Sensorless Sinusoidal Brushless Motor Drive Circuit Using TC78B011FTG

Design guide

RD239-DGUIDE-01

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Table of Contents

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1. Introduction

This Design Guide (hereafter referred to as this guide) describes the reference design (hereafter referred to as this design) of Sensorless Sinusoidal Brushless Motor Drive Circuit Using TC78B011FTG.

The use of brushless motors is increasing in various applications and as a result the requirement for a stable brushless motor control with less noise and customizable speed profile is also increasing. This design is based on Toshiba's TC78B011FTG (hereafter referred to as MCD (Motor Control Driver)) which is a 3-phase PWM chopper predriver, it uses the sensorless sinusoidal control method to run a brushless motor. Sinusoidal drive motor control makes it possible to run the motor with less noise and vibration. It also provides closed loop motor speed control without requiring any external microcontroller for a more stable motor speed control. The speed profile curve can be set in this MCD for precise motor control.

The motor control settings are done in MCD registers via I2C communication. Once these settings are done, the motor can be controlled via external signals which affect motor speed, direction, brake etc. The motor speed can be controlled via three different input methods, which includes PWM, analog voltage and I2C. The motor control setting of MCD registers can be stored in its internal non-volatile memory (NVM), and the registers are loaded when the MCD starts next time. Therefore, stable motor control can be achieved by simply performing various settings without an external microcontroller.

This design also uses Toshiba's TPH1R204PB power MOSFETs to drive the brushless motor and TCR1HF50B LDO to produce a 5 V power supply. We also developed a GUI to easily perform the MCD register setting via I2C communication. An USB-I2C converter is used for communication between the GUI (on PC) and the board (PCB) of this design is also prepared.

Applications of this design include server fans, blowers, pumps, vacuum cleaners, etc.

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2. Specifications and Block Diagram

Table 2.1 lists the main specifications of the board (PCB) of this design.

Table 2.1 Specifications of This Design

Item	Specifications
Input Power Supply Voltage	DC 11 to 27 V
Input Control Signal Voltage	DC 5 V
Rated Output Current	20 A (Max.)
Driven Motor Type	Brushless Motor
Motor Control Type	Sensorless Sinusoidal Drive
MCD Setting Method	I2C
Main Motor Control Signals	Brake, Direction, Speed signal
Board Size	90 x 50 mm (Consisting Main Board of 39 x 50 mm)
Board Layer Configuration	4-layer through-hole (outer layer 35 μm, inner layer 70 μm)

Fig. 2.1 shows the block diagram of the board (PCB) of this design.

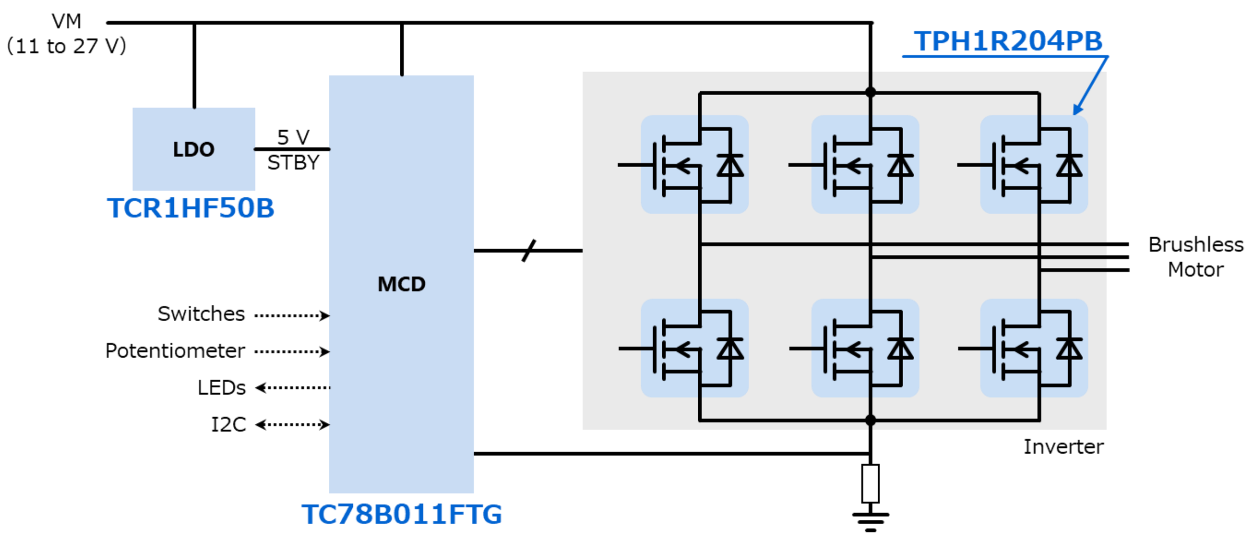


Fig. 2.1 Circuit Block Diagram of Sensorless Sinusoidal Brushless Motor Drive Circuit Using TC78B011FTG

3. Components Used

This section introduces the components that are used in this inverter. Toshiba has an extensive lineup of power semiconductors, driver couplers, and LDOs, including those used in this design.

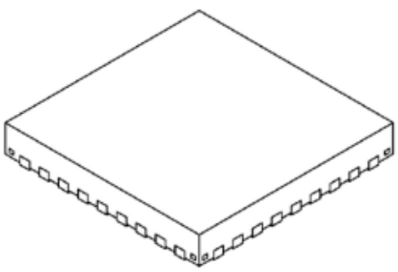
3.1. Brushless Motor Predriver TC78B011FTG

This design uses TC78B011FTG MCD for driving the brushless motor via an inverter circuit.

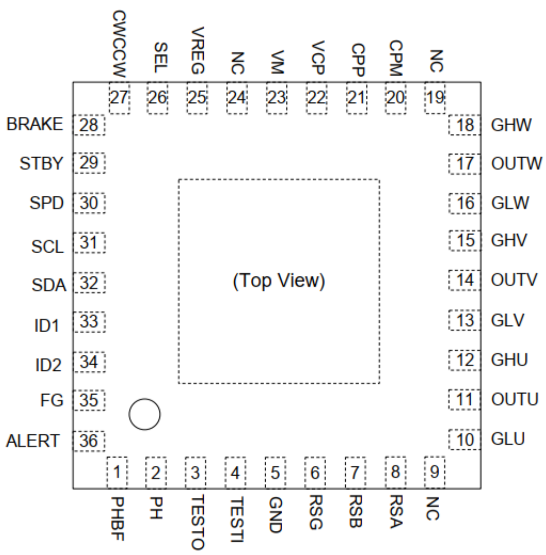
Features

- Sine-wave drive
- Sensorless PWM drive
- Capable to drive Delta or Wye configured motors
- Operating voltage: 5.5 to 27 V (absolute maximum rating: 30 V)
- Predriver for high side and low side N-ch MOSFETs drive
- 8 selectable levels of gate drive current
- Built-in closed loop speed control with adjustable speed curve
- Motor speed control by analog voltage, PWM duty cycle, or I2C
- Serial interface (I2C) for various settings
- Standby mode (by STBY pin)
- Current monitor output (PHBF pin)
- CW/CCW control (CWCCW pin)
- Brake input pin (BRAKE pin)
- Rotation speed output (FG pin)
- Abnormality detection output (ALERT pin)
- Thermal shutdown (TSD)
- Under voltage lockout (UVLO)
- Charge pump low voltage detection (CPVSD)
- Output current limit (OCP)
- Over current detection (ISD)
- Lock protection
- Small QFN36 package

Appearance and Pin Layout



P-WQFN36-0505-0.50-001



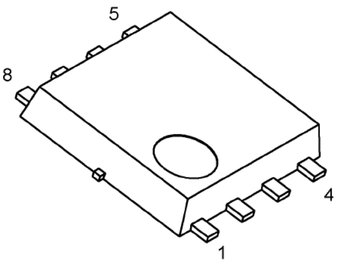
3.2. Power MOSFET TPH1R204PB

This design uses TPH1R204PB MOSFETs in the inverter circuit which is used for driving brushless motor.

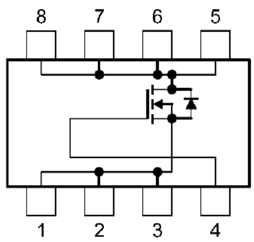
Features

- High-speed switching
- Small gate charge: Q_{SW} = 21 nC (Typ.)
- Small output charge: Q_{OSS} = 56 nC (Typ.)
- Low on-resistance: $R_{DS(ON)}$ = 0.85 mΩ (Typ.) (V_{GS} = 10 V)
- Low leakage current: I_{DSS} = 10 μA (Max.) (V_{DS} = 40 V)
- Enhancement mode: V_{th} = 2.0 to 3.0 V (V_{DS} = 10 V, I_D = 0.5 mA)

Appearance and Pin Layout



SOP Advance



1, 2, 3: Source
4: Gate
5, 6, 7, 8: Drain

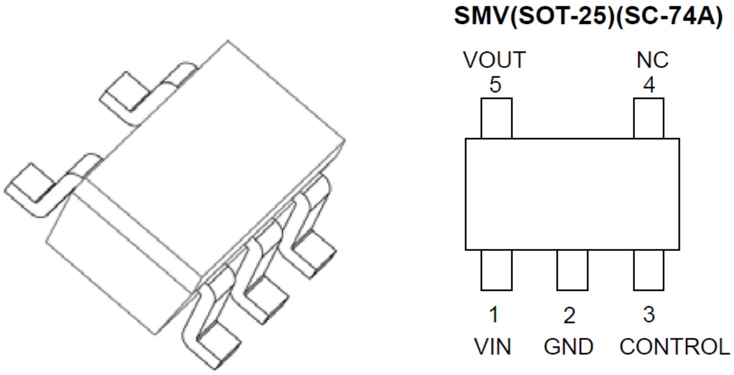
3.3. LDO TCR1HF50B

This design uses TCR1HF50B as a stabilized power source for 5 V.

Features

- High input voltage 40 V (Absolute Maximum ratings), 4 V to 36 V (Operation input voltage)
- Low quiescent current I_{BON}: 1 μA (Typ.) @ I_{OUT} = 0 mA
- High response load transient
  -60 mV / +50 mV, I_{OUT} = 0 mA ↔ 10 mA
- Output voltage V_{OUT} = 5.0 V
- High accuracy output voltage ± 1 % (Ta = 25 °C)
- Overcurrent protection
- Thermal shutdown
- In rush current reduction
- Pull up connection between CONTROL and VIN
- Ceramic capacitors can be used
- General package SMV (SOT-25) (2.8 mm x 2.9 mm x 1.1 mm)

Appearance and Pin Layout



4. Circuit Design

This section describes the gist of the circuit design. Refer to RD239-SCHEMATIC-xx.pdf for the schematic and to RD239-BOM-xx.pdf for the bill of material. The block diagram of this design is shown in Fig. 2.1.

4.1. Power Supply Circuit

Motor power supply (VM) is the main power supply in this design, and it is input via the motor power supply input connector CN1. This power supply is sent directly to the TC78B011FTG motor predriver IC and to the inverter circuit made up of TPH1R204PB MOSFETs. Fig. 4.1 shows the VM power supply input circuit. VM LED (DS1, Orange) turns on when VM power supply is available. VM input voltage range is from 11 to 27 V.

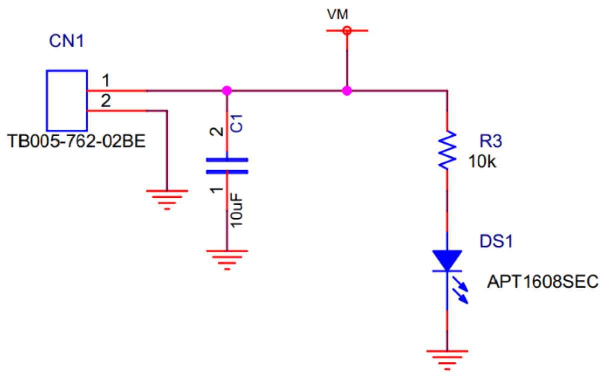


Fig. 4.1 VM Power Supply Input Circuit

A voltage of 5 V(VLDO) is required to pull up various signals like STBY, SPD, etc. in this design. This 5 V(VLDO) voltage is produced by TCR1HF50B LDO using VM as input voltage as shown in Fig. 4.2. TCR1HF50B LDO supports wide input voltage range from 4 to 36 V which is idea for use in this design as the range of input voltage VM is from 11 to 27 V. VLDO LED (DS2, Green) turns on when VLDO power supply is available.

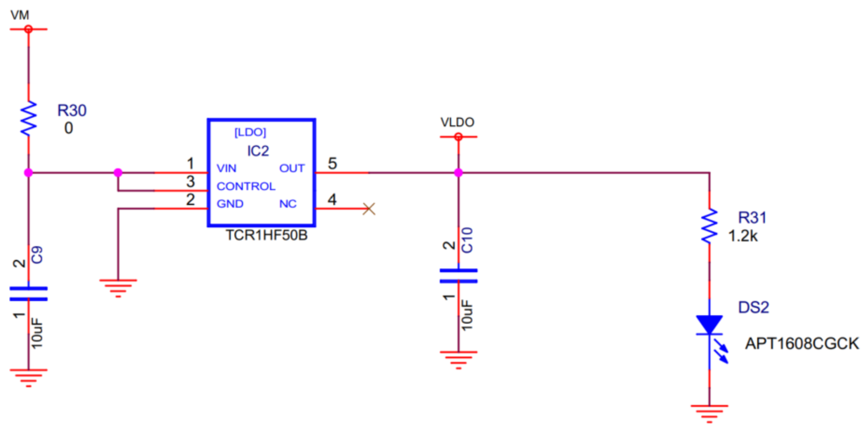


Fig. 4.2 VLDO Power Supply Circuit

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4.2. Inverter Circuit

The inverter circuit is used to drive a 3-phase brushless motor by using the DC power supply (VM). Six high speed TPH1R204PB MOSFETs are used as switching devices in this inverter. These MOSFETs are controlled by TC78B011FTG. The inverter circuit of this design is shown in the following Fig. 4.3.

Pull down resistors like R18 are used between the gate and source of each MOSFET to turn off the MOSFET when the gate signal is not high. Series resistors like R17 are used between TC78B011FTG and gate of each MOSFET to control the charge and discharge rate of the gate terminal which affects the turn on and turn off time of the MOSFET. Therefore, these series resistors can be changed to adjust the turn on and turn off time of MOSFET according to the required application. A shunt resistor R27 is used to monitor the total current flowing through the inverter and the motor. This current is calculated by TC78B011FTG by measuring the voltage difference across this shunt resistor R27 via kelvin connection using RSB and RSG signals.

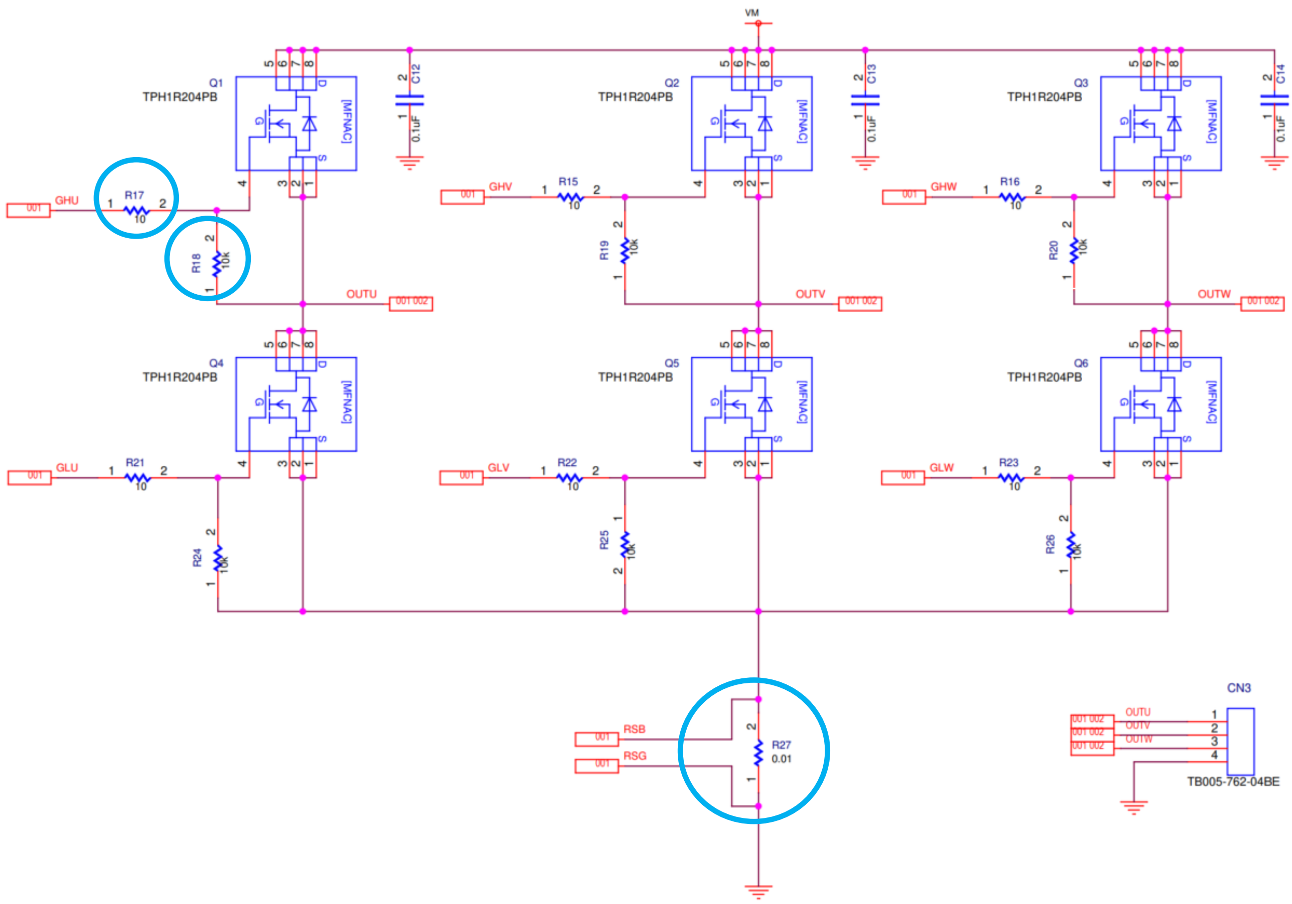

Fig. 4.3 Inverter Circuit

4.3. MCD Input Control Signal Circuit

MCD input control signals are used by the user to control the motor operation. These signals include ID1, ID2, STBY, SEL, CWCCW, BRAKE, SPD. This design allows the user to set these signals in three ways, first by using switches and potentiometer on the sub board, second by connecting an external MCU to the CN6 connector on the sub board, and third by using solder jumpers (SJP1 to SJP8) on the main board. Refer to the operation modes in reference guide document (RD239-RGUIDE-xx.pdf) for more information about these modes.

The main circuit of MCD input control signals is shown in following image. The circuit on the sub board is such that the signals from external MCU coming via CN6 takes priority over the signals coming from the switches and potentiometer on the sub board. This is achieved by using series resistors, for example resistor R39 in the case of BRAKE signal. When the external controller is not connected to the BRAKE signal on CN6, the BRAKE signal going to MCD is controlled by SW4 switch. Although whenever an external controller is connected to the BRAKE signal on CN6, the BRAKE signal going to MCD is controlled by external controller irrespective of the position of switch SW4. Similarly other signals are also controlled.

The jumper JP1 for SPD signal can be used to completely disconnect the potentiometer while using the high frequency PWM speed control from the external MCU.

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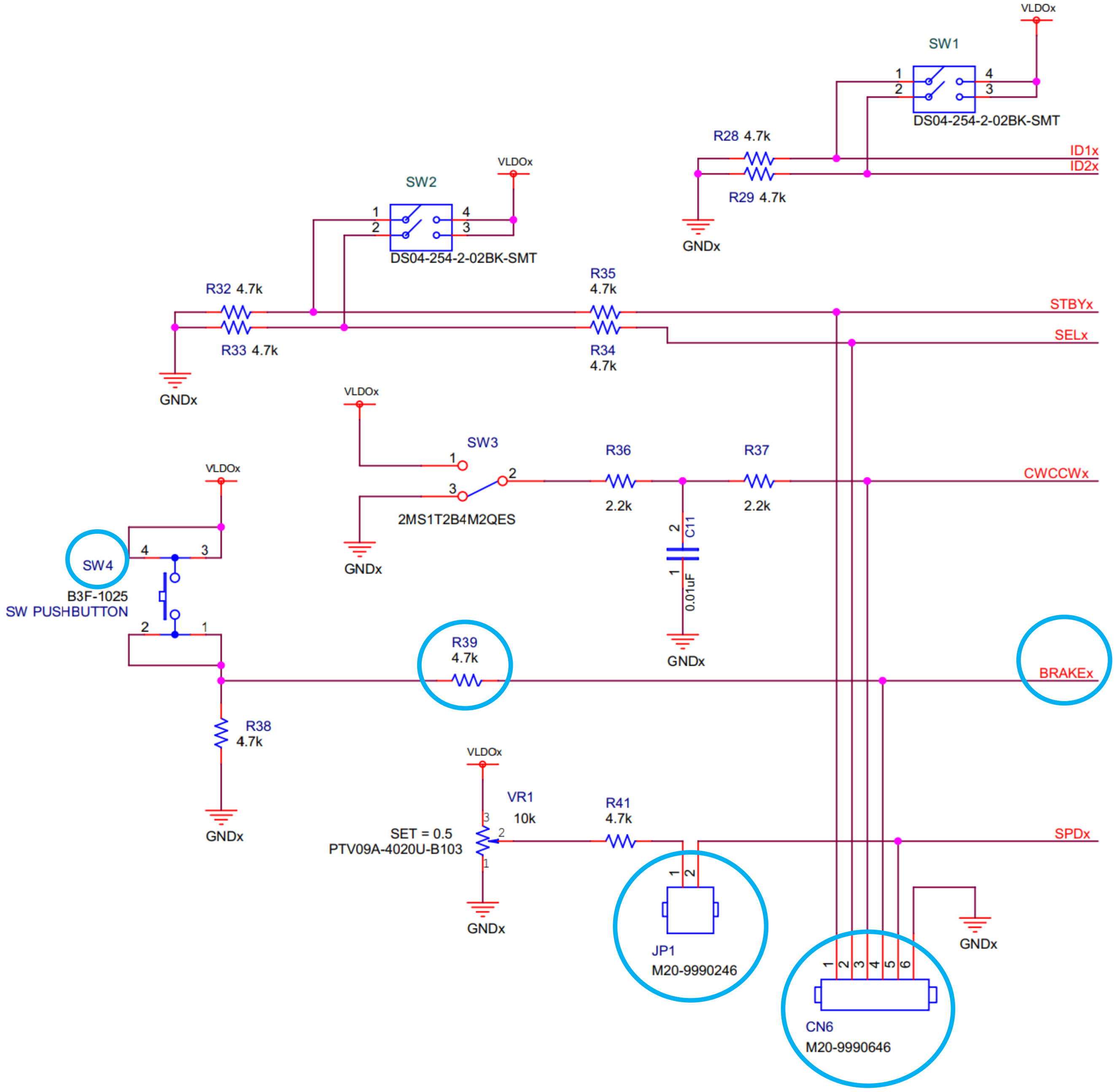

Fig. 4.4 MCD Input Control Signal Circuit

4.4. MCD Output Signal Circuit

Output signals from MCD are ALERT, FG and CMO. LEDs DS3(blue) and DS4(red) are used to indicate the status of ALERT and FG signals. All the output signals can also be read by the external MCU connected to CN8. CMO signal represents the motor current; refer to section 4.5 for more details.

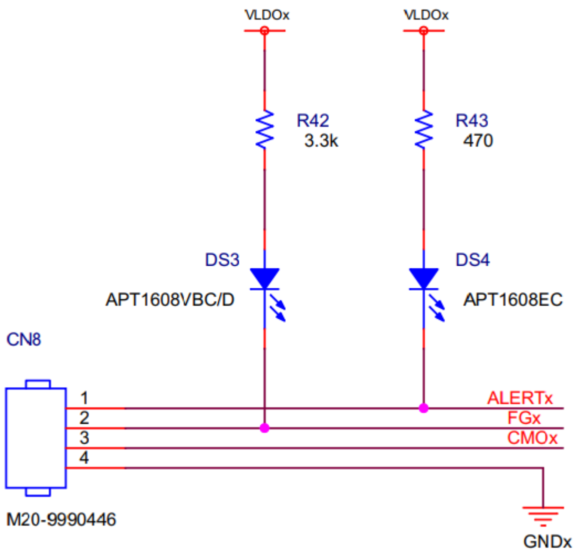

Fig. 4.5 MCD Output Signal Circuit

4.5. Motor Current Detection Circuit

The kelvin connection from shunt resistor R27 (RSB and RSG signals) is used to monitor motor current as described in section 4.2. In addition, the RSB signal is also input to RSA pin and is also used for output over-current detection function. In addition, the motor current value is amplified and output at the PHBF pin of TC78B011FTG for the user to monitor the motor current. C6 and R13 are used to form a low pass filter which provides a dc analog voltage output (CMO) corresponding the motor current value. PH pin is used to configure the internal peak hold circuit. It is recommended to use a resistor of 100 kΩ and a capacitor of 0.1 μF in parallel between PH pin and GND.

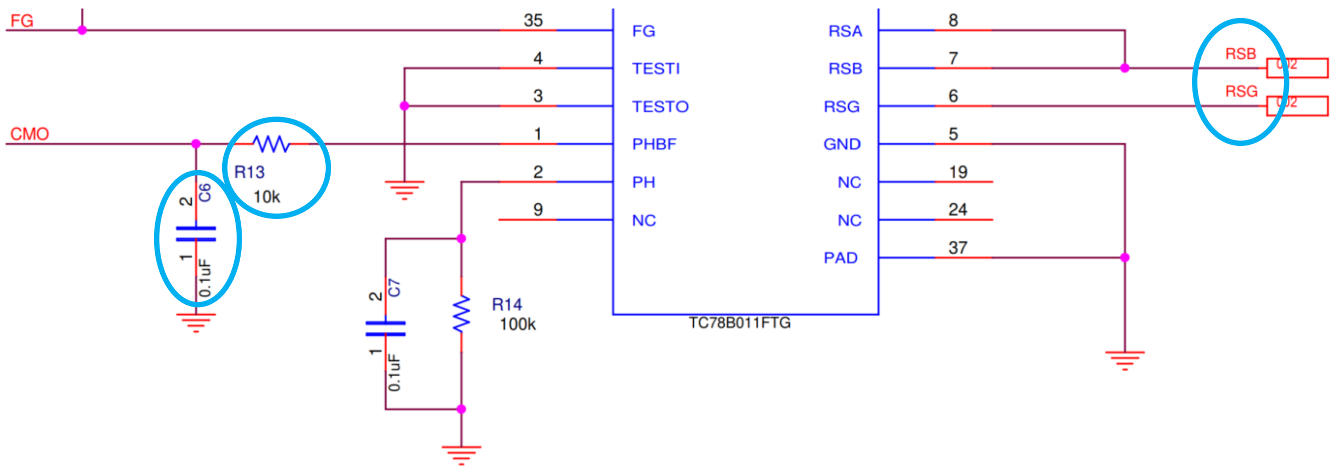

Fig. 4.6 Motor Current Detection Circuit

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5. Pattern Design

5.1. Kelvin Connection for Sensing Current

Kelvin connection is used for the reliable measurement of voltage difference across the motor current sensing shunt resistor R27. TC78B011FTG uses dedicated RSB and RSG inputs for sensing the motor current. The shunt resistor R27 and the pattern for RSB and RSG inputs are shown in the following Fig. 5.1.

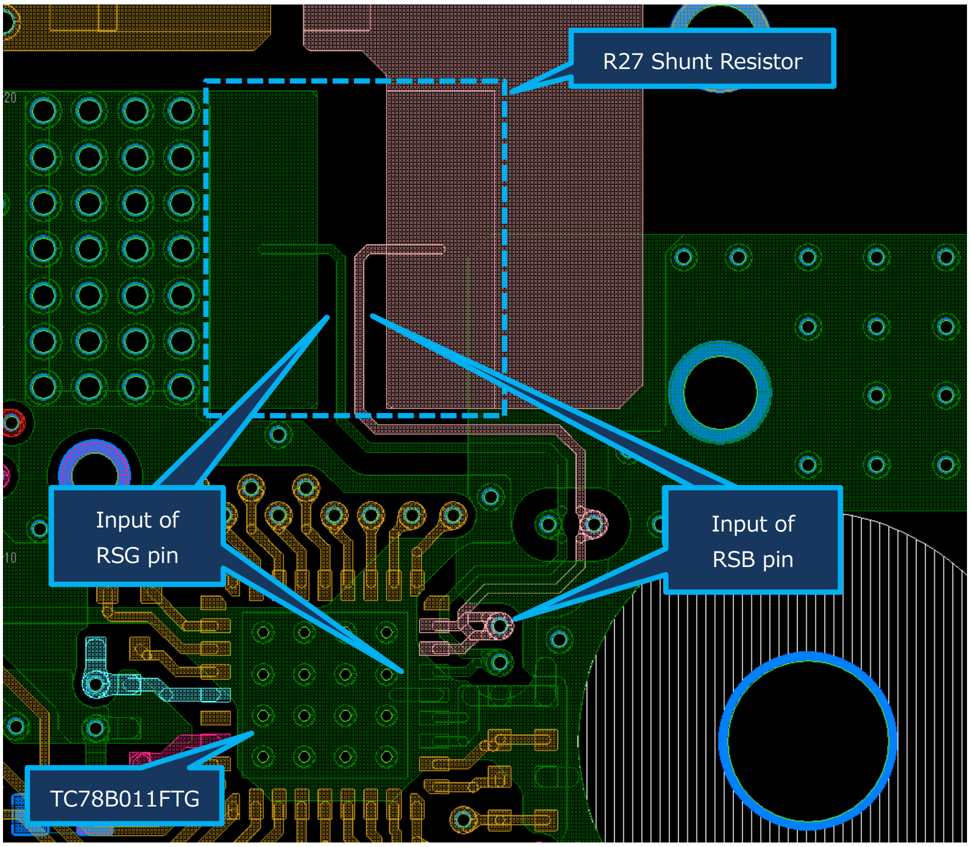

Fig. 5.1 Pattern for Kelvin Connection for Sensing Current

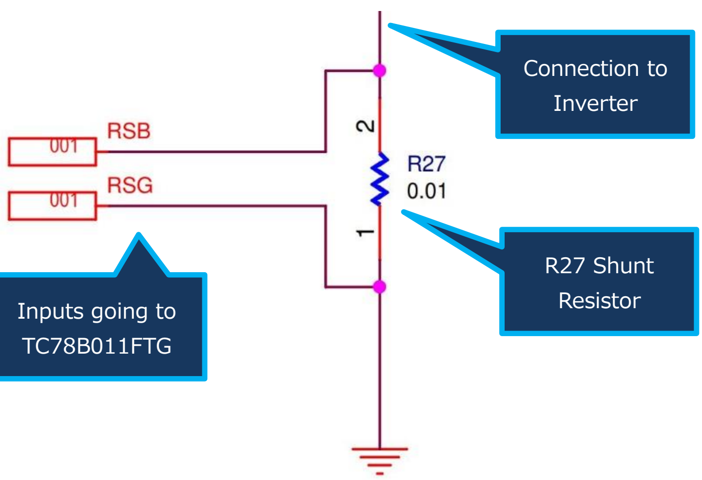

Fig. 5.2 Circuit of Kelvin Connection for Sensing Current

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