Load Switch
Application and Operation of the TCK301G, TCK302G, and TCK303G

Reference Guide

TOSHIBA ELECTRONIC DEVICES & STORAGE CORPORATION
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1. Overview

Fabricated using a high-voltage CMOS process, the TCK301G, TCK302G, and TCK303G load switches operate with an input voltage of up to 28V. These load switches provide inrush current limiting, thermal shutdown, overvoltage lockout, undervoltage lockout, and a flag output signal.

These features make the TCK301G, TCK302G, and TCK303G suitable rapid charging, which is nowadays considered important for applications powered by lithium-ion and other rechargeable batteries, as well as for high-current, high-voltage power management required for systems incorporating power-saving features.

Among the many features of the TCK301G, TCK302G, and TCK303G, this reference guide focuses on their operation and application of the slew rate control circuitry designed for inrush current limiting that is crucial for high-current switching applications.

For detail of the other protection features and other details of the TCK301G, TCK302G, and TCK303G, see their datasheet.

To download the datasheet for the TCK301G, TCK302G and TCK303G → [Click Here]

1.1. Target applications

- Main switches of USB PD-enabled rapid-charging circuits for electronic devices with USB Type-C™ ports
- Main switches of 5 to 12V power supply input circuits that support various modes of rapid charging and wireless power transfer
- Switches for the power management of systems requiring power-saving modes

Circuit example: Main switch of a rapid-charging circuit

* Toshiba offers TVS diodes for charger and other high-current applications. For details of TVS diodes → [Click Here]
2. Application circuit example and bill of materials

2.1. Application circuit example

Figure 2.1.1 shows an example of an application circuit for the TCK301G, TCK302G, and TCK303G.

![Application circuit diagram](image)

Figure 2.1.1 Application circuit for the TCK301G, TCK302G, and TCK303G

2.2. Bill of materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Ref.</th>
<th>Qty</th>
<th>Value</th>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Packaging</th>
<th>Typical Dimensions mm (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IC1</td>
<td>1</td>
<td>—</td>
<td>TCK301G</td>
<td>TOSHIBA</td>
<td>Load Switch IC</td>
<td>WCSP9</td>
<td>1.5 x 1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TCK302G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TCK303G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>R1</td>
<td>1</td>
<td>10kΩ</td>
<td></td>
<td>Carbon, ±5%</td>
<td></td>
<td>—</td>
<td>1.0 x 0.5 (0402)</td>
</tr>
<tr>
<td>3</td>
<td>C1</td>
<td>1</td>
<td>1μF</td>
<td>Ceramic, 50V, ±10%</td>
<td></td>
<td></td>
<td>—</td>
<td>3.2 x 1.6 (1206)</td>
</tr>
<tr>
<td>4</td>
<td>C2</td>
<td>1</td>
<td>1μF</td>
<td>Ceramic, 50V, ±10%</td>
<td></td>
<td></td>
<td>—</td>
<td>3.2 x 1.6 (1206)</td>
</tr>
</tbody>
</table>
3. Inrush current limiting

The TCK301G, TCK302G, and TCK303G incorporate a slew rate control driver (i.e., a slow starter circuit) designed to limit inrush current during switching transitions. In cases where a power management IC supplies power to multiple lines, a system might experience an overall shutdown or failure if inrush current momentarily exceeds the current limit of the power management IC during its switching transitions. A similar situation might also occur in the load circuit. To prevent a system shutdown or failure, it is necessary to limit the inrush current. Figure 3.1 illustrates the output voltage ($V_{OUT}$) and output current ($I_{OUT}$) waveforms from circuits with and without a slew rate control driver.

Figure 3.1 Output voltage ($V_{OUT}$) and output current ($I_{OUT}$) waveforms from circuits with and without a slew rate control driver

The $V_{OUT}$ rise time and the transient inrush current depend on the slow starter circuit that is determined by the time constant of the internal driver circuit, as well as capacitance ($C_L$) and equivalent resistance ($R_L$). Figure 3.2 shows an example of the $V_{OUT}$ and $I_{OUT}$ waveforms measured under typical test conditions.

Figure 3.2 $V_{OUT}$ and $I_{OUT}$ waveforms of the TCK303G (under typical test conditions)

Test conditions:
- $V_{IN} = 3.8V$
- $CE = Open$
- $V_{CT} = 0 \Rightarrow 3.8V$
- $Ta = 25^\circ C$
- $R_L = 50\Omega$
- $C_L = 1\mu F$
- $C_{IN} = 1\mu F$

$tr = 1.84 \text{ ms (10\% to 90\%)}$
Figure 3.3 and Figure 3.4 show examples of $V_{\text{OUT}}$ and $I_{\text{OUT}}$ waveforms measured at the maximum and minimum operating ambient temperatures specified in the datasheet. Figure 3.3 shows the waveforms at 85°C while Figure 3.4 shows the waveforms at -40°C.

**Figure 3.3 $V_{\text{OUT}}$ and $I_{\text{OUT}}$ waveforms of the TCK303G (at 85°C ambient temperature; otherwise, under typical test conditions)**

**Figure 3.4 $V_{\text{OUT}}$ and $I_{\text{OUT}}$ waveforms of the TCK303G (at -40°C ambient temperature; otherwise, under typical test conditions)**
Figure 3.5 and Figure 3.6 show examples of $V_{OUT}$ and $I_{OUT}$ waveforms measured with different capacitances ($C_L$). A larger $C_L$ causes the charge current to increase, resulting in a faster $V_{OUT}$ rise time and higher $I_{OUT}$, compared with the case of a typical $C_L$. The TCK301G, TCK302G, and TCK303G incorporate a slow starter circuit, which causes the output current to change slowly in order to suppress inrush current. Due to the slow starter circuit, the $V_{OUT}$ waveforms with $C_L$ values of 2.2μF and 4.7μF shown in Figure 3.5 and Figure 3.6 are stable and do not differ significantly from the waveform with a typical $C_L$ value of 1μF shown in Figure 3.2.

Figure 3.5 $V_{OUT}$ and $I_{OUT}$ waveforms of the TCK303G ($C_L$=2.2μF; otherwise, under typical test conditions)

Test conditions:
$V_{IN} = 3.8V$,  
$CE = Open$,  
$V_{CT} = 0 \leftrightarrow 3.8V$,  
$T_a = 25^\circ C$,  
$R_L = 50\Omega$,  
$C_L = 2.2\mu F$,  
$C_{IN} = 1\mu F$

Test conditions:
$V_{IN} = 3.8V$,  
$CE = Open$,  
$V_{CT} = 0 \leftrightarrow 3.8V$,  
$T_a = 25^\circ C$,  
$R_L = 50\Omega$,  
$C_L = 2.2\mu F$,  
$C_{IN} = 1\mu F$

Figure 3.6 $V_{OUT}$ and $I_{OUT}$ waveforms of the TCK303G ($C_L$=4.7μF; otherwise, under typical test conditions)
4. Design considerations

- **External capacitors**
  Add external input and output capacitors at least 1μF to achieve the guaranteed performance and improve the stability of a power supply.

- **Board assembly**
  Provide as large a GND plane as possible to reduce wire impedance. Voltage overshoot and undershoot may happen depending on transient responses of the input and output voltage and current, a PCB layout, and internal parasitic of an IC.

- **Reverse-current blocking**
  The TCK301G, TCK302G, and TCK303G have a reverse-current blocking circuit. While the n-channel output MOSFET is off and the input voltage ($V_{IN}$) is within the operating range, the reverse-current blocking circuit constantly monitors the output voltage ($V_{OUT}$) and prevents a current from flowing from $V_{OUT}$ to $V_{IN}$ in the reverse direction. The purpose of the reverse-current blocking circuit is to protect a power supply and other circuits connected to the $V_{IN}$ pin.

- **Protection circuits**
  The TCK301G, TCK302G, and TCK303G have reverse-current blocking circuit, thermal shutdown, overvoltage lockout, and undervoltage lockout circuits which are not intended to guarantee that the ICs always remain below their absolute maximum ratings. You should apply the above design considerations, and derate the absolute maximum rated values as described in the Toshiba Semiconductor Reliability Handbook to ensure that none of the absolute maximum ratings will be exceeded under any circumstances. It is also recommended to add fail-safe and other safety features to an application system.

- **Power dissipation**
  Designing PCB, the IC temperature remains well below the maximum rated temperature during operation even at the maximum power dissipation point. For PCB design, ambient temperature, input voltage, and output current, and other environmental conditions should also be considered.
5. Product overview

5.1. TCK301G, TCK302G and TCK303G

5.1.1 Overview

Fabricated using a high-voltage CMOS process, the TCK301G, TCK302G, and TCK303G load switches operate with an input voltage of up to 28V. These load switches feature a typical low on-resistance of 73mΩ (at $V_{IN} = 4.5V$ and $I_{OUT} = 1.0A$), a maximum output current of 3A, and a wide operating input voltage range from 2.3V to 28V.

- Small package: WCSP9 with a 0.5mm ball pitch (1.5mm x 1.5mm, t: 0.5mm typical), PD = 1.65W
- High input voltage: $V_{IN}$ (max) = 28V
- High output current: $I_{OUT}$ (DC) = 3.0A
- Low on-resistance: $R_{ON} = 73mΩ$ (typical) at $V_{IN} = 4.5V$ and $I_{OUT} = 1.0A$
- Inrush current limiting (slew rate control) circuit
- Overvoltage lockout (OVLO): TCK301G = 6.6V, TCK302G = 10.5V, TCK303G = 15.5V (typical)
- Undervoltage lockout (UVLO): 2.9V (typical)
- FLAG output
- The FLAG output indicates input overvoltage and undervoltage conditions even when the output is disabled via the $V_{CT}$ pin.
- Output startup hold time: 15ms
- Reverse-current blocking (switch-off state)
- Thermal shutdown circuit
5.1.2. External view and pin assignment

![External view and pin assignment](image)

Figure 5.1.1 External view, marking, and pin assignment of the TCK301G, TCK302G, and TCK303G

5.1.3 Product list

Table 5.1 Product list

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Overvoltage Lockout</th>
<th>CE Pin</th>
<th>V_CT Active Logic</th>
<th>V_CT Resistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCK301G</td>
<td>6.6 V (typ.)</td>
<td>Active-Low</td>
<td>Active-High</td>
<td>Pull-up</td>
</tr>
<tr>
<td>TCK302G</td>
<td>10.5V (typ.)</td>
<td>Active-Low</td>
<td>Active-High</td>
<td>Pull-up</td>
</tr>
<tr>
<td>TCK303G</td>
<td>15.5V (typ.)</td>
<td>Active-Low</td>
<td>Active-High</td>
<td>Pull-up</td>
</tr>
</tbody>
</table>
5.1.4 Internal block diagram

![Internal block diagram of the TCK301G, TCK302G, and TCK303G]

Figure 5.1.2 Internal block diagram of the TCK301G, TCK302G, and TCK303G
5.1.5 Operation logic table

Table 5.1.2 Operation logic table of the TCK301G, TCK302G and TCK303G

<table>
<thead>
<tr>
<th>V_{UVL} &lt; V_{IN} &lt; V_{OVL}</th>
<th>\overline{CE}: “L”</th>
<th>V_{UVL} &gt; V_{IN} \text{ or } V_{IN} &gt; V_{OVL}</th>
<th>\overline{CE}: “H”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1 (V_{OUT})</td>
<td>ON (V_{OUT})</td>
<td>ON (V_{OUT})</td>
<td>OFF (Output disabled)</td>
</tr>
<tr>
<td>Q2 (FLAG)</td>
<td>ON (LOW)</td>
<td>OFF (High-Z)</td>
<td>OFF (High-Z)</td>
</tr>
<tr>
<td>Reverse-Current Blocking</td>
<td>Disabled</td>
<td>Disabled</td>
<td>Enabled</td>
</tr>
<tr>
<td>VCT: “H” or open</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1 (V_{OUT})</td>
<td>OFF (Output disabled)</td>
<td>OFF (Output disabled)</td>
<td>OFF (Output disabled)</td>
</tr>
<tr>
<td>Q2 (FLAG)</td>
<td>ON (LOW)</td>
<td>OFF (High-Z)</td>
<td>OFF (High-Z)</td>
</tr>
<tr>
<td>Reverse-Current Blocking</td>
<td>Enabled</td>
<td>Enabled</td>
<td>Enabled</td>
</tr>
<tr>
<td>VCT: “L”</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.1.6 Pin description

Table 5.1.3 Pins of the TCK301G, TCK302G and TCK303G

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>FLAG</td>
<td>Open-drain acknowledge output. After hold time, if V_{IN} is between the operation range, FLAG goes “L”. Otherwise, FLAG goes “High-Z”.</td>
</tr>
<tr>
<td>B1, C1</td>
<td>V_{IN}</td>
<td>Power Input. Integrated overvoltage lockout (OVLO) and undervoltage lockout (UVLO) circuits.</td>
</tr>
<tr>
<td>A2</td>
<td>V_{CT}</td>
<td>Switch control. The V_{CT} input is internally connected to VOP via a pullup resistor.</td>
</tr>
<tr>
<td>B2, C2</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>A3</td>
<td>CE</td>
<td>Chip Enable. The CE pin has an internal pulldown resistor. A Low on CE enables V_{OUT}. When CE is High or open, V_{OUT} is disabled.</td>
</tr>
<tr>
<td>B3, C3</td>
<td>V_{OUT}</td>
<td>Output.</td>
</tr>
</tbody>
</table>
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