# TMPM4KN

# Motor Sample Software

# Application Note

## Rev. 1.0

Table of Contents

# 1. Overview

## 1.1 Introduction

The operation of this motor control sample software has been checked using the SBK-M4KN (TMPM4KN microcontroller evaluation board) by ESP and the KES-P2 (inverter board). Please contact ESP (http://esp.co.jp/) for details on this evaluation board.

## 1.2 Specifications

- Application Products Brushless DC motor control software (using vector engine "VE")
- Microcontroller TMPM4KNFYAFG
- Clock 80 MHz

- Development Environment
  - IAR Embedded Workbench for ARM 8.50.6
  - Arm® KEIL® MDK 5.31.0.0
  - Evaluation Board: ESP
    SBK-M4KN + KES-P2
  - Motor: Tsukasa Electric - TG611B
  - Operating Voltage 24V

- Outlines
  - Brushless DC Motor Vector Control
  - Speed Control
  - Evaluation Purpose
    - DAC Output (variable analogue output)
    - Inverter Board Temperature Detection
    - UART Output (initial status checking using Tera Term, etc.)
    - LED Output (Monitor LED)

- Motor Control

| Item | Control |
|---|---|
| Rotation Speed Control Method | Constant Rotation Speed Control (use of a variable resistor) |
| Rotation Direction | CW/CCW (use of a switch) |
| Modulation | Three-phase modulation or two-phase modulation |
| Current Detection | 3-shunt or 1-shunt |
| Position Detection | Sensor-less |
| Op Amplifier | Built-In Microcontroller or External |

Precautions

When an EMG occurs, use "Reset" for releasing.

When operating with 1-shunt, check the setups as follows:

- D_Para_CHx.h

```
#define cSHUNT_TYPE_CHx (1)
#define cBOOT_TYPE_CHx (cBoot_v)
```

- B_User.c

```
Motor_chx.usr.com_user.spwm = 1;
```

* Choose a suitable number from "0–2" for "x" according to the channel of the motor used.

### 1.3 Process Overview

The vector control software consists of three layers: the application that takes care of the user interface processing, the motor controller that controls the motor operation status with the state transition and the motor driver that takes care of the motor drive processing by directly accessing the motor driver circuit.

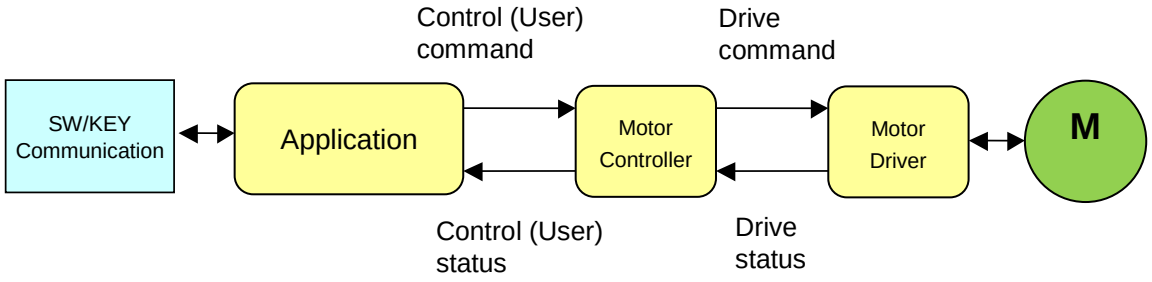



Fig. 1.1 Vector Control Software Configuration

i. The application will input the control commands that are set up through the switches, keys, communication, etc. and give it to the motor controller together with other control commands. Furthermore, it acquires the control status from the motor controller and as well as conducting the necessary processing, it outputs to the ports, etc.

ii. The motor controller reads the control commands that are given from the application, converts it into the more specific drive commands according to the motor operating status, and gives it to the motor driver. Furthermore, it acquires the driver status from the motor driver and as well as conducting the necessary processing, transfers it to the application.

iii. The motor driver reads the drive commands that are given from the motor controller and drives the motor. Furthermore, it monitors the motor operation and, as well as conducting the necessary processing according to the status, transfers the driver status to the motor controller.

For example, when a new control target speed is given from the application during the rotation of motor, it will be temporarily converted to the gradually varying driving target speed in the motor controller and be given to the motor driver because the motor driver cannot respond to an abrupt change in the target speed.

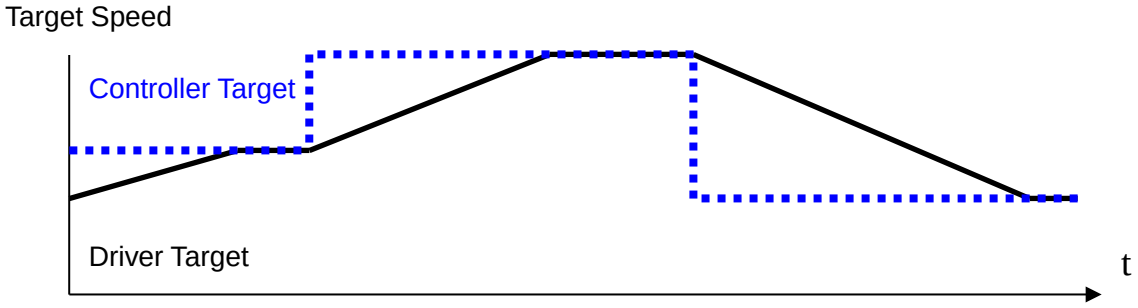



Fig. 1.2 Controller Target Speed and Driver Target Speed

## 2. System Block Diagram

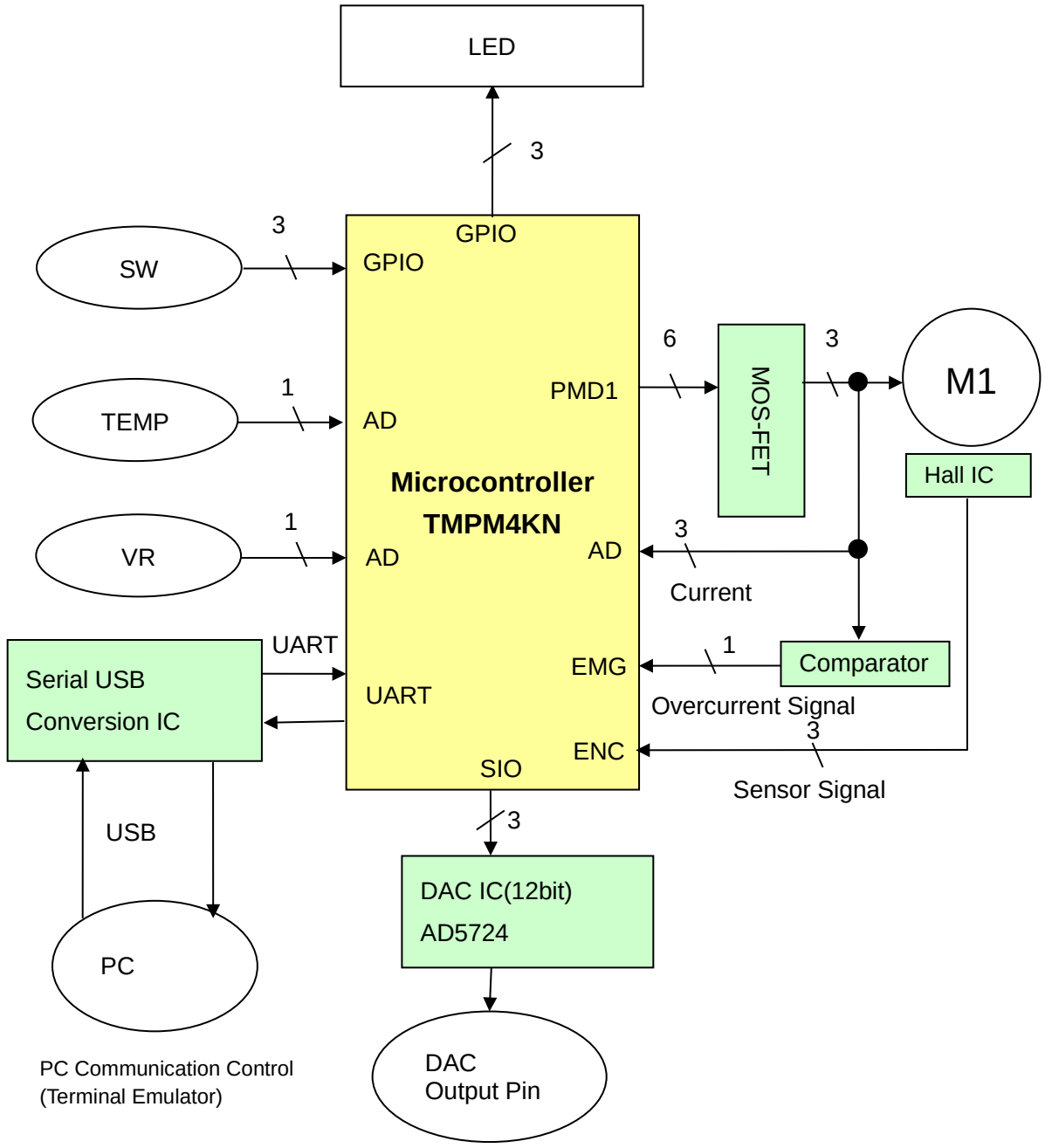



Fig. 2.1 System Block Diagram

## 3. Source File Configuration

```
source
├ B_User.c            Vector Control User Setup Source File
├ B_User.h            Vector Control User Setup Header File
├ C_Control.c         Vector Control Control Source File
├ C_Control.h         Vector Control Control Header File
├ D_Driver.c          Vector Control Driver Source File
├ D_Driver.h          Vector Control Driver Header File
├ E_Sub.c             Computing Function Source File
├ E_Sub.h             Computing Function Header File
├ H_Hall.c            Hall Sensor Function Source File
├ H_Hall.h            Hall Sensor Function Header File
├ initial.c           Microcontroller Initial Setup Source File
├ initial.h           Microcontroller Initial Setup Header File
├ ipdefine.h          Microcontroller Setup Header File
├ ipdrv.c             Microcontroller Hardware Reference Source File
├ ipdrv.h             Microcontroller Hardware Reference Header File
├ main.c              Main Routine
├ sys_macro.h         Macro Definition Header File
├ system_int.c        Interruption Function Source File
├ system_int.h        Interruption Function Header File
├ usercon.c           User Control Source File
├ usercon.h           User Control Header File
├ v7z_board.c         V7Z Board Operation Source File
├ v7z_board.h         V7Z Board Operation Header File
│
└─driver              Device Driver files are stored.
  ├ D_Para.h          Vector Control Parameter (common to channels) Header File
  ├ D_Para_ch0.h      Vector Control Parameter (Channel 0) Header File
  ├ D_Para_ch1.h      Vector Control Parameter (Channel 1) Header File
  ├ D_Para_ch2.h      Vector Control Parameter (Channel 2) Header File
  ├ dac_drv.c         DAC IC Driver Source File
  ├ dac_drv.h         DAC IC Driver Header File
  ├ interrupt.c       Interruption Control Source File
  ├ interrupt.h       Interruption Control Header File
  ├ mcuip_drv.c       Microcontroller Hardware Setup Driver Source File
  ├ mcuip_drv.h       Microcontroller Hardware Setup Driver Header File
  │
  └─Libraries                                  The library for CMSIS Core and individual IPs are stored.
    └─CMSIS                                    CMSIS Core is stored.
      ├ │ system_TMPM4KyA.c                    Microcontroller Initial Setup Source File
      ├ │ system_TMPM4KyA.h                    Microcontroller Initial Setup Header File
      ├ │ TMPM4KNA.h                          Microcontroller Register Definition Header File
      ├ │ TMPM4KyA.h                          TMPM4KyA Group Definition Header File
      ├ └─startup
      ├ ├─arm                                  Start Up Assembler Source (arm)
      ├ │ startup_TMPM4KHA.s
      ├ │ startup_TMPM4KLA.s
      ├ │ startup_TMPM4KMA.s
      ├ │ startup_TMPM4KNA.s
      ├ └─iar                                  Start Up Assembler Source (IAR)
      ├ startup_TMPM4KHA.s
      ├ startup_TMPM4KLA.s
      ├ startup_TMPM4KMA.s
      ├ startup_TMPM4KNA.s
      │
      └─IP_Driver                              Peripheral Driver is stored.
        ipdrv_adc.c
        ipdrv_adc.h
        ipdrv_cg.c
        ipdrv_cg.h
        ipdrv_common.h
        ipdrv_enc.c
        ipdrv_enc.h
        ipdrv_siwdt.c
        ipdrv_siwdt.h
```

ipdrv_t32a.c
ipdrv_t32a.h
ipdrv_tspi.c
ipdrv_tspi.h

### 3.1 DAC Output

Equipped with the DAC output function for viewing the fluctuation of variables with the Oscilloscope.

For enabling the DAC output, enable the following definitions for D_Para.h

#define __USE_DAC

The variables for executing the DAC output are listed in the function UiOutDataStart() in the file usercon.c.

Add a variable as necessary if any variable for checking is missing.

<<DAC Output Setup Variables>>

| | |
|---|---|
| dac.select | Selecting a DAC Output |
| dac.motch | Set up a Motor CH for DAC Output |
| dac.datsft0 - 3 | Set up the amount of left shifting (x) for the bit data.<br>Formula (x): data x (2^x) |

### 3.2 User Interface

The following functions are provided as the user interface:

<<User Interface>>

1. Rotation Direction
   Rotation direction of motor is changed over by switching the SW (S_SW1).
   High: CW, Low: CCW

2. Phase Modulation
   Rotation direction of motor is changed over by switching the SW (S_SW2).
   High: two-phase modulation, Low: three-phase modulation

3. Rotation Speed Control
   Rotation speed of motor is designated by operating VR1.
   Speed Range: 12 rps to 200 rps (electrical angle)

4. DAC Mode Changeover
   The DAC modes are changed over according to the table below by pressing the SW (USW1).

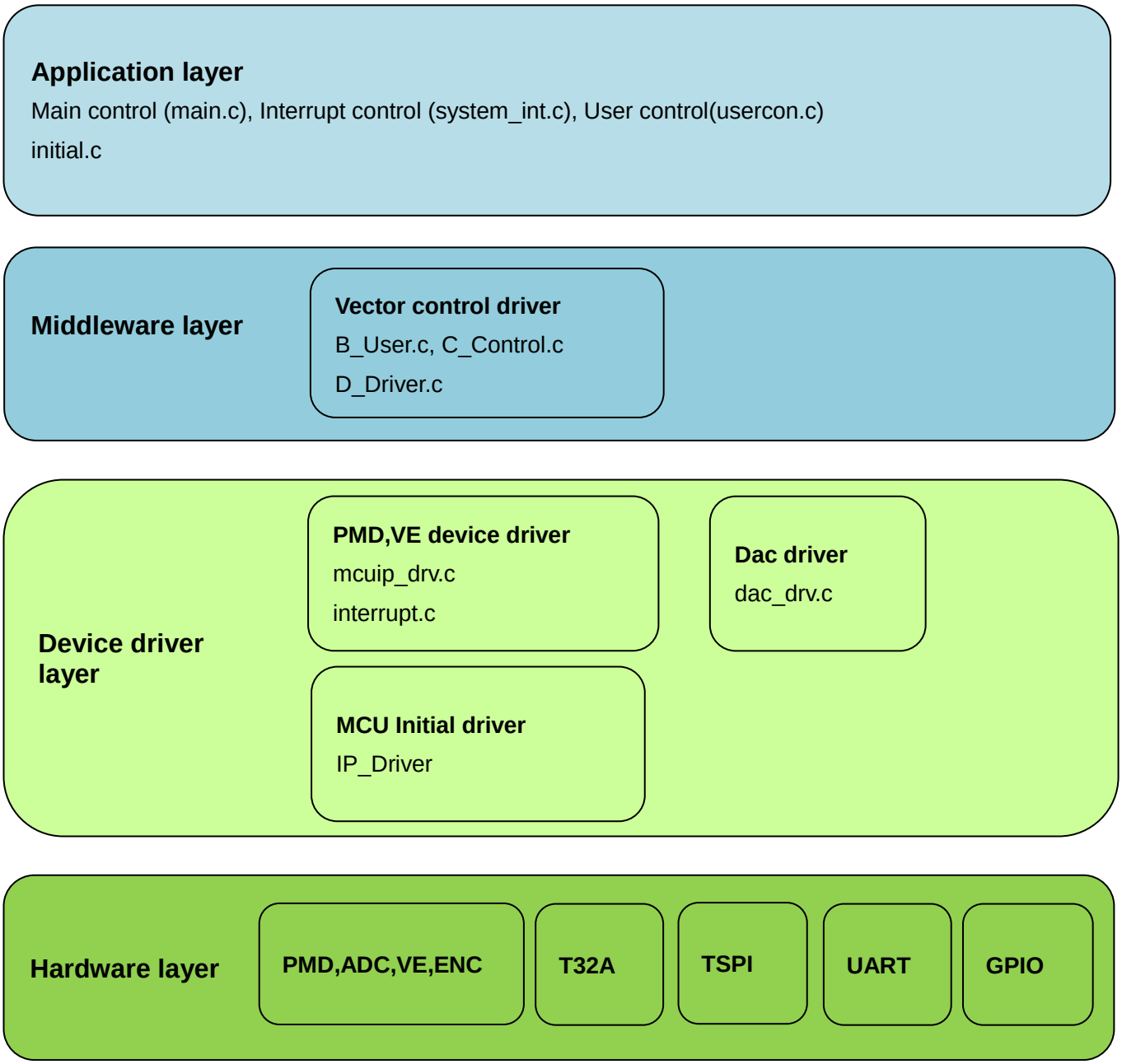
| No. | Current mode | After Pressing a SW |
|---|---|---|
| 1 | Mode 0 | Mode 1 |
| 2 | Mode 1 | Mode 2 |
| 3 | Mode 2 | Mode 3 |
| 4 | Mode 3 | Mode 0 |

5. LED Display
   The motor status is checked by the LED4 to LED6.
   1. Rotation Status LED (LED4)
      Rotation Stop: Lights OFF
      Rotation (forced commutation): Lights ON
      Rotation (steady): Lights OFF
   2. VE Interruption Indicator LED (LED5)
      VE Interruption Processing: Lights ON
      Other: Lights OFF
   3. EMG Status LED (LED6)
      EMG No Detection: Lights OFF
      EMG Detection: Lights ON

6. Initial Status Display
   Initial status can be checked after releasing the reset.

See 14. Status Check Monitor for details.

## 4. Module Configuration



## 5. Microcontroller Hardware Assignment

### 5.1 IP

| IP | | Control | Remarks |
|---|---|---|---|
| TMRB | channel 0 | 4 kHz Interruption | |
| | channel 1 | Not Used | |
| | channel 2 | Not Used | |
| | channel 3 | Not Used | |
| | channel 4 | Not Used | |
| | channel 5 | Not Used | |
| TSPI | channel 0 | Not Used | |
| | channel 1 | DAC IC Control | SIO Mode |
| UART | channel 0 | PC Connection | UART0 |
| | channel 1 | Not Used | |
| | channel 2 | Not Used | |
| | channel 3 | Not Used | |
| ADC | Unit A | Get Motor Current and Temperature | |
| | Unit B | Not Used | |
| | Unit C | Rotation Speed Control VR | |
| PMD | channel 0 | Motor CH0 Control | |
| | channel 1 | Motor CH1 Control | |
| | channel 2 | Motor CH2 Control | |
| VE | channel 0 | Motor CH0 Control | |
| EMC | channel 0 | Motor CH0 Encoder Signal Control | |
| | channel 1 | Motor CH1 Encoder Signal Control | |
| | channel 2 | Motor CH2 Encoder Signal Control | |

### 5.2 Interruption

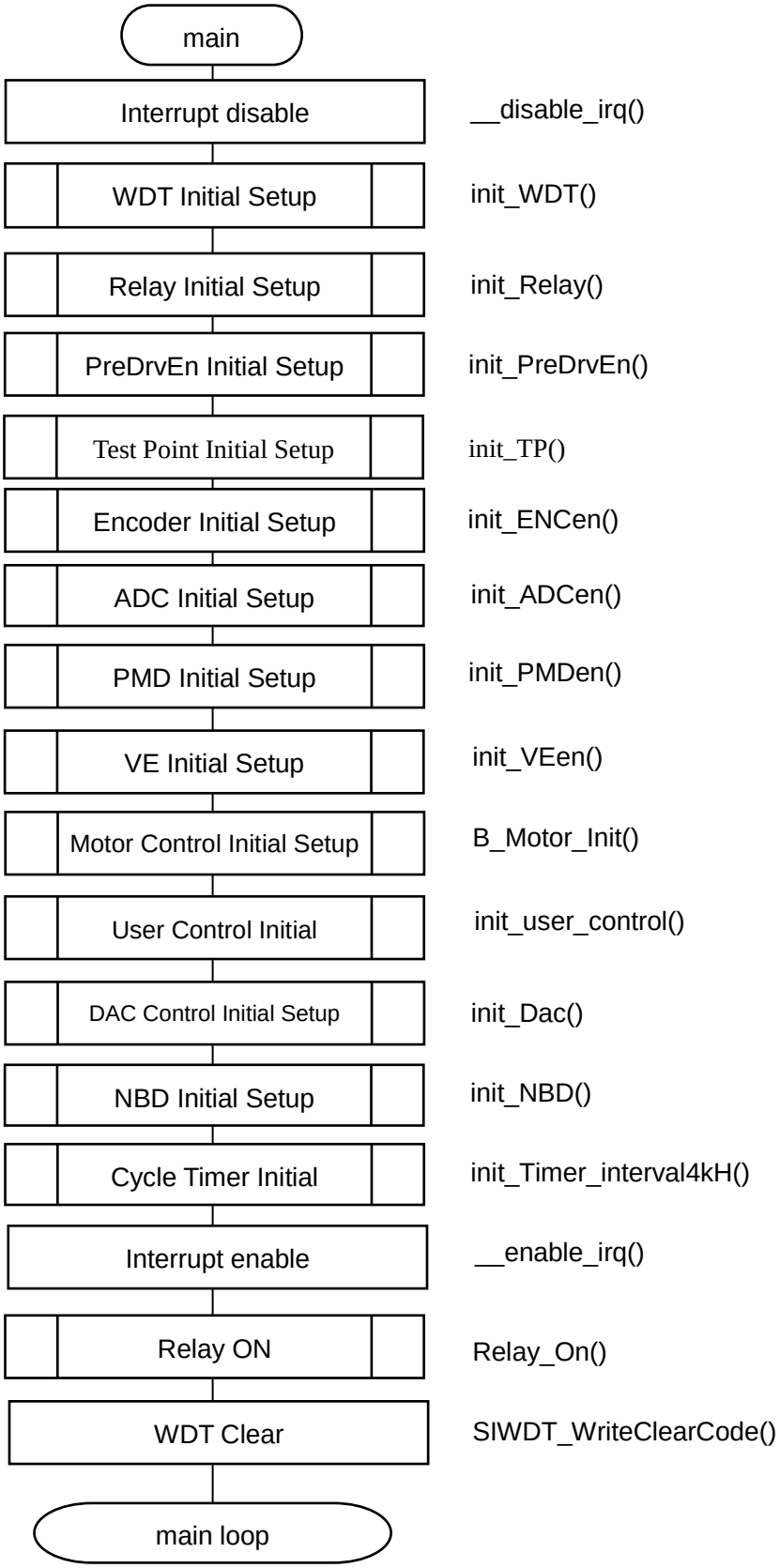
| Cause | Process | Function |
|---|---|---|
| INTTB00IRQn | 4 kHz Interval Timing Generation | INTTB00_IRQHandler |
| INTVCN0_IRQn | Vector Control Software Processing for CH0 | INTVCN0_IRQHandler |
| INTADAPDA_IRQn | Vector Control Suspension for CH0 | INTADAPDA_IRQHandler |
| INTSC0TX_IRQn | UART Transmission Complete Interruption Processing | INTSC0TX_IRQHandler |
| INTSC1TX_IRQn | DAC IC Control | INTSC1TX_IRQHandler |

The priority of interruption may be changed using the following constants for ipdefine.h.

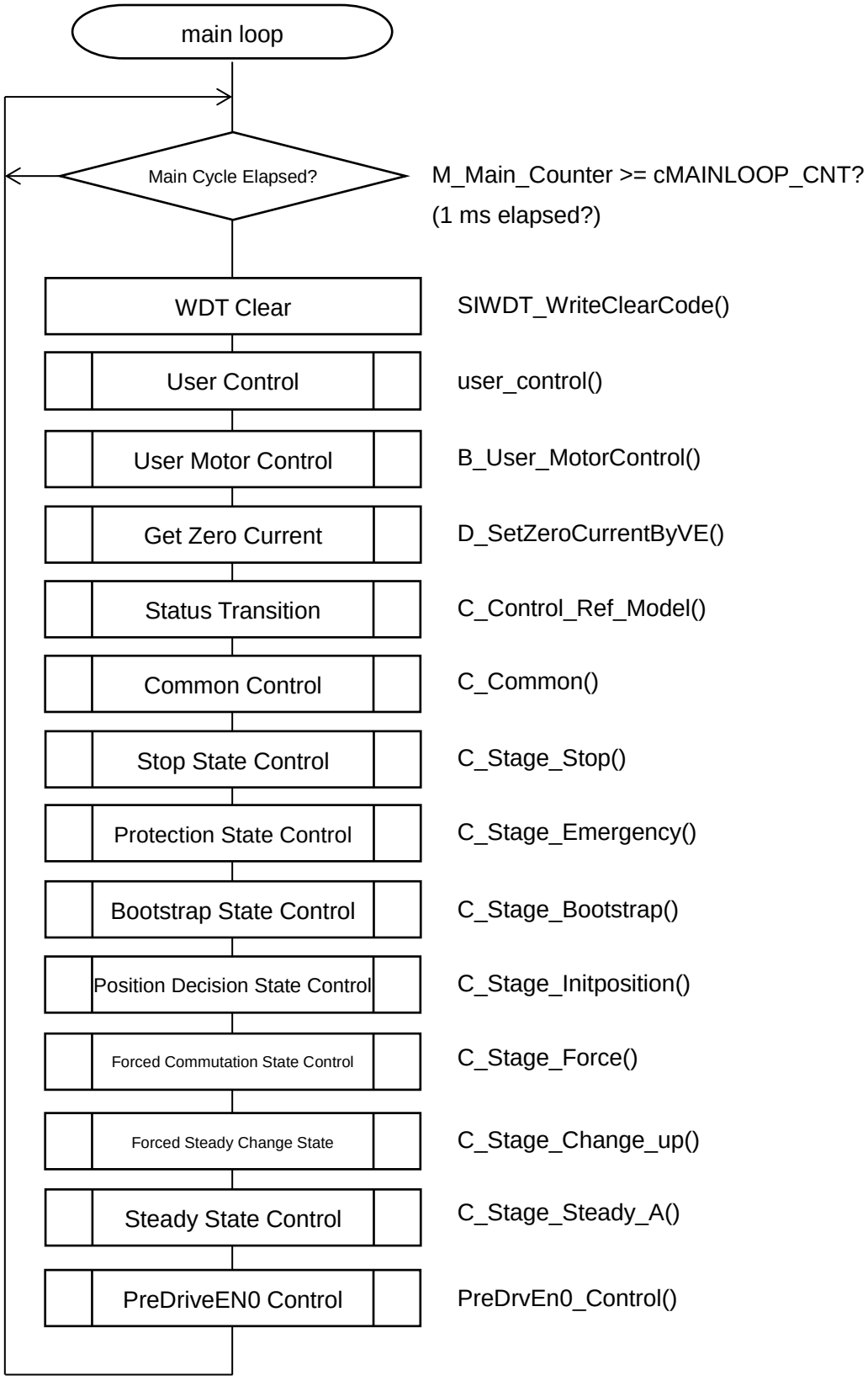
```
/* High Low */
/*  0 ---- 7  */

#define  INT4KH_LEVEL        5      /* 4kH interval timer interrupt */
#define  INT_VC_LEVEL        3      /* VE interrupt */
#define  INT_ADC_LEVEL       3      /* ADC interrupt */
#define  INT_DAC_LEVEL       6      /* SIO interrupt for Dac */
```

## 6. General Flow

### 6.1 Main Routine (main)

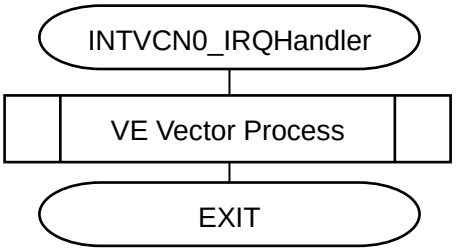


### 6.2 Main Loop (main_loop)



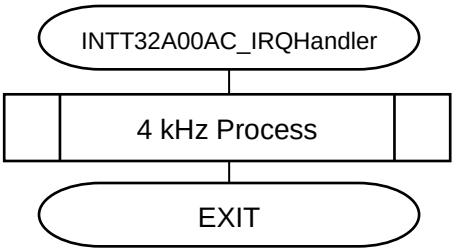
### 6.3 Interruption

VE Schedule Complete



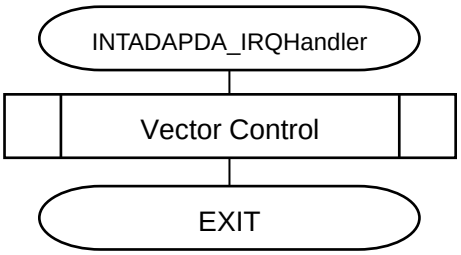

INT_VectorContorlByVE_CH0 ()

Every 4 kHz cycle



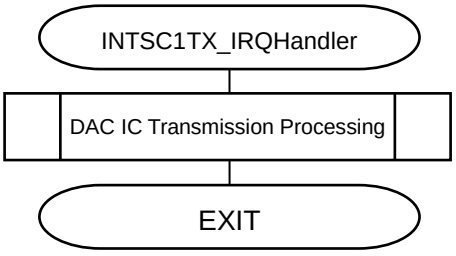

INT_interval_4kHz ()

AD Interruption



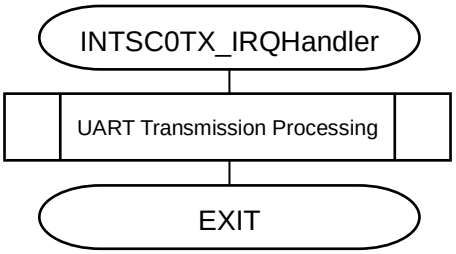

INT_VectorControlBySoft_CH0 ()

DAC Communication 8-bit Transmission Complete



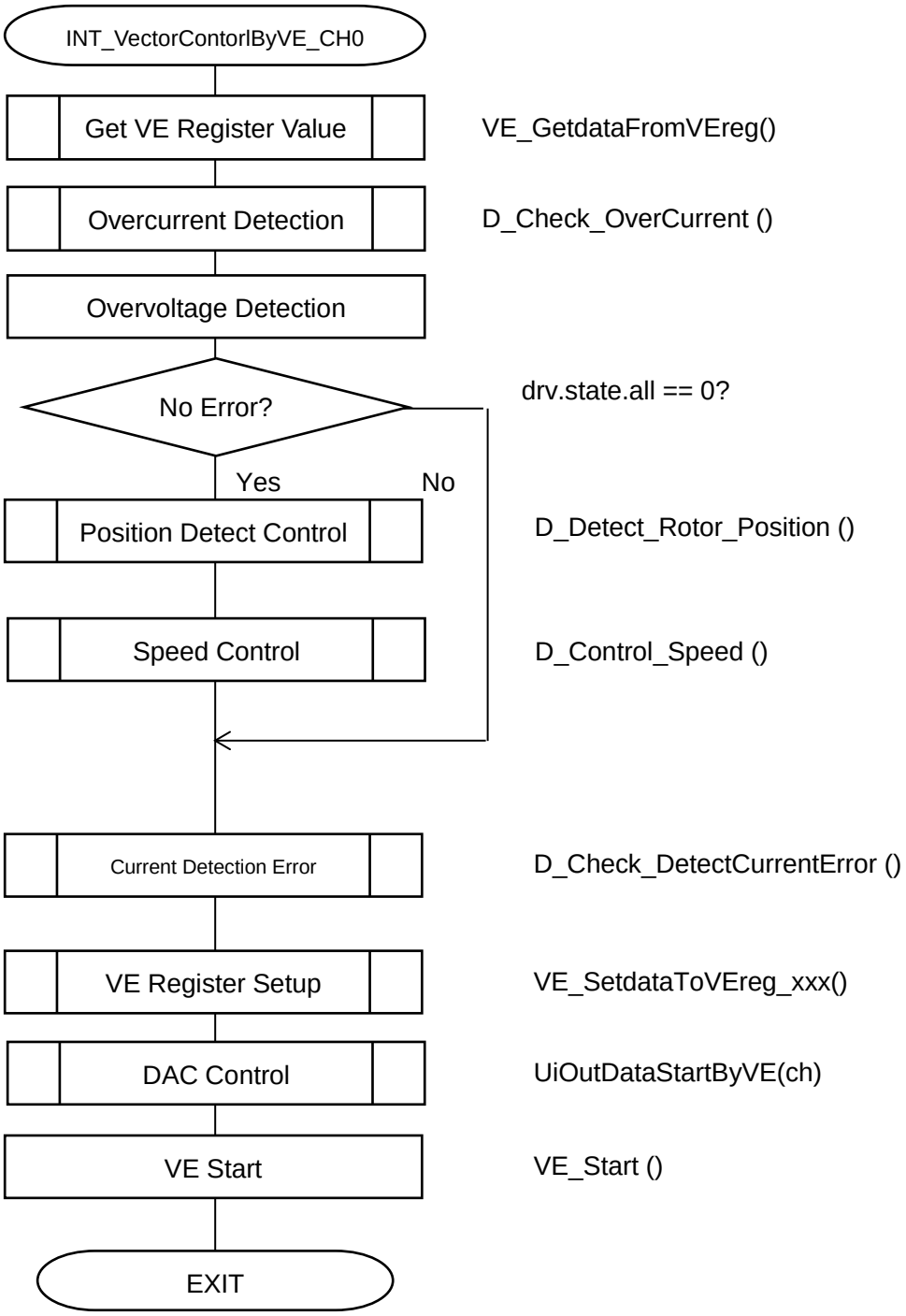

DacWriteContinue ()

UART 8-bit Transmission Complete

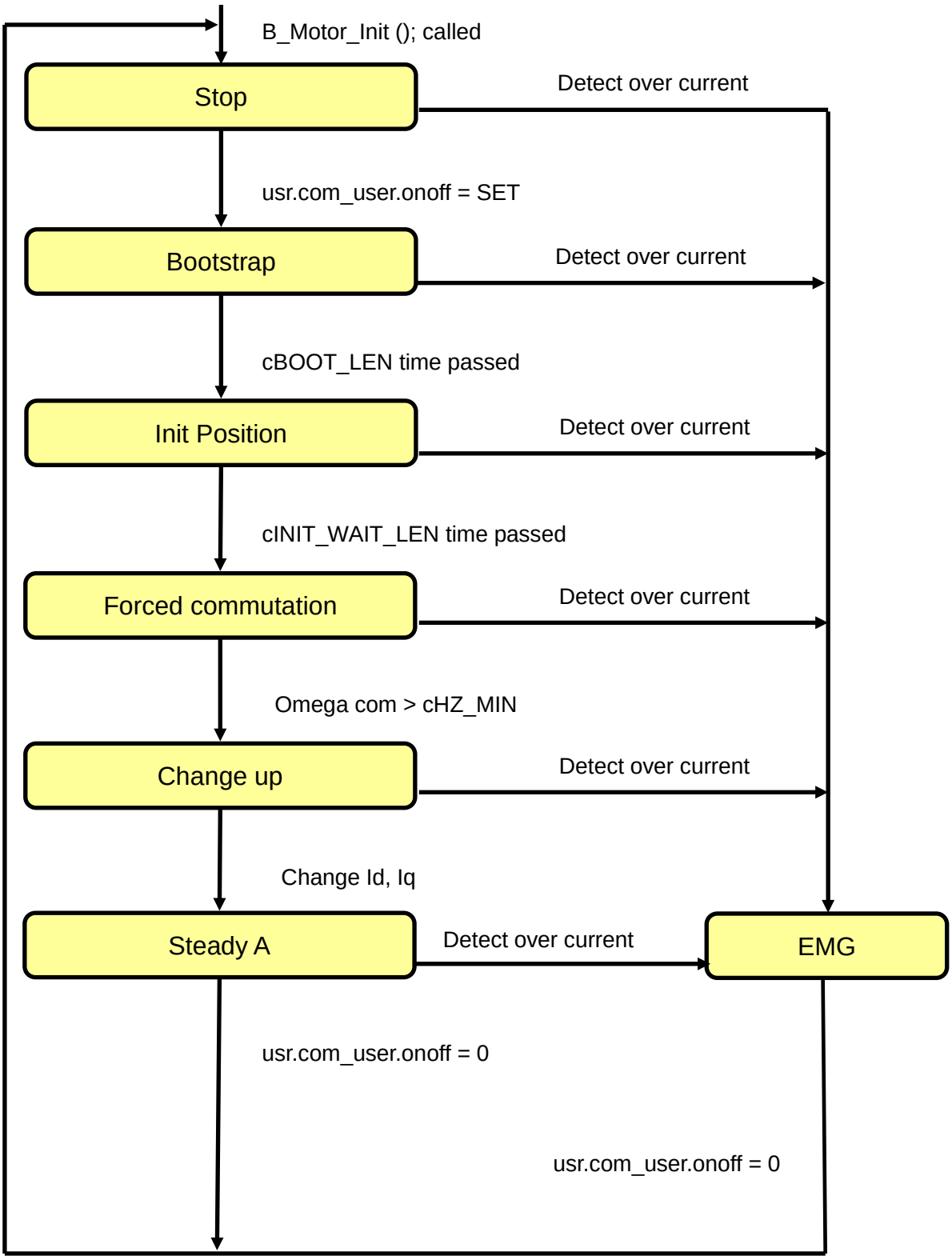



INT_uart0tx ()

### 6.3.1 VE Vector Processing (INT_VectorControl_byVE)



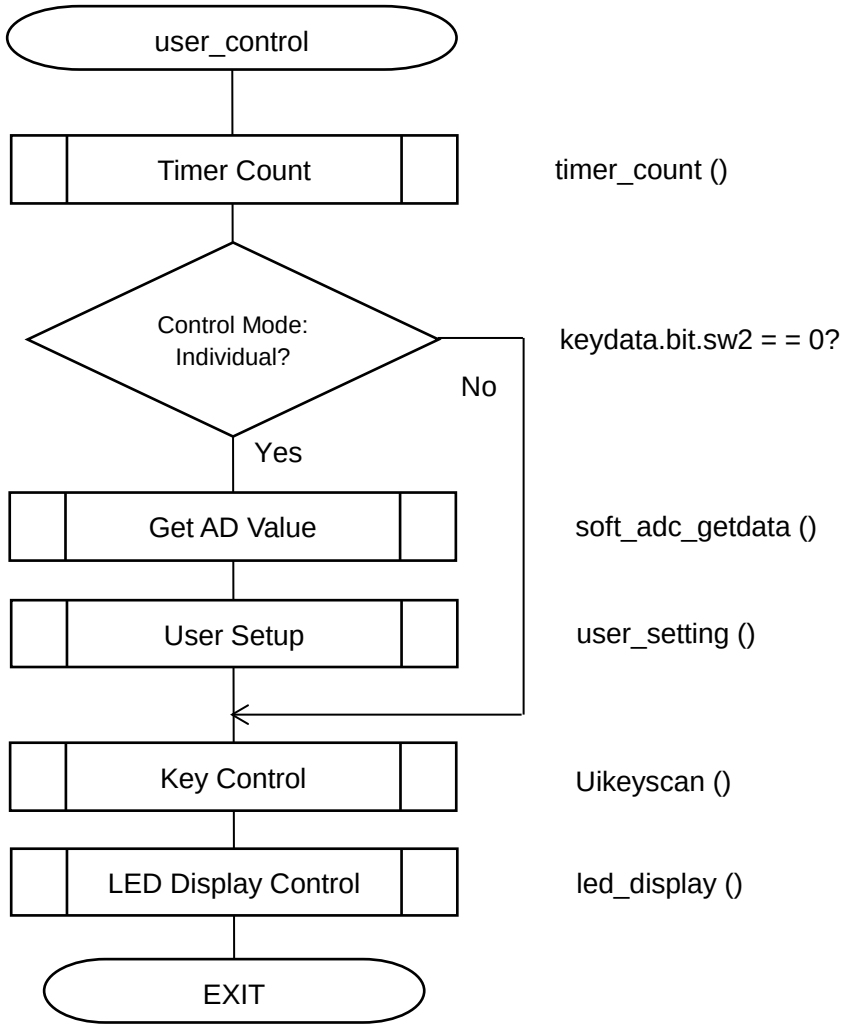
## 7. Motor Operation Status Transition (stage)



# 8. User Application

## 8.1 User Control

Each of user application is processed once every lapse of main cycle (1 ms).



### 8.1.1 Get AD Value (soft_adc_getdata)

Get AD values of VR1 and Inverter Temperature (12 bit) with the individual conversion setup.
After getting 10 times, the average of 8 times of data excluding the max and min. for VR1 and the inverter temperature will be stored in ad_vr.avedat and ad_inv.avedat, respectively, as the effective values for each.

### 8.1.2 Key Control (Uikeyscan)

Process the key scan for S_SW1, S_SW2 and USW1
Each of the key data will be finalized when an identical value is continuously acquired 20 times and the S_SW1 and S_SW2 will be stored in the keydata and the USW1 in swdata.

### 8.1.3 User Setup (user_interface)

Set up the following according to the VR1 input by the user operation.

1. Motor Speed Control
   Set the ad_vr.avedat to the 8-bit resolution and the following are determined according to the value:
   Less than 0 x 10: 0 (0 Hz)
   0 x F0 and over: 200 (max speed)
   0 x 10 to 0 x EF: Taken as an effective value and the speed is computed.
2. Motor Rotation Direction Changeover
   The setup of rotation direction rote_dir according to the value of keydata.sw1.
   When keydata.sw1 = 1, rote_dir: 1 (forward)
   When keydata.sw1 = 0, rote_dir: 0 (reverse)
3. Modulation Type Changeover
   According to the value of keydata.sw2, the setup of modulation type Motor_chx.usr.co_user.modul is changed over (x = 0, 1).
   When keydata.sw2 = 1, Motor_chx.usr.com_user.modul: 1 (two-phase modulation)
   When keydata.sw2 = 0, Motor_chx.usr.com_user.modul: 0 (three-phase modulation)
4. DAC Mode
   Every time swdata.sw becomes "1," the setup of dac.select is changed over.

### 8.1.4 LED Display Control (led_display)

The lighting of LED4 is controlled according to the rotation status.
See 3.2 User Interface for details.

### 8.1.5 UART Transmitting Data Setup (send_data_set)

Set up the motor initial setups and the current rotation speed monitoring data.
The setups for communication are, 115,200 bps, data 8-bit, stop bit 1 bit, without parity and without flow control.

## 9. Functions

The following are the interface between the application and the motor controller, and the motor controller and the motor driver.

### 9.1 Control Commands

The control commands are listed as below:

#### 9.1.1 Control Method (usr.com_user)

- Motor start and stop
- Encoder equipped or not
- Modulation Type (two-phase modulation, three-phase modulation)
- Shift PWM ON/OFF (Enabled only when VE is used and 1-shunt two-phase modulation)

```
typedef struct {
  uint16_t reserve:   12;     /* reserve */
  uint16_t spwm:      1;      /* Shift PWM 0=off 1=on */
  uint16_t modul:     1;      /* PWM Modulation 0=3phase modulation 1=2phase modulation */
  uint16_t encoder:   1;      /* Position detect     0=Current 1=Encoder */
  uint16_t onoff:     1;      /* PWM output 0=off 1=on */
} command_t;
```

```
command_t       com_user;
```

usr.com_user is set up as a control command in the application.

#### 9.1.2 Control Target Speed (usr.omega_user)

```
q31_u     omega_user;     /* [Hz/maxHz] OMEGA command, Q31 */
```

usr.omega_user is set up as a control target speed in the application.

#### 9.1.3 Starting Current (usr.Id_st_user, usr.Iq_st_user)

```
q15_t     Id_st_user;           /* [A/maxA] d-Axis start current reference, Q15 */
q15_t     Iq_st_user;           /* [A/maxA] q-Axis start current reference, Q15 */
```

usr.Id_st_user and usr.Iq_st_user are set up as the start current references in the application.

### 9.2 Drive Command

Drive Commands are listed as below:

#### 9.2.1 Driving Method (drv.command)

```
command_t command;
```

The motor control will transfer the driving method to the motor control driver side via the drv.command.

#### 9.2.2 Vector Control Command (drv.vector_cmd)

A command for executing vector control computation and it administers the stage by stage processing.

```
typedef struct
{
  uint16_t reserve: 9;                /* reserve */
  uint16_t F_vcomm_theta: 1; /* Omega to Theta 0=command value 1=Calculate the theta from omega.*/
  uint16_t F_vcomm_omega: 1; /* Omega by 0=command value 1=Result of Estimation position */
  uint16_t F_vcomm_current: 1; /* Current by 0=command value 1=Result of Speed Control */
  uint16_t F_vcomm_volt: 1; /* Voltage by 0=command value 1=Result of Current Control */
  uint16_t F_vcomm_Edetect: 1; /* Position detect 0=off 1=on */
  uint16_t F_vcomm_Idetect: 1; /* Current detect 0=off 1=on */
  uint16_t F_vcomm_onoff: 1; /* Motor output 0=off 1=on */
} vectorcmd_t;
```

The vector control drive command (drv.vector_cmd) is set up as below in each stage and a command is given to the motor drive.
In the vector control using VE, F_vcomm_volt or F_vcomm_Idetect are not used.

| cmd / Stage | theta | omega | current | Volt | Edetect | Idetect | onoff |
|---|---|---|---|---|---|---|---|
| Stop | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR |
| Bootstrap | - | - | - | - | - | - | - |
| InitPosition | CLEAR | CLEAR | CLEAR | SET | CLEAR | SET | SET |
| Forced | SET | CLEAR | CLEAR | SET | SET | SET | SET |
| Change_up | SET | SET | CLEAR | SET | SET | SET | SET |
| Steady | SET | SET | SET | SET | SET | SET | SET |
| Emergency | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR | CLEAR |

1) F_vcomm_theta

For the rotor position estimation computation, the estimated value is adopted as the rotor position when SET. The reference value is adopted as the rotor position when CLEAR.

2) F_vcomm_omega

For the rotor position estimation computation, the estimated value is adopted as the speed ω when SET. The reference value is adopted as the speed ω when CLEAR.

3) F_vcomm_current

For the speed control, gives a command for the calculation method for the standard values of d- and q-axis currents.

The value acquired using the speed deviation through the PI control is adopted as a standard value when SET. The PI control is not executed when CLEAR but the reference value is directly adopted as a standard value.

4) F_vcomm_volt

For the current control, the calculation methods for the d- and q-axis voltage standard values are given as a command.

The value acquired using the speed deviation through the PI control is adopted as a standard value when SET.

The PI control is not executed when CLEAR but the reference value is directly adopted as a standard value.

5) F_vcomm_Edetect

The induced voltage computation is executed when SET, and the rotor position estimation computation is executed.

The induced voltage computation is not executed when CLEAR, but the induced voltage is set to 0 and the reference value is adopted as the rotor position.

6) F_vcomm_Idetect

The Input coordinate axis conversion computation is executed when SET.

The computation is not executed when CLEAR, but the value is cleared.

### 9.3 Driver Status

#### 9.3.1 Error Status (drv.state)

```
typedef union {
  struct {
        uint16_t reserve:12;  /* reserve */
        uint16_t Loss_sync: 1;      /* 0:normal, 1: Loss of synchronism      */
        uint16_t emg_DC:1;          /* 0:normal, 1: Over Vdc                 */
        uint16_t emg_I:1;           /* 0:normal, 1: Current detect error     */
        uint16_t emg_S:1;           /* 0:normal, 1: Over current(soft)             */
        uint16_t emg_H:1;           /* 0:normal, 1: Over current(hard)             */
  } flg;
  uint16_tall;
} state_t;
```

| | | | |
|---|---|---|---|
| 1) | Loss_sync | Step-Out Detection | SET when a step-out is detected (not implemented). |
| 2) | emg_DC | Abnormal Voltage Detection | SET when an abnormal voltage is detected. |
| 3) | emg_I | Current Detection Abnormality | SET when a current detection abnormality is detected. |
| 4) | emg_S | Software Overcurrent Detection | SET when an overcurrent is detected during the software processing. |
| 5) | emg_H | Hardware Overcurrent Detection | SET when an overcurrent is detected in the microcontroller hardware function. |

### 9.4 Motor Control Structure

Motor Control Structure (vector_t) is defined in the ipdefine.h.

The variables are declared per motor channel as below:

e.g.)

```
vector_t    Motor_ch0;    /* Motor data for ch0 */
vector_t    Motor_ch1;    /* Motor data for ch1 */
vector_t    Motor_ch2;    /* Motor data for ch2 */
```

### 9.4.1 List of Variables

| Type | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| main_stage_e | stage.main | Main Stage | --- | cStop<br>cBootstrap<br>cInitposition<br>cForce<br>cChange_up<br>cSteady_A<br>cEmergency |
| sub_stage_e | stage.sub | Sub Stage | --- | cStep0<br>cStep1<br>cStep2<br>cStep3<br>cStepEnd |
| itr_stage_e | stage.itr | Interruption Stage | --- | ciStop<br>ciBootstrap<br>ciInitposition_i<br>ciInitposition_v<br>ciForce_i<br>ciForce_v<br>ciChange_up<br>ciSteady_A<br>ciEmergency |
| q31_u | drv.omega_com | Driving Speed Reference Value | Q31 | |
| q31_u | drv.omega | Estimated Speed | Q31 | |
| q15_t | drv.omega_dev | Speed Deviation | Q15 | |
| q31_u | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| q31_u | drv.Iq_com | q-Axis Current Reference Value | Q31 | |
| q15_t | drv.Id_ref | d-Axis Current Standard Value | Q15 | |
| q15_t | drv.Iq_ref | q-Axis Current Standard Value | Q15 | |
| q15_t | drv.Id | d-Axis Current | Q15 | |
| q15_t | drv.Iq | q-Axis Current | Q15 | |
| q31_u | drv.Iq_ref_I | q-Axis Current Integrated Value | Q31 | |
| uint16_t | drv.theta_com | Electrical Angle Reference Value | Q0 | |
| uint32_u | drv.theta | Rotor Position | Q0 | |
| q15_t | drv.Vdc | Power supply voltage | Q15 | |
| q31_u | drv.Vdc_ave | (Not Used) | --- | |
| q31_u | drv.Vd | d-Axis Voltage | Q31 | |
| q31_u | drv.Vq | q-Axis Voltage | Q31 | |
| q15_t | drv.Vdq | (Not Used) | --- | |
| q31_u | drv.Vdq_ave | (Not Used) | --- | |
| q31_t | drv.Vd_out | Output Voltage | Q31 | |
| q15_t | drv.Ed | d-Axis Induced Voltage | Q15 | |
| q15_t | drv.Eq | (Not Used) | --- | |

| Type | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| q31_t | drv.Ed_I | d-Axis Induced Voltage Integrated Value | Q31 | |
| q31_t | drv.Ed_PI | d-Axis Induced Voltage PI Value | Q31 | |
| state_t | drv.state | Motor Abnormality Status | --- | |
| command_t | drv.command | Driving Method | --- | (See 9.2.1) |
| vectorcmd_t | drv.vector_cmd | Vector Control Command | --- | (See 9.2.2) |
| q15_t | drv.spwm_threshold | Shift Switch Speed | Q15 | 1-shunt only |
| uint16_t | drv.chkpls | Current Detection Protection Duty Width | Q0 | |
| uint8_t | drv.idetect_error | Current Detection Status | --- | 0: Detection Enabled<br>1: Detection Disabled |
| q15_t | drv.Ia_raw | Phase-a Current (raw data) | Q15 | |
| q15_t | drv.Ib_raw | Phase-b Current (raw data) | Q15 | |
| q15_t | drv.Ic_raw | Phase-c Current (raw data) | Q15 | |
| q15_t | drv.Ia | Phase-a Current (detection error protection) | Q15 | |
| q15_t | drv.Ib | Phase-b Current (detection error protection) | Q15 | |
| q15_t | drv.Ic | Phase-c Current (detection error protection) | Q15 | |
| q31_u | drv.Iao_ave | Phase-a Zero Current Average AD | Q0 | |
| q31_u | drv.Ibo_ave | Phase-b Zero Current Average AD | Q0 | |
| q31_u | drv.Ico_ave | Phase-c Zero Current Average AD | Q0 | |
| uint8_t | drv.spdprd | Speed Control Cycle | Q0 | |
| q15_t | drv.omega_enc | Encoder Speed | Q15 | |
| q15_t | drv.omega_enc_raw | Encoder Speed | Q15 | |
| q31_u | drv.omega_enc_ave | Encoder Average Speed | Q31 | |
| uint32_t | drv.theta_enc | Encoder Angle | Q0 | |
| int16_t | drv.EnCnt | Encoder Counter Value | Q0 | |
| int16_t | drv.EnCnt1 | Encoder Counter Previous Value | Q0 | |
| int16_t | drv.EnCnt_dev | Encoder Counter Deviation | Q0 | |
| q31_u | usr.omega_user | Controller Target Speed | Q31 | |
| q15_t | usr.Id_st_user | Starting Id-Current | Q15 | |
| q15_t | usr.Iq_st_user | Starting Iq-Current | Q15 | |
| uint16_t | usr.lambda_user | Initial Rotor Position | Q0 | |
| command_t | usr.com_user | Control Method | --- | (See 9.1.1) |
| command_t | usr.com_user_1 | Control Method Previous | --- | |
| q15_t | para.omega_min | Forced Commutation End Speed | Q15 | |
| q15_t | para.omega_v2i | Current Control Changeover Speed | Q15 | |
| q15_t | para.spwm_threshold | Shift PWM Changeover Speed | Q15 | |
| q31_t | para.vd_pos | Positioning Reference Voltage | Q31 | |

| Type | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| q31_t | para.spd_coef | Output Voltage Factor | Q15 | |
| q31_u | para.sp_ud_lim_f | Drive Speed Increase/Decrease Limit | Q31 | |
| q31_u | para.sp_up_lim_s | Drive Speed Increase Limit | Q31 | |
| q31_u | para.sp_dn_lim_s | Drive Speed Decrease Limit | Q31 | |
| uint16_t | para.time.initpos | Positioning Time | Q0 | |
| uint16_t | para.time.initpos2 | Positioning Status Standby Time | Q0 | |
| uint16_t | para.time.bootstp | Bootstrap Time | Q0 | |
| uint16_t | para.time.go_up | Standby Time after Change Up | Q0 | |
| q31_t | para.iq_lim | q-Axis Current Limit | Q31 | |
| q31_t | para.id_lim | d-Axis Current Limit | Q31 | |
| q15_t | para.err_ovc | Overcurrent Setup Value | Q15 | |
| q31_t | para.pos.kp | Position Estimation Proportional Gain | Q15 | |
| q31_t | para.pos.ki | Position Estimation Integration Gain | Q15 | |
| int32_t | para.pos.ctrlprd | Position Estimation Control Cycle | Q16 | |
| q31_t | para.spd.kp | Speed Control Proportional Gain | Q15 | |
| q31_t | para.spd.ki | Speed Control Integration Gain | Q15 | |
| uint8_t | para.spd.pi_prd | (Not Used) | Q0 | |
| q31_t | para.crt.dkp | d-Axis Current Control Proportional Gain | Q15 | |
| q31_t | para.crt.dki | d-Axis Current Control Integration Gain | Q15 | |
| q31_t | para.crt.qkp | q-Axis Current Control Proportional Gain | Q15 | |
| q31_t | para.crt.qki | q-Axis Current Control Integration Gain | Q15 | |
| q31_t | para.motor.r | Motor Winding Resistance | Q15 | |
| q31_t | para.motor.Lq | Motor q-Axis Inductance | Q15 | |
| q31_t | para.motor.Ld | Motor d-Axis Inductance | Q15 | |
| uint32_t | para.enc.pls2theta | Computation factor from the number of pulses to the angle | Q32 | |
| q15_t | para.enc.pls2omega | Computation factor from the number of pulses to the speed | Q15 | |
| int32_t | para.enc.plsnum | Number of encoder pulses | Q0 | |
| int32_t | para.enc.ctrlprd | Encoder Control Cycle | Q16 | |
| uint32_t | para.enc.deg_adjust | Electrical Angle Adjustment | Q0 | |
| int32_t | para.delta_lambda | Current changeover phase when changing up | Q0 | |
| uint16_t | para.chkpls | Current Detection Protection Duty Width | Q0 | |
| uint32_t | stage_counter | Stage Counter | Q0 | |
| shunt_type_e | shunt_type | Shunt Type | --- | c1shunt<br>c3shunt |
| boot_type_e | boot_type | Starting Type | --- | cBoot_i<br>cBoot_v |

## 9.5 Function Details

### 9.5.1 Encoder Initial Setup (init_ENCen)

**Syntax**

void init_ENCen(void)

Parameter:

None

Returned Value:

None

**Process**

Initial setup of encoder circuit

- Encoder circuit setup
- Port setup

### 9.5.2 ADC Initial Setup (init_ADCen)

**Syntax**

void init_ADCen(void)

Parameter:

None

Returned Value:

None

**Process**

Initial setup of ADC

- Motor AD Setup
- ADC Permission

### 9.5.3 PMD Initial Setup (init_PMDen)

**Syntax**

void init_PMDen(void)

Parameter:

None

Returned Value:

None

**Process**

Initial Setup of PMD (programmable motor driver)

### 9.5.4 VE Initial Setup (init_VEen)

**Syntax**

void init_VEen(void)

Parameter:

None

Returned Value:

None

**Process**

Initial Setup of VE (vector engine)

- VE Interruption Setup
- VE Setup

### 9.5.5 Motor Control Initial Setup (B_Motor_Init)

**Syntax**

void B_Motor_Init(void)

Parameter:

None

Returned Value:

None

**Variable**

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Output | shunt_type | Shunt Type | --- | |
| | boot_type | Driver Type | --- | |
| | usr.com_user.encoder | Encoder Control | — | |
| | stage.main | Main Stage | --- | |
| | stage.sub | Sub Stage | --- | |
| | drv.Iao_ave | Phase-u Zero Current Average AD | Q0 | |
| | drv.Ibo_ave | Phase-v Zero Current Average AD | Q0 | |
| | drv.Ico_ave | Phase-w Zero Current Average AD | Q0 | |
| | usr.Iq_st_user | Starting Iq-Current | Q15 | |
| | usr.Id_st_user | Starting Id-Current | Q15 | |
| | usr.lambda_user | Initial Rotor Position | Q0 | |
| | para.motor.r | Motor Winding Resistance | Q15 | |
| | para.motor.Lq | Motor q-Axis Inductance | Q15 | |
| | para.motor.Ld | Motor d-Axis Inductance | Q15 | |
| | para.spwm_threshold | Shift PWM Changeover Speed | Q15 | |
| | para.chkpls | Current Detection Protection Duty Width | Q0 | |
| | para.vd_pos | Positioning Reference Voltage | Q31 | Voltage Start only |
| | para.spd_coef | Output Voltage Factor | Q15 | Voltage Start only |
| | para.sp_ud_lim_f | Drive Speed Increase/Decrease Limit | Q31 | |
| | para.sp_up_lim_s | Drive Speed Increase Limit | Q31 | |
| | para.sp_dn_lim_s | Drive Speed Decrease Limit | Q31 | |
| | para.time.bootstp | Bootstrap Time | Q0 | |
| | para.time.initpos | Positioning Time | Q0 | |
| | para.time.initpos2 | Positioning Status Standby Time | Q0 | |
| | para.time.go_up | Standby Time after Change Up | Q0 | |
| | para.omega_min | Forced Commutation End Speed | Q15 | |
| | para.omega_v2i | Current Control Changeover Speed | Q15 | |
| | para.delta_lambda | Current changeover phase when changing up | Q0 | |
| | para.pos.ki | Position Estimation Integration Gain | Q15 | |
| | para.pos.kp | Position Estimation Proportional Gain | Q15 | |
| | para.pos.ctrlprd | Position Estimation Control Cycle | Q16 | |
| | para.spd.ki | Speed Control Integration Gain | Q15 | |
| | para.spd.kp | Speed Control Proportional Gain | Q15 | |
| | para.crt.dki | d-Axis Current Proportional Gain | Q15 | |
| | para.crt.dkp | d-Axis Current Integration Gain | Q15 | |
| | para.crt.qki | q-Axis Current Proportional Gain | Q15 | |
| | para.crt.qkp | q-Axis Current Integration Gain | Q15 | |
| | para.iq_lim | q-Axis Current Limit | Q31 | |
| | para.id_lim | d-Axis Current Limit | Q31 | |
| | para.err_ovc | Overcurrent Setup Value | Q15 | |
| | para.enc.pls2theta | Computation factor from the number of pulses to the angle | Q32 | |
| | para.enc.deg_adjust | Electrical Angle Adjustment | Q0 | |
| | para.enc.plsnum | Number of encoder pulses | Q0 | |
| | para.enc.pls2omega | Computation factor from the number of pulses to the speed | Q15 | |
| | para.enc.ctrlprd | Encoder Control Cycle | Q16 | |
| | para.TrgComp | Trigger Timing Compensation | Q15 | |

**Process**

Initializing the motor control parameters.

Setup of the variable whose setups are not changed during the control.

### 9.5.6 DAC Control Initial Setup (init_Dac)

**Syntax**

void init_DAC(TSB_TSPI_TypeDef* const TSPIx)

Parameter:

TSB_TSPI_TypeDef* const TSPIx: Select a TSPI address.

Returned Value:

None

**Process**

Initial Setup of DAC IC Control

- SIO Permission
- Port Initial Setup
- SIO Initial Setup
- DAC IC Initialization Communication
- SIO Interruption Level Setup
- SIO Interruption Suspension Clear
- Transmission Interruption Permission

### 9.5.7 Cycle Timer Initial Setup (init_Timer_interval4kHz)

**Syntax**

void init_Timer_interval4kHz(void)

Parameter:

None

Returned Value:

None

**Process**

Initial setup of timer for generating the 4 kHz cycle timing.

### 9.5.8 User Control Initial Setup (init_user_control)

**Syntax**

void init_user_control(void)

Parameter:

None

Returned Value:

None

**Process**

Initial setups for executing the user control, such as the SW.

- Digital Port Initial Setup
- Analogue Port Initial Setup
- LED Initial Setup
- UART Initial Setup

### 9.5.9 User Control (uart_control)

**Syntax**

void user_control(void)

Parameter:

None

Returned Value:

None

**Process**

Control according to the external statuses, such as VR and SW.

- Drive speed control using VR1
- Rotation direction changeover using S_SW1 (*)
- two-phase/three-phase modulation changeover using S_SW2 (*)
- DAC changeover using USW1
- Outputting the rotation speed information to UART
- Displaying the internal status on LED

* The motor operation will be stopped immediately after a changeover of SW.
Set the speed setup of VR to 0 (0 V) after stopping.

### 9.5.10 User Motor Control (B_User_MotorControl)

#### Syntax

void B_User_MotorControl(void)

Parameter:

None

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | target_spd | Target Speed | --- | User Command |
| Output | usr.omega_user | Controller Target Speed | Q31 | |
| | usr.com_user.onoff | Motor ON/OFF | --- | |
| | drv.state | Motor Abnormality Status | --- | |

#### Process

Setup Motor ON/OFF, rotation speed, driving method, etc.

Check overcurrent (hardware EMG) status.

### 9.6 Motor Control Function

The motor control processing is controlled using the following functions:

C_Control_Ref_Model

C_Common

C_Stage_Stop

C_Stage_Bootstrap

C_Stage_Initposition

C_Stage_Force

C_Stage_Change_up

C_Stage_Steady_A

C_Stage_Emergency

Each stage has the internal status (sub stages).

The internal status (sub stages) starts from Step0 and when the processing is complete until StepEnd, the stage will be transferred to the next.

When a motor abnormality is detected, it will be transferred to the protection stop status (emergency).

### 9.6.1 Status Transfer Processing Function (C_Control_Ref_Model)

#### Syntax

void C_Control_Ref_Model(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | usr.com_user.onoff | Control Command | --- | |
| | drv.state.all | Error Status | --- | |
| I/O | stage.main | Main Stage | --- | |
| | stage.sub | Sub Stage | --- | |
| | usr.com_user_1.onoff | Previous Control Command | --- | |

#### Process

Monitor the control command given from the application and the current statuses and executes the status transferring.

Each status is separated into the more detailed sub statuses. The transfer of sub stages is executed within the processing function for each stage instead of within the stage transfer processing function.

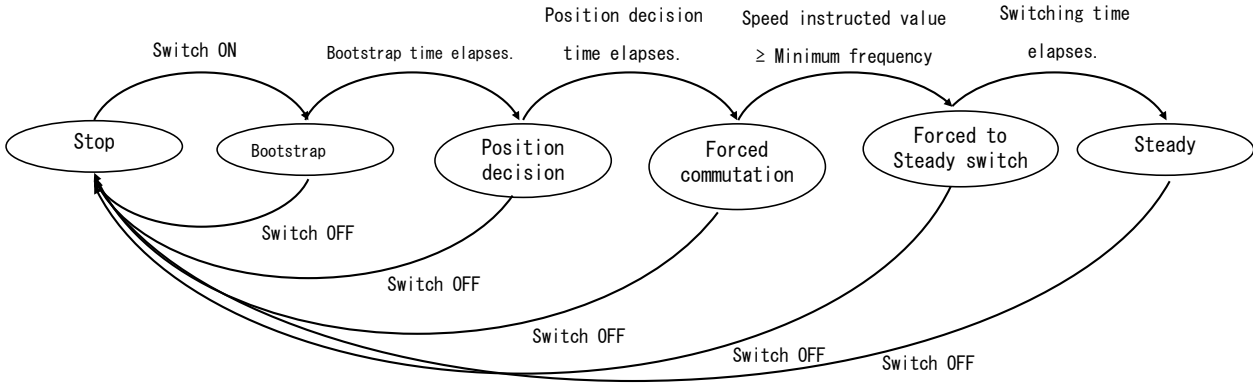



Fig. 9.1 State transition chart of Motor control

### 9.6.2 Motor Control Common Processing Function (C_Common)

**Syntax**

void C_Common(vector_t* const _motor)
Parameter:
vector_t* const _motor: Motor Control Structure
Returned Value:
None

**Variable**

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | usr.com_user.encoder | Encoder Control Command | — | |
| | usr.com_user.modul | Modulation Method Control Command | — | two-phase or three-phase Modulation |
| Output | drv.command.encoder | Encoder Drive Command | — | |
| | drv.command.modul | Modulation Method Drive Command | — | two-phase or three-phase Modulation |

**Process**

A common process to various motor control statuses is executed.

9.6.10 Shift PWM Control (C_ShiftPWM_Control) is executed.

### 9.6.3 Stop Stage Function (C_Stage_Stop)

**Syntax**

void C_Stage_Stop(vector_t* const _motor)
Parameter:
vector_t* const _motor: Motor Control Structure
Returned Value:
None

**Variable**

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| I/O | stage.sub | Sub Stage | --- | |
| Output | stage.itr | Interruption Stage | --- | |
| | drv.theta_com | Electrical Angle Reference Value | Q0 | |
| | drv.theta | Rotor Position | Q0 | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | drv.omega | Speed | Q31 | |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| | drv.Iq_com | q-Axis Current Reference Value | Q31 | |

**Process**

Stops the motor. (Stops the PWM output)

### 9.6.4 Bootstrap Stage Function (C_Stage_Bootstrap)

**Syntax**

void C_Stage_Bootstrap(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

**Variable**

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| | para.time.bootstp | Bootstrap Time | Q0 | * MainLoopPrd(s) |
| I/O | stage.sub | Sub Stage | --- | |
| | stage_counter | Stage Counter | Q0 | * MainLoopPrd(s) |
| Output | stage.itr | Interruption Stage | --- | |

**Process**

Outputs the waveform of upper phase All OFF and Lower phase All ON and charges the bootstrap capacitor.

Continues this process during the Bootstrap Time and determines the charging amount for the capacitor based on the Bootstrap Time

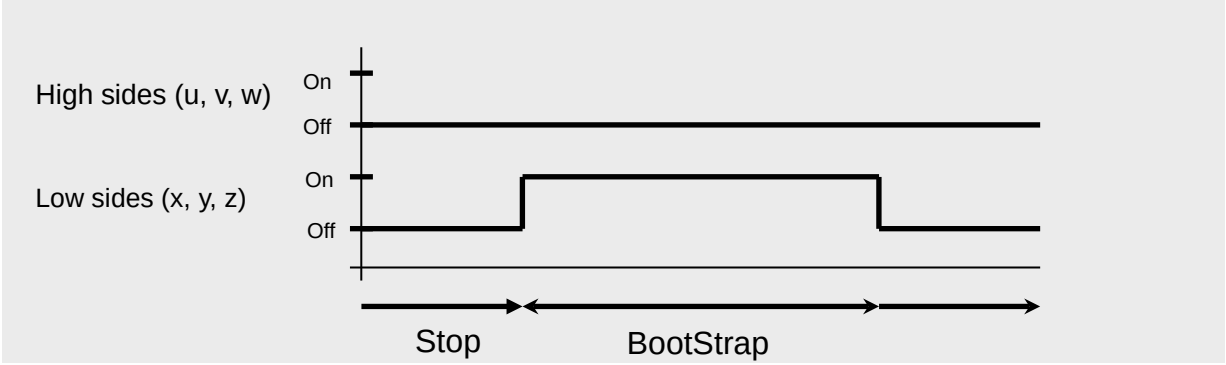
Controls the bootstrap status by separating it into the following sub-stages.

a) Initial Status

Initial setup of bootstrap status.

b) Time Lapse Standby Stage

Wait for the lapse of specified bootstrap time and transfers to the positioning stage.



### 9.6.5 Positioning Stage Function (C-Stage_Initposition)

#### Syntax

void C_Stage_Initposition(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| | boot_type | Starting Type | --- | |
| | usr.Id_st_user | Starting Id-Current | Q15 | |
| | usr.lambda_user | Initial Rotor Position | Q0 | |
| | para.vd_pos | Positioning Reference Voltage | Q31 | |
| | para.time.initpos | Positioning Time | Q0 | * MainLoopPrd(s) |
| | para.time.initpos2 | Positioning Status Standby Time | Q0 | * MainLoopPrd(s) |
| I/O | stage.sub | Sub Stage | --- | |
| | stage_counter | Stage Counter | Q0 | * MainLoopPrd(s) |
| | drv.Vd_out | Output Voltage | Q31 | Enabled only during voltage drive |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| Output | stage.itr | Interruption Stage | --- | |
| | drv.vector_cmd | Vector Control Command | --- | |
| | drv.Iq_com | q-Axis Current Reference Value | Q31 | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | drv.theta_com | Electrical Angle Reference Value | Q0 | |

#### Process

Fixes the rotor to the initial position.

While fixing θ to the Initial Position, ω to 0 and Iq to 0, gradually increases Id from 0.

Continues this process during the Positioning Time and finally Id reaches the Start Id Current. Determines the increment of Id per unit time based on the Positioning Time and the Start Id Current

After Id reaches the Start Id Current and after the lapse of Positioning Standby Time, the stage will be transferred to the next.

The positioning stages will be separated into the following sub stages for controlling.

a) Initial Status

Initial setup of positioning stages.

b) Id Increasing Stage

Id will be gradually increased to the setup value.

### 9.6.6 Forced Commutation Stage Function (C_Stage_Force)

#### Syntax

void C_Stage_Force(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| | boot_type | Starting Type | --- | Current or Voltage |
| | usr.Id_st_user | Starting Id-Current | Q15 | |
| | usr.omega_user | Controller Target Speed | Q31 | |
| | para.omega_v2i | Current Control Changeover Speed | Q15 | Enabled only during voltage drive |
| | para.spd_coef | Output Voltage Factor | Q15 | Enabled only during voltage drive |
| | para.vd_pos | Positioning Output Voltage | Q31 | Enabled only during voltage drive |
| | para.omega_min | Forced Commutation End Speed | Q15 | |
| | para.sp_ud_lim_f | Drive Speed Increase/Decrease Limit | Q31 | |
| I/O | stage.sub | Sub Stage | --- | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| Output | drv.vector_cmd | Vector Control Command | --- | |
| | stage.itr | Interruption Stage | --- | |
| | drv.Iq_com | q-Axis Current Reference Value | Q31 | |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| | drv.Vd_out | Output Voltage | Q31 | Enabled only during voltage drive |

#### Process

Starts the rotation of rotor. In this stage, a rotation magnetic field is forcibly applied instead of the feedback processing with vector control, and the rotor will follow it and be rotated.

The drive speed reference, $\omega_{com}$, will be gradually increased while fixing the Id to Start Id Current and Iq to 0.

Acquire θ from $\omega_{com}$ ($\theta=\omega_{com} \times t$). This process will be continued until ω reaches the Forced Commutation End Speed

The Drive Target Speed will be increased with a constant increment for approaching Control Target Speed The Drive Target Speed reaches ω.

### 9.6.7 Forced Steady Changeover Stage Function (C_Stage_Change_up)

#### Syntax

void C_Stage_Change_up(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| | usr.Id_st_user | Starting Id-Current | Q15 | |
| | usr.Iq_st_user | Starting Iq-Current | Q15 | |
| | usr.omega_user | Controller Target Speed | Q31 | |
| | para.delta_lambda | Current changeover phase when changing up | Q0 | |
| | para.sp_ud_lim_f | Drive Speed Increase/Decrease Limit | Q31 | |
| | para.time.go_up | Standby Time after Change Up | Q0 | * MainLoopPrd(s) |
| I/O | stage.sub | Sub Stage | --- | |
| | stage_counter | Stage Counter | Q0 | * MainLoopPrd(s) |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| Output | stage.itr | Interruption Stage | --- | |
| | drv.vector_cmd | Vector Control Command | --- | |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| | drv.Iq_com | q-Axis Current Reference Value | Q31 | |

#### Process

Decreases Id to 0 and increases Iq to Start Iq Current and controls the orientation of magnetic field to directly downwards with respect to the rotor.

Generates the torque component.

Acquire ω and θ through the position estimation computation.

The Drive Target Speed will be increased with a constant increment for approaching Control Target Speed. However, the Drive Target Speed will not be used for controlling because the speed control is not conducted in this stage.

The forced steady changeover stage will be controlled by separating it into the following sub-stages.

a) Initial Status

Initial setup of forced steady changeover stages.

b) Id and Iq Changeover Stages

Gradually decreases Id to 0 and gradually increases Iq to the specified value simultaneously. The increasing/decreasing curves are not linear but follows the triangular function curve. After the completion of changeover, the stage will be transferred to the time lapse standby.

c) Time Lapse Standby Stage

Waits for the lapse of the specified forced steady changeover time and transfers to the steady stage.

### 9.6.8 Steady Stage Function (C_Stage_Steady_A)

**Syntax**

void C_Stage_Steady_A(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

**Variable**

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| | usr.omega_user | Controller Target Speed | Q31 | |
| | para.sp_up_lim_s | Drive Speed Increase Limit | Q31 | |
| | para.sp_dn_lim_s | Drive Speed Decrease Limit | Q31 | |
| I/O | stage.sub | Sub Stage | --- | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| Output | drv.vector_cmd | Vector Control Command | Q0 | |
| | stage.itr | Interruption Stage | --- | |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |

**Process**

Executes the process of steady stage.

The Drive Target Speed is increased with a constant increment and approaches the Control Target Speed

### 9.6.9 Protection Stage Function (C_Stage_Emergency)

#### Syntax

void C_Stage_Emergency(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | stage.main | Main Stage | --- | |
| I/O | stage.sub | Sub Stage | --- | |
| Output | drv.vector_cmd | Vector Control Command | --- | |
| | stage.itr | Interruption Stage | --- | |

#### Process

When an overcurrent occurs, the stage will be transferred to this.

When a hardware overcurrent is detected, the motor drive output u, v, w, x, y, and z are all Hi-z.

When a software overcurrent is detected, the motor drive output u, v, w, x, y, and z are all OFF.

The rotor will be rotated by the inertia. This stage will be maintained until the overcurrent status restoration process is executed.

### 9.6.10 Shift PWM Control (C_ShiftPWM_Control)

#### Syntax

void C_ShiftPWM_Control(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| Direction | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | shunt_type | Shunt Type | — | |
| | stage.itr | Interruption Stage | — | |
| | usr.com_user.spwm | Shift PWM Control Method | — | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | para.spwm_threshold | Shift PWM Changeover Speed | Q15 | |
| | para.minpls | Minimum Pulse Width | Q0 | |
| Output | drv.minpls | Minimum Pulse Width | Q0 | |
| | drv.command.spwm | Shift PWM Drive Command | — | |

#### Process

This control is enabled only during 1-shunt.

Setup of minimum duty value for using the shift PWM ON/OFF and the previous current detection value.

Determines the shift PWM drive method based on the shift PWM control method, interruption stage and the target speed.

The sample software is set up according to the conditions in the table.

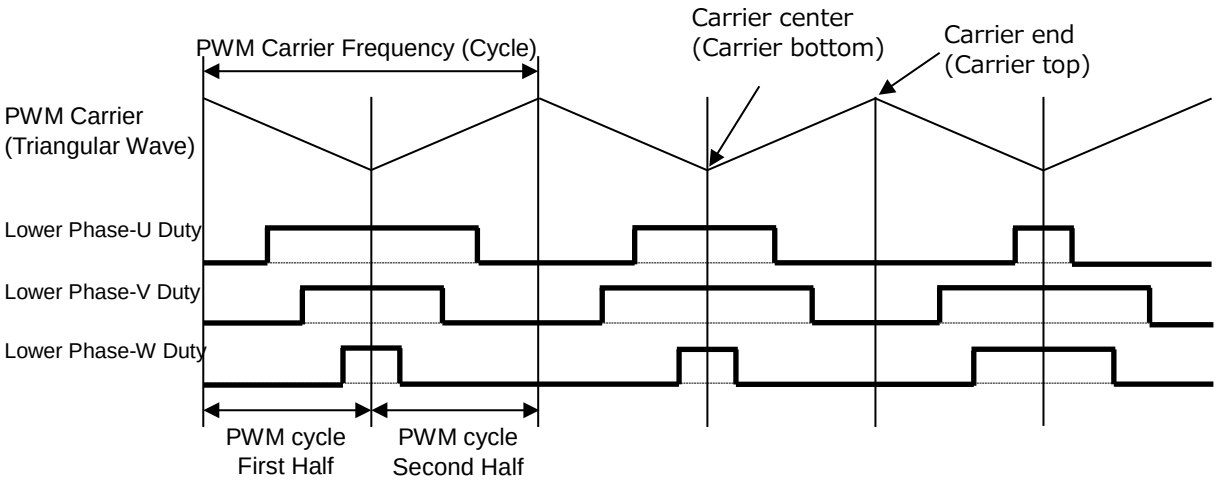
Table 9.1 Shift PWM Drive Method Conditions

| **Shift PWM Control Method** usr.com_user.spwm | **Interruption Stage** stage.itr | **Target Speed** drv.omega_com | **Shift PWM Drive Method** drv.command.spwm |
|---|---|---|---|
| OFF (0) | All | All | OFF (0) |
| ON (1) | Stop | All | OFF (0) |
| | Emergency | All | OFF (0) |
| | Initposition_i | All | OFF (0) |
| | Force_i<br>Change_up<br>Steady_A | Target Speed ≥<br>Shift Switch Speed<br>drv.omega_com ≥<br>para.spwm_threshold | OFF (0) |
| | | Target Speed <<br>Shift Switch Speed<br>drv.omega_com <<br>para.spwm_threshold | ON (1) |

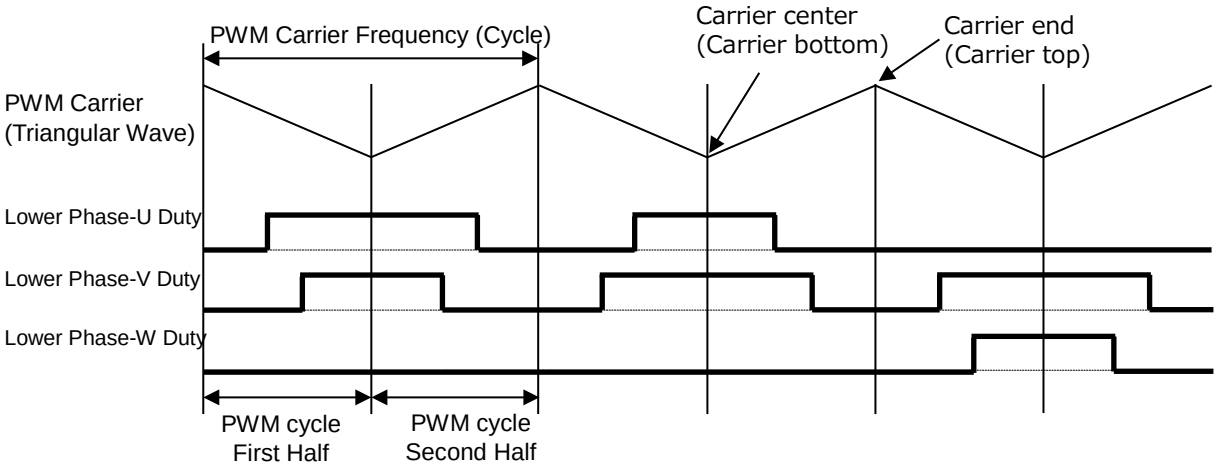
## 9.7 Motor Drive Function

### 9.7.1 Explanation of Terms

#### 3-phase Modulation




#### 2-phase Modulation




### 9.7.2 Motor Current, Power Supply Voltage Gain (VE_GetdataFromVEreg)

#### Syntax

void VE_GetdataFromVEreg(const ipdrv_t* const _ipdrv, vector_t* const _motor)

Parameter:

ipdrv_t* const _ipdrv: Select an IP table address.

vector_t* const _motor: Motor Control Structure

Returned Value:

None

### Variable

| I/O | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | drv.Sector1 | Previous Sector | Q0 | 0 to 5 |
| | drv.TrgMd | Current Detection Mode | — | 3-shunt<br>1-shunt first half<br>1-shunt second half |
| I/O | drv.Iao_ave | Phase-U Zero Current Average | Q15 | 3-shunt only |
| | drv.Ibo_ave | Phase-V Zero Current Average | Q15 | 3-shunt only |
| | drv.Ico_ave | Phase-W Zero Current Average | Q15 | 3-shunt only |
| | drv.Idco_ave | Zero Current Average | Q15 | 1-shunt only |
| Output | drv.Ia | Phase-U Current | Q15 | |
| | drv.Ib | Phase-V Current | Q15 | |
| | drv.Ic | Phase-W Current | Q15 | |
| | drv.Vdc | Power supply voltage | Q15 | |
| | drv.Ia_adc | Phase-U Current Conversion Result | Q15 | 3-shunt only |
| | drv.Ib_adc | Phase-V Current Conversion Result | Q15 | 3-shunt only |
| | drv.Ic_adc | Phase-W Current Conversion Result | Q15 | 3-shunt only |
| | drv.Idc1_adc | Phase-1st Current Conversion Result | Q15 | 1-shunt only |
| | drv.Idc2_adc | Phase-2nd Current Conversion Result | Q15 | 1-shunt only |
| | drv.Vdc_adc | Power Supply Voltage Conversion Result | Q15 | |

### Process

Acquires the AD conversion result and computes the power supply voltage and the motor current.

1. Checks the completion of AD conversion with the PMD trigger and when the conversion is complete, acquires the conversion results according to the table below.
   When the conversion is not complete, continue standing by until the completion of conversion (Never occurs under normal conditions, but as a failsafe process, the standby process is executed).
2. Computes the power supply voltage and the motor current based on the acquired AD conversion results.

- Power supply voltage

| | |
|---|---|
| Power Supply Voltage Conversion Result<br>drv.Vdc_adc | AD Conversion Result 3<br>ADxREG3 |

As the power supply voltage being unsigned, the AD conversion result is right shifted by 1 bit and converted to the Q15 format variable.

drv.Vdc = drv.Vdc_adc >>1

- Motor Current

<Current Detection Mode: 3-shunt>

| | Sector | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Phase-U Current Conversion Result drv.Ia_adc | AD Conversion Result 2 ADxREG2 | AD Conversion Result 1 ADxREG1 | AD Conversion Result 1 ADxREG1 | AD Conversion Result 0 ADxREG0 | AD Conversion Result 0 ADxREG0 | AD Conversion Result 2 ADxREG2 |
| Phase-V Current Conversion Result drv.Ib_adc | AD Conversion Result 0 ADxREG0 | AD Conversion Result 2 ADxREG2 | AD Conversion Result 2 ADxREG2 | AD Conversion Result 1 ADxREG1 | AD Conversion Result 1 ADxREG1 | AD Conversion Result 0 ADxREG0 |
| Phase-W Current Conversion Result drv.Ic_adc | AD Conversion Result 1 ADxREG1 | AD Conversion Result 0 ADxREG0 | AD Conversion Result 0 ADxREG0 | AD Conversion Result 2 ADxREG2 | AD Conversion Result 2 ADxREG2 | AD Conversion Result 1 ADxREG1 |

The AD conversion result when the motor is stopped is regarded as the zero current and stored in the following variables.

| | |
|---|---|
| Phase-U Zero Current Conversion Result drv.Iao_ave | Phase-U Current Conversion Result drv.Ia_adc |
| Phase-V Zero Current Conversion Result drv.Ibo_ave | Phase-V Current Conversion Result drv.Ib_adc |
| Phase-W Zero Current Conversion Result drv.Ico_ave | Phase-W Current Conversion Result drv.Ic_adc |

The values of three-phase current will be computed in accordance with the following table based on the AD conversion result with zero current (motor stop) and the phase current conversion result.

| | Sector | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Phase-U Current drv.Ia | -Ib-Ic | .Iao_ave - .Ia_adc | .Iao_ave - .Ia_adc | .Iao_ave - .Ia_adc | .Iao_ave - .Ia_adc | -Ib-Ic |
| Phase-V Current drv.Ib | .Ibo_ave - .Ib_adc | -Ia-Ic | -Ia-Ic | .Ibo_ave - .Ib_adc | .Ibo_ave - .Ib_adc | .Ibo_ave - .Ib_adc |
| Phase-W Current drv.Ic | .Ico_ave - .Ic_adc | .Ico_ave - .Ic_adc | .Ico_ave - .Ic_adc | -Ia-Ib | -Ia-Ib | .Ico_ave - .Ic_adc |

<Current Detection Mode: 1-shunt First Half and the Second Half>

Current Detection Mode: During the first half of 1-shunt, the AD conversion result is acquired at the position of the first half of PWM cycle.

Current Detection Mode: During the second half of 1-shunt, the AD conversion result is acquired at the position of the second half of PWM cycle.

| Current Acquisition Position / Conversion Result | PWM Cycle Second Half | PWM Cycle First Half |
|---|---|---|
| Current Conversion Result 1<br>drv.Idc1_adc | AD Conversion Result 0<br>ADxREG0 | AD Conversion Result 1<br>ADxREG1 |
| Current Conversion Result 2<br>drv.Idc2_adc | AD Conversion Result 1<br>ADxREG1 | AD Conversion Result 0<br>ADxREG0 |

The AD conversion result when the motor is stopped is regarded as the zero current and stored in the following variables.

| Zero Current Conversion Result<br>drv.Idco_ave | AD Conversion Result 0<br>ADxREG0 |
|---|---|

The values for the three-phase current are computed in accordance with the table below based on the AD conversion result, Zero Current Conversion Result, during the zero current (motor stop) and the AD conversion results at the two timings.

| | Sector | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Phase-U Current<br>drv.Ia | -(Idco_adc-Idc2_adc) | -Ib-Ic | Idco_adc-Idc1_adc | Idco_adc-Idc1_adc | -Ib-Ic | -(Idco_adc-Idc2_adc) |
| : Phase-V Current<br>drv.Ib | -Ia-Ic | -(Idco_adc-Idc2_adc) | -(Idco_adc-Idc2_adc) | -Ia-Ic | Idco_adc-Idc1_adc | Idco_adc-Idc1_adc |
| : Phase-W Current<br>drv.Ic | Idco_adc-Idc1_adc | Idco_adc-Idc1_adc | -Ia-Ib | -(Idco_adc-Idc2_adc) | -(Idco_adc-Idc2_adc) | -Ia-Ib |

### 9.7.3 Clarke Conversion (E_Clarke)

**Syntax**

void E_Clarke(q15_t _iu, q15_t _iv, q15_t _iw, q15_t* _ialpha, q15_t* _ibeta)
Parameter:
q15_t _iu : Phase-U Current
q15_t _iv : Phase-V Current
q15_t _iw : Phase-W Current
q15_t* _ialpha :α-Axis Current Storage Address
q15_t* _ibeta : β-Axis Current Storage Address
Returned Value:
None

**Process**

The three-phase currents (Iu, Iv, Iw) are converted to two-phase (Iα, Iβ).

Iα and Iβ are computed using the following computation formulas:

$$\mathrm{I}\alpha = \frac{2}{3} \times (\mathrm{Iu} \times \cos 0 + \mathrm{Iv} \times \cos 120 + \mathrm{Iw} \times \cos 240) = \frac{2}{3} \times \left(\mathrm{Iu} - \frac{1}{2}\mathrm{Iv} - \frac{1}{2}\mathrm{Iw}\right)$$

$$\mathrm{I}\beta = \frac{2}{3} \times (\mathrm{Iu} \times \sin 0 + \mathrm{Iv} \times \sin 120 + \mathrm{Iw} \times \sin 240) = \frac{2}{3} \times \left(\frac{\sqrt{3}}{2}\mathrm{Iv} - \frac{\sqrt{3}}{2}\mathrm{Iw}\right)$$

* Factors $\frac{2}{3}$ are used for making the amplitude equivalent, which is $\frac{3}{2}$ when the three-phase current is converted to those of two-phase αβ axes.

Because the total sum of three-phase currents will be 0, $\mathrm{I}\alpha = \mathrm{Iu}$ $\mathrm{I}\beta = (\mathrm{Iu} + 2 \times \mathrm{Iv})/\sqrt{3}$ is derived with Iu + Iv + Iw = 0.

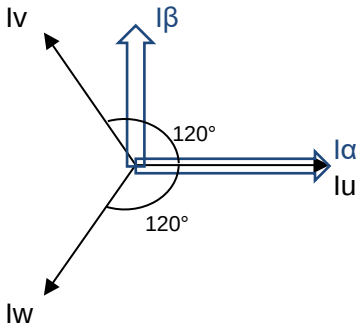



Fig. 9.2 Clarke Conversion

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### 9.7.4 Park Conversion (E_Park)

#### Syntax

void E_Park(q15_t _ialpha, q15_t _ibeta, uint16_t _theta, q15_t* _id, q15_t* _iq)

Parameter:

| | |
|---|---|
| q15_t _ialpha | : α-Axis Current Iα |
| q15_t _ibeta | : β-Axis Current Iβ |
| q15_t _theta | : Rotor Position θ: 0 ≤ Position <360° (0 to 0xFFFF) |
| q15_t* _id | : d-Axis Current Id Storage Address |
| q15_t* _iq | : q-Axis Current Iq Storage Address |

Returned Value:

None

#### Process

Conversion from the static coordinate of αβ-axes to the dq-axes of rotational coordinate.

Id and Iq are computed using the following computation formulas:

$$Id = I\alpha \times \cos\theta + I\beta \times \sin\theta$$

$$Iq = I\alpha \times (-\sin\theta) + I\beta \times \cos\theta$$

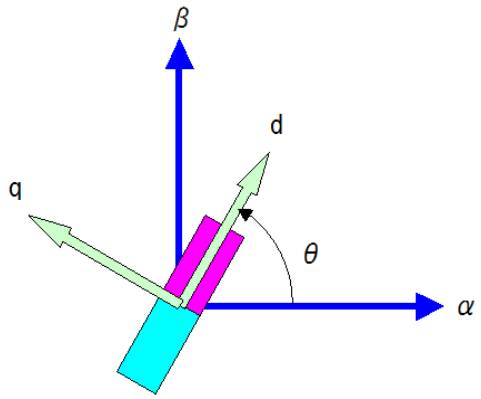



Fig. 9.3 Park Conversion

### 9.7.5 Position Estimation Function (D_Detect_Rotor_Position)

#### Syntax

void D_Detect_Rotor_Position(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| I/O | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | drv.command.encoder | Encoder Drive Command | --- | |
| | drv.vector_cmd.F_vcomm_Edetect | Induced Voltage Control Command | --- | |
| | drv.vector_cmd.F_vcomm_omega | Estimated Speed Control Command | --- | |
| | drv.vector_cmd.F_vcomm_theta | Estimated Rotor Position Control Command | --- | |
| | drv.Id | d-Axis Current | Q15 | |
| | drv.Iq | q-Axis Current | Q15 | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | drv.theta_com | Electrical Angle Reference Value | Q0 | |
| | drv.Vd | d-Axis Voltage | Q31 | |
| | para.motor.Lq | Motor q-Axis Inductance | Q12 | |
| | para.motor.r | Motor Winding Resistance | Q12 | |
| | para.pos.ctrlprd | Position Estimation Control Cycle | Q0 | |
| | para.pos.ki | Position Estimation Integration Gain | Q15 | |
| | para.pos.kp | Position Estimation Proportional Gain | Q15 | |
| I/O | drv.Ed | d-Axis Induced Voltage | Q15 | |
| | drv.Ed_I | d-Axis Induced Voltage Integrated Value | Q31 | |
| | drv.Ed_PI | d-Axis Induced Voltage PI Value | Q31 | |
| | drv.omega | Estimated Speed | Q31 | |
| Output | drv.theta | Rotor Position | Q0 | |

#### Process

The PI control is executed by regarding the estimate speed $\omega_{est}$ of motor drive signal as the amount of operation and the d-axis induced voltage Ed as the amount of control.

For information, the target value for Ed is always 0. Accordingly, the deviation is -Ed.

The rotor position θ (angle) is acquired by integrating the estimated speed $\omega_{est}$ acquired through the PI control.

The equivalent circuit equation with regard to the d-axis of motor is expressed as below:

$$V_d = R \cdot I_d + L_d \cdot pI_d - \omega_{est} \cdot L_q \cdot I_q + E_d$$

(p = d/dt, Id ≈ constant, then regarded as pId = 0)

| | |
|---|---|
| Vd | : Motor Applied Voltage |
| Id,Iq | : Motor Current |
| $\omega_{est}$ | : Estimated Angular Speed |
| R | : Resistance |
| Ld,Lq | : Inductance |

Consequently, the induced voltage Ed of the d-axis is acquired using the following computation formula:

Ed = Vd - R・Id + $\omega_{est}$・Lq・Iq

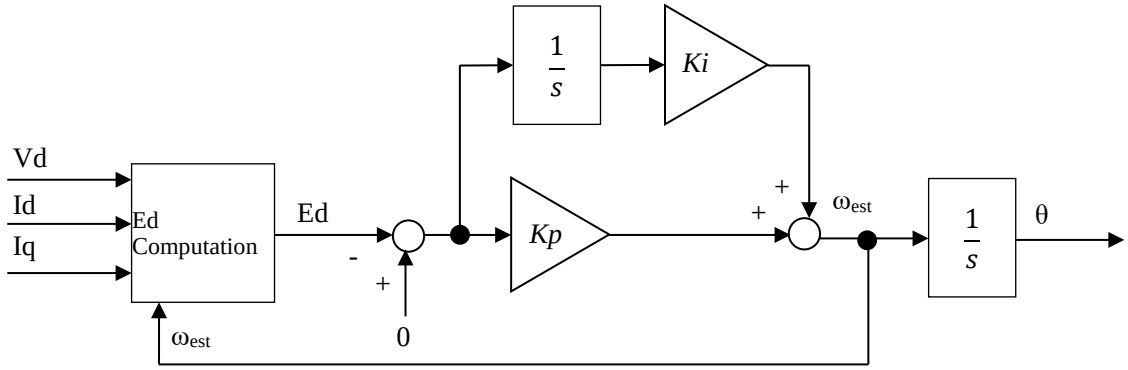



Fig. 9.4 Position Estimation Block Diagram based on Induced Voltage Ed of the d-Axis

### 9.7.6 Encoder Control Function (H_Encoder)

**Syntax**

void H_Encoder(vector_t* const _motor, TSB_EN_TypeDef* const ENx)

Parameter:

| | |
|---|---|
| vector_t* const _motor | : Motor Control Structure |
| TSB_EN_TypeDef* const ENx | : ENC Address |

Returned Value:

No

**Variable**

| I/O | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | drv.command.encoder | Encoder Drive Command | — | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | drv.theta_com | Electrical Angle Reference Value | Q0 | |
| | drv.vector_cmd.F_vcomm_omega | Estimated Speed Control Command | — | |
| | drv.vector_cmd.F_vcomm_theta | Estimated Rotor Position Control Command | — | |
| | para.enc.ctrlprd | Encoder Control Cycle | Q16 | |
| | para.enc.deg_adjust | Electrical Angle Adjustment | Q0 | |
| | para.enc.pls2omega | Computation factor from the number of pulses to the speed | Q15 | |
| | para.enc.pls2theta | Computation factor from the number of pulses to the angle | Q32 | |
| | para.enc.plsnum | Number of encoder pulses | Q0 | |
| I/O | drv.EnCnt | Encoder Counter Value | Q0 | |
| | drv.EnCnt_dev | Encoder Counter Deviation | Q0 | |
| | drv.EnCnt1 | Encoder Counter Previous Value | Q0 | |
| | drv.omega_enc | Encoder Speed | Q15 | |
| | drv.omega_enc_ave | Encoder Average Speed | Q31 | |
| | drv.omega_enc_raw | Encoder Speed | Q15 | |
| | drv.theta_enc | Encoder Angle | Q0 | |
| Output | drv.omega | Speed | Q31 | |
| | drv.theta | Rotor Position | Q0 | |

## Process

Reads the number of incremental encoder pulses and processes the calculation of rotor position (angle) θ and speed ω.

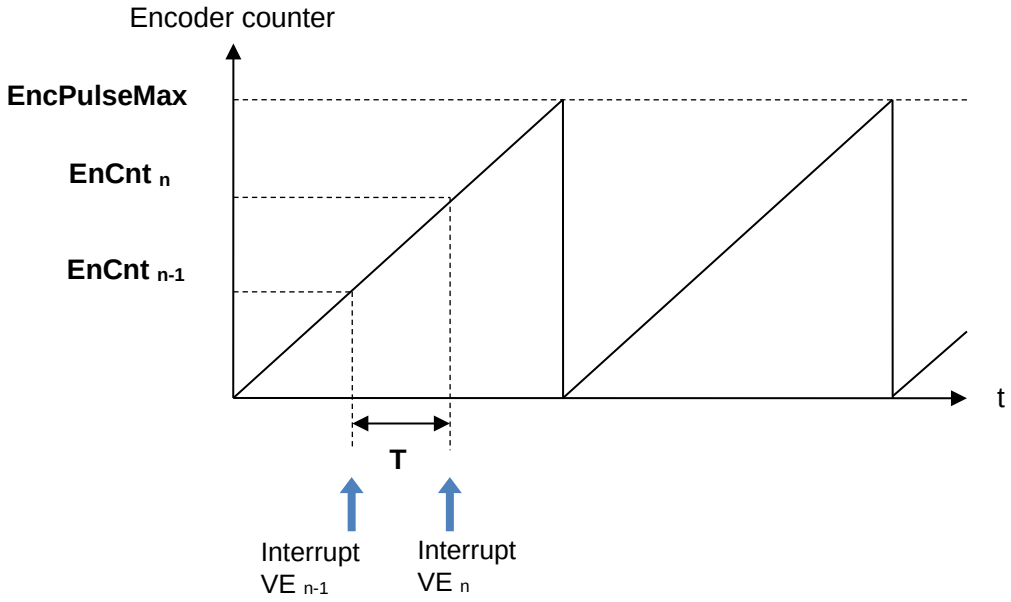



Fig. 9.5 Computation of Position and Speed using Encoder Pulse

Reads the number of pulses at every VE interruption and computes the following:

Computes θ using the formula below based on the current encoder pulse counter reading.

$$\theta = \mathrm{EnCnt_n} \times (360°/\mathrm{EncPulseMax}) \times (\mathrm{Pole}/2)$$

Computes the speed ω using the formula below based on the difference of the encoder pulse counter reading of previous (n-1) and current (n).

$$\omega = \{(\mathrm{EnCnt_n} - \mathrm{EnCnt_{n-1}}) \times (360°/(\mathrm{EncPulsMax}/(\mathrm{Pole}/2))\}/\mathrm{T}$$

| | |
|---|---|
| $\mathrm{EnCnt_n}$ | Current Encoder Counter Reading |
| $\mathrm{EnCnt_{n-1}}$ | Previous Encoder Counter Reading |
| EncPulseMax | Number of Encoder Pulses [ppr] x Multiplier (4) |
| Pole | Number of Poles |
| θ | Angle [deg.] |
| ω | Speed [Hz] |
| T | Speed Computing Cycle [s] |

### 9.7.7 Speed Control Function (D_Control_Speed)

#### Syntax

void D_Control_Speed(vector_t* const _motor)

Parameter:

vector_t* const _motor: Motor Control Structure

Returned Value:

None

#### Variable

| I/O | Code | Description | Q Format | Remarks |
|---|---|---|---|---|
| Input | drv.vector_cmd.F_vcomm_current | Current Reference Control Command | --- | |
| | drv.Id_com | d-Axis Current Reference Value | Q31 | |
| | drv.Iq_com | d-Axis Current Reference Value | Q31 | |
| | drv.omega | Estimated Speed | Q31 | |
| | drv.omega_com | Driving Speed Reference Value | Q31 | |
| | para.id_lim | d-Axis Current Limit | Q31 | |
| | para.iq_lim | q-Axis Current Limit | Q31 | |
| | para.spd.ki | Speed Control Integration Gain | Q15 | |
| | para.spd.kp | Speed Control Proportional Gain | Q15 | |
| I/O | drv.Iq_ref_I | q-Axis Current Integrated Value | Q31 | |
| | drv.omega_dev | Speed Deviation | Q15 | |
| Output | drv.Id_ref | d-Axis Current Standard Value | Q15 | |
| | drv.Iq_ref | q-Axis Current Standard Value | Q15 | |

**Process**

Executes the PI control by regarding the output frequency ω as the controlled amount and the q-axis current Iq as the operated amount.

Determines the d-axis and q-axis current standard values based on the deviation of the speed reference and the measured speed.

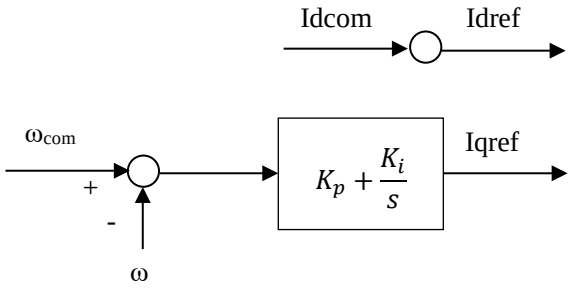



Fig. 9.6 Speed Control Block Diagram

### 9.7.8 Inverse Park Conversion (E_InvPark) Syntax

void E_InvPark(q31_t _d, q31_t _q, uint16_t _theta, q31_t* _alpha, q31_t* _beta) Parameter:

q31_t _d: d-Axis
q31_t _q: q-Axis
q31_t _theta : Rotor Position θ: 0 ≤ Position <360° (0 to 0xFFFF)
q31_t _alpha : α-Axis Storage Address
q31_t _beta : β-Axis Storage Address

Returned Value:

No

**Process**

Converts from the dq-axes of rotational coordinate to the static coordinate of the αβ-axes.

Vα and Vβ are computed using the following computation formulas:

$$V\alpha = Vd \times \cos\theta - Vq \times \sin\theta$$

$$V\beta = Vd \times \sin\theta + Vq \times \cos\theta$$

### 9.7.9 Sector Computation

**Syntax**

uint8_t D_CalSector(q31_t _valpha, q31_t _vbeta)

Parameter:

q31_t _valpha : α-Axis Voltage

q31_t _vbeta : β-Axis Voltage

Returned Value:

Sector

**Process**

Computes the sector based on the αβ-axis voltage.

Stores the previous sector values and determines the current sector values using the conditional formula below:

| Condition | | Sector Value |
|---|---|---|
| Condition 1 | Condition 2 | |
| $(V\alpha \geq 0)$ & $(V\beta \geq 0)$ | $V\alpha \geq (V\beta/\sqrt{3})$ | 0 |
| | $V\alpha < (V\beta/\sqrt{3})$ | 1 |
| $(V\alpha < 0)$ & $(V\beta \geq 0)$ | $\lvert V\alpha\rvert < (V\beta/\sqrt{3})$ | 1 |
| | $\lvert V\alpha\rvert \geq (V\beta/\sqrt{3})$ | 2 |
| $(V\alpha < 0)$ & $(V\beta < 0)$ | $\lvert V\alpha\rvert \geq (\lvert V\beta\rvert/\sqrt{3})$ | 3 |
| | $\lvert V\alpha\rvert < (\lvert V\beta\rvert/\sqrt{3})$ | 4 |
| $(V\alpha \geq 0)$ & $(V\beta < 0)$ | $V\alpha < (\lvert V\beta\rvert/\sqrt{3})$ | 4 |
| | $V\alpha \geq (\lvert V\beta\rvert/\sqrt{3})$ | 5 |

### 9.7.10 Spatial Vector Modulation (D_SVM)

**Structure**

void D_SVM(q31_t _valpha, q31_t _vbeta, q15_t _vdc, uint8_t _sector,
uint8_t _modul, uint16_t* _p_vu, uint16_t* _p_vv, uint16_t* _p_vw)

Parameter:

| | |
|---|---|
| q31_t _valpha | : α-Axis Vα |
| q31_t _vbeta | : β-Axis Vβ |
| q31_t _vdc | : Power supply voltage |
| uint8_t _sector | : Sector |
| uint8_t _modul | : Modulation |
| uint16_t* _p_vu | : Phase-U Duty Ratio Du Storage Address |
| uint16_t* _p_vv | : Phase-U Duty Ratio Dv Storage Address |
| uint16_t* _p_vw | : Phase-U Duty Ratio Dw Storage Address |

Returned Value:

None

## Process

Acquires the duty ratio of the three-phase PWM from the two-phase αβ-axis voltages.
Acquires the PWM duty ratio of each phase using the spatial vector modulation.

● What is the Spatial Vector Modulation?

As the switching elements in the inverter drive circuit are in the statuses where, the elements of the upper phase are ON or OFF and those of the lower phase are in the inverse status (the dead time is ignored);

There are eight patterns as shown in Table 9.1.

Where these eight patterns are defined as V0 thru V7, the vectors V0 and V7 are located at the origin due to no line voltage, and the remaining six vectors (V1 thru V6) are expressed at every 60 degrees as shown in Fig. 9.7.

By combining the neighboring two vectors together, an arbitrary output voltage vector V is acquired.

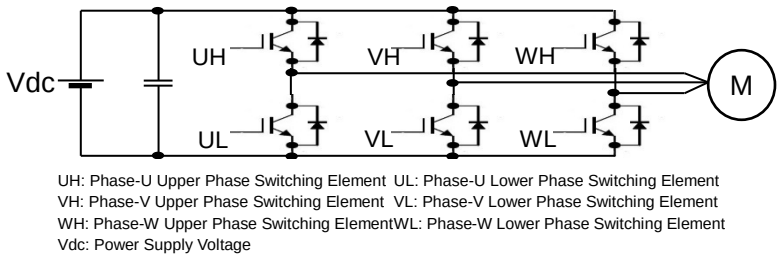



Fig. 9.7 Inverter Drive Circuit

Table 9.1 Inverter Switching Status1

| U | V | W | Vector |
|---|---|---|---|
| 0 | 0 | 0 | V0 (0 0 0) |
| 1 | 0 | 0 | V1 (1 0 0) |
| 1 | 1 | 0 | V2 (1 1 0) |
| 0 | 1 | 0 | V3 (0 1 0) |
| 0 | 1 | 1 | V4 (0 1 1) |
| 0 | 0 | 1 | V5 (0 0 1) |
| 1 | 0 | 1 | V6 (1 0 1) |
| 1 | 1 | 1 | V7 (1 1 1) |

0: Upper Phase OFF, Lower Phase ON
1: Upper Phase ON, Lower Phase OFF

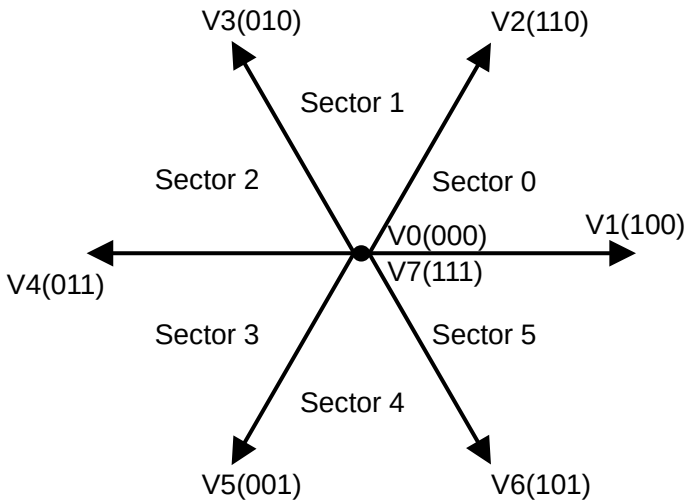



Fig. 9.8 Spatial Vector

7

- When the output voltage vector V is at Sector 0

For example in Fig. 9.8, the composite vector V of Vα and Vβ is located at the sector 0, accordingly it is acquired as a composite vector of V1' and V2' acquired by multiplying the voltage vectors V1 and V2 with factors t1 and t2, respectively. If they are expressed in the PWM waveform, V is composed by generating V1 and V2 for the duration of t1 and t2, respectively, in the half cycle of PWM as shown in Fig. 9.9.

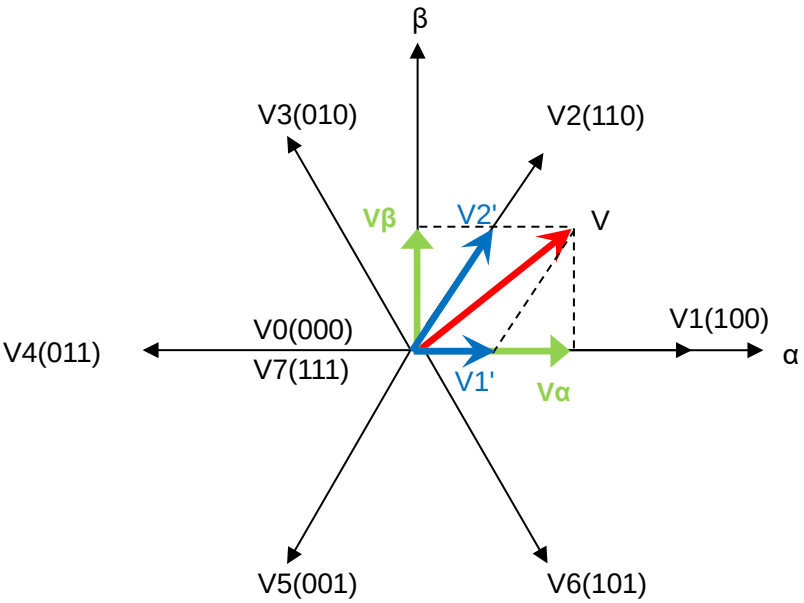



Fig. 9.9 Voltage Vector at Sector

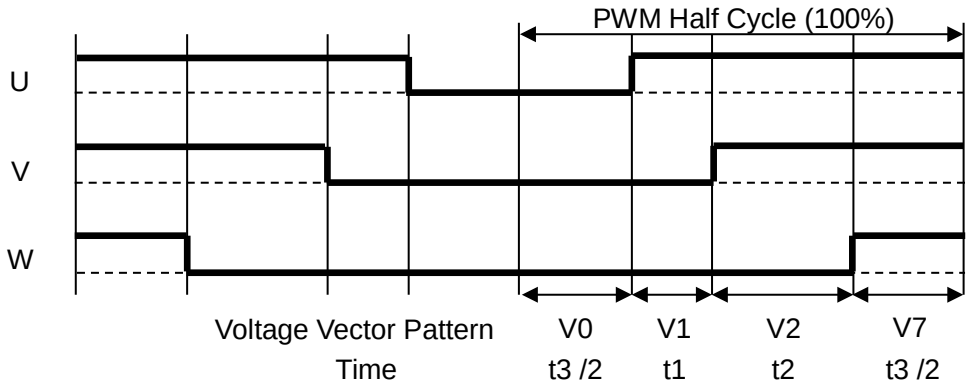



Fig. 9.10 three-phase Modulation PWM Waveform

From Fig. 9.8, Vα and Vβ are expressed as below:

$$V\alpha = V1' \times \cos 0° + V2' \times \cos 60° = V1' + \frac{V2'}{2}$$

$$V\beta = V1' \times \sin 0° + V2' \times \sin 60° = \frac{\sqrt{3}}{2} \times V2'$$

Consequently, V1' and V2' are as below:

$$V2' = \frac{2}{\sqrt{3}} V\beta$$

$$V1' = V\alpha - \frac{V2'}{2} = V\alpha - \frac{1}{\sqrt{3}} V\beta$$

Where the motor power supply voltage is Vdc,

$$V1' = t1 \times Vdc$$

$$V2' = t2 \times Vdc$$

Consequently, the ratio of t1, t2, and t3 are as below:

$$t1 = k \times \frac{V\alpha - \frac{1}{\sqrt{3}} V\beta}{Vdc}$$

$$t2 = k \times \frac{\frac{2}{\sqrt{3}} V\beta}{Vdc}$$

$$t3 = 100\% - t1 - t2$$

where, k is a conversion factor 3/2 for making the size to a certain level when converting from three-phase to two-phase.

The definition of occurrence duration for vectors V0 and V7 as t3/2 respectively is the three-phase modulation, whereas the definitions of occurrence duration for vector V0 as t3 and that for V7 as 0 are the two-phase modulation.

Consequently, the duties for the three phases are acquired using the following calculations from t1, t2 and t3.

Phase-U Duty = t1 + t2 + (t3/2)
Phase-V Duty = t2 + (t3/2)
Phase-W Duty = t3/2

Similarly, for every sector of the output voltage, the OFF Duty D0, the Duty D1 when only one phase is ON and the Duty D2 when two phases are ON are computed using the formula for the Duty On duration per the sectors in Table 9.2.

Table 9.2 Formulas for Duty On Duration per Sector2

| Sector | Duty when only one of the phases is ON. D1 | Duty when two phases are ON D2 | OFF Duty D0 |
|---|---|---|---|
| 0 | $k \times \frac{V\alpha - \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | $k \times \frac{\frac{2}{\sqrt{3}}V\beta}{Vdc}$ | 100% – D1 – D2 |
| 1 | $k \times \frac{-V\alpha + \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | $k \times \frac{V\alpha + \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | |
| 2 | $k \times \frac{\frac{2}{\sqrt{3}}V\beta}{Vdc}$ | $k \times \frac{-V\alpha - \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | |
| 3 | $-k \times \frac{\frac{2}{\sqrt{3}}V\beta}{Vdc}$ | $k \times \frac{-V\alpha + \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | |
| 4 | $k \times \frac{-V\alpha - \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | $k \times \frac{V\alpha - \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | |
| 5 | $k \times \frac{V\alpha + \frac{1}{\sqrt{3}}V\beta}{Vdc}$ | $-k \times \frac{\frac{2}{\sqrt{3}}V\beta}{Vdc}$ | |

where, k is a factor 3/2 for making the amplitudes before and after conversion to a certain level. The duties for U, V and W phases are computed from D0, D1 and D2 using the formulas in Table 9.3.

Table 9.3 Relationship of Sectors and Duties of Phases3

| Sector | three-phase Modulation | | | two-phase Modulation | | |
|---|---|---|---|---|---|---|
| | Phase-U Duty | Phase-V Duty | Phase-W Duty | Phase-U Duty | Phase-V Duty | Phase-W Duty |
| 0 | D1+D2+(D0/2) | D2+(D0/2) | D0/2 | D1+D2 | D2 | 0 |
| 1 | D2+(D0/2) | D1+D2+(D0/2) | D0/2 | D2 | D1+D2 | 0 |
| 2 | D0/2 | D1+D2+(D0/2) | D2+(D0/2) | 0 | D1+D2 | D2 |
| 3 | D0/2 | D2+(D0/2) | D1+D2+(D0/2) | 0 | D2 | D1+D2 |
| 4 | D2+(D0/2) | D0/2 | D1+D2+(D0/2) | D2 | 0 | D1+D2 |
| 5 | D1+D2+(D0/2) | D0/2 | D2+(D0/2) | D1+D2 | 0 | D2 |

# 10. Explanation of Definitions for Constants

## 10.1 Motor Driver Setting Parameter (D-Para.h)

### 10.1.1 Motor Control Channel Selection

**__CONTROL_MOTOR_CH0** : Define when controlling the CH0
**__CONTROL_MOTOR_CH1** : Define when controlling the CH1
**__CONTROL_MOTOR_CH2** : Define when controlling the CH2

### 10.1.2 Selecting a DAC Output

**__USE_DAC** : Define when executing the DAC control for outputting the variables for evaluation.

### 10.1.3 Selection of Unit for Command Speed

**__TGTSPD_UINT**: Selection of unit for command speed
0: Hz of Electrical angle
1: RPS of mechanical angle
2: RPM of mechanical angle

### 10.1.4 Parameter List

| Parameter Name | Description |
|---|---|
| cMAINLOOP_PRD | Main Cycle Setup |
| | Unit [s] Resolution 4 kHz |
| | Set up the main cycle time. |
| cIXO_AVE | Zero Current Filtering Factor |
| | -- |
| | Set up the filtering factor.<br>The setup of larger value will stabilize but will delay the response. |
| cVDQ_AVE | Filtering Factors for Power Supply Voltage Vdc and Output Voltage Vdq |
| | -- |
| | Set up the filtering factor.<br>The setup of larger value will stabilize but will delay the response. |
| cOMEGAENC_AVE | Filtering Factor for Speed Detection Value using the Number of Encoder Pulses |
| | -- |
| | Set up the filtering factor for speed detection.<br>Use a larger value when the number of encoder pulses is small.<br>However, the larger value will bring about the delay of detection. Set up a value that gives the tolerable delay. |

### 10.2 Motor Driver Setting Parameter Motor Channel (D_Para_chx.h) x = 0, 1, 2

Various motors are driven by changing the parameters in the motor driver.

#### 10.2.1 Selection of Control

**Selection of AMP**

__USE_INAMP Define when the built-in AMP is used.

**Choice of Sensor-less/Sensor**

__USE_ENCODER Define when the encoder control is used.

#### 10.2.2 Parameter List per Motor Channel

| Parameter Name | Description |
|---|---|
| cPOLH | Upper Phase Drive Logical Setup |
| | 0: Low active/ 1: High active |
| | Change the values according to the board design.<br>Set up the logic for the upper phase driver. |
| cPOLL | Logical Setup for Lower Phase Driver |
| | 0: Low active/ 1: High active |
| | Change the values according to the board design.<br>Setup the logic for the lower phase driver. |
| cV_MAX | Setup of Max Voltage |
| | Unit [V] |
| | Change the values according to the board design.<br>Setup the value of power supply voltage variation [V] x 2^12 with regard to the variation of 1LSB in the AD conversion. |
| cA_MAX | Setup of Max Current |
| | Unit [A] |
| | Change the values according to the board design.<br>Setup the value of phase current variation [A] x 2^11 with regard to the variation of 1 LSB in the AD conversion. |
| cSHUNT_TYPE | Setup of Current Acquisition Method (3-shunt) |
| | 3:3-shunt |
| | Setting of other than 3-shunt will cause an error. |
| cBOOT_TYPE | Setup of Drive Type when Starting |
| | cBoot_i: Current Type Drive/ cBoot_v: Voltage Type Drive |
| | Set up the drive type for starting. |

| | |
|---|---|
| cSHUNT_ZERO_OFFSET | Setup of Offset Voltage |
| | Unit [V] |
| | Set up the shunt voltage when no current flows.<br>This value will be used as the initial value of average zero current. |
| cADCH_CURRENT_U | Setup of Phase-U Current Acquisition AD Channel |
| | AINx |
| | Set up the AD channel for detecting the Phase-U current |
| cADCH_CURRENT_V | Setup of Phase-V Current Acquisition AD Channel |
| | AINx |
| | Set up the AD channel for detecting the Phase-V current |
| cADCH_CURRENT_W | Setup of Phase-W Current Acquisition AD Channel |
| | AINx |
| | Set up the AD channel for detecting the Phase-W current |
| cADCH_CURRENT_IDC | Setup of Current Acquisition AD Channel (1-shunt) |
| | AINx |
| | Set up the AD channel for detecting the current. |
| cADCH_VDC | Setup of Power Supply Voltage Acquisition AD Channel |
| | AINx |
| | Set up the AD channel for detecting the power supply voltage Vdc. |
| cOVC | Setup of Overcurrent Detecting Value |
| | Unit [A] |
| | Set up the overcurrent value.<br>When a coil current exceeding this setup value is detected, the output will be turned OFF by the software. |
| cVDC_MINLIM | Setup of Min Power Supply Voltage Vdc |
| | Unit [V] |
| | Set up the Min value of power supply voltage Vdc.<br>When voltage lower than this value is detected, the motor will be stopped. |
| cVDC_MAXLIM | Setup of Max Power Supply Voltage Vdc |
| | Unit [V] |
| | Set up the Max of power supply voltage Vdc.<br>When voltage higher than this value is detected, the motor will be stopped. |
| cPWMPRD | Setup of PWM Cycle |
| | Unit [μs] Resolution 16.67ns@120MHz |
| | Set up the cycle for the PWM carrier. |
| cDEADTIME | Setup of Dead Time |

| | |
|---|---|
| | Unit [μs] Resolution 66.67ns@120MHz |
| | Set up the dead time. |
| cREPTIME | Setup of the number of skipped software control. |
| | Unit [times]: 1 to 15 |
| | The timing for executing the vector computation software processing may be skipped.<br>Setting to "1" will execute the software processing of vector computation once every PWM cycle.<br>Setup of "2" will execute the software processing of vector computation one time every two PWM cycles. |
| cID_ST_USER_ACT | Setup of d-Axis Start Current |
| | Unit [A] |
| | Set up the d-axis start current.<br>This current value will be used for positioning and forced commutation.<br>Set up the value of approximately 10% of the rated commutation.<br>When the motor does not operate, gradually increase the value until it operates. |
| cIQ_ST_USER_ACT | Setup of q-Axis Start Current |
| | Unit [A] |
| | Set up the q-axis start current.<br>Set up a value of approximately 1/2 of d-axis start current.<br>If the motor abruptly accelerates when transferring from the forced commutation (d-axis control) to the steady (q-axis control), set a smaller value and, if the motor stops, set a larger value. |
| cMOTOR_R | Motor Coil Resistance |
| | Unit [Ω] |
| | Set up a resistance equivalent to that of the single phase of motor coil. |
| cMOTOR_LQ | q-Axis Inductance |
| | Unit [mH] |
| | Set up the inductance of q-axis of motor coil |
| cMOTOR_LD | d-Axis Inductance (not used) |
| | Unit [mH] |
| | Set up the inductance of d-axis of motor coil |
| cPOLE | Setup of the Number of Motor Poles |
| | Unit [poles] |
| | Set up the number of motor poles. |
| cID_KP | d-Axis Current Control Proportional Gain |
| | Unit [V/A] |
| | Set up the d-axis current control proportional gain. |

| | |
|---|---|
| cID_KI | d-Axis Current Control Integration Gain |
| | Unit [V/As] |
| | Set up the d-axis current control integration gain. |
| cIQ_KP | q-Axis Current Control Proportional Gain |
| | Unit [V/A] |
| | Set up the q-axis current control proportional gain. |
| cIQ_KI | q-Axis Current Control Integration Gain |
| | Unit [V/As] |
| | Set up the q-axis current control integration gain. |
| cPOSITION_KP | Position Estimation Proportional Gain |
| | Unit [Hz/V] |
| | Set up the position estimation proportional gain. |
| cPOSITION_KI | Position Estimation Integration Gain |
| | Unit [Hz/Vs] |
| | Set up the position estimation integration gain. |
| cSPEED_KP | Speed Control Proportional Gain |
| | Unit [A/Hz] |
| | Set up the speed control proportional gain. |
| cSPEED_KI | Speed Control Integration Gain |
| | Unit [A/Hzs] |
| | Set up the speed control integration gain. |
| cSPD_PI_PRD | Setup of Speed PI Control Cycle |
| | [Time] |
| | Set up the speed PI control cycle.<br>Setting to "1" will execute the speed PI computation once every PWM cycle.<br>Setting to "2" will execute the speed PI computation once every two PWM cycles. |
| cFCD_UD_LIM | Drive Speed Acceleration Rate (Forced Commutation) |
| | Unit [Hz/s] |
| | Setup the speed acceleration rate during the forced commutation.<br>Decrease the value when the motor speed does not follow the output of forced commutation. |
| cSTD_UP_LIM | Drive Speed Acceleration Rate (Steady) |
| | Unit [Hz/s] |
| | Set up the speed acceleration rate during the steady state. |

| | |
|---|---|
| cSTD_DW_LIM | Drive Speed Deceleration Rate (Steady) |
| | Unit [Hz/s] |
| | Set up the deceleration rate during the steady state. |
| cBOOT_LEN | Bootstrap Waveform Output Duration |
| | Unit [s] Resolution: 1 ms |
| | Set up the output duration for the bootstrap waveform. |
| cINIT_LEN | Positioning Time |
| | Unit [s] Resolution: 1 ms |
| | Set up the positioning duration. |
| cINIT_WAIT_LEN | Standby Time after Positioning |
| | Unit [s] Resolution: 1 ms |
| | Set up the standby time after positioning. |
| cGOUP_DELAY_LEN | Standby Time after Change Up |
| | Unit [s] Resolution: 1 ms |
| | Set up the standby time after change up. |
| cHZ_MAX | Max Frequency |
| | Unit [Hz] |
| | Set up the max frequency to be detected by the microcontroller.<br>Set up a value increased by 10% to 20% than the max frequency used for controlling.<br>A smaller value will enhance the precision of computation, but if the detected value exceeds this figure, the control will collapse. |
| cHZ_MIN | Changeover speed from forced commutation to steady. |
| | Unit [Hz] |
| | Set up a speed for transferring from the forced commutation to steady.<br>Set up a speed that permits the position estimation (the induced voltage will be detected). |
| cID_LIM | d-Axis Current Limit |
| | Unit [A] |
| | Set up the d-axis current limit. |
| cIQ_LIM | q-Axis Current Limit |
| | Unit [A] |
| | Set up the q-axis current limit. |
| cINITIAL_POSITION | Initial Position |
| | Unit [deg] |
| | Set up the angle for positioning in the electrical angle. |

| | |
|---|---|
| cVD_POS | Positioning output voltage during the voltage drive |
| | Unit [V] |
| | Set up the voltage for positioning.<br>Enabled only when the cBOOT_TYPE is "cBoot_v"<br>See “Constants for Voltage Type Starting” for details. |
| cSPD_COEF | Forced Commutation Output Voltage Factor during Voltage Drive |
| | Set a value x: 0 < x <1 |
| | Determine the output voltage during the forced commutation.<br>The multiplication of this setup and the reference speed is defined as the output voltage.<br>Vd = cSPD_COEF × Omega_com<br>Enabled only when the cBOOT_TYPE is "cBoot_v"<br>See “Constants for Voltage Type Starting” for details. |
| cHZ_V2I | Changeover Speed from Voltage Control to Current Control |
| | Unit [Hz] |
| | Set up a speed for changeover from the voltage control to the current control.<br>Setting to a value larger than the cHZ_MIN will execute the transfer to a steady value equal to cHZ_MIN and over and will change over to the current control.<br>Enabled only when the cBOOT_TYPE is "cBoot_v" |
| cENC_PULSE_NUM | Setup of the Number of Encoder Pulses |
| | Unit [ppr] |
| | Set up the number of pulses for the encoder.<br>Small value for the number of encoder pulses will degrade the speed detection accuracy.<br>If the detected speed is not stable, increase the filtering factor cOMEGAENC_AVE. |
| cENC_DEG_ADJUST | Encoder Position Adjustment |
| | Unit [deg.] |
| | Set up the shifted positional angle of phase-Z with regard to the electrical angle 0° |
| cENC_NOISE_TIME | Setup of Encoder Input Signal Noise Cancellation Time (Only A-ENC is enabled) |
| | Unit [μs] Resolution fc (8.33ns@120MHz) |
| | Set up the noise cancellation time of the encoder input signal.<br>The signals shorter than this setup time will be canceled.<br>This setup will be enabled only for the microcontroller equipped with A-ENC. |
| __FIXED_VDC | Setup of Power Supply Voltage Fixing |
| | 0: Detected Value, 1: Fixed Value |
| | When setting the power supply voltage to a fixed value, set up to "1" |

| | |
|---|---|
| cVDC | Fixed Power Supply Voltage |
| | Unit [V] |
| | Set up the power supply voltage.<br>Enabled only when the __FIXED_VDC is "1" |

### 10.2.3 Relationship of Constant Setups and Waveform

**Constants for Current Type Starting**

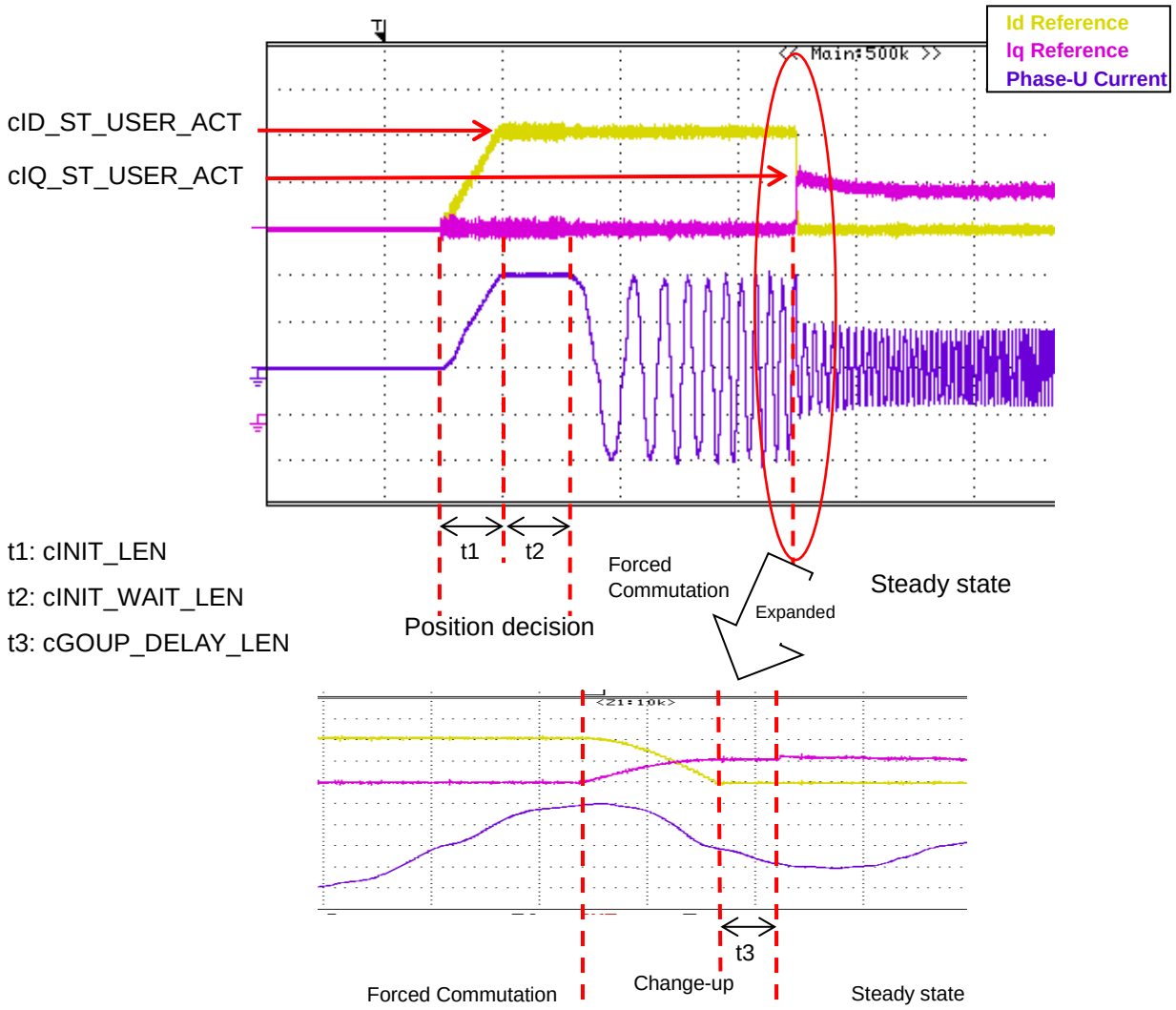



Fig. 10.1 Starting Current Waveform (Positioned to electrical angle 0°)

Switch the values cID_ST_USER_ACT and cIQ_ST_USER_ACT during the change up stage.

After switching, the control will be conducted with a constant reference value of Iq during the time of cGOUP_DELAY_LEN.

After transferring to steady, the Iq reference value will be computed by the PI control.

**Constants for Voltage Type Starting**

Determine the constants while checking the current waveform on an oscilloscope.

Observing the current waveform, the cVD_POS value should be adjusted to be the target current value.

The voltage Vd during the forced commutation is calculated by the following formula.
Speed × Constant value cSPD_COEF
The cSPD_COEF value should be adjusted for the current in the forced commutation to be constant.

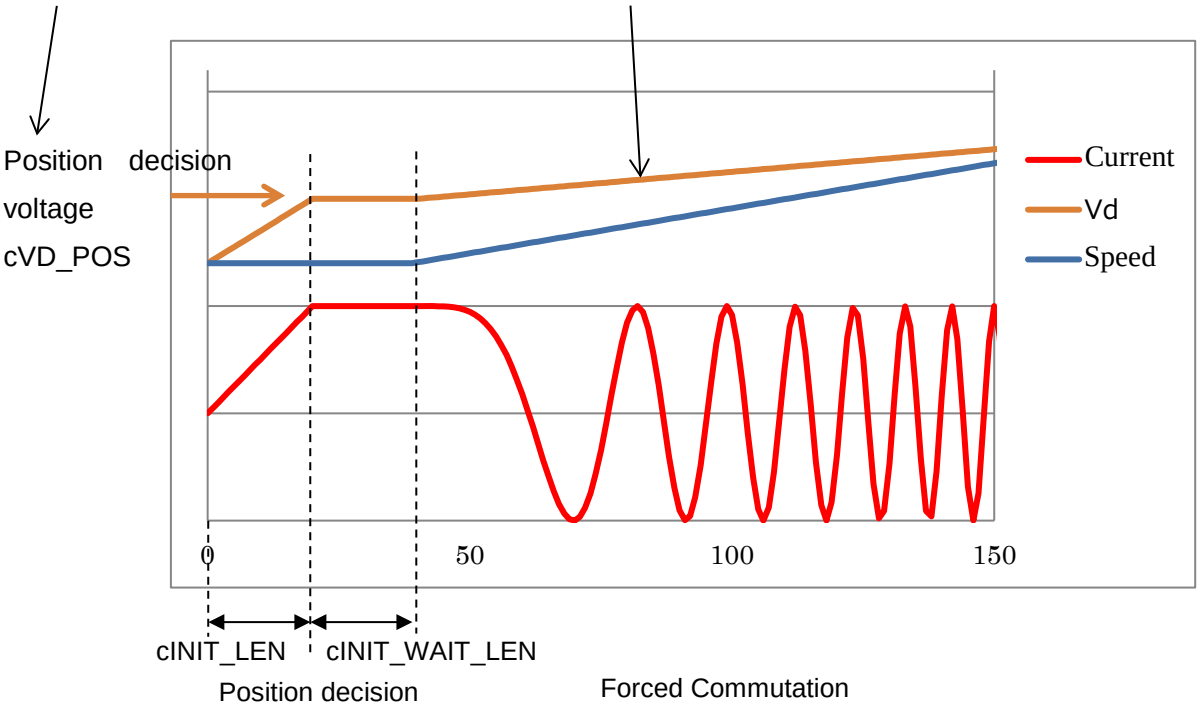



Fig. 10.2 Parameter adjustment at Voltage drive

### 10.3 Constants for User Control

```
/*Initial value*/
#define cININT_VALUE     (0)
#define cININT_FF                (0xff)

/* Key setting */
#define P_SW1            TSB_PG_DATA_PG3      /* slideSW1 or 8(KEY1) */
#define P_SW2            TSB_PG_DATA_PG4      /* slideSW2 or 9(KEY2) */
#define P_PSW1           TSB_PD_DATA_PD1      /* pushSW1 DACSW */

#define cKEY_CHATA_CNT           (20)     /* [cnt] chattering counter for KEY SW */
#define cNO_ENTER_KEY            (0)      /* Soft ADC Setting */
#define cADUNIT_USR      TSB_ADC          /* User ad data ADCUnit */
#define cADAUNIT_USR     TSB_ADA          /* User ad data ADAUnit */
#define cADTRG_USR       ADC_TRG_SINGLE       /* ADC Trigger Type */
```

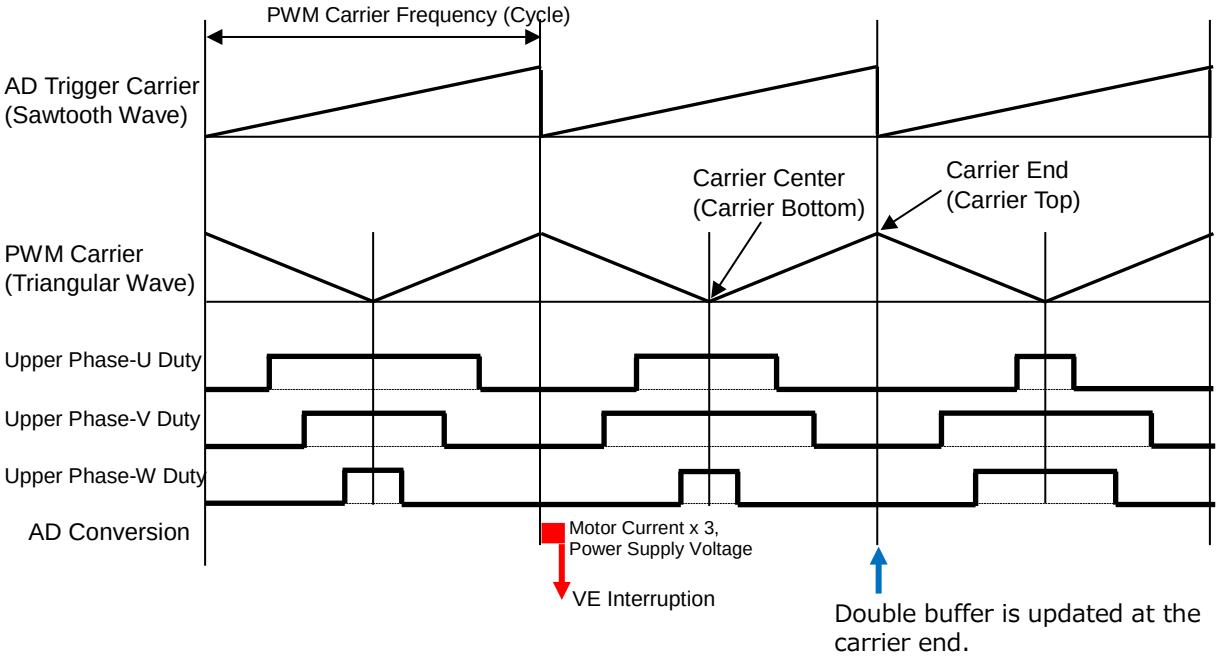
```
#define cADCH_ADKEY             ADC_AIN0        /* ADC Channel for AD Key */
#define cADREG_ADKEY            ADC_REG4        /* Result register No for AD Key */
#define cADCH_VR                ADC_AIN0        /* ADC Channel for VR */
#define cADREG_VR               ADC_REG4        /* Result register No for VR */
#define cADCH_TEMP              ADC_AIN13       /* ADA Channel for TEMP */
#define cADREG_TEMP             ADC_REG7        /* Result register No for TEMP */
#define cADAVECNT               (10)            /* ADC average count */
#define cPUSHSW_CHATA_CNT       (5)             /* [cnt] Chattering counter for Push SW */


/* AD speed control setting */
#define cAD_MIN                 (0x10)          /* Voltage value 0.3V */
#define cAD_MAX                 (0xF0)          /* Voltage value 4.7V */
#define cSPEED_USER_MIN         (12)            /* [Hz] Min Target speed of motor */
#define cSPEED_USER_MAX         (200)           /* [Hz] Max Target speed of motor */


/* AD Temp setting */
#define cONE_ABOVE              (1)


/* DACMODE setting */
#define cDACMODE_MIN  (0)               /* DACMODE count0 */
#define cDacMODE_MAX  (3)               /* DACMODE count3 */


/* LED setting */
#define LED_FORCED      TSB_PV_DATA_PV0         /* LED4 */
#define LED_EMG         TSB_PB_DATA_PB6         /* LED6 */
#define cLED_ON                 (1)             /* LED ON level */
#define cLED_OFF                (0)             /* LED OFF level */


/* flag status */
#define cFLG_ON                 (1)
#define cFLG_OFF                (0)
```

```
/* UART Setting */
#define UART_BRD_INIT          ((uint32_t)0x00A6002B)
#define UART_CLK_INIT          ((uint32_t)0x00000000)
#define UART_CR0_INIT          ((uint32_t)0x00000001)
#define UART_CR1_INIT          ((uint32_t)0x00000040)
#define UART_SEND_WAIT         (1000)
#define UART_COUNT             (0)
#define c10MHz                 (1000000)
#define cLOW_ACTIVE            (0)
#define cSWRST10               (0x2U)
#define cSWRST01               (0x1U)
#define cSWRSTF                (0x80)


/* User_interface Setting */
#define cROTATION_CW           (1)
#define cROTATION_CCW          (0)
#define cPSW1_Hi               (1)
#define cPSW1_Low              (0)
#define cStrCH0                ("CH0")
#define cINV_MIN_TEMP          (-20)
#define cINV_MAX_TEMP          (100)

#define cSendBufSIZE           (80+1)
```

# 11. Timings for Control and Data Update

## 11.1 Vector Control Using VE

### 11.1.1 3-shunt Control




**Carrier Waveform**

| Type | Waveform |
|---|---|
| PWM | Triangular Wave<br>(for 3 phases) |
| AD Trigger | Sawtooth Wave |

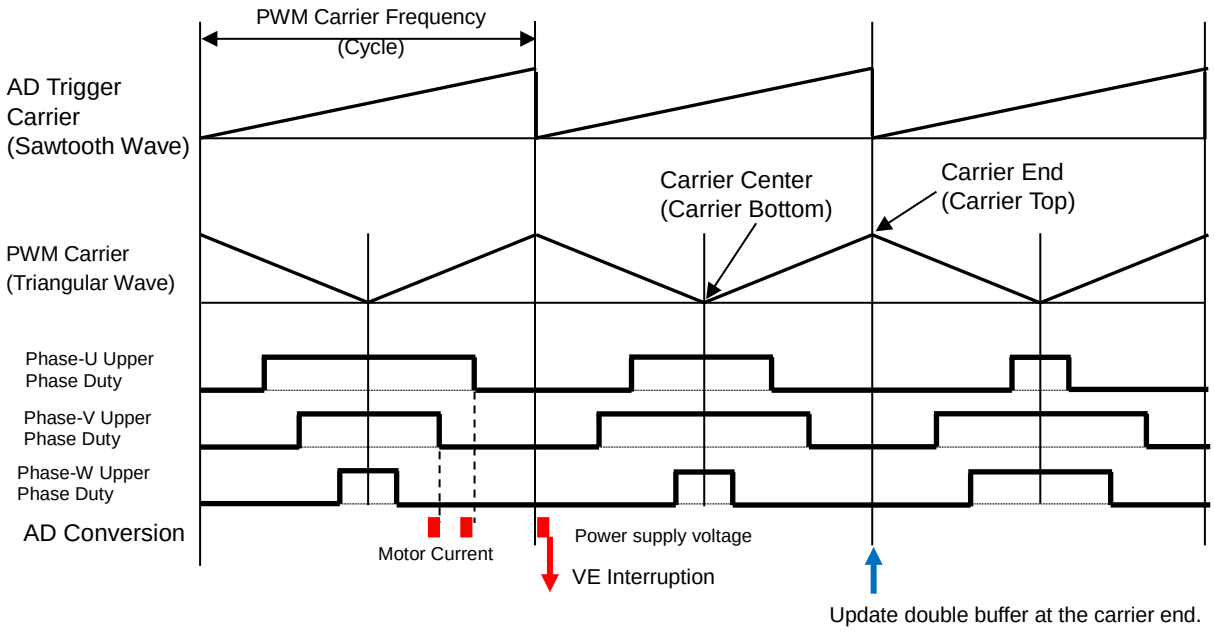
**Double Buffer Update Timing**

| Data | Update Timing |
|---|---|
| PWN Cycle (RATE) | Carrier End |
| Duty Value (CMPU, CMPV, CMPW) | Carrier End |
| Trigger Position (TRGCMPx) | Carrier End |
| Output Setup (MDOUT) | Carrier End |

**Interruption**

| Interruption Request | Interruption | Timing |
|---|---|---|
| VE | Permitted | After completion of VE input schedule |
| PWM(PMD) | Prohibited | Once every one time, twice and four times. |
| AD Conversion Complete | Prohibited | After completing the AD conversion for all of motor current x 3 and power supply voltage. |
| AD Trigger | — | Same frequency as PWM |

### 11.1.2 1-shunt Control




#### Carrier Waveform

| Type | Waveform |
|---|---|
| PWM | Triangular Wave (for all three phases) |
| AD Trigger | Sawtooth Wave |

#### Double Buffer Update Timing

| Data | Update Timing |
|---|---|
| PWN Cycle (RATE) | Carrier End |
| Duty Value (CMPU, CMPV, CMPW) | Carrier End |
| Trigger Position (TRGCMPx) | Carrier End |
| Output Setup (MDOUT) | Carrier End |

#### Interruption

| Interruption Request | Interruption | Timing |
|---|---|---|
| VE | Permitted | After completion of VE input schedule |
| PWM(PMD) | Prohibited | Once every one time, twice and four times. |
| AD Conversion Complete | Prohibited | After completion of AD conversion of power supply voltage |
| AD Trigger | — | Same frequency as PWM |

# 12. Peripheral Driver

## 12.1 Vector Engine (A-VE+)

### 12.1.1 Specifications of Functions

**IP_VE_init**

VE Initial Setup

**API:**

void IP_VE_init(TSB_VE_TypeDef* const VEx, VE_InitTypeDef* const _initdata)

**Parameters:**

**VEx:** Selection of VE address

**_initdata:** VE Initial Setup Data Structure

See VE_InitTypeDef for details.

**Function:**

Initial Setup of VE

**Supplement:**

Call up during VE suspension with prohibited interruption.

**Return Parameter:**

None

**VE_Start**

VE Start

**API:**

VE_Start(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Starts VE.

**Supplement:**

None

**Return Parameter:**

None

### VE_GetPhaseCurrent

Acquisition of Phase Current

**API:**

void

VE_GetPhaseCurrent(const ipderv_t* const _ipdrv,

q15_t* _ia, q15_t* _ib, q15_t* _ic)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_ia:** Setup of an address for the variable to store the phase-a current.

**_ib:** Setup of an address for the variable to store the phase-b current.

**_ic:** Setup of an address for the variable to store the phase-c current.

**Function:**

Acquires the current values for each phase.

The value of phase-U current is stored in phase-a, phase-V current in phase-b and phase-W current in phase-c.

**Supplement:**

None

**Return Parameter:**

None

### VE_GetCurrentAdcData

Acquisition of Current AD Value

**API:**

void

VE_GetCurrentAdcData(const ipdrv_t* const _ipdrv,

uint32_t* _adc_ia, uint32_t* _adc_ib, uint32_t* _adc_ic)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_adc_ia:** Setup of an address for a variable to store the AD value for the phase-a current.

**_adc_ib:** Setup of an address for a variable to store the AD value for the phase-b current.

**_adc_ic:** Setup of an address for a variable to store the AD value for the phase-c current.

**Function:**

Acquires the values of IAADCx, IBADCx, and ICADCx registers in the current AD values for each phase.

**Supplement:**

None

**Return Parameter:**

None

### VE_GetdataFromVEreg

Acquisition of VE Register Data

**API:**

void VE_GetdataFromVEreg(const ipdrv_t* const _ipdrv, vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Selecting an address for the vector control variable structure

**Function:**

Stores the values; motor voltage Vdc, d-axis voltage Vd, q-axis voltage Vq, d-axis current Id, and q-axis current Iq from the VE register to each variable.

At the time when the current is not detectable due to the duty width, the previously detected values of d-axis current Id and q-axis current Iq will be written in the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_GetPWM_DutyU

Acquisition of Phase-U Duty Value

**API:**

uint32_t VE_GetPWM_DutyU(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the value of phase-U duty register.

**Supplement:**

None

**Return Parameter:**

Phase-U Duty

### VE_GetPWM_DutyV

Acquisition of Phase-V Duty Value

**API:**

uint32_t VE_GetPWM_DutyV(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the value of phase-V duty register.

**Supplement:**

None

**Return Parameter:**

Phase-V Duty

### VE_GetPWM_DutyW

Acquisition of Phase-W Duty Value

**API:**

uint32_t VE_GetPWM_DutyW(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the value of phase-W duty register.

**Supplement:**

None

**Return Parameter:**

Phase-W Duty

### VE_GetPWM_DutyMed

Acquisition of Duty Median

**API:**

uint32_t VE_GetPWM_DutyMed(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the duty medians for phases U, V, and W.

**Supplement:**

None

**Return Parameter:**

Duty Median

### VE_GetPWM_Modulation

Acquisition of Modulation Type

**API:**

int VE_GetPWM_Modulation(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the modulation type.

**Supplement:**

None

**Return Parameter:**

Modulation Type 0: three-phase modulation, 1: two-phase modulation

### VE_GetSector

Acquisition of Current Sector

**API:**

uint32_t VE_GetSector(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the current sector value.

**Supplement:**

None

**Return Parameter:**

Current Sector Value [0 - 11]

### VE_GetShiftPWMState

Acquisition of Shift PWM Status

**API:**

int VE_GetShiftPWMState(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the shift PWM status.

**Supplement:**

None

**Return Parameter:**

Shift PWM Status 0: Ordinary PWM, 1: Shift PWM

### VE_GetOutPutMode

Acquisition of PWM Output Status

**API:**

int VE_GetOutputMode(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Acquires the PWM output status.

**Supplement:**

None

**Return Parameter:**

| | |
|---|---|
| PWM Status | OCRMD_OUT_OFF: Output OFF |
| | OCRMD_OUT_ON: Output ON |
| | OCRMD_OUT_ON_LOWPH: Only Lower Phase ON |

### VE_SetdataToVEreg_Stop

Data Setting to VE Register (Stop)

**API:**

void

VE_SetdataToVEreg_Stop(const ipdrv_t* const _ipdrv, const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of VE register during the stop status.

Initializes the current control gain integration register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Bootstrap

Data Setting to VE Register (Bootstrap)

**API:**

void

VE_SetdataToVEreg_ Bootstrap(const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of VE register during the bootstrap status.

Through the VE register, a waveform that is ON only at the L-side is output by setting to the two-phase modulation and setting the output voltage to 0.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Initposition_i

Data Setup to VE Register (Initposition current control type)

**API:**

void

VE_SetdataToVEreg_ Initposition_i (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of the current control type positioning status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Initposition_v

Data Setup to VE Register (Initposition voltage control type)

**API:**

void

VE_SetdataToVEreg_ Initposition_v (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of voltage control type positioning status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Force_i

Data Setup to VE Register (forced commutation, current control type)

**API:**

void
VE_SetdataToVEreg_Force_i (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of current control type forced commutation status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Force_v

Data Setting to VE Register (forced commutation, voltage control type)

**API:**

void
VE_SetdataToVEreg_Force_v(const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of voltage control type forced commutation status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Change_up

Data Setup to VE Register (change up)

**API:**

void
VE_SetdataToVEreg_ Change_up (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setting of change up status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Steady_A

Data Setup to VE Register (Steady)

**API:**

void

VE_SetdataToVEreg_Steady_A (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of steady status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetdataToVEreg_Emergency

Data Setup to VE Register (EMG)

**API:**

void

VE_SetdataToVEreg_ Emergency (const ipdrv_t* const _ipdrv,
const vector_t* const _motor)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_motor:** Setup of an address for the vector control variable structure.

**Function:**

Processes the setup of emergency status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetZeroCurrentData

Zero Current Setup

**API:**

void

VE_SetZeroCurrentData(const ipdrv_t* const _ipdrv,

uint32_t _z_ia, uint32_t _z_ib, uint32_t _z_ic)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_z_ia:** Setup of the phase-a zero current AD value

**_z_ib:** Setup of the phase-b zero current AD value

**_z_ic:** Setup of the phase-c zero current AD value

**Function:**

Setup of zero current AD value to the VE register.

**Supplement:**

None

**Return Parameter:**

None

### VE_SetVDCreg

Setup of Motor Voltage and Vdc

**API:**

void VE_SetVDCreg(const ipdrv_t* const _ipdrv, q15_t _dat)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_dat:** Setup of motor voltage.

**Function:**

Setup of motor voltage to the VE register.

**Supplement:**

None

**Return Parameter:**

None

**VE_SetSpwmMode**

Shift PWM Mode Setting

**API:**

void

VE_SetSpwmMode(TSB_VE_TypeDef* const VEx, uint8_t _dat);

**Parameters:**

**VEx:** Selection of VE address

**_dat:** Setup of shift PWM mode

**Function:**

Setup of shift PWM mode status to the VE register.

**Supplement:**

None

**Return Parameter:**

None

**VE_SetModulType**

Setup of Modulation Type

**API:**

void VE_SetModulType (const ipdrv_t* const _ipdrv, uint8_t _dat)

**Parameters:**

**_ipdrv:** Select an IP table address.

**_dat:** Setup of modulation type

**Function:**

Setup of modulation type to VE register.

**Supplement:**

None

**Return Parameter:**

None

### 12.1.2 Data Structure

**VE_InitTypeDef**

**Data Fields:**

uint8_t ve_ch: Vector Engine Channel

0: Channel 0

1: Channel 1

uint8_t shunt: Shunt Type
3:3-shunt
1:1-shunt
uint16_t pwmfreq: Carrier Frequency
uint16_t reptime: Repeat Frequency (1 to 15)
uint16_t trgmode: Start Trigger
TRGMODE_UNITA: Starts with an interruption when the ADCA PMD0 trigger synchronized conversion is complete.
TRGMODE_UNITB: Starts with an interruption when the ADCB PMD1 trigger synchronized conversion is complete.
uint16_t tpwm: PWM Cycle Time (phase interpolation)
A value for setting to the VETPWM register.
uint16_t idkp: d-Axis Current Control Proportional Gain
uint16_t idki: d-Axis Current Control Integration Gain
uint16_t iqkp: q-Axis Current Control Proportional Gain
uint16_t iqki: q-Axis Current Control Integration Gain
uint16_t zerooffset: Zero Current Offset

## 12.2 Motor Control Circuit (PMD)

### 12.2.1 Specifications of Functions

**IP_PMD_init**

PMD Initial Setup

**API:**

void
IP_PMD_init(TSB_PMD_TypeDef* const PMDx, PMD_InitTypeDef* const _initdata)

**Parameters:**

**PMDx:** Select a PMD address
**_initdata:** PMD Initial Setup Data Structure
See PMD_InitTypeDef for details.

**Function:**

Initial setup of PMD.

**Supplement:**

Call up during PMD suspension with prohibited interruption.

**Return Parameter:**

None

**PMD_GetEMG_Status**

Acquisition of EMG Protection Status

**API:**

emg_status_e PMD_GetEMG_Status(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv: Select an IP table address.**

**Function:**

Acquires the EMG protection status.

**Supplement:**

None

**Return Parameter:**

**emg_status_e:** EMG Protection Status

**cNormal:** Normal

**cEMGProtected:** Protected

**PMD_ReleaseEMG_Protection**

EMG Protection Status Released

**API:**

void PMD_ReleaseEMG_Protection(const ipdrv_t* const _ipdrv)

**Parameters:**

**_ipdrv:** Select an IP table address.

**Function:**

Releases the EMG protection status.

**Supplement:**

Even if this function is called up, the protection status will not be released unless the MDOUT is 0 and the EMG port is H.

**Return Parameter:**

None

### 12.2.2 Data Structure

**PMD_InitTypeDef**

**Data Fields:**

uint8_t **shunt:** Shunt Type
3:3 shunt
1:1 shunt

uint8_t **poll:** L-Side Polarity
0:L active
1:H active

uint8_t **polh:** H-Side Polarity
0:L active
1:H active
uint16_t **pwmfreq:** PWM Frequency
A value to be set up to PMDxMDPDR
uint16_t **deadtime:** Dead Time
A value to be set up to PMDxDTR

### 12.3 Analogue Digital Converter (ADC)

#### 12.3.1 Specifications of Functions

**IP_ADC_init**

ADC Initial Setup

**API:**

void IP_ADC_init(TSB_AD_TypeDef* const ADx, AD_InitTypeDef* const _initdata)

**Parameters:**

**ADx:** Select an ADC Address

**_initdata:** ADC Initial Setup Data Structure

See AD_InitTypeDef for details.

**Function:**

Initial setup of ADC

**Supplement:**

Call up during ADC suspension with prohibited interruption.

**Return Parameter:**

None

#### 12.3.2 Data Structure

**AD_InitTypeDef**

Data Fields:

uint8_t shunt: Shunt Type
3:3 shunt
1:1 shunt
uint8_t iuch: Phase-U Current Input AD Channel No. (3-shunt)
uint8_t ivch: Phase-V Current Input AD Channel No. (3-shunt)
uint8_t iwch: Phase-W Current Input AD Channel No. (3-shunt)
uint8_t idcch: DC Current Input AD Channel No. (1-shunt)
uint8_t vdcch: Motor Voltage Vdc Input AD Channel No.

uint8_t pmd_ch: Select a PMD Channel
cPMD: PMD Channel 0
cPMD: PMD Channel 1
cPMD: PMD Channel 2
uint8_t pints: Select Interruption for PM Trigger
cPINTS_B:ITTADxPDA
cPINTS_B:ITTADxPDB

### 12.4 Explanation of Constants

#### 12.4.1 Constants for Microcontroller equipped with A--VE (mcuip_drv.h)

**PMD**

| For MDCR Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cWPWMMD | W-phase mode | PWMMD_SWTOOTH | edge-aligned PWM, sawtooth wave |
| | | PWMMD_TRIANGLAR | center-aligned PWM, triangular wave |
| | | PWMMD_SWRROTH_REV | |
| | | PWMMD_TRAIN | |
| cVPWMMD | V-phase mode | PWMMD_SWTOOTH | edge-aligned PWM, sawtooth wave |
| | | PWMMD_TRIANGLAR | center-aligned PWM, triangular wave |
| | | PWMMD_SWRROTH_REV | |
| | | PWMMD_TRAIN | |
| cUPWMMD | phase-U mode | PWMMD_SWTOOTH | edge-aligned PWM, sawtooth wave |
| | | PWMMD_TRIANGLAR | center-aligned PWM, triangular wave |
| | | PWMMD_SWRROTH_REV | |
| | | PWMMD_TRAIN | |
| cDSYNCS | Double buffer update timing for the duty compare register and PWM period register. | DSYNCS_INTCYC | Depends on interrupt cycle setting |
| | | DSYNCS_CENTER | Updates at PWM carrier center |
| | | DSYNCS_END | Updates at PWM carrier end |
| | | DSYNCS_CENTER_END | Updates at both PWM carrier center and end |
| cDCMEN | Port output mode | DCMEN_DISABLE | Correction disable |
| | | DCMEN_ENABLE | Correction enable |
| cDTCREN | Dead time correction | DTCREN_DISABLE | Correction disable |
| | | DTCREN_ENABLE | Correction enable |
| cPWMSYNT | Port output mode | SYNTMD_0 | |
| | | SYNTMD_1 | |
| cPWMSPCFY | Duty mode | DTYMD_COMMON | three-phase common mode |
| | | DTYMD_INDEPENDENT | three-phase independent mode |
| cPWMINT | PWM interrupt timing | PINT_BOTTOM | Interrupt request when PWM counter PMD1MDCNT<MDCNT[15:0]> = |

| | | | |
|---|---|---|---|
| | | | 0x0001 |
| | | PINT_TOP | Interrupt request when PWM counter PMD1MDCNT<MDCNT[15:0]> = <MDPRD[15:0]> |
| cPWMINTPRD | PWM interrupt period | INTPRD_HALF | Interrupt request at every 0.5 PWM period |
| | | INTPRD_1 | Interrupt request at every PWM period |
| | | INTPRD_2 | Interrupt request at every 2 PWM periods |
| | | INTPRD_4 | Interrupt request at every 4 PWM periods |

| For MDPOT Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cSYNCS | MDOUT transfer timing for trigger synchronous. | SYNCS_ASYNC | Asynchronous |
| | | SYNCS_INTENC | when INTENCx (ENCx interrupt request) occurs |
| | | SYNCS_NTTB | when INTT32Ax0 (TMRBx interrupt request) occurs |
| | | SYNCS_CTRGO | when CTRGO(ENCx MCMP completed) occurs |
| cPSYNCS | MDOUT transfer timing for PWM synchronous. | PSYNCS_WRITE | Reflect when write |
| | | PSYNCS_CENTER | Reflect when PWM carrier center |
| | | PSYNCS_END | Reflect when PWM carrier end |
| | | PSYNCS_CENTER_END | Reflect when PWM carrier center and end |

| For PORTMD Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cPORTMD | Port control settings at tool break | PORTMD_ALLHIZ | Upper phases = High-z / lower phases = High-z |
| | | PORTMD_UHIZ_LON | Upper phases = High-z / lower phases = PMD output |
| | | PORTMD_UON_LHIZ | Upper phases = PMD output / lower phases = High-z |
| | | PORTMD_ALLON | Upper phases = PMD output / lower phases = PMD output |

| For TRGCR Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cTRGMD_3SHT | Trigger timing setting for 3-shunt | TRGMD_DIS | Trigger output disabled |
| | | TRGMD_DOWN | Trigger output at down-count match |
| | | TRGMD_UP | Trigger output at up-count match |
| | | TRGMD_UPDOWM | Trigger output at up-/down-count match |
| | | TRGMD_PEAK | Trigger output at PWM carrier peak |
| | | TRGMD_BOTTOM | Trigger output at PWM carrier |

| | | | |
|---|---|---|---|
| | | | bottom |
| | | TRGMD_PEAKBOTTOM | Trigger output at PWM carrier peak and bottom |
| cTRGMD_1SHT | Trigger timing setting for 1-shunt | TRGMD_DIS | Trigger output disabled |
| | | TRGMD_DOWN | Trigger output at down-count match |
| | | TRGMD_UP | Trigger output at up-count match |
| | | TRGMD_UPDOWM | Trigger output at up-/down-count match |
| | | TRGMD_PEAK | Trigger output at PWM carrier peak |
| | | TRGMD_BOTTOM | Trigger output at PWM carrier bottom |
| | | TRGMD_PEAKBOTTOM | Trigger output at PWM carrier peak and bottom |
| cBUFSYNC | Triger Buffer update timing | TRGBE_SYNC | Sync |
| | | TRGBE_ASYNC | Async<br>The value written to PMDTRGx is immediately reflected.) |
| cCARSEL | Selection of a comparison career | CARSEL_BASE | Compared by the base carrier |
| | | CARSEL_PHASE | Compared by TEMPREG0/1=U,REG2=V,REG3=W-phase carrier |

| For TRGMD Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cEMGTGE | Output enable in EMG protection state | EMGTGE_DISABLE | Disable trigger output in the protection state |
| | | EMGTGE_ENABLE | Enable trigger output in the protection state |

| For EMGCR Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cEMGCNT | EMG input detection time | 0 to 15 | The noise removes time value.<br>cEMGCNT × 16/fsys.<br>(resolution:200[ns] at 80MHz)<br>cEMGCNT ≥ 0 to 15.<br>When cEMGCNT=0, the noise filter is bypassed. |
| cINHEN | Tool break enable setting | INHEN_DISABLE | Tool break disable |
| | | INHEN_ENABLE | Tool break enable |
| cEMGMD | EMG protection mode select | EMGMD_ALLHIZ | All phases High-Z |
| | | EMGMD_UON_LHIZ | Lower phases High-Z |
| | | EMGMD_UHIZ_LON | Upper phases High-Z |
| | | EMGMD_ALLHIZ2 | All phases High-Z |

| For OVVCR Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cOVVCNT | OVV input detection time | 0 to 15 | The noise removes time value.<br>cEMGCNT × 16/fsys.<br>(resolution:200[ns] at 80MHz)<br>cEMGCNT ≥ 0 to 15. |

| | | | |
|---|---|---|---|
| | | | When cEMGCNT=0, the noise filter is bypassed. |
| cADIN1EN | ADC B monitor interrupt input enable | ADIN1EN_DISABLE | Disable input |
| | | ADIN1EN_ENABLE | Enable input |
| cADIN0EN | ADC A monitor interrupt input enable | ADIN0EN_DISABLE | Disable input |
| | | ADIN0EN_ENABLE | Enable input |
| cOVVMD | OVV protection mode | OVVMD_NOCON | No output control |
| | | OVVMD_UON_LOFF | All upper phases ON, all lower phases OFF |
| | | OVVMD_UOFF_LON | All upper phases OFF, all lower phases ON |
| | | OVVMD_ALLOFF | All phases OFF |
| cOVVISEL | OVV input select | OVVISEL_PORT | Port input |
| | | OVVISEL_ADC | ADC monitor signal |
| cOVVRS | OVV protection release | OVVRS_NORMAL | Disable automatic release of OVV protection |
| | | OVVRS_AUTO | Enable automatic release of OVV protection |

**VE**

cTADC Set up AD conversion time for 1-shunt shift PWM.

| For FMODE Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cSPWMMD | Selects a PWM shift mode | SPWMMD_SPWM1 | Shift 1 |
| | | SPWMMD_SPWM2U | Shift 2 (phase-U Normal PWM) |
| | | SPWMMD_SPWM2V | Shift 2 (V-phase Normal PWM) |
| | | SPWMMD_SPWM2W | Shift 2 (W-phase Normal PWM) |
| cCCVMD | Phase-change mode selection | CCVMD_RELATIVE | relative |
| | | CCVMD_ABSOLUTE | absolute |
| cPHCVDIS | Phase transformation | PHCVDIS_ENABLE | 2-3 phase transformation is enabled |
| | | PHCVDIS_DISABLE | 2-3 phase transformation is disabled |
| cVSLIMMD | Controls voltage scalar limitation | VSLIMMD_DIS | Scalar limitation is disabled |
| | | VSLIMMD_D | Limits the voltage on the d-axis |
| | | VSLIMMD_Q | Limits the voltage on the q-axis |
| | | VSLIMMD_DQ | dq proportional limitation |
| cMREGDIS | Keep the previous value of SIN/COS/SECTOR | MREGDIS_EFFECTIVE | Effective |
| | | MREGDIS_NOEFFECTIVE | No effective |
| cCRCEN | Trigger correction | CRCEN_DISABLE | Disable trigger correction. |

| | | | |
|---|---|---|---|
| | | CRCEN_ENABLE | Enable trigger correction. |
| cIDQSEL | De-coupling mode selection | IDQSEL_FEEDBACK | Feedback current(ID, IQ) |
| | | IDQSEL_INSTRUCTION | Instruction current(IDREF, IQREF) |
| cIAPLMD | Direction of current detection | IPLMD_SHUNT | Shunt |
| | | IPLMD_SENSOR | Sensor |
| cIBPLMD | Direction of current detection | IPLMD_SHUNT | Shunt |
| | | IPLMD_SENSOR | Sensor |
| cICPLMD | Direction of current detection | IPLMD_SHUNT | Shunt |
| | | IPLMD_SENSOR | Sensor |

| For MODE Register Setting | | | |
|---|---|---|---|
| Name of Constants | Description | Selected Data | Description |
| cIPDEN | Current polarity determination | IPDEN_DISABLE | Current polarity determination is disabled. |
| | | IPDEN_ENABLE | Current polarity determination is enabled. |
| cPMDDTCEN | Dead time correction control of the PMD | PMDDTCEN_DISABLE | Dead time correction of the PMD is disabled. |
| | | PMDDTCEN_ENABLE | Dead time correction of the PMD is enabled. |
| cPWMFLEN | Duty of 100% setting when the upper-limit | PWMFLEN_DISABLE | Duty of 100% setting is disabled. |
| | | PWMFLEN_ENABLE | Duty of 100% setting is enabled. |
| cPWMBLEN | Duty of 0% setting when the lower-limit | PWMBLEN_DISABLE | Duty of 0% setting is disabled. |
| | | PWMBLEN_ENABLE | Duty of 0% setting is enabled. |
| cNICEN | Non-interference control | NICEN_DISABLE | Non-interference control is disabled. |
| | | NICEN_ENABLE | Non-interference control is enabled. |
| cT5ECEN | Expansion control | T5ECEN_DISABLE | Expansion control is disabled. |
| | | T5ECEN_ENABLE | Expansion control is enabled. |
| cAWUMD | Specifies anti-windup (AWU) control | AWUMD_DISABLE | AWU control is disabled. |
| | | AWUMD_ENABLE4 | Substitutes the result from amount of limitation / 4 into the integral term. |
| | | AWUMD_ENABLE2 | Substitutes the result from amount of limitation / 2 into the integral term. |
| | | AWUMD_ENABLE1 | Substitutes the amount of limitation into the integral term. |
| cCLPEN | Phase clipping control | CLPEN_DISABLE | Clipping is disabled. |
| | | CLPEN_ENABLE | Clipping is enabled. |
| cATANMD | Specifies ATAN calculation control | ATANMD_DISABLE | Calculation is disabled. |
| | | ATANMD_IDQ | Calculates the declination angle on d-q coordinate of current vector. |
| | | ATANMD_EDQ | Calculates the declination angle on d-q coordinate of induced voltage vector. |
| cVDCSEL | Selects the supply voltage store | VDCSEL_VDC | Stored in VExVDC. |
| | | VDCSEL_VDCL | Stored in VExVDCL. |

| | | | |
|---|---|---|---|
| | register | | |
| cZIEN | Zero current detection | ZIEN_DISABLE | Disable |
| | | ZIEN_ENABLE | Enable |
| cPVIEN | Phase interpolation | PVIEN_DISABLE | Disable |
| | | PVIEN_ENABLE | Enable |

## 13. Temperature Measuring

### 13.1 Measuring Method

Computed to one decimal place by acquiring the AD value of Temp0 and using a linear equation between temperatures in reference to the values in the table.

e.g.)

20°C AD Judgment Value = 2146 (table) / 30°C AD Judgment Value = 1755 (table) / Temp0 = 1790

2146–1755 = 391 (fixed gradient within 20°C to 30°C)

2146–1790 = 356 (deviation from 20°C)

Interpolation 10°C × 356 / 391 = 9.1°C

20°C + 9.1°C = 29.1°C

## 14. Status Check Monitor

Monitoring of current rotation speed, etc. on the TeraTerm is provided.

- TeraTerm Communication Setting

115,200 bps, data 8-bit, stop bit 1-bit, without parity and without flow control.

### 14.1 Initial Display

The initial status below is transmitted one time after releasing the reset.

Initial Status

Control ch = CH0

Carrier Frequency = xxxxx Hz

Dead Time = x.x μs

Gate Active = H/H or L/L

Position Detect = 3Shunt

VDC Voltage = xx.x V

Inverter Temp = xx.x degree

UVW 0A Voltage = x.xx V/x.xx V/x.xx V

DAC Data = A:xx B:xx C:xx D:xx (DAC mode 0 is displayed)

Internal AMP = Yes or No

Direction = CW or CCW

Modulation = two-phase or three-phase

Key Operation = Volume SW

### 14.2 Display during Rotation

The current rotation speed is displayed after the occurrence of the motor rotation command.

The displays including when the rotation is stopped and when the EMG is detected are as follows:

During Rotation (every single second): xx Hz

Rotation --> Stop: 0 Hz

Rotation --> EMG Detection: EMG_S

### 14.3 DAC Mode Changeover Display

The following DAC modes are displayed when the DAC mode is changed over.

Mode 0: DAC Data = A: TMPREG0, B: TMPREG1, C: TMPREG2, D: theta.half[1]

Mode 1: DAC Data = A: Id_ref, B: Id, C:Iq,_ref, D: Iq

Mode 2: DAC Data = A: omega_com.half[1], B: omega.half[1], C: omega_def, D: Iq_ref

Mode 3: DAC Data = A: TMPREG0, B: Iq_ref, C: Id_ref, D: omega.half[1]

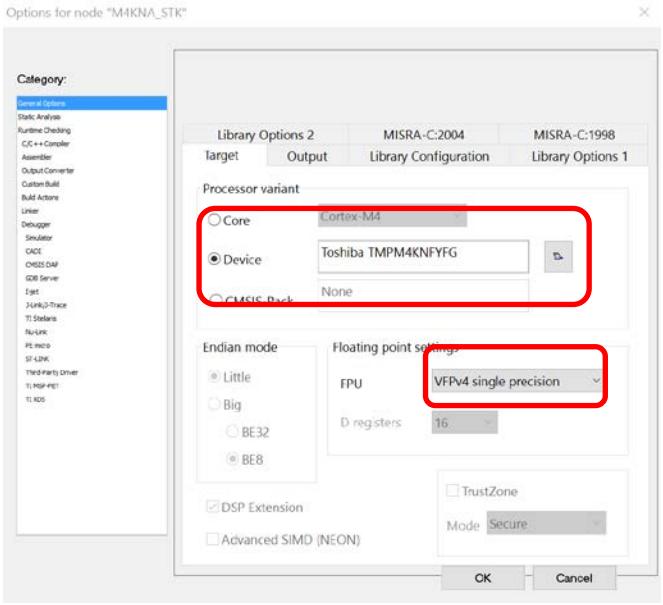
## 15. FAQ

### 15.1 When the EWARM project setup is deleted.

The setups may be deleted when a project is opened using an IDE of different version.
Conduct the setup again in accordance with the following:

1. Project Menu > Option > General Option

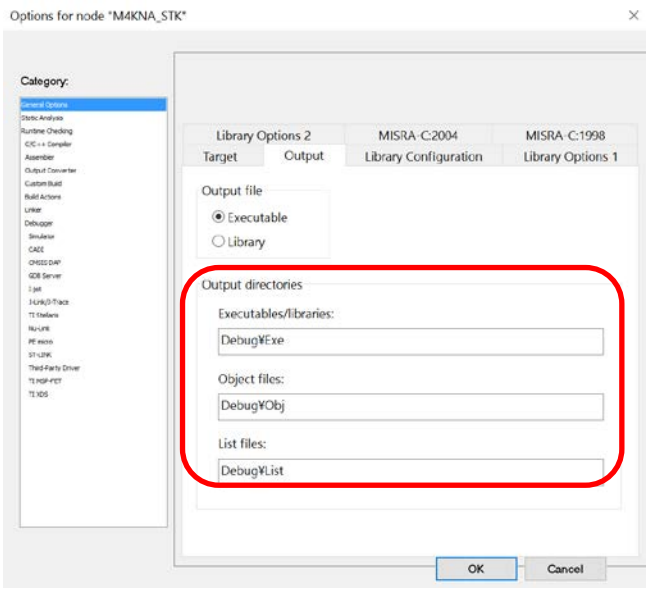
<Target> Tab




Select TMPM4KNFYAFG.

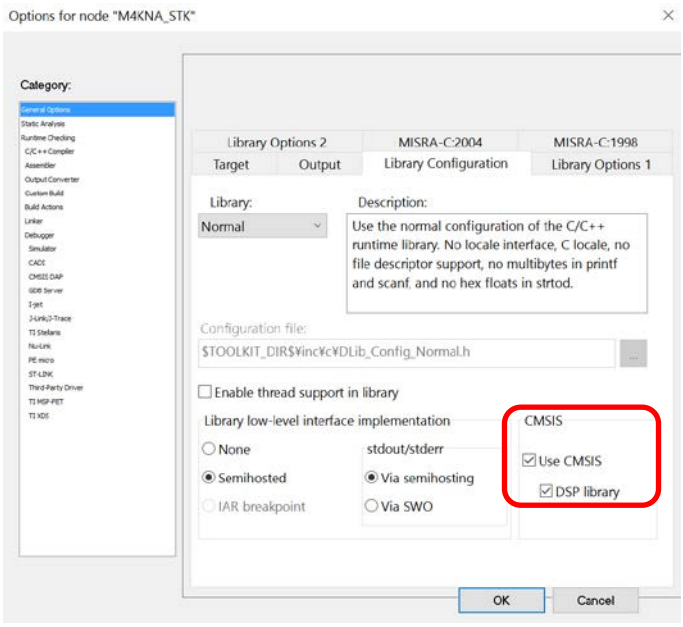
Select VFPv4 where the selection of FPU is possible.

<Output> Tab




Set up the output directories. Defaults will not be problematic but it is recommended to set up to a directory different from other projects.

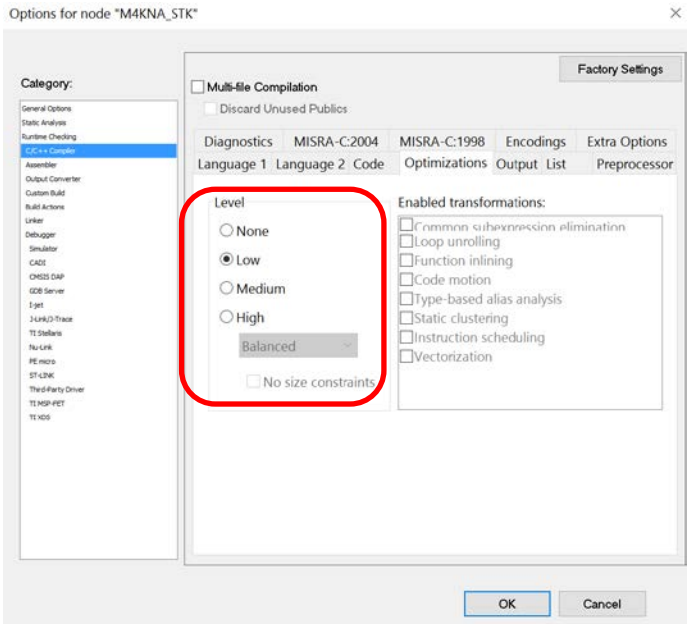
<Library Setup> Tab




Check "Use CMCIS" and "DSP Library"

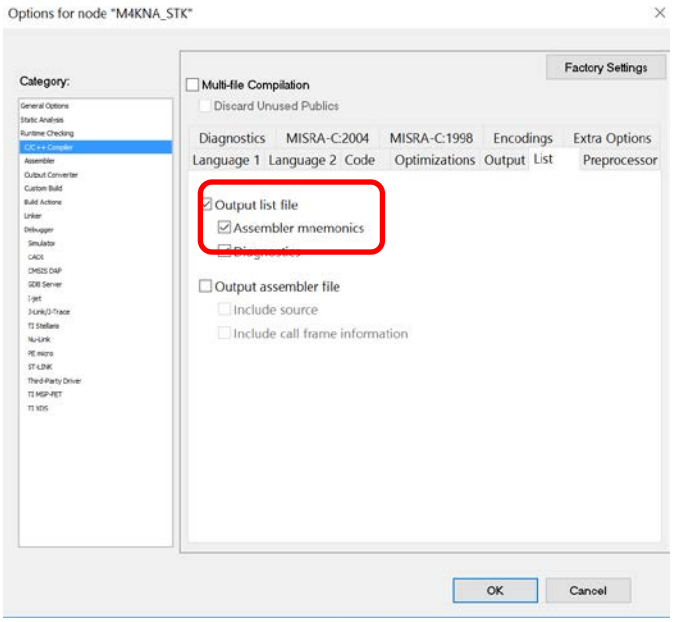
2. Project Menu > Option > C/C ++ Compiler

<Optimization> Tab



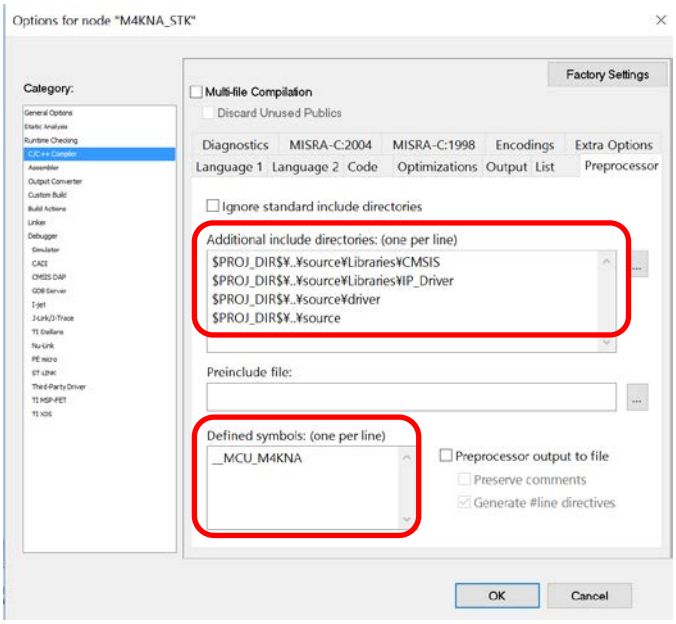

Set up the optimization level.

<List> Tab




Check "Output List File"
The compilation is possible without writing a check, but it would be convenient for evaluations if the list file is created.

<Pre-Processor> Tab

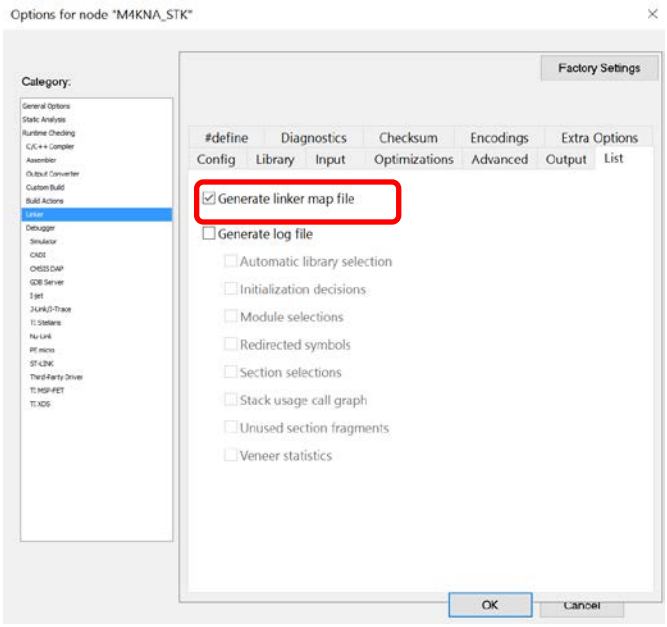



Add the setups below in the additionally included directories and the symbol definitions.

[TMPM4KNA]
- Additionally Included Directory
$PROJ_DIR$\..\source
$PROJ_DIR$\..\source\driver
$PROJ_DIR$\..\source\Libraries\CMSIS
$PROJ_DIR$\..\source\Libraries\IP_Driver
- Symbol Definition
__MCU_M4KNA

3. Project Menu > Option > Linker

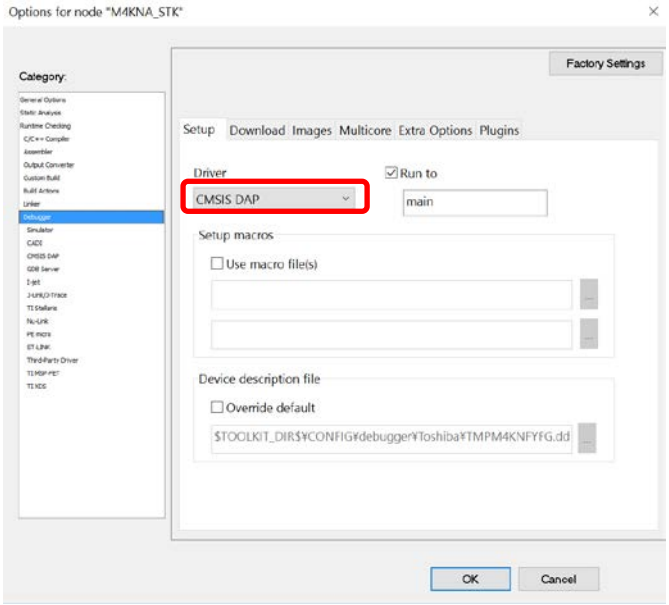
<List> Tab




Check "Display Linker Map File"
The compilation is possible without writing a check but it would be convenient for evaluations if the map file is created.

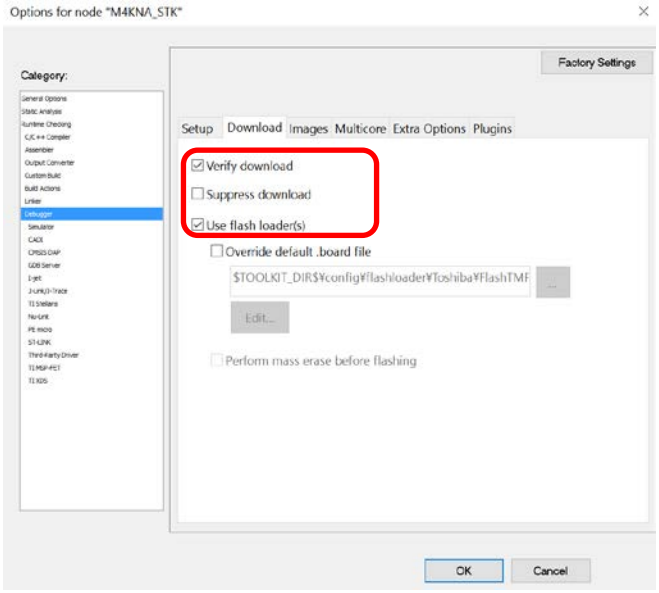
4. Project Menu > Option > Debugger

<Setup> Tab




Select a tool to use.
Select "CMSIS-DAP" for boards equipped with an onboard ICE.

<Download> Tab



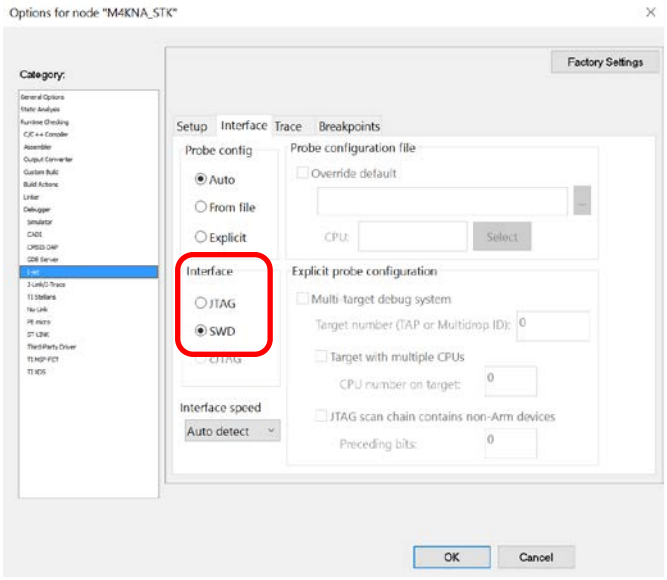

Check "Verify"

Check "Use Flash Loader"

5. Project Menu > Option > MSIS DAP or I-jet/JTAGjet

- I-jet

<Interface> Tab




Select "SWD"

# 16. Appendix

## 16.1 Fixed Decimal Point Processing

The decimal arithmetic is executed with fixed decimal point in this software. A general explanation is given on the fixed decimal point computation.

## 16.2 Normalization

The normalization is to deform the data in accordance with the certain rules for ease of utilization.
In this application note, the most significant bit is used as the sign bit (0: positive, 1: negative) and a decimal point is placed between the next bit, and normalized in such a way that the maximum possible value (0 x 7fff) for the data will be "1" and the minimum value (0 x 8000) will be "-1."

e.g.)

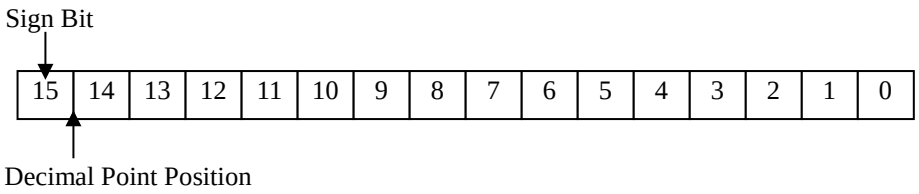



Fig. 3 Example of 16-Bit Data3

In this application note, the maximum value of current data is defined as cA_Max: For example, A_Max(A) when a 16 bit current data is 0x7fff and -A_Max(A) for the case of 0x8000.

## 16.3 Data Format

The fixed decimal point computation is used in the motor controller of this application.
The number of bits in the decimal fraction is expressed in Q format in the fixed decimal point computation.
Basically for the case of 16-bit data, computed using Q15 format (15 bits for decimal fraction) and Q31 format for the case of 32-bit data (31 bits for decimal fraction).
The value that can be displayed in the decimal format depends on the format.

Table 4 Single Precision (16-bit) Decimal Fraction Format4

| Q Format | Number of Bits for Decimal Fraction | Positive Maximum Value (0x7FFF) | Negative Maximum Value (0x8000) |
|---|---|---|---|
| Q15 | 15 | 0.999969482421875 | -1 |
| Q14 | 14 | 1.999938964843750 | -2 |
| Q13 | 13 | 3.999877929687500 | -4 |
| Q12 | 12 | 7.999755859375000 | -8 |
| Q11 | 11 | 15.999511718750000 | -16 |
| Q10 | 10 | 31.999023437500000 | -32 |
| Q9 | 9 | 63.998046875000000 | -64 |
| Q8 | 8 | 127.996093750000000 | -128 |

| | | | |
|---|---|---|---|
| Q7 | 7 | 255.992187500000000 | -256 |
| Q6 | 6 | 511.984375000000000 | -512 |
| Q5 | 5 | 1023.968750000000000 | -1024 |
| Q4 | 4 | 2047.937500000000000 | -2048 |
| Q3 | 3 | 4095.875000000000000 | -4096 |
| Q2 | 2 | 8191.750000000000000 | -8192 |
| Q1 | 1 | 16383.500000000000000 | -16384 |
| Q0 | 0 | 32767.000000000000000 | -32768 |

Table 5 Double Precision (32-bit) Decimal Fraction Format5

| Q Format | Number of Bits for Decimal Fraction | Positive Maximum Value (0x7FFFFFFF) | Negative Maximum Value (0x80000000) |
|---|---|---|---|
| Q31 | 31 | 0.999999999534338 | -1 |
| Q30 | 30 | 1.999999999068670 | -2 |
| Q29 | 29 | 3.999999998137350 | -4 |
| Q28 | 28 | 7.999999996274700 | -8 |
| Q27 | 27 | 15.999999992549400 | -16 |
| Q26 | 26 | 31.999999985098800 | -32 |
| Q25 | 25 | 63.999999970197600 | -64 |
| Q24 | 24 | 127.999999940395000 | -128 |
| Q23 | 23 | 255.999999880790000 | -256 |
| Q22 | 22 | 511.999999761581000 | -512 |
| Q21 | 21 | 1023.999999523160000 | -1024 |
| Q20 | 20 | 2047.999999046320000 | -2048 |
| Q19 | 19 | 4095.999998092650000 | -4096 |
| Q18 | 18 | 8191.999996185300000 | -8192 |
| Q17 | 17 | 16383.999992370600000 | -16384 |
| Q16 | 16 | 32767.999984741200000 | -32768 |
| Q15 | 15 | 65535.999969482400000 | -65536 |
| Q14 | 14 | 131071.999938965000000 | -131072 |
| Q13 | 13 | 262143.999877930000000 | -262144 |
| Q12 | 12 | 524287.999755859000000 | -524288 |
| Q11 | 11 | 1048575.999511720000000 | -1048576 |
| Q10 | 10 | 2097151.999023440000000 | -2097152 |
| Q9 | 9 | 4194303.998046870000000 | -4194304 |
| Q8 | 8 | 8388607.996093750000000 | -8388608 |
| Q7 | 7 | 16777215.992187500000000 | -16777216 |
| Q6 | 6 | 33554431.984375000000000 | -33554432 |
| Q5 | 5 | 67108863.968750000000000 | -67108864 |
| Q4 | 4 | 134217727.937500000000000 | -134217728 |
| Q3 | 3 | 268435455.875000000000000 | -268435456 |
| Q2 | 2 | 536870911.750000000000000 | -536870912 |
| Q1 | 1 | 1073741823.500000000000000 | -1073741824 |
| Q0 | 0 | 2147483647.000000000000000 | -2147483648 |

### 16.4 Computation with Fixed Decimal Point

In the four arithmetic operations of fixed decimal point computation, addition and subtraction are performed as if they were integers, but in multiplication and division, the decimal point position of the result of computation will be shifted; accordingly, it is necessary to restore the original decimal point position.

(1) Multiplication

In the case of multiplication between decimal fraction formats, for example, when multiplying Q15 format data, the result will be in the double precision Q30 format. When the Q31 format data is required, a double precision Q31 format is acquired by the left shifting of computation result by 1 bit.

$Q15 * Q15 = 2^{-15} * 2^{-15} = 2^{(-15 + -15)} = 2^{-30} = Q30$

(2) Division

In the case of division between decimal fraction formats, for example, when the Q31 format is divided by the Q15 format, the result will be in the Q16 format. When the Q15 format data is required, the Q15 format data is acquired by right shifting of divisor by 1 bit before computing.

$Q31 / Q15 = 2^{-31} / 2^{-15} = 2^{(-31 - (-15))} = 2^{-16} = Q16$

## 17. Revision History

| Date | Rev. | Description |
|---|---|---|
| 2021-11-08 | 1.0 | First release |

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