R01AN3596EJ0110
Rev.1.10
Oct 02, 2017

# RL78/G1F

## Sensorless detection of initial position of the rotor


## Summary

This application note aims at explains sample programs of sensorless detection of initial position of the rotor in a permanent magnetic synchronous motor using the RL78/G1F microcontroller and how to use the motor control development support tool, 'Renesas Motor Workbench'.

These sample programs are only to be used as reference and Renesas Electronics Corporation does not guarantee the operations. Please use them after carrying out a thorough evaluation in a suitable environment.

To operate the program targeted by this application note, it is necessary to modify the circuit of Renesas Solution Starter Kit 24V Motor Control Evaluation System for RX23T. If you modify the circuit, other programs for Renesas Solution Starter Kit 24V Motor Control Evaluation System for RX23T will not be able to operate. Regarding circuit modification, we do not guarantee the operation of this program after amendment.


## Operation checking device

Operations of the sample programs have been checked by using the following device.

- RL78/G1F(R5F11BLEAFB)

## Target sample programs

The target sample programs of this application note are as follows.

RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CA_V110 (IDE：CS+ for CA,CX)

RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CC_V110 (IDE：CS+ for CC)

RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_E2S_CC_V110 (IDE：$e^2$studio)

RL78/G1F Detection initial position of the rotor sample program for
24V Motor Control Evaluation System and RL78/G1F CPU CARD

## Reference


- RL78/G1F Group User's Manual: Hardware (R01UH0516EJ0110)
- Renesas Solution Starter Kit 24V Motor Control Evaluation System for RX23T User's Manual (R20UT3697EJ0110)
- RL78/G1F CPU Card User's Manual (R12UZ0014EJ0100)
- Renesas Motor Workbench V.1.00 User's Manual (R21UZ0004EJ0100)

## Contents

# 1. Overview

This application note explains how to implement sample program the sensorless detection of initial position of the rotor for permanent magnetic synchronous motor (PMSM) using the RL78/G1F microcontroller and how to use the motor control development support tool, 'Renesas Motor Workbench'.

## 1.1 Development environment

Table 1-1 and Table 1-2 show development environment of the programs explained in this application note.

**Table 1-1 Development Environment (H/W)**

| Microcontroller | Evaluation board | Motor |
|---|---|---|
| RL78/G1F (R5F11BLEAFB) | 24V inverter board (Note 1) and RL78/G1F CPU Card (Note 2) | TG-55L (Note 3) |

**Table 1-2 Development Environment (S/W)**

| CS+ version | Tool chain version |
|---|---|
| V4.00.01 | CA78K0R V1.72 |
| V6.00.00 | CC-RL V1.05.00 |

| $e^2$studio version | Tool chain version |
|---|---|
| 5.4.0.018 | CC-RL V1.05.00 |

For purchase and technical support contact, Sales representatives and dealers of Renesas Electronics Corporation.

Notes: 1. 24V inverter board (RTK0EM0001B00012BJ) is a product of Renesas Electronics Corporation.

2. You can use below two kinds of RL78/G1F CPU Card

- RTK0EML240C03000BJ : Renesas Electronics
- T5103 : Desk Top Laboratories Inc. Desk Top Laboratories Inc. (http://desktoplab.co.jp/)

3. TG-55L is a product of TSUKASA ELECTRIC.
TSUKASA ELECTRIC. (http://www.tsukasa-d.co.jp/en/)

## 1.2 Modifying the Evaluation Board

For the sample programs in this application note, the 24V Inverter Board and RL78/G1F CPU Card should be modified according to below explanations.

(1) Modification of the 24V Inverter Board

(a) Change 3-Shunt to 1-Shunt to detect the current in one port.

I. Remove R72 and R97.
II. Connect TH1, TH2 and TH3.

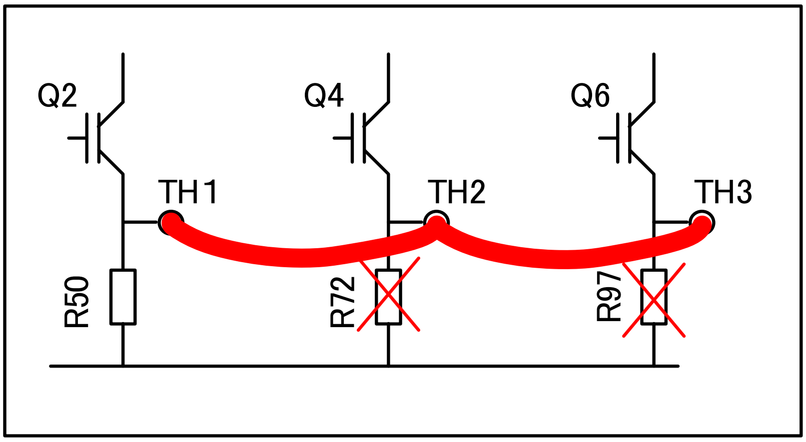
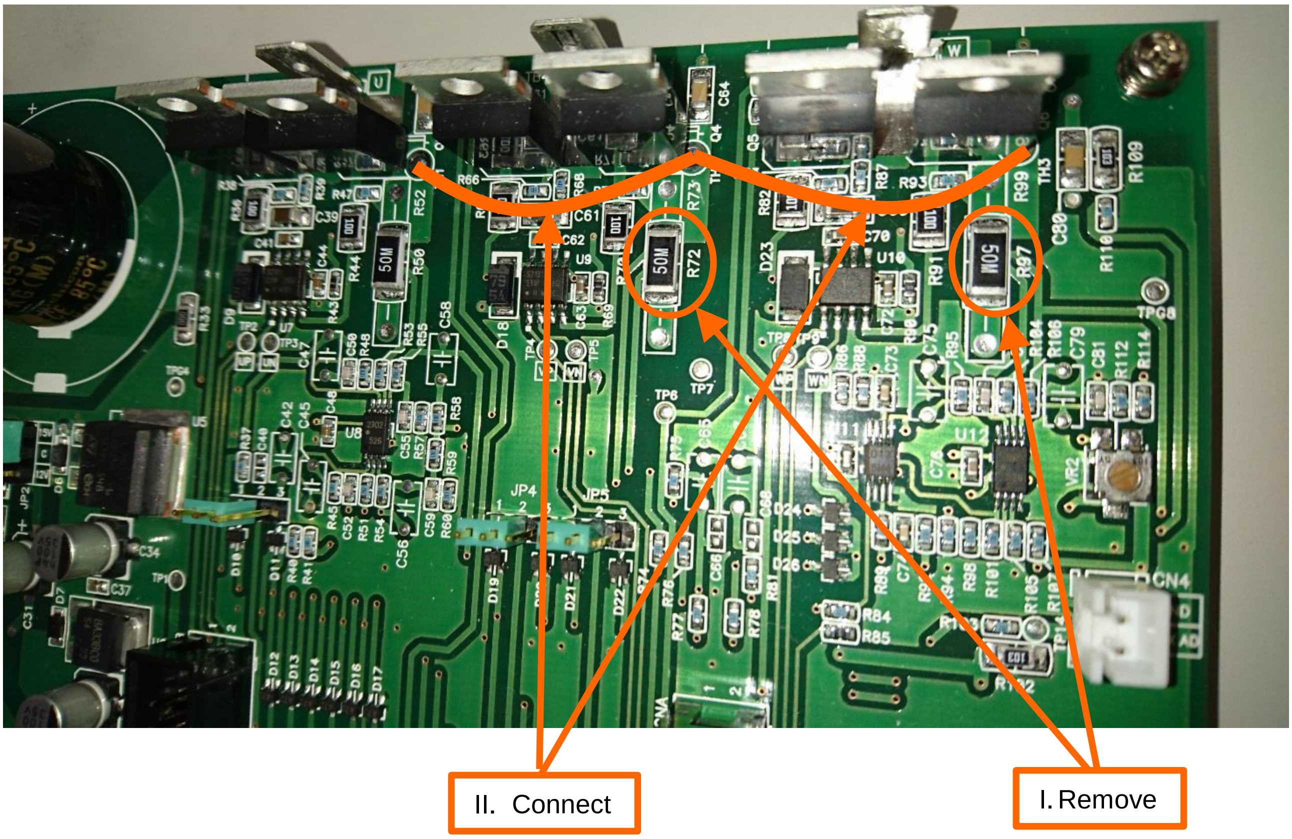



**Figure 1-1 Change 3-shunt to 1-shunt**



(b) Modification for the circuit to sensing voltage of each phase, because original parameter is not suitable.

I. Mount 10k Ohms on R34, R61, R79.
II. Mount 510 Ohms on R67.
III. Change resisters R42, R46 and R49 from 470 Ohms to 1.5k Ohms
IV. Mount 0.33uF on C60.
V. Remove C49/C51/C53.

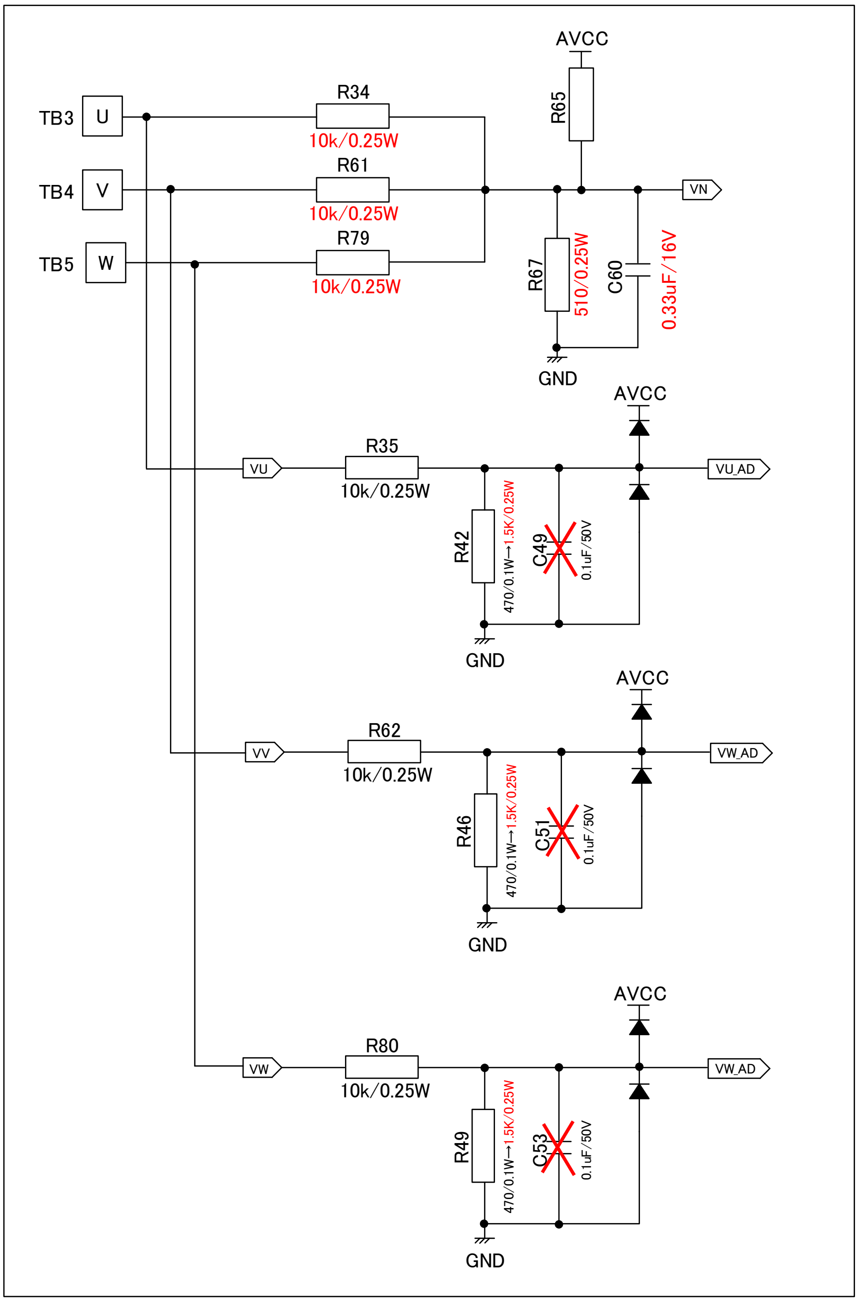
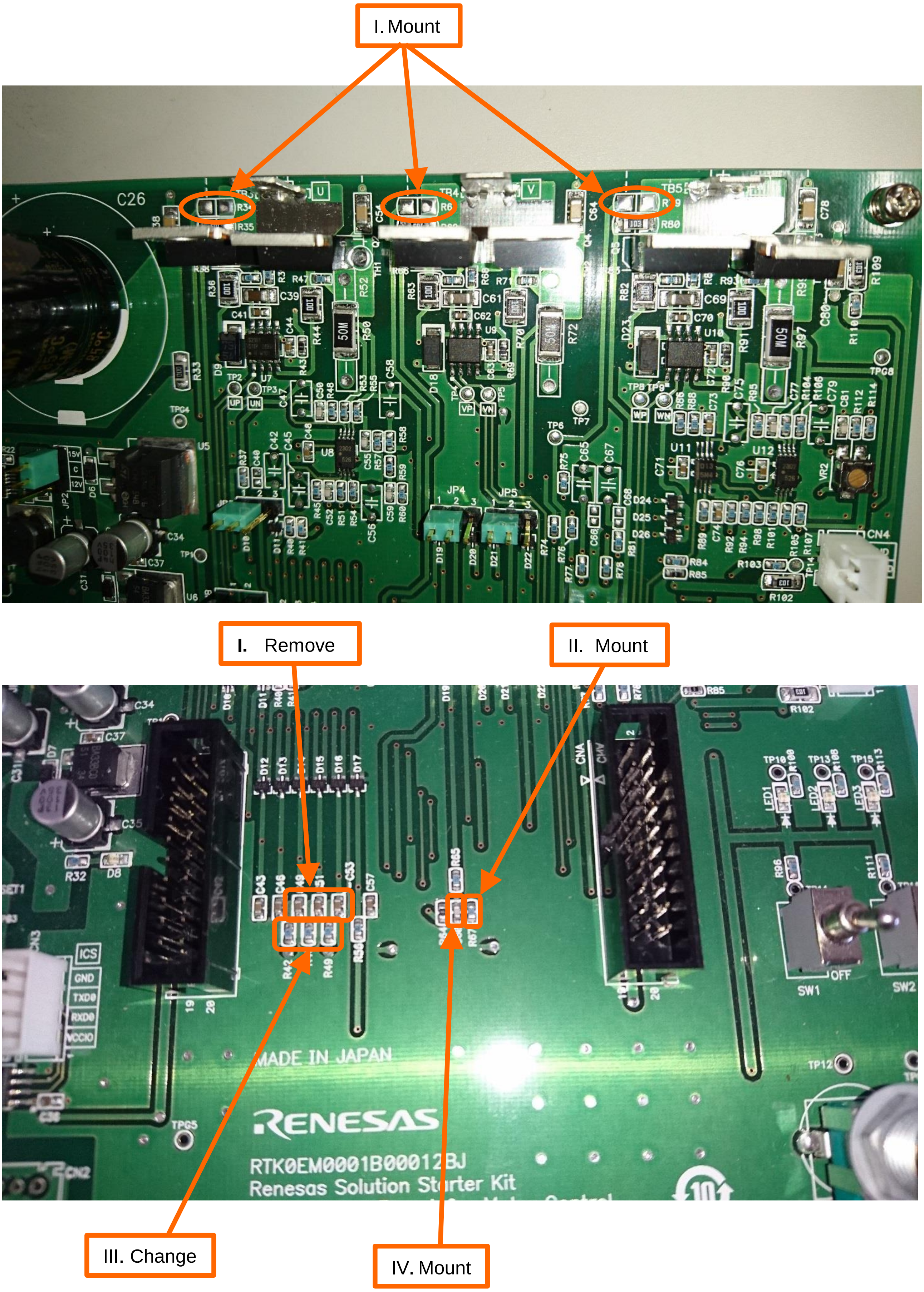



**Figure 1-2 Modification for the circuit to sensing voltage of each phase**


I. Mount
I. Remove
II. Mount
III. Change
IV. Mount
MADE IN JAPAN
RENESAS
RTK0EM0001B00012BJ
Renesas Solution Starter Kit

(2) Modification of the RL78/G1F CPU Card (T5103)

This modification is no need for Renesas CPU Card "RTK0EML240C03000BJ".

I. Remove C3, C5, C6, C7, C8, C13, C14, C18, C19 and C22.
II. Change C4 1000pF -> 0.1uF.
III. Add the circuits which are explained by red items in below Figure 1-3.

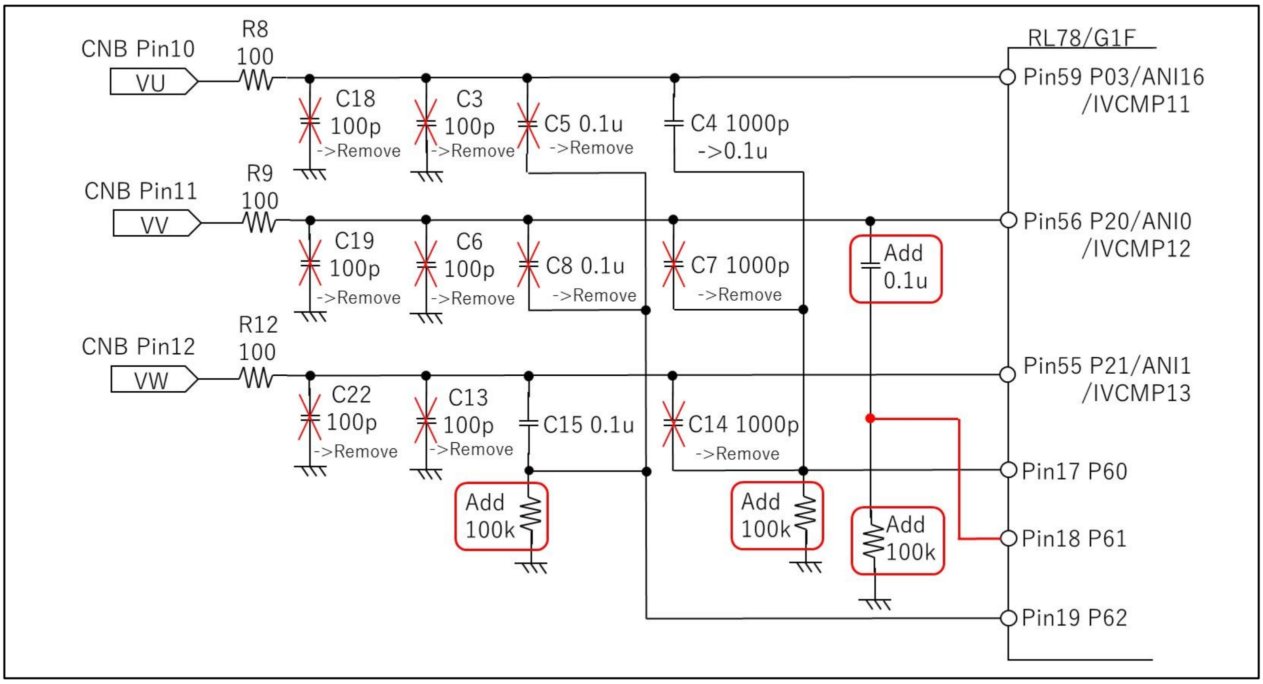



**Figure 1-3 Modification of CPU card (T5103)**

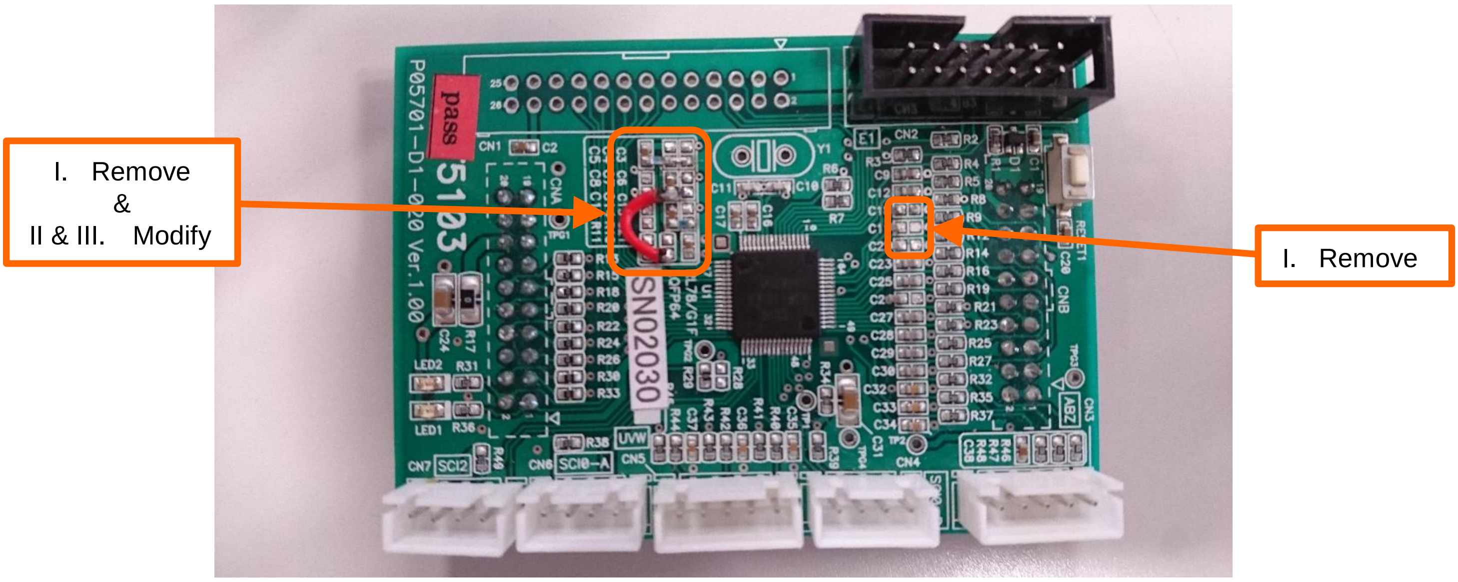



**Figure 1-4 Sample of the modification**

# 2. System overview

Overview of this system is explained below.

## 2.1 Hardware configuration

The hardware configuration is shown below.

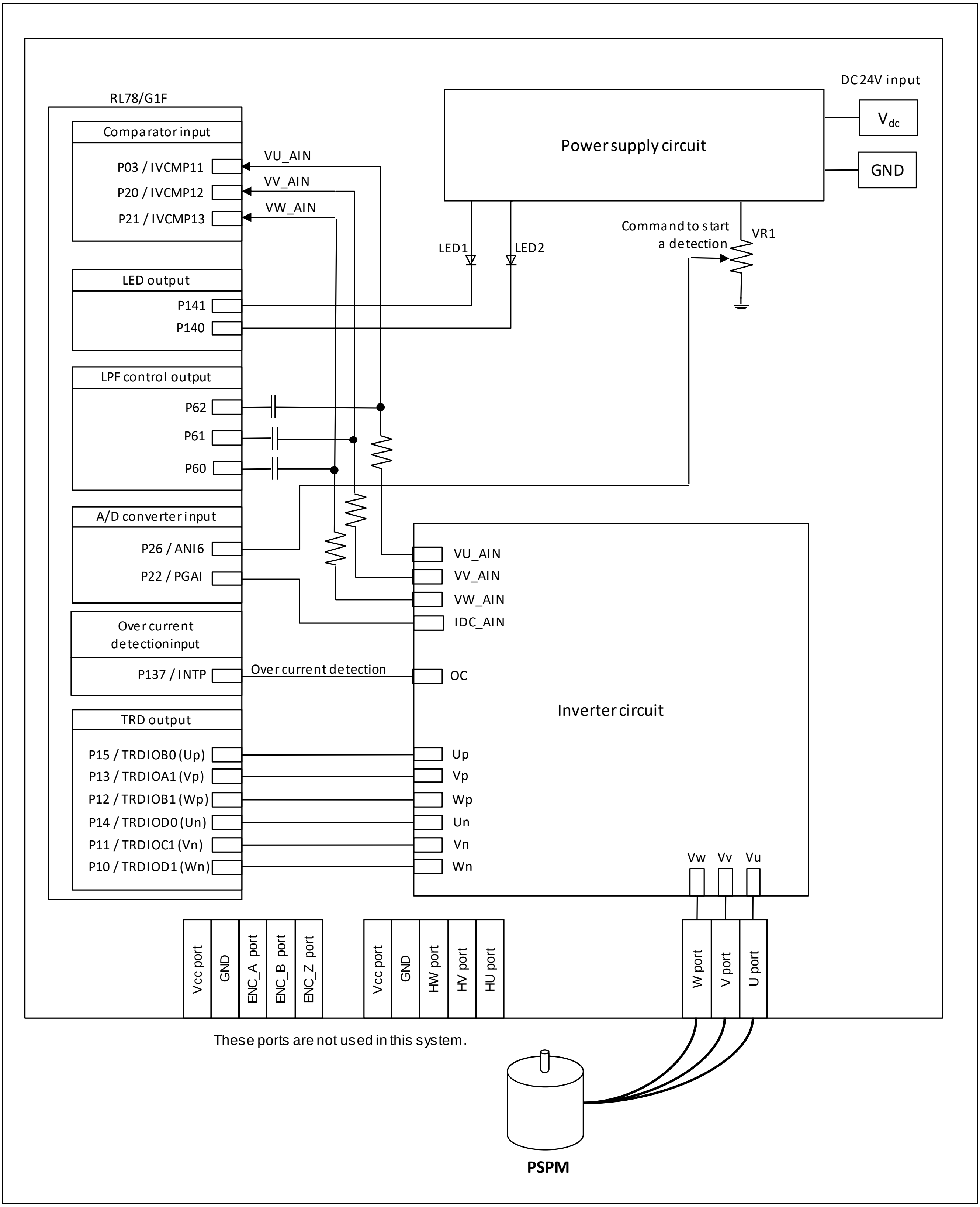



**Figure 2-1 Hardware Configuration Diagram**

## 2.2 Hardware specifications

### 2.2.1 User interface

Table 2-1 is a list of user interfaces of this system.

**Table 2-1 User Interface**

| Item | Interface component | Function |
|---|---|---|
| Start detection | Variable resistance (VR1) | Start the sequence to detect the initial position |
| LED1 | Yellow green LED | - When the detection finished without error: ON<br>- Error happened: OFF |
| LED2 | Yellow green LED | - When the detection finished with a trouble: ON<br>- When the detection finished without error: OFF |
| RESET | Push switch (RESET1) | System reset |

Table 2-2 is a list of port interfaces of RL78/G1F microcontroller of this system.

**Table 2-2 Port Interface**

| R5F11BLEAFB Port name | Function |
|---|---|
| P26 / ANI6 | Start the detection (analog values) |
| P141 | LED1 ON/OFF control |
| P140 | LED2 ON/OFF control |
| P03 / IVCMP11 | U Phase voltage measurement(use the comparator) |
| P20 / VCMP12 | V Phase voltage measurement(use the comparator) |
| P21 / IVCMP13 | W Phase voltage measurement(use the comparator) |
| P22 / PGAI | Shunt current input |
| P15 / TRDIOB0 | PORT output / PWM output ($U_p$) |
| P13 / TRDIOA1 | PORT output / PWM output ($V_p$) |
| P12 / TRDIOB1 | PORT output / PWM output ($W_p$) |
| P14 / TRDIOD0 | PORT output / PWM output ($U_n$) |
| P11 / TRDIOC1 | PORT output / PWM output ($V_n$) |
| P10 / TRDIOD1 | PORT output / PWM output ($W_n$) |
| P137 / INTP0 | PWM emergency stop input at the time of overcurrent detection (use an external circuit) |

### 2.2.2 Peripheral functions

Table 2-3 is a list of peripheral functions used in this system.

**Table 2-3 List of Peripheral Functions**

| Peripheral Function | Purpose |
|---|---|
| 10bit A/D converter | - Command to start the detection<br>- Measurement of shunt current |
| Timer Array Unit(TAU) | Delay timer at the estimation of rotor's angle |
| Timer RD(TRD) | Complementary PWM output<br>(only pulse output to measurement) |
| Timer RX(TRX) | Free-running timer to measure the inductance effect |
| Interval Timer | 1[ms] interval timer |
| Comparator CMP1 | Detection of voltage reaching to a reference |
| Programmable Gain Amp (PGA) | Amplitude the shunt current input |
| External Interrupt (INTP0) | Overcurrent detection |

(1) 10-bit A/D converter

Measure the voltage by VR1 input to start the sequence to detect the initial position.

And also measure the shunt current at the detection of the direction of polarity.

The operation mode is set as below.

The channel selection mode: the select-mode
The conversion operation mode: the one-shot conversion mode.

And software trigger is used.

(2) Timer Array Unit (TAU)

The channel 3 is used as delay timer to start the process to estimate the rotor's angle.

(3) Timer RD (TRD)

Output signals with using the Complementary PWM Mode ("High" active). Output ports are also used as general ports.

(4) Timer RX (TRX)

Timer RX(TRX) is used as free-running timer for the measurement of inductance effect when the estimation of the rotor's angle. Start timing of Timer RX is synchronous with Timer RD0 of TRD. And the counter is transferred to the buffer at CMP1 interrupt.

(5) Interval Timer

Interval Timer is used as 1[ms] interval timer.

(6) Comparator CMP1

CMP1 is used to detect each phase voltage reaches the reference at the estimation of the rotor's angle. The interrupt is not used.

(7) Programmable Gain Amp (PGA)

PGA is used to amplitude the shunt current at the detection of the rotor's polarity.

(8) External interrupt (INTP0)

An overcurrent is detected by an external circuit.

## 2.3 Software structure

### 2.3.1 Software file structure

The folder and file configurations of the programs are given below.

**Table 2-4 Folder and File Configuration**

| Project | Folder | File | Content |
|---|---|---|---|
| RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CA_V110<br><br>RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CC_V110<br><br>RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_E2S_CC_V110 | inc | main.h | Main function, user interface control header |
| | | mtr_common.h | Common definition header |
| | | mtr_ctrl_mrssk.h | Board dependent processing part header |
| | | mtr_ctrl_rl78g1f.h | RL78/G1F dependent processing part header |
| | | mtr_ctrl_rl78g1f_mrssk.h | RL78/G1F and board dependent processing part header |
| | | mtr_spm_detect_init_posi.h | Detection process of the initial rotor position part header |
| | ics | ics_RL78G1F.obj | Library for ICS |
| | | ics_RL78G1F_Lx.h | Header for ICS |
| | | RL78G1F_vector.c | Interrupt processing part for ICS |
| | prj | RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CA_V110.dr | Link directive file (Note) |
| | src | main.c | Main function, user interface control |
| | | mtr_ctrl_mrssk.c | Board dependent processing part |
| | | mtr_ctrl_rl78g1f.c | RL78/G1F dependent processing part |
| | | mtr_ctrl_rl78g1f_mrssk.c | RL78/G1F and board dependent processing part |
| | | mtr_interrupt.c | Interrupt handler |
| | | mtr_spm_detect_init_posi.c | Detection process of the initial rotor position |

Notes: Link directive file is included only in RL78G1F_MRSSK_SPM_DETECT_INIT_POSI_CSP_CA_V110.

### 2.3.2 Module configuration

Figure 2-2 and Table 2-5 show module configuration.

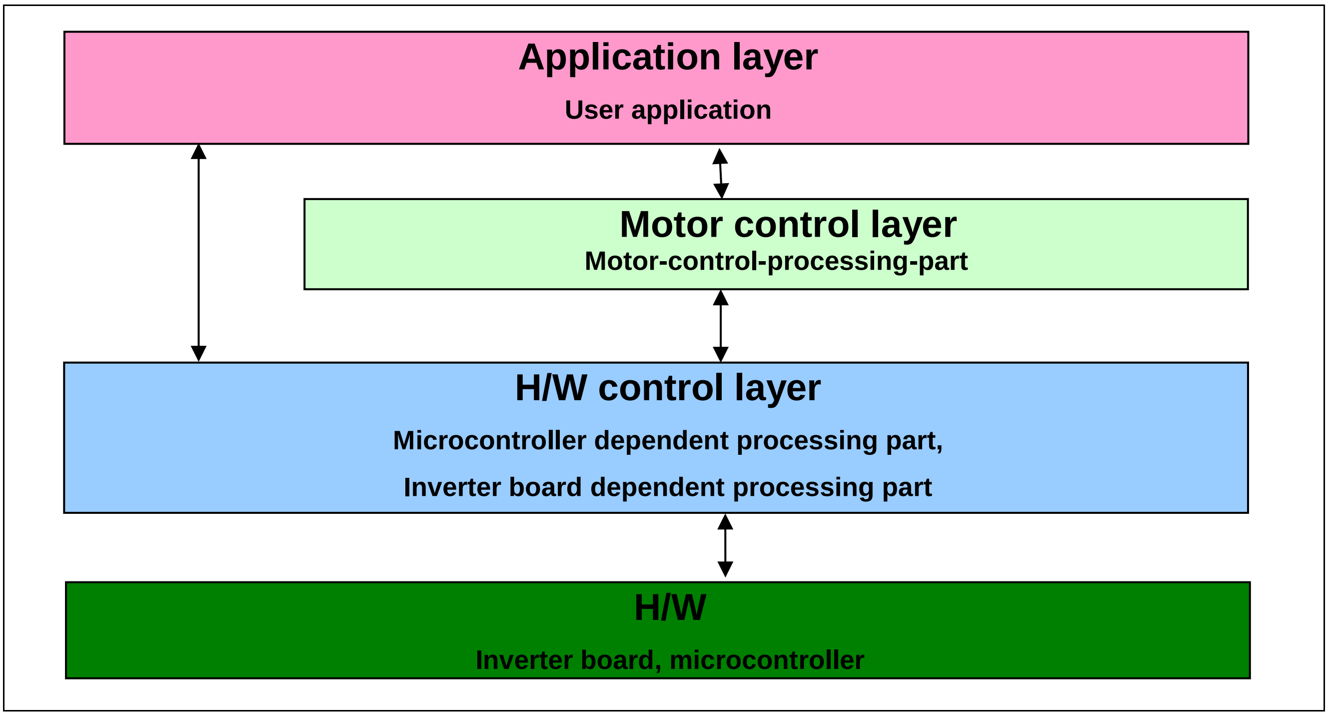



**Figure 2-2 Module Configuration**

**Table 2-5 Module Configuration**

| Layers | File name |
|---|---|
| Application layer | main.c |
| Motor control layer | mtr_spm_detect_init_posi.c<br>mtr_interrupt.c(Note) |
| H/W control layer | mtr_ctrl_rl78g1f_mrssk.c<br>mtr_ctrl_rl78g1f.c<br>mtr_ctrl_mrssk.c<br>mtr_interrupt.c(Note) |

Note: "mtr_interrupt.c" is belong to the motor control layer and H/W control layer.

## 2.4 Software specifications

Table 2-6 shows the basic specifications of the software.

**Table 2-6 Basic Specifications of Software**

| Item | Content |
|---|---|
| Detection method | - Estimate the rotor’s angle with the linkage function between a timer and a comparator in RL78/G1F<br>- Detect the rotor’s polarity with the magnetic saturation |
| Input voltage | DC24[V] |
| Main clock frequency | CPU clock : $f_{CLK}$ 32[MHz]<br>TRX clock : $f_{HOCO}$ 64[MHz] |
| Control cycle | Detection sequence is implemented in 1 [ms] cyclic timer. |
| Optimization | Default |

# 3. Descriptions of the control program

The target sample programs of this application note are explained here.

## 3.1 Contents of control

### 3.1.1 Detection start/stop

The detection process is started by input from MRSSK Support Tool or VR1 is rotated clockwise over 60degrees from the center position once.

At power on stage (reset start) the detection process is automatically started.

### 3.1.2 Estimate the rotor's angle with the linkage function between TimerRX and comparator

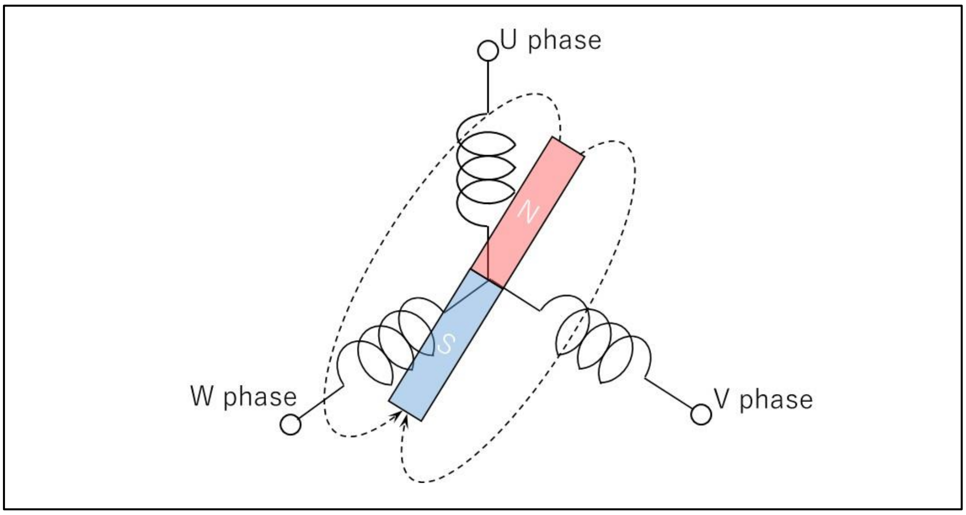



**Figure 3-1 Relation between the rotor's angle and each phase**

In Figure 3-1, each phase receives different magnetic effect from the rotor according to its angle. At this time, if voltage is excited through U->V, V->W, W->V path, the voltage of the lower phase (i.e. in U->V case, V phase) reaches the excited voltage in different time, because the current is received magnetic effect from the rotor. In Figure 3-1, when voltage is excited W->U path, the effect maybe biggest.

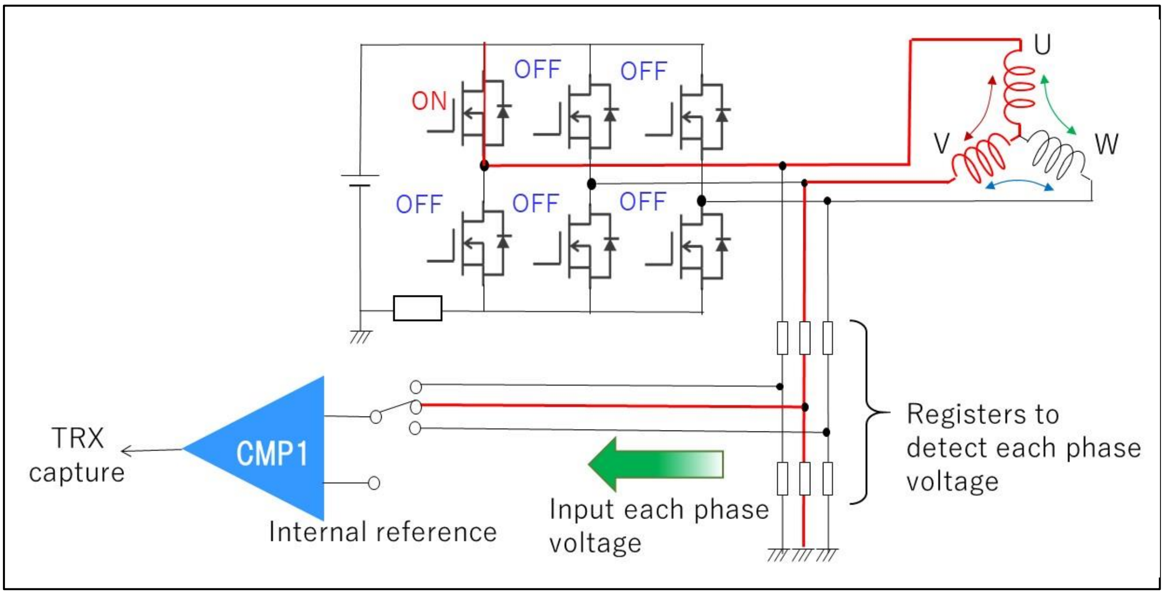



**Figure 3-2 Pattern diagram to estimate the rotor's angle**

Figure 3-2 explains the pattern diagram of this system to estimate the rotor's angle.

Estimation is performed in below procedure.

- Pulse voltage "Vi" is excited through U->V, V->W, W->U path in order.
- Measure the time that the voltage on registers reaches a reference value (little bit smaller than Vi) by internal timer at each path(U->V, V->W, W->U).
- Compare the measured time and judge the rotor's angle with 60degrees resolution in 180degrees range (electrical angle).

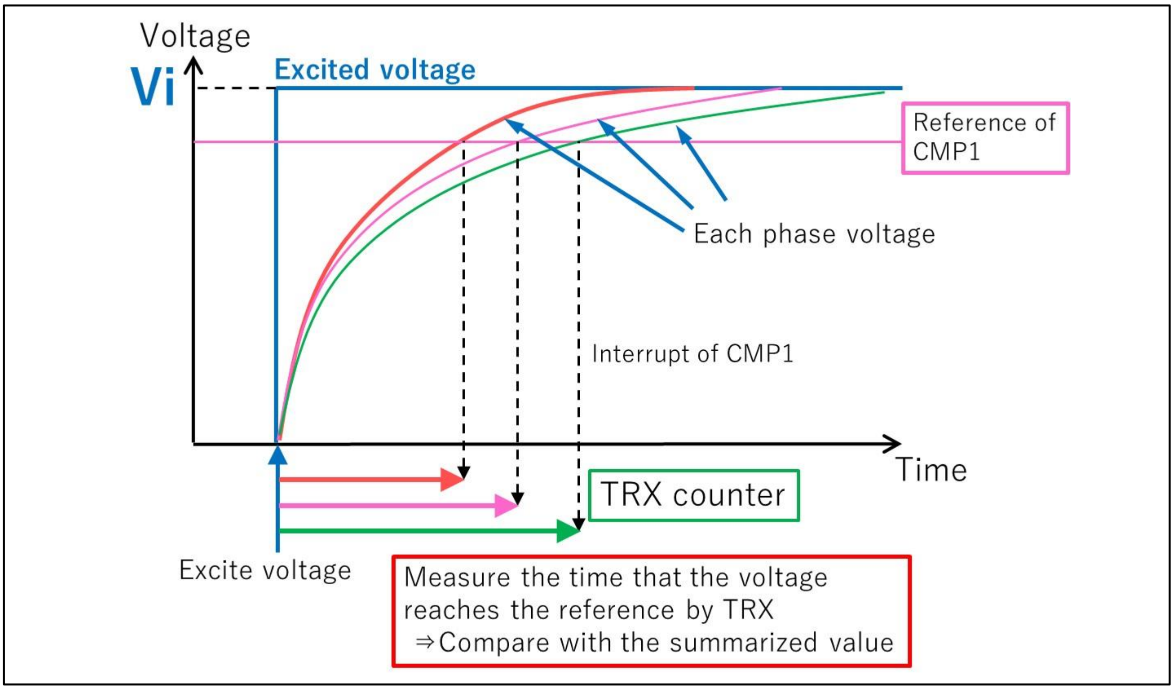



**Figure 3-3 Measure the time in which the voltage of each phase reaches the reference**

In the program of this application note, this time is measured with Timer RX(TRX) on RL78/G1F.

Pulse voltage is excited to each phase with TRD complementally PWM mode.
At that time, TRX starts counting by using a signal from timer RD as a trigger. And measure the time in which the voltage of each phase reaches the reference by linkage function between TRX and CMP1. That is, CMP1 detected the voltage reaches the reference, TRX counter is captured into TRXBUF.

With comparing the summarize time of each phase, the rotor's angle is estimated with 60degrees resolution in electrical 180degrees range. The measurement is finished when the difference between the biggest summarized value and next value reaches the threshold (user configurable). However, if CMP1 cannot detect the voltage reach or the difference doesn't reach 30% of the threshold after the measurement was performed in maximum counts, it is handled as an error (stop the detection sequence).

After the measurement was performed in maximum counts, the difference is between 30% to 99% of the threshold, the variable "g_u1_induct_effect_reach_max_cnts" is set to "1" to indicate the situation.

The threshold to judge the estimation, maximum counts of measurement, the reference voltage on CMP1, and the percentage to judge an error, are all configurable value to users.

Flowchart of the estimation of the rotor's position is explained below.

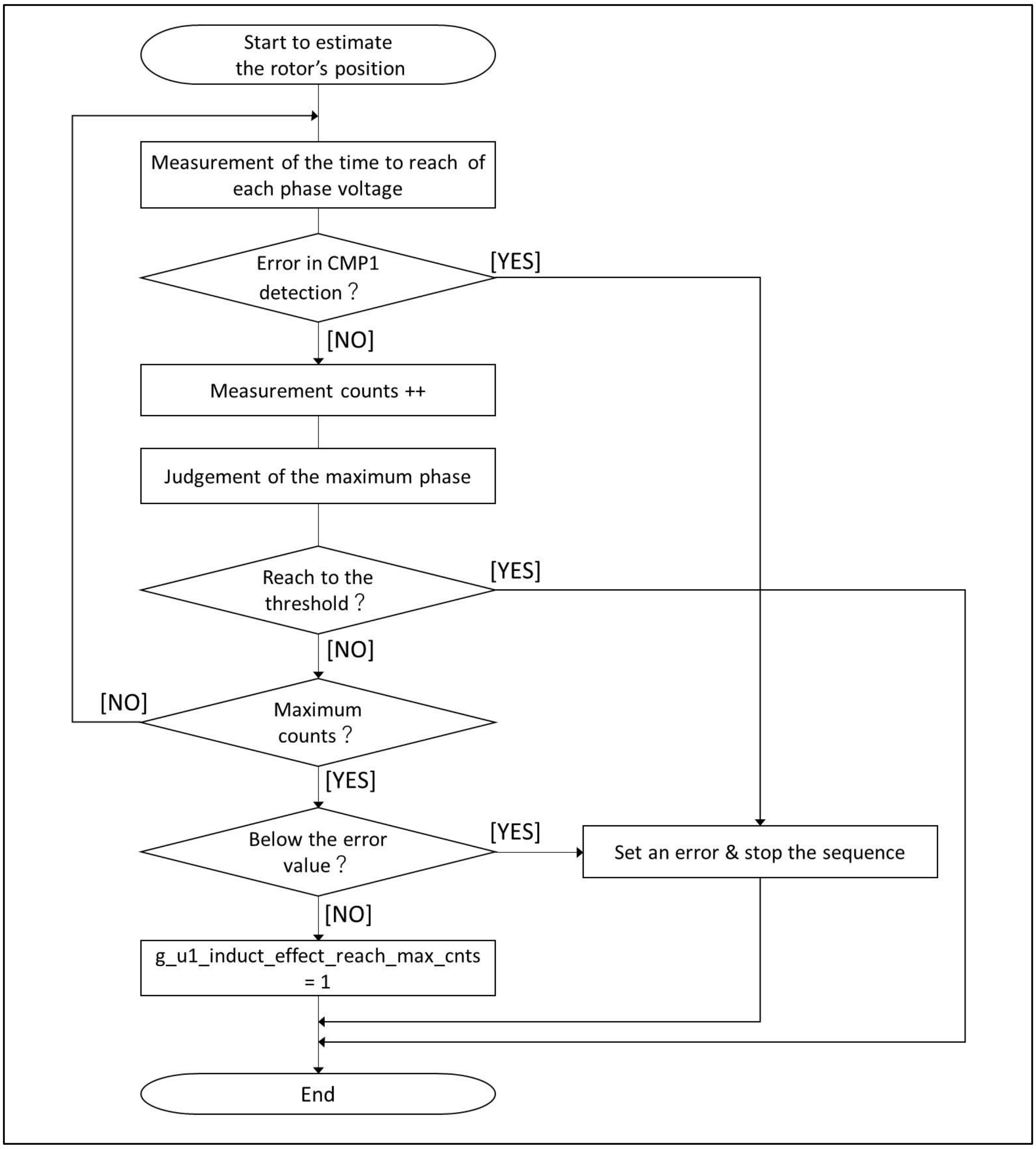



**Figure 3-4 Flowchart of the estimation of the rotor's angle**

### 3.1.3 Detection of the rotor's polarity with the magnetic saturation by A/D convertor

The rotor's polarity is impossible to be detected with 3.1.2 "Estimate the rotor's angle with the linkage function between TimerRX and comparator". Because the magnetic effect is no directionality. Therefore, the rotor's position is estimated with 60degrees resolution in 180degrees range (electrical angle).

Then the rotor's polarity is detected with the magnetic saturation.
The polarity is detected with using the characteristic that the current flow is different when the direction of magnetic field and current flow are same or not.

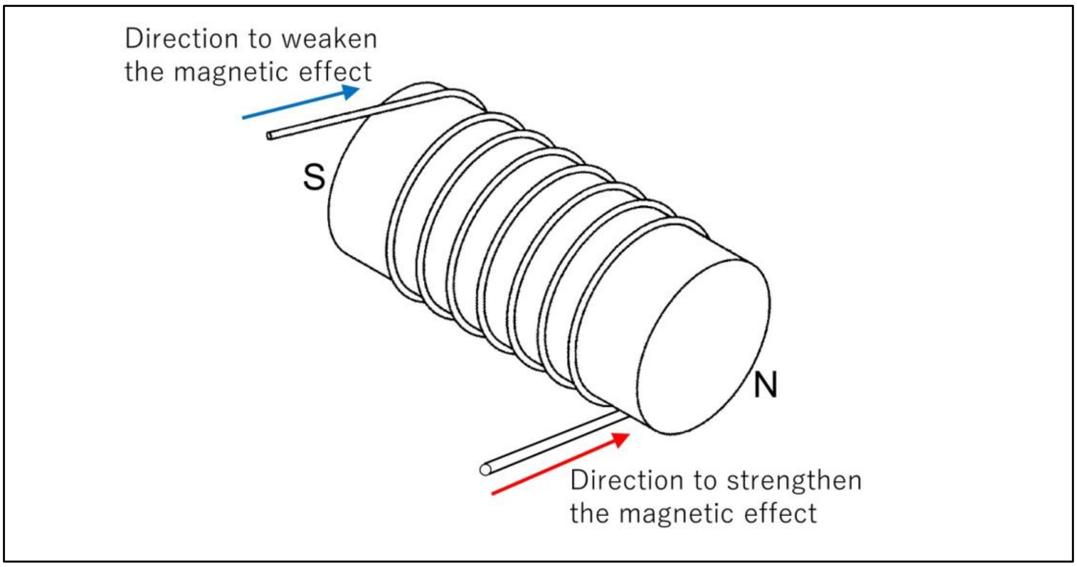



**Figure 3-5 Example of a magnet with winding a coil**

In case that the rotor magnet and coils exist nearby like as a SPM, magnetic flux by the rotor and by the coil passes through the core with synthesize.

Therefore if current is excited to the coil like as above Figure 3-5, a difference of actual current value can be detected between the direction of current like as Figure 3-6. Because the inductance becomes smaller in strengthen direction, as a result the current becomes easy to flow. In a motor the coil isn't winded to the magnet directly, but the similar effect happens. Therefore, the rotor's polarity can be detected.

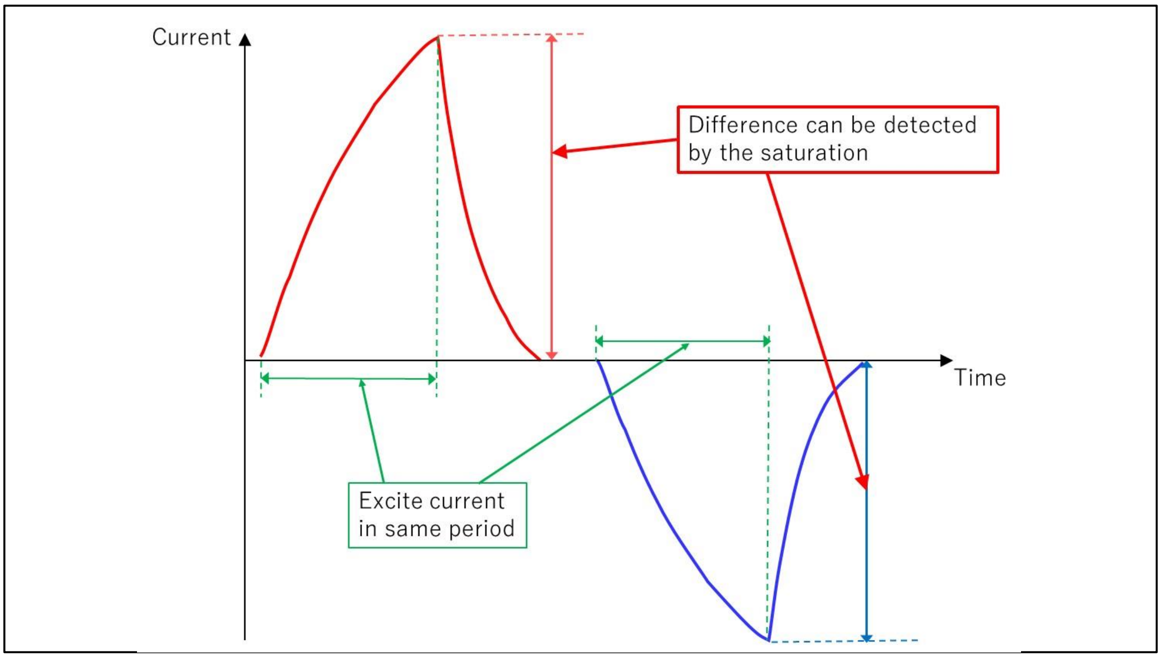



**Figure 3-6 Difference of current between the excited direction**

In particular, already the estimation of the rotor's angle was finished, so pulse current is excited according to the result of the estimation to arise the magnetic saturation.

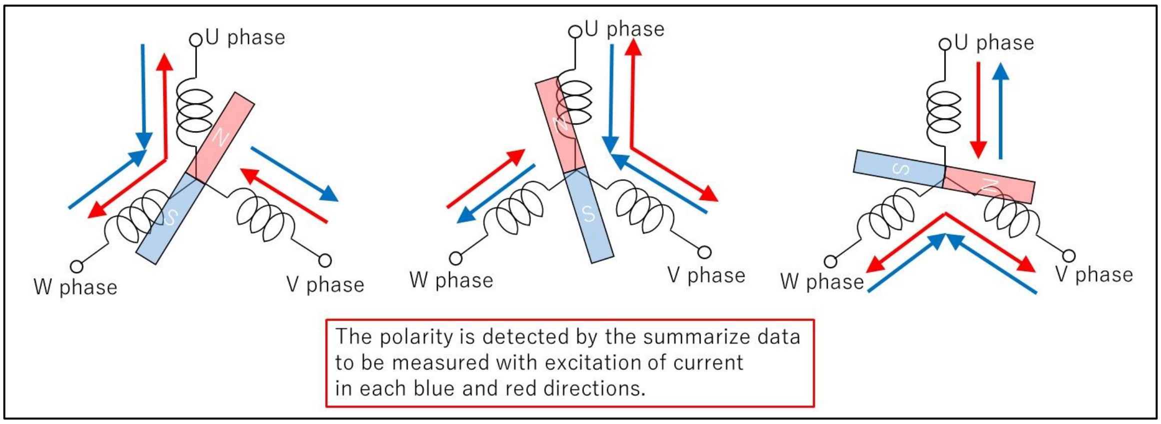



**Figure 3-7 Pattern of current to arise the magnetic saturation (sample)**

At that time, the current value is measured by A/D convertor with the shunt register. To made clearly the difference, the measurement shall be performed repeatedly. Then the rotor's polarity is judged.

In this measurement, PWM ports are used as general ports and the voltage is excited as a pulse.
The detection is performed with a comparison of the summarized data. When the difference between each direction reaches the threshold, the measurement is finished. However, if the difference doesn't reach 30% of the threshold after the measurement was performed in maximum counts, it is handled as an error (stop the detection sequence).

After the measurement was performed in maximum counts, the difference is between 30% to 99% of the threshold, the variable "g_u1_saturation_effect_reach_max_cnts" is set to "1" to indicate the situation.
The threshold to judge the detection, maximum counts of measurement, and the percentage to judge an error, are all configurable value to users. Also pulse width of excited voltage is configurable.

Flowchart of the detection of the rotor's polarity is explained below.

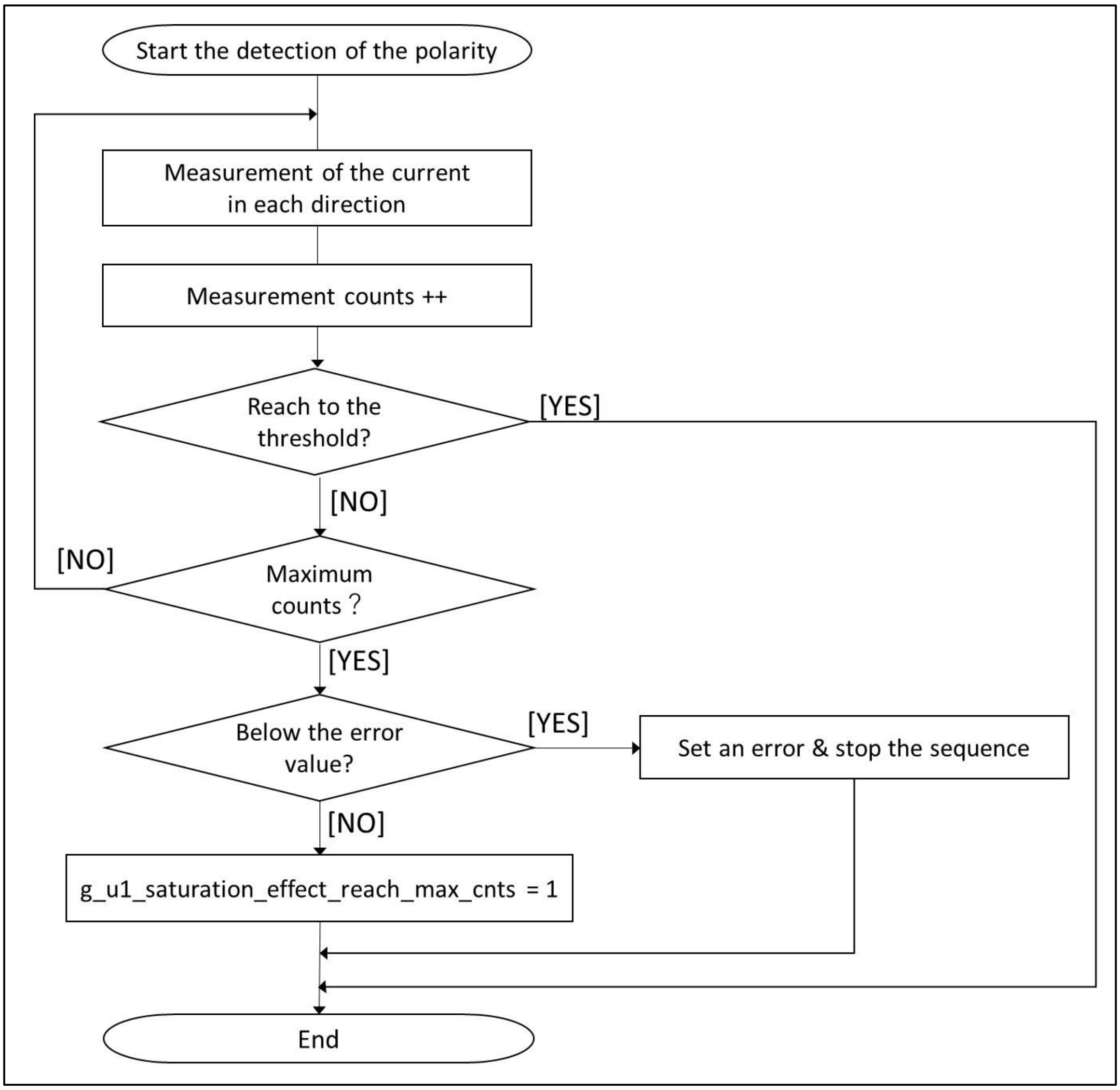



**Figure 3-8 Flowchart of the detection of the polarity**

### 3.1.4 User configurable variables and these initial value

As written in above, some variables to detect the initial position of the rotor are configurable to users.

The list of variables and these initial value is shown below.

**Table 3-1 User configurable variables and these initial value**

| Variable | Range | Initial value | Comment |
|---|---|---|---|
| com_u1_cmp1_vol_ref | 0 - 255 | 120 | Reference value to CMP1 |
| com_u1_measure_induct_effect_max_cnt | 0 - 255 | 8 | Maximum counts of measurement to estimate the rotor's angle |
| com_u1_ inductance_effect_thsld | 0 - 255 | 30 | Threshold to judge the estimation of the rotor's angle |
| com_u1_inductance_effect_percentage | 0 - 100 | 30 | Percentage of the threshold to judge an error at maximum count |
| com_u2_measure_induct_effect_intvl | 0 - 65535 | 150 | Period for natural discharge at the estimation of the rotor's angle |
| com_u2_pulse_width | 0 - 65535 | 1600 | Pulse width to excite the voltage at the detection of the rotor's polarity |
| com_u1_saturation_effect_thsld | 0 - 255 | 10 | Threshold to judge the rotor's polarity |
| com_u1_saturation_effect_max_cnt | 0 - 255 | 16 | Maximum counts of measurement to detect the rotor's polarity |
| com_u1_saturation_effect_percentage | 0 - 100 | 30 | Percentage of the threshold to judge an error at maximum count |

Each initial values are decided according to the result of measurement with TG-55L.

## 3.2 Function specifications

Multiple control functions are used in this control program. However, functions which are not used in this system are undescribed.

**Table 3-2 List of Functions "main.c"**

| File name | Function name | Process overview |
|---|---|---|
| main.c | main<br>Input: None<br>Output: None | - Hardware initialization function call<br>- User interface initialization function call<br>- Initialization function call of the variables used in the main process<br>- Global variables initialization function call<br>- GUI initialization function call<br>- Main process<br>⇒ Start the detection sequence by VR1<br>⇒ LED turn on/off control<br>⇒ User interface call<br>⇒ Watchdog timer clear function call |
| | ics_ui<br>Input: None<br>Output: None | Use "Motor RSSK Support Tool"<br>- Start the detection sequence<br>- Get user configurable variables |
| | software_init<br>Input: None<br>Output: None | Initialization of variables used in the main process |

**Table 3-3 List of Functions "mtr_ctrl_mrssk.c"**

| File name | Function name | Process overview |
|---|---|---|
| mtr_ctrl_mrssk.c | get_vr1<br>Input: None<br>Output: (uint16) u2_ad_data / A/D conversion result | VR1 status acquisition |
| | led1_on<br>Input: None<br>Output: None | Turning LED1 ON |
| | led2_on<br>Input: None<br>Output: None | Turning LED2 ON |
| | led1_off<br>Input: None<br>Output: None | Turning LED1 OFF |
| | led2_off<br>Input: None<br>Output: None | Turning LED2 OFF |

**Table 3-4 List of Functions “mtr_ctrl_rl78g1f.c” [1/2]**

| File name | Function name | Process overview |
|---|---|---|
| mtr_ctrl_rl78g1f.c | R_MTR_InitHardware<br>Input: None<br>Output: None | Initialization of the clock and peripheral functions |
| | clear_wdt<br>Input: None<br>Output: None | Clear the watchdog timer(WDT) |
| | mtr_clear_oc_flag<br>Input: None<br>Output: None | Cancel the forced cutoff of the pulse output |
| | mtr_set_delay_timert<br>Input: (uint16)u2_count / delay counts<br>(VOID_FUNC_POINTER)ptr_func / pointer for<br>reserved function at delay interrupt<br>Output: None | Set delay counts and reserved function for delay interrupt |
| | mtr_start_delay_timer<br>Input: None<br>Output: None | Start delay timer |
| | mtr_stop_delay_timer<br>Input: None<br>Output: None | Stop delay timer |
| | mtr_dummy_for_delay_timer<br>Input: None<br>Output: None | Dummy function for reset reserved function of delay timer |
| | mtr_start_trx<br>Input: None<br>Output: None | Start Timer RX (TRX) |
| | mtr_stop_trx<br>Input: None<br>Output: None | Stop Timer RX (TRX) |
| | mtr_disble_cmp1_intr<br>Input: None<br>Output: None | Disable the interrupt of CMP1 |
| | mtr_set_cmp1_input<br>Input: (uint8) u1_input / plus side input of CMP1<br>(uint8) u1_edge / detection edge<br>(Up edge / Down edge)<br>Output: None | Set the detected signal pattern of CMP1 |
| | mtr_prepare_measure_ie<br>Input: None<br>Output: None | Set peripherals to measure inductance effect as preparation |
| | mtr_init_clock<br>Input: None<br>Output: None | Initialization of clock |
| | mtr_init_interval_timer<br>Input: None<br>Output: None | Initialization of interval timer (1[ms] cyclic process) |
| | mtr_init_tau<br>Input: None<br>Output: None | Initialization of the Timer Array Unit (TAU) |

**Table 3-5 List of Functions "mtr_ctrl_rl78g1f.c" [2/2]**

| File name | Function name | Process overview |
|---|---|---|
| mtr_ctrl_rl78g1f.c | mtr_init_trx<br>Input: None<br>Output: None | Initialization of Timer RX (TRX) |
| | mtr_init_cmp1<br>Input: None<br>Output: None | Initialization of Comparator1 (CMP1) |

**Table 3-6 List of Functions "mtr_ctrl_rl78g1f_mrssk.c"**

| File name | Function name | Process overview |
|---|---|---|
| mtr_ctrl_rl78g1f_mrssk.c | mtr_init_trd<br>Input: None<br>Output: None | Initialization of Timer RD (TRD) |
| | mtr_init_ad_converter<br>Input: None<br>Output: None | Initialization of the A/D converter |
| | init_ui<br>Input: None<br>Output: None | Initialization of user interface |
| | mtr_get_adc<br>Input: (uint8) u1_ad_ch / target A/D conversion channel<br>Output: (int16) s2_temp / A/D conversion value | Get the result of A/D conversion |
| | mtr_output_UP<br>Input: None<br>Output: None | Excite voltage in U->V path at the estimation of the rotor's angle |
| | mtr_output_VP<br>Input: None<br>Output: None | Excite voltage in V->W path at the estimation of the rotor's angle |
| | mtr_output_WP<br>Input: None<br>Output: None | Excite voltage in W->U path at the estimation of the rotor's angle |
| | mtr_output_stop<br>Input: None<br>Output: None | Set all PWM ports to OFF |
| | mtr_output_low_on<br>Input: None<br>Output: None | Set all low side PWM ports to ON |

### Table 3-7 List of Functions “mtr_interrupt.c”

| File name | Function name | Process overview |
|---|---|---|
| mtr_interrupt.c | mtr_over_current_interrupt<br>Input: None<br>Output: None | Overcurrent detection process (Hardware detection)<br>- Disable INTP0 interrupt servicing<br>- Stop the detection sequence<br>- Set error information (overcurrent occurred) |
| | mtr_1ms_interrupt<br>Input: None<br>Output: None | Calling every 1 [ms]<br>- Call the GUI communication function<br>- Call the function to reflect user input data to variables<br>- Call the detection sequence of initial position of the rotor<br>- Call the function to clear the interrupt flag of interval timer |
| | mtr_delay_interrupt<br>Input: None<br>Output: None | Perform reserved function after the set delay<br>- Stop delay timer<br>- Perform the reserved function |

### Table 3-8 List of Functions “mtr_spm_detect_init_posi.c”

| File name | Function name | Process overview |
|---|---|---|
| mtr_spm_detect_init_posi.c | mtr_measure_inductance_effect<br>Input: u1_crt_pattern / Current pattern to be excited<br>Output: u2_trx_buf / measured counts of TRX counter | Measure the effect of inductance |
| | mtr_detect_magnetic_pole<br>Input: None:<br>Output: None | Detect the rotor position on 3 pattern with using TRX timer |
| | mtr_measure_saturation_effect<br>Input: u1_direction / current direction<br>Output: None | Rotor direction is detected with the measurement using saturation |
| | mtr_seq_judge_polarity<br>Input: None<br>Output: None | Sequence to judge the rotor polarity with saturation |
| | mtr_start_detect_sequence<br>Input: None<br>Output: None | Start the detection sequence of initial position of the rotor<br>- Set the state to start<br>- Clear error<br>- Call the function to cancel the forced cutoff of the pulse output |
| | mtr_start_initt<br>Input: None<br>Output: None | Initialize global variables |
| | R_MTR_IcsInput<br>Input: (MTR_ICS_INPUT*) ics_input / structure for ICS<br>Output: None | Set GUI input value to the buffer |
| | mtr_set_variables<br>Input: None<br>Output: None | Set input variables according to control layer |

## 3.3 List of variables

Lists of variables used in this control program are given below. However, note that the local variables are not mentioned.

**Table 3-9 List of variables[1/2]**

| Variable name | Type | Content | Remarks |
|---|---|---|---|
| g_u1_restart_detection | uint8 | Flag to start the detection sequence for user control | |
| g_s2_enable_write | int16 | Flag to accept user input data | |
| st_ics_input | MTR_ICS _INPUT | Structure for user input data from GUI | |
| g_u1_flg_req_restart | uint8 | Flag to request start the detection sequence | |
| g_u1_chtring_cnt | uint8 | VR1 determination counter | Chattering removal |
| g_u1_trig_enable_write | uint8 | Enable flag to reflect input data to internal data | |
| st_ics_input_buff | MTR_ICS _INPUT | Structure for Input data buffer from GUI | |
| g_u1_initial_position | uint8 | Detected rotor's position data | Indicate each 60degrees with 0 - 5 |
| g_u1_max_phase | uint8 | Estimated rotor's angle by measurement of inductance effect | |
| g_u2_state_judge_polarity | uint16 | Status management of the sequence to detect the polarity | |
| g_u2_state_detection | uint16 | Status management of the detection sequence of initial position of the rotor | |
| g_u2_sum_trx_u2v | uint16 | Summarized counter data of measurement of inductance effect with U->V path | |
| g_u2_sum_trx_v2w | uint16 | Summarized counter data of measurement of inductance effect with V->W path | |
| g_u2_sum_trx_w2u | uint16 | Summarized counter data of measurement of inductance effect with W->U path | |
| g_u1_cmp1_vol_ref | uint8 | Reference voltage of CMP1 to compare with each phase | (this variable) / 255 * 5.0 [V] |
| g_u1_measure_induct_effect_max_cnt | uint8 | Maximum counts to measure the inductance effect | Default : 8 |
| g_u1_inductance_effect_thsld | uint8 | Threshold to judge the estimation of rotor's angle | Default : 30 |
| g_u2_measure_induct_effect_intvl | uint16 | Interval of measurement the inductance effect between each phase | Default : 120 |
| g_u1_measure_induct_effect_cnt | uint8 | Counter of the measurement of inductance effect | |
| g_u2_inductance_effect_percentage | uint16 | Error detection threshold to estimate the rotor's angle | |
| g_u1_induct_effect_reach_max_cnts | uint8 | Flag to indicate the measurement of inductance effect reaches the maximum counts | |
| g_u1_flg_cmp1_error | uint8 | Flag to CMP1 cannot detect phase voltage | |
| g_u2_sum_adc_p | uint16 | Summarize data of measurement of saturation effect in positive direction | |
| g_u2_sum_adc_n | uint16 | Summarize data of measurement of saturation effect in negative direction | |

**Table 3-10 List of variables[2/2]**

| Variable name | Type | Content | Remarks |
|---|---|---|---|
| g_u1_saturation_effect_max_cnt | uint8 | Maximum counts to measure the saturation effect | Default : 16 |
| g_u1_saturation_effect_thsld | uint8 | Threshold to judge the detection of rotor's polarity | Default : 30 |
| g_u2_pulse_width | uint16 | Pulse width to be excited at measurement of saturation effect | Default : 1600 |
| g_u1_saturation_effect_cnt | uint8 | Counter of the measurement of saturation effect | |
| g_u2_saturation_effect_percentage | uint16 | Error detection threshold to detect the rotor's polarity | |
| g_u1_saturation_effect_reach_max_cnts | uint8 | Flag to indicate the measurement of saturation effect reaches the maximum counts | |
| g_u2_error_status | uint16 | Error status | |
| g_ptr_delay_func | VOID_FUNC_POINTER | Pointer of function for delay timer | |

## 3.4 List of structure

List of structure used in this control program is given below.

**Table 3-11 List of structure**

| Structure | Member | Type | Content | Remarks |
|---|---|---|---|---|
| MTR_ICS_INPUT | u1_cmp1_vol_ref | uint8 | Reference voltage of CMP1 to compare with each phase | (this variable) / 255 * 5.0 [V] |
| | u1_measure_induct_effect_max_cnt | uint8 | Maximum counts to measure the inductance effect | |
| | u1_inductance_effect_thsld | uint8 | Threshold to judge the estimation of rotor's angle | |
| | u2_measure_induct_effect_intvll | uint16 | Interval of measurement the inductance effect between each phase | |
| | u1_inductance_effect_percentage | uint8 | Error detection threshold to estimate the rotor's angle (percentage of u1_inductance_effect_thsld) | |
| | u2_pulse_width | uint16 | Pulse width to be excited at measurement of saturation effect | |
| | u1_saturation_effect_thsld | uint8 | Threshold to judge the detection of rotor's polarity | |
| | u1_saturation_effect_max_cnt | uint8 | Maximum counts to measure the saturation effect | |
| | u1_saturation_effect_percentage | uint8 | Error detection threshold to detect the rotor's polarity (percentage of u1_saturation_effect_thsld) | |

## 3.5 Macro definitions

Lists of macro definitions used in this control program are given below.

**Table 3-12 List of Macro definitions "main.h"**

| File name | Macro name | Definition value | Remarks |
|---|---|---|---|
| main.h | SW_ON | 0 | Active in case of "Low" |
| | SW_OFF | 1 | |
| | CHATTERING_CNT | 10 | Counts to remove chattering |
| | MTR_RESTART_THRSLD | 0x03FF * 2/3 | Value to 60degrees from the center of VR1 |
| | ICS_ADDR | 0xFE00 | Address data for ICS |
| | ICS_INT_LEVEL | 2 | Interrupt priority level for ICS |
| | ICS_NUM | CA : 0x50<br>CC-RL : 0x40 | Size of data on ICS interface |
| | ICS_BRR | 15 | Selection of bitrate register on ICS<br>(only CC-RL) |
| | ICS_INT_MODE | 0 | Setting of ICS interrupt mode<br>(only CC-RL) |

**Table 3-13 List of Macro definitions "mtr_ctrl_mrssk.h"**

| File name | Macro name | Definition value | | | | Remarks |
|---|---|---|---|---|---|---|
| mtr_ctrl_mrssk.h | MTR_PORT_SW1 | CA | P0.5 | CC-RL | P0_bit.no5 | SW1 input port |
| | MTR_PORT_SW2 | | P0.6 | | P0_bit.no6 | SW2 input port |
| | MTR_PORT_LED1 | | P14.1 | | P14_bit.no1 | LED1 output port |
| | MTR_PORT_LED2 | | P14.0 | | P14_bit.no0 | LED2 output port |
| | MTR_PORT_LED3 | | P0.4 | | P0_bit.no4 | LED3 output port |
| | MTR_LED_ON | 0 | | | | LED On/Off<br>(Low active) |
| | MTR_LED_OFF | 1 | | | | |
| | MTR_ADCCH_VR1 | 6 | | | | A/D channel : VR1 |
| | MTR_ADDCH_IDC | 25 | | | | A/D channel : shunt current |

**Table 3-14 List of Macro definitions "mtr_ctrl_rl78g1f.h"**

| File name | Macro name | Definition value | Remarks |
|---|---|---|---|
| mtr_ctrl_rl78g1f.h | PARITYCTL_BIT | CA : RPECTL.7<br>CC-RL : RPECTL_bit.no7 | Set enable RAM parity error detection |
| | mtr_clear_interval_timer_intflag() | ITIF = 0 | Clear the interrupt flag of interval timer |
| | MTR_INPUT_SELECT_VN | 0 | Select Input signal of CMP1<br>Select: center voltage |
| | MTR_INPUT_SELECT_VU | 1 | Select Input signal of CMP1<br>Select: voltage of U phase |
| | MTR_INPUT_SELECT_VV | 2 | Select Input signal of CMP1<br>Select: voltage of V phase |
| | MTR_INPUT_SELECT_VW | 3 | Select Input signal of CMP1<br>Select: voltage of W phase |
| | MTR_INPUT_SELECT_UP_EDGE | 0 | Up edge is used to detection |
| | MTR_INPUT_SELECT_DOWN_EDGE | 1 | Down edge is used to detection |
| | mtr_check_cmp1_detection() | 1 == C1MON | Confirm CMP1 detection |
| | mtr_check_trx_overflow() | 1 == TRXOVF | Confirm the over flow of TRX |

**Table 3-15 List of Macro definitions "mtr_ctrl_rl78g1f_mrssk.h"**

| File name | Macro name | Definition value | | | | Remarks |
|---|---|---|---|---|---|---|
| mtr_ctrl_rl78g1f_mrssk.h | MTR_PWM_TIMER_FREQ | 64.0f | | | | PWM timer count frequency [MHz] |
| | MTR_TRD_INIT_VALUE | 0xFFFF | | | | Initial value of TRD counter |
| | MTR_PORT_UP | CA | P1.5 | CC-RL | P1_bit.no5 | U phase (positive phase) output port |
| | MTR_PORT_UN | | P1.4 | | P1_bit.no4 | U phase (negative phase) output port |
| | MTR_PORT_VP | | P1.3 | | P1_bit.no3 | V phase (positive phase) output port |
| | MTR_PORT_VN | | P1.1 | | P1_bit.no1 | V phase (negative phase) output port |
| | MTR_PORT_WP | | P1.2 | | P1_bit.no2 | W phase (positive phase) output port |
| | MTR_PORT_WN | | P1.0 | | P1_bit.no0 | W phase (negative phase) output port |
| | MTR_TRX_CNT | TRX | | | | Counter register of TRX |
| | MTR_TRXBUF_CNT | TRXBUF | | | | Counter register of TRXBUF |
| | mtr_start_trd() | TRDSTR = 0x0F | | | | Start TRD |
| | mtr_stop_trd() | TRDSTR = 0x00 | | | | Stop TRD |
| | MTR_OC_HW_FLG | TRDSHUTS | | | | Forced cutoff flag |
| | MTR_OC_INTR_MASK | PMK0 | | | | INTP0 interrupt mask |
| | MTR_DISABLE_OC_INTR | 1 | | | | Disable INTP0 interrupt service |
| | MTR_ENABLE_OC_INTR | 0 | | | | Enable INTP0 interrupt service |

**Table 3-16 List of Macro definitions “mtr_spm_detect_init_posi.h” [1/2]**

| File name | Macro name | Definition value | Remarks |
|---|---|---|---|
| mtr_spm_detect_init_posi.h | MTR_FLG_CLR | 0 | Flag management |
| | MTR_FLG_SET | 1 | |
| | MTR_ICS_DECIMATION | 2 | Number of function call decimation times for GUI |
| | MTR_MEASURE_RX_U2V | 1 | Pattern of current path at estimation of the rotor’s angle |
| | MTR_MEASURE_RX_V2W | 2 | |
| | MTR_MEASURE_RX_W2U | 3 | |
| | MTR_PHASE_UNDETECT | 0 | Detected angle in 60degrees resolution at estimation of the rotor’s angle<br>“0” is undetected. |
| | MTR_PHASE_U2V | 1 | |
| | MTR_PHASE_V2W | 2 | |
| | MTR_PHASE_W2U | 3 | |
| | MTR_TRX_OVER_COUNTS | 3000 | Limit of TRX at measurement of inductance effect |
| | MTR_CMP1_VOL_REF | 120 | Default value of the reference of CMP1 |
| | MTR_MEASURE_IE_THSLD | 30 | Threshold to judge the finish of measurement of inductance effect |
| | MTR_MEASURE_IE_INTERVAL | 150 | Interval for natural discharge during the measurement of inductance effect |
| | MTR_MEASURE_IE_MAX_COUNTS | 8 | Maximum counts of the measurement of inductance effect |
| | MTR_MEASURE_IE_PERCENTAGE | 30 | Percentage to judge the error of measurement of inductance effect |
| | MTR_MEASURE_SATURATION_POSITIVE | 1 | Pattern of exciting voltage at detection of the rotor’s polarity |
| | MTR_MEASURE_SATURATION_NEGATIVE | 0 | |
| | MTR_MEASURE_SAT_PULSE_WIDTH | 1600 | Pulse width of exciting voltage at the measurement of saturation effect |
| | MTR_MEASURE_SAT_THSLD | 10 | Threshold to judge the finish of measurement of saturation effect |
| | MTR_MEASURE_SAT_MAX_COUNTS | 16 | Maximum counts of the measurement of saturation effect |
| | MTR_MEASURE_SAT_PERCENTAGE | 30 | Percentage to judge the error of measurement of saturation effect |
| | MTR_CORRECT_POSITION | 3 | Correction value at detection of the rotor’s polarity |
| | MTR_ERROR_POSITION | 10 | Error value to detect the initial position |
| | MTR_STATE_NONE | 0 | State information of sequence to detect initial position of the rotor<br>0 : Not active<br>1 : Start the detection<br>2 : Wait the estimation of the rotor’s angle<br>3 : Start the detection of the polarity<br>4 : The polarity detecting<br>5 : Finish of the detection of initial position |
| | MTR_STATE_START_DETECTION | 1 | |
| | MTR_STATE_WAIT_DETECT_MAGNETIC_POLE | 2 | |
| | MTR_STATE_START_JUDGE_POLARITY | 3 | |
| | MTR_STATE_JUDGE_POLARITY | 4 | |
| | MTR_STATE_DETECTION_FINISH | 5 | |
| | MTR_STATE_JUDGE_POLARITY_NONE | 0 | State information of the detection of the polarity<br>0 : Not active<br>1 : Measurement in positive side<br>2 : Measurement In negative side and judgement of the result |
| | MTR_STATE_JUDGE_POLARITY_POSITIVE | 1 | |
| | MTR_STATE_JUDGE_POLARITY_NEGATIVE | 2 | |

**Table 3-17 List of Macro definitions "mtr_spm_detect_init_posi.h" [2/2]**

| File name | Macro name | Definition value | Remarks |
|---|---|---|---|
| mtr_spm_detect_init_posi.h | MTR_ERROR_NONE | 0x00 | Error status<br>0x00 : No error<br>0x01 : CMP1 detect fault error<br>0x02 : Error of the estimation of the rotor's angle<br>0x04 : Error of the detection of the rotor's polarity<br>0x08 : overcurrent |
| | MTR_ERROR_CMP1_NOT_REACH_REF | 0x01 | |
| | MTR_ERROR_DETECT_MAGNETIC_POLE | 0x02 | |
| | MTR_ERROR_JUDGE_POLARITY | 0x04 | |
| | MTR_ERROR_OVER_CURRENT | 0x08 | |

## 3.6 Control flows (flow charts)

### 3.6.1 Main process

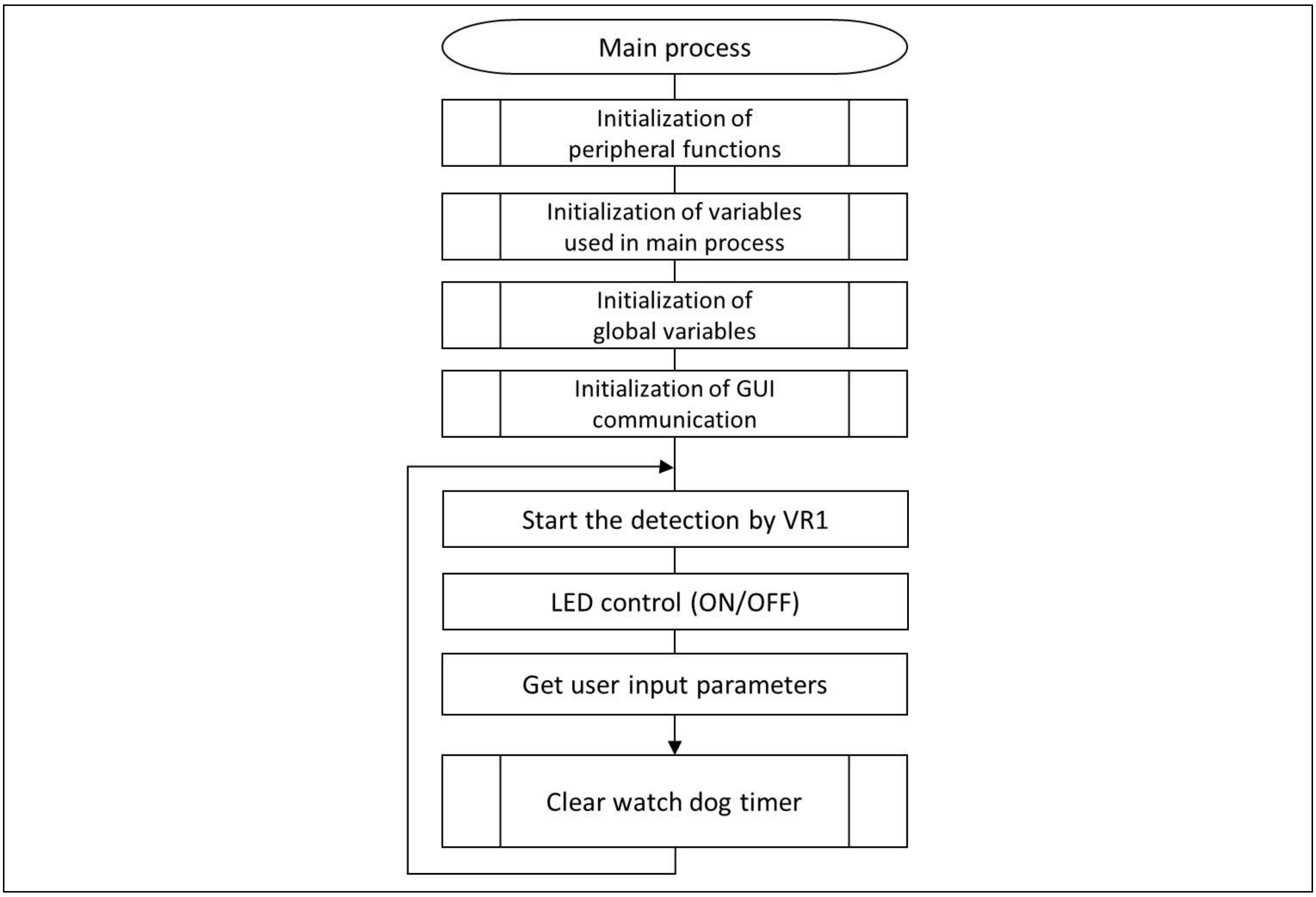



**Figure 3-9 Main Process Flowchart**

### 3.6.2 1 [ms] interrupt handling

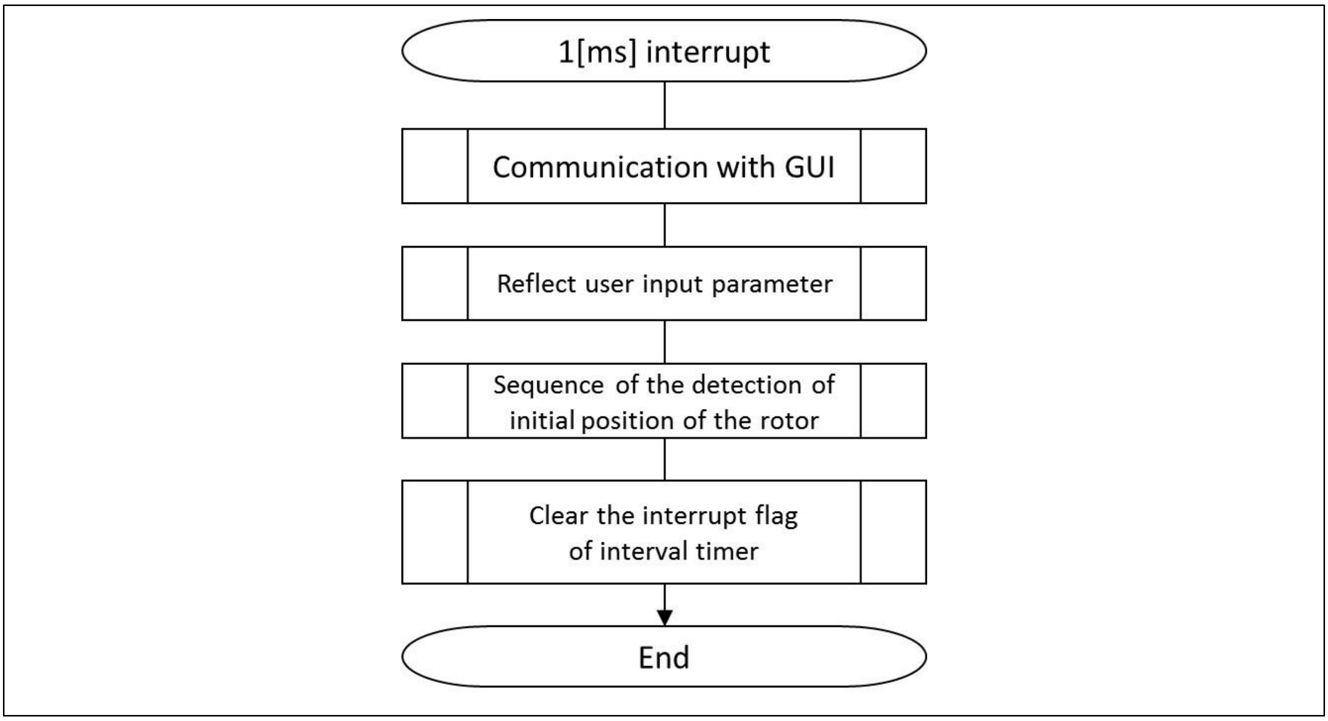



**Figure 3-10 1 [ms] Interrupt Handling**

### 3.6.3 Delay timer interrupt handling

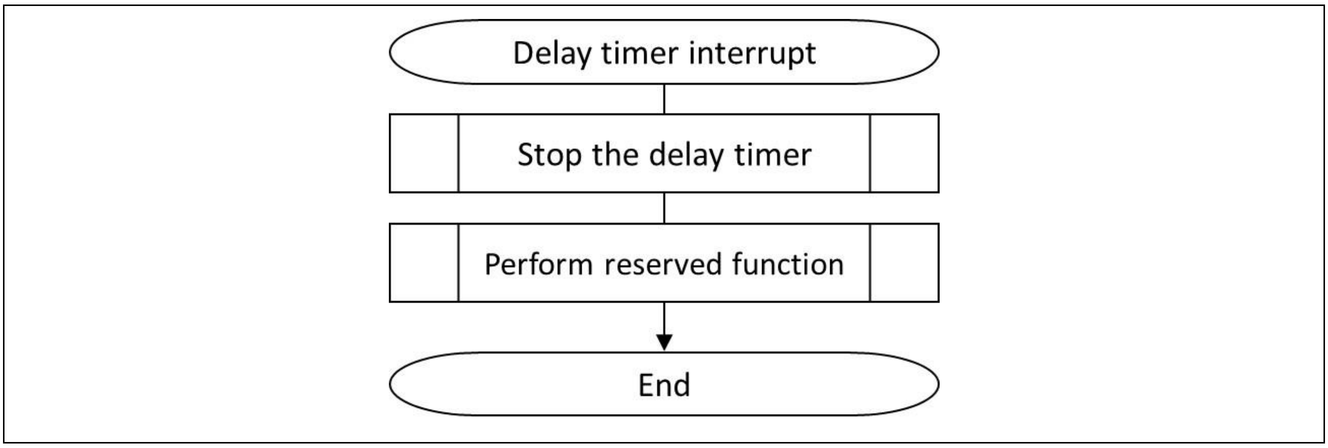



**Figure 3-11 Delay Timer Interrupt Handling**

### 3.6.4 Overcurrent interrupt handling

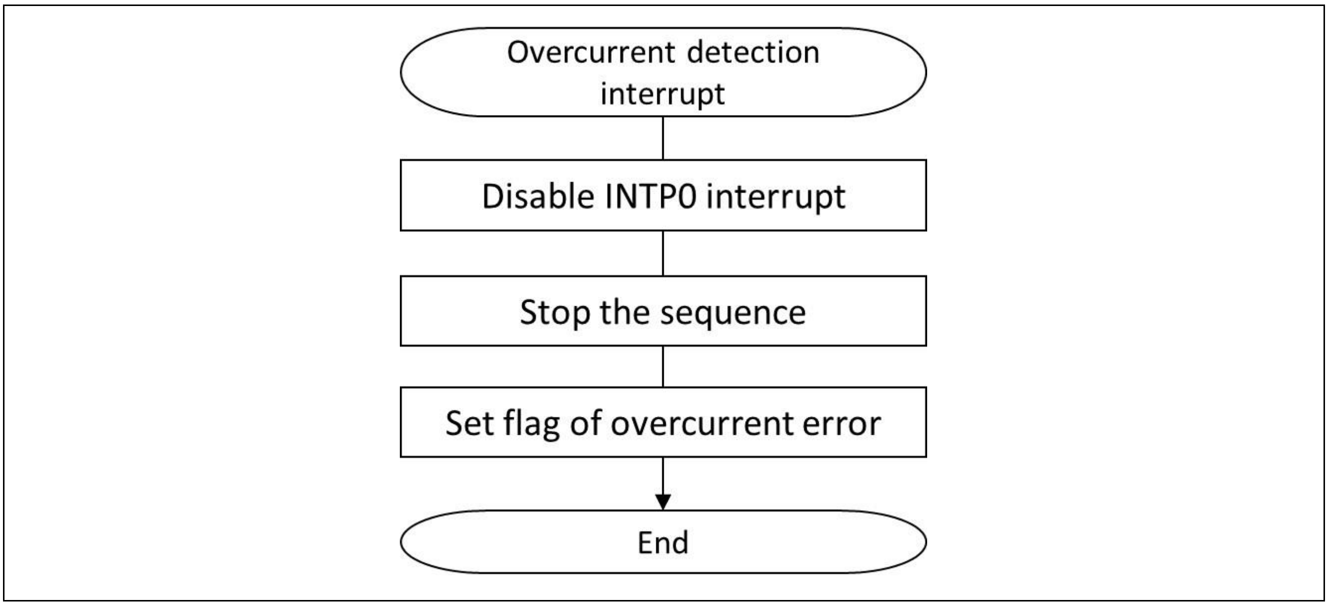



**Figure 3-12 Over Current Detection Interrupt Handling**

# 4. Motor Control Development Support Tool, 'Renesas Motor Workbench'

## 4.1 Overview

In the sample programs described in this application note, the detection can be started by the motor control development support tool, 'Renesas Motor Workbench'. Please refer to 'Renesas Motor Workbench V.1.00 User's Manual' for usage and more details.

You can find 'Renesas Motor Workbench' on Renesas Electronics Corporation website.

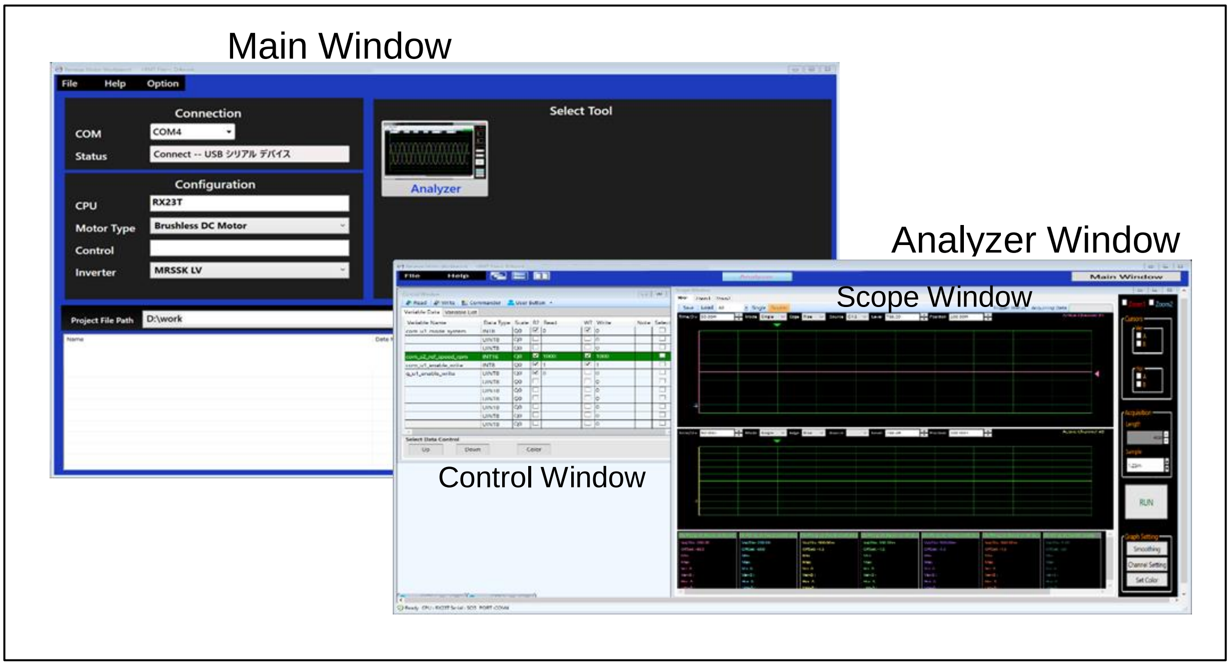
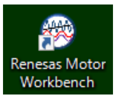



**Figure 4-1 Renesas Motor Workbench – Appearance**

<u>Set up for Motor control development support tool</u>

(1) Start 'Motor RSSK Support Tool' by clicking this icon. 


(2) Drop down menu [File] → [Open RMT File(O)].

And select RMT file in '[Project Folder]/ics/'.

(3) Use the 'Connection' [COM] select menu to choose the COM port to be connected with the Motor RSSK.

(4) Click the 'Analyzer' icon in right side of Main Window. (Then, "Analyzer Window" will be displayed.)

(5) Please refer to '4.3 Operation Example for Analyzer' to start the detection.

## 4.2 List of variables for Analyzer

Table 4-1 is a list of variables for Analyzer. These variables are reflected to the protect variables when the same values as g_s2_enable_write are written to com_s2_enable_write except com_u1_restart_detection.

**Table 4-1 List of Variables for Analyzer**

| Variable name | Type | Content | Remarks<br>( [ ]: reflection variable name) |
|---|---|---|---|
| com_u1_cmp1_vol_ref | uint8 | Reference value to CMP1 | 【g_u1_cmp1_vol_ref】 |
| com_u1_measure_induct_effect_max_cnt | uint8 | Maximum counts of measurement to estimate the rotor's angle | 【g_u1_measure_induct_effect_max_cnt】 |
| com_u1_inductance_effect_thsld | uint8 | Threshold to judge the estimation of the rotor's angle | 【g_u1_inductance_effect_thsld】 |
| com_u1_inductance_effect_percentage | uint8 | Percentage of the threshold to judge an error at maximum count | 【g_u2_inductance_effect_percentage】 |
| com_u2_measure_induct_effect_intvl | uint16 | Period for natural discharge at the estimation of the rotor's angle | 【g_u2_measure_induct_effect_intvl】 |
| com_u2_pulse_width | uint16 | Pulse width to excite the voltage at the detection of the rotor's polarity | 【g_u2_pulse_width】 |
| com_u1_saturation_effect_thsld | uint8 | Threshold to judge the rotor's polarity | 【g_u1_saturation_effect_thsld】 |
| com_u1_saturation_effect_max_cnt | uint8 | Maximum counts of measurement to detect the rotor's polarity | 【g_u1_saturation_effect_max_cnt】 |
| com_u1_saturation_effect_percentage | uint8 | Percentage of the threshold to judge an error at maximum count | 【g_u2_saturation_effect_percentage】 |
| com_u1_restart_detection | uint8 | Reference value to CMP1 | 【g_u1_restart_detection】 |
| com_s2_enable_write | int16 | Maximum counts of measurement to estimate the rotor's angle | |

## 4.3 Operation Example for Analyzer

Show an example below that start the detection operation using Analyzer. Operation is using “Control Window” showed in Figure 4-1. Refer to ‘Renesas Motor Workbench V.1.00 User’s Manual’ for ‘Control Window’ in detail.

- Start the detection of initial position of the rotor
  (1) The [W?] check boxes contain checkmark for “com_u1_restart_detection”.
  (2) Input same value as “g_u1_restart_detection” in the [Write] box of “com_u1_restart_detection”.
  (3) Click the “Write” button.

.

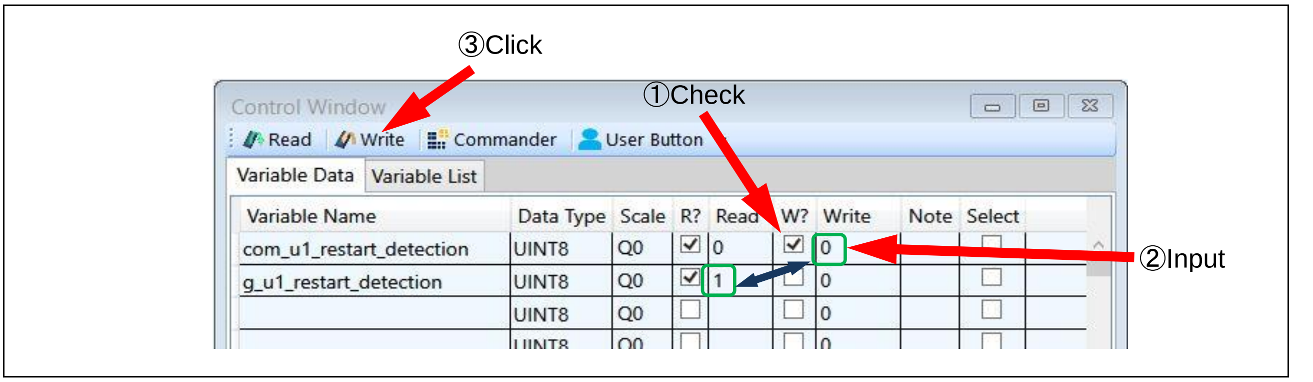



**Figure 4-2 Procedure – Start the detection**

## Website and Support

Renesas Electronics Website
http://www.renesas.com/

Inquiries
http://www.renesas.com/contact/

## Revision History

| Rev. | Date | Description | |
|---|---|---|---|
| | | Page | Summary |
| 1.00 | Jan.13.2017 | - | First edition issued |
| 1.10 | Oct.02.2017 | - | - Add notice on cover page<br>- Changing description by source code disclosure |

## General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Handling of Unused Pins

   Handle unused pins in accordance with the directions given under Handling of Unused Pins in the manual.

   — The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on

   The state of the product is undefined at the moment when power is supplied.

   — The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the moment when power is supplied.
   In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the moment when power is supplied until the reset process is completed.
   In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses

   Access to reserved addresses is prohibited.

   — The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals

   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has stabilized.

   — When the clock signal is generated with an external resonator (or from an external oscillator) during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Moreover, when switching to a clock signal produced with an external resonator (or by an external oscillator) while program execution is in progress, wait until the target clock signal is stable.

5. Differences between Products

   Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.

   — The characteristics of Microprocessing unit or Microcontroller unit products in the same group but having a different part number may differ in terms of the internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

**SALES OFFICES** Renesas Electronics Corporation http://www.renesas.com

Refer to "http://www.renesas.com/" for the latest and detailed information.

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