MOSFET Driver IC
Application and Circuit of the TCK402G

Reference Guide

RD003-RGUIDE-02

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION

Table of Contents

1. Overview

The TCK402G driver IC can drive two N-channel MOSFETs which has back-to-back connection and contribution high-current bidirectional switch designed to enable rapid charging of host and client devices specified by the USB Power Delivery (USB PD) Specification.

Using low-on-resistance N-channel MOSFETs, the TCK402G allows a bidirectional switch to be configured minimum power dissipation and heat generation. The USB PD Specification requires not only high charging voltage but also high charging current to reduce the charging time. The TCK402G operates wide input voltage range from 2.7V to 28V so the maximum 20V input can be applied specified by USB PD. Also the slew rate control driver contributes avoiding unexpected inrush current during switching transitions in order to protect next stage electronic circuits. In addition the auto output discharge function at switch-off feature can be used for applications requiring stringent power management without any concern about time lag between a switch-off signal and the output voltage reaching to zero. This reference guide focuses on the slew rate control and the auto output discharge function of the TCK402G.

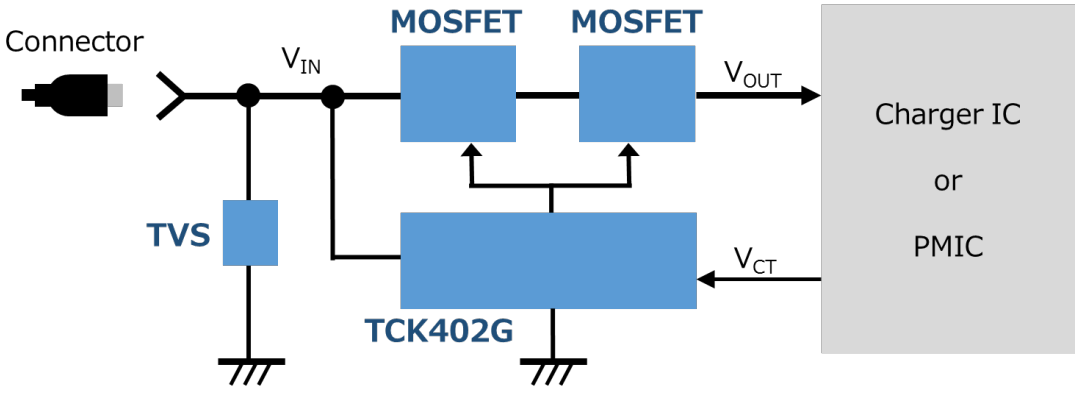
For details of other features and functions of the TCK402G, see the datasheet.

To download the datasheet for the TCK402G → Click Here

1.1. Target applications

- Power management for battery charger and other applications
- Charging circuits for devices with a USB connector

Circuit example



* Toshiba offers a portfolio of MOSFETs which suit these applications.

  For details of MOSFETs → Click Here

* Toshiba offers TVS diodes which suit charger and other high-current applications.

  For details of TVS diodes → Click Here

2. Application circuit example and its bill of materials

2.1. Application circuit example

Figure 2.1.1 shows an example of an application circuit using the TCK402G MOSFET driver IC.

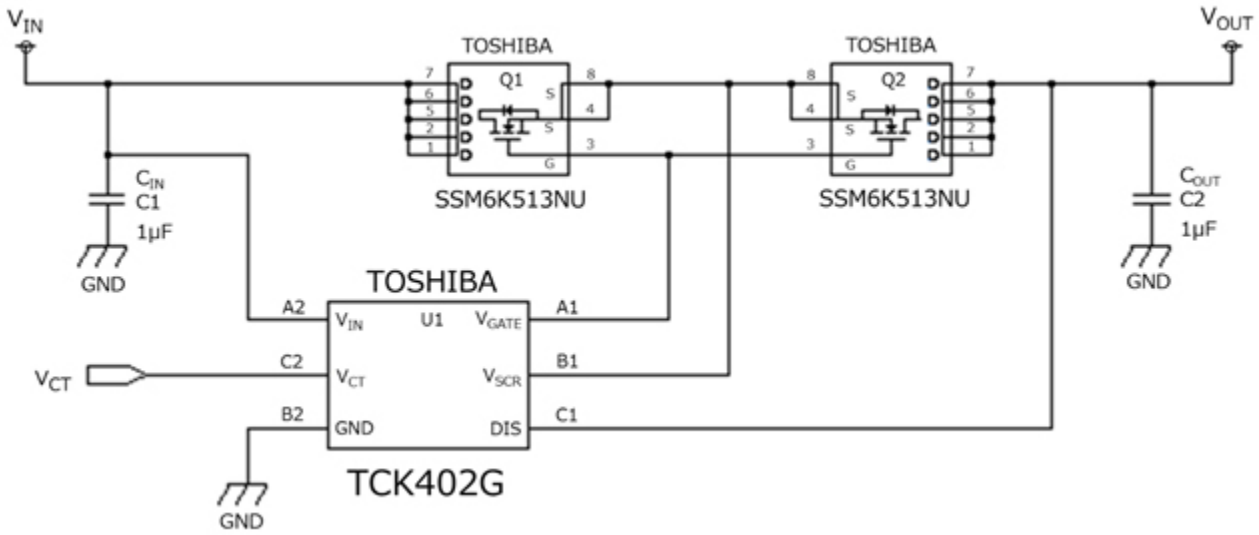


Figure 2.1.1 Application circuit example for the TCK402G MOSFET driver IC

2.2. Bill of materials

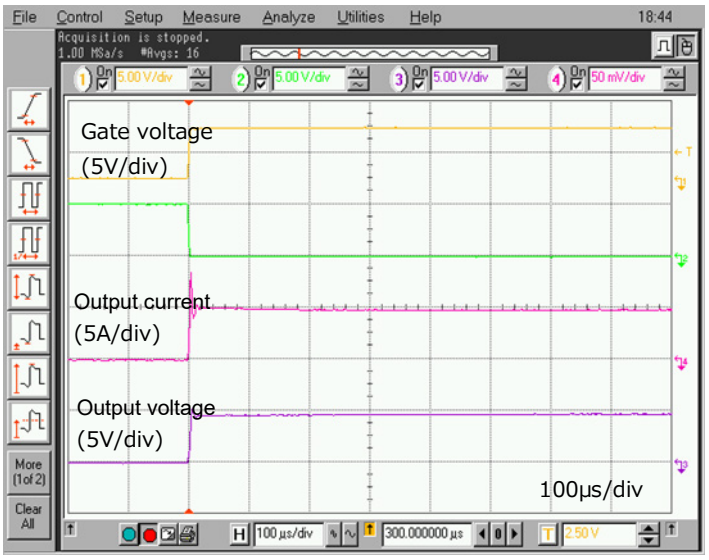
Table 2.2.1 Bill of materials

No.	Ref.	Qty	Value	Part Number	Manufacturer	Description	Packaging	Typical Dimensions mm (inches)
1	C1, C2	2	1 µF	—	—	Ceramic, 50 V, ±10%	—	3.2 x 1.6 (1206)
2	Q1, Q2	2	-	SSM6K513NU	TOSHIBA	—	UDFN6B	2.0 x 2.0
3	U1	1	-	TCK402G	TOSHIBA	—	WCSP6E	1.2 x 0.8

3. Major features

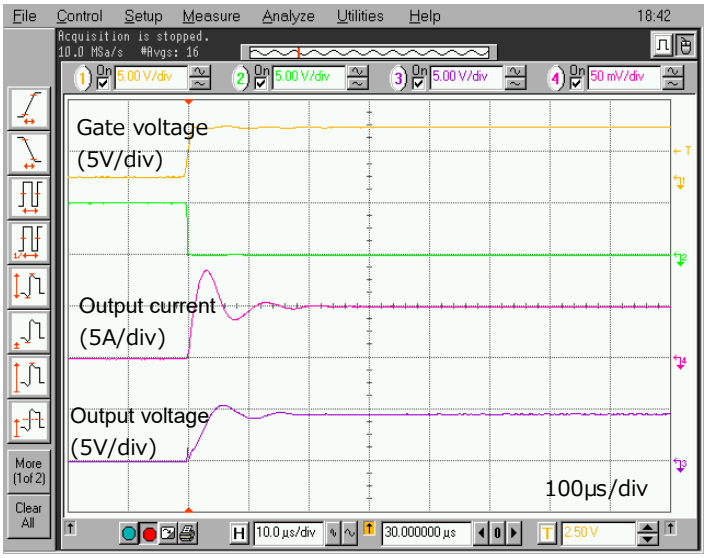
3.1. Slew rate control

Figure 3.1.1 shows the switch-on waveforms of a load switch with discrete solution having only back-to-back MOSFETs. For this evaluation, a 4.7μF output capacitor was used. The peak output current reached 7 to 8A when the load current was set to 5A. The load might be broken or damaged by the peak current, depending on a type of load. In addition, the ringing caused by the peak current might generate electromagnetic interference (EMI) that affects bad impact to electronic circuits. So it is necessary to suppress inrush current during switch-on transitions. Figure 3.1.2 shows an enlarged view of the ringing waveforms.



Test conditions:
Input voltage = 5V
Gate voltage = 0 ⇔ 5V
Output current = 5A
C_{OUT}=4.7μF

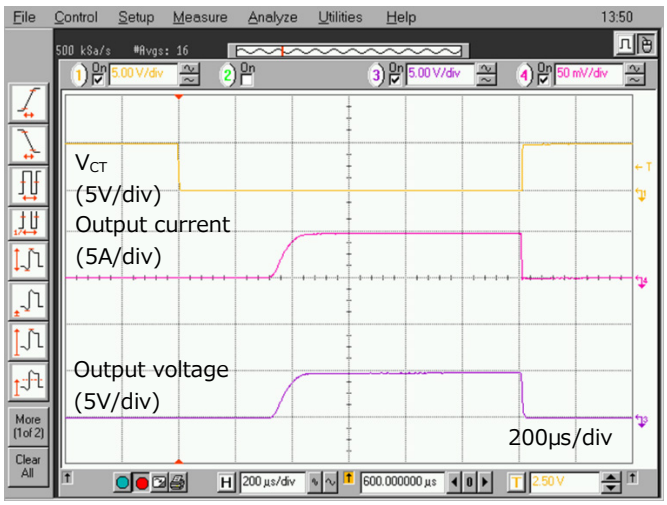
Figure 3.1.1 Example of waveforms of a load switch with discrete solution



Test conditions:
Input voltage = 5V
Gate voltage = 0 ⇔ 5V
Output current = 5A
C_{OUT} = 4.7μF

Figure 3.1.2 Example of waveforms of a load switch with discrete solution (enlarged view)

The TCK402G has slew rate control circuit which limits inrush current during switch-on transitions. Figure 3.1.3 shows an example of switching waveforms of back-to-back MOSFETs using TCK402G.



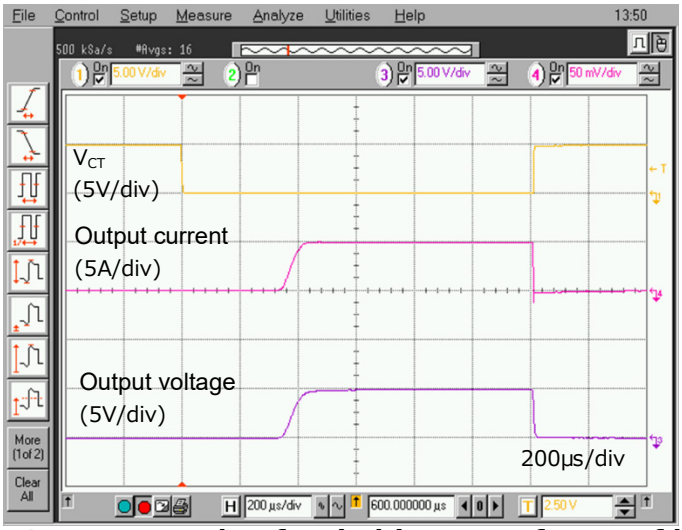
Test conditions:
- V_{IN} = 5V
- V_{CT} = 0 ⇔ 5V
- Output current = 5A
- C_{OUT} = 4.7µF
- T_a = 25°C

Figure 3.1.3 Example of switching waveforms of back-to-back MOSFETs with TCK402G

As shown in Figure 3.1.3, reducing the rising slew rate helps suppress inrush current and reduce ringing and EMI.

Note that delay time may happens from V_{CT} signal applied to the TCK402G to activate the driver stage of the TCK402G. This delay is caused by the time required for signal processing in the TCK402G. The V_{GATE} output of the TCK402G drives the MOSFET gate inputs and the V_{GATE} ON time (t_{ON}) is specified in the datasheet. Note that in actual circuit, ON time (t_{ON}) is not a specification that defines the switching time of external MOSFETs. In actual circuit, the turn-on time of the MOSFETs depends on their gate capacitance and threshold voltage (V_{th}). The TCK402G specifies V_{GATE} ON time (t_{ON}) at a gate capacitance of 2000 pF. The assumption comes from the TCK402G being used to drive two back-to-back MOSFETs and each gate capacitance has roughly 1000pF. When the TCK402G drives MOSFETs with lower gate capacitance, V_{GATE} ON time is less than the number in the datasheet. This means the switching time of external MOSFETs becomes faster. On the other hand, when the TCK402G drives MOSFETs with higher gate capacitance, the MOSFET switching time becomes slower because of a longer V_{GATE} ON time. When MOSFETs with a high threshold voltage (V_{th}) are used, it is recommended to use the TCK402G at an input voltage (V_{IN}) with high as possible in order to raise the V_{GATE} voltage. For a details of the specification on the V_{GATE} ON time, see Section 4, “Design considerations.”

Figure 3.1.4 and Figure 3.1.5 show examples of switching waveforms of back-to-back MOSFETs driven by the TCK402G at -40°C and 85°C.



Test conditions:

V_{IN} = 5V

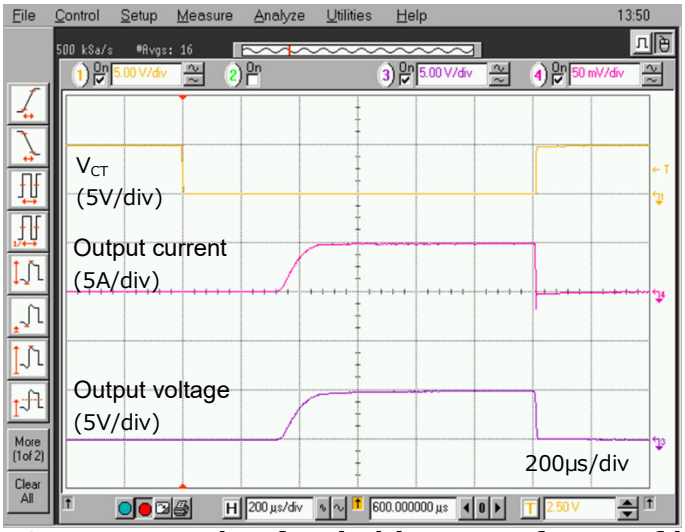
V_{CT} = 0 ⇔ 5V

Output current = 5A

C_{OUT} = 4.7µF

T_a = -40°C

Figure 3.1.4 Example of switching waveforms of back-to-back MOSFETs driven by the TCK402G (-40°C)



Test conditions:

V_{IN} = 5V

V_{CT} = 0 ⇔ 5V

Output current = 5A

C_{OUT} = 4.7µF

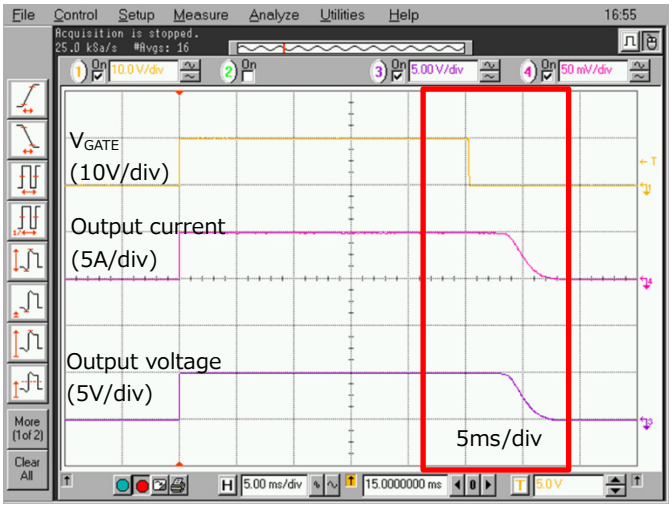
T_a = 85°C

Figure 3.1.5 Example of switching waveforms of back-to-back MOSFETs driven by the TCK402G (85℃)

3.2. Auto output discharge function

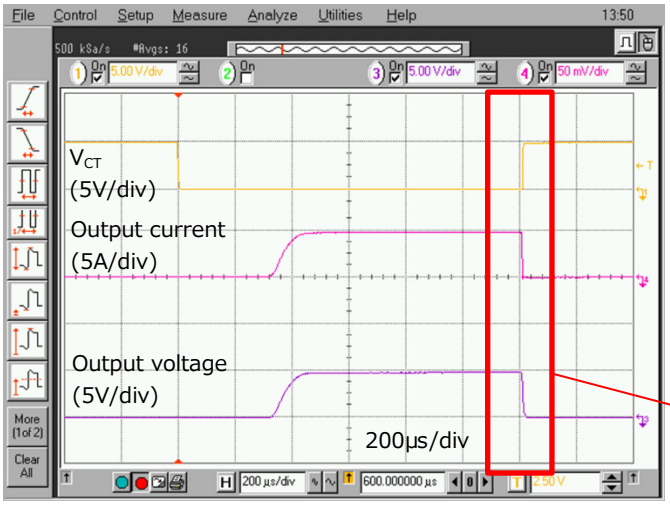
For the purpose of requiring low power consumption application, it is general that average power consumption goes down balancing total system utilization and supplying power. Especially smartphone and tablet, there is a trade-off between the size and weight of the device and their battery capacity while a high level of power management is necessary, but in the application there are various electronic circuits including wireless communication, camera, display, audio, and storage circuits, so it is necessary to control their power supplies surely. Due to the decreasing voltage and increasing clock rate of system-on-chips (SoCs) at the same time, their power consumption has been increasing today and the future so the trend of the output capacitors which for power management circuit used to stabilize the power supplies to the SoCs becomes increasing. When a system needs to shut down a power supply for a SoC, the amount of charge remaining in a large-value capacitor could be uncontrollable and cause system malfunction.

To avoid this problem, the TCK402G has the auto output discharge function, which is designed to discharge the remaining amount of charge from the output capacitors for external MOSFETs at switch-off in order to pull down quickly the output voltage to zero. If the DIS pin of the TCK402G is connected to the outputs of external N-channel MOSFETs, the TCK402G automatically discharges the remaining amount of charge from the output capacitors through the DIS pin when the V_{CT} pin is set Low to switch off the MOSFETs. The auto output discharge function requires no further adjustment or setting. Figure 3.2.1 shows an example of MOSFET switching waveforms obtained without using the TCK402G whereas Figure 3.2.2 shows waveforms obtained with the auto output discharge function of the TCK402G.



Test conditions:
- V_{IN} = 5V
- V_{GATE} = 0 ⇔ 10V
- I_{OUT} = 5A
- C_{OUT} = 4.7μF
- T_a = 25°C

Figure 3.2.1 Output waveforms without the auto output discharge function

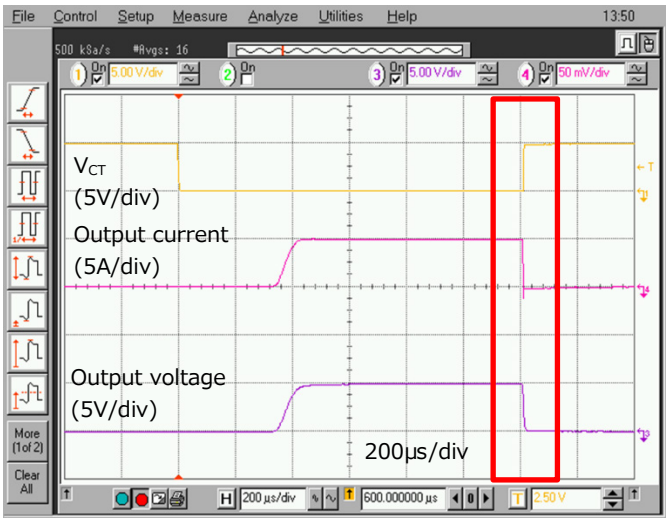


Test conditions:
V_{IN} = 5V
V_{CT} = 0 ⇔ 5V
I_{OUT} = 5A
C_{OUT} = 4.7µF
T_a = 25°C

The output drops to zero quickly.

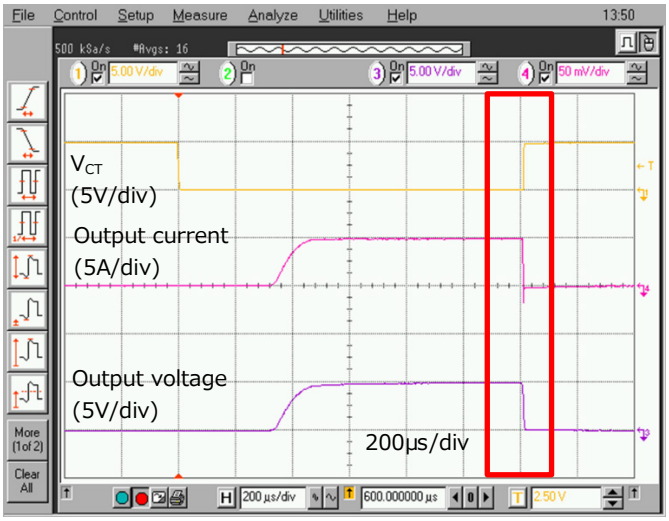
Figure 3.2.2 Output waveforms with the auto output discharge function

The auto output discharge function of the TCK402G is designed to work properly regardless of the ambient temperature. Figure 3.2.3 and Figure 3.2.4 show examples of MOSFET switching waveforms at -40°C and 85°C.



Test conditions:
V_{IN} = 5V
V_{CT} = 0 ⇔ 5V
Output current = 5A
C_{OUT} = 4.7µF
T_a = -40°C

Figure 3.2.3 Output waveforms with the auto output discharge function (-40°C)



Test conditions:

V_{IN} = 5V

V_{CT} = 0 ⇔ 5V

Output current = 5 A

C_{OUT} = 4.7µF

T_a = 85°C

Figure 3.2.4 Output waveforms with the auto output discharge function (85℃)

4. Design considerations

- Input and output capacitors

  It is recommended to add input capacitor C_{IN} (C1) and output capacitor C_{OUT} (C2) to ensure stable operation of the TCK402G. Place capacitors of at least 1.0 µF closer to the input and output pins. The tolerant voltage of these capacitors should be sufficiently higher than their operating voltage.

- V_{CT} pin

  The V_{CT} pin of the TCK402G is a Schmitt-trigger input. The V_{CT} pin is tolerant of a voltage higher than the specified control voltage.

- V_{GATE} pin

  The V_{GATE} output drives the gate inputs of external MOSFETs. When the V_{CT} input goes High, V_{GATE} output goes High with the TCK402G boosting up the voltage from V_{IN} input. The following shows the slew rate control function specification in the TCK402G datasheet.

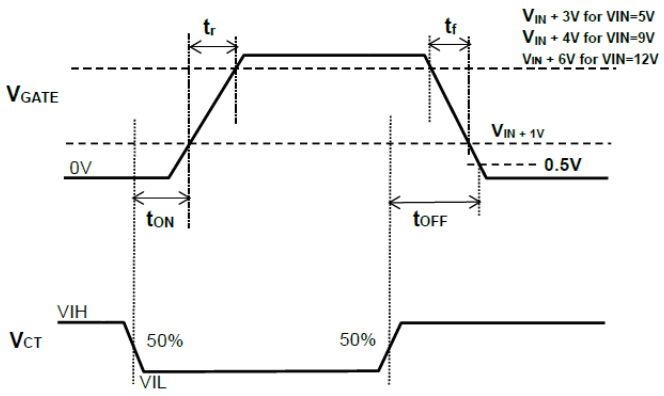


Figure 4.1 Timing charts of the V_{CT} and V_{GATE} (excerpt from the TCK402G datasheet)

Figure 4.1 shows the timing chart of the V_{CT} and V_{GATE} pins. The V_{GATE} ON time (t_{ON}) shown in the AC Characteristics table in the datasheet is the time required from the 50% point of V_{CT} rise edge when the V_{GATE} voltage reaches V_{IN}+1V. The slew rate control circuit maintains the slope of the V_{GATE} output. Therefore, the higher the V_{IN} voltage, the longer the V_{GATE} ON time (t_{ON}). The V_{GATE} OFF time (t_{OFF}) shown in the AC Characteristics table in the datasheet is the time required from the 50% point of V_{CT} fall edge when the V_{GATE} voltage reaches 0.5V.

- V_{SRC} pin

  In the circuit which the TCK402G drives two MOSFETs, the V_{SRC} pin has internal MOSFET and make short-circuits to the V_{GATE} output through the source of the MOSFETs when the TCK402G turns off. The V_{SRC} pin may be left open if the MOSFET gate-source voltage (V_{GS}) has enough margin. In cases of the TCK402G driveing only one MOSFET, the V_{SRC} pin may also be left open if the MOSFET gate-source voltage (V_{GS}) has enough margin. It is recommended to connect V_{SRC} to V_{OUT} if V_{GS} does not have an enough margin.

- DIS pin

  Connect the DIS pin to V_{OUT} if automatic output discharge is necessary when the TCK402G turns off. Otherwise, the DIS pin may be left open.

- Overvoltage protection “off” time (t_{OVP})

  Overvoltage lockout (OVLO) trips to turn off V_{GATE} when V_{IN} exceeds the maximum value of V_{in_opr}. The OVLO “off” time (t_{OVP}) is equal to the V_{GATE} OFF time (t_{OFF}).

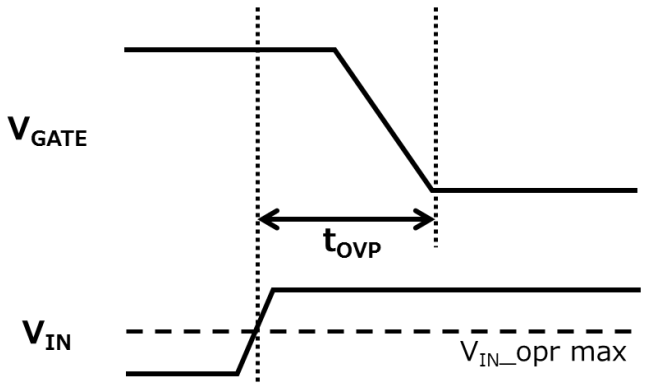


Figure 4.2 T_{OVP} timing chart

- Undervoltage lockout (UVLO) circuit

  Undervoltage lockout (UVLO) trips to turn off V_{GATE} when V_{IN} drops below the minimum value of V_{in_opr}.

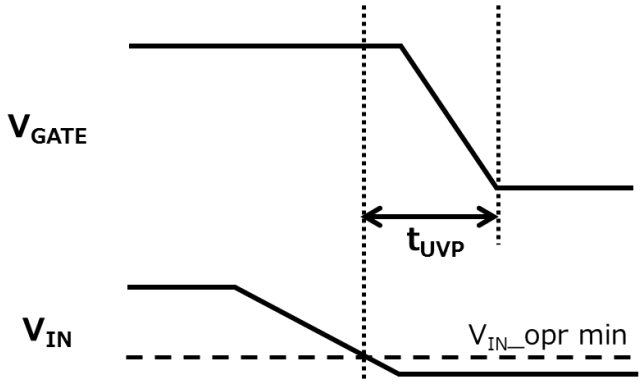


Figure 4.3 UVLO timing chart

5. Product overview

5.1. TCK402G

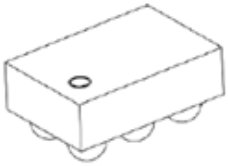
5.1.1 Overview

The TCK402G MOSFET driver IC operates over a wide input voltage range of up to 28V.

- MOSFET driver IC in a small package
- High maximum input voltage: V_{IN} (max) = 40V
- Wide input voltage range: V_{IN} = 2.7 to 28V
- Auto output discharge function
- Charge pump for V_{GATE}
- Inrush current reduction circuit
- Overvoltage lockout (≥28V)
- Undervoltage lockout (≤2.7V)
- Protection against reverse current from external back-to-back MOSFETs
- Package: WCSP6E (0.8 mm x 1.2 mm x 0.55 mm)

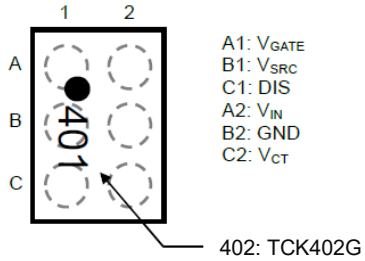
5.1.2. External view and pin assignment

External view and marking

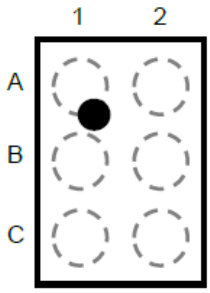


Bottom View

Marking (top view)



Pin assignment (Top view)



Pin #	Name	Pin #	Name
A1	V_{GATE}	A2	V_{IN}
B1	V_{SRC}	B2	GND
C1	DIS	C2	V_{CT}

Figure 5.1.1 External view, marking, and pin assignment of the TCK402G

5.1.3 Internal block diagram

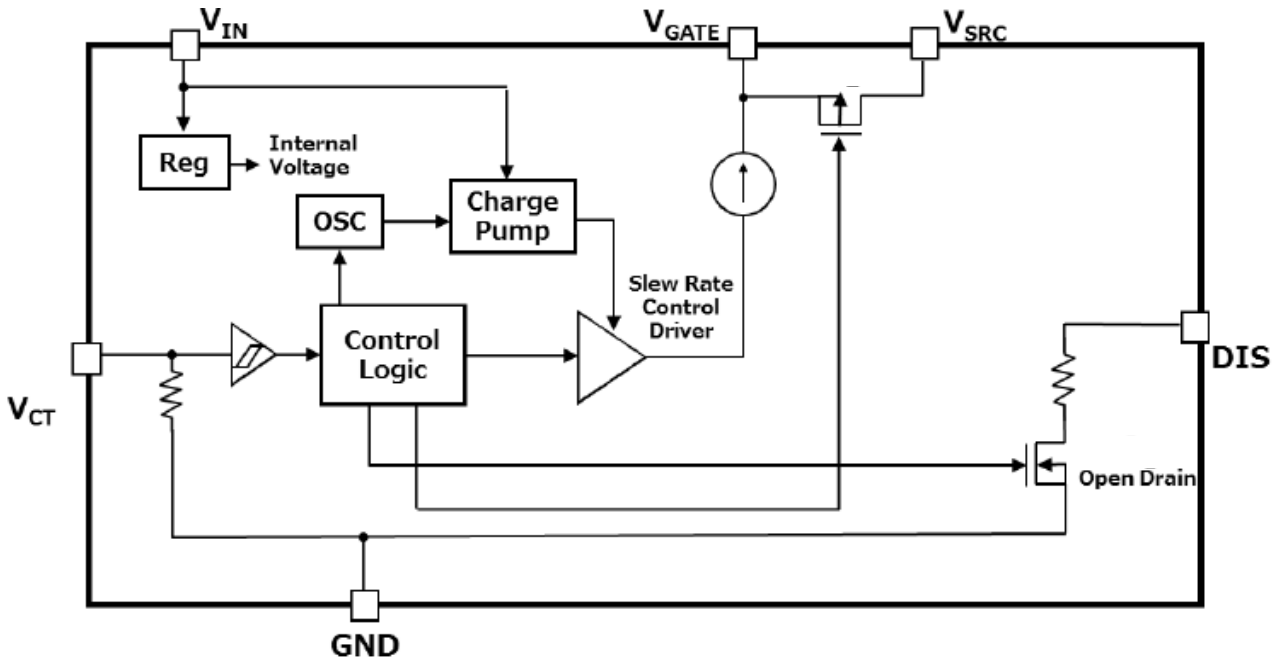


Figure 5.1.2 Internal block diagram of the TCK402G

5.1.4 Pin description

Table 5.1.1 Pins of the TCK402G

Pin	Name	Description
A1	V_{GATE}	Gate driver output
A2	V_{IN}	Supply voltage
B1	V_{SRC}	It is recommended to connect the V_{SRC} output to the common source of external MOSFETs.
B2	GND	Ground
C1	DIS	Output discharge pin
C2	V_{CT}	Mode Control pin External MOSFETs turn on when V_{CT} = Low and turn off when V_{CT} = High.

5.2. SSM6K513NU

5.2.1 Overview

The SSM6K513NU is a silicon N-channel MOSFET for power management switch applications.

- High drain-source breakdown voltage: $V_{(BR)DSS}$ = 30 V(min)

  $R_{DS(ON)}$ = 8.0 mΩ (typical) (@V_{GS} = 4.5V)

  $R_{DS(ON)}$ = 6.5mΩ (typical) (@V_{GS} = 10V)

5.2.2. External view and pin assignment

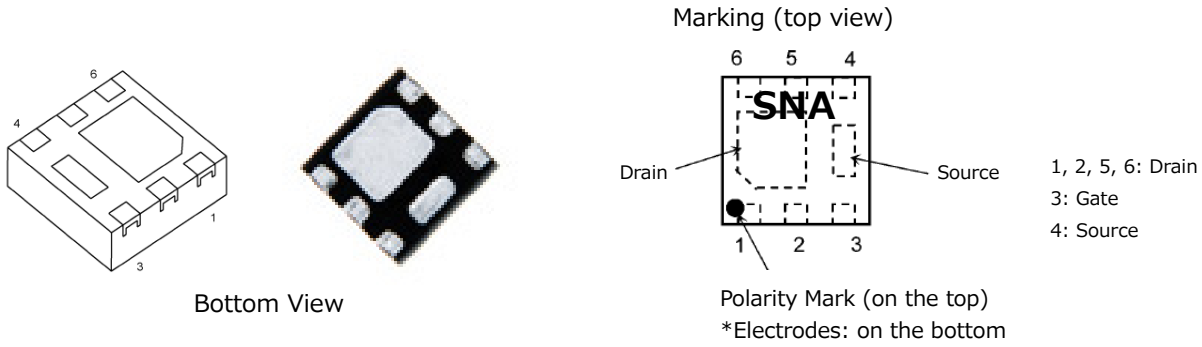


Figure 5.2.1 External view, marking, and pin assignment of the SSM6K513NU

5.2.3 Internal block diagram

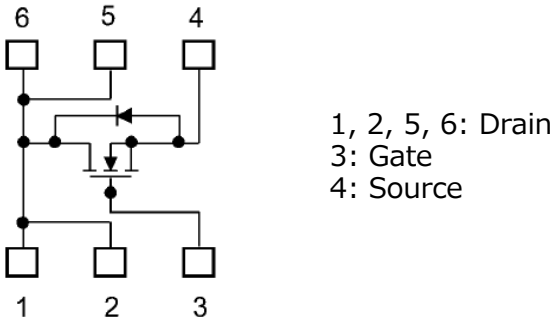


Figure 5.2.2 Internal block diagram of the SSM6K513NU

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