Matrix LED Headlight

Design Guide

RD209-DGUIDE-01

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Table of Contents

1. INTRODUCTION 3

2. CIRCUIT DESIGN...4

2.1. Circuit Specifications 4

2.2. Circuit Block Diagrams 4

2.3. Load Switch and Reverse Connection Protection Circuit 5

2.4. Power Supply Circuit for MCU 6

2.5. Constant Current Boost Power Supply Circuit.................................. 7

2.6. LED Dimming Control Circuit 8

2.7. LED Lighting Control Circuit 9

3. PCB DESIGN 11

3.1. Component Layout Example 11

3.2. Design Precautions 12

4. PRODUCT OVERVIEW 13

4.1. Power MOSFET XPN3R804NC 13

4.2. High Side Power MOSFET Driver TPD7104AF 14

4.3. Regulator TB9005FNG for Automotive CPUs 14

4.4. Bipolar Transistor TTA005 15

4.5. Power MOSFET XPN2400ANC 15

4.6. Zener diode CUZ6V8 16

4.7. High-Speed Rectifier Diode CMF02A 16

4.8. Compact, Low Drain-source On-resistance MOSFET SSM6K809R 17

4.9. Small Signal MOSFET SSM6J808R.. 18

4.10. Bias Resistor Built-in Transistor RN1907FE 18

4.11. Zener Diode XCUZ16V... 19

1. Introduction

This design guide (hereinafter referred to as "this guide") describes the circuit design, PCB design and overview of adopted products of the Matrix LED Headlight.

Active matrix LED that detect pedestrians in front of vehicles and dynamically control headlight illumination in specific areas ahead are becoming increasingly popular. This Matrix LED Headlight reference circuit consists of two boards: a Headlight Power Supply Board (RD209-1) and a Headlight LED Board (RD209-2). The active matrix LED can be realized by combining the control unit with image recognition.

The Headlight Power Supply Board uses a 12 V power supply as an input, is equipped with 7 blocks of a step-up power supply circuits with constant current (maximum 500 mA) output, and drives 6 LEDs per block, making a total of 42 LEDs with independent lighting control. Dimming control of the LED is possible for each block by external dimming signal. It is also equipped with a linear power supply, which can provide a 5 V constant voltage output with maximum current of 1 A for the external MCU.

The Headlight LED Board has 42 LEDs arranged in a matrix on the board, and these LEDs are controlled by external control signals.

2. Circuit Design

2.1. Circuit Specifications

Table 2.1 lists the Matrix LED Headlight specifications described in this guide.

Table 2.1 Matrix LED Headlight Specifications

Item	Specifications
Input voltage	12 V (5 A maximum)
Number of LEDs	42 LEDs (6 LEDs per block, 6 blocks of white and 1 block of amber)
Used LEDs	White LEDs: KW CELNM1.TG (OSRAM) Amber LEDs: KY CELNM2.FY (OSRAM)
LED drive current	Up to 500 mA, dimming can be done for each block
Power supply output for LED	Constant current 500 mA × 7 blocks
Power supply output for MCU	Constant Voltage 5.0 V, 1.0 A

2.2. Circuit Block Diagrams

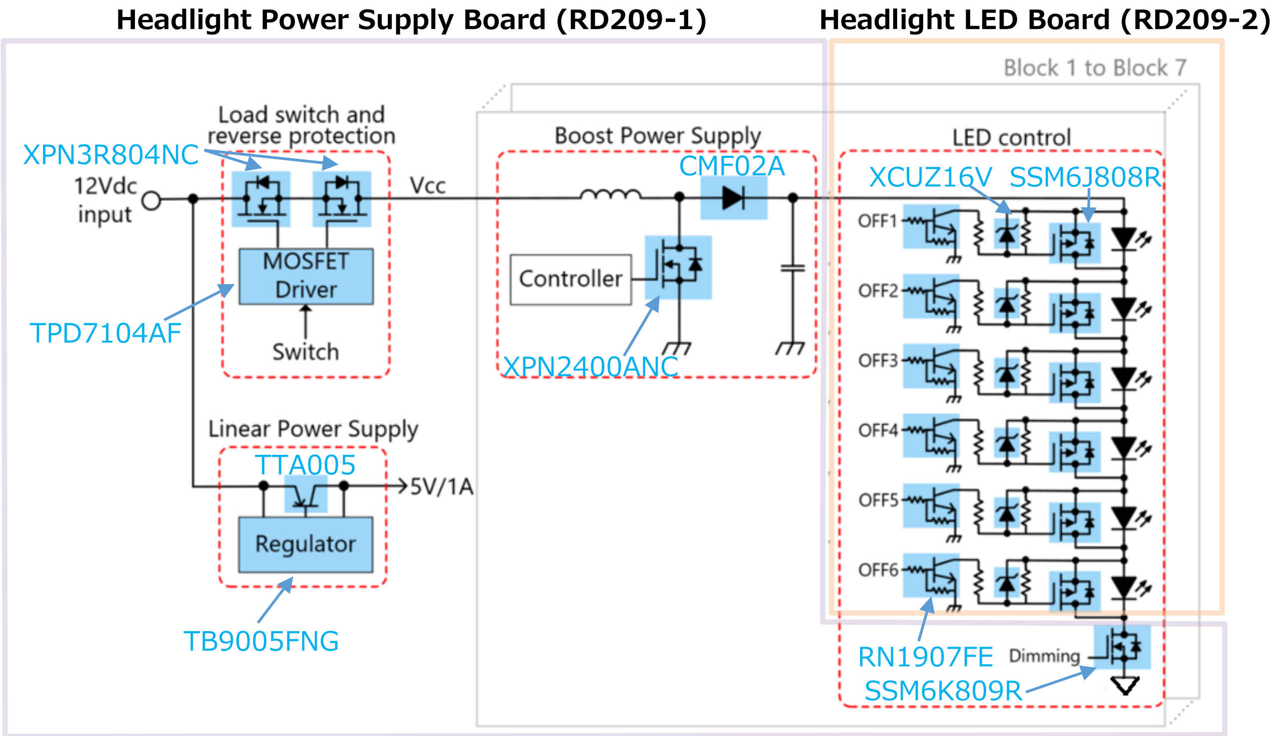


Fig. 2.1 Matrix LED Headlight Block Diagram

2.3. Load Switch and Reverse Connection Protection Circuit

The load switch and reverse connection protection circuit on the Headlight Power Supply Board are shown below.

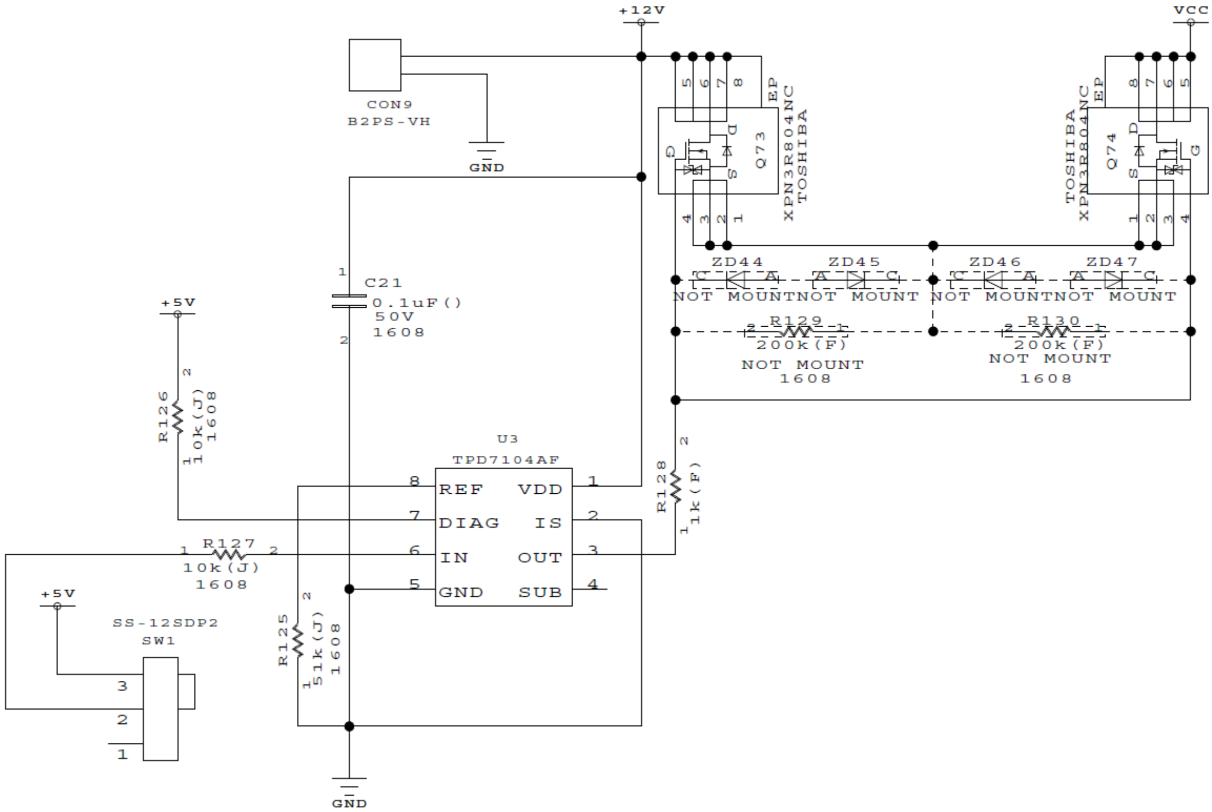


Fig. 2.2 Load Switch and Reverse Connection Protection Circuit

XPN3R804NC (Q73) is a U-MOSVIII N-ch MOSFET with a maximum drain-to-source voltage of 40 V and a maximum drain current of 40 A. It operates as a load switch when supplying 12 V power (+12V) from the power connector (CON9) to the internal 12 V power supply (VCC). In addition, XPN3R804NC (Q74) operates as a reverse-connection protective switch that prevents the overcurrent which occurs when the polarity of the external power supply is incorrectly connected. These MOSFETs are source-to-source (back-to-back) connected and are switched using a gate signal driven by the high-side power MOSFET driver TPD7104AF (U3). When the power switch (SW1) is turned ON (shorted between pins 2 and 3), 5 V is supplied to the IN input of TPD7104AF, the gate is turned ON and power is supplied to the internal 12 V power supply (VCC). TPD7104AF has a function to detect short-circuit (overcurrent), but this function is not used in this circuit.

2.4. Power Supply Circuit for MCU

The power supply circuit for the MCU on the Headlight Power Supply Board is shown below.

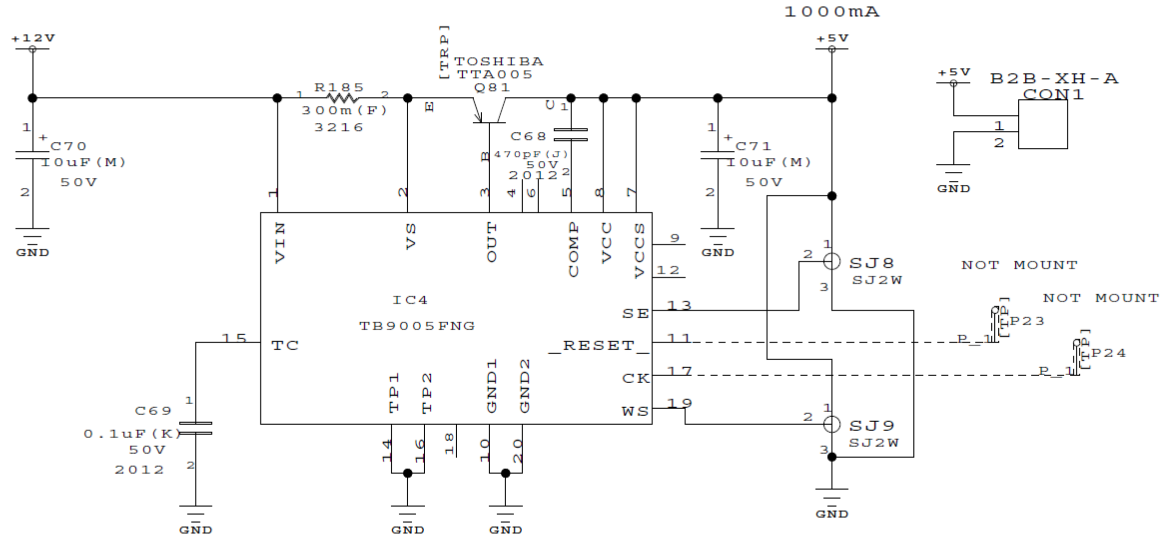


Fig. 2.3 Power Supply Circuit for MCU

A 5 V power supply used in external MCU circuitry is generated from the 12 V power supply and is output to the MCU power supply connector (CON1). The 5 V supply is generated by a power supply circuit, which consists of TB9005FNG (IC4) (IC for in-vehicle system power supply) and a PNP-type bipolar transistor TTA005 (Q81) with a maximum collector-emitter voltage of -50 V and a maximum collector current of -5 A. When the potential difference between the VIN pin and the VS pin becomes 0.3 V or more, the current is limited, so the supply current is 1000 mA maximum.

This IC has a reset output function, and a negative logic reset signal is output from pin 11 (_RESET_). The reset detection voltage is set to 4.75 V for the 1-2 pin short of the solder jumper SJ8, and 4.25 V for the 2-3 pin short.

This IC also has a watchdog timer interlock reset function. This function is disabled when the 1-2 pins of the solder jumper SJ9 are short, and enabled when 2-3 pins are short. This IC detects the rising edge of the watchdog signal input from pin 17 (CK), and if no watchdog signal is input during the watchdog interval TWD (ms), a negative logic reset signal during TRST (ms) is output. This period can be set by the capacitance of the capacitor (C69) connected to the TC pin. In this circuit, TWD = approx. 20 ms, TRST = approx. 0.8 ms.

2.5. Constant Current Boost Power Supply Circuit

The constant current boost power supply circuit on the Headlight Power Supply Board is shown below. The figure below shows a circuit for one block, although the same power supply circuit is built for all seven blocks on the board.

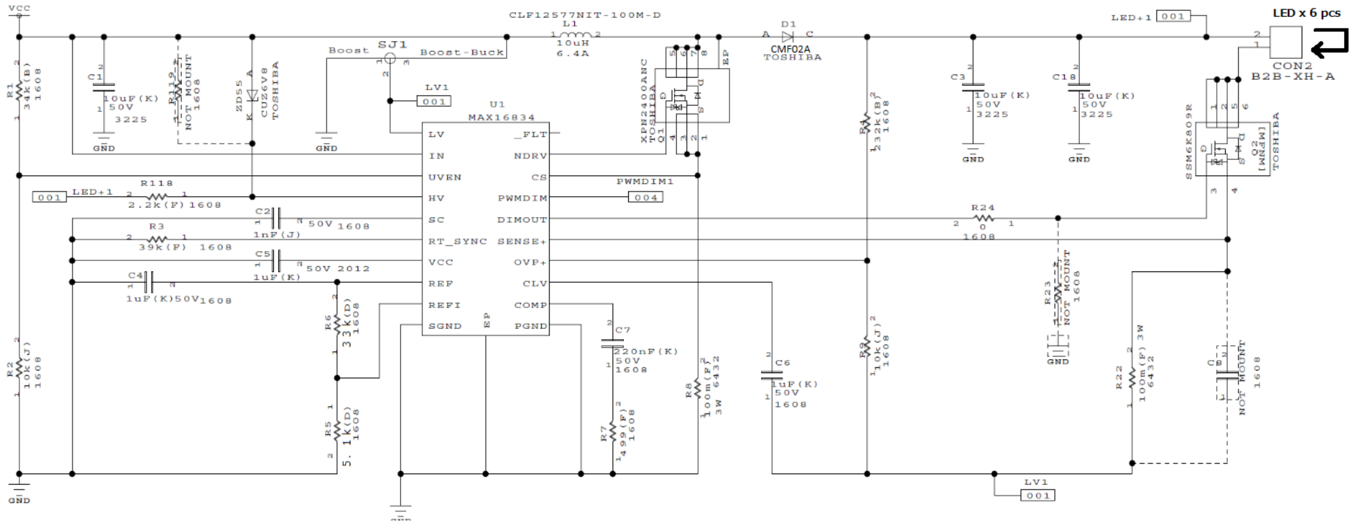


Fig. 2.4 Constant Current Boost Power Supply Circuit

Maxim Integrated's MAX16834 (controller) is used as a constant current power supply controller for driving LEDs. The voltage is boosted from the input voltage (VCC) by the step-up chopper to the voltage required for multi-stage cascaded LED drive, and constant current is supplied to the LED from the connector (CON2). For detailed designs around the controller, refer to the datasheets of Maxim Integrated's MAX16834 and related documents.

The main set values are as follows and are identical for all blocks.

$$\text{LED Current } I_{LED} = \frac{V_{REF} \times R5}{R22 \times (R5 + R6) \times 9.9} = \frac{3.7 \times 5.1k}{100m \times (5.1k + 33k) \times 9.9} \cong 500 \ (mA)$$

$$\text{Switching Frequency } f_{OSC} = \frac{5000 \ (\text{k}\Omega)}{R3 \ (\text{k}\Omega)} = \frac{5000}{39} \cong 128 \ (\text{kHz})$$

$$\text{UVLO Threshold Voltage } V_{UVEN} = 1.435 \times \frac{R1 + R2}{R2} = 1.435 \times \frac{34k + 10k}{10k} \cong 6.31 \ (\text{V})$$

$$\text{OV Threshold Voltage } V_{OV} = 1.435 \times \frac{R4 + R9}{\text{R9}} = 1.435 \times \frac{232k + 10k}{10k} \cong 34.73 \ (\text{V})$$

The solder jumper SJ1 sets the power-out configuration. Shorting 1 and 2 sets the boost output configuration. Shorting 2 and 3 sets the boost-buck configuration. The boost-buck configuration is used in following description.

Power switching uses a U-MOSVIII-H N-ch MOSFET XPN2400ANC (Q1) with a maximum drain-source voltage of 100 V, a maximum drain current of 20 A, and a low on-resistance, and a diode CMF02A (D1) with an average forward current of 1.0 A (as a rectifier diode) to realize a low-loss power supply. The forward voltage of each LED is approximately 3 V and these are lit in a stack of up to 6 stages. In the boost-buck configuration, the power supply input voltage VCC=12 V is added to the voltage required for 6 LEDs, so the power supply output is 30 V or more. Since the input voltage at the HV terminal of the controller must be 28 V or less, the input voltage at the HV pin is limited to a maximum of 18.8 V using a zener diode CUZ6V8 (ZD55) with a zener voltage of 6.8 V.

For the switching MOSFET, in addition to the above-mentioned power supply output, it is necessary to consider a maximum of 1.1 V as the forward voltage of the rectifier diode and a withstand voltage of at least 38 V when a margin of 20% is added.

For other resistors and capacitor constants, refer to the controller data sheet.

2.6. LED Dimming Control Circuit

The LED dimming control circuit on the Headlight Power Supply Board is shown below.

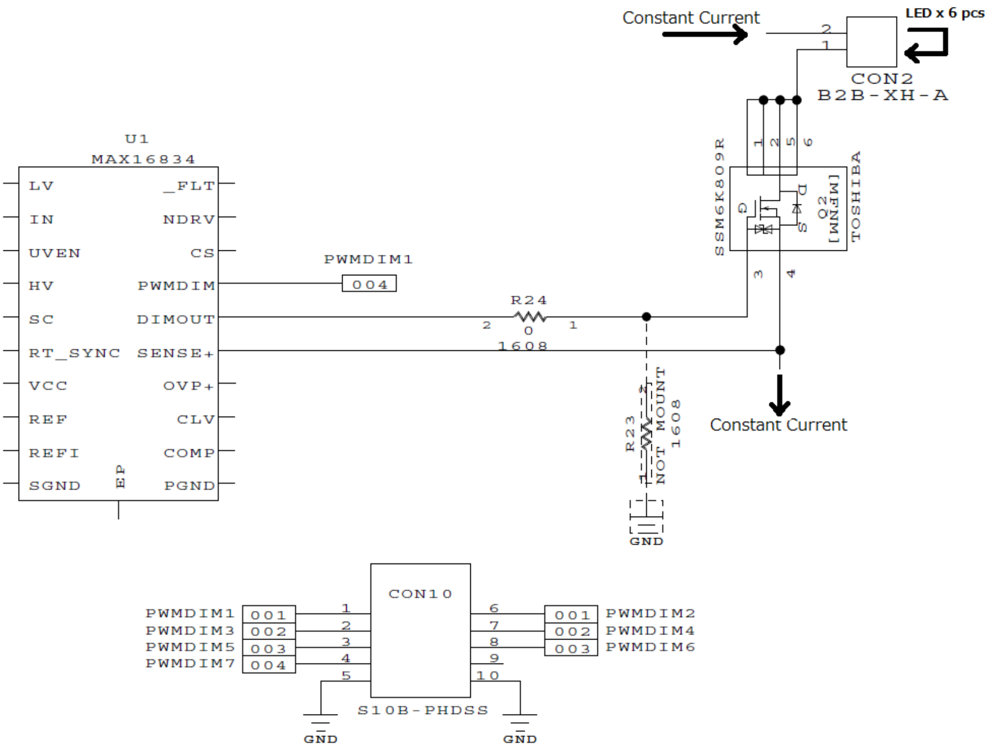


Fig. 2.5 LED Dimming Circuit

The current through the LED is switched by U-MOSVIII-H N-ch MOSFET SSM6K809R (Q2) which comes in a small package with a maximum drain-to-source voltage of 60 V and a maximum drain current of 6 A. Each block can be switched independently, and the LED switch control signal input from an external MCU control unit via the LED switch control connector (CON10) drives the MOSFET by the gate driver built into the controller. When the LED switch control signal from an external source is OFF (L level), the LED current in the block is shut off, and all LEDs are turned off. Dimming control of the LED is enabled by using the PWM pulse as a switch control signal.

2.7. LED Lighting Control Circuit

The LED lighting control circuit on the Headlight LED Board is shown below. The lighting control circuit on the right side of the figure is one block containing six circuits. Six LEDs of one block are connected in series with a constant current power supply for lighting. A total of seven blocks of the same circuit are mounted on the board. The lighting control signal input from the LED lighting control connector (CON9, CON10) enables independent lighting control of all LEDs (LED1～LED42).

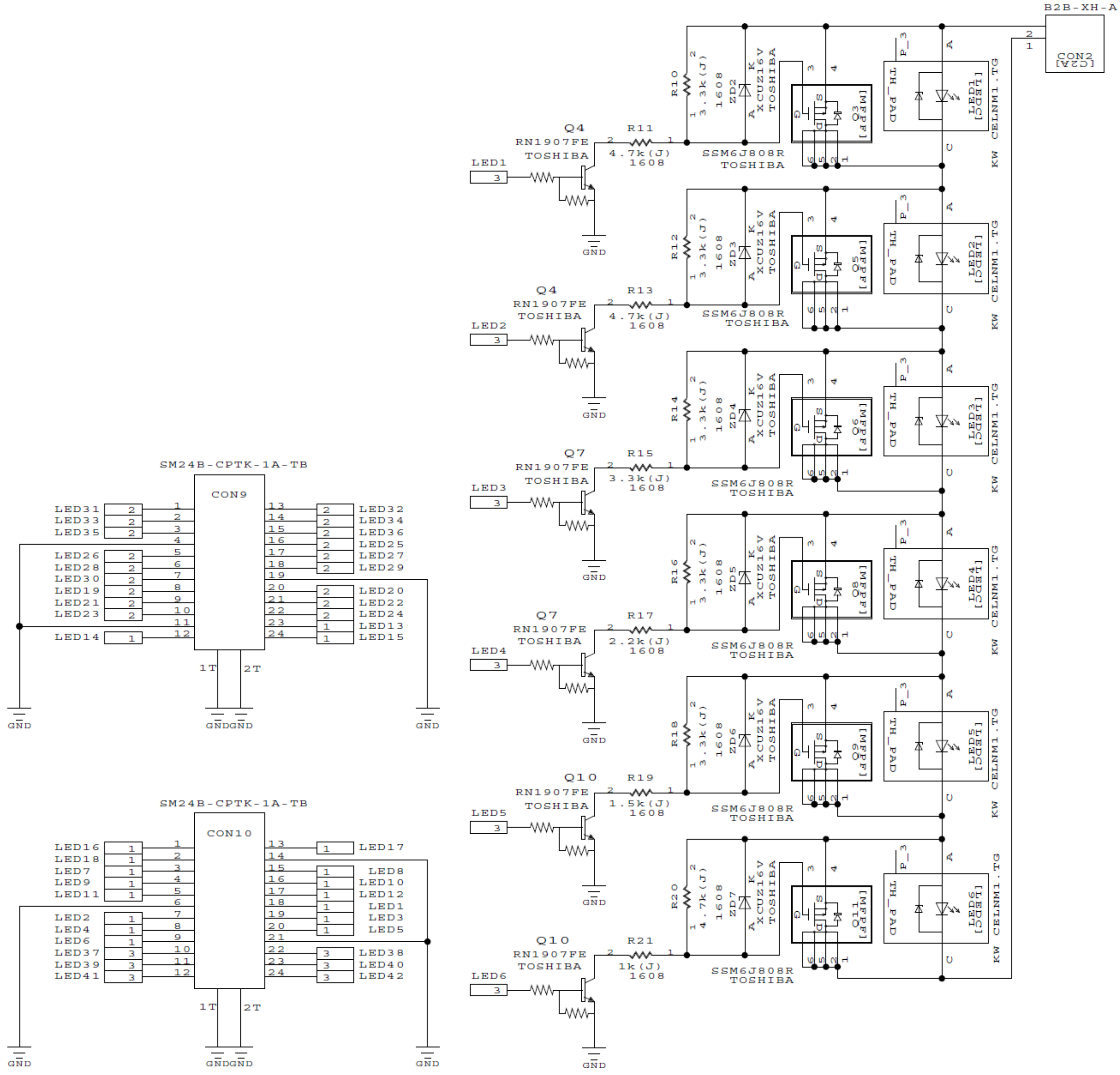


Fig. 2.6 LED Lighting Control Circuit

The lighting circuitry for LED1 is as follows.

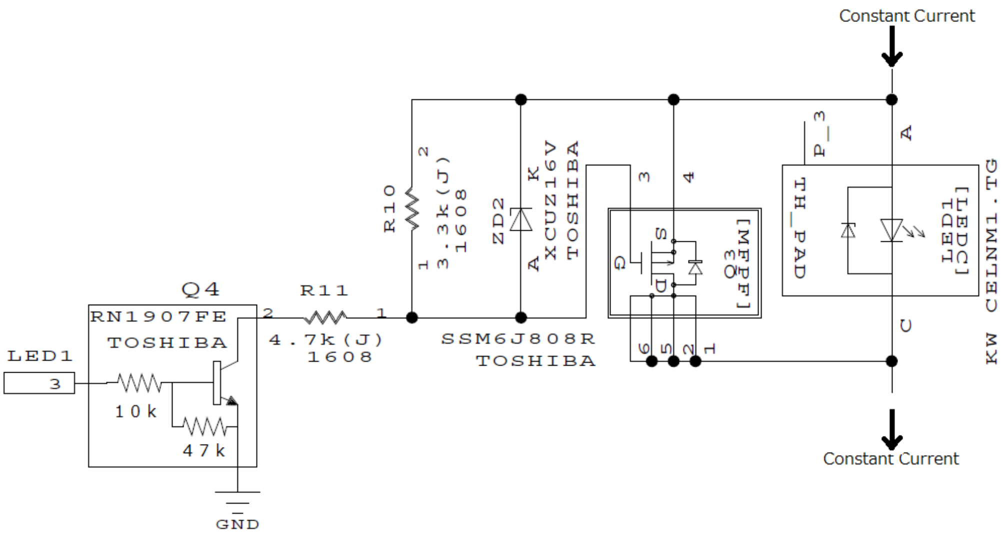


Fig. 2.7 Details of LED Lighting Control Circuit

The lighting control signal from the MCU goes to BRT (Bias Register Build-in Transistor) RN1907FE (Q4), which generates the gate voltage for U-MOSVI P-ch MOSFET SSM6J808R (Q3) with a maximum drain-to-source voltage of -40 V and a maximum drain current of -7 A. When the lighting control signal (LED1) is OFF (L level), the transistor output of Q4 is off, the gate V_{GS} potential difference of P-ch MOSFET Q3 for LED current short circuit is 0V, and the source drain is cut off, so current flows to the LED side and the LED is lit. When the lighting control signal is ON (H level =5 V), the transistor output of Q4 is turned on, a V_{GS} potential difference is generated due to the division of voltage between R11 and R10, and thus the current flows between the source and drain of Q3, so no current flows to the LED side, and the LED turns off.

Since the source voltage of the LED current short-circuit P-ch MOSFET varies depending on the number of LED stages and the LED lighting status at the lower row, the voltage divider resistance values shown in Table 2.2 are used so that V_{GS} is at least-10 V while V_{GS} at which MOSFET turns ON is less than or equal to -4 V within the expected source voltage variation range.

Table 2.2 Divider Resistance Values in LED Lighting Control Circuit

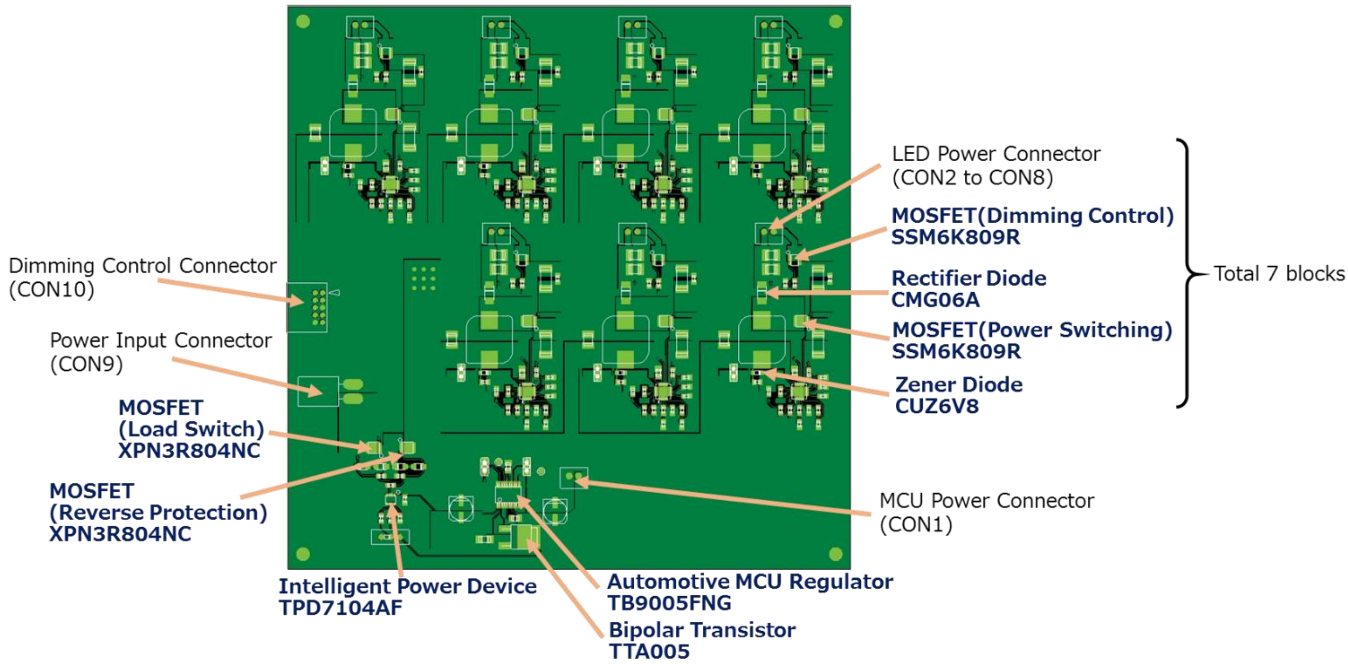
LED stage number	During LED lighting Assumed Source Voltage (V)	Source to Gate Voltage divider resistance (Ω)	Gate to BRT Voltage divider resistance (Ω)	V_{GS} when BRT is ON (V)
6th stage	14.8 ～ 27.2	3.3k	4.7k	-11.2 ～ -6.1
5th stage	12.0 ～ 24.2	3.3k	4.7k	-10.0 ～ -5.0
4th stage	12.0 ～ 21.2	3.3k	3.3k	-10.6 ～ -6.0
3rd stage	12.0 ～ 18.2	3.3k	2.2k	-10.9 ～ -7.2
2nd stage	12.0 ～ 15.2	3.3k	1.5k	-10.5 ～ -8.3
1st stage	12.0 ～ 12.2	4.7k	1.0k	-10.1 ～ -9.9

V_{GS} generated by the voltage divider resistor must be -20 V or higher according to the specification of Q3. To protect V_{GS} voltage from a change in the source potential and other factors, a zener diode XCUZ16V (ZD2) with a zener voltage of 16 V is inserted into the voltage divider resistor between the gate and source to prevent the voltage from falling below -16 V.

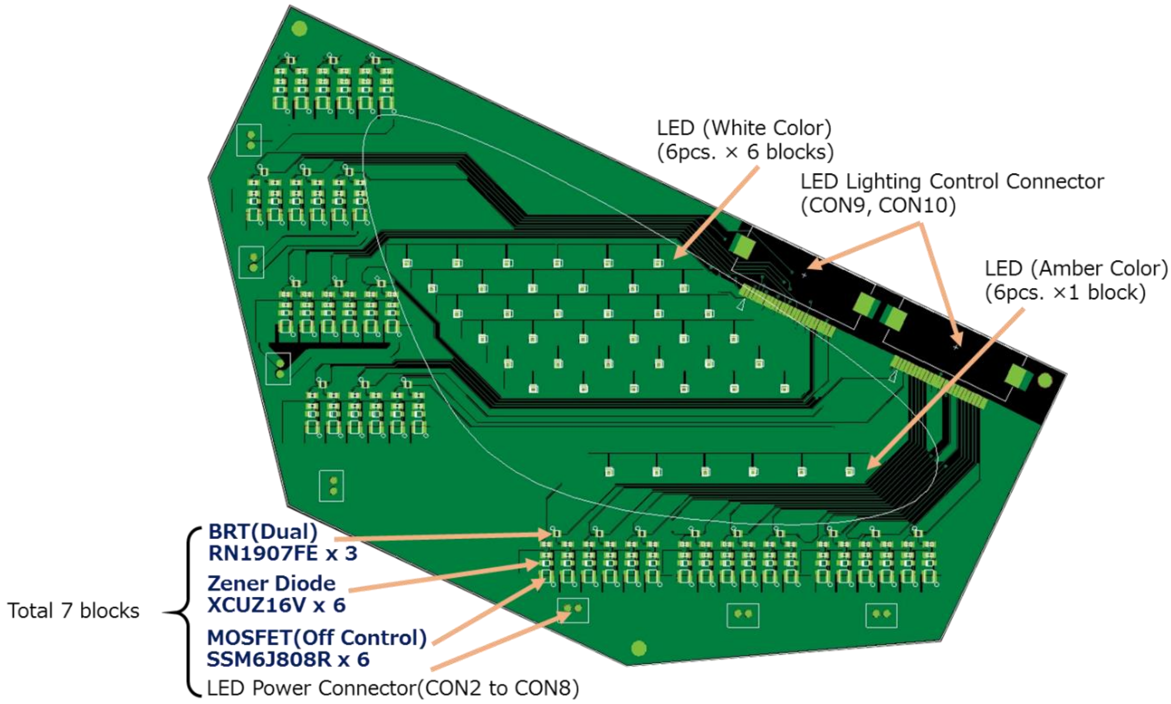
3. PCB Design

3.1. Component Layout Example

Fig. 3.1 shows an example of component layout.



<Headlight Power Supply Board RD209-1>



<Headlight LED Board RD209-2>

Fig. 3.1 Main Component Layout on Each Board

3.2. Design Precautions

Consider the following design when designing the pattern.

- Pattern Design Considering Current

  Since the Headlight Power Supply Board and Headlight LED Board have circuits that carry large currents, sufficient pattern widths must be ensured during pattern design to prevent problems caused by either temperature rises or IR drops due to patterns when a current with margin-added to the maximum current is applied.

- Pattern Design Considering Heat Dissipation

  MOSFET, bipolar transistors, diodes, and LEDs used to drive the power supply generate heat, which requires a patterned design that takes into account heat generation. It is necessary to operate the product within the power dissipation specified for each product. However, the power dissipation may vary depending on the board pattern. For details, refer to the data sheet of each product.

- MOSFET Related Pattern Design in Constant Current Boost Power Supply Circuitry

  Fig. 3.2 shows the pattern precautions for the constant-current boost power supply circuit.

  (1) Reduce the pattern between the drain of the switching MOSFET (Q1) and the anode of the rectifier diode (D1).

  (2) Shorten the pattern between the cathode of the rectifier diode (D1) and the output capacitor (C3, C18).

  (3) Connect the GND end of the current detection resistor (R5) or output capacitor (C3, C18) to the GND plane.

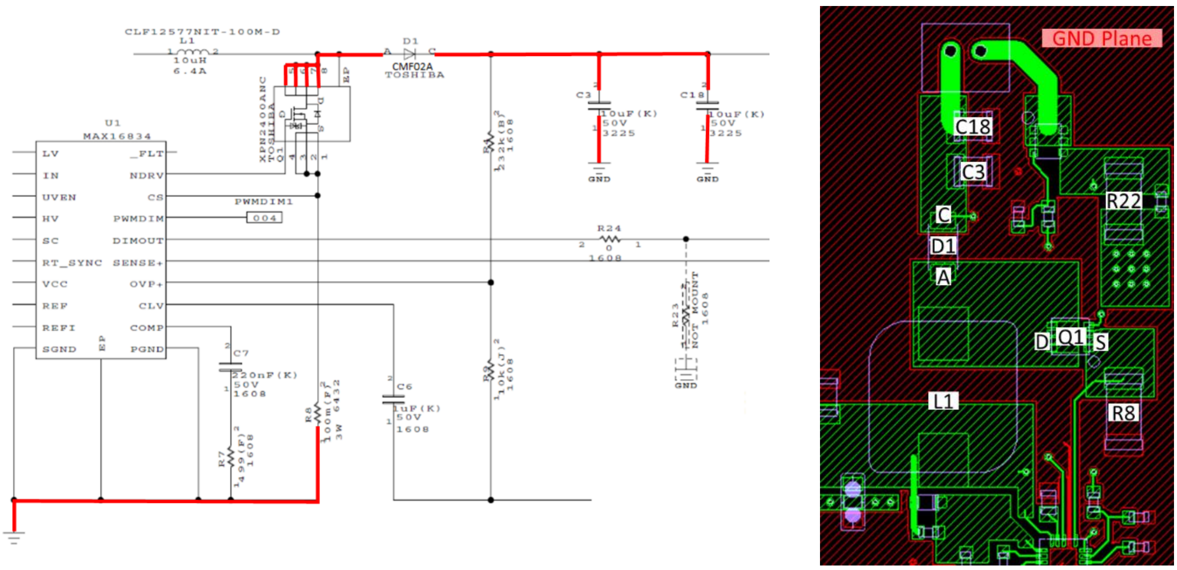
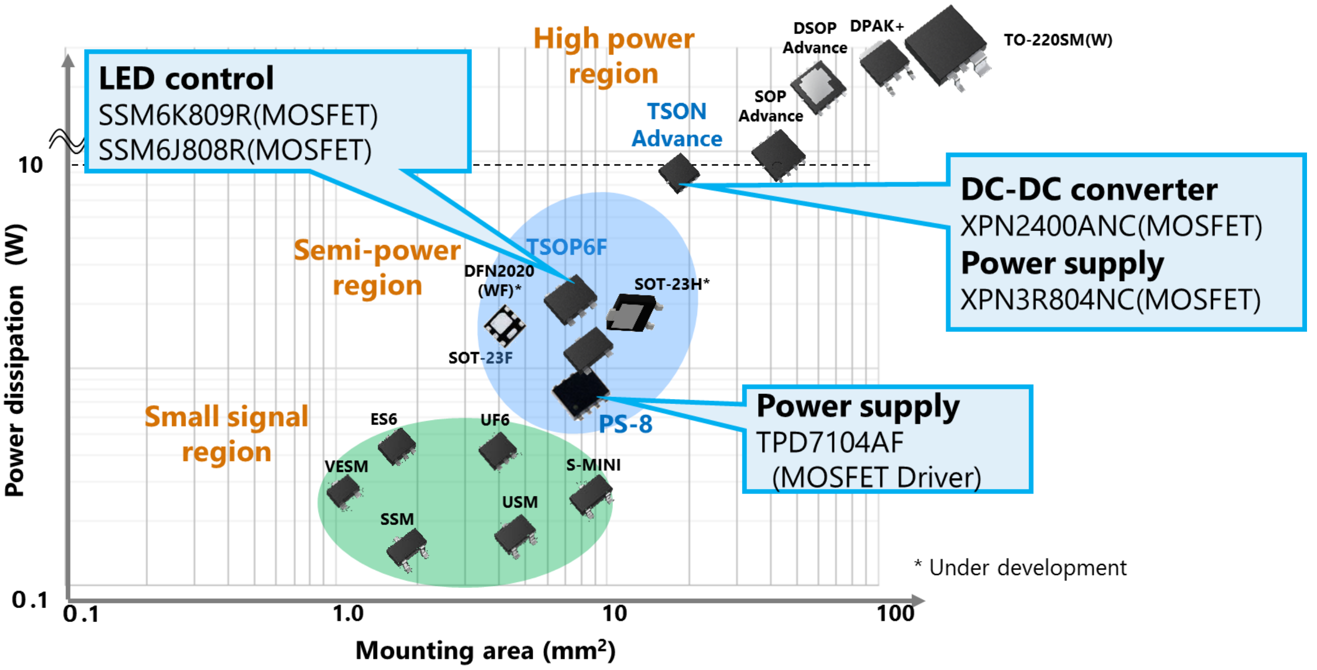


Fig. 3.2 Pattern Notes for Constant Current Boost Power Supply Circuit

4. Product Overview

This section describes the products used in this circuit. These products are automotive compatible. As for power semiconductors, we have prepared an extensive lineup of packages, including MOSFET and MOSFET drivers used this time, as shown below.



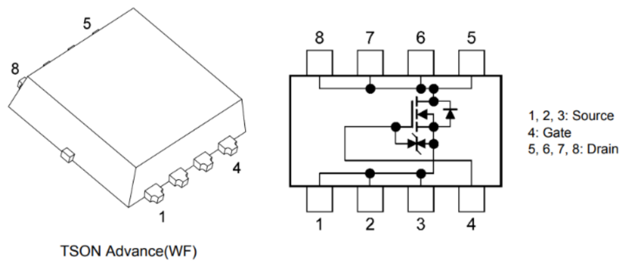
4.1. Power MOSFET XPN3R804NC

This component is used as a load switch and a reverse connection protection switch on the Headlight Power Supply Board. Please click here for more information.

Features

- V_{DSS} = 40 V (Max.), I_D = 40 A (Max.)
- AEC-Q101 qualified
- Small size, thin size and small mounting area
- Low drain-source on-resistance: $R_{DS(ON)}$ = 3.0 mΩ (Typ.) (V_{GS} = 10 V)
- Low leakage current: I_{DSS} = 10 μA (Max.) (V_{DS} = 40 V)
- Enhancement mode: V_{th} = 1.5～2.5 V (V_{DS} = 10 V, I_D = 0.3 mA)

Appearance and Terminal Arrangement



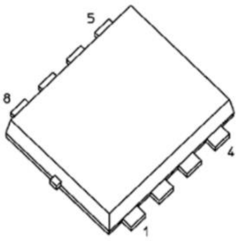
4.2. High Side Power MOSFET Driver TPD7104AF

This component is used as a driver for the load switch and reverse connection protection switch on the Headlight Power Supply Board. Please click here for more information.

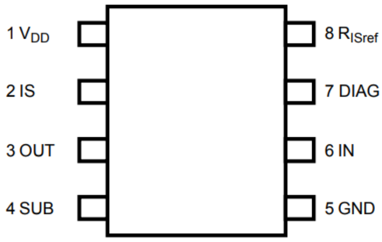
Features

- Built-in charge pump circuit
- Built-in load short (overcurrent detection) and power reverse connection protection
- Package is compact and surface mount type

Appearance and Terminal Arrangement



SON8-P-0303-0.65S



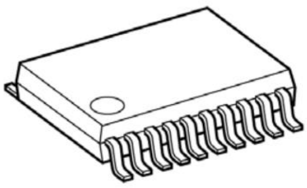
4.3. Regulator TB9005FNG for Automotive CPUs

This component is used as a regulator for the MCU power supply on the Headlight Power Supply Board. Please click here for more information.

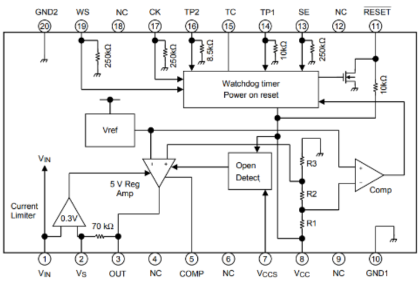
Features

- Output voltage : 5.0 V ± 0.1 V (−40~125 °C)
- Low current consumption: 90 μA (V_{IN} = 12V, T_a = 25 °C) @ 5 V constant voltage output + reset timer
- Reset function: Low-voltage monitoring/power-on reset/watchdog timer
- Built-in current limiter: adjustable with an external resistance
- Operating temperature range : −40~125 °C
- V_{CC} discconnection (open) detection function
- Small flat package: SSOP-20pin (0.65 mm pitch)

Appearance and Terminal Arrangement



SSOP20-P-225-0.65A



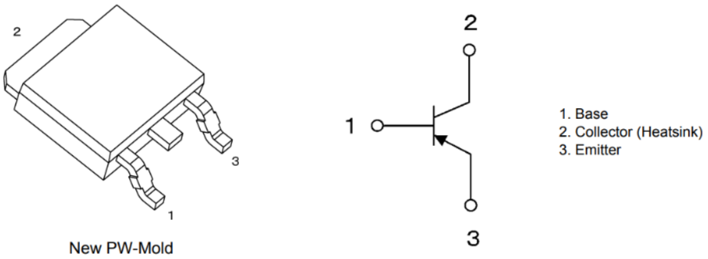
4.4. Bipolar Transistor TTA005

This component is used as a driver for MCU power supply on the Headlight Power Supply Board. Please click here for more information.

Features

- V_{CEO} = -50 V (Max.), I_C = -5 A (Max.)
- High DC current gain: h_{FE} = 200 ～ 500 (I_C = -0.5 A)
- Low collector-emitter saturation voltage: $V_{CE(sat)}$ = -0.27 V (Max.) (I_C = -1.6 A , I_B = -53 mA)
- High-speed switching: t_f = 55 ns (Typ.)

Appearance and Terminal Arrangement



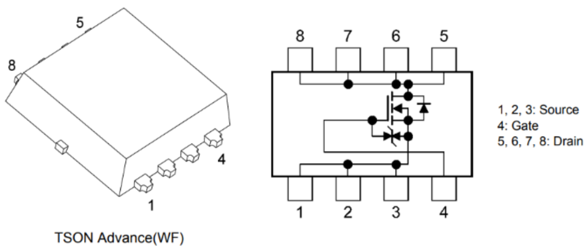
4.5. Power MOSFET XPN2400ANC

This component is used as a switch element for the power controller on the Headlight Power Supply Board. Toshiba's automotive MOSFETs offer a wide range of low-noise, low-loss products suitable for various automotive applications by using the latest trench-gate process. This product is an eighth-generation product. Compared to other companies' products, this product reduces ringing time by 40% (as of 2021 survey by us) and contributes to reducing power consumption in various applications, including DC-DC converters.

Features

- V_{DSS} = 100 V (Max.), I_D = 20 A (Max.)
- AEC-Q101 qualified
- Small and thin package with small mounting area
- Low drain-source on-resistance: $R_{DS(ON)}$ = 19.7 mΩ (Typ.) (V_{GS} = 10 V)
- Low leakage current: I_{DSS} = 10 μA (Max.) (V_{DS} = 100 V)
- Enhancement mode: V_{th} = 1.5～2.5 V (V_{DS} = 10 V, I_D = 0.2 mA)

Appearance and Terminal Arrangement



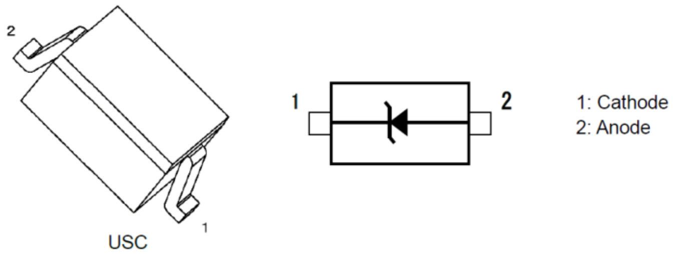
4.6. Zener diode CUZ6V8

This component is used to protect the pin input voltage of the power controller on the Headlight Power Supply Board. Please click here for more information.

Features

- Zener voltage V_Z = 6.8 V (Typ.)
- Small package

Appearance and Terminal Arrangement



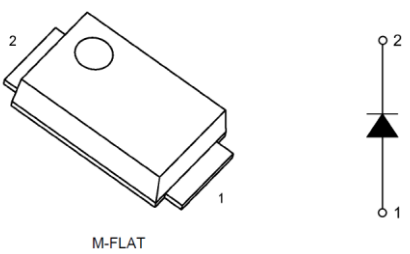
4.7. High-Speed Rectifier Diode CMF02A

This component is used as a rectifier diode in the constant-current power supply circuit on the Headlight Power Supply Board. Please click here for more information.

Features

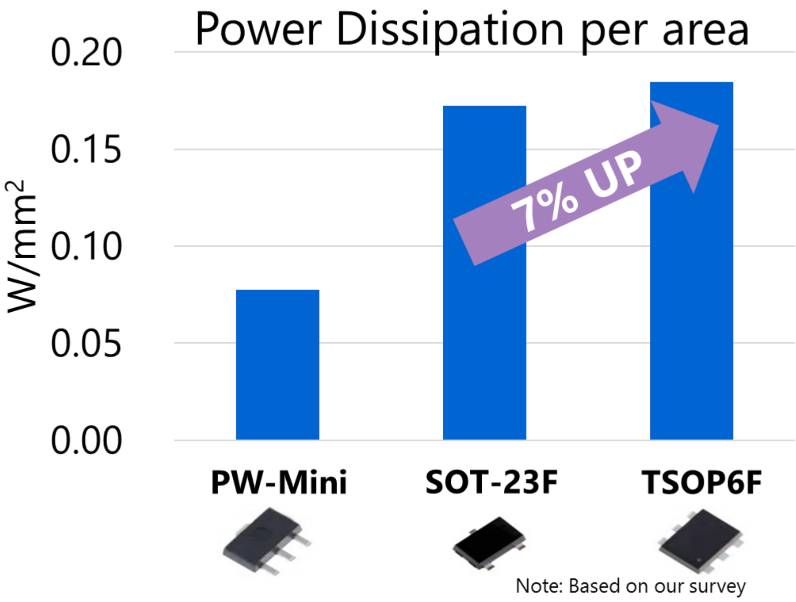
- Repetitive peak reverse voltage: V_{RRM} = 600 V
- Average forward current: I_F (AV) = 1.0 A
- Peak forward voltage: V_{FM} = 2.0 V (Max.) @I_{FM} = 1.0 A (pulse measurement)
- Reverse recovery time: trr = 100 ns (Max.) @I_F = 1.0 A, di/dt = -30 A/μs
- Small and thin surface mount package

Appearance and Terminal Arrangement



4.8. Compact, Low Drain-source On-resistance MOSFET SSM6K809R

This component is used for LED switches in the LED dimming control circuit on the Headlight Power Supply Board. Please click here for more information. The power dissipation per unit area of TSOP6F package of this product is 7% higher than that of the conventional package (SOT23F package). Despite its compact size, the power dissipation is 3.0W (t<10 s). The compact high power dissipation package and the latest trench gate structure contribute to the miniaturization of equipment.

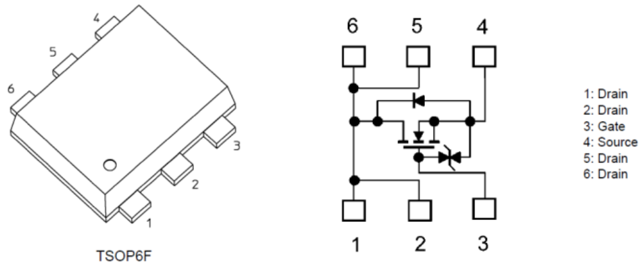


Features

- V_{DSS} = 60 V (Max.), I_D = 6 A (Max.)
- AEC-Q101 qualified
- Supports 175°C
- 4.0 V drive
- Low drain-source on-resistance :

  $R_{DS(ON)}$ = 28 mΩ (Typ.) (@V_{GS} = 10 V)
  $R_{DS(ON)}$ = 36 mΩ (Typ.) (@V_{GS} = 4.5 V)
  $R_{DS(ON)}$ = 43 mΩ (Typ.) (@V_{GS} = 4 V)

Appearance and Terminal Arrangement



4.9. Small Signal MOSFET SSM6J808R

This component is used as a switch for LED lighting control on the Headlight LED Board. Please click here for more information.

Features

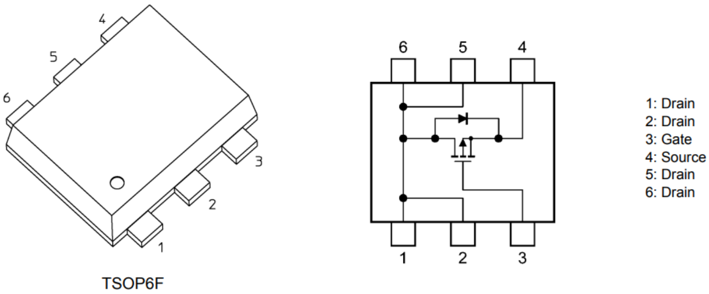
- V_{DSS} = -40 V (Max.), I_D = -7 A (Max.)
- AEC-Q101 qualified
- 4.0 V drive
- Low drain-source on-resistance :

  $R_{DS(ON)}$ = 28 mΩ (Typ.) (@V_{GS} = -10 V)

  $R_{DS(ON)}$ = 35 mΩ (Typ.) (@V_{GS} = -4.5 V)

  $R_{DS(ON)}$ = 38 mΩ (Typ.) (@V_{GS} = -4 V)

Appearance and Terminal Arrangement



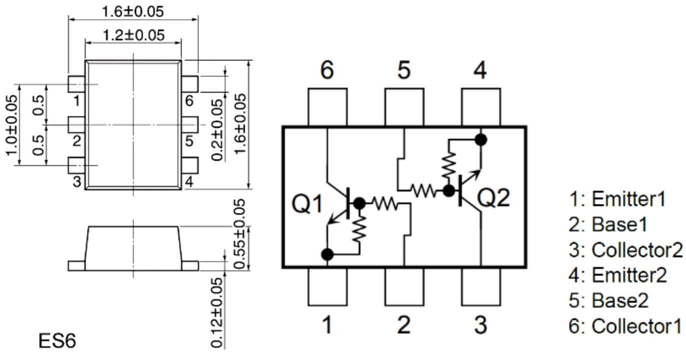
4.10. Bias Resistor Built-in Transistor RN1907FE

This component is used as a driver for the LED lighting control switch on the Headlight LED Board. Please click here for more information.

Features

- V_{CEO} = 50 V (Max.), I_C = 0.1 A (Max.)
- Integrated 2 elements in Extreme Supermini (6-terminal) package
- Since the bias resistor is built into the transistor, making it possible to reduce system size and assembly time.

Appearance and Terminal Arrangement



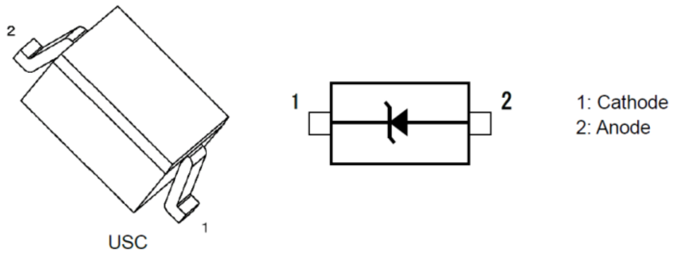
4.11. Zener Diode XCUZ16V

This component is used to protect the gate-source voltage of the LED short MOSFET on the Headlight LED Board.

Features

- Zener voltage V_Z = 16.0 V (Typ.)
- Small package

Appearance and Terminal Arrangement



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