Power Multiplexer Circuit

Reference Guide

RD221-RGUIDE-02

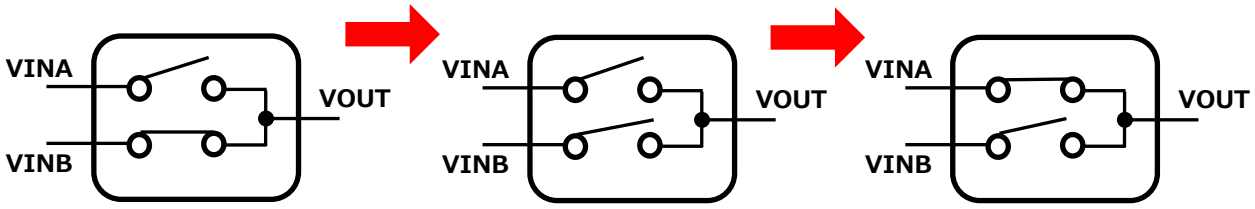
TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Table of Contents

1. Introduction

Demand for power multiplexer circuits used for switching and supply power from multiple sources such as USB terminal, a non-contact power supply terminal, and a built-in battery such as a lithium-ion battery is increasing in consumer applications such as mobile devices like smartphones, PCs, tablets, and wearable devices as well as game devices and charging devices for various types of batteries. In addition, high-current battery recharging, such as USB Power Delivery and quick recharging, requires a low-loss MOSFET to provide power. In addition, it is necessary to prevent reverse current flow to the input side when switching the power supply source and seamlessly switch the output voltage (ideal diode characteristic). This requires a BBM (Break-Before-Make) or MBB (Make-Before-Break) operation to achieve these characteristics.

This power multiplexer circuit is introduced in this reference design (hereinafter referred to as "this design"). This reference guide (hereinafter referred to as this guide) describes the specifications, operation procedures, and operation overview of the 2-input, 1-output power multiplexer circuit that is ideal for such applications.

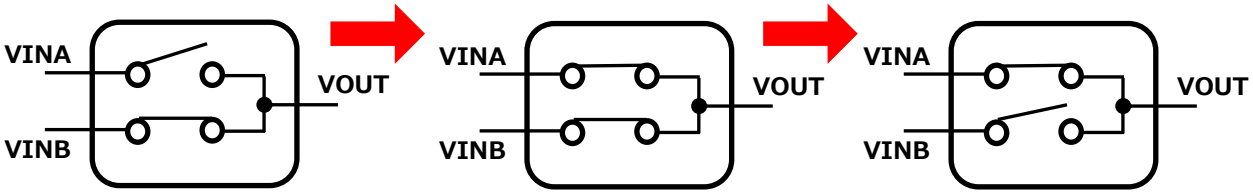


① Status before switching: VINB and VOUT are connected.

② Status during switching: VINB and VINA are disconnected from VOUT

③ Status after switching: VINA and VOUT are connected.

Fig. 1.1 BBM (Break-Before-Make) Operation



①Status before switching: VINB and VOUT are connected.

② Status during switching: VINB and VINA are connected to VOUT

③ Status after switching: VINA and VOUT are connected.

Fig. 1.2 MBB (Make-Before-Break) Operation

The power multiplexer circuit in this design consists of a module board and a base board.

Five types of power multiplexer module boards with two inputs and one output are available. Four of these are equipped with MOSFET and MOSFET Gate Driver IC TCK42xG Series, which are compatible with BBM and MBB operation, and also have an auto-switching function to the specified input-source. This driver IC is equipped with an overvoltage protection function. However, a Zener Diode CUHZ series has been added to the input terminal as an optional additional protection function. The LDO regulator TCR1HF series with an input rating of up to 40 V and low current consumption is used as the power supply for the module board control, and

the small package MOSFETs with low on-resistance are connected in the common drain configuration for output. In this design, we also introduce circuit using eFuse IC as a type that emphasizes high-density mounting by enhancing protective functions such as short-circuit and overcurrent protection.

The base board is a circuit for evaluating the module board. It is equipped with Nch power MOSFET TPHR8504PL1, MOSFET gate driver IC TCK402G, transistor with built-in resistor for signal control, one-gate logic IC TC7PZ17FU and CMOS logic IC 74HC123D.

2. Specifications

2.1 Power Multiplexer Specifications

Table 2.1 and Table 2.2 list the main specifications of this circuit.

Table 2.1 Module Board Specifications

Board Name	Board Type	Input Voltage VINA/VINB	Maximum Output Current *	BBM Operation Support	MBB Operation Support	Switching Element		For Output MOSFET
MUX1	Standard 1	20 V 5 V	3 A	Yes	Yes	Gate Driver IC	TCK421G TCK425G	TPHR6503PL1
MUX2	Standard 2	12 V 5 V	3 A	Yes	Yes	Gate Driver IC	TCK423G TCK425G	TPN1R603PL
MUX3	High Power 1	20 V 9 V	5 A	Yes	Yes	Gate Driver IC	TCK421G TCK424G	TPN1R603PL
MUX4	eFuse IC	12 V 5 V	3 A	Yes	-	eFuse IC	TCKE812NA TCKE712BNL	SSM6K513NU -
MUX5	High Power 2	24 V 12 V	5 A	Yes	Yes	Gate Driver IC	TCK420G TCK422G	TPHR8504PL1

* The product can carry a current exceeding the specified value. However, the board should be used within the range not exceeding the specified value due to heat dissipation design.

Table 2.2 Base Board Specifications

Input	VINA input (VINA 5 to 24 V) VINB input (VINB 5 to 12 V) Drive power supply (VDD 5 to 12 V)
Output	Output load A to D (LOAD-A～LOAD-D, each Load can have both resistive load and capacitive load, Max current 3 A or 5 A depending on module board) FLAG output (H-level (approx. 3.3 V) is output when VINA is input)

2.2 Block Diagram

Fig. 2.1 and Fig. 2.2 show the block diagrams of this circuit.

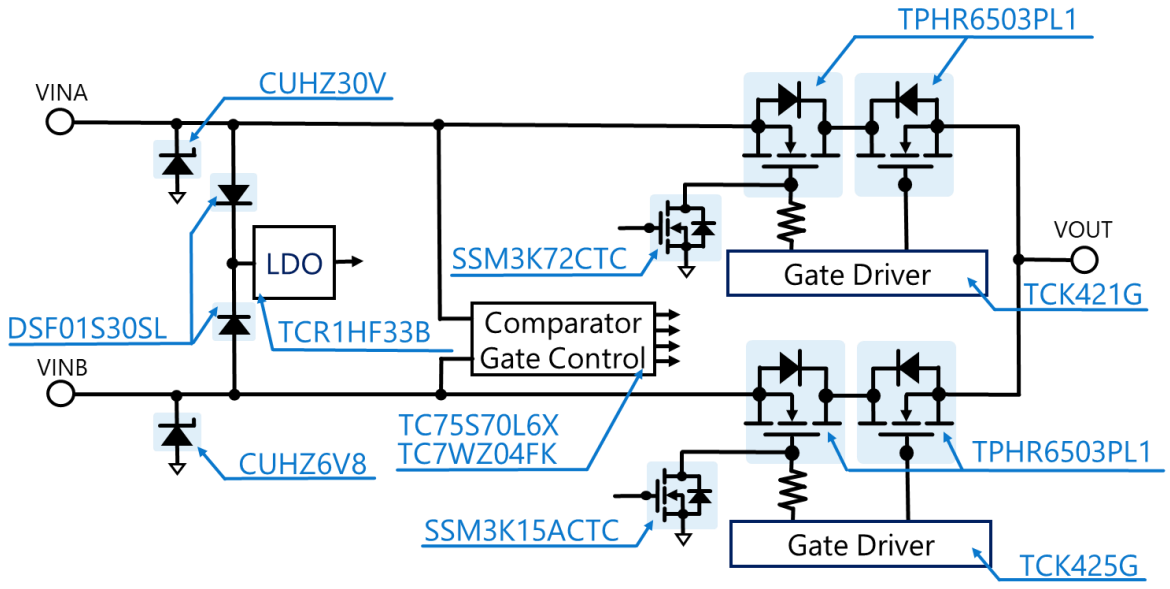


Fig. 2.1 Block Diagram (Module Board – Example MUX1)

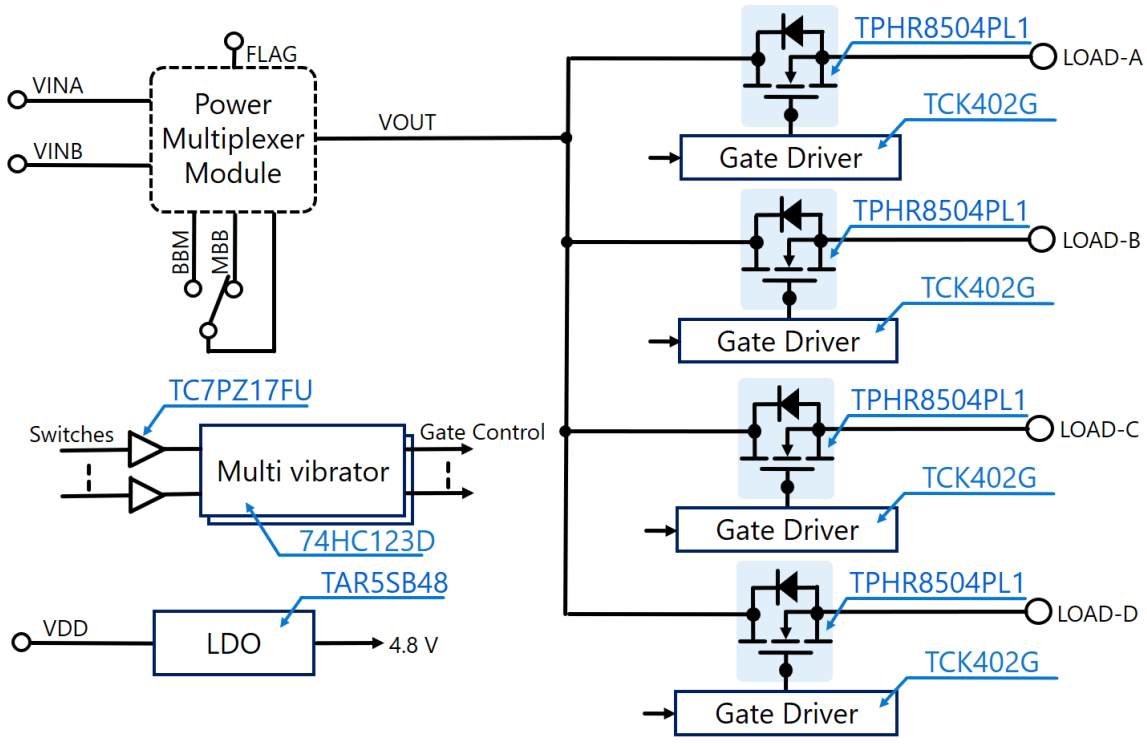


Fig. 2.2 Block Diagram (Base Board)

2.3 External View and Component Layout

This section shows the external view and main component layout of the module board and base board.

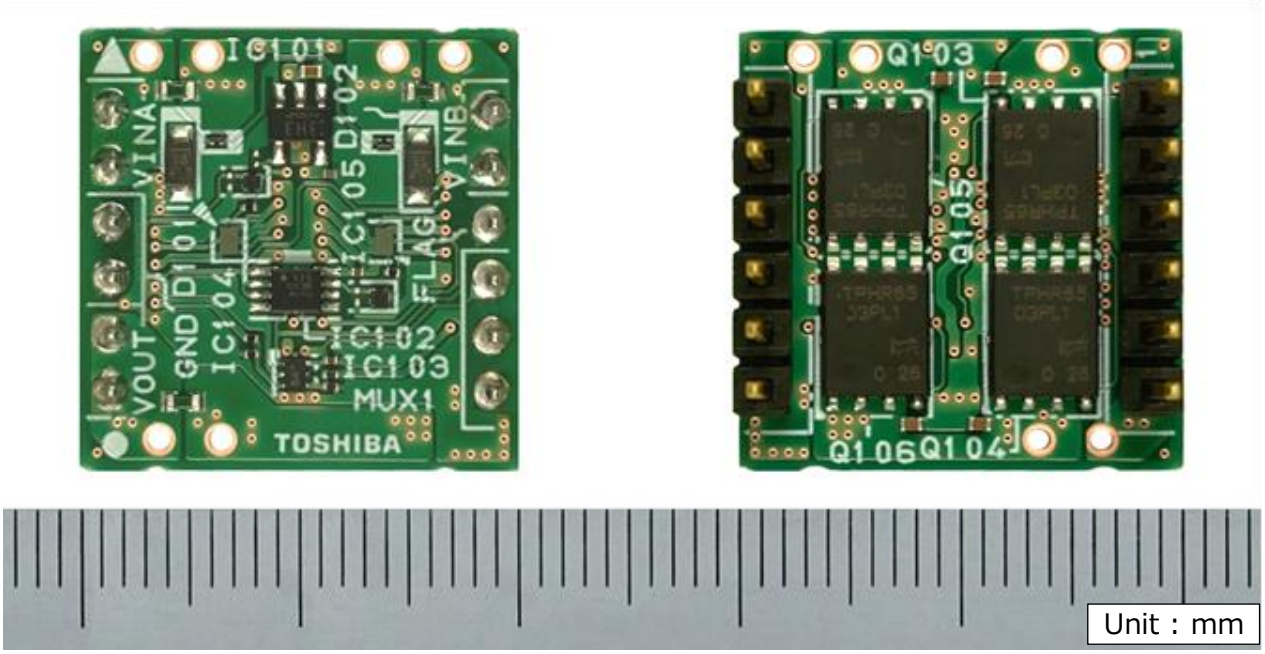


Fig. 2.3 External View of Module Board (Example MUX1)

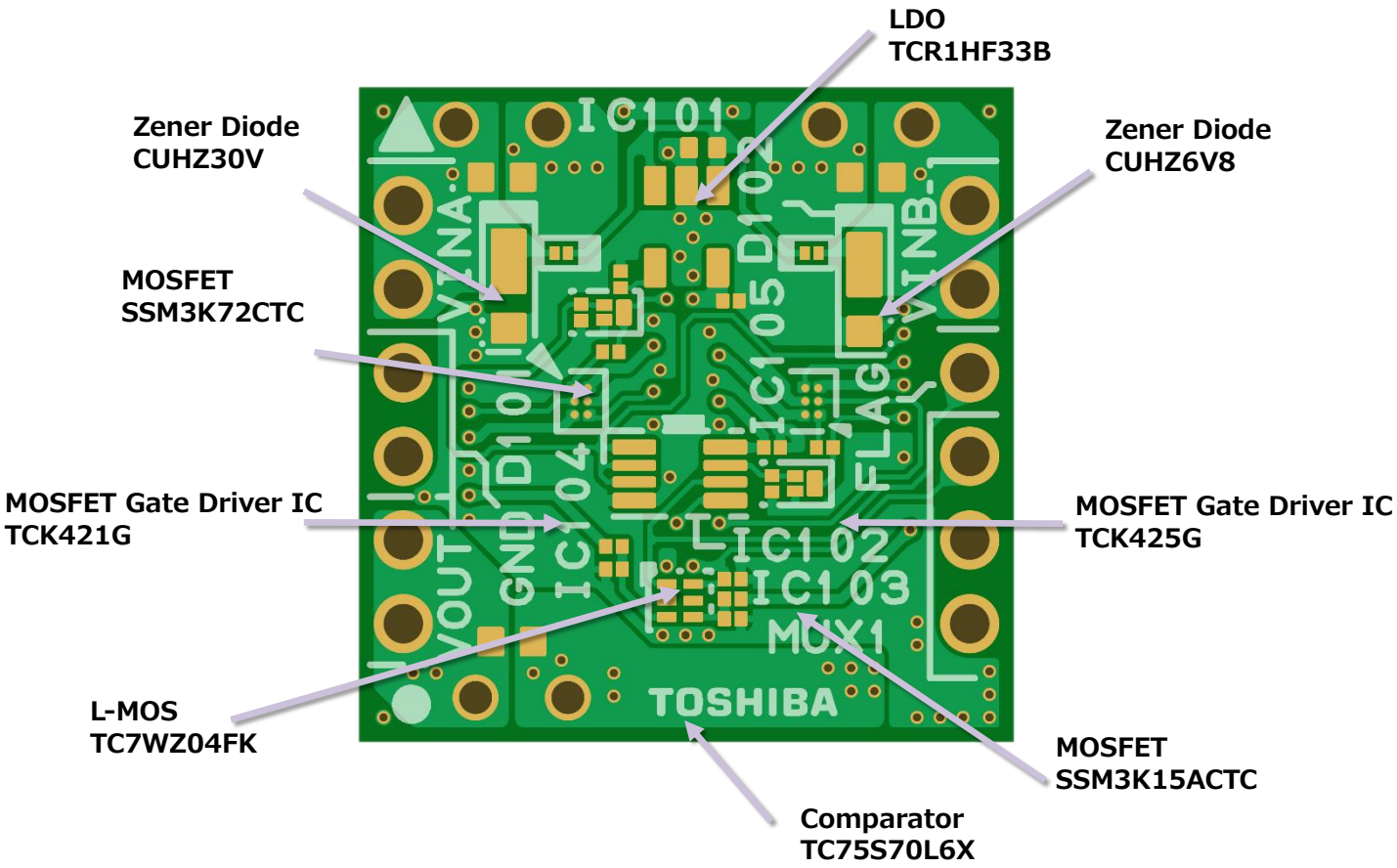


Fig. 2.4 (a) Module Board Main Component Layout (Front Side - Example MUX1)

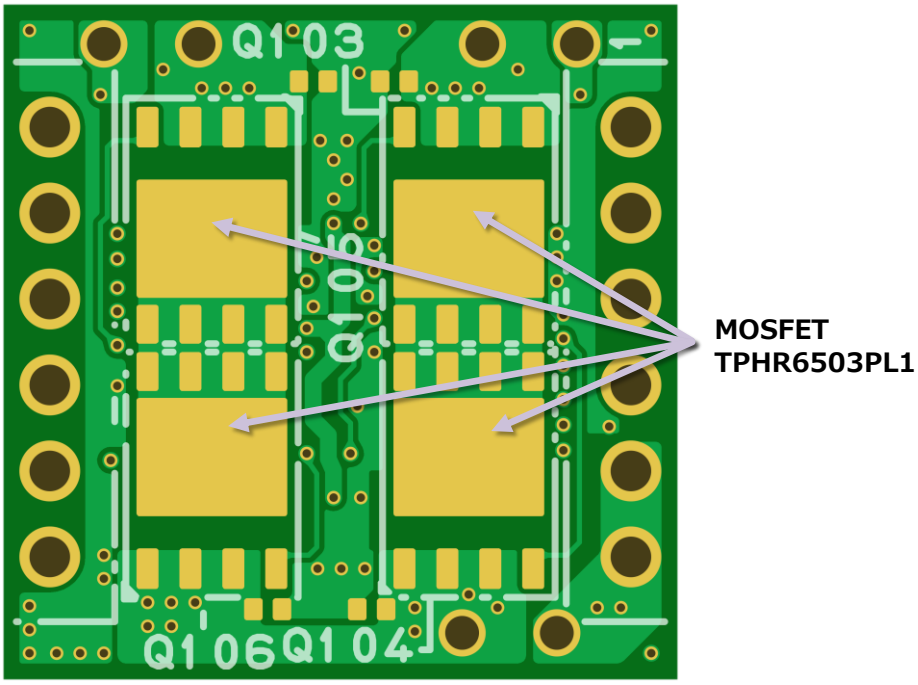


Fig. 2.4 (b) Module Board Main Component Layout (Back Side - Example MUX1)

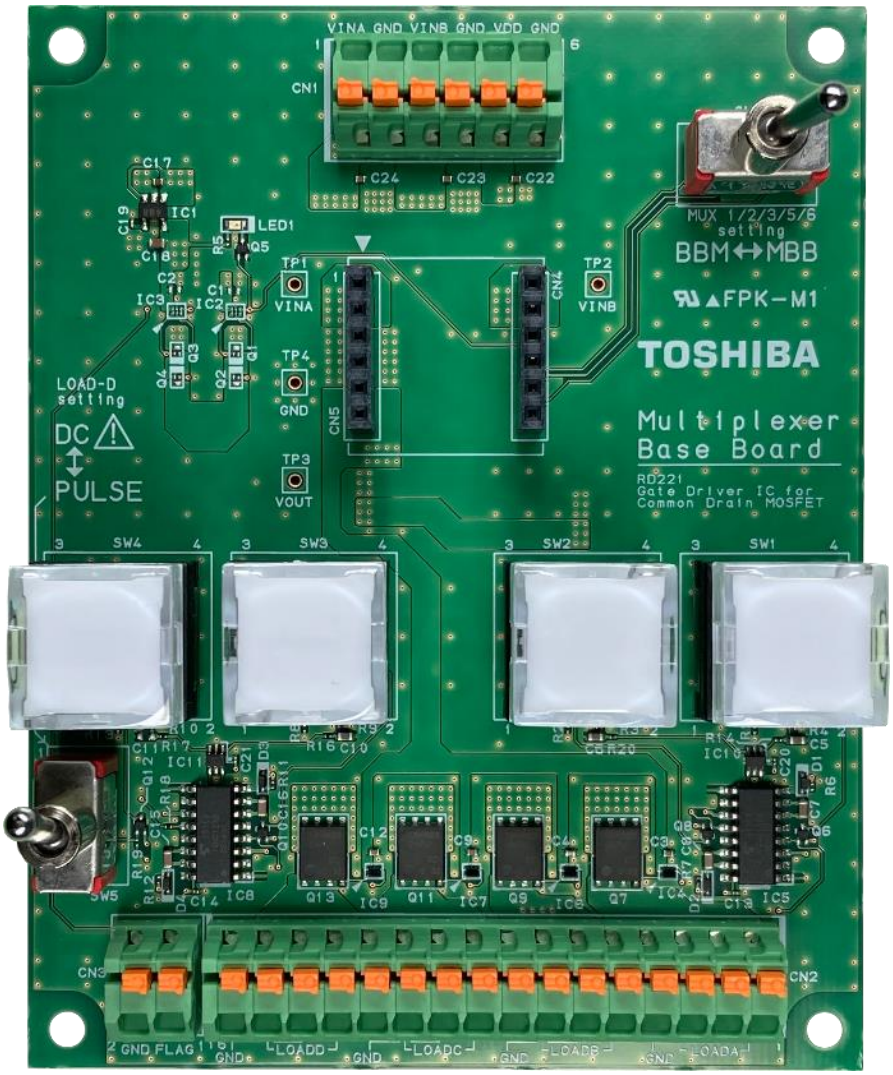


Fig. 2.5 External View of Base Board

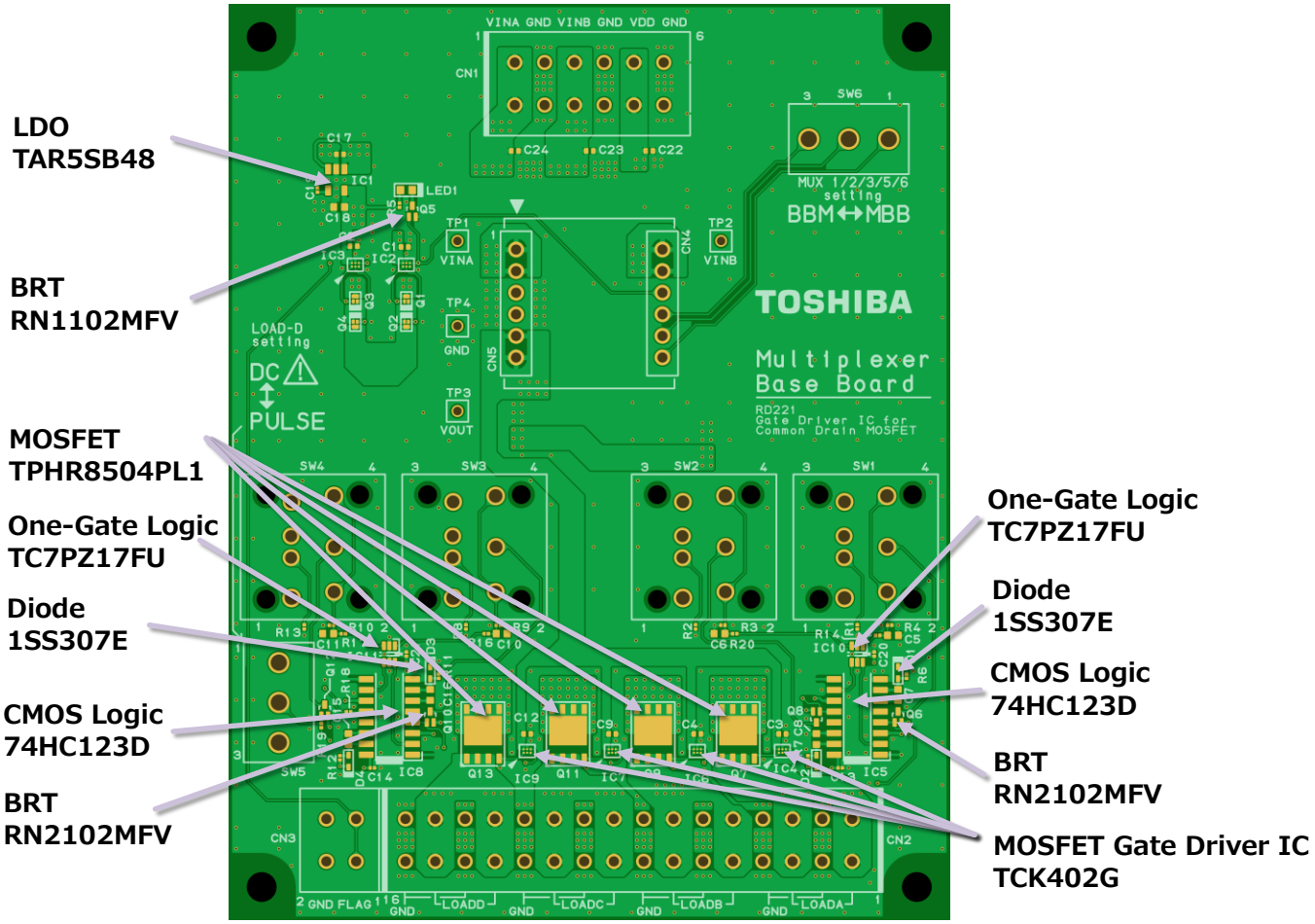


Fig. 2.6 Main Component Layout (Base Board)

3. Circuit Diagram, Bill of Material, and PCB Pattern

3.1 Circuit Diagram

Refer the following files:

Base board	RD221-SCHEMATIC7-xx.pdf
Module board (MUX1)	RD221-SCHEMATIC1-xx.pdf
Module board (MUX2)	RD221-SCHEMATIC2-xx.pdf
Module board (MUX3)	RD221-SCHEMATIC3-xx.pdf
Module board (MUX4)	RD221-SCHEMATIC4-xx.pdf
Module board (MUX5)	RD221-SCHEMATIC5-xx.pdf

(xx is the revision number)

3.2. Bill of Material

Refer the following files:

Base board	RD221-BOM7-xx.pdf
Module board (MUX1)	RD221-BOM1-xx.pdf
Module board (MUX2)	RD221-BOM2-xx.pdf
Module board (MUX3)	RD221-BOM3-xx.pdf
Module board (MUX4)	RD221-BOM4-xx.pdf
Module board (MUX5)	RD221-BOM5-xx.pdf

(xx is the revision number)

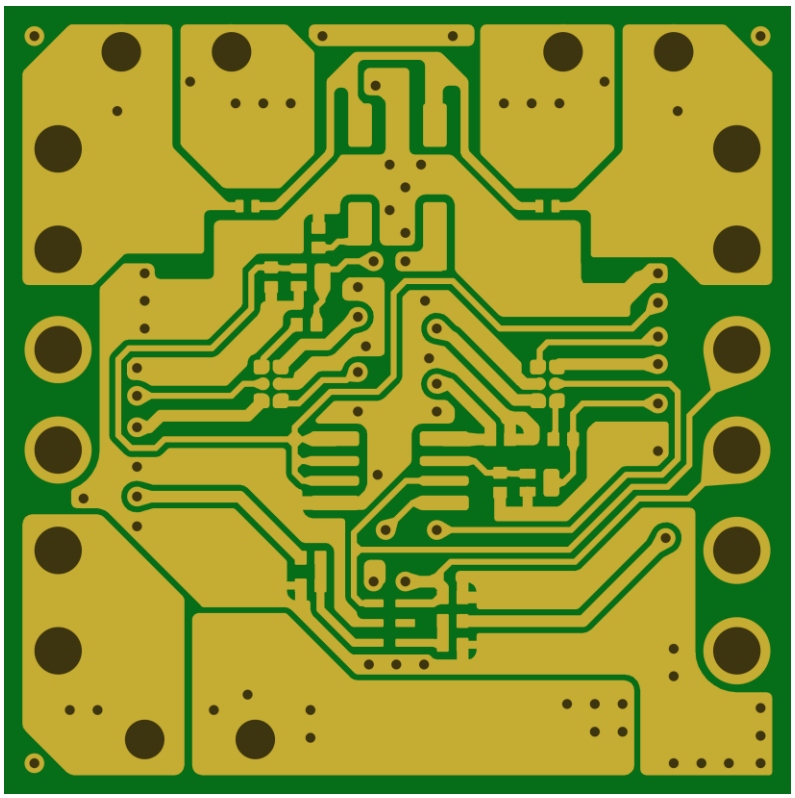
3.3.PCB Pattern

Fig. 3.1 shows the pattern diagram of the module board, and Fig. 3.2 shows the pattern diagram of the base board.

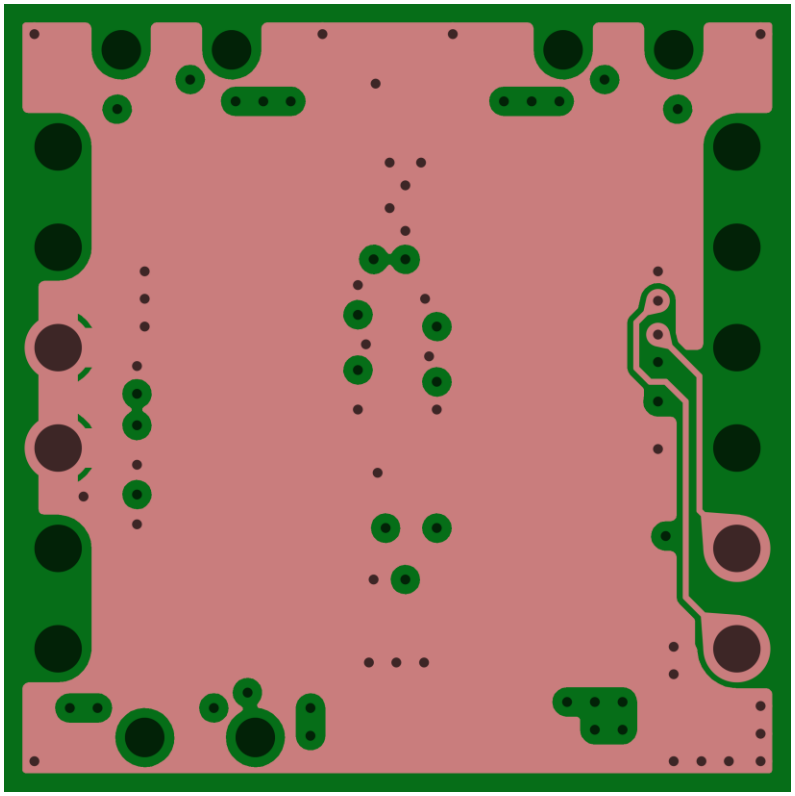
Refer the following files:

Base board	RD221-LAYER7-xx.pdf
Module board (MUX1)	RD221-LAYER1-xx.pdf
Module board (MUX2)	RD221-LAYER2-xx.pdf
Module board (MUX3)	RD221-LAYER3-xx.pdf
Module board (MUX4)	RD221-LAYER4-xx.pdf
Module board (MUX5)	RD221-LAYER5-xx.pdf

(xx is the revision number)

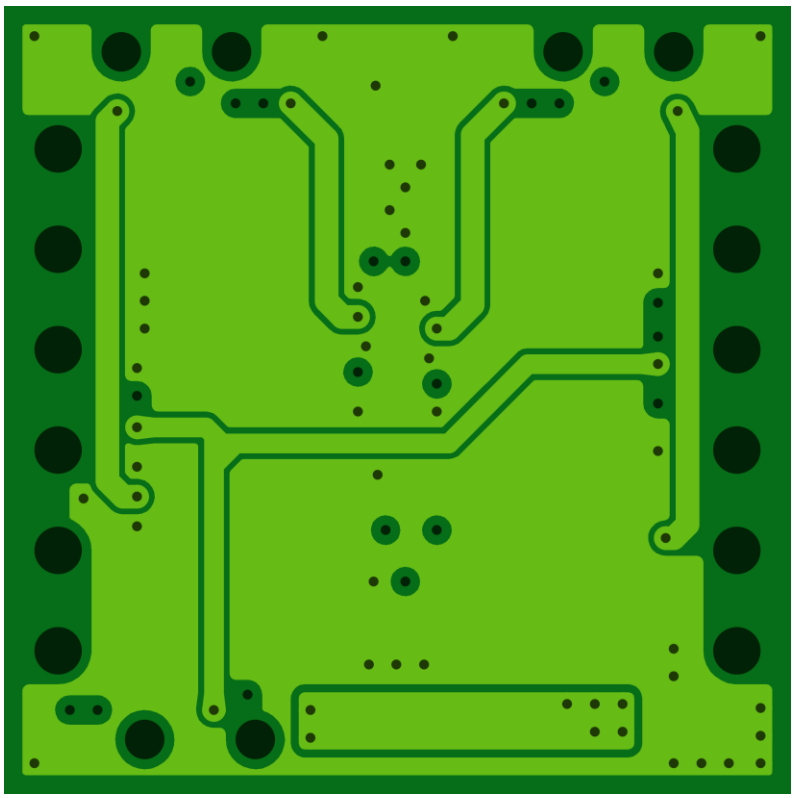


<LAYER1 Front>



<LAYER2>

Fig. 3.1 (a) Module Board Pattern Diagram (Front View - Example MUX1)



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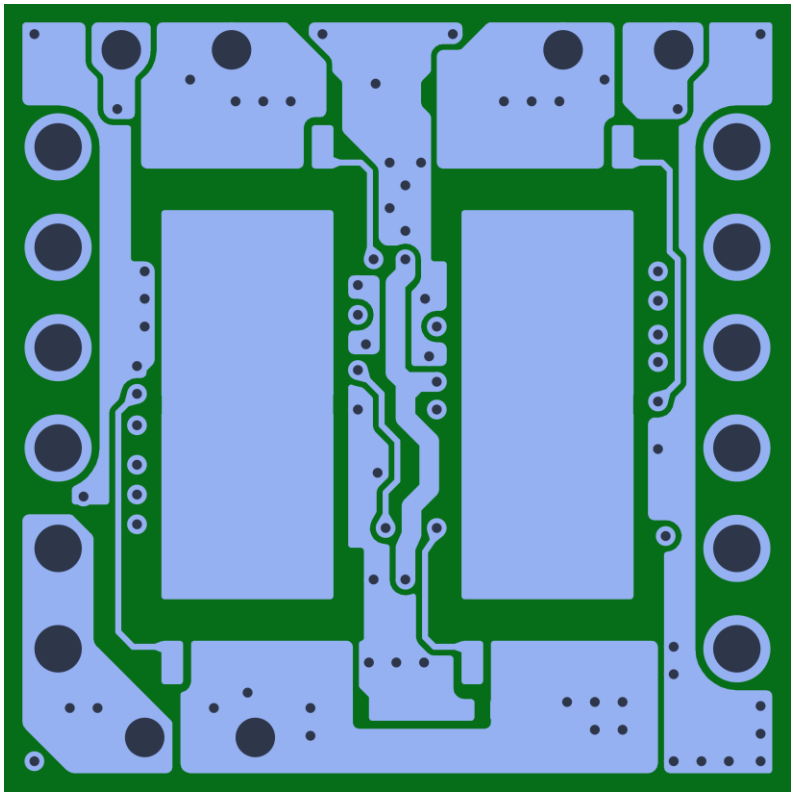
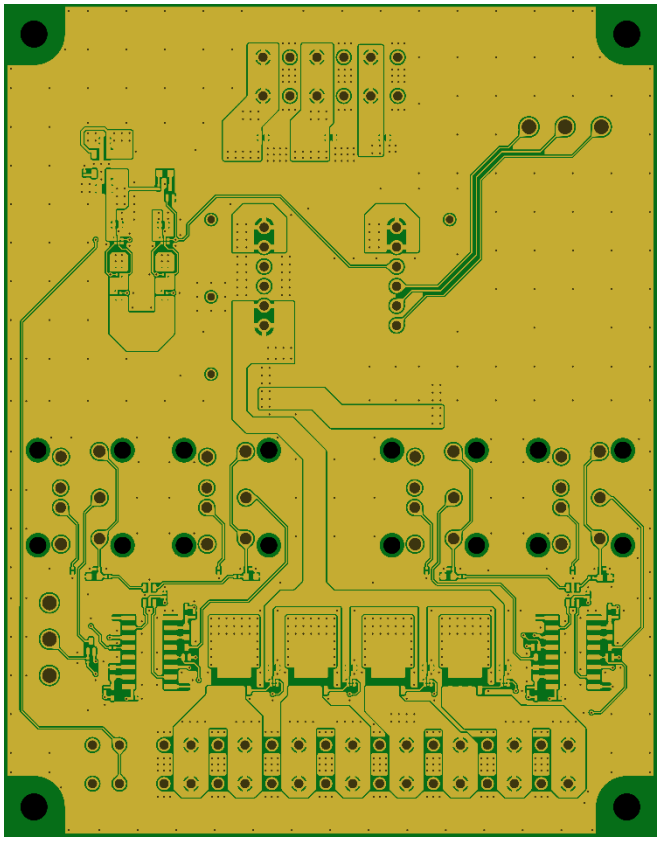
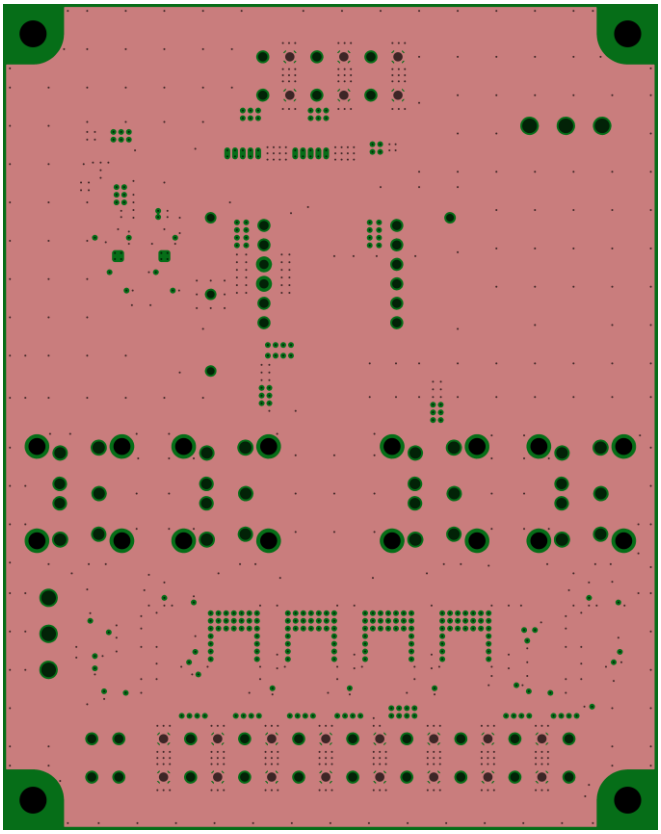


<LAYER4 Back>

Fig. 3.1 (b) Module Board Pattern Diagram (Front View – Example MUX1)

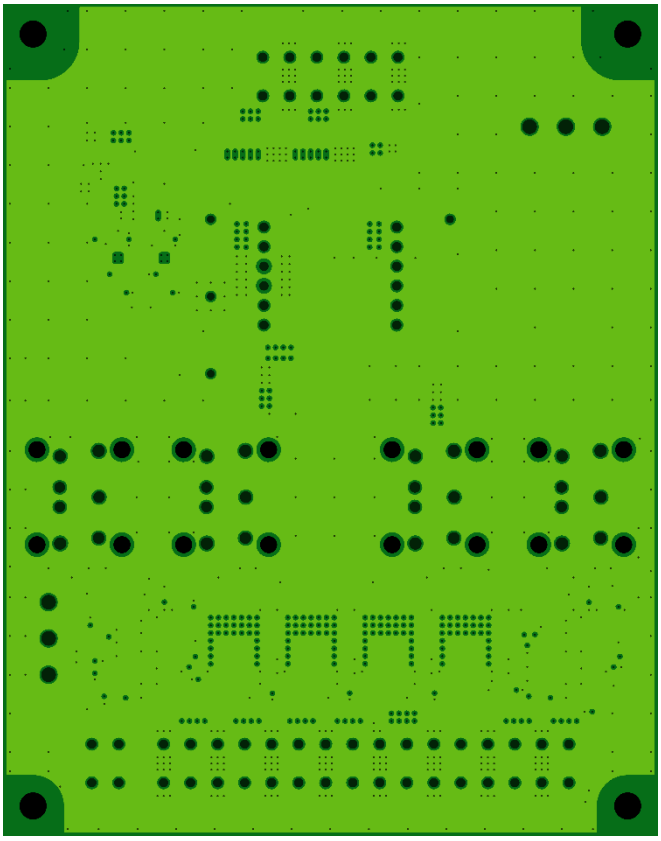


<LAYER1 Front>



<LAYER2>

Fig. 3.2 (a) Base Board Pattern Diagram (Front View)



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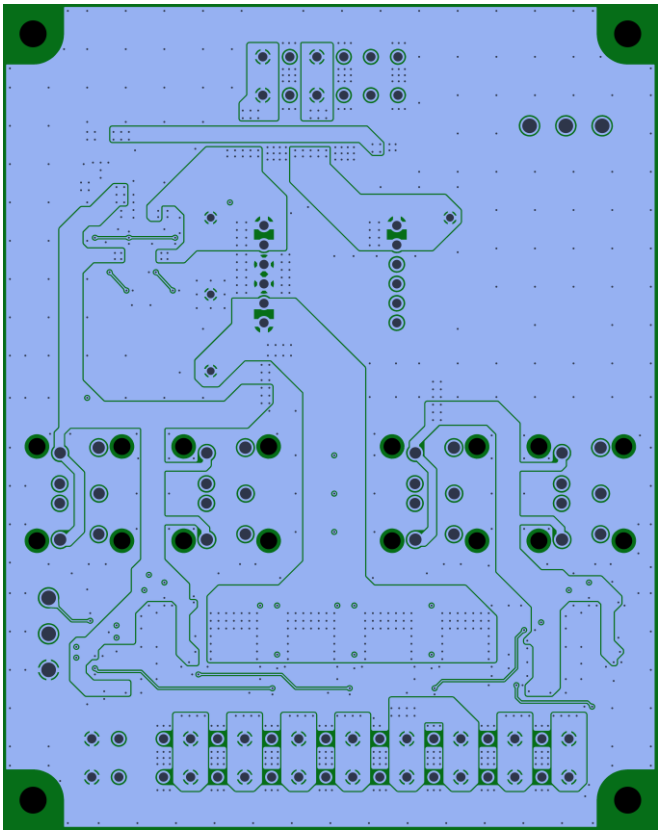

<LAYER4 Back>

Fig. 3.2 (b) Base Board Pattern Diagram (Front View)

4. Operation

4.1 Operation Method

The standard procedure for starting this circuit is as follows.

1. Connect the module board to the module board connector (CN4, CN5) on the base board as shown in Fig. 4.2.
2. Connect the required load resistance and load capacitance to the output load connector (CN2). Check FLAG out (CN3) as needed.
3. After applying the VDD power supply (5 to 12 V) to the input connector (CN1), connect VINA power supply and VINB power supply.
4. After switching the DC energization/pulse energization changeover switch to the pulse energization side, if the pulse energization switch of the load (LOAD-A～LOAD-D) is pressed, a voltage is output to the output load connector for approximately 1 second. To perform continuous energization of the output, set the DC energization/pulse energization switch to the DC energization side. DC power is available only for LOAD-D loads.
5. BBM/MBB selector switch allows you to switch between BBM operation and MBB operation. (MUX4 always operates in the BBM mode regardless of the switch setting.)

6.To stop the operation, turn off the VDD power supply after turning off VINA power supply and VINB power supply.

*Be careful not to get burned due to overheating of the load resistance.

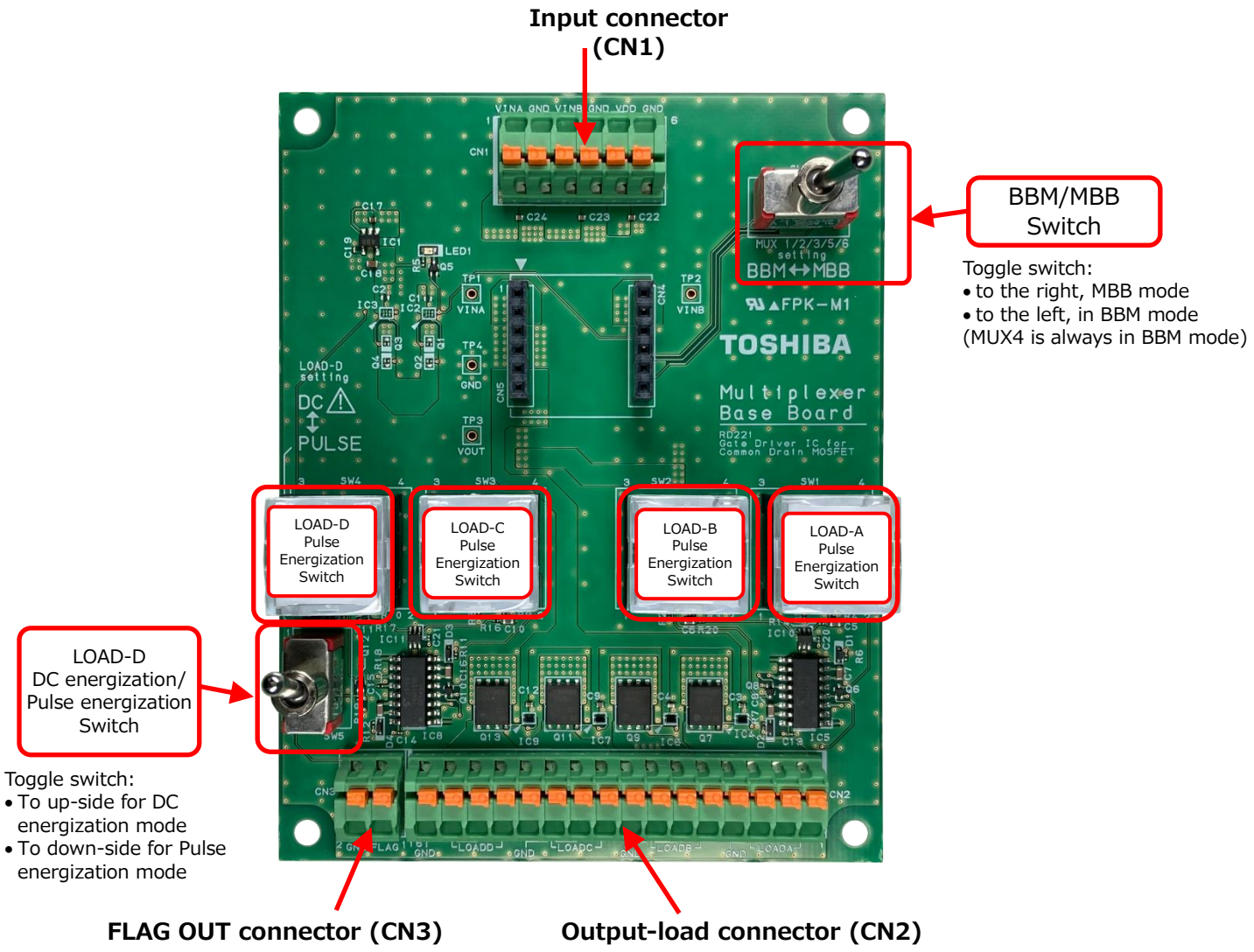

Fig. 4.1 Connectors and Switches on the Base Board

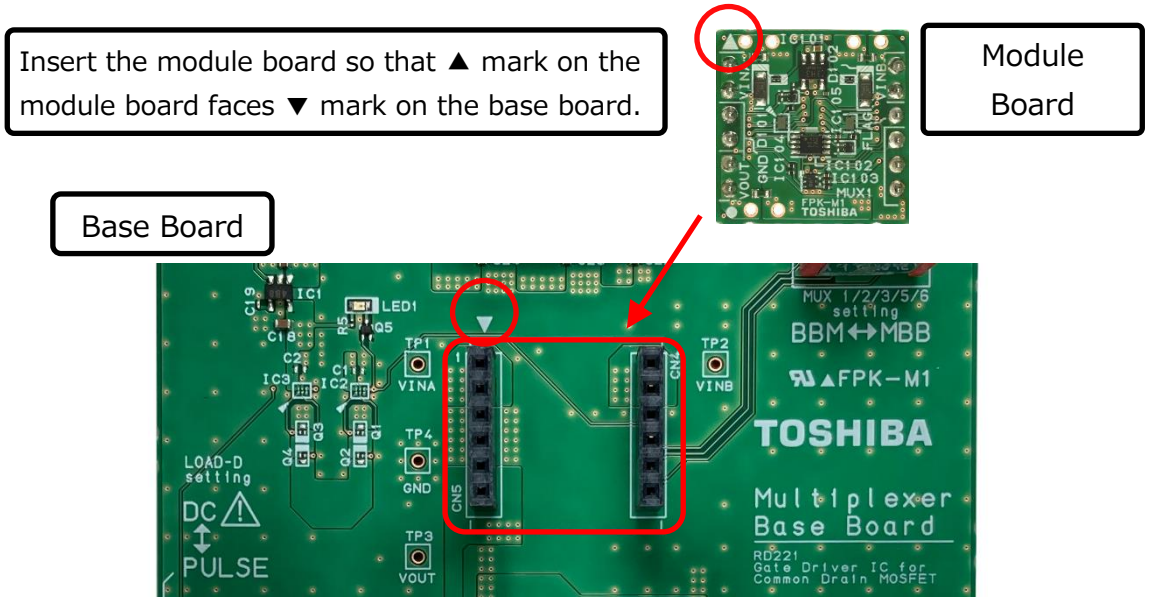

Fig. 4.2 Connection between Base Board and Module Board

4.2 External Connector Specifications

The external connector specifications of the base board of this circuit are as follows.

Table 4.1 Input Connector (CN1) Specifications

Pin Number	Input Pin Name	Description	Applied Voltage Range	Current Rating
1	VINA	Multiplexer VINA input pin	Depends on the module board to be mounted (max. 24 V)	Maximum 3 to 5 A* (depends on the module board)
2	GND	(GND of above pin)		
3	VINB	Multiplexer VINB input pin	Depends on the module board to be mounted (max. 9 V)	Maximum 3 to 5 A* (depends on the module board)
4	GND	(GND of above pin)		
5	VDD	Power supply pin for driving base board	5 to 12 V	-
6	GND	(GND of above pin)		

* Individual component specifications allow a current flow greater than this value. However, the current on this board should not exceed this value because of heat dissipation design.

Table 4.2 Output Load Connector (CN2) Specifications

Pin Number	Output Load Name	
1	LOAD-A	For resistive load connection
2		(GND of above pin)
3		For capacitive load connection
4		(GND of above pin)
5	LOAD-B	For resistive load connection
6		(GND of above pin)
7		For capacitive load connection
8		(GND of above pin)
9	LOAD-C	For resistive load connection
10		(GND of above pin)
11		For capacitive load connection
12		(GND of above pin)
13	LOAD-D	For resistive load connection
14		(GND of above pin)
15		For capacitive load connection
16		(GND of above pin)

Table 4.3 FLAG Output Connector (CN3) Specifications

Pin Number	Output Pin Name	
1	FLAG	FLAG output Becomes High (approx. 3.3 V) when VINA is input
2	GND	(GND of above pin)

4.3 Outline of Operation

4.3.1 BBM Operation

Fig. 4.3 shows the waveform when the module board MUX1 is operated in the BBM mode.

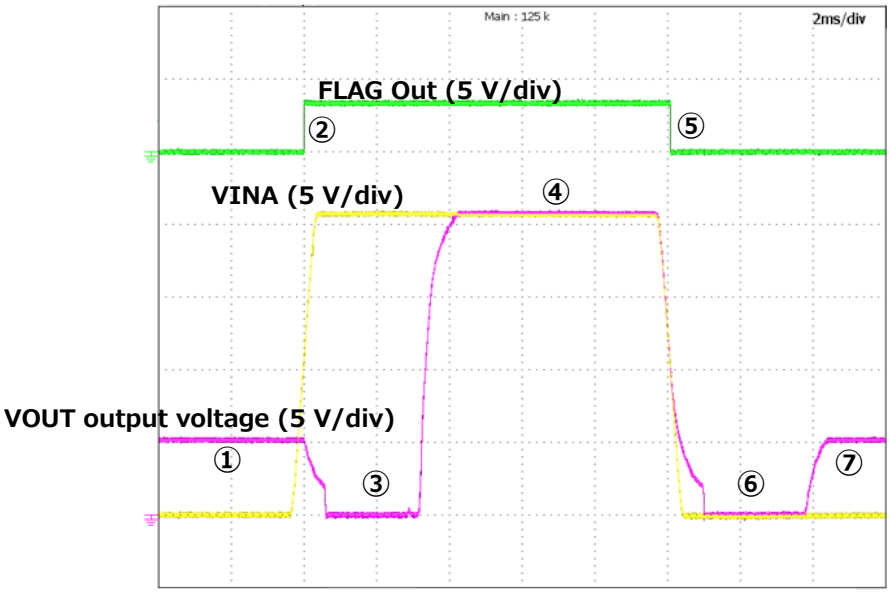

Fig. 4.3 Waveform during BBM Operation
2 ms/div, VINA = 20 V, VINB = 5 V, RL = 300 Ω, CL = None

VINB is continuously energized with 5 V, and 20 V voltage pulses of 10 ms are applied to VINA. When 20 V is applied to VINA and the output voltage switches from 5 V to 20 V, there is a start-up-time t_{ON} of approximately 3 ms when MOSFET driver IC TCK421G that controls VINA voltage is turned on, and the output voltage during this time is 0 V. Also, when VINA pin becomes 0 V and the output voltage switches from 20 V to 5 V, there is a start-up time t_{ON} of about 3 ms when MOSFET driver IC TCK425G that controls VINB voltage is turned on in the same way, and the output voltage during this time becomes 0 V. FLAG output is High (approx. 3.3 V) while VINA is applied.

Details of each operation in the waveform are as follows.

① 5 V is applied to VINB, and VINB voltage (approx. 5 V) is output.
② When 20 V is applied to VINA, FLAG output becomes High (approx. 3.3 V). VINA driver (TCK421G) starts operating at this timing.
③ 0 V is output because of VINB driver (TCK425G) is off.
④ VINA voltage (about 20 V) is generated after t_{ON} of VINA driver (TCK421G).
⑤ When the voltage at VINA becomes 0 V, FLAG output becomes Low (0 V). VINB driver (TCK425G) starts operating at this timing.
⑥ 0 V is output because VINA driver (TCK421G) is off.
⑦ VINB voltage (approximately 5 V) is output after t_{ON} of VINB driver (TCK425G).

4.3.2 MBB Operation

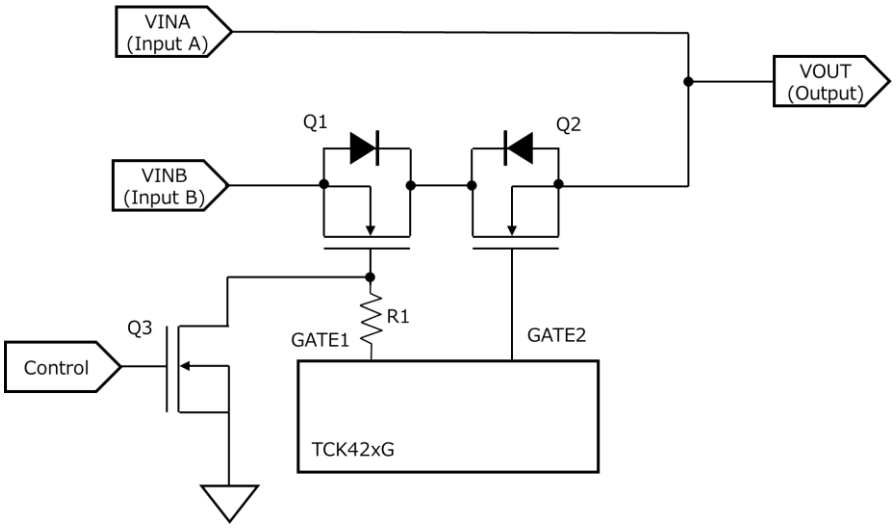

Fig. 4.4 MBB Operation Circuit

The MBB operation outline of this circuit is described below. The MBB operation circuit shown in Fig. 4.4 assumes that VINA voltage > VINB voltage and VINB is continuously energized.

① Apply voltage to VINB (VINA voltage is off). Common drain connected MOSFET Q1 and Q2 are turned on by MOSFET driver IC TCK42xG, and VINB voltage is output to VOUT .

② When VINA is detected, the Gate Shut-off MOSFET Q3 is turned on. This causes the voltage at the gate of MOSFET Q1 to become 0 V and Q1 is turned off. Therefore the voltage dropped by the forward voltage of the body diode of Q1 from VINB voltage is output to VOUT.

③ Even when voltage is applied from VINA, reverse current does not flow to VINB because of the body diode of Q1.

The above operation allows seamless voltage-output switching from VINB to VINA by MBB operation.

In addition, the following operations enable seamless voltage-output switching to VINB from VINA by MBB operation.

① VINA is turned off (0 V) while VINA is being supplied.

② The voltage dropped by the forward voltage of the body diode of Q1 from VINB voltage is output to VOUT.

③ Q3 turns off. Thus Q1 is turned ON. VINB voltage is output to VOUT.

Table 4.4 shows the timing transition table of MBB operation, and Fig. 4.5 shows the timing chart of MBB operation. The operation assumes that VINA voltage > VINB voltage.

Table 4.4 Timing Transitions of MBB Operation (Input VINA Voltage > VINB Voltage)

Time (state)	t1	t2	t3	t4	t5	t6
VINA In	0 V	0 V	ON	ON	0 V	0 V
VINB In	0 V	ON	ON	ON	ON	ON
FLAG Out*	L	L	H	H	L	L
Q1 Gate	OFF	ON	OFF	OFF	OFF	ON
Q2 Gate	OFF	ON	ON	ON	ON	ON
Q3 Gate Shut-off	OFF	OFF	ON	ON	ON	OFF
VOUT	0 V	VINB end	**	VINA end ***	**	VINB end

* H output (approx. 3.3 V) when there is VINA input, and L output (0 V) when there is no VINA input

** The voltage dropped by the forward voltage of the body diode of Q1 from VINB voltage is output to VOUT.

*** VINA voltage is reached after t_{ON} of TCK42xG (about 3 ms). It holds the voltage of the previous timing until then

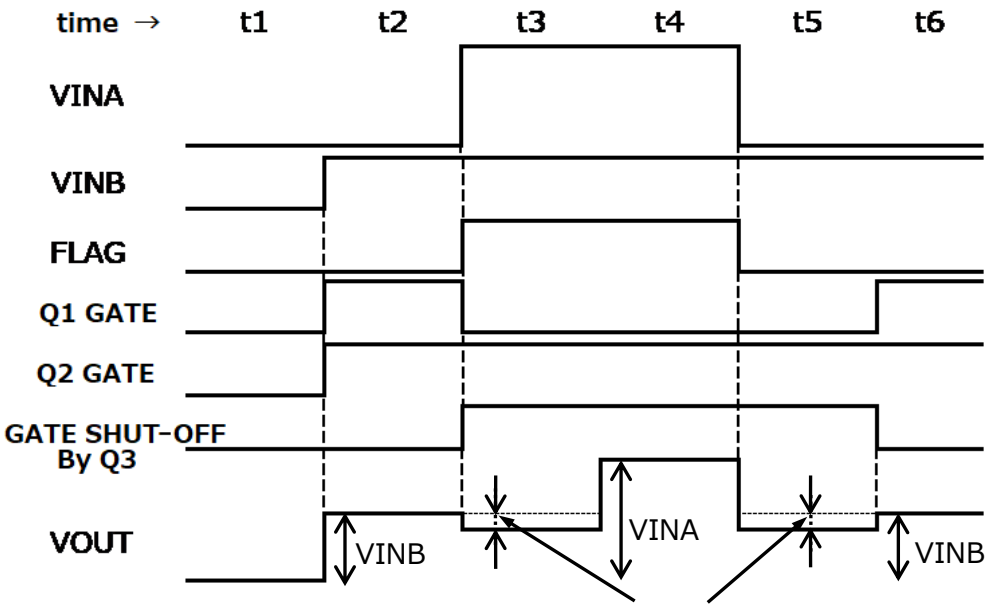

Fig. 4.5 MBB Operation Timing Chart

Fig. 4.6 shows the waveforms during actual MBB operation (of MUX1 as an example).

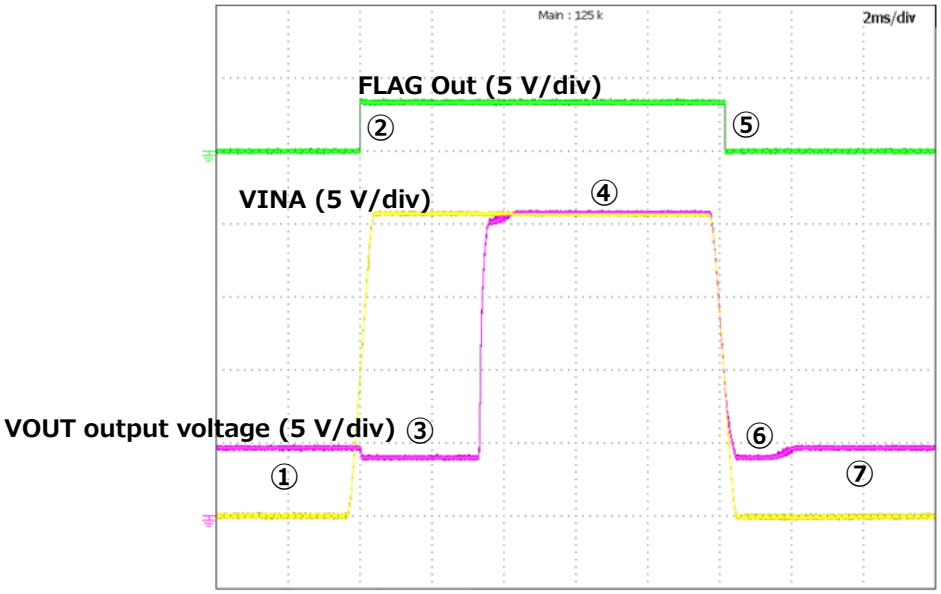

Fig. 4.6 MBB Operation Waveform (2 ms/div)
VINA = 20 V, VINB = 5 V, RL = 300 Ω, CL = None

This section describes the operation of seamlessly switching the voltage without dropping to 0 V when VINB is continuously energized as 5 V and 20 V pulses of 10 ms are applied to VINA.

① 5 V is applied to VINB, and VINB voltage (about 5 V) is sent to the output.
② When 20 V is applied to VINA, the FLAG output becomes High (approx. 3.3 V). And VINA driver (TCK421G) starts operating at this timing.
③ In VINB driver circuit, the gate-shut-off MOSFET SSM3K15ACTC corresponding to Q3 in Fig. 4.4 is turned on, and MOSFET TPHR6503PL1 corresponding to Q1 is turned off. During the start-up time t_{ON} after TCK421G is turned on in ② (about 3 ms), the voltage dropped by the forward voltage of the body diode of Q1 from VINB voltage is output to VOUT.
④ VINA voltage (about 20 V) is output after t_{ON} period of TCK421G from the time it turned on in step ③.
⑤ When the applied voltage of VINA becomes 0 V, FLAG output becomes Low (0 V).
⑥ Since VINA voltage became 0 V, the Gate Shut-off MOSFET corresponding to Q3 in Fig. 4.4 is turned off, and TPH6503PL1 corresponding to Q1 starts turn-on operation. During this time, voltage dropped by the forward voltage of the body diode of Q1 from VINB voltage is output to VOUT.
⑦ TPH6503PL1 corresponding to Q1 is turned on. VINB voltage (approx. 5 V) is output.

4.3.3 Ideal Diode Characteristic

Fig. 4.7 shows the forward voltage (V_F) versus forward current (I_F) characteristics of the Schottky barrier diode (SBD) CRS30I30A (30 V/3 A/S-FLAT package) as a plot of the difference in input/output voltage (VIN-VOUT) versus output current (IOUT) between the input VINA-and output VOUT of MUX1.

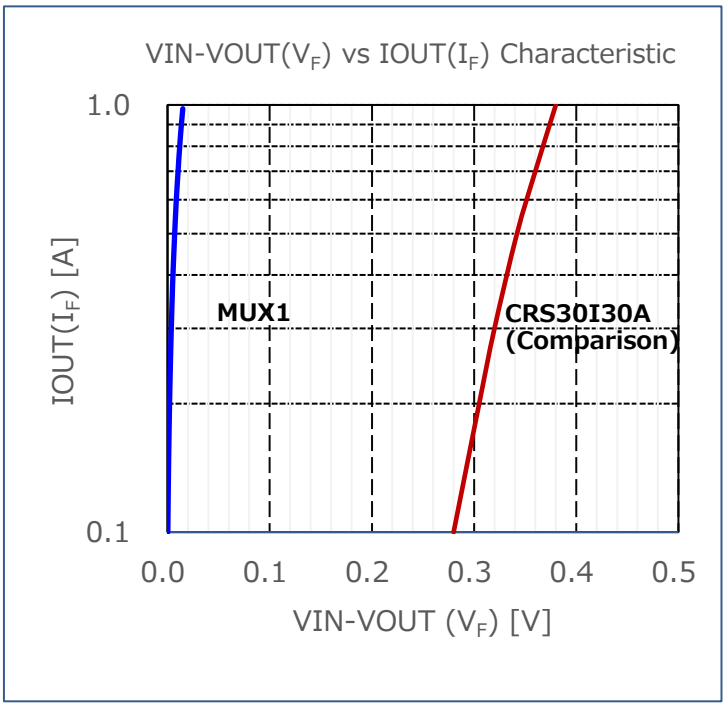

Fig. 4.7 Characteristics of MUX1 and CRS30I30A

The forward voltage drop (V_F) of CRS30I30A is approximately 0.38 V when 1 A current is applied. It is approximately 15 mV for MUX1, which is approximately 1/25. Therefore, MUX1 shows ideal diode characteristic. Since the drop voltage between the input and output pins is small when the power multiplexer is operated, this circuit can achieve a lower loss than when the Schottky barrier diode (SBD) is used as OR-ing circuit.

4.3 Operation Waveform

4.3.1 Module Board MUX1

The operation waveform of the module board MUX1 is shown below.

Fig. 4.8 External View of Module Board MUX1 (Front Side, Back Side)

Operation Waveform of MUX1 in BBM mode (at 1 A Output Current)

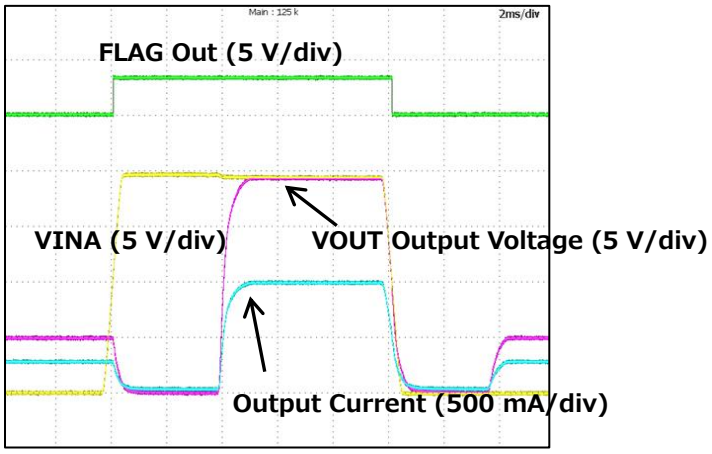

Fig. 4.9 BBM Operation Waveform (2 ms/div)
VINA = 20 V, VINB = 5 V, RL = 20 Ω, CL = 6.8 μF

Operation Waveform of MUX1 in MBB mode (at 1 A Output Current)

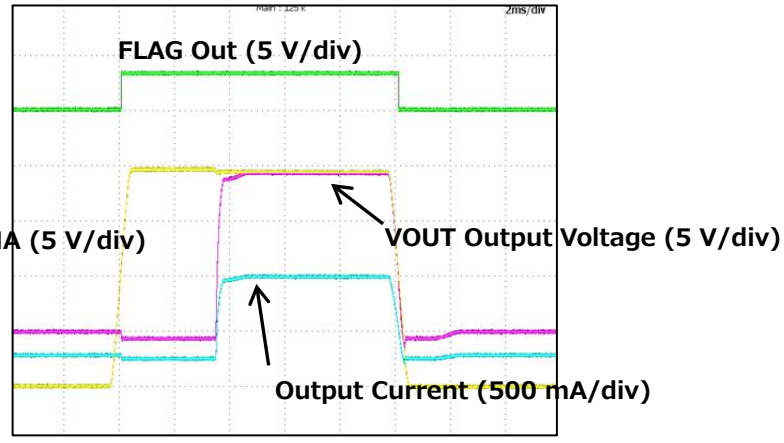

Fig. 4.10 MBB Operation Waveform (2 ms/div)
VINA = 20 V, VINB = 5 V, RL = 20 Ω, CL = 6.8 μF

4.3.2 Module Board MUX2

The operation waveform of the module board MUX2 is shown below.

Fig. 4.11 External View of Module Board MUX2 (Front Side, Back Side)

Operation Waveform of MUX2 in BBM mode (at 1 A Output Current)

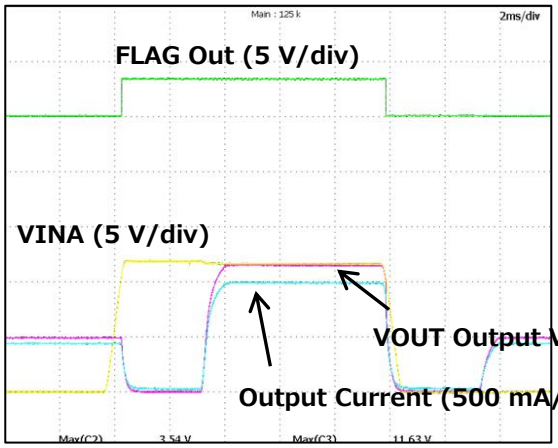

Fig. 4.12 BBM Operation Waveform (2 ms/div)
VINA = 12 V, VINB = 5 V, RL = 12 Ω, CL = 6.8 μF

Operation Waveform of MUX2 in MBB mode (at 1 A Output Current)

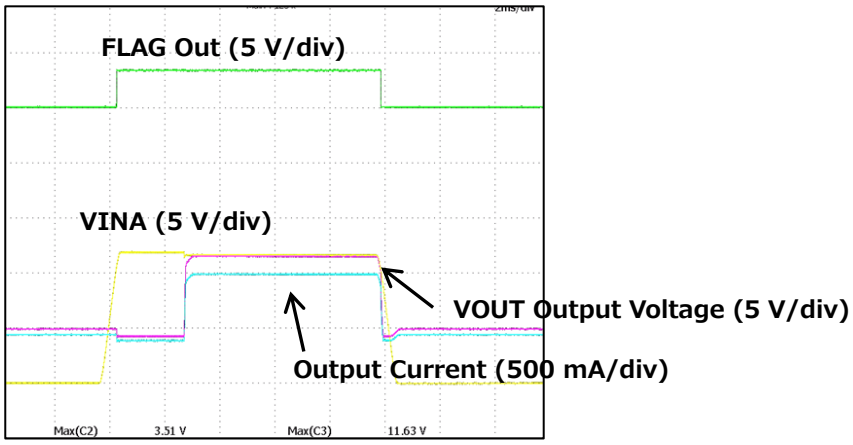

Fig. 4.13 MBB Operation Waveform (2 ms/div)
VINA = 12 V, VINB = 5 V, RL = 12 Ω, CL = 6.8 μF

4.3.3 Module Board MUX3

The operation waveform of the module board MUX3 is shown below.

Fig. 4.14 External View of Module Board MUX3 (Front Side, Back Side)

Operation Waveform of MUX3 in BBM mode (at 1 A Output Current)

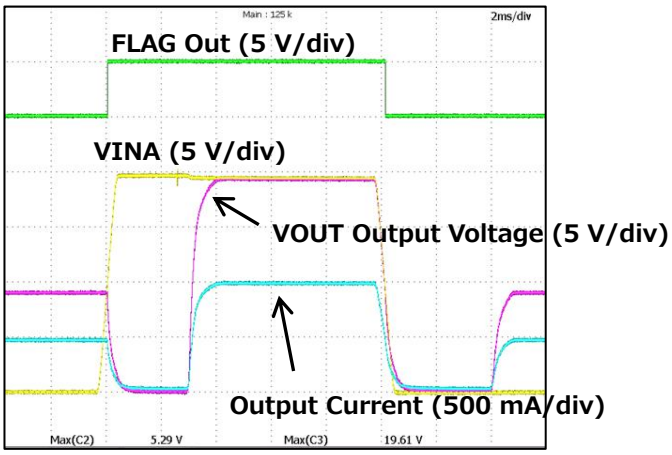

Fig. 4.15 BBM Operation Waveform (2 ms/div)
VINA = 20 V, VINB = 9 V, RL = 20 Ω, CL = 6.8 μF

Operation Waveform of MUX3 in MBB mode (at 1 A Output Current)

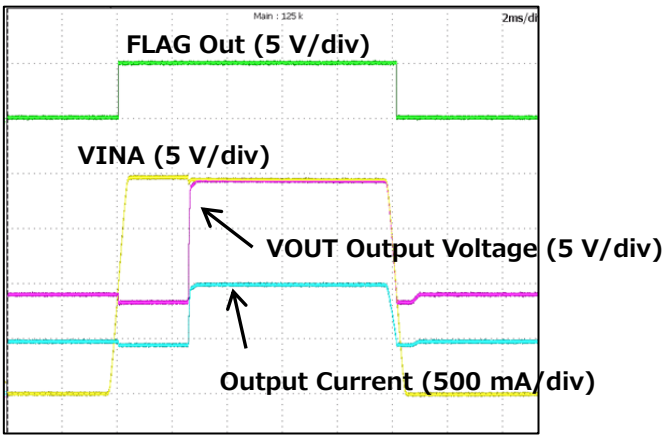

Fig. 4.16 MBB Operation Waveform (2 ms/div)
VINA = 20 V, VINB = 9 V, RL = 20 Ω, CL = 6.8 μF

4.3.4 Module Board MUX4

The operation waveform of the module board MUX4 is shown below.

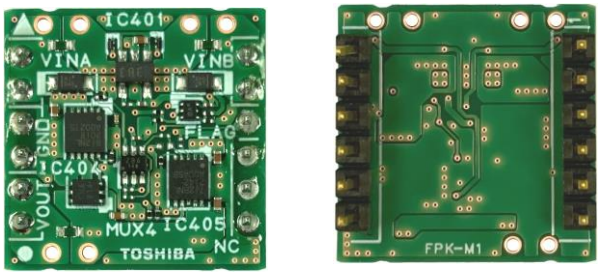

Fig. 4.17 External View of Module Board MUX4 (Front Side, Back Side)

Operation Waveform of MUX4 in BBM mode (at 1 A Output Current)

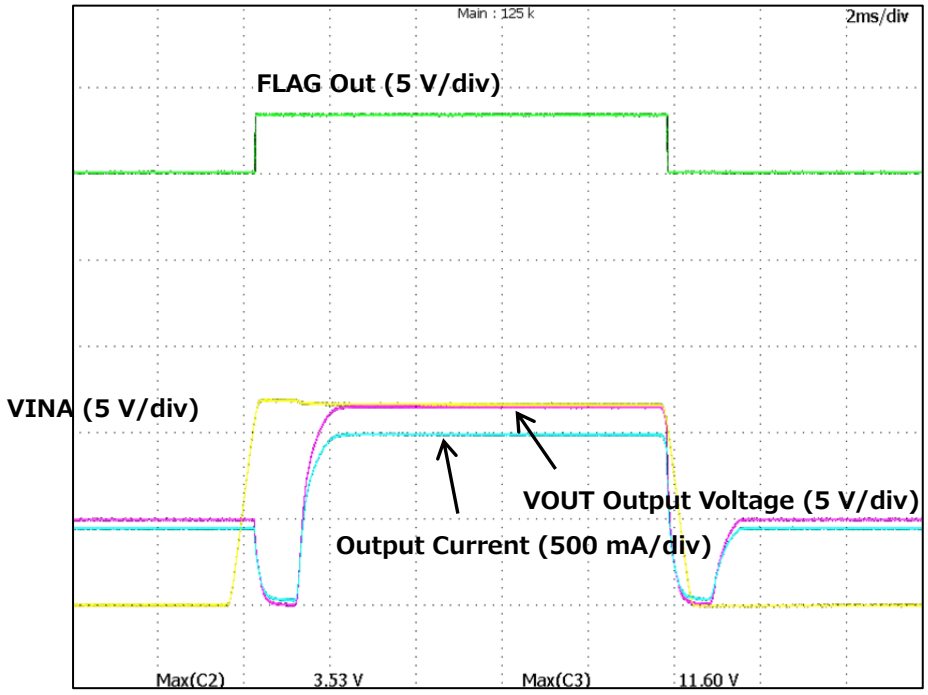

Fig. 4.18 BBM Operation Waveform (2 ms/div)
VINA = 12 V, VINB = 5 V, RL = 12 Ω, CL = 6.8 μF

Since the module board MUX4 uses a eFuse IC, only BBM mode can be used and MBB mode cannot be used.

4.3.5 Module Board MUX5

The operation waveform of the module board MUX5 is shown below.

Fig. 4.19 External View of Module Board MUX5 (Front Side, Back Side)

Operation Waveform of MUX5 in BBM mode (at 1 A Output Current)

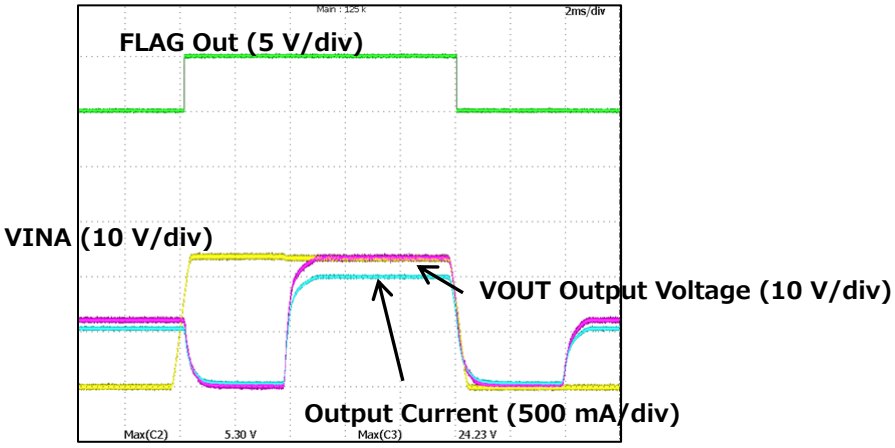

Fig. 4.20 BBM Operation Waveform (2 ms/div)
VINA = 24 V, VINB = 12 V, RL = 24 Ω, CL = 6.8 µF

Operation Waveform of MUX5 in MBB mode (at 1 A Output Current)

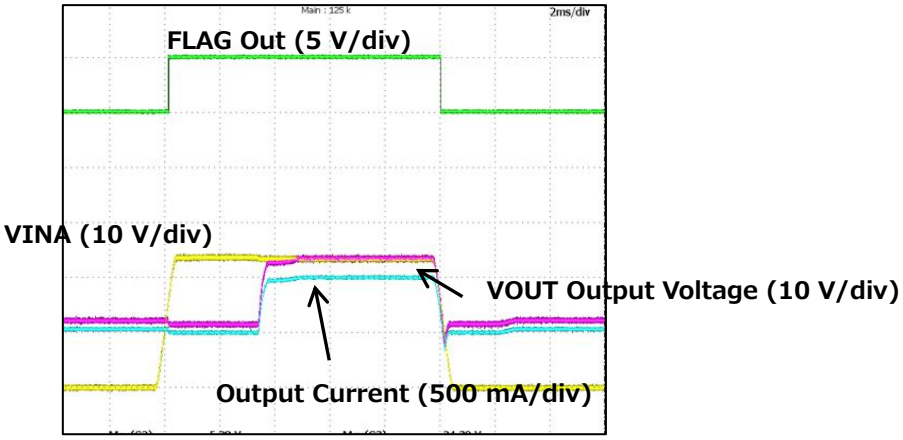

Fig. 4.21 MBB Operation Waveform (2 ms/div)
VINA = 24 V, VINB = 12 V, RL = 24 Ω, CL = 6.8 µF

5. Precautions for Use

・In order to perform the designed operation as expected, it should be used with appropriate output capacitance value and proper start-up sequence design.

・Be careful not to get an electric shock because the applied voltage is high.

・Be careful not to burn yourself due to overheating or overheating of the load added to the output terminal.

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