

TPD2017FN

Application Notes

Overview

TPD2017FN is a low-side switch (8 channels) with MOSFET out. It can be driven directly from CMOS, TTL logic circuitry (MCUs, etc.) and is suitable for driving inductive and resistive loads such as industrial programmable logic controllers, motors and lamps in factory automation equipment, etc. This product has built-in overcurrent and over temperature protection functions, which contribute to improving the stability of the system. This guide explains detailed operations related to basic characteristics and protective functions, as well as precautions for use.

. Do not design your products or systems based on the information on this document. Please contact your Toshiba sales representative for updated information before designing your products.

Table of Contents

Overview	1
Table of Contents	2
1. Product comparison (TPD2007F, TPD2017FN)	4
2. Outline of 8ch output low side switch	5
2.1. Operating range of power supply voltage	5
2.2. Power on/off method	5
2.3. Normal operation waveform	6
3. Control input	7
3.1. IN1 to IN8 pins	7
4. Application circuit example	8
5. Protection features	10
5.1. Over temperature protection	10
5.2. Overcurrent protection	11
5.2.1. Load short-circuited after IC is turned on	11
5.2.2. IC on after load short circuit	12
5.3. Active clamp operation	13
6. Power dissipation	15
7. Evaluation board	16
7.1. Appearance of evaluation board	16
7.2. Circuit diagrams	17
7.3. Bill of materials	18
7.4. Board layout	19
Points to note in the description	20
IC usage consideration	20
Notes on handling of ICs	20
Precautions for use	20
RESTRICTIONS ON PRODUCT USE	21

List of Figures

Fig. 2.1 Control Input Sequence	5
Fig. 2.2 Normal operation waveform	6
Fig. 2.3 Example of normal operation circuit	6
Fig. 3.1 Pin assignments.....	7
Fig. 4.1 Application circuit example	8
Fig. 5.1 Example of over temperature protection operation waveform	10
Fig. 5.2 Example of over temperature protection test circuit.....	10
Fig. 5.3 Waveform of overcurrent protection operation (Load short circuit after turned on)	11
Fig. 5.4 Example of overcurrent protection test circuit (Load short circuit after turned on)	11
Fig. 5.5 Waveform of overcurrent protection operation (IC is turned on after a load short circuit)	12
Fig. 5.6 Example of overcurrent protection operation circuit (IC is turned on after a load short circuit)).	12
Fig. 5.7 Active clamp operation waveform.....	13
Fig. 5.8 Example of active clamp operation circuit	13
Fig. 5.9 Waveform during active clamp operation	14
Fig. 6.1 Internal block diagram and external connection conditions example	15
Fig. 7.1 External View of TPD2017FN evaluation board.....	16
Fig. 7.2 TPD2017FN evaluation board circuit.....	17
Fig. 7.3 TPD2017FN evaluation board layout diagram	19

List of Tables

Table 1.1 Product comparison table	4
Table 2.1 Operating range of power supply voltage	5
Table 4.1 Recommended values (capacitors for power supply terminals).....	9
Table 6.1 Loss breakdown ($V_{OUT} = 24\text{ V}$, $V_{DD(opr)} = 5.5\text{ V}$, $f_{PWM} = 50\text{ Hz}$, Duty = 50 %, $I_{load} = 0.48\text{ A}$).....	15
Table 7.1 BOM list.....	18

1. Product comparison (TPD2007F, TPD2017FN)

The main differences between the products are shown in the table below.

Table 1.1 Product comparison table



Item	TPD2007F	TPD2017FN
Operating Power Supply V_{DD}	3.9 to 6.0 V (supply voltage from input terminal)	2.7 to 5.5 V
Operating Temperature T_{opr}	-40 to 85 °C	-40 to 110 °C
On-resistance $R_{ON}@ V_{IN} = 5 V, I_{OUT} = 0.5 A,$ $T_j = 25 °C$	1.4 Ω (max)	0.55 Ω (max)
Recommended Input voltage	5.0 V	3.3 V / 5.0 V
Output voltage	40 V (max)	40 V (max)
Overcurrent protection	Current clamping system	PWM system
Over current detection	1.0 A (min)	1.0 A (min)
Output clamp voltage	40 V (min)	40 V (min)
Single pulse energy	10 mJ (max)	30 mJ (max)
Over temperature protection	160 °C	175 °C
Power Dissipation	1.2 W	1.8 W
Number of channels	8 channels	8 channels
Package	SSOP24 (1.0mm-pitch) 	SSOP30 (0.65 mm-pitch) 
Package size	13.0 mm × 8.0 mm	9.7 mm × 7.6 mm

Table 1.1 shows the product comparison table. TPD2007F is our conventional product. It is an 8-channel output low-side switch. TPD2017FN will be a product that is smaller and has improved properties by reviewing the wafer process and packaging. The main improvement points are the expansion of the operating temperature range up to 110 °C and the reduction of on-resistance by about 60 %. SSOP30 (0.65 mm pitch) package size reduces the mounting area by approximately 30% from the conventional SSOP24 (1.0 mm pitch).

2. Outline of 8ch output low side switch

The low-side switch is a switch circuit that adjusts the current supplied to the load by placing a switching element such as a MOSFET on the ground side and connecting an inductive load or a resistive load between the power supply and the switching element. This product has eight channels of low-side switches, each of which can be controlled independently.

2.1. Operating range of power supply voltage

V_{DD} is the power supply for the control circuitry inside the ICs. Do not apply voltage exceeding the absolute maximum rating.

Table 2.1 Operating range of power supply voltage

Item	Symbol	Operating Power Supply Voltage Range	Absolute maximum rating	Unit
Power voltage for driving	$V_{DD(opr)}$	2.7 to 5.5	6.0	V

The absolute maximum rating is a standard that must not be exceeded instantaneously.

2.2. Power on/off method

Apply V_{DD} to the voltage above 2.7 V, and then apply a control input signal V_{IN} . Also, set the control input pin to 0 V when the power is turned on. The control input sequence is shown below.

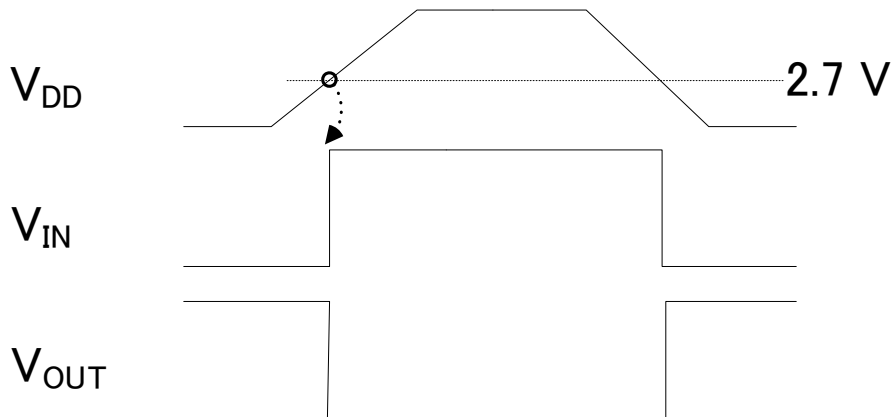


Fig. 2.1 Control Input Sequence

2.3. Normal operation waveform

Fig. 2.2 and Fig. 2.3 show the operation waveforms and measurement circuit diagrams as examples of normal operation. This product absorbs the back electromotive force when the inductive load is turned off without exceeding the element withstand voltage by the active clamp circuit. As shown in Fig. 2.3, even when an inductive load of 50 mH is connected to the output, it can be confirmed that the output is clamped at a voltage of about 45.6 V. During this time, the inductance current flows to the GND-side via OUT1 terminal (Refer to 5.3 for the active clamping operation).

Ch1: $V_{IN1\ to\ 8}$
5.0 V/div

Ch2: $V_{OUT1\ to\ 8}$
10.0 V/div

Ch3: $I_{OUT1\ to\ 8}$
100 mA/div

2.0 ms/div

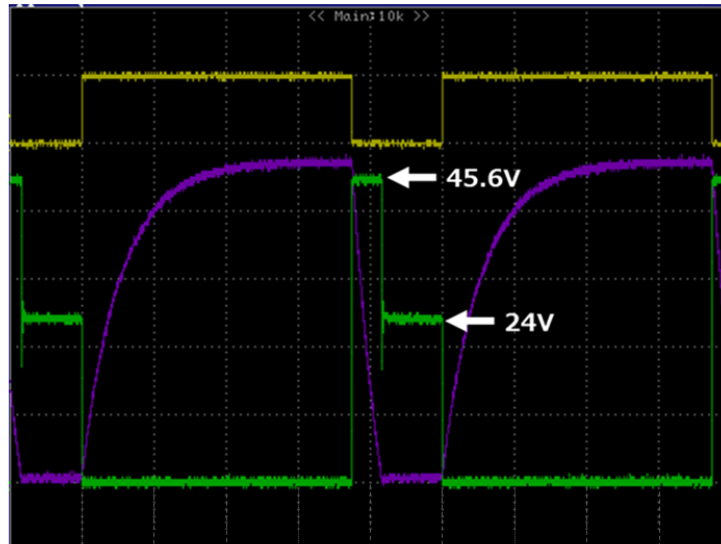


Fig. 2.2 Normal operation waveform

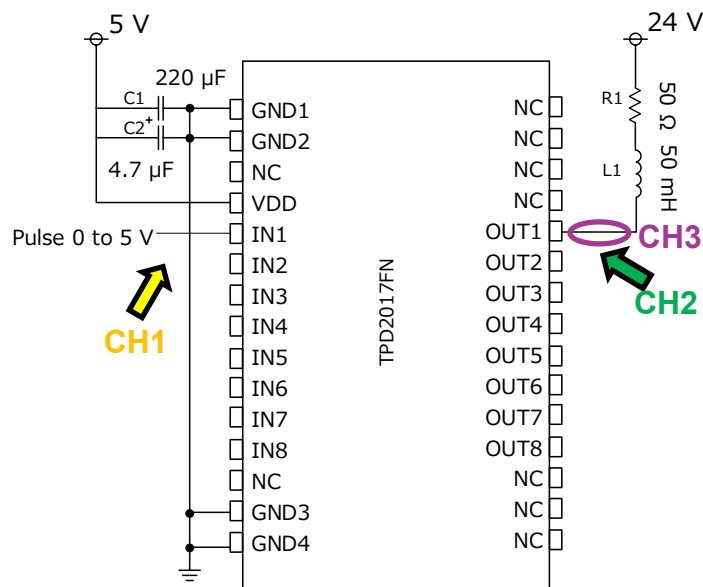


Fig. 2.3 Example of normal operation circuit

3. Control input

3.1. IN1 to IN8 pins

The input pins of TPD2017FN have IN1 to IN8, but each of these input pins corresponds to the output pins of OUT8 from OUT1, and each channel is controlled independently. Each input pin has an internal pull-down resistor of 300 k Ω (typ.), which is in the L state even when the input pin is open. Since V_{IH} is 2.0 V (min), control is available not only for 5.0 V MCUs but also for 3.3 V MCUs. Refer to the datasheet of this product for detailed electrical characteristics. Keep the NC pin open to prevent short-circuiting with adjacent terminals.


GND1	1		30	NC
GND2	2		29	NC
NC	3		28	NC
VDD	4		27	NC
IN1	5		26	OUT1
IN2	6		25	OUT2
IN3	7		24	OUT3
IN4	8		23	OUT4
IN5	9		22	OUT5
IN6	10		21	OUT6
IN7	11		20	OUT7
IN8	12		19	OUT8
NC	13		18	NC
GND3	14		17	NC
GND4	15		16	NC

Fig. 3.1 Pin assignments

4. Application circuit example

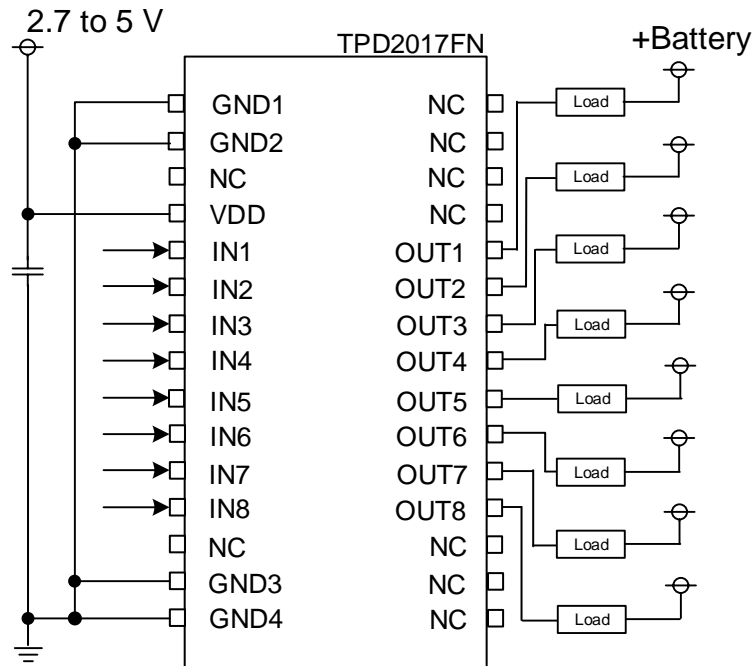


Fig. 4.1 Application circuit example

NOTE : Connect the power supply capacitor as close to the IC as possible.

Precautions for use

- Apply a voltage of 40 V or less to the + Battery.
- A resistive load or an inductive load is assumed in the load section. However, connect a load with a minimum value of 1.0 A or less, which is the minimum value for overcurrent detection.
- IN1 to IN8 are assumed to be 3.3 V or 5.0 V MCUs or TTLs. Do not apply voltage exceeding the absolute maximum rating.

(1) Capacitor for power supply terminal

Connect a capacitor as close as possible between V_{DD} and GND pins of the ICs.

Table 4.1 Recommended values (capacitors for power supply terminals)

Item	Recommended value	Remarks
$V_{DD} - GND$	0.1 to 1 μF	Ceramic capacitors

5. Protection features

5.1. Over temperature protection

Over temperature protection is used to protect the system from heat generation due to loss during IC operation and from an increase in ambient temperature. When the temperature rises above T_{SD} (175 °C typ.), all OUT1 to OUT8 transit to the off-state. Fig. 5.1 shows the operation waveform. Fig. 5.2 shows an example of a test circuit diagram when each output is operated with a current load of approximately 1.5 A to generate a loss in the IC. The output has stopped 820 ms after the IC was turned on, because over temperature protection was activated. When the over temperature protection is activated, the IC is turned off, so the loss is reduced, and the IC returns to the on-state after several tens of ms when T_j drops to the hysteresis ΔT_{SD} (15 °C typ.). If the cause of the over temperature protection operation is not eliminated, the factor that over temperature protection works is not eliminated, T_j rises again and over temperature protection works → the output is off → T_j is decreasing → the output will turn on repeatedly. Since the stability of the system and the reliability of the IC are concerned when the over temperature protection state continues for a long time, it is necessary to provide a fail-safe function as a system when the protection function is activated.

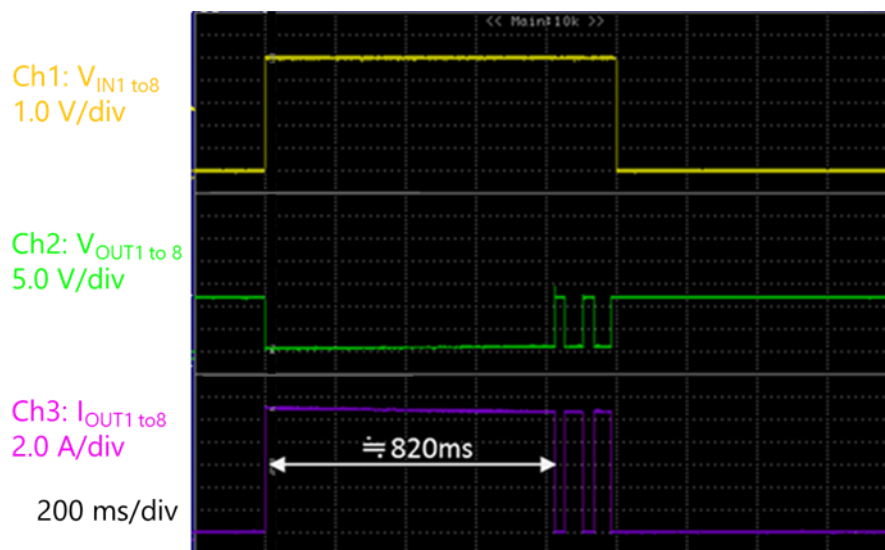


Fig. 5.1 Example of over temperature protection operation waveform
($V_{DD} = 5\text{ V}$, $V_{IN} = 0\text{ to }5\text{ V}$ $f = 0.5\text{ Hz}$, $R_{load} = 1.0\ \Omega$, $T_a = 25\text{ }^\circ\text{C}$)

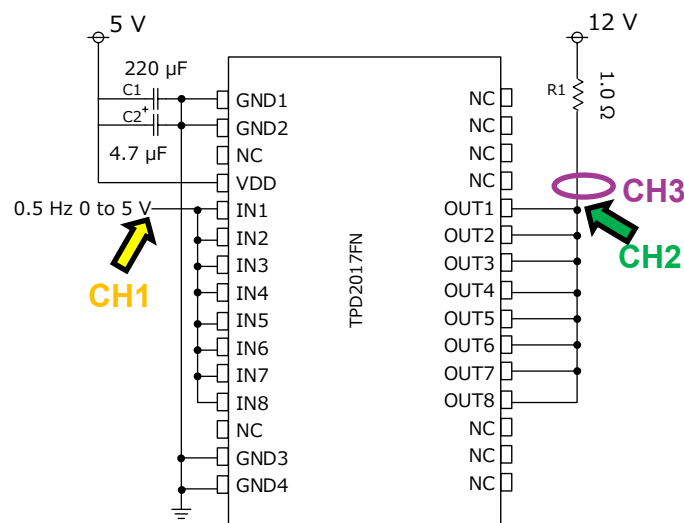


Fig. 5.2 Example of over temperature protection test circuit

5.2. Overcurrent protection

Overcurrent protection is a function that limits the output voltage and output current when an overcurrent occurs due to a load short circuit, etc., to prevent damage to this product and peripheral elements. There are two possible cases where a load short circuit occurs. This section describes the case (5.2.1) of the load short circuit (ceiling) when the IC is on and the case (5.2.2) in which the product transitions to on when the load is short-circuited.

5.2.1. Load short-circuited after IC is turned on

Fig. 5.4 is an example of a test circuit for reproducing a load short circuit when the IC is on. Q1 (80 mΩ typ.) was used as a switching element for short-circuit operation. If the load is short-circuited (Q1 is turned on) while the IC is on, the IC's overcurrent detection I_{OC} is 1.5 A typ. However, as shown in Fig. 5.3, I_{OUT1} current may flow up to about 18 A due to the delay of the overcurrent detector operation. The time for generating the current is about 7 μs, which does not lead to device breakage or fusing. The PWM-type IC is designed to reduce the power dissipation of the IC itself. The overcurrent protection operation time is 3.0 ms typ. It will be about. In Fig. 5.3, after 2.8 ms, normal operation is restored, and it can be confirmed that the output is stopped after detecting a short-circuit condition.

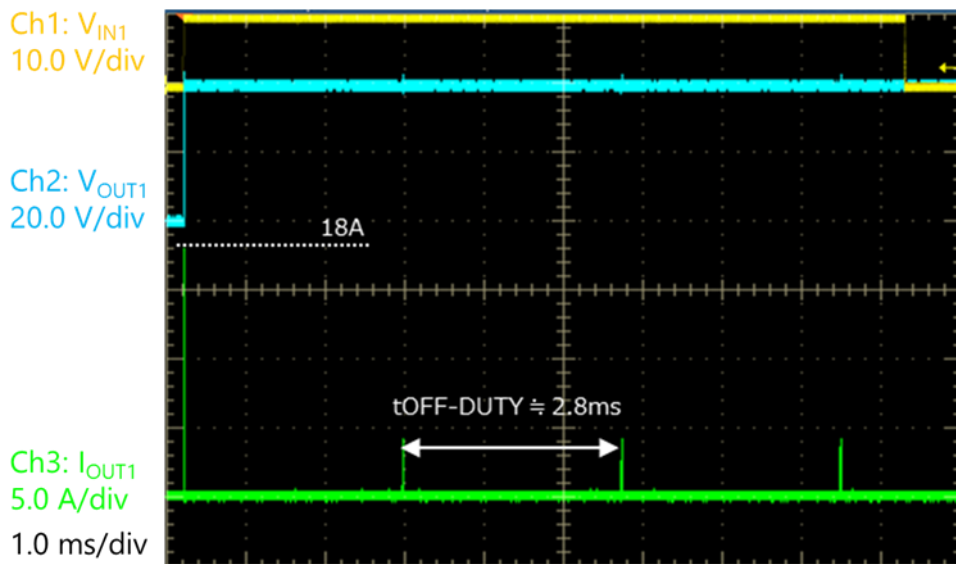


Fig. 5.3 Waveform of overcurrent protection operation (Load short circuit after turned on)

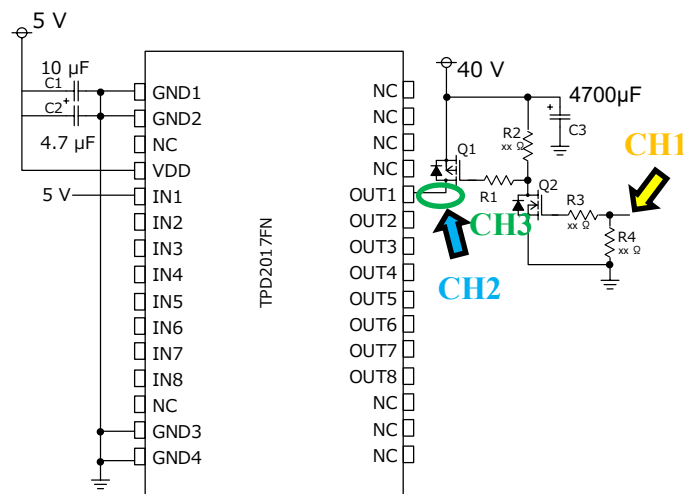


Fig. 5.4 Example of overcurrent protection test circuit (Load short circuit after turned on)

5.2.2. IC on after load short circuit

In Fig. 5.6, a control signal is input to IN1 pin with OUT1 pin shorted to a voltage source of 40 V. Fig. 5.5 shows the operation waveform when the input is set to the H state and the output is turned on. When the output is in a ceiling-fault condition, the current also depends on the gain of the IC's output, but you can see that overcurrent protection is activated at the 4.0 A peak. The overcurrent protection in this state operates at the first peak current lower than that in 5.2.1.

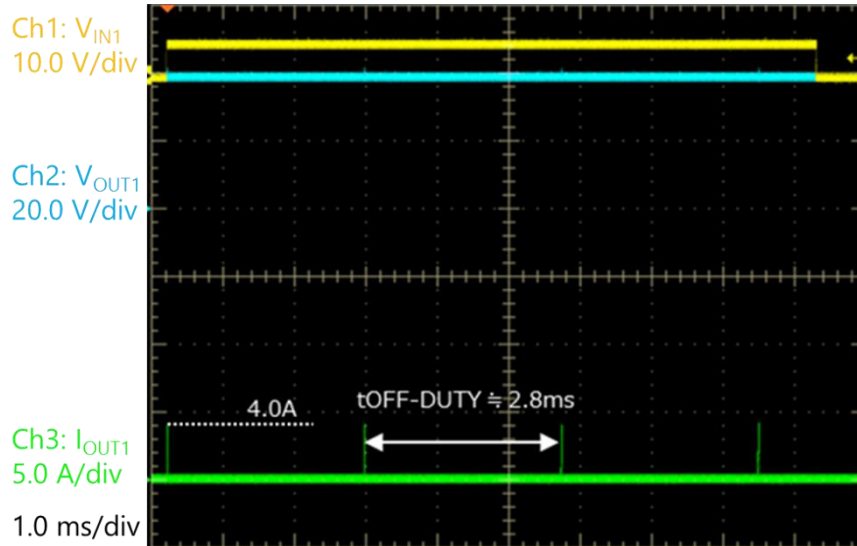


Fig. 5.5 Waveform of overcurrent protection operation (IC is turned on after a load short circuit)

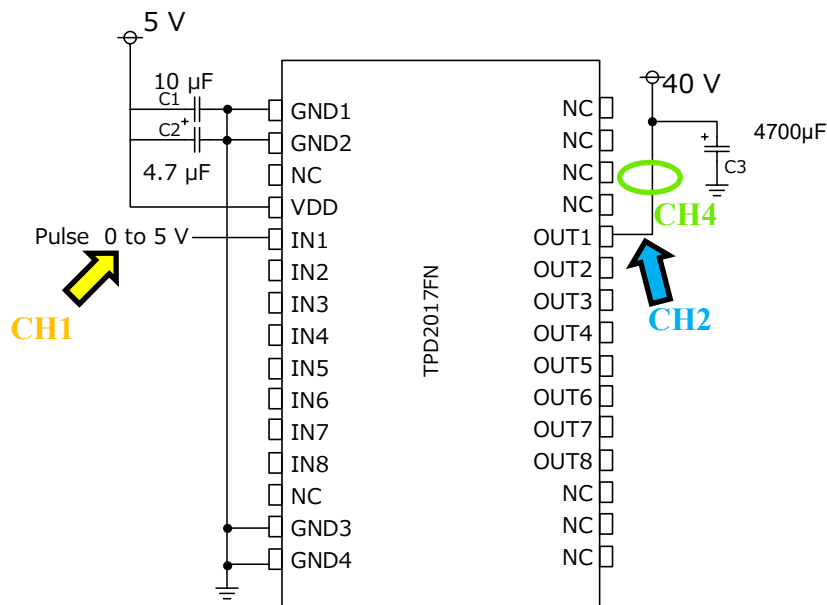


Fig. 5.6 Example of overcurrent protection operation circuit (IC is turned on after a load short circuit)

5.3. Active clamp operation

Active clamping operation is a function to forcibly switch MOSFET to the on-state by incorporating a clamping circuit so that the breakdown voltage is not reached beyond the breakdown voltage of the output element due to the back electromotive force generated by the inductive load connected to the output. As shown in Fig. 5.7, it can be confirmed that V_{OUT1} is clamped at about 46.4 V after turning off. You can see that the power supply is clamped at a voltage lower than 50 V, which is the rated output voltage V_{OUT} of the power supply. Ch3 is the current that flows through the ICs during clamping operation. During clamping operation, loss occurs in the IC, and when the withstand capacity is exceeded, it will lead to destruction. This product shows the result that a back electromotive force of about 150 mJ is applied under the condition shown in Fig. 5.8 and does not lead to destruction. In actual use, the design should not exceed 30 mJ (minimum value) of the active clamp tolerance stated in the data sheet.

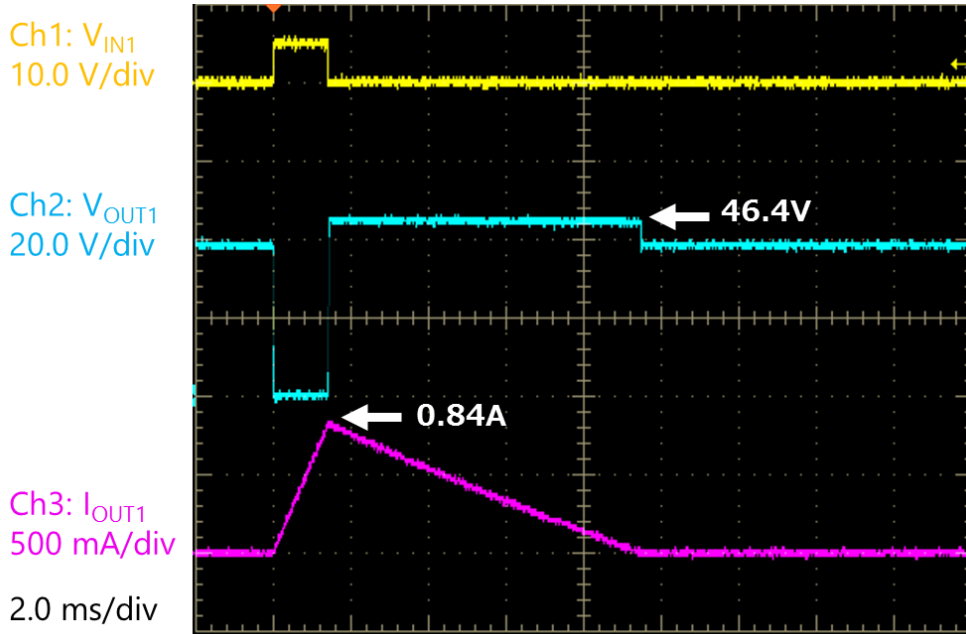


Fig. 5.7 Active clamp operation waveform

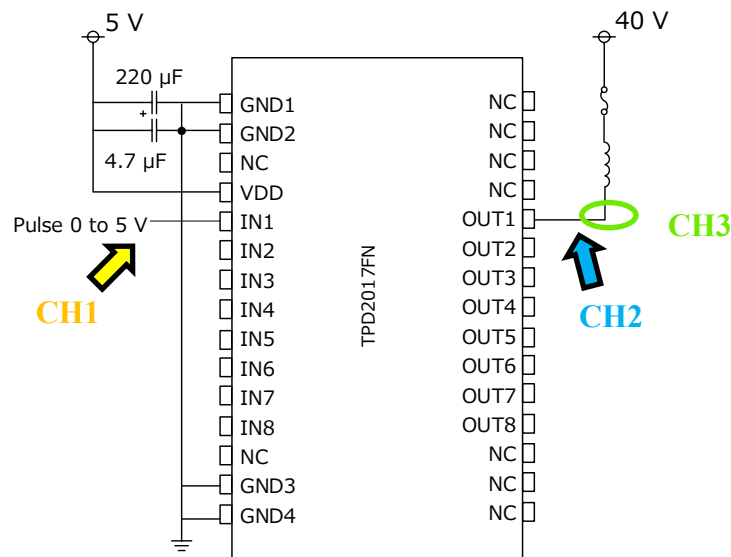


Fig. 5.8 Example of active clamp operation circuit

The following formula is used to calculate the energy during the active clamp operation. For more information on avalanche energy, please refer to our application note "Power MOSFET Max Ratings".

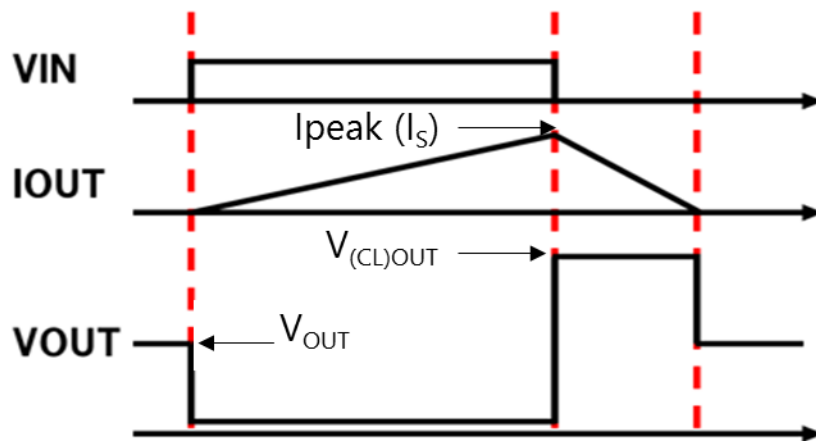


Fig. 5.9 Waveform during active clamp operation

$$E_S = \frac{1}{2} L I_S^2 \frac{V_{(CL)OUT}}{V_{(CL)OUT} - V_{OUT}} \quad (5-1)$$

$$\cong 150 \text{ mJ}$$

6. Power dissipation

The power consumed by this product can be divided into two parts: the power consumed by the transistor in the output section, and the power consumed by the logic section and the pre-driver circuit. An example of loss calculation for inductive load of this product is shown below. As shown in the breakdown of the loss in Table 6.1, the loss during the active clamp operation is very large compared to the conduction loss and switching loss. However, when using in periodic continuous operation, it is not limited to the following formula, so it is necessary to thoroughly examine beforehand.

$$P_{Logic\ loss} = I_{DD(ON)} \times V_{DD(opr)} \quad (6-1)$$

$$P_{Conduction\ loss} = I^2 \times R_{DS(ON)} \quad (6-2)$$

$$P_{Switching\ loss} = \frac{1}{6} \times V_{OUT} \times I_{load} \times (t_{ON} + t_{OFF}) \times f_{pwm} \quad (6-3)$$

$$P_{Active\ clamp\ loss} = 0.473 \times V_{(CL)OUT} \times I_{load} \times \left(\frac{t_w}{1/f_{PWM}}\right) \quad (6-4)$$

$$t_w = L \times \frac{I_{Load}}{V_{(CL)OUT} - V_{OUT}} \quad (6-5)$$

Table 6.1 Loss breakdown (V_{OUT} = 24 V, V_{DD(opr)} = 5.5 V, f_{PWM} = 50 Hz, Duty = 50 %, I_{load} = 0.48 A)

item	V (V)	V _{BR} (V)	I _{Load} (mA)	R _{DS(ON)} (Ω)	duty (%)	t _{ON} (μs)	t _{OFF} (μs)	L (mH)	f _{PWM} (Hz)	ch number	Loss (W)
A Logic loss	5.5		3.1							1	0.0171
B Conduction loss			480	0.55	50%					1	0.0634
Switching loss	24		480		50%	10	8		50	1	0.0017
Active clamp loss		45.6	480					50	50	1	0.5752
total											0.6573

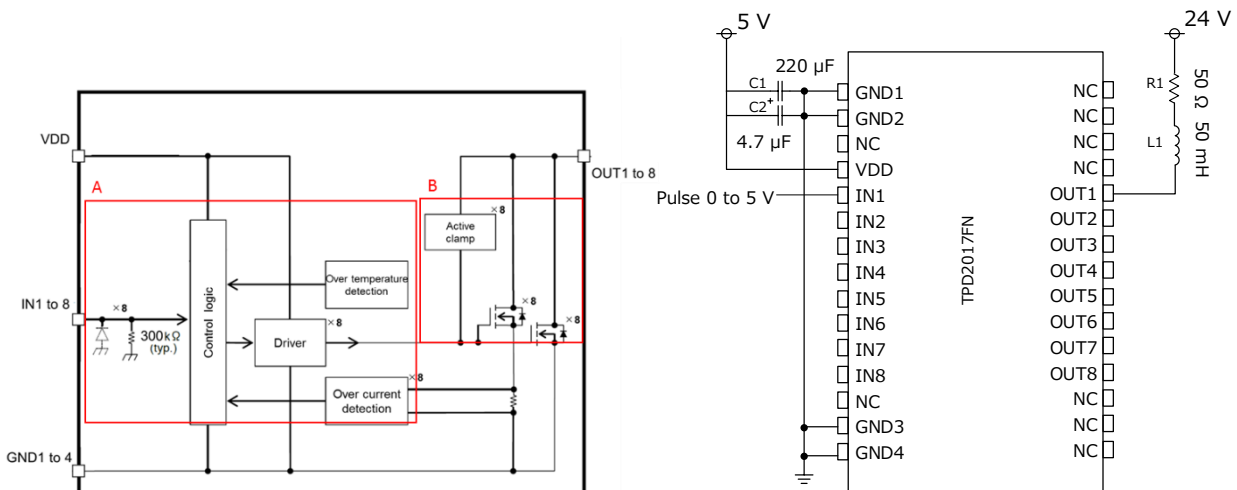


Fig. 6.1 Internal block diagram and external connection conditions example

7. Evaluation board

7.1. Appearance of evaluation board

We prepare this product and an evaluation board that mounts peripheral devices. This function allows you to check the function and the protection diagnosis function at the actual load.

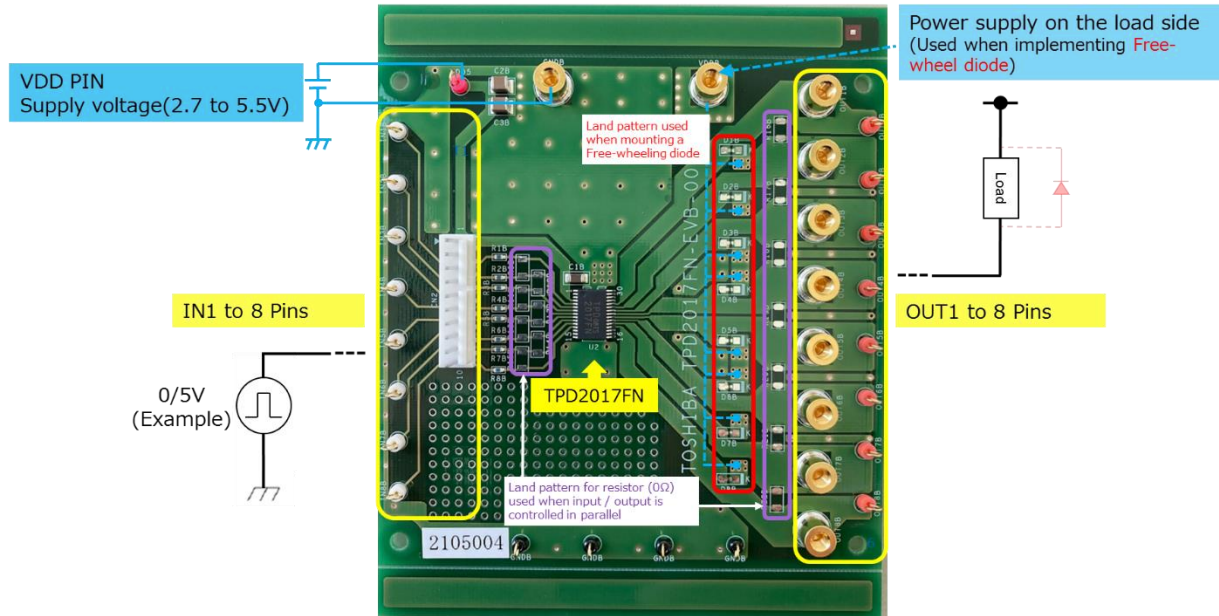


Fig. 7.1 External View of TPD2017FN evaluation board

7.2. Circuit diagrams

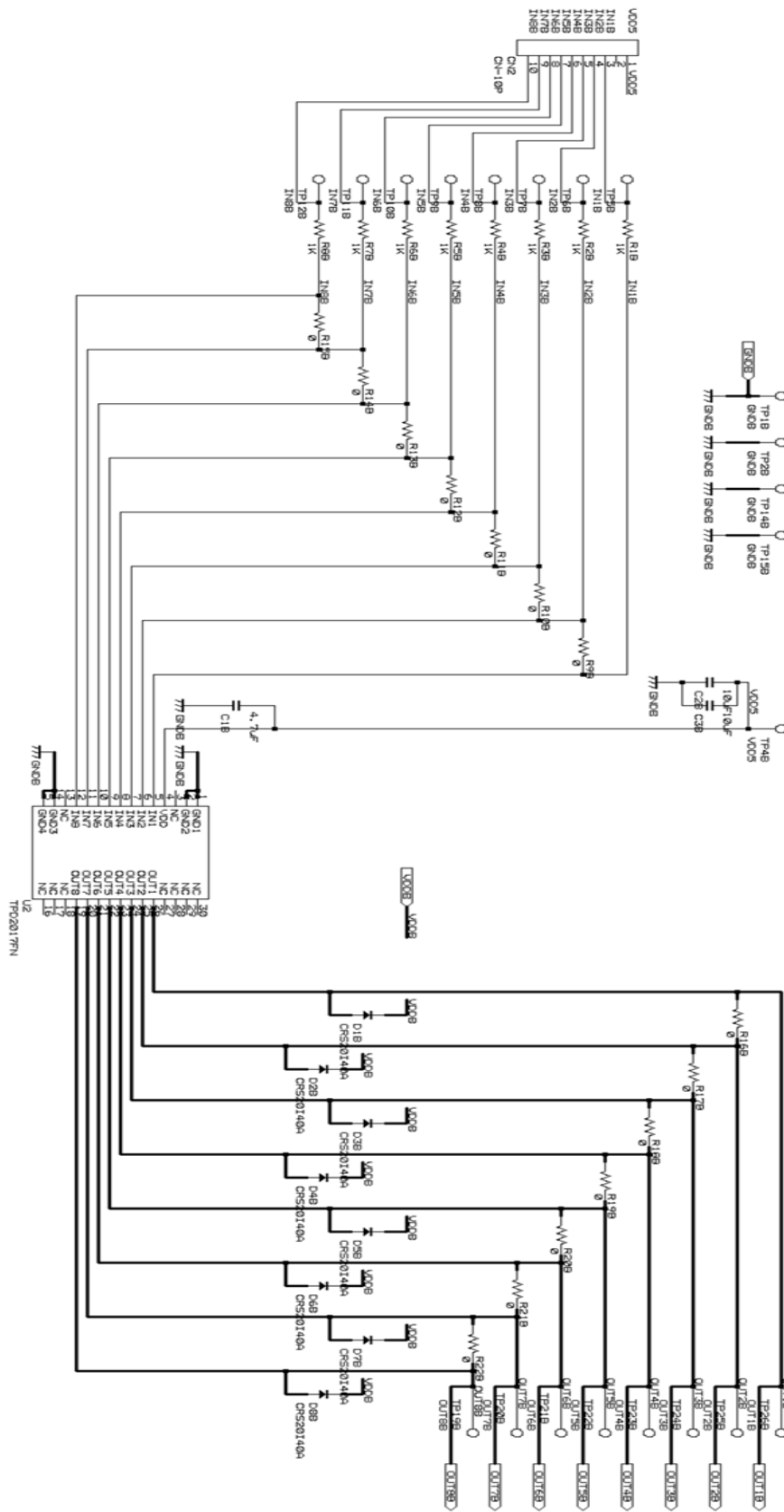


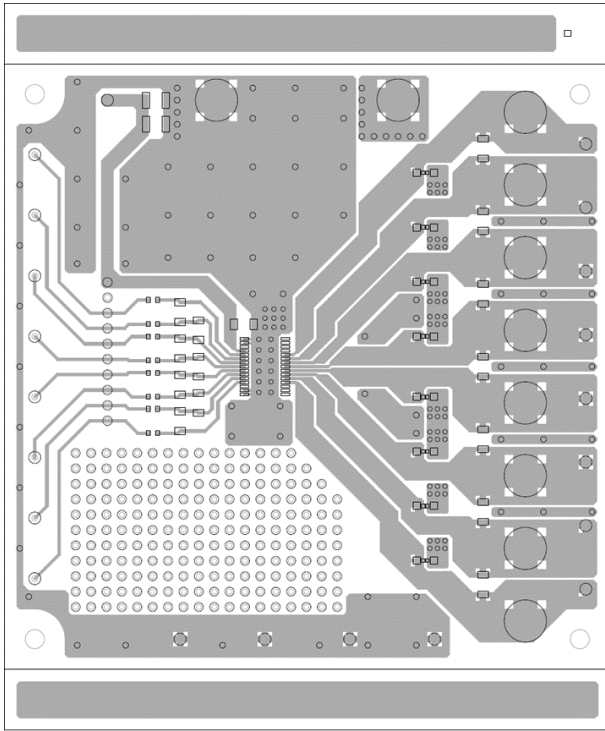
Fig. 7.2 TPD2017FN evaluation board circuit

7.3. Bill of materials

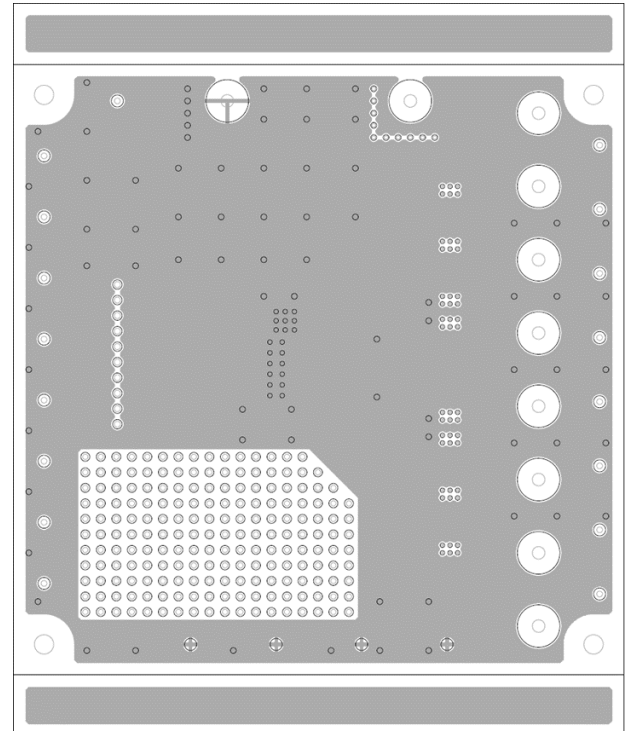
Table 7.1 BOM list

Parts number	Parts	Model number / Norm	Spec1	Spec2	Maker
U2	IPD	TPD2017FN	-	-	TOSHIBA
R1B to R8B	Chip resistance	RK3H1JTDD1001F	1kΩ	0.125W, ±1%	KOA
C1B	Ceramic capacitors	GRM31CR71H475KA12L	4.7μF / 50V	±10%, X7R	Murata
C2B, C3B	Ceramic capacitors	GRM32ER71H106KA12L	10μF / 50V	±10%, X7R	Murata
CN2	10-pole 1-row connector	22-23-2101	-	-	molex
-	Terminal	PB-1G	-	-	MAC8
TP1B, TP2B, TP14B, TP15B, TP4B, TP5B to TP12B, TP19B to TP26B	Monitor pin		-	-	MAC8

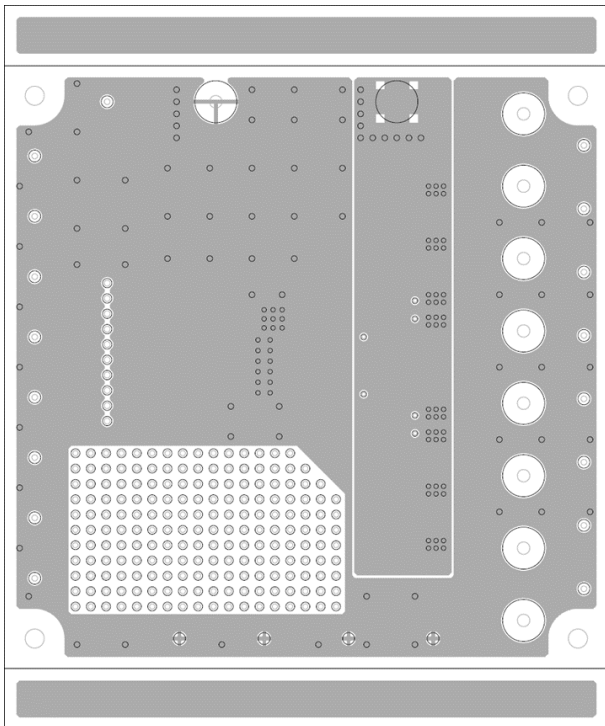
7.4. Board layout



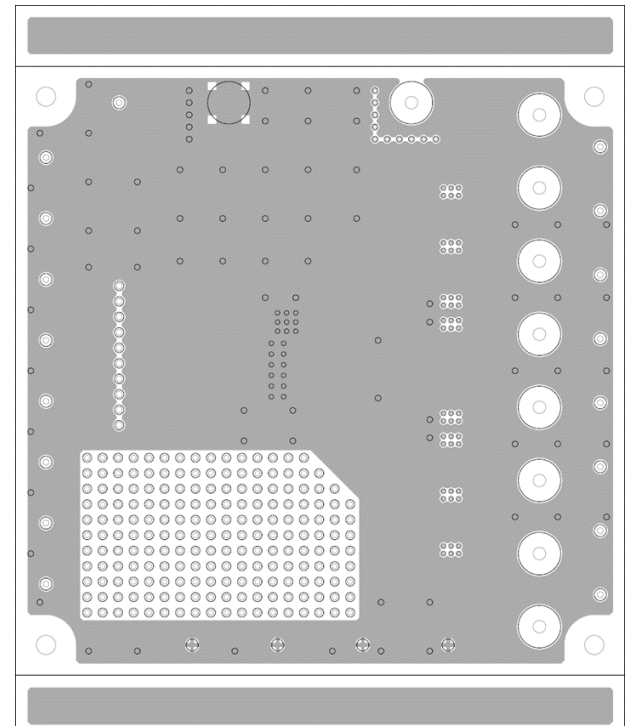
1st layer



2nd layer



3rd layer



4th layer

Fig. 7.3 TPD2017FN evaluation board layout diagram

Points to note in the description**1. Block diagram**

Function blocks, circuits, constants, etc. in the block diagram are partially omitted or simplified for explanation of functions.

2. Equivalent circuit

The equivalent circuit may be partially omitted or simplified for explanation of the circuit.

IC usage consideration**Notes on handing of ICs**

- (1) The absolute maximum ratings of a semiconductor device are a set of ratings that must not be exceeded, even for a moment.

- (2) Use an appropriate power supply fuse to prevent large currents from continuing to flow in the event of an overcurrent or malfunction of the IC. The IC may be damaged due to use exceeding the absolute maximum ratings, incorrect wiring, or abnormal pulse noise induced by wiring or load. As a result, if a large current continues to flow through the IC, it may lead to smoking or ignition. Appropriate settings such as fuse capacity, blowing time, and insertion circuit position are required in order to minimize the effect of large current inflow and outflow during breakage.

Precautions for use**(1) Over-current protection circuit**

The overcurrent protection circuit does not protect the IC in any case. After operation, promptly reset the overcurrent state.

If the absolute maximum rating is exceeded, the IC may be damaged or the over-current limit circuit may not operate properly or may be damaged before operation. In addition, if an overcurrent continues to flow for a long time after operation, the IC may be damaged due to heat generation, etc., depending on the use method and conditions.

(2) Thermal protection circuits

An over temperature protection circuit (usually a thermal shutdown circuit) does not protect the IC in any case. After operation, promptly reset the heating condition.

If the IC is used outside of the absolute maximum ratings, the over temperature protection circuit may not operate properly or the IC may be damaged before operation, depending on the usage and conditions.

RESTRICTIONS ON PRODUCT USE

Toshiba Corporation and its subsidiaries and affiliates are collectively referred to as "TOSHIBA". Hardware, software and systems described in this document are collectively referred to as "Product".

- TOSHIBA reserves the right to make changes to the information in this document and related Product without notice.
- This document and any information herein may not be reproduced without prior written permission from TOSHIBA. Even with TOSHIBA's written permission, reproduction is permissible only if reproduction is without alteration/omission.
- Though TOSHIBA works continually to improve Product's quality and reliability, Product can malfunction or fail. Customers are responsible for complying with safety standards and for providing adequate designs and safeguards for their hardware, software and systems which minimize risk and avoid situations in which a malfunction or failure of Product could cause loss of human life, bodily injury or damage to property, including data loss or corruption. Before customers use the Product, create designs including the Product, or incorporate the Product into their own applications, customers must also refer to and comply with (a) the latest versions of all relevant TOSHIBA information, including without limitation, this document, the specifications, the data sheets and application notes for Product and the precautions and conditions set forth in the "TOSHIBA Semiconductor Reliability Handbook" and (b) the instructions for the application with which the Product will be used with or for. Customers are solely responsible for all aspects of their own product design or applications, including but not limited to (a) determining the appropriateness of the use of this Product in such design or applications; (b) evaluating and determining the applicability of any information contained in this document, or in charts, diagrams, programs, algorithms, sample application circuits, or any other referenced documents; and (c) validating all operating parameters for such designs and applications. **TOSHIBA ASSUMES NO LIABILITY FOR CUSTOMERS' PRODUCT DESIGN OR APPLICATIONS.**
- **PRODUCT IS NEITHER INTENDED NOR WARRANTED FOR USE IN EQUIPMENTS OR SYSTEMS THAT REQUIRE EXTRAORDINARILY HIGH LEVELS OF QUALITY AND/OR RELIABILITY, AND/OR A MALFUNCTION OR FAILURE OF WHICH MAY CAUSE LOSS OF HUMAN LIFE, BODILY INJURY, SERIOUS PROPERTY DAMAGE AND/OR SERIOUS PUBLIC IMPACT ("UNINTENDED USE").** Except for specific applications as expressly stated in this document, Unintended Use includes, without limitation, equipment used in nuclear facilities, equipment used in the aerospace industry, lifesaving and/or life supporting medical equipment, equipment used for automobiles, trains, ships and other transportation, traffic signaling equipment, equipment used to control combustions or explosions, safety devices, elevators and escalators, and devices related to power plant. **IF YOU USE PRODUCT FOR UNINTENDED USE, TOSHIBA ASSUMES NO LIABILITY FOR PRODUCT.** For details, please contact your TOSHIBA sales representative or contact us via our website.
- Do not disassemble, analyze, reverse-engineer, alter, modify, translate or copy Product, whether in whole or in part.
- Product shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable laws or regulations.
- The information contained herein is presented only as guidance for Product use. No responsibility is assumed by TOSHIBA for any infringement of patents or any other intellectual property rights of third parties that may result from the use of Product. No license to any intellectual property right is granted by this document, whether express or implied, by estoppel or otherwise.
- **ABSENT A WRITTEN SIGNED AGREEMENT, EXCEPT AS PROVIDED IN THE RELEVANT TERMS AND CONDITIONS OF SALE FOR PRODUCT, AND TO THE MAXIMUM EXTENT ALLOWABLE BY LAW, TOSHIBA (1) ASSUMES NO LIABILITY WHATSOEVER, INCLUDING WITHOUT LIMITATION, INDIRECT, CONSEQUENTIAL, SPECIAL, OR INCIDENTAL DAMAGES OR LOSS, INCLUDING WITHOUT LIMITATION, LOSS OF PROFITS, LOSS OF OPPORTUNITIES, BUSINESS INTERRUPTION AND LOSS OF DATA, AND (2) DISCLAIMS ANY AND ALL EXPRESS OR IMPLIED WARRANTIES AND CONDITIONS RELATED TO SALE, USE OF PRODUCT, OR INFORMATION, INCLUDING WARRANTIES OR CONDITIONS OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, ACCURACY OF INFORMATION, OR NONINFRINGEMENT.**
- Do not use or otherwise make available Product or related software or technology for any military purposes, including without limitation, for the design, development, use, stockpiling or manufacturing of nuclear, chemical, or biological weapons or missile technology products (mass destruction weapons). Product and related software and technology may be controlled under the applicable export laws and regulations including, without limitation, the Japanese Foreign Exchange and Foreign Trade Law and the U.S. Export Administration Regulations. Export and re-export of Product or related software or technology are strictly prohibited except in compliance with all applicable export laws and regulations.
- Please contact your TOSHIBA sales representative for details as to environmental matters such as the RoHS compatibility of Product. Please use Product in compliance with all applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive. **TOSHIBA ASSUMES NO LIABILITY FOR DAMAGES OR LOSSES OCCURRING AS A RESULT OF NONCOMPLIANCE WITH APPLICABLE LAWS AND REGULATIONS.**

Toshiba Electronic Devices & Storage Corporation

<https://toshiba.semicon-storage.com/>