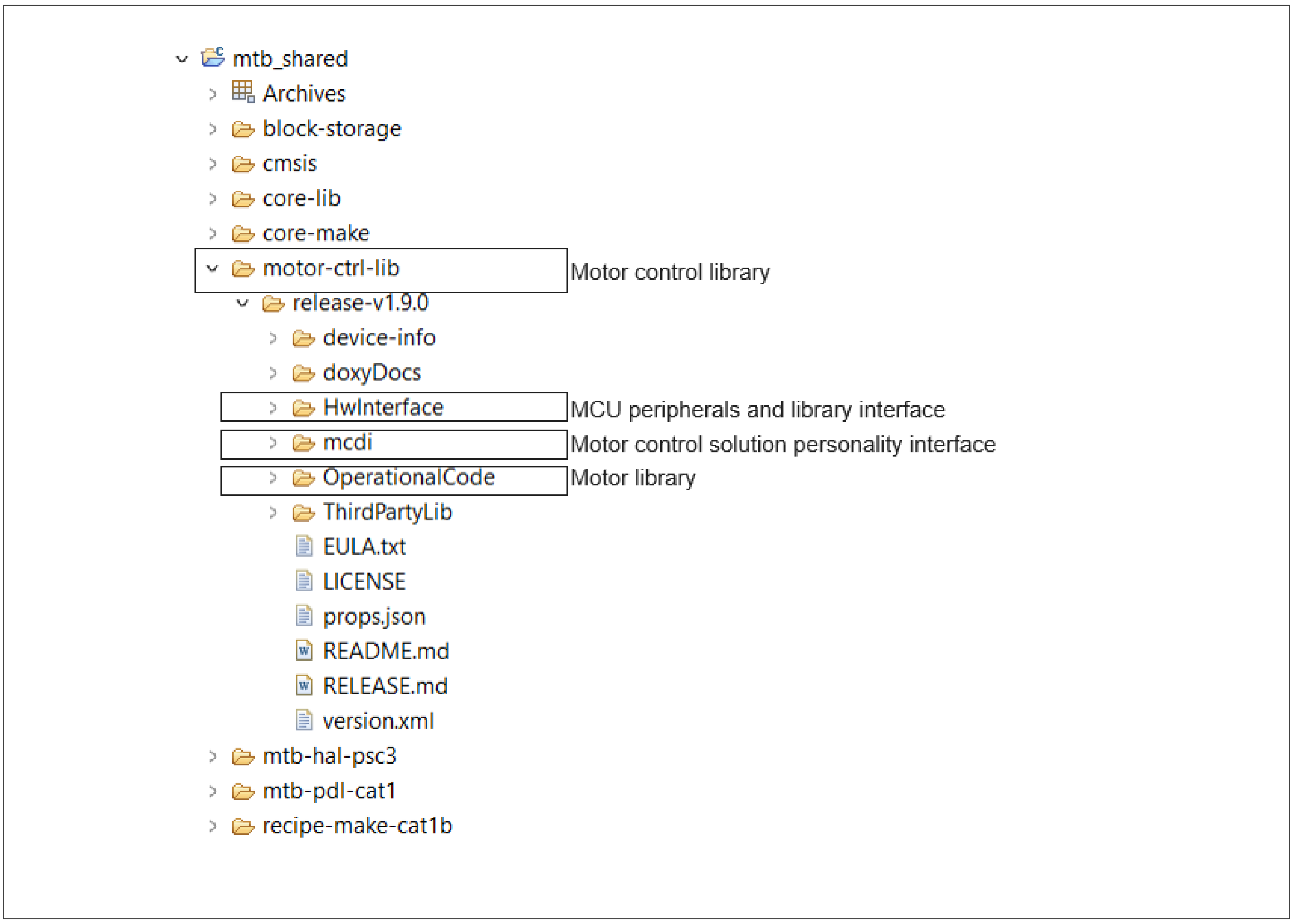
motor-ctrl-lib

Motor control library provides the motor control driver interface in along with implementation of motor control algorithm to various control methods, control types and different motors

Version details: 1.9.0 release

**Figure 2** **Motor control library**

It has a well-defined layered architecture including the hardware interface layer as shown in Figure 3.



```
mtb_shared
  Archives
  block-storage
  cmsis
  core-lib
  core-make
  motor-ctrl-lib                 Motor control library
    release-v1.9.0
      device-info
      doxyDocs
      HwInterface                MCU peripherals and library interface
      mcdi                       Motor control solution personality interface
      OperationalCode            Motor library
      ThirdPartyLib
      EULA.txt
      LICENSE
      props.json
      README.md
      RELEASE.md
      version.xml
  mtb-hal-psc3
  mtb-pdl-cat1
  recipe-make-cat1b
```

**Figure 3** **Motor library folder structure**

Hardware interface layer provide the interface functions to integrate the device agnostic library to the hardware modules.

# 2 PMSM sensorless FOC basics

This section introduces the different types of PMSM motors and the structure of a typical sensorless FOC system.

## 2.1 Types of synchronous motors

There are two types of PMSMs, the salient and the non-salient type of motor. They differ in how magnets are placed in the rotor. Figure 4 shows the non-salient surface mounted permanent magnet synchronous motor (PMSM/SMPMSM) [left] and a salient interior permanent magnet synchronous motor (IPMSM) [right].

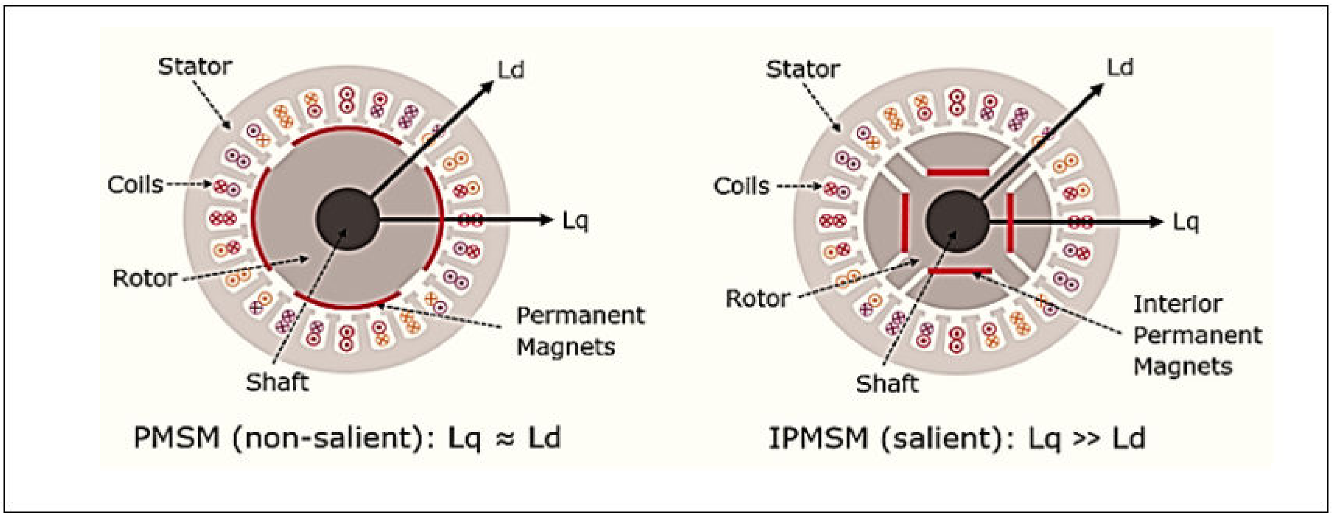

Stator
Ld
Coils
Lq
Rotor
Permanent Magnets
Shaft
PMSM (non-salient): Lq ≈ Ld
Stator
Ld
Coils
Lq
Rotor
Interior Permanent Magnets
Shaft
IPMSM (salient): Lq >> Ld

**Figure 4** **Structure for SMPMSM and IPMSM**

IPMSM has distributed windings with interior permanent magnets inside the rotor causing a saliency and therefore, also reluctance torque. In SMPMSM, magnets are placed on the surface of the rotor, it has no saliency. In the non-salient type of synchronous motor, the stator inductance is not dependent on the rotor position whereas in the salient type of motor the stator inductance is dependent on the rotor position.

Synchronous motors can provide torque when a rotating electromagnetic field and a constant field are standing still relative to each other. To develop a constant torque, the stator field must rotate synchronously with the rotor (permanent magnets) which is excited by a DC power supply.

The d-axis refers to the direct axis (main flux path axis that is normally in the orientation of the permanent magnets) of a synchronous machine, while the q-axis refers to the quadrature axis.

## 2.2 Sensorless FOC system overview

FOC is also known as vector control, it provides better efficiency at higher speeds than sinusoidal control. Vector control guarantees optimized efficiency even during transient operation by perfectly maintaining the stator and rotor fluxes. It gives better performance on dynamic load changes when compared to all other control techniques. Figure 5 shows the hardware block diagram of a typical sensor less FOC system. It consists of MCU, inverter, motor, current sensing circuit, and communication interfaces. These components can be on the same controller board or separated in the system such as on an MCU board and an inverter board.

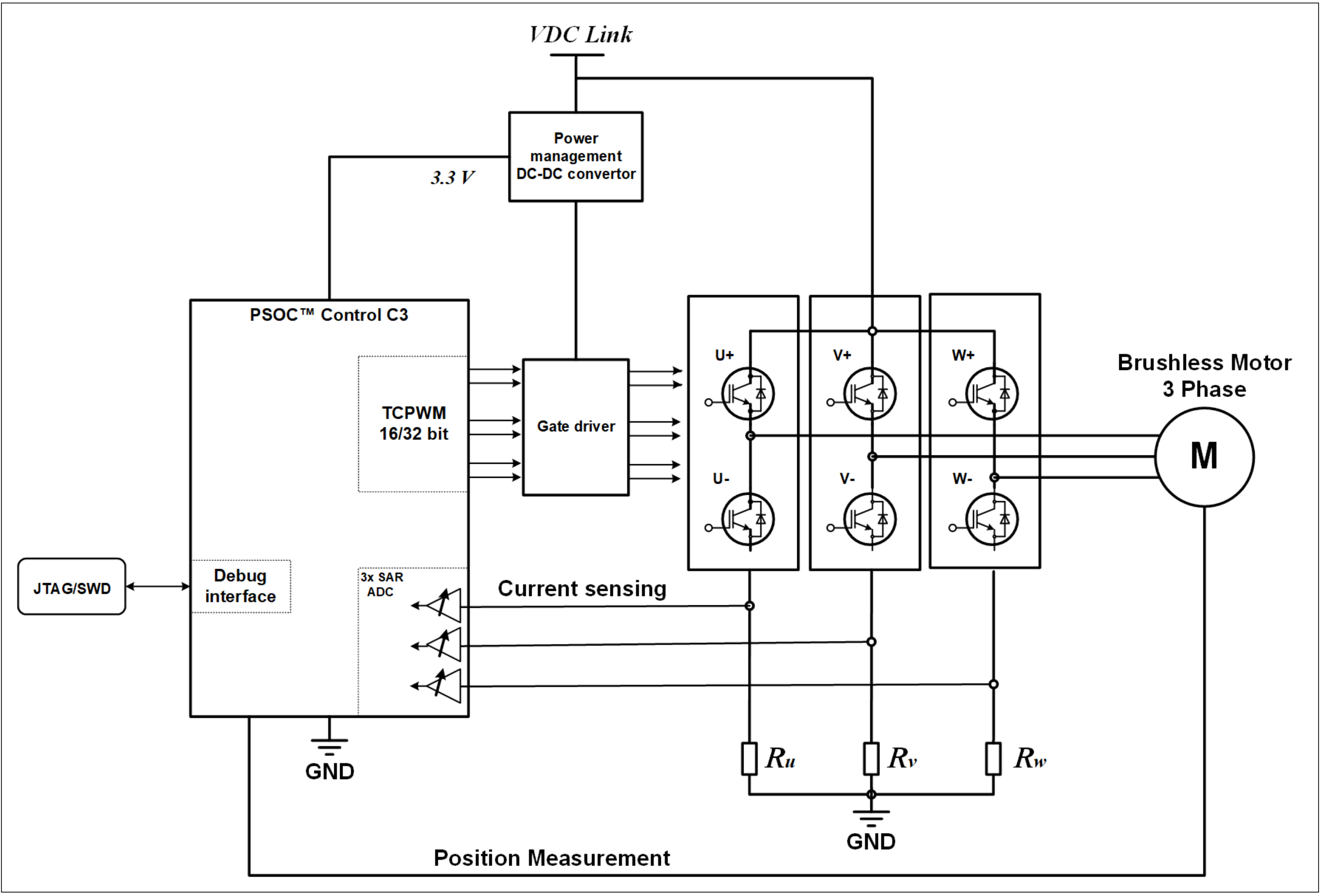


**Figure 5** **Overview of a typical FOC system**

## 2.3 Inverter

The objective of any motor control method is to generate a reference voltage to be applied to the motor windings using an inverter. Since the inverter is made of discrete switching devices, it cannot produce a continuous voltage on its output. Therefore, a modulation scheme is needed to create a voltage that has an average equal to the reference voltage. Figure 6 shows the basics of modulation.

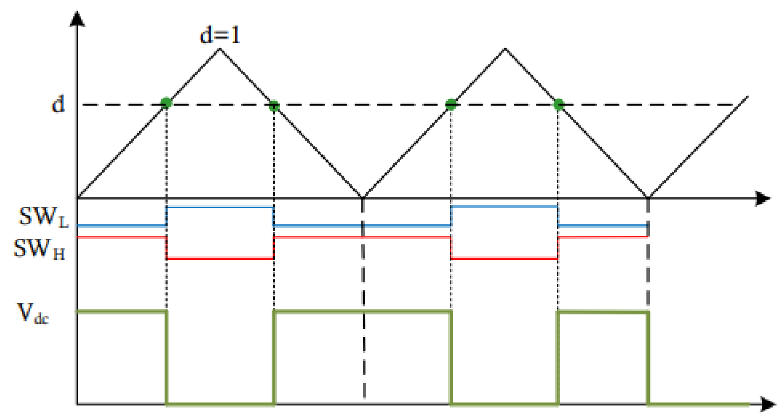


**Figure 6** **Voltage modulation**

As shown in Figure 6, the reference voltage $d$ generated by the controller is compared with a triangular waveform which creates the switching signals for low side SWL and high side SWH switches in the associated leg of an inverter. The result would be the voltage waveform with an average of $d$ x $V$dc in the leg of the inverter (with respect to the negative DC bus).

In a three-phase inverter, the maximum voltage vector that can be generated depends on the modulation scheme. As it is shown in the following figure, the maximum voltage that can be generated by the inverter is 2/3 × $Vdc$ (with respect to the neutral point of the motor). Space Vector Modulation (SVM) and Neutral Point Modulation can both produce 1/√3 × $Vdc$ . These modulation schemes will be discussed in the following sections.

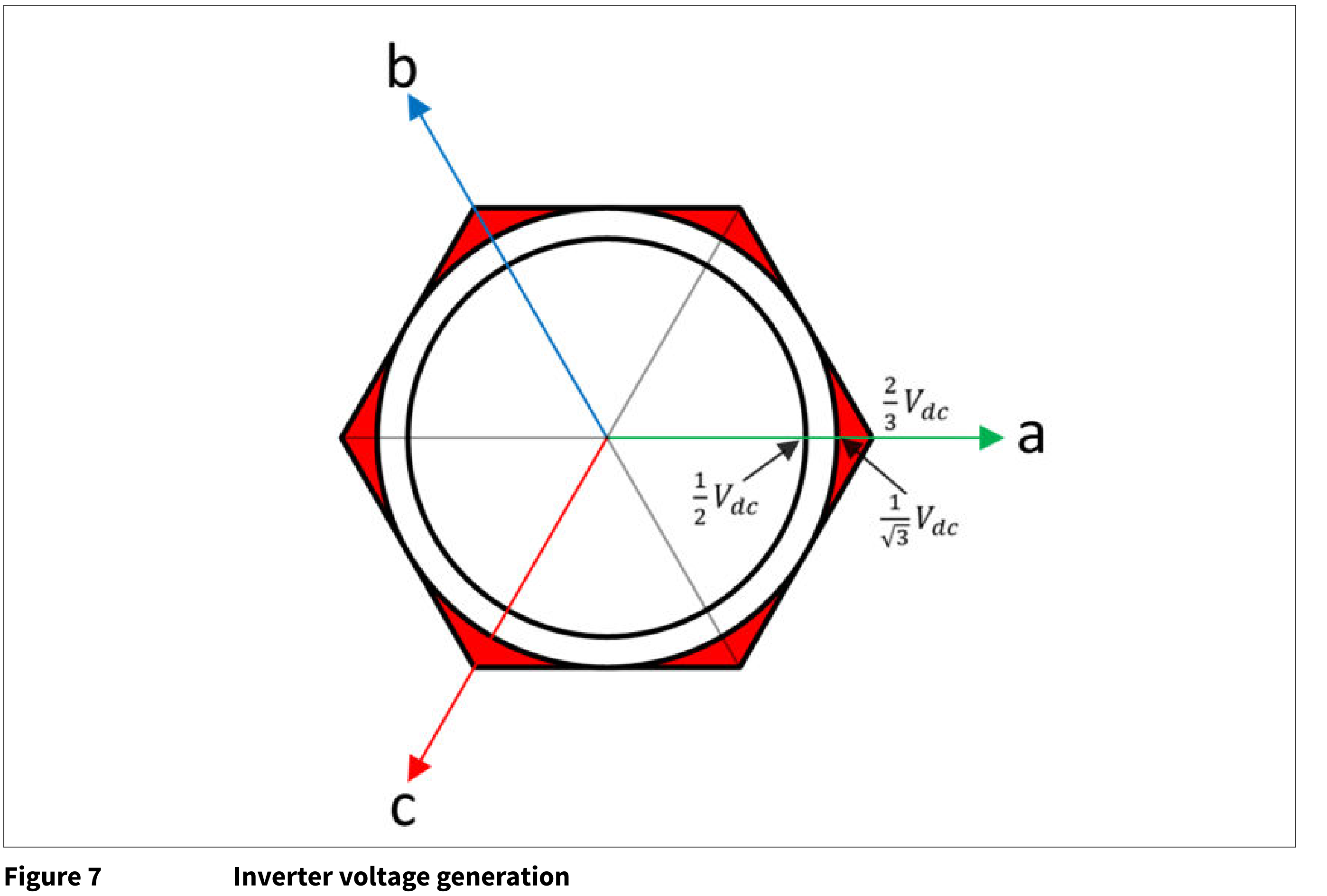


**Figure 7** **Inverter voltage generation**

## 2.4 Space vector modulation

In the SVM method, the voltage reference is created using the two adjacent voltage vectors as shown in Figure 8.

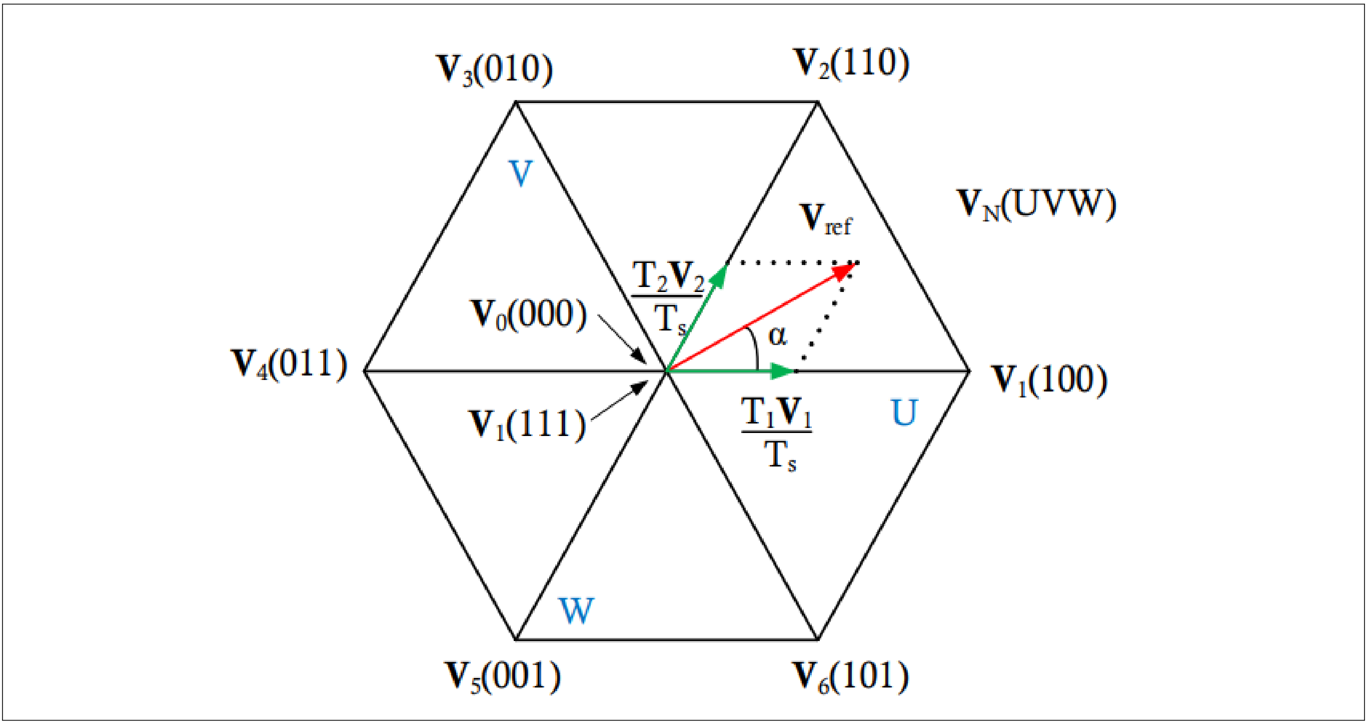


**Figure 8** **SVM voltage creation**

With a switching period of $Ts$, the reference voltage is created by applying $V_1$ and $V_2$ for $T_1$ and $T_2$ respectively and $T_0$ and $T_7$ for the rest of the period. Therefore,

$$V_{ref} = \frac{T_0 V_0 + T_1 V_1 + T_2 V_2 + T_7 V_7}{T_S} = d_1 V_1 + d_2 V_2$$

and the duration of each voltage vector can be calculated as:

$$d_1 = \sqrt{3}\frac{V_{ref}}{V_{dc}}\sin\left(\frac{\pi}{3} - \alpha\right) = \frac{\sqrt{3}}{2} m \sin\left(\frac{\pi}{3} - \alpha\right)$$

$$d_2 = \sqrt{3}\frac{V_{ref}}{V_{dc}}\sin \alpha = \frac{\sqrt{3}}{2} m \sin \alpha$$

$$d_0 + d_7 = 1 - \left(d_1 + d_2\right)$$

where $m$ is the modulation index and defined as:

$$m = 2\frac{V_{ref}}{V_{dc}}$$

Figure 8 shows the two different switching schemes for each leg of the inverter based on the timings acquired for each voltage vector. There are a few different switching schemes that can be used to create the vectors determined by the SVM method. However, 7 segment and 5 segment switching methods as shown in the following figure are the most popular ($T_0 = T_7$).

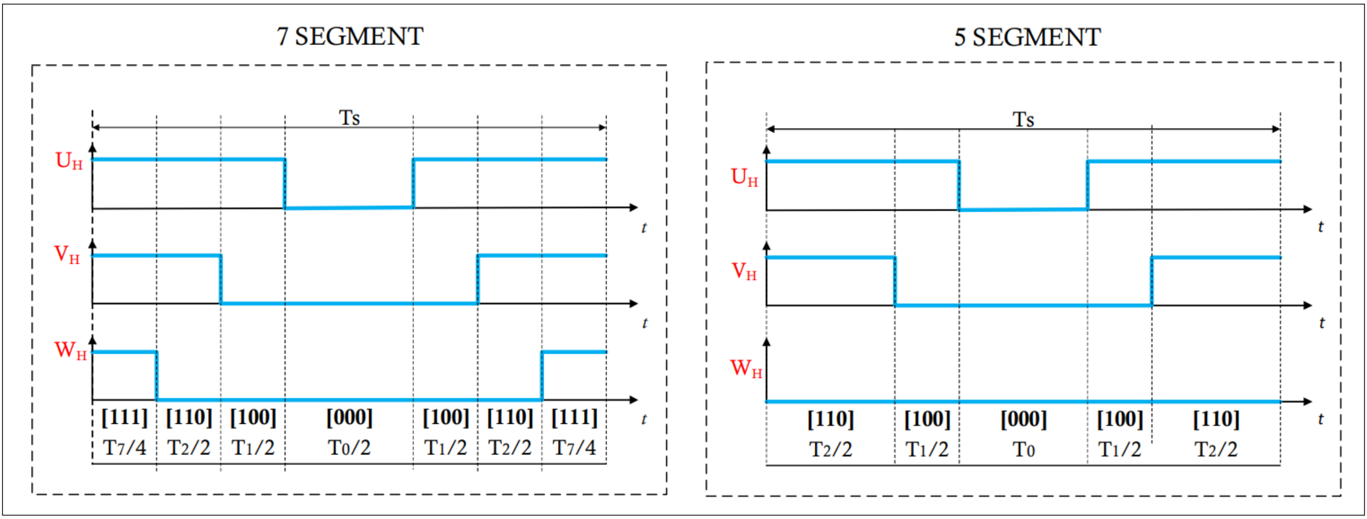


**Figure 9** **SVM switching methods**

The difference between the two switching methods is that in 7 segment, both $V_0$ and $V_7$ times are used to create zero voltage while in 5 segment only $V_0$ is used to create zero voltage.

Note that the 5 segment switching method creates less switching compared to the 7 segment which reduces the switching losses. However, the current ripple in this switching method is higher compared to 7 segment.

## 2.5 Neutral point modulation

Neutral point modulation is another method to increase the modulation index beyond 1.0, similar to the SVM method. This modulation method can be used to increase the modulation index to 1.15. Figure 10 shows the type of modulation work.

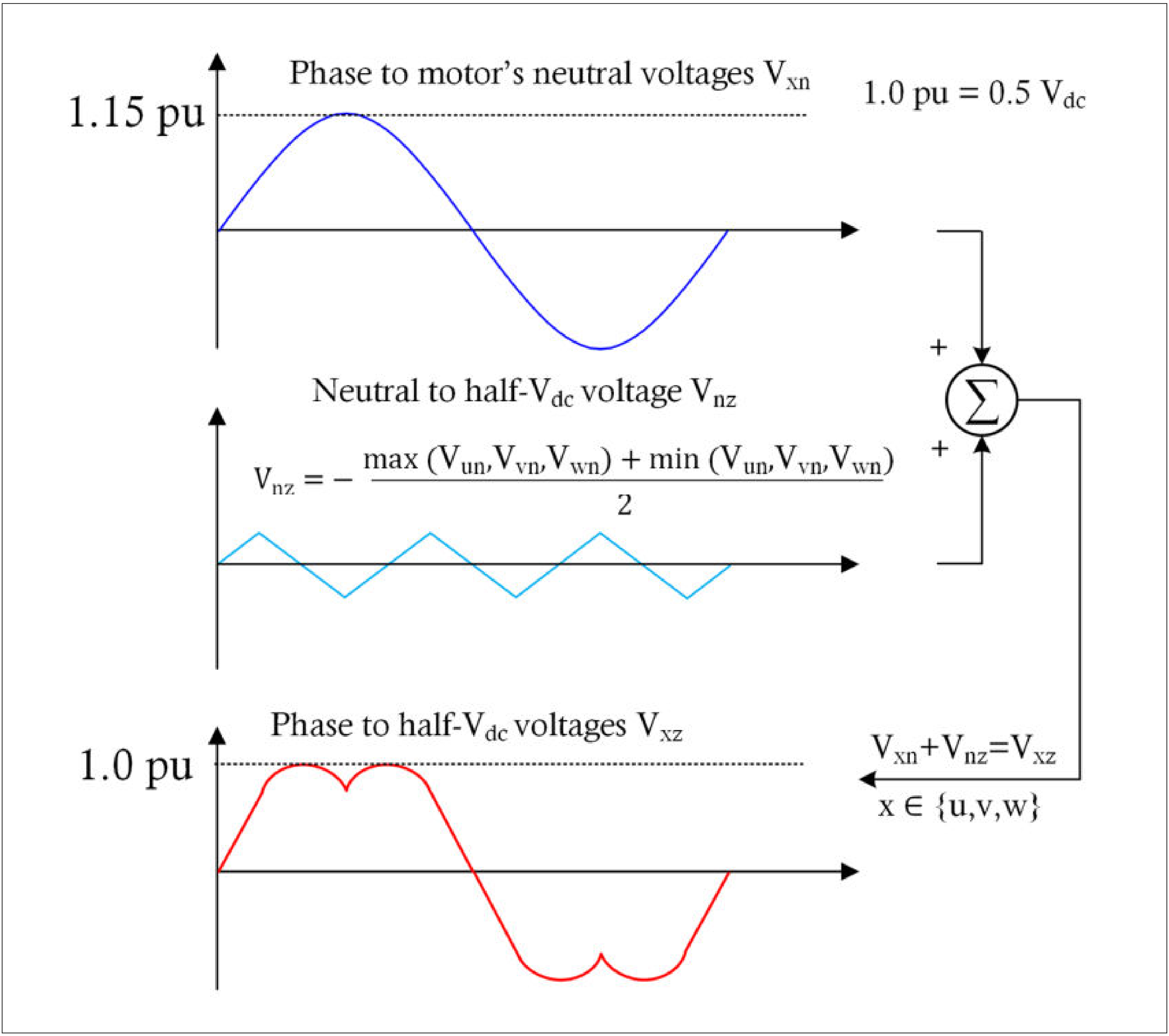

Phase to motor's neutral voltages $V_{xn}$
1.15 pu
1.0 pu = 0.5 $V_{dc}$
Neutral to half-$V_{dc}$ voltage $V_{nz}$
$V_{nz} = -\frac{\max(V_{un}, V_{vn}, V_{wn}) + \min(V_{un}, V_{vn}, V_{wn})}{2}$
+
+
Phase to half-$V_{dc}$ voltages $V_{xz}$
1.0 pu
$V_{xn}+V_{nz}=V_{xz}$
$x \in \{u,v,w\}$

**Figure 10** **Neutral point modulation scheme**

In Figure 10, the $Vxn$ is the phase reference voltage created by the controller. Note that this voltage is phase-to-neutral not phase-to-phase. $Vnz$ is a common mode voltage that must be added to all the three-phase voltage references. This voltage is calculated as:

$$V_{nz} = -\frac{max\ (V_{un},\ V_{vn},\ V_{wn})\ +\ min\ (V_{un},\ V_{vn},\ V_{wn})}{2}$$

The voltages with respect to the half $Vdc$ point of the inverter are denoted as $Vxz$ as shown in Figure 10.

As mentioned, this is a simple modulation strategy to increase the effective modulation index which creates results that are identical to those of SVM while being less computationally demanding. The switching can also be scheduled like the SVM method according to the SVM switching methods image.

## 2.6 Current sensing in sensorless FOC

FOC needs phase currents as input to control the motor. In sensorless FOC, phase currents are needed to estimate the rotor position in addition to field-oriented control. Therefore, fast and accurate current sensing is the core of PMSM sensorless FOC. It enhances the system performance by reducing the torque ripple or noise.

The delay in current sensing path or inaccurate current sensing leads to a distorted current waveform and it produces torque ripple, which results in inefficient performance.

The three-phase or two-phase current sampling must be done when the low-side switches are ON, and the current sampling point must be synchronized with the pulse-width modulation (PWM). Different current sampling techniques and associated challenges are described in the following sections.

### 2.6.1 Three-shunt current sensing

This technique uses low-side current sensing in which shunt resistors located at the base of the inverter bridge to measure the currents that are flowing through the phases as shown in the Figure 11.

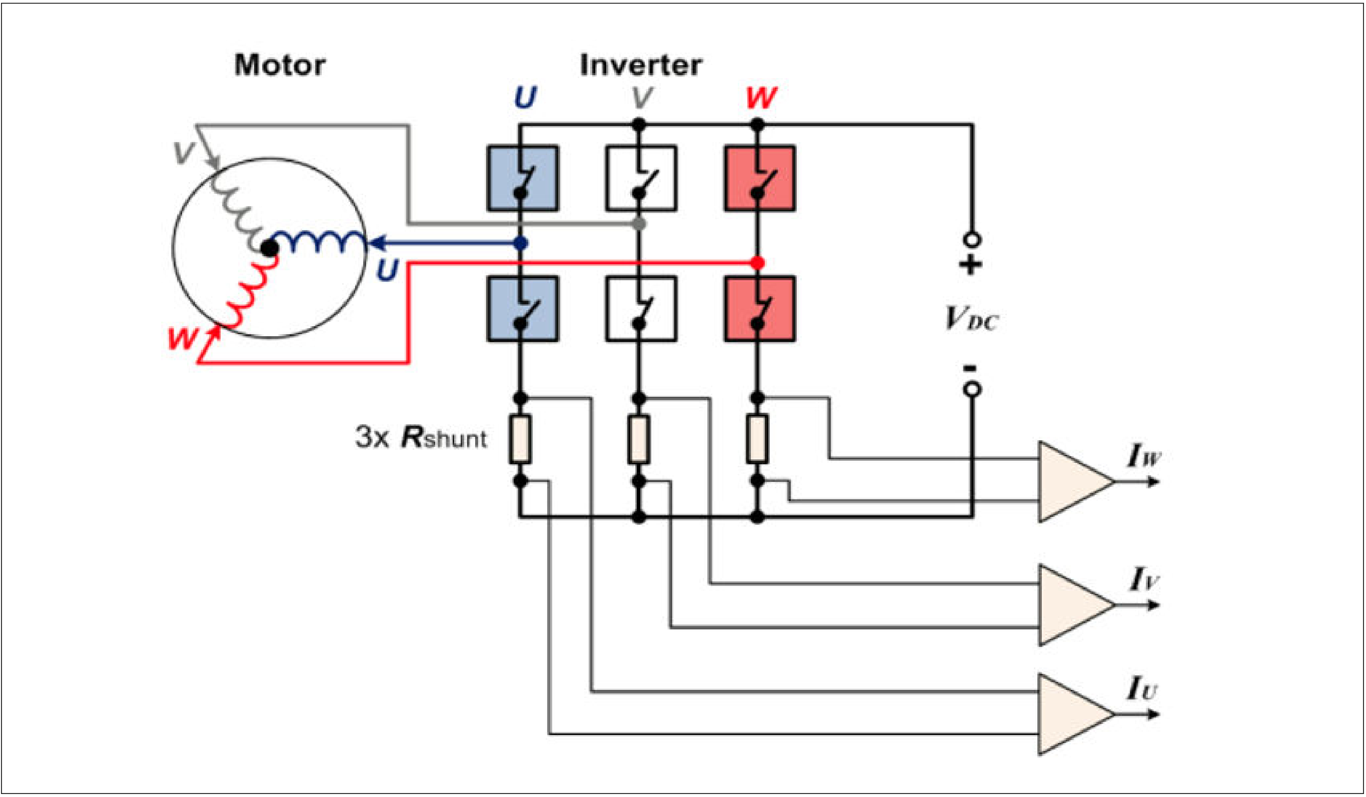


**Figure 11** **Three-shunt current measurement**

In three-shunt current sensing, the ADC conversion trigger is set at half of the PWM cycle where all the low side switches are on, and the high side switch is off. In each SVM sector, the all three-phase currents are assigned to be measured at the same time as shown in Figure 12.

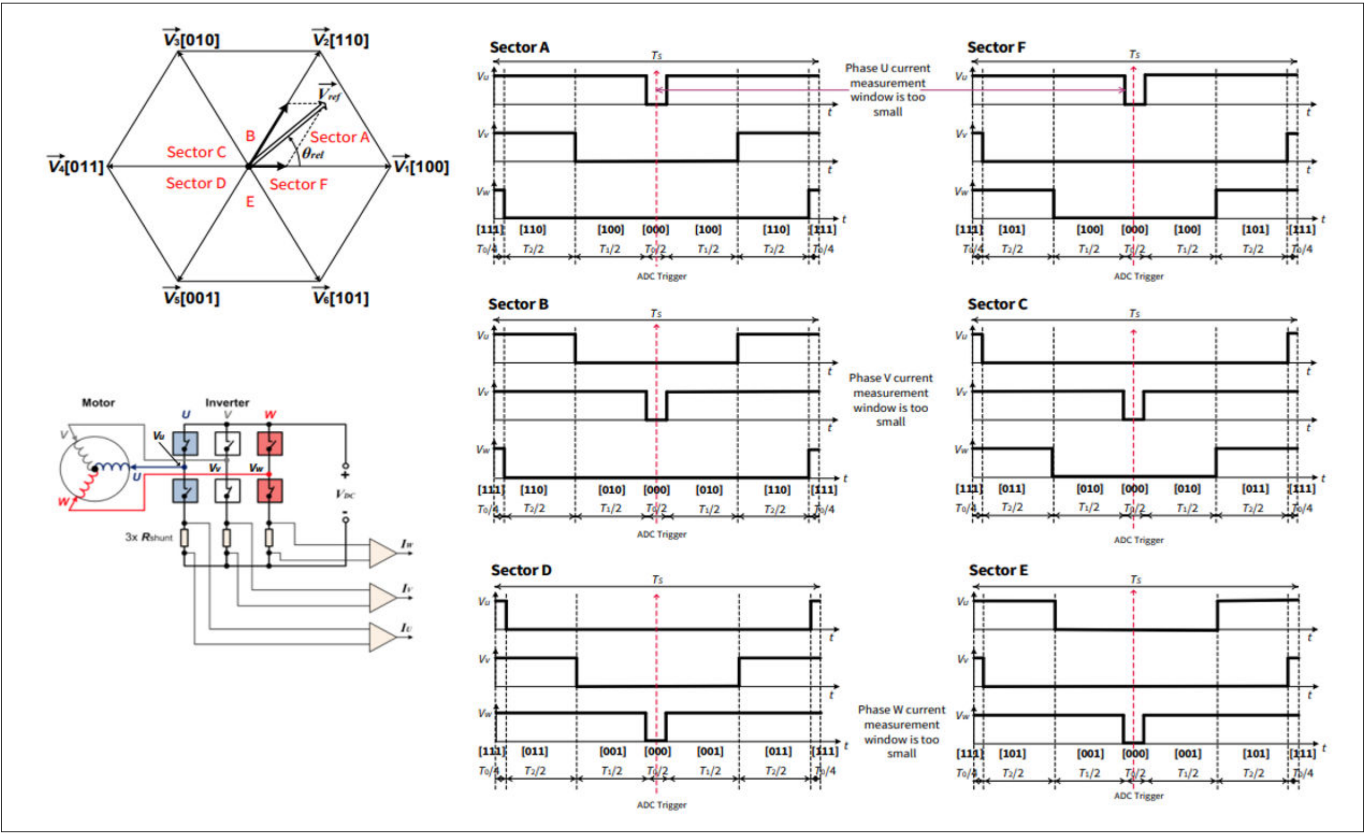

Sector A
Sector B
Sector C
Sector D
Sector E
Sector F
Phase U current measurement window is too small
Phase V current measurement window is too small
Phase W current measurement window is too small
ADC Trigger
Motor
Inverter
3x Rshunt

Figure 12 Three-shunt current sampling with respect to SVM sectors

In the case of over modulation, phase current is immeasurable in certain regions due to insufficient current measurement time that results in inaccurate sampling of current. The immeasurable area is shown in the following figure.

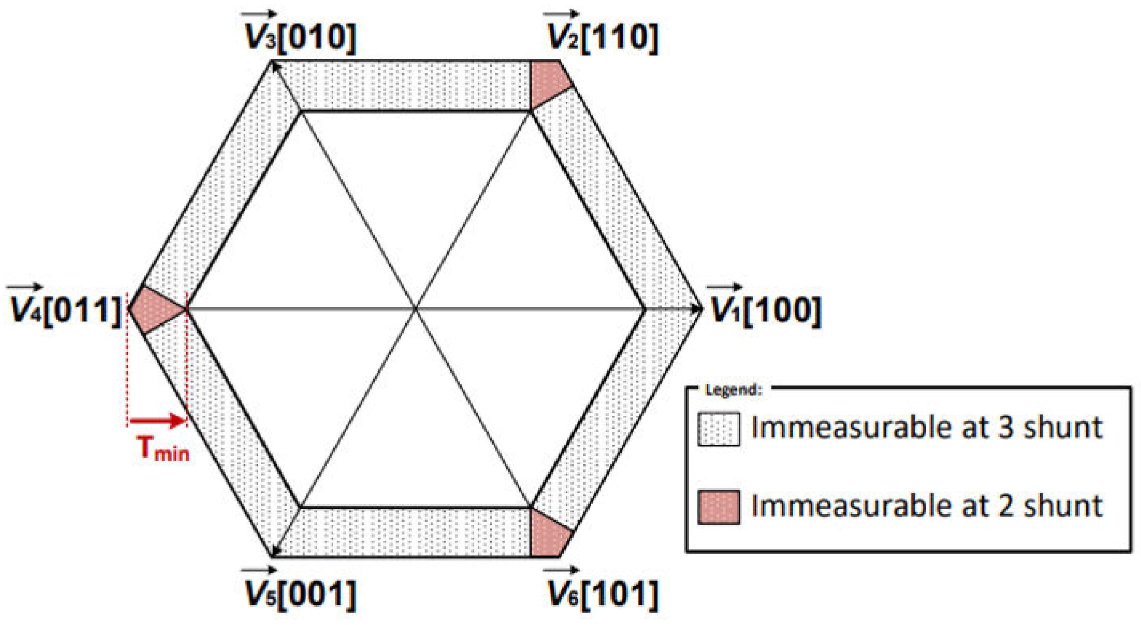


Figure 13 Immeasurable areas

For example, in SVM sector A and F shown in Figure 12, the two most critical phase currents are $IV$ and $IW$ as the phase U current can be inaccurate. This is because with a high modulation index, the window to measure phase U current can be short and the reading of the phase U current could be inaccurate.

# 3 Sensorless FOC implementation with PSOC™ Control C3 MCU

This chapter describes the implementation of a sensorless FOC using the Infineon's PSOC™ Control C3 MCU.

## 3.1 Sensorless FOC block diagram

Figure 14 shows a block diagram of the sensorless FOC algorithm implemented using the PSOC™ Control C3 MCU. It shows the major software components and their connections.

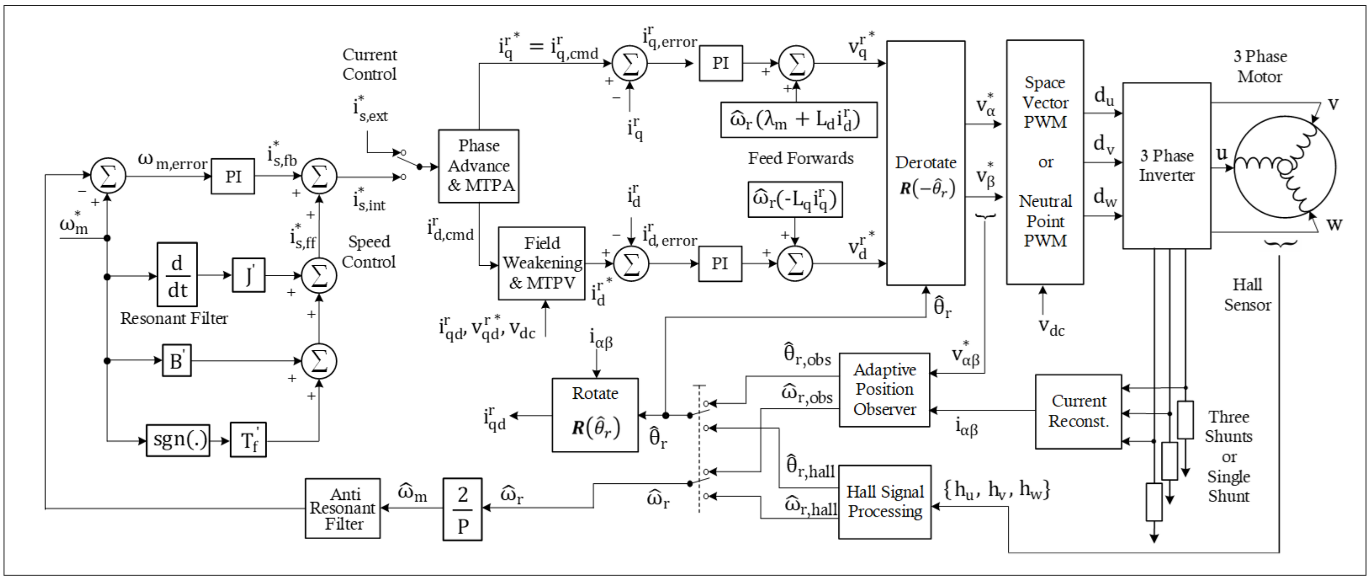


**Figure 14** **Sensorless FOC block diagram**

## 3.2 PSOC™ Control C3 features for FOC

Multiple TCPWM units, high-performance programmable analog subsystem (HPPASS), flexible signal connectivity across different peripherals, idle ADC channel sampling, and the CPU performance makes the PSOC™ Control C3 MCU an ideal device for PMSM FOC applications.

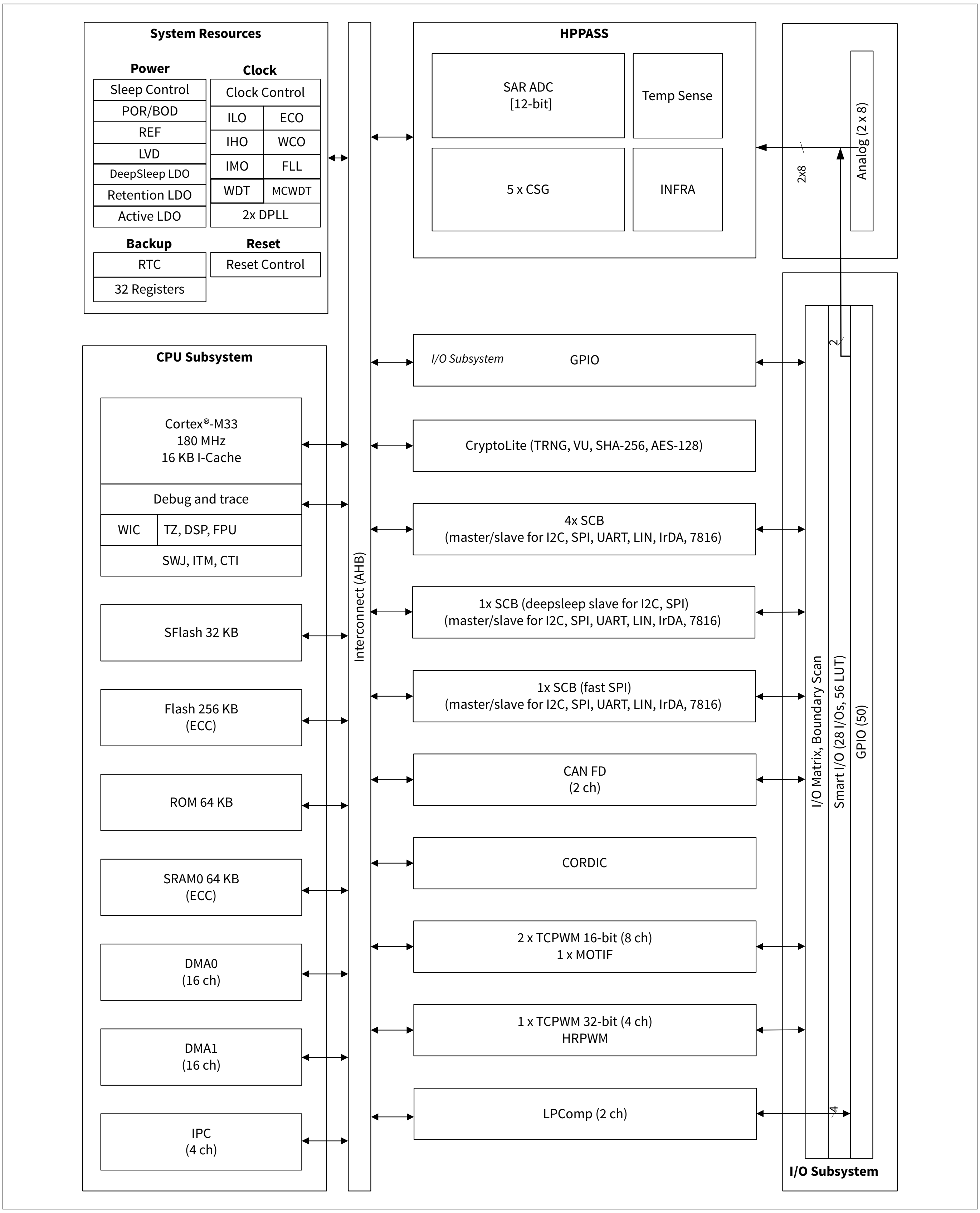


**Figure 15** **PSOC™ Control C3 functional block diagram**

The following sections explain the usage of the key hardware modules of PSOC™ Control C3 for sensorless FOC applications.

### 3.2.1 PWMs

The space vector modulation (SVM) transforms the stator voltage vectors into PWM signals (compare match values). The TCPWM timer unit of PSOC™ Control C3 MCU has been designed to generate the PWM signals. Three channels of TCPWM Group-1 are used to generate six PWM signals for the SVM as shown in Figure 16. The PWM period (TPWM) is setup according to the PWM frequency, whereas the three compare values define the ON-time for the three phases. TCPWM Group-1 channel 4 (ADC trigger timer) is used in sync with the PWM timer to generate the trigger events for the ADC conversion. A compare event is used for triggering the current sampling. Sampling starts automatically on the defined compare match event.

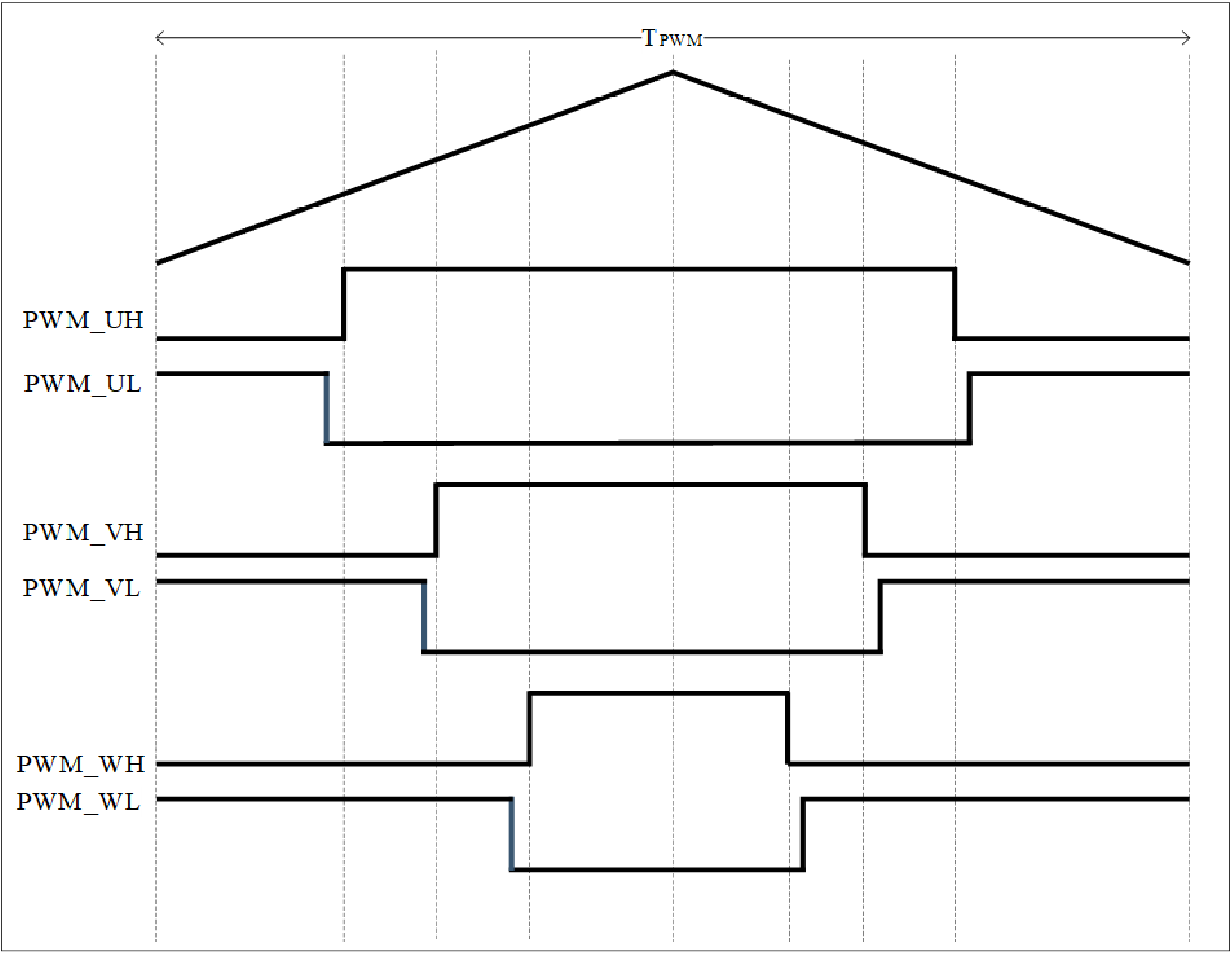


**Figure 16** **PWM signals with dead-times (center-aligned mode)**

#### 3.2.1.1 Dead-time configuration

To guarantee the safety of the inverter bridge, the TCPWM unit contains a programmable dead-time generation block. Dead-time insertion prevents the short circuits of switches. It adds a delay between the switch-off time of MOSFET and the switch-on time of its complementary MOSFET to avoid the short circuit shown in Figure 17.

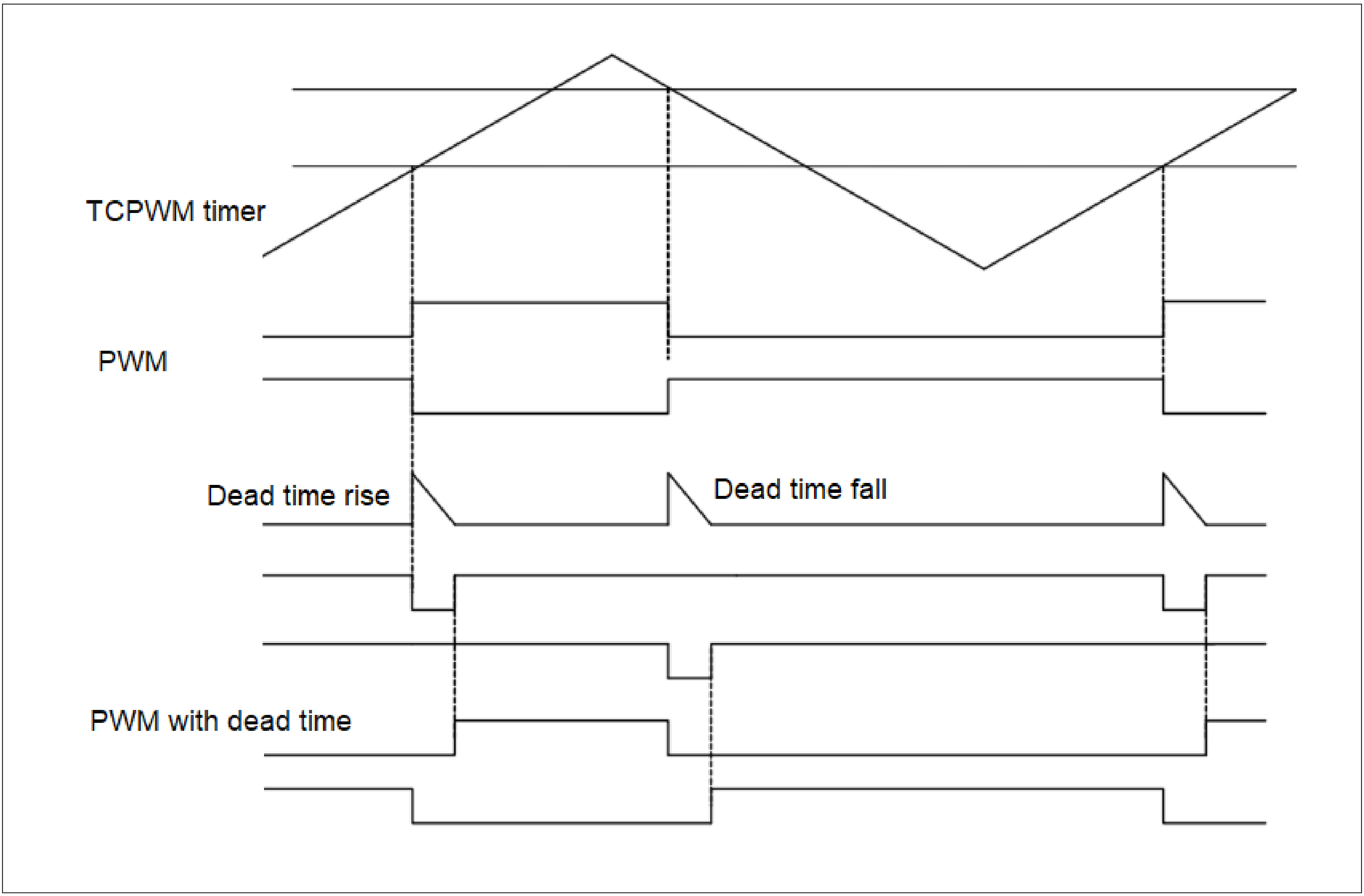


**Figure 17** **PWM with dead-time**

### 3.2.1.2 Synchronization of timer counters

All PWM and ADC trigger timers need to start simultaneously in the FOC algorithm. In PSOC™ Control C3 MCU it can be achieved using a hardware trigger or synchronized software-based event generation.

In FOC code example, one timer instance "PWM_START" is configured in single shot mode and the overflow event signal is used as a trigger pulse to start all PWM and ADC trigger timers. Application uses the software API to start the "PWM_START" timer.

## 3.2.2 Current sensing

The ADC block of the HPPASS module is used to convert the current measurement from the shunt resistance to a digital value that can be used in the software. A simplified block diagram of HPPASS is shown in Figure 18.

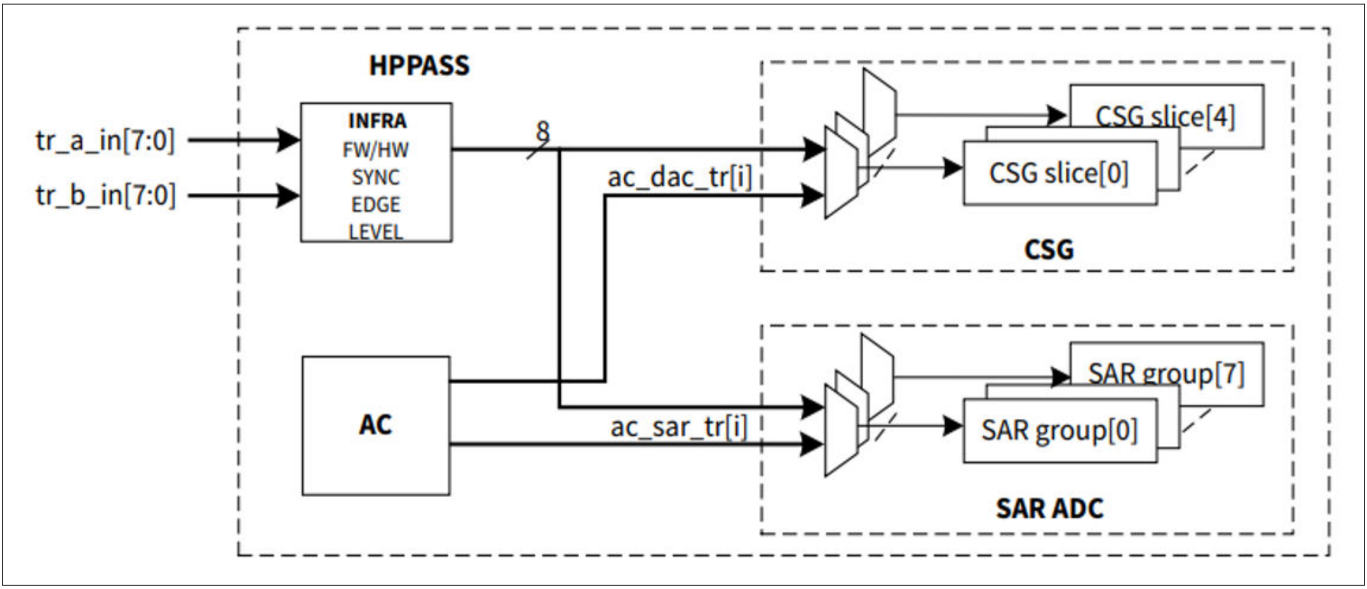


**Figure 18** **HPPASS overview**

The PMSM FOC sensorless solution configures the ADC channels of the HPPASS module for current measurement, DC bus voltage measurement, analog speed measurement, and power board temperature measurement.

The PSOC™ Control C3 provides an extremely fast ADC with a direct trigger from the PWM unit to the ADC. This optimizes the system performance and CPU load significantly, resulting in improved current sampling performance. The current sampling point in sync with PWM is described in the following sections.

### Three-shunt current measurement

In PSOC™ Control C3, the capture compare 0 event of the ADC trigger (ADC0_ISR0) timer is used for current triggering. The ADC trigger timer is running in sync with the PWM timer. The measurement of ADC is set at half of the PWM in each PWM cycle where all the low-side switches are ON as shown in Figure 19.

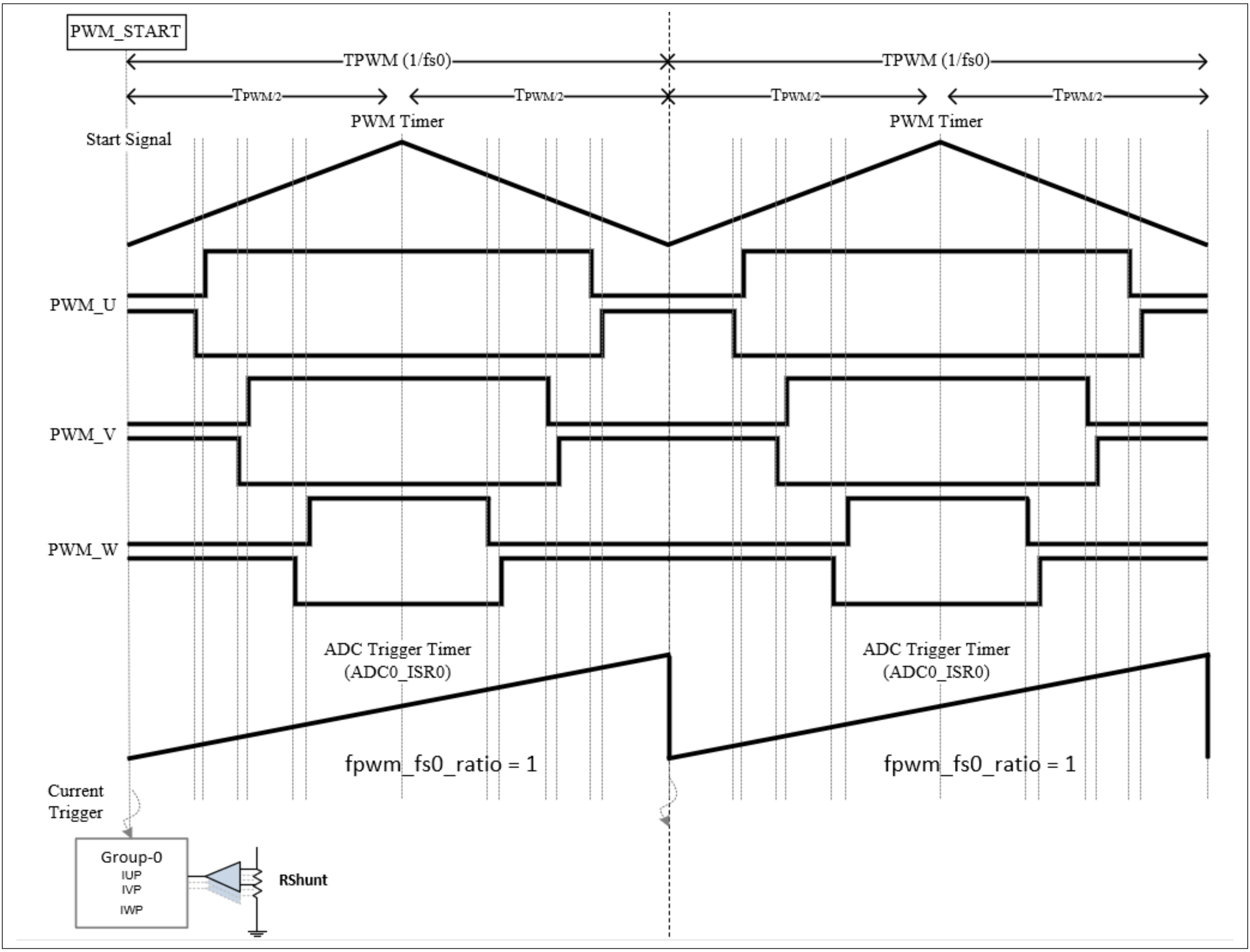


**Figure 19** **Three shunt current measurement**

All direct ADC channels exhibits the property of idle sampling (zero sample time from the trigger instance). This solution uses 6 ADC channels, divided into two groups as shown in Figure 20.

- **High-priority group:** Contains all current channels (direct channels)
- **Low-priority group:** Contains the bus voltage (direct channel), speed, and temperature sense channels

On a trigger event, all channels transition to the HOLD state simultaneously. The channels associated with the high-priority group are converted first, followed by the low-priority group channels. Conversion complete of a high-priority group is connected to an interrupt service routine, called the fast control loop. Fast control loop ISR reads the conversion result and execute the control loop.

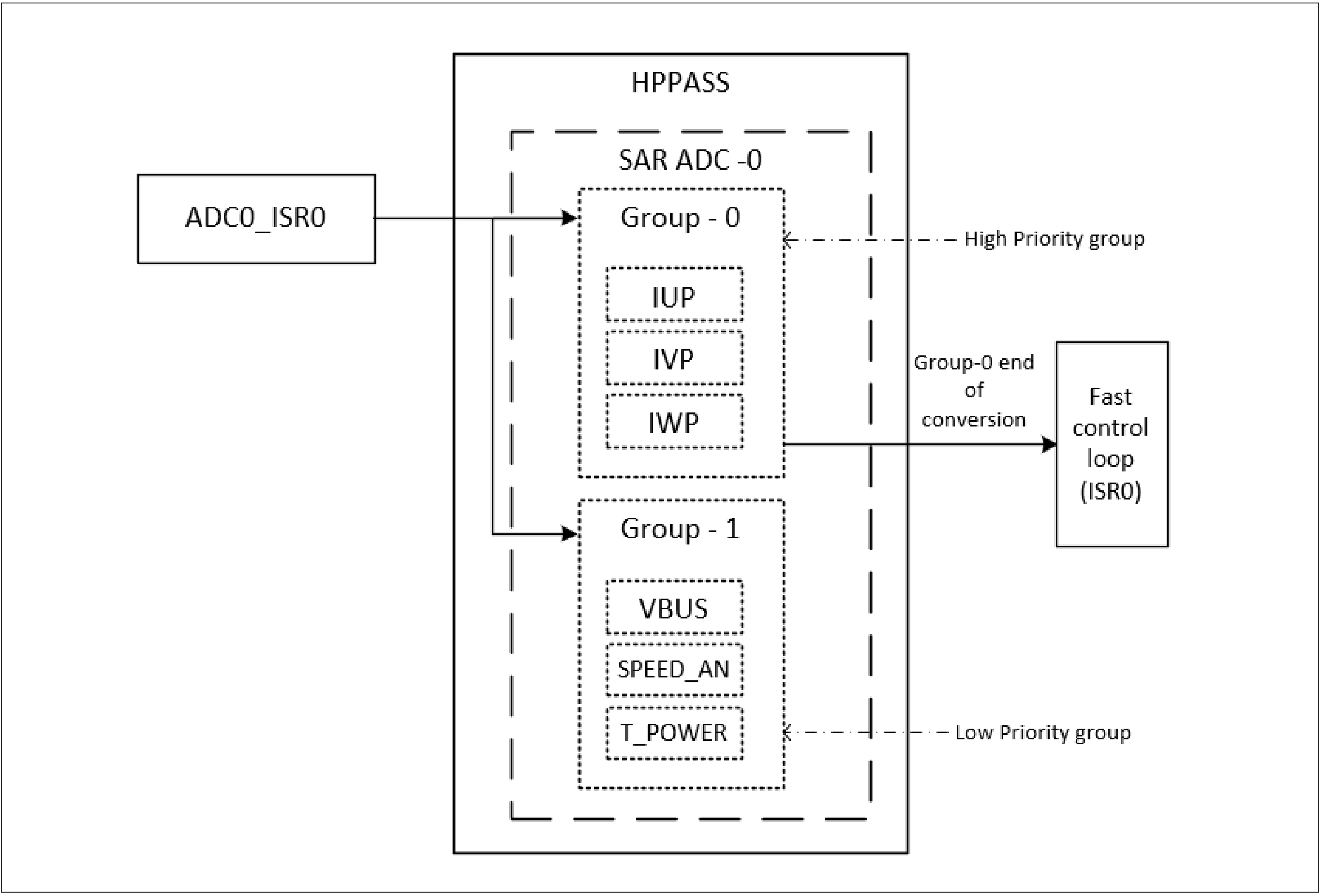


**Figure 20** **HPPASS configuration for three shunt FOC**

### 3.2.2.1 ADC post-processing

The PSOC™ Control C3 SAR ADC has various post-processing features including the average and FIR filter of the converted result. These features can eliminate the requirements of software filters or any additional hardware to filter the noisy signal. For example, these features can be utilized in the motor control application to filter out noise from the DC bus voltage, the analog speed signals, or the temperature sense output without any additional software or added hardware cost.

### 3.2.3 Protection

### 3.2.3.1 PWM kill

The TCPWM of PSOC™ Control C3 has a PWM kill feature that provides hardware protection. The PWM kill is connected to the fault input pin. If a fault is detected, the kill signal latches the PWM outputs without any software intervention. An example of PWM kill is shown in Figure 21.

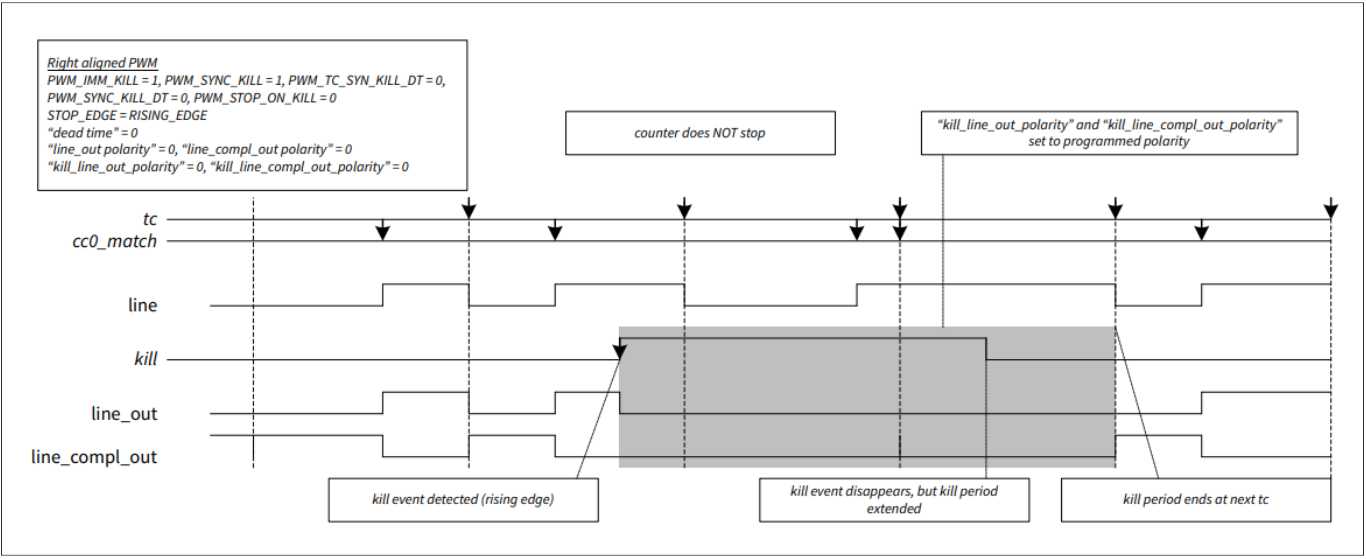

Right aligned PWM
PWM_IMM_KILL = 1, PWM_SYNC_KILL = 1, PWM_TC_SYN_KILL_DT = 0,
PWM_SYNC_KILL_DT = 0, PWM_STOP_ON_KILL = 0
STOP_EDGE = RISING_EDGE
"dead time" = 0
"line_out polarity" = 0, "line_compl_out polarity" = 0
"kill_line_out_polarity" = 0, "kill_line_compl_out_polarity" = 0
counter does NOT stop
"kill_line_out_polarity" and "kill_line_compl_out_polarity" set to programmed polarity
tc
cc0_match
line
kill
line_out
line_compl_out
kill event detected (rising edge)
kill event disappears, but kill period extended
kill period ends at next tc

**Figure 21** **Synchronous PWM kill**

Additionally, the PWM kill signal can be connected to the ISR. In the ISR state machine, states can be handled. PWM kill has different modes of configuration to provide flexibility while integrating in the FOC solution.

### 3.2.3.2 ADC result monitoring

The ADC result monitoring mechanism can automatically compare the conversion result to a configured upper and a lower boundary value as shown in Figure 22 and issue service requests based on predefined conditions. This feature can be utilized in the various protection mechanisms that minimize the CPU load.

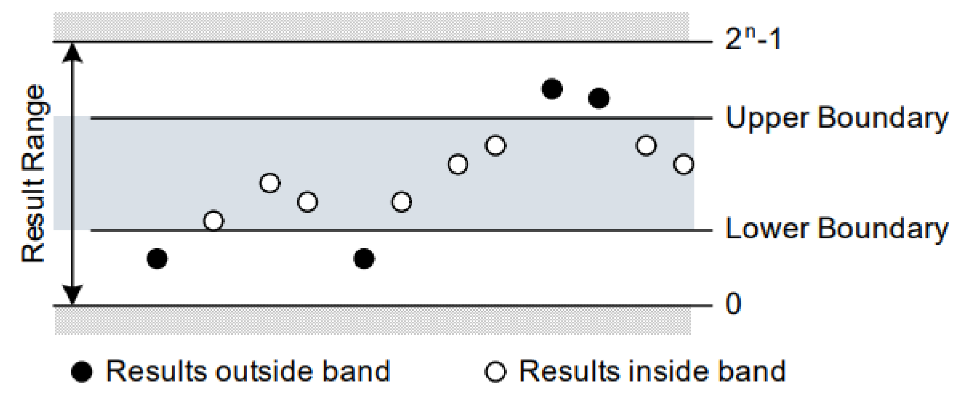


**Figure 22** **ADC result monitoring through limit checking**

For example, during motor control, overvoltage and undervoltage faults can be handled using the ADC result monitoring feature without the need for software overheads.

### 3.2.3.3 Temperature sensor

The PSOC™ Control C3 MCU has an on-chip temperature sensor that is used to measure the internal die temperature. This on-chip temperature sensor can be used for cost-optimized MCU ambient temperature measurements.

## 3.3 Fast control loop

In the PMSM FOC solution, the fast control loop ISR is set up to execute the FOC current-control loop. If there is no fault in the system, this ISR reads the current, executes the FOC loop, and updates the PWM duty cycle.

## 3.4 Slow control loop

In the PMSM FOC solution, the TCPWM timer is set up to provide a slow control loop ISR. The slow control loop ISR is used by the state machine handling and other miscellaneous activities in the FOC algorithm.

## 3.5 Motor control solution personality

The motor control solution personality middleware can be accessed through ModusToolbox™ Library Manager as shown in Figure 2. After the addition of the library, the solution personality GUI will be available in the ModusToolbox™ Device Configurator, as shown in Figure 23.

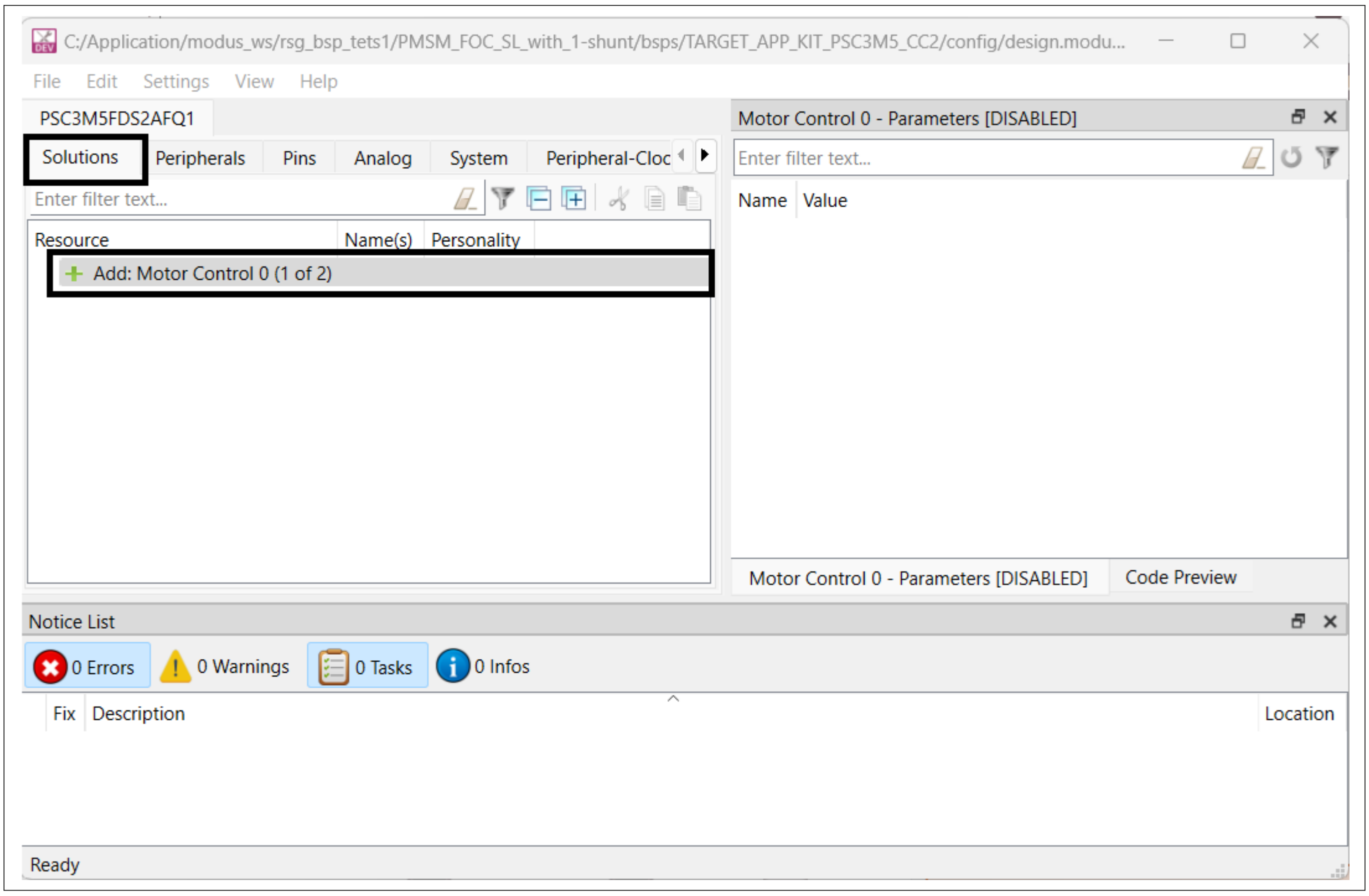


**Figure 23** **ModusToolbox™ solution personality**

It can be used to configure the peripherals required for motor control functionality without the need to configure individual peripheral personality. Peripheral resources used by solution personality are marked reserved and cannot be edited by the individual personalities directly in the Device Configurator. The solution personality ensures resource conflict or provide feedback to fix it.

Solution personality uses is demonstrated using code example "PMSM FOC SL with 3-shunt" in the Infineon ModusToolbox™ ecosystem. This code example integrate the Infineon motor control library with solution personality-generated configuration and demonstrate the application.

# 4 Motor state machine

The state entry function is called to enter in any state and similarly the corresponding state exit function is called to exit from a particular state. In each state, there are functions to call from fast control and slow control ISRs respectively. The structure of a state machine is as follows:

```
typedef struct
{
    STATE_t states[State_ID_Max];      //State call back functions
    STATE_ID_t current;                // Current state ID
    STATE_ID_t next;                   // Next state ID
    STATE_VARS_t vars;                 // State variables
    STATE_ADD_CALLBACK add_callback;   // Additional call back functions
} STATE_MACHINE_t;
```

The following state machine explain the different states of V/Hz start-up based FOC. Initialization function "STATE_MACHINE_Init ()", enter the control into the "Init" state.

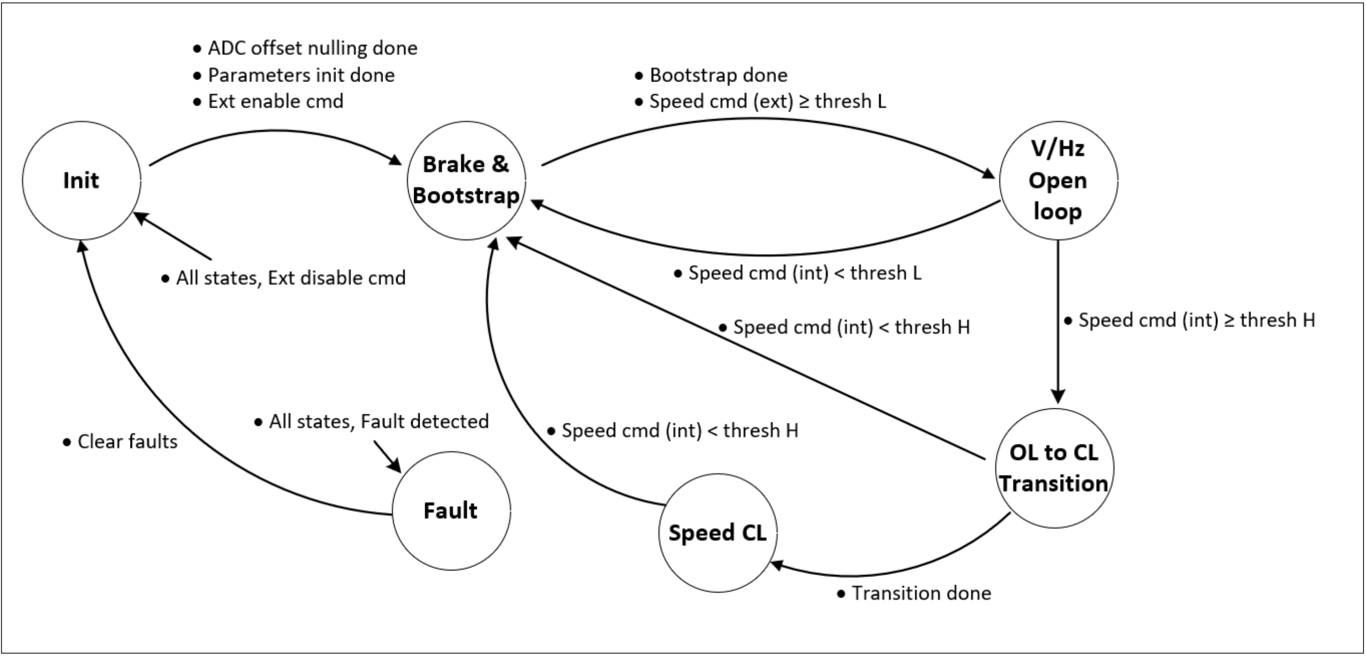

• ADC offset nulling done
• Parameters init done
• Ext enable cmd
• Bootstrap done
• Speed cmd (ext) ≥ thresh L
Init
Brake & Bootstrap
V/Hz Open loop
• All states, Ext disable cmd
• Speed cmd (int) < thresh L
• Speed cmd (int) < thresh H
• Speed cmd (int) ≥ thresh H
• All states, Fault detected
• Clear faults
• Speed cmd (int) < thresh H
OL to CL Transition
Fault
Speed CL
• Transition done

**Figure 24** **State machine**

# 5 Example software

This section describes the practical aspects of using the Infineon FOC solution on PSOC™ Control C3 MCU using the ModusToolbox™. ModusToolbox™ supports the "KIT_PSC3M5_MC1" kit and the associated code examples. Visit the ModusToolbox™ software webpage for more information and support.

## 5.1 Test setup

The test environment consists of a PSOC™ Control C3 motor control drive card connected to an adapter board, a standard motor drive power board, USB-A to USB-C cable, power supply, and motor. The power board is rated at 250 W output power and 24 V input DC voltage.

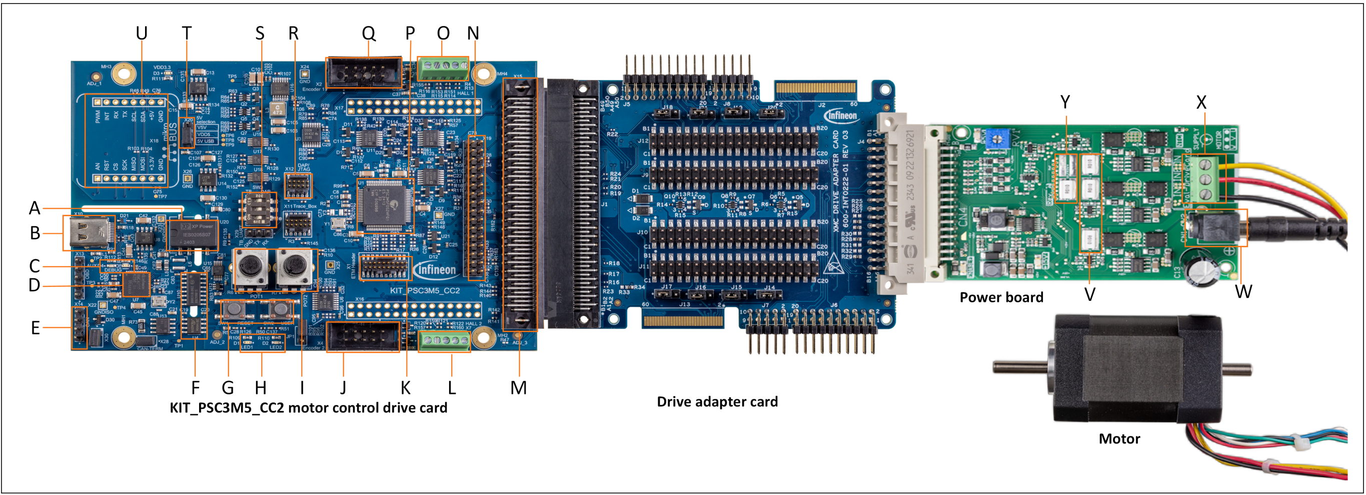


**Figure 25** **Test setup - KIT_PSC3M5_MC1**

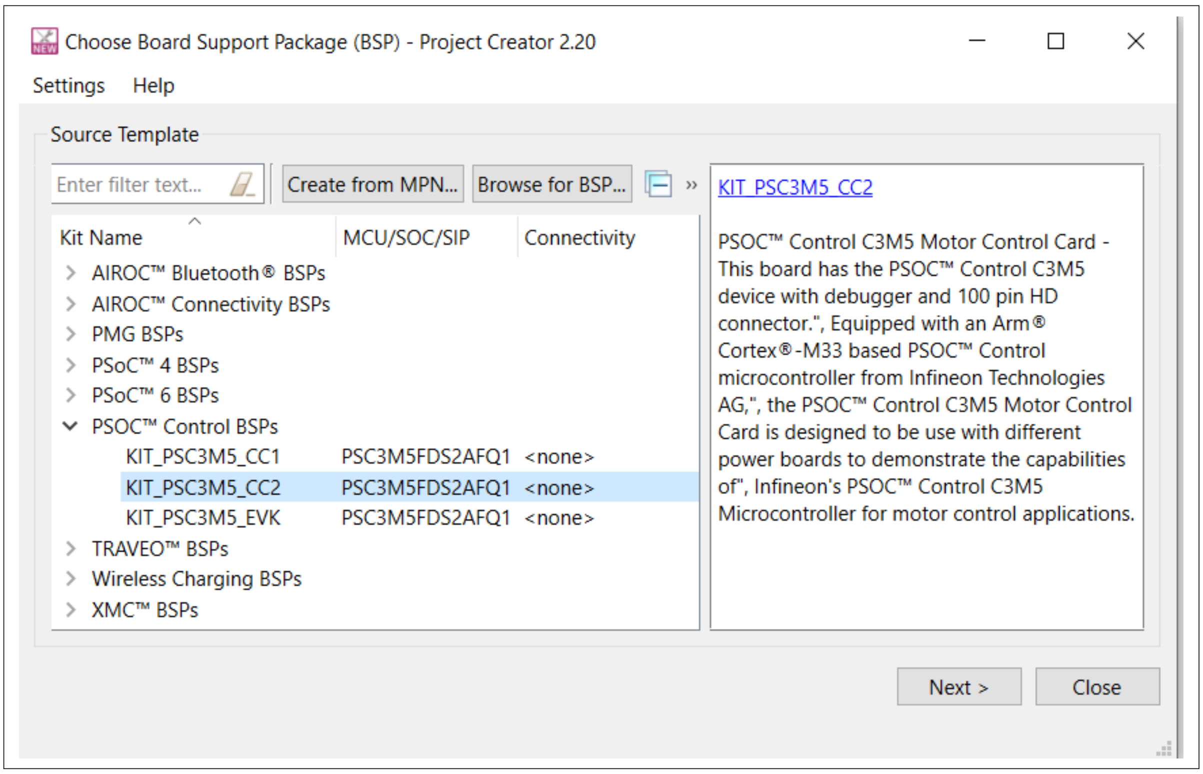
- A - Isolated DC-DC (U20)
- B - USB-C socket (X10)
- C - DEBUG LED (D5) and AUX LED (D4)
- D - XMC4200 MCU (J-Link - U7)
- E - Isolated CAN header (X14)
- F - SWD/UART and CAN isolators (U10, U4)
- G - User button (SW2) and reset button (SW1)
- H - User LED1 (D1) and user LED2 (D2)
- I - Potentiometers (R6, R7)
- J - Motor 2 encoder input (X4)
- K - ETM header (X1)
- L - Motor 2 Hall sensor input (X7)
- M - 100-pin HD connector (X15)
- N - MADK M5 pinout header (X19)
- O - Motor 1 Hall sensor input (X3)
- P - PSC3M5FDS2AFQ1 target MCU (U1)
- Q - Motor 1 encoder input (X2)
- R - 10-pin SWD/JTAG header (X12)
- S - Debug interface selection (SW3)
- T - Supply selection jumper (X20)

- U - mikroBUS header (X18)
- V - Three-phase shunt registers
- W - DC power supply connector
- X - Motor phase connector
- Y - DC-link shunt register

## 5.2 Example code

Follow these steps to create the example project using ModusToolbox™.

1. Open Eclipse IDE for ModusToolbox™, create the workspace and select the launch
2. Select **New Application** in the Quick Panel
3. Select **KIT_PSC3M5_CC2** from PSOC™ Control BSPs and click **Next >**



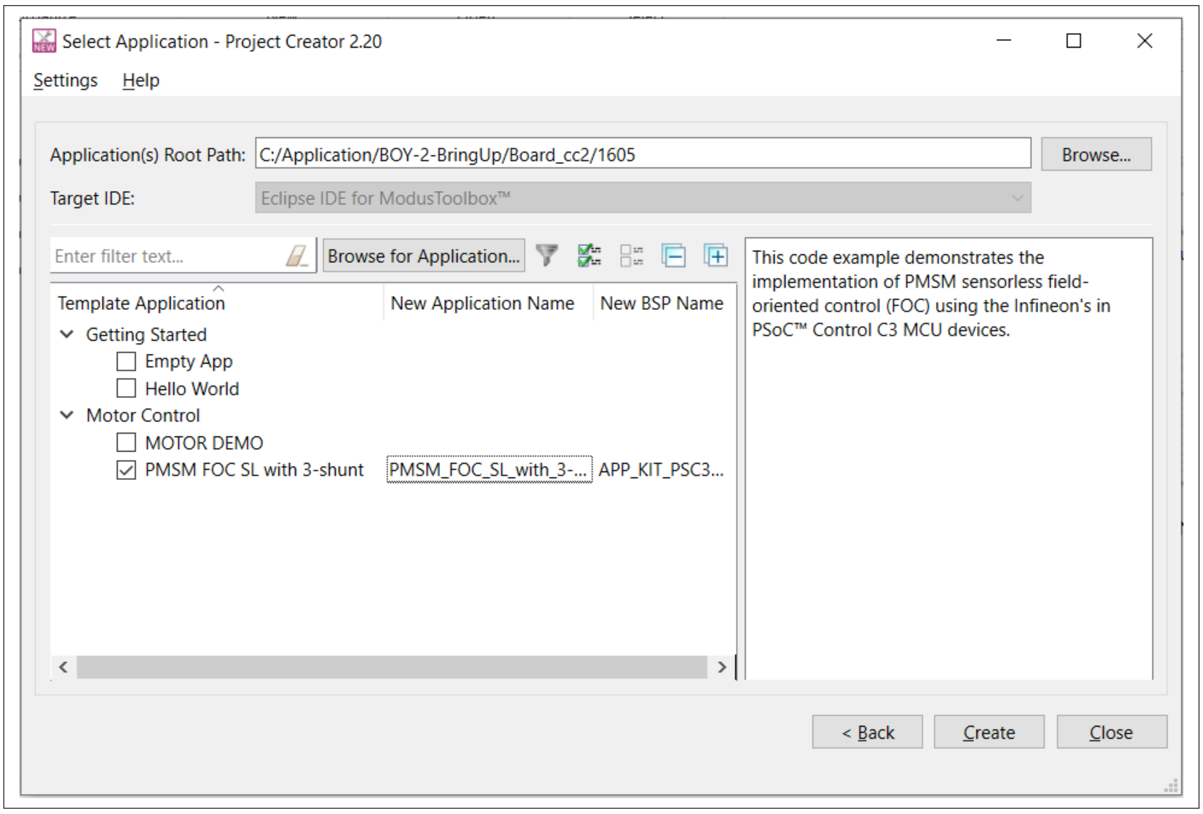
| Kit Name | MCU/SOC/SIP | Connectivity |
|---|---|---|
| AIROC™ Bluetooth® BSPs | | |
| AIROC™ Connectivity BSPs | | |
| PMG BSPs | | |
| PSoC™ 4 BSPs | | |
| PSoC™ 6 BSPs | | |
| PSOC™ Control BSPs | | |
| KIT_PSC3M5_CC1 | PSC3M5FDS2AFQ1 | <none> |
| KIT_PSC3M5_CC2 | PSC3M5FDS2AFQ1 | <none> |
| KIT_PSC3M5_EVK | PSC3M5FDS2AFQ1 | <none> |
| TRAVEO™ BSPs | | |
| Wireless Charging BSPs | | |
| XMC™ BSPs | | |

KIT_PSC3M5_CC2

PSOC™ Control C3M5 Motor Control Card - This board has the PSOC™ Control C3M5 device with debugger and 100 pin HD connector.", Equipped with an Arm® Cortex®-M33 based PSOC™ Control microcontroller from Infineon Technologies AG,", the PSOC™ Control C3M5 Motor Control Card is designed to be use with different power boards to demonstrate the capabilities of", Infineon's PSOC™ Control C3M5 Microcontroller for motor control applications.

**Figure 26 BSP selection**

4. Select **PMSM FOC SL with 3-shunt** within the Motor Control to create a 3-shunt FOC project for KIT_PSC3M5_CC2 kit as shown in Figure 27


Select Application - Project Creator 2.20

Application(s) Root Path: C:/Application/BOY-2-BringUp/Board_cc2/1605

Target IDE: Eclipse IDE for ModusToolbox™

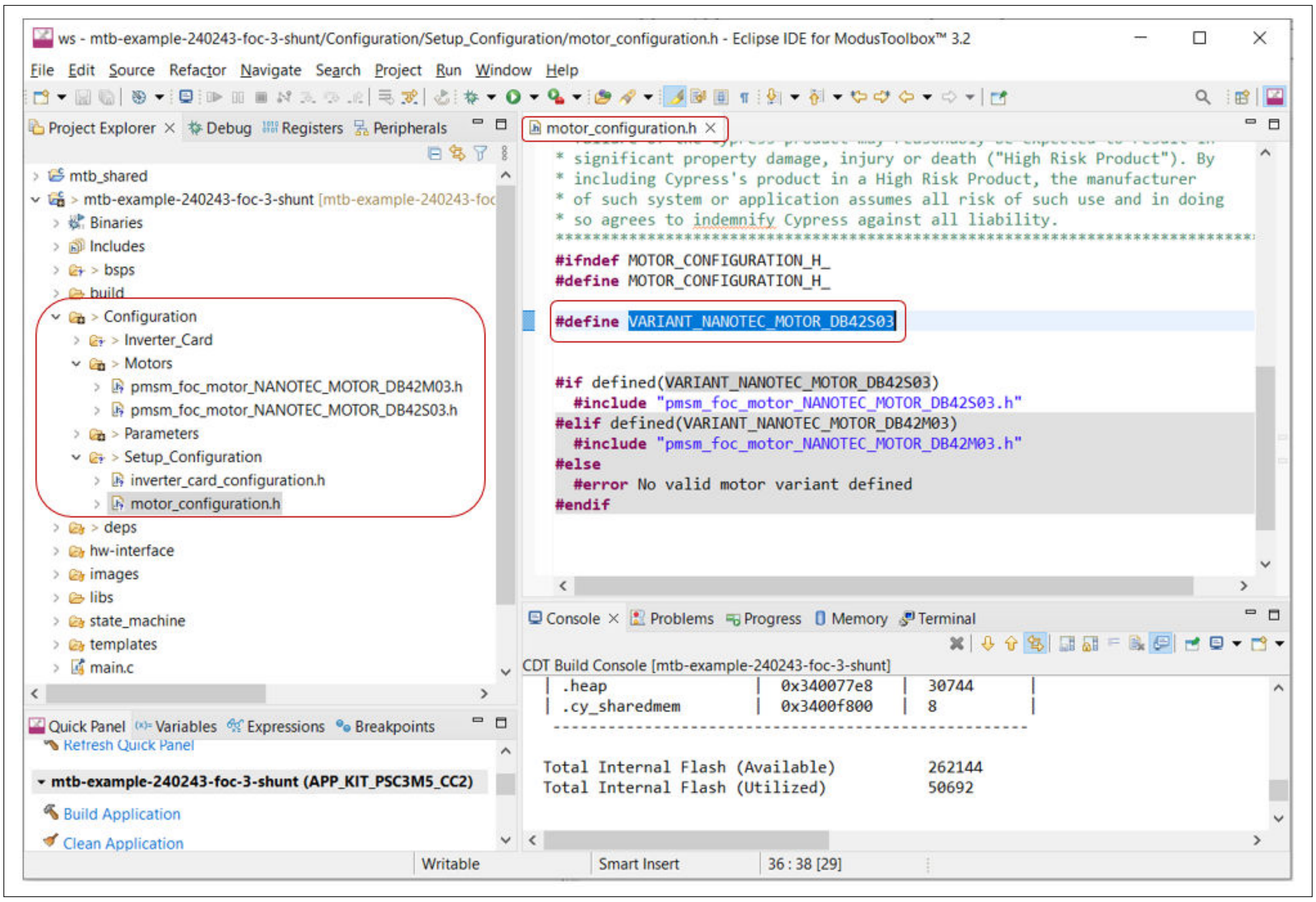
| Template Application | New Application Name | New BSP Name |
|---|---|---|
| Getting Started | | |
| ☐ Empty App | | |
| ☐ Hello World | | |
| Motor Control | | |
| ☐ MOTOR DEMO | | |
| ✓ PMSM FOC SL with 3-shunt | PMSM_FOC_SL_with_3-... | APP_KIT_PSC3... |

This code example demonstrates the implementation of PMSM sensorless field-oriented control (FOC) using the Infineon's in PSoC™ Control C3 MCU devices.

Figure 27 Code example selection

### 5.2.1 Test setup configuration

There is a configuration folder in the layered architecture of the code example to setup the motor and power board parameters. This folder has a predefined set of configuration parameters for motor and drives. Select the appropriate motor or drive card variant in the configuration file as shown in Figure 28.


ws - mtb-example-240243-foc-3-shunt/Configuration/Setup_Configuration/motor_configuration.h - Eclipse IDE for ModusToolbox™ 3.2

File Edit Source Refactor Navigate Search Project Run Window Help

Project Explorer | Debug | Registers | Peripherals

```
> mtb_shared
v > mtb-example-240243-foc-3-shunt [mtb-example-240243-foc
  > Binaries
  > Includes
  > > bsps
  > build
  v > Configuration
    > > Inverter_Card
    v > Motors
      > pmsm_foc_motor_NANOTEC_MOTOR_DB42M03.h
      > pmsm_foc_motor_NANOTEC_MOTOR_DB42S03.h
    > > Parameters
    v > Setup_Configuration
      > inverter_card_configuration.h
      > motor_configuration.h
  > > deps
  > hw-interface
  > images
  > libs
  > state_machine
  > templates
  > main.c
```

motor_configuration.h

```
 * significant property damage, injury or death ("High Risk Product"). By
 * including Cypress's product in a High Risk Product, the manufacturer
 * of such system or application assumes all risk of such use and in doing
 * so agrees to indemnify Cypress against all liability.
*******************************************************************************
#ifndef MOTOR_CONFIGURATION_H_
#define MOTOR_CONFIGURATION_H_

#define VARIANT_NANOTEC_MOTOR_DB42S03


#if defined(VARIANT_NANOTEC_MOTOR_DB42S03)
  #include "pmsm_foc_motor_NANOTEC_MOTOR_DB42S03.h"
#elif defined(VARIANT_NANOTEC_MOTOR_DB42M03)
  #include "pmsm_foc_motor_NANOTEC_MOTOR_DB42M03.h"
#else
  #error No valid motor variant defined
#endif
```

Quick Panel | Variables | Expressions | Breakpoints

Refresh Quick Panel

mtb-example-240243-foc-3-shunt (APP_KIT_PSC3M5_CC2)

Build Application

Clean Application

Console | Problems | Progress | Memory | Terminal

CDT Build Console [mtb-example-240243-foc-3-shunt]

```
 | .heap            | 0x340077e8  | 30744    |
 | .cy_sharedmem    | 0x3400f800  | 8        |
 ----------------------------------------------------

  Total Internal Flash (Available)          262144
  Total Internal Flash (Utilized)           50692
```

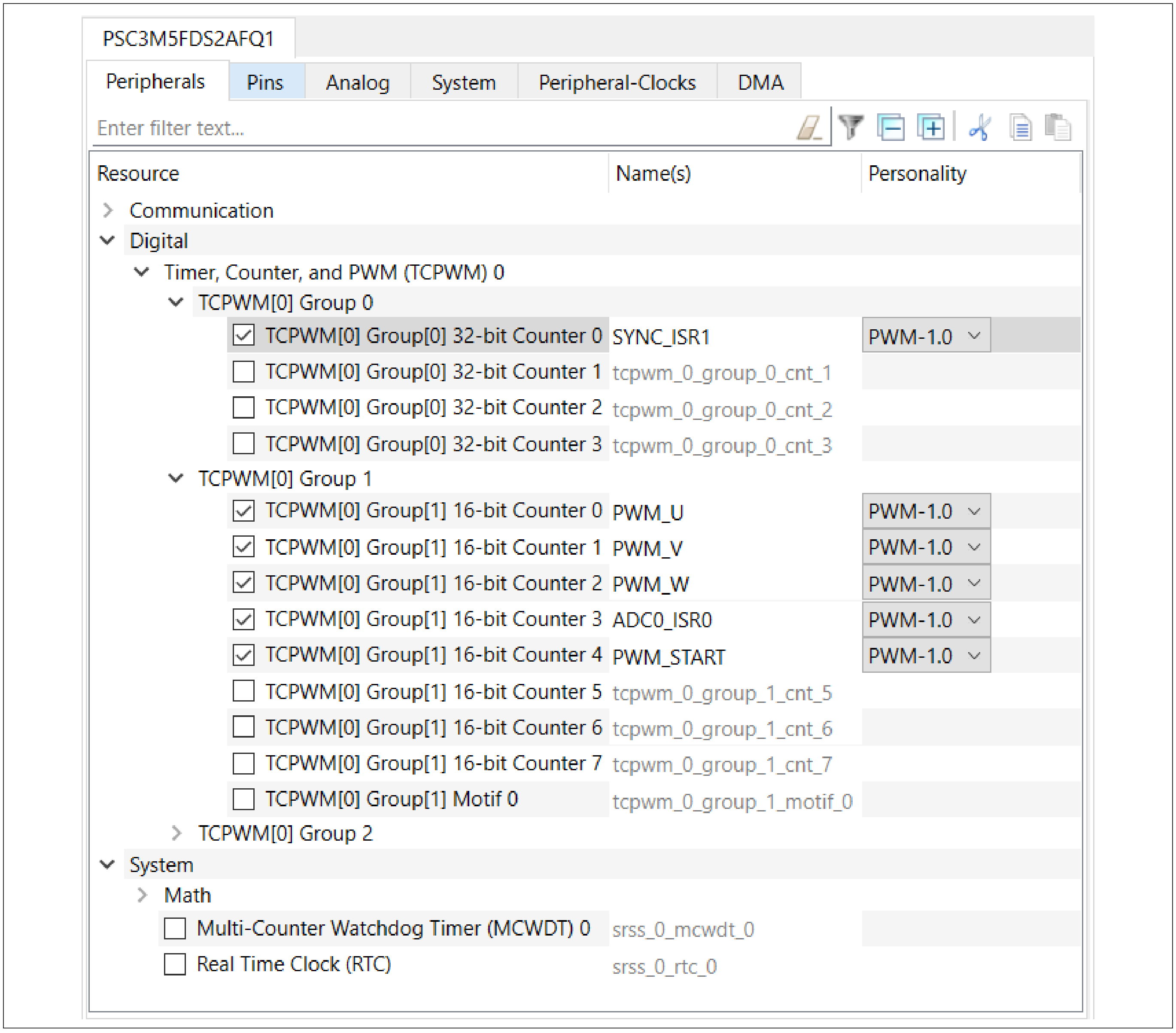
Writable | Smart Insert | 36 : 38 [29]

Figure 28 Test setup configuration

## 5.3 Peripheral configuration

### TCPWM configuration

A 3-shunt FOC consumes 6 TCPWM channels. Configuration details of each TCPWM has been provided in the following sections.

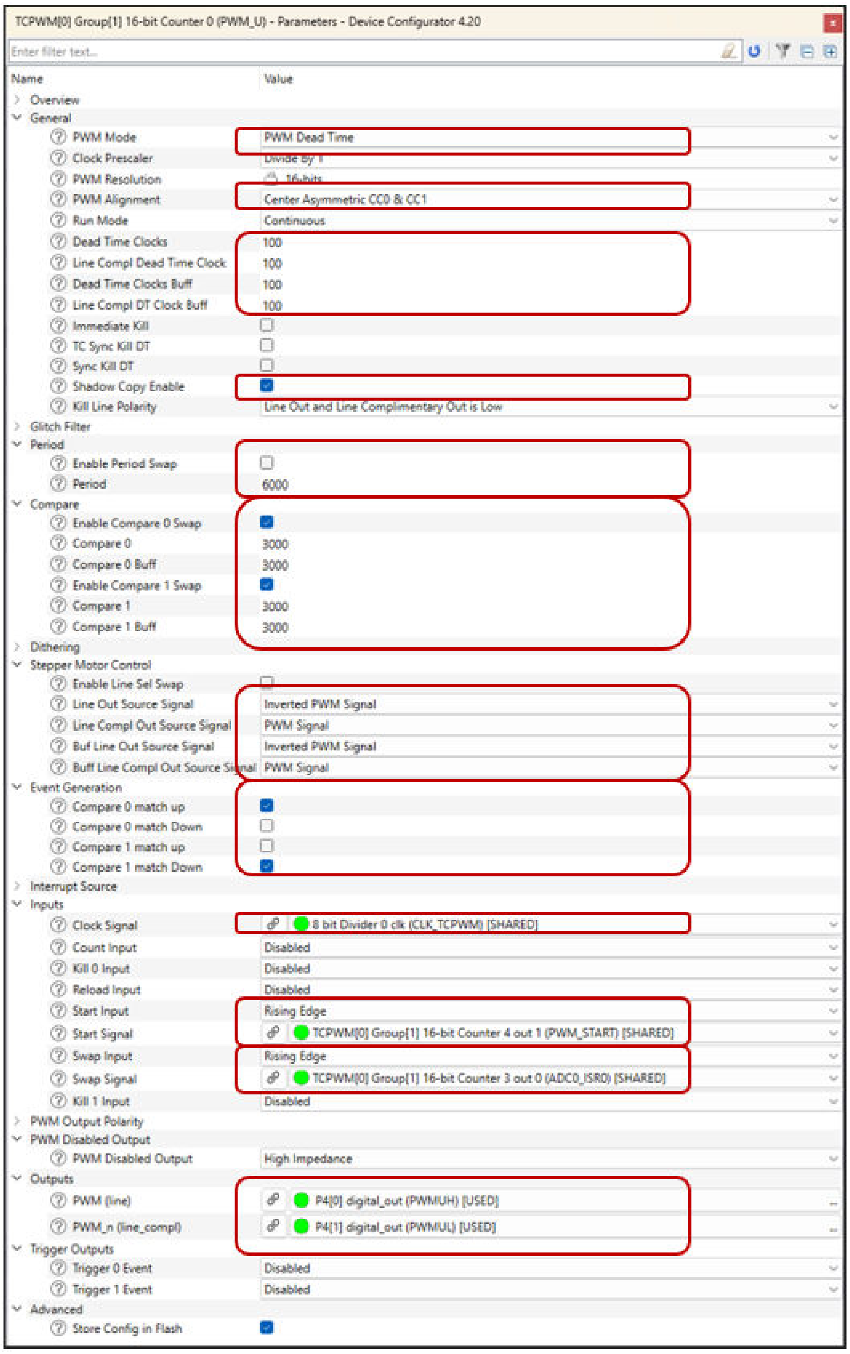


| Resource | Name(s) | Personality |
|---|---|---|
| Communication | | |
| Digital | | |
| Timer, Counter, and PWM (TCPWM) 0 | | |
| TCPWM[0] Group 0 | | |
| ✓ TCPWM[0] Group[0] 32-bit Counter 0 | SYNC_ISR1 | PWM-1.0 |
| ☐ TCPWM[0] Group[0] 32-bit Counter 1 | tcpwm_0_group_0_cnt_1 | |
| ☐ TCPWM[0] Group[0] 32-bit Counter 2 | tcpwm_0_group_0_cnt_2 | |
| ☐ TCPWM[0] Group[0] 32-bit Counter 3 | tcpwm_0_group_0_cnt_3 | |
| TCPWM[0] Group 1 | | |
| ✓ TCPWM[0] Group[1] 16-bit Counter 0 | PWM_U | PWM-1.0 |
| ✓ TCPWM[0] Group[1] 16-bit Counter 1 | PWM_V | PWM-1.0 |
| ✓ TCPWM[0] Group[1] 16-bit Counter 2 | PWM_W | PWM-1.0 |
| ✓ TCPWM[0] Group[1] 16-bit Counter 3 | ADC0_ISR0 | PWM-1.0 |
| ✓ TCPWM[0] Group[1] 16-bit Counter 4 | PWM_START | PWM-1.0 |
| ☐ TCPWM[0] Group[1] 16-bit Counter 5 | tcpwm_0_group_1_cnt_5 | |
| ☐ TCPWM[0] Group[1] 16-bit Counter 6 | tcpwm_0_group_1_cnt_6 | |
| ☐ TCPWM[0] Group[1] 16-bit Counter 7 | tcpwm_0_group_1_cnt_7 | |
| ☐ TCPWM[0] Group[1] Motif 0 | tcpwm_0_group_1_motif_0 | |
| TCPWM[0] Group 2 | | |
| System | | |
| Math | | |
| ☐ Multi-Counter Watchdog Timer (MCWDT) 0 | srss_0_mcwdt_0 | |
| ☐ Real Time Clock (RTC) | srss_0_rtc_0 | |

**Figure 29** **TCPWM configuration**

**PWM timers (PWM_U, PWM_V, and PWM_W)**

- Start in sync and generate PWM signals to drive the motor
- PWM pins are configurable
- PWM frequency (fs0) 20 kHz



TCPWM[0] Group[1] 16-bit Counter 0 (PWM_U) - Parameters - Device Configurator 4.20

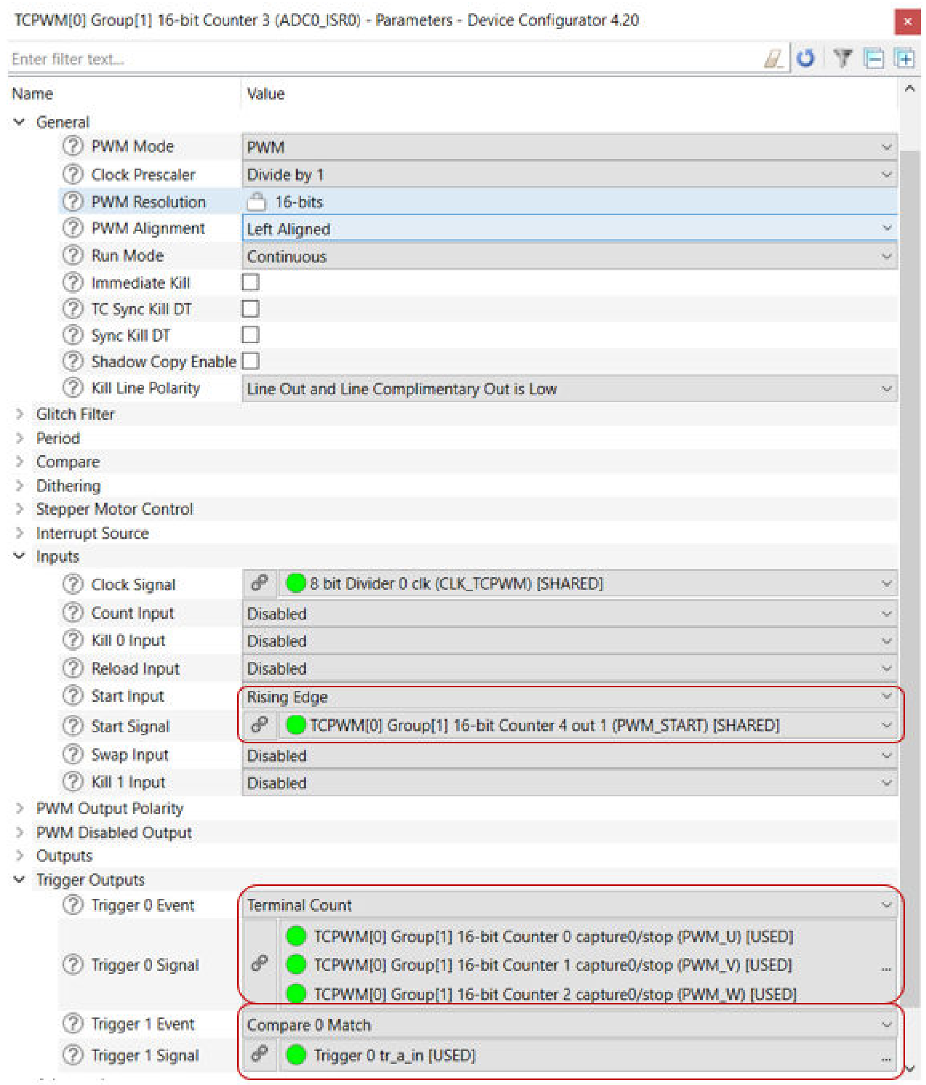
Enter filter text...

| Name | Value |
|---|---|
| › Overview | |
| ⌄ General | |
| PWM Mode | PWM Dead Time |
| Clock Prescaler | Divide by 1 |
| PWM Resolution | 16-bits |
| PWM Alignment | Center Asymmetric CC0 & CC1 |
| Run Mode | Continuous |
| Dead Time Clocks | 100 |
| Line Compl Dead Time Clock | 100 |
| Dead Time Clocks Buff | 100 |
| Line Compl DT Clock Buff | 100 |
| Immediate Kill | ☐ |
| TC Sync Kill DT | ☐ |
| Sync Kill DT | ☐ |
| Shadow Copy Enable | ☑ |
| Kill Line Polarity | Line Out and Line Complimentary Out is Low |
| › Glitch Filter | |
| ⌄ Period | |
| Enable Period Swap | ☐ |
| Period | 6000 |
| ⌄ Compare | |
| Enable Compare 0 Swap | ☑ |
| Compare 0 | 3000 |
| Compare 0 Buff | 3000 |
| Enable Compare 1 Swap | ☑ |
| Compare 1 | 3000 |
| Compare 1 Buff | 3000 |
| › Dithering | |
| ⌄ Stepper Motor Control | |
| Enable Line Sel Swap | ☐ |
| Line Out Source Signal | Inverted PWM Signal |
| Line Compl Out Source Signal | PWM Signal |
| Buf Line Out Source Signal | Inverted PWM Signal |
| Buff Line Compl Out Source Signal | PWM Signal |
| ⌄ Event Generation | |
| Compare 0 match up | ☑ |
| Compare 0 match Down | ☐ |
| Compare 1 match up | ☐ |
| Compare 1 match Down | ☑ |
| › Interrupt Source | |
| ⌄ Inputs | |
| Clock Signal | ● 8 bit Divider 0 clk (CLK_TCPWM) [SHARED] |
| Count Input | Disabled |
| Kill 0 Input | Disabled |
| Reload Input | Disabled |
| Start Input | Rising Edge |
| Start Signal | ● TCPWM[0] Group[1] 16-bit Counter 4 out 1 (PWM_START) [SHARED] |
| Swap Input | Rising Edge |
| Swap Signal | ● TCPWM[0] Group[1] 16-bit Counter 3 out 0 (ADC0_ISR0) [SHARED] |
| Kill 1 Input | Disabled |
| › PWM Output Polarity | |
| ⌄ PWM Disabled Output | |
| PWM Disabled Output | High Impedance |
| ⌄ Outputs | |
| PWM (line) | ● P4[0] digital_out (PWMUH) [USED] |
| PWM_n (line_compl) | ● P4[1] digital_out (PWMUL) [USED] |
| ⌄ Trigger Outputs | |
| Trigger 0 Event | Disabled |
| Trigger 1 Event | Disabled |
| ⌄ Advanced | |
| Store Config in Flash | ☑ |

**Figure 30** **PWM_U, PWM_V, and PWM_W timer configuration**

**ADC0_ISR0**

- Start in sync with PWM_U, PWM_V, and PWM_W timer
- Compare-0 match triggers the ADC group-0 (high priority group) for all the three-phase current conversion
- Sampling frequency is 20 kHz. Since fpwm_fs0_ratio = 1U


TCPWM[0] Group[1] 16-bit Counter 3 (ADC0_ISR0) - Parameters - Device Configurator 4.20

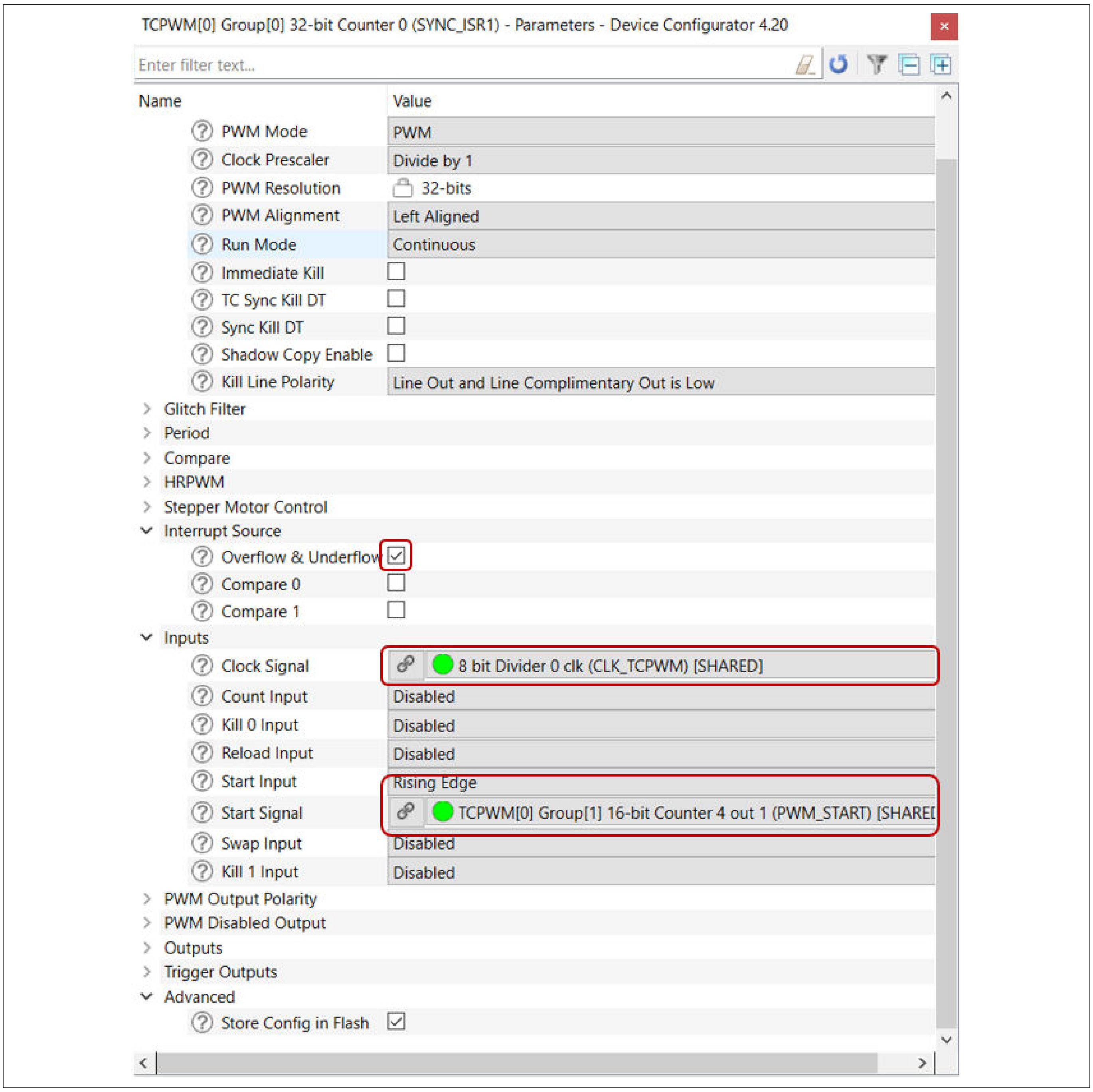
Enter filter text...

| Name | Value |
|---|---|
| **General** | |
| PWM Mode | PWM |
| Clock Prescaler | Divide by 1 |
| PWM Resolution | 16-bits |
| PWM Alignment | Left Aligned |
| Run Mode | Continuous |
| Immediate Kill | ☐ |
| TC Sync Kill DT | ☐ |
| Sync Kill DT | ☐ |
| Shadow Copy Enable | ☐ |
| Kill Line Polarity | Line Out and Line Complimentary Out is Low |
| Glitch Filter | |
| Period | |
| Compare | |
| Dithering | |
| Stepper Motor Control | |
| Interrupt Source | |
| **Inputs** | |
| Clock Signal | 🟢 8 bit Divider 0 clk (CLK_TCPWM) [SHARED] |
| Count Input | Disabled |
| Kill 0 Input | Disabled |
| Reload Input | Disabled |
| Start Input | Rising Edge |
| Start Signal | 🟢 TCPWM[0] Group[1] 16-bit Counter 4 out 1 (PWM_START) [SHARED] |
| Swap Input | Disabled |
| Kill 1 Input | Disabled |
| PWM Output Polarity | |
| PWM Disabled Output | |
| Outputs | |
| **Trigger Outputs** | |
| Trigger 0 Event | Terminal Count |
| Trigger 0 Signal | 🟢 TCPWM[0] Group[1] 16-bit Counter 0 capture0/stop (PWM_U) [USED]<br>🟢 TCPWM[0] Group[1] 16-bit Counter 1 capture0/stop (PWM_V) [USED]<br>🟢 TCPWM[0] Group[1] 16-bit Counter 2 capture0/stop (PWM_W) [USED] |
| Trigger 1 Event | Compare 0 Match |
| Trigger 1 Signal | 🟢 Trigger 0 tr_a_in [USED] |

**Figure 31** **ADC0_ISR0 timer configuration**

**SYNC_ISR1**

- Start in sync with PWM timer, trigger source PWM_START timer
- Overflow event connected to slow loop ISR
- Default sampling frequency is 2 kHz ( fs0_fs1_ratio = 10U)



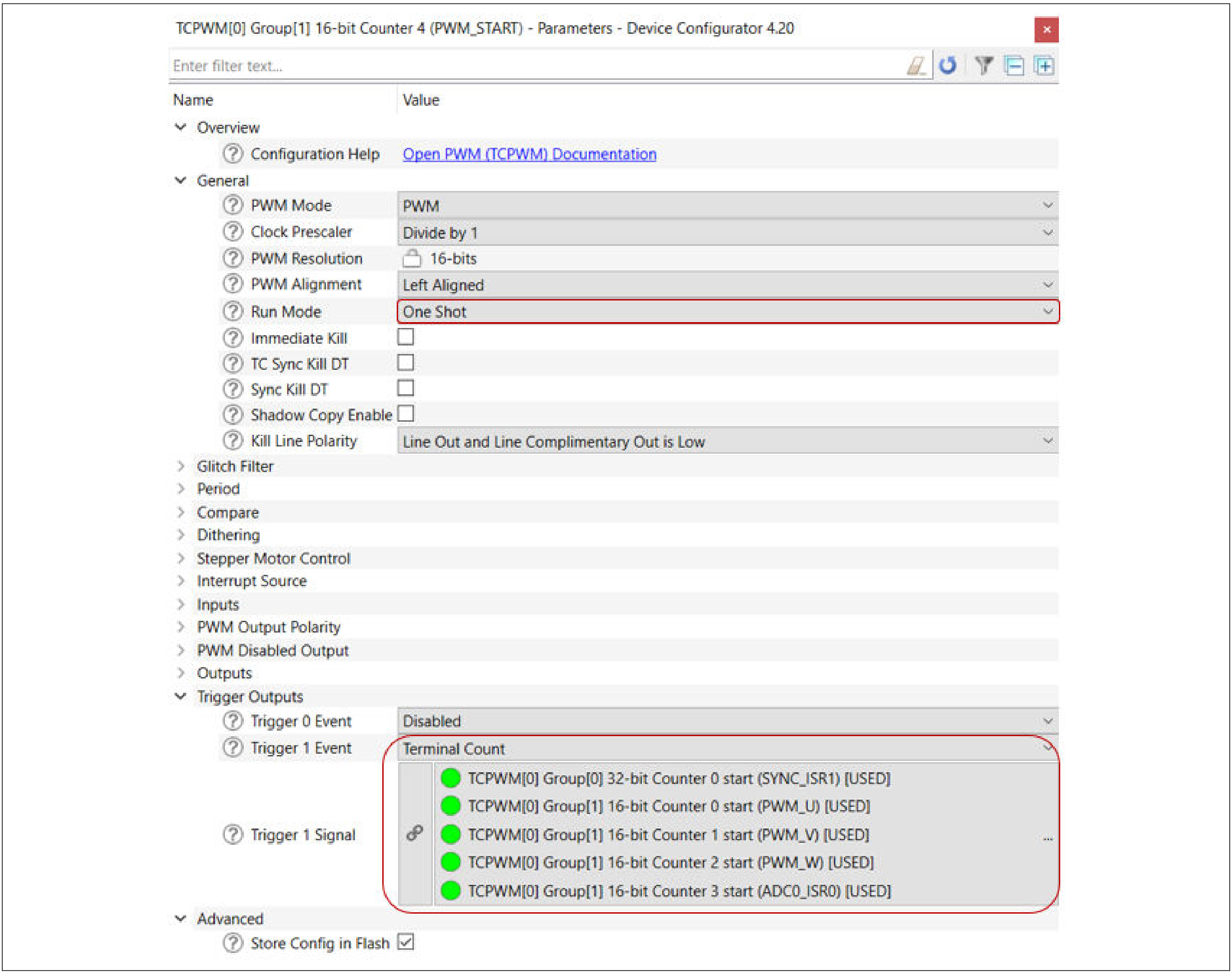
TCPWM[0] Group[0] 32-bit Counter 0 (SYNC_ISR1) - Parameters - Device Configurator 4.20

| Name | Value |
|---|---|
| PWM Mode | PWM |
| Clock Prescaler | Divide by 1 |
| PWM Resolution | 32-bits |
| PWM Alignment | Left Aligned |
| Run Mode | Continuous |
| Immediate Kill | ☐ |
| TC Sync Kill DT | ☐ |
| Sync Kill DT | ☐ |
| Shadow Copy Enable | ☐ |
| Kill Line Polarity | Line Out and Line Complimentary Out is Low |
| Glitch Filter | |
| Period | |
| Compare | |
| HRPWM | |
| Stepper Motor Control | |
| Interrupt Source | |
| Overflow & Underflow | ✓ |
| Compare 0 | ☐ |
| Compare 1 | ☐ |
| Inputs | |
| Clock Signal | 8 bit Divider 0 clk (CLK_TCPWM) [SHARED] |
| Count Input | Disabled |
| Kill 0 Input | Disabled |
| Reload Input | Disabled |
| Start Input | Rising Edge |
| Start Signal | TCPWM[0] Group[1] 16-bit Counter 4 out 1 (PWM_START) [SHAREI |
| Swap Input | Disabled |
| Kill 1 Input | Disabled |
| PWM Output Polarity | |
| PWM Disabled Output | |
| Outputs | |
| Trigger Outputs | |
| Advanced | |
| Store Config in Flash | ✓ |

**Figure 32 SYNC_ISR1 timer configuration**

**PWM_START**

- Configured in **One Shot** mode
- Terminal count is connected to the start of other timers

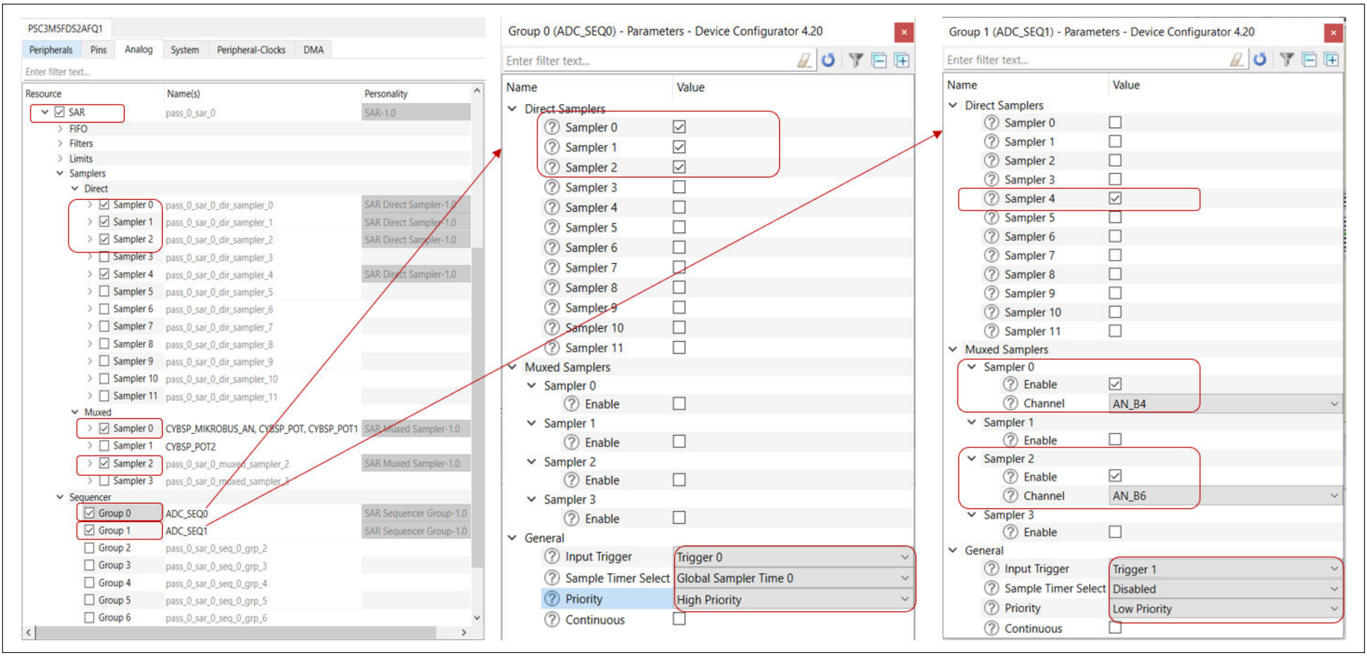

TCPWM[0] Group[1] 16-bit Counter 4 (PWM_START) - Parameters - Device Configurator 4.20

| Name | Value |
|---|---|
| Overview | |
| Configuration Help | Open PWM (TCPWM) Documentation |
| General | |
| PWM Mode | PWM |
| Clock Prescaler | Divide by 1 |
| PWM Resolution | 16-bits |
| PWM Alignment | Left Aligned |
| Run Mode | One Shot |
| Immediate Kill | ☐ |
| TC Sync Kill DT | ☐ |
| Sync Kill DT | ☐ |
| Shadow Copy Enable | ☐ |
| Kill Line Polarity | Line Out and Line Complimentary Out is Low |
| Glitch Filter | |
| Period | |
| Compare | |
| Dithering | |
| Stepper Motor Control | |
| Interrupt Source | |
| Inputs | |
| PWM Output Polarity | |
| PWM Disabled Output | |
| Outputs | |
| Trigger Outputs | |
| Trigger 0 Event | Disabled |
| Trigger 1 Event | Terminal Count |
| Trigger 1 Signal | ● TCPWM[0] Group[0] 32-bit Counter 0 start (SYNC_ISR1) [USED]<br>● TCPWM[0] Group[1] 16-bit Counter 0 start (PWM_U) [USED]<br>● TCPWM[0] Group[1] 16-bit Counter 1 start (PWM_V) [USED]<br>● TCPWM[0] Group[1] 16-bit Counter 2 start (PWM_W) [USED]<br>● TCPWM[0] Group[1] 16-bit Counter 3 start (ADC0_ISR0) [USED] |
| Advanced | |
| Store Config in Flash | ☑ |

Figure 33 PWM_START timer configuration

## ADC configuration

Enabled 6 ADC channels and assigned into two different groups, Group 0, and Group 1. Used direct channel sampler 0, 1, 2, and sampler 4 for phase U, phase V, phase W, and DC bus voltage respectively. Muxed sampler 0 and 2 used for potentiometer and temperature reading.



PSC3M5FDS2AFQ1 — Peripherals | Pins | Analog | System | Peripheral-Clocks | DMA

| Resource | Name(s) | Personality |
|---|---|---|
| ☑ SAR | pass_0_sar_0 | SAR-1.0 |
| FIFO | | |
| Filters | | |
| Limits | | |
| Samplers | | |
| Direct | | |
| ☑ Sampler 0 | pass_0_sar_0_dir_sampler_0 | SAR Direct Sampler-1.0 |
| ☑ Sampler 1 | pass_0_sar_0_dir_sampler_1 | SAR Direct Sampler-1.0 |
| ☑ Sampler 2 | pass_0_sar_0_dir_sampler_2 | SAR Direct Sampler-1.0 |
| ☐ Sampler 3 | pass_0_sar_0_dir_sampler_3 | |
| ☑ Sampler 4 | pass_0_sar_0_dir_sampler_4 | SAR Direct Sampler-1.0 |
| ☐ Sampler 5 | pass_0_sar_0_dir_sampler_5 | |
| ☐ Sampler 6 | pass_0_sar_0_dir_sampler_6 | |
| ☐ Sampler 7 | pass_0_sar_0_dir_sampler_7 | |
| ☐ Sampler 8 | pass_0_sar_0_dir_sampler_8 | |
| ☐ Sampler 9 | pass_0_sar_0_dir_sampler_9 | |
| ☐ Sampler 10 | pass_0_sar_0_dir_sampler_10 | |
| ☐ Sampler 11 | pass_0_sar_0_dir_sampler_11 | |
| Muxed | | |
| ☑ Sampler 0 | CYBSP_MIKROBUS_AN, CYBSP_POT, CYBSP_POT1 | SAR Muxed Sampler-1.0 |
| ☐ Sampler 1 | CYBSP_POT2 | |
| ☑ Sampler 2 | pass_0_sar_0_muxed_sampler_2 | SAR Muxed Sampler-1.0 |
| ☐ Sampler 3 | pass_0_sar_0_muxed_sampler_3 | |
| Sequencer | | |
| ☑ Group 0 | ADC_SEQ0 | SAR Sequencer Group-1.0 |
| ☑ Group 1 | ADC_SEQ1 | SAR Sequencer Group-1.0 |
| ☐ Group 2 | pass_0_sar_0_seq_0_grp_2 | |
| ☐ Group 3 | pass_0_sar_0_seq_0_grp_3 | |
| ☐ Group 4 | pass_0_sar_0_seq_0_grp_4 | |
| ☐ Group 5 | pass_0_sar_0_seq_0_grp_5 | |
| ☐ Group 6 | pass_0_sar_0_seq_0_grp_6 | |

Group 0 (ADC_SEQ0) - Parameters - Device Configurator 4.20

| Name | Value |
|---|---|
| Direct Samplers | |
| Sampler 0 | ☑ |
| Sampler 1 | ☑ |
| Sampler 2 | ☑ |
| Sampler 3 | ☐ |
| Sampler 4 | ☐ |
| Sampler 5 | ☐ |
| Sampler 6 | ☐ |
| Sampler 7 | ☐ |
| Sampler 8 | ☐ |
| Sampler 9 | ☐ |
| Sampler 10 | ☐ |
| Sampler 11 | ☐ |
| Muxed Samplers | |
| Sampler 0 – Enable | ☐ |
| Sampler 1 – Enable | ☐ |
| Sampler 2 – Enable | ☐ |
| Sampler 3 – Enable | ☐ |
| General | |
| Input Trigger | Trigger 0 |
| Sample Timer Select | Global Sampler Time 0 |
| Priority | High Priority |
| Continuous | ☐ |

Group 1 (ADC_SEQ1) - Parameters - Device Configurator 4.20

| Name | Value |
|---|---|
| Direct Samplers | |
| Sampler 0 | ☐ |
| Sampler 1 | ☐ |
| Sampler 2 | ☐ |
| Sampler 3 | ☐ |
| Sampler 4 | ☑ |
| Sampler 5 | ☐ |
| Sampler 6 | ☐ |
| Sampler 7 | ☐ |
| Sampler 8 | ☐ |
| Sampler 9 | ☐ |
| Sampler 10 | ☐ |
| Sampler 11 | ☐ |
| Muxed Samplers | |
| Sampler 0 – Enable | ☑ |
| Sampler 0 – Channel | AN_B4 |
| Sampler 1 – Enable | ☐ |
| Sampler 2 – Enable | ☑ |
| Sampler 2 – Channel | AN_B6 |
| Sampler 3 – Enable | ☐ |
| General | |
| Input Trigger | Trigger 1 |
| Sample Timer Select | Disabled |
| Priority | Low Priority |
| Continuous | ☐ |

**Figure 34** **ADC configuration**

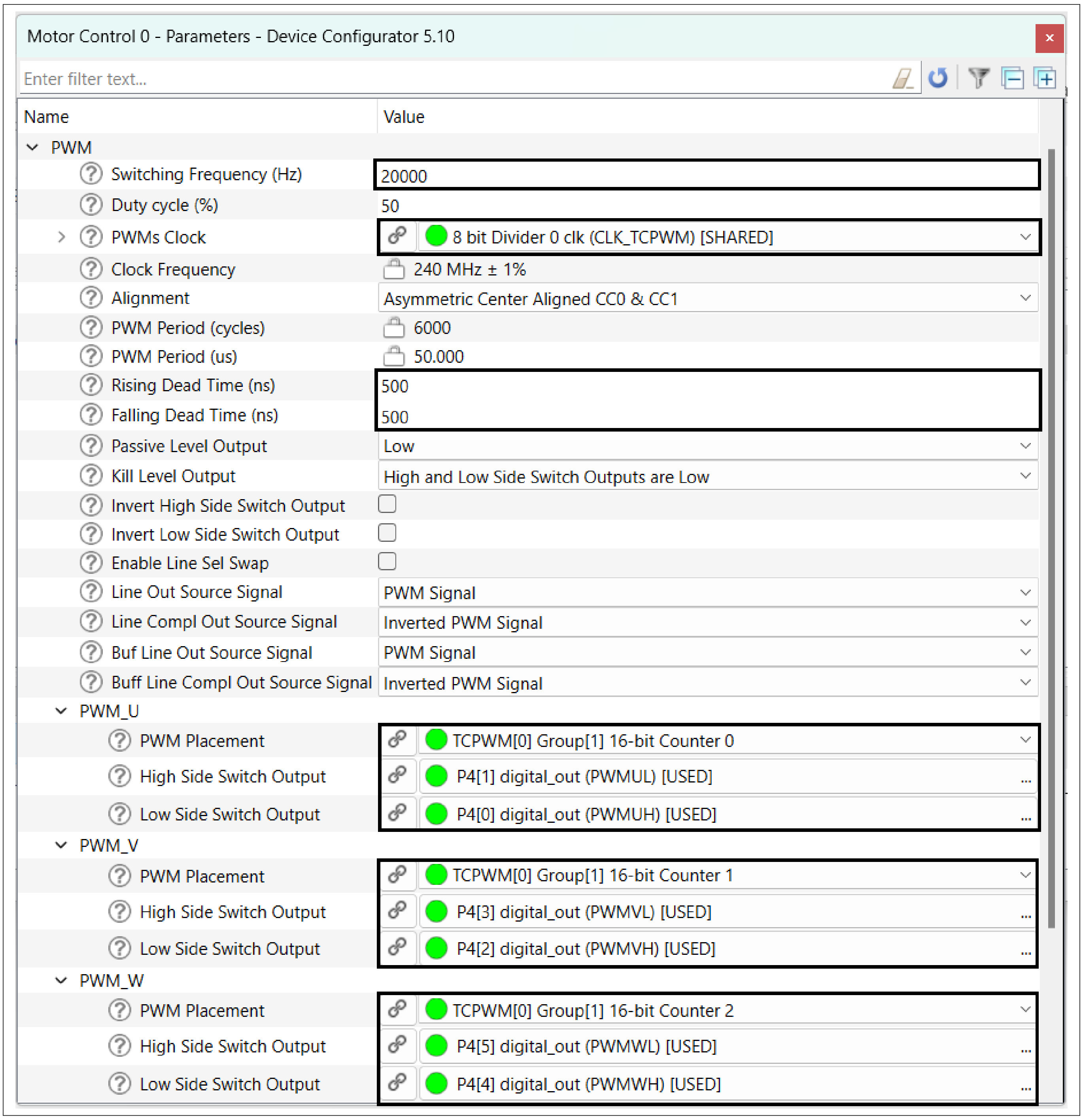
- Group 0 property
  - High priority group
  - Trigger input: Hardware trigger
  - End of group conversion ISR executes the FOC loop (Fast loop)
- Group 1
  - Low priority group
  - Trigger input: Firmware pulse

## 5.3.1 Peripheral configuration using solution personality

In ModusToolbox™, the solution personality is the alternate way to provide easy initialization of multiple peripherals required by the motor control application. After saving, the configuration data structure and APIs are generated and stored in the `mcdi` (motor control driver interface) folder, which are used by the motor control solution for selected topology. Configuration details are discussed in the following sections.

### PWM configuration

In this section, the TCPWM timer is configured to generate six PWM outputs to drive the inverter module. Configurations are common to all the three PWM timers.



Motor Control 0 - Parameters - Device Configurator 5.10

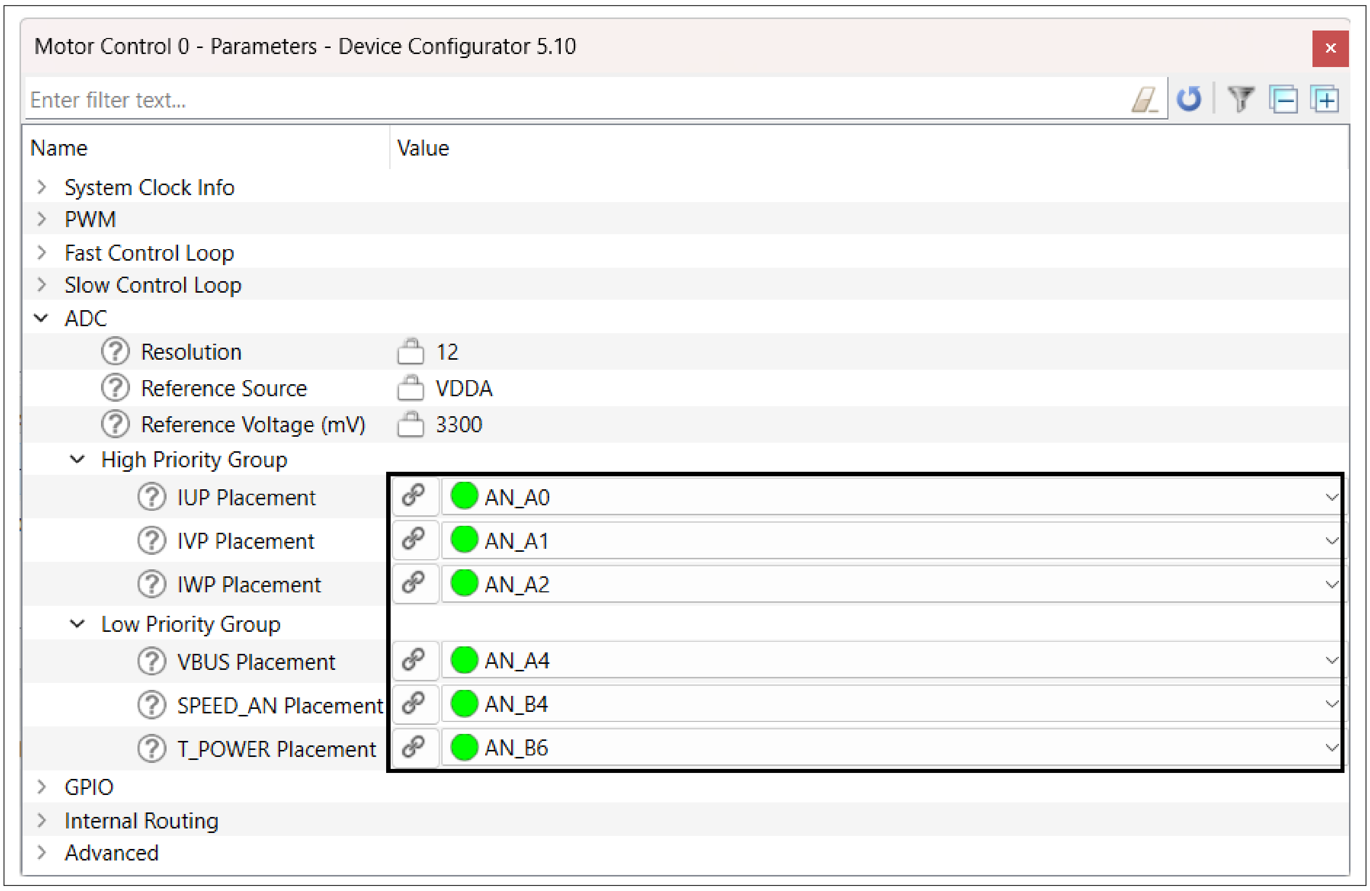
Enter filter text...

| Name | Value |
|---|---|
| PWM | |
| Switching Frequency (Hz) | 20000 |
| Duty cycle (%) | 50 |
| PWMs Clock | 8 bit Divider 0 clk (CLK_TCPWM) [SHARED] |
| Clock Frequency | 240 MHz ± 1% |
| Alignment | Asymmetric Center Aligned CC0 & CC1 |
| PWM Period (cycles) | 6000 |
| PWM Period (us) | 50.000 |
| Rising Dead Time (ns) | 500 |
| Falling Dead Time (ns) | 500 |
| Passive Level Output | Low |
| Kill Level Output | High and Low Side Switch Outputs are Low |
| Invert High Side Switch Output | ☐ |
| Invert Low Side Switch Output | ☐ |
| Enable Line Sel Swap | ☐ |
| Line Out Source Signal | PWM Signal |
| Line Compl Out Source Signal | Inverted PWM Signal |
| Buf Line Out Source Signal | PWM Signal |
| Buff Line Compl Out Source Signal | Inverted PWM Signal |
| PWM_U | |
| PWM Placement | TCPWM[0] Group[1] 16-bit Counter 0 |
| High Side Switch Output | P4[1] digital_out (PWMUL) [USED] |
| Low Side Switch Output | P4[0] digital_out (PWMUH) [USED] |
| PWM_V | |
| PWM Placement | TCPWM[0] Group[1] 16-bit Counter 1 |
| High Side Switch Output | P4[3] digital_out (PWMVL) [USED] |
| Low Side Switch Output | P4[2] digital_out (PWMVH) [USED] |
| PWM_W | |
| PWM Placement | TCPWM[0] Group[1] 16-bit Counter 2 |
| High Side Switch Output | P4[5] digital_out (PWMWL) [USED] |
| Low Side Switch Output | P4[4] digital_out (PWMWH) [USED] |

**Figure 35** **PWM configuration**

### ADC configuration

This section configures the six analog pins to read the three-phase current, DC bus voltage, potentiometer for speed control, and temperature sense for protection.

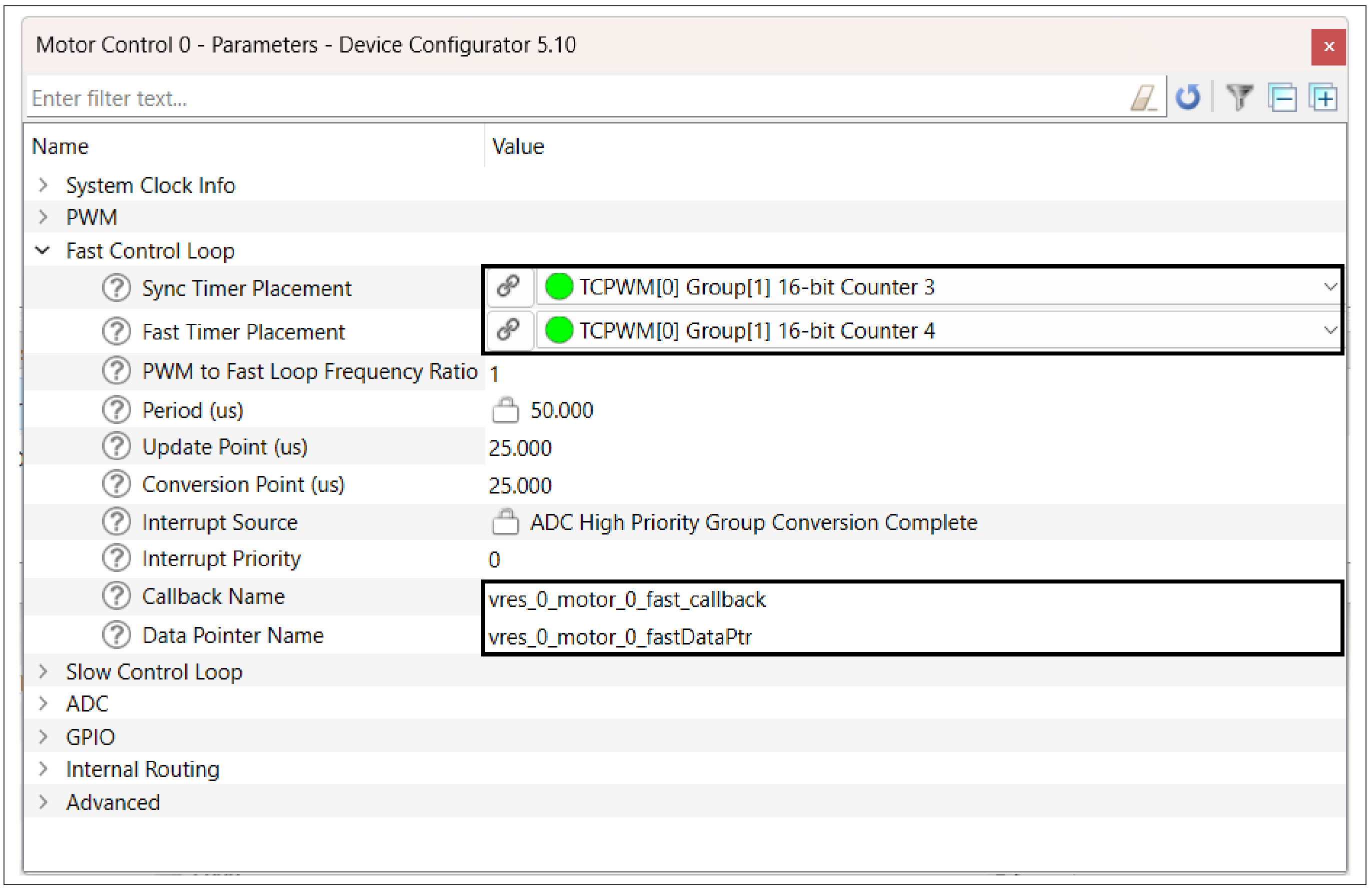

Motor Control 0 - Parameters - Device Configurator 5.10

| Name | Value |
|---|---|
| System Clock Info | |
| PWM | |
| Fast Control Loop | |
| Slow Control Loop | |
| ADC | |
| Resolution | 12 |
| Reference Source | VDDA |
| Reference Voltage (mV) | 3300 |
| High Priority Group | |
| IUP Placement | AN_A0 |
| IVP Placement | AN_A1 |
| IWP Placement | AN_A2 |
| Low Priority Group | |
| VBUS Placement | AN_A4 |
| SPEED_AN Placement | AN_B4 |
| T_POWER Placement | AN_B6 |
| GPIO | |
| Internal Routing | |
| Advanced | |

**Figure 36** **ADC configuration**

## Fast control loop configuration

- Sync timer - Provides swap trigger signal to PWM timers
- Fast timer - Provides triggers to ADC. High priority group end of conversion generate fast control loop ISR
- vres_0_motor_0_fast_callback - Fast control loop callback function (ISR)
- vres_0_motor_0_fastDataPtr - Stores the result of three current channels



Motor Control 0 - Parameters - Device Configurator 5.10

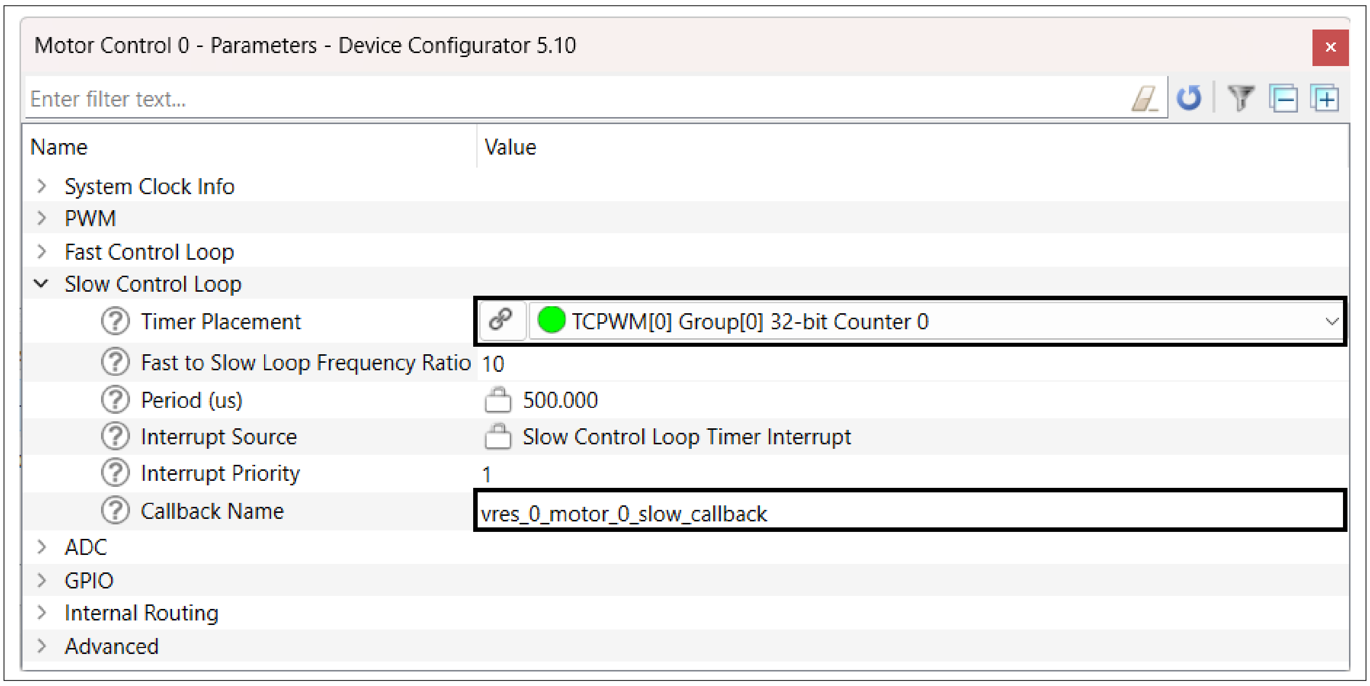
Enter filter text...

| Name | Value |
|---|---|
| › System Clock Info | |
| › PWM | |
| ⌄ Fast Control Loop | |
| Sync Timer Placement | TCPWM[0] Group[1] 16-bit Counter 3 |
| Fast Timer Placement | TCPWM[0] Group[1] 16-bit Counter 4 |
| PWM to Fast Loop Frequency Ratio | 1 |
| Period (us) | 50.000 |
| Update Point (us) | 25.000 |
| Conversion Point (us) | 25.000 |
| Interrupt Source | ADC High Priority Group Conversion Complete |
| Interrupt Priority | 0 |
| Callback Name | vres_0_motor_0_fast_callback |
| Data Pointer Name | vres_0_motor_0_fastDataPtr |
| › Slow Control Loop | |
| › ADC | |
| › GPIO | |
| › Internal Routing | |
| › Advanced | |

**Figure 37** **Fast control loop configuration**

## Slow control loop configuration

- Slow control loop timer - Generates slow control loop ISR
- vres_0_motor_0_slow_callback - Slows control loop callback function (ISR)



Motor Control 0 - Parameters - Device Configurator 5.10

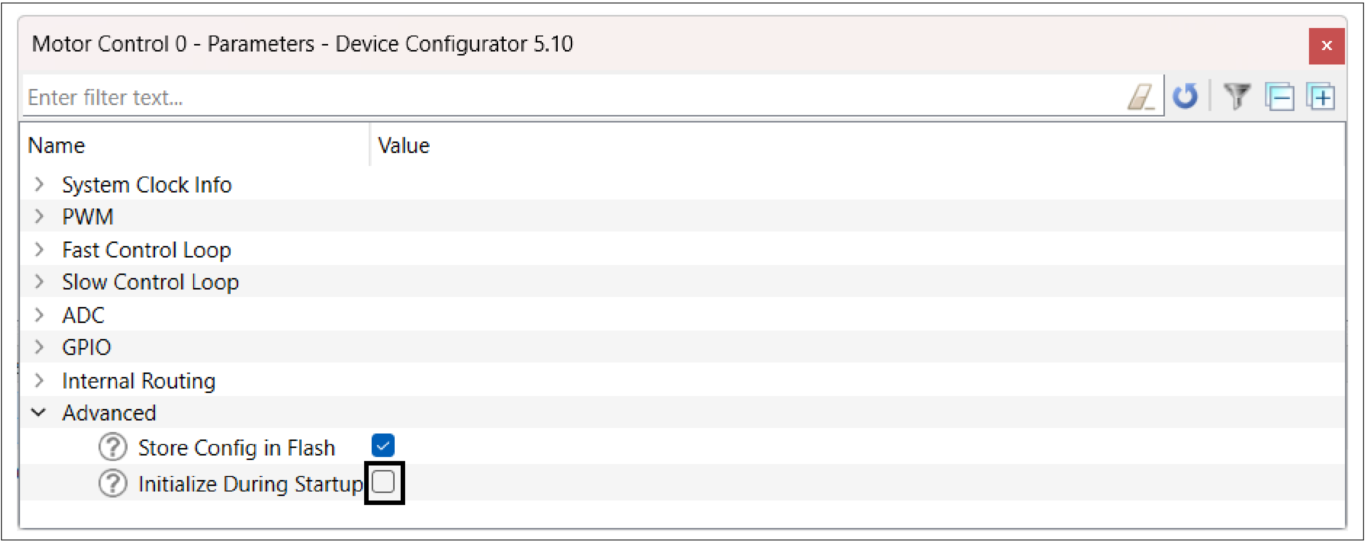
Enter filter text...

| Name | Value |
|---|---|
| › System Clock Info | |
| › PWM | |
| › Fast Control Loop | |
| ⌄ Slow Control Loop | |
| Timer Placement | TCPWM[0] Group[0] 32-bit Counter 0 |
| Fast to Slow Loop Frequency Ratio | 10 |
| Period (us) | 500.000 |
| Interrupt Source | Slow Control Loop Timer Interrupt |
| Interrupt Priority | 1 |
| Callback Name | vres_0_motor_0_slow_callback |
| › ADC | |
| › GPIO | |
| › Internal Routing | |
| › Advanced | |

**Figure 38** **Slow control loop configuration**

### Peripheral initialization

An option available to enable and disable peripheral initialization during startup.


Motor Control 0 - Parameters - Device Configurator 5.10

Enter filter text...

| Name | Value |
|---|---|
| System Clock Info | |
| PWM | |
| Fast Control Loop | |
| Slow Control Loop | |
| ADC | |
| GPIO | |
| Internal Routing | |
| Advanced | |
| Store Config in Flash | ✓ |
| Initialize During Startup | ☐ |

**Figure 39** **Peripheral initialization during startup**

## 5.4 Parameter configuration

This section describes the important parameters to spin the motor.

There are two ways to update the parameters either using the Motor Suite GUI or ModusToolbox™. If you are not using GUI, then ensure `PARAMS_ALWAYS_OVERWRITE` macro in `param.h` file is changed from false to true. Otherwise, any change in the `param.c` file will not be effective.

```
#define PARAMS_ALWAYS_OVERWRITE (true) // This will ensure parameters are always overwritten.
```

### Basic and advanced parameters

There are a few basic parameters and advanced parameters which are derived from basic parameters. After proper configuration of basic parameters you can spin and control their PMSM or BLDC motors.

The following code shows the parameter structure of the motor control library. These parameters will be used for motor tuning and control.

### Parameter structure

```
/* Motor parameters */
typedef struct
{
    float               P;          // [#], Number of poles
    float               lq;         // [H], q-axis inductance
    float               ld;         // [H], d-axis inductance
    float               lam;        // [Wb], permanent magnet's flux linkage
    float               r;          // [ohm], stator resistance
    float               T_max;      // [Nm], maximum torque
    float               i_cont;     // [A], continuous current rating
    float               i_peak;     // [A], peak current rating
    float               id_max;     // [A], maximum demagnetization current
    float               v_nom;      // [Vpk-ln], nominal voltage peak, line to neutral
    ELEC_t              w_nom;      // [Ra/sec-elec], nominal speed
    ELEC_t              w_max;      // [Ra/sec-elec], maximum speed
    float               zeta;       // [#], saliency ratio = lq/ld
    I2T_PARAMS_t        i2t;
} MOTOR_PARAMS_t;
```

```
/* System parameters */
typedef struct
{
    SAMPLE_PARAMS_t       samp;       // [], sampling parameters
    LUT_PARAMS_t          lut;        // [#], luts
    ANALOG_SENS_PARAMS_t  analog;     // [], analog sensor parameters
    RATE_LIM_PARAMS_t     rate_lim;   // [], rate limiter parameters
    FAULT_PARAMS_t        faults;     // [], fault parameters
    CMD_PARAMS_t          cmd;        // [], command parameters
    FB_PARAMS_t           fb;         // [#], feedback parameters
    float                 boot_time;  // [sec], time for charging bootstrap capacitors
    float                 vdc_nom;    // [], dc bus voltage parameters
} SYS_PARAMS_t;
```

```
/* Parameter configuration structure*/
typedef struct
{
    PARAMS_ID_t           id;
    MOTOR_PARAMS_t        motor;
    SYS_PARAMS_t          sys;
    OBS_PARAMS_t          obs;
    MECH_PARAMS_t         mech;
    FILTER_PARAMS_t       filt;
    CTRL_PARAMS_t         ctrl;
} PARAMS_t;
```

```
/*Parameter Configuration Object*/
PARAMS_t params
```

The basic parameters are divided into multiple categories, such as:

- **Motor parameters:** params.motor
- **System parameter:** params.sys
- **Observer parameters:** params.obs
- **Motor mechanical parameters:** params.mech
- **Filter parameters:** params.filtand
- **Control parameters:** params.ctrl

### Motor parameters

- `motor.P` represents the number of poles
- The current values are based on the peak values, not rms
- `motor.i_cont` is the continuous current rating of the motor
- `motor.i_peak` is the peak current rating of the motor. Set this value to 2.5 to 3x of `motor.i_cont`, if not specified in the motor datasheet

```
    params.motor.P          = 8.0f; // [#]
    params.motor.lq         = 670.0E-6f; // [H]
    params.motor.ld         = 670.0E-6f; // [H]
    params.motor.lam        = 6.0E-3f; // [Wb]
    params.motor.r          = 450.0E-3f; // [Ohm]
    params.motor.T_max      = 0.390f; // [Nm]
    params.motor.i_peak     = 10.80f; // [A]
    params.motor.i_cont     = 3.50f; // [A]
    params.motor.id_max     = 1.75f; // [A]
    params.motor.v_nom      = LINE_TO_PHASE(24.0f); // [Vpk-ln]
    params.motor.w_nom.elec = MECH_TO_ELEC(HZ_TO_RADSEC(RPM_TO_HZ(4000.0f)), params.motor.P);
    params.motor.w_max.elec = MECH_TO_ELEC(HZ_TO_RADSEC(RPM_TO_HZ(6000.0f)), params.motor.P);
```

### System parameters

- Set the shunt type to three shunts or single shunt based on inverter setup
- Set the current sensing opamp gain based on the inverter setup
- `hyb_mod.adc_t_min` and `hyb_mod.ki` belong to single shunt-based control

- `shunt.res` is a key parameter and represents the shunt value for both single shunt and three shunt control. The value is set in the `MotorCtrlHWConfig.h` file

```
    params.sys.analog.shunt.type                =Three_Shunt;
    params.sys.analog.shunt.opamp_gain          = ADC_CS_OPAMP_GAIN;
    params.sys.analog.shunt.hyb_mod.adc_t_min   = 3.0E-6f;          // [sec]
    params.sys.analog.shunt.hyb_mod.ki          = 0.5f;             // [#]
    params.sys.analog.shunt.res                 = ADC_CS_SHUNT_RES; // [Ohm]
```

- Sampling parameters

```
    params.sys.samp.fs0                 = 15.0E3;  // PWM frequency
    params.sys.samp.fpwm_fs0_ratio = 1U;     // ISR-0 to PWM frequency ratio (1x slower)
    params.sys.samp.fs0_fs1_ratio  = 15U;    // ISR-1 to ISR-0 ratio (15x slower)
```

- `cmd.w_max.mech` is the maximum motor speed controlled by a potentiometer. For example, set `motor.w_max.elec` to 6000 rpm but if you set `cmd.w_max.mech` to 3000 rpm, then maximum motor speed using potentiometer would be 3000 rpm instead of 6000 rpm

```
params.sys.cmd.w_max.mech = HZ_TO_RADSEC(RPM_TO_HZ(4000.0f));
```

- `vdc_nom` is the power supply voltage. Ideally, this number is the same as the `motor.v_nom`. However, you can apply 24 V to a 48 V motor. To get this, set `vdc_nom` as 24 V rather than 48 V.

```
params.sys.vdc_nom = 24.0f;
```

- **Command parameters:** The default source of speed control is a potentiometer. It can be changed to external source

```
params.sys.cmd.source = Potentiometer;
```

### Observer parameters

Setting the observer parameters are important for sensorless FOC operation.

- `w_thresh.elec` is the speed at which the transition from open loop to close loop FOC happens. This is a key parameter to tune if the transition to closed loop does not happen smoothly
- `lock_time` is the time expected for the observer to lock to the rotor angle, to be tuned as required

```
params.obs.w_thresh.elec = params.motor.w_nom.elec * 0.20f;
params.obs.lock_time     = 0.500f;
```

### Mechanical parameters

The mechanical parameters cannot be found in the motor datasheet. They depend mostly on the mechanical load attached to the motor's shaft. It is best to derive and set them properly.

```
params.mech.inertia  = 1.1E-5f;
params.mech.viscous  = 1.2E-5f;
params.mech.friction = 6.0E-3f;
```

### Control parameters

Control parameters are divided into subcategories as follows:

- **Control mode:** Multiple control modes are available to select in the firmware. You can set the control mode in `param.c` file. Configuration options are available in the `param.h` file

  ```
  params.ctrl.mode = Speed_Mode_FOC_Sensorless_Volt_Startup;
  ```

- **Speed controller**

  `speed.bw` is a key parameter for the speed loop controller. Kp and Ki for the controller are automatically calculated from the given bandwidth and motor mechanical parameters in the function `PARAMS_InitAutoCalc()`

  ```
  params.ctrl.speed.bw = HZ_TO_RADSEC(15.0f);
  ```

- **Current controller**

  `ctrl.curr.bw` is a key for the current loop controller. Kp and Ki for the controller are automatically calculated from motor electrical parameters including stator inductance and resistance in function`PARAMS_InitAutoCalc()`. Set the value of `ctrl. curr.bw` at least 3~5 times lower than the switching frequency. In addition, set it to be higher than `speed.bw`

  ```
  params.ctrl.curr.bw = HZ_TO_RADSEC(750.0f); // [Ra/sec]
  ```

- **Voltage controller**

  The following parameters are the key to start spinning the motor

- `w_thresh.elec` is the minimum speed that will activate open loop voltage control. Any speed commanded under this threshold will not spin the motor
- `v_min` is the minimum voltage that needs to apply right before the motor start spinning in an open loop

- `v_to_f_ratio` is the V/F constant required to spin a motor in an open loop.

```
params.ctrl.volt.w_thresh.elec = params.motor.w_nom.elec * 0.05f;
    params.ctrl.volt.w_hyst.elec = params.ctrl.volt.w_thresh.elec * 0.5f;
    params.ctrl.volt.v_min = 0.15f;
    params.ctrl.volt.v_to_f_ratio = 7.5E-3f;
```

- **Modulation method configuration**

```
params.ctrl.volt.mod_method=Space_Vector_Modulation;
```

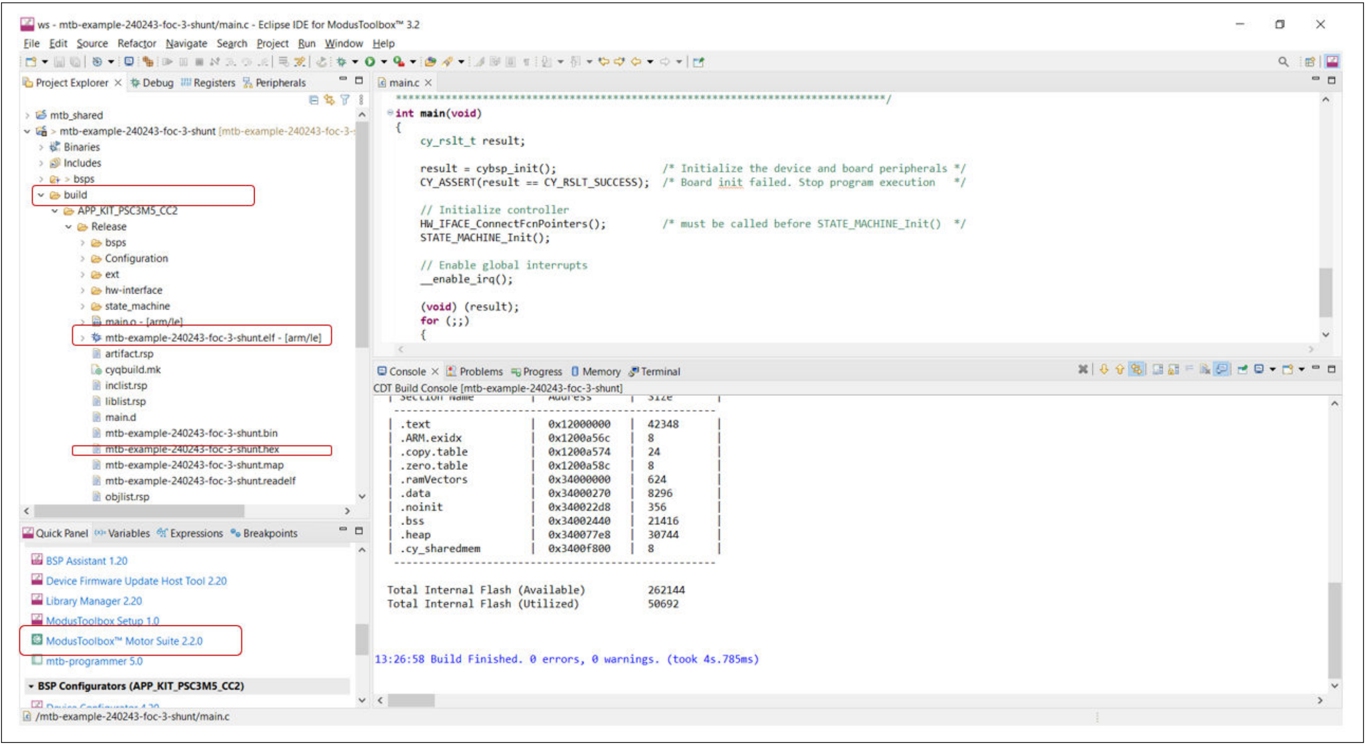
## 5.5 ModusToolbox™ Motor Suite

ModusToolbox™ Motor Suite is a GUI integrated with the ModusToolbox™ ecosystem to configure, control, and monitor the motor control parameters.

GUI has two options to flash the firmware onto the target board.

- Option-1 (default): Flash the default executable
- Option-2: Compile the project and flash the custom executable

GUI can be installed from Infineon Developer Center (IDC) or launch from ModusToolbox™ Quick Panel (highlighted) in the bottom-left corner shown in Figure 40.


ws - mtb-example-240243-foc-3-shunt/main.c - Eclipse IDE for ModusToolbox™ 3.2
File Edit Source Refactor Navigate Search Project Run Window Help
Project Explorer
Debug
Registers
Peripherals
mtb_shared
mtb-example-240243-foc-3-shunt [mtb-example-240243-foc-3-
Binaries
Includes
bsps
build
APP_KIT_PSC3M5_CC2
Release
bsps
Configuration
ext
hw-interface
state_machine
main.o - [arm/le]
mtb-example-240243-foc-3-shunt.elf - [arm/le]
artifact.rsp
cyqbuild.mk
inclist.rsp
liblist.rsp
main.d
mtb-example-240243-foc-3-shunt.bin
mtb-example-240243-foc-3-shunt.hex
mtb-example-240243-foc-3-shunt.map
mtb-example-240243-foc-3-shunt.readelf
objlist.rsp
Quick Panel
Variables
Expressions
Breakpoints
BSP Assistant 1.20
Device Firmware Update Host Tool 2.20
Library Manager 2.20
ModusToolbox Setup 1.0
ModusToolbox™ Motor Suite 2.2.0
mtb-programmer 5.0
BSP Configurators (APP_KIT_PSC3M5_CC2)
Device Configurator 4.20
/mtb-example-240243-foc-3-shunt/main.c
main.c
Console
Problems
Progress
Memory
Terminal
CDT Build Console [mtb-example-240243-foc-3-shunt]

```
*******************************************************************************/
int main(void)
{
    cy_rslt_t result;

    result = cybsp_init();                  /* Initialize the device and board peripherals */
    CY_ASSERT(result == CY_RSLT_SUCCESS);   /* Board init failed. Stop program execution   */

    // Initialize controller
    HW_IFACE_ConnectFcnPointers();          /* must be called before STATE_MACHINE_Init()  */
    STATE_MACHINE_Init();

    // Enable global interrupts
    __enable_irq();

    (void) (result);
    for (;;)
    {
```

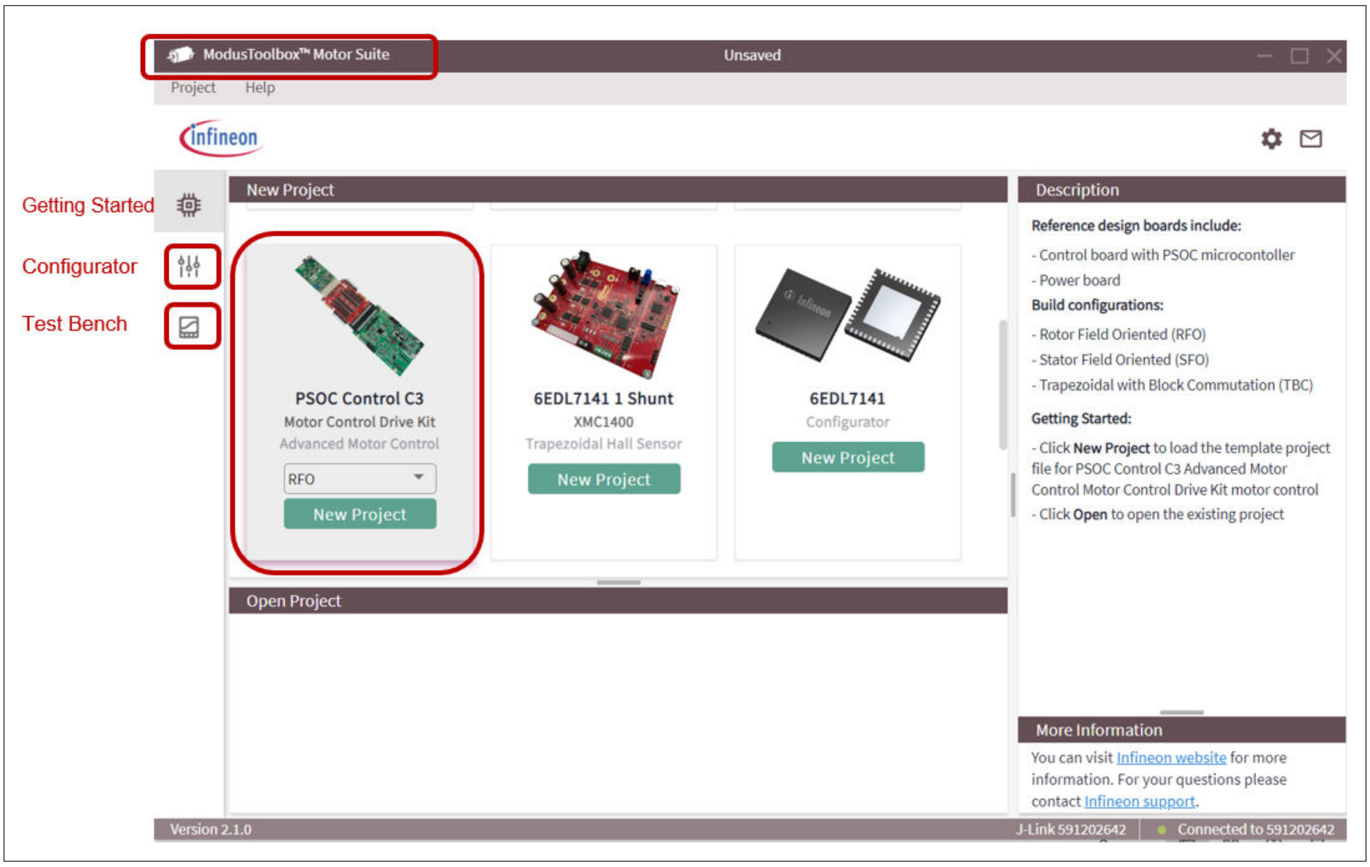
```
 | Section Name          |  Address     |  Size      |
 ----------------------------------------------------
 | .text                 |  0x12000000  |  42348     |
 | .ARM.exidx            |  0x1200a56c  |  8         |
 | .copy.table           |  0x1200a574  |  24        |
 | .zero.table           |  0x1200a58c  |  8         |
 | .ramVectors           |  0x34000000  |  624       |
 | .data                 |  0x34000270  |  8296      |
 | .noinit               |  0x340022d8  |  356       |
 | .bss                  |  0x34002440  |  21416     |
 | .heap                 |  0x340077e8  |  30744     |
 | .cy_sharedmem         |  0x3400f800  |  8         |
 ----------------------------------------------------

Total Internal Flash (Available)          262144
Total Internal Flash (Utilized)           50692


13:26:58 Build Finished. 0 errors, 0 warnings. (took 4s.785ms)
```

**Figure 40 GUI launch panel**

Double-click on ModusToolbox™ Motor Suite in the Quick Panel, a new window opens as shown in Figure 41.



**Reference design boards include:**
- Control board with PSOC microcontoller
- Power board

**Build configurations:**
- Rotor Field Oriented (RFO)
- Stator Field Oriented (SFO)
- Trapezoidal with Block Commutation (TBC)

**Getting Started:**
- Click **New Project** to load the template project file for PSOC Control C3 Advanced Motor Control Motor Control Drive Kit motor control
- Click **Open** to open the existing project

You can visit Infineon website for more information. For your questions please contact Infineon support.

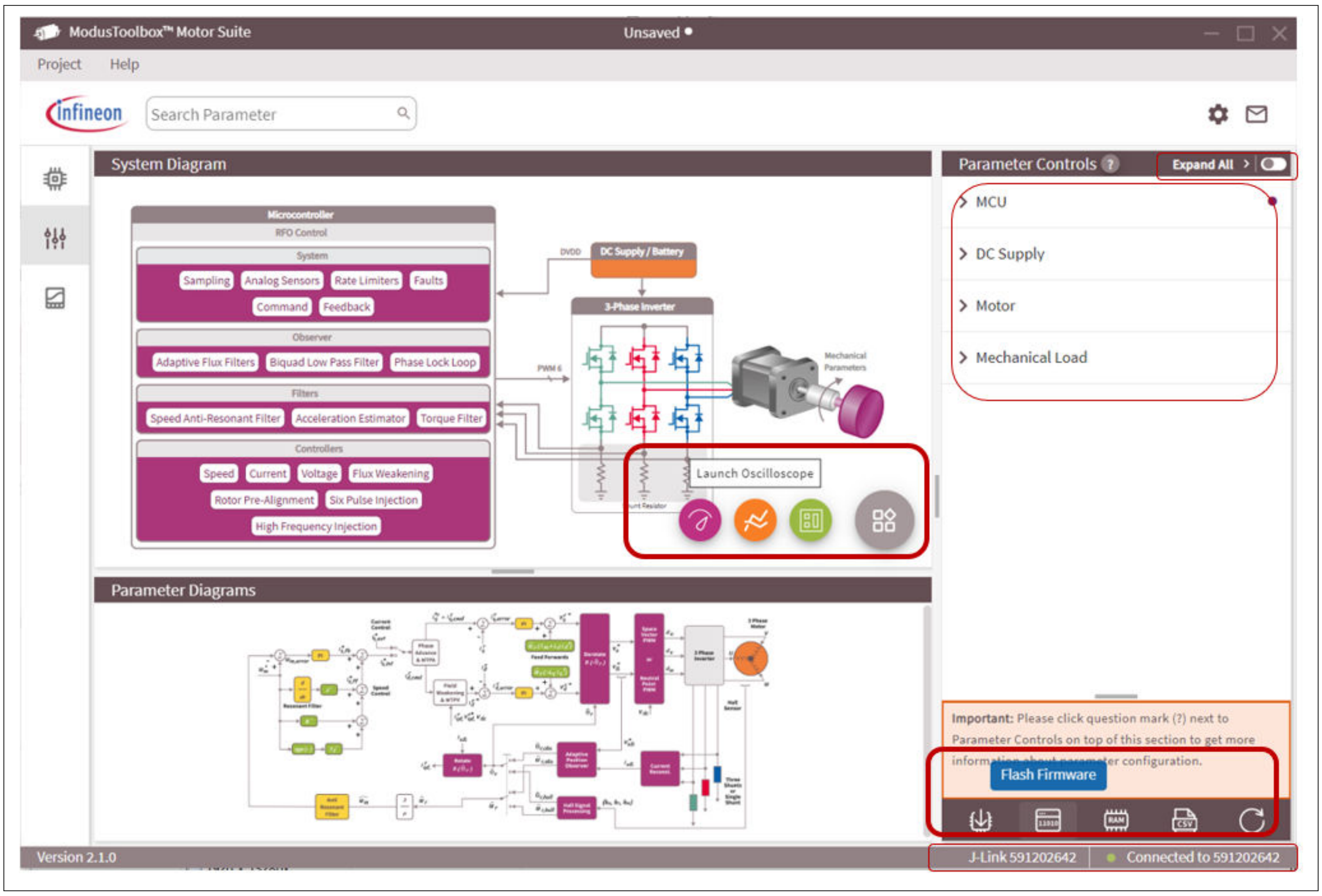
**Figure 41 ModusToolbox™ Motor Suite**

Select the PSOC™ Control C3 motor control drive kit and create a new project. The configurator page will pop-up with an addition icon for the Test Bench.

## 5.5.1 Configurator

ModusToolbox™ Motor Suite Configurator provides the following:

- Displays the J-Link connection establishment in the right bottom corner indicated by a green LED
- Flash Firmware option for default as well as custom executable
- Static parameter configuration for motor control application
- Option to launch the oscilloscope



Important: Please click question mark (?) next to Parameter Controls on top of this section to get more information about parameter configuration.

**Figure 42** **Configurator**

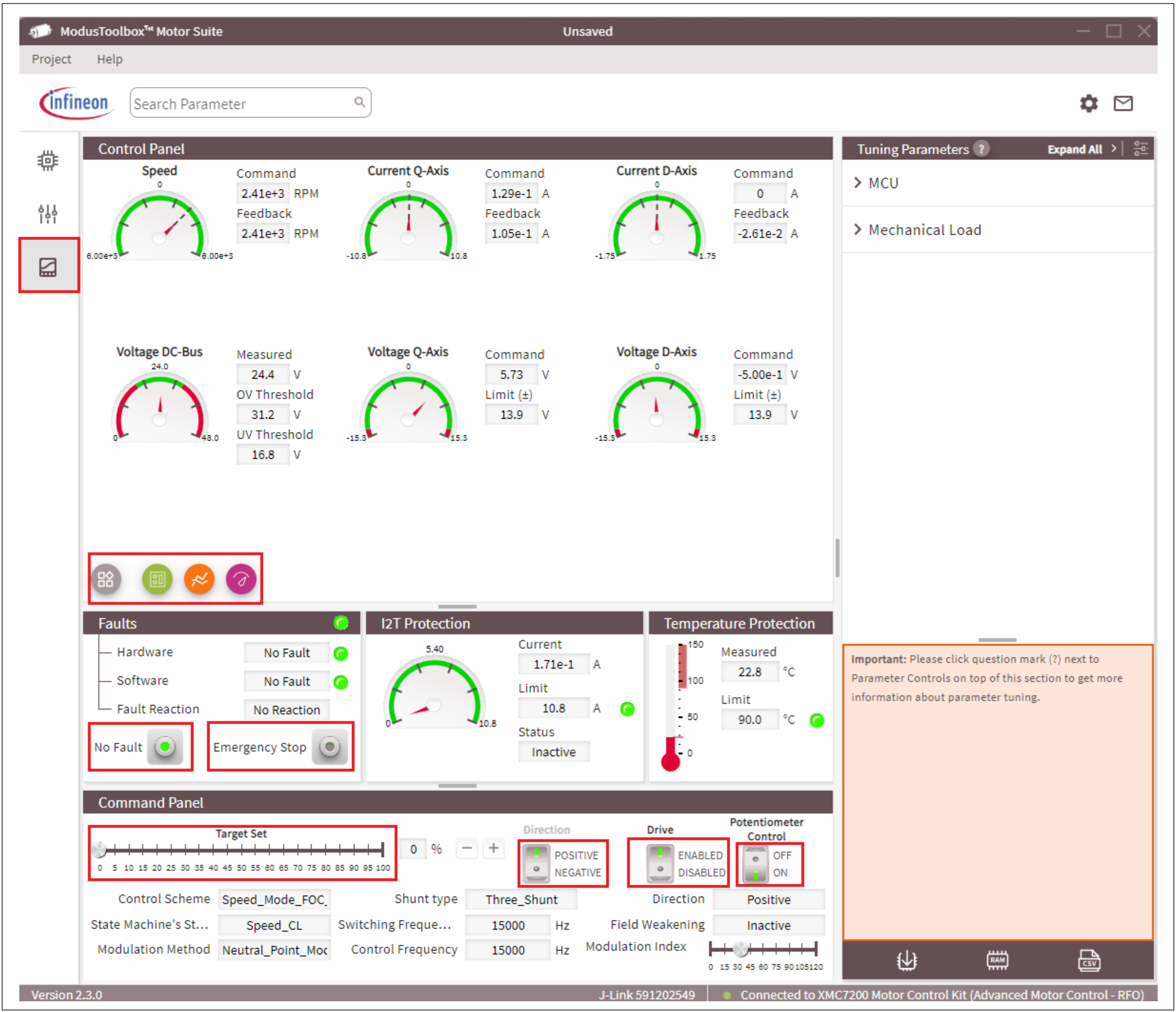
For more details, click **Help** in the left top corner of the window.

## 5.5.2 Test Bench

Test Bench provide the run time control and monitor of the motor parameters.

### Control parameters

- **Drive:** Enable/disable the drive
- **Potentiometer:**
  - Switch on to control motor speed using a potentiometer (hardware)
  - Switch off to control motor speed using the **Target Set** slider in the GUI
- **Direction:** Change the motor direction
- **Emergency Stop:** Stop and reset



Speed: Command 2.41e+3 RPM; Feedback 2.41e+3 RPM

Current Q-Axis: Command 1.29e-1 A; Feedback 1.05e-1 A

Current D-Axis: Command 0 A; Feedback -2.61e-2 A

Voltage DC-Bus: Measured 24.4 V; OV Threshold 31.2 V; UV Threshold 16.8 V

Voltage Q-Axis: Command 5.73 V; Limit (±) 13.9 V

Voltage D-Axis: Command -5.00e-1 V; Limit (±) 13.9 V

Faults: Hardware No Fault; Software No Fault; Fault Reaction No Reaction; No Fault; Emergency Stop

I2T Protection: Current 1.71e-1 A; Limit 10.8 A; Status Inactive

Temperature Protection: Measured 22.8 °C; Limit 90.0 °C

Important: Please click question mark (?) next to Parameter Controls on top of this section to get more information about parameter tuning.

Command Panel: Target Set 0 %; Direction POSITIVE / NEGATIVE; Drive ENABLED / DISABLED; Potentiometer Control OFF / ON

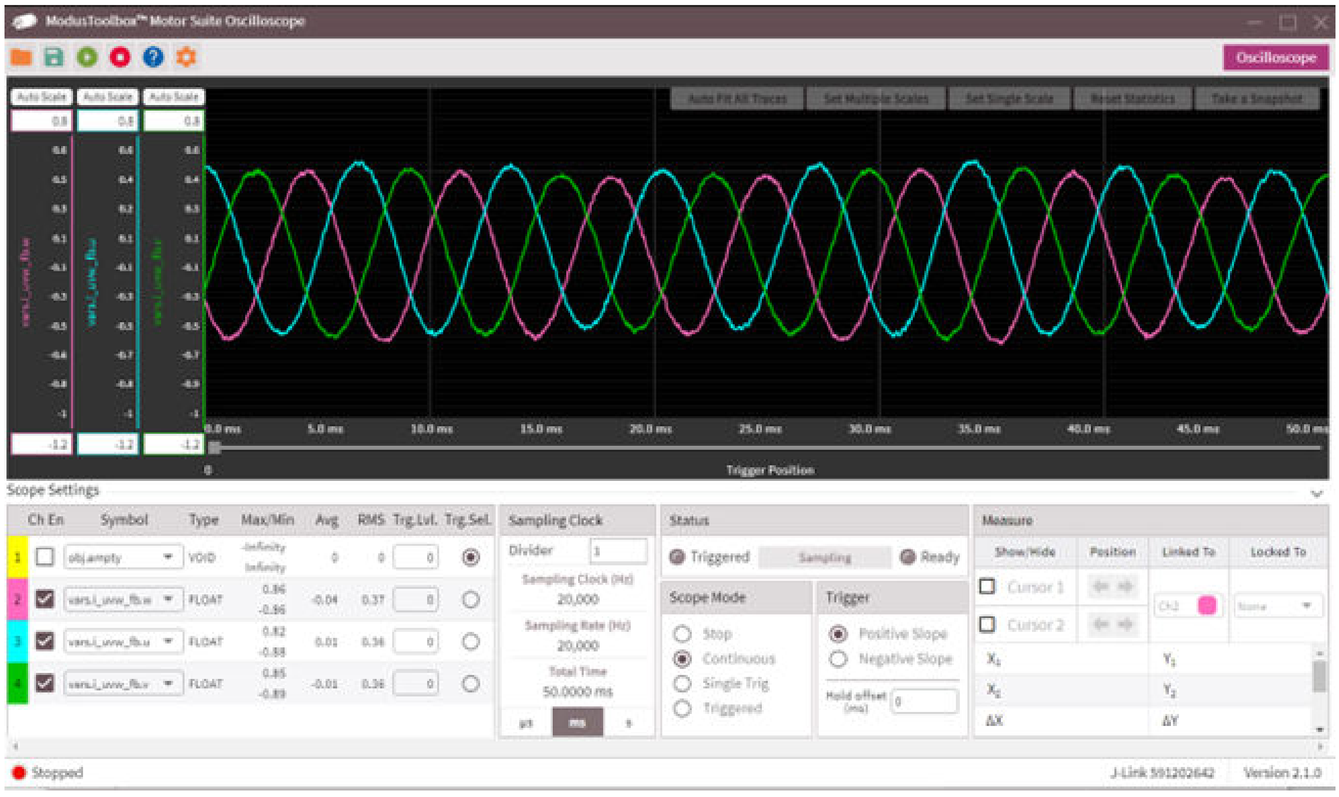
| | | | | | |
|---|---|---|---|---|---|
| Control Scheme | Speed_Mode_FOC_ | Shunt type | Three_Shunt | Direction | Positive |
| State Machine's St... | Speed_CL | Switching Freque... | 15000 Hz | Field Weakening | Inactive |
| Modulation Method | Neutral_Point_Moc | Control Frequency | 15000 Hz | Modulation Index | |

Version 2.3.0 J-Link 591202549 Connected to XMC7200 Motor Control Kit (Advanced Motor Control - RFO)

**Figure 43** **Motor Test Bench**

## 5.5.3 Oscilloscope

ModusToolbox™ Motor Suite support a high-speed oscilloscope to monitor any firmware variable, at a time it monitors up to four variables. In the oscilloscope window, configure the **Divider** value and select **Auto Scale** to get the optimum resolution.



Scope Settings

| Ch | En | Symbol | Type | Max/Min | Avg | RMS | Trg.Lvl. | Trg.Sel. |
|---|---|---|---|---|---|---|---|---|
| 1 | ☐ | obj.empty | VOID | -Infinity / Infinity | 0 | 0 | 0 | ● |
| 2 | ✓ | vars.i_uvw_fb.w | FLOAT | 0.86 / -0.86 | -0.04 | 0.37 | 0 | ○ |
| 3 | ✓ | vars.i_uvw_fb.u | FLOAT | 0.82 / -0.88 | 0.01 | 0.36 | 0 | ○ |
| 4 | ✓ | vars.i_uvw_fb.v | FLOAT | 0.85 / -0.89 | -0.01 | 0.36 | 0 | ○ |

Sampling Clock: Divider 1; Sampling Clock (Hz) 20,000; Sampling Rate (Hz) 20,000; Total Time 50.0000 ms; µs [✓ ms] s

Status: Triggered, Sampling, Ready

Scope Mode: Stop [✓ Continuous] Single Trig Triggered

Trigger: [✓ Positive Slope] Negative Slope; Hold offset (ms) 0

Measure: Show/Hide, Position, Linked To, Locked To; Cursor 1, Cursor 2; CH2; None; $X_1$ $Y_1$ $X_2$ $Y_2$ ΔX ΔY

Stopped    J-Link 591202642    Version 2.1.0

**Figure 44** **Oscilloscope**

In the Figure 44, three motor phase current has been monitor while Channel 1 is unused. Channel 2, channel 3, and channel 4 are used for phase current vars.i_uvw_fb.w, vars.i_uvw_fb.u, and vars.i_uvw_fb.v respectively.

## 5.5.4 Motor profiler

The motor profiler estimates the following electrical and mechanical parameters of the motor.

### Electrical parameters

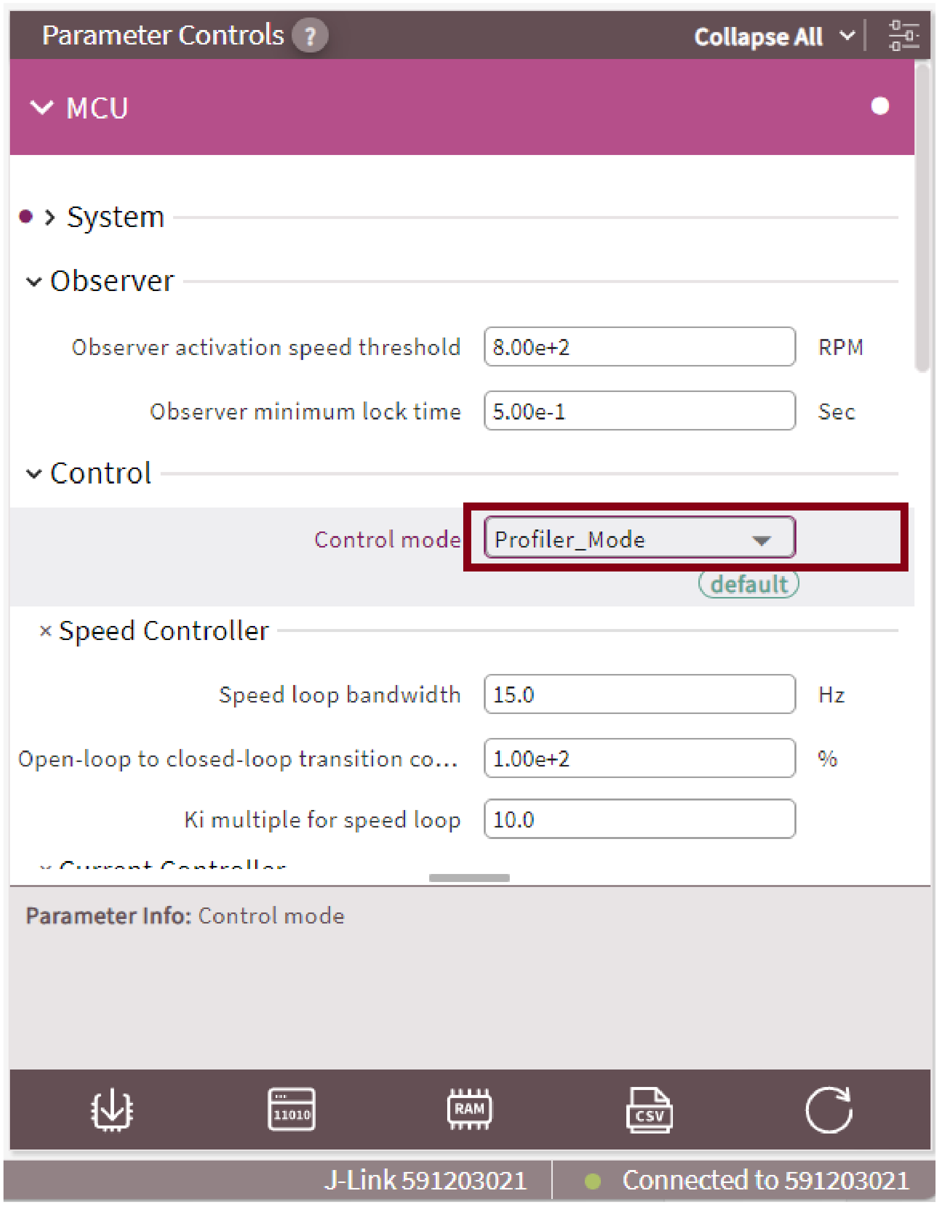
- Stator inductance both d and q axis
- Stator resistance, and
- Rotor flux

### Mechanical parameters

- Inertia (J)
- Viscous friction coefficient (B)
- Coulomb friction (Tf)

Additionally, the motor profiler calculates the open-loop V/Hz constant as well.

To use a motor profiler, configure the control mode as **Profiler_Mode** from the dropdown menu in the configurator view of Motor Suite as shown in Figure 45.



Parameter Controls ?  Collapse All

MCU

System

Observer

Observer activation speed threshold: 8.00e+2 RPM

Observer minimum lock time: 5.00e-1 Sec

Control

Control mode: Profiler_Mode (default)

Speed Controller

Speed loop bandwidth: 15.0 Hz

Open-loop to closed-loop transition co...: 1.00e+2 %

Ki multiple for speed loop: 10.0

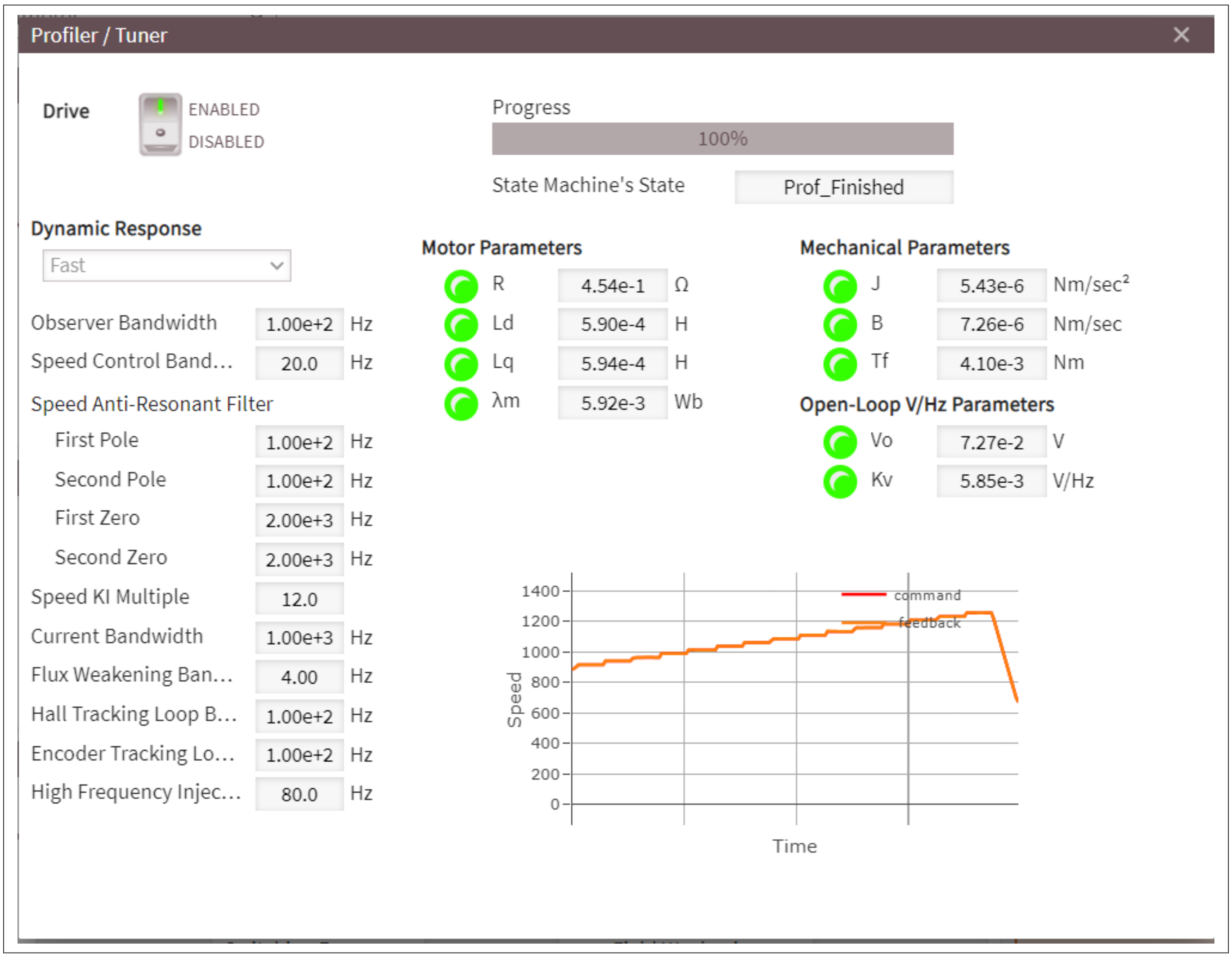
Parameter Info: Control mode

J-Link 591203021 | Connected to 591203021

**Figure 45** **Motor profiler mode configuration**

Select the test bench view of Motor Suite and launch the Profiler/Tuner to run the motor profiler.

Profiler provides the option to select the dynamic response of the speed control loop. There are three options available: Slow, Moderate, and Fast as shown in Figure 46.



Profiler / Tuner

Drive: ENABLED / DISABLED

Progress: 100%

State Machine's State: Prof_Finished

Dynamic Response: Fast

| | | |
|---|---|---|
| Observer Bandwidth | 1.00e+2 | Hz |
| Speed Control Band… | 20.0 | Hz |
| Speed Anti-Resonant Filter | | |
| First Pole | 1.00e+2 | Hz |
| Second Pole | 1.00e+2 | Hz |
| First Zero | 2.00e+3 | Hz |
| Second Zero | 2.00e+3 | Hz |
| Speed KI Multiple | 12.0 | |
| Current Bandwidth | 1.00e+3 | Hz |
| Flux Weakening Ban… | 4.00 | Hz |
| Hall Tracking Loop B… | 1.00e+2 | Hz |
| Encoder Tracking Lo… | 1.00e+2 | Hz |
| High Frequency Injec… | 80.0 | Hz |

Motor Parameters

| | | |
|---|---|---|
| R | 4.54e-1 | Ω |
| Ld | 5.90e-4 | H |
| Lq | 5.94e-4 | H |
| λm | 5.92e-3 | Wb |

Mechanical Parameters

| | | |
|---|---|---|
| J | 5.43e-6 | Nm/sec² |
| B | 7.26e-6 | Nm/sec |
| Tf | 4.10e-3 | Nm |

Open-Loop V/Hz Parameters

| | | |
|---|---|---|
| Vo | 7.27e-2 | V |
| Kv | 5.85e-3 | V/Hz |

**Figure 46** **Motor profiler**

# 6 Summary

This application note shows how to develop the sensorless FOC scheme in a straightforward hardware and software implementation with the PSOC™ Control C3 MCU. It is indeed possible to integrate HPPASS and TCPWM so that the timing and synchronization required by the complexity is accommodated.

The capabilities of the PSOC™ Control C3 MCU are demonstrated by the easy-to-use PMSM sensorless FOC code examples that can be downloaded through the ModusToolbox™. FOC code example is a useful starting point for developing typical applications, you can set up, personalize, and optimize the scheme to its own use cases.

# References

Contact Infineon Support to obtain these documents.

- Application notes
  - AN238329 - Getting started with PSOC™ Control C3 MCU on ModusToolbox™ software
  - AN239969 - How to use ADC features of PSOC™ Control C3 MCU for motor control
- Datasheet
  - 002-36422 - PSOC™ Control C3 MCU - PSC3P2xD, PSC3M3xD
- Reference manuals
  - 002-39348 - PSOC™ Control C3 MCU architecture reference manual
  - 002-39445 - PSOC™ Control C3 MCU registers reference manual
  - 002-39971 - PSOC™ Control C3 motor control evaluation kit user guide
- Hardware design files
  - KIT_PSC3M5_CC2 - PSOC™ Control C3 motor drive card

## Revision history

| Document revision | Date | Description of changes |
|---|---|---|
| ** | 2024-08-02 | Initial release |
| *A | 2024-12-03 | Added the following sections:<br>• Motor control solution personality<br>• Peripheral configuration using solution personality<br>• Motor profiler<br>Updated the following sections:<br>• Parameter configuration<br>• References<br>Updated Figure 1, Figure 2, Figure 3, Figure 5, Figure 14, Figure 24, Figure 25, and Figure 43 |

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**Edition 2024-12-03**

**Published by**

**Infineon Technologies AG**

**81726 Munich, Germany**

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**Document reference**
**IFX-ztr1710129593683**

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