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Application Note

Inverter Control by V850 Series

120° Excitation Method Control by Zero-Cross Detection Using Real-Time Output Function (RTO)

V850ES/KJ1
Other microcontrollers with internal RTO

Document No. U17362EJ1V0AN00 (1st edition)
Date Published December 2004 N CP(K)

[MEMO]

NOTES FOR CMOS DEVICES

① **VOLTAGE APPLICATION WAVEFORM AT INPUT PIN**

Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (MAX) and V_{IH} (MIN) due to noise, etc., the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (MAX) and V_{IH} (MIN).

② **HANDLING OF UNUSED INPUT PINS**

Unconnected CMOS device inputs can be cause of malfunction. If an input pin is unconnected, it is possible that an internal input level may be generated due to noise, etc., causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using pull-up or pull-down circuitry. Each unused pin should be connected to V_{DD} or GND via a resistor if there is a possibility that it will be an output pin. All handling related to unused pins must be judged separately for each device and according to related specifications governing the device.

③ **PRECAUTION AGAINST ESD**

A strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it when it has occurred. Environmental control must be adequate. When it is dry, a humidifier should be used. It is recommended to avoid using insulators that easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors should be grounded. The operator should be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with mounted semiconductor devices.

④ **STATUS BEFORE INITIALIZATION**

Power-on does not necessarily define the initial status of a MOS device. Immediately after the power source is turned ON, devices with reset functions have not yet been initialized. Hence, power-on does not guarantee output pin levels, I/O settings or contents of registers. A device is not initialized until the reset signal is received. A reset operation must be executed immediately after power-on for devices with reset functions.

⑤ **POWER ON/OFF SEQUENCE**

In the case of a device that uses different power supplies for the internal operation and external interface, as a rule, switch on the external power supply after switching on the internal power supply. When switching the power supply off, as a rule, switch off the external power supply and then the internal power supply. Use of the reverse power on/off sequences may result in the application of an overvoltage to the internal elements of the device, causing malfunction and degradation of internal elements due to the passage of an abnormal current.

The correct power on/off sequence must be judged separately for each device and according to related specifications governing the device.

⑥ **INPUT OF SIGNAL DURING POWER OFF STATE**

Do not input signals or an I/O pull-up power supply while the device is not powered. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements.

Input of signals during the power off state must be judged separately for each device and according to related specifications governing the device.

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- Device availability
- Ordering information
- Product release schedule
- Availability of related technical literature
- Development environment specifications (for example, specifications for third-party tools and components, host computers, power plugs, AC supply voltages, and so forth)
- Network requirements

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J04.1

INTRODUCTION

Target Readers

This application note is intended for users who understand real-time output functions (RTO), and who design application systems using the function. The applicable products are all products with internal RTO functions such as V850ES/KJ1. Applicable products for the V850ES/KJ1 are shown below.

- V850ES/KJ1

  Standard products: μPD703216, 703216Y, 703217, 703217Y, 70F3217, 70F3217H, 70F3217HY, 70F3217Y, 70F3218H, 70F3218HY

  Special products: μPD703216(A), 703216Y(A), 703217(A), 703217Y(A), 70F3217(A), 70F3217Y(A), 703216(A1), 703216Y(A1), 703217(A1), 703217Y(A1), 703216(A2), 703216Y(A2), 703217(A2), 703217Y(A2)

Purpose

The purpose of this application note is to help the user understand how a brushless DC motor is controlled via the 120° sensorless drive excitation method using a system example of RTO functions.

Organization

This application note is divided into the following sections.

- Control method
- Hardware configuration
- Software configuration
- Program list

How to Use This Manual

It is assumed that the reader of this application note has general knowledge in the fields of electrical engineering, logic circuits, and microcontrollers.

Cautions

1. Of the products that have internal RTO functions, the V850ES/KJ1 is described in this manual as a typical microcontroller.

2. Application examples in this manual are intended for the “standard” quality models for general-purpose electronic systems. When using an example in this manual for an application that requires the “special” quality grade, evaluate each component and circuit to be actually used to see if they satisfy the required quality standard.

3. When using the special grade product manuals, read the following part numbers on the V850ES/KJ1 as follows. This also applies to products other than the V850ES/KJ1 that have internal RTO functions.

μPD703216 → μPD703216(A), 703216(A1), 703216(A2)
μPD703216Y → μPD703216Y(A), 703216Y(A1), 703216Y(A2)
μPD703217 → μPD703217(A), 703217(A1), 703217(A2)
μPD703217Y → μPD703217Y(A), 703217Y(A1), 703217Y(A2)
μPD70F3217 → μPD70F3217(A)
μPD70F3217Y → μPD70F3217Y(A)

For details of hardware functions (especially register functions, setting methods, etc.) and electrical specifications

→ See the user's manual for products with internal RTO functions (such as **V850ES/KJ1 Hardware User's Manual**).

For details of instruction functions

→ See the architecture user's manual for products with internal RTO functions (such as **V850ES Architecture User's Manual**).

Conventions

Data significance:	Higher digits on the left and lower digits on the right	
Active low representation:	$\overline{\text{xxx}}$ (overscore over pin or signal name)	
Memory map address:	Higher addresses on the top and lower addresses on the bottom	
Note:	Footnote for item marked with **Note** in the text	
Caution:	Information requiring particular attention	
Remark:	Supplementary information	
Numeric representation:	Binary ... xxxx or xxxxB	
	Decimal ... xxxx	
	Hexadecimal ... xxxxH	
Prefix indicating the power of 2 (address space, memory capacity):	K (kilo):	2^{10} = 1,024
	M (mega):	2^{20} = $1,024^2$
	G (giga):	2^{30} = $1,024^3$
Data type:	Word:	32 bits
	Halfword:	16 bits
	Byte:	8 bits

Related Documents

The related documents indicated in this publication may include preliminary versions. However, preliminary versions are not marked as such.

Documents related to V850ES/KJ1

Document Name	Document No.
V850ES Architecture User's Manual	U15943E
V850ES/KJ1 Hardware User's Manual	U16889E
Inverter Control by V850 Series 120° Excitation Method Control by Zero-Cross Detection Using Real-Time Output Function (RTO) Application Note	This manual

Documents related to V850ES/KJ1 development tools (user's manuals)

Document Name		Document No.
IE-V850ES-G1 (In-Circuit Emulator)		U16313E
IE-703217-G1-EM1 (In-Circuit Emulator Option Board)		U16594E
CA850 Ver. 3.00 C Compiler Package	Operation	U17293E
	C Language	U17291E
	Assembly Language	U17292E
	Link Directives	U17294E
PM+ Ver. 6.00		U17178E
ID850 Ver. 2.50 Integrated Debugger	Operation	U16217E
ID850QB Ver. 2.80 Integrated Debugger	Operation	U16973E
TW850 Ver. 2.00 Performance Analysis Tuning Tool		U17241E
SM850 Ver. 2.50 System Simulator	Operation	U16218E
SM850 Ver. 2.00 or Later System Simulator	External Part User Open Interface Specifications	U14873E
SM+ System Simulator	Operation	U17246E
	User Open Interface	U17247E
RX850 Ver. 3.13 or Later Real-Time OS	Basics	U13430E
	Installation	U13410E
	Technical	U13431E
RX850 Pro Ver. 3.15 Real-Time OS	Basics	U13773E
	Installation	U13774E
	Technical	U13772E
RD850 Ver. 3.01 Task Debugger		U13737E
RD850 Pro Ver. 3.01 Task Debugger		U13916E
AZ850 Ver. 3.10 System Performance Analyzer		U14410E
PG-FP4 Flash Memory Programmer		U15260E

CONTENTS

CHAPTER 1 CONTROL METHOD

1.1 Outline of Brushless DC Motor Control

A brushless DC (BLDC) motor consists of a stator, coil, and rotor. The rotor, which includes a permanent magnet, is rotated by the action of the magnetic field generated by the coil of the stator.

The magnetic field is generated by exciting the coil wound around the stator in a specific sequence. By controlling the intensity and cycle of the magnetic field with a microcontroller, the torque response and the number of revolutions of the motor can be controlled.

This section explains how to control a BLDC motor without a sensor by using the V850ES/KJ1 as a typical microcontroller of the products that have internal real-time output functions (RTO).

Figure 1-3 shows an example of the circuit of a three-phase brushless DC motor. The internal PWM output function of the microcontroller is used to control the current that flows through the motor, by using a transistor array consisting of six transistors.

The magnetic field is generated by controlling the excitation pattern of the six transistors as shown in Table 1-1.

Table 1-1. Excitation Pattern

Excitation Pattern	Upper Arm			Lower Arm			Excitation Direction
	U	V	W	$\overline{U}$	$\overline{V}$	$\overline{W}$	
<1>	Active	Inactive	Inactive	Inactive	Active	Inactive	$U \rightarrow \overline{V}$
<2>	Active	Inactive	Inactive	Inactive	Inactive	Active	$U \rightarrow \overline{W}$
<3>	Inactive	Active	Inactive	Inactive	Inactive	Active	$V \rightarrow \overline{W}$
<4>	Inactive	Active	Inactive	Active	Inactive	Inactive	$V \rightarrow \overline{U}$
<5>	Inactive	Inactive	Active	Active	Inactive	Inactive	$W \rightarrow \overline{U}$
<6>	Inactive	Inactive	Active	Inactive	Active	Inactive	$W \rightarrow \overline{V}$

Figure 1-1. Three-Phase DC Motor Voltage Waveform

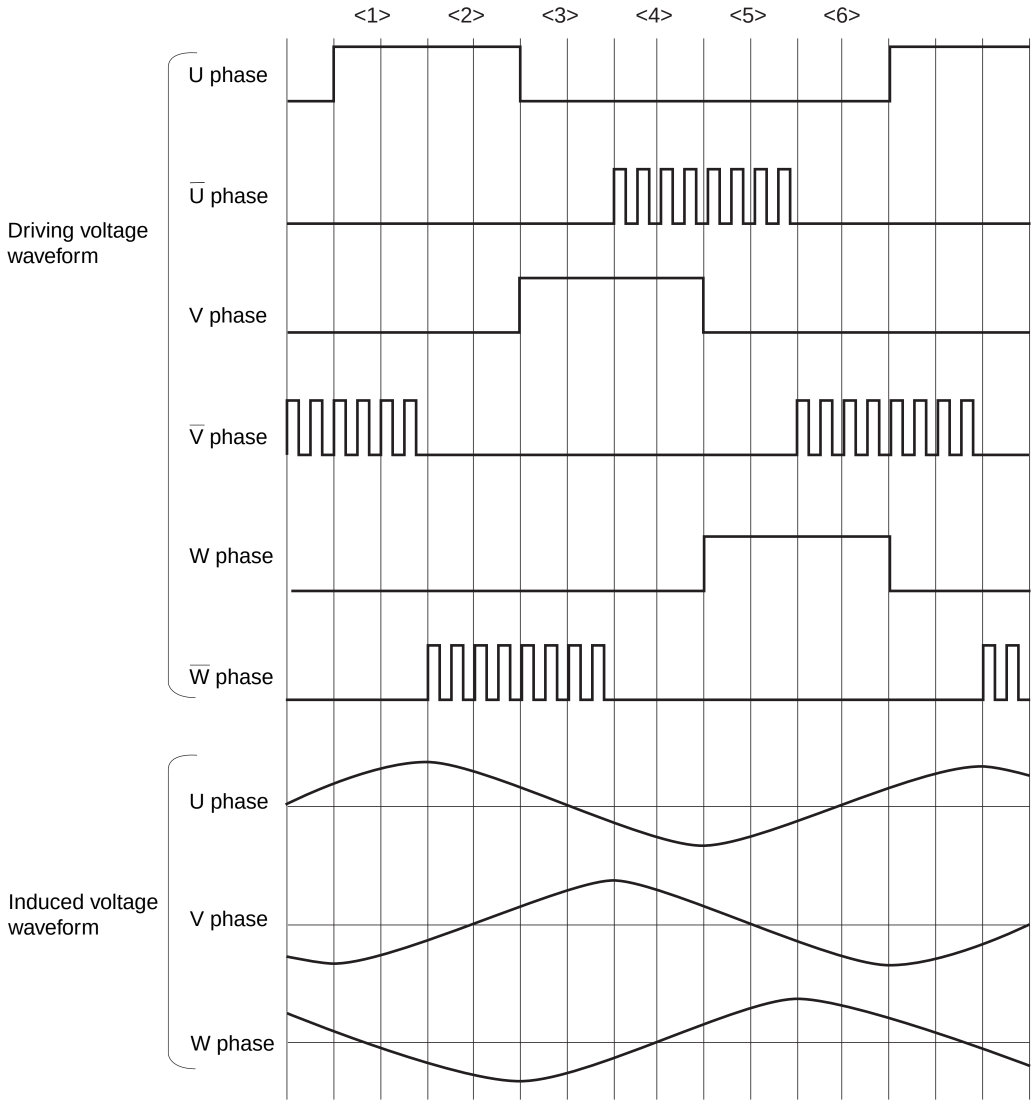
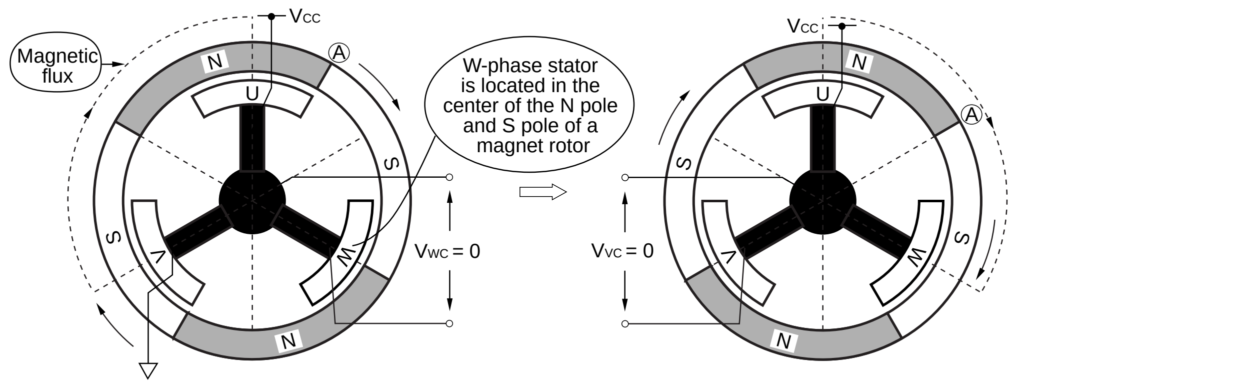
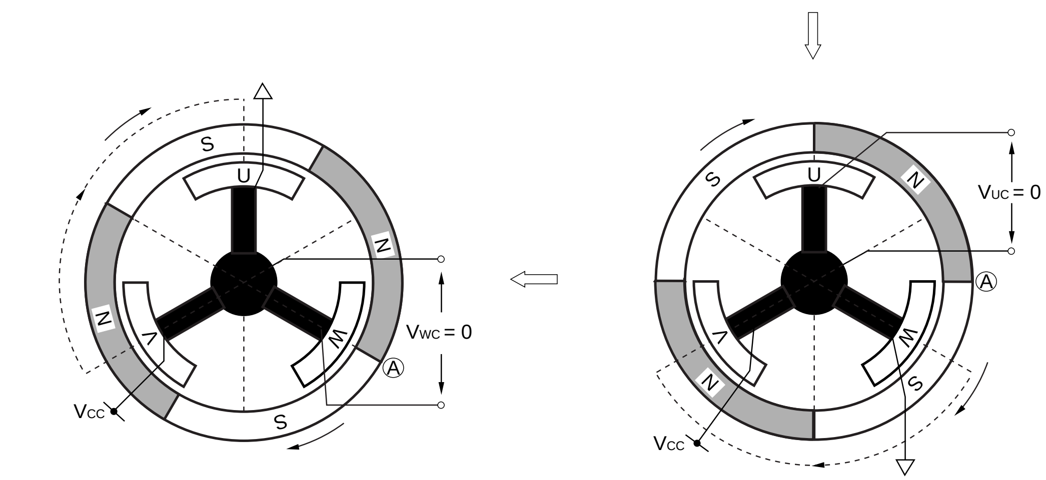


Figure 1-2. Rotor Position Detection Principle



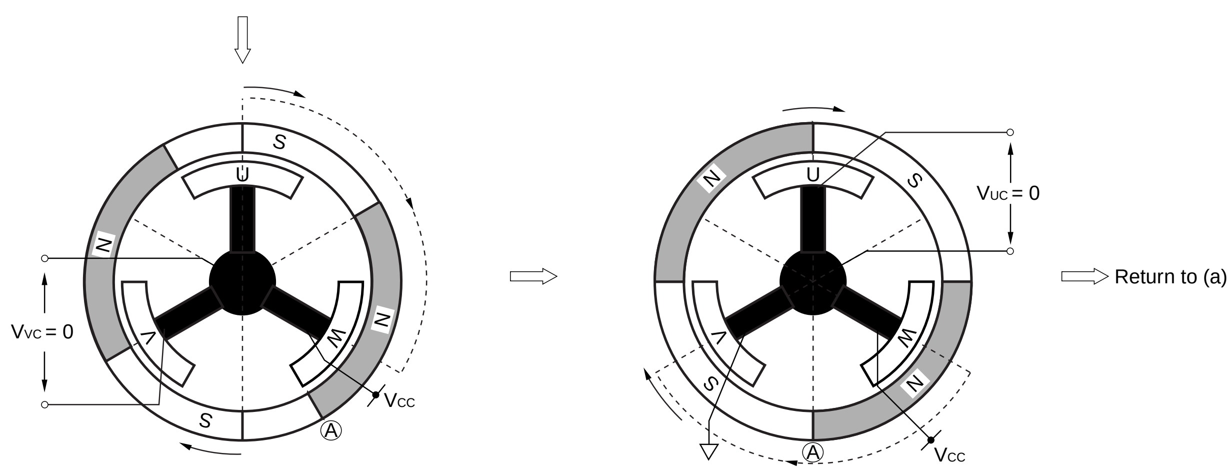
(a) Rotor position <1> … U-phase stator: S pole
V-phase stator: N pole
W-phase stator: Center point

(b) Rotor position <2> … U-phase stator: S pole
V-phase stator: Center point
W-phase stator: N pole



(d) Rotor position <4> … U-phase stator: N pole
V-phase stator: S pole
W-phase stator: Center point

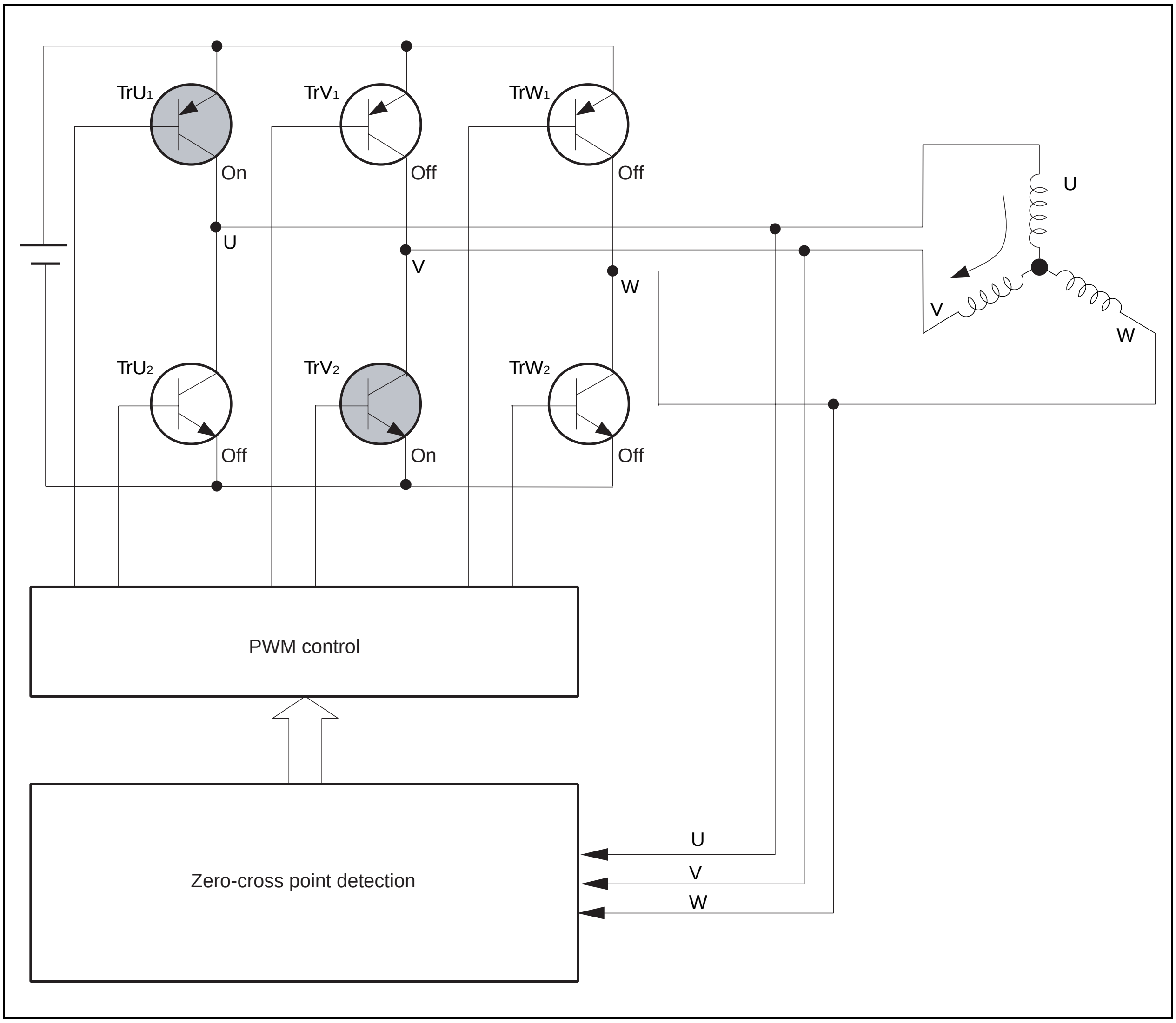
(c) Rotor position <3> … U-phase stator: Center point
V-phase stator: S pole
W-phase stator: N pole



(e) Rotor position <5> … U-phase stator: N pole
V-phase stator: Center point
W-phase stator: S pole

(f) Rotor position <6> … U-phase stator: Center point
V-phase stator: N pole
W-phase stator: S pole

Figure 1-3. Configuration of Three-Phase Brushless DC Motor



The 120° control method for a BLDC motor without a sensor is described below.

To control a BLDC motor, the rotor position must be known.
To control a BLDC motor without a sensor, the rotor position is estimated using induced voltage.

The induced voltage is in phase with the driving voltage waveform and its waveform is close to a sine wave, as shown in Figure 1-1. Figure 1-2 illustrates how the polarity of the stator of the motor is switched and how the magnet rotor revolves.

As shown in Figures 1-1 and 1-2, a three-phase DC motor rotates its rotor by switching the three driving current patterns on the three coil phases.

During period <1> in Figure 1-1, for example, transistor TrU_1 in Figure 1-3 is turned on by the U-phase driving pin, and TrV_2 is turned on by the V-phase driving pin, causing the current to flow from the U-phase driving pin toward the V-phase driving pin. At this time, the W-phase coil seems to be disconnected from the driver circuit and induced voltage is generated.

This induced voltage is used to detect the rotor position.

To control the number of revolutions of the motor, the voltage applied to the motor is controlled to change the current flowing through the coil. To change the voltage, a waveform that is controlled by PWM is applied to the transistor.

The voltage is changed by applying a waveform (PWM waveform) in proportion to the voltage to be applied, to the transistors on the lower arm side (TrU_2, TrV_2, and TrW_2) while the transistors on the upper arm side (TrU_1, TrV_1, and TrW_1) are on.

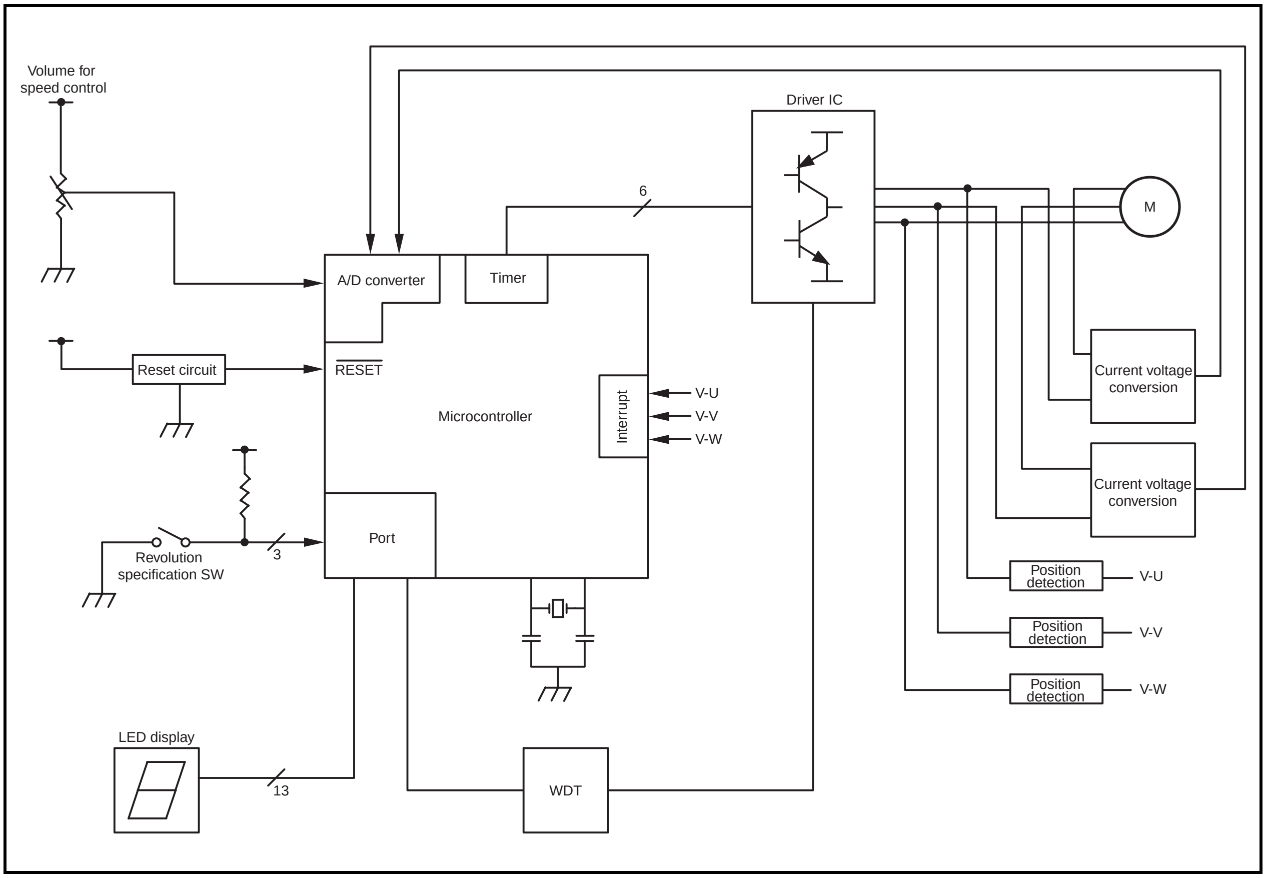
CHAPTER 2 HARDWARE CONFIGURATION

This chapter describes the hardware configuration.

2.1 Configuration

The reference system's main functions are described below. In this reference system, when the revolution specification switch is pressed after power application, the motor starts revolving in the direction specified.

Figure 2-1. Overall System Configuration



(1) Volume for speed control
Volume for increasing and decreasing the number of revolutions of the motor

(2) Revolution specification SW
CW, CCW, and STOP switches

(3) LED display
LED displaying the number of revolutions, operation time, etc.

(4) WDT
Watchdog timer

(5) Driver IC
Driver for driving motor

(6) Current voltage converter
Converting the motor driving current to voltage, used for detecting overcurrent

(7) Position detector
Rotor position estimation signal output from the induced voltage

2.2 Circuit Diagram

Figure 2-2 shows a diagram of the sample reference system circuit.

This sample reference system circuit diagram includes the V850ES/KJ1, a reset circuit, oscillator, a pin handling microcontroller peripheral block, operation mode switch block, LED output block, watchdog timer circuit block, drive circuit block, motor controller, and motor revolution indicator.

(1) Microcontroller and microcontroller peripheral block

The V850ES/KJ1 includes a reset circuit, an oscillator that uses a resonator, and a block for handling the unused pins.

(2) Operation mode switch block

This block includes switches that set the operation mode as CW or CCW operation.

(3) LED output block

This block includes 16 LEDs, which are used to indicate the revolution speed (rpm), errors, etc.

(4) Watchdog timer circuit block

This block outputs stop signals when pulse output from the V850ES/KJ1 stops for one ms or longer.

(5) Drive circuit block

The 6-phase outputs from the inverter timer are converted to U-, V-, and W-phase output for the motor driver. This drive circuit is not shown in detail in this example, since it varies depending on the motor’s specifications.

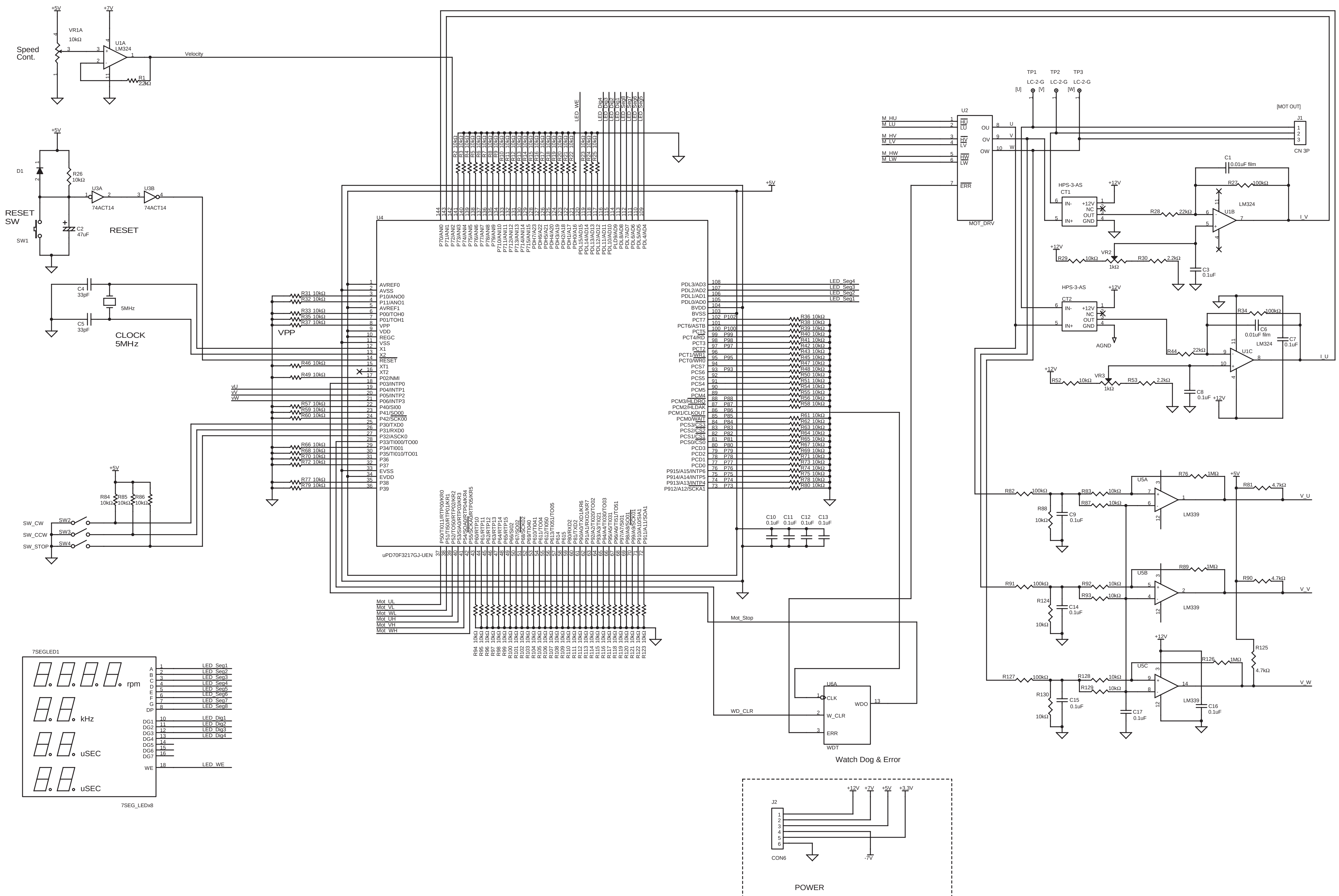
(6) Motor controller

This block includes the HPS-3-AS, LM324, and other devices that are used to measure the motor’s U and V drive currents via A/D conversion.

(7) Motor revolution indicator

This block includes a volume adjuster and the LM324 for setting the motor’s revolution speed (rpm).

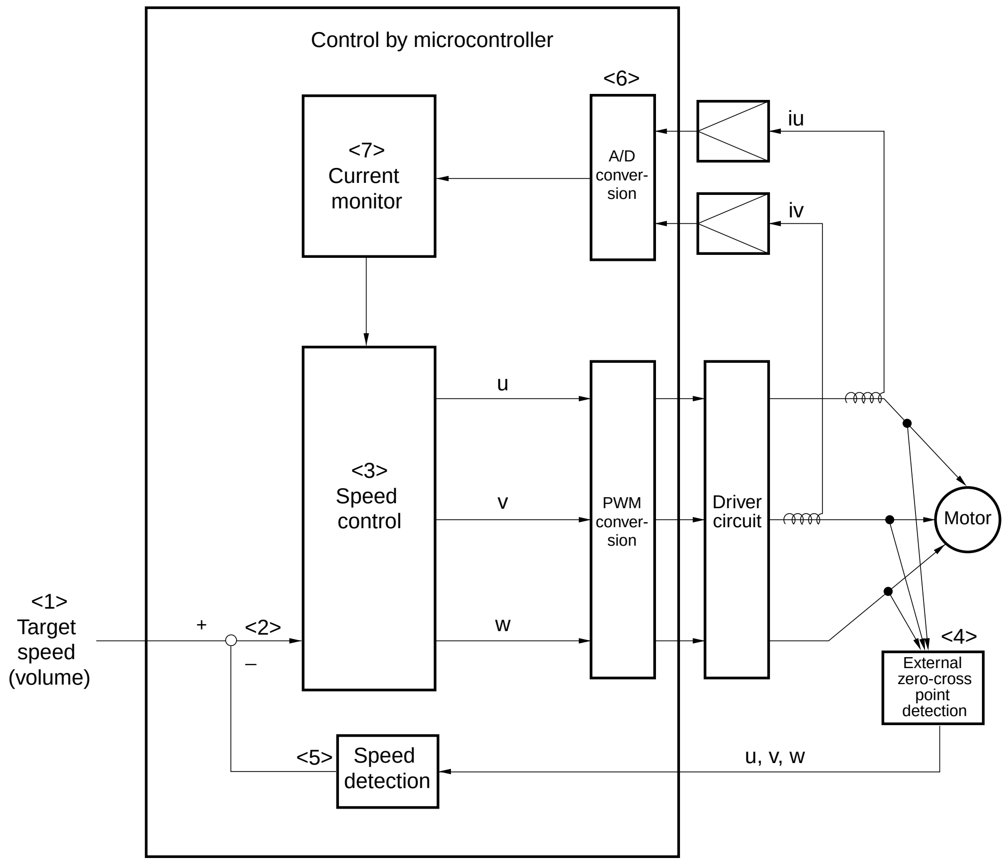
Figure 2-2. Circuit Diagram of V850ES/KJ1



3.1 Control Block

Figure 3-1 shows a diagram of the software control block of the reference system.

Figure 3-1. Diagram of Software Control Block of Reference System



<1> The volume is loaded by the A/D converter as a target speed.

<2> The speed to be calculated is determined by the difference from the present speed.

<3> Values of phases U, V, and W are set.

<4> The zero-cross point is detected by an induced voltage (by hardware).

<5> The speed is calculated by the interval of zero-cross point in each phase.

<6> An overcurrent is detected by the A/D converter.

<7> The speed is controlled by a current value.

3.2 Peripheral I/O

The following types of peripheral I/O functions are used in this reference system.

Table 3-1. List of Peripheral I/O Functions

Function	Peripheral I/O Function Name
Inverter timer	RTO (RTP00 to RTP05)
10 ms timer	Timer 01 (TM01)
Motor control timer	Timer 00 (TM00)
Speed measuring timer	Timer 04 (TM04)
U-phase current	ANI0
V-phase current	ANI1
Setting speed (volume)	ANI2
U-phase zero-cross input	INTP1
V-phase zero-cross input	INTP2
W-phase zero-cross input	INTP3
CW key input	P30
CCW key input	P31
STOP key input	P32
WDT reset output	P33
LED output	PDL0 to PDL11, PDL15

(1) Description of peripheral I/O functions

(a) Inverter timer

The RTP00 to RTP05 pins are used to output PWM waveforms.
In this reference system, the settings are as shown below.

- Inverter timer output: Low active
- When INTP0 pin input is at high level, PWM output is stopped.

(b) Motor control timer

Motor control timers are used to issue interrupts at a 50 μs interval.

(c) 10 ms timer

10 ms timers are used to issue interrupts at a 10 ms interval.

(d) Speed measuring timer

Used for measuring the revolution speed of the motor.

(e) Current value input

ANI0: U-phase current value (−5 to +5 A)
ANI1: V-phase current value (−5 to +5 A)

(f) Speed specification volume value input

ANI2 is used to input a value from 0 to 1,023.

3.3 PWM Control

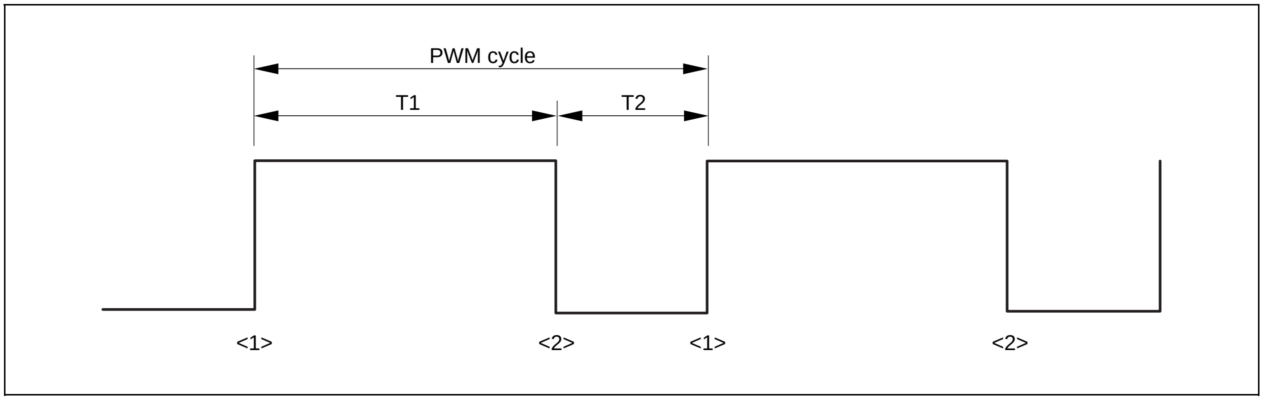
In the reference system, PWM is controlled by using the real-time output function (RTO).

(1) PWM waveform creation method

The PWM waveform has intervals T1 and T2 in the PWM cycle as shown below. The PWM waveform control can be realized by outputting the output patterns to the port alternately at time intervals of T1 and T2 using the timer with real-time output function.

In this method, there will be no <1> or <2> in the case of duty ratio of 100% or 0%, the duty ratio is restricted to the minimum and maximum ranges.

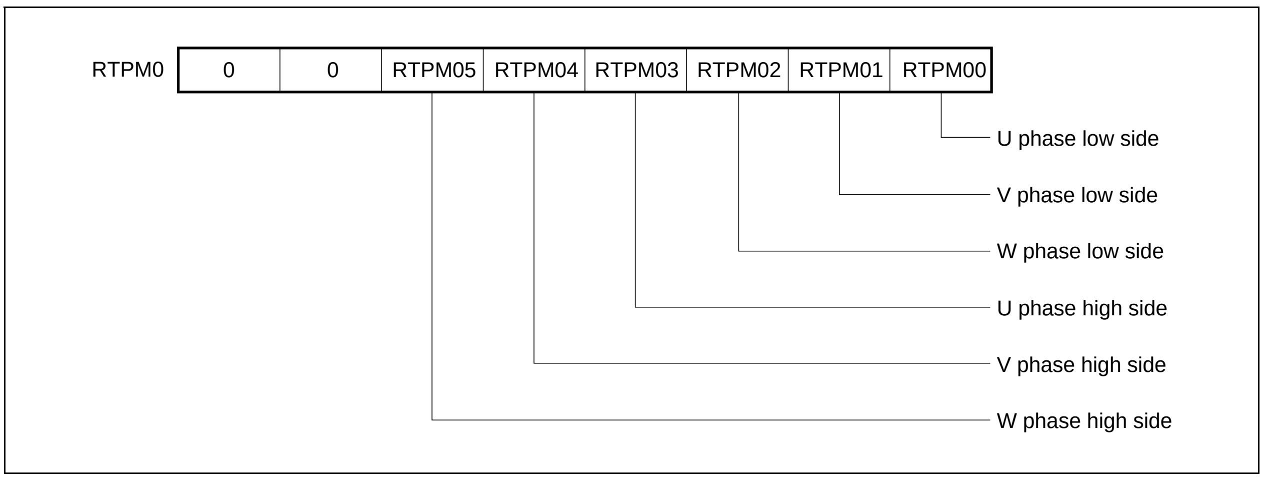
Figure 3-2. PWM Waveform Creation Method



(2) Allocation of real-time output port of sample circuit

In the sample circuit, the PWM control pins are allocated to the real-time output port as shown below.

Figure 3-3. Allocation of Real-Time Output Port of Sample Circuit



3.4 Software Processing Structure

The software processing structure is shown below.

Figure 3-4. Main Processing Structure

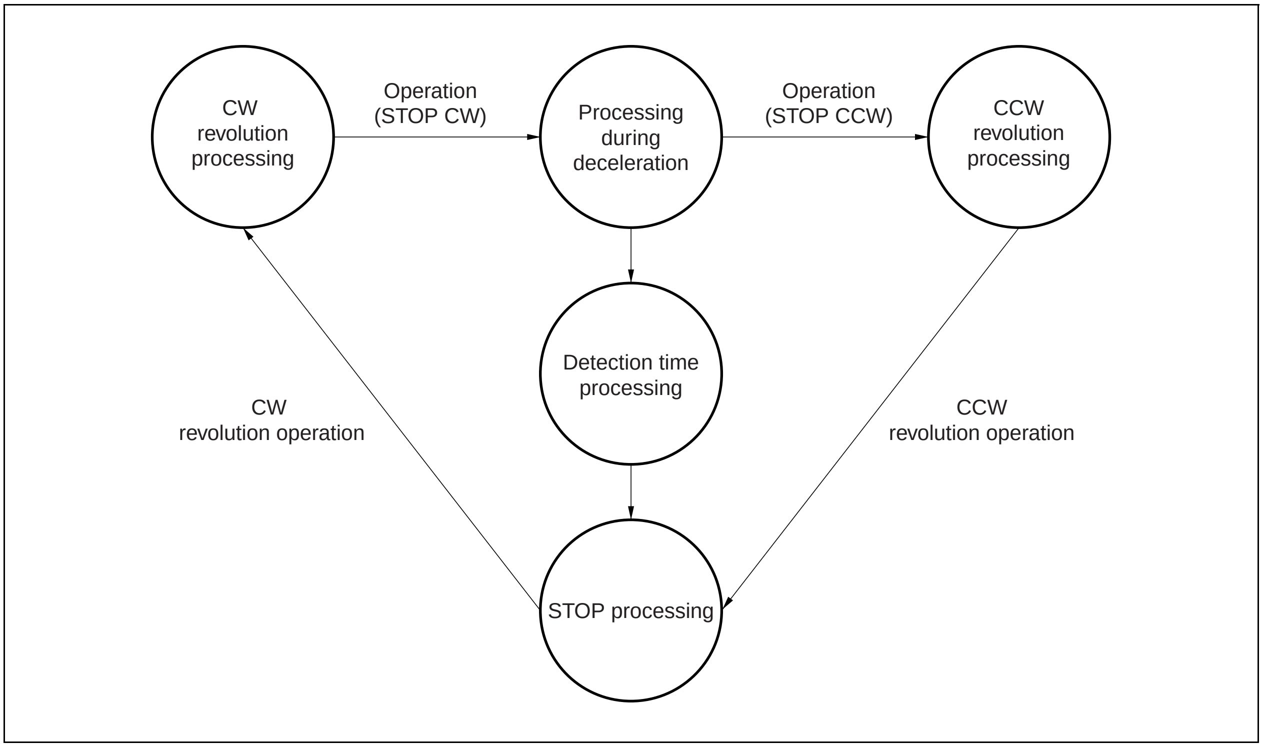
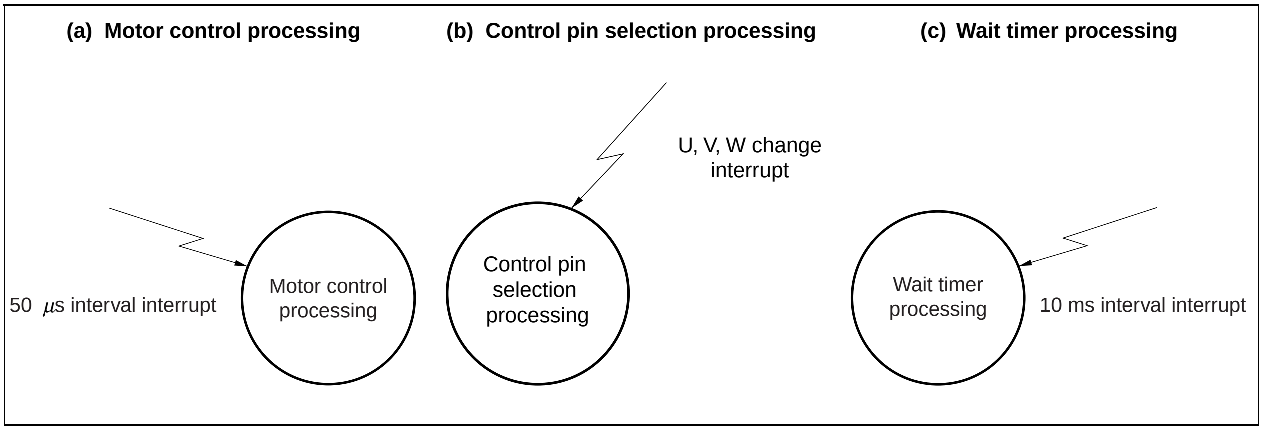


Figure 3-5. Interrupt Processing Structure



The status of the operation mode switch is monitored by the main processing, and processing is transferred to CW, CCW, and stop status. The motor is controlled in the specified status by using a 50 μs interval interrupt.

There are the following three motor control statuses.

- Stop status
  The motor is not controlled.
- Initial operation status
  Estimated revolution control is performed up to the speed at which the zero-cross point of electromotive force can be detected.
- Speed control status
  Feedback revolution control is performed so that the indication speed is attained.

3.5 Flowchart

3.5.1 Main processing

Figure 3-6 shows the flowchart of the main processing.

Figure 3-6. Main Processing

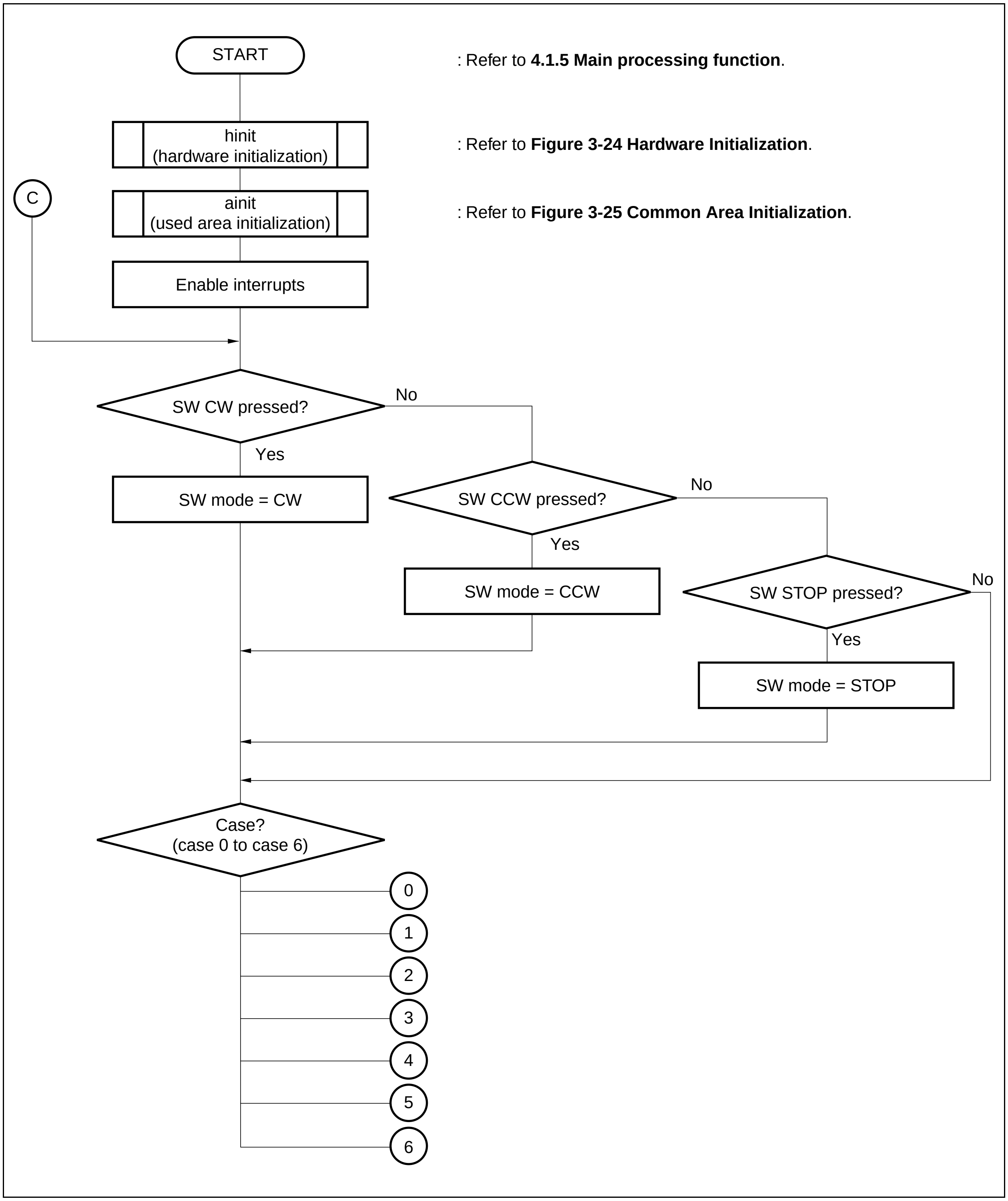


Figure 3-7. Case 0 (Processing During Stoppage)

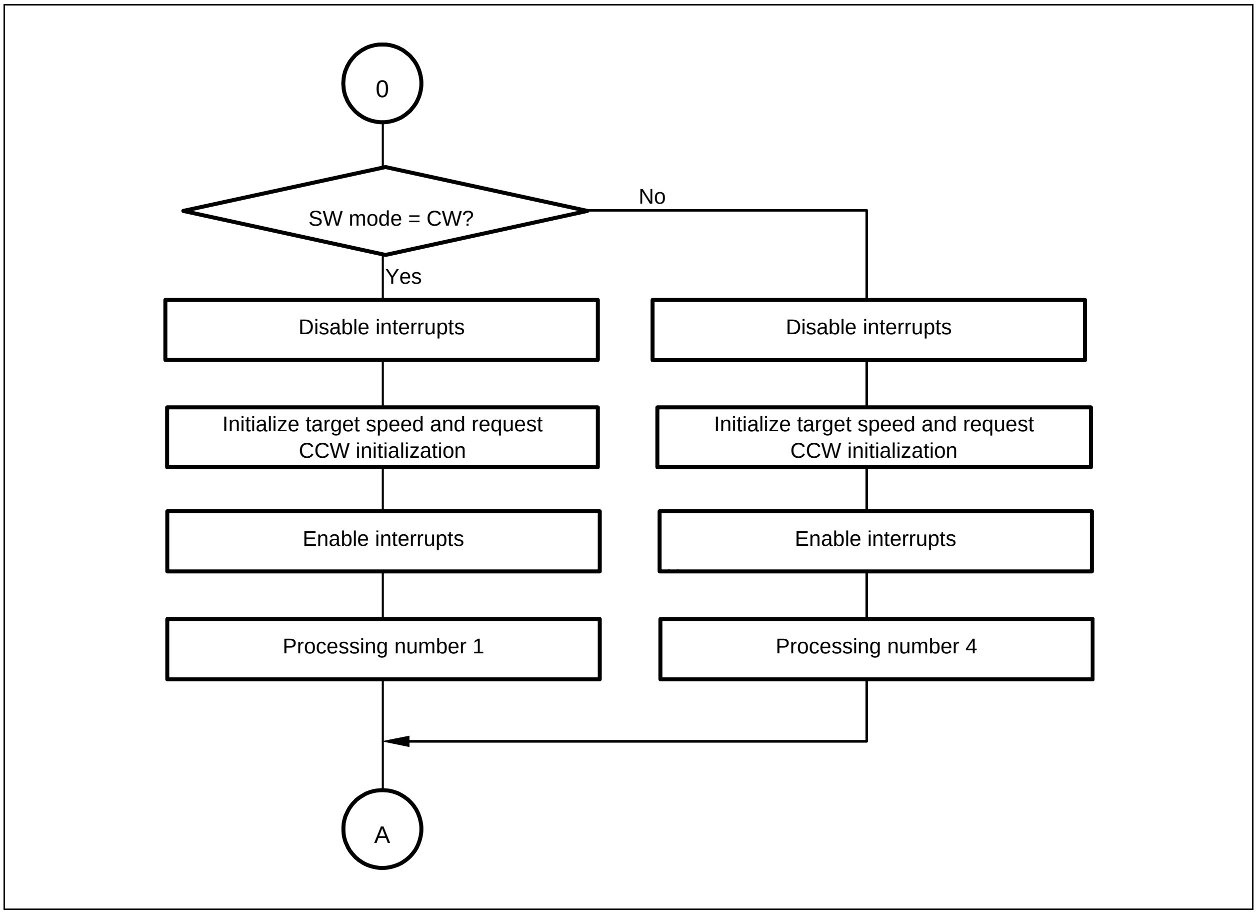


Figure 3-8. Case 1 (CW Acceleration Processing)

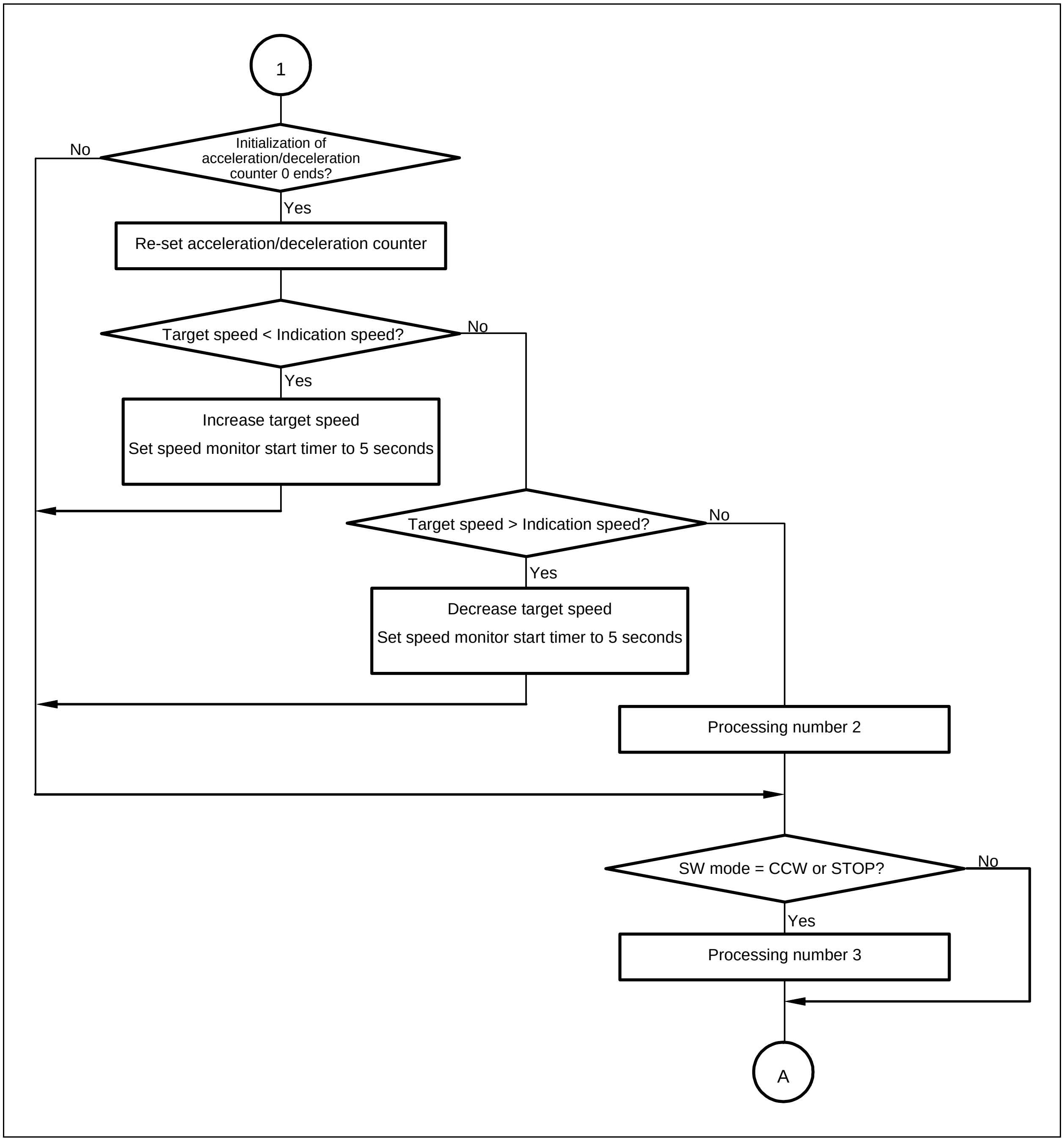


Figure 3-9. Case 2 (CW Constant-Speed Processing)

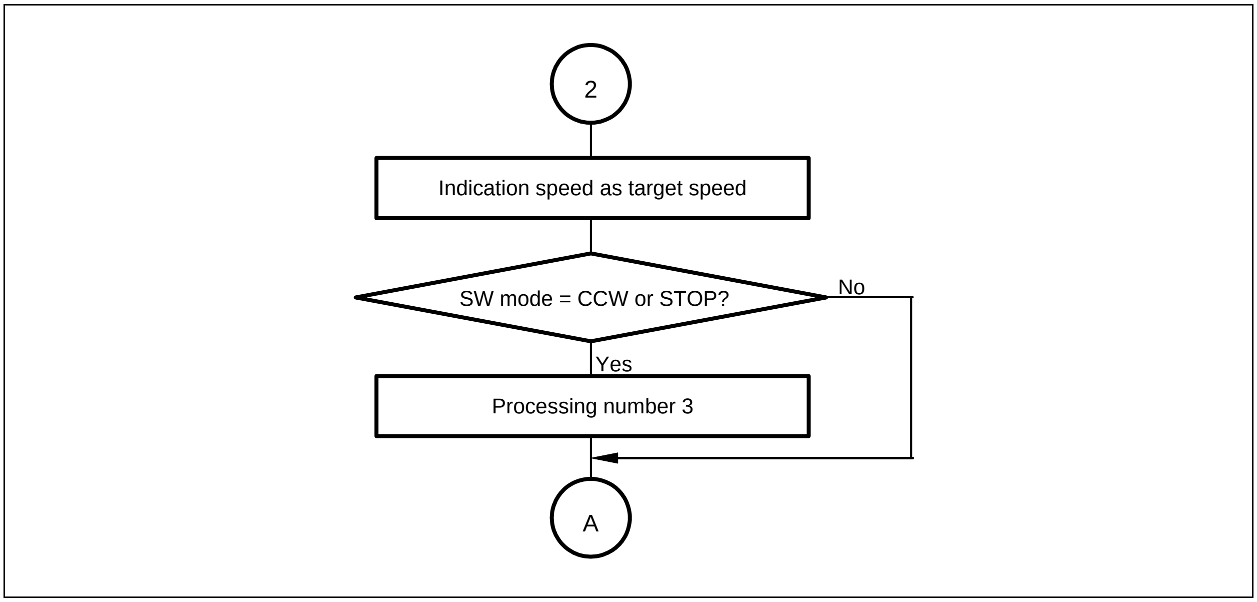


Figure 3-10. Case 3 (CW Stop Processing)

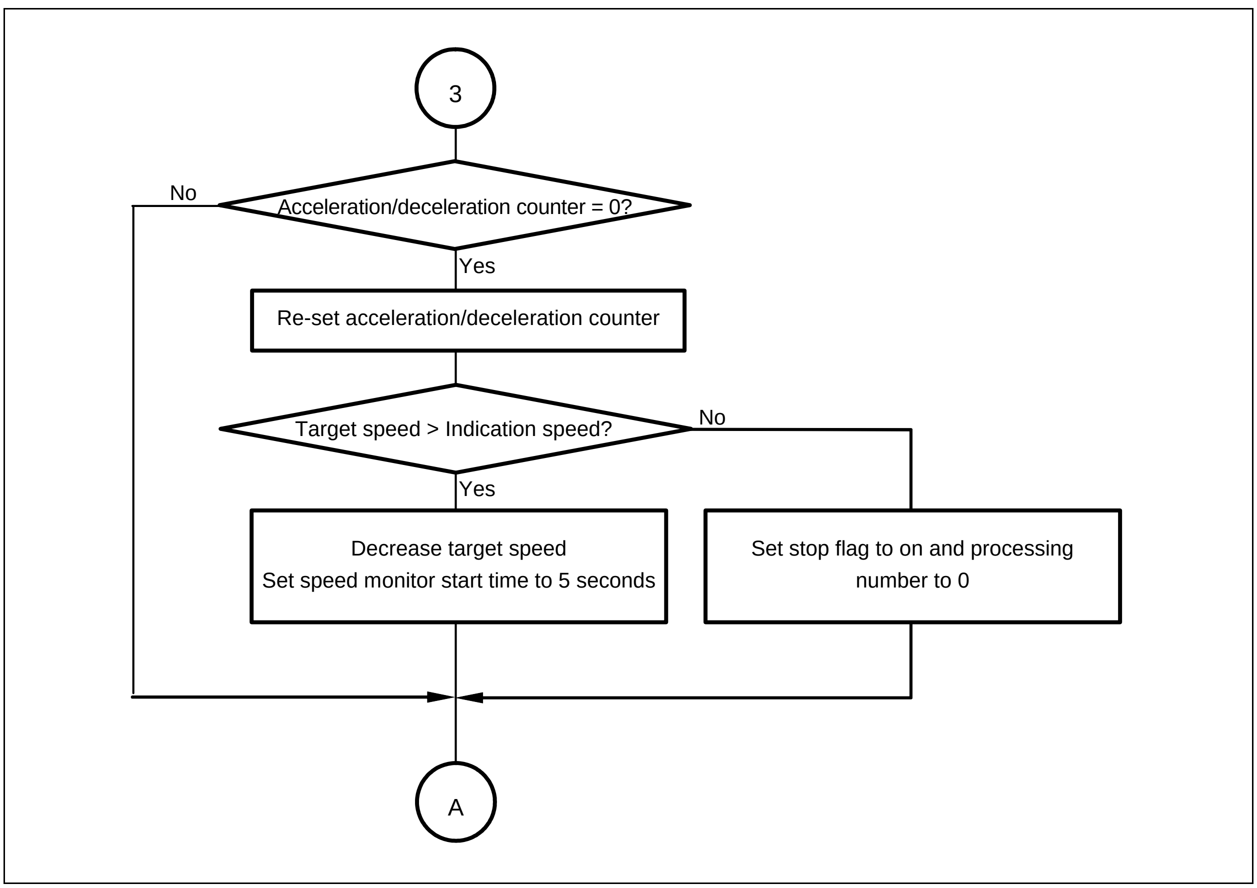


Figure 3-11. Case 4 (CCW Acceleration Processing)

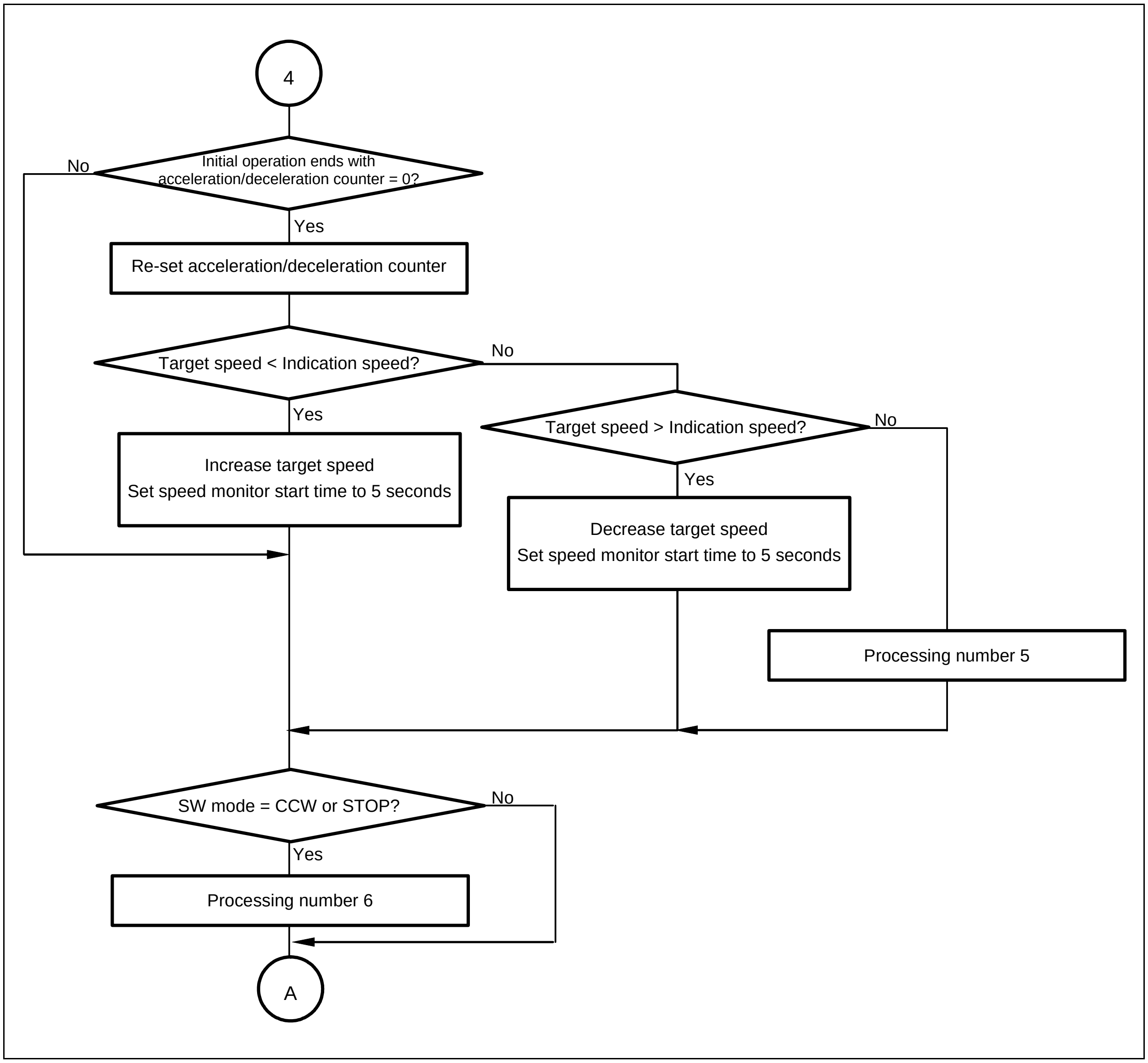


Figure 3-12. Case 5 (CCW Constant-Speed Processing)

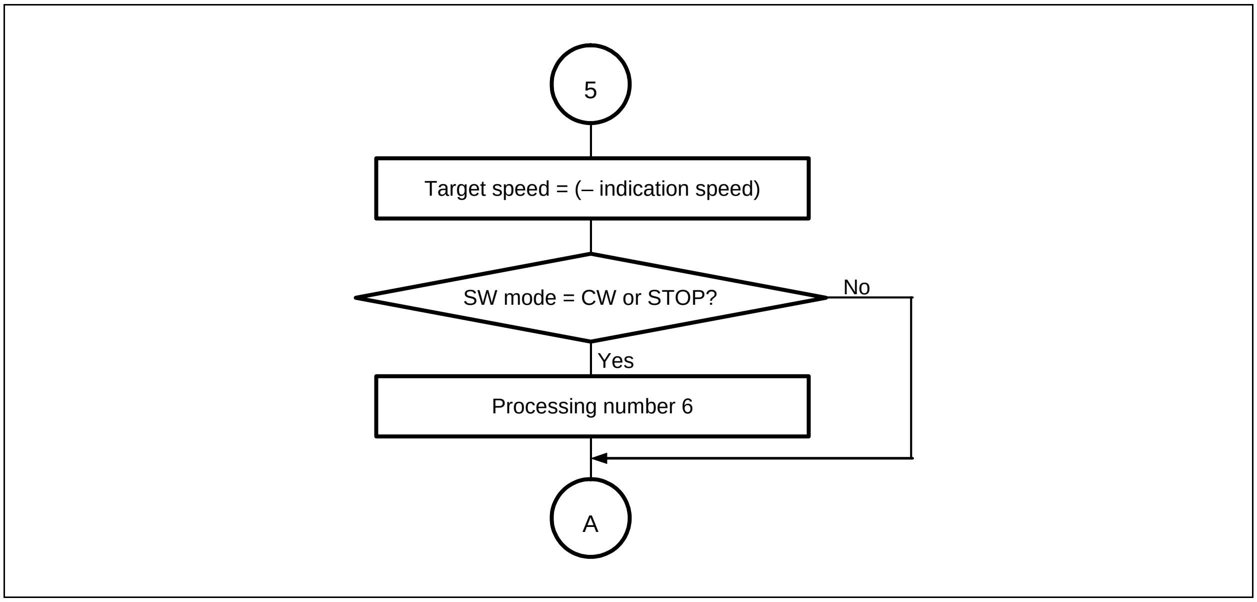


Figure 3-13. Case 6 (CCW Stop Processing)

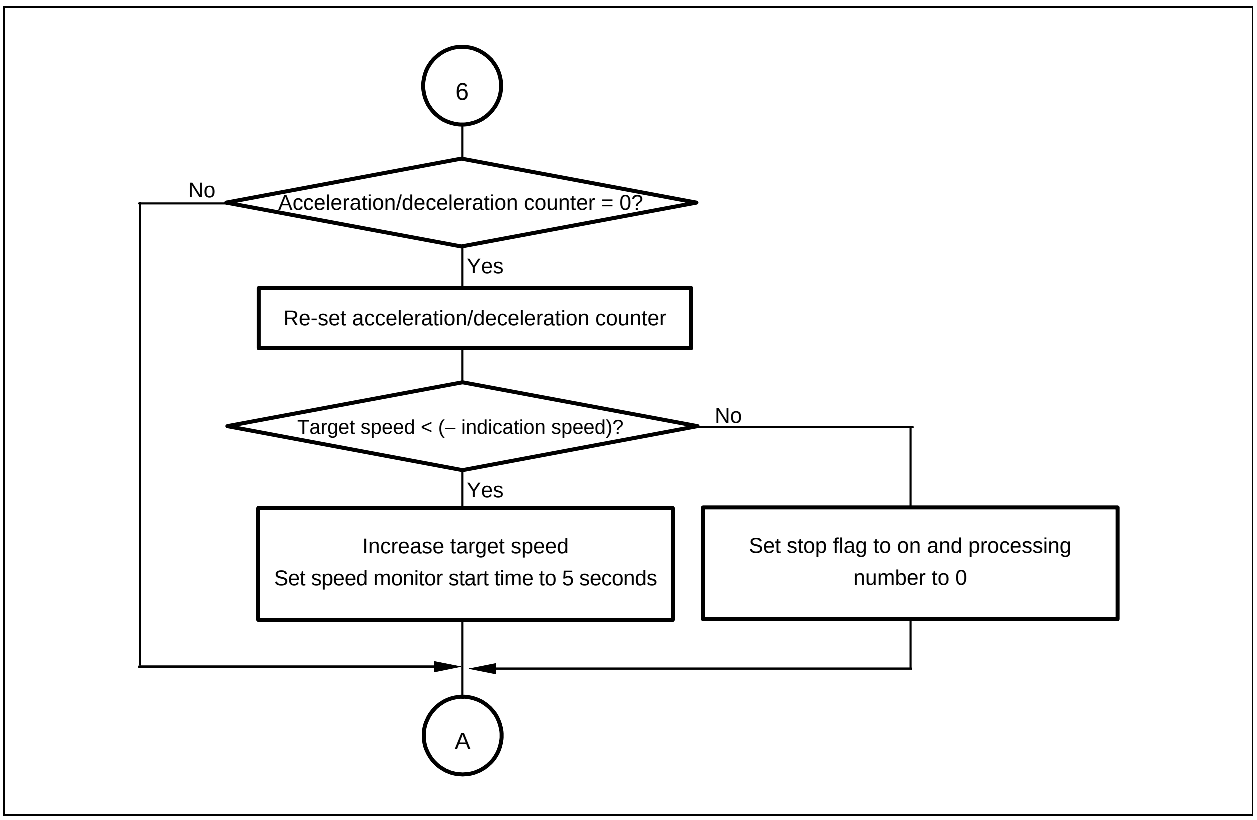


Figure 3-14. Detect Wait (1/2)

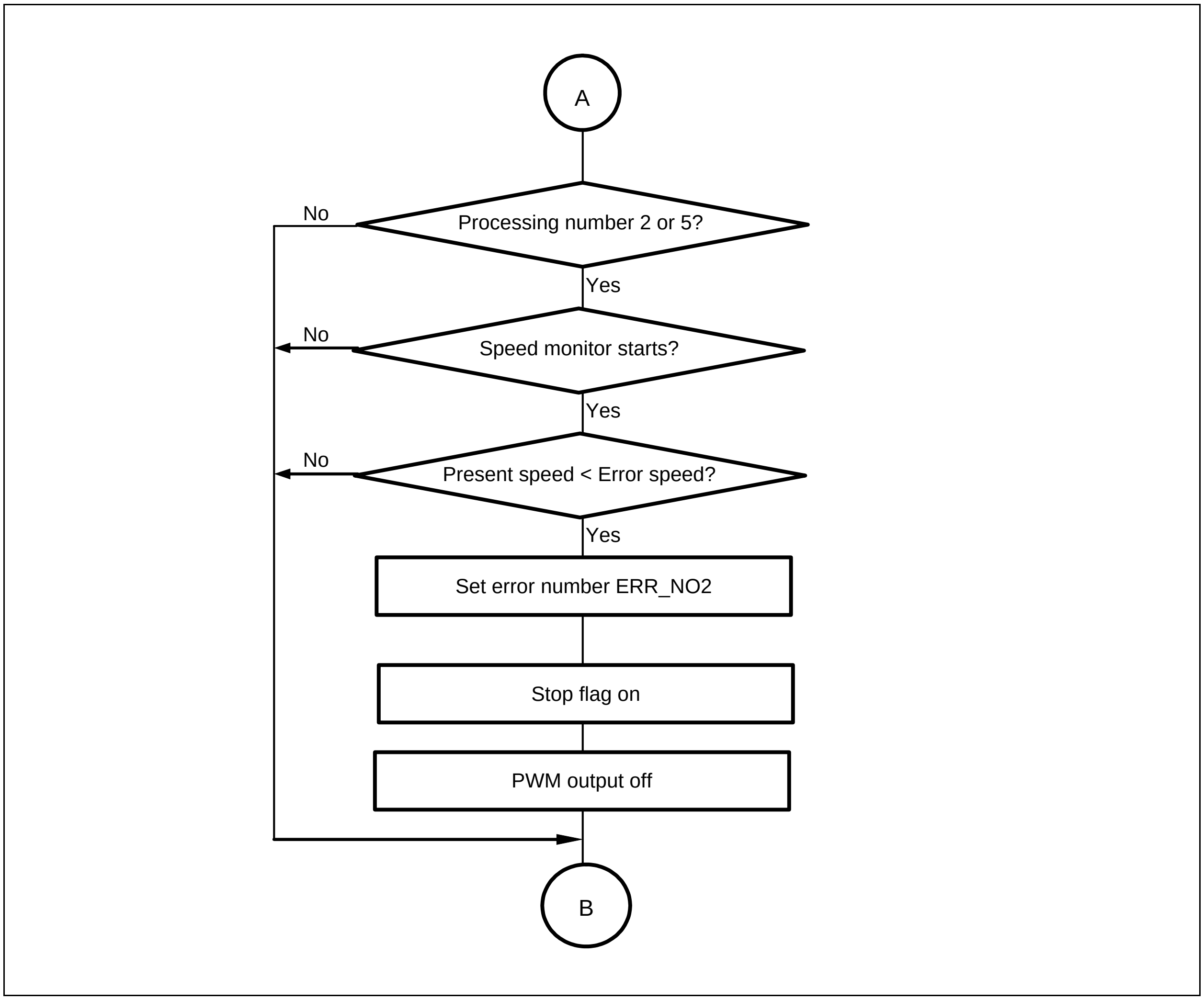
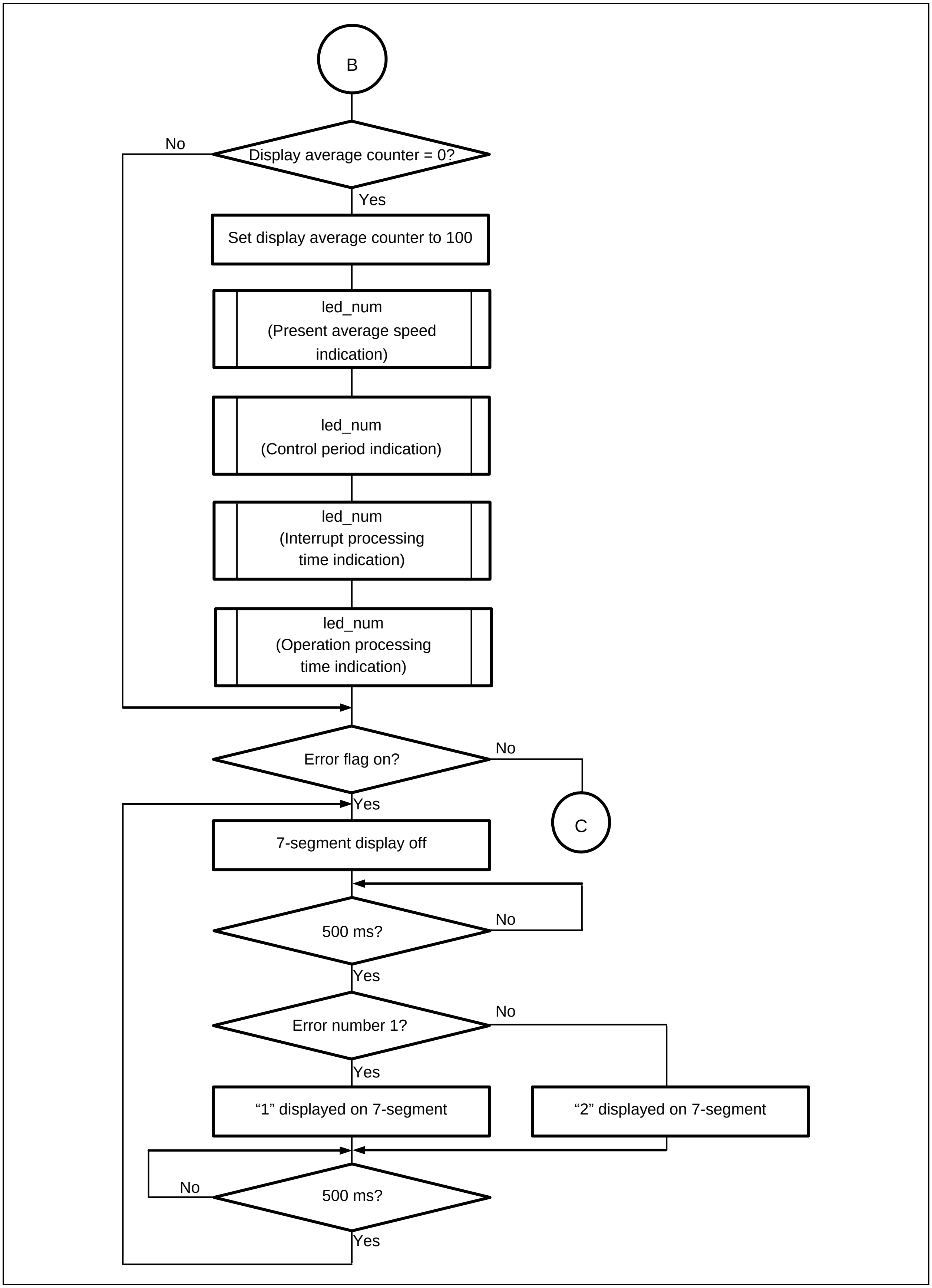
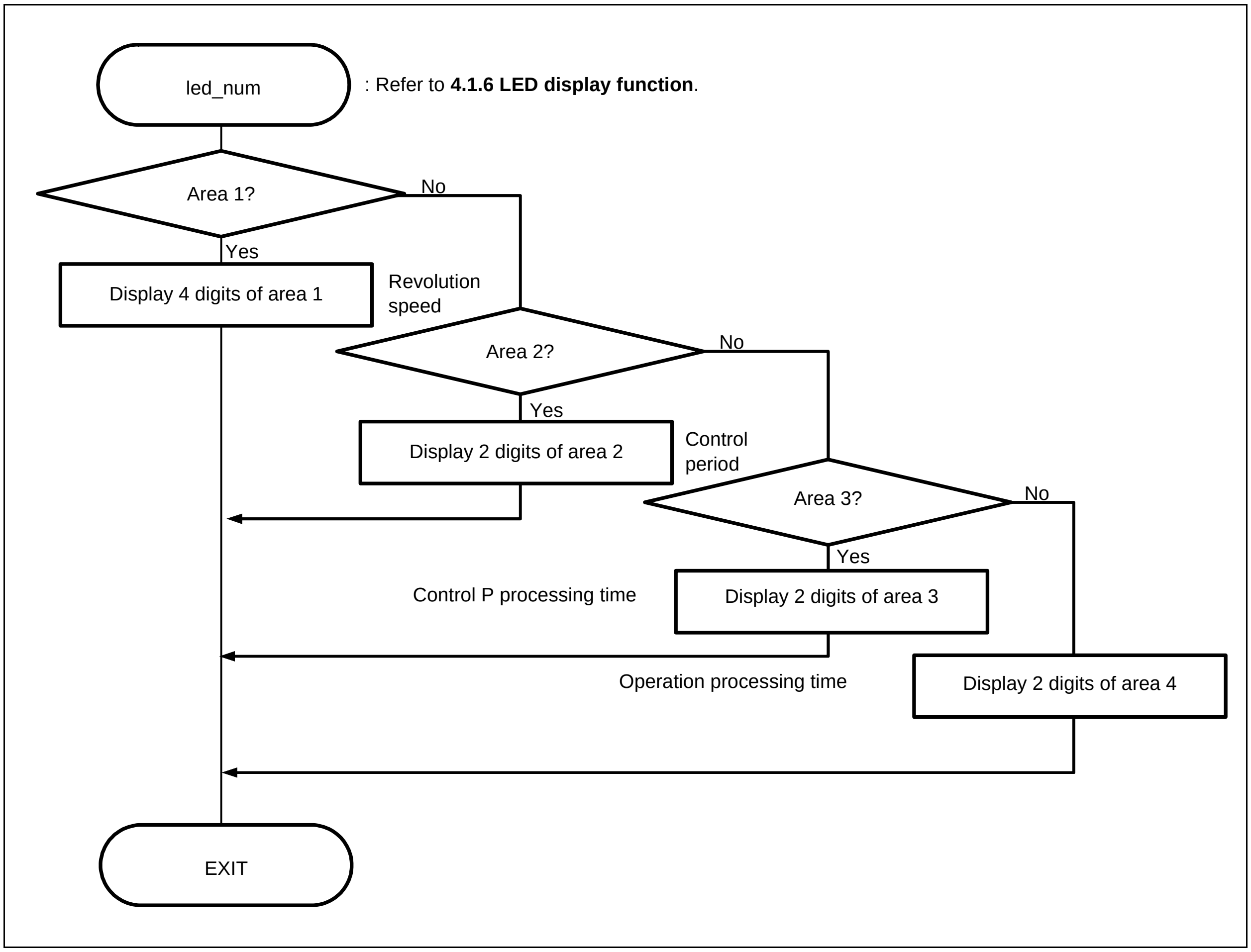


Figure 3-14. Detect Wait (2/2)



3.5.2 LED display

Figure 3-15. LED Display



3.5.3 Motor control processing

Figure 3-16. Control Interrupt Processing (1/5)

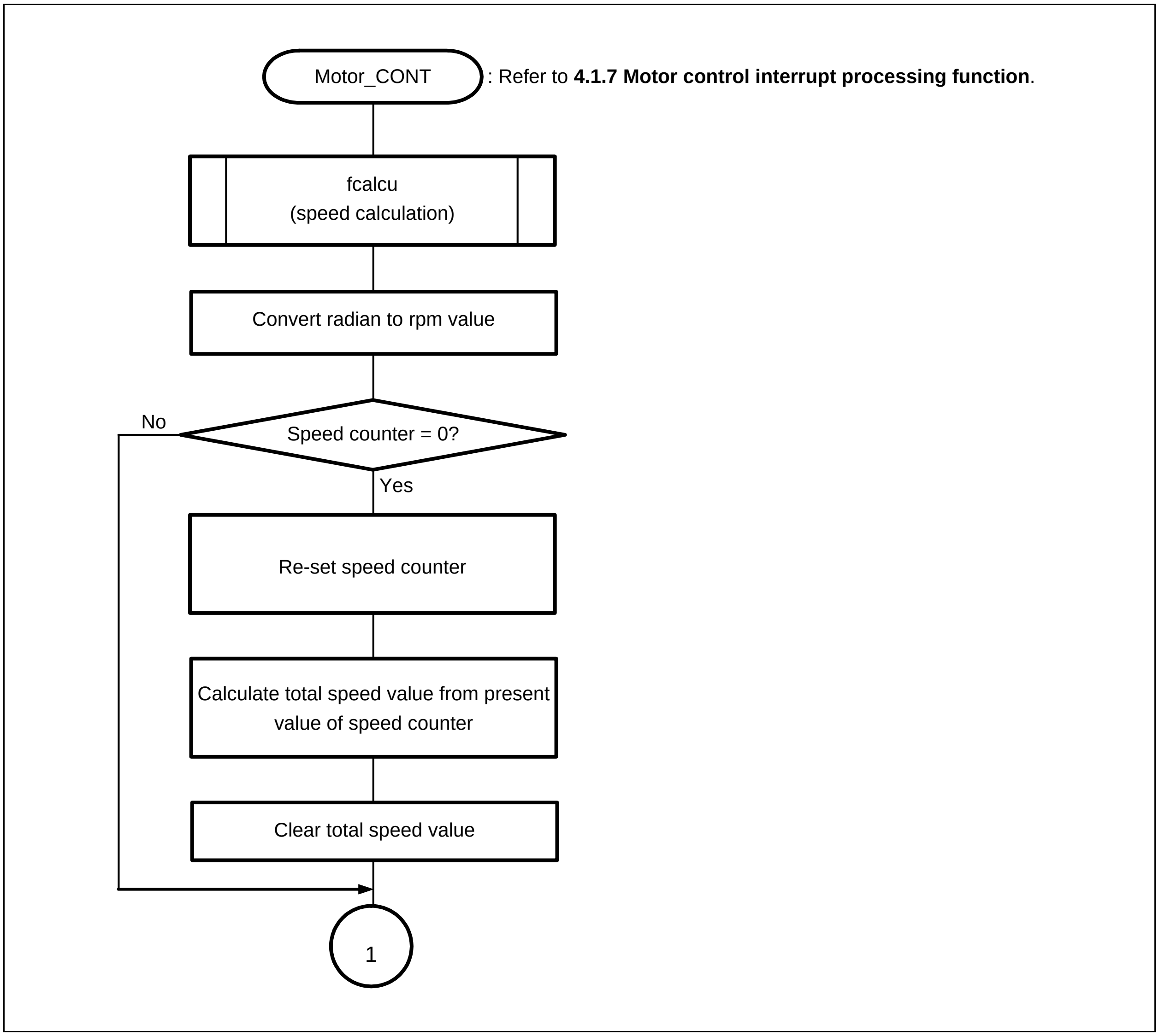


Figure 3-16. Control Interrupt Processing (2/5)

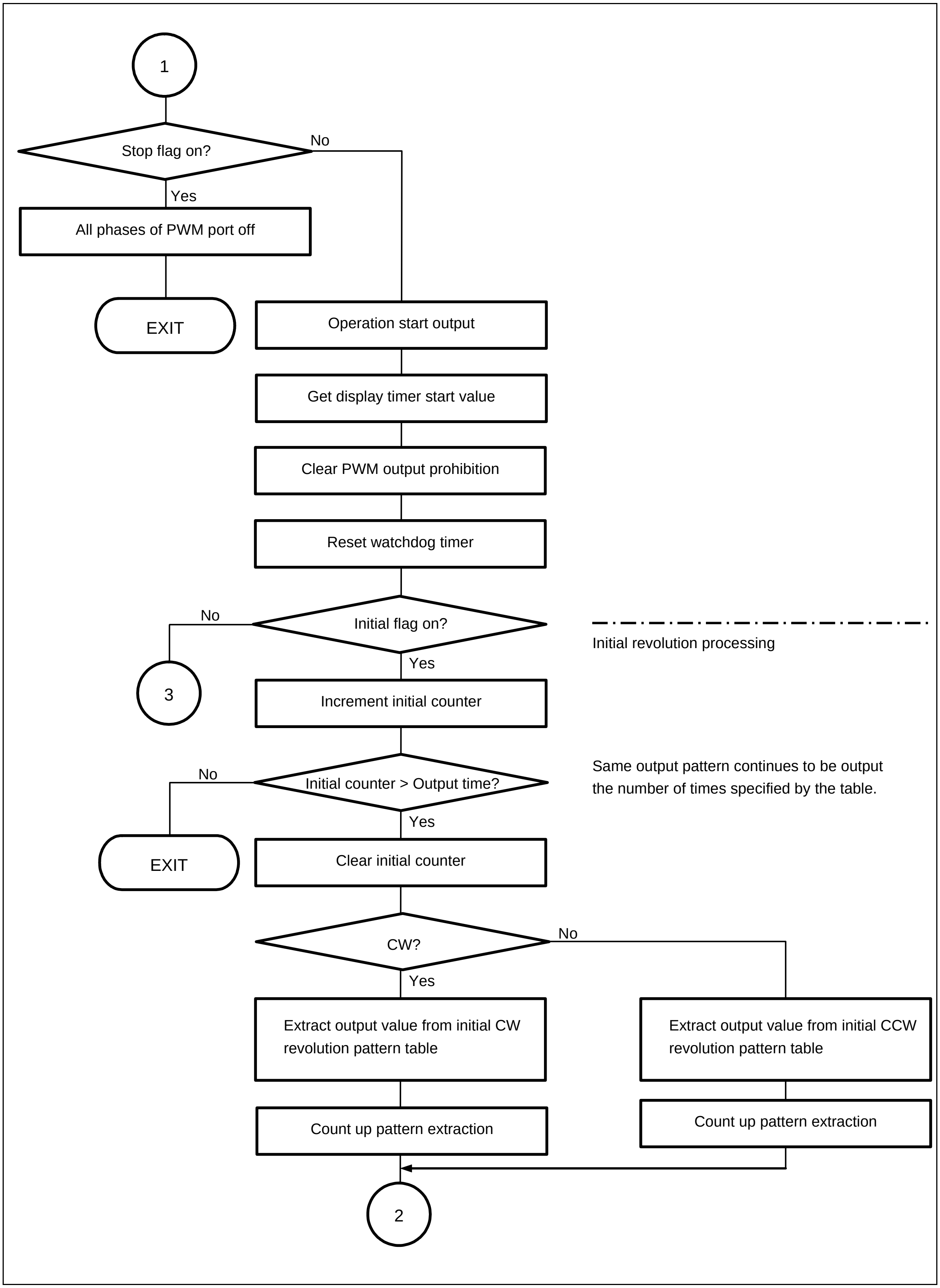


Figure 3-16. Control Interrupt Processing (3/5)

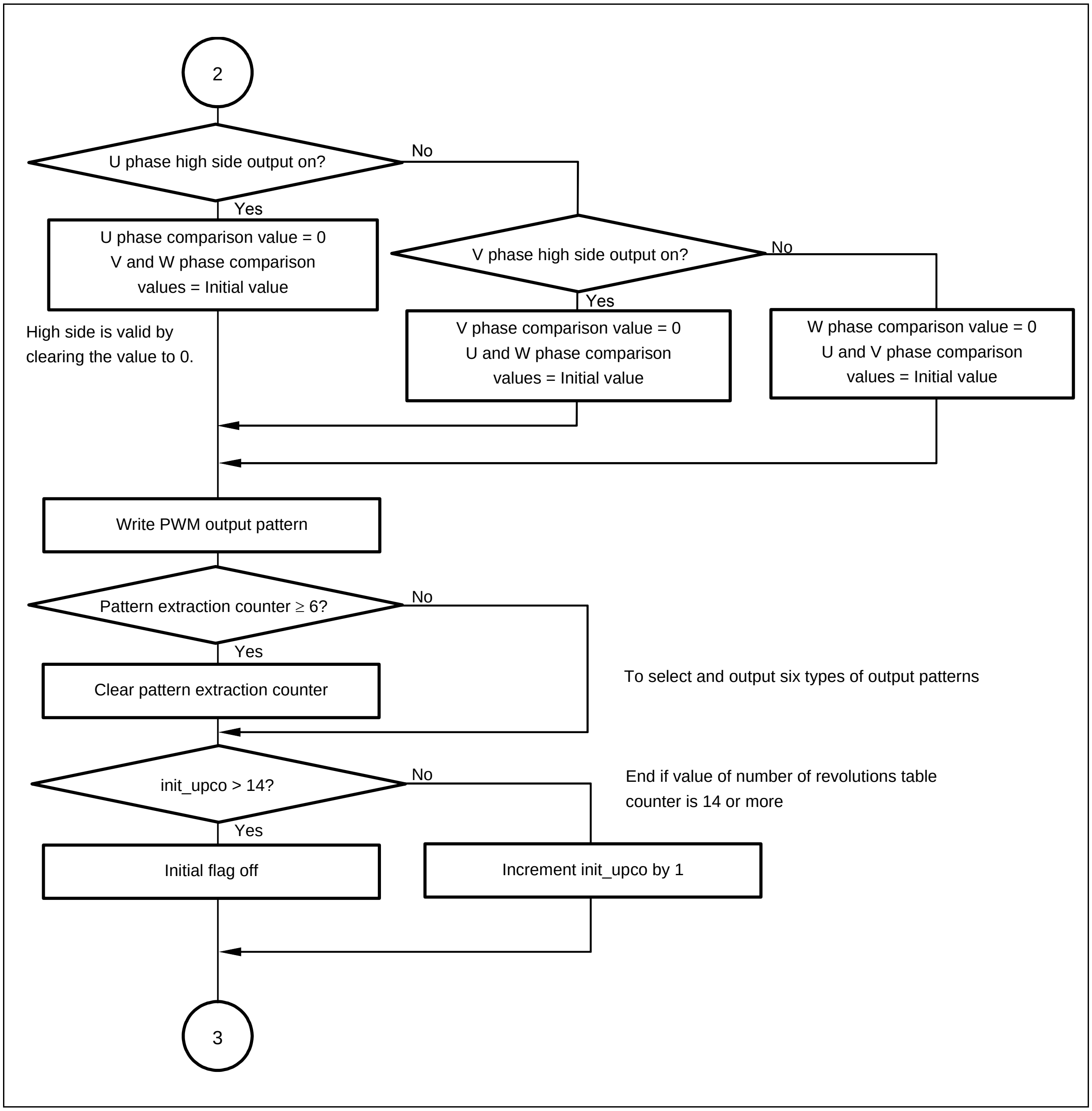
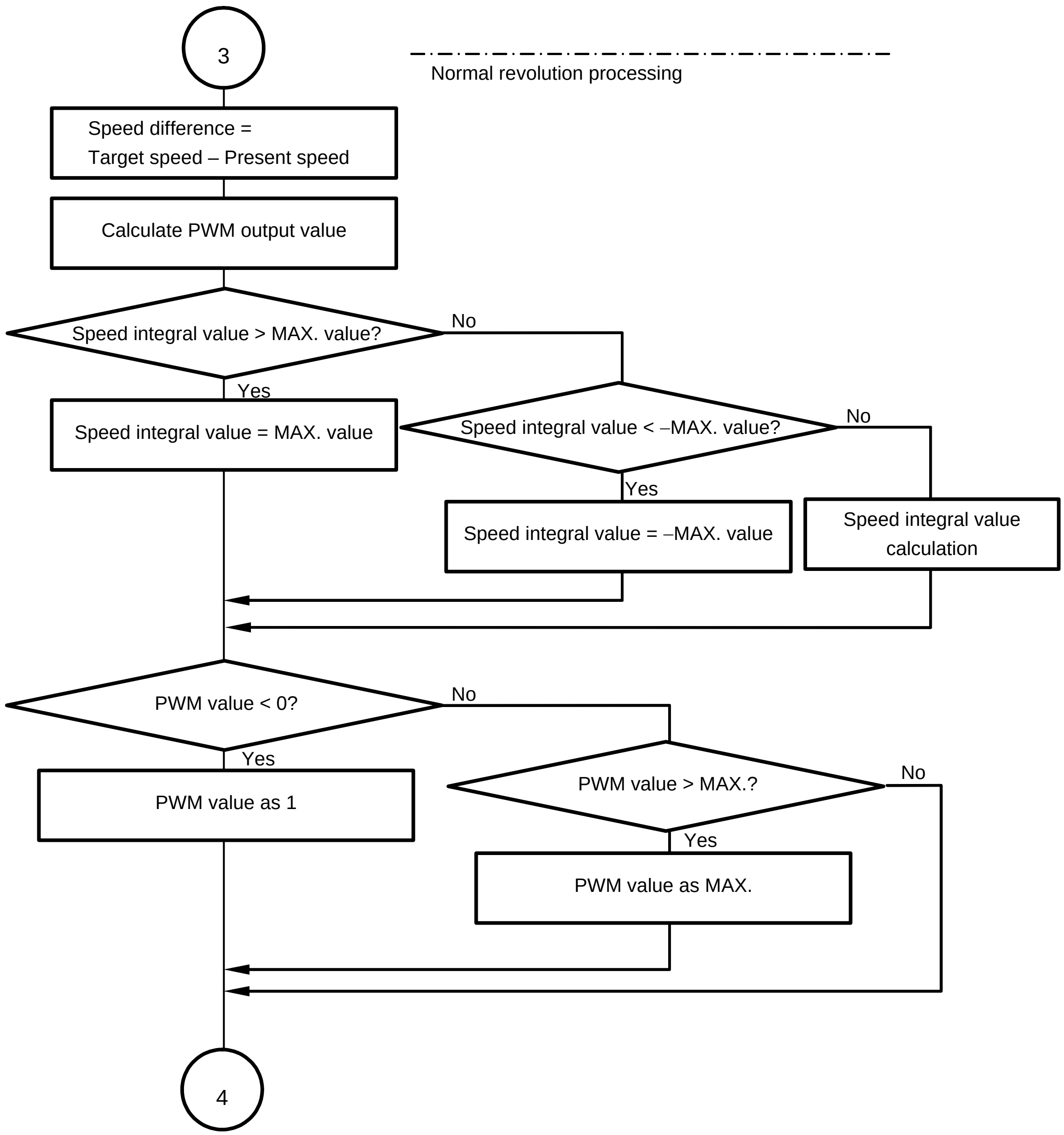


Figure 3-16. Control Interrupt Processing (4/5)



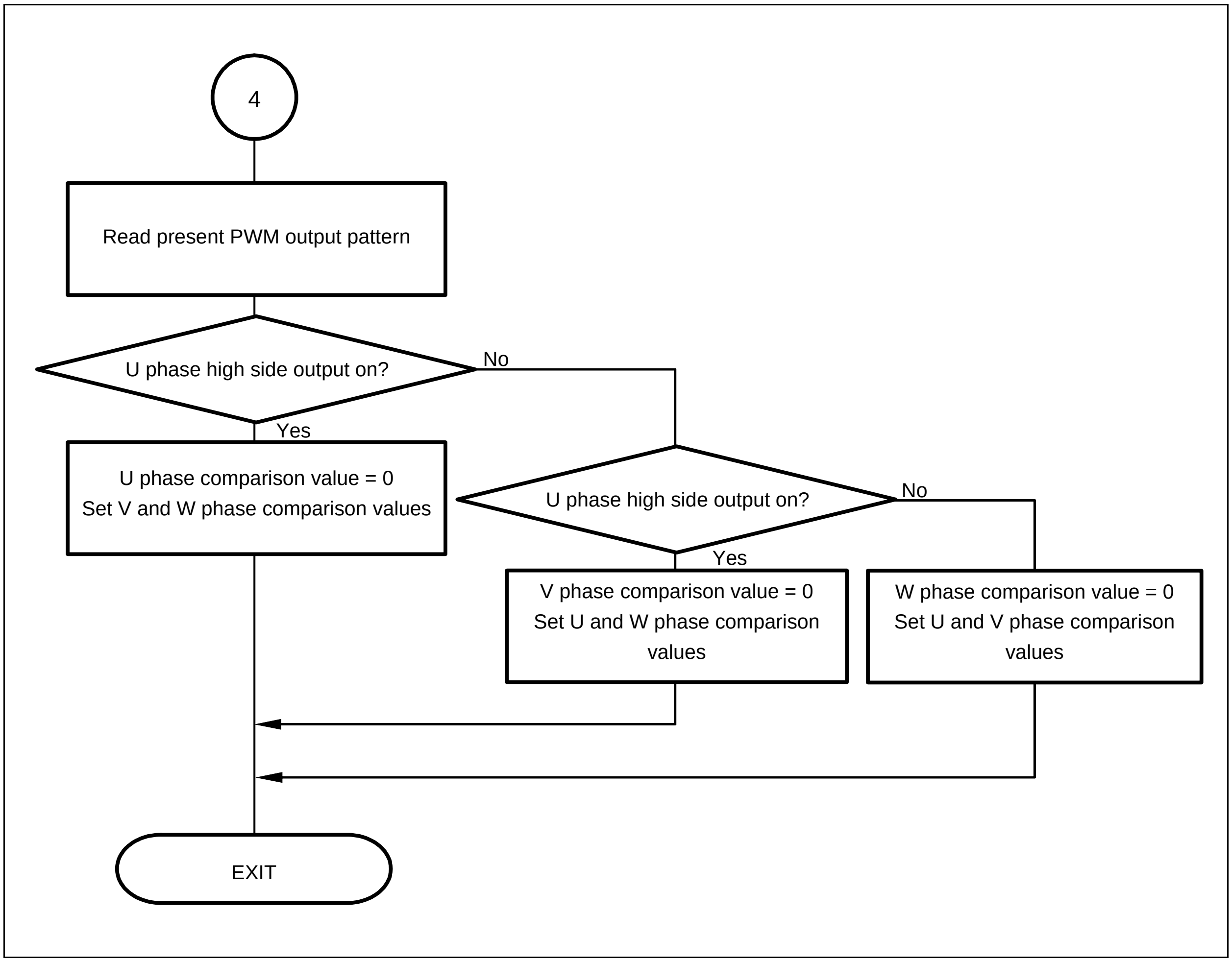
Remarks 1. PWM = (Present speed × ksp) + (Speed difference × ksp/10) + Speed integral value + Speed offset value

2. Speed integral value = Speed integral value + (Speed difference × ksi)

3. ksp: Speed proportion gain

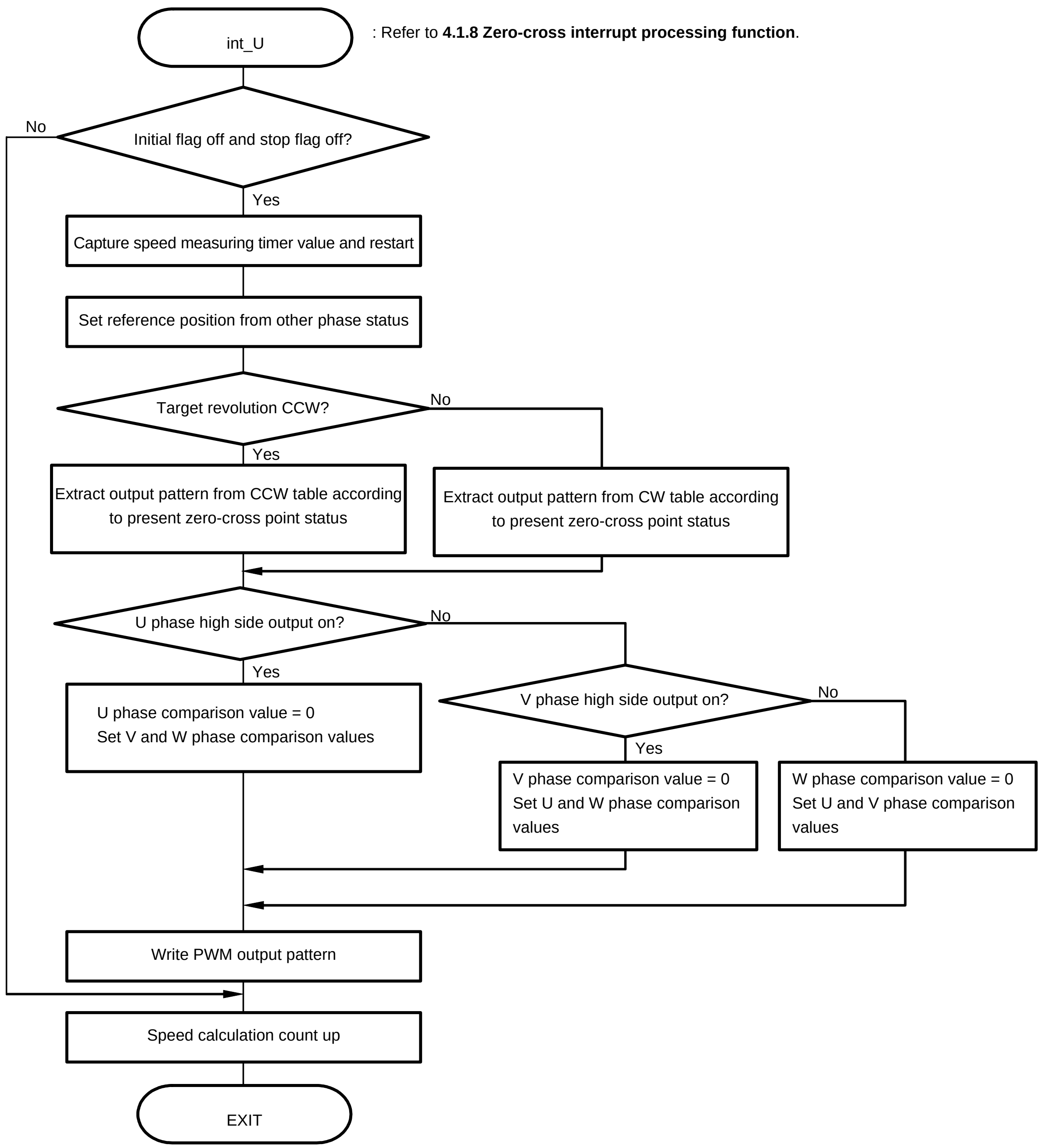
ksi: Speed integral gain

Figure 3-16. Control Interrupt Processing (5/5)



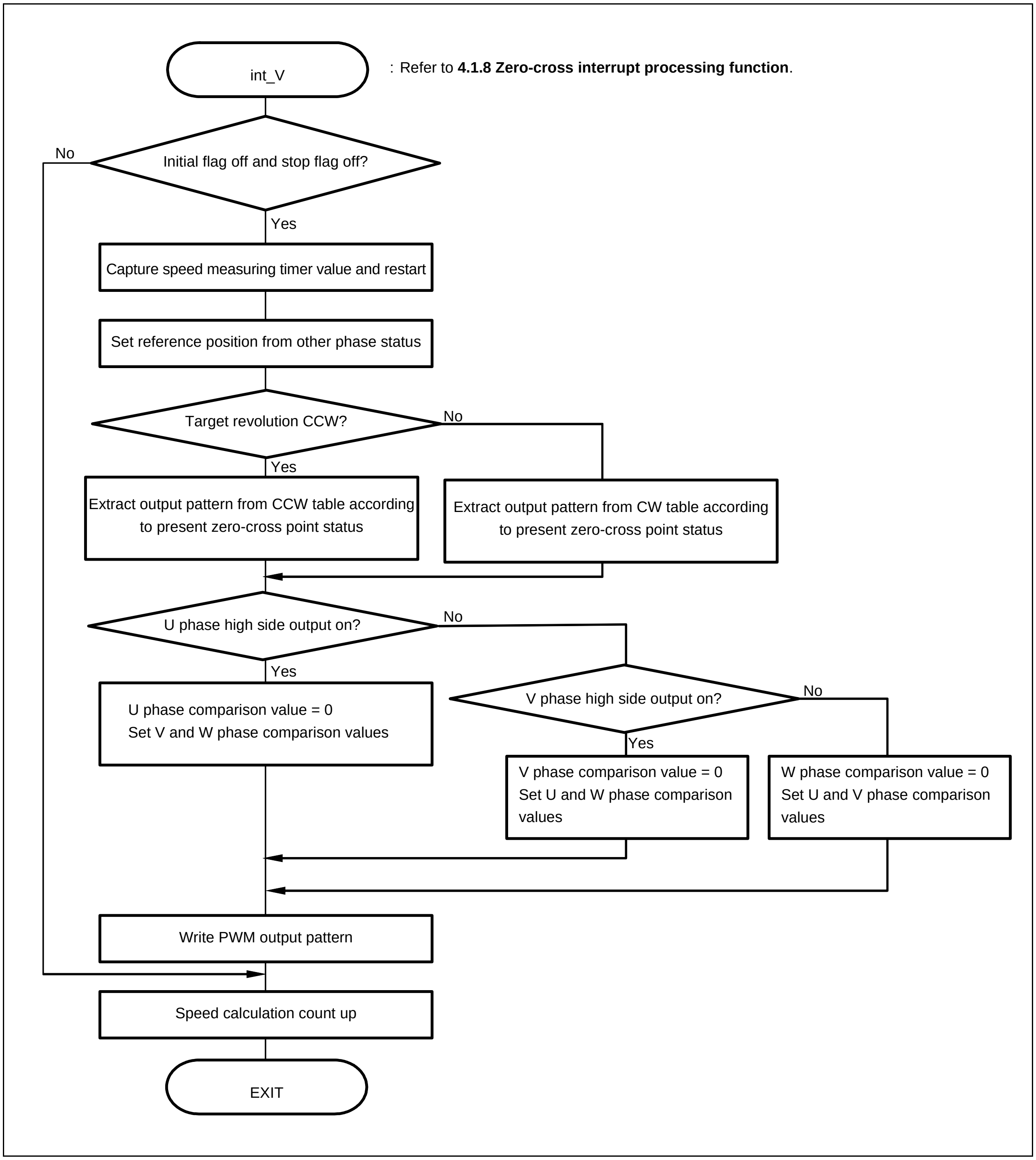
3.5.4 U zero-cross point interrupt processing

Figure 3-17. U Zero-Cross Point Interrupt Processing



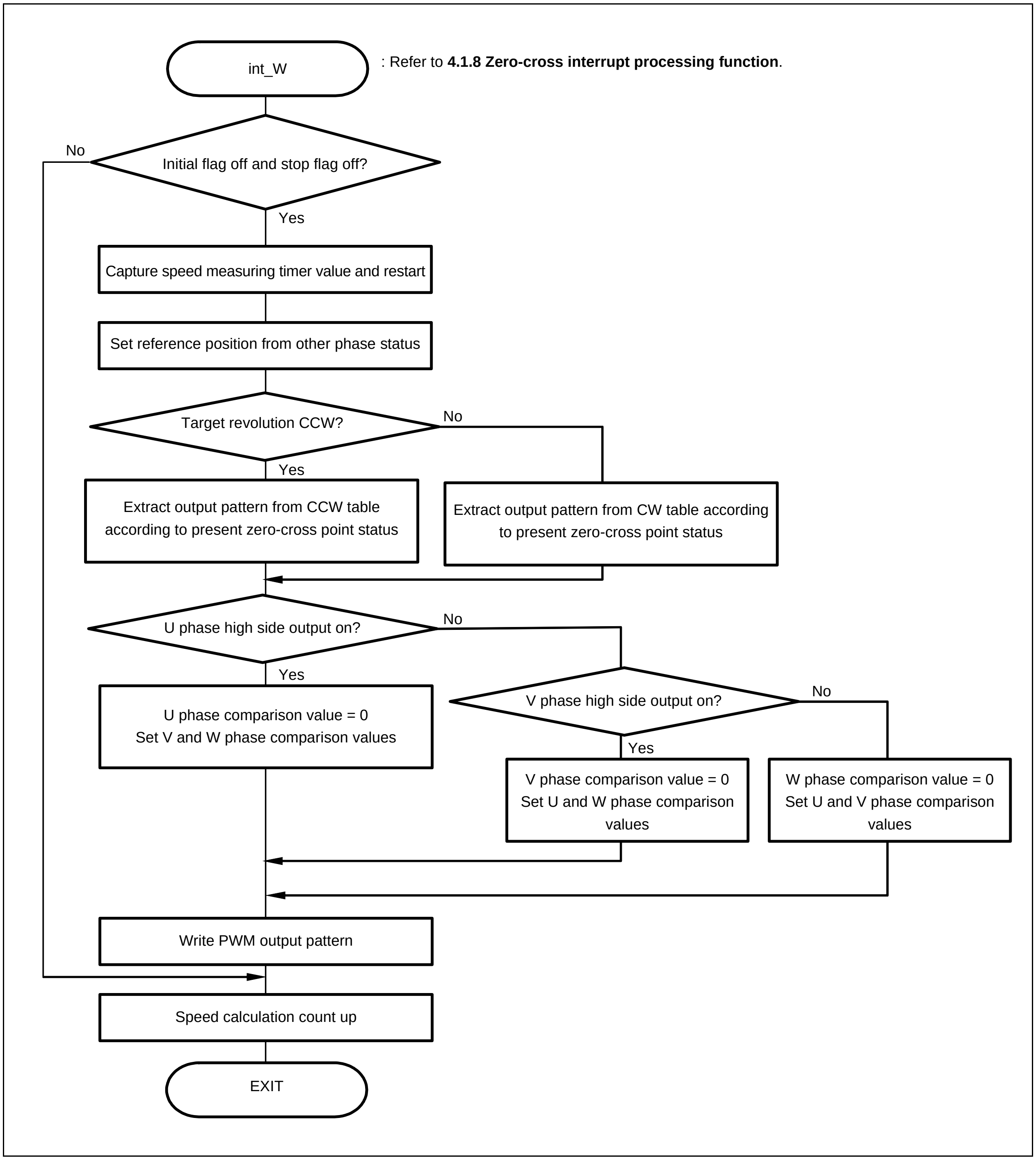
3.5.5 V zero-cross point interrupt processing

Figure 3-18. V Zero-Cross Point Interrupt Processing



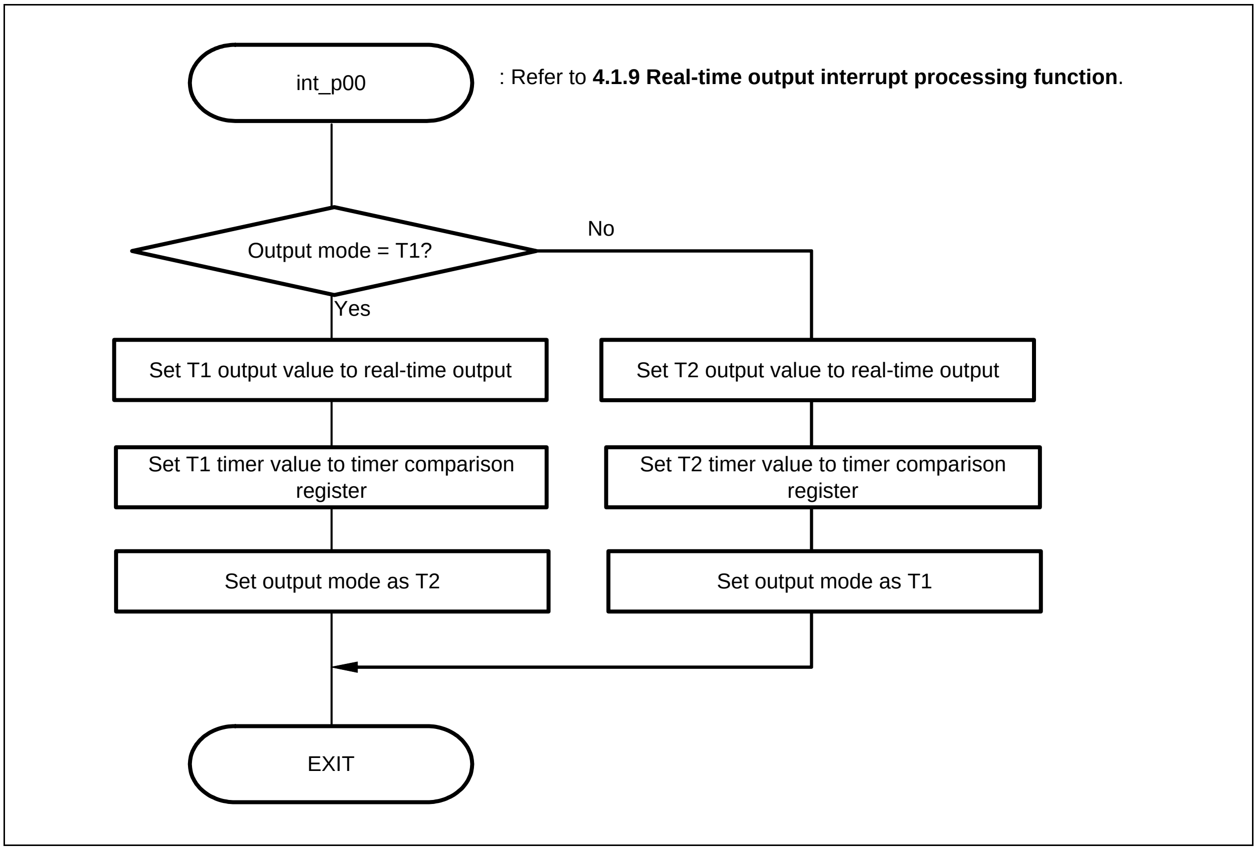
3.5.6 W zero-cross point interrupt processing

Figure 3-19. W Zero-Cross Point Interrupt Processing



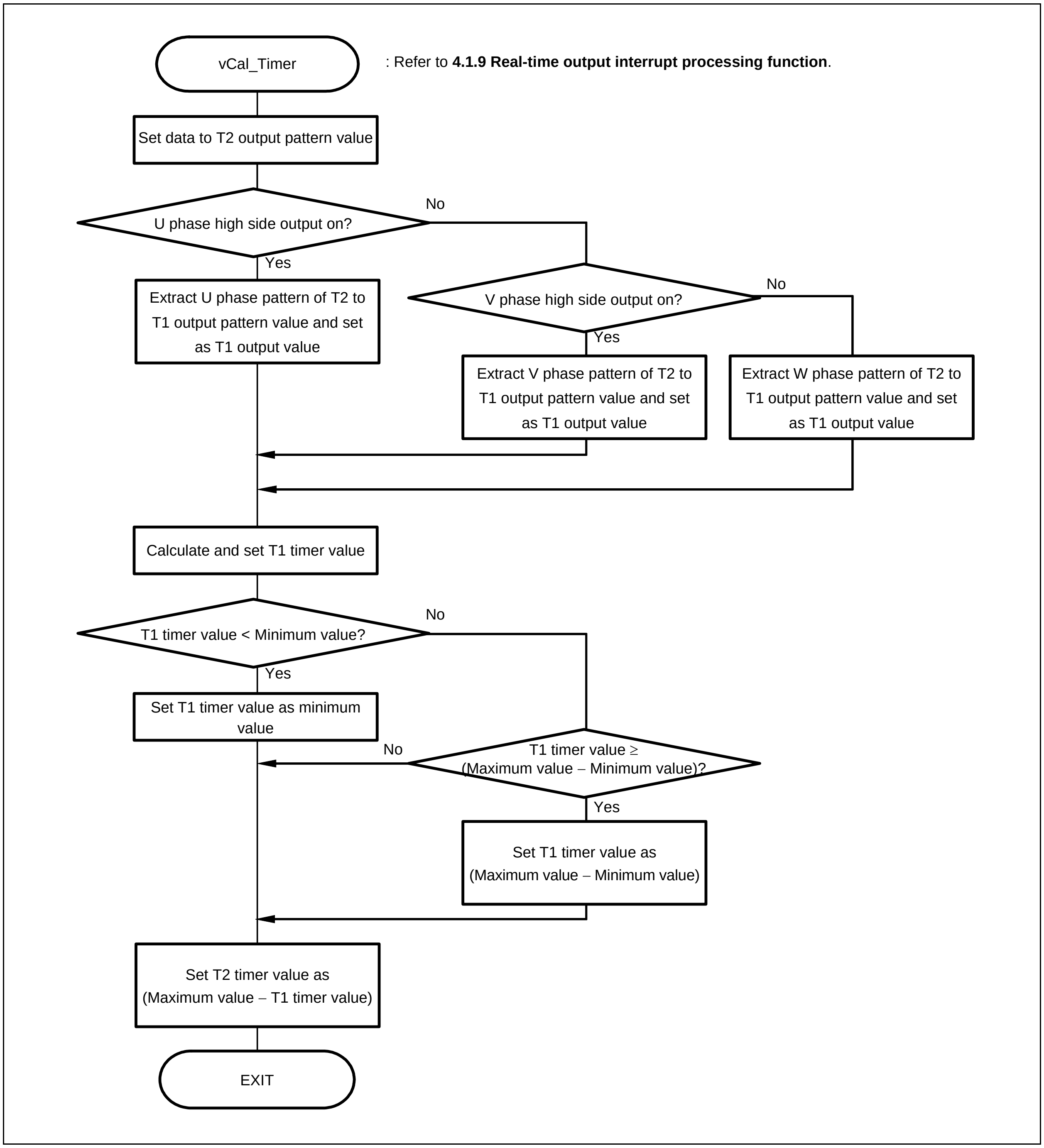
3.5.7 Real-time output timer interrupt processing

Figure 3-20. Real-Time Output Timer Interrupt Processing



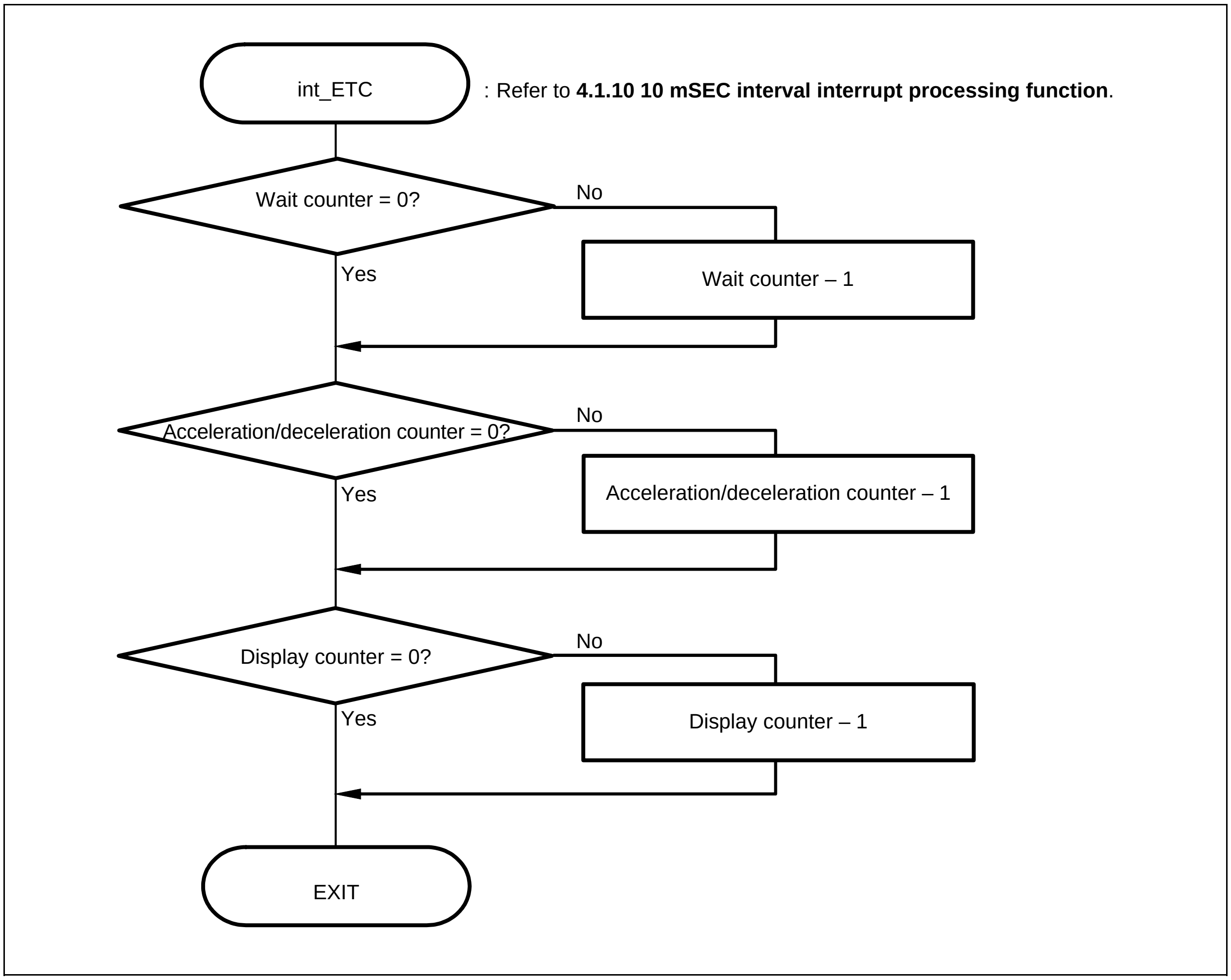
3.5.8 Real-time output value set processing

Figure 3-21. Real-Time Output Value Set Processing



3.5.9 10 mSEC interval interrupt processing

Figure 3-22. 10 mSEC Interval Interrupt Processing



3.5.10 A/D converter interrupt processing

Figure 3-23. A/D Converter Interrupt Processing (1/2)

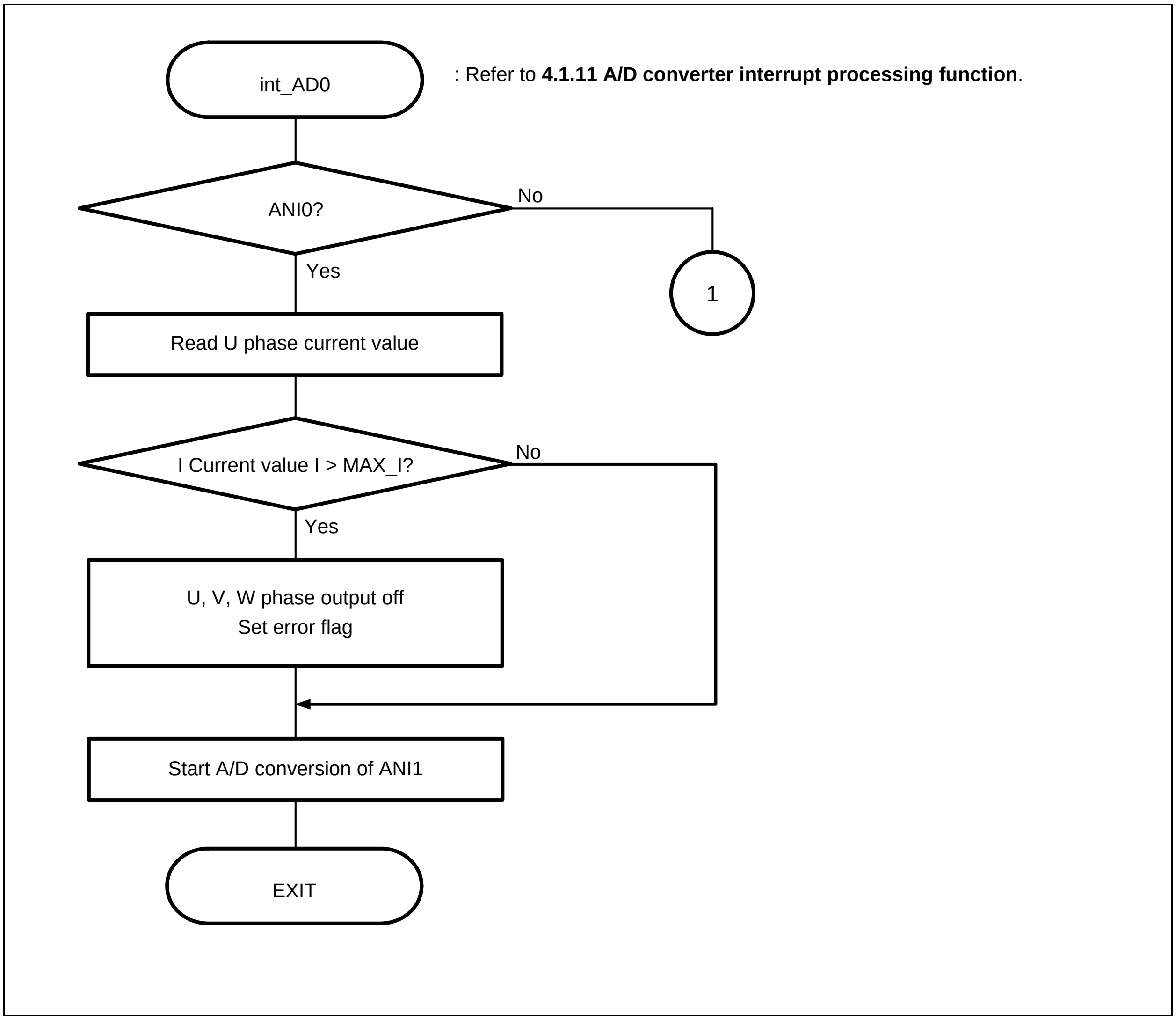
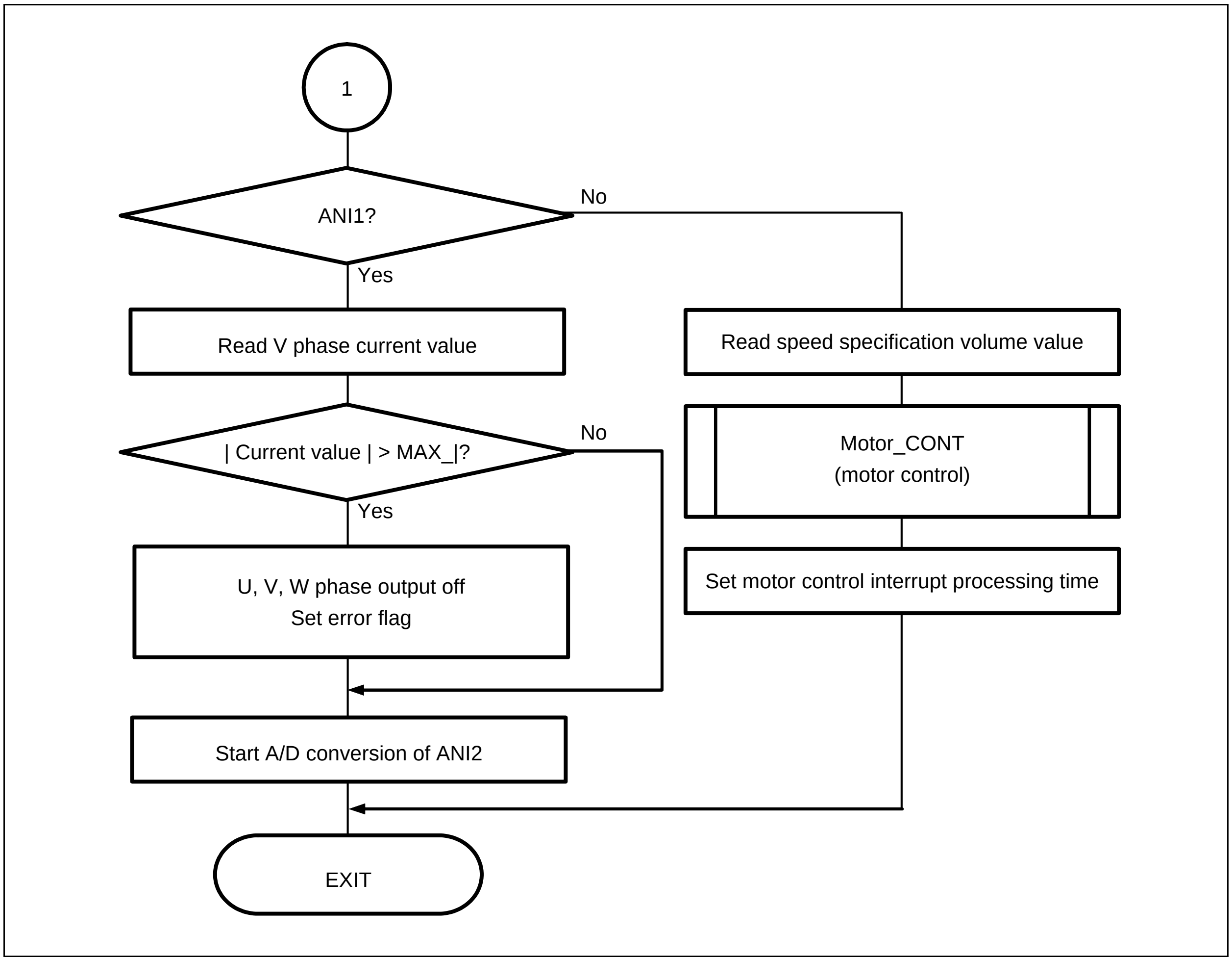
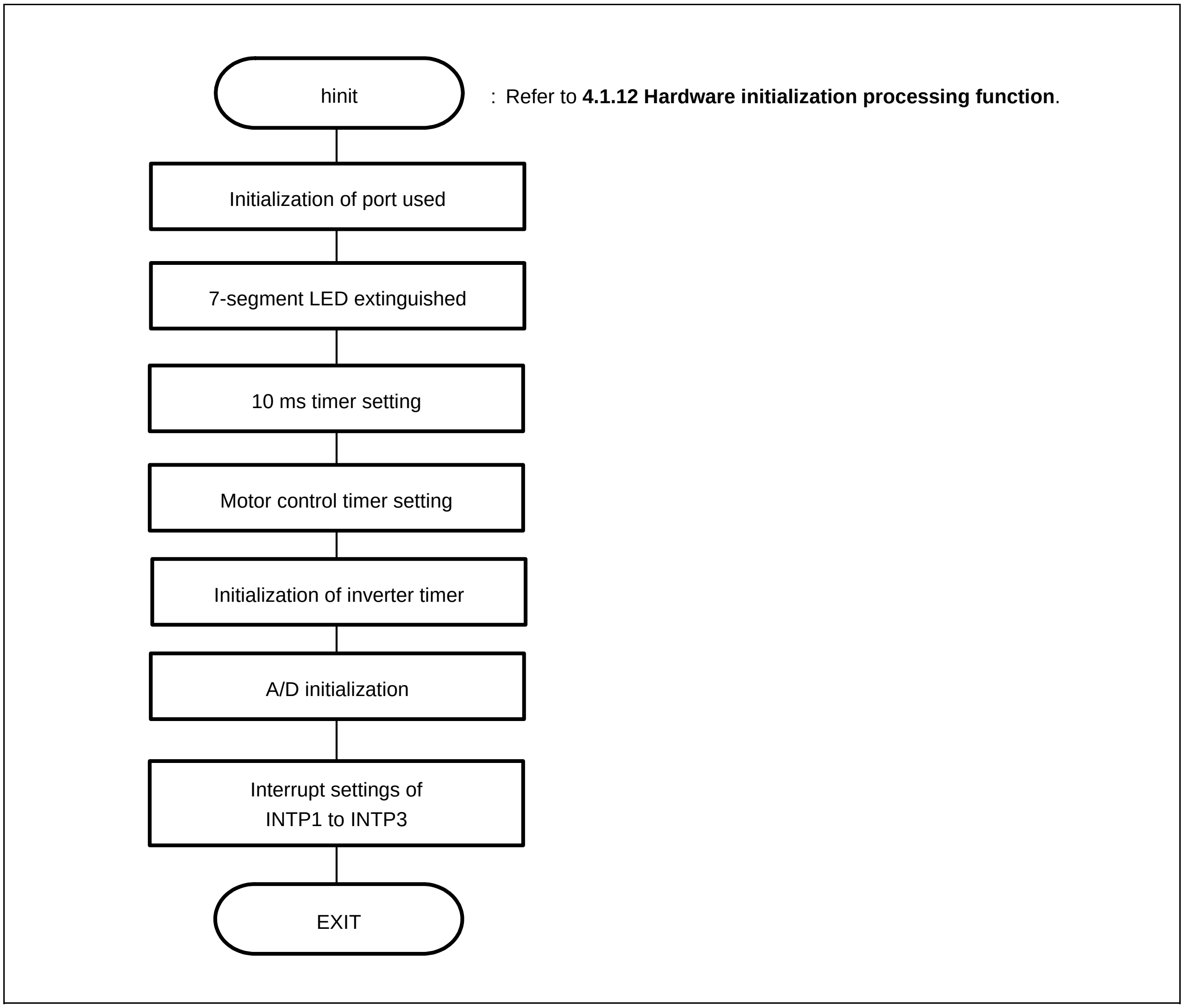


Figure 3-23. A/D Converter Interrupt Processing (2/2)



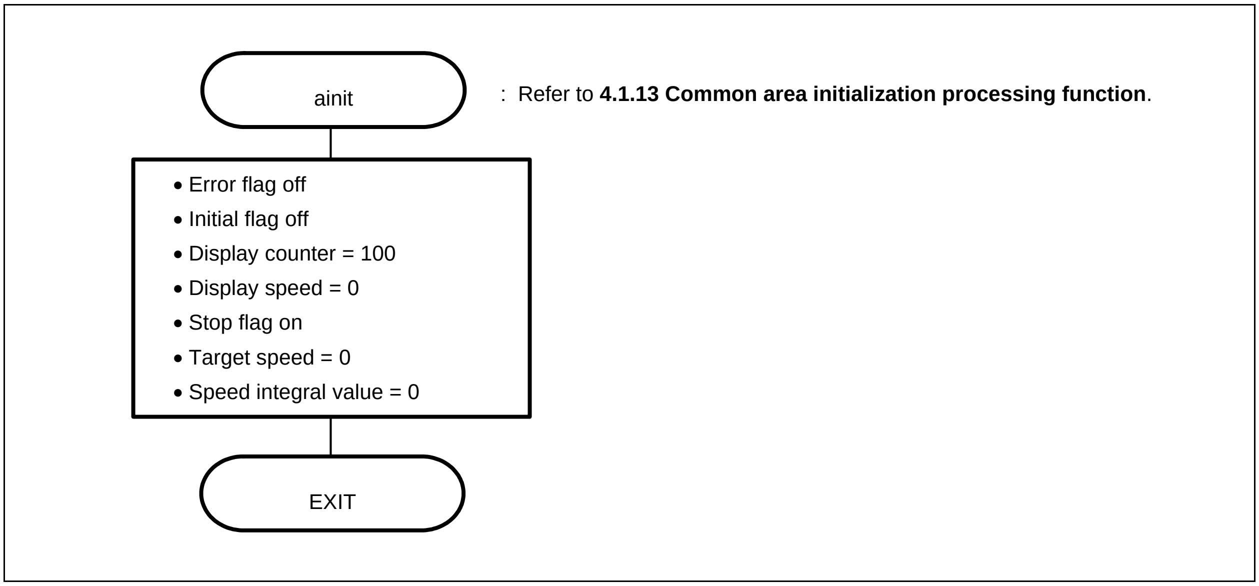
3.5.11 Hardware initialization

Figure 3-24. Hardware Initialization



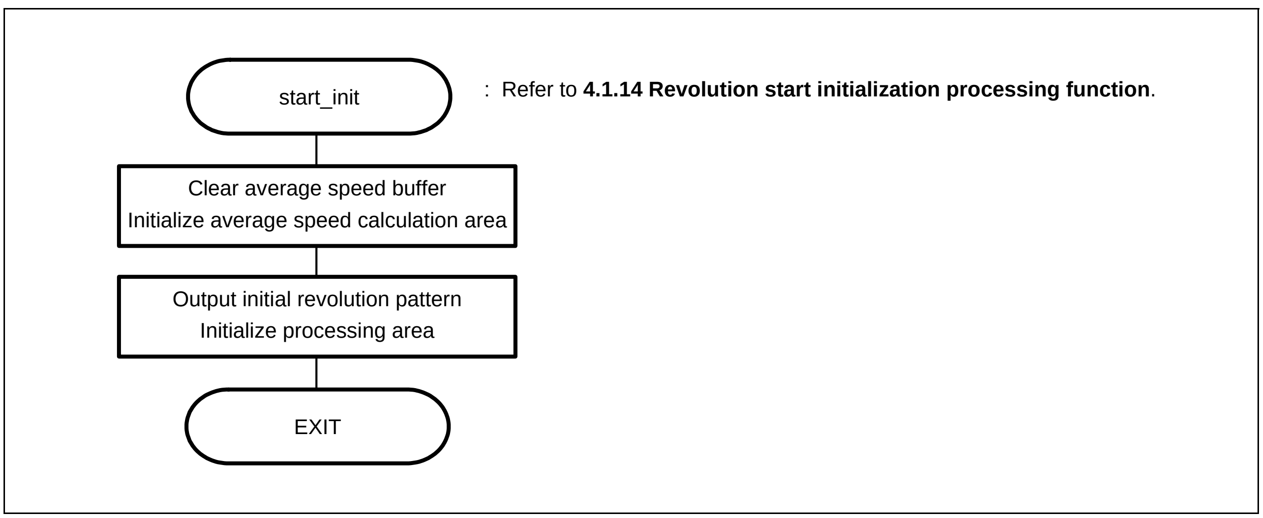
3.5.12 Common area initialization

Figure 3-25. Common Area Initialization



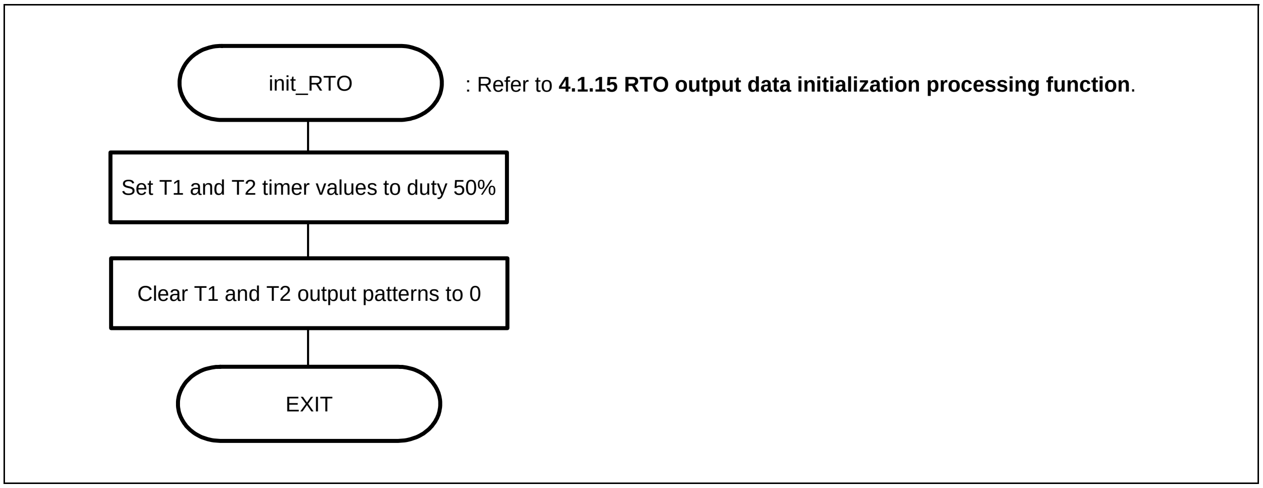
3.5.13 Revolution start initialization

Figure 3-26. Revolution Start Initialization



3.5.14 RTO output data initialization

Figure 3-27. RTO Output Data Initialization



3.6 Common Areas

The following table shows the major common areas used by the reference system.

Table 3-2. Common Area List

Symbol	Type	Usage	Set Value
error_flag	unsigned char	Error flag	0: No error ERR_NO1: Overcurrent ERR_NO2: Speed difference error
init_flag	unsigned char	Indicates initial revolution	ON: Initial revolution in progress OFF: Stop or normal revolution in progress
cont_time	unsigned short	Interrupt processing time	1 μs units
cont_time1	unsigned short	Vector operation time	1 μs units
disp_co	unsigned short	Average speed counter for display	
volume	unsigned short	Speed volume value	
timer_count	unsigned short	Time wait counter	10 ms units
accel_count	unsigned short	Acceleration/deceleration operation time counter	10 ms units
stop_flag	unsigned char	Stop flag	ON: Stopped OFF: Revolving
before_posi[21][2]	signed short	Position buffer	
total_sa	signed short	Position total difference	
sum_speed	signed int	Total value area for average speed calculation	0, 1, …
speed_co	signed int	Counter for average speed calculation	0, 1, …
now_speed	signed int	Present speed	rpm
object_speed	signed int	Target speed	rpm
d_speed	unsigned int	Display speed	rpm
iua	signed short	U-phase current	
iva	signed short	V-phase current	
o_iqai	signed int	Speed integral value	
base_position	signed int	Speed estimation value reference point	
sa_time	unsigned int	Speed measurement value	
timer_count	unsigned short	Time wait counter	
accel_count	unsigned short	Acceleration/deceleration operation time counter	
init_co	unsigned short	Output selection monitor counter during initial revolution	0, 1, …
init_pat	unsigned char	Initial revolution output pattern number	0 to 5
init_upco	unsigned short	Initial revolution output table number	0 to 10
int_co	unsigned int	U, V, W interrupt counter	0, 1, …
pwm_value	signed int	PWM output value	Output bit pattern
ucRTO_Mode	unsigned char	Real-time output selection	0: T1 1: T2
usT1_Timer	unsigned short	T1 timer value	
usT2_Timer	unsigned short	T2 timer value	
ucT1_Value	unsigned char	T1 output pattern	
ucT2_Value	unsigned char	T2 output pattern	

3.7 Tables

(1) LED output pattern

Contains display pattern data 0 to 9.

```
unsigned short led_pat[10] = { 0xfc. 0x60, ~ };
```

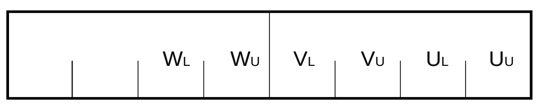
(2) Initial CW output pattern

Contains an output pattern for CW initial operation.

```
unsigned short cw_data[6][2] = { { 0x09, 0x00 }, { 0x21, 0x00 }, ~ };Note
```

Note The underlined values differ depending on the target microcontroller.

Figure 3-28. Bit Assignment



(3) Initial CCW output pattern

Contains an output pattern for CCW initial operation.

```
unsigned short ccw_data[6][2] = { { 0x18, 0x00 }, { 0x12, 0x00 }, ~ };Note
```

Note The underlined values differ depending on the target microcontroller.

(4) Initial revolution pattern output time

The initial pattern is output with the revolution speed increased each time the interrupt of this table occurs.

```
unsigned short up_data[ ] = { 255, 242, ~ };
```

(5) Normal CW revolution output pattern

Contains an output pattern in accordance with the status of the zero-cross point during normal CW revolution.

```
unsigned short run_cw_data[8][2] = { { 0x00, 0x00 }, { 0x21, 0x00 }, ~ };Note
```

Note The underlined values differ depending on the target microcontroller.

(6) Normal CCW revolution output pattern

Contains an output pattern in accordance with the status of the zero-cross point during normal CCW revolution.

```
unsigned short run_ccw_data[8][2] = { { 0x00, 0x00 }, { 0x09, 0x00 }, ~ };Note
```

Note The underlined values differ depending on the target microcontroller.

3.8 Constant Definitions

The following table shows the major constants used by the reference system.

Symbol	Usage	Value[Note]
PAI	π	3.141592
TH_U	Radian value, jack-up constant	1000
RAD	Radian value of one revolution	2 × PAI × TH_U
OFFSET	Original point OFFSET	1945
RPM_RADS	rpm → radian conversion constant	2 × PAI × TH_U/60
KSP	Speed proportion constant	750
KSI	Speed integral constant	10
P	Number of motor poles	2
KSPGETA	Speed proportion constant jack-up constant	10
KSIGETA	Speed integral constant jack-up constant	14
SGETA	sin jack-up constant	14
PWM_TS	PWM cycle	80 μs
PWM_DATA	PWM set value	PWM_TS/0.2
SPEED_MAX	Maximum speed	3000 rpm
SPEED_MINI	Minimum speed	800 rpm
SPEED_INIT	Initial revolution speed	700 rpm
SA_SPEED_MAX	Maximum speed difference	800 rpm
IQAMAX	Maximum speed integral value	200000
MAX_I	Maximum current value	800
TS	Motor control period	80 μs
ACCEL_TIME	Acceleration/deceleration time constant, 10 ms	1
ACCEL_DATA	Number of acceleration/deceleration incremental revolutions	40 rpm
WATCH_START	Speed monitor start time, 10 ms	500
ACCEL_VAL_1ST	Initial acceleration/deceleration time constant	50
ACCEL_VAL	Acceleration/deceleration time constant	3
ACCEL_SPD	Acceleration/deceleration constant	50
PWM_INIT	PWM initial value	PWM_DATA/4
TMCNT_MAX	PWM maximum value	400 (80 μs)
TMCNT_MIN	PWM minimum value	50 (10 μs)

Note Value used in the V850ES/KJ1

CHAPTER 4 PROGRAM LIST

4.1 Program List (V850ES/KJ1)

4.1.1 Symbol definition

```
/******************************************************************************* /
/*      Common area                                                              */
/******************************************************************************* /
unsigned char   ram_start ;
unsigned char   error_flag ;          /* Error flag */
unsigned char   init_flag ;           /* Initial flag */
unsigned short  cont_time ;           /* Interrupt control time uSEC */
unsigned short  cont_time1 ;          /* Vector operation time uSEC */
unsigned short  disp_co ;             /* Interrupt control time display timer */
unsigned short  volume ;              /* Volume value */
unsigned short  timer_count ;         /* Time wait counter */
unsigned short  accel_count ;         /* Acceleration/deceleration operation time */
                                      /* counter */
unsigned char   stop_flag ;           /* Stop flag */
signed short    before_posi[21][2] ;  /* Position buffer */
signed short    total_sa ;            /* Position total difference */
signed int      sum_speed ;
signed int      speed_co ;
signed int      now_speed ;           /* Present speed rms */
signed int      object_speed ;        /* Target speed rms */
unsigned int    d_speed ;             /* Display speed rms */
unsigned char   ram_end ;

#pragma section const begin
const unsigned short led_pat[10] = { 0xfc, 0x60, 0xda, 0xf2, 0x66, 0xb6, 0xbe, 0xe0,
                                     0xfe, 0xe6 } ;
#pragma section const end
/******************************************************************************* /
/*      Common flags                                                             */
/******************************************************************************* /
extern unsigned char   ram_start ;
extern unsigned char   error_flag ;         /* Error flag */
extern unsigned char   init_flag ;          /* Initial flag */
extern unsigned short  cont_time ;          /* Interrupt control time uSEC */
extern unsigned short  cont_time1 ;         /* Vector operation time uSEC */
extern unsigned short  disp_co ;            /* Interrupt control time display timer */
extern unsigned short  volume ;             /* Volume value */
extern unsigned short  timer_count ;        /* Time wait counter */
extern unsigned short  accel_count ;        /* Acceleration/deceleration operation */
                                            /* time counter */
extern unsigned char   stop_flag ;          /* Stop flag */
```

```
extern signed short    before_posi[21][2] ; /* Position buffer */
extern signed short    total_sa ;           /* Position total difference */
extern signed int      sum_speed ;
extern signed int      speed_co ;
extern signed int      now_speed ;          /* Present speed rms */
extern signed int      object_speed ;       /* Target speed rms */
extern unsigned int    d_speed ;            /* Display speed rms */
extern unsigned char   ram_end ;

#pragma section const begin
extern const unsigned short led_pat[] ;;
#pragma section const end
/*************************************************************************** /
/*     Motor common definition                                              */
/*************************************************************************** /
extern signed short    iua ;              /* U-phase current */
extern signed short    iva ;              /* V-phase current */
extern signed int      o_iqai ;           /* Speed integral value area */
extern signed int      base_position ;    /* Speed estimation value reference point */
extern unsigned int    sa_time ;          /* Speed measurement value */
extern unsigned short  timer_count ;      /* Time wait counter */
extern unsigned short  accel_count ;      /* Acceleration/deceleration operation */
                                          /* time counter */

extern unsigned short  init_co ;          /* Initial interrupt counter */
extern unsigned char   init_pat ;         /* Initial pattern counter */
extern unsigned short  init_upco ;        /* Initial speed-up counter */
extern unsigned int    int_co ;           /* UVW interrupt counter */
extern signed int      pwm_value ;        /* PWM output value */
extern unsigned char   ucRTO_Mode ;       /* Real-time output selection 0:T1 1:T2 */
extern unsigned short  usT1_Timer ;       /* T1 timer count */
extern unsigned short  usT2_Timer ;       /* T2 timer count */
extern unsigned char   ucT1_Value ;       /* T1 RTBL output value */
extern unsigned char   ucT2_Value ;       /* T2 RTBL output value */

#pragma section const begin
extern const unsigned char cw_data[][2] ;
extern const unsigned char ccw_data[][2] ;
extern const unsigned char up_data[] ;
extern const unsigned char run_cw_data[][2] ;
extern const unsigned char run_ccw_data[][2] ;
#pragma section const end
```

4.1.2 Constant definition

```
/*************************************************************************** /
/*      I/O                                                                 */
/*************************************************************************** /
```

```
#define BASE_IO   0xc200000
#define LED11     3
#define LED12     2
#define LED13     1
#define LED14     0
#define LED21     5
#define LED22     4
#define LED31     7
#define LED32     6
#define LED41     9
#define LED42     8

#define DIPSW     0x10
#define SW        0x20
#define DA1       0x30
#define DA2       0x40
#define DA3       0x50
#define WRESET    0x60
#define MODE      0x70
/****************************************************************************** /
/*      Constant                                                              */
/****************************************************************************** /
#define ON        1
#define OFF       0
#define CW        1                      /* CW operation mode */
#define CCW       2                      /* CCW operation mode */
#define STOP      0                      /* Operation stop mode */
#define ERR_NO1   1                      /* Overcurrent error */
#define ERR_NO2   2                      /* Speed difference error */
/****************************************************************************** /
/*      Motor constant                                                        */
/****************************************************************************** /
/* Motor constant */
#define PAI           3.14159265             /* π */
#define TH_U          1000                   /* Radian value  jack-up constant */
#define RAD           (int)(2*PAI*TH_U)      /* Radian value of one revolution */
#define OFFSET        1945                   /* Original point OFFSET */
#define RPM_RADS      (int)((2*PAI*TH_U)/60) /* rpm -> radian conversion constant */
/* Motor constant */
#define KSP           750                    /* Speed proportion constant */
#define KSI           10                     /* Speed integral constant */
#define P             2                      /* Number of poles */

#define KSPGETA       10                     /* KSP jack-up constant */
#define KSIGETA       14                     /* KSI jack-up constant */
#define SGETA         14                     /* sin jack-up constant */

#define PWM_TS        80                     /* PWM cycle */
```

```
#define PWM_DATA      (PWM_TS/0.2)          /* PWM set value */
#define SPEED_MAX     3000                  /* Maximum speed 3000 rpm */
#define SPEED_MINI    800                   /* Minimum speed 800 rpm */
#define SPEED_INIT    700                   /* Initial revolution speed rpm */
#define SA_SPEED_MAX  800                   /* Maximum speed difference rpm */
#define IQAMAX        200000                /* Maximum speed integral value */
#define MAX_I         800                   /* Maximum current value */
#define TS            80                    /* Motor control time interval uSEC */
#define ACCEL_TIME    1                     /* Acceleration/deceleration time */
                                            /* constant 10 mSEC */
#define ACCEL_DATA    40                    /* Number of acceleration/deceleration */
                                            /* incremental revolutions rpm */
#define WATCH_START   500                   /* Speed monitor start time 10 mSEC */
#define ACCEL_VAL_1ST 50                    /* Initial acceleration/deceleration */
                                            /* time constant */
#define ACCEL_VAL     3                     /* Acceleration/deceleration time */
                                            /* constant */
#define ACCEL_SPD     50                    /* Acceleration/deceleration constant */
#define PWM_INIT      PWM_DATA/4            /* PWM initial value */
#define TMCNT_MAX     PWM_DATA              /* TM00 counter maximum value */
#define TMCNT_MIN     50                    /* TM00 counter minimum value 10 uSEC for */
                                            /* the present */
/******************************************************************************* /
/*      Function constant                                                       */
/******************************************************************************* /
void            fcalcu( signed int *wrm, signed int *trm );
void            OUT_data( unsigned short reg, unsigned short data );
unsigned short  IN_data( int reg );
void            led_num( int no, long data ) ;
void            vCal_Timer(int iVal,int iPWN );
void            init_RTO( void );
/******************************************************************************* /
/*      Motor-related common area                                               */
/******************************************************************************* /
signed short    iua ;             /* U-phase current */
signed short    iva ;             /* V-phase current */
signed int      o_iqai ;          /* Speed integral value area */
signed int      base_position ;   /* Speed estimation value reference point */
unsigned int    sa_time ;         /* Speed measurement value */
unsigned short  timer_count ;     /* Time wait counter */
unsigned short  accel_count ;     /* Acceleration/deceleration operation time counter */

unsigned short  init_co ;         /* Initial interrupt counter */
unsigned char   init_pat ;        /* Initial pattern counter */
unsigned short  init_upco ;       /* Initial speed-up counter */
unsigned int    int_co ;          /* UVW interrupt counter */
signed int      di ;
signed int      pwm_value ;       /* PWM output value */
```

```
unsigned char   ucRTO_Mode ;     /* Real-time output selection 0:T1 1:T2 */
unsigned short  usT1_Timer ;     /* T1 timer count */
unsigned short  usT2_Timer ;     /* T2 timer count */
unsigned char   ucT1_Value ;     /* T1 RTBL output value */
unsigned char   ucT2_Value ;     /* T2 RTBL output value */
unsigned short  tp3_buf[5] ;     /* TP3 output status management for measuring */
                                 /* free time */
unsigned short  tp3_co ;         /* TP3 output status management for measuring */
                                 /* free time */

#pragma section const begin
const unsigned char cw_data[6][2] = { {0x0a,0x00},{0x0c,0x00},{0x14,0x00},
                                      {0x11,0x00},{0x21,0x00},{0x22,0x00} };
const unsigned char ccw_data[6][2] = { {0x22,0x00},{0x21,0x00},{0x11,0x00},
                                       {0x14,0x00},{0x0c,0x00},{0x0a,0x00} };
const unsigned char up_data[] = { 255, 242, 229, 217, 206, 195, 185, 176, 166, 158,
                                  158, 158, 158, 158, 158, 158, 158, 158, 158, 158 } ;
const unsigned char run_cw_data[8][2] = { {0x00,0x00},{0x0c,0x00},{0x11,0x00},
                                          {0x14,0x00},{0x22,0x00},{0x0a,0x00},
                                          {0x21,0x00},{0x00,0x00} };
const unsigned char run_ccw_data[8][2] = { {0x00,0x00},{0x0a,0x00},{0x14,0x00},
                                           {0x0c,0x00}, {0x21,0x00},{0x22,0x00},
                                           {0x11,0x00},{0x00,0x00} };
#pragma section const end
```

4.1.3 Interrupt handler setting

```
/****************************************************************************** /
/*     Interrupt symbol table                                                  */
/****************************************************************************** /
       .extern _ _start
       .extern _int_MOTOR
       .extern _int_U
       .extern _int_V
       .extern _int_W
       .extern _int_AD0
       .extern _int_ETC

       .globl V_RESET
       .globl V_U
       .globl V_V
       .globl V_W
       .globl V_ETC
       .globl V_MOTOR
       .globl V_AD0
#******************************************************************************
       .section ".handler",text
V_RESET:
```

```
        jr          _start
V_U:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_U                  -- INTP1
V_V:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_V                  -- INTP2
V_W:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_W                  -- INTP3
V_ETC:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_ETC                -- Other timers
V_MOTOR:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_MOTOR              -- Speed control timer
V_AD0:
        ld.w        [sp],r1
        add         4,sp
        jr          _int_AD0                -- A/D converter CH0

        .extern V_RESET
        .extern V_U
        .extern V_V
        .extern V_W
        .extern V_ETC
        .extern V_MOTOR
        .extern V_AD0
/******************************************************************************* /
/*      Interrupt jump table                                                    */
/******************************************************************************* /
        .section ".vect_RESET",text
        mov         #V_RESET,r1
        jmp         [r1]

        .section ".id_NO",text
        .byte       0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff,0xff

        .section ".vect_U",text
        add         -4,sp
        st.w        r1,[r3]
        mov         #V_U,r1
        jmp         [r1]
```

```
       .section ".vect_V",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_V,r1
       jmp      [r1]

       .section ".vect_W",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_W,r1
       jmp      [r1]

       .section ".vect_ETC",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_ETC,r1
       jmp      [r1]

       .section ".vect_MOTOR",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_MOTOR,r1
       jmp      [r1]

       .section ".vect_AD0",text
       add      -4,sp
       st.w     r1,[r3]
       mov      #V_AD0,r1
       jmp      [r1]
```

4.1.4 Startup routine setting

```
#==============================================================================
# DESCRIPTIONS:
#      This assembly program is a sample of start-up module for ca850.
#    If you modified this program, you must assemble this file, and
#    locate a given directory.
#
#    Unless -G is specified, sections are located as the following.
#
#                 |       :       |
#                 |       :       |
#          tp -> -+-------------- + _ _start   _ _tp_TEXT
#                 | start up      |
#                 |-------------- |
# text section    |               |
#                 | user program  |
```

```
#                 |               |
#                 |-------------- |
#                 | library       |
#                -+-------------- +
#                 |               |
# sdata section   |               |
#                 |               |
#          gp -> -+-------------- +            _ _ssbss
#                 |               |
# sbss section    |               |
#                 |               |
#                 +-------------- + _ _stack   _ _esbss     _ _sbss
#                 | stack area    |
# bss section     |               |
#                 | 0x400 bytes   |
#          sp -> -+-------------- + _ _stack + STACKSIZE    _ _ebss
#                 |       :       |
#                 |       :       |
#                 |       :       |
#          ep -> -+-------------- + _ _ep_DATA
# tidata section  |               |
#                -+-------------- +
# sidata section  |               |
#                -+-------------- +
#                 |       :       |
#                 |       :       |
#
#=============================================================================
#-----------------------------------------------------------------------------
#       special symbols
#-----------------------------------------------------------------------------
        .extern _ _tp_TEXT, 4
        .extern _ _gp_DATA, 4
        .extern _ _ep_DATA, 4
        .extern _ _ssbss, 4
        .extern _ _esbss, 4
        .extern _ _sbss, 4
        .extern _ _ebss, 4


#-----------------------------------------------------------------------------
#       C program main function
#-----------------------------------------------------------------------------
        .extern _main


#-----------------------------------------------------------------------------
#       dummy data declaration for creating sbss section
```

```
#-----------------------------------------------------------------------------
        .sbss
        .lcomm _ _sbss_dummy, 0, 0


#-----------------------------------------------------------------------------
#       system stack
#-----------------------------------------------------------------------------
        .set   STACKSIZE, 0x400
        .bss
        .lcomm _ _stack, STACKSIZE, 4

#-----------------------------------------------------------------------------
#       start up
#             pointers: tp - text pointer
#                       gp - global pointer
#                       sp - stack pointer
#                       ep - element pointer
#       exit status is set to r10
#-----------------------------------------------------------------------------
        .text
        .align 4
        .globl _ _start
        .globl _exit
        .globl _ _exit
_ _start:
        mov      0x12,r10
        st.b     r10,VSWC[r0]                -- Set peripheral I/O wait

        mov      0x07,r10                    -- ×10
        st.b     r0,PHCMD[r0]
        st.b     r10,CKC[r0]                 -- PLL xx multiplication
        nop
        nop
        nop
        nop
        nop

        mov      #_ _tp_TEXT, tp             -- set tp register
        mov      #_ _gp_DATA, gp             -- set gp register offset
        add      tp, gp                      -- set gp register
        mov      #_ _stack+STACKSIZE, sp     -- set sp register
        mov      #_ _ep_DATA, ep             -- set ep register
#
        mov      #_ _ssbss, r13              -- clear sbss section
        mov      #_ _esbss, r12
        cmp      r12, r13
        jnl      .L11
```

```
.L12:
        st.w     r0, [r13]
        add      4, r13
        cmp      r12, r13
        jl       .L12
.L11:
#
        mov      #_ _sbss, r13              -- clear bss section
        mov      #_ _ebss, r12
        cmp      r12, r13
        jnl      .L14
.L15:
        st.w     r0, [r13]
        add      4, r13
        cmp      r12, r13
        jl       .L15
.L14:
#
        jarl     _main, lp                  -- call main function
_ _exit:
        halt                                -- end of program
_ _startend:
        nop
#                                                                              #
#--------------------------- end of start up module ---------------------------#
#                                                                              #
```

4.1.5 Main processing function

```
#include    "Common.h"
#include    "Motor.h"
#pragma     ioreg                          /* Peripheral I/O register definition */

static int save_psw;
/******************************************************************************* /
/*     3-phase motor control program                                             */
/******************************************************************************* /
void   main()
{
unsigned char  proc_no ;                    /* Present processing number */
signed int     speed ;                      /* Indication speed rms */
signed int     accel_spd ;
int            sw, sw_mode ;
/* */
   hinit() ;                                /* Hardware initialization */
   ainit() ;                                /* Initialization of area used */
   proc_no = 0 ;
   _ _EI();
```

```
  while( 1 ) {
      accel_spd = ( SPEED_MAX - SPEED_MINI ) / 100;
      speed  = ( ( SPEED_MAX - SPEED_MINI ) * volume  / 1024 )
                 + SPEED_MINI ;                /* Indication speed calculation by volume */
      sw =  ~IN_data( SW ) & 0x07 ;            /* Read operation button */
      if  ( sw == 1 ) {
          sw_mode = CW ;
      } else if  ( sw == 2 ) {
          sw_mode = CCW ;
      } else if  ( sw == 4 ) {
          sw_mode = STOP ;
      }
      switch( proc_no ) {
/* STOP processing */
          case 0 :
              if  ( sw_mode == CW ) {
                  _ _DI() ;
                  object_speed  = SPEED_MINI ;   /* Set target speed to minimum value */
                  stop_flag = OFF ;
                  timer_count = WATCH_START ;    /* Set speed monitor start time to 5 SEC */
                  accel_count = ACCEL_VAL_1ST ;  /* Set acceleration/deceleration counter */
                  init_flag = 2 ;                /* CCW initial request */
                  start_init() ;                 /* Initialize revolution start */
                  _ _EI() ;
                  proc_no = 1 ;                  /* Set next processing number */
              } else if  ( sw_mode == CCW ) {
                  _ _DI() ;
                  stop_flag = OFF ;              /* Stop flag off */
                  object_speed = -SPEED_MINI ;   /* Set target speed to minimum value */
                  timer_count = WATCH_START ;    /* Set speed monitor start time to */
                                                 /* 5 SEC */
                  accel_count = ACCEL_VAL_1ST ;  /* Set acceleration/deceleration counter */
                  init_flag = 3 ;                /* CCW initial request */
                  start_init() ;                 /* Initialize revolution start */
                  _ _EI() ;
                  proc_no = 4 ;                  /* Set CCW processing number */
              }
              break ;
/* CW processing, acceleration */
          case 1 :
              if  ( accel_count == 0 ) {
                  accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                  if  ( object_speed  < speed ) {
                      object_speed += accel_spd ;
                      if  ( object_speed > speed ) object_speed = speed;
                      timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                  } else if ( object_speed  > speed ) {
                      object_speed -= accel_spd ;
```

```
                if  ( object_speed < speed ) object_speed = speed;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 2 ;               /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                   /* Deceleration, set processing number */
        }
        break ;
/* CW processing, constant-speed */
    case 2 :
        object_speed = speed ;
        if  ( (sw_mode == CCW) || (sw_mode == STOP) ) {
            proc_no = 3 ;                   /* Deceleration, set processing number */
        }
        break ;
/* CW stop processing */
    case 3 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;       /* Set acceleration/deceleration counter */
            if  ( object_speed  > SPEED_MINI ) {
                object_speed -= accel_spd ;
                if  ( object_speed < SPEED_MINI ) object_speed = SPEED_MINI;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else {
                stop_flag = ON ;            /* Stop flag on */
                proc_no = 0 ;               /* Set stop processing number */
            }
        }
        break ;
/* CCW processing, acceleration */
    case 4 :
        if  ( accel_count == 0 ) {
            accel_count = ACCEL_VAL ;       /* Set acceleration/deceleration counter */
            if  ( object_speed  < -speed ) {
                object_speed += accel_spd ;
                if  ( object_speed > -speed ) object_speed = -speed;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else if ( object_speed  > -speed ) {
                object_speed -= accel_spd ;
                if  ( object_speed < -speed ) object_speed = -speed;
                timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
            } else {
                proc_no = 5 ;               /* Constant-speed processing */
            }
        }
        if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
```

```
                proc_no = 6 ;                  /* Deceleration, set processing number */
            }
            break ;
/* CCW processing, constant-speed */
        case 5 :
            object_speed = -speed ;
            if  ( (sw_mode == CW) || (sw_mode == STOP) ) {
                proc_no = 6 ;                  /* Deceleration, set processing number */
            }
            break ;
/* CCW stop processing */
        case 6 :
            if  ( accel_count == 0 ) {
                accel_count = ACCEL_VAL ;      /* Set acceleration/deceleration counter */
                if  ( object_speed  < -SPEED_MINI ) {
                    object_speed += accel_spd ;
                    if  ( object_speed > -SPEED_MINI ) object_speed = -SPEED_MINI;
                    timer_count = WATCH_START ; /* Set speed monitor start time to 5 SEC */
                } else {
                    stop_flag = ON ;           /* Stop flag on */
                    proc_no = 0 ;              /* Set stop processing number */
                }
            }
            break ;
    }

    if  ( ( proc_no == 2 ) || ( proc_no == 5 ) ) {
        if  (  timer_count == 0 ) {
            if  ( abs( object_speed - now_speed ) > SA_SPEED_MAX ) {
                error_flag = ERR_NO2 ;         /* Set error No. */
            }
        }
    }

    if  ( disp_co == 0 ) {
        led_num(1, d_speed / 100 );            /* Number of revolutions */
        d_speed = 0 ;
        disp_co = 100 ;
        if  ( abs(now_speed) == 0 ) {
            disp_co = 0;
        }
        led_num(2, 1000/PWM_TS );              /* Carrier frequency */
        led_num(3, cont_time );                /* Overall processing time */
        led_num(4, cont_time1 );               /* Vector operation processing time */
    }
    if  ( error_flag ) {
        while( 1 ) {
            OUT_data( LED41, ~0x00 ) ;         /* LED display off */
```

```
            OUT_data( LED42, ~0x00 ) ;
            timer_count = 50 ;
            while( timer_count ) ;
            if  ( error_flag == ERR_NO1 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E1 display */
               OUT_data( LED42, ~0x60 ) ;
            } else if ( error_flag == ERR_NO2 ) {
               OUT_data( LED41, ~0x9e ) ;     /* E2 display */
               OUT_data( LED42, ~0xda ) ;
            } else {
               OUT_data( LED41, ~0x9e ) ;     /* E3 display */
               OUT_data( LED42, ~0xf2 ) ;
            }
            timer_count = 50 ;
            while( timer_count ) ;
         }
      }
   }
}
```

4.1.6 LED display function

```
/******************************************************************************* /
/*     LED value display subroutine                                             */
/*              no  : Display area number (1 to 4)                              */
/*              data: Display data (0 to 99)                                    */
/******************************************************************************* /
void led_num( int no, long data )
{
   if  ( no == 1 ) {
      data = data % 10000;
      OUT_data( LED11, ~led_pat[data/1000]&0xff ) ;
      OUT_data( LED12, ~led_pat[(data%1000)/100]&0xff ) ;
      OUT_data( LED13, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED14, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 2 ) {
      OUT_data( LED21, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED22, ~led_pat[data%10]&0xff ) ;
   } else if  ( no == 3 ) {
      OUT_data( LED31, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED32, ~led_pat[data%10]&0xff ) ;
   } else {
      OUT_data( LED41, ~led_pat[(data%100)/10]&0xff ) ;
      OUT_data( LED42, ~led_pat[data%10]&0xff ) ;
   }
}
/******************************************************************************* /
/*     External I/O output subroutine                                           */
```

```
/*              reg : Output register number                                    */
/*              data: Output data                                               */
/******************************************************************************* /
void   OUT_data( unsigned short reg, unsigned short data )
{
       if  ( reg == WRESET ) {
              P4.3 = 0;
              data = 1;                       /* Dummy step */
              P4.3 = 1;
       } else {
              PDL = data | ( reg << 8 );
              PDL = reg | ( reg << 8 ) | 0x8000;
       }
}
/******************************************************************************* /
/*     External I/O input subroutine                                            */
/*           reg: Input register number                                         */
/******************************************************************************* /
unsigned short  IN_data( int reg )
{
unsigned char *po;
/*  */
       if    ( reg == SW ) {
               return P4;
       } else {
               return 0;
       }
}
```

4.1.7 Motor control interrupt processing function

```
#include     "Common.h"
#include     "Motor.h"
#pragma      ioreg            /* Peripheral I/O register definition */
/******************************************************************************* /
/*      Motor control timer interrupt processing                                */
/******************************************************************************* /
_ _interrupt
void    int_MOTOR(void)
{
   ADS = 0x00 ;              /* Start AD conversion */
   ADM = 0x80 ;
}
/******************************************************************************* /
/*      Motor control processing                                                */
/******************************************************************************* /
void    Motor_CONT(void)
{
```

```
signed int      wrm, wre, trm, tre ;
signed int      o_wre, we, o_iqap, o_iqa ;
signed int      s_time, ek, sa ;
unsigned char   wk ;
signed int      cow ;
signed int      o_vua, o_vva, o_vwa ;
signed int      o_vda, o_vqa ;
/* */
/*********************************************************************** /
/*      Calculation processing of speed and rotor position              */
/*********************************************************************** /
   fcalcu( &wrm, &trm ) ;
   sum_speed += ( wrm * TH_U / RPM_RADS ) ; /* Radian -> rpm */
   if  ( --speed_co == 0 ) {
      speed_co = 100000 / TS ;             /* Set 100 mSEC counter value */
      now_speed = sum_speed / speed_co ;
      sum_speed = 0 ;
   }
   wrm = now_speed * RPM_RADS / TH_U ;
   wre = wrm * P ;
   tre = ( trm * P + OFFSET ) % RAD ;

   if  ( ( stop_flag == OFF ) && ( error_flag == 0 ) ) {
      s_time = TM00 ;
      OUT_data( WRESET, 0 ) ;              /* Reset watchdog timer */
/*********************************************************************** /
/*     Initial revolution processing                                    */
/*********************************************************************** /
      if  ( init_flag ) {
         cow = init_upco ;
         if  ( cow > 4 ) cow = 4;
         if  ( ++init_co > ( (long)up_data[ cow ] * 34000L / ( SPEED_INIT * TS ) ) ) {
            init_co = 0 ;
            if  ( init_flag == 2 ) {
               wk  = cw_data[ init_pat++  ][0] ;
            } else {
               wk  = ccw_data[ init_pat++ ][0] ;
            }
            vCal_Timer(wk,PWM_INIT) ;
            if  ( init_pat >= 6 ) {
               init_pat = 0 ;
               if  ( init_upco > 14 ) {
                  init_flag = 0 ;
               } else {
                  init_upco++ ;
               }
            }
         }
```

```
      } else {
/******************************************************************************* /
/*    Normal revolution processing                                              */
/******************************************************************************* /
          o_wre = abs(object_speed) * RPM_RADS * P / TH_U ;  /* rpm -> radian conversion */
          we =  o_wre - wre ;

          o_iqap  = ( ( wre * KSP ) + ( we * KSP ) ) >> KSPGETA ;
          o_iqa   = o_iqap + ( o_iqai >> KSIGETA ) ;

          if  ( o_iqai > IQAMAX ) {
             o_iqai = IQAMAX ;
          } else if ( o_iqai < -IQAMAX ) {
             o_iqai = -IQAMAX ;
          } else {
             o_iqai += ( KSI * we ) ;
          }

          pwm_value = o_iqa ;
          if  ( pwm_value <= 0 ) {
             pwm_value = 1 ;
          } else if  ( pwm_value >= PWM_DATA  ) {
             pwm_value = ( PWM_DATA  ) - 1 ;
          }
          cont_time1 = ( TM00 - s_time ) / 10 ; /* Convert to uSEC */
       }
   } else {
       init_RTO() ;                             /* All phases off  */
       now_speed = 0;
       cont_time1 = 0;
   }
}
/******************************************************************************* /
/*     Calculation processing of speed, etc.                                    */
/******************************************************************************* /
void   fcalcu( signed int *wrm, signed int *trm )
{
signed short  es_trm, cur_time, delta, i ;
signed int    wwrm, wk, *p1, *p2;
//
//      Speed and position calculation from zero-cross point
//
   cur_time = TM04 ;
   delta = ( (RAD/6/P) * cur_time ) / sa_time ;  /* Calculation of rotor position */
                                                 /* difference from reference */
                                                 /* position (radian) */
   if  ( object_speed >= 0 ) {
       es_trm = base_position + delta;
```

```
    } else {
        es_trm = base_position - delta;
        if  ( es_trm < 0 ) es_trm += (RAD/P);
    }

    total_sa -= before_posi[20][1] ;

    p1 = (int *)before_posi[19] ;
    p2 = (int *)before_posi[20] ;
    for ( i = 0; i <= 19 ; i++ ) {
        *p2-- = *p1-- ;
    }
    before_posi[0][0] = *trm = es_trm % (RAD/P) ;

    wk = before_posi[0][0] - before_posi[1][0] ;
    if  ( abs(wk) > (RAD/2/P) ) {
        if  ( wk < 0 ) {
            wk = (RAD/P) + wk ;
        } else {
            wk = wk - (RAD/P) ;
        }
    }

    before_posi[1][1] = wk ;
    total_sa += wk ;                           /* Total difference in average buffer */
    wwrm = ( total_sa * ( 1000000 / 20 / TH_U ) / TS );
    *wrm = wwrm ;                               /* Speed  radian/second */
}
```

4.1.8 Zero-cross interrupt processing function

```
/*************************************************************************** /
/*      U zero-cross point interrupt                                       */
/*************************************************************************** /
_ _interrupt
void  int_U(void)
{
unsigned char   wk ;
/*  */
    if  ( ( ( init_flag == 0 ) && ( stop_flag == OFF) ) ) {
        PIC1 = 0x00 ;                           /* INTP1 interrupt */
        sa_time =  TM04 ;
        TMC04  = 0x00;
        TMC04  = 0x04;                          /* Restart timer */

        if  ( ~P0 & 0x40 ) {                    /* Check W phase */
            base_position = 0 ;
        } else {
```

```
            base_position = RAD/2/P ;
        }

        if  ( object_speed < 0 ) {
            wk = run_ccw_data[ (P0 >> 4) & 0x07 ][0] ;
        } else {
            wk = run_cw_data[ (P0 >> 4) & 0x07 ][0] ;
        }
        vCal_Timer(wk,pwm_value) ;
    }
    int_co++ ;
}
/******************************************************************************* /
/*     V zero-cross point interrupt                                             */
/******************************************************************************* /
_ _interrupt
void   int_V(void)
{
unsigned char   wk ;
/*  */
    if  ( ( ( init_flag == 0 ) && ( stop_flag == OFF) ) ) {
        PIC2 = 0x00 ;                           /* INTP2 interrupt */
        sa_time =  TM04 ;
        TMC04  = 0x61;
        TMC04  = 0x63;                          /* Restart timer */

        if  ( ~P0 & 0x10 ) {                    /* Check U phase */
            base_position = RAD/3/P ;
        } else {
            base_position = RAD*5/6/P ;
        }

        if  ( object_speed < 0 ) {
            wk = run_ccw_data[ (P0 >> 4) & 0x07 ][0] ;
        } else {
            wk = run_cw_data[ (P0 >> 4) & 0x07 ][0] ;
        }
        vCal_Timer(wk,pwm_value) ;
    }
    int_co++ ;
}
/******************************************************************************* /
/*     W zero-cross point interrupt                                             */
/******************************************************************************* /
_ _interrupt
void   int_W(void)
{
unsigned char   wk ;
```

```
/*  */
    if  ( ( ( init_flag == 0 ) && ( stop_flag == OFF) ) ) {
        PIC3 = 0x00 ;                             /* INTP3 interrupt */
        sa_time =  TM04 ;
        TMC04  = 0x00;
        TMC04  = 0x04;                            /* Restart timer */

        if  ( ~P0 & 0x20 ) {                      /* Check V phase */
            base_position = RAD*2/3/P ;
        } else {
            base_position = RAD/6/P ;
        }

        if  ( object_speed < 0 ) {
            wk = run_ccw_data[ (P04 >> 4) & 0x07 ][0] ;
        } else {
            wk = run_cw_data[ (P04 >> 4)  & 0x07 ][0] ;
        }
        vCal_Timer(wk,pwm_value) ;
    }
    int_co++ ;
}
```

4.1.9 Real-time output interrupt processing function

```
/******************************************************************************* /
/*      Real-time output timer interrupt                                        */
/******************************************************************************* /
_ _interrupt
void   int_p00(void)
{
    if ( ucRTO_Mode == 0 ) {
    /* T1 interrupt */
        RTBL0 = ucT1_Value ;                     /* Set next real-time output data */
        TMC00= 0x00 ;                            /* Stop timer (reset counter) */
        CR000= usT1_Timer ;                      /* Set timer value */
        TMC00 = 0x0C ;                           /* Start timer */
        ucRTO_Mode = 1 ;                         /* Next T2 */
    }
    else {
        RTBL0 = ucT2_Value ;                     /* Set next real-time output data */
        TMC00 = 0x00 ;                           /* Stop timer (reset counter) */
        CR000 = usT2_Timer ;                     /* Set timer value */
        TMC00 = 0x0C ;                           /* Start timer */
        ucRTO_Mode = 0 ;                         /* Next T1 */
    }
}
/******************************************************************************* /
```

```
/*     Set real-time output timer value to common                              */
/******************************************************************************* /
void   vCal_Timer(int iVal,int iPWN )
{
   ucT2_Value = ( unsigned char) iVal ;
   if ( ucT2_Value & 0x08 ) {
      ucT1_Value = ucT2_Value & 0x09 ;
   } else if ( ucT2_Value & 0x10 ) {
      ucT1_Value = ucT2_Value & 0x12 ;
   } else {
      ucT1_Value = ucT2_Value & 0x24 ;
   }
   usT1_Timer = ( iPWN * TMCNT_MAX ) / PWM_DATA  ;
   if ( usT1_Timer < TMCNT_MIN ) {
      usT1_Timer = TMCNT_MIN ;
   }
   else if ( usT1_Timer >= ( TMCNT_MAX - TMCNT_MIN ) ) {
      usT1_Timer = TMCNT_MAX - TMCNT_MIN ;
   }
   usT2_Timer = TMCNT_MAX - usT1_Timer ;
}
```

4.1.10 10 mSEC interval interrupt processing function

```
/******************************************************************************* /
/*     Other timer interrupt processing (10 mSEC interval)                     */
/******************************************************************************* /
_ _multi_interrupt
void   int_ETC(void)
{
/* Wait timer processing */
   if  ( timer_count != 0 ) {
      timer_count -= 1 ;
   }
/* Acceleration/deceleration timer processing */
   if  ( accel_count != 0 ) {
      accel_count -= 1 ;
   }
/* */
   if  ( disp_co != 0 ) {
      d_speed += abs( now_speed ) ;
      disp_co -= 1 ;
   }
}
```

4.1.11 A/D converter interrupt processing function

```
/******************************************************************************* /
```

```
/*     A/D converter interrupt processing for current and speed volume         */
/******************************************************************************* /
_ _multi_interrupt
void   int_AD0(void)
{
   unsigned char ucADS ;
   unsigned short usData ;
   int wk ;
/*  */
   ucADS = ADS ;                          /* Input channel */
   usData = ADCR ;                        /* Input data */
   usData = ( usData >> 6 ) & 0x3FF ;     /* Higher 10 bits */
   switch ( ucADS ) {
      case 0:
         iua = usData - 0x200 ;
         if  ( abs(iua) > MAX_I ) {
            init_RTO() ;                  /* All phases off */
            error_flag = ERR_NO1 ;        /* Set error No. */
         }
         ADS = 0x01 ;                     /* Next ANI1 */
         ADM = 0x80 ;
         break ;
      case 1:
         iva = usData - 0x200 ;
         if  ( abs(iva) > MAX_I ) {
            init_RTO() ;                  /* All phases off */
            error_flag = ERR_NO1 ;        /* Set error No. */
         }
         ADS = 0x02 ;                     /* Next ANI2 */
         ADM = 0x80 ;
         break ;
      case 2:
         wk = 1023 - usData ;             /* Set volume value */
         ADM = 0x00 ;
         Motor_CONT() ;
         cont_time = TM00 / 10 ;          /* Convert to uSEC */
         break ;
   }
}
```

4.1.12 Hardware initialization processing function

```
/******************************************************************************* /
/*     Hardware (peripheral I/O) initialization                                */
/******************************************************************************* /
void   hinit( void )
{
/* Port mode register initialization */
```

```
    PM3 = 0x00f7 ;
    PMDL = 0x0000 ;

    OUT_data( LED11, 0xff ) ;              /* LED OFF */
    OUT_data( LED12, 0xff ) ;
    OUT_data( LED13, 0xff ) ;
    OUT_data( LED14, 0xff ) ;
    OUT_data( LED21, 0xff ) ;
    OUT_data( LED22, 0xff ) ;
    OUT_data( LED31, 0xff ) ;
    OUT_data( LED32, 0xff ) ;
    OUT_data( LED41, 0xff ) ;
    OUT_data( LED42, 0xff ) ;
/* Set 10 mSEC timer TM01 */
    TMC01 = 0x00;                          /* Stop operation */
    PRM01 = 0x01;                          /* fXX/4 200 ns */
    CRC01 = 0x00;
    CR010 = 50000 ;                        /* 10 mSEC */
    TMC01 = 0x0C;                          /* Start operation */
    TM0IC10 = 0x03 ;                       /* Enable interrupt level 3 */
/* Set motor control interrupt timer TM00 */
    TMC00 = 0x00;                          /* Stop operation */
    CRC00 = 0x00;
    PRM00 = 0x00;                          /* fXX/2 100 ns */
    CR000 = TS * 10;                       /* 0.05 mSEC */
    TMC00 = 0x0C;                          /* Start operation */
    TM0IC00 = 0x02 ;                       /* Enable interrupt level 2 */
/* Real-time output function */
    RTPC0 = 0x00 ;                         /* Disable output */
    PMC5 = 0x3F ;                          /* RTP00 to RTP05 output */
    PFC5 = 0x3F ;
    RTPM0 = 0x3F ;
    RTPC0 = 0x70 ;
    RTBL0 = 0x00 ;                         /* Output data initialization */
    RTPC0 = 0xF0 ;                         /* Start real-time output function */
/* Set A/D */
    ADM = 0x00 ;                           /* Stop conversion operation */
    PFM = 0x00 ;                           /* Power fail comparison mode off */
    ADIC = 0x03 ;                          /* Enable interrupt level 3 */
    ADM = 0x80 ;                           /* Start conversion operation */
/* Set zero-cross signal interrupt pin */
    INTR0 = 0x70 ;                         /* Both-edge interrupt */
    INTF0 = 0x70 ;
    PIC1 = 0x00 ;                          /* INTP1 interrupt */
    PIC2 = 0x00 ;                          /* INTP2 interrupt */
    PIC3 = 0x00 ;                          /* INTP3 interrupt */
}
```

4.1.13 Common area initialization processing function

```
/***************************************************************************** /
/*     Common area initialization                                             */
/***************************************************************************** /
void   ainit( void )
{
/* Initialization of flags */
   error_flag = 0 ;                      /* Clear error flag */
   init_flag = OFF ;                     /* Initial flag off */
   disp_co = 100 ;
   d_speed = 0 ;
/* Motor control area initialization */
   stop_flag = ON ;                      /* Stop flag on */
   object_speed = 0 ;                    /* Target speed 0 */
   o_iqai = 0 ;                          /* Speed integral value 0 */
}
```

4.1.14 Revolution start initialization processing function

```
/***************************************************************************** /
/*     Revolution start initialization                                        */
/***************************************************************************** /
void   start_init( void )
{
   int  i;
/*  */
   for ( i = 0 ; i < 21 ; i++ ) before_posi[i][1] = 0;
   total_sa = 0 ;
   sum_speed = 0 ;
   speed_co = 100000 / TS ;

   init_co = 0 ;
   init_pat = 0 ;
   init_upco = 0 ;
}
```

4.1.15 RTO output data initialization processing function

```
/***************************************************************************** /
/*     RTO output data initialization                                         */
/***************************************************************************** /
void   init_RTO( void )
{
   usT1_Timer = TMCNT_MAX / 2 ;          /* Initial value  half timer */
   usT2_Timer = TMCNT_MAX / 2 ;
   ucT1_Value = 0 ;                      /* No data output */
   ucT2_Value = 0 ;
```

```
}
```

4.1.16 Link directive file for V850ES/KJ1

```
/****************************************************************************** /
/*     Link directive file for V850ES/KJ1                                      */
/****************************************************************************** /
VECT_RESET: !LOAD ?RX V0x0000000 {
       .vect_RESET  = $PROGBITS ?AX .vect_RESET;
};
ID_NO: !LOAD ?RX V0x0000070 {
       .id_NO  = $PROGBITS ?AX .id_NO;
};
VECT_U: !LOAD ?RX V0x00000a0 {
       .vect_U  = $PROGBITS ?AX .vect_U;
};
VECT_V: !LOAD ?RX V0x00000b0 {
       .vect_V  = $PROGBITS ?AX .vect_V;
};
VECT_W: !LOAD ?RX V0x00000c0 {
       .vect_W  = $PROGBITS ?AX .vect_W;
};
VECT_MOTOR: !LOAD ?RX V0x0000100 {
       .vect_MOTOR  = $PROGBITS ?AX .vect_MOTOR;
};
VECT_ETC: !LOAD ?RX V0x0000120 {
       .vect_ETC  = $PROGBITS ?AX .vect_ETC;
};
VECT_AD0: !LOAD ?RX V0x0000220 {
       .vect_AD0  = $PROGBITS ?AX .vect_AD0;
};

HANDLER: !LOAD ?RX V0x00001000 {
       .handler  = $PROGBITS ?AX .handler;
};
TEXT:  !LOAD ?RX {
       .text  = $PROGBITS ?AX .text;
};

CONST : !LOAD ?R {
       .const = $PROGBITS ?A .const;
};

DATA : !LOAD ?RW V0x03ffe000 {
       .data  = $PROGBITS ?AW  ;
       .sdata = $PROGBITS ?AWG ;
       .sbss  = $NOBITS   ?AWG ;
       .bss   = $NOBITS   ?AW  ;
```

```
};

_ _tp_TEXT @ %TP_SYMBOL;
_ _gp_DATA @ %GP_SYMBOL &_ _tp_TEXT{DATA};
_ _ep_DATA @ %EP_SYMBOL;
```