# Automotive Brushed DC Motor Control Circuit Using TB9103FTG

# Design Guide

## RD245-DGUIDE-01

Toshiba Electronic Devices & Storage Corporation

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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 Automotive Brushed DC Motor Control Circuit Using TB9103FTG.

Brushed DC motors are extensively used in actuators for doors, windows, seats, etc. of the modern automobiles. Toshiba's automotive 2-channel half-bridge gate driver IC TB9103FTG provides many features for better motor control. It can be used to control two motors in half-bridge mode or one motor in H-bridge mode. Its Dead time control, various fault detection functions, and fault detection output signals help in the safer implementation of motor operation. Its wide input voltage range makes it suitable for various applications. It also comes in a small QFN24 package (4 x 4mm) that enables compact implementation.

This design provides an easy way to test and evaluate various features and functions of TB9103FTG. It also allows the user to control the motor in two ways, first by manually adjusting the switches on the board and second by using an external microcontroller (MCU). This design also provides an option to test two types of power MOSFETs for driving the motor. These power MOSFETs are XPN7R104NC and XPH3R304PS which support the maximum current of 10A and 20A respectively. In addition, this design also features a reverse connection protector circuit which uses XPH1R104PS power MOSFET to protect the circuit if the polarity of input power supply is not correct. This design uses a TB9005FNG voltage regulator IC to generate 5V power supply. This 5V power supply is used in this design and can also be used to supply 5V power to an external MCU. TB9005FNG also features low-voltage reset, power-on reset, and watchdog timer function for better MCU operation.

# 2. Specifications and Block Diagram

Table 2.1 lists the main specifications of this design.

**Table 2.1 Specifications of This Design**

| Item | Specifications |
|---|---|
| Input Power Supply Voltage | DC 8V to 18V |
| Control Signal Voltage | DC 5V |
| Output Current | 10A (Max.) with XPN7R104NC MOSFETs<br>20A (Max.) with XPH3R304PS MOSFETs |
| Driven Motor Type | Brushed DC Motor |
| Motor Control Modes | Half-Bridge Mode, and<br>H-Bridge Mode |
| Board Size | 75 x 75mm |
| Board Layer Configuration | 4-Layer Through-Hole (All Layers: 35μm each) |

Fig. 2.1 shows the block diagram of this design.

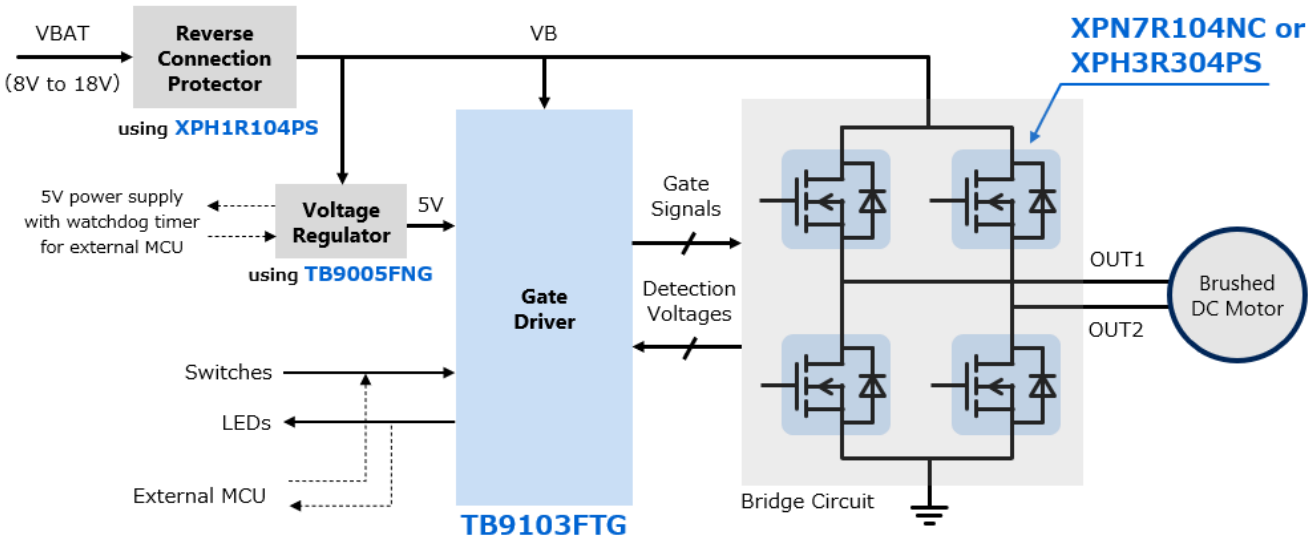



**Fig. 2.1 Block Diagram of This Design**

# 3. Components Used

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

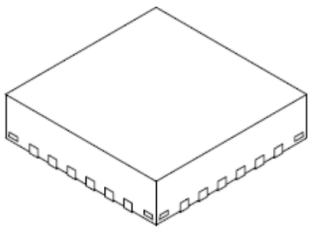
## 3.1. Automotive 2-Channel Half-Bridge Gate Driver IC TB9103FTG

This design uses TB9103FTG for driving brushed DC motor(s) via MOSFETs.

### Features

- Two control modes: Half-bridge mode, H-bridge mode
- Two independent channels in half-bridge mode
- Dead time control and shutdown control
- Low power sleep mode
- Various fault detections:
  - VB low voltage detection, VCC low voltage detection, VCP high voltage detection
  - Gate-source voltage detection, gate voltage fault shutdown
  - Drain-source voltage detection, overcurrent shutdown
  - Overheat detection, shutdown
  - Notification from the open-drain output terminal when a fault is detected
- Operating voltage range: 7 to 18V
- AEC-Q100 Rev-J Grade 1 compliance
- Small QFN24 package (4mm x 4mm)

### Appearance and Pin Layout



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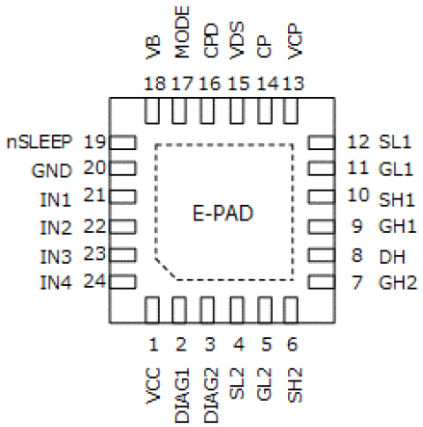


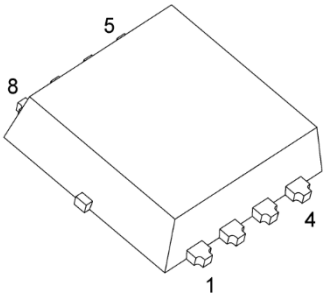
## 3.2. Power MOSFET XPN7R104NC

This design provides an option to use either one of the two types of power MOSFETs for driving the motor. Either XPN7R104NC or XPH3R304PS power MOSFET can be used. This section describes the features of XPN7R104NC power MOSFET.

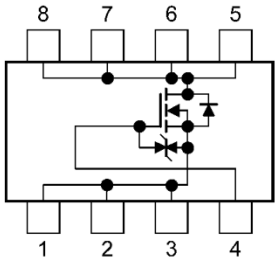
### Features

- AEC-Q101 qualified
- Small, thin package: TSON Advance(WF)
- Low drain-source on-resistance: $R_{DS(ON)}$ = 5.6mΩ (Typ.) ($V_{GS}$ = 10V)
- Drain current: $I_D$ = 20A (Max.)
- Low leakage current: $I_{DSS}$ = 10μA (Max.) ($V_{DS}$ = 40V)
- Enhancement mode: $V_{th}$ = 1.5 to 2.5V ($V_{DS}$ = 10V, $I_D$ = 0.2mA)

### Appearance and Pin Layout




TSON Advance(WF)




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

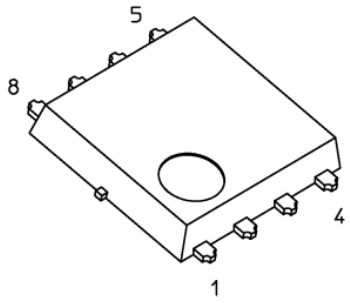
## 3.3. Power MOSFET XPH3R304PS

This design provides an option to use either one of the two types of power MOSFETs for driving the motor. Either XPN7R104NC or XPH3R304PS power MOSFET can be used. This section describes the features of XPH3R304PS power MOSFET.

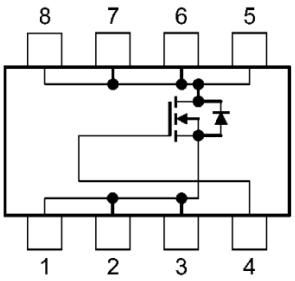
### Features

- AEC-Q101 qualified
- Small, thin package: SOP Advance(WF)
- Low drain-source on-resistance: $R_{DS(ON)}$ = 2.5mΩ (Typ.) ($V_{GS}$ = 10V)
- Drain current: $I_D$ = 60A (Max.)
- Low leakage current: $I_{DSS}$ = 10μA (Max.) ($V_{DS}$ = 40V)
- Enhancement mode: $V_{th}$ = 2.0 to 3.0V ($V_{DS}$ = 10V, $I_D$ = 0.2mA)

### Appearance and Pin Layout




SOP Advance(WF)




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

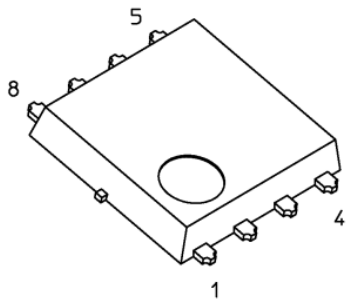
## 3.4. Power MOSFET XPH1R104PS

This design uses the high current supporting power MOSFET XPH1R104PS in the reverse connection protector circuit.

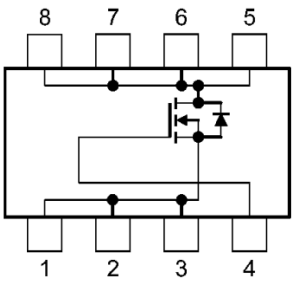
### Features

- AEC-Q101 qualified
- Small, thin package: SOP Advance(WF)
- Low drain-source on-resistance: $R_{DS(ON)}$ = 0.95mΩ (Typ.) ($V_{GS}$ = 10V)
- Drain current: $I_D$ = 120A (Max.)
- Low leakage current: $I_{DSS}$ = 10μA (Max.) ($V_{DS}$ = 40V)
- Enhancement mode: $V_{th}$ = 2.0 to 3.0V ($V_{DS}$ = 10V, $I_D$ = 0.5mA)

### Appearance and Pin Layout




SOP Advance(WF)




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

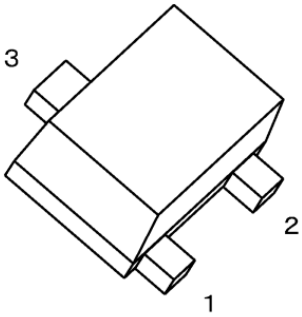
## 3.5. MOSFET SSM3J66MFV

This design uses P-channel MOSFET SSM3J66MFV for driving the output signal LEDs.

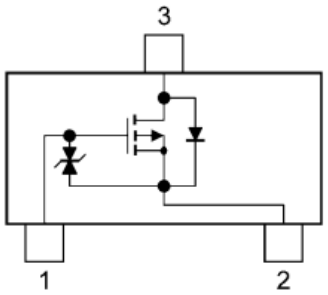
### Features

- AEC-Q101 qualified
- 1.2V drive
- Low drain-source on-resistance: $R_{DS(ON)}$ = 390mΩ (Typ.) ($V_{GS}$ = -4.5V)

### Appearance and Pin Layout




VESM




1. Gate
2. Source
3. Drain

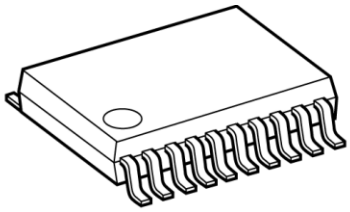
## 3.6. Voltage Regulator TB9005FNG

This design uses the voltage regulator TB9005FNG to create a 5V power supply on the board. This design also provides an option to supply this 5V to power an external microcontroller via CN4.

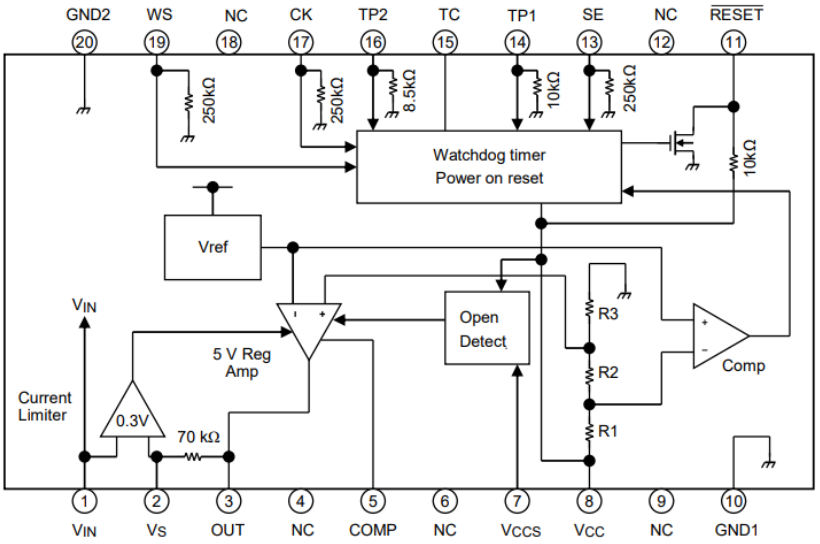
### Features

- Accurate output: 5.0V ± 0.1V (−40 to 125°C)
- Low current consumption: 90μA (VIN = 12V, Ta = 25°C) at 5V output + reset timer
- Reset functions: Low-voltage reset/power-on reset/watchdog timer
- Current limiter: Adjustable with external resistor
- Operating temperature: −40 to 125°C
- Built-in VCC-open detector
- Small SMD package: SSOP-20-pin(0.65mm pitch)

### Appearance and Pin Layout



SSOP20

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# 4. Circuit Design

This section describes the gist of the circuit design. Refer to RD245-SCHEMATIC-xx.pdf for the schematic and to RD245-BOM-xx.pdf for the bill of material of this design. The block diagram of this design is shown in Fig. 2.1.

## 4.1. Power Supply Circuit

Battery power supply (VBAT) is the main power supply of this design, and as shown in Fig. 4.1, VABT is input via the input power supply connector CN1. As shown in Fig. 2.1 and Fig. 4.2, this VBAT power supply goes through reverse connection protector circuit and becomes VB. And this VB power supply is used to power TB9103FTG and drive the motor via the bridge circuit which can be configured as H-bridge or Half-bridge. VBAT input voltage range is from 8V to 18V.

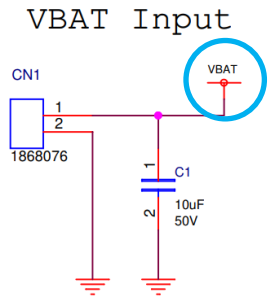


**Fig. 4.1 VBAT Power Supply Input Circuit**

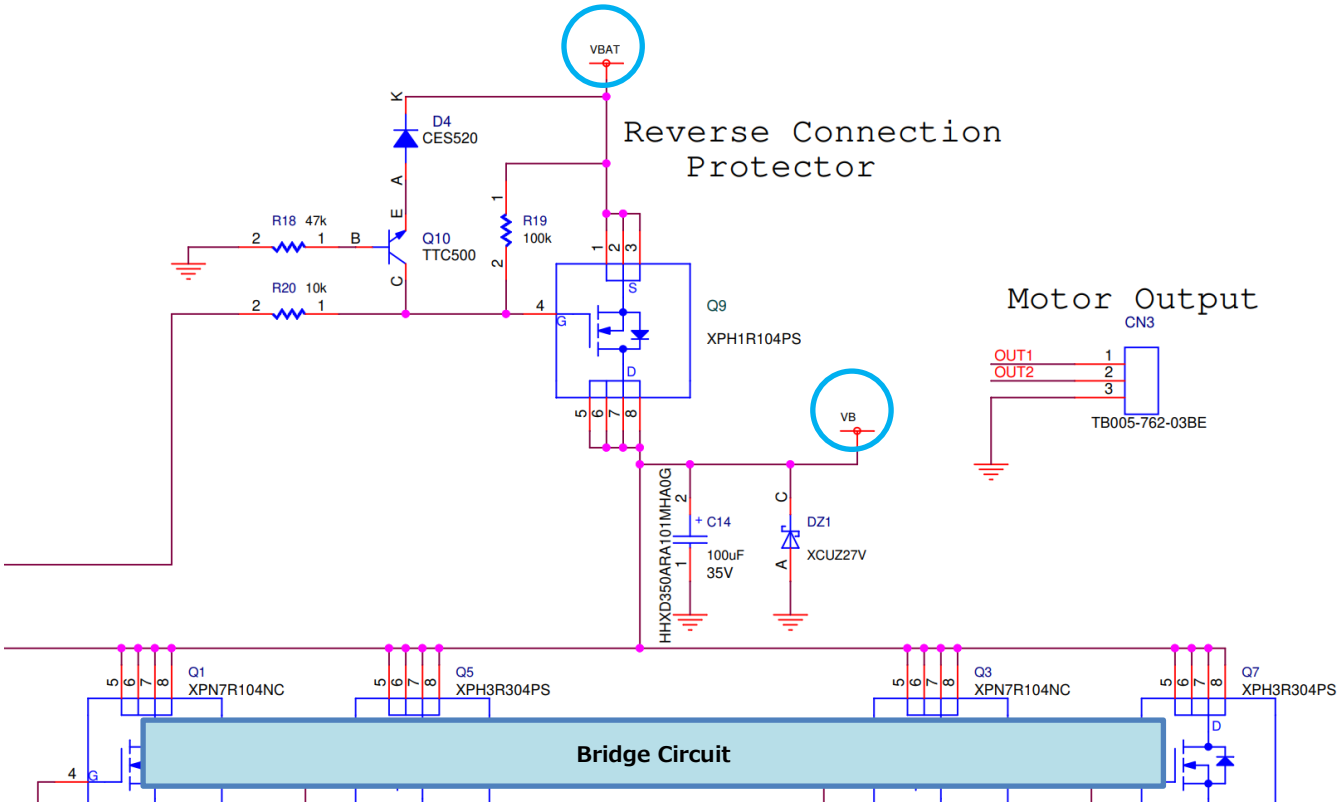


**Fig. 4.2 Reverse Connection Protector Circuit**

A voltage of 5V(D5V) is also required to power TB9103FTG and it is produced by the TB9005FNG voltage regulator circuit using VB as the input voltage as shown in Fig. 4.3. It is also used to power LEDs and to pull up various signals like nSLEEP, IN1, MODE, DIAG1 etc. in this design. LED1(Yellow Green) indicating D5V voltage turns on when this D5V power supply is available.

This design also provides an option to supply 5V from the External MCU Connector (CN2), and this 5V power supply is called VEXT. VEXT and 5V voltage regulator circuit outputs are connected using diodes D2 & D3 to prevent high current flow if both power supplies are active at the same time. This design also provides an option to disconnect the 5V voltage regulator circuit output by desoldering resistor R1.

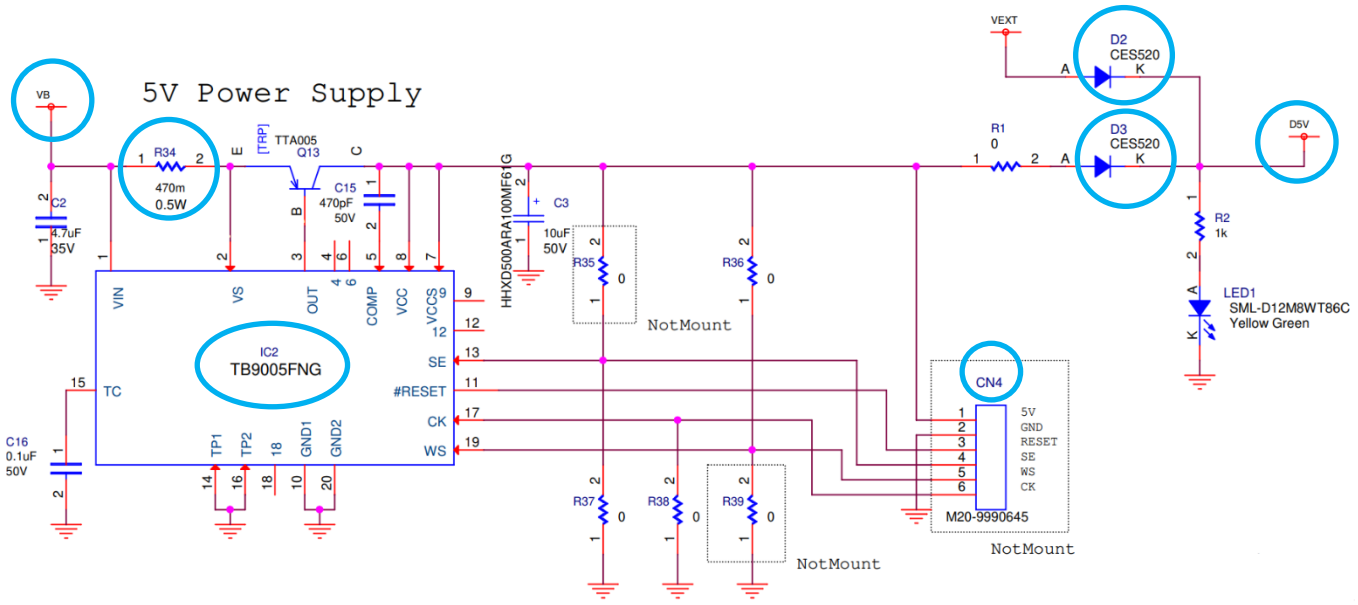


**Fig. 4.3 5V Power Supply Circuit**

TB9005FNG provides an overcurrent protection function and uses a current detecting resistor (R34) to limit the current. R34 is connected between pins VIN and VS as shown in Fig. 4.3. The maximum voltage drop across the resistor R34 can be 0.3V. And since the value of R34 used in this design is 470mΩ, the current limit value becomes 0.3V/470mΩ = 0.638A.

The 5V output of TB9005FNG can also be used to power an external microcontroller via CN4. TB9005FNG also provide features such as low-voltage reset, power-on reset, and watchdog timer reset functions, along with a RESET signal output for the external MCU. Kindly refer to the reference guide document or TB9005FNG datasheet for more details.

Note: Proper thermal design must be done for the 5V voltage regulator circuit according to the required power of the target application.

## 4.2. Bridge Circuit for Driving Motor

In this design the power MOSFETs are used to drive the brushed DC motor. These MOSFETs are connected in a H-bridge configuration. The circuit of this design provides an option to use one of the two types of power MOSFETs. These MOSFETs are XPN7R104NC and XPH3R304PS which feature different current ratings and come in TSON Advance(WF) package and SOP Advance(WF) packages respectively. The MOSFET circuit is shown in Fig. 4.4. These MOSFETs are controlled by the gate driver TB9103FTG.

Each gate drive pin of TB9103FTG has an inbuilt gate pull-down resistor of 150kΩ. In addition, this design provides an option to add external pull-down resistances in place of resistors like R24 (not mounted). Series resistors like R22 are used between TB9103FTG and gate of each MOSFET to control the charge and discharge rate of the gate terminals 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 the MOSFET according to the application requirement. VDS and VGS voltages of all the MOSFETs are monitored by TB9103FTG to detect various faults.

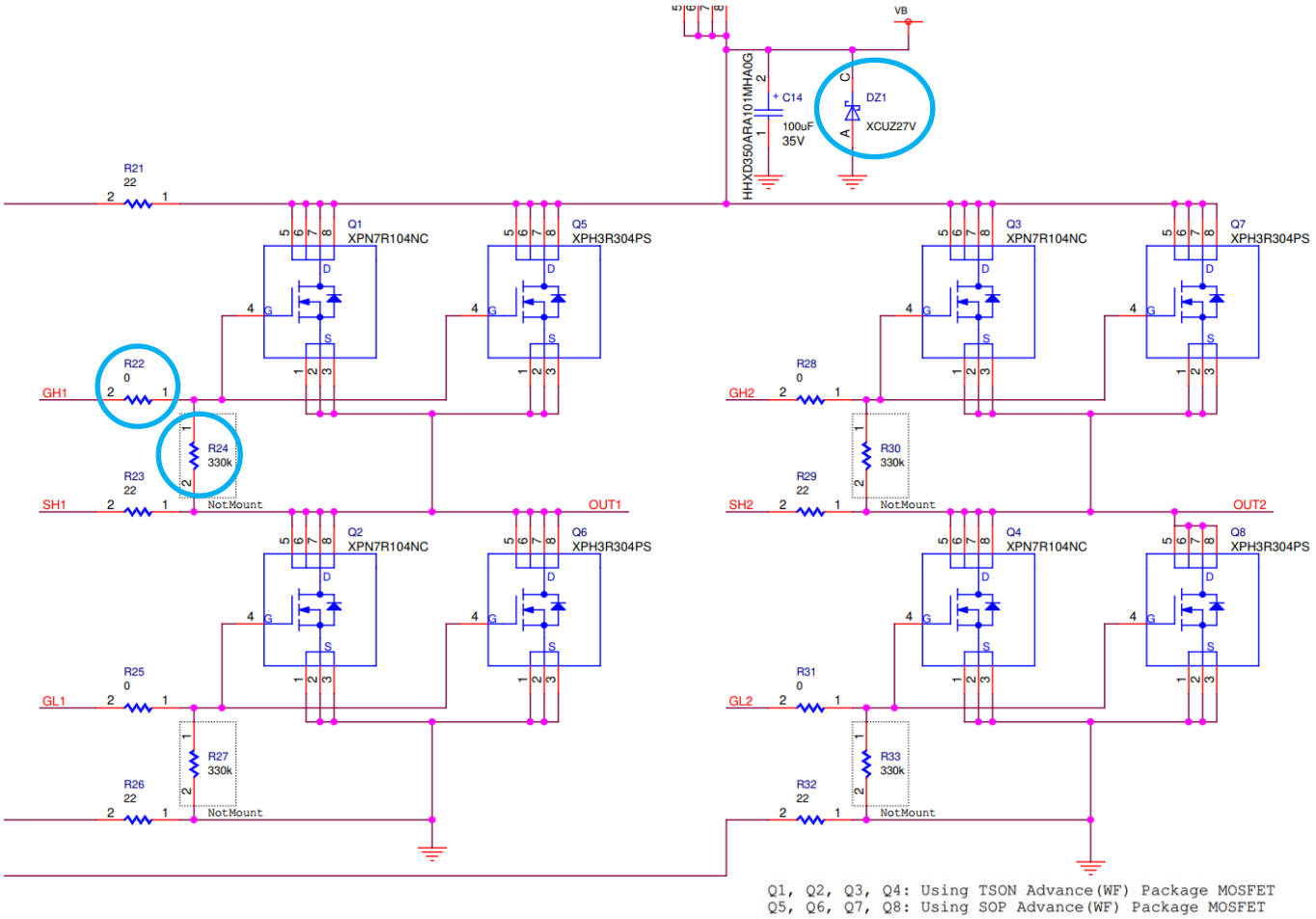


**Fig. 4.4 Bridge Circuit for Driving Motor**

The Zener diode XCUZ27V (DZ1) is used to limit the voltage fluctuations which might be created by the running motor. And the capacitor C14 is used to stabilize the VB voltage.

## 4.3. Input Control Signal Circuit

The input control signals are used by the user to control the motor operation. These signals include nSLEEP, IN1, IN2, IN3, IN4, and MODE. This design allows the user to set these signals in two ways, first by using switches (SW1 to SW6), and second by connecting an external MCU to the CN2 connector. For more details about the operation, refer to the operation section in the reference guide document (RD245-RGUIDE-xx.pdf).

The circuit of input control signals is shown in following image. The circuit of this design is such that the signals from external MCU coming via CN2 takes priority over the signals coming from the switches SW1 to SW6. This is achieved by using series resistors (R7 to R12), for example resistor R7 in the case of nSLEEP signal. When the external controller is not connected to nSLEEP signal via the CN2 connector, the nSLEEP signal going to TB9103FTG is controlled by SW1 switch. Although whenever an external controller is connected to the nSLEEP signal via the CN2 controller, the nSLEEP signal is controlled by the external controller irrespective of the position of switch SW1. This happens because the output impedance of microcontroller is lower than output impedance of switch because of the 10kΩ series resistor. The Capacitors C4 to C8 and C17 are used to remove the unwanted signal transitions produced due to switch bouncing. Other input signals are also controlled in the similar manner.

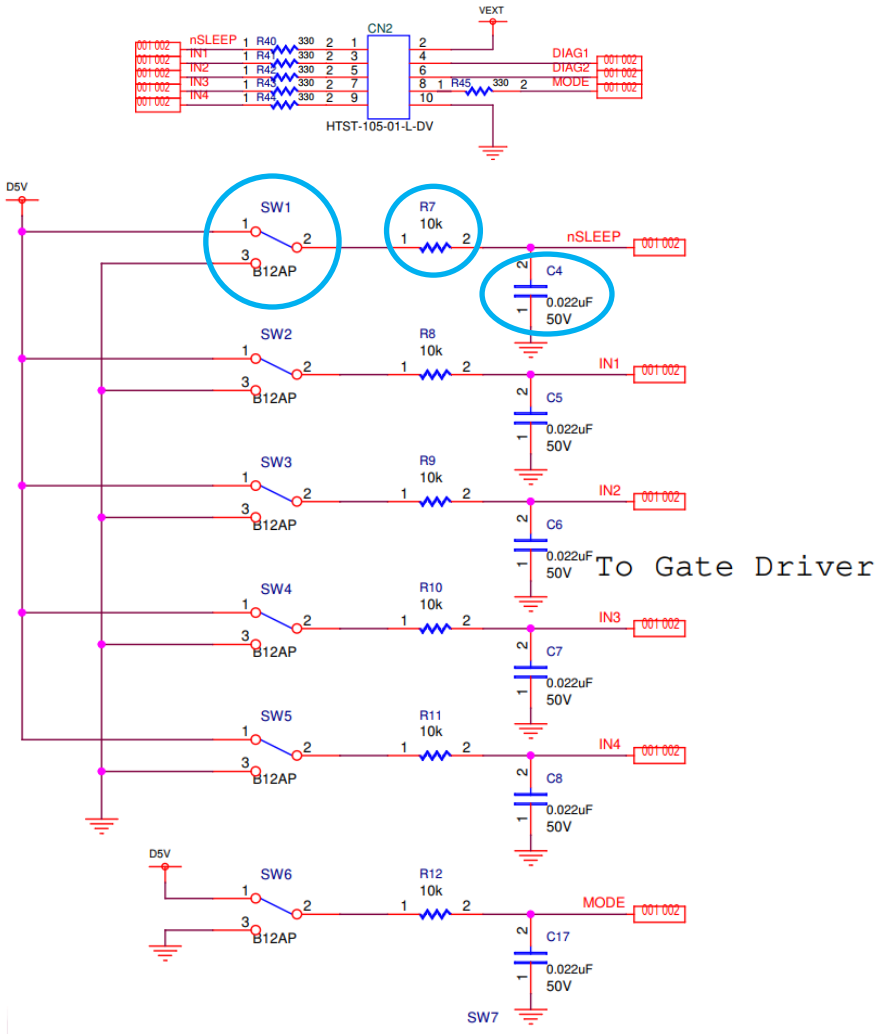


**Fig. 4.5 Input Control Signal Circuit**

## 4.4. Output Signal Circuit

Output signals of TB9103FTG are DIAG1 and DIAG2. LED2 (Red) and LED3 (Yellow) are used to indicate the status of DIAG1 and DIAG2 signals respectively. The output signal circuit is shown in Fig. 4.6. These output signals can also be monitored by an external MCU connected via CN2.

These signals are active low, therefore high-side switches configured using p-channel MOSFETs (Q11, Q12) are used to turn on the LEDs whenever the corresponding signal is low. The overview of fault detection is shown in Table 4.1, and for more details refer to the datasheet of TB9103FTG.

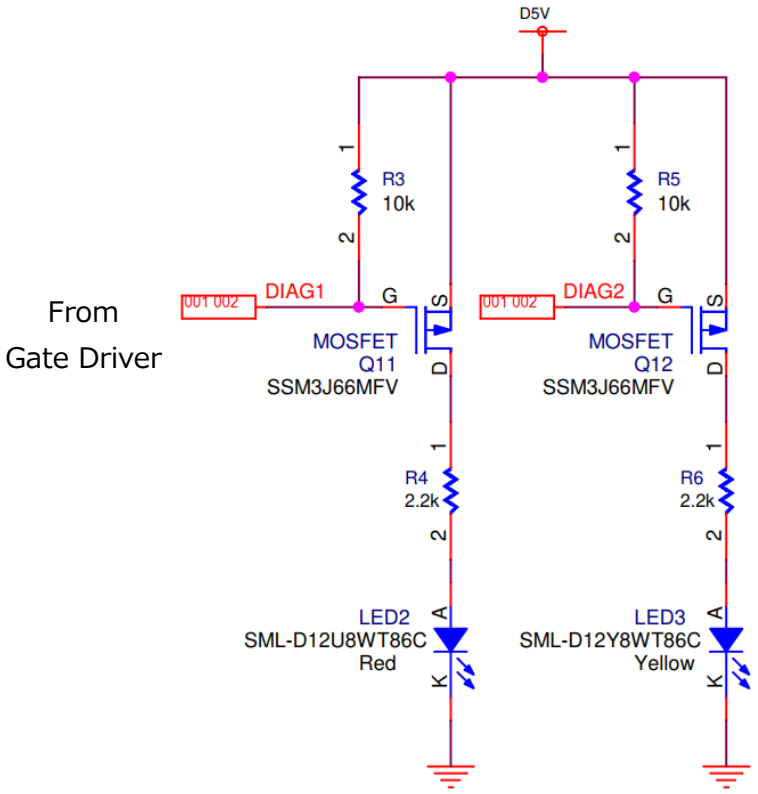


**Fig. 4.6 Output Signal Circuit**

**Table 4.1 Fault Detection Overview**

| LED2 (DIAG1) | LED3 (DIAG2) | DIAG1 Level Status | DIAG2 Level Status | Detected Fault |
|---|---|---|---|---|
| On | Off | Low | High | Fault on CH1 |
| Off | On | High | Low | Fault on CH2 |
| On | On | Low | Low | Fault common to both channels |
| Off | Off | High | High | - |

## 4.5. Reverse Connection Protector Circuit

This circuit protects this design when the input power supply (VBAT) at CN1 is accidently connected in reverse. Fig. 4.7 shows the overview of this circuit, and Fig. 4.8 shows the actual circuit with components used in this design. This circuit uses the 120A high current power MOSFET XPH1R104PS as a switch to provide protection.

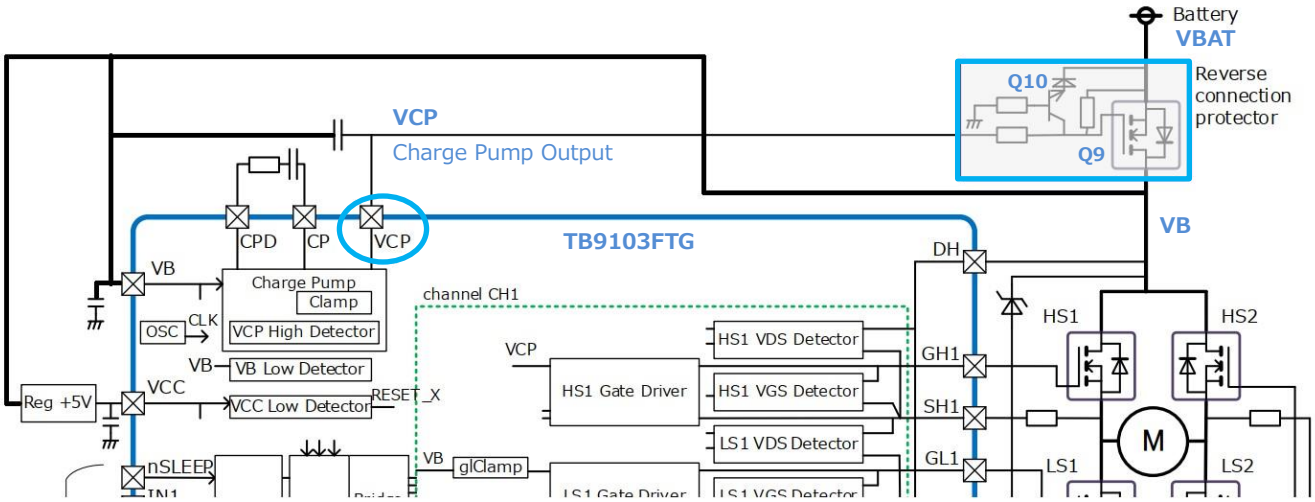


**Fig. 4.7 Reverse Connection Protector Circuit Overview**

When the input power supply at CN1 is connected in the correct way, initially the internal diode of the MOSFET Q9 allows the necessary current to flow until the MOSFET Q9 is turned on as described hereafter. The gate driver IC TB9103FTG produces a high voltage using charge pump at VCP terminal. This charge pump output voltage is more than VBAT, and it makes the VGS voltage of MOSFET Q9 more than its threshold voltage and therefore turns on the power MOSFET Q9. And during this time the transistor Q10 remains disabled because its base voltage is lower than its emitter voltage. Therefore, during correct connection, the reverse connection protector circuit acts as a short circuit and thus enables the operation of this design.

And when the input power supply at CN1 is connected in reverse, which means the higher voltage of the input power supply gets connected to the GND of this design and the lower voltage of the input power supply gets connected to the VBAT of this design. This sets the GND of this design at a higher voltage than VBAT of this design. In this situation, the internal diode of the MOSFET Q9 is reverse biased and blocks the current flow, furthermore the base-emitter junction of the transistor Q10 becomes forward bias and turns on the transistor Q10. This makes the VGS voltage of the MOSFET Q9 very low which turns off the MOSFET Q9. Therefore, during reverse connection of input voltage at CN1, the reverse connection protector circuit of this design acts as an open circuit and provides protection to this design.

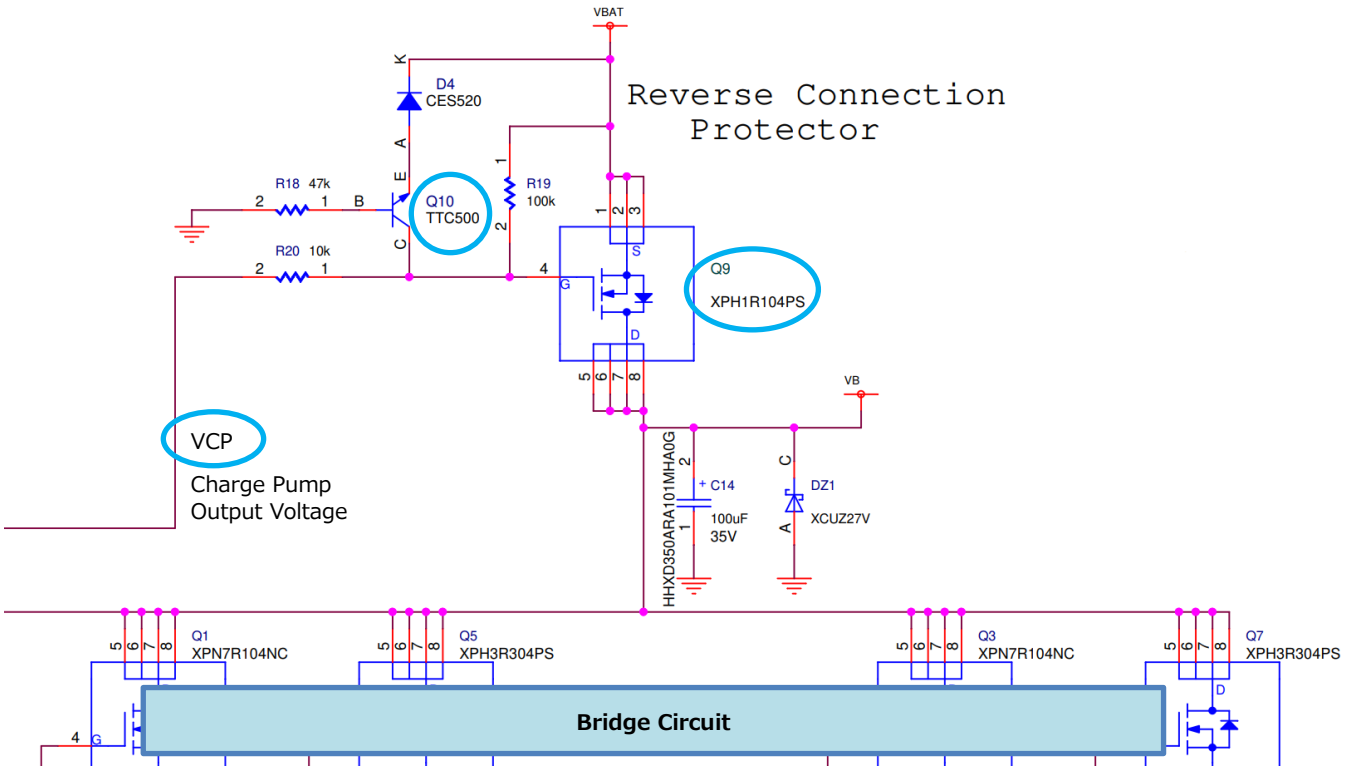


**Fig. 4.8 Reverse Connection Protector Circuit**

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