NEC

User's Manual

3-Phase Brushless DC Motor Control 120-Degree Trapezoidal Drive with Hall Sensors for MC-LVKIT-714 Motor Control Evaluation System

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CAUTION

This is a Test- and Measurement equipment with possibility to be significantly altered by user through hardware enhancements/modifications and/or test or application software. Thus, with respect to Council Directive 89/336/EEC (Directive on compliance with the EMC protection requirements), this equipment has no autonomous function. Consequently this equipment is not marked by the CE-symbol.

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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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Preface

Readers

This manual is intented for users who want to understand the functions of the 3-phase brushless DC motor control 120-degree trapezoidal drive with Hall sensors for MC-LVKIT-714 motor control evaluation system.

Purpose

This manual presents the hardware manual of the 3-phase brushless DC motor control 120-degree trapezoidal drive with Hall sensors for MC-LVKIT-714 motor control evaluation system.

Organization

This system specification describes the following sections:

- Controlling a BLDCM
- System overview
- Design
- Development environment

Legend

Symbols and notation are used as follows:

Weight in data notation	:	Left is high-order column, right is low order column
Active low notation	:	$\overline{\text{xxx}}$ (pin or signal name is over-scored) or /xxx (slash before signal name)
Memory map address:	:	High order at high stage and low order at low stage
Note	:	Explanation of (Note) in the text
Caution	:	Item deserving extra attention
Remark	:	Supplementary explanation to the text
Numeric notation	:	Binary... xxxx or xxxB Decimal... xxxx Hexadecimal... xxxxH or 0x xxxx

Prefixes representing powers of 2 (address space, memory capacity)

K (kilo): $2^{10} = 1024$

M (mega): $2^{20} = 1024^2 = 1,048,576$

G (giga): $2^{30} = 1024^3 = 1,073,741,824$

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Chapter 1 Introduction

This document describes the specifications and design of a software package used with the Low-Voltage Motor Control Evaluation System (MC-LVKIT-714) from NEC Electronics to drive a low-voltage, 3-phase brushless DC (BLDC) motor using 120-degree trapezoidal waves and Hall sensors for rotor position detection. The software is supplied with the kit as open source and offers a quick start for anyone interested in learning and developing brushless DC motor (hereafter referred as “BLDCM”) control applications with NEC Electronics’ µPD78F0714 microcontroller (MCU). The code example described here supports NEC Electronics’ low-voltage motor control starter kit when used with the MC-CPU-78F0714 micro-board (MC-LVKIT-714).

For information about the electrical characteristics and hardware functions (especially the motor control functions and setting of registers), refer to µPD78F0714 Preliminary User’s Manual (U16928E).

For information about instruction functions, refer to 78K/0 Series Instruction User’s Manual (U12326E).

For information on the Motor Control Evaluation System and its components, consult the following documents.

Table 1-1: Documents Related to Motor Control Evaluation System Components

Document Name	Number
MC-CPU-78F0714 Micro-Board User’s Manual	U17707E
MC-I/O-GENERAL Board User’s Manual	U17857E
Low-Voltage Power Module for Motor Control User’s Manual	U18052E

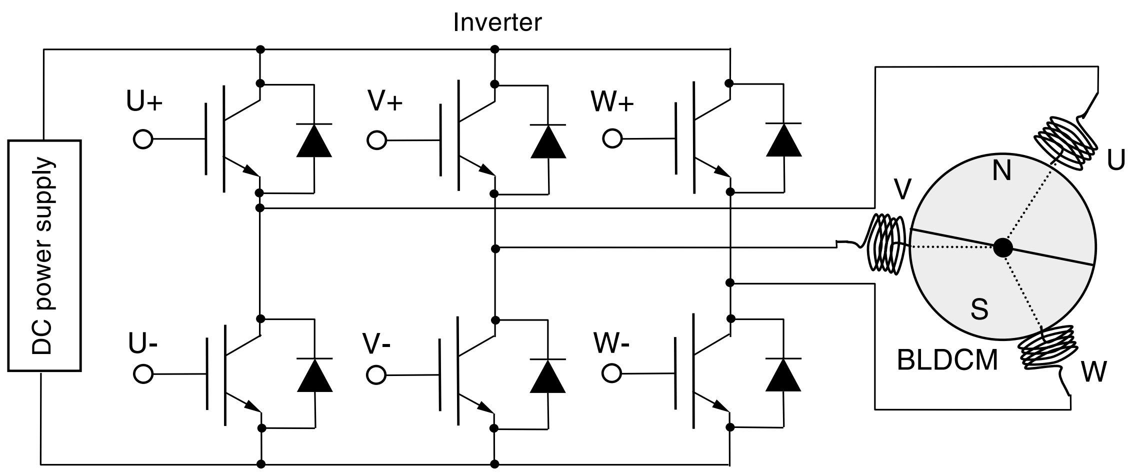
Chapter 2 Controlling a BLDCM

A BLDCM revolves as a result of the interaction of its permanent magnet rotor with a magnetic field generated when a DC voltage is connected across a set of stator coils. To maintain rotation, the orientation of the magnetic field in the stator has to be rotated sequentially. This is accomplished by connecting the DC voltage across the next set of stator coils as the rotor revolves. To maintain synchronization with the rotating stator magnetic field, the rotor position must be known at fixed angular intervals. BLDCM are also known as electronically commutated (EC) motors and are driven by a DC-to- AC power inverter controlled with a dedicated MCU.

2.1 Driving by Inverter

The generation of the rotating magnetic field is implemented using a 6-transistor inverter bridge as shown in Figure 2-1.

Figure 2-1: Six-Transistor Inverter Bridge

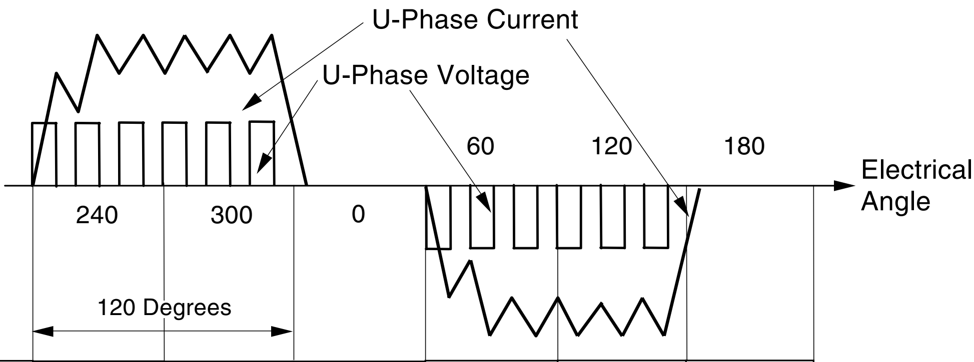


By controlling the commutation of six switching elements, the DC bus voltage can be applied across any combination of two stator coils of the BLDCM.

2.2 120-Degree Excitation Mode

Figure 2-2 shows the 120-degree excitation method.

Figure 2-2: 120-Degree Excitation Pattern and U-Phase Current Waveform



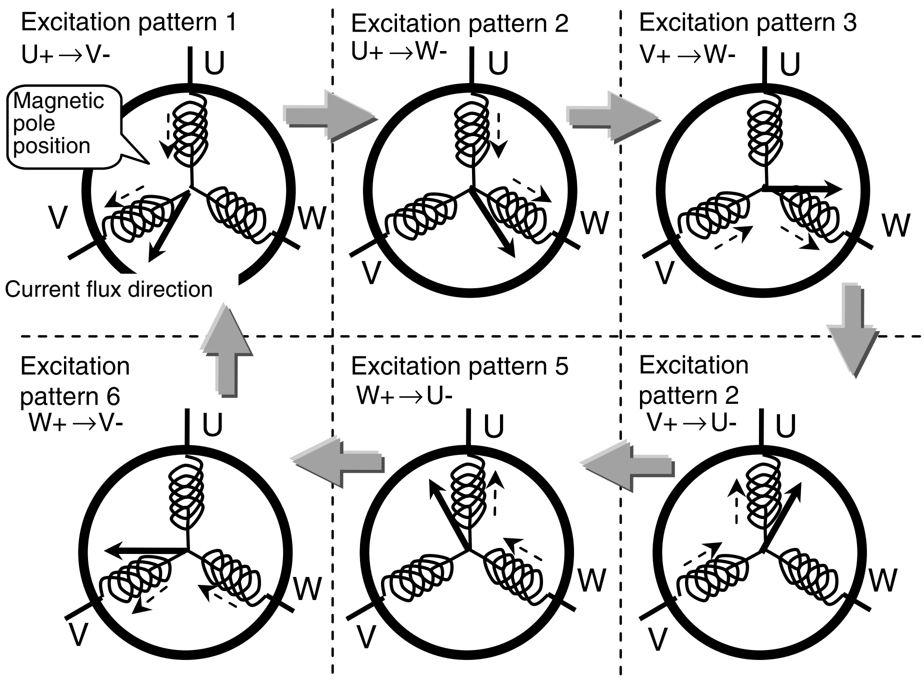
Excitation Pattern	1	2	3	4	5	6
Excited Phases	U+	U+	V+	V+	W+	W+
	V-	W-	W-	U-	U-	V-

To drive the BLDCM, the DC bus voltage is connected across two stator phases at any given time by turning on one upper and one lower transistor pair for 60 electrical degrees. For a six-element bridge, there are six distinct switching configurations: U+/V-, U+/W-, V+/W-, V+/U-, W+/U-, W+/V-. The BLDCM rotates 360 electrical degrees if the six switching configurations are changed sequentially at 60-degree intervals in synchronization with the rotor position. After completing the six steps, the sequence is repeated. This method is called the 120-degree method because every switching element is turned on for 120 electrical degrees.

2.3 Excitation Pattern

Figure 2-3 shows the six excitation patterns and the directions of the magnetic flux generated by the stator coils.

Figure 2-3: Excitation Patterns and Current Flux Directions



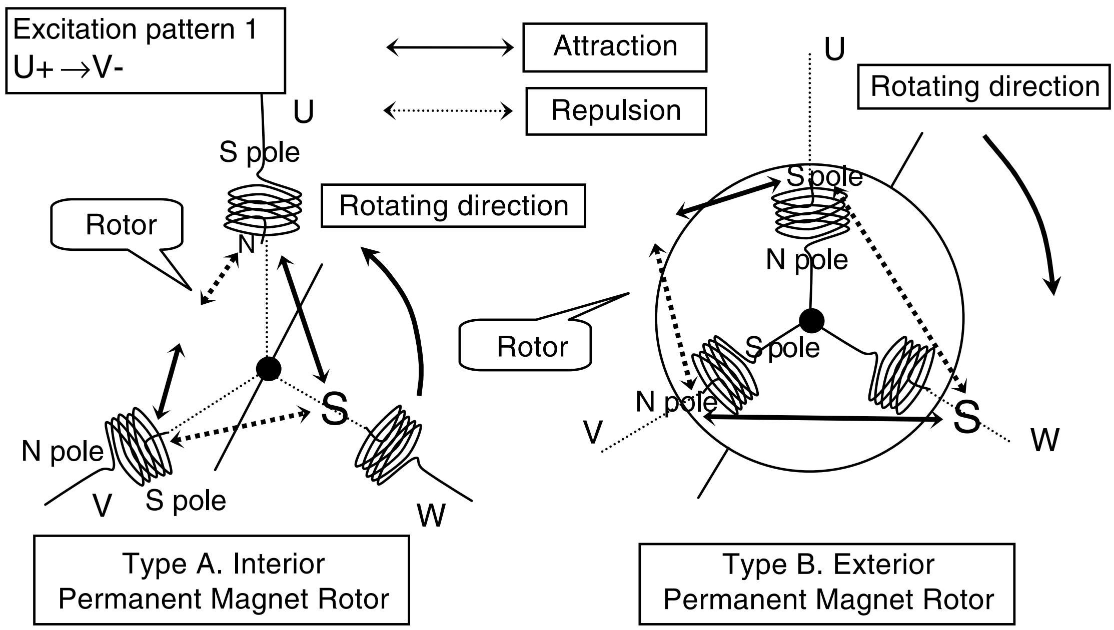
A BLDCM revolves by the attraction and repulsion between the poles of the rotating magnetic field of the stator coils and the magnetic poles of the permanent magnet rotor. The torque developed is at maximum when the angle between the two magnetic poles is 90 degrees (the position of the permanent magnet poles changes as the rotor revolves).

In the 120-degree method, the commutation patterns are changed so that the angle between the magnetic pole of the rotor and rotating magnetic field of the stator is in a range of 60 to 120 degrees (the direction of the stator flux depends on how the coils are wound).

There are two types of BLDCM, type A with an interior rotor and type B with and exterior rotor. Their principals of operation are similar.

Figure 2-4 shows the attraction and repulsion between the poles of the rotating magnetic field and the permanent magnet.

Figure 2-4: Attraction and Repulsion of Magnetic Poles

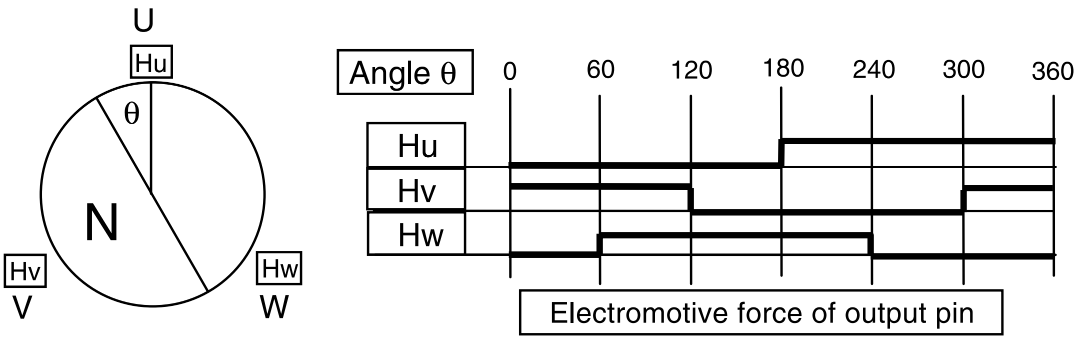


The direction of rotation depends on the position of the rotor (permanent magnet) as well as on the combination and polarity of energized phases.

2.4 Position Detection

For 120-degree or 6-step driving method the rotor position has to be known at 60-degree intervals. Figure 2-5 shows an example of a magnetic pole position detection using Hall effect sensors.

Figure 2-5: Hall IC



To detect the rotor position, three Hall sensors are placed around the rotor perimeter at equal angular intervals. For a two-pole rotor, the Hall sensors are placed at 120 degrees. The logic state of each sensor changes every 180 degrees but the combination pattern of the three sensors changes every 60-degree intervals. If the rotor has four poles, distinct positions can be detected at every 30 degrees physical angle: (physical angle = electrical angle/number of poles facing each other).

More commonly, a BLDCM with four rotor poles has the Hall sensors spaced at 60-degree intervals so that the rotor position can be detected at 60 electrical degrees and 30 physical degrees.
Table 2-1shows an example of an excitation pattern change based on the Hall sensor logic states.

Table 2-1: Relationship Between Hall ICs and Excitation Patterns

Excitation Pattern	1	2	3	4	5	6
Hu	Hi	Lo	Lo	Lo	Hi	Hi
Hv	Hi	Hi	Hi	Lo	Lo	Lo
Hw	Lo	Lo	Hi	Hi	Hi	Lo

This relationship depends on the mounting positions (positional relationship of the stator of each phase) of the Hall sensor.

2.5 Speed Detection

The revolution speed of the motor is calculated from the time interval measured between the Hall sensor transitions. A 16-bit timer counts 12.8 µs time intervals between the Hall sensor transitions.

2.6 Speed Control

2.6.1 Voltage control

The revolution speed of the BLDCM is directly proportional to the voltage applied to the stator coils. Turning on and off the switching elements with a pulse-width modulation (PWM) signal during the 120-degree excitation period can control the amplitude of the voltage. The chopping effect on the phase voltage controls the current through the coils and the torque developed in the rotor.

2.6.2 PID control

To maintain a constant revolution speed, a proportional integral derivative PID) controller is use. The controller compares the speed measured by the Hall sensors with a “set” speed and adjusts the duty factor of the PWM signal accordingly.

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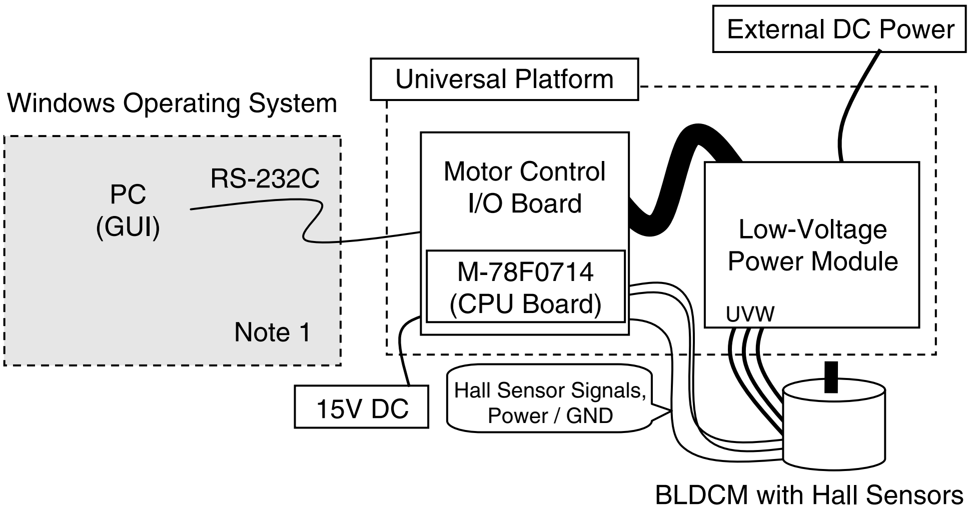
Chapter 3 System Overview

3.1 Configuration

Figure 3-1: System Configuration

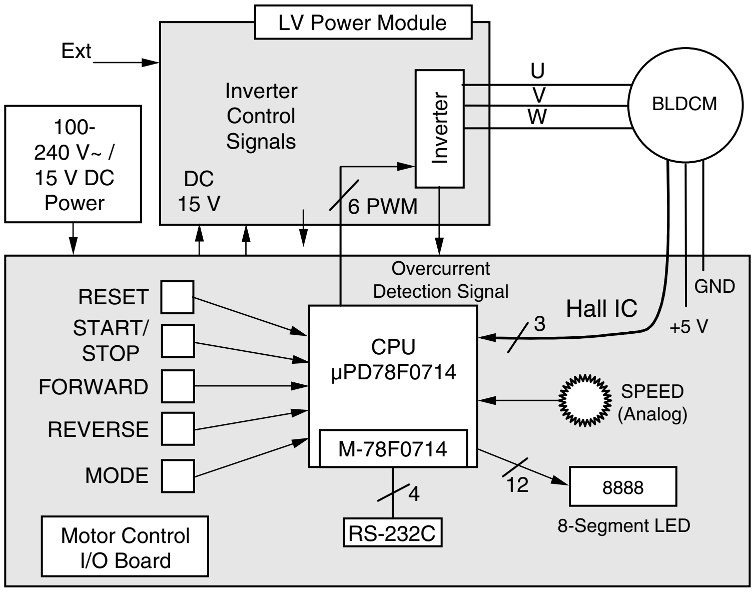


Note: Only the communication commands are described in this document

The system consists of a motor drive module containing the power switching transistors, a motor control I/O board equipped with operator interface elements to control the motor, and the M-78F0714 CPU board.

The BLDCM is a three-phase, four rotor-pole (two poles facing each other) motor, with Hall sensors mounted at 60-degree intervals between the stator coils. This configuration detects the rotor position changes at every 60 electrical degrees and every 30 physical degrees.

Figure 3-2: Block Configuration of the Universal Platform



The motor can be controlled with the push buttons on the motor control I/O board or with the PC GUI through the RS-232C port. Motor speed or operation mode is displayed on the 8-segment LED. The same information can also be displayed in the PC GUI.

3.2 Operational Controls

The system described here has the following operational controls:

- RESET switch to reboot the system reboot
- START/STOP switch to start and stop motor revolution
- FORWARD and REVERSE switches to change revolution direction
- MODE switch to change control mode
- SPEED potentiometer to change revolution speed
- Revolutions per minute (rpm) display
- Automatic emergency shutdown function in case of a motor over-current detection
- Commands to control the system from the computer (RS-232C)

3.3 User Interface

The user interfaces hardware and functions are listed in Table 3-1.

Table 3-1: User Interface

Parts Number	Function Name	Function
SW1	RESET	Reset
SW2	START/STOP	Start/stop
SW3	FORWARD	Revolution direction (CW)
SW4	REVERSE	Revolution direction (CCW)
SW5	MODE	Changing control mode
R52	SPEED	Changing target speed
DISP1 to 4		Displaying speed (rpm)*

Notes: 1. The target speed is always displayed while the motor is stopped.

2. The actual motor speed is displayed while the motor is revolving.

3. To display target speed while the motor is running press MODE button

4. If “PC” is displayed, the motor can be controlled through a PC GUI.

5. In PC mode, only the RESET function can be used.

Table 3-2 lists the μPD78F0714 MCU pins used for interfacing with the motor drive.

Table 3-2: Pin Interface Functions

Pin Number	Pin Name	Function
8	$\overline{\text{RESET}}$	RESET(SW1) *1
27 to 32	TW0TO0 to 5	3-phase PWM inverter selection
11	P01/INTP1	Hall IC signal (U phase)
10	P02/INTP2	Hall IC signal (V phase)
9	P03/INTP3	Hall IC signal (W phase)
20	P53/INTP5	Revolution speed measurement
49 to 52	P64 to P67	8-segment LED selection (LD_LED0 to 3)
56	P73	START/STOP (SW2)
55	P72	FORWARD (SW3)
54	P71	REVERSE (SW4)
53	P70	MODE (SW5)
41 to 48	P40 to P47	Output data to 8-segment LED
12	TW0TOFFP/INTP0	Over-current detection (+5V →0V)
60	ANI4	Speed change (R52)
33	P10	Communication via RS-232C (CTS)
34	P11	Communication via RS-232C (RTS)
36	P13/RXD00	Communication via RS-232C (RXD)
37	P14/TXD00	Communication via RS-232C (TXD)

Note: Pins 1 and 2 of 2JP7 are short-circuited.

In PC mode, the commands listed in Table 1-3 can be executed to control operation of the motor.

Table 3-3: Communication Commands

Command from PC	Parameter	Return Value	Description
Get product ID	None	Product ID	Gets ID of firm
Get version	None	Version	Gets firm version
Reset	None	ACK	Resets program of firm
Start revolution	None	ACK	Starts revolving motor
Stop revolution	None	ACK	Stops revolving motor
Set PID gain	Kp, Ki, Kd	ACK	Changes gain of PID
Get PID gain	None	Kp, Ki, Kd	Gets gain of PID
Set target number of revolutions	Number of revolu-tions	ACK	Specifies target number of revolutions
Get target number of revolutions	None	Target number of revolutions	Gets target number of revolutions of motor
Get actual number of revolutions	None	Actual number of revolutions	Gets actual number of revolutions of motor

3.4 Peripheral I/O

This system uses the peripheral I/O registers of the μPD74F0714 MCU.

Table 3-4: Peripheral I/Os

Function	Peripheral I/O Function Name (μPD78F0714)
Inverter timer	10-bit inverter control timer; default value of carrier frequency is 10 kHz (symmetrical triangular wave)
Real-time output	Real-time output port; 16-bit timer capture/compare register 01 (CR01)
Feedback time	8-bit timer/event counter 51; (default value: 100 ms)
Wait processing	8-bit timer/event counter 50; generating 1-ms timer
Reading specified speed	A/D converter (ANI4)
Overcurrent interrupt	Interrupt function (INTP0)
Speed measurement	U-phase Hall IC interrupt (INTP5); 8-bit timer/event counter 00 (TM00: 12.8 μs)
Communication with PC	Serial interface UART00
Fail safe/reset	Watchdog timer

Chapter 4 Design

4.1 Motor Speed

With a 3-phase, 4-pole BLDCM, the value of the U-phase Hall sensor IC changes 4 times per motor revolution. The speed is calculated using a timer tick of 12.8 µs with the equation N = 60/(s * n * 4), where

- N = number of revolutions per minute (rpm)
- S = timer ticks (12.8 µs)
- N = timer value
- This system supports a speed range of 300 rpm to 3000 rpm.

4.2 PID Operation

To maintain a constant motor speed regardless of the load the reference speed set by the potentiometer on the MC-I/O board is compared with the actual speed measured with the Hall sensors and PID control operation is performed on the resulting speed error signal. The result of the PID algorithm controls the duty factor (voltage) of the PWM signals to reduce the speed error to zero. The PWM signal's duty factor is calculated based on the following speed-type PID algorithm suitable for the sampling method used (discrete value). These values were manipulated (scaled) to be able to use them as 16-bit integers.

MVn	MVn-1 + ∆MVn
∆MVn	Kp (en – (en-1))+ Ki*en + Kd ((en – (en-1) – (en-1) – (en-2))
MVn	Current manipulated variable
MVn-1	Previous manipulated variable
∆MVn	Difference between current and previous manipulated variables
En	Current deviation (difference between specified speed and actual speed)
en-1	Previous deviation
en-2	Deviation before previous deviation
Kp	Proportional gain constant
Ki	Integral gain constant
Kd	Derivative gain constant

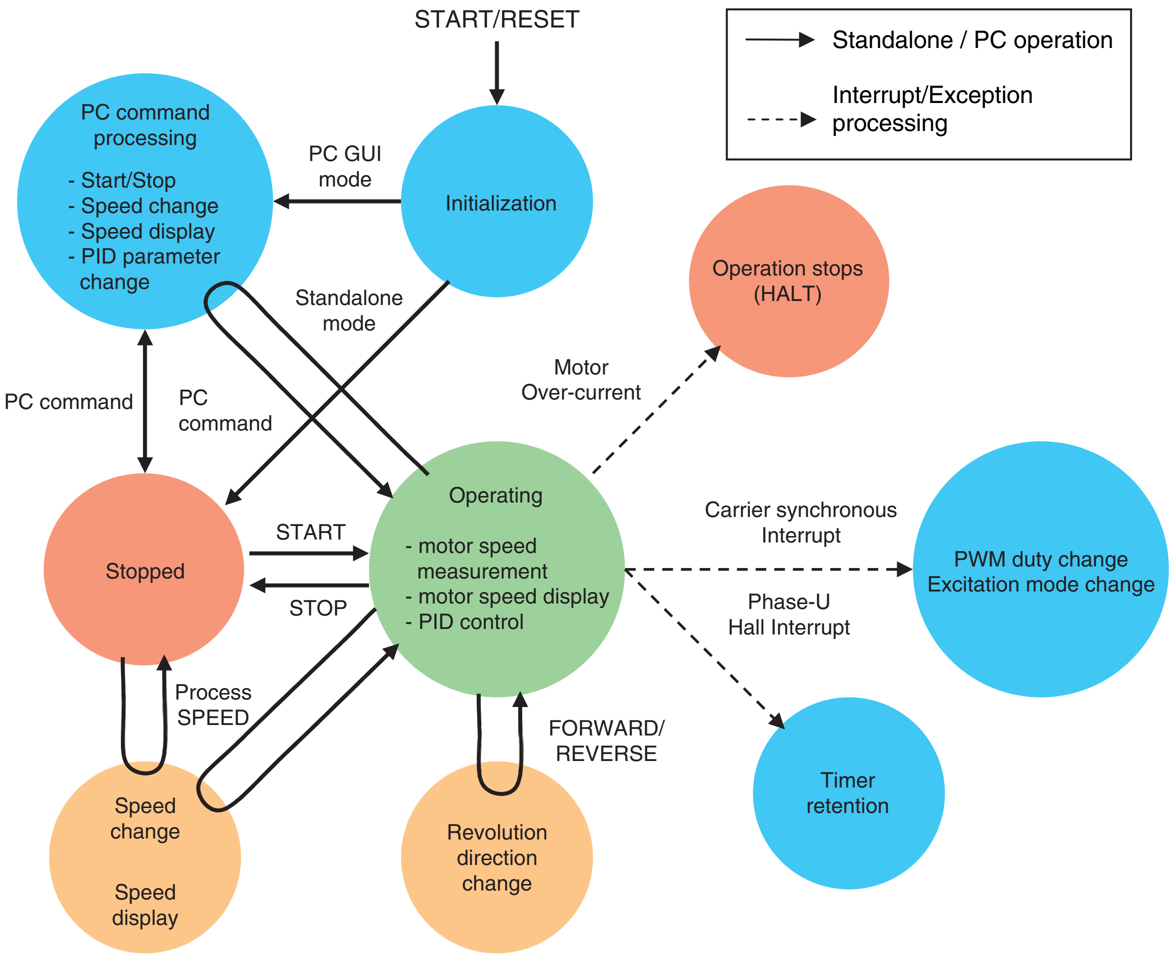
The optimum values of the gain constants depend on the motor characteristics and the presence or absence of a load. In this system, the values were chosen experimentally on trial by error basis and default values were verified during operation.

The interval of PID control is set to be longer (100 ms) than the interval (50 ms at 300 rpm) of updating the revolution speed.

4.3 Software Module Configuration

Figure 4-1 shows status transitions of the system.

Figure 4-1: Status Transition of System



The carrier synchronous interrupt is generated every 100 μs (default).

Table 4-1 shows the modules of the system and their main processing.

Table 4-1: Module and Main Processing

Module Name	Main Processing
Initialization	Initializes peripheral I/O
	Unmasks overcurrent interrupt
Main	Clears watchdog timer
	Checks specified speed (speed display)
	Reads switch pattern
	Starts motor if START/STOP switch is pressed while motor is stopped
	Stops motor if START/STOP switch is pressed while motor is revolving
	Changes revolution to clockwise if FORWARD command is received while motor is revolving
	Changes revolution to counterclockwise if REVERSE command is received while motor is revolving
	Calculates actual speed
	Performs PID control every 20 ms while motor is revolving
Check specified speed	Executes A/D conversion of specified speed (voltage)
	Converts read value (0 to 1023) to speed measurable at interval (time) of carrier synchronous interrupt
	Displays converted speed on LED
U-phase Hall IC interrupt	Retains timer value
Carrier synchronous interrupt	Reads the pattern of Hall sensors
	Sets the excitation pattern corresponding to Hall pattern
Overcurrent interrupt	Stops 10-bit inverter control timer and 16-bit timer/event counter 00
	Displays characters 0–C on the LED
	Stops processing when HALT instruction is executed

4.4 Processing Flow

The flow of processing of each module is illustrated below:

Figure 4-2: Initialization

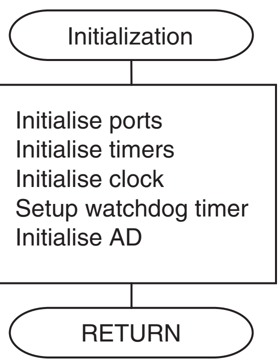


Figure 4-3: Main

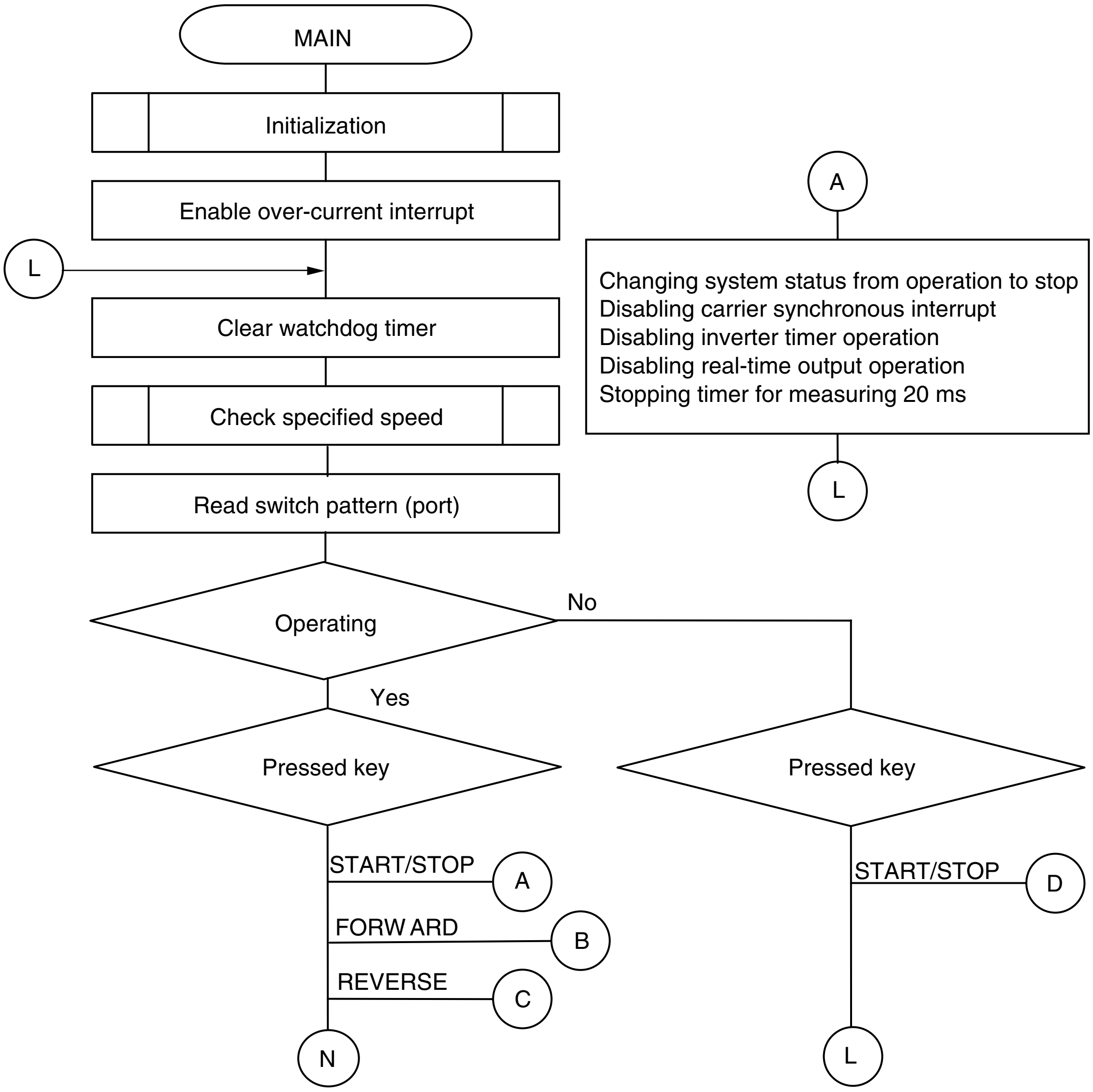


Figure 4-4: Changing Revolution Direction

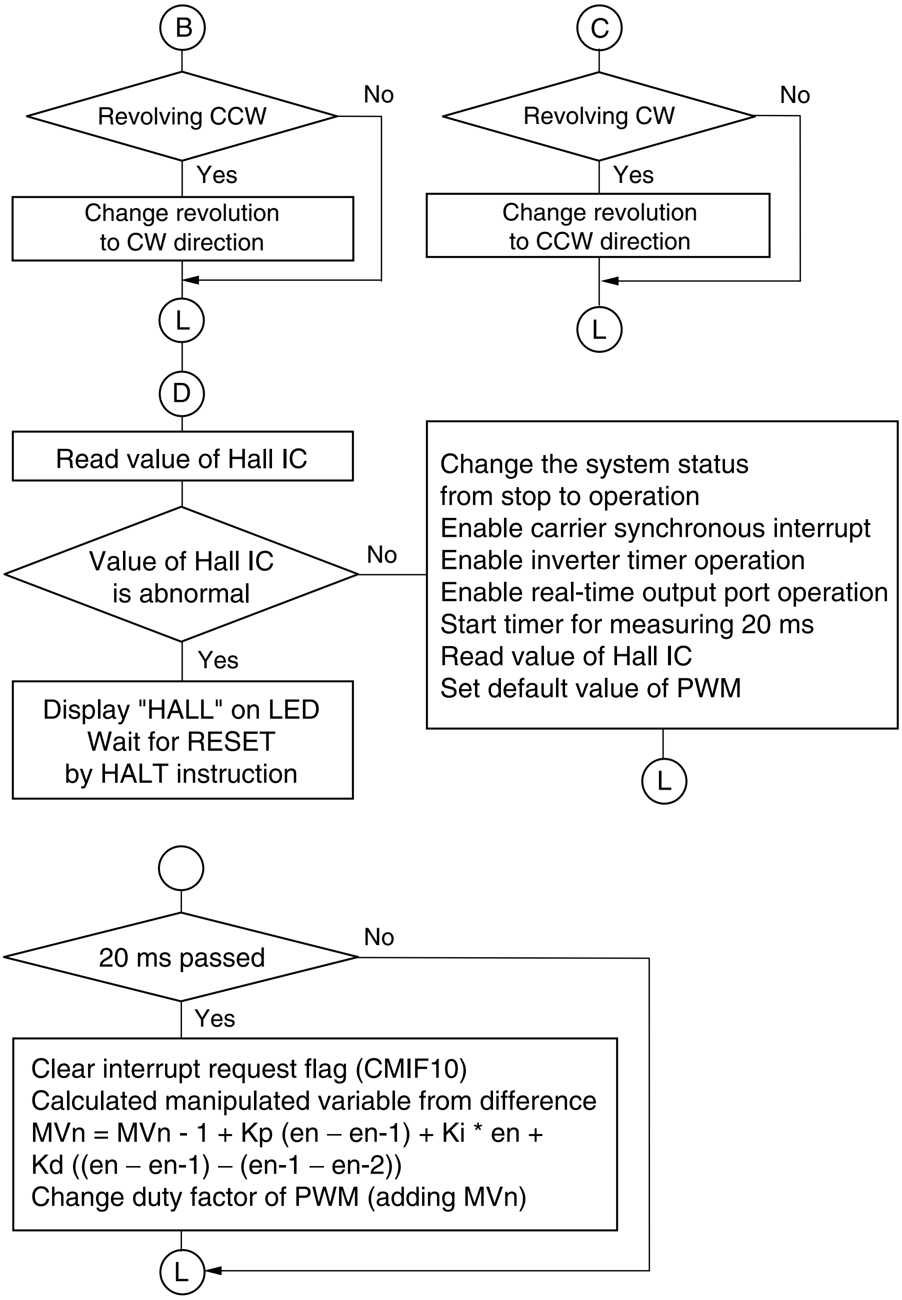


Figure 4-5: Checking Specified Speed

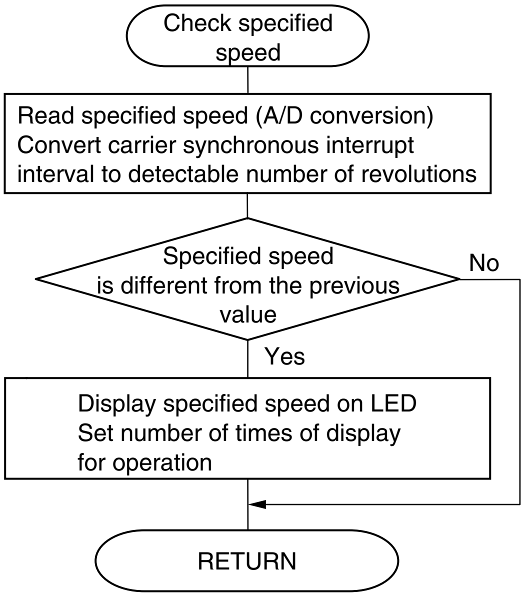


Figure 4-6: Synchronous Carrier Interrupt

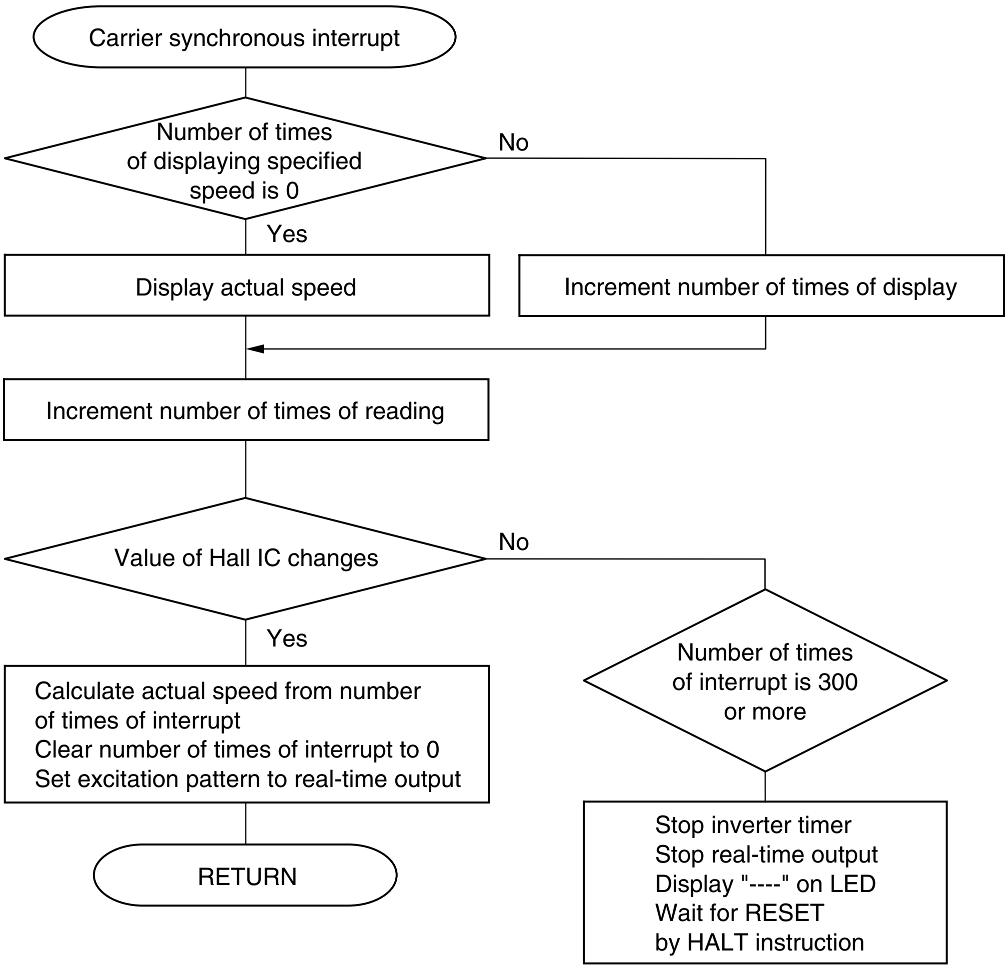
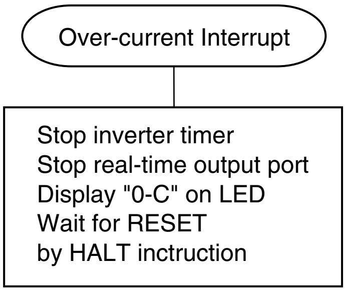


Figure 4-7: Over-current Interrupt



Chapter 5 Development Environment

5.1 Hardware

- Low-voltage starter kit MC-LVKIT-714
  - MC-CPU-78F0714 micro-board
  - MCI/O user interface board
  - MC-LV-INVERTER low-voltage power module
- BLDCM (PITTMAN N2311 motor)

5.2 Software

- PM plus environment platform
- CC78K0 compiler
- RA78K0 assembler
- DF0714.78K device file