

Toshiba BiCMOS Linear Integrated Circuits — silicon monolithic

TB9083FTG

Automotive GATE-driver for Brushless motor

1. INTRODUCTION

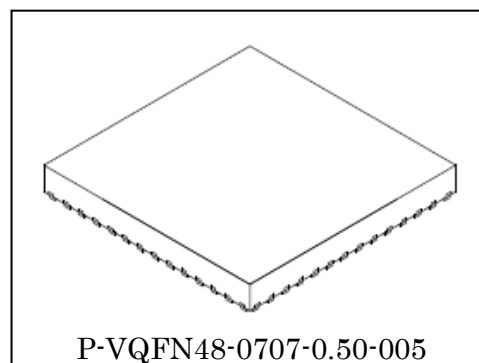
The TB9083FTG is a pre-driver IC for brushless motors in vehicle application.

It features a built-in safety relay pre-driver in addition to the three-phase pre-driver.

It also has a charge pump, a motor current detector circuit, an oscillator circuits and an SPI communication circuit.

It has multiple error detection features. Trigger threshold, response action and other settings are modified via the SPI.

The TB9083FTG is also equipped with ABIST/LBIST for testing and evaluation of the error detection functions.



weight: T.B.D. g (typ.)

2. APPLICATIONS

Used mainly on EPS, powered brakes and pumps

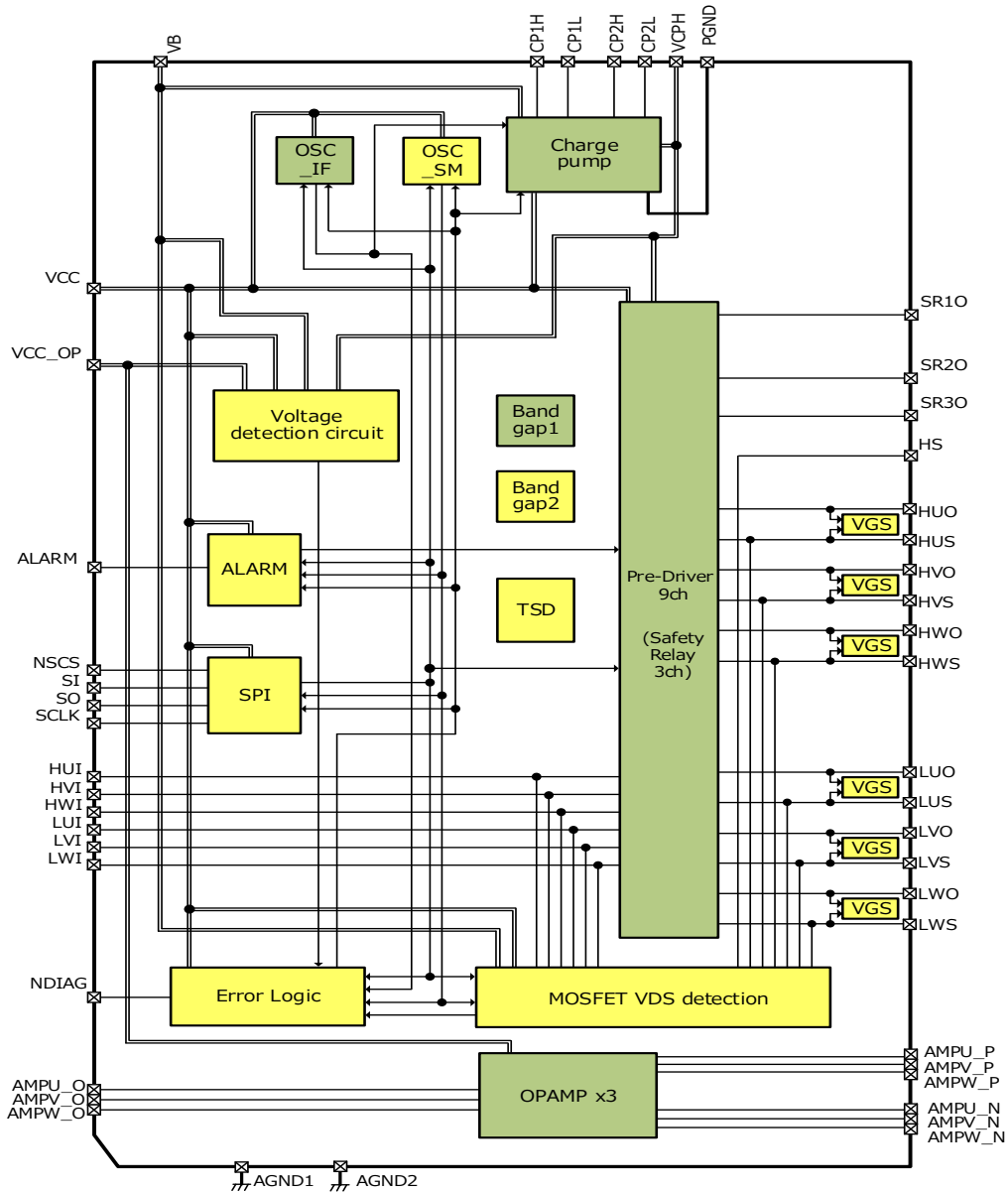
3. FEATURES AND BENEFITS

- Three-phase pre-driver PWM control up to 20 kHz
- Fail-safe relay pre-driver
- Built-in charge pump circuit
- Built-in current detector circuit
- Error detection functionality: undervoltage (VB, VCC, VCC_OP), overvoltage (VCC, VCC_OP, VCPH, external MOSFET VGS), overtemperature, external MOSFET VDS detector
- Built-in ABIST / LBIST
- AEC-Q100 (TBC)
- Operating voltage range VB: 4.5 to 28 V, VCC: 3.0 to 5.5 V
- Operating temperature range Ta: -40°C to 150°C, Tj: -40°C to 175°C
- Package P-VQFN48-0707-0.50-005 (Wettable flank, 0.5 mm pitch)
- Functional safety
 - Developed in accordance with ISO 26262 2nd Ed. (TBC)
 - Safety manual and safety evaluation report
 - Redundancy and built-in ABIST/LBIST
 - SPI interface with CRC check

The product(s) is/are compatible with RoHS regulations (EU directive 2011 / 65 / EU) as indicated, if any, on the packaging label ("[[G]]/RoHS COMPATIBLE", "[[G]]/RoHS [[Chemical symbol(s) of controlled substance(s)]]", "RoHS COMPATIBLE" or "RoHS COMPATIBLE, [[Chemical symbol(s) of controlled substance(s)]]>MCV").

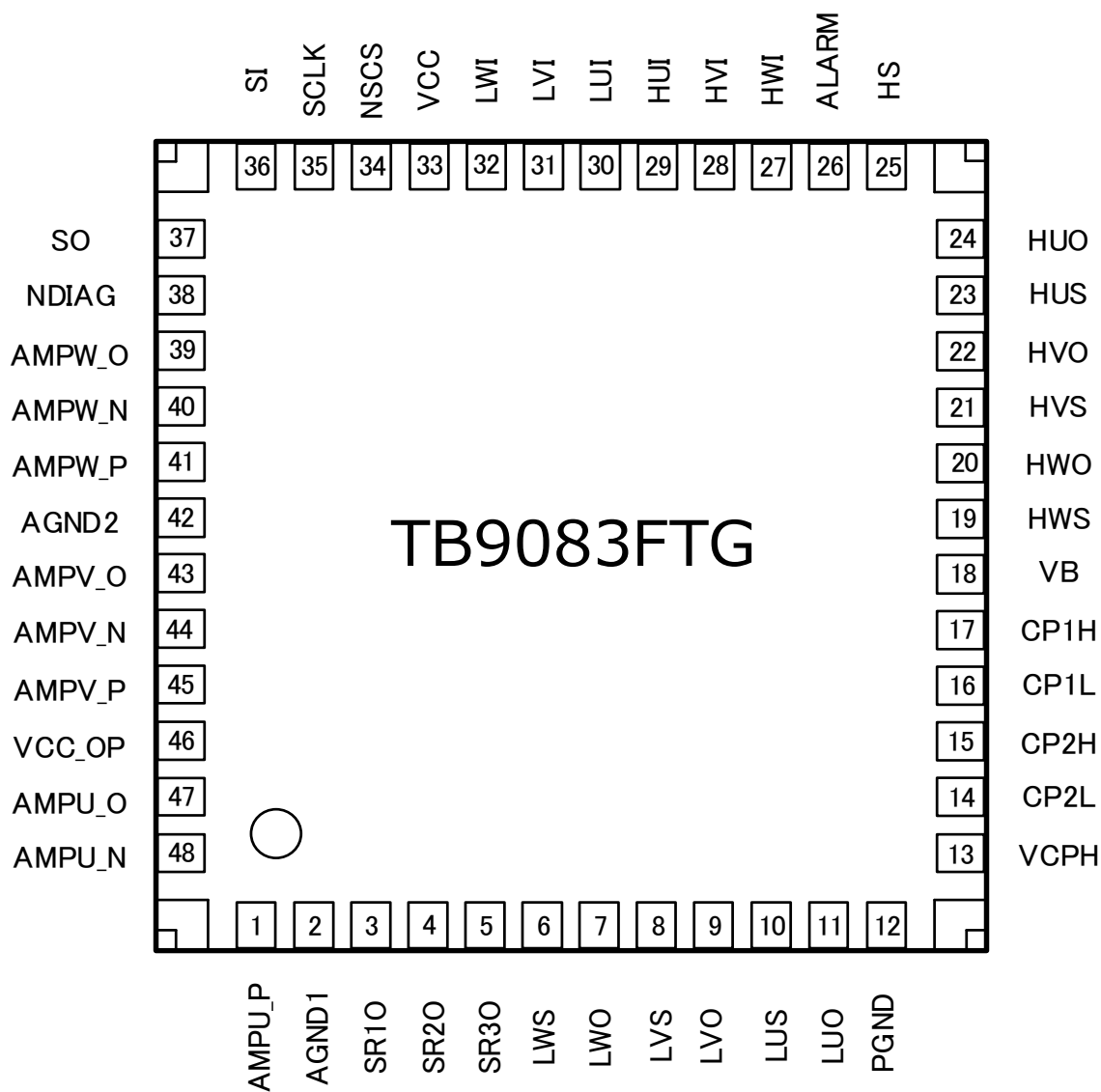
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4. BLOCK DIAGRAM



Note 1: Functional blocks and wiring scheme have been simplified for the purpose of clarity (including individual block diagrams)

5. Terminal layout (top view)



6. Terminals

| Pin No | Name | I/O | Description | Pull-up/down resistor | Remark |
|--------|--------|--------------|---|-----------------------------------|---|
| 1 | AMPU_P | IN | Current sense amplifier positive input for U phase | - | - |
| 2 | AGND1 | GND | GND 1 for analog circuits | - | - |
| 3 | SR1O | OUT | Safety relay 1 output | - | SPI setting |
| 4 | SR2O | OUT | Safety relay 2 output | - | SPI setting |
| 5 | SR3O | OUT | Safety relay 3 output | - | SPI setting |
| 6 | LWS | IN | Pre-driver reference input for W phase low side (source) | - | - |
| 7 | LWO | OUT | Pre-driver output for W phase low side | Pull-down to LWS | - |
| 8 | LVS | IN | Pre-driver reference input for V phase low side (source) | - | - |
| 9 | LVO | OUT | Pre-driver output for V phase low side | Pull-down to LVS | - |
| 10 | LUS | IN | Pre-driver reference input for U phase low side (source) | - | - |
| 11 | LUO | OUT | Pre-driver output for U phase low side | Pull-down to LUS | - |
| 12 | PGND | GND | Power GND | - | - |
| 13 | VCPH | Power supply | Charge pump output voltage | Pull-down to VB | - |
| 14 | CP2L | OUT | Charge pump output 2 | - | - |
| 15 | CP2H | I/O | Charge pump drive output 2 | - | - |
| 16 | CP1L | OUT | Charge pump output 1 | - | - |
| 17 | CP1H | I/O | Charge pump drive output 1 | - | - |
| 18 | VB | Power supply | VB input | - | - |
| 19 | HWS | IN | Pre-driver reference input for W phase high side (source) | Pull-up to HS Pull-down to LWS | Pull-up and pull-down resistors can be connected only in the external FET test mode (FET_TEST). |
| 20 | HWO | OUT | Pre-driver output for W phase high side | Pull-down to HWS | - |
| 21 | HVS | IN | Pre-driver reference input for V phase high side (source) | Pull-up to HS Pull-down to LVS | Pull-up and pull-down resistors can be connected only in the external FET test mode (FET_TEST). |
| 22 | HVO | OUT | Pre-driver output for V phase high side | Pull-down to LVS | - |
| 23 | HUS | IN | Pre-driver reference input for U phase high side (source) | Pull-up to HS Pull-down to LUS | Pull-up and pull-down resistors can be connected only in the external FET test mode (FET_TEST). |
| 24 | HUO | OUT | Pre-driver output for U phase high side | Pull-down to HUS | - |
| 25 | HS | IN | VDS sense input for external high side MOSFET | - | - |
| 26 | ALARM | IN | Enable input for pre-driver | Pull-down to GND | - |
| 27 | HWI | IN | Pre-driver input for W phase high side | Pull-down to GND | - |
| 28 | HVI | IN | Pre-driver input for V phase high side | Pull-down to GND | - |
| 29 | HUI | IN | Pre-driver input for U phase high side | Pull-down to GND | - |
| 30 | LUI | IN | Pre-driver input for U phase low side | Pull-down to GND | - |
| 31 | LVI | IN | Pre-driver input for V phase low side | Pull-down to GND | - |
| 32 | LWI | IN | Pre-driver input for W phase low side | Pull-down to GND | - |
| 33 | VCC | Power supply | 5V/3.3V supply input | - | - |
| 34 | NSCS | IN | SPI chip select | Pull-up to VCC | - |
| 35 | SCLK | IN | SPI clock input | Pull-down to GND | - |
| 36 | SI | IN | SPI input | Pull-down to GND | - |
| 37 | SO | OUT | SPI output | - | - |
| 38 | NDIAG | OUT | Diagnosis output | - | - |
| 39 | AMPW_O | OUT | Current sense amplifier output for W phase | - | - |
| 40 | AMPW_N | IN | Current sense amplifier negative input for W phase | - | - |
| 41 | AMPW_P | IN | Current sense amplifier positive input for W phase | - | - |
| 42 | AGND2 | GND | GND 2 for analog circuits | - | - |
| 43 | AMPV_O | OUT | Current sense amplifier output for V phase | - | - |
| 44 | AMPV_N | IN | Current sense amplifier negative input for V phase | - | - |
| 45 | AMPV_P | IN | Current sense amplifier positive input for V phase | - | - |
| 46 | VCC_OP | Power supply | 5V/3.3V supply input for current sense amplifiers | - | - |
| 47 | AMPU_O | OUT | Current sense amplifier output for U phase | - | - |
| 48 | AMPU_N | IN | Current sense amplifier negative input for U phase | - | - |

• Internal signals

| Internal Signal | Description | State | |
|-----------------|--|-----------------|------------------|
| | | H | L |
| (abst_pass) | ABIST normal signal | ABIST normal | ABIST abnormal |
| (abst_end) | ABIST end signal | ABIST completed | ABIST incomplete |
| (gate_en_u) | Pre-driver output enabling signal for U Phase | Enable | Disable |
| (gate_en_v) | Pre-driver output enabling signal for V Phase | Enable | Disable |
| (gate_en_w) | Pre-driver output enabling signal for W Phase | Enable | Disable |
| (gate_en_r) | Pre-driver output enabling signal for safety relay | Enable | Disable |
| (gate_off_u) | Pre-driver off signal other than ALARM factor for U Phase. | - | - |
| (gate_off_v) | Pre-driver off signal other than ALARM factor for V Phase. | - | - |
| (gate_off_w) | Pre-driver off signal other than ALARM factor for W Phase. | - | - |
| (gate_off_r) | Relay off signal other than ALARM factor. | - | - |
| (cp_en) | Charge pump enable signal | Enable | Disable |
| (cp_off) | Charge pump off signal | - | - |
| (vbl) | VB under voltage detection signal | Detection | Release |
| (vcphh) | VCPH overvoltage detection signal | Detection | Release |
| (vcl1) | VCC undervoltage detection signal 1 | Detection | Release |
| (vcl2) | VCC undervoltage detection signal 2 | Detection | Release |
| (por_x) | Internal reset signal | Reset release | Reset |
| (vccopl) | VCC_OP undervoltage detection signal | Detection | Release |
| (vccoph) | VCC_OP overvoltage detection signal | Detection | Release |
| (vch) | VCC overvoltage detection signal | Detection | Release |
| (tsddet) | Thermal shutdown detection signal | Detection | Release |
| (clk4m_if) | 4MHz clock (oscillation for IF) | - | - |
| (clk4m_sm) | 4MHz clock (oscillation for SM) | - | - |
| (vdsuho) | External MOSFET Vds detection signal for U phase low side | Detection | Release |
| (vdsvho) | External MOSFET Vds detection signal for V phase low side | Detection | Release |
| (vdswho) | External MOSFET Vds detection signal for W phase low side | Detection | Release |
| (vdsulo) | External MOSFET Vds detection signal for U phase high side | Detection | Release |
| (vdsvlo) | External MOSFET Vds detection signal for V phase high side | Detection | Release |
| (vdswho) | External MOSFET Vds detection signal for W phase high side | Detection | Release |

Power/ground terminals

| Symbol | Pin Name | Description |
|--------|-------------|--|
| Vb | VB | Battery power supply input |
| Vcc | VCC | 5V/3.3V supply input |
| Vccop | VCC_OP | 5V/3.3V supply input for current sense amplifier |
| Vcph | VCPH | Charge pump voltage (high side) |
| AGND | AGND1,AGND2 | GND for analog circuits |
| PGND | PGND | Power GND |

7. FUNCTIONS AND FEATURES

7.1. Charge pump circuit

If V_{cph} for the pre-driver charge pump that drives the external MOSFET reaches $V_b + 14\text{ V}$ (Typ.), the charge pump will be shut down by the internal circuit controller.

The switching circuit (CP_SW) on the V_b side of the charge pump can switch the transistor off and shut off the supply from V_b to V_{cph} . When CP_SW switches the transistor off, the charge pump stops and the VCPH terminal output voltage becomes V_b . CP_SW also switches the transistor off when the VCC voltage falls below the VCC undervoltage detection threshold. It is also possible to make CP_SW switch the transistor off via the SPI. Meanwhile, the CP_CL current limiter circuit monitors current on the VB to VCPH supply line to prevent excess current.

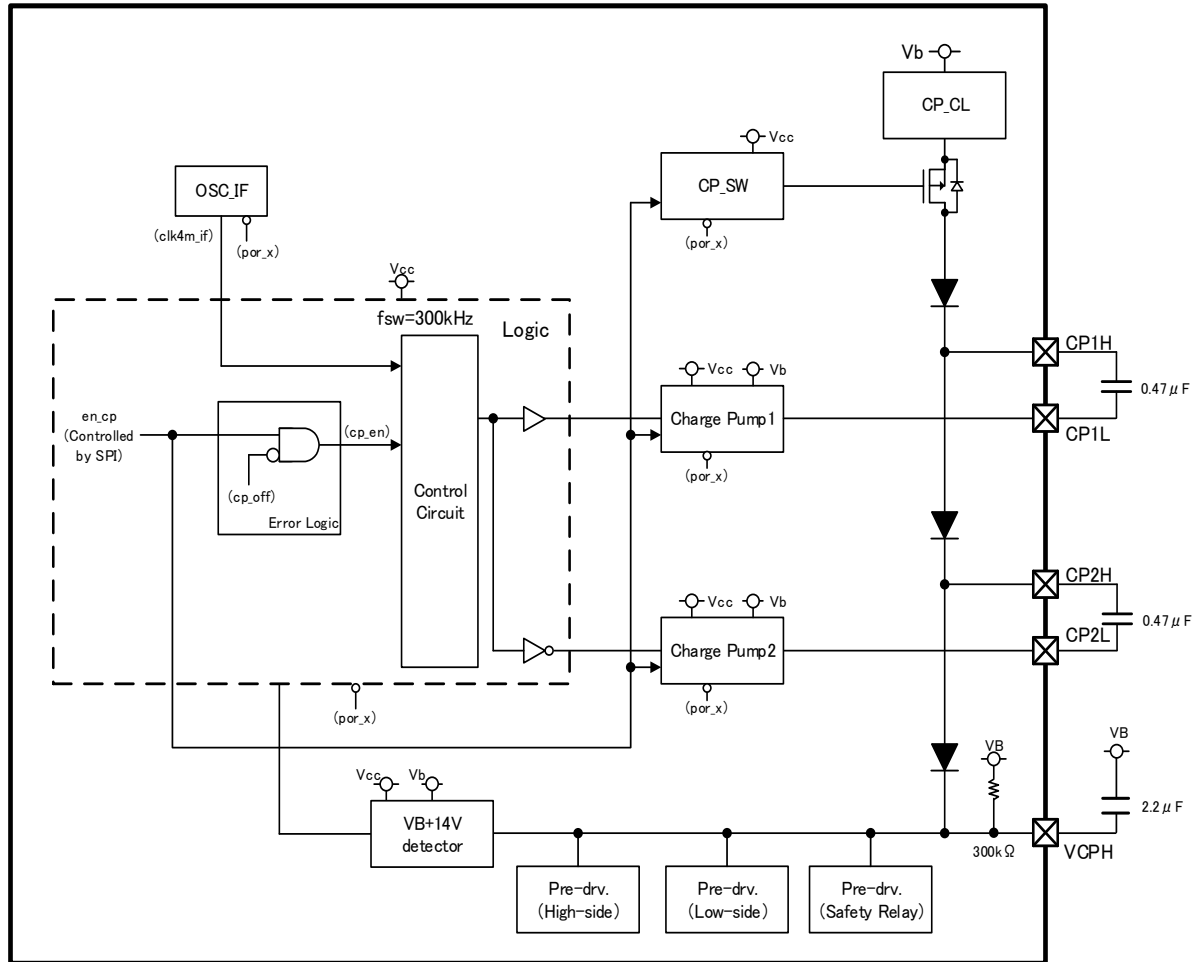


Fig. 7.1-a Block diagram for charge pump circuit

7.2. Pre-driver circuit

The pre-driver circuit consists of pre-drivers for high side, low side and power/motor safety relay drives.

High side and low side pre-drivers have separate input and output terminals and are controlled by signal at the input terminals.

The safety relay pre-driver is controlled by the [CP_RLY_CTRL](#) register. It has a built-in 500 Ω resistor and backflow prevention diode for reverse connection (see Figure 7.2-c). When a pull-down resistor is connected to the motor relay, there may be a voltage differential with the gate voltage. There is no restriction on external series resistance if safety relay outputs SR10, SR20 and/or SR30 are incorporated into the power supply relay.

A resistor for maintaining the HUS, HVS and HWS terminals at the median voltage is used only when performing an initial diagnosis as described in Section 7.8.

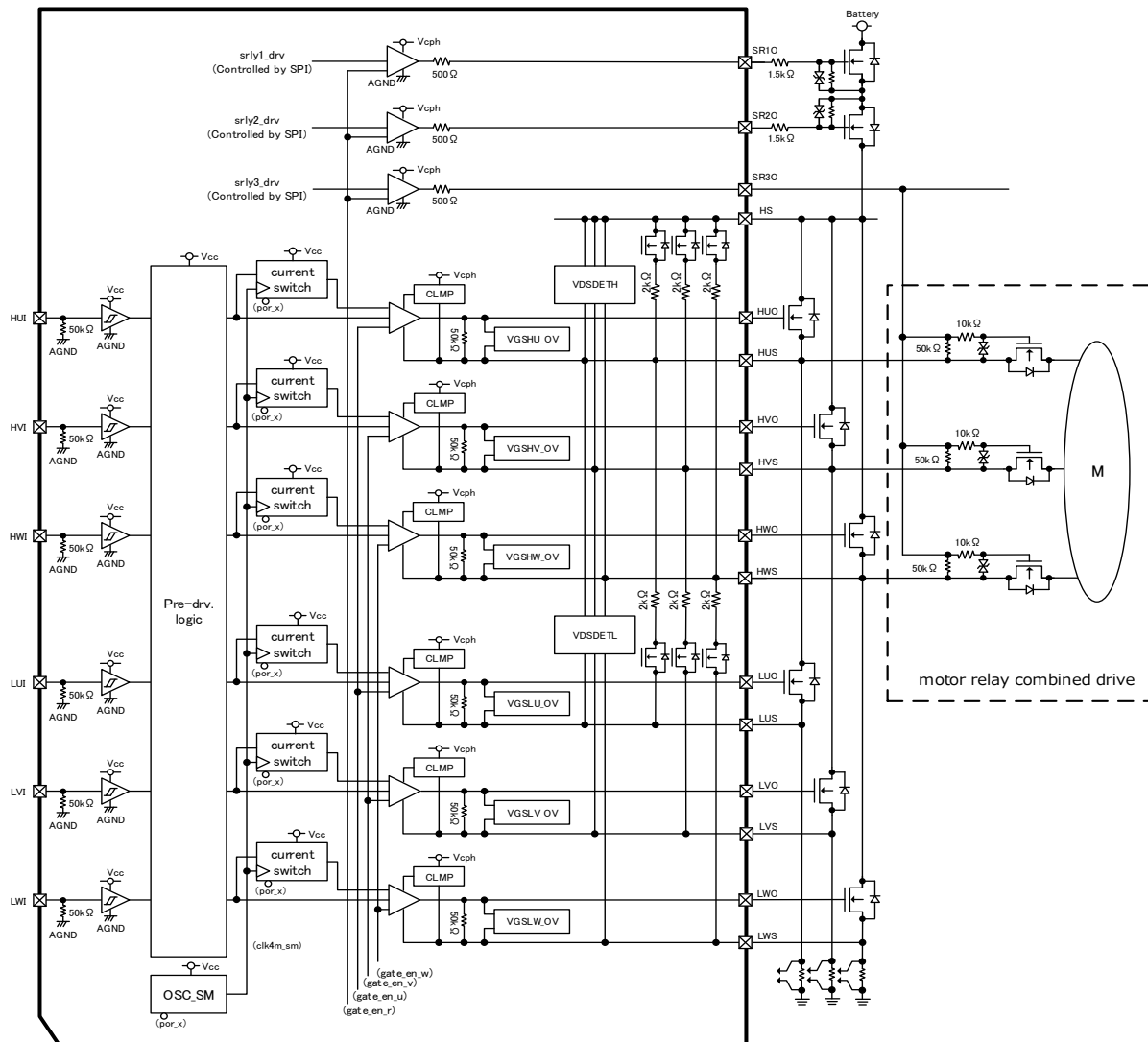


Fig. 7.2-a Block diagram for pre-driver circuit (motor relay combined drive)

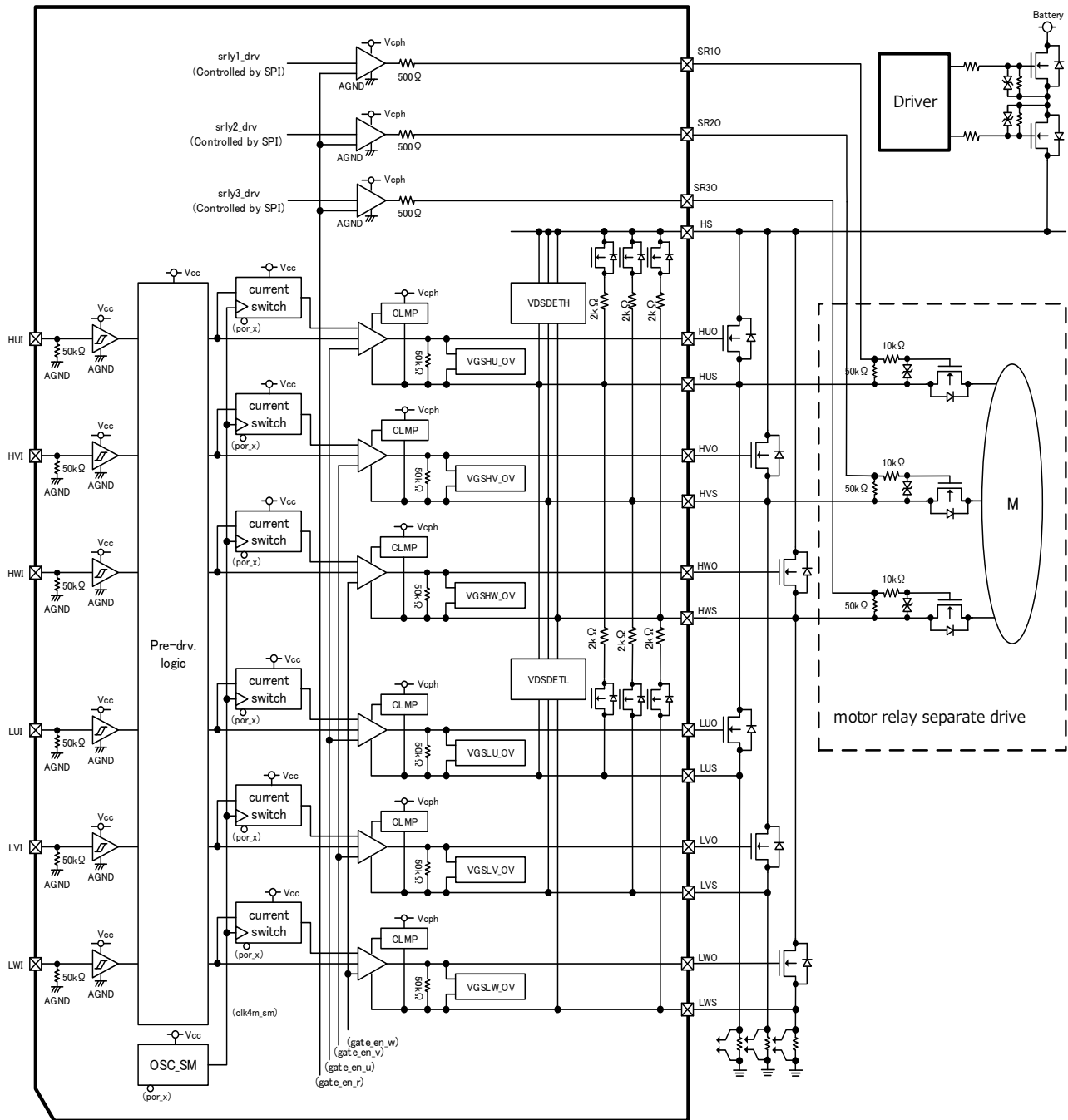


Fig. 7.2-b Block diagram for pre-driver circuit (motor relay separate drive)

Safety relay (power/motor relay) driver

The safety relay driver controls the power or motor relay. The safety relay pre-driver circuit is controlled via the [CP_RLY_CTRL](#) register. It has a built-in 500 Ω resistor and backflow prevention diode for reverse connection (see Figure 7.2-c).

Table 7.2-a shows the truth table. Refer to Section 7.6 for details of internal signals (gate_en_r) listed in the truth table.

Table 7.2-a I/O truth table for safety relay driver

• Power/motor relay driver 1 (SR10)

| Internal Signal | Input (SPI) | Output | Remark |
|-----------------|--------------------|--------|--------|
| (gate_en_r) | Register srly1_drv | SR10 | |
| "L" | * | "L" | - |
| "H" | "0" | "L" | - |
| | "1" | "H" | - |

• Power/motor relay driver 2 (SR20)

| Internal Signal | Input (SPI) | Output | Remark |
|-----------------|--------------------|--------|--------|
| (gate_en_r) | Register srly2_drv | SR20 | |
| "L" | * | "L" | - |
| "H" | "0" | "L" | - |
| | "1" | "H" | - |

• Power/motor relay driver 3 (SR30)

| Internal Signal | Input (SPI) | Output | Remark |
|-----------------|--------------------|--------|--------|
| (gate_en_r) | Register srly3_drv | SR30 | |
| "L" | * | "L" | - |
| "H" | "0" | "L" | - |
| | "1" | "H" | - |

*:Don't care

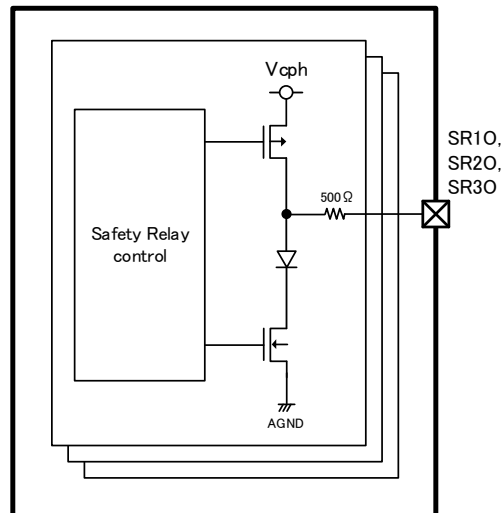


Fig. 7.2-c Block diagram for safety relay circuit

High side and low side drivers

The high side driver drives the MOSFET on the high side, while the low side driver drives the MOSFET on the low side. The high and low side drivers both have three built-in channels. Input signal (HUI/HVI/HWI, LUI/LVI/LWI) is converted to output signal (HUO/HVO/HWO, LUO/LVO/LWO) by the control block.

> Current limiter

Depending on the t_{lim} setting in the [T_ILIM](#) register, the high-side and / or low-side driver can limit the current (I_{o_lmth}/ I_{o_lmtl}) after a certain period from the on / off drive transition point. A register value of $t_{lim}="11"$ denotes no current limiting (the preset constant current); $t_{lim} = "00"$ to $"10"$ applies current limiting for the specified period.

> Inhibited input

Figure 7.2-b shows the truth table, using U phase as an example. The action for HUI=LUI="H" when the pre-driver is enabled ($gate_en_u="H"$) can be selected via the [PL_CTRL](#) register. Input prohibit mode is engaged when the plu_dis bit is "L," and the output is HUO=LUO="L." At this time, pl_op can be used to specify whether the status register is set to "H." When pl_op is "H," err_pl_u is set to "H." When pl_op is "L," err_pl_u is not set to "H." The DIAG terminal follows the status register. When plu_dis is "H," the prohibited input detector itself is disabled and HUO=LUO="H" output is possible. Refer to Section 7.6 for details of internal signals listed in the truth table ($gate_en_u$, $gate_en_v$, $gate_en_w$).

Table 7.2-b I/O truth table (high side and low side drivers)

•MOSFET driver 1 (U phase)

| Internal Signal (gate_en_u) | Input | | Register | | Output | | status | Remark |
|--------------------------------|-------|-----|----------|-------|--------|-----|----------|---------------------------------------|
| | HUI | LUI | plu_dis | pl_op | HUO | LUO | err_pl_u | |
| "L" | "L" | * | * | * | "L" | "L" | - | - |
| | * | "L" | * | * | | | - | - |
| | "H" | "H" | "L" | "L" | | | - | Inhibit input mode without status |
| | | | "L" | "H" | | | "set" | Inhibit input mode with status |
| | | | "H" | * | | | - | Inhibit input mode disabled (U phase) |
| "H" | "L" | "L" | * | * | "L" | "L" | - | - |
| | "L" | "H" | * | * | "L" | "H" | - | - |
| | "H" | "L" | * | * | "H" | "L" | - | - |
| | "H" | "H" | "L" | "L" | "L" | "L" | - | Inhibit input mode without status |
| | | | "L" | "H" | "L" | "L" | "set" | Inhibit input mode with status |
| | | | "H" | * | "H" | "H" | - | Inhibit input mode disabled (U phase) |

•MOSFET driver 2 (V phase)

| Internal Signal | Input | | Register | | Output | | status | | Remark |
|-----------------|-------------|-----|---------------------------------------|---------|---------------------------------------|-----|--------|-----------------------------------|--------|
| | (gate_en_v) | HVI | LVI | plv_dis | pl_op | HVO | LVO | err_pl_v | |
| "L" | "L" | * | * | * | "L" | "L" | - | - | |
| | * | "L" | * | * | | | - | - | |
| | "H" | "H" | "L" | "L" | | | - | Inhibit input mode without status | |
| | | | "L" | "H" | | | "set" | Inhibit input mode with status | |
| "H" | * | - | Inhibit input mode disabled (V phase) | | | | | | |
| "H" | "L" | "L" | * | * | "L" | "L" | - | - | |
| | "L" | "H" | * | * | "L" | "H" | - | - | |
| | "H" | "L" | * | * | "H" | "L" | - | - | |
| | "H" | "H" | "L" | "L" | "L" | "L" | - | Inhibit input mode without status | |
| | | | "L" | "H" | "L" | "L" | "set" | Inhibit input mode with status | |
| "H" | * | "H" | "H" | - | Inhibit input mode disabled (V phase) | | | | |

•MOSFET driver 3 (W phase)

| Internal Signal | Input | | Register | | Output | | status | | Remark |
|-----------------|-------------|-----|---------------------------------------|---------|---------------------------------------|-----|--------|-----------------------------------|--------|
| | (gate_en_w) | HWI | LWI | plw_dis | pl_op | HWO | LWO | err_pl_w | |
| "L" | "L" | * | * | * | "L" | "L" | - | - | |
| | * | "L" | * | * | | | - | - | |
| | "H" | "H" | "L" | "L" | | | - | Inhibit input mode without status | |
| | | | "L" | "H" | | | "set" | Inhibit input mode with status | |
| "H" | * | - | Inhibit input mode disabled (W phase) | | | | | | |
| "H" | "L" | "L" | * | * | "L" | "L" | - | - | |
| | "L" | "H" | * | * | "L" | "H" | - | - | |
| | "H" | "L" | * | * | "H" | "L" | - | - | |
| | "H" | "H" | "L" | "L" | "L" | "L" | - | Inhibit input mode without status | |
| | | | "L" | "H" | "L" | "L" | "set" | Inhibit input mode with status | |
| "H" | * | "H" | "H" | - | Inhibit input mode disabled (W phase) | | | | |

*:Don't care

Note: DIAG terminals are linked to status. Use the err_pl*_cl bit to clear the status.

7.3. Current detector circuit

7.3.1. Circuit structure

The current detector circuit has three motor current detector amps and a reference voltage generator amp (see Figures 7.3-a and 7.3-b). The motor current detector amps can amplify the difference voltage attributable to current in the shunt resistor connected to the motor drive. The reference voltage generator amp serves as a reference voltage generator buffer amp. The external composition of the current detector can be single or triple shunt.

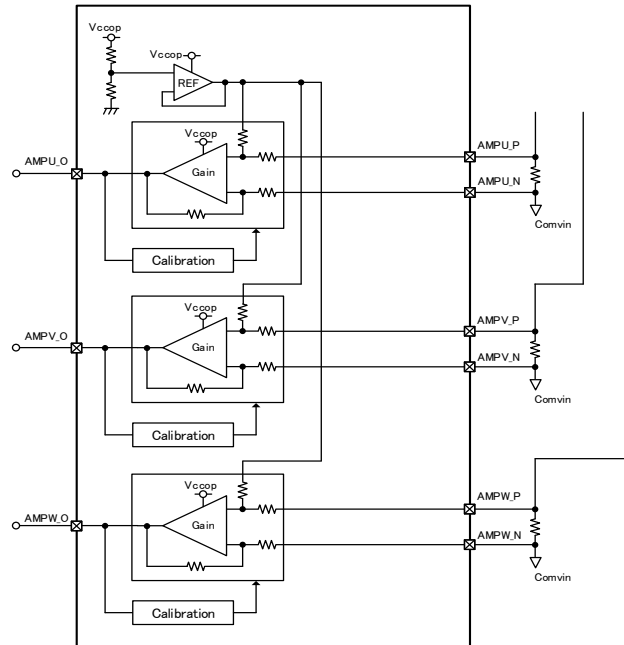


Fig. 7.3-a Block diagram for motor current detector circuit (triple shunt)

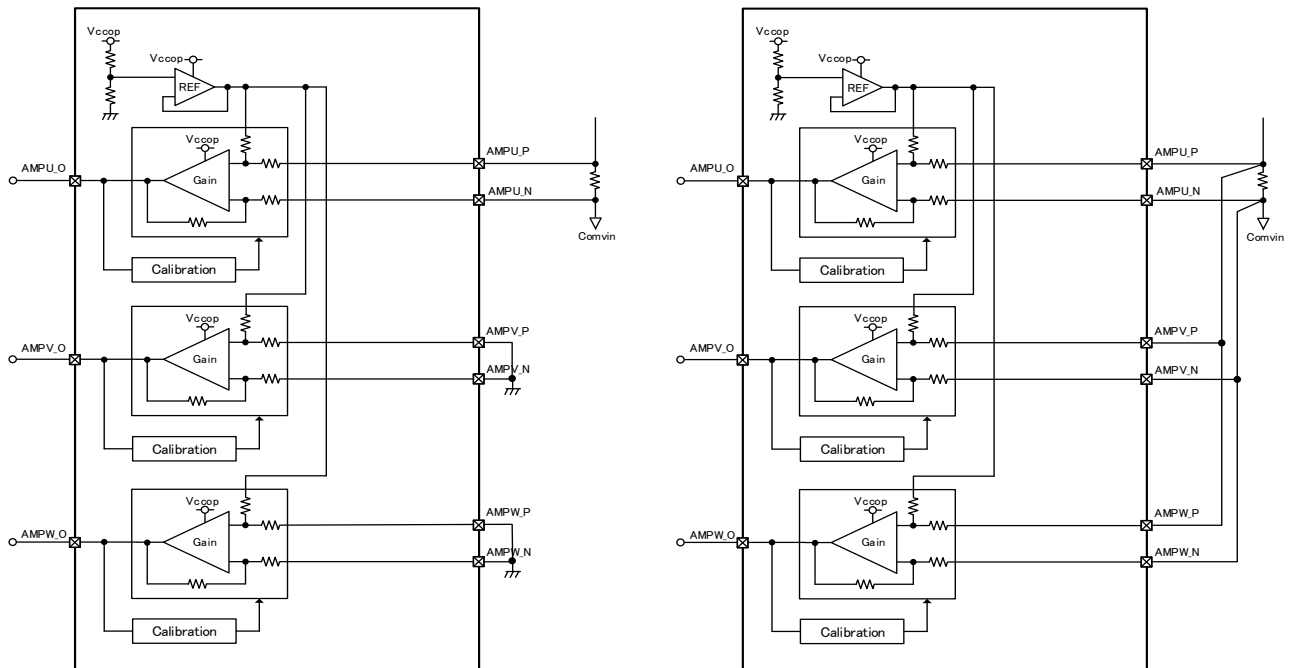


Fig. 7.3-b Block diagram for motor current detector circuit (single shunt)

7.3.2. Offset calibration

A cal_amp_* (where * denotes u, v or w) value of "1" in the [AMP_CTRL](#) register is used to perform offset calibration of the current detection amp. To ensure accurate calibration, the input difference voltage must be 0 V (equivalent potential). Figure 7.3-c shows the block diagram. Cal_amp_* initiates the offset calibration procedure and updates the [AMP_STAT](#) register cal_en to "H." For the duration of the procedure, GAIN_SEL is fixed at 5 h (equivalent to 30 x). The offset

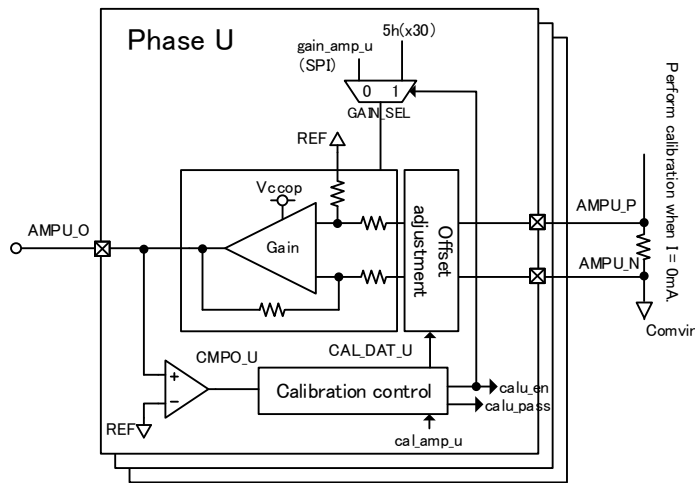


Fig. 7.3-c Block diagram for offset calibration

calibration value is determined by varying CAL_DAT_* and monitoring amp output against REF. When calibration is complete, cal_en changes to "L" and the calibration result is evaluated and then forwarded to cal*_pass. If cal*_pass is "H" the calibration result is retained as the adjustment value; if cal*_pass is "L" the result is discarded and the default (reset) value is restored.

Where multiple bits have been set simultaneously in cal_amp_* in the [AMP_CTRL](#) register, offset calibrations are performed simultaneously for the corresponding phases. When cal_en in the [AMP_STAT](#) register changes to "L" and

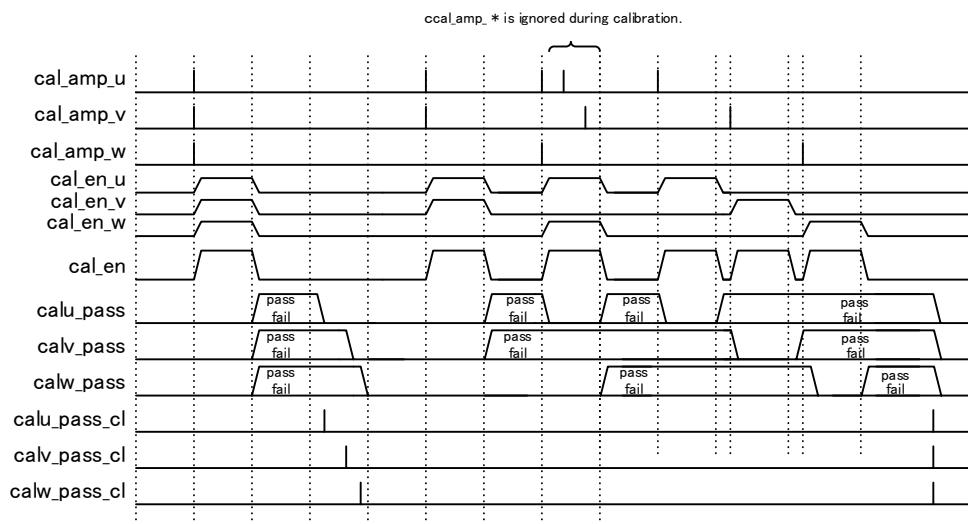


Fig. 7.3-d Offset calibration

calibration is complete, cal*_pass is registered. The status can be cleared at any time by writing "1" to the cal*_pass_cl bit in the [AMP_STAT_CLR](#) register. Note that cal*_pass automatically updates to "L" when calibration for the corresponding phase begins. During calibration, cal_en is "H" and cal_amp_* settings will be ignored.

7.4. Oscillator circuits

The TB9083FTG has two internal oscillator circuits: OSC_IF is used by the charge pump, and OSC_SM is used by the system clock, monitoring and SPI communication. Both oscillators have built-in CR and oscillate at 4 MHz (typ.). The oscillator circuits start up when the internal signal por_x is cancelled. The reference voltage source used for the two oscillators are independent of each other(BG1,BG2).

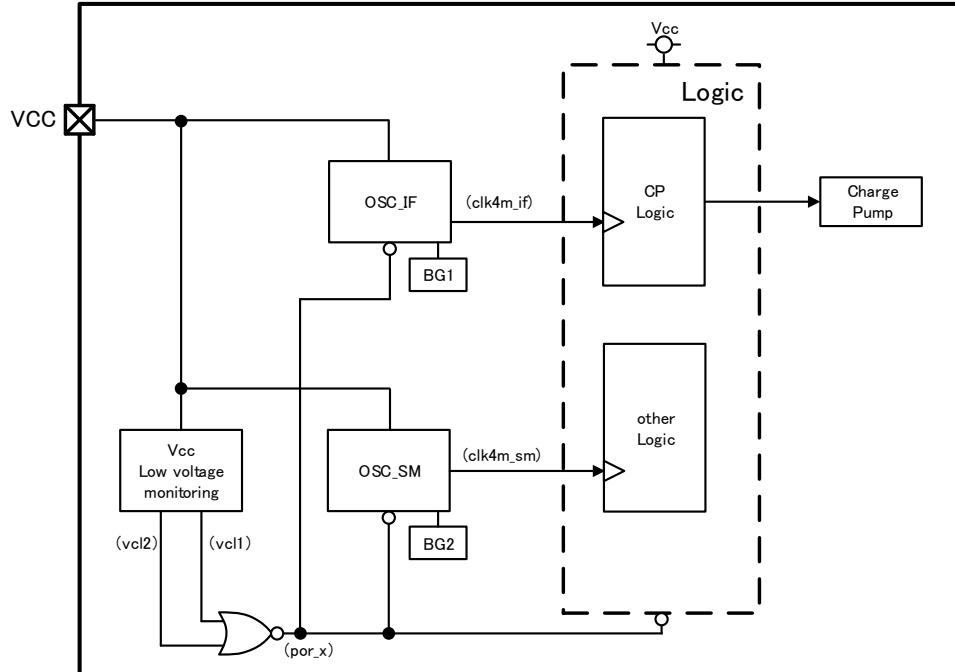


Fig. 7.4-a Oscillator block diagram

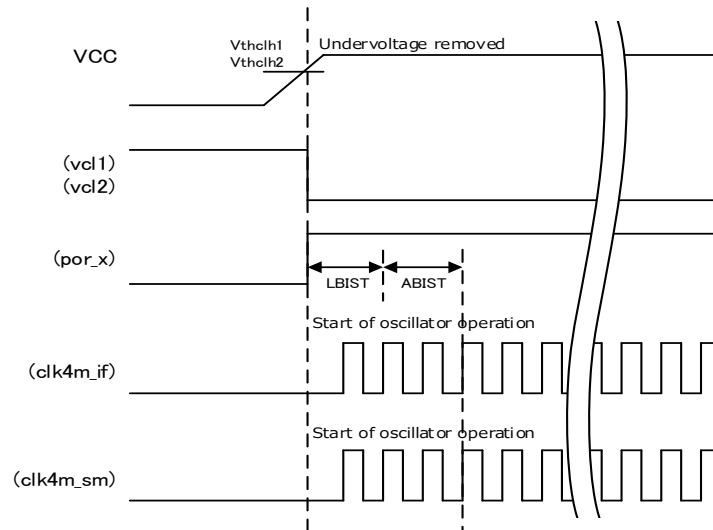


Fig. 7.4-b Oscillator circuit timing chart

7.5. Error detection circuits

The TB9083FTG has error detection circuits for undervoltage (VB, VCC, VCC_OP), overvoltage (VCPH, VCC, VCC_OP, external MOSFET VGS), overtemperature, external MOSFET VDS and abnormal frequency. For operational descriptions refer to Section 7.5.1 onwards. When an error is detected and the pre-driver circuit has been switched off, external MOSFET VDS detection is disabled. Once the error has been rectified and the pre-driver circuit is operational, the external MOSFET VDS detection is re-enabled.

Table 7.5-a Monitoring functions

| Monitoring features | Reg. setting | Bit setting | Operation in detection (Note4,5,6,7) | Initial state | BI S T (Note8) | Status Reg. (Note2) | Status Clear (Note1) | ND IAG (Note3) | |
|---|--------------|-------------|--|---------------|----------------|---------------------|----------------------|----------------|-----|
| VCC undervoltage1 VCC undervoltage 2 | — | — | All(9ch) pre-drivers: OFF, Charge pump: OFF, Oscillator: OFF | — | — | — | — | "L" | |
| VB undervoltage | uvb_op | "000" | All(9ch) pre-drivers: OFF | — | A | uvb | uvb_cl | "L" | |
| | | "001" | All(9ch) pre-drivers: OFF | X | | | — | "L" | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | — | "H" | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | uvb_cl | "L" | |
| | | "100" | Motor (6ch) pre-driver: OFF | — | | | — | "L" | |
| | | "101" | Motor (6ch) pre-driver: OFF | — | | | — | "H" | |
| VCPH overvoltage | ocph_op | "000" | Detection disabled | X | A | ocph | — | — | "H" |
| | | "001" | Continued operation | — | | | ocph_cl | "L" | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "101" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| VCC overvoltage | ovc_op | "000" | Detection disabled | — | A | ovcc | — | — | "H" |
| | | "001" | Continued operation | — | | | ovcc_cl | "L" | |
| | | "010" | All(9ch) pre-drivers: OFF | X | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "101" | All(9ch) pre-drivers: OFF (hold), Charge pump: OFF (hold) | — | | | | | |
| VCC_OP undervoltage | uvccop_op | "000" | Detection disabled | X | A | uvccop | — | — | "H" |
| | | "001" | Continued operation | — | | | uvccop_cl | "L" | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "101" | All(9ch) pre-drivers: "L"(hold), Charge pump: OFF (hold) | — | | | | | |
| VCC_OP overvoltage | ovccop_op | "000" | Detection disabled | X | A | ovccop | — | — | "H" |
| | | "001" | Continued operation | — | | | ovccop_cl | "L" | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "101" | All(9ch) pre-drivers: "L"(hold), Charge pump: OFF (hold) | — | | | | | |

| | | | | | | | | | |
|-------------------------------------|----------|--------|---|---|---|---------|--|--|-----|
| Over temperature | tsd_op | "000" | Detection disabled | — | A | — | — | "H" | |
| | | "001" | Continued operation | — | | | | | |
| | | "010" | All(9ch) pre-drivers: OFF | X | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF Charge pump: OFF | — | | tsd | tsd_cl | "L" | |
| | | "101" | All(9ch) pre-drivers: OFF (hold) Charge pump: OFF (hold) | — | | | | | |
| ALARM | alr_op | "0" | All(9ch) pre-drivers: OFF | X | — | alm_det | — | "L" | |
| | | "1" | Motor (6ch) pre-driver: OFF | — | | | | | |
| External MOSFET Vds (high side) | vdsh_op | "0000" | Detection disabled | — | | — | — | "H" | |
| | | "0001" | Continued operation | — | | | | | |
| | | "0010" | Detected phase pre-driver: OFF | — | | | | | |
| | | "0011" | Detected phase pre-driver: OFF(hold) | — | | | | | |
| | | "0100" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "0101" | All(9ch) pre-drivers: OFF(hold) | — | | | | | |
| | | "0110" | Motor (6ch) pre-driver: OFF | | | | | | |
| | | "0111" | Motor (6ch) pre-driver: OFF(hold) | X | | | vds_uh vds_vh vds_wh | vds_uh_cl vds_vh_cl vds_wh_cl | "L" |
| | | "1000" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "1001" | All(9ch) pre-drivers: OFF(hold), Charge pump: OFF (hold) | — | | | | | |
| External MOSFET Vds (low side) | vds_l_op | "0000" | Detection disabled | — | | — | — | "H" | |
| | | "0001" | Continued operation | — | | | | | |
| | | "0010" | Detected phase pre-driver: OFF | — | | | | | |
| | | "0011" | Detected phase pre-driver: OFF(hold) | — | | | | | |
| | | "0100" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "0101" | All(9ch) pre-drivers: OFF(hold) | — | | | | | |
| | | "0110" | Motor (6ch) pre-driver: OFF | | | | | | |
| | | "0111" | Motor (6ch) pre-driver: OFF(hold) | X | | | vds_ul vds_vl vds_wl | vds_ul_cl vds_vl_cl vds_wl_cl | "L" |
| | | "1000" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | | | | |
| | | "1001" | All(9ch) pre-drivers: OFF(hold), Charge pump: OFF (hold) | — | | | | | |
| external MOSFET Vgs overvoltage | vgs_op | "000" | Detection disabled | — | | — | — | "H" | |
| | | "001" | Continued operation | — | | | | | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | A | vgs_uh vgs_ul vgs_vh vgs_vl vgs_wh vgs_wl | vgs_uh_cl vgs_ul_cl vgs_vh_cl vgs_vl_cl vgs_wh_cl vgs_wl_cl | "L" |
| | | "101" | All(9ch) pre-drivers: OFF(hold), Charge pump: OFF (hold) | X | | | | | |
| Abnormalities in frequency (Note 9) | ferr_op | "000" | Detection disabled | ○ | | — | — | "H" | |
| | | "001" | Continued operation | — | | | | | |
| | | "010" | All(9ch) pre-drivers: OFF | — | | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | | |
| | | "100" | All(9ch) pre-drivers: OFF, Charge pump: OFF | — | | L | err_of err_uf | err_of_cl err_uf_cl | "L" |
| | | "101" | All(9ch) pre-drivers: OFF(hold), Charge pump: OFF (hold) | — | | | | | |
| Pre-driver | pl_op | "0" | Detected phase pre-driver: OFF | ○ | — | — | — | "H" | |

| | | | | | | | | |
|-------------------------|--------|-------|--|---|---|----------------------------------|---|-----|
| Inhibition input | | "1" | Detected phase pre-driver: OFF | — | | err_pl_u err_pl_v err_pl_w | err_pl_u_cl err_pl_v_cl err_pl_w_cl | "L" |
| SPI communication error | — | — | Detection disabled | — | — | err_spi | err_spi_cl | "L" |
| QA calculation | qat_op | "001" | Continued operation | ○ | L | err_qac | err_qac_cl | "L" |
| | | "010" | All(9ch) pre-drivers: OFF(hold) | — | | | | |
| | | "011" | Motor (6ch) pre-driver: OFF | — | | | | |
| | | "100" | All(9ch) pre-drivers: OFF(hold), Charge pump: OFF (hold) | — | | | | |

Notes

- In settings modes where the status clear bit is shown in the Status Clear column, once a status bit has been set by the error detection function, it will be retained until cleared by writing "1" to the corresponding status clear bit. A retained status register cannot be cleared while the error detection circuit is still showing an error. In operation modes that do not have a status clear bit in the Status Clear column, the status bit is cleared when error detection is resolved.
- A dash in the Status Reg column indicates that no value is set in the status register for that operating mode.
- "H" in the NDIAG column means that the NDIAG terminal does not change to "L" when an error is detected. "L" in the NDIAG column means that the NDIAG terminal will be the same as the status register (with the exception of VCC undervoltage detection). NDIAG output is "L" while the status register is retained, but reverts to "H" when all status registers are cleared. In operating modes where the status register is not retained, NDIAG reverts to "H" when error detection is cleared, irrespective of whether the status register has been cleared.
- "(Retained)" in the Response to Detection column means that the response is dictated by the retained status register. To revert to the standard response, the status register needs to be cleared. Where "(Retained)" does not appear, this means that the normal response will be restored once error detection is cleared, without needing to clear the status register.
- The value ****_op in the settings register for a monitoring function can be modified at any time; however, ****_op has no effect on actual operations while the corresponding status register is indicating that an error has been detected.
- "Charge pump off" means the CP_SW is off and the CP driver stopped.
- "All (9ch) pre-drivers:OFF", the pre-driver is driven to "L" so that the external FET including the safety relay is turned off. "Motor (6ch) pre-drivers:OFF" drives the pre-driver to "L" so that the external FET except the safety relay is turned off. "Detected phase pre-driver : OFF", the pre-driver is driven to "L" to turn off the high-side and low-side FET of the phase where the abnormality is detected.
- A = ABIST, L = LBIST
- If the OSC_SM clock is lost, the detection response can still be executed but NDIAG will not change to "L."

7.5.1. VCC undervoltage detection 1 and 2

This circuit has two built-in comparators for detecting low VCC voltage; an "H" value from either of the comparators indicates undervoltage. The band gap voltages used as the baseline reference by the comparators are generated by band gap circuits BG1 and BG2.

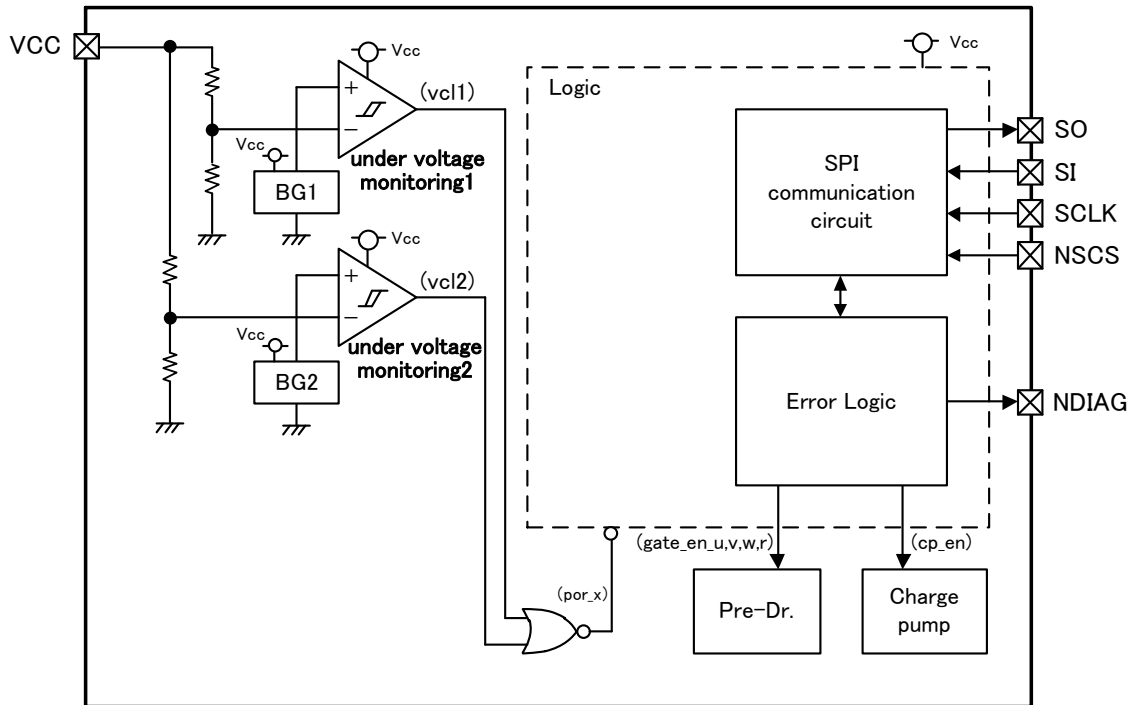


Fig. 7.5.1-a Block diagram for VCC undervoltage detector

> (1) VCC voltage drops

VCC voltage drops below the undervoltage V_{thcll1}/V_{thcll2} .

> (2) VCC undervoltage detected

After the response time T_{cl} , VCC undervoltage signal (vcl1), (vcl2) "H" denotes undervoltage detection, (por_x) changes to "L" and NDIAG output is "L." The motor drive (6 ch) pre-driver, safety relay (3 ch) pre-driver, charge pump and oscillator circuits all switch off and remain off until the undervoltage is cancelled.

> (3) VCC voltage restored (undervoltage cancelled)

When VCC voltage is greater than V_{thclh1}/V_{thclh2} , VCC undervoltage signal (vcl1), (vcl2) changes to "L" and undervoltage is cancelled.

> (4) Normal operation resumes

If a BIST diagnosis of OK is returned after LBIST/ABIST execution, normal operation resumes. The charge pump circuit starts operating and the pre-driver circuits are re-enabled. If an NG diagnosis is returned, the charge pump and pre-driver circuits will not operate. NDIAG output is "H" for an OK diagnosis and "L" for a NG diagnosis. (See Section 7.7 for details.)

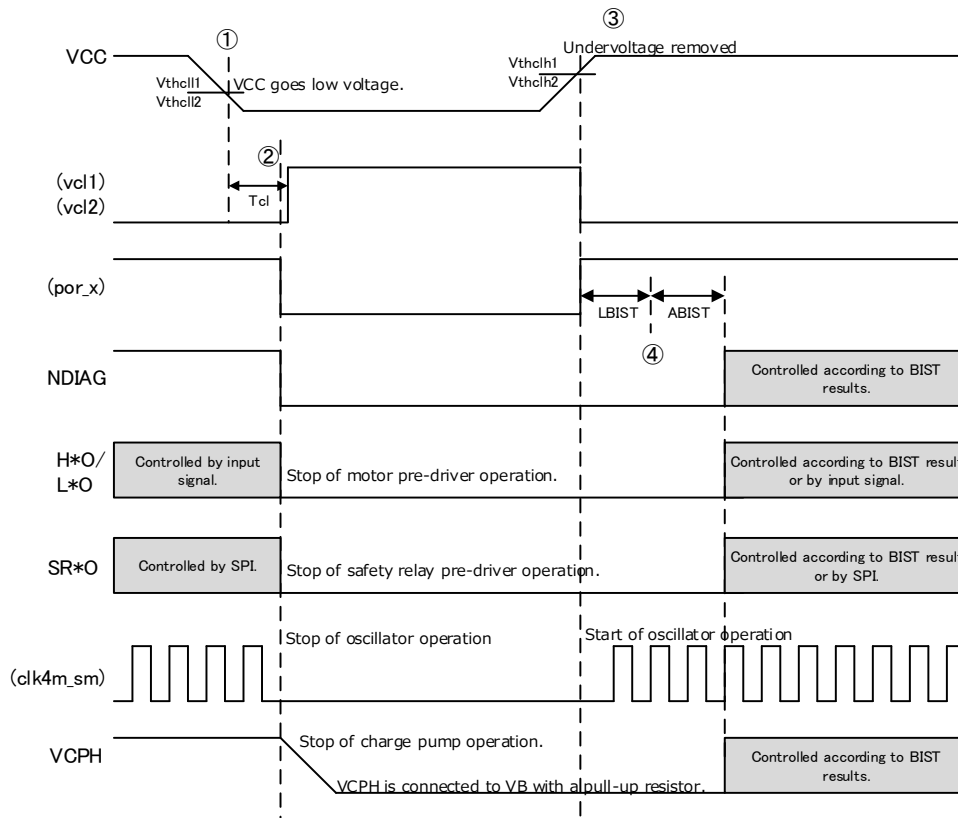


Fig. 7.5.1-b Timing chart for VCC undervoltage detection

Note: If the Vcc voltage falls further below the undervoltage threshold, standby mode will be engaged, whereby all functions other than Vcc undervoltage detection are switched off.

7.5.2. VB undervoltage detection

This circuit comprises a comparator and a filter for detecting VB undervoltage; filter output of "H" indicates undervoltage. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

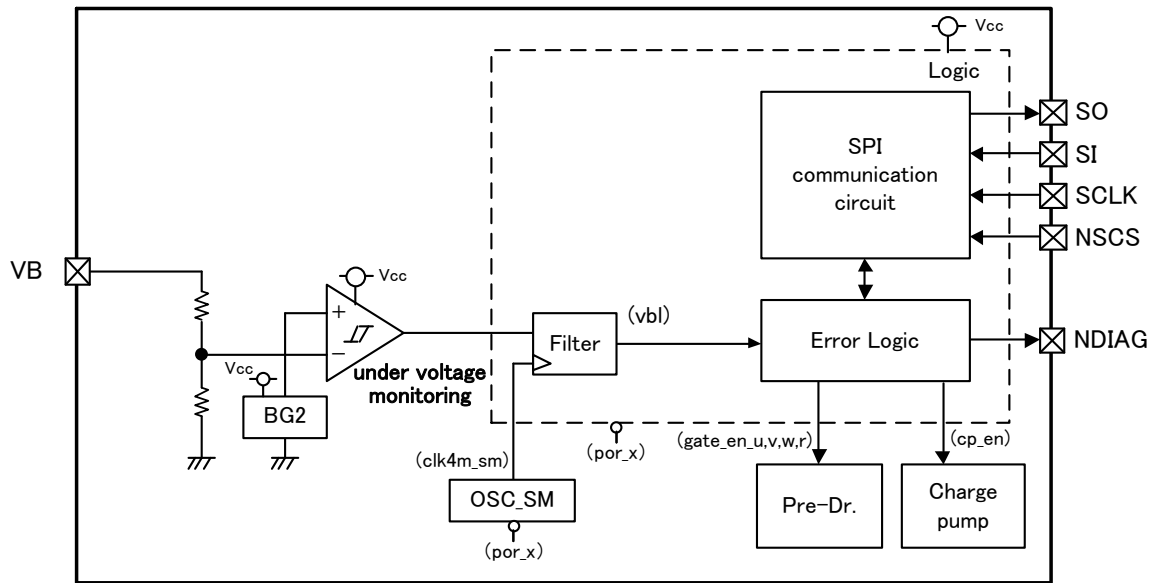


Fig. 7.5.2-a Block diagram for VB undervoltage detection

> (1) VB voltage drops

VB voltage drops below the undervoltage threshold V_{thbl} . Vb L detection comparator outputs H.

> (2) VB undervoltage detected

After the detection filter time T_{bl} has elapsed, VB undervoltage signal (vbl) "H" indicating undervoltage is generated, and all (9 ch) pre-driver circuits including safety relay switch off, as well as the motor drive (6 ch) pre-driver circuit. Note that the oscillator and charge pump circuits do not switch off. Pre-driver circuits remain off until undervoltage is cancelled.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during VB undervoltage, settings will not be enabled until the undervoltage is cancelled and the uvb register is cleared.

> (3) VB voltage restored (undervoltage cancelled)

Once the VB voltage exceeds V_{thbh} , the VB undervoltage signal (vbl) changes to "L," undervoltage is cancelled and normal operation resumes.

If NDIAG output is "L," clear the uvb register via the SPI to change it back to "H."

During an undervoltage, uvb register cannot be cleared and NDIAG output is "L."

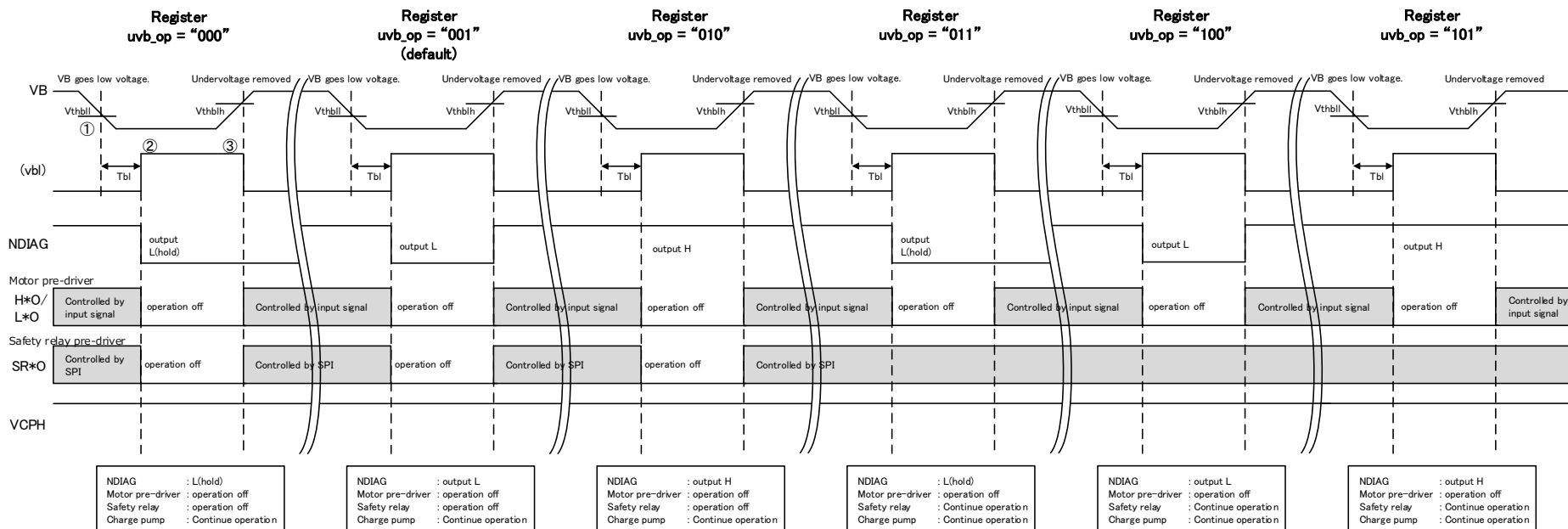


Fig. 7.5.2-b Timing chart for VB undervoltage detection

7.5.3. VCPH overvoltage detection

This circuit comprises a comparator and a filter; filter output of "H" indicates overvoltage. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

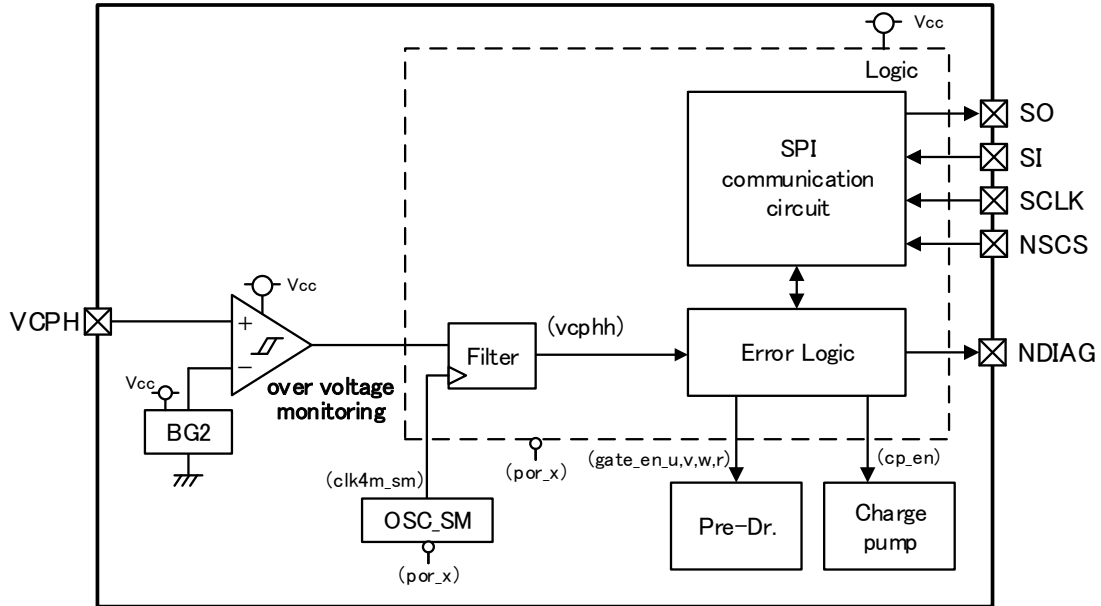


Fig. 7.5.3-a Block diagram for VCPH overvoltage

> ① VCPH voltage rises

VCPH voltage exceeds the overvoltage threshold V_{thcphh} . VCPH H detection comparator outputs "H."

> ② VCPH overvoltage detected

After the filter time T_{cphh} has elapsed, VCPH overvoltage signal (vcphh) "H" indicating overvoltage is generated and NDIAG output is "L," except where the register *ocph_op* is "000," in which case NDIAG output remains at "H" and all circuits continue to operate as normal.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during VCPH overvoltage, settings will not be enabled until the overvoltage is cancelled and the *ocph* register is cleared.

> ③ VCPH voltage restored (overvoltage cancelled)

Once the VCPH voltage drops below V_{thcphl} , the VCPH overvoltage signal (vcphh) changes to "L" and the overvoltage is cancelled.

When register *ocph_op* is "101," the charge pump and pre-drivers remain off after the overvoltage is cancelled and NDIAG remains at "L."

When register *ocph_op* is "001," "010," "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

When register *ocph* is cleared via SPI, NDIAG changes to "H."

During an overvoltage, register *ocph* cannot be cleared and NDIAG output is "L."

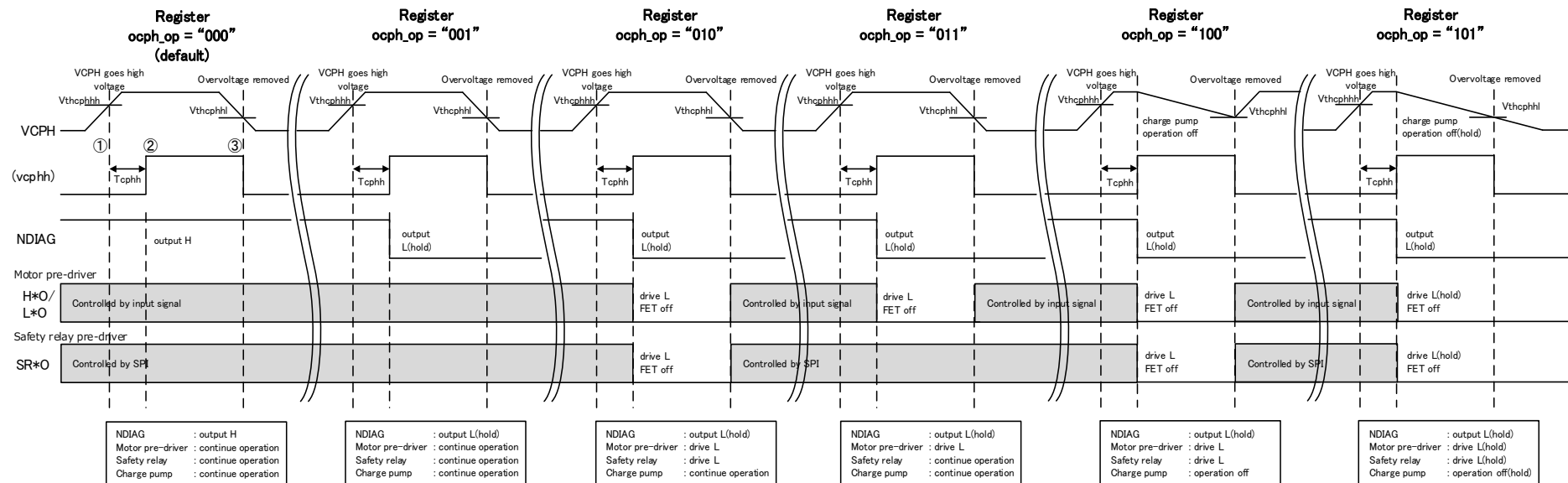


Fig. 7.5.3-b Timing chart for VCPH overvoltage

7.5.4. VCC overvoltage detection

This circuit comprises a comparator and a filter; filter output of "H" indicates overvoltage. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

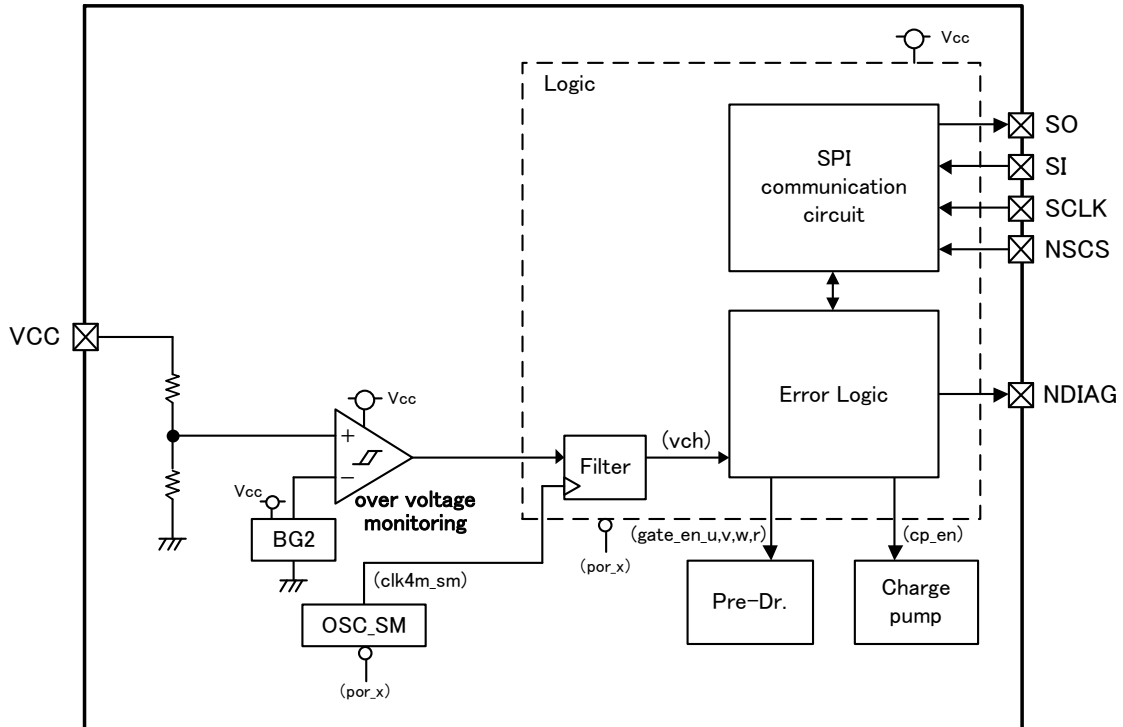


Fig. 7.5.4-a Block diagram for VCC overvoltage detection

> ① VCC voltage rises

VCC voltage exceeds the overvoltage threshold V_{thchh} . VCC H detection comparator outputs "H."

> ② VCC overvoltage detected

After the filter time T_{ch} has elapsed, VCC overvoltage signal (vch) "H" indicating overvoltage is generated and NDIAG output is "L," except where the register `ovc_op` is "000," in which case NDIAG output remains at "H" and all circuits continue to operate as normal.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during VCC overvoltage, settings will not be enabled until the overvoltage is cancelled and the `ovc` register is cleared.

> ③ VCC voltage restored (overvoltage cancelled)

Once the VCC voltage drops below V_{thchl} , the VCC overvoltage signal (vch) changes to "L" and the overvoltage is cancelled.

When register `ovc_op` is "101," the charge pump and pre-drivers remain off after the overvoltage is cancelled and NDIAG remains at "L."

When register `ovc_op` is "001," "010," "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

When register `ovc` is cleared via the SPI, NDIAG changes to "H."

During an overvoltage, register `ovc` cannot be cleared and NDIAG output is "L."

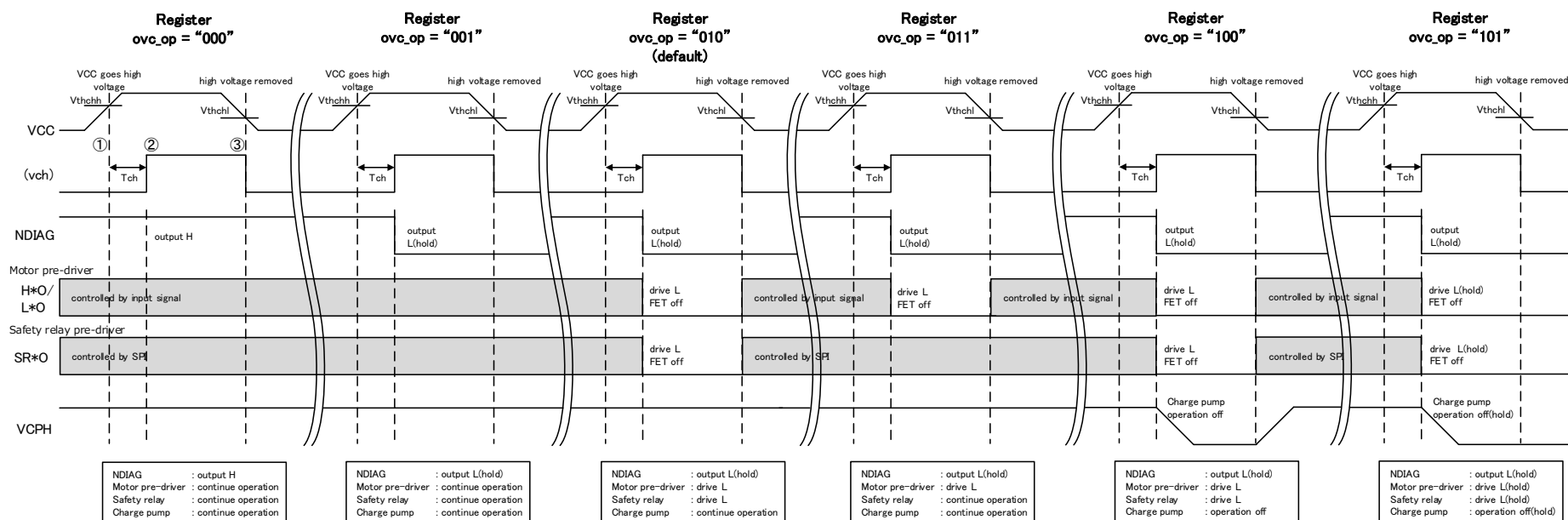


Fig. 7.5.4-b Timing chart for VCC overvoltage detection

7.5.5. VCC_OP undervoltage detection

This circuit comprises a comparator and a filter; filter output of "H" indicates undervoltage. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

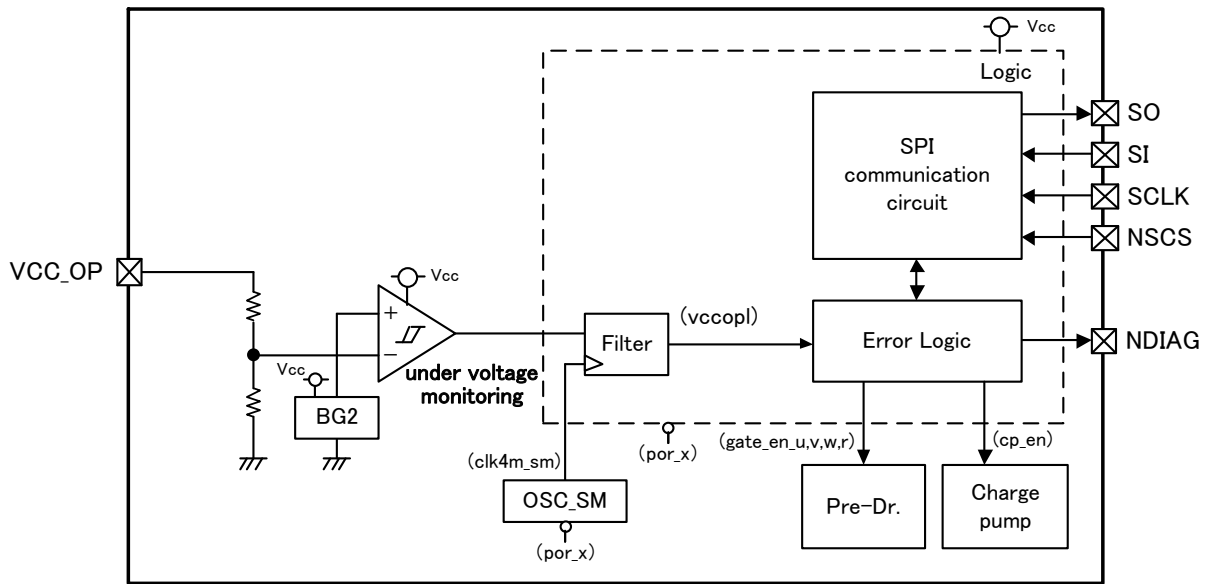


Fig. 7.5.5-a Block diagram for VCC_OP undervoltage detection

➤ ① VCC_OP voltage drops

VCC_OP voltage drops below the undervoltage threshold $V_{thccopl}$. VCC_OP L detection comparator outputs "H."

➤ ② VCC_OP undervoltage detected

After the detection filter time T_{ccopl} has elapsed, VCC_OP undervoltage signal (vccopl) "H" indicating undervoltage is generated and NDIAG becomes "L," except where the register uvccop_op is "000," in which case NDIAG output remains at "H" and all circuits continue to operate as normal.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during VCC_OP undervoltage, settings will not be enabled until the undervoltage is cancelled and the uvccop_op register is cleared.

➤ ③ VCC_OP voltage restored (undervoltage cancelled)

Once the VCC_OP voltage rises above $V_{thccopl}$, the VCC_OP undervoltage signal (vccopl) changes to "L" and the undervoltage is cancelled.

When register uvccop_op is "101," the charge pump and pre-drivers remain off after the overvoltage is cancelled and NDIAG remains at "L."

When register uvccop_op is "001," "010," "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

When register uvccop is cleared via the SPI, NDIAG changes to "H."

During an overvoltage, register uvccop cannot be cleared and NDIAG output is "L."

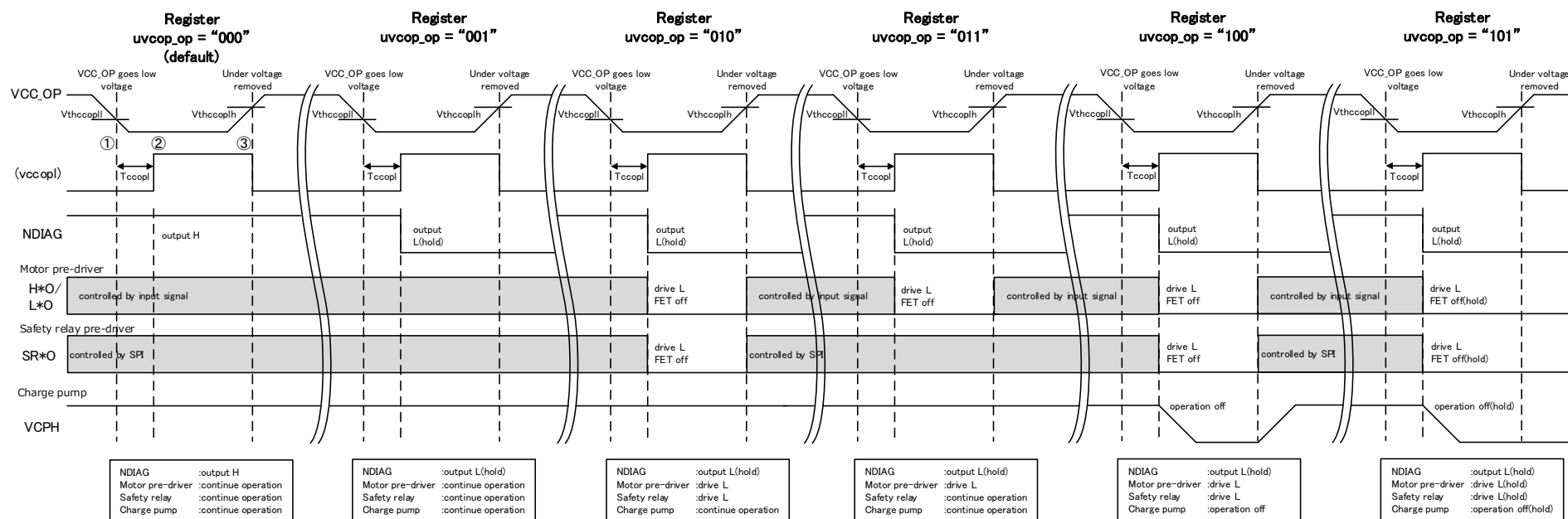


Fig. 7.5-5-b Timing chart for VCC_OP undervoltage detection

7.5.6. VCC_OP overvoltage detection

This circuit comprises a comparator and a filter; filter output of "H" indicates overvoltage. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

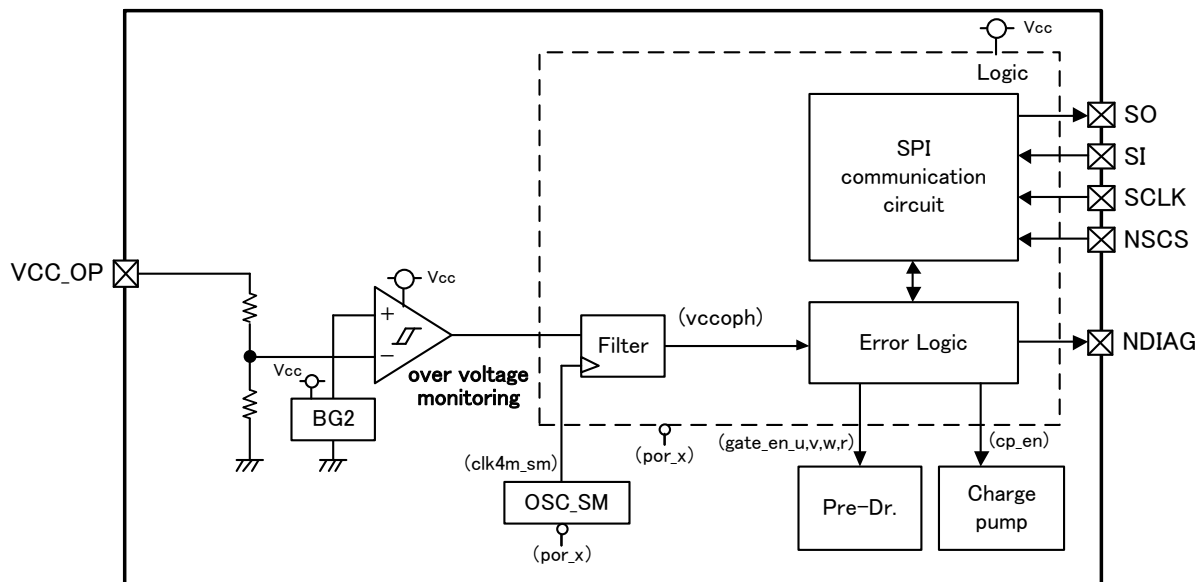


Fig. 7.5.6-a Block diagram for VCC_OP overvoltage detection

➤ ① VCC_OP voltage rises

VCC_OP voltage exceeds the overvoltage threshold $V_{thccoph}$. VCC_OP H detection comparator outputs "H."

➤ ② VCC_OP overvoltage detected

After the filter time T_{ccoph} has elapsed, VCC_OP overvoltage signal (vccoph) "H" indicating overvoltage is generated and NDIAG output is "L," except where the register ovcop_op is "000," in which case NDIAG output remains at "H" and all circuits continue to operate as normal.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during VCC_OP overvoltage, settings will not be enabled until the overvoltage is cancelled and the ovccop register is cleared.

➤ ③ VCC_OP voltage restored (overvoltage cancelled)

Once the VCC_OP voltage drops below $V_{thccopl}$, the VCC_OP overvoltage signal (vccoph) changes to "L" and the overvoltage is cancelled.

When register ovcop_op is "101," the charge pump and pre-drivers remain off after the overvoltage is cancelled and NDIAG remains at "L."

When register ovcop_op is "001", "010", "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

When register ovccop is cleared via the SPI, NDIAG changes to "H."

During an overvoltage, register ovccop cannot be cleared and NDIAG output is "L."

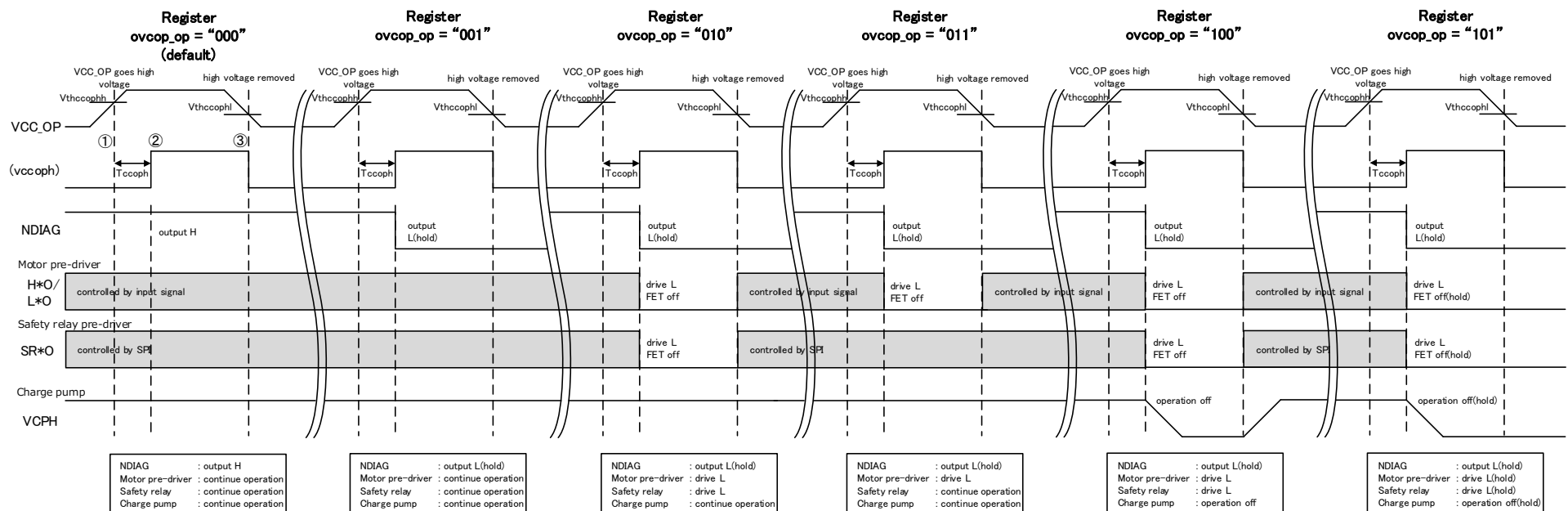


Fig. 7.5.6-b Timing chart for VCC_OP overvoltage detection

7.5.7. Overtemperature detection

The built-in overtemperature detector comprises a detection comparator and a filter; filter output of "H" indicates overtemperature. The band gap voltage used as the baseline reference by the comparator is generated by the band gap circuit BG2.

A chip temperature higher than T_{sdh} is deemed by the overtemperature detection comparator to be an overtemperature. When the internal temperature falls below T_{sdl} , the overtemperature is cancelled. At this point one of six operating modes can be selected via the SPI.

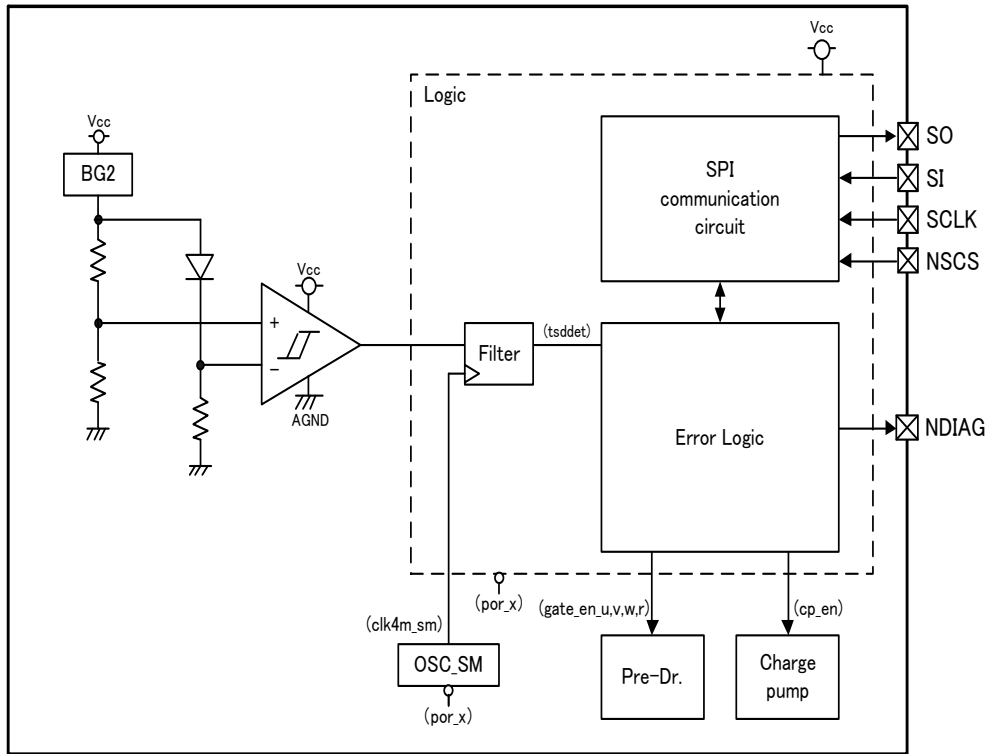


Fig. 7.5.7-a Overtemperature detection block diagram

➤ ① Overtemperature detected

If the temperature exceeds T_{sdh} then, after the detection filter time T_{tsd} has elapsed, the overtemperature detected signal (tsddet) "H" is generated to indicate an overtemperature, and NDIAG changes to "L" except where register tsd_op is "000," in which case NDIAG remains at "H" and all circuits operate as normal.

At this point one of six operating modes can be selected via the SPI.

If the mode is changed during an overtemperature, settings will not be enabled until the overtemperature is cancelled and the tsd register is cleared.

➤ ② Overtemperature cancelled

Once the temperature drops below T_{sdl} the overtemperature detected signal (tsddet) changes to "L" and the overtemperature is cancelled.

When register tsd_op is "101," the charge pump and pre-drivers remain off after the overtemperature is cancelled and NDIAG remains at "L."

When register tsd_op is "001", "010", "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

If register tsd is cleared via the SPI, NDIAG changes to "H."

During an overtemperature, register tsd cannot be cleared and NDIAG output is "L."

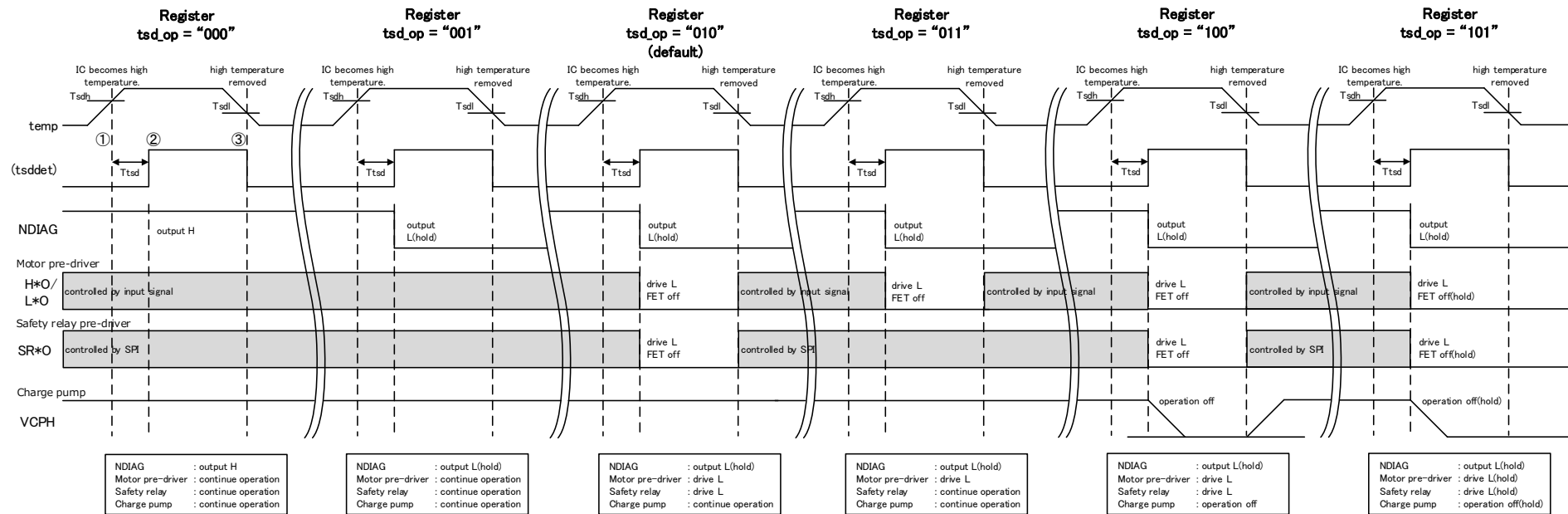


Fig. 7.5.7-b Timing chart for overtemperature detection

7.5.8. External MOSFET VDS detection

The external MOSFET drain and source terminals are monitored. The response to abnormal VDS is specified via the [FET OPSEL](#) register (see Table 7.5-a for details). Similarly, the threshold voltage (value 12) and detection period (value 4) can be modified via the [HS VDS SEL](#) and [LS VDS SEL](#) registers. The HUS, HVS and HWS terminals are equipped with internal pull-up and pull-down resistors, though these are normally off (refer to Section 7.8 for details). In a phase where a fault has been detected and pre-drivers are disabled, VDS detection is switched off; consequently, other VDS factors will not be latched. VDS detection can be disabled on individual channels via the [FET DET SEL](#) register.

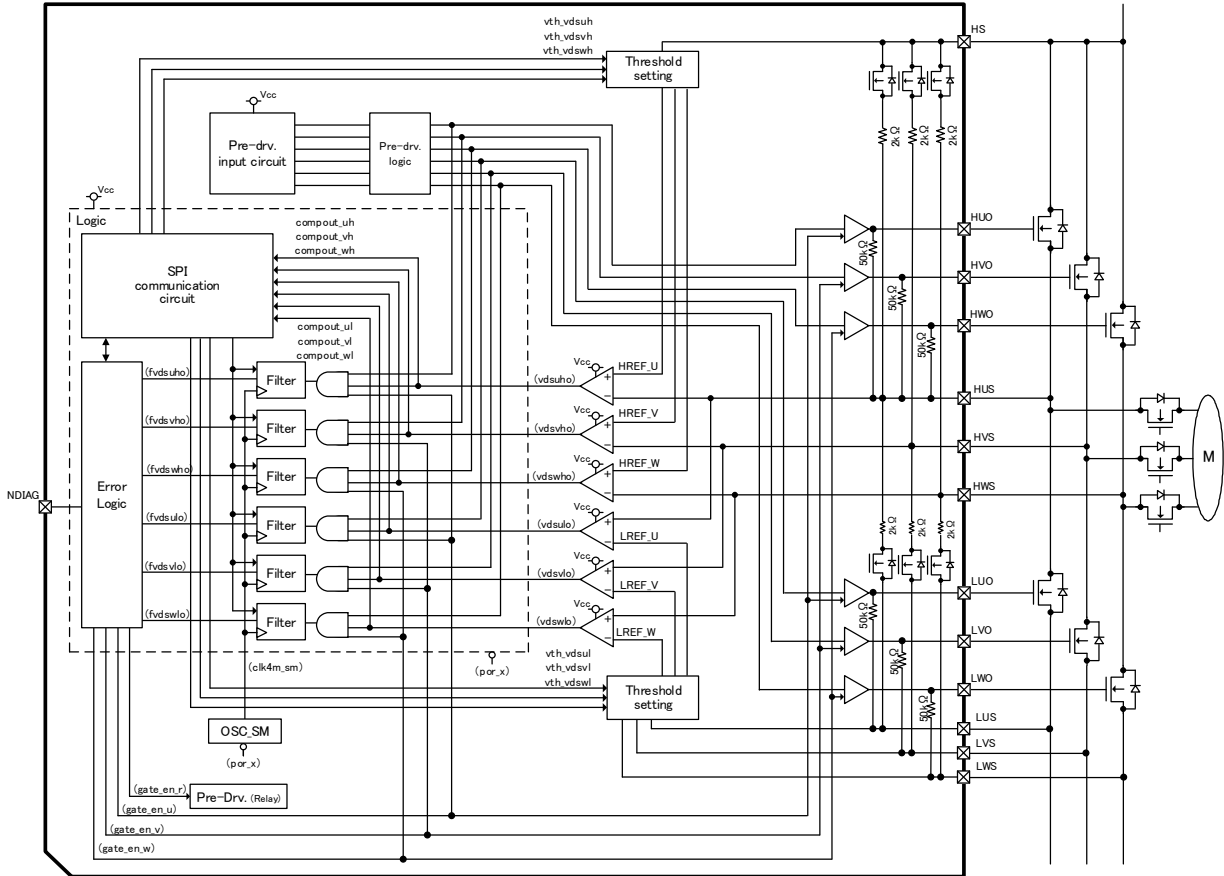


Fig. 7.5.8-a Block diagram for external MOSFET VDS detection

Table 7.5.8-a VDS detection scenarios

| Comparator output comparison | Comparator Output | Input Signal | Description |
|---------------------------------|-------------------|--------------|--|
| $V_{HUS}-V_{LUS} > V_{thvdsul}$ | (vdsulo) = "H" | LUI = "H" | VDS fault for low side U phase MOSFET |
| $V_{HVS}-V_{LVS} > V_{thvdsvl}$ | (vdsvlo) = "H" | LVI = "H" | VDS fault for low side V phase MOSFET |
| $V_{HWS}-V_{LWS} > V_{thvdswl}$ | (vdsvlo) = "H" | LWI = "H" | VDS fault for low side W phase MOSFET |
| $V_{HS}-V_{HUS} > V_{thvdsuh}$ | (vdsuho) = "H" | HUI = "H" | VDS fault for high side U phase MOSFET |
| $V_{HS}-V_{HVS} > V_{thvdsvh}$ | (vdsvho) = "H" | HVI = "H" | VDS fault for high side V phase MOSFET |
| $V_{HS}-V_{HWS} > V_{thvdswh}$ | (vdswho) = "H" | HWI = "H" | VDS fault for high side W phase MOSFET |

Note

- The high side threshold voltage for detection is defined by the voltage across HS-H*S at the IC terminal. This value should take into account the high side MOSFET drain-source voltage.
- The low side threshold voltage for detection is defined by the voltage across H*S-L*S at the IC terminal. This value should take into account the low side MOSFET drain-source voltage.
- Asterisks (*) denote U, V and W.

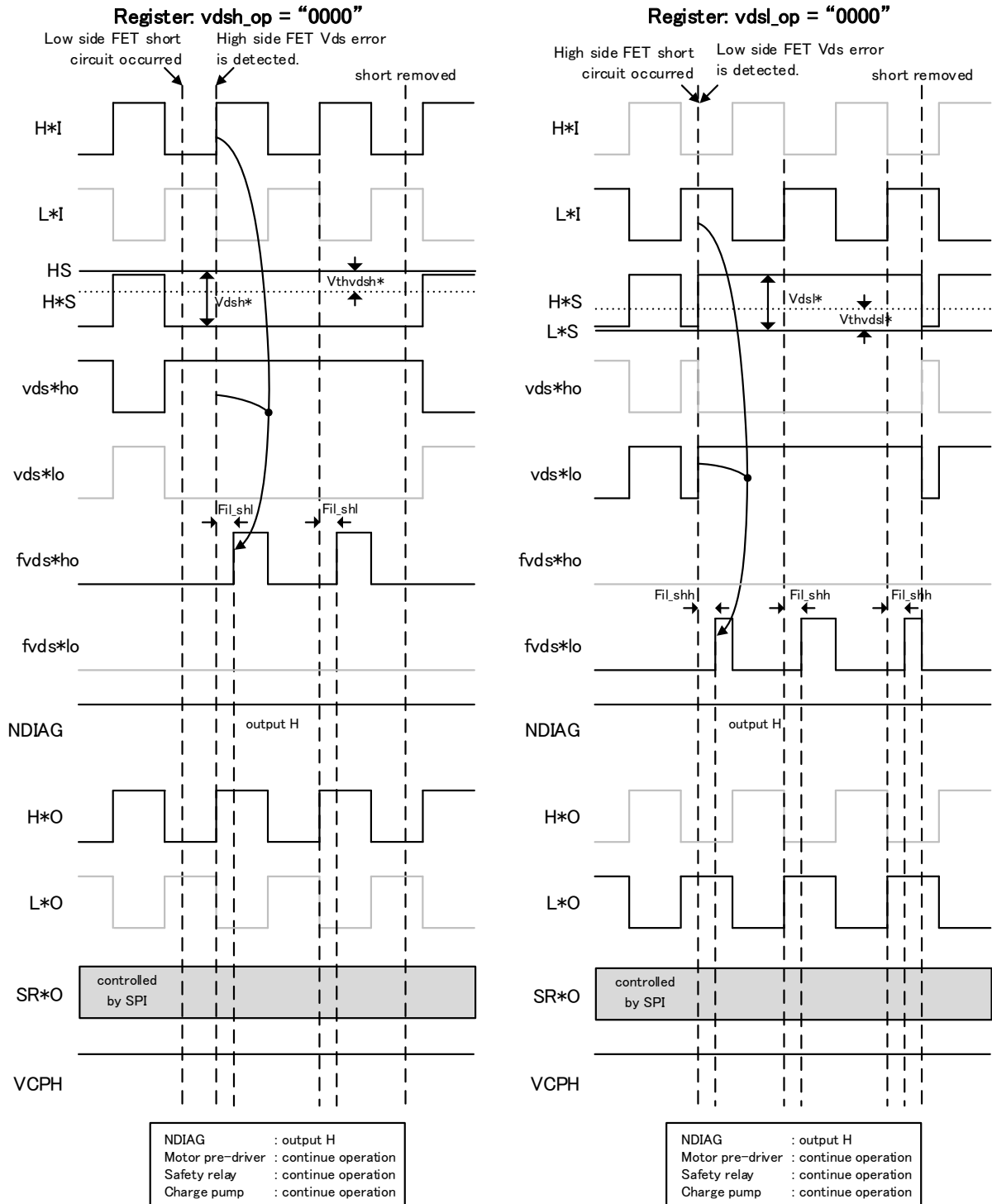


Fig. 7.5.8-b Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0000")

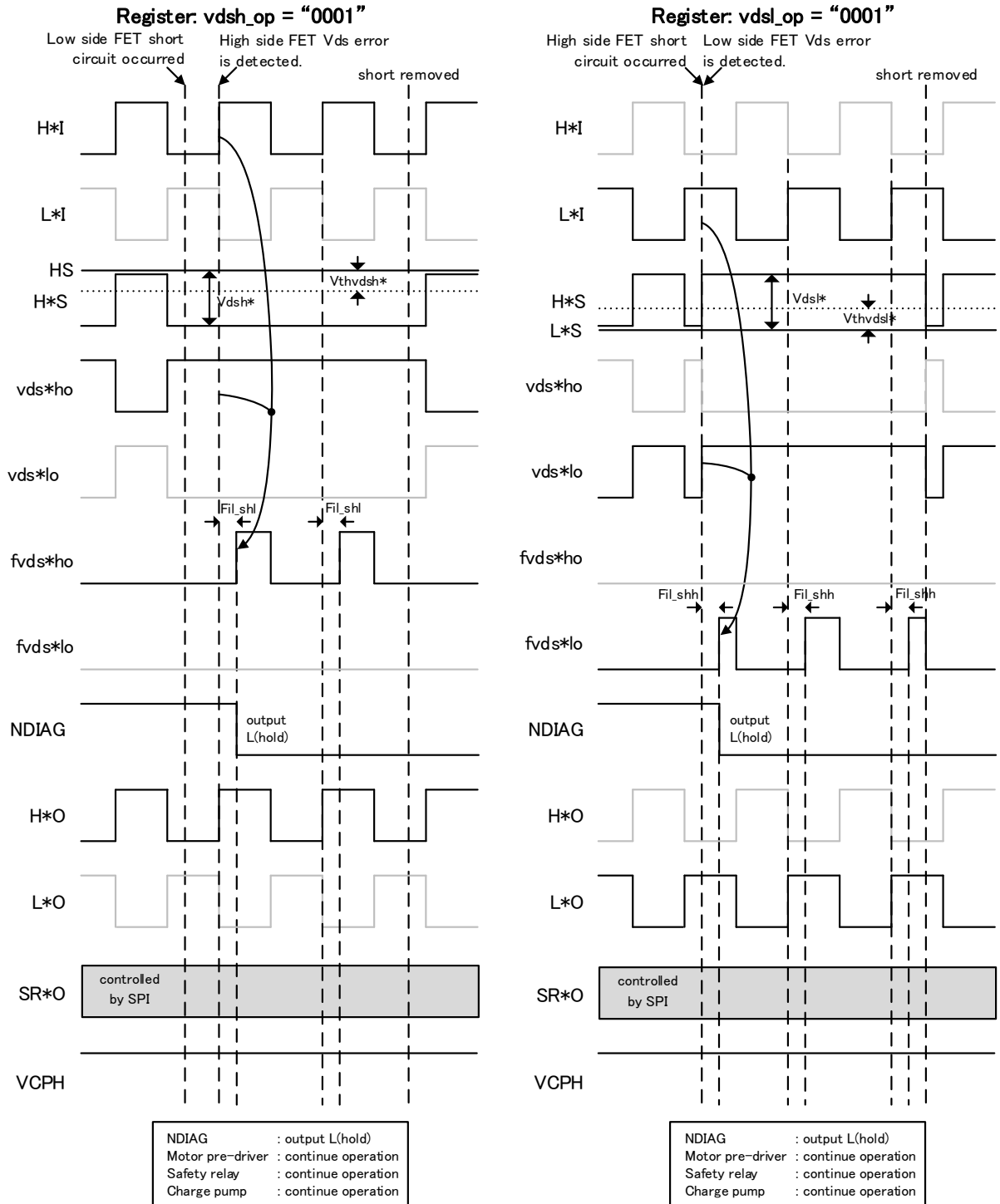


Fig. 7.5.8-c Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0001")

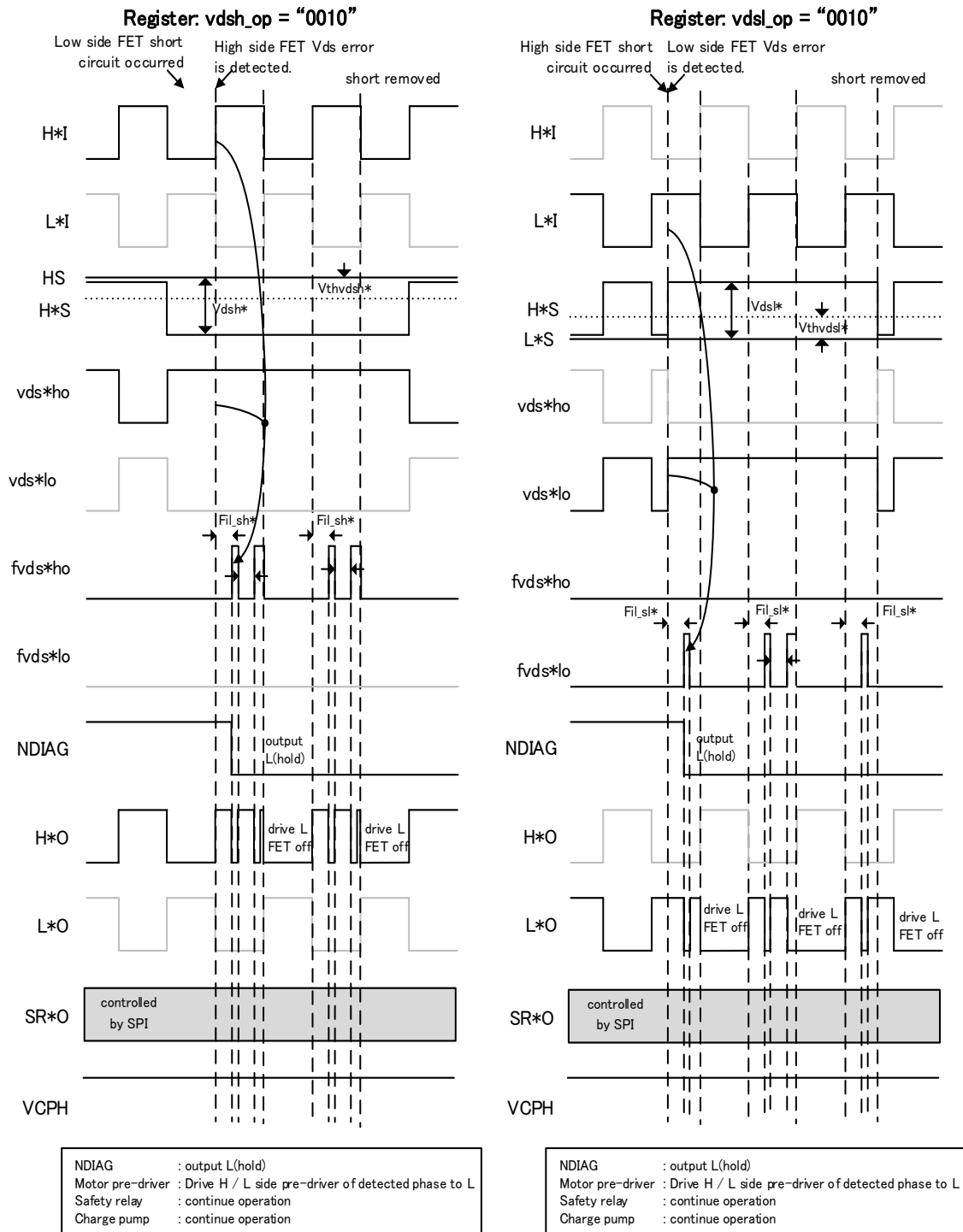


Fig. 7.5.8-d Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0010")

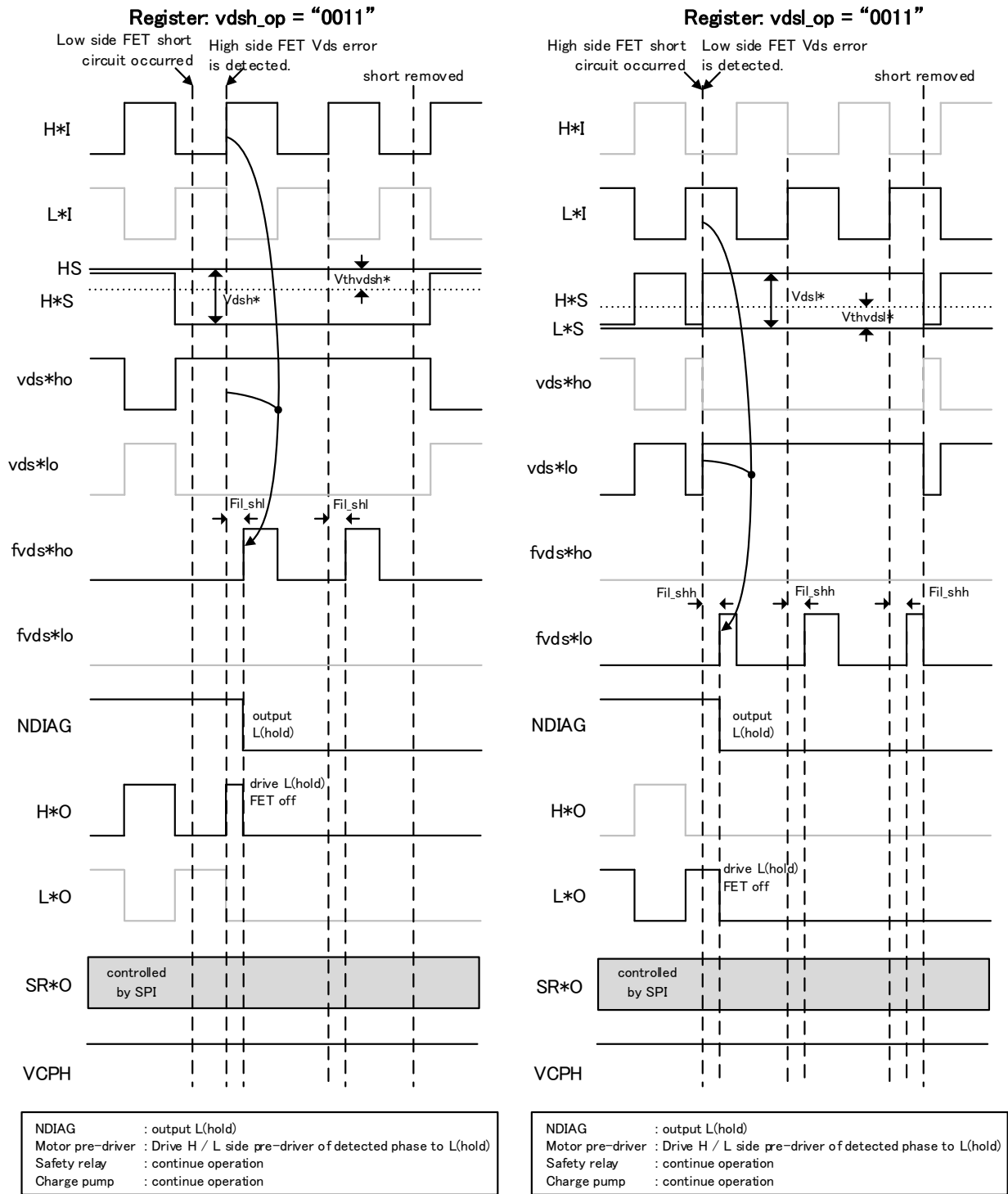


Fig. 7.5.8-e Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0011")

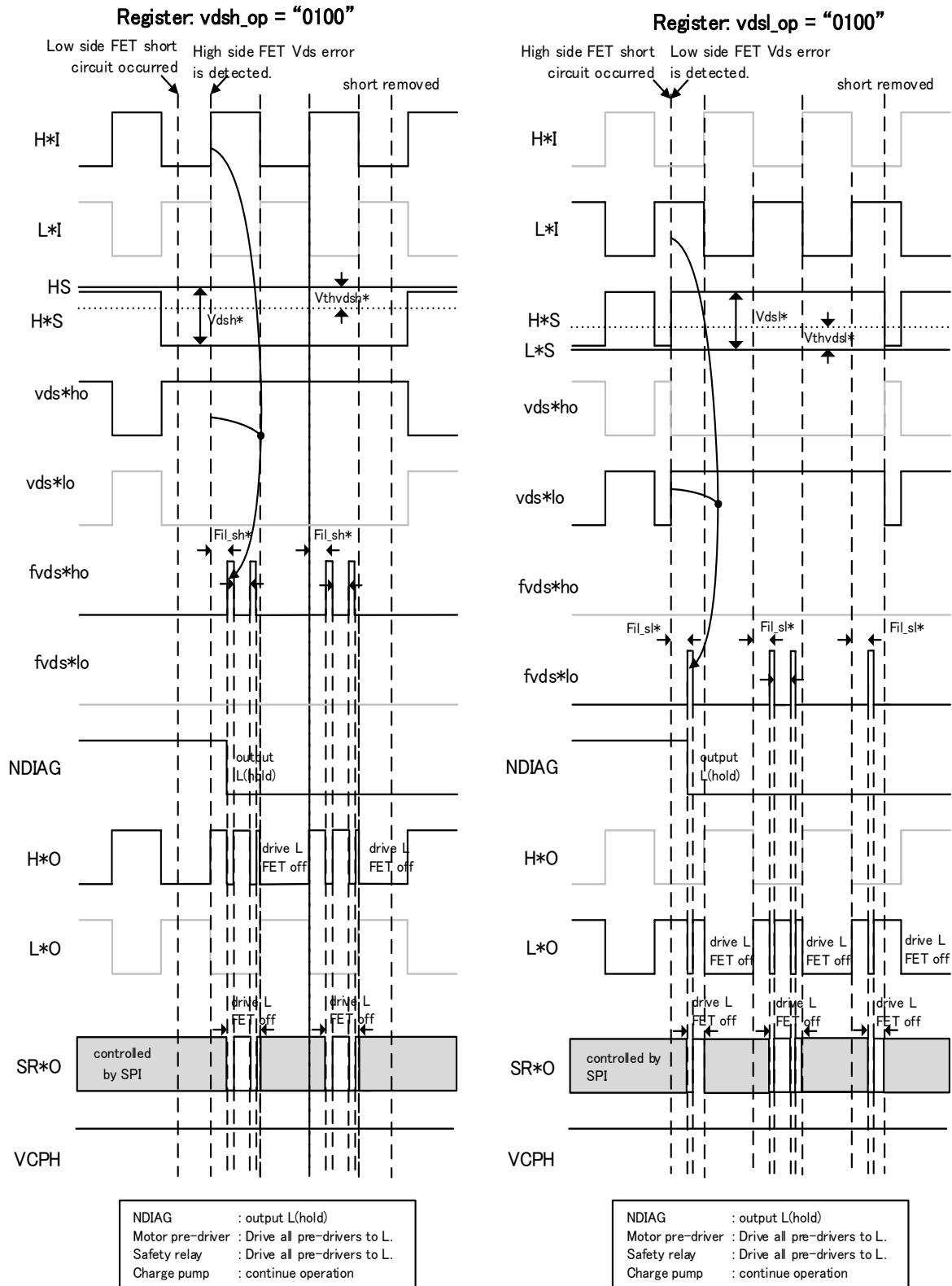


Fig. 7.5.8-f Timing chart for short-circuit detection (register vds_op = vds_op "0100")

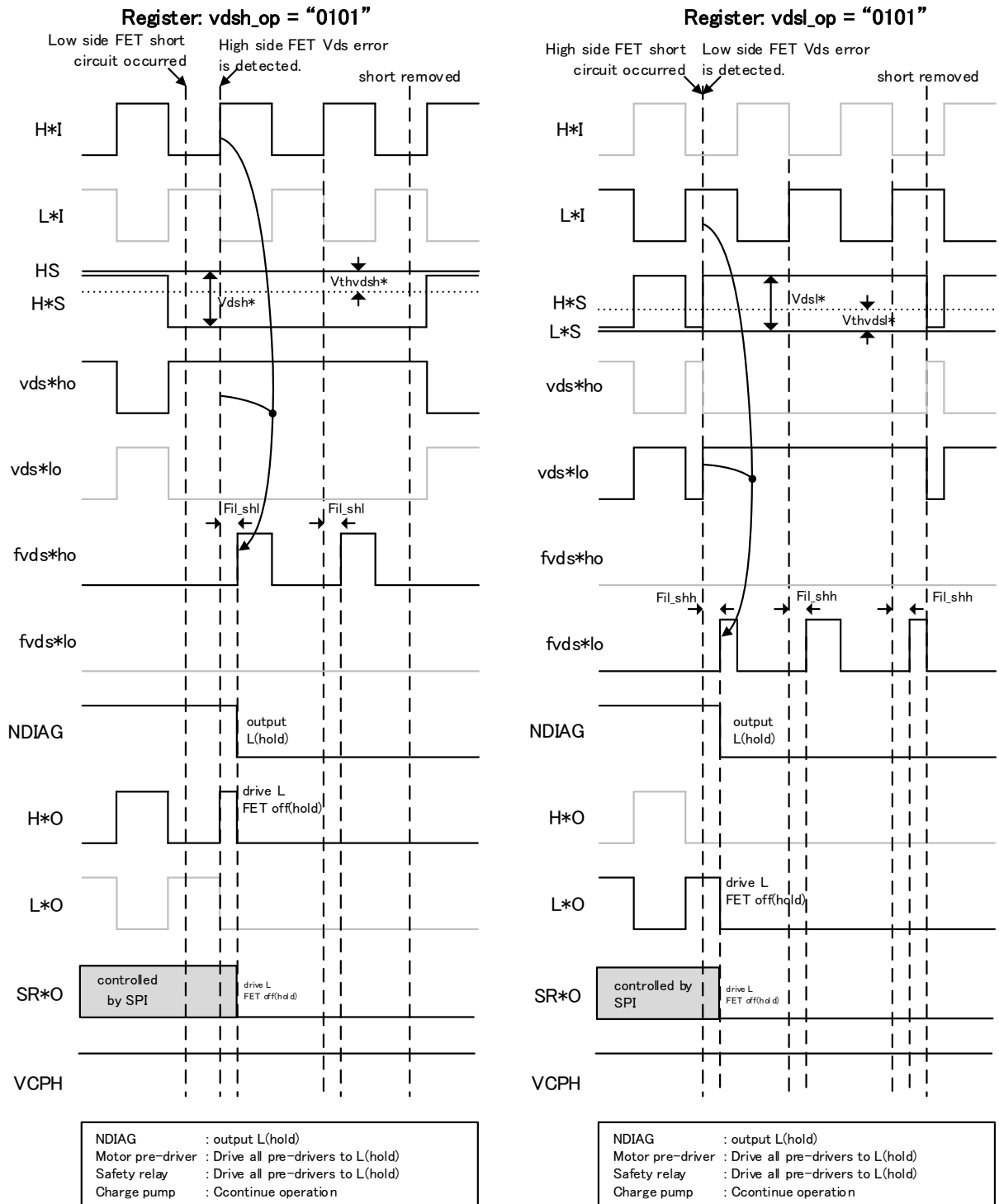


Fig. 7.5.8-g Timing chart for short-circuit detection (register vds_op = vds_op "0101")

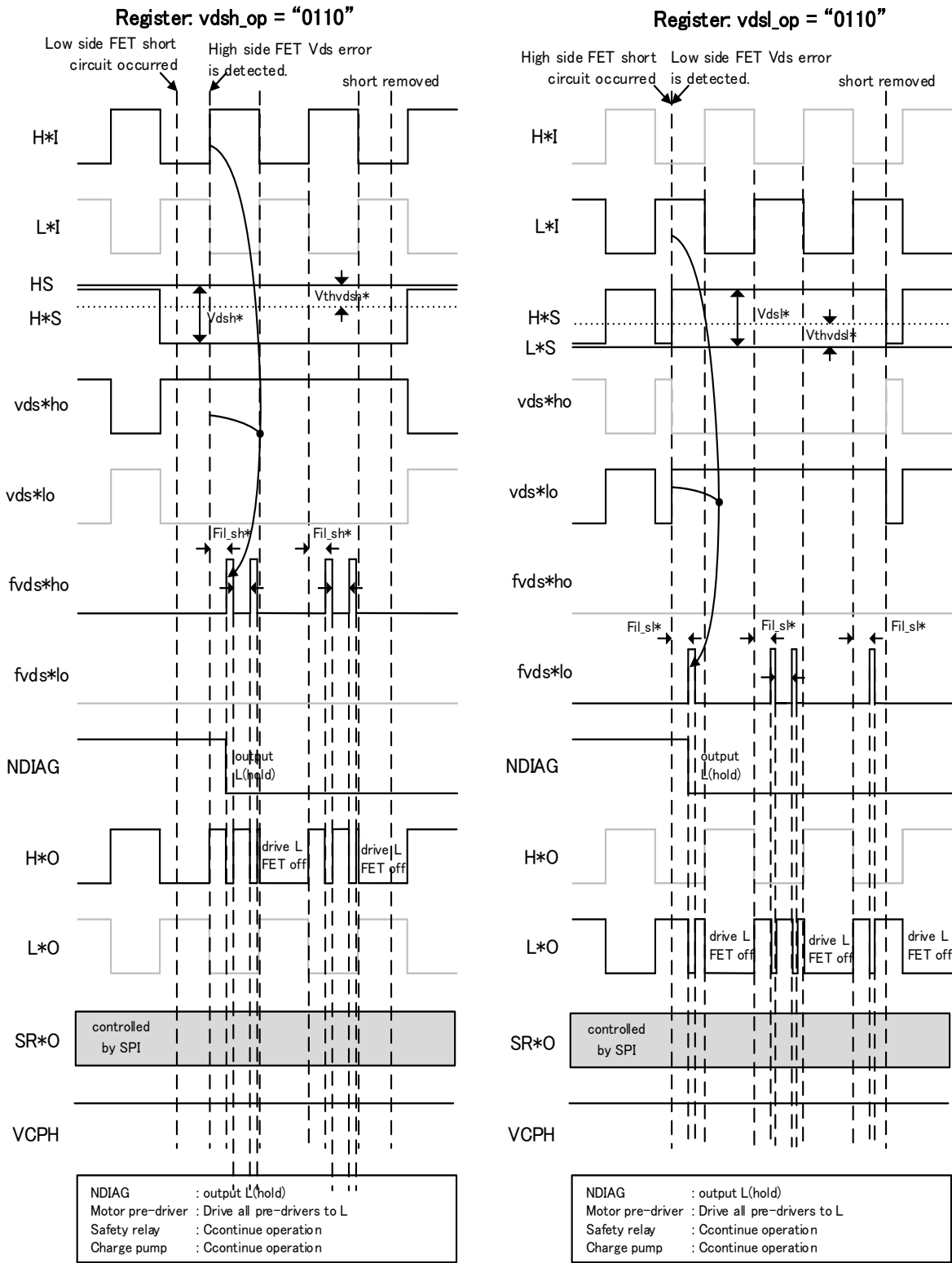


Fig. 7.5.8-h Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0110")

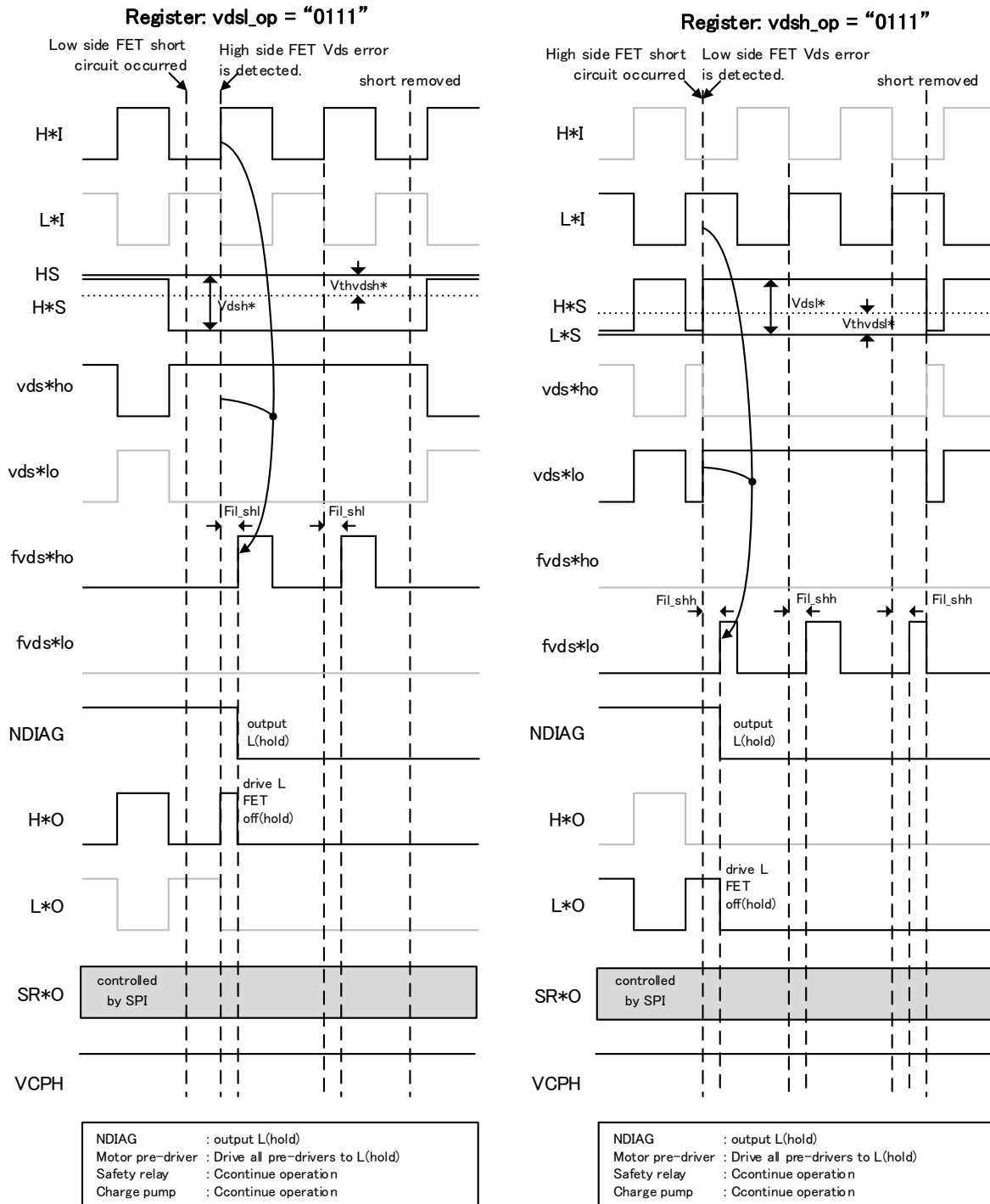


Fig. 7.5.8-i Timing chart for short-circuit detection (register vds_l_op = vds_h_op "0111")

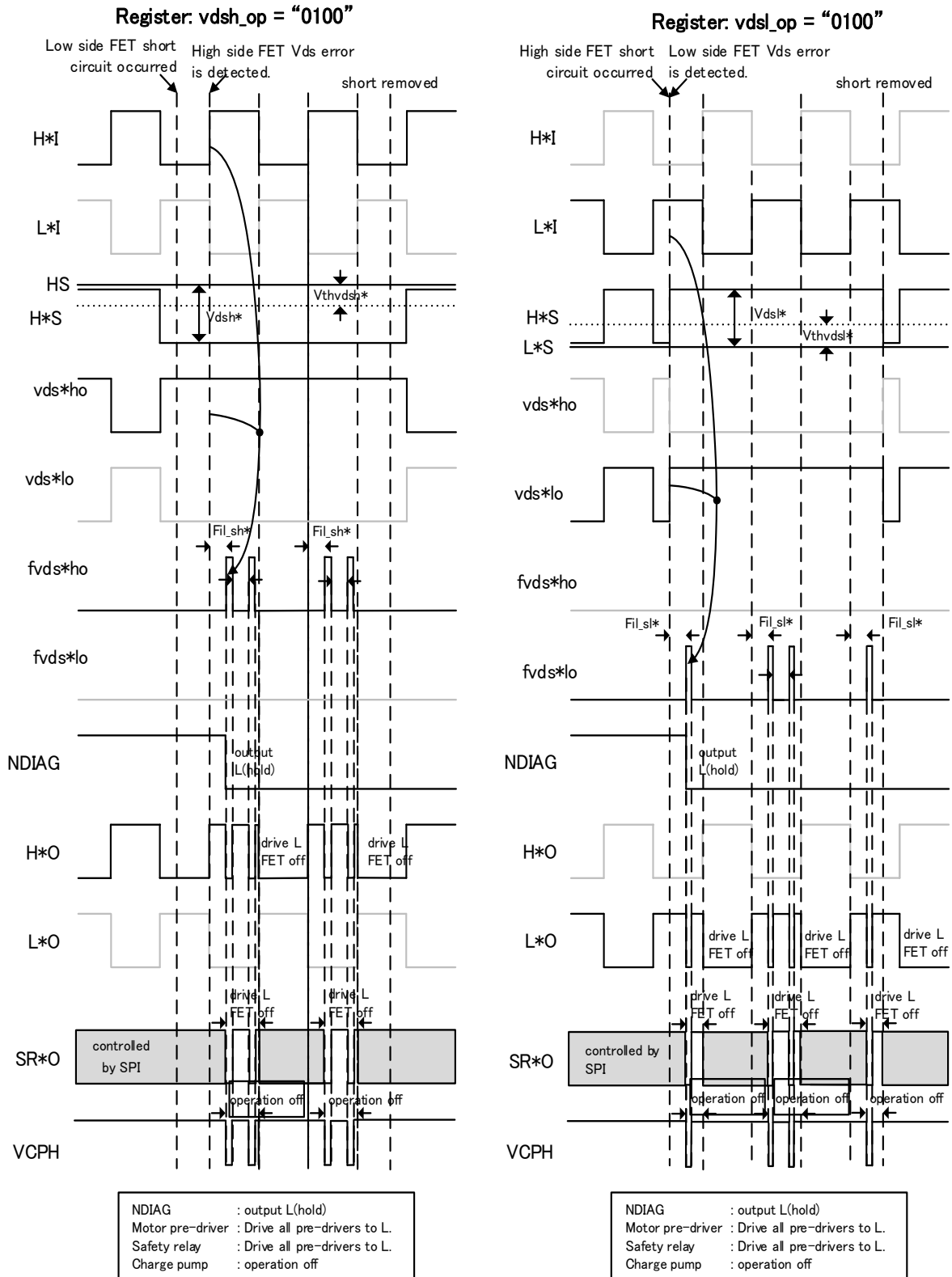


Fig. 7.5.8-j Timing chart for short-circuit detection (register vds_op = vds_op "1000")

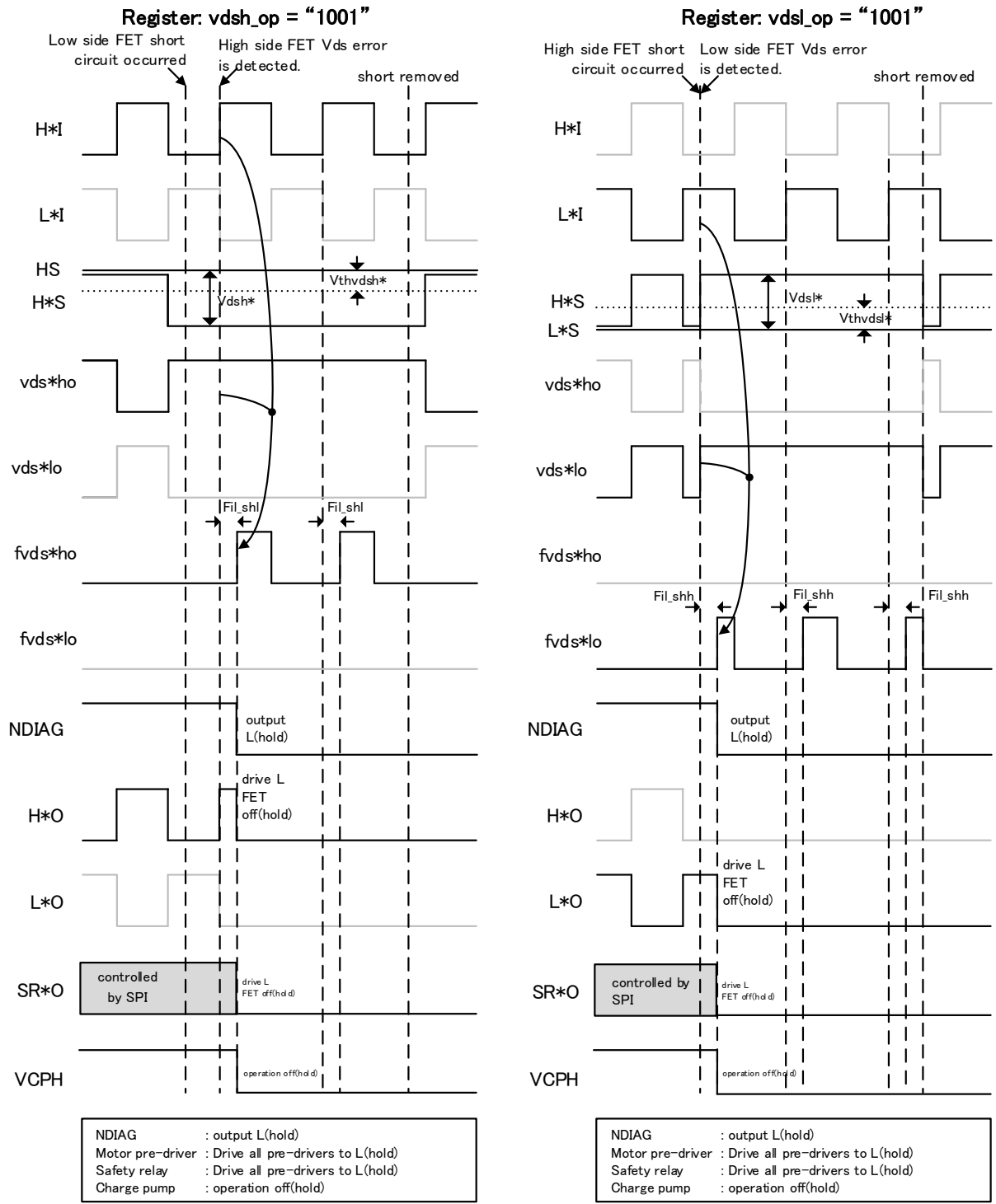


Fig. 7.5.8-k Timing chart for short-circuit detection (register vds_l_op = vds_h_op "1001")

7.5.9. External MOSFET VGS overvoltage detection

The external MOSFET gate and source terminals are monitored for VGS in excess of the specified threshold. VGS overvoltage detection is applied to each external MOSFET separately.

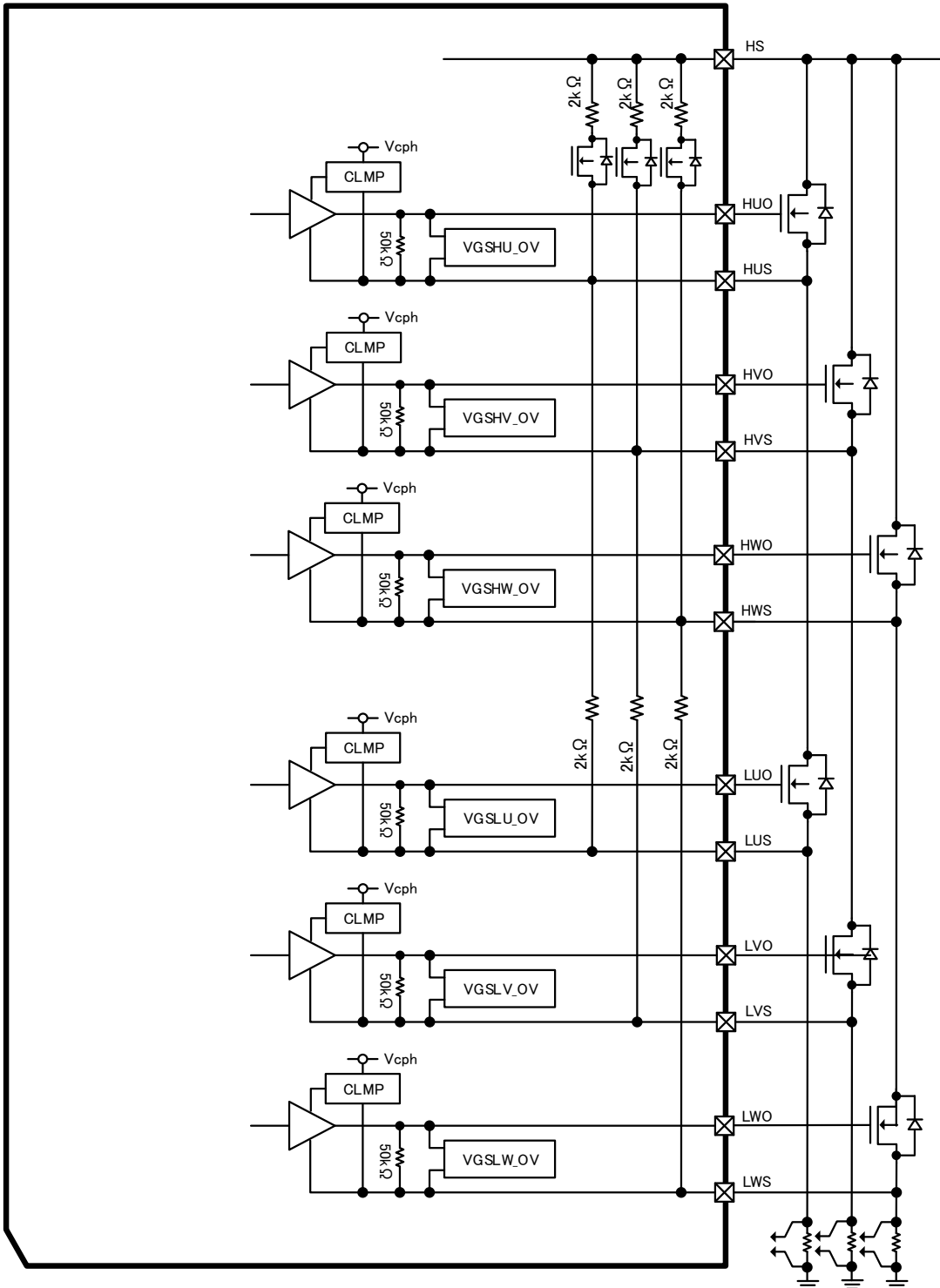


Fig. 7.5.9-a Block diagram for VGS overvoltage detection

The response to VGS overvoltage is specified via the [FET_OPSEL](#) register. Power cannot be cut from pre-drivers on individual channels; however, switching the charge pump off will shut off the power to the pre-drivers. Overvoltage threshold values can be specified for individual channels using different reference voltages to VBG1 and VBG2. Up to six VGS overvoltage detection events can be viewed in the [STAT2](#) register. The [FET_DET_SEL](#) register is used to enable/disable VGS overvoltage detection on each channel.

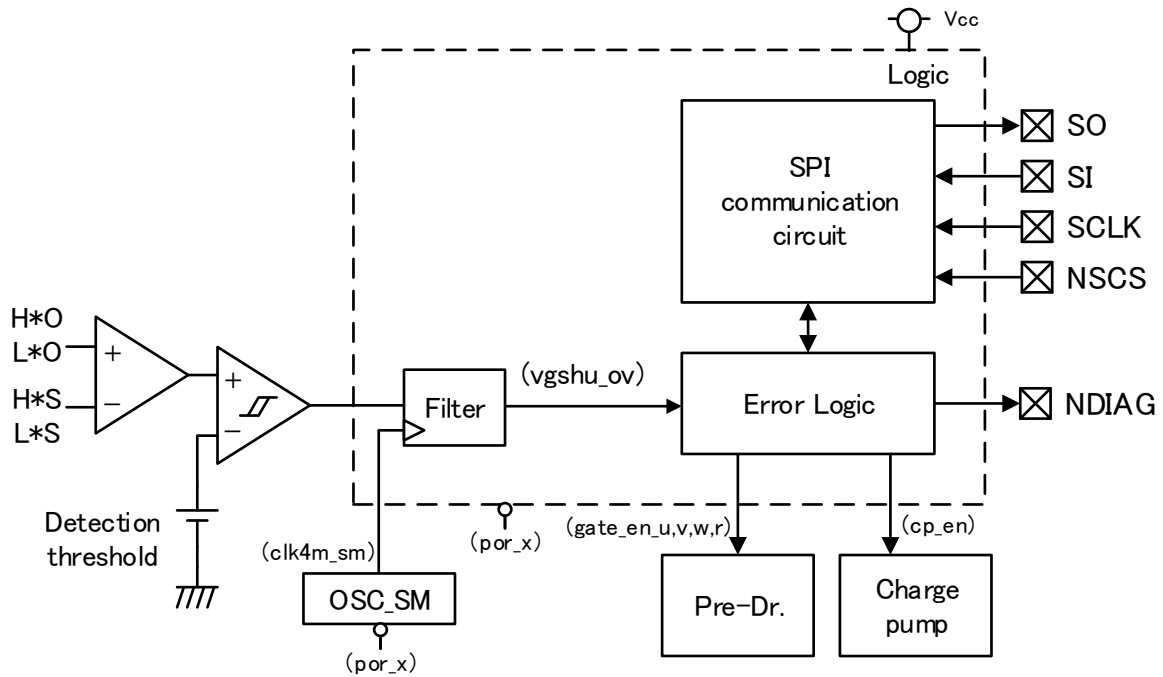


Fig. 7.5.9-b VGS overvoltage detection circuit diagram

➤ ① VGS overvoltage detected

When VGS voltage exceeds V_{th_vgsh} , VGS overvoltage signal ($vgs[h/l][u/v/w]_{ov}$) "H" is generated after the filter time Fil_vgs has elapsed. NDIAG output is "L," except where register vgs_op is "000," in which case the VGS overvoltage is ignored, NDIAG remains at "H" and all circuits continue to operate as normal. At this point one of six operating modes can be selected via the SPI. Note that if the overvoltage response mode register is modified during an overvoltage event, changes will not take effect until the VGS overvoltage has been cancelled and register vgs_op has been cleared.

➤ ② VGS overvoltage cancelled

Once the VGS voltage drops below V_{th_vgsL} , the VGS overvoltage signal ($tvgs[h/l][u/v/w]$) changes to "L" and the overvoltage is cancelled.

When register vgs_op is "101," the charge pump and pre-drivers remain off after the overvoltage is cancelled and NDIAG remains at "L."

When register vgs_op is "001", "010", "011" or "100," the charge pump and pre-drivers operate normally but the status register is retained and NDIAG remains at "L."

When register $vgs[h/l][u/v/w]_{ov}$ is cleared via the SPI, NDIAG changes to "H."

During an overvoltage, register $vgs[h/l][u/v/w]_{ov}$ cannot be cleared and NDIAG output is "L."

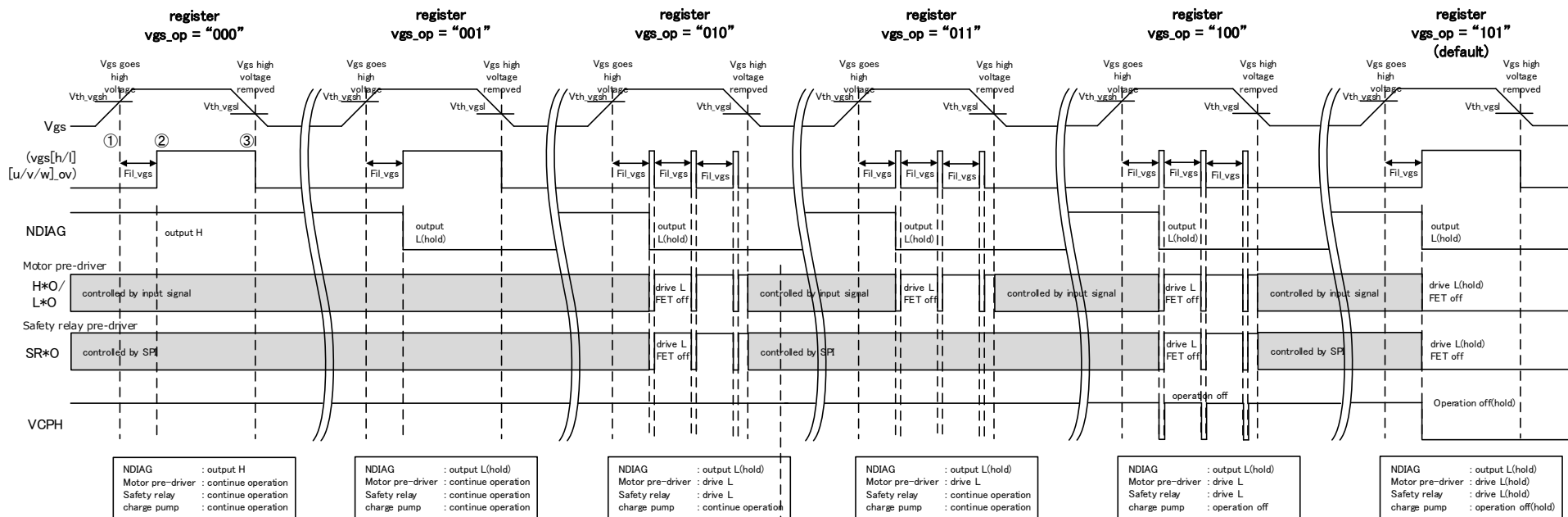


Fig. 7.5.9-c Operational chart for VGS overvoltage detection

7.5.10. Two-way internal oscillator frequency monitoring

Each of the two internal oscillators OSC_IF and OSC_SM monitors the other's oscillation frequency. If the OSC_IF frequency is found to be $1/K_{\text{freqdet}}$ or more below the OSC_SM frequency, the err_uf register is set; if the OSC_IF frequency is K_{freqdet} or more above the OSC_SM frequency, the err_of register is set. The OSC_IF and OSC_SM frequencies are monitored at all times except during BIST.

The ferr_op register offers a choice of six modes for the action taken in response to a frequency error. See Table 7.5-a for details. Modifications to the ferr_op register made during a frequency error event will be registered but will not be enabled until the frequency error has been cancelled and the err_of/err_uf register has been cleared.

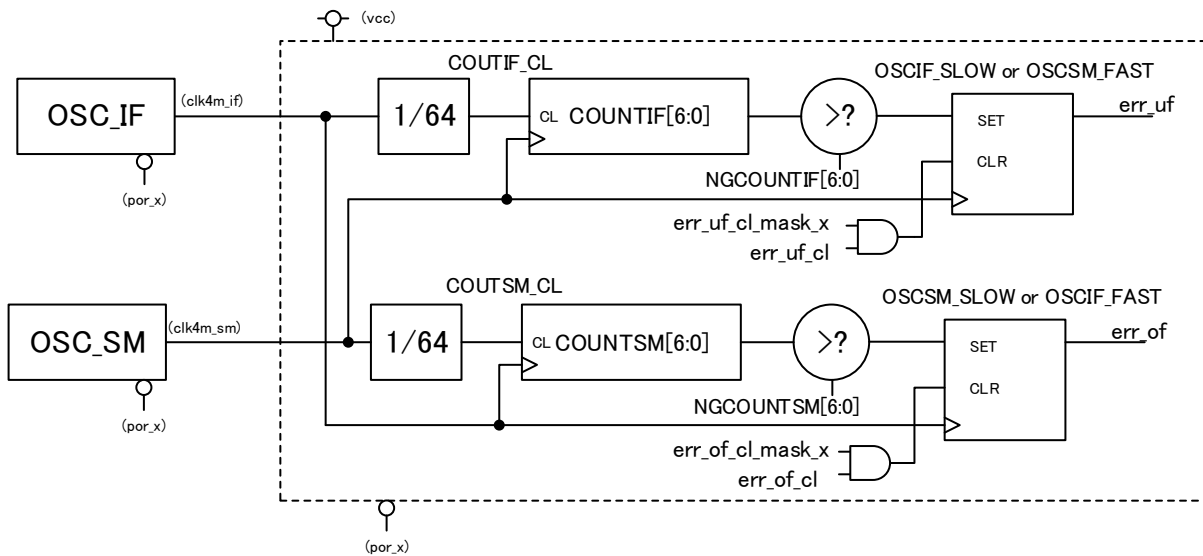


Fig. 7.5.10-a Circuit diagram for two-way internal frequency monitoring

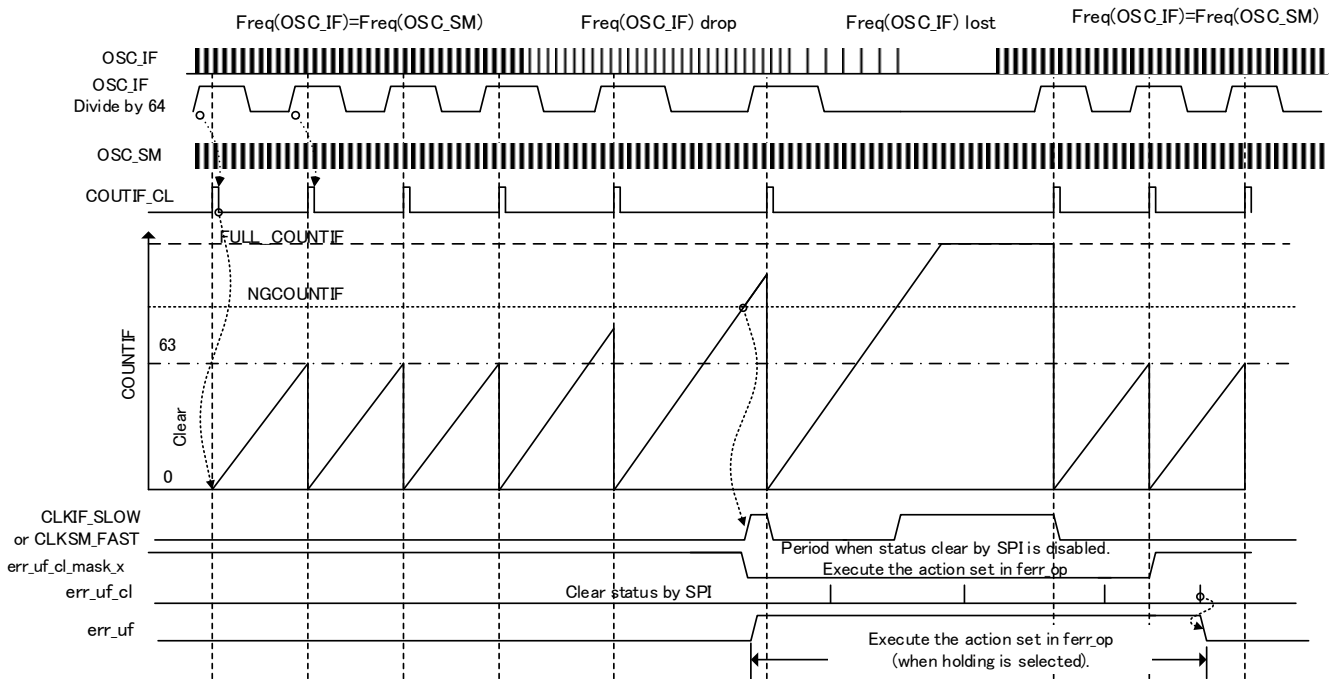


Fig. 7.5.10-b Timing chart for two-way internal frequency monitoring — Part 1

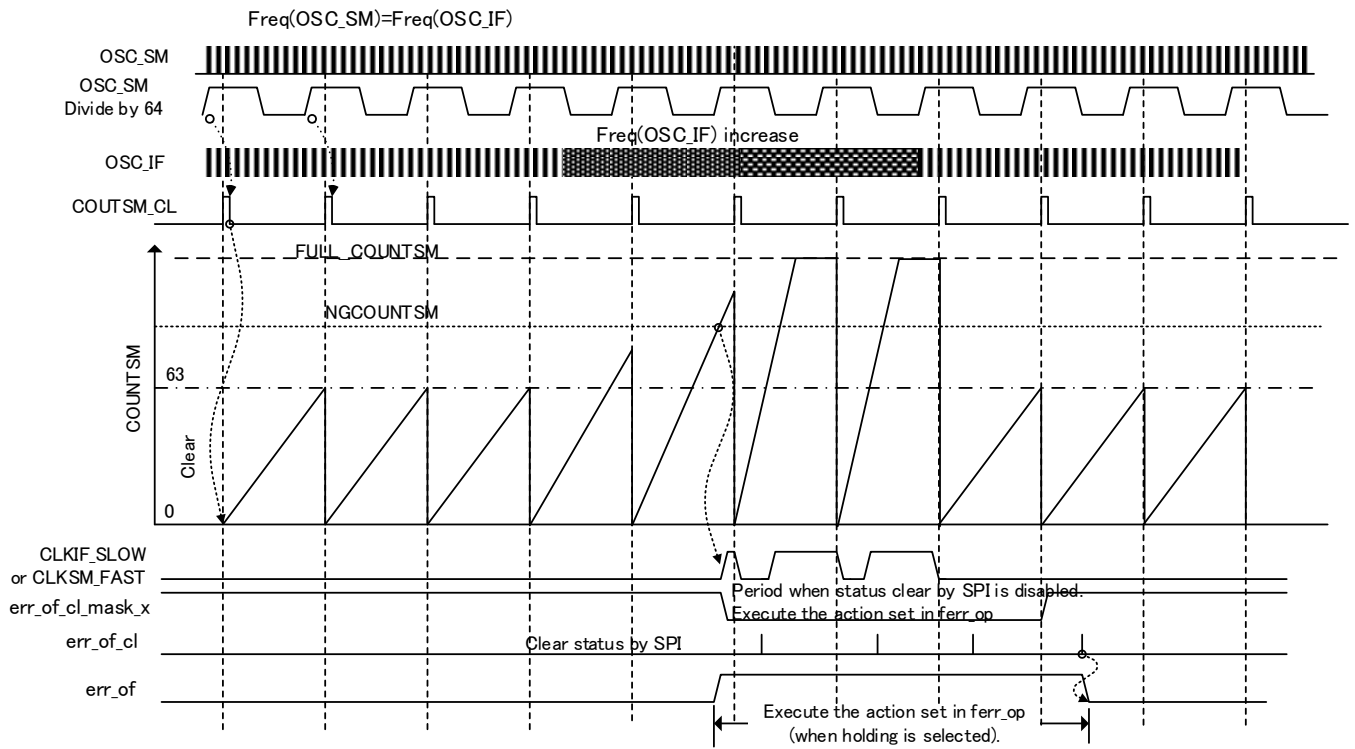


Fig. 7.5.10-c Timing chart for two-way internal frequency monitoring — Part 2

When ferr_op is 000, oscillator frequency detection is disabled.

When ferr_op is any other value, err_of status will be set if the OSC_IF frequency is Kfreqdet or more above the OSC_SM frequency, and err_uf status will be set if the OSC_IF frequency is 1/Kfreqdet or more below the OSC_SM frequency. The NDIAG terminal changes to "L" for both err_uf and err_of statuses. NDIAG can be restored to "H" by clearing the status register. Note that the status register can only be cleared when the most recent frequency comparison shows the OSC_IF frequency within the required range (no higher than Kfreqdet and no lower than 1/Kreqdet).

When ferr_op is 010 and the frequency is outside the required range, pre-drivers and relay output are switched off.

When ferr_op is 011 and the frequency is outside the required range, pre-driver outputs are switched off.

When ferr_op is 100 and the frequency is outside the required range, pre-drivers, relays and the charge pump are switched off.

When ferr_op is 101 and there is a status register set, pre-drivers, relays and the charge pump are switched off.

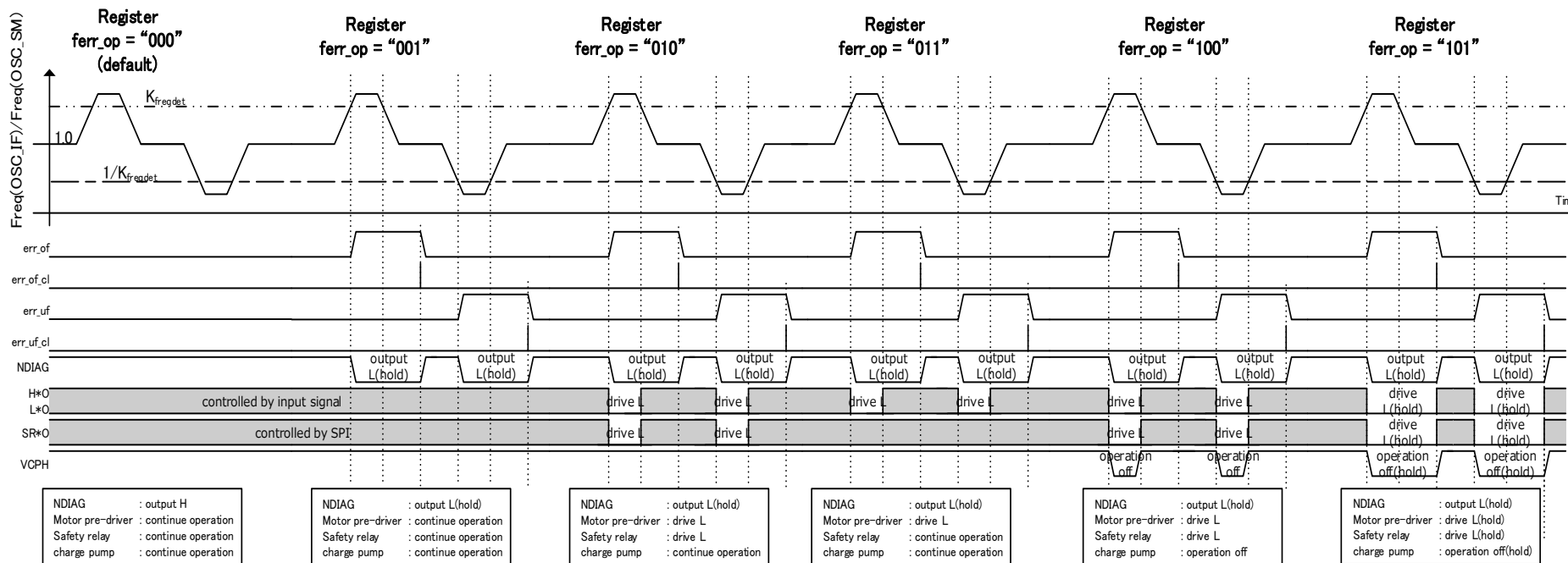


Fig. 7.5.10-d Operating modes in the event of a frequency error

7.5.11. QA detection

The SPI communication block is equipped with a QA detection feature. Refer to Section 7.9.2 and Table 7.5-a for details

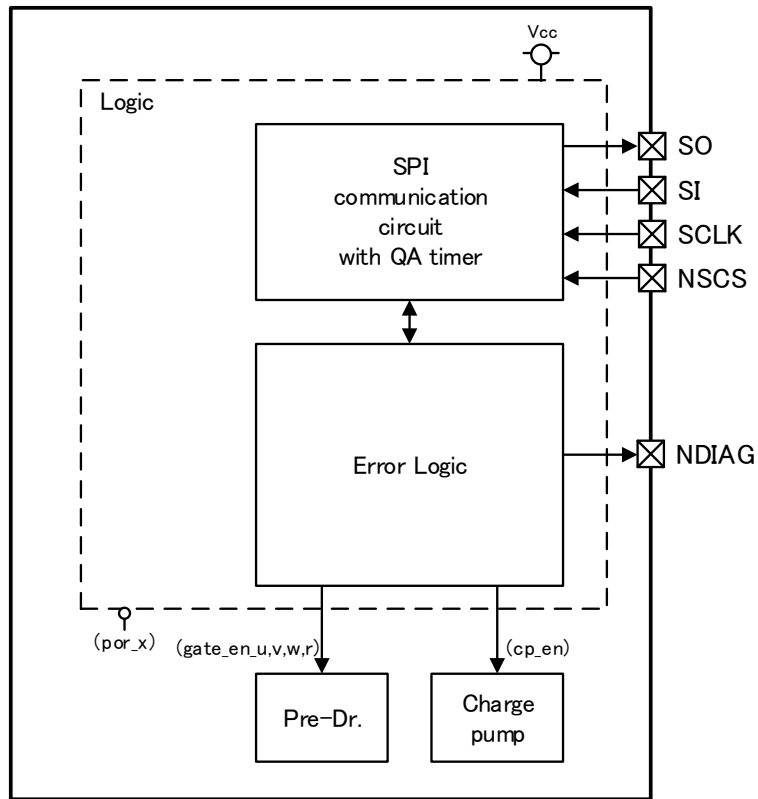


Fig. 7.5.11-a Block diagram for QA detection

➤ I-① QA operation error detection

When a QA operation error is detected, register err_qa changes to "H" and NDIAG changes to "L." If a QA timeout is detected, register err_qato changes to "H" and NDIAG is "L."

➤ I-② QA error cumulative detection

When a cumulative QA error is detected, register err_qac changes to "H" and the action specified in register qat_op is executed. At this point there are four operating modes that can be selected via the SPI.

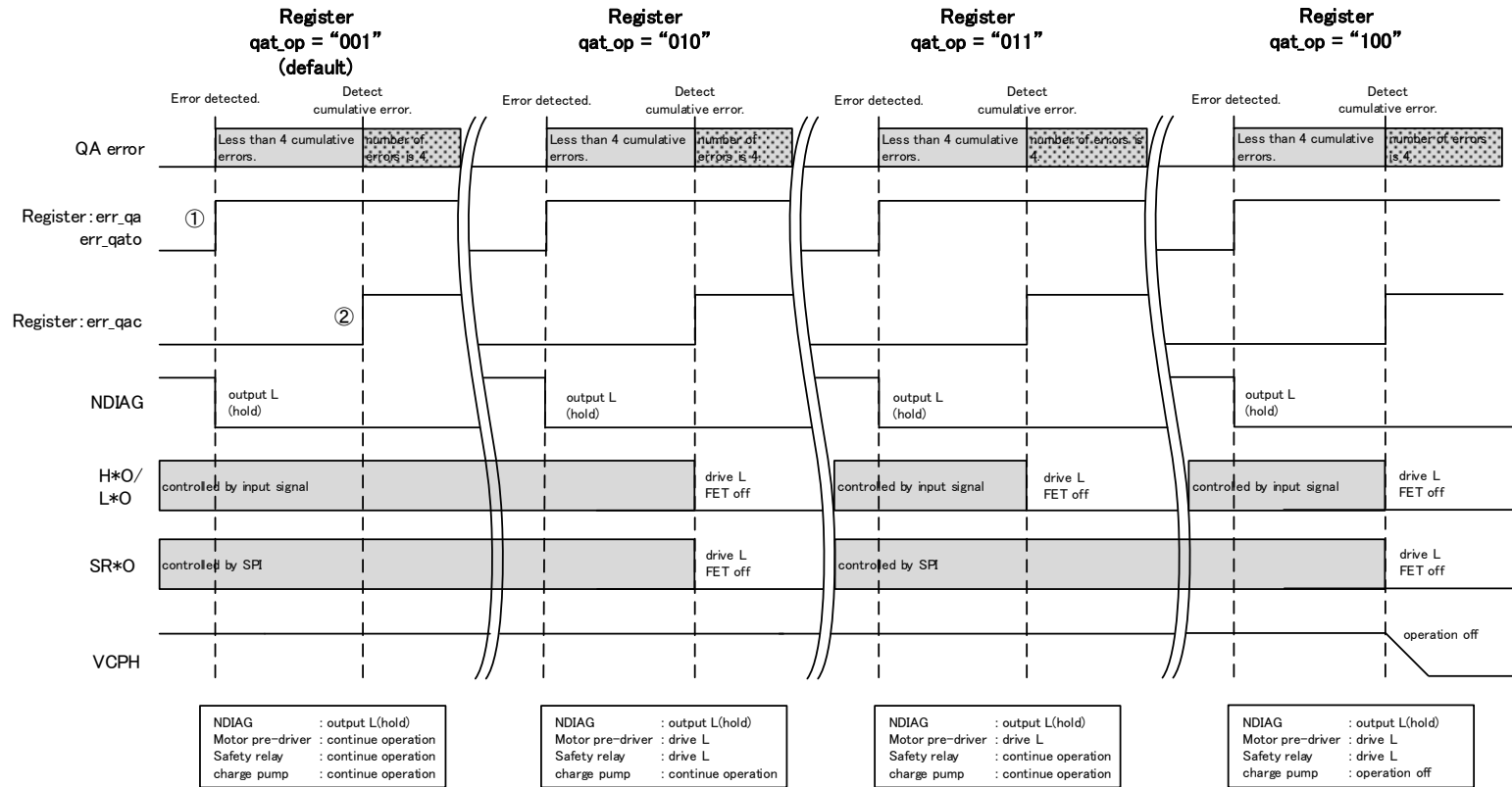


Fig. 7.5.11-b Timing chart for QA error detection

7.6. ALARM input circuit

The ALARM terminal is reserved for microcomputer pre-driver shut down commands. The ALARM signal is an internal signal using either OSC_SM or OSC_IF that is used to enable and disable motor drive and safety relay pre-driver circuits.

- When ALARM is "L," pre-driver circuits specified in the [ALM_CTRL](#) register are disabled.
- When ALARM is "H," pre-driver circuit input and internal signal can be used for enable/disable operations.
- The input side of the ALARM terminal is equipped with a digital filter (D.F.) to filter out noise.
- The digital filter time can be enabled in the [ALM_CTRL](#) register.
- OSC_SM signals are the only alm_det details in the ALARM detection status [STAT1](#) register that can be accessed through the SPI.

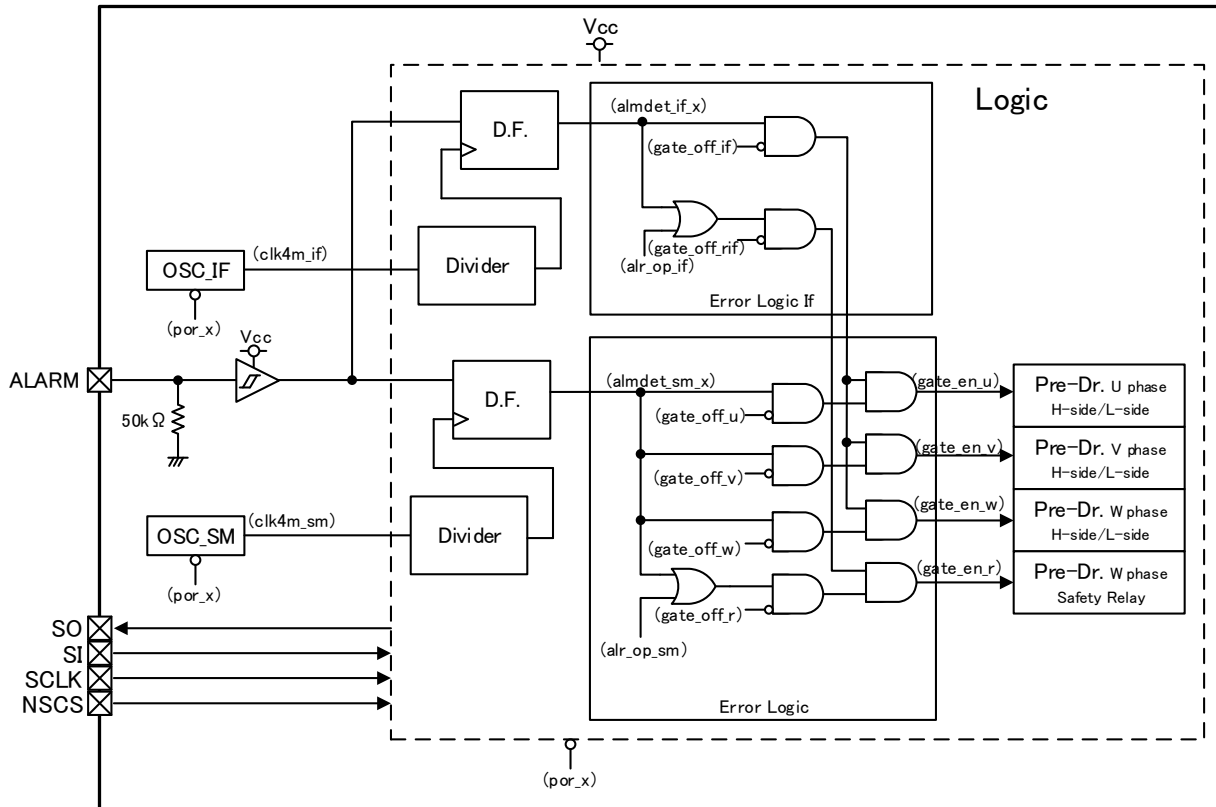


Table 7.6-a Truth table for MOSFET driver controller

| por_x | alr_op | almdet_if_x | almdet_sm_x | gate_en_u | gate_en_v | gate_en_w | gate_en_r |
|-------|--------|-------------|-------------|-------------|-------------|-------------|-------------|
| L | * | * | * | L | L | L | L |
| L | L | L | * | L | L | L | L |
| | | * | L | L | L | L | L |
| | | H | H | ~gate_off_u | ~gate_off_v | ~gate_off_w | ~gate_off_r |
| | | L | * | L | L | L | ~gate_off_r |
| H | H | * | L | L | L | L | ~gate_off_r |
| | | H | H | ~gate_off_u | ~gate_off_v | ~gate_off_w | ~gate_off_r |

Note

- * denotes "don't care"
- The gate_off_u, gate_off_v, gate_off_w and gate_off_r commands are used to stop pre-drivers for reasons other than an alarm
- The gate_off_if and gate_off_rif commands are used to stop pre-drivers for reasons other than an alarm (frequency error detection using OSC_IF)

7.7. ABIST/LBIST

ABIST/LBIST performs a diagnosis at IC startup to check that error detection functions are working normally.

- At IC startup, oscillator circuits start after a VCC undervoltage has been cancelled and the ABIST diagnosis begins after LBIST is finished.
- If LBIST returns a NG result, the ABIST diagnosis is cancelled and the charge pump and pre-drivers are disabled.
- Once ABIST starts, turning on the diagnosis switch toggles the comparator input voltage and inverts the detection comparators.
- The diagnosis is synchronized to the clock. Diagnostic data is input to the ABIST evaluation circuit. NDIAG remains at "L" while the diagnosis is in progress.
- When the diagnosis process is completed, the IC switches to normal operation.
- If no errors are detected during diagnosis, NDIAG changes to "H."
- If errors are detected, NDIAG remains at "L" and the diagnostic data is retained.
- Table 7.5-a lists the diagnostics points.

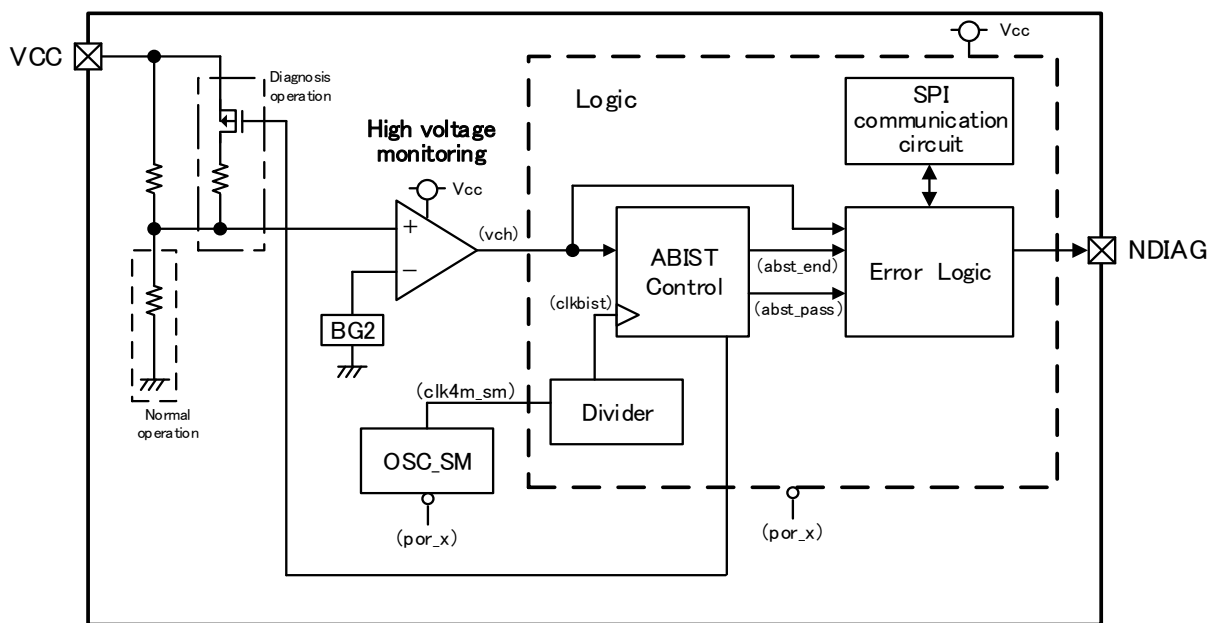


Fig. 7.7-a ABIST block diagram (VCC overvoltage detection)

Since the en_cp bit in the [CP_RLY_CTRL](#) register has a default value of 1, the charge pump is enabled when ABIST finishes normally.

Table 7.7-a Truth table for charge pump circuit operations

| ABIST | ABSIT results | Abnormalities other than ABSIT are detected. | en_cp [SPI] | Internal signal cp_en | Charge pump circuit |
|--------------|---------------|--|-------------|-----------------------|---------------------|
| Before ABIST | * | * | * | L | Disable |
| During ABIST | | | | | |
| After ABSIT | NG | TRUE | L | H | Enable |
| | OK | FALSE | | | |
| | | | | H | |

Note: Vcph = Vb during ABIST/LBIST since due to influence of internal pull-up/pull-down resistors

Table 7.7-b Truth table for pre-driver circuit operations

| ABIST | ABSIT results | Abnormalities other than ABSIT are detected. | Internal signal gete_en_u/v/w | Pre-driver circuit |
|--------------|---------------|--|-------------------------------|--------------------|
| Before ABIST | * | * | L | Disable |
| During ABIST | | | | |
| After ABSIT | NG | TRUE | H | Enable |
| | OK | FALSE | | |
| | | | | |

< ABIST Overall operation/Start-up operation >

> ① IC launch

When the IC is launched, as the low voltage of Vcc is released, the divider circuit starts to operate.

> ② LBIST execution

The divider circuit starts to operate, starting LBIST.

> ③ ABIST launch

After LBIST, ABIST is started. By switching detection comparators periodically, it diagnoses whether the detection comparators correctly output fault detection signals.

> ④ Diagnosis

Judgment on the respective comparator below is made.

VB low voltage, VCPH high voltage, VCC high voltage, VCC_OP low voltage, VCC_OP high voltage, overtemperature.

> ⑤ ABIST shut-down

When the diagnosis is completed on the all comparators, the IC switches to the normal operation mode, the charge pump circuit starts operating, and the pre-driver circuit can be turned on. And the diagnosis result is output to NDIAG.

When the diagnosis result is NG, the charge pump circuit and pre-driver circuit remain "off."

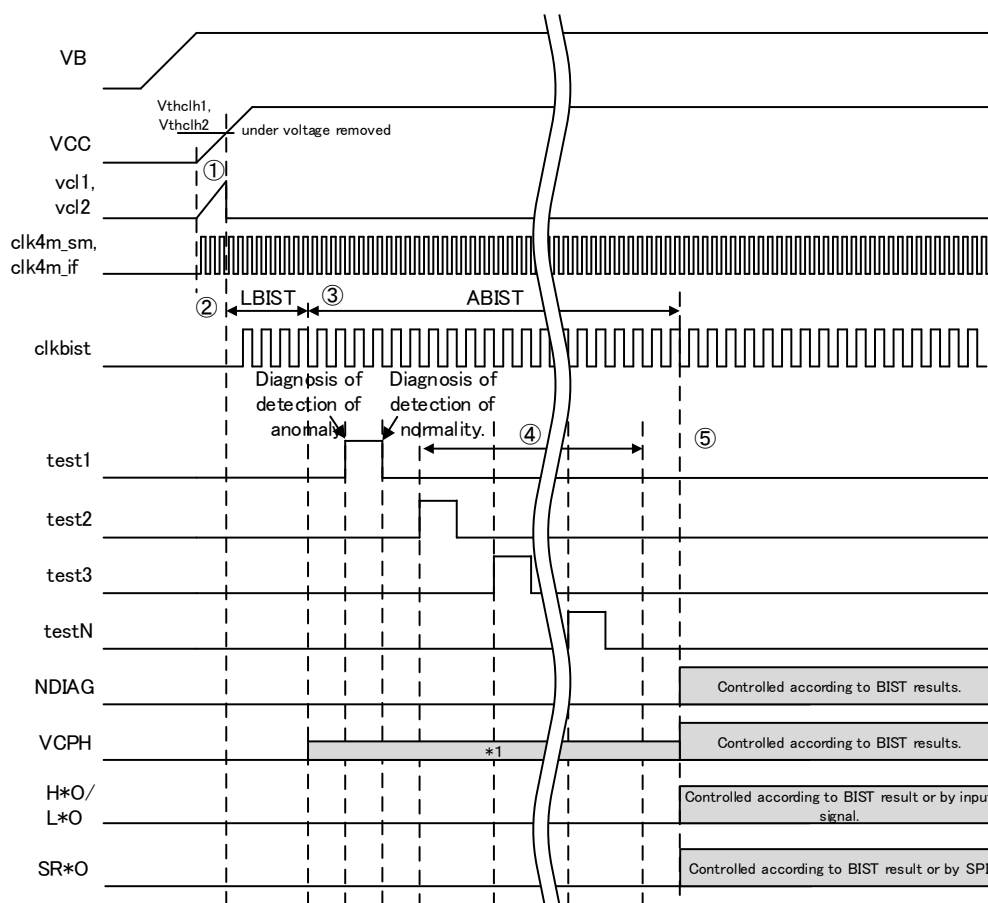


Fig. 7.7-b ABIST timing chart

*1 Dependent on the internal pull-up/down resistance while ABIST / LBIST is being executed, and Vcph=Vb.

*2 There is no starting sequence for VB and VCC. If VB undervoltage detection and VCC_OP undervoltage detection are not released at the start of ABIST, the ABIST result will be abnormal.

Slew rates of Vb and Vcc should be within the ranges below.

Vb= less than 8V/μs

Vcc= less than 0.3V/μs

*3 The execution period of LBIST and ABIST combined is about 2.6ms (typ.), 4.0ms(max). Start SPI communication after LBIST and ABIST are completed.

7.8. Initial diagnosis circuit for external FETs and relays

7.8.1. Block diagram

Fig. 7.8-a shows the block diagram (this is a conceptual diagram and not a practical circuit). An inspection circuit (FET_TEST block) is fitted for executing the initial diagnosis on the external FETs and relays. During the inspection, VDS abnormality detection is disabled and the circuit for detecting VDS abnormality is used for inspecting external FETs and relays (FET_TEST hereafter). Even during FET_TEST, when a "pre-driver off" instruction appears (when gate_en_*="L") for reasons other than VDS abnormality detection, the pre-driver is turned off. During the FET_TEST period, pre-driver control signals for motor control is controlled by the FET_TEST block. Relays always follow [CP RLY CTRL](#) register setting.

The resistors to maintain HUS, HVS, HWS terminals to the mid-voltage when the pre-drivers are off are connected while an inspection by FET_TEST is being executed.

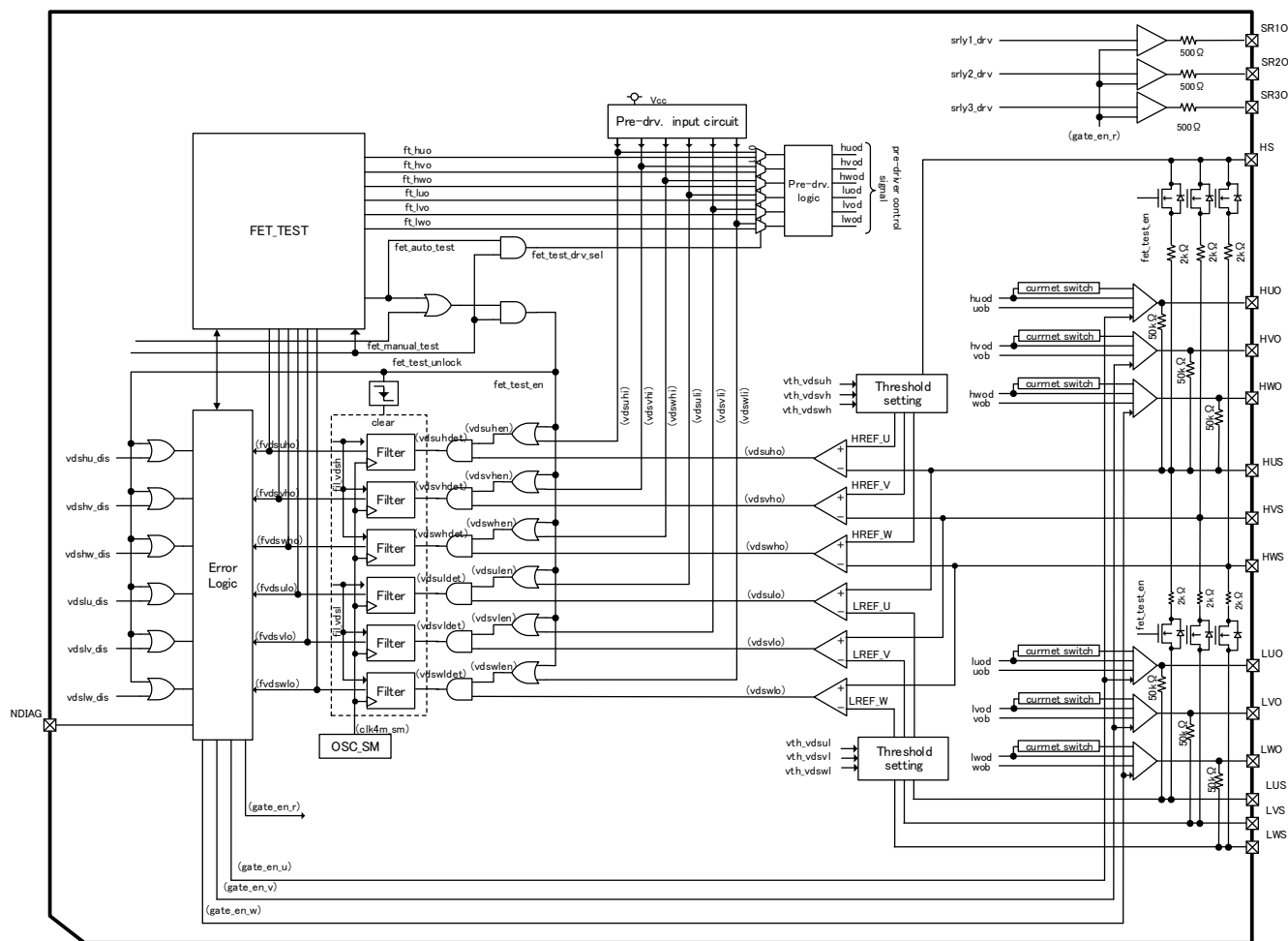


Fig. 7.8-a Block diagram of the diagnosis circuit for external FETs and relays

7.8.2. Classification of inspection modes

Table 7.8-b shows a list of inspection modes. When fet_test_unlock=0, it provides normal operation.

By setting fet_manual_test = 1 during the period of fet_test_unlock = 1, the external FET can be inspected manually. In this mode, relay drive signals are controlled by the register, FET drive signals are controlled by the input terminal, and the control method is the same as in the normal operation. In normal operation, the VDS detection comparator output is input to the noise filter only for the channels where the FET control input terminal is controlled to "H", but in the manual test mode, the comparator output for VDS detection is input to the noise filter regardless of the state of the input terminal for FET control. In manual test mode, VDS detection is disabled because the VDS detection circuit is used for FET inspection. fet_rmidonU, fet_rmidonV, fet_rmidonW are the control bits to set U phase, V phase and W phase of the mid-voltage generating resistors to ON, respectively. Set each bit to ON depending on the inspection method that the user assumes. When multiple bits are turned ON simultaneously, resistors of the corresponding phases are turned ON simultaneously. The inspection is through expectation comparison by the microcomputer that reads the comparator output (after being filtered) for VDS detection from the VDS_COMP_STAT register.

By setting the fet_test_start bit while fet_test_unlock=1, an inspection sequence is started, and when fet_auto_test="H," timing control of FET drive and saving of the output results of VDS detection comparators are performed by this IC automatically. The FET drive patterns are previously assumed pre-defined drive patterns for Type A, B and C, but for Type D, arbitrary patterns can be set by the register. Since the circuit for VDS abnormality detection is used for FET inspection, VDS abnormality detection is disabled. The resistors for generating the mid-voltage are ON for all phases while the automatic sequence is running. Since FETs are driven by previously assumed pre-defined drive patterns for Type A, B and C, the comparator output is automatically compared with expected values within the IC, but since the drive patterns can be arbitrarily set by the user for Type D, expectation comparison is conducted by the microcomputer.

When fet_manual_test and fet_auto_test become valid simultaneously, fet_auto_test is given priority. When fet_manual_test_[U,V,W] sets multiple bits simultaneously, mid-voltage generating resistors of the phases that are set to 1 are turned ON simultaneously. "*" In Table 7.8-a means Don't 'care.

Table 7.8-b List of inspection modes

| Register setting or status flag | | | | | | | Operation of each circuit element | | | | | Expected value comparison. | Overview | |
|---------------------------------|---------------|-----------------|-------------|-------------|-------------|-----------------------------|-----------------------------------|---|--------------------------|--|------------------------------------|----------------------------|---|-----------------------------|
| fet_test_unlock | fet_auto_test | fet_manual_test | fet_rmidonU | fet_rmidonV | fet_rmidonW | fet_test_type | Relay drive signal | FET drive signal | VDS detection | VDS detect ion compa rator (with Filter) | mid- voltage generati ng resistors | | | |
| 0 | * | * | * | * | * | * | Controlled by input terminal. | Controlled by input terminal. | Valid | VDS detect ion | OFF | - | Normal operation | |
| | | 0 | 0 | 0 | 0 | FET test unlock state. | | | | | | | | |
| | 0 | 1 | 1 | 0 | 0 | Judgment by microcomp uter. | | | | | | Manual FET test. | | |
| | | | 0 | 1 | 0 | | | | | | | | | |
| | | | 0 | 0 | 1 | | | | | | | | | |
| 1 | 1 | * | | | | | A | Controlled by register setting by microcomp uter. | Automatic control by IC. | Invalid | Exter nal FET diagn osis | All phases ON | Expected value compariso n by IC. | Automatic FET test Type A. |
| | | | | | | | B | | | | | | | Automatic FET test Type B. |
| | | | | | | | C | | | | | | | Automatic FET test Type C. |
| | | | | | | | D | | | | | | Controlled by register setting by microcomp uter. | Judgment by microcomp uter. |

7.8.3. FET manual inspection

By setting fet_manual_test to "H" in the [FET TEST CNT1](#) register after setting fet_test_unlock="H" in the [FET TEST CNT2](#) register, FET manual inspection can be conducted. In the FET manual inspection mode, FET control signals are controlled from input terminals as in the normal operation. The VDS abnormality detection circuit is changed to FET inspection mode, and the VDS comparator output signal is input to the noise filter regardless of the FET control input signal. Since the circuit for VDS abnormality detection is used for FET inspection, VDS abnormality detection is disabled. In addition, according to the setting of 3 bits of fet_rmidonU, fet_rmidonV, and fet_rmidonW, the U phase, V phase, and W phase mid-voltage generating resistors can be turned ON individually. When multiple bits are turned ON at the same time, the resistance of the corresponding phase is turned ON simultaneously.

By setting ft_comp_sel="H," VDS detection comparator (after being filtered) output can be read from [VDS_COMP_STAT](#) register. Have the microcomputer read these values during inspection and confirm the expected operation.

When fet_manual_test and fet_auto_test become valid simultaneously, fet_auto_test is given priority and an automatic inspection sequence is started. And Fig. 7.8-b shows a period "Normal operation," which indicates that the IC operation has exited FET_TEST mode. Please set fet_test_nulock="L" during the period of "normal operation in which actually driving a motor is intended" at the system level to prevent FET_TEST from being invoked incorrectly.

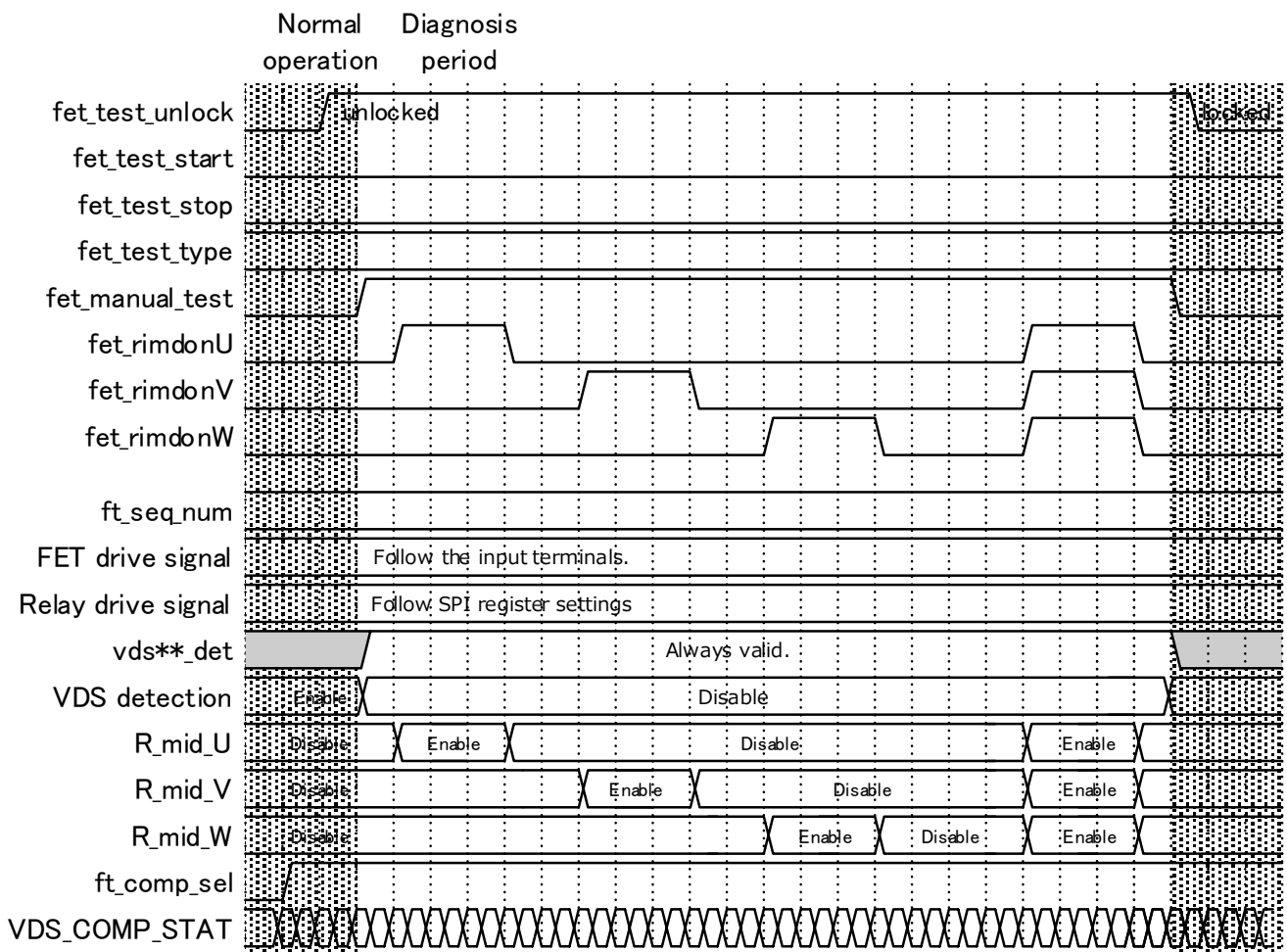


Fig. 7.8-b Operation waveforms in the manual inspection mode

7.8.4. Inspection method Type A

This type is intended to be performed while motor relays are off. Before starting inspection, set motor relays OFF by the [CP_RLY_CTRL](#) register. By selecting fet_test_type=A and setting fet_test_start while fet_test_unlock="H," a Type A inspection sequence is started. When a Type A inspection sequence is started, this IC turns on the mid-voltage generating resistors and waits for a certain period of time. After that, this IC turns all pre-drivers for motor control OFF and performs expectation comparison. Then, this IC compares comparator output (after being noise filtered) with expected values while tuning ON the pre-drivers for motor control one by one. While an inspection sequence is being executed, resistors for maintaining HUS, HVS, and HWS at the mid-voltage when pre-drivers are off are tuned ON. During an inspection sequence, VDS comparator (after being filtered) output is stored in registers according to the predefined timing. Have the microcomputer check the inspection result after confirming that the sequence is completed by fet_auto_test="L." When no disagreement with expected values is found, fet_test_err="L" is given. When there is any disagreement with the expected values, the sequence is stopped when a disagreement is found, and at what step the disagreement is generated can be checked by reading ft_seq_num. The comparator (after being noise filtered) output stored when a disagreement is detected can be checked by reading [VDS_COMP_STAT](#) after setting ft_comp_sel="L." Where the fault has occurred can be presumed by comparing the sequence number when the expectation disagreement is generated, expected values in Table 7.8-b, with the comparator output.

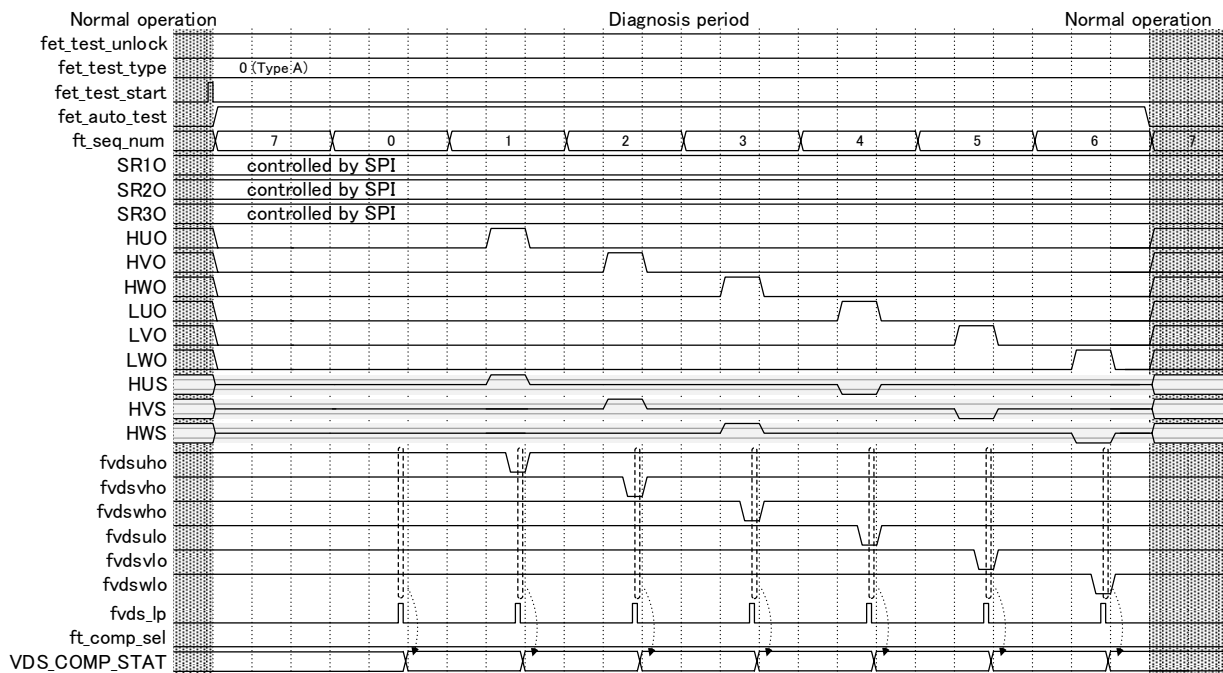


Fig. 7.8-c Operation waveforms in the inspection method Type A

Table 7.8-c Expected values in the inspection method Type A

| | | VDS_COMP_STAT | | | | | | HEX |
|------------|---|---------------|------------|------------|------------|------------|------------|------|
| | | D10 | D8 | D6 | D4 | D2 | D0 | |
| | | compout_uh | compout_ul | compout_vh | compout_vl | compout_wh | compout_wl | |
| ft_seq_num | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0555 |
| | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0155 |
| | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 0515 |
| | 3 | 1 | 1 | 1 | 1 | 0 | 1 | 0551 |
| | 4 | 1 | 0 | 1 | 1 | 1 | 1 | 0455 |
| | 5 | 1 | 1 | 1 | 0 | 1 | 1 | 0545 |
| | 6 | 1 | 1 | 1 | 1 | 1 | 0 | 0554 |

7.8.5. Inspection method Type B

This type is intended to be performed while motor relays are ON. Before starting inspection, set motor relays ON by the [CP_RLY_CTRL](#) register. By selecting fet_test_type=B and setting fet_test_start while fet_test_unlock="H," a Type B inspection sequence is started. When a Type B inspection sequence is started, this IC turns on the mid-voltage generating resistors and waits for a certain period of time. After that, this IC turns all pre-drivers for motor control OFF and performs expectation comparison. Then, this IC compares comparator output (after being noise filtered) with expected values while tuning ON the pre-drivers for motor control one by one. While an inspection sequence is being executed, resistors for maintaining HUS, HVS, and HWS at the mid-voltage when pre-drivers are off are tuned ON. During an inspection sequence, VDS comparator (after being filtered) output is stored in registers according to the predefined timing. Have the microcomputer check the inspection result after confirming that the sequence is completed by fet_auto_test="L." When no disagreement with expected values is found, fet_test_err="L" is given. When there is any disagreement with the expected values, the sequence is stopped when a disagreement is found, and at what step the disagreement is generated can be checked by reading ft_seq_num. The comparator (after being noise filtered) output stored when a disagreement is detected can be checked by reading VDS_COMP_STAT after setting ft_comp_sel="L." Where the fault has occurred can be presumed by comparing the sequence number when the expectation disagreement is generated, expected values in Table 7.8-d, with the comparator output.

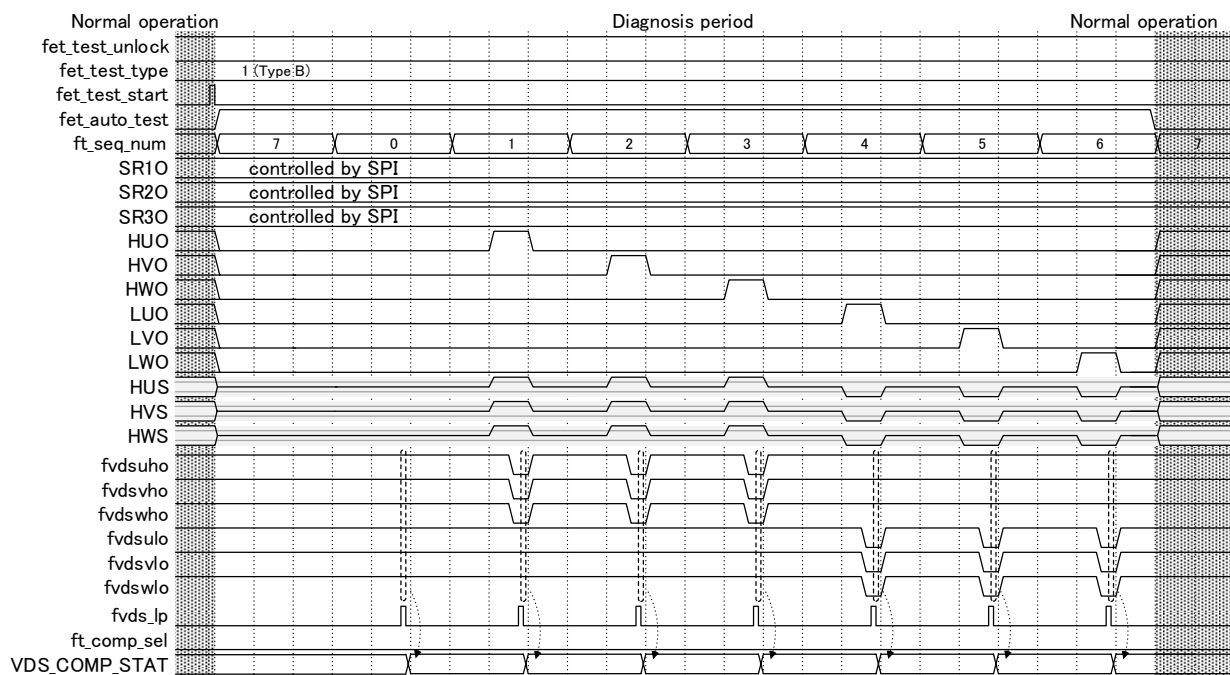


Fig. 7.8-d Operation waveforms in the inspection method Type B

Table 7.8-e Expected values in the inspection method Type B

| | | VDS_COMP_STAT | | | | | | HEX |
|------------|---|---------------|------------|------------|------------|------------|------------|------|
| | | D10 | D8 | D6 | D4 | D2 | D0 | |
| | | compout_uh | compout_ul | compout_vh | compout_vl | compout_wh | compout_wl | |
| ft_seq_num | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0555 |
| | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0111 |
| | 2 | 0 | 1 | 0 | 1 | 0 | 1 | 0111 |
| | 3 | 0 | 1 | 0 | 1 | 0 | 1 | 0111 |
| | 4 | 1 | 0 | 1 | 0 | 1 | 0 | 0444 |
| | 5 | 1 | 0 | 1 | 0 | 1 | 0 | 0444 |
| | 6 | 1 | 0 | 1 | 0 | 1 | 0 | 0444 |

7.8.6. Inspection method Type C

This type is intended to be used when inspecting whether pre-drivers for motor control can be stopped when abnormality is detected. When motor relays or power supply relays are used, perform the inspection after stopping the pre-drivers by setting ALARM terminal = "L" on the microcomputer or other means after setting the relay operation by [CP_RLY_CTRL](#) register so that FETs for motor control operate normally. At this time, set alr_op="H" in [ALM_CTRL](#) so that only the pre-drivers for motor control should stop and relays should not stop when ALARM is detected.

By selecting fet_test_type=C and setting fet_test_start while fet_test_unlock="H," a Type C inspection sequence is started. When a Type C inspection sequence is started, this IC turns on the mid-voltage generating resistors and waits for a certain period of time. After that, this IC turns all pre-drivers for motor control off and performs expectation comparison. Then, this IC compares comparator output (after noise filtered) signals with the expected values for two cases: when three channels of the motor control pre-drivers in the high side are turned ON simultaneously and when three channels in the low side are turned ON simultaneously. While an inspection sequence is being executed, resistors for maintaining HUS, HVS, and HWS at the mid-voltage when pre-drivers are off are tuned ON. During an inspection sequence, VDS comparator (after being filtered) output is stored in registers according to the predefined timing. Have the microcomputer check the inspection result after confirming that the sequence is completed by fet_auto_test="L." When no disagreement with expected values is found, fet_test_err="L" is given. When there is any disagreement with the expected values, the sequence is stopped when a disagreement is found, and at what step the disagreement is generated can be checked by reading ft_seq_num. The comparator (after being noise filtered) output stored when a disagreement is detected can be checked by reading VDS_COMP_STAT after setting ft_comp_sel="L." Where the fault has occurred can be presumed by comparing the sequence number when the expectation disagreement is generated, expected values in Table 7.8-f, with the comparator output.

Table 7.8-g Expected values in the inspection method Type C

| | | Normal operation | | Diagnosis period | | | Normal operation | |
|------------|---|------------------|----------------|-------------------|------------|---------|------------------|------|
| | | fet_test_unlock | | VDS_COMP_STAT | | | | |
| | | fet_test_type | | 2(Type C) | | | | |
| | | D10 | fet_test_start | D6 | D4 | D2 | D0 | HEX |
| | | compout_uh | fet_auto_test | compout_vh | compout_vl | compout | compout_wl | |
| ft_seq_num | 0 | 1 | \$R10 | controlled by SPI | | | 1 | 0555 |
| | 1 | 1 | \$R20 | controlled by SPI | | | 1 | 0555 |
| | 2 | 1 | \$R30 | controlled by SPI | | | 1 | 0555 |
| | | | HUO | 1 | 1 | 1 | 1 | |
| | | | LHO | | | | | |
| | | | HVO | | | | | |
| | | | LVO | | | | | |
| | | | HUS | | | | | |
| | | | HVS | | | | | |
| | | | HWS | | | | | |
| | | | fvdsuho | | | | | |
| | | | fvdsvho | | | | | |
| | | | fvdswho | | | | | |
| | | | fvdsulo | | | | | |
| | | | fvdsvlo | | | | | |
| | | | fvdswlo | | | | | |
| | | | fvds_lp | | | | | |
| | | | ft_comp_sel | | | | | |
| | | | VDS_COMP_STAT | | | | | |

Fig. 7.8-e Operation waveforms in the inspection method Type C

7.8.7. Inspection method Type D

This model is intended to be used when inspecting the independence of the motor relays, but allows any combination of FET drives to be set by the [FET TEST CNT2](#) register, so can be used for general purposes. A Type D inspection is executed for a single pattern only. The Type D inspection allows any combination of FET drives to be set but uses the values at the timing when the Type D inspection sequence is started, so set the desired values before starting. When a drive pattern in which both high side and low side are ON simultaneously, both the high and low sides are treated as OFF. The IC does not perform expectation comparison but the comparator output (after being noise filtered) signals can be read for six channels. While an inspection sequence is being executed, resistors for maintaining HUS, HVS, and HWS at the mid-voltage when pre-drivers are off are tuned ON.

By selecting fet_test_type=D and setting the fet_test_start during a fet_test_unlock=H period, a Type D inspection sequence is started. When a Type D inspection sequence is started, this IC turns on the mid-voltage generating resistors and waits for a certain period of time. After that, FETs are driven by the drive pattern set in the FET_TEST_CONT2 register. During an inspection sequence, VDS comparator (after being filtered) output is stored in registers according to the predefined timing. Have the microcomputer check the inspection result after confirming that the sequence is completed by fet_auto_test="L." The comparator (after being noise filtered) output stored during the inspection can be checked by reading [VDS_COMP_STAT](#), so, have the microcomputer check whether the operation is as expected or not.

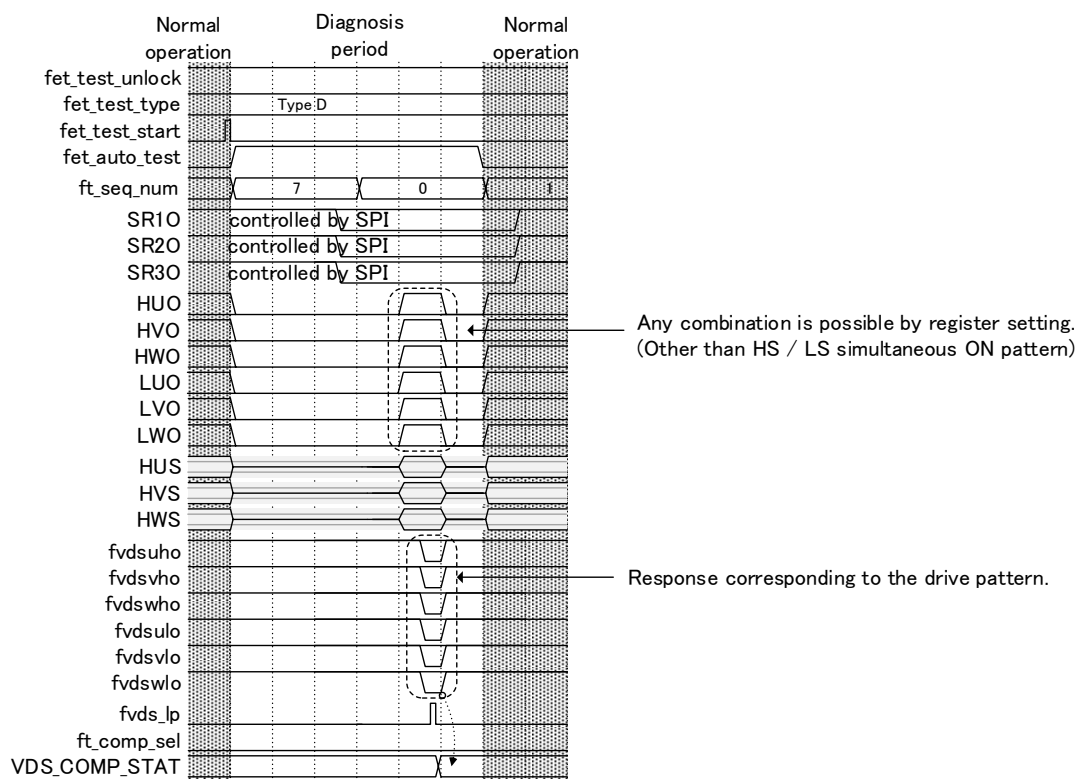


Fig. 7.8-f Operation waveforms in the inspection method Type D

7.8.8. Starting and ending an inspection sequence

By setting the fet_test_start bit after setting fet_test_unlock="H," inspection is started. Fig. 7.8 g shows a period described as "Normal operation, which indicates that the IC's operation has gotten out of the FET_TEST mode. Please set fet_test_nulock="L" during the period of "normal operation in which actually driving a motor is intended" at the system level to prevent FET_TEST from being invoked incorrectly. Even if fet_test_start is received during an inspection, it is ignored. While FET_TEST is being executed, pre-drivers for motor control are controlled by the FET_TEST block. To prevent FETs from being unintentionally driven when FET_TEST is started and ended, have the microcomputer control FETs' control signals (HUI, HVI, HWI, LUI, LVI, LWI terminal input) so that FETs are turned OFF before executing FET_TEST.

There are two ways to stop an inspection: using fet_test_stop and fet_test_unlock="L."

When stopped by fet_test_stop, the inspection stops when a step being executed is completed (the ft_seq_num after the inspection completion is number of the inspection step executed last). However, when fet_test_stop is received in the final inspection step in each inspection sequence, it is ignored (ft_seq_num=6h in a Type A or Type B inspection sequence, ft_seq_num=2h in a Type C inspection sequence, Type D inspection sequence).

When fet_test_unlock="L" is used, the inspection is forced to return to the normal operation state when fet_test_unlock="L" is received irrespective of whether the inspection step being executed has been completed or not (the relation between ft_seq_num and stored comparator output results is not guaranteed).

The vds**_det which is the input signal to the noise filter for VDS detection is enabled only during periods when the applicable channels are controlled to be ON and used for VDS voltage abnormality detection, but is always enabled for FET inspection during the FET_TEST periods. However, VDS abnormality detection is disabled during FET_TEST periods, so VDS abnormality is not detected during a FET_TEST period. While FET_TEST is being executed, resistors for maintaining the mid-voltage are tuned ON.

For inspection methods Type A and Type B, when there is no disagreement with expected values, an inspection stops at ft_seq_num=7h, and for Type C inspection method, at ft_seq_num=3h. The fet_auto_test is a register that can be read and becomes "H" while FET_TEST is being executed.

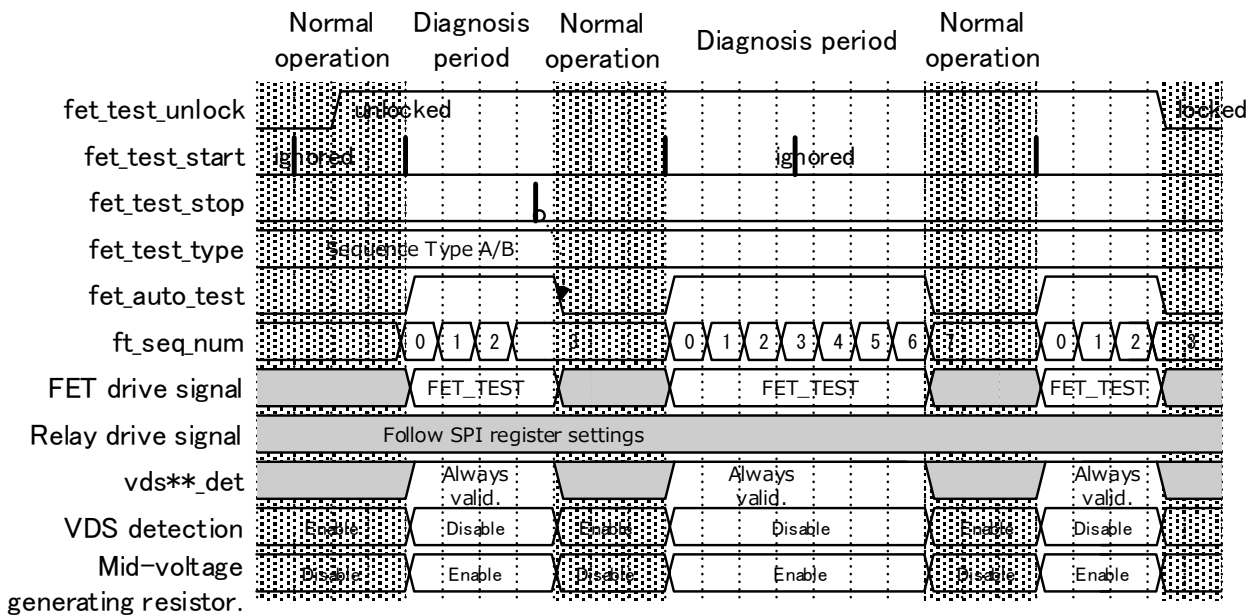


Fig. 7.8-g Operation waveforms related to the starting and ending of FET inspection

7.8.9. Operation when disagreement with any expected value occurs

In an inspection of Type A/Type B/Type C, expectation comparison is performed during the inspection. When disagreement with any expected value occurs, the inspection sequence is stopped and fet_test_err="H" is set. At this time, the number of the inspection sequence at which the expectation disagreement occurred is stored in ft_seq_num. In ft_comp_save (data when VDS_COMP_STAT's ft_comp_sel="L"), the comparator output (after being noise filtered) signals in the inspection performed last (expectation disagreement occurred) are stored for six channels. By reading these values, the microcomputer can check at what output at what inspection step the disagreement occurred. The fet_test_err register and ft_comp_save register are cleared when a new inspection is started or the ft_save_cl bit is set.

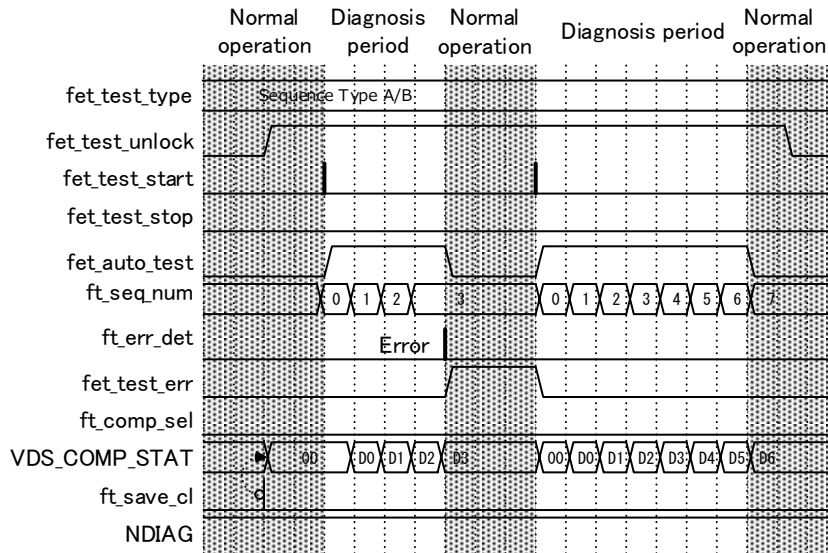


Fig. 7.8-h Operation waveforms when expectation disagreement is detected

7.8.10. Selecting data to be read

Data to be read by the VDS_COMP_STAT register can be selected by setting the ft_comp_sel bit from data during an automatic sequence and current values of VDS comparator output. The ft_comp_sel is only a setting bit to select which data to read, and does not affect data stored in automatic sequences. There is no restriction that ft_comp_sel="L" has to be always set during an automatic sequence. It is enough to set ft_comp_sel="L" when checking the results stored in an automatic sequence.

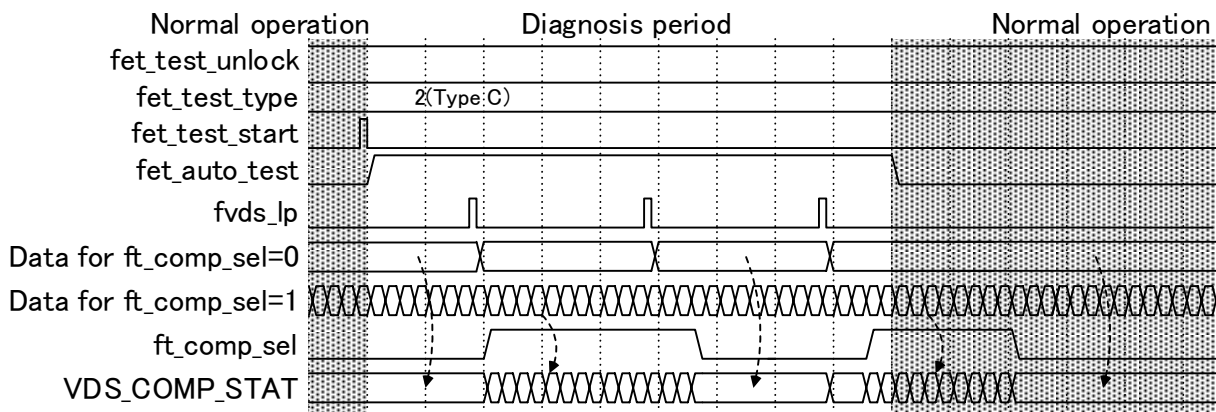


Fig. 7.8-i Selecting data to be read by setting ft_comp_sel

7.8.11. Output to NDIAG during FET inspection

Setting ft_ndiag_sel="H" allows NDIAG="L" to be set while FET_TEST is being executed (during a fet_auto_test="H" period) and when expectation disagreement is detected during an inspection (during a fet_test_err="H" period). The fet_test_err is cleared when a new inspection is started or the ft_save_cl bit.

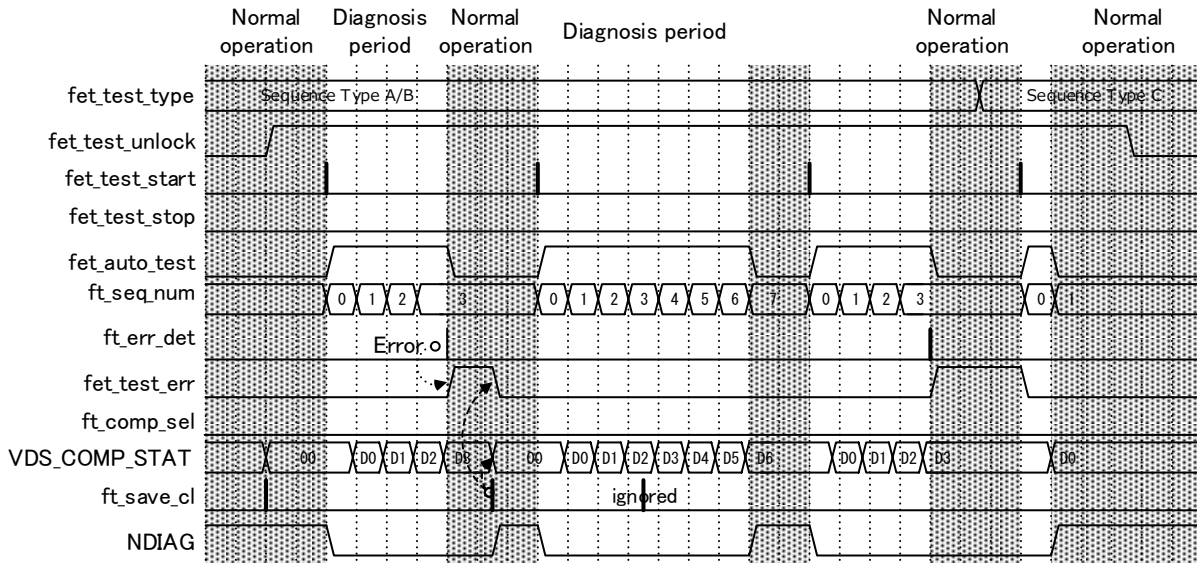


Fig. 7.8-j Operation waveform when outputting to NDIAG during inspection

Table 7.8-e shows the FET inspection time when there is no error. When ft_ndiag_sel = "H" is set it is the same as the length of the NDIAG = "L" period.

Table 7.8-e FET inspection time

| Test Type | Typ. | Max |
|-----------|--------------|--------------|
| Type A | 1024 μ s | 1576 μ s |
| Type B | 1024 μ s | 1576 μ s |
| Type C | 512 μ s | 788 μ s |
| Type D | 256 μ s | 394 μ s |

7.9. SPI communication circuit

The SPI communication circuit consists of the SPI core circuit and register read circuit. Only when NSCS="L," communication with a microcomputer is possible. At a rising edge of the clock, the microcomputer writes data to SI and at the next falling edge, the IC reads the data. And at a rising edge of the clock, the IC writes data to SO and at the next falling edge, the microcomputer reads the data. SI receives data bits from the microcomputer from MSB to LSB. SO sends data bits to the microcomputer from MSB to LSB. The output is in a push-pull configuration and becomes a high impedance when NSCS="H." And in the IC, the NSCS terminal is pulled up by a resistor, and SCLK and SI terminals are pulled down by resistors.

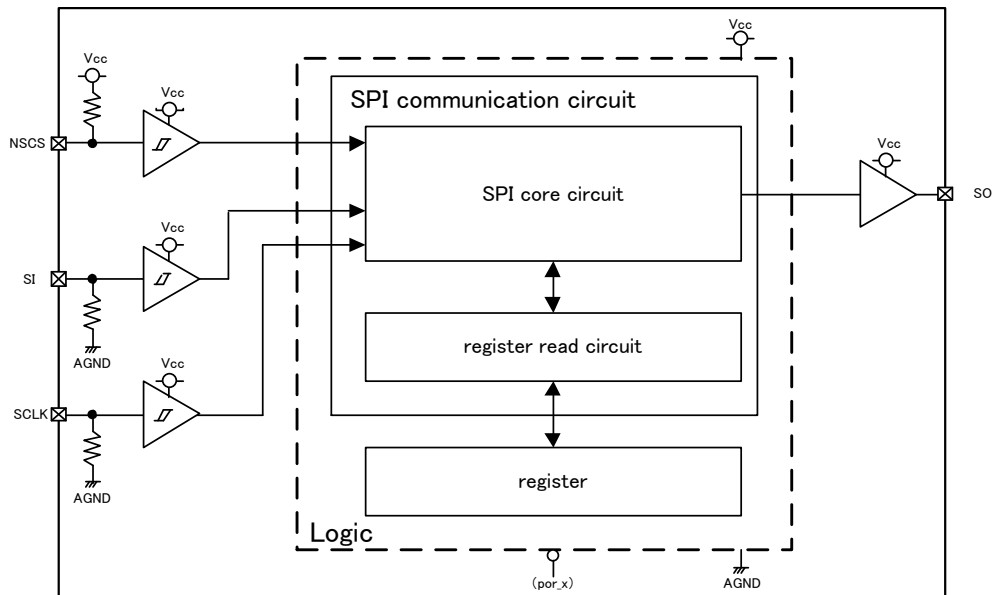


Fig. 7.9-a SPI communication circuit block diagram

7.9.1. SPI communication operation

When NSCS="L," serial data is transmitted in sync with SCLK. When NSCS="H," the SO output becomes a high impedance. The frame length is 32 bits. Two functions are provided: read operation and write operation, and selection between read operation and write operation can be made by "RW" bit (Address [7]). Address [0] is not used for address selection. The "Dummy" bit does not affect operation.

<Write operation>

The data format in the write operation is shown in Fig. 7.9 b.

SI consists of Address[7:0], address specifying bits, Write_Data[15:0], write data specifying bits, and CRC[7:0], bits for checking data. When writing, an address is specified by setting Address[7]=0. Address[0] is not used for address selection. CRC covers Address[7:0] and Write_Data[15:0].

SO outputs data of the address set by SI to Previous_Data[15:0], after dummy data (0x00) is output in 8 bits during the SI's address setting period. At this time, the address data used for SO output is not checked by CRC. For write-only registers, output data from SO is zero. Previous_Data [15: 0] is the data immediately before Write_Data [15: 0] of the register specified by Address [7: 0] to be written. CRC covers Previous_Data[15:0].

After writing, always confirm that correct data is written by reading the data. And empty bits having no register are read as 0 when read.

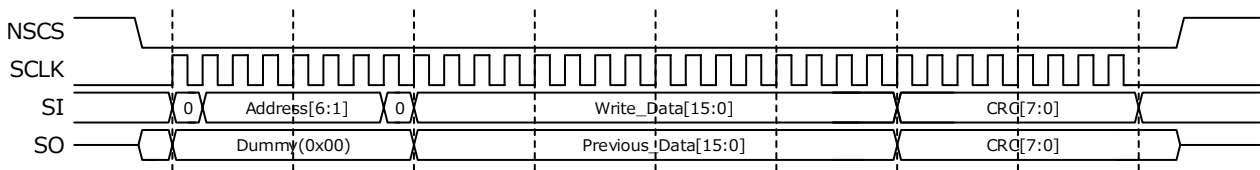


Fig. 7.9-b Data format during write operation

< Read operation>

The data format in the read operation is shown in Fig. 7.9-c.

SI consist of Address[7:0], address specifying bits, Dummy[7:0], dummy data, and CRC[7:0], bits for checking data. When reading, an address is specified by setting Address[7]=1. Address[0] is not used for address selection. CRC covers Address[7:0].

SO outputs of the address set by SI to Read_Data[15:0], after dummy data (0x00) is output during SI's address setting period. Empty bits having no register are read as 0 when read. CRC covers Read_Data[15:0].

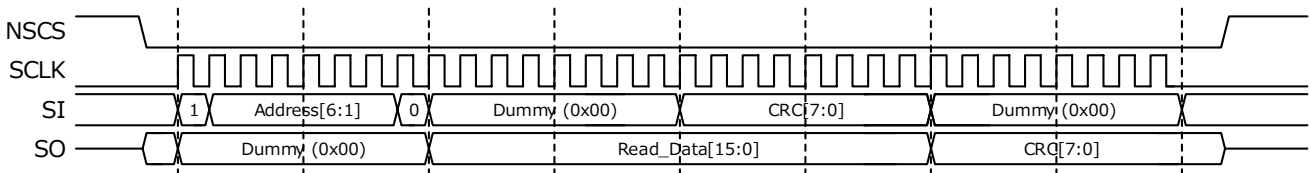


Fig. 7.9-c Data format during read operation

<CRC error check>

CRC error check is conducted to check whether data communication was correctly performed or not. The generating polynomial is shown below. Its initial value is 0xFF.

$$x^8+x^4+x^3+x^2+1$$

When a CRC error is found, the operation is as shown below.

(1) In write operation

When a CRC error is found, data is not written to the IC.

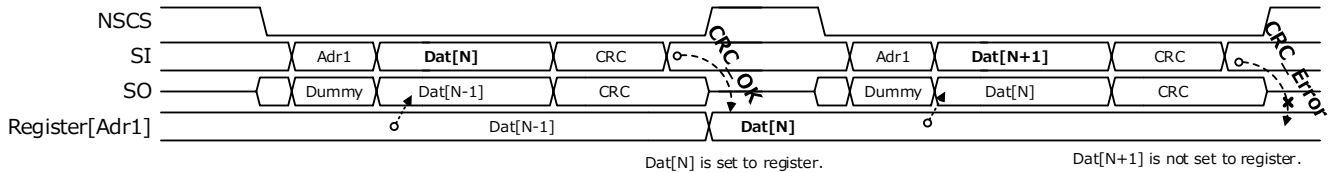


Fig. 7.9-d CRC error during write operation

(2) In read operation

When a CRC error is found, a bad CRC intentionally created is returned from SO in the same frame. This makes the microcomputer detect the CRC error.

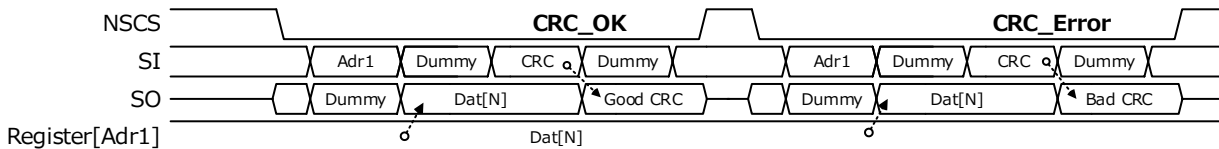


Fig. 7.9-e CRC operation during read operation

<When Vcc drop is detected>

When a Vcc drop is detected, SPI communication cannot be conducted.

When a Vcc drop is detected, SO is fixed to "0." (both in write operation and in read operation)

<During LBIST>

SPI communication cannot be conducted.

<Judged as Fail>

In SPI communication, the IC judges that an communication error has occurred in the following cases, and sets NDIAG="L," and "1" is written to err_spi: register of SPI communication abnormality.

(1) When an address with no register is accessed, an error is generated. For address judgment, Address[7:1] is used (When data is to be written to a register to which any write address is assigned, no data is written to the IC). Address[0] is ignored.

- SO data in write operation is Dummy="0," Previous_Data="0." And since no data is written to registers, register data maintains the previous state (or default values).

- SO data in read operation is "0."

(2) When the frame length is other than 32 bits, a communication error is generated.

- When the frame length in write operation is other than 32 bits, nothing is written to the IC.

- When the frame length is less than 32 bits in read operation, SO is HiZ when NSCS="H."

- When the frame length is 33 bits or longer in read operation, SO is "0" output for the 33rd bit and later in the transmission frame.

(3) When a CRC error is detected, a communication error is generated.

- When a CRC error is detected in write operation, nothing is written to the IC.

- When a CRC error is detected in read operation, an intentionally created bad CRC is returned.

*An intentionally created bad CRC is made of bits generated by inverting all bits of a normal CRC for Read_Data[15:0] output from SO.

7.9.2. QA timer function

The SPI circuit contains QA operation and timer functions, and this IC can perform protection operation such as checking whether the microcomputer's arithmetic function works correctly at a certain level and turning pre-drivers off when pre-defined conditions are not met. With the [QA_CTRL](#) register, timeout enabled/disabled, timeout time, and operation when an accumulated error value has exceeded the pre-defined value are set. By using [ANSWER_SET](#) register's qa_code[3:0] or qa_dat[3:0], for the QA timer block, starting the QA timer (Start command), setting answers to the QA timer (AnsSet command) and stopping the QA timer (Stop command) can be performed. In the calculation of answer data of the QA timer, by reading the [QA_COUNT](#) register, data such as QA timer's sequence number at a read operation and expected value data in the previous sequence can be read. So, use these values to create answer data in the microcomputer side and set them in this IC.

7.9.2.1. Start command

By setting qa_code[3:0]=0xA (Start command) in the ANSWER_SET register, a QA timer sequence is started. Set an initial value that is expected as an answer to qa_dat[3:0] at this time (the initial value cannot be set arbitrarily).

When en_qat="H" has been set, timeout measurement starts at a rising edge of NSCS signal which is a related signal of SPI. As the determination of a sequence start uses qa_code[3:0]=0xA only, the QA timer sequence is started even if the value of qa_dat[3:0] is not valid. However, since the set data is an error, the error accumulation counter is incremented. When a QA timer sequence has already been started and an additional Start command is received, the error accumulation counter is incremented. When a CRC error is generated at the SPI communication level, the sequence is not started as it is discarded as an SPI communication error.

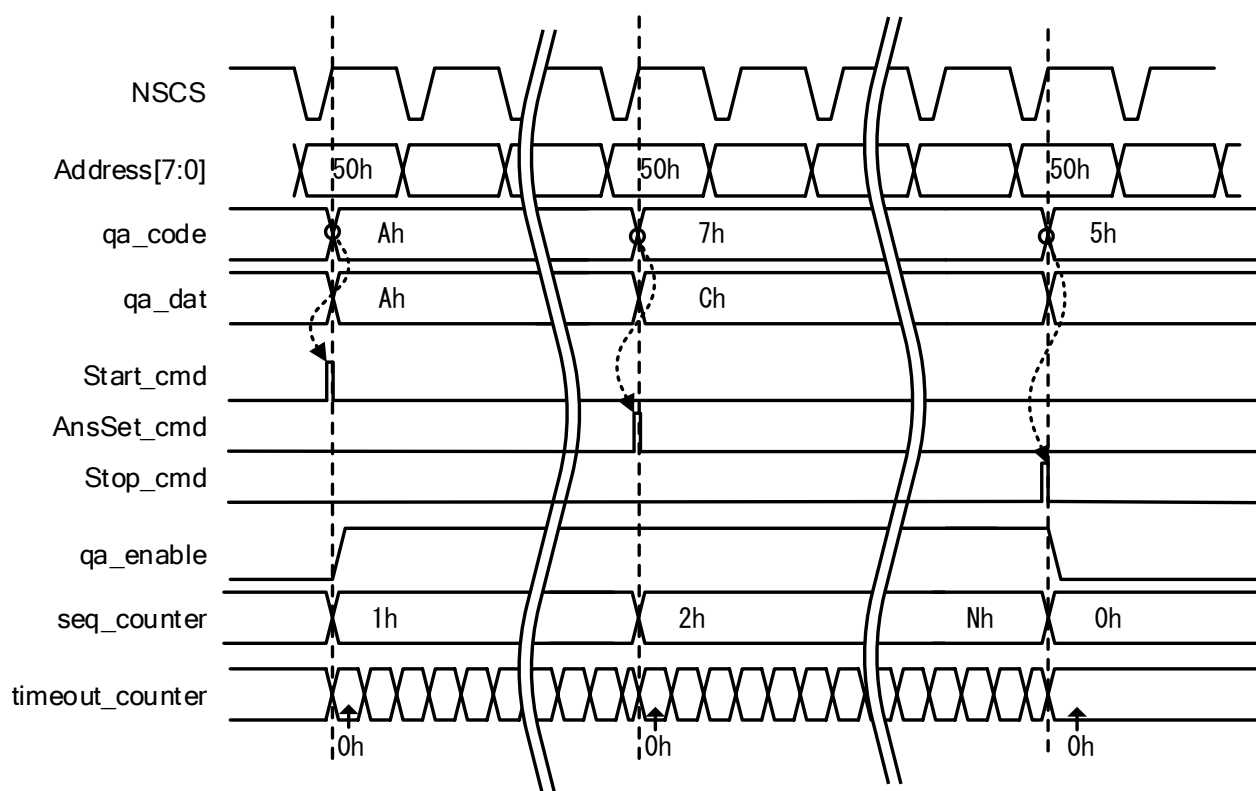


Fig. 7.9-f Start / AnsSet / Stop command

7.9.2.2. AnsSet command

By setting qa_code[3:0]=0x7 (AnsSet command) in the ANSWER_SET register, an answer value in the QA timer's sequence can be set in qa_dat[3:0]. When the setting is for a period when a sequence of the QA timer has not been started, the setting is invalid and discarded.

When en_qat="L," timeout measurement is not performed. When the value of qa_dat[3:0] agrees with the expected value, the error accumulation counter is reset, the sequence counter is incremented, and a next answer is awaited. When the value of qa_dat[3:0] disagrees with the expected value, the error accumulation counter is incremented, the sequence counter is incremented, and a next answer is awaited. When a CRC error is generated at the SPI communication level, QA timer

judgment is not performed as it is discarded as an SPI communication error. The sequence counter is also not incremented.

When en_qat="H," timeout measurement as well as answer value check are performed at the same time. Measurement starts from the rising edge of the NSCS signal of the previous Start command or from the rising edge of the NSCS signal of the previous AnsSet command, and whether the next AnsSet command is set within Tqa which is the timeout time set in the register is checked in advance. When an AnsSet command has not been set within the expected time or the value of qa_dat[3:0] that has been set does not agree with the expected value, the error accumulation counter and sequence counter are incremented to wait for the next answer. The timeout measuring counter is reset when the value of the sequence counter has changed, and measurement is started again. When an CRC error is generated at the SPI communication level, AnsSet command is not set as it is discarded as an SPI communication error.

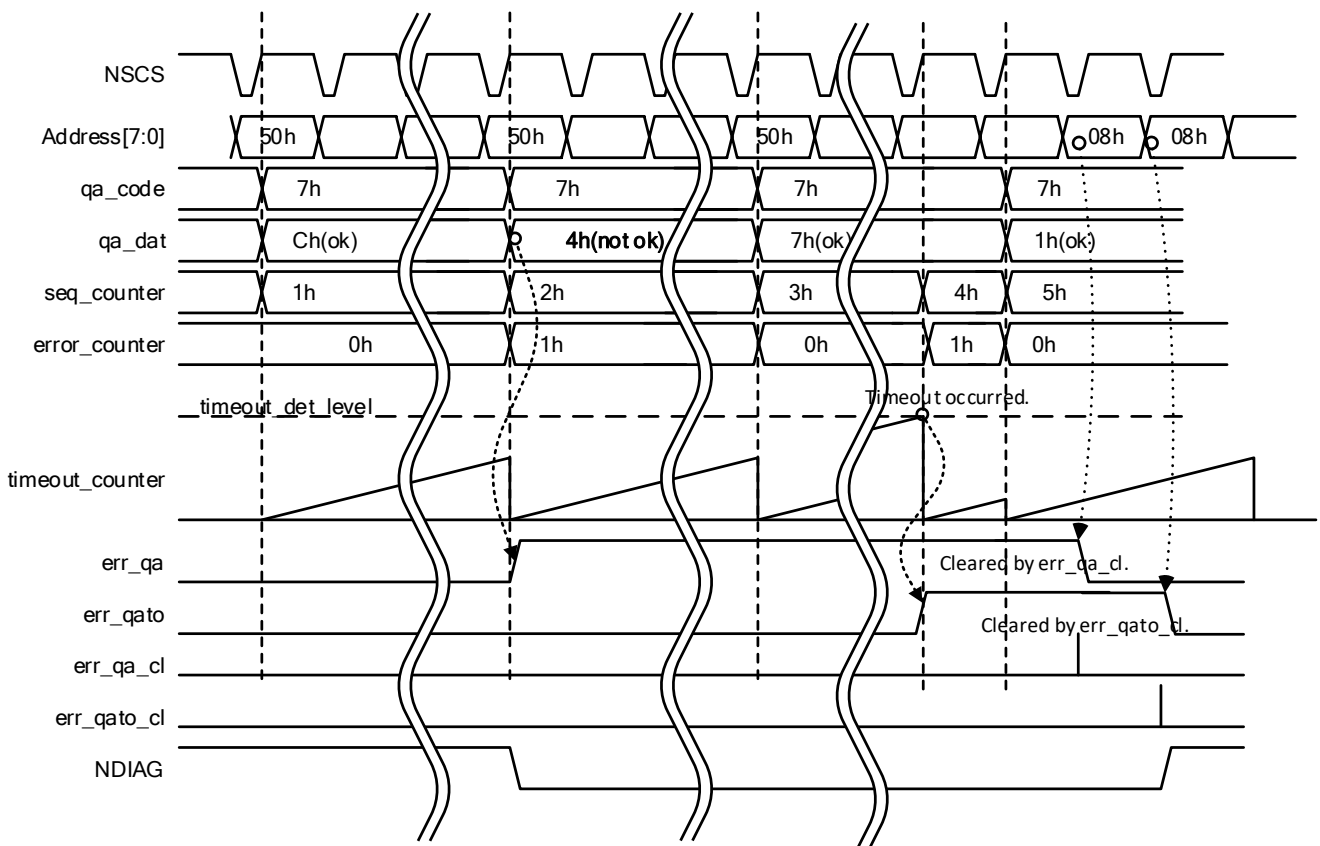


Fig. 7.9-g Operation waveforms when the calculation result is NG, when timeout occurred

7.9.2.3. Stop command

By setting qa_code[3:0]=0x5 (Stop command) in the ANSWER_SET register, the QA timer sequence is stopped. At this time, qa_dat[3:0] is ignored. The Stop command is valid while a QA timer sequence has been started and discarded when issued for other periods. When an CRC error is generated at the SPI communication level, a Stop command is not received as it is discarded as an SPI communication error.

7.9.2.4. Invalid command codes

When a command code other than AnsSet command and Stop command is specified to qa_code[3:0] in the ANSWER_SET register while a QA timer sequence has been started, the error accumulation counter is incremented. The sequence counter is not incremented, and the timeout counter is not cleared.

7.9.2.5. Various statuses and error accumulation counter

The status bit `err_qa` is set to "H" for a sequence where answer data has turned out to be invalid, and it is maintained until it is cleared by the `err_qa_cl` bit.

The status bit `err_qato` is set to "H" for a sequence where answer data has not been obtained within the pre-defined time, and it is maintained until it is cleared by the `err_qato_cl` bit.

The status bit `err_qac` is set to "H" for a sequence where the error accumulation counter value has reached 4, and it is maintained until it is cleared by the `err_qac_cl` bit.

Table 7.9-a Conditions to increment and clear the sequence counter

| Increment | Clear |
|---|-----------------------|
| Received Start command / AnsSet command | Received Stop command |
| Timeout detected | |

Table 7.9-b Conditions to increment and clear the error accumulation counter

| Increment | Clear |
|---|--|
| The data set from the microcomputer is invalid Data was not set within the specified time when <code>en_qat = "H"</code> was set A code other than AnsSet / Stop command was received while the QA timer sequence was valid | Sequence started by Start command When the error accumulation counter is less than 4 and <code>err_qac = "L"</code> , and the data set from the microcomputer matches the expected value. Furthermore, when <code>en_qat = "H"</code> , data is set within the timeout period. When the error accumulation flag is cleared by the <code>err_qac_cl</code> bit. |

Table 7.9-c Conditions to increment and clear the timeout counter

| Increment | Clear |
|---|--|
| Increment automatically by internal clock | When the sequence counter value changes, the timeout counter is cleared and re-measurement is started. |

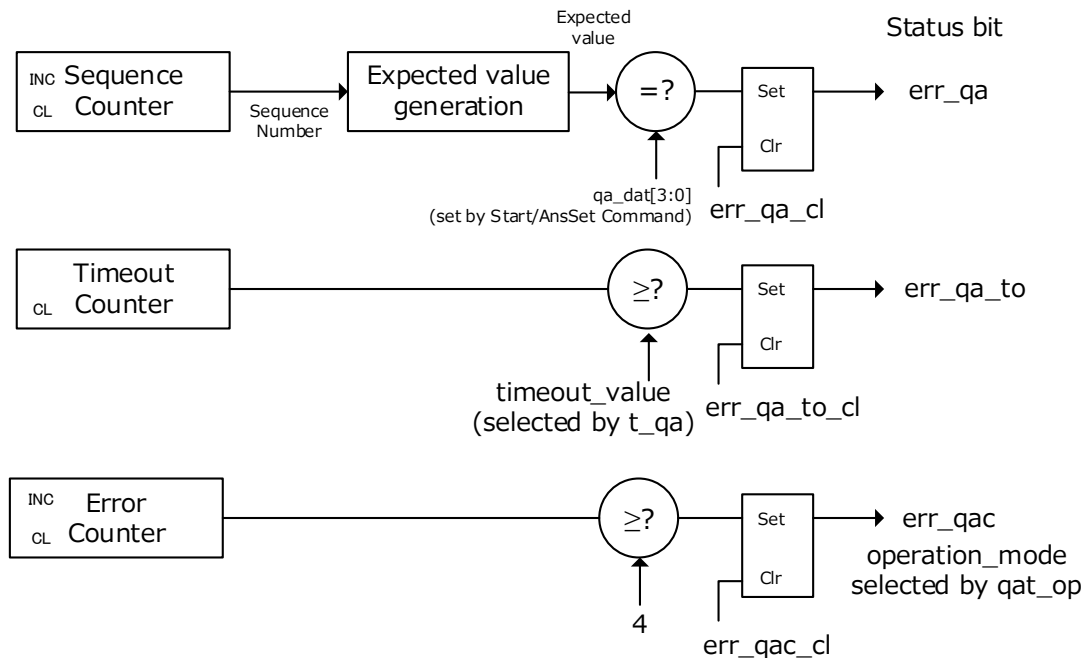


Fig. 7.9-h Generation of various status bits

7.9.2.6. Operation linked with status bits

NDIAG becomes "L" while any of err_qa, err_qato, and err_eqc has been set. While err_eqc is set to "H," the operation of the charge pump and pre-drivers follows what has been set by qat_op. The value qat_op can be modified at any time; however, qat_op has no effect on actual operations while err_qac="H". The new qat_op value takes effect after err_qac = "L".

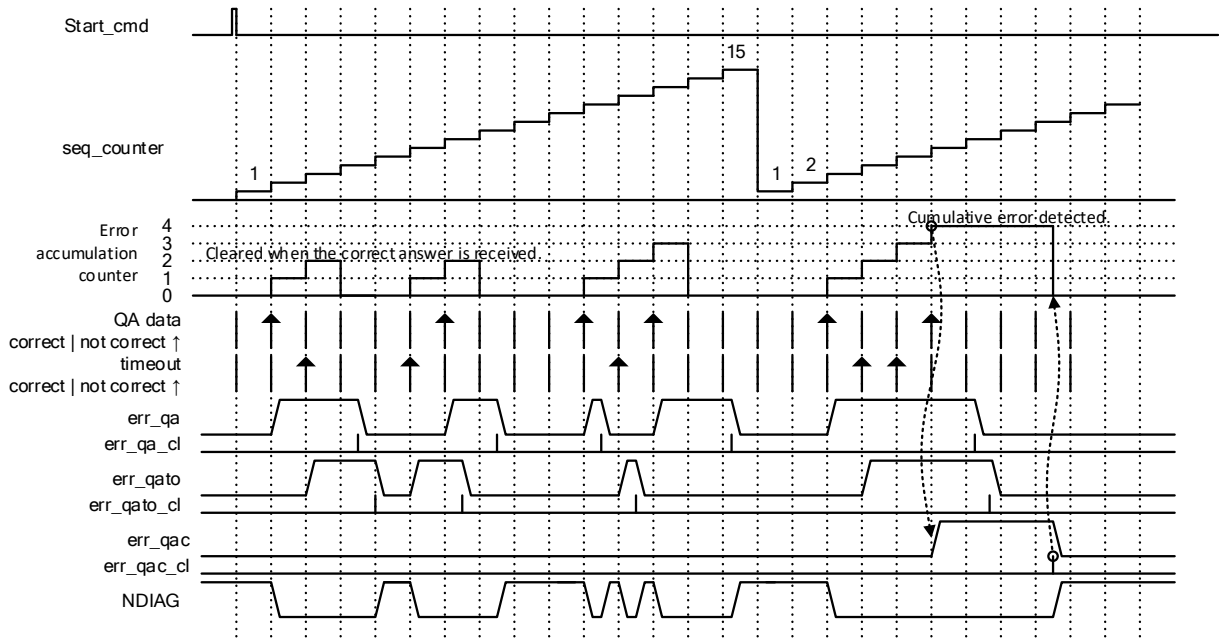


Fig. 7.9-i Behavior by various flags and clear bit at the time of error occurrence

7.9.2.7. Calculation of answer values

By reading `current_seq_number` of the `QA_COUNT` register, the QA timer's current sequence number can be read. The microcomputer can use `current_seq_number` when it generates an answer value from the table of expected values. By reading `prev_expected_value` of the `QA_COUNT` register, the expected value of the previous sequence can be read. When the microcomputer calculates the answer value, it can obtain the answer value by shifting the value of `prev_expected_value` by 4 bits according to the generating polynomial.

The formula of the QA arithmetic function compares computation results in 4 bits generated by the formula below and computation results received from the microcomputer.

$$x^4 + x^3 + 1$$

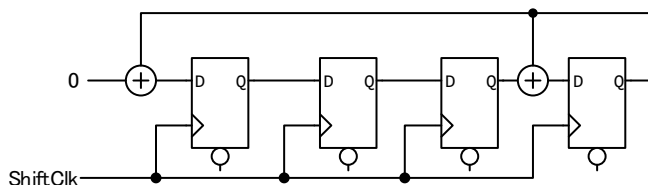


Fig. 7.9-j Set `prev_expected_value` and shift 4 bits

The number of calculation times has 16 values, and when the number of calculation times is 15, `current_seq_number`=1.

Table 7.9-d Calculation of expected values from read data

| 0x0D:QA_COUNT(Read) | | 0x50:ANSWER_SET |
|---------------------|---------------------|-----------------|
| current_seq_number | prev_expected_value | qa_dat |
| Initial Value 0 | Fh | Ah |
| 1 | Ah | Ch |
| 2 | Ch | 8h |
| 3 | 8h | 7h |
| 4 | 7h | Dh |
| 5 | Dh | 1h |
| 6 | 1h | 9h |
| 7 | 9h | Eh |
| 8 | Eh | 3h |
| 9 | 3h | 2h |
| 10 | 2h | Bh |
| 11 | Bh | 5h |
| 12 | 5h | 6h |
| 13 | 6h | 4h |
| 14 | 4h | Fh |
| 15 | Fh | Ah |

7.9.3. Register map

| Symbol | WRITE_AD DRESS | READ_ADD RESS | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | | |
|-----------------|-------------------|------------------|---------|---------------|-------|---------|-------------|---------------|---------------|---------------|---------------|---------------|-----------------|-----------------|-----------------|---------------|----------------|----------------|-----------------|----------------|
| OPSEL1 | 00 h | 0000_ 000* | 80 h | 1000_ 000* | - | ocph_op | | - | ovc_op | | | - | ovccop_op | | | - | uvccop_op | | | |
| OPSEL2 | 04 h | 0000_ 010* | 84 h | 1000_ 010* | - | - | - | - | tsd_op | | | - | ferr_op | | | - | uvb_op | | | |
| STAT1 | - | - | 88 h | 1000_ 100* | uvb | ovc | ocph | uvcco | ovcco | tsd | err_of | err_uf | err_pl | err_pl | err_pl | alm_d | err_sp | err_q | err_q | err_qa |
| STAT1_C LR | 08 h | 0000_ 100* | - | - | uvb_c | ovc_cl | ocph_ cl | uvcco p_cl | ovcco p_cl | tsd_cl | err_of _cl | err_uf _cl | err_pl _u_cl | err_pl _v_cl | err_pl _w_cl | - | err_sp i_cl | err_q a_cl | err_q ato_cl | err_qa c_cl |
| STAT2 | - | - | 8C h | 1000_ 110* | - | - | - | - | vgs_u | vds_u | vgs_u | vds_u | vgs_v | vds_v | - | - | vgs_w | vds_w | vgs_w | vds_w |
| STAT2_C LR | 0C h | 0000_ 110* | - | - | - | - | - | - | vgs_u h_cl | vds_u h_cl | vgs_u l_cl | vds_u l_cl | vgs_v h_cl | vds_v h_cl | vgs_vl _cl | vds_vl _cl | vgs_w h_cl | vds_w wh_cl | vgs_w l_cl | vds_w _cl |
| CP_RLY_ CTRL | 14 h | 0001_ 010* | 94 h | 1001_ 010* | - | - | - | en_cp | - | - | - | srly3_ drv | - | - | - | srly2_ drv | - | - | - | srly1_ drv |
| PL_CTRL | 18 h | 0001_ 100* | 98 h | 1001_ 100* | - | - | - | pl_op | - | - | - | plu_di s | - | - | - | plv_di s | - | - | - | plw_di s |
| T_ILIM | 1C h | 0001_ 110* | 9C h | 1001_ 110* | - | - | t_ilim | | - | - | - | - | - | - | - | - | - | - | - | - |
| FET_OPS EL | 24 h | 0010_ 010* | A4 h | 1010_ 010* | - | - | - | - | - | vgs_op | | | vdsh_op | | | vdsl_op | | | | |
| HS_VDS_ SEL | 28 h | 0010_ 100* | A8 h | 1010_ 100* | - | - | fil_vdsh | | vth_vdsuh | | | vth_vdsvh | | | vth_vdswh | | | | | |
| LS_VDS_ SEL | 2C h | 0010_ 110* | AC h | 1010_ 110* | - | - | fil_vdsl | | vth_vdsul | | | vth_vdsvl | | | vth_vdswl | | | | | |
| FET_DET _SEL | 30 h | 0011_ 000* | B0 h | 1011_ 000* | - | - | - | - | vgshu | vdshu | vgslu | vdslu | vgshv | vdshv | vgslv | vdslv | vgshw | vdshw | vgslw | vdslw |
| AMP_CTR L | 40 h | 0100_ 000* | C0 h | 1100_ 000* | - | - | - | - | cal_a | gain_amp_u | | | cal_a | gain_amp_v | | | cal_a | gain_amp_w | | |

| | | | | | | | | | | | | | | | | | | | | |
|-------------------|---------|---------------|---------|---------------|-----------|-----------|-----------|-------------------------|--------------------------|---------------------|---------------------|----------------------|----------------|--------------------|-----------------------|---------------------|------------------------|------------------------|------------------------|---------------------|
| AMP_STA T_CLR | 44 h | 0100_ 010* | - | - | - | - | - | - | - | - | - | calu_ pass_ cl | - | - | - | calv_p ass_cl | - | - | - | calw_p ass_cl |
| AMP_STA T | - | - | C4 h | 1100_ 010* | - | - | - | cal_e n | - | - | - | calu_ pass | - | - | - | calv_p ass | - | - | - | calw_p ass |
| ALM_CTR L | 48 h | 0100_ 100* | C8 h | 1100_ 100* | - | - | - | alr_op | - | - | - | - | - | - | - | - | - | - | - | fil_alm |
| QA_CTRL | 4C h | 0100_ 110* | CC h | 1100_ 110* | - | qat_op | | | - | - | t_qa | - | - | - | - | - | - | - | - | en_qat |
| ANSWER _SET | 50 h | 0101_ 000* | - | - | - | - | - | - | - | - | - | - | qa_code | | | qa_dat | | | | |
| QA_COU NT | - | - | D0 h | 1101_ 000* | - | - | - | - | acc_count | | | seq_number | | | prev_expected_value | | | | | |
| BIST_DIA G | 54 h | 0101_ 010* | D4 h | 1101_ 010* | - | - | - | - | - | - | - | - | - | - | - | rebst | - | - | - | diag_d g |
| BIST_ST AT | - | - | D8 h | 1101_ 100* | - | - | - | - | - | - | - | - | - | - | lbst_fl ag | lbst_e nd | - | - | abst_f lag | abst_e nd |
| FET_TES T_CNT1 | 5C h | 0101_ 110* | D Ch | 1101_ 110* | - | - | - | - | fet_m annual _test | fet_r midon U | fet_r midon V | fet_r midon W | ft_sav e_cl | - | ft_ndi ag_sel | ft_co mp_s el | fet_te st_typ e1 | fet_te st_ty pe0 | fet_te st_sta rt | fet_tes t_stop |
| FET_TES T_CNT2 | 60 h | 0110_ 000* | E0 h | 1110_ 000* | - | - | - | fet_te st_unl ock | - | typed _uhd | - | typed _uld | - | typed _vhd | - | typed _vld | - | typed _whd | - | typed _wld |
| FET_TES T_STAT | - | - | E4 h | 1110_ 010* | - | - | - | - | - | - | - | - | - | - | fet_au to_tes t | fet_te st_err | - | ft_se q_nu m2 | ft_seq _num 1 | ft_seq _num 0 |
| VDS_CO MP_STAT | - | - | E8 h | 1110_ 100* | - | - | - | - | - | comp out_u h | - | comp out_ul | - | comp out_v h | - | comp out_vl | - | comp out_w h | - | compo ut_wl |
| DUMMY Write | 7c h | 111_ 1100 | FC h | 1111_ 1100 | dmy 15 | dmy 14 | dmy 13 | dmy 12 | dmy 11 | dmy 10 | dmy9 | dmy8 | dmy7 | dmy6 | dmy5 | dmy4 | dmy3 | dmy2 | dmy1 | dmy0 |

*When an attempt is made to write data to a bit that is not assigned (described as "-" in the register map) and the data is set, it is discarded. When the bit is read, it is read as "0."

7.9.3.1. OPSEL1 Write Address=00h / Read Address=80h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 | |
|---------------|-----|---------|-----|-----|-----|-----|--------|----|--|
| Symbol | - | ocph_op | | | | - | ovc_op | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | |
|---------------|----|-----------|----|----|----|----|-----------|----|--|
| Symbol | - | ovccop_op | | | | - | uvccop_op | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |

| bit | Symbol | R/W | Function |
|---------|-----------|-----|---|
| [14:12] | ocph_op | R/W | Operation selection at VCPH high voltage detection "000"=NDIAG:Output "H", continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |
| [10:8] | ovc_op | R/W | Operation selection when VCC high voltage is detected "000"=NDIAG:Output H, continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-driver drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-driver drive FET off(hold), Charge pump off(hold) |
| [6:4] | ovccop_op | R/W | Operation selection when VCC_OP high voltage is detected "000"=NDIAG:Output H, continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |
| [2:0] | uvccop_op | R/W | Operation selection when VCC_OP low voltage is detected "000"=NDIAG:Output H, continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

7.9.3.2. OPSEL2 Write Address=04h / Read Address=84h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|--------|----|----|
| Symbol | - | - | - | - | - | tsd_op | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|---------|----|----|----|--------|----|----|
| Symbol | - | ferr_op | | | - | uvb_op | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

| bit | Symbol | R/W | Function |
|--------|----------|-----|---|
| [10:8] | tsd_op*1 | R/W | Operation selection when overtemperature is detected "000"=NDIAG:Output H, continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |
| [6:4] | ferr_op | R/W | Operation selection when oscillation frequency abnormality is detected "000"=NDIAG:Output "H", continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |
| [2:0] | uvb_op | R/W | Operation selection when VB low voltage is detected "000"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "001"=NDIAG:Output "L",9ch all pre-drivers drive FET off "010"=NDIAG:Output "H",9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold),6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L",6ch motor pre-drivers drive FET off "101"=NDIAG:Output "H",6ch motor pre-drivers drive FET off |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

*1 If the pin short between the VCPH and CP2L pins and between the CP2H and CP1L pins cannot be countermeasured externally to the IC, select "charge pump off" or "charge pump off(hold)" for tsd_op.

7.9.3.3. STAT1_CLR Write Address=08h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|--------|--------|---------|-----------|-----------|--------|-----------|-----------|
| Symbol | uvb_cl | ovc_cl | ocph_cl | uvccop_cl | ovccop_cl | tsd_cl | err_of_cl | err_uf_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-------------|-------------|-------------|----|------------|-----------|-------------|------------|
| Symbol | err_pl_u_cl | err_pl_v_cl | err_pl_w_cl | - | err_spi_cl | err_qa_cl | err_qato_cl | err_qac_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-------------|-----|--|
| 15 | uvb_cl | W | Clear status bit uvb (valid when uvb_op = 3'b000, 3'b011) "0"=Invalid "1" = Clear status bit |
| 14 | ovc_cl | W | Clear status bit ovc "0"=Invalid "1" = Clear status bit |
| 13 | ocph_cl | W | Clear status bit ocph "0"=Invalid "1" = Clear status bit |
| 12 | uvccop_cl | W | Clear status bit uvccop "0"=Invalid "1" = Clear status bit |
| 11 | ovccop_cl | W | Clear status bit ovccop "0"=Invalid "1" = Clear status bit |
| 10 | tsd_cl | W | Clear status bit tsd "0"=Invalid "1" = Clear status bit |
| 9 | err_of_cl | W | Clear status bit err_of "0"=Invalid "1" = Clear status bit |
| 8 | err_uf_cl | W | Clear status bit err_uf "0"=Invalid "1" = Clear status bit |
| 7 | err_pl_u_cl | W | Clear status bit err_pl_u "0"=Invalid "1" = Clear status bit |
| 6 | err_pl_v_cl | W | Clear status bit err_pl_v "0"=Invalid "1" = Clear status bit |
| 5 | err_pl_w_cl | W | Clear status bit err_pl_w "0"=Invalid "1" = Clear status bit |
| 3 | err_spi_cl | W | Clear status bit err_spi "0"=Invalid "1" = Clear status bit |
| 2 | err_qa_cl | W | Clear status bit err_qa "0"=Invalid "1" = Clear status bit |
| 1 | err_qato_cl | W | Clear status bit err_qato |

| | | | |
|---|------------|---|--|
| | | | <u>"0"=Invalid</u> "1" = Clear status bit |
| 0 | err_qac_cl | W | Clear status bit err_qac <u>"0"=Invalid</u> "1" = Clear status bit |

*After migrating to the normal state, the status bit is cleared by writing "1." The cleared register becomes "0" (initial value). In this case, NDIAG="H," returning to the normal operation. Writing "0" is invalid.

* In a state where abnormality has been detected, even if "1" is written, the status registers to be cleared are not cleared.

* The clear bit of a status bit does not need to be returned to 0 after 1 is written.

7.9.3.4. STAT1 / Read Address=88h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|------|--------|--------|-----|--------|--------|
| Symbol | uvb | ovc | ocph | uvccop | ovccop | tsd | err_of | err_uf |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----------|----------|----------|---------|---------|--------|----------|---------|
| Symbol | err_pl_u | err_pl_v | err_pl_w | alm_det | err_spi | err_qa | err_qato | err_qac |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|----------|-----|--|
| 15 | uvb | R | VB undervoltage detection "0"=undetected "1"=detected |
| 14 | ovc | R | VCC overvoltage detection "0"=undetected "1"=detected |
| 13 | ocph | R | VCPH overvoltage detection "0"=undetected "1"=detected |
| 12 | uvccop | R | VCC_OP undervoltage detection "0"=undetected "1"=detected |
| 11 | ovccop | R | VCC_OP overvoltage detection "0"=undetected "1"=detected |
| 10 | tsd | R | Overtemperature detection "0"=undetected "1"=detected |
| 9 | err_of | R | Anomaly detection by Two-way internal oscillator frequency monitoring(OSC_IF high frequency anomaly) "0"=undetected "1"=detected |
| 8 | err_uf | R | Anomaly detection by Two-way internal oscillator frequency monitoring(OSC_IF low frequency anomaly) "0"=undetected "1"=detected |
| 7 | err_pl_u | R | Inhibit input error detection of U-phase pre-driver "0"=undetected "1"=detected |
| 6 | err_pl_v | R | Inhibit input error detection of V-phase pre-driver "0"=undetected "1"=detected |
| 5 | err_pl_w | R | Inhibit input error detection of W-phase pre-driver "0"=undetected "1"=detected |
| 4 | alm_det | R | ARALRM pin input detection "0"=undetected "1"=detected |
| 3 | err_spi | R | SPI communication error detection "0"=undetected "1"=detected |

| | | | |
|---|----------|---|---|
| 2 | err_qa | R | QA calculation error detection "0"=undetected "1"=detected |
| 1 | err_qato | R | QA timeout error detection "0"=undetected "1"=detected |
| 0 | err_qac | R | QA calculation error accumulation detection "0"=undetected "1"=detected |

7.9.3.5. STAT2_CLR Write Address=0Ch

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----------|-----------|-----------|-----------|
| Symbol | - | - | - | - | vgs_uh_cl | vds_uh_cl | vgs_ul_cl | vds_ul_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Symbol | vgs_vh_cl | vds_vh_cl | vgs_vl_cl | vds_vl_cl | vgs_wh_cl | vds_wh_cl | vgs_wl_cl | vds_wl_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-----------|-----|--|
| 11 | vgs_uh_cl | W | Clear status bit vgs_uh "0"=Invalid "1" = Clear status bit |
| 10 | vds_uh_cl | W | Clear status bit vds_uh "0"=Invalid "1" = Clear status bit |
| 9 | vgs_ul_cl | W | Clear status bit vgs_ul "0"=Invalid "1" = Clear status bit |
| 8 | vds_ul_cl | W | Clear status bit vds_ul "0"=Invalid "1" = Clear status bit |
| 7 | vgs_vh_cl | W | Clear status bit vgs_vh "0"=Invalid "1" = Clear status bit |
| 6 | vds_vh_cl | W | Clear status bit vds_vh "0"=Invalid "1" = Clear status bit |
| 5 | vgs_vl_cl | W | Clear status bit vgs_vl "0"=Invalid "1" = Clear status bit |
| 4 | vds_vl_cl | W | Clear status bit vds_vl "0"=Invalid "1" = Clear status bit |
| 3 | vgs_wh_cl | W | Clear status bit vgs_wh "0"=Invalid "1" = Clear status bit |
| 2 | vds_wh_cl | W | Clear status bit vds_wh "0"=Invalid "1" = Clear status bit |
| 1 | vgs_wl_cl | W | Clear status bit vgs_wl "0"=Invalid "1" = Clear status bit |
| 0 | vds_wl_cl | W | Clear status bit vds_wl "0"=Invalid "1" = Clear status bit |

*After migrating to the normal state, the status bit is cleared by writing "1." The cleared register becomes "0" (initial value). In this case, NDIAG="H," returning to the normal operation. Writing "0" is invalid.

* In a state where abnormality has been detected, even if "1" is written, the status registers to be cleared are not cleared.

* The clear bit of a status bit does not need to be returned to 0 after 1 is written.

7.9.3.6. STAT2 / Read Address=8Ch

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|--------|--------|--------|--------|
| Symbol | - | - | - | - | vgs_uh | vds_uh | vgs_ul | vds_ul |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|--------|--------|--------|--------|--------|--------|--------|--------|
| Symbol | vgs_vh | vds_vh | vgs_vl | vds_vl | vgs_wh | vds_wh | vgs_wl | vds_wl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|--------|-----|--|
| 11 | vgs_uh | R | External MOSFET VGS overvoltage detection(U phase high side) "0"=undetected "1"=detected |
| 10 | vds_uh | R | External MOSFET VDS detection(U phase high side) "0"=undetected "1"=detected |
| 9 | vgs_ul | R | External MOSFET VGS overvoltage detection(U phase low side) "0"=undetected "1"=detected |
| 8 | vds_ul | R | External MOSFET VDS detection(U phase low side) "0"=undetected "1"=detected |
| 7 | vgs_vh | R | External MOSFET VGS overvoltage detection(V phase high side) "0"=undetected "1"=detected |
| 6 | vds_vh | R | External MOSFET VDS detection(V phase high side) "0"=undetected "1"=detected |
| 5 | vgs_vl | R | External MOSFET VGS overvoltage detection(V phase low side) "0"=undetected "1"=detected |
| 4 | vds_vl | R | External MOSFET VDS detection(V phase low side) "0"=undetected "1"=detected |
| 3 | vgs_wh | R | External MOSFET VGS overvoltage detection(W phase high side) "0"=undetected "1"=detected |
| 2 | vds_wh | R | External MOSFET VDS detection(W phase high side) "0"=undetected "1"=detected |
| 1 | vgs_wl | R | External MOSFET VGS overvoltage detection(W phase low side) "0"=undetected "1"=detected |
| 0 | vds_wl | R | External MOSFET VDS detection(W phase low side) "0"=undetected "1"=detected |

7.9.3.7. CP_RLY_CTRL Write Address=14h / Read Address=94h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-------|-----|-----|----|-----------|
| Symbol | - | - | - | en_cp | - | - | - | srly3_drv |
| Initial Value | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|-----------|----|----|----|-----------|
| Symbol | - | - | - | srly2_drv | - | - | - | srly1_drv |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-----------|-----|--|
| 12 | en_cp | R/W | Charge pump control "0"=Charge pump output OFF "1"=Charge pump output ON |
| 8 | srly3_drv | R/W | Safety relay 3 control "0"=Safety relay OFF "1"=Safety relay ON |
| 4 | srly2_drv | R/W | Safety relay 2 control "0"=Safety relay OFF "1"=Safety relay ON |
| 0 | srly1_drv | R/W | Safety relay 1 control "0"=Safety relay OFF "1"=Safety relay ON |

7.9.3.8. PL_CTRL Write Address=18h / Read Address=98h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-------|-----|-----|----|---------|
| Symbol | - | - | - | pl_op | - | - | - | plu_dis |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|---------|----|----|----|---------|
| Symbol | - | - | - | plv_dis | - | - | - | plw_dis |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|---------|-----|--|
| 12 | pl_op | R/W | Select operation when inhibited input of pre-driver controll signal is detected. "0"=Inhibit input detection result is not set in the status register. NDIAG:"H" "1"=Inhibit input detection result is set in the status register. NDIAG:"L"(hold) |
| 8 | plu_dis | R/W | Enable / disable selection of inhibited input of pre-driver controll signal detection (phase U) "0"=Enable "1"=Disable |
| 4 | plv_dis | R/W | Enable / disable selection of inhibited input of pre-driver controll signal detection (phase V) "0"=Enable "1"=Disable |
| 0 | plw_dis | R/W | Enable / disable selection of inhibited input of pre-driver controll signal detection (phase W) "0"=Enable "1"=Disable |

*When detection of inhibited input is disabled by the pl*_dis bit, detection itself is disabled. So, even if H*I=L*I="H" is input, the output is H*O=L*O="H," the status bit is not set, and the DIAG terminal does not become "L." (* is U/V/W.) Refer to Table 7.2-b.

7.9.3.9. T_ILIM Write Address=1Ch / Read Address=9Ch

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-------|-----|-----|-----|----|----|
| Symbol | - | - | t_ilm | | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|----|----|----|----|----|
| Symbol | - | - | | | - | - | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|---------|--------|-----|--|
| [13:12] | t_ilm | R/W | Select pre-driver output current limit time "00"=8 μ s "01"=16 μ s "10"=32 μ s "11"= No current limit. |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

※1) "No current limit" modes for pre-driver output current limit time are not recommended to select normally because continuous large current may go through H*O pin and L*O pin.

7.9.3.10. FET_OPSEL Write Address=24h / Read Address=A4h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|--------|----|----|
| Symbol | - | - | - | - | - | vgs_op | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|---------|----|----|----|---------|----|----|----|
| Symbol | vdsh_op | | | | vdsl_op | | | |
| Initial Value | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |

| bit | Symbol | R/W | Function |
|--------|-----------|-----|---|
| [10:8] | vgs_op*1 | R/W | Operation selection when detecting VGS overvoltage of external MOSFET "000"=NDIAG:Output H, continue operation [Detection disabled] "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "011"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold),Charge pump off(hold) |
| [7:4] | vdsh_op*2 | R/W | Operation selection when VDS abnormality of external MOSFET is detected (high side) "0000"=NDIAG:Output H, continue operation [Detection disabled] "0001"=NDIAG:Output "L"(hold), continue operation "0010"=NDIAG:Output "L"(hold), detected phase H / L pre-drivers drive FET off "0011"=NDIAG:Output "L"(hold), detected phase H / L pre-drivers drive FET off(hold) "0100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "0101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold) "0110"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "0111"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off(hold) "1000"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "1001"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold),Charge pump off(hold) |
| [3:0] | vdsl_op*3 | R/W | Operation selection when VDS abnormality of external MOSFET is detected (low side) "0000"=NDIAG:Output H, continue operation [Detection disabled] "0001"=NDIAG:Output "L"(hold), continue operation "0010"=NDIAG:Output "L"(hold), detected phase H / L pre-drivers drive FET off "0011"=NDIAG:Output "L"(hold), detected phase H / L pre-drivers drive FET off(hold) "0100"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off "0101"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold) "0110"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off "0111"=NDIAG:Output "L"(hold), 6ch motor pre-drivers drive FET off(hold) "1000"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off, Charge pump off "1001"=NDIAG:Output "L"(hold), 9ch all pre-drivers drive FET off(hold), Charge pump off(hold) |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

*1 The selection of "010"/"011"/"100" to drive "FET OFF" is not recommended for normal use because it is not the expected operation.

*2 The selection of "0010"/"0100"/"0110"/"1000" to drive "FET OFF" is not recommended for normal use because it is not the expected operation.

*3The selection of "0010"/"0100"/"0110"/"1000" to drive "FET OFF" is not recommended for normal use because it is not expected operation.

7.9.3.11. HS_VDS_SEL Write Address=28h / Read Address=A8h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|----------|-----|-----------|-----|----|----|
| Symbol | - | - | fil_vdsh | | vth_vdsuh | | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------|----|----|----|-----------|----|----|----|
| Symbol | vth_vdsvh | | | | vth_vdswh | | | |
| Initial Value | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

| bit | Symbol | R/W | Function |
|---------|-----------|-----|---|
| [13:12] | fil_vdsh | R/W | External MOSFET VDS detection filter time (high side) selection "00"=6 μ s "01"=8 μ s "10"=10 μ s "11"=12 μ s |
| [11:8] | vth_vdsuh | R/W | External MOSFET VDS detection threshold voltage (U-phase high side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V "1010"=1.1V "1011"=1.2V |
| [7:4] | vth_vdsvh | R/W | External MOSFET VDS detection threshold voltage (V-phase high side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V "1010"=1.1V "1011"=1.2V |
| [3:0] | vth_vdswh | R/W | External MOSFET VDS detection threshold voltage (W-phase high side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V |

| | | |
|--|--|----------------------------|
| | | "1010"=1.1V "1011"=1.2V |
|--|--|----------------------------|

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

7.9.3.12. LS_VDS_SEL Write Address=2Ch / Read Address=ACH

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|----------|-----|-----------|-----|----|----|
| Symbol | - | - | fil_vdsl | | vth_vdsul | | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------|----|----|----|-----------|----|----|----|
| Symbol | vth_vdsvl | | | | vth_vdswl | | | |
| Initial Value | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |

| bit | Symbol | R/W | Function |
|---------|-----------|-----|--|
| [13:12] | fil_vdsl | R/W | External MOSFET VDS detection filter time (low side) selection "00"=6 μ s "01"=8 μ s "10"=10 μ s "11"=12 μ s |
| [11:8] | vth_vdsul | R/W | External MOSFET VDS detection threshold voltage (U-phase low side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V "1010"=1.1V "1011"=1.2V |
| [7:4] | vth_vdsvl | R/W | External MOSFET VDS detection threshold voltage (V-phase low side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V "1010"=1.1V "1011"=1.2V |
| [3:0] | vth_vdswl | R/W | External MOSFET VDS detection threshold voltage (W-phase low side) selection "0000"=0.1V "0001"=0.2V "0010"=0.3V "0011"=0.4V "0100"=0.5V "0101"=0.6V "0110"=0.7V "0111"=0.8V "1000"=0.9V "1001"=1.0V |

| | | |
|--|--|----------------------------|
| | | "1010"=1.1V "1011"=1.2V |
|--|--|----------------------------|

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

7.9.3.13. FET_DET_SEL Write Address=30h / Read Address=B0h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----------|-----------|-----------|-----------|
| Symbol | - | - | - | - | vgshu_dis | vdshu_dis | vgslu_dis | vdslu_dis |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Symbol | vgshv_dis | vdshv_dis | vgslv_dis | vdslv_dis | vgshw_dis | vdshw_dis | vgslw_dis | vdslw_dis |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-----------|-----|--|
| 11 | vgshu_dis | R/W | selection of VGS detection of external MOSFET (U phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 10 | vdshu_dis | R/W | selection of VDS detection of external MOSFET (U phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 9 | vgslu_dis | R/W | selection of VGS detection of external MOSFET (U phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 8 | vdslu_dis | R/W | selection of VDS detection of external MOSFET (U phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 7 | vgshv_dis | R/W | selection of VGS detection of external MOSFET (V phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 6 | vdshv_dis | R/W | selection of VDS detection of external MOSFET (V phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 5 | vgslv_dis | R/W | selection of VGS detection of external MOSFET (V phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 4 | vdslv_dis | R/W | selection of VDS detection of external MOSFET (V phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 3 | vgshw_dis | R/W | selection of VGS detection of external MOSFET (W phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 2 | vdshw_dis | R/W | selection of VDS detection of external MOSFET (W phase high side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 1 | vgslw_dis | R/W | selection of VGS detection of external MOSFET (W phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |
| 0 | vdslw_dis | R/W | selection of VDS detection of external MOSFET (W phase low side) "0"=enable "1"=disable (No new detection, status already detected is not affected) |

7.9.3.14. AMP_CTRL Write Address=40h / Read Address=C0h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----------|------------|----|----|
| Symbol | - | - | - | - | cal_amp_u | gain_amp_u | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------|------------|----|----|-----------|------------|----|----|
| Symbol | cal_amp_v | gain_amp_v | | | cal_amp_w | gain_amp_w | | |
| Initial Value | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |

| BIT | SYMBOL | R/W | FUNCTION |
|--------|------------|-----|---|
| 11 | CAL_AMP_U | W | OPAMP CALIBRATION SELECTION (U PHASE) "0"=INVALID "1"= EXECUTE OPAMP CALIBRATION (CLEARED REGARDLESS OF WHETHER CALIBRATION IS COMPLETED.) |
| [10:8] | GAIN_AMP_U | R/W | CURRENT DETECTION OPAMP GAIN SELECTION (U PHASE) "000"=x7.5 "001"=x10 "010"=x12.5 "011"=x15 "100"=x20 "101"=x27.5 "110"=x27.5 "111"=x27.5 |
| 7 | CAL_AMP_V | W | OPAMP CALIBRATION SELECTION (V PHASE) "0"=INVALID "1"= EXECUTE OPAMP CALIBRATION (CLEARED REGARDLESS OF WHETHER CALIBRATION IS COMPLETED.) |
| [6:4] | GAIN_AMP_V | R/W | CURRENT DETECTION OPAMP GAIN SELECTION (V PHASE) "000"=x7.5 "001"=x10 "010"=x12.5 "011"=x15 "100"=x20 "101"= x27.5 "110"=x27.5 "111"= x27.5 |
| 3 | CAL_AMP_W | W | OPAMP CALIBRATION SELECTION (W PHASE) "0"=INVALID "1"= EXECUTE OPAMP CALIBRATION (CLEARED REGARDLESS OF WHETHER CALIBRATION IS COMPLETED.) |
| [2:0] | GAIN_AMP_W | R/W | CURRENT DETECTION OPAMP GAIN SELECTION (W PHASE) "000"=x7.5 "001"=x10 "010"=x12.5 "011"=x15 "100"=x20 "101"= x27.5 "110"=x27.5 "111"= x27.5 |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

7.9.3.15. AMP_STAT_CLR Write Address=44h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|-----|----|--------------|
| Symbol | - | - | - | - | - | - | - | calu_pass_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|--------------|----|----|----|--------------|
| Symbol | - | - | - | calv_pass_cl | - | - | - | calw_pass_cl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|--------------|-----|---|
| 8 | calu_pass_cl | W | Clear current detection AMP offset calibration test result flag (U phase) "0"=invalid "1"=Clear the flag (There is no need to write this bit back to zero.) |
| 4 | calv_pass_cl | W | Clear current detection AMP offset calibration test result flag (V phase) "0"=invalid "1"=Clear the flag (There is no need to write this bit back to zero.) |
| 0 | calw_pass_cl | W | Clear current detection AMP offset calibration test result flag (W phase) "0"=invalid "1"=Clear the flag (There is no need to write this bit back to zero.) |

*The clear bit of a status bit does not need to be returned to 0 after 1 is written.

7.9.3.16. AMP_STAT / Read Address=C4h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|--------|-----|-----|----|-----------|
| Symbol | - | - | - | cal_en | - | - | - | calu_pass |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|-----------|----|----|----|-----------|
| Symbol | - | - | - | calv_pass | - | - | - | calw_pass |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-----------|-----|---|
| 12 | cal_en | R | Current detection AMP offset calibration operation flag "0"=Calibration stopped "1"=During calibration |
| 8 | calu_pass | R | Current detection AMP offset calibration test result flag (U phase) "0"=Failed or not calibrated "1"=Pass |
| 4 | calv_pass | R | Current detection AMP offset calibration test result flag (V phase) "0"=Failed or not calibrated "1"=Pass |
| 0 | calw_pass | R | Current detection AMP offset calibration test result flag (W phase) "0"=Failed or not calibrated "1"=Pass |

*When the electric current detection AMP calibration of the executed phase is completed normally and its result is Pass, register: cal*_pass becomes "1."

When the result of the electric current detection AMP calibration of the executed phase is failure, register: cal*_pass becomes "0."

** is U, V, or W.

7.9.3.17. ALM_CTRL Write Address=48h / Read Address=C8h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|--------|-----|-----|----|----|
| Symbol | - | - | - | alr_op | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|----|----|----|---------|----|
| Symbol | - | - | - | - | - | - | fil_alm | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-------|---------|-----|---|
| 12 | alr_op | R/W | Operation selection when ALARM is detected "0"=NDIAG:Output "L",9ch all pre-drivers drive FET off "1"=NDIAG:Output "L",6ch motor pre-drivers drive FET off |
| [1:0] | fil_alm | R/W | ALARM digital filter setting (high side / low side common) "00"=16μs *16x2 ² x(1/4MHz)+(1/4MHz) "01"=1ms *1000x2 ² x(1/4MHz)+(1/4MHz) "10"=2ms *2000x2 ² x(1/4MHz)+(1/4MHz) "11"=4ms *4000x2 ² x(1/4MHz)+(1/4MHz) |

7.9.3.18. QA_CTRL Write Address=4Ch / Read Address=CCh

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|--------|-----|-----|-----|-----|----|------|
| Symbol | - | qat_op | | | | - | - | t_qa |
| Initial Value | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|----|----|----|----|--------|
| Symbol | - | - | - | - | - | - | - | en_qat |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|---------|--------|-----|---|
| [14:12] | qat_op | R/W | Operation selection when QA accumulated error is detected "001"=NDIAG:Output "L"(hold), continue operation "010"=NDIAG:Output "L"(hold),9ch all pre-drivers drive FET off(hold) "011"=NDIAG:Output "L"(hold),6ch motor pre-drivers drive FET off(hold) "100"=NDIAG:Output "L"(hold),9ch all pre-drivers drive FET off(hold),Charge pump off(hold) |
| [9:8] | t_qa | R/W | QA timeout period "00"=1ms "01"=2ms "10"=4ms "11"=8ms |
| 0 | en_qat | R/W | selection of QA timeout detection "0"= QA timeout detection disabled "1"= QA timeout detection enabled |

*When a value that is not indicated as a set value is set, the set value for the Symbol is not updated and its previous value is maintained.

*This register is always rewritable, but the set value actually used by the QA timer is the value when the start command is set by qa_code of the ANSWER_SET register.

7.9.3.19. ANSWER_SET Write Address=50h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|-----|----|----|
| Symbol | - | - | - | - | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|---------|----|----|----|--------|----|----|----|
| Symbol | qa_code | | | | qa_dat | | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-------|---------|-----|--|
| [7:4] | qa_code | W | Command selection for QA timer function "5h" = Stop command "7h" = AnsSet command "Ah" = Start command 0h-4h, 6h, 8h, 9h, Bh-Fh: QA command not assigned (If set during the QA sequence, the error accumulation counter is incremented) |
| [3:0] | qa_dat | W | QA timer response data setting area |

7.9.3.20. QA_COUNT / Read Address=D0h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----------|-----|----|----|
| Symbol | - | - | - | - | acc_count | | | |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|-----------------|----|----|----|---------------------|----|----|----|
| Symbol | current_seq_num | | | | prev_expected_value | | | |
| Initial Value | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |

| bit | Symbol | R/W | Function |
|--------|---------------------|-----|---|
| [11:8] | acc_count | R | Cumulative error count of QA timer function |
| [7:4] | current_seq_num | R | Current sequence number of QA timer function |
| [3:0] | prev_expected_value | R | Expected data in the previous sequence of QA timer function |

7.9.3.21. BIST_DIAG Write Address=54h / Read Address=D4h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|-----|----|----|
| Symbol | - | - | - | - | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|----|-------|----|----|----|---------|
| Symbol | - | - | - | rebst | - | - | - | diag_dg |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|---------|-----|--|
| 4 | rebst | W | BIST restart setting "0"=No restart of LBIST / ABIST (normal) "1"=LBIST / ABIST restart execution |
| 0 | diag_dg | R/W | NDIAG function diagnosis selection by SPI communication "0"=NDIAG normal operation "1"=Force NDIAG to output "L" |

*Register: rebst is enabled only when either LBIST or ABIST is judged NG. When BIST is restarted, register: rebst is cleared. In normal operation, even if register: rebst="1" is set, BIST is not restarted.

7.9.3.22. BIST_STAT / Read Address=D8h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|-----|----|----|
| Symbol | - | - | - | - | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|------------|-----------|----|----|-----------|----------|
| Symbol | - | - | lbtst_flag | lbtst_end | - | - | abst_flag | abst_end |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|------------|-----|---|
| 5 | lbtst_flag | R | LBIST result flag "0"=Failure "1"=Pass |
| 4 | lbtst_end | R | LBIST end flag "0"=LBIST not finished (SPI communication is not possible while LBIST is running) "1"=LBSIT finished |
| 1 | abst_flag | R | ABIST result flag "0"=Failure "1"=Pass |
| 0 | abst_end | R | ABISTend flag "0"=ABIST not finished "1"=ABIST finished |

*When ABIST and LBIST are completed normally and the results are Pass, registers: abst_flag, lbtst_flag become "1."

When the results of ABIST and LBIST are failures, registers: abst_flag, lbtst_flag become "0."

* When ABIST and LBIST are completed, registers: abst_end, lbtst_end become "1."

ABIST and LBIST are not completed due to abnormality, registers: abst_end, lbtst_end become "0."

7.9.3.23. FET_TEST_CNT1 Write Address=5Ch / Read Address=DCh

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|---------------------|-----------------|-----------------|-----------------|
| Symbol | - | - | - | - | fet_manu al_test | fet_rmido nU | fet_rmido nV | fet_rmido nW |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|------------|----|------------------|-----------------|--------------------|--------------------|--------------------|-------------------|
| Symbol | ft_save_cl | - | ft_ndiag_s el | ft_comp_s el | fet_test_t ype1 | fet_test_t ype0 | fet_test_s tart | fet_test_s top |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-------|--------------------|-----|---|
| 11 | fet_manual_test | R/W | Mode selection for VDS detection and VDS detection comparator output. (acceptable when fet_test_unlock = "H") "0"=Normal operation "1"= Disable VDS detection and set VDS detection comparator output to FET test mode |
| 10 | fet_rmidoU | R/W | Control the U-phase mid-voltage generating resistors. (acceptable when fet_test_unlock = "H") "0"=Turn off U-phase mid-voltage generating resistors. "1"=Turn on U-phase mid-voltage generating resistors. |
| 9 | fet_rmidoV | R/W | Control the V-phase mid-voltage generating resistors. (acceptable when fet_test_unlock = "H") "0"=Turn Off V-phase mid-voltage generating resistors. "1"=Turn On V-phase mid-voltage generating resistors. |
| 8 | fet_rmidoW | R/W | Control the W-phase mid-voltage generating resistors. (acceptable when fet_test_unlock = "H") "0"=Turn Off W-phase mid-voltage generating resistors. "1"=Turn On W-phase mid-voltage generating resistors. |
| 7 | ft_save_cl | R/W | Clear VDS comparator output (after noise filter) of VDS_COMP_STAT register and error flag FET_TEST_STAT / fet_test_err saved by FET_TEST. "0"=Invalid "1"=Clear (No need to write back to 0. 0 can be read when reading) |
| 5 | ft_ndiag_sel | R/W | Select whether to output to NDIAG when executing FET_TEST "0"=Does not output to NDIAG when executing FET_TEST. "1"= Set NDIAG to "L" during FET_TEST and when expected value mismatch is detected |
| 4 | ft_comp_sel | R/W | Select the contents to read from VDS_COMP_STAT "0"=VDS detection comparator output saved with FET_TEST (after noise filter) "1"= Current value of VDS detection comparator (after noise filter) |
| [3:2] | fet_test_type[1:0] | R/W | Select the test type to be executed with FET_TEST "00"=Type A "01"=Type B "10"=Type C "11"=Type D |
| 1 | fet_test_start | R/W | Start FET_TEST sequence (acceptable when fet_test_unlock = "H") "0"=Invalid "1"=Sequence start (There is no need to write back to 0. 0 can be read when reading.) |
| 0 | fet_test_stop | R/W | Stop the FET_TSET sequence "0"=Invalid "1"=Stop sequence (fet_test_stop has priority if set at the same time as fet_test_start) |

* fet_manual_test, fet_rmidon[U,V,W] bits and fet_test_start bit can be set only when fet_test_unlock="H."

* fet_manual_test, fet_rmidon[U,V,W] bits cannot be set when fet_test_unlock="L." A previously set value is cleared by fet_test_unlock="L."

7.9.3.24. FET_TEST_CNT2 Write Address=60h / Read Address=E0h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----------------|-----|-----------|----|-----------|
| Symbol | - | - | - | fet_test_unlock | - | typed_uhd | - | typed_uld |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|-----------|----|-----------|----|-----------|----|-----------|
| Symbol | - | typed_vhd | - | typed_vld | - | typed_whd | - | typed_wld |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-----|-----------------|-----|--|
| 12 | fet_test_unlock | R/W | Allow test operation by FET_TEST (both automatic / manual) "0"=Does not accept start of FET_TEST operation, forcibly cancels test operation when set during FET_TEST execution "1"= Accept start of FET_TEST operation |
| 10 | typed_uhd | R/W | Specify U-phase high-side pre-driver output value for Type D test sequence "0"=off "1"=on |
| 8 | typed_uld | R/W | Specify U-phase low-side pre-driver output value for Type D test sequence "0"=off "1"=on |
| 6 | typed_vhd | R/W | Specify V-phase high-side pre-driver output value for Type D test sequence "0"=off "1"=on |
| 4 | typed_vld | R/W | Specify V-phase low-side pre-driver output value for Type D test sequence "0"=off "1"=on |
| 2 | typed_whd | R/W | Specify W-phase high-side pre-driver output value for Type D test sequence "0"=off "1"=on |
| 0 | typed_wld | R/W | Specify W-phase low-side pre-driver output value for Type D test sequence "0"=off "1"=on |

* When a phase which is set to ON for both high and low sides, the phase is controlled to OFF for high and low sides.

7.9.3.25. FET_TEST_STAT / Read Address=E4h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|-----|----|----|
| Symbol | - | - | - | - | - | - | - | - |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|----|-------------------|------------------|----|-----------------|-----------------|-----------------|
| Symbol | - | - | fet_auto_t est | fet_test_e rr | - | ft_seq_nu m2 | ft_seq_nu m1 | ft_seq_nu m0 |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|-------|-----------------|-----|--|
| 5 | fet_auto_test | R | FET_TEST sequence execution flag "0"=FET_TEST is stopped "1"=FET_TSET is running |
| 4 | fet_test_err | R | Whether or not an expected value mismatch occurred during execution of FET_TEST (only valid for Type A / Type B / Type C) "0"=No expected value mismatch detected "1"=Expected value mismatch detected |
| [2:0] | ft_seq_num[2:0] | R | Sequence number executed last by FET_TEST (when the expected value mismatch occurs, it is the step number where the mismatch occurred) |

7.9.3.26. VDS_COMP_STAT / Read Address=E8h

| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
|---------------|-----|-----|-----|-----|-----|------------|----|------------|
| Symbol | - | - | - | - | - | compout_uh | - | compout_ul |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---------------|----|------------|----|------------|----|------------|----|------------|
| Symbol | - | compout_vh | - | compout_vl | - | compout_wh | - | compout_wl |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function | |
|-----|------------|-----|---|---|
| | | | ft_comp_sel="L" | ft_comp_sel="H" |
| 10 | compout_uh | R | Last saved data with FET_TEST (U phase high side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (U phase high side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |
| 8 | compout_ul | R | Last saved data with FET_TEST (U phase low side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (U phase low side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |
| 6 | compout_vh | R | Last saved data with FET_TEST (V phase high side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (V phase high side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |
| 4 | compout_vl | R | Last saved data with FET_TEST (V phase low side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (V phase low side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |
| 2 | compout_wh | R | Last saved data with FET_TEST (W phase high side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (W phase high side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |
| 0 | compout_wl | R | Last saved data with FET_TEST (W phase low side) "0"= FET_TEST saved data is "L" "1"= FET_TEST saved data is "H" | External MOSFET VDS monitor (W phase low side) "0" = Comparator output (after filter) is "L" "1" = Comparator output (after filter) is "H" |

7.9.3.27. DUMMY Write Address=7ch / Read Address=FCh

| | | | | | | | | |
|---------------|-------|-------|-------|-------|-------|-------|------|------|
| Bit | D15 | D14 | D13 | D12 | D11 | D10 | D9 | D8 |
| Symbol | dmy15 | dmy14 | dmy13 | dmy12 | dmy11 | dmy10 | dmy9 | dmy8 |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | |
|---------------|------|------|------|------|------|------|------|------|
| Bit | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
| Symbol | dmy7 | dmy6 | dmy5 | dmy4 | dmy3 | dmy2 | dmy1 | dmy0 |
| Initial Value | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| bit | Symbol | R/W | Function |
|--------|--------|-----|-----------|
| [15:0] | dummy | R/W | dummy bit |

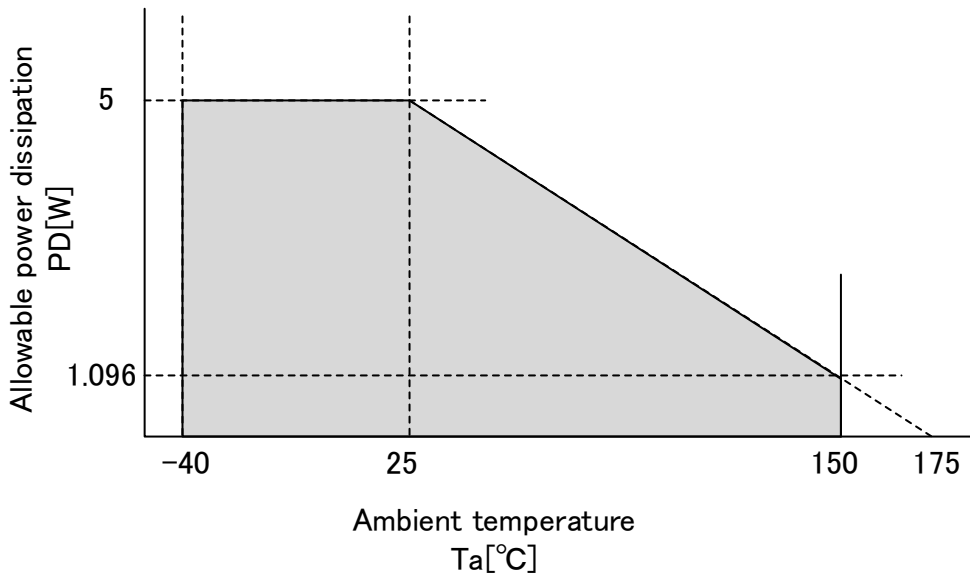
8. Absolute maximum ratings (Ta = 25°C)

Voltages are all based on AGND unless otherwise specified.

| Parameter | Applied Pins | Symbol | Ratings | Unit | Condition |
|--------------------------------------|--|--------|--|------|--|
| Power supply voltage | VB | Vb | -0.3 to 28(DC), 28 to 40(≤1s) | V | - |
| | VCPH | Vcph | -0.3 to 44.5(DC), 44.5 to 60(≤1s) | V | - |
| | VCC | Vcc | -0.3 to 6 | V | - |
| | VCC_OP | Vccop | -0.3 to 6 | V | - |
| Voltage difference between AGND-PGND | AGND1, AGND2, PGND | Vgnd | -0.3 to 0.3 | V | - |
| Input voltage | HS | Vin1 | -18 to Vb+0.3 | V | Vin1≤40V |
| | HUS, HVS, HWS | Vin2 | -7 to Vcph +0.3, -14 to -7(≤1μs,20kHz) | V | Vin2≤40V |
| | LUS, LVS, LWS | Vin3 | -7 to Vcph +0.3, -10 to -7(≤1μs,20kHz) | V | Vin3≤40V |
| | LUI, LVI, LWI, HUI, HVI, HWI, SCLK, NSCS, SI, ALARM | Vin4 | -0.3 to Vcc+0.3 | V | Vin4≤6V |
| | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Vin5 | -7 to Vb+0.3(DC), -10 to -7(≤1μs,20kHz) | V | Vin5≤28V |
| Output voltage | SR1O, SR2O, SR3O, CP1H, CP2H | Vout1 | -0.3 to Vcph+0.3 | V | Vout1≤60V |
| | HUO, HVO, HWO | Vout2 | -7 to Vcph+0.3(DC), -14 to -7(≤1μs,20kHz) | V | Vout2≤60V |
| | CP1L, CP2L | Vout3 | -0.3 to Vb+0.3 | V | Vout3≤28V(DC), Vout3≤40V(≤1s) |
| | LUO, LVO, LWO | Vout4 | -7 to Vcph+0.3(DC), -10 to -7(≤1μs,20kHz) | V | Vout4≤60V |
| | AMPU_O, AMPV_O, AMPW_O | Vout5 | -0.3 to Vccop+0.3 | V | Vout5≤6V |
| | NDIAG, SO | Vout6 | -0.3 to Vcc+0.3 | V | Vout6≤6V |
| Input current | HUS, HVS, HWS | Iin1 | T.B.D. | mA | - |
| | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Iin2 | 1.2 | A | t=200ns (Reference values) |
| Output current | HUO, HVO, HWO, LUO, LVO, LWO | Iout1 | -0.5 to 2 | mA | - |
| | | Iout2 | -10 to 20 | mA | - |
| | AMPU_O, AMPV_O, AMPW_O | Iout3 | - 1 | A | Time shorter than output current switching time (Tsw) |
| | NDIAG, SO | Iout4 | ±5 | mA | - |
| Operating ambient temperature | - | Ta | -40 to 150 | °C | - |
| Junction temperature (Maximum value) | - | Tj | 175 | °C | - |
| Storage temperature | - | Tstg | -55 to 150 | °C | - |
| Allowable power dissipation | - | PD | 1.096 | W | Mounted on board, JEDEC 4 layers , Ta=150°C, Rthj-a=30°C /W |

«Notes for users»

- * The absolute maximum rating is a standard that must not be exceeded even for a moment and even a single item must not be exceeded for use.
- * Electric current flowing into this IC is shown with '+' and electric current flowing out of this IC is shown with '-'.
- * Absolute maximum rating values limit the ranges in the condition fields.
- * Marks in the above maximum absolute maximum ratings (Vb, Vcph, Vcc, Vccop) mean the added voltages and output voltages of respective terminals (VB, VCPH, VCC, VCC_OP).
- * The slew rates of Vb and Vcc shall be within the following ranges.
 Vb: less than 8V/μs, Vcc: less than 0.3V/μs
- * This product assumes to be used with a 12V battery.



(For reference)
 Board: JEDEC 4 layers board
 Thermal resistance: 22.8°C/W

Allowable dissipation curve

9. Electrical characteristics

Operating voltage ranges

| Parameter | Applied pin | Symbol | Ratings | Unit | Condition |
|---------------|-------------|--------|------------|------|-----------|
| Input voltage | VB | Vb | 4.5 to 28 | V | DC |
| | VCC | Vcc | 3.0 to 5.5 | V | DC |
| | VCC_OP | Vccop | 3.0 to 5.5 | V | DC |

*This product assumes to be used with a 12V battery.

Consumption current

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Vccop=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit |
|------------------------|-------------|--------|---|-------|-------|-------|------|
| Standby current (Vb) | VB | Istb1 | Vb=12V, Vcc=Vccop=0V, -40≤Ta≤85°C | - | 0.05 | 3.5 | μA |
| | | Istb2 | Vb=12V, Vcc=Vccop=0V, 85≤Ta≤125°C | - | - | 6.0 | μA |
| | | Istb3 | Vb=12V, Vcc=Vccop=0V, 125≤Ta≤150°C | - | - | 7.0 | μA |
| Supply current (Vb) | VB | Ib1 | Vb=13.5V HUO, HVO, HWO=20kHz LUO, LVO, LWO=20kHz Pre-driver output load: Rload=0Ω, Cload=15000pF Safety Relay output load: Rload=1.5kΩ, Cload=15000pF | - | 90 | (180) | mA |
| | | Ib2 | Vb=17V HUO,HVO,HWO=20kHz LUO,LVO,LWO=20kHz Pre-driver output load: Rload=0Ω, Cload=15000pF Safety Relay output load: Rload=1.5kΩ, Cload=15000pF | - | (60) | (120) | mA |
| | | Ib3 | Vb=28V HUO,HVO,HWO=20kHz LUO,LVO,LWO=20kHz Pre-driver output load: Rload=0Ω, Cload=15000pF Safety Relay output load: Rload=1.5kΩ, Cload=15000pF | - | (60) | (120) | mA |
| Supply current (Vcc) | VCC | Icc1 | Vcc=5V | (4) | (8) | (16) | mA |
| | | Icc2 | Vcc=3.3V | (1.2) | (2.5) | (5.0) | mA |
| Supply current (Vccop) | VCC_OP | Iccop1 | Vccop=5V | (3) | (6) | (12) | mA |
| | | Iccop2 | Vccop=3.3V | (3) | (6) | (12) | mA |

* A drop in Vcc leads to a stand-by state. The electric current in the stand-by state is provided by Istb1, Istb2, Istb3.

* External constants of the charge pumps of Ib1, Ib2, Ib3 are those of the application circuit example.

Charge pump circuit

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless otherwise specified

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|----------------------------|-------------|---------|---|--------|-------|---------|------|--------|
| Output voltage | VCPH | Vcph1 | Vb=4.5 to 5.5V Output load =28mA | Vb+5.6 | - | - | V | - |
| | | Vcph2 | Vb=5.5 to 7V Output load =28 | Vb+6.1 | - | - | V | - |
| | | Vcph3 | Vb=7 to 28V Output load =34mA(15000pF) | Vb+9.6 | Vb+14 | Vb+16.5 | V | - |
| Rise time | VCPH | Tcp | From 10% to 90% of VCPH voltage | - | - | 1 | ms | - |
| Operating frequency | | clk_cp | | 185 | 286 | 386 | kHz | |
| Pre-charging time | | Tpch_cp | | 290 | 400 | 620 | μs | |
| Enable time for pre-driver | | Tpre_en | The time between when register [en_cp="1"] is written and when pre-driver is allowed to turn on | 0.85 | 1.2 | 1.9 | ms | |

* Reference values of Ccp (charge pump capacitance), Cvcph (charge pump voltage terminal capacitance) are as follows.
Ccp = 0.47 [μF], Cvcph = 2.2 [μF]

Determine the external circuits after a sufficient evaluation and check on a unit board, assuming the conditions of the operating environment.

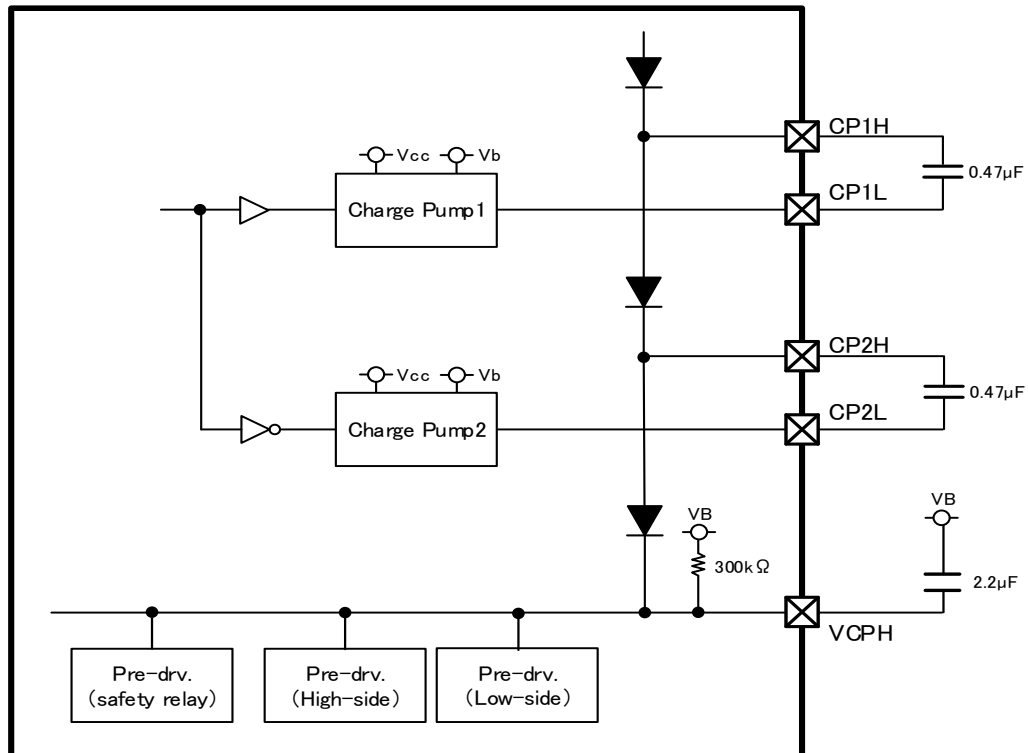


Fig. 9-a Charge pump application circuit diagram

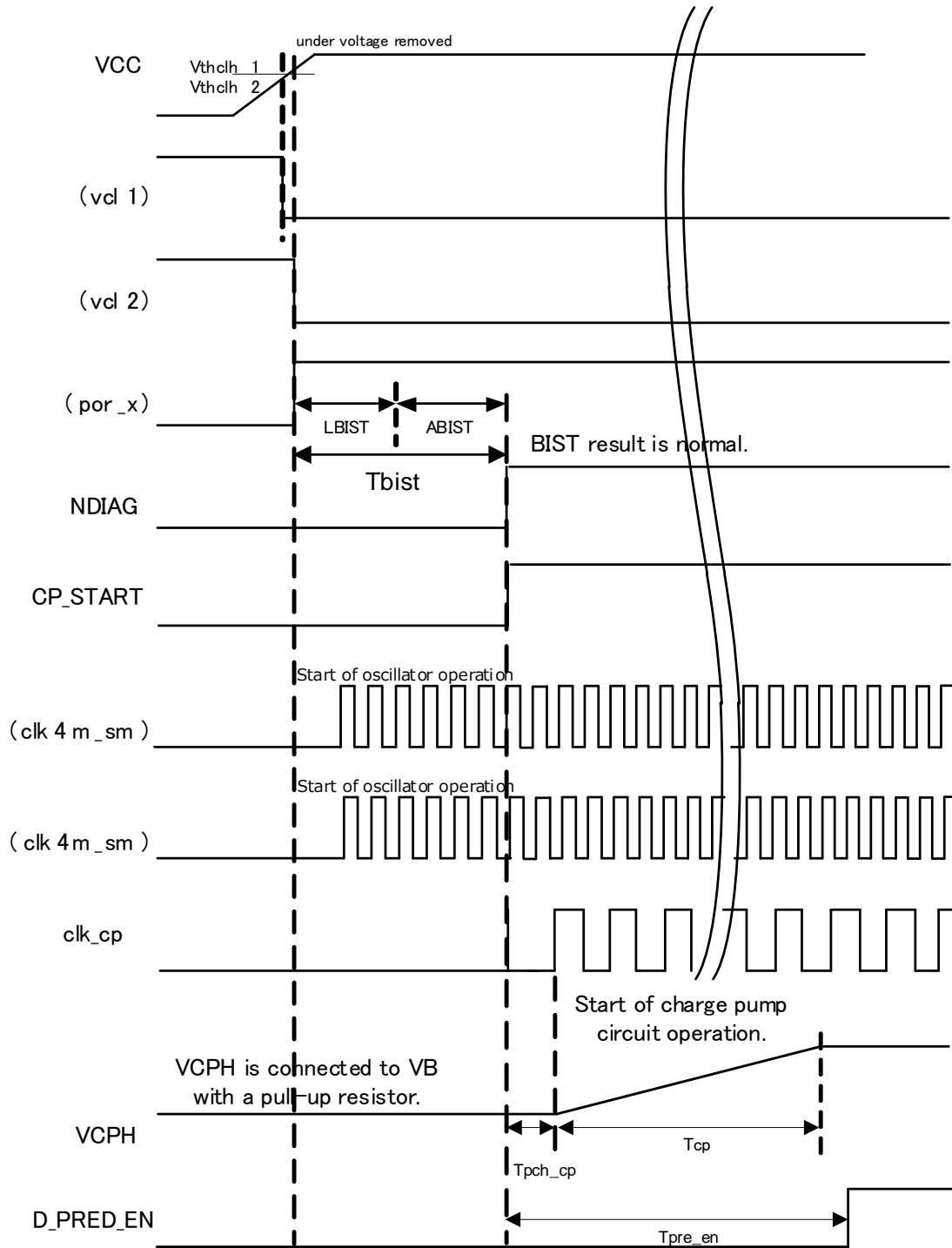


Fig. 9-b Charge pump circuit timing chart

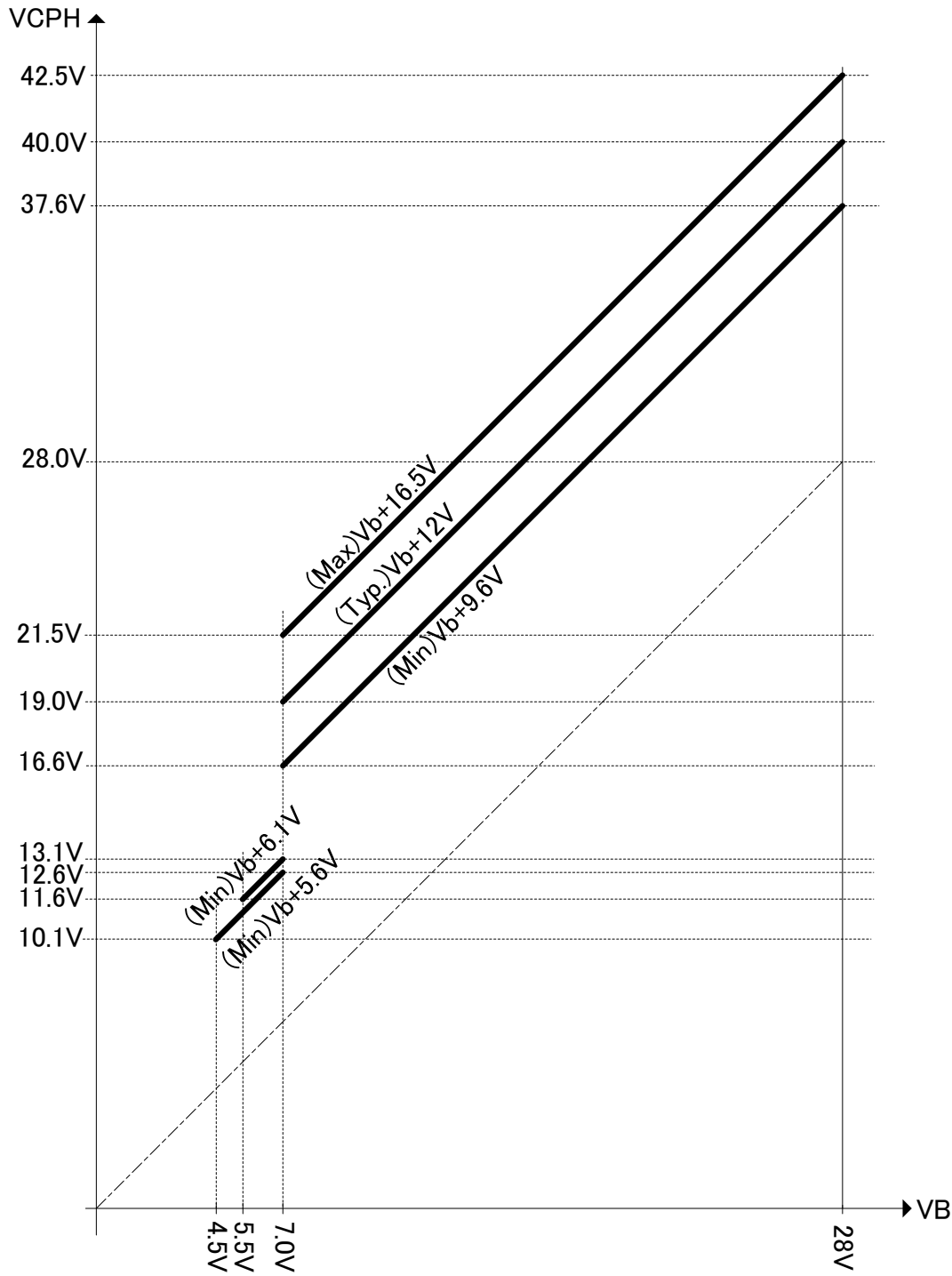


Fig. 9-c Charge pump voltage dependence

Pre-driver circuit

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|------------------------------------|------------------------------|--------|---|------------|------|-----------|------|--------|
| High level input current | HUI, HVI, HWI, LUI, LVI, LWI | Iih | Vcc= 5.0V, Vin = 5.0V | 50 | 100 | 200 | μA | - |
| Low level input current | HUI, HVI, HWI, LUI, LVI, LWI | Iil | Vcc = 5.0V, Vin = 0V | -5 | - | 5 | μA | - |
| High level input detection voltage | HUI, HVI, HWI, LUI, LVI, LWI | Vih | - | 0.75× Vcc | - | - | V | - |
| Low level input detection voltage | HUI, HVI, HWI, LUI, LVI, LWI | Vil | - | - | - | 0.25× Vcc | V | - |
| Output voltage1 | HUO,HVO,HWO | Voh1 | Voltage between HUO(HVO, HWO) and HUS(HVS, HWS), Iload=-100μA Vb=6.5 to 28V, HUS(HVS, HWS)=0V | 6.7 | 10 | 12 | V | - |
| | | Voh1_2 | Voltage between HUO(HVO, HWO) and AGND Iload=-100μA Vb=4.5 to 7.0V | (Vcph-0.3) | - | Vcph | V | - |
| | | Vol1 | Voltage between HUO(HVO, HWO) and HUS(HVS,HWS), Iload=100μA | 0 | - | 0.2 | V | - |
| Output voltage2+ | LUO, LVO, LWO | Voh2 | Voltage between LUO(LVO, LWO) and LUS(LVS,LWS), LUS(LVS,LWS),=0V, Iload=-100μA | 6.7 | 11 | 12 | V | - |
| | | Vol2 | Voltage between LUO(LVO, LWO) and LUS(LVS,LWS), Iload=100μA | 0 | - | 0.2 | V | - |
| Output voltage3 | SR10, SR20, SR30 | Voh3 | Iload=-100μA | Vcph-0.1 | - | Vcph | V | - |
| | | Vol3 | Iload=100μA | - | - | 0.9 | V | - |
| Output resistance1 | HUO,HVO,HWO | Rohh | HUI,HVI,HWI = VCC Iload = 50 mA | — | 4.4 | 12 | Ω | - |
| | | Roh l | HUI,HVI,HWI = 0V Iload = 50 mA | — | 1.2 | 3 | Ω | - |
| Output resistance2 | LUO, LVO, LWO | Rolh | LUI,LVI,LWI = VCC Iload = 50 mA | — | 4.4 | 12 | Ω | - |
| | | Roll | LUI,LVI,LWI = 0V Iload = 50 mA | — | 1.2 | 3 | Ω | - |

* Safety relay output: SR10, SR20, SR30 do not contain pull-down resistors. When pull-down resistors are required for the system, add them on the ECU board. When connecting a pull-down resistor close to MOSFET, determine the resistor's constant taking into consideration the drop of the output voltage of the safety relay.

* For the measurement circuit, see Fig. 9-d and エラー! 参照元が見つかりません. .

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---|---|----------|---|------|------|-----|------|--|
| Output resistance | SR10, SR20, SR30 | Rosh | srly1_drv="1", srly2_drv="1", srly3_drv="1" Iload=-5mA | 400 | 500 | 650 | Ω | - |
| | | Rosl | srly1_drv="0", srly2_drv="0", srly3_drv="0" Rosl =Vd/4mA | 400 | 500 | 650 | Ω | Refer to Fig. 9-f |
| Pull-down resistance 1 | HUO,HVO,HWO | Rpd1 | ALARM=0V | 25 | 50 | 100 | kΩ | - |
| Pull-down resistance 2 | LUO, LVO, LWO | Rpd2 | ALARM=0V | 25 | 50 | 100 | kΩ | - |
| On reverse connection VB leakage current | SR10, SR20, SR30 | Iol | SR10, SR20, SR30=-18V PGND=0V | 0 | 0.01 | 1.0 | μA | - |
| Output limit current | HUO,HVO,HWO,LUO, LVO, LWO | Io_lmth | When turned on, after Tsw | - | -10 | - | mA | Refer to Fig. 9-e |
| | | Io_lmthl | When turned off, after Tsw | - | 10 | - | mA | Refer to Fig. 9-e |
| Output current switching time | HUO,HVO,HWO,LUO, LVO, LWO | Tsw0 | - | 5 | 8 | 14 | μs | t_ilm = "00" Refer to Fig. 9-e |
| | | Tsw1 | - | 10 | 16 | 28 | μs | t_ilm = "01" Refer to Fig. 9-e |
| | | Tsw2 | - | 20 | 32 | 56 | μs | t_ilm = "10" Refer to Fig. 9-e |
| When turned on, input propagation delay time | HUI, HVI, HWI, HUO,HVO,HWO | Tdonh | Rload=T.B.D., Cload=T.B.D. pF | 20 | 120 | 250 | ns | Refer to Fig.9-d and Fig. 9-e |
| | LUI, LVI, LWI, LUO, LVO, LWO | Tdonl | Rload=T.B.D., Cload=T.B.D. pF | 20 | 120 | 250 | ns | Refer to Fig.9-d and Fig. 9-e |
| When turned off, input propagation delay time | HUI, HVI, HWI, HUO,HVO,HWO | Tdoffh | Rload=T.B.D., Cload=T.B.D. pF | 20 | 180 | 300 | ns | Refer to Fig.9-d and Fig. 9-e |
| | LUI, LVI, LWI, LUO, LVO, LWO | Tdoffl | Rload=T.B.D., Cload=T.B.D. pF | 20 | 180 | 300 | ns | Refer to Fig.9-d and Fig. 9-e |
| Input propagation delay time difference | HUI, HVI, HWI, LUI, LVI, LWI, HUO,HVO,HWO,LUO, LVO, LWO | Dtd | Tdonh-Tdoffl, Tdonl-Tdoffh | -125 | - | 125 | ns | Time difference between high side and low side (U/V/W) |

* To safety relay output: SR10, SR20, SR30, connect an external series resistor of 1.5kΩ or larger.

* Safety relay output: SR10, SR20, SR30 do not contain pull-down resistors. When pull-down resistors are required for the system, add them on the ECU board. When connecting a pull-down resistor close to MOSFET, determine the resistor's constant taking into consideration the drop of the output voltage of the safety relay.

* For the measurement circuit, see Fig. 9-d

* Specifications shown in (brackets) are design values and not tested for delivery.

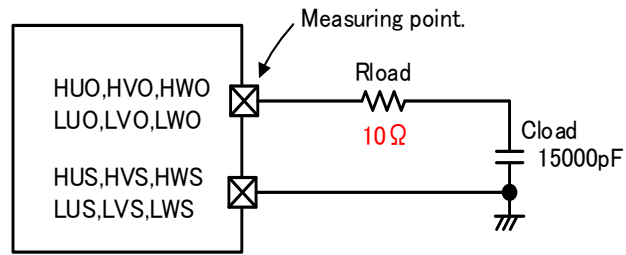


Fig. 9-d Measurement circuit diagram (high side/low side)

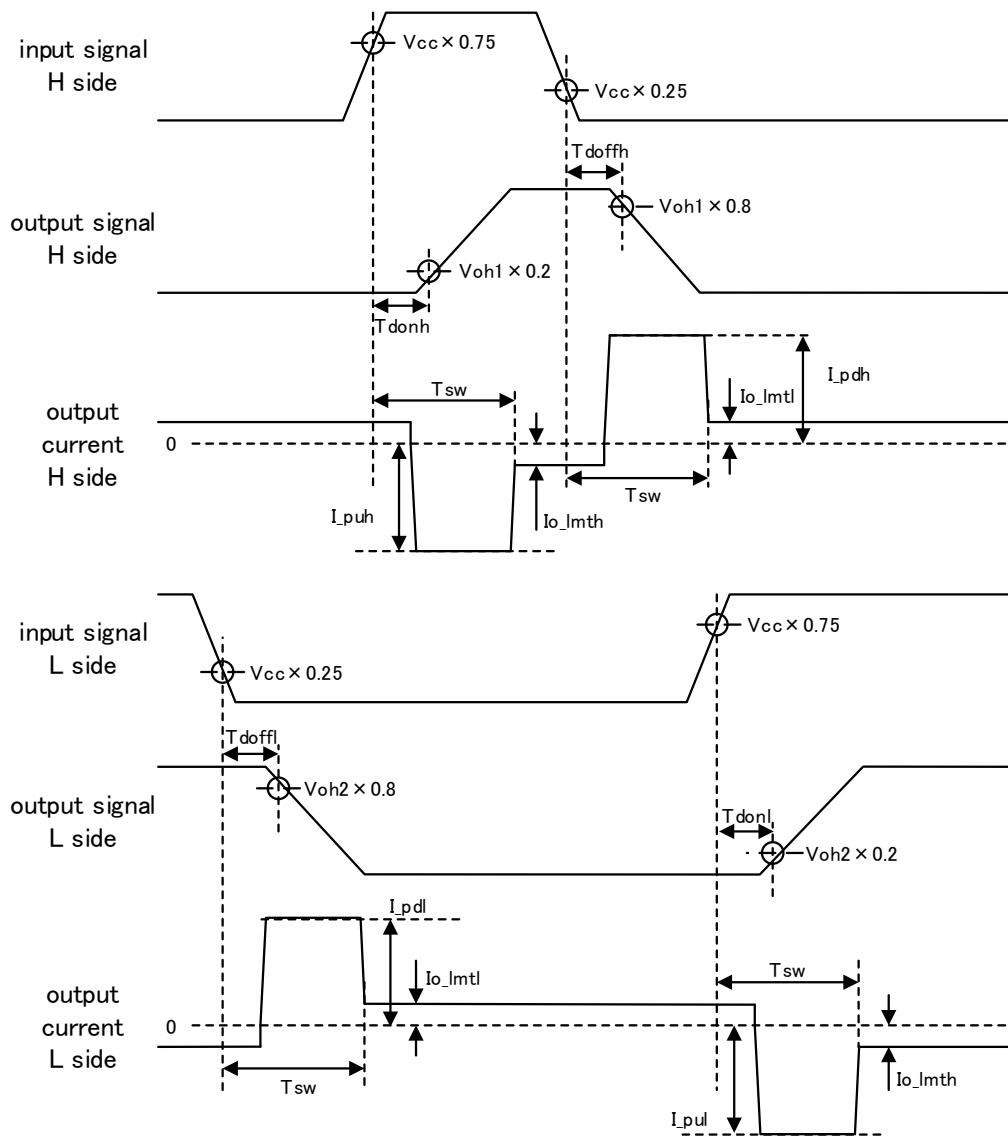


Fig. 9-e Timing charts of output current switching time, input propagation delay time

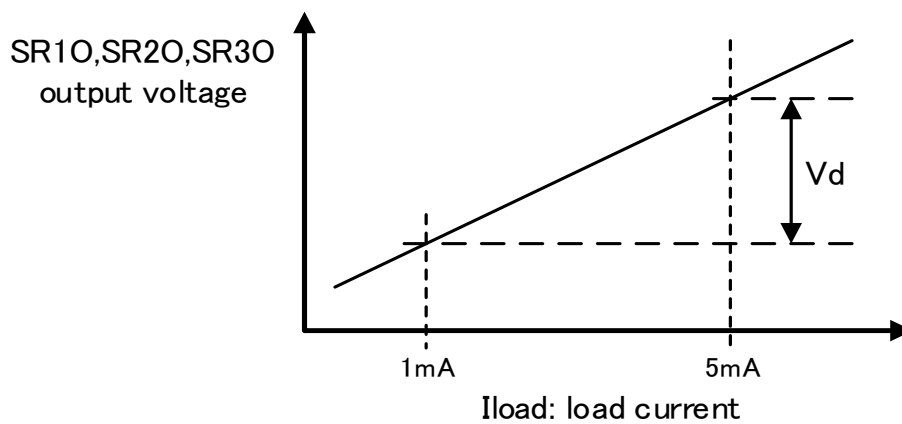


Fig. 9-f How to measure SR10,SR20,SR30 output resistance

Current detection circuit

Vb=4.5 to 28V, Vccop=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symb ol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---|--|----------|--|-------------|---------|--------|-------|--|
| Input offset voltage 1 | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Voff1 | After calibration, Ta=25°C Gain=15 Comvin=0V Iload=0.5mA | -1 | - | 1 | mV | gain_amp_u="011", gain_amp_v="011", gain_amp_w="011" |
| Input offset voltage 2 | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Voff2 | Before calibration, Ta=25°C Gain=15 Comvin=0V Iload=0.5mA | -7 | - | 7 | mV | gain_amp_u="011", gain_amp_v="011", gain_amp_w="011" |
| Input offset voltage temperature characteristic 1 | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | VoffdT 1 | After calibration, Gain=15 Comvin=0V Iload=0.5mA | -10 | - | 10 | µV/°C | gain_amp_u="011", gain_amp_v="011", gain_amp_w="011" shown in (brackets) are design values |
| Input offset voltage temperature characteristic 2 | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | VoffdT 2 | Before calibration, Gain=15, Comvin=0V Iload=0.5mA | -10 | - | 10 | µV/°C | gain_amp_u="011", gain_amp_v="011", gain_amp_w="011" shown in (brackets) are design values |
| Input bias current | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Iin | Measurement target terminal = 0V | -100 | - | 100 | µA | - |
| Output voltage 1 | AMPU_O, AMPU_O, AMPU_O | Vohop | Gain=15 Vinr=0.1×Vccop Iload = -500µA | Vccop -0.15 | - | Vccop | V | - |
| | | Volop | Gain=15 Vinr=-0.1×Vccop Iload = +500µA | 0 | - | 0.15 | V | - |
| Reference voltage | - | Vref | | Typ.-9 | Vccop/2 | Typ.+9 | mV | shown in (brackets) are design values |
| Reference temperature characteristic | - | Vref_dT | | -10 | - | 10 | µV/°C | shown in (brackets) are design values |
| GAIN | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N, AMPU_O, AMPV_O, AMPW_O | Gain0 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 7.5 | 1% | - | gain_amp_u="000", gain_amp_v="000", gain_amp_w="000" |
| | | Gain1 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 10 | 1% | - | gain_amp_u="001", gain_amp_v="001", gain_amp_w="001" |
| | | Gain2 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 12.5 | 1% | - | gain_amp_u="010", gain_amp_v="010", gain_amp_w="010" |
| | | Gain3 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 15 | 1% | - | gain_amp_u="011", gain_amp_v="011", gain_amp_w="011" |
| | | Gain4 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 20 | 1% | - | gain_amp_u="100", gain_amp_v="100", gain_amp_w="100" |
| | | Gain5 | Vinr=-0.5V to 0.5V, Iload=No load | -1% | 27.5 | 1% | - | gain_amp_u="101", gain_amp_v="101", gain_amp_w="101" |

* For the amplifier configuration, use the polarity in Fig. 9-

* Specifications shown in (brackets) are design values and not tested for delivery.

V_b=4.5 to 28V, V_{ccop}=3.0 to 5.5V, T_j=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---------------------------------|--|------------------------|--|------|-------|-------|------|--|
| Slew rate | AMPU_O, AMPV_O, AMPW_O | Sr1 | VCC_OP=5.0V Gain=15 Rload=1kΩ, Cload=220pF Slew rate from 20% of Vout to 80% | 4.5 | 10 | 20 | V/μs | Refer to Fig. 9- Gain is set to register by SPI. |
| | | | VCC_OP=3.3V Gain=15 Rload=1kΩ, Cload=220pF Slew rate from 20% of Vout to 80% | 2.5 | 10 | 20 | V/μs | Refer to Fig. 9- Gain is set to register by SPI. |
| | | Sr2 | VCC_OP=5.0V Gain=15 Rload=1kΩ, Cload=220pF Slew rate from 20% of Vout to 80% | -20 | -10 | -4.5 | V/μs | Refer to Fig. 9- Gain is set to register by SPI. |
| | | | VCC_OP=3.3V Gain=15 Rload=1kΩ, Cload=220pF Slew rate from 20% of Vout to 80% | -20 | -10 | -2.5 | V/μs | Refer to Fig. 9- Gain is set to register by SPI. |
| Settling time | AMPU_O, AMPV_O, AMPW_O | Tset | Rload=1kΩ, Cload=220pF Time for output voltage to converge to ±2%. | - | - | (1.5) | μs | shown in (brackets) are design values |
| Input common mode voltage | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N | Comvin | Input range where amplifier outputs can ensure ±1% gain error with AMP*_P and AMP*_N shorted | -0.5 | - | 2.0 | V | - |
| PSRR | VCC_OP | Psrrop | 1KHz input to VCC_OP, but excluding the effect of VREF | - | (60) | - | dB | shown in (brackets) are design values |
| CMRR | AMPU_P, AMPV_P, AMPW_P, AMPU_N, AMPV_N, AMPW_N, AMPU_O, AMPV_O, AMPW_O | Cmrrop | Gain=15, Comvin=200mVp- p, 100KHz | (80) | (100) | - | dB | shown in (brackets) are design values |
| Offset calibration time | - | T _{ampofscal} | - | - | - | 108 | μs | - |

* For the amplifier configuration, use the polarity in Fig. 9-.

* Specifications shown in (brackets) are design values and not tested for delivery.

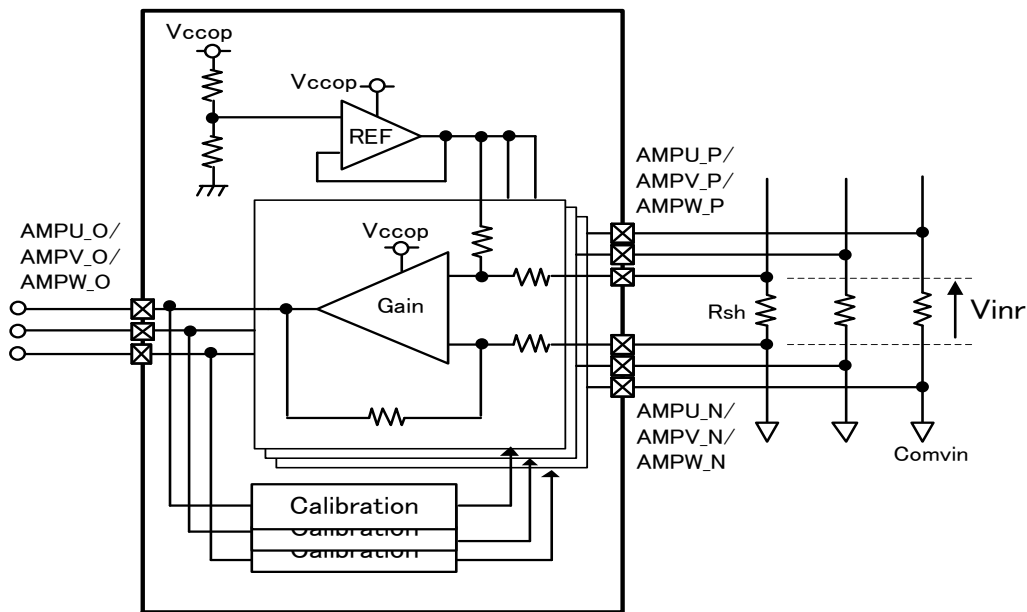


Fig. 9-g Measurement circuit diagram

$$\begin{aligned} \text{※SR1} &= 0.6 \times (V_{ccop} - 0.3) / \Delta T_r \\ \text{※SR2} &= -0.6 \times (V_{ccop} - 0.3) / \Delta T_f \end{aligned}$$

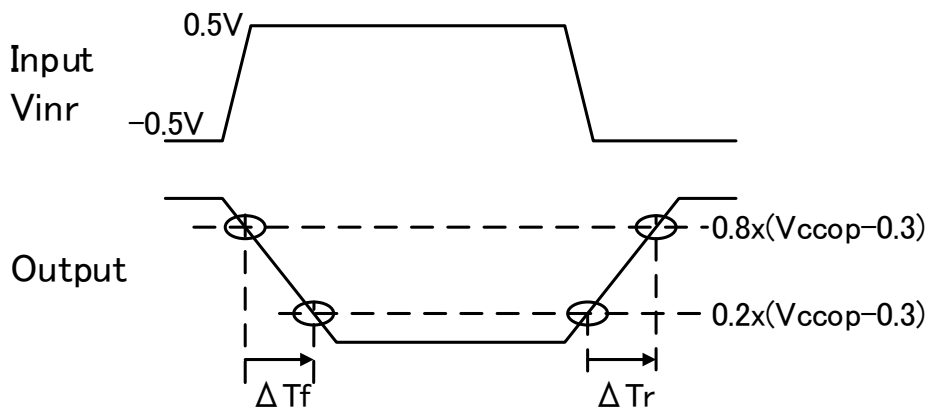


Fig. 9-h Slew rate timing

Oscillation circuit

V_b=4.5 to 28V, V_{cc}=3.0 to 5.5V, T_j=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|--------------------------------|-------------|------------------|-----------------|-----|------|-----|------|--------|
| Internal oscillation frequency | - | F _c | - | 2.6 | 4 | 5.4 | MHz | - |
| Frequency for monitor | - | F _{csm} | - | 2.6 | 4 | 5.4 | MHz | - |

Abnormality detection circuit

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|--|---------------------|---------------------|--|-------|-------|-------|------|---------------------------------------|
| VCC undervoltage detection threshold 1, 2 | VCC | Vthcll1, Vthcll2 | - | 2.55 | 2.75 | 2.95 | V | - |
| VCC undervoltage detection threshold 1,2 for removal | | Vthclh1, Vthclh2 | - | 2.65 | 2.85 | 3.05 | V | - |
| Filtering time for VCC undervoltage | VCC | Tel | - | 10 | 20 | 40 | μs | - |
| VB undervoltage detection threshold | VB | Vthbll | - | 3.6 | 3.9 | 4.2 | V | - |
| Threshold for VB undervoltage detection removal | | Vthblh | - | 3.9 | 4.2 | 4.5 | V | - |
| Filtering time for VB undervoltage detection | | Tbl | - | 12 | 20 | 34 | μs | - |
| VCPH overvoltage detection threshold | VCPH | Vthcphhh | - | 53.0 | 56.0 | 59.0 | V | - |
| Threshold for VCPH overvoltage detection removal | | Vthcphhl | - | 52.0 | 55.0 | 58.0 | V | - |
| Filtering time for VCPH overvoltage detection | | Tcphh | - | 12 | 20 | 34 | μs | - |
| VCC overvoltage detection threshold | VCC | Vthchh | - | 5.5 | 5.75 | 6.0 | V | - |
| Threshold for VCC overvoltage detection removal | | Vthchl | - | 5.4 | 5.65 | 5.9 | V | - |
| Filtering time for VCC overvoltage detection | VCC | Tch | - | 12 | 20 | 34 | μs | - |
| VCC_OP undervoltage detection threshold | VCC_OP | Vthccopl | - | 2.55 | 2.75 | 2.95 | V | - |
| Threshold for VCC_OP undervoltage detection removal | | Vthccoplh | - | 2.65 | 2.85 | 3.05 | V | - |
| Filtering time for VCC_OP overvoltage detection | VCC_OP | Tccopl | - | 12 | 20 | 34 | μs | - |
| VCC_OP overvoltage detection threshold | VCC_OP | Vthccophh | - | 5.5 | 5.75 | 6.0 | V | - |
| Threshold for VCC_OP overvoltage detection removal | | Vthccophl | - | 5.4 | 5.65 | 5.9 | V | - |
| Filtering time for VCC_OP overvoltage detection | VCC_OP | Tccoph | - | 13 | 20 | 34 | μs | - |
| Overtemperature detection | - | Tsdh | - | (175) | (195) | (215) | °C | shown in (brackets) are design values |
| Temperature for overtemperature detection removal | | Tsdl | - | (165) | (185) | (205) | °C | shown in (brackets) are design values |
| Filtering time for overtemperature detection | | Ttsd | - | (12) | (20) | (34) | μs | shown in (brackets) are design values |
| VDS detection input current 1 for external MOSFET | HUS, HVS, HWS | I_vds1_Roff | VB=HS=H*S=13.5V | -650 | -400 | -250 | μA | - |
| | | I_vds1_Ron | VB=HS=H*S=13.5V In external MOSFET inspection mode. | 4.5 | 6.8 | 8.5 | mA | - |
| VDS detection input current 2 for external MOSFET | HUS, HVS, HWS | I_vds2_Roff | VB=HS=13.5V H*S=0V | -650 | -450 | -250 | μA | - |
| | | I_vds2_Ron | VB=HS=13.5V H*S=0V In external MOSFET inspection mode. | -8.5 | -6.8 | -4.5 | mA | - |
| Midpoint voltage divider ratio | | | In external MOSFET test mode | 0.4 | 0.5 | 0.6 | - | - |

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|-----------|-------------|--------|-----------------|-----|------|-----|------|--------|
| BIST time | - | Tbist | | - | 2.6 | 4 | ms | |

* Specifications shown in (brackets) are design values and not tested for delivery.

* When Vcc drops below the Vcc low voltage detection voltage, it leads to a stand-by state.

* Low voltage detection (VB, VCC, VCC_OP), high voltage detection (VCPH, VCC, VCC_OP) and overtemperature detection circuits are equipped with hysteresis.

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---|-------------|-----------|-----------------|------|------|------|------|--|
| High side filtering time for external MOSFET VDS detection | - | Fil_vdsh0 | - | 3.9 | 6 | 8.1 | μs | fil_vdsh="00" |
| | | Fil_vdsh1 | - | 5.2 | 8 | 10.8 | μs | fil_vdsh="01" |
| | | Fil_vdsh2 | - | 6.5 | 10 | 13.5 | μs | fil_vdsh="10" |
| | | Fil_vdsh3 | - | 7.8 | 12 | 16.2 | μs | fil_vdsh="11" |
| Low side filtering time for external MOSFET VDS detection | - | Fil_vdsl0 | - | 3.9 | 6 | 8.1 | μs | fil_vdsl="00" |
| | | Fil_vdsl1 | - | 5.2 | 8 | 10.8 | μs | fil_vdsl="01" |
| | | Fil_vdsl2 | - | 6.5 | 10 | 13.5 | μs | fil_vdsl="10" |
| | | Fil_vdsl3 | - | 7.8 | 12 | 16.2 | μs | fil_vdsl="11" |
| Threshold voltage for external MOSFET VDS detection high side | - | Vth_vdsh0 | - | 0.04 | 0.1 | 0.16 | V | vth_vdsuh="0000", vth_vdsvh="0000", vth_vdswH="0000" |
| | | Vth_vdsh1 | - | 0.14 | 0.2 | 0.26 | V | vth_vdsuh="0001", vth_vdsvh="0001", vth_vdswH="0001" |
| | | Vth_vdsh2 | - | 0.24 | 0.3 | 0.36 | V | vth_vdsuh="0010", vth_vdsvh="0010", vth_vdswH="0010" |
| | | Vth_vdsh3 | - | 0.34 | 0.4 | 0.46 | V | vth_vdsuh="0011", vth_vdsvh="0011", vth_vdswH="0011" |
| | | Vth_vdsh4 | - | 0.44 | 0.5 | 0.56 | V | vth_vdsuh="0100", vth_vdsvh="0100", vth_vdswH="0100" |
| | | Vth_vdsh5 | - | 0.54 | 0.6 | 0.66 | V | vth_vdsuh="0101", vth_vdsvh="0101", vth_vdswH="0101" |
| | | Vth_vdsh6 | - | 0.63 | 0.7 | 0.77 | V | vth_vdsuh="0110", vth_vdsvh="0110", vth_vdswH="0110" |
| | | Vth_vdsh7 | - | 0.72 | 0.8 | 0.88 | V | vth_vdsuh="0111", vth_vdsvh="0111", vth_vdswH="0111" |
| | | Vth_vdsh8 | - | 0.81 | 0.9 | 0.99 | V | vth_vdsuh="1000", vth_vdsvh="1000", vth_vdswH="1000" |
| | | Vth_vdsh9 | - | 0.9 | 1.0 | 1.1 | V | vth_vdsuh="1001", vth_vdsvh="1001", vth_vdswH="1001" |
| | | Vth_vdshA | - | 0.99 | 1.1 | 1.21 | V | vth_vdsuh="1010", vth_vdsvh="1010", vth_vdswH="1010" |
| | | Vth_vdshB | - | 1.08 | 1.2 | 1.32 | V | vth_vdsuh="1011", vth_vdsvh="1011", vth_vdswH="1011" |

* VDS detection threshold voltage (high side) is provided by the voltage between the IC terminals: HS-H*S.

* VDS detection threshold voltage (low side) is provided by the voltage between the IC terminals: H*S-L*S.

* * is U, V, W.

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---|-------------|-----------|-----------------------------------|-------------|------|--|------|--|
| External MOSFET VDS detection low side voltage threshold | - | Vth_vdsl0 | - | 0.04 | 0.1 | 0.16 | V | vth_vdsul="0000", vth_vdsvl="0000", vth_vdswl="0000" |
| | | Vth_vdsl1 | - | 0.14 | 0.2 | 0.26 | V | vth_vdsul="0001", vth_vdsvl="0001", vth_vdswl="0001" |
| | | Vth_vdsl2 | - | 0.24 | 0.3 | 0.36 | V | vth_vdsul="0010", vth_vdsvl="0010", vth_vdswl="0010" |
| | | Vth_vdsl3 | - | 0.34 | 0.4 | 0.46 | V | vth_vdsul="0011", vth_vdsvl="0011", vth_vdswl="0011" |
| | | Vth_vdsl4 | - | 0.44 | 0.5 | 0.56 | V | vth_vdsul="0100", vth_vdsvl="0100", vth_vdswl="0100" |
| | | Vth_vdsl5 | - | 0.54 | 0.6 | 0.66 | V | vth_vdsul="0101", vth_vdsvl="0101", vth_vdswl="0101" |
| | | Vth_vdsl6 | - | 0.63 | 0.7 | 0.77 | V | vth_vdsul="0110", vth_vdsvl="0110", vth_vdswl="0110" |
| | | Vth_vdsl7 | - | 0.72 | 0.8 | 0.88 | V | vth_vdsul="0111", vth_vdsvl="0111", vth_vdswl="0111" |
| | | Vth_vdsl8 | - | 0.81 | 0.9 | 0.99 | V | vth_vdsul="1000", vth_vdsvl="1000", vth_vdswl="1000" |
| | | Vth_vdsl9 | - | 0.9 | 1.0 | 1.1 | V | vth_vdsul="1001", vth_vdsvl="1001", vth_vdswl="1001" |
| | | Vth_vdslA | - | 0.99 | 1.1 | 1.21 | V | vth_vdsul="1010", vth_vdsvl="1010", vth_vdswl="1010" |
| Vth_vdslB | - | 1.08 | 1.2 | 1.32 | V | vth_vdsul="1011", vth_vdsvl="1011", vth_vdswl="1011" | | |
| External MOSFET VGS overvoltage detection threshold | - | Vth_vgsh | - | 15.5 | 17.5 | 19.5 | V | - |
| Threshold for external MOSFET VGS overvoltage detection removal | - | Vth_vgsl | - | 14.5 | 16.5 | 18.5 | V | - |
| Filtering time for external MOSFET VGS overvoltage detection | - | Fil_vgs | - | 5.2 | 8 | 10.8 | μs | - |
| NDIAG output voltage | NDIAG | Voh | Ioh = -5mA | 0.9× Vcc | - | - | V | - |
| | | Vol | Iol = 5mA | - | - | 0.1× Vcc | V | - |
| L hold voltage | NDIAG | Vlk | Vcc=1.1V to Vthell Iol = 100μA | 0 | - | 0.3 | V | Refer to Fig. 9-i |
| Frequency mutual comparison error detection coefficient | - | Kfreqdet | OSC_IF<12 MHz OSC_SM<1 2MHz | - | 2.1 | - | A.U. | |

* VDS detection threshold voltage (high side) is provided by the voltage between the IC terminals: HS-H*S.

* VDS detection threshold voltage (low side) is provided by the voltage between the IC terminals: H*S-L*S.

* * is U, V, W.

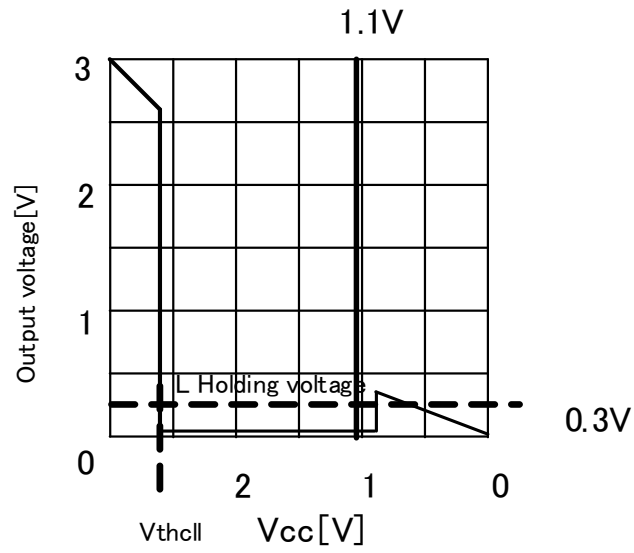


Fig. 9-i L Holding voltage

ALARM input circuit

Vb=4.5 to 28V, Vcc=3.0 to 5.5V, Tj=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Symbol | Test conditions | Min | Typ. | Max | Unit | Remark |
|------------------------------------|-------------|--------|---------------------------|----------|------|----------|------|--|
| High level input current | ALARM | Iih | Vcc = 5.0V, Vin = 5.0V | 50 | 100 | 200 | μA | - |
| Low level input current | | Iil | Vcc = 5.0V, Vin = 0V | -5 | - | 5 | μA | - |
| High level input detection voltage | ALARM | Vih | - | 0.75×Vcc | - | - | V | - |
| Low level input detection voltage | | Vil | - | - | - | 0.25×Vcc | V | - |
| Pulse width of input detection | ALARM | Twmin0 | High, Low level detection | 16.25 | - | - | μs | fil_alm="00" 16x2 ² x(1/4MHz)+(1/4MHz) |
| | | Twmin1 | | 1.00025 | - | - | ms | fil_alm="01" 1000x2 ² x(1/4MHz)+(1/4MHz) |
| | | Twmin2 | | 2.00025 | - | - | ms | fil_alm="10" 2000x2 ² x(1/4MHz)+(1/4MHz) |
| | | Twmin3 | | 4.00025 | - | - | ms | fil_alm="11" 4000x2 ² x(1/4MHz)+(1/4MHz) |
| Pulse width of input removal | ALARM | Twmax0 | High, Low level detection | - | - | 14.75 | μs | fil_alm="00" 15x2 ² x(1/4MHz)-(1/4MHz) |
| | | Twmax1 | | - | - | 0.99875 | ms | fil_alm="01" 999x2 ² x(1/4MHz)-(1/4MHz) |
| | | Twmax2 | | - | - | 1.99875 | ms | fil_alm="10" 1999x2 ² x(1/4MHz)-(1/4MHz) |
| | | Twmax3 | | - | - | 3.99875 | ms | fil_alm="11" 3999x2 ² x(1/4MHz)-(1/4MHz) |

* The input detection pulse width (Twmin) means the width of pulses appearing in the output after passing the digital filter, and input elimination pulse width (Twmax) means the width of pulses eliminated by the digital filter (Fig. 9-j).

* Calculated, assuming ALARM digital filter setting: (1/4MHz)=250[ns].

ALARM terminal input signal

Output signal from digital filter

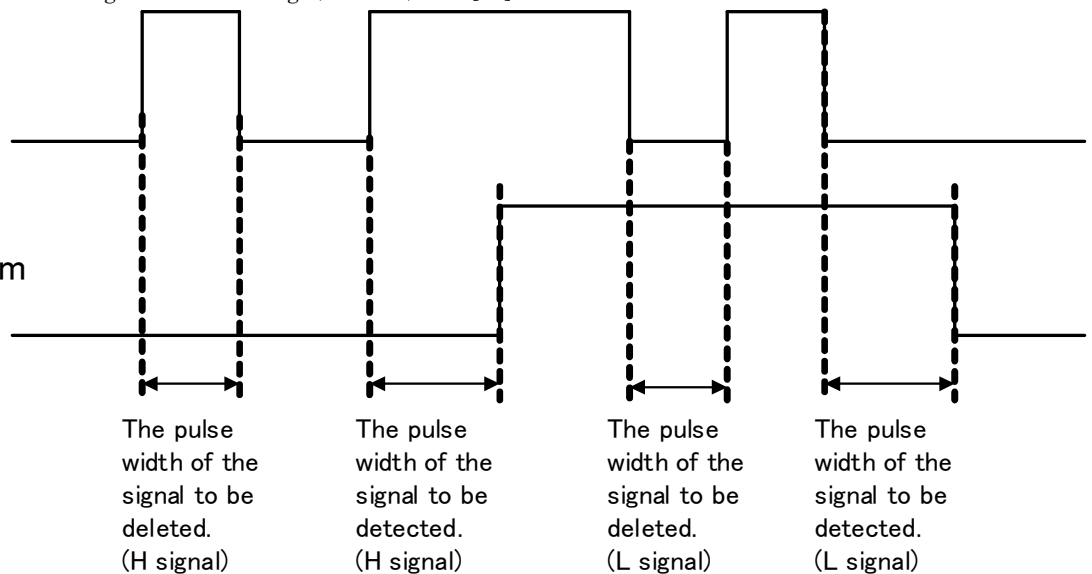


Fig. 9-j Input elimination pulse width (with a filter) and input detection pulse width (with a filter)

SPI communication circuit

SPI communication specifications (AC)

V_b=4.5 to 28V, V_{cc}=3.0 to 5.5V, T_j=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Sym bol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---|-------------|-----------------|--------------------------|-----|------|-----|------|--|
| Delay time from NSCS falling edge to SO | NSCS, SO | Tcsdo | Cl _{oad} =100pF | - | - | 100 | ns | Time from NSCS falling edge to SO removed from HiZ state |
| Valid standby time | NSCS, SCLK | Tcsck | F _{op} = 2MHz | 100 | - | - | ns | Time from NSCS falling edge to SCLK rising edge |
| Invalid standby time | SCLK, NSCS | Tckcs | - | 100 | - | - | ns | Time from falling edge of the last pulse of SCLK to NSCS rising edge |
| SI setup time | SI, SCLK | Tdick | - | 50 | - | - | ns | SI data setup time |
| SI hold time | SI, SCLK | Tckdi | - | 50 | - | - | ns | SI data hold time |
| SO valid time | SCLK, SO | Tckdo | Cl _{oad} =100pF | - | - | 100 | ns | Time from SCLK rising edge to SO data output |
| NSCS invalid time | NSCS | Tcsh | - | 2 | - | - | μs | Time from NSCS rising edge to NSCS falling edge |
| Delay time from SO to NSCS rising edge | NSCS, SO | Tdocs | Cl _{oad} =100pF | - | - | 100 | ns | Time from NSCS rising edge to SO turning to HiZ state |
| Communication frequency | SCLK | F _{op} | - | - | - | 2 | MHz | - |

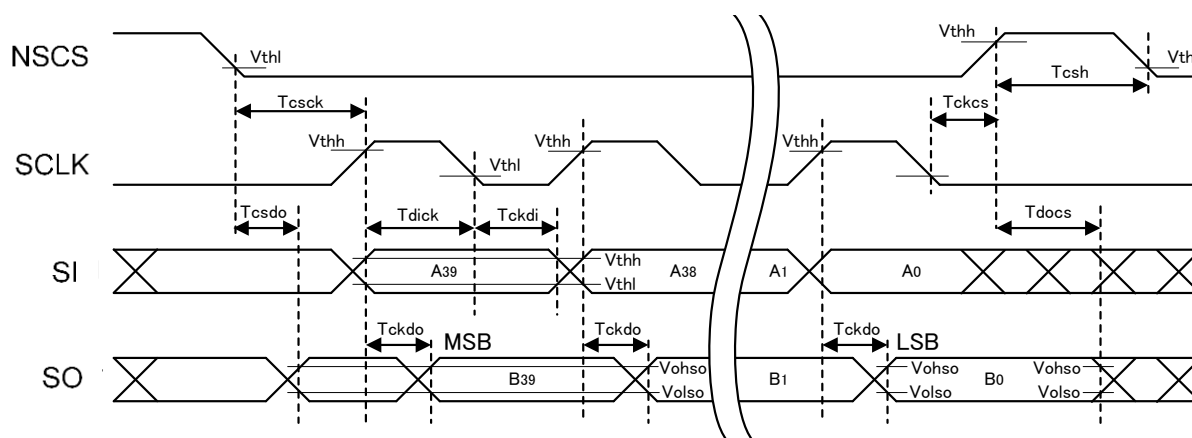


Figure 9-k SPI timing chart

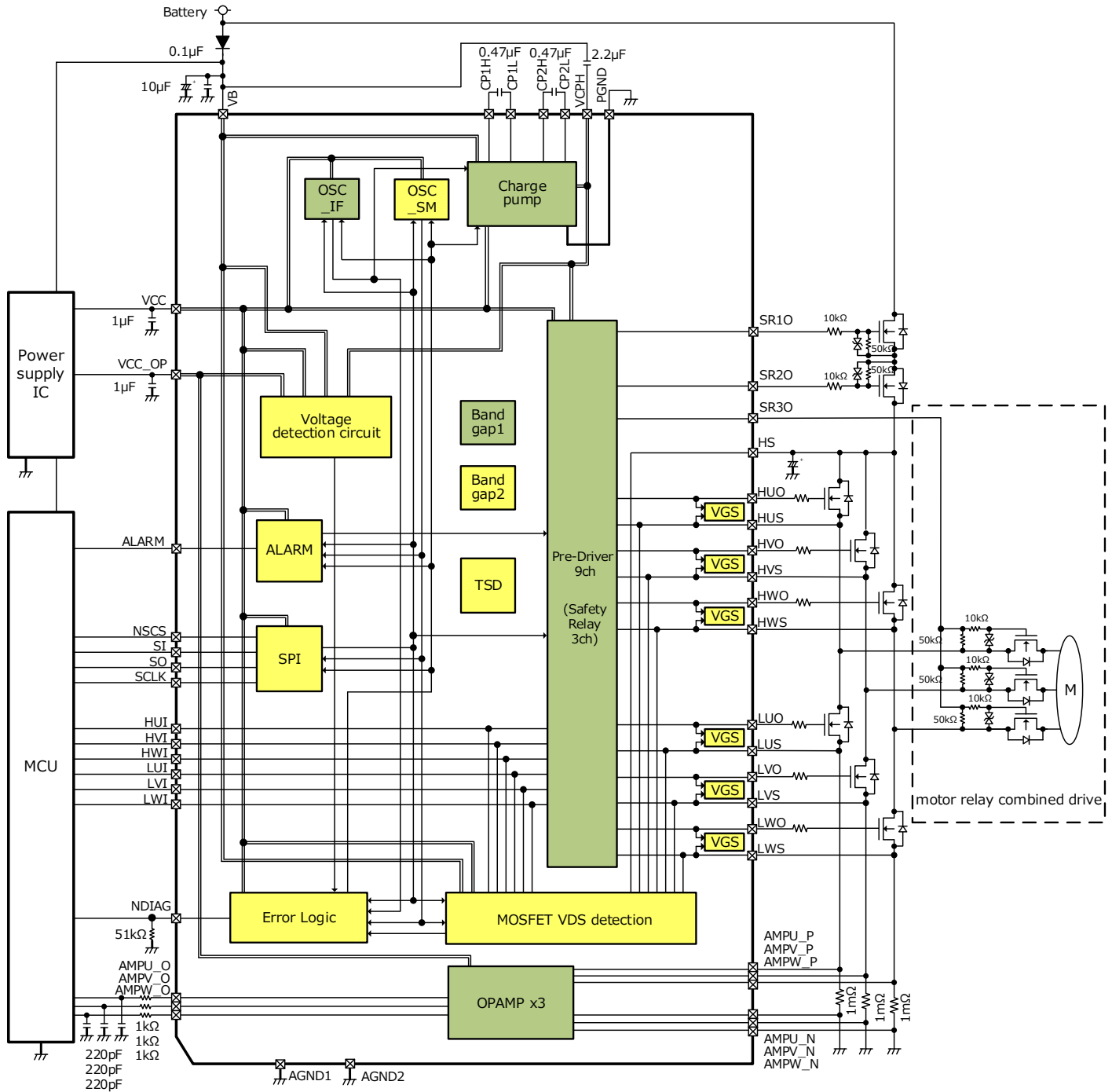
SPI communication specifications (DC)V_b=4.5 to 28V, V_{cc}=3.0 to 5.5V, T_j=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Sym bol | Test conditions | Min | Typ. | Max | Unit | Remark |
|---------------------------|----------------------|-------------------|---|--------------------------|------|--------------------------|------|--------|
| High level input voltage | SI, SCLK, NSCS | V _{thh} | - | 0.75× V _{cc} | - | - | V | - |
| Low level input voltage | | V _{thl} | | - | - | 0.25× V _{cc} | V | - |
| High level input current | NSCS | I _{ih} | V _{cc} = 5.0V, V _{in} = 5.0V | -5 | - | 5 | μA | - |
| Low level input current | | I _{il} | V _{cc} = 5.0V, V _{in} = 0V | -200 | -100 | -50 | μA | - |
| High level input current | SI, SCLK | I _{ih} | V _{cc} = 5.0V, V _{in} = 5.0V | 50 | 100 | 200 | μA | - |
| Low level input current | | I _{il} | V _{cc} = 5.0V, V _{in} = 0V | -5 | - | 5 | μA | - |
| High level output voltage | SO | V _{ohso} | I _{ohso} = -5mA | 0.9× V _{cc} | - | - | V | - |
| Low level output voltage | | V _{olso} | I _{olso} = 5mA | - | - | 0.1× V _{cc} | V | - |

QA timerV_b=4.5 to 28V, V_{cc}=3.0 to 5.5V, T_j=-40 to 175°C unless specified otherwise

| Parameter | Applied pin | Sym bol | Test conditions | Min | Typ. | Max | Unit | Remark |
|--------------|-------------|------------------|-----------------|------|------|-------|------|--------|
| Timeout time | - | T _{qa0} | - | 0.65 | 1 | 1.36 | ms | - |
| | | T _{qa1} | | 1.3 | 2 | 2.72 | ms | - |
| | | T _{qa2} | | 2.6 | 4 | 5.44 | ms | - |
| | | T _{qa3} | | 5.2 | 8 | 10.88 | ms | - |

10. Application circuit example



When driving motor relays collectively

« Notes for users »

* The circuit constants are for the application circuit example, and not guaranteed.

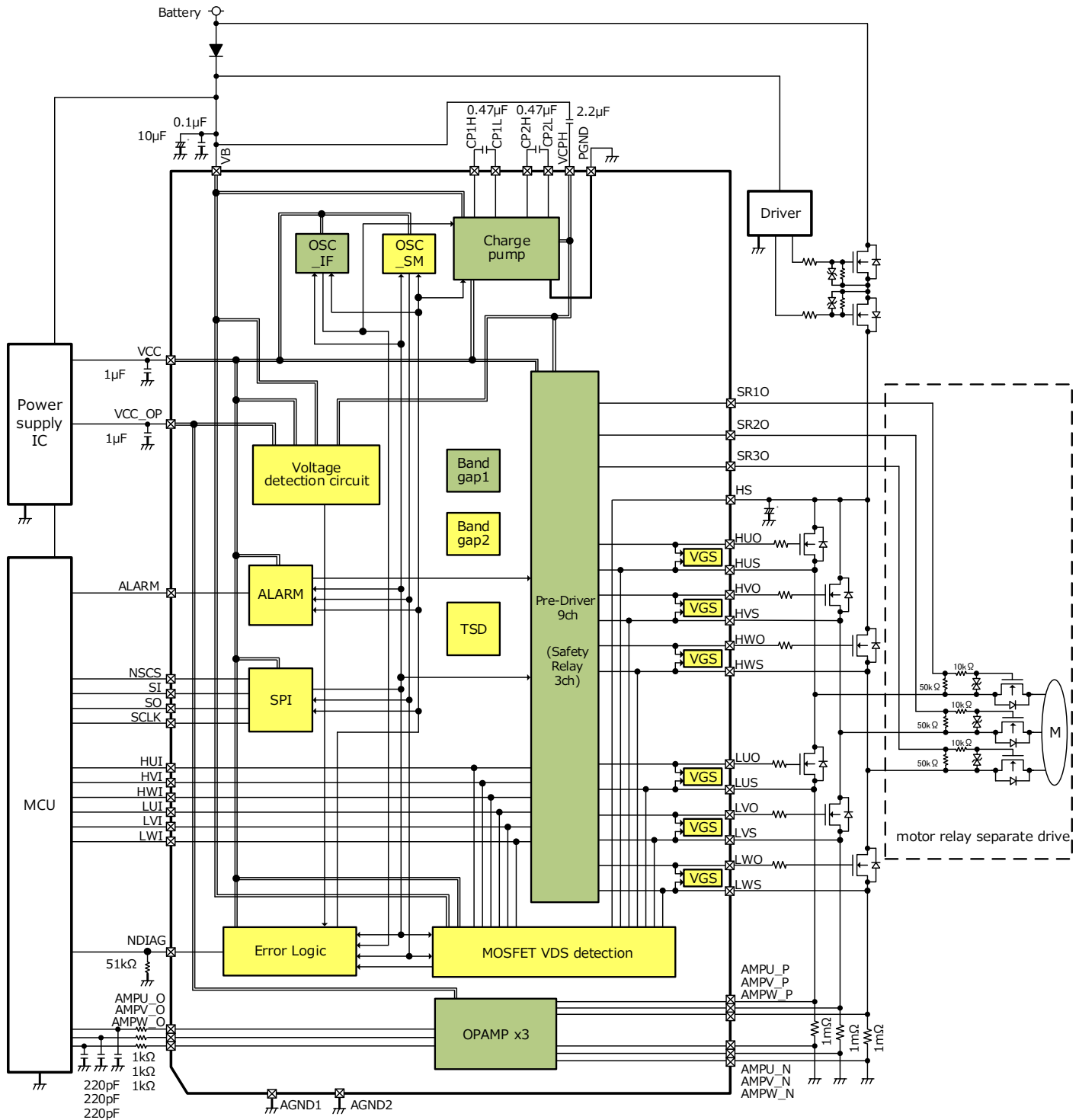
Determine the external circuits after a sufficient evaluation and check on a unit board, assuming the conditions of the operating environment.

* The smoothing capacitors externally added to the power supply terminals (VB, VCC, VCC_OP, VCPH) should be located as close to the roots of the IC as possible.

* AGND1, 2 and PGND should be the solid GND (same potential ±0.3V) on the unit board.

* When designing a unit, take into consideration the notes of the individual blocks as well.

* Do not connect the IC incorrectly. It may destroy the IC and/or damage the devices.



When driving motor relays individually

«Notes for users»

* The circuit constants are for the application circuit example, and not guaranteed.

Determine the external circuits after a sufficient evaluation and check on a unit board, assuming the conditions of the operating environment.

* The smoothing capacitors externally added to the power supply terminals (VB, VCC, VCC_OP, VCPH) should be located as close to the roots of the IC as possible.

* AGND1, 2 and PGND should be the solid GND (same potential ±0.3V) on the unit board.

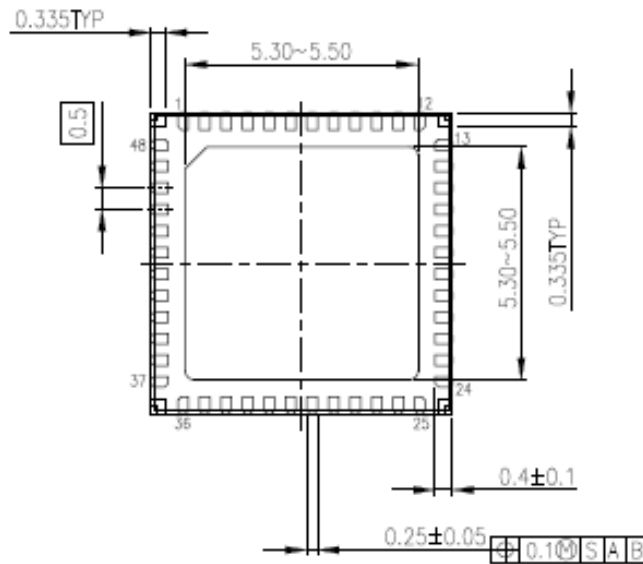
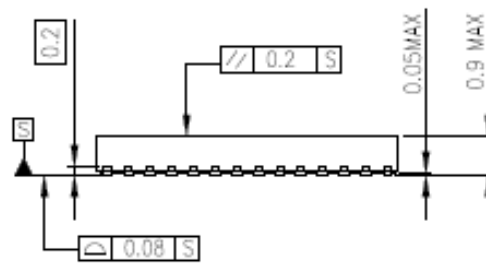
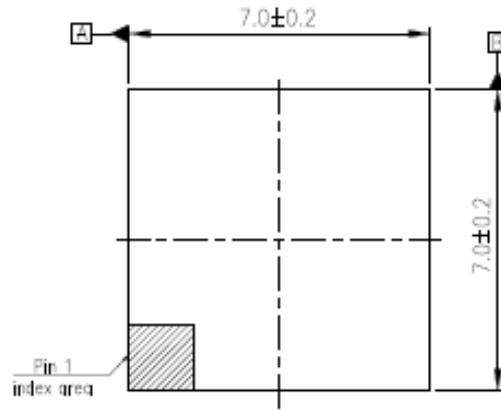
* When designing a unit, take into consideration the notes of the individual blocks as well.

* Do not connect the IC incorrectly. It may destroy the IC and/or damage the devices.

11. Outline drawing

Package dimensions
P-VQFN48-0707-0.50-005

"Unit:mm"



Rev01

Before creating and producing designs and using, customers must also refer to and comply with the latest versions of all relevant TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION information and the instructions for the application that Product will be used with or for.

weight: T.B.D. g (typ.)

12. Revision history

| Specification Ver. | Specification changes | Dates of creation/changes |
|--------------------|--|---------------------------|
| 0.1 | Newly created | 2019/8/8 |
| 0.2 | 7.2 Pre-driver circuit Switches of mid-voltage resistors added to the figure. 7.5.8 DS Detection block diagram modified (Switches of mid-voltage resistors added). Detection state table modified. Signal names in the timing chart corrected. 8 Absolute maximum ratings Specifications on the input voltage of HUS, HVS, LWS added. Specifications on the output voltage of HUO, HVO, HWO added. | 2019/8/8 |
| 0.3 | 7.5.11, 7.9.2, 7.9.3.18, 7.9.3.19, 7.9.3.20QA timer related items undated. | 2019/8/19 |
| 0.4 | 7.3, 7.9.3.15 Electric current related items updated. | 2019/8/28 |
| 0.5 | Fig. 7.9-f Fig. 7.9-i "seq_coutner" value when QA timer start command is received is corrected. Various statuses and error accumulation counter The status bit err_qa is set to "H" for a sequence where answer data has turned out to be invalid, and it is maintained until it is cleared by the err_qa_cl bit. The status bit err_qato is set to "H" for a sequence where answer data has not been obtained within the pre-defined time, and it is maintained until it is cleared by the err_qato_cl bit. The status bit err_qac is set to "H" for a sequence where the error accumulation counter value has reached 4, and it is maintained until it is cleared by the err_qac_cl bit. Table 7.9-a, Fig. 7.9-i Corrected so that "seq_coutner" not cleared by "err_qac_cl." 7.9.3.18: Stated that register setting uses values at a time when a Start command is received. | 2019/09/02 |
| 0.6 | Table 7.7-a, Table 7.7-b Operation of charge pump and pre-drivers related to ABIST updated. Table 7.2-b Truth table regarding the prohibited input updated. 7.9.3.8 Description on registers regarding the prohibited input updated. 7.1,10 Description on the charge pump current limit added. 7.3.2, 7.9.3.15, 7.9.3.16 Description on the current detection amplifier offset calibration updated. | 2019/09/03 |
| 0.7 | Fig. 7.5.8-a Stated that VDS detection is disabled while pre-drivers are disabled. 7.2 Stated that series resistance value is not limited when the relay control output is used for power supply relay. | 2019/09/05 |
| 0.8 | 7.8 Description the initial diagnosis circuit for external FETs and relays added. 7.9.3.23 - 7.9.3.26 Registers related to the initial diagnosis for external FETs and relays added. 7.8.3 Register map updated. | 2019/9/20 |
| 0.9 | 7.9.3.23 Modified typeC description to Type D 7.9.3.23 Added fet_test_manual bit 7.8.3 FET manual inspection The explanation was corrected. 7.9.3.9, エラー! 参照元が見つかりません。 Change the setting range of current value. 9 SPI communication circuit NSCS invalid time is corrected to 2us Fig. 7.8-c, Fig. 7.8-d, Fig. 7.8-e, Fig. 7.8-f Clarified existence of waiting time after turning on the mid-voltage generating resistor. | 2019/12/4 |
| 0.10 | Change motor relay application | 2019/12/19 |
| 1.0 | 7.2. Pre-Driver Circuit Deleted the description of constant current drive Deleted the clump circuit of Fig.7.2a and b. Added the gate resistors. 7.9.3 Resister map Deleted HS_ISEL ith_puh/ith_pdh. Deleted LS_ISEL ith_pul/ith_pdl. Changed HS_ISEL to T_ILIM. Added a note about 32 μs and no current limit to the T_ILIM table. 9. Electrical characteristics Consumption current Set Standby current (Vb)/ Supply current (Vb) Supply current (Vcc)/ Supply current (Vccop). Charge pump circuit Changed Vcph1:Vb=4.5 to 7V Output load =T.B.D.(8500pF) to Vb=4.5 to 5.5V Output load =28mA Changed Min:Vb+5.5 to Vb+5.3 Changed Vcph2:Vb=5.5 to 7V Output load =34mA(15000pF) to 28mA Changed Vcph3:Vb=7 to 28V Output load =34mA(15000pF) to 28mA Changed Typ.:Vb+14 to Vb+11 Max.:Vb+16.5 to Vb+12 | 2020/09/18 |

| Specification Ver. | Specification changes | Dates of creation/changes |
|--------------------|--|---------------------------|
| | <p>Deleted current Limitation. Added Operating frequency</p> <p>Pre-driver circuit Changed Output voltage¹¹ Voh1 Test conditions: Voltage between H*O and H*S to Voltage between H*O and AGND Changed min.(Vcph-0.3)/max.Vcph Changed Output voltage 2 min.(6.7)/max.(12)</p> <p>Deleted High side pull-up current¹ to 7. Deleted High side pull-down current¹ to 7. Deleted Low side pull-up current¹ to 7. Deleted Low side pull-down current¹ to 7. Added Output resistance¹ and 2. Changed When turned on, input propagation delay time min:50 to 20n. Changed When turned off, input propagation delay time min:50 to 20n. Set VDS detection input current 1 for external MOSFET min.-850 typ.-650 max. -450 μA Set VDS detection input current 2 for external MOSFET min.5 typ.6.8 max.7.6mA に設定 Set External MOSFET VGS overvoltage detection threshold min.15.5V typ.17.5V に設定 Set Threshold for external MOSFET VGS overvoltage detection removal min. 14.5 typ.16.5 max.18.5V</p> <p>•10. Application circuit example Added Gate resistors.</p> | |
| 1.1 | <p>7.2. Pre-driver circuit Added Clump circuits of Fig.7.2a and b 8. Absolute maximum ratings (Ta = 25°C) Changed Input voltage HS: -0.3 to Vb+0.3 to -18 to Vb+0.3. 9. Electrical characteristics Charge pump circuit Updated Operating frequency Added Pre-charging time and Enable time for pre-driver Updated Fig. Fig. 9 b Charge pump circuit timing chart •Pre-ri-ver circuit Added Output voltage 1 Voh1(Vb=7.0 to 28V) and Voh1_2 Changed Output voltage 1 Voh1 Test conditions : Voltage between H*O and AGND to Voltage between H*O and H*S Added Output voltage² Test conditions L*S=0V •Abnormality detection circuit Added BIST time.</p> | 2020/11/9 |
| 1.2 | <p>7.1 Charge pump Deleted operating frequency in description 9. Electrical characteristics •Pre-driver Updated Output resistance¹ and 2(Tentative value).</p> | 2021/4/26 |
| 1.3 | <p>7.2 Pre-driver circuit→Corrected description of Current limiter 7.5.8. External MOSFET VDS detection Corrected a typographical error in the filter symbol in the timing chart Updated Fig. 7.5.8 d Timing chart for short-circuit detection (register vds_{l_op} = vdsh_op "0010") Updated Fig. 7.5.8 f Timing chart for short-circuit detection (register vds_{l_op} = vdsh_op "0100") Updated Fig. 7.5.8 h Timing chart for short-circuit detection (register vds_{l_op} = vdsh_op "0110") Updated Fig. 7.5.8 j Timing chart for short-circuit detection (register vds_{l_op} = vdsh_op "1000") 7.5.9. External MOSFET VGS overvoltage detection Updated Fig. 7.5.9 c Operational chart for VGS overe detection 7.7 ABIST/LBIST Fig. 7.7 b ABIST timing chart→Updated description of *2 If VB undervoltage detection and VCC_OP undervoltage detection are not released at the start of ABIST, the ABIST result will be abnormal. 7.9.3. Register map 7.9.3.2. OPSEL2 Write Address=04h / Read Address=84h→Added *1 7.9.3.11. FET_OPSEL Write Address=24h / Read Address=A4h→Added *1 and *2 7.9.3.15. AMP_CTRL Write Address=40h / Read Address=C0h→gain_amp_u/v/w Updated "101"=x30→x27.5 Added "110"=x27.5 Updated "111"=x1 →x27.5 10. 8. Absolute maximum ratings (Ta = 25°C) Updated Allowable dissipation curve and Thermal resistance 9. Electrical characteristics Current detection circuit GAIN Gain5: updated x30 to x27.5</p> | 2021/10/06 |

| Specification Ver. | Specification changes | Dates of creation/changes |
|--------------------|---|---------------------------|
| | Slew rate: updated with descriptions for the respective voltages(VCC_OP=5V and 3.3V) Input common mode voltage Updated min:-1.8V to -0.5V and max:2.0V to 0.5V | |
| 1.4 | <p>7.3.3 Check output voltage with 1x gain → Delete content</p> <p>7.9.3 Register map 7.9.3.9. delete note about 32μs in T_ILIM 7.9.3.28. add DUMMY</p> <p>8. absolute maximum ratings (Ta = 25°C) VCPH -0.3~40(DC),40~60(≤1s) to -0.3~44.5(DC),44.5~60(≤1s) Input voltage: HUS, HVS, HWS -7~ Vb+0.3 to -7~ Vcph+0.3 LUS, LVS, LWS -7~ Vb+0.3 to -7~ Vcph+0.3 Input voltage: LUO, LVO, LWO -7~ Vcpl+0.3 to -7~ Vcph+0.3 Changed from Vout4≤20V to Vout4≤60V Input current : HUS, HVS, HWS lin1: 1A AMPV_P, AMPV_N, AMPW_P, AMPW_N lin2: -0.5 to 2mA Output current: HUO, HVO, HWO HUO, HVO, HWO, LUO, LVO, LWO Iout1: -10 to 20mA Iout2: 1A AMPV_O, AMPW_O Iout3: ±5mA NDIAG, SO: Iout4: ±10mA</p> <p>9. Electrical Characteristics</p> <p>Consumption current Consumption current (Vb) Ib1/ Ib2/ Ib3 → Pre-Driver output load: Rload=0Ω, Cload=15000pF Add Safety Relay output load: Rload=1.5kΩ, Cload=15000pF</p> <p>Pre-Driver Circuit Output Resistor: SR10/SR20/SR30 Max changed from 600Ω to 650Ω Output resistor 1: HUO, HVO, HWO Rohh Max 12Ω Output resistor 2: LUO, LVO, LWO Rohh Max 12Ω Fig. 10 d Measurement circuit diagram (High side/Low side) Rload=10Ω Fig. 10 e Measurement circuit diagram Measurement circuit diagram (safety relay) deleted Fig. 10 f Output current switching time, input propagation delay time timing chart → updated to switch control</p> <p>Current detection circuit Settling time Time to converge to Rload=1kΩ, Cload=220pF output voltage ±2% was added to the measurement conditions. Added the input range where amplifier output can secure ±1% gain error when AMP*_P and AMP*_N are short-circuited as a measurement condition and changed max. to 2.0V. PSRR measurement condition was updated to "Input 1KHz to VCC_OP, but exclude the effect of VREF" and "min" was updated to "-". CMRR measurement condition: "Gain=15, Comvin=200mVp-p, 1KHz" was added. min was updated to "-".</p> <p>Abnormality Detection Circuit VDS detection input current of external MOSFET 1 I_vds1_Roff min:-650 typ:-400 max:-250 I_vds1_Ron min:4.5 typ:6.8 max:8.5 VDS detection input current 2 I_vds2_Roff min:-650 typ:-450 max:-250 I_vds2_Ron min:-8.5 typ:-6.8 max:-4.5 Dividing resistor current ratio for midpoint voltage generation → specified as Midpoint voltage divider ratio min. 0.4 typ. 0.5 max. 0.6</p> <p>10. application circuit example Add external element constants</p> | 2022/08/18 |

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