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TEA19051BT

USB-PD 2.0/USB-PD 3.0/QC 2.0/QC 3.0/QC 4 (+) controller for SMPS

Rev. 1 — 13 February 2018

Product data sheet

1 General description

The TEA19051BT is a highly configurable secondary side SMPS controller that is available in many factory configured versions. [Section 15](#) gives an overview of the available off-the-shelf versions of the TEA19051BT. To inquire about the possibilities of customer-specific versions, contact your local sales representative.

The TEA19051BT supports the following protocols:

- USB Type-C v.1.3
- USB Power Delivery (USB-PD) including Programmable Power Supply (PPS)
- Battery Charging 1.2 (BC1.2)
- Qualcomm® QuickCharge™ QC2.0, QC3.0, and QC4+

A complete smart-charging Switch Mode Power Supply (SMPS) can be built in combination with the TEA193x primary controller and the TEA199x secondary side Synchronous Rectifier (SR) controller.

The TEA19051BT can be provided in several small packages with low pin count. Due to its small number of external components, a small form factor SMPS can be built that meets efficiency requirements like CoC Tier-2, EuP lot6, and DOE v6 with an extremely no-load power (< 30 mW).

The TEA19051BT has a high level of digital integration. It incorporates all required circuits, including a charge pump to drive an external NMOS load switch directly, a USB-PD physical interface (PHY), and an integrated driver for fast output discharge.

The output voltage and output current are continuously measured and are used to control the SMPS. Two GPIO pins measure the adapter temperature and the temperature in the cable/connector. Optionally, the GPIO pins can be used for other features, like supply (see [Table 4](#)). The die temperature of the TEA19051BT is monitored via an internal temperature sensor.

Multiple protections ensure the best-in-class charging safety for the TEA19051BT.

To ensure correct operation under all conditions, all protections except UVP are implemented in hardware. The response of these protections can be programmed as latched or safe restart. Although not recommended, these protections can also be disabled individually via the settings in the non-volatile Multi-Time Programmable (MTP) memory.

If an output short circuit occurs, the power dissipation in the adapter can be below 50 mW.

For output voltage regulation, current regulation, and protection, only a single optocoupler is required in the application.

The TEA19051BT operates in CV mode with a better than 2 % voltage accuracy. In CC mode, it operates with a better than 2 % full-load current accuracy.



2 Features and benefits

2.1 General

- Best-in-class fail-safe application for high-power adapters; gives complete protection against overload conditions in the load (e.g. phone)
- Wide output voltage operating range (2.9 V to 21 V)
- Ultra-high efficiency together with TEA193x QR/DCM controller and TEA199x SR controller
- Very low no-load power (< 30 mW for the complete system solution)
- High power density
- Dedicated SW pin to drive external NMOS directly
- Constant Voltage (CV) and Constant Current (CC) control (programmable level)
- Precise voltage and current control with low minimum step size (voltage 12-bit DAC, current 10-bit DAC)
- Continuous accurate measurement of output voltage and output current with a better than 2 % accuracy
- Low-cost SO14 package (suitable for reflow soldering and wave soldering)
- Low-cost Bill Of Materials (BOM; ≈15 external components)
- Embedded MCU (with ROM, RAM, and MTP memory)
- Discharge pin for fast output voltage ramp down
- Built-in series regulator and programmable cable compensation
- Non-volatile MTP memory for storage of system configuration parameters

2.2 Protocol support

- USB Type-C v.1.3
- USB Power Delivery (USB-PD) 2.0 and 3.0 including Programmable Power Supply (PPS)
- Supports Qualcomm® QuickCharge™ QC2.0, QC3.0, and QC4+ protocols
- Battery Charging 1.2 (BC 1.2)
- Supports unstructured Vendor Defined Messages (VDMs), which can be used for MTP programming, e.g. to get Vendor IDs

2.3 Protections

- OverTemperature Protection (OTP): one internal and two external
- Adaptive OverVoltage Protection (OVP)
- Adaptive UnderVoltage Protection (UVP)
- OverCurrent Protection (OCP)
- UnderVoltage LockOut (UVLO) protection
- Output Short Protection (OSP)
- Open-Supply Protection (OSUP)
- Open-ground protection (OGP)
- Overvoltage protection DP, DM, CC1, and CC2 pins
- Soft short protection at the CC1 and CC2 pins
- Soft short protection at the output

Due to dedicated functionality to drive an external load switch, which is available in hardware, the TEA19051BT ensures safe operation under all conditions.

3 Applications

- USB chargers for smart phones and tablets supporting the Qualcomm® QuickCharge™ QC2.0, QC3.0, and QC4+ protocols
- USB-PD 3.0, type C 1.3 chargers with optional VDM support for smartphones and tablets

4 Ordering information

Table 1. Ordering information

| Type number | Package | | |
|----------------|---------|---|----------|
| | Name | Description | Version |
| TEA19051BAAT/1 | SO14 | plastic small outline package; 14 leads; body width: 3.9 mm | SOT108-1 |

5 Marking

Table 2. Marking

| Type number | Marking code |
|--------------|--------------|
| TEA19051BAAT | A19051BAA |

6 Block diagram

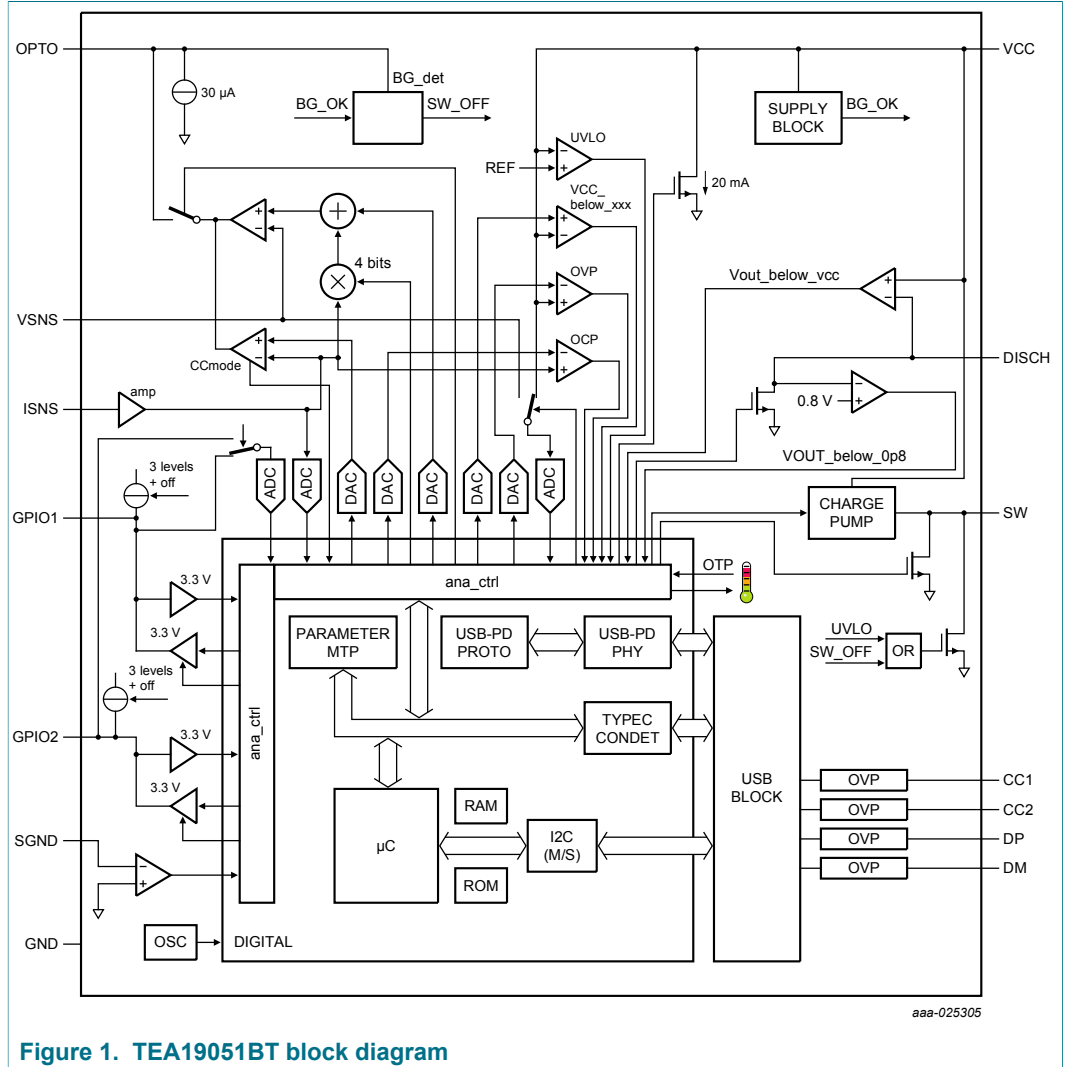


Figure 1. TEA19051BT block diagram

7 Pinning information

7.1 Pinning

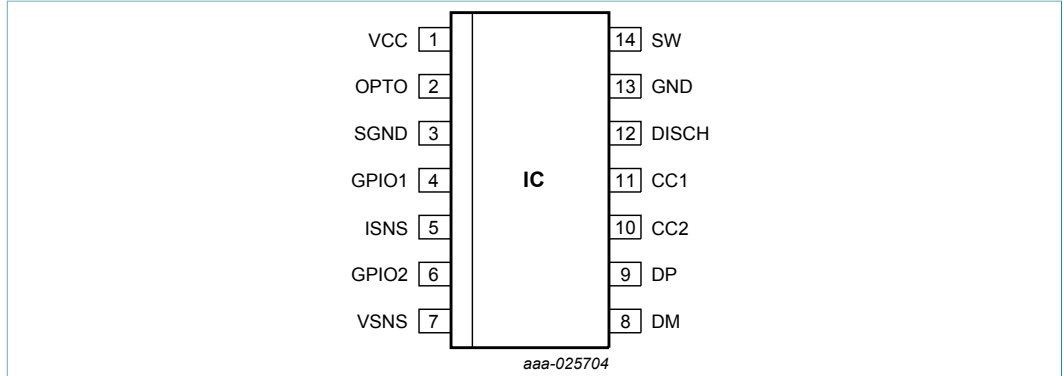


Figure 2. TEA19051BT pinning diagram (SOT108-1)

7.2 Pin description

Table 3. Pin description

| Symbol | Pin | Description |
|--------|-----|--|
| VCC | 1 | supply voltage |
| OPTO | 2 | OPTO driver |
| SGND | 3 | sense ground |
| GPIO1 | 4 | general purpose Input/output |
| ISNS | 5 | current sense input |
| GPIO2 | 6 | general purpose input/output |
| VSNS | 7 | voltage sense input |
| DM | 8 | negative terminal of the data communication line |
| DP | 9 | positive terminal of the data communication line |
| CC2 | 10 | type C CC2 line detection and USB-PD communication |
| CC1 | 11 | type C CC1 line detection and USB-PD communication |
| DISCH | 12 | fast discharge sink |
| GND | 13 | ground |
| SW | 14 | NMOS gate drive output |

8 Functional description

The TEA19051BT can be considered as a versatile programmable replacement for the well-known TL431 shunt regulator series, where:

- The VSNS pin takes the role of the REF input of the TL431
- The OPTO pin takes the role of the cathode
- The GND pin takes the role of the anode

In addition to the Constant Voltage (CV) mode, which is regulated via the VSNS pin, the system supports Constant Current (CC) mode. The current control loop is regulated and the cable compensation is added via the ISNS pin.

Alternatively, the ISNS input can be used for OverCurrent Protection (OCP; see [Table 4](#)). Several other protections are available. Many of these protections are programmable as latched or safe restart. For guaranteed safety, all protections are implemented in hardware. So, even when the microcontroller stops, the protections are still functional.

The output voltage and the output current can be controlled via USB-PD using the CC pins. They can also be controlled via QC using the DP and DM pins.

The output current and the output voltage are continuously measured via an integrated AD-converter. The values can be made available continuously via the USB-PD protocol. The applied time constant of the digital filter is initialized via the firmware. A dedicated signal that indicates a stable output voltage/output current for a reliable measurement is available. It can be used, for example, to determine and monitor the cable resistance in the portable device.

The external temperatures, measured via the GPIO1 and GPIO2 pins, are continuously monitored. From the GPIO voltages and applied currents, the controller calculates the corresponding temperatures. These temperatures can be communicated to the portable device. Optionally, an OTP function is added to this external temperature measurement, which is programmable via MTP (see [Table 4](#)).

The available protections are implemented in hardware. They are independent of processor actions. These protections in combination with the NMOS load switch ensure a fully safe operation with only one optocoupler. When the optocoupler fails, the OVP of the primary side controller (TEA1936x) limits the maximum output voltage.

The TEA19051BT fully supports the type-C connector standard.

When a Type C receptacle is used, the CC1/CC2 pair is used for plug attach/detach detection. It is also meant to support the USB-PD communication standard. The DP/DM pair is meant to support:

- Battery Charging 1.2
- Qualcomm® QuickCharge™ QC2.0 and QC3.0

The USB-PD specification requires the use of a load switch and certain discharge behavior of the output voltage at the connector V_{bus} . So, to drive the gate of an external NMOS switch, the TEA19051BT is equipped with an SW pin. To be able to discharge V_{bus} using an external resistor in series with an internal switch, the TEA19051BT is equipped with a DISCH pin.

User-defined parameters can be stored in the non-volatile Multi-Time Programmable (MTP) memory.

8.1 Start-up and supply

The TEA19051BT is supplied via the VCC pin connected to the secondary DC voltage of an AC-to-DC SMPS converter (see Figure 7). To control the primary side controller, this VCC voltage is regulated via an integrated voltage/current control loop with external loop compensation and an external optocoupler. This optocoupler is part of the gain loop of the primary side SMPS controller.

At each start-up and after power-on reset, the optocoupler current is initially zero. So, the AC-to-DC converter starts up with full output power, resulting in a rapid increase of the VCC voltage. Due to the low $V_{CC(start)}$ level ($\approx 3\text{ V}$), the TEA19051BT ensures that it is fully operating before the V_{CC} reaches the default initial regulation level. The default values of the initial regulation level are 5 V and 3 A and they are programmed in the non-volatile memory (MTP).

At power-on reset, the safe default values, which are read from MTP, are set.

When the V_{CC} voltage is below the UVLO level, the external NMOS load switch is off. When the output is shorted while the load switch is closed, the UVLO is also triggered. The load switch is then immediately opened and the system restarts after the safe restart timer.

When the V_{CC} exceeds the UVLO level, all circuits, the initial DAC value, and the resistive divider ratio are initialized. The system regulates the output to 5 V with a limited output current of 3 A. All these values can be set via the MTP.

To minimize the output voltage overshoot after start-up, an internal 20 mA current sink is applied to VCC when the VCC voltage exceeds $1.05 \times V_{o(default)}$. The sink current remains active until the VCC voltage has dropped to below $1.05 \times V_{o(default)}$ again.

After the output voltage has stabilized, the load switch becomes conducting and the system waits for an attach. Before the attach, only the essential circuits are working which reduces the no-load power to its minimum.

When the voltage on one of the CC pins drops to below the $V_{IH(Rd)}$ level, an attach is detected and all circuits are enabled.

If a protocol is detected, it is allowed to change the voltage and current.

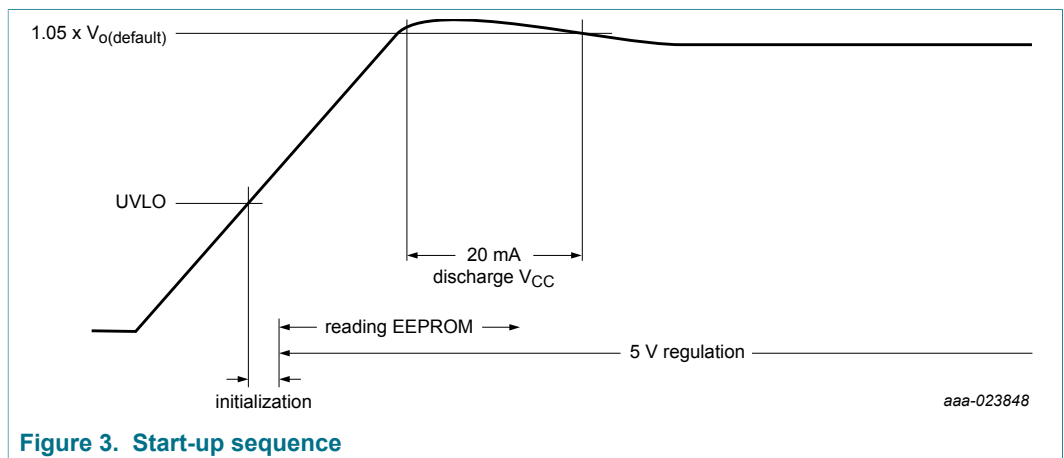


Figure 3. Start-up sequence

The TEA19051BT operates on supply voltages up to 21 V. The voltage on the VCC pin is used to detect an OVP and UVP. The OVP and UVP level are set as a percentage of the requested output voltage level.

If the supply voltage drops to below the UVLO level, the system returns to the no-supply state and opens the load switch. Analog circuits are reset below UVLO. The internal digital circuits are reset below the band gap voltage reference level.

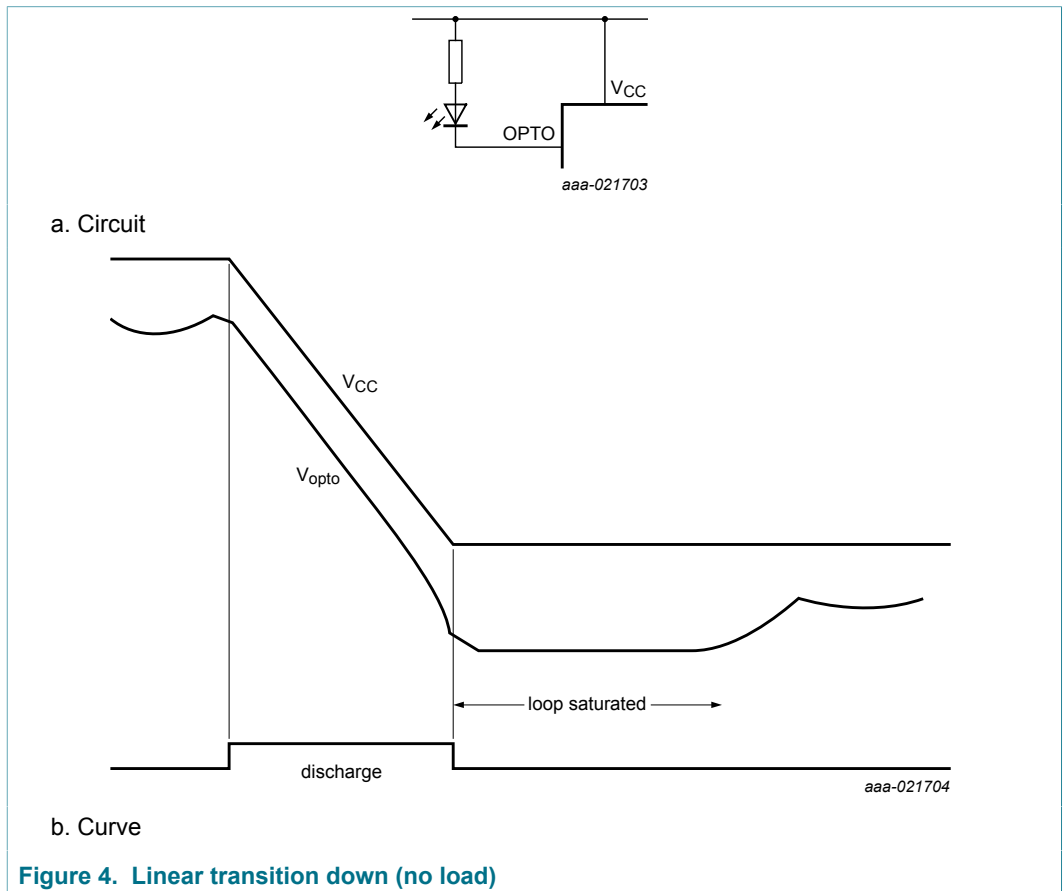
8.2 Voltage loop

The analog Constant Voltage (CV) loop regulates VCC such that the voltage on the VSNS pin equals the internal reference voltage. An external resistor divider is connected between VCC, the VSNS pin, and ground. The value of this divider must match the value that is programmed in MTP exactly. It depends on the maximum voltage in the application. The divider values are:

- 1/2.5; maximum PDO voltage ≤ 6 V
- 1/5.476; maximum PDO voltage ≤ 13 V
- 1/8.325; maximum PDO voltage ≤ 20 V

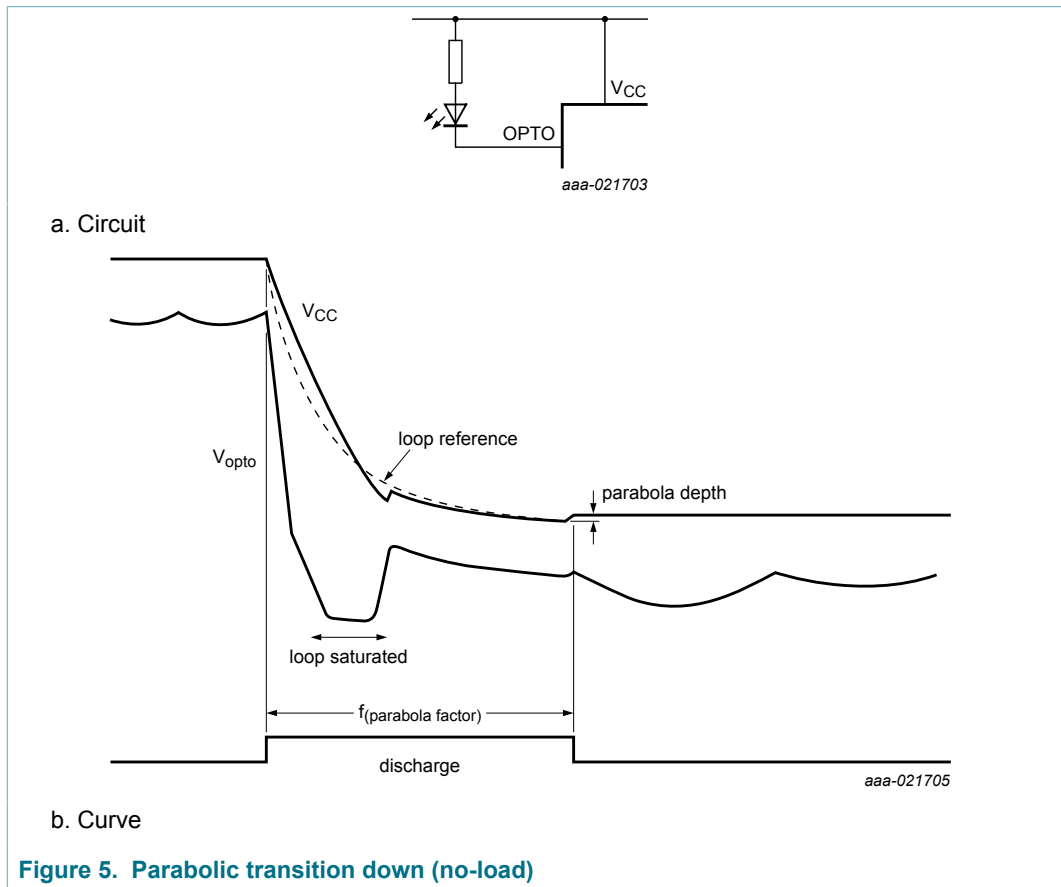
The CV loop is regulated by varying the current through an optocoupler diode similar to a TL431 driven control loop commonly used in switch mode power supplies. The RC combination between the OPTO and VSNS pin determines the dynamic behavior of the integrating part of the control loop. The resistor in series with the optocoupler diode determines the dynamic behavior of the proportional part of the control loop. To prevent saturation of the control loop during switching, a diode is placed in parallel to this resistor. See [Section 13.3](#) for more information about the control loop.

When the voltage loop reference is set to a higher value using the USB-PD or the QC protocol, the internal reference voltage is updated to the new setting within 20 μ s. The output voltage is regulated to the requested voltage with a speed determined by the control loop. If there is a transition down, a predefined ramp down sequence is followed to prevent a high undershoot. Depending on the step size, the ramp down either follows a linear or a parabolic slope. For a transition up, no special measures are required to prevent an overshoot. The reason is that the charging current of the loop capacitor lifts the voltage on the VSNS pin when the V_{CC} voltage in the application increases.



A linear ramp-down (see [Figure 4](#)) can yield a perfect linear ramp of the output voltage without any undershoot. However, depending on the loop bandwidth, the voltage loop can end up in saturation. Saturation hampers a fast response to a load step immediately following the end of the ramp (most protocols do not allow any load to be drawn during a transition). Making the ramp down slower can prevent saturation of the loop. However, a slower ramp down can contradict with the maximum discharge time most protocols specify.

A parabolic discharge curve (see [Figure 5](#); patent pending) initially causes the voltage loop to saturate, due to the initial rapid ramp down. However, it allows the loop to recover and to resume regulation toward the end of the curve. The total parabolic sequence time must be chosen such that no undershoot under the final end value occurs.



8.3 Current loop

The voltage drop across a small external series resistor between the output return terminal and the converter ground is supplied to the ISNS pin. An internal amplifier multiplies the voltage on the ISNS pin by a factor of 50. The output voltage of the amplifier must remain below 2.5 V. The external resistor value can be chosen from 2 mΩ up to 22.5 mΩ in steps of 0.02 mΩ. The external resistor value must correspond to the programmed value in MTP. Any deviation from this MTP value, e.g. due to PCB-layout imperfections, causes a current error and must be corrected (see [Section 13.2](#)). The ground connection of the external sense resistor must be connected to the SGND pin via an independent sense wire.

The combination of the maximum current in the application, the sense resistor, and the gain of the internal amplifier must be chosen such that the output voltage of the internal amplifier remains below 2.5 V.

When the application is used in CC-mode, an RC-combination must be connected between the OPTO pin and the ISNS pin (see [Section 13.4](#)).

8.4 Cable compensation

With cable compensation enabled, the output voltage is increased when the output current increases to compensate for the voltage drop over the cable. The value of the cable compensation is the same for all PDOs. It is set in MTP between the minimum and maximum values (see [Table 4](#)).

Setting the cable compensation above 200 mV/A is not recommendable. The cable compensation can be enabled/disabled for each individual PDO.

8.5 Load switch

A low-cost NMOS transistor is used as load switch between V_{CC} and V_{bus} (see [Figure 7](#)). A dedicated switch-drive output pin (SW pin) controls this NMOS transistor. The output (high) level of the switch drive output is $V_{CC} + 6$ V using an internal charge pump.

As long as V_{CC} is below the UVLO level or if the VCC connection is open, the SW pin is held low, ensuring that the load switch is off. To ensure that the NMOS is also kept off when the SW pin is disconnected, an external (high-ohmic) resistor is required between the gate of the NMOS and V_{bus} .

To avoid charging V_{CC} via the back-gate diode of the load switch, it is possible to apply two NMOS switches in series, with their sources connected together.

8.6 Discharge function

The DISCH pin, which has an internal low-ohmic switch, provides the means to discharge the output V_{bus} quickly. An external series resistor limits the maximum current and the IC dissipation.

To check if the output voltage has dropped to below 0.8 V, a comparator is implemented. This voltage drop is a requirement of the USB-PD specification (vSafe0V) if there is a hard reset.

When the internal DISCH switch is activated, the voltage at the DISCH pin is always low, because of the external current limiting resistor. A mechanism has been implemented to check the real output voltage. During a hard reset discharge sequence, when V_{CC} is below vSafe5V, the switch is opened every millisecond for 20 μ s to check the output voltage at the end of the 20 μ s period. The check of the output voltage is done until the voltage remains below 0.7 V and the hard reset discharge sequence is terminated. For this check to work properly, the capacitance on the DISCH pin and the external current limiting resistor must have a time constant that is short enough.

To ensure that the output remains low, a 1 mA sink current is present on the DISCH pin when both the load switch and discharge switch are off. The period that the DISCH pin is active in unattached state ($t_{d(\text{act})}$) is typically 100 ms. The reason for this limitation is to prevent that excessive power dissipation occurs if an external V_{bus} voltage is applied.

8.7 Detach detection

When the voltage on one of the cc pins is greater than 1.2 V, a detach is detected. If the type C cable is disconnected, the output voltage is regulated to its default value (5 V) after 200 μs .

8.8 Internal temperature measurement

The internal die temperature is monitored continuously. Its value can be requested with the appropriate Vendor Defined Message (VDM). When the internal OTP (see [Table 5](#)) is enabled, the internal OTP is triggered when the die temperature exceeds the value that is programmed in MTP.

8.9 GPIO pins

The internal hardware of the GPIO1 and GPIO2 pins is identical.

In the MTP, the following functions can be selected for each GPIO pin:

- Off
- NTC
- NTC + OTP
- Supply

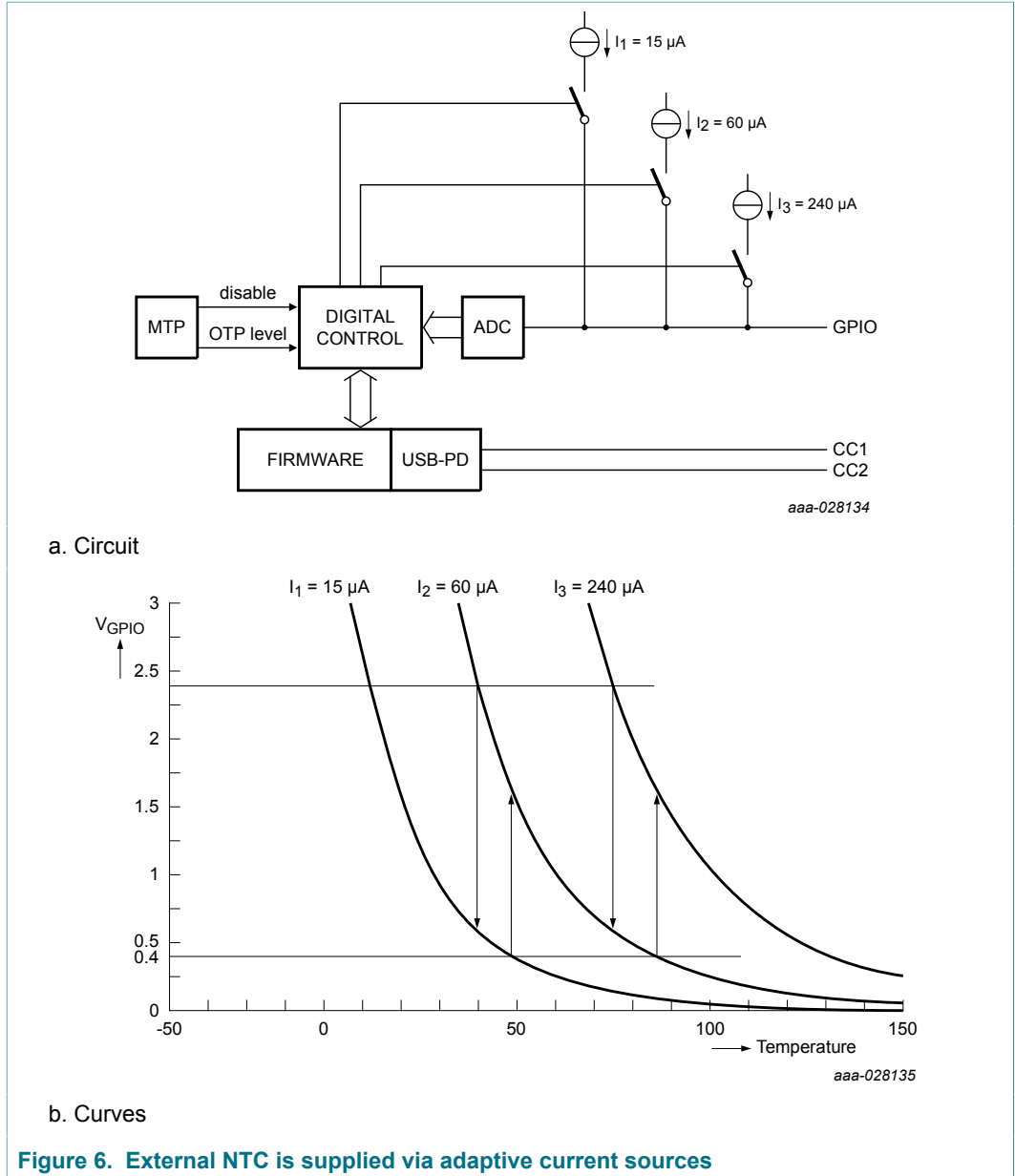
In the sections below, the functions are further explained.

8.9.1 Off

The GPIO pin is disabled and can be connected to ground.

8.9.2 NTC

With the NTC function enabled, the GPIO pins can be used to measure the adapter and cable connector temperature via NTC resistors. The NTC connected to GPIO1 is meant for measuring the (cable) connector temperature. The NTC connected to GPIO2 for measuring the adapter temperature. The temperature values can be requested with the appropriate VDM command. To ensure an accurate temperature measurement over the complete temperature range, both external NTCs are supplied via an adaptive current source (see [Figure 6](#)).



The voltage at a GPIO pin is measured via an internal A-to-D converter. If the voltage on the GPIO pin drops to below 400 mV, the source current is increased. If the voltage on the GPIO pin exceeds 2.4 V, the source current is decreased. When a 47 kΩ NTC resistor with a Beta of 4108 is used, the temperature is accurately measured with a better than < 5 °C accuracy within a range of 0 °C to > 120 °C.

8.9.3 NTC + OTP

With this function enabled, an OTP function is added to the NTC function. The OTP function is integrated in hardware. The OTP level is set in MTP.

When the NTC (+ OTP) function is enabled for a GPIO pin, but this GPIO pin is not used in the application, it must be connected to ground via a fixed 47 k Ω resistor. Do not leave the unused pin floating or connect it to ground.

8.9.4 Supply

When the supply functionality is chosen for the GPIO pin in MTP, the output of the GPIO can be used to supply, e.g., an EEPROM. The following modes can be chosen via MTP:

- The supply signal is high continuously
- Dynamic switching of the I²C slave supply on the GPIO pin.
When the master activates I²C communication, the supply is turned on first. After a delay, the I²C communications start. When I²C communications stops for 1 s, the supply is turned off.
- The signal on the GPIO can have inverted behavior

8.10 Communication

If a type-C receptacle is used, attach/detach detection and USB-PD communication is provided on the CC pins.

DP and DM provide the communication interface for QC2.0 and QC3.0.

If a type-A receptacle is used, attach/detach detection can be disabled (via MTP). The load switch is closed (when no protection is triggered).

8.10.1 USB Type-C

The TEA19051BT complies with the USB Type-C 1.3 specification (see [Section 17](#)) in the sense that the distinct pull-up current values support attach/detach and current capability advertising. The attach/detach detection is done in the hardware. So, if there is a detach, a return of V_{bus} to vSafe5V is always ensured. The hardware implementation of the return of V_{bus} to vSafe5V eliminates the risk of software implementations where V_{bus} may stay at an unsafe level if the program execution stalls.

To support currents higher than 3 A, use a captive cable. V_{conn} is not supported.

8.10.2 USB-PD

The TEA19051BT supports the USB-PD, release 3.0 specification (see [Section 17](#)) as far as it is required for a DFP.

The TEA19051BT supports the Programmable Power Supply (PPS) part of the USB-PD 3.0 specification.

The TEA19051BT can be programmed such that it only complies with the USB-PD 2.0 specification. With these MTP settings, power-brick USB-PD-2.0 testing can be done and USB-PD 2.0 qualification is possible.

Maximum seven different Power Data Objects (PDO) can be defined in the non-volatile memory (MTP). Released types have a predefined set of PDOs programmed (see [Table 4](#)). For each PDO, current limit type (OCP/CC) and cable compensation on/off can be set. However, any other voltage or current within the range can be defined in a PDO.

Four of the seven PDOs can be set as Programmable Power Supply (PPS) instead of a Fixed Power Supply via MTP.

The TEA19051BT supports the QC4+ VDMs.

To make USB-PD certification possible, QC2.0 and QC3.0 must be disabled. Disabling QC2.0 and QC3.0 can be done in MTP or by not connecting the TEA19051BT DP and DM pins. To pass BC1.2, the DP and DM pins of the connector must be connected to each other.

8.10.3 Discover identification

The TEA19051BT supports the discover identification protocol in USB-PD. It is possible to program VID, PID, and BCD values in MTP. These values can be requested via VDM messages.

The maximum power, which is used to determine the power profile, can be set in MTP.

8.10.4 Battery charging

The standard battery charging protocol is supported according to the BC1.2 specification (see [Ref. 1](#)).

8.10.5 Quick charge

The Qualcomm® QuickCharge™ QC2.0, QC3.0, and QC4+ protocols are fully supported (see [Section 17](#)). The required fixed and PPS PDOs can be configured in MTP. The fixed PDO settings that are used for QC2.0 can be set via MTP.

When QC 3.0 is used, the voltage can be set via this protocol from 3.6 V to 12 V in steps of 200 mV. The maximum voltage can be limited if wanted via MTP settings.

8.10.6 MTP configuration

The TEA19051BT is configurable via MTP. The different types are defined in [Section 15](#). [Table 4](#) gives an overview of the programmability with their minimum/maximum values.

Table 4. MTP configuration options

| Function | Options | minimum level | maximum level | step size |
|--|---|---------------|----------------------------|------------------------|
| default output voltage | - | 3 V | 10 V | 50 mV |
| default maximum output current | - | 0.3 A | 5 A | 20 mA |
| GPIO1 | disable; NTC; NTC with OTP ^[1] ; Supply | - | - | - |
| GPIO1 protection level | - | 62 °C | 111 °C | variable but < 5 °C |
| GPIO2 | disable; NTC; NTC with OTP ^[1] ; Supply | - | - | - |
| GPIO2 protection level | - | 62 °C | 111 °C | variable but < 5 °C |
| OTP internal | - | 27 °C | 135 °C | 4.3 °C |
| external sense resistor(R_{sns}) | - | 2 mΩ | 22 mΩ | 0.02 mΩ |
| external resistor divider VCC/ VSNS (=DIV) ^[2] | 8.325; 2.5; 5.476 | - | - | - |
| cable compensation ^[3] | - | 0 mV/A | $R_{sns} * DIV * 8$ V/A | variable |
| CC mode or OCP mode | OCP-mode/CC-mode | - | - | - |
| PDO1 | 5 V 3 A | - | - | - |
| PDO2; PDO3; PDO4; PDO5; PDO6; PDO7 | - - | 3 V 0.3 A | 20 V 10 A | 0.05 V 0.01 A |
| OVP level (PDO) ^[4] | 120 %; 125 %; 130 % | - | - | - |
| UVP level (PDO) ^[4] | off; 60 %; 70 %; 80 % | - | - | - |
| UVP level (APDO) ^[4] | off; 70 %; 80 %; 90 % | - | - | - |
| PDO QC enable ^[4] | TRUE/FALSE | - | - | - |
| PDO PPS enable ^[5] | TRUE/FALSE | - | - | - |
| QC3.0 cable compensation enable | TRUE/FALSE | - | - | - |
| QC3.0 maximum power | - | 0 W | 102.3 W | 0.1 W |
| USB3.0 enable | TRUE/FALSE | - | - | - |
| power limit PPS | TRUE/FALSE | - | - | - |
| minimum voltage APDO | - | 3.3 V | 20 V | - |

[1] The NTC readout and OTP levels are defined with an NTC of 47 kΩ and a B-constant of 4108.

[2] Maximum output voltage for 5.476 is 13 V. Maximum output voltage for 2.5 V is 6 V.

[3] Cable compensation above 200 mV/A is not recommended.

[4] Can be selected for each PDO individually.

[5] Maximum 4 PDOs can be an APDO.

8.11 Protections

Table 5 gives an overview of the available protections. All protections except the OGP operate in safe restart mode. All protections except UVP are implemented in hardware. When a fault condition occurs, the load switch is immediately opened. When the fault condition is removed, the load switch is closed again. The VCC is set to default and the minimum delay defined in MTP is passed.

8.11.1 Protections overview

Table 5. Overview of protections

| Protection | Description | Implementation | Default filter |
|------------------------|---|----------------|----------------|
| UVLO | undervoltage lockout | hardware | - |
| OVP | overvoltage protection | hardware | 30 μ s |
| OCP | overcurrent protection | hardware | 20 ms |
| OTP (internal) | overtemperature protection | hardware | - |
| 2 times OTP (external) | overtemperature protection | hardware | - |
| OGP | open-ground protection | hardware | - |
| UVP | undervoltage protection | software | - |
| OSUP | open-supply (VCC) protection | hardware | - |
| OV_DP_DM | overvoltage protection DP and DM pins | hardware | 127 μ s |
| OV_CC1_CC2 | overvoltage protection CC1 and CC2 pins | hardware | 127 μ s |

8.11.2 Secondary side safe restart protection

When a safe restart protection is triggered, the load switch is immediately turned off. The voltage loop is kept on and is regulated to the initial value (5 V typical). As the load switch is immediately turned off before the regulation reduces the output power, the VCC voltage may increase. To ensure that the VCC voltage has dropped to a safe value, before the load switch is turned on again, V_{CC} is discharged via an internal current source of 20 mA if it exceeds the level of $1.05 \times V_{\text{default}}$.

When the protection is triggered, the safe restart timer is started. After 1 s (default value), a restart sequence is performed, which reinitializes all circuits. Optionally, most protections can be changed to latched protections in MTP.

8.11.3 UnderVoltage LockOut (UVLO)

The level at which the UVLO protection is triggered is fixed. When V_{CC} drops to below the UVLO level, the load switch is immediately turned off. All settings are reset to their initial values. Internal circuitries are disabled.

8.11.4 OverVoltage Protection (OVP)

The OVP level is set as a percentage of the requested output voltage level. The OVP level is set to default 125 % ($V < 9\text{ V}$) or 120 % ($V \geq 9\text{ V}$) of the programmed output voltage. When V_{CC} continuously exceeds this level for longer than the minimum OVP time (default 30 μs), the OVP protection is triggered.

8.11.5 OverCurrent Protection (OCP)

The default TEA19051BT setting is CC mode. In CC mode, the current loop defines the maximum current. Instead, the OCP mode can be selected via MTP. The OCP level can be programmed individually for each PDO. OCP is only triggered if the OCP mode is set for the corresponding PDO and the output current is continuously higher than the programmed current level for more than the programmed OCP blanking time.

8.11.6 OverTemperature Protection (OTP)

8.11.6.1 Internal OTP

When the internally measured temperature exceeds the programmed OTP setting, OTP is triggered, unless the protection is disabled in MTP. The temperature level can be defined in MTP. The default value is 113 °C.

Furthermore, the internal temperature sensor can be used to measure the temperature. The measured temperature can be sent via USB-PD.

8.11.6.2 External OTP

When the mode "NTC+OTP" is selected for GPIO1 (cable connector temperature) or GPIO2 (adapter temperature) in the MTP and the externally measured temperature exceeds the programmed OTP setting, OTP is triggered. The temperature level can be defined in MTP. The default value is 90 °C (see [Section 15](#) and [Table 4](#)).

8.11.7 Open-Ground Protection (OGP)

An open-ground event is detected by monitoring the difference in voltage between the GND and SGND pins. When the difference is greater than the specified maximum voltage difference, OGP is triggered, unless the protection is disabled.

This feature protects the application from supplying high currents to the load when the ground pins of the sense resistor are not properly connected.

8.11.8 Open-Supply Protection (OSUP)

When the IC is not supplied via the VCC pin any more, the voltage on the OPTO pin is used to open the external load switch. Opening the external load switch prevents that the load is damaged if the VCC pin is disconnected.

8.11.9 UnderVoltage Protection (UVP)

The UVP level is set to 60 % PDO level. The reaction to a triggering of UVP is programmed in the firmware. The protection is a safe restart protection by default. The level can never be lower than the UVLO level. The level can be adjusted via MTP.

8.11.10 Output Short Protection (OSP)

At a shorted output, the VCC voltage drops to below the UVLO level. The load switch is turned off. After the programmed safe restart time, the output is enabled again. To meet the average input power requirement at a shorted output, a proper safe restart time must be chosen. When the VCC voltage exceeds the UVLO level, the primary controller initially limits the maximum output power.

Because the safe restart time is set to 1 s, the dissipation is limited to < 50 mW. This limitation prevents that the application heats up when the output is shorted.

8.11.11 OVP DP and DM pins (OV_DP_DM)

The overvoltage protection of the DP and DM pins can be enabled in MTP. However, it is switched off by default.

OV_DP_DM is a safe restart protection. When the DP or DM pin is shorted to V_{bus} , this protection is triggered. The trigger level of the OV_DP_DM is at 4.5 V. To prevent unwanted triggering, it has a 127 μ s (default) blanking time.

8.11.12 OVP CC1 and CC2 pins (OV_CC1_CC2)

The overvoltage protection of the CC1 and CC2 pins can be enabled in MTP. However, it is switched off by default.

OV_CC1_CC2 is a safe restart protection. When the CC1 or CC2 pin is shorted to V_{bus} , this protection is triggered. The trigger level of the OV_CC1_CC2 is at 4.5 V. To prevent unwanted triggering, it has a 127 μ s (default) blanking time.

8.11.13 Soft short protection CC pins (SHORT_CC1_CC2)

The CC pins are protected with a soft-short protection that measures the impedance of the CC lines. When the measured impedance is not according to the USB-PD specification, the load switch is opened.

9 Limiting values

Table 6. Limiting values

In accordance with the Absolute Maximum Rating System (IEC 60134).

| Symbol | Parameter | Conditions | Min | Max | Unit |
|--------------------------------------|---------------------------------|----------------------------|-------|---------------------|------|
| Voltages | | | | | |
| V _{VCC} | voltage on pin VCC | | -0.5 | +26 | V |
| V _{OPTO} | voltage on pin OPTO | | -0.5 | +26 | V |
| V _{CC1} | voltage on pin CC1 | | -0.5 | +26 | V |
| V _{CC2} | voltage on pin CC2 | | -0.5 | +26 | V |
| V _{DP} | voltage on pin DP | | -0.5 | +6 | V |
| V _{DM} | voltage on pin DM | | -0.5 | +6 | V |
| V _{SW} | voltage on pin SW | | -0.5 | V _{CC} + 9 | V |
| V _{DISCH} | voltage on pin DISCH | | -0.5 | +26 | V |
| V _{VSNS} | voltage on pin VSNS | | -0.5 | +3.6 | V |
| V _{ISNS} | voltage on pin ISNS | | -0.5 | +3.6 | V |
| V _{GPIO1} | voltage on pin GPIO1 | | -0.5 | +3.6 | V |
| V _{GPIO2} | voltage on pin GPIO2 | | -0.5 | +3.6 | V |
| General | | | | | |
| T _{stg} | storage temperature | | -65 | +150 | °C |
| T _j | junction temperature | | -40 | +150 | °C |
| ElectroStatic Discharge (ESD) | | | | | |
| V _{ESD} | electrostatic discharge voltage | Human Body Model (HBM) | -2000 | +2000 | V |
| | | Charged Device Model (CDM) | -500 | +500 | V |
| | | Machine Model (MM) | -200 | +200 | V |

10 Recommended operating conditions

Table 7. Recommended operating conditions

| Symbol | Parameter | Conditions | Min | Max | Unit |
|--------------------|----------------------|------------|-----|---------------------|------|
| Voltages | | | | | |
| V _{VCC} | voltage on pin VCC | | 0 | 21 | V |
| V _{OPTO} | voltage on pin OPTO | | 0 | 21 | V |
| V _{CC1} | voltage on pin CC1 | | 0 | 5 | V |
| V _{CC2} | voltage on pin CC2 | | 0 | 5 | V |
| V _{DP} | voltage on pin DP | | 0 | 5 | V |
| V _{DM} | voltage on pin DM | | 0 | 5 | V |
| V _{SW} | voltage on pin SW | | 0 | V _{CC} + 6 | V |
| V _{DISCH} | voltage on pin DISCH | | 0 | 21 | V |
| V _{VSNS} | voltage on pin VSNS | | 0 | 2.5 | V |
| V _{ISNS} | voltage on pin ISNS | | 0 | 3.3 | V |
| V _{GPIO1} | voltage on pin GPIO1 | | 0 | 2.5 | V |
| V _{GPIO2} | voltage on pin GPIO2 | | 0 | 3.3 | V |
| General | | | | | |
| T _j | junction temperature | | -20 | +105 | °C |

11 Thermal characteristics

Table 8. Thermal characteristics

| Symbol | Parameter | Conditions | Typ | Unit |
|----------------------|---|------------------|-----|------|
| R _{th(j-a)} | thermal resistance from junction to ambient | JEDEC test board | 104 | K/W |
| R _{th(j-c)} | thermal resistance from junction to case | JEDEC test board | 42 | K/W |

12 Characteristics

Table 9. Characteristics

$T_{amb} = 25\text{ °C}$; $V_{CC} = 5.0\text{ V}$; all voltages are measured with respect to GND; currents are positive when flowing into the IC; unless otherwise specified.

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|---|--------------------------------|---|------|-------------------------------------|------|---------------|
| Supply (VCC pin) | | | | | | |
| $V_{th(UVLO)}$ | undervoltage lockout threshold | falling | - | 2.85 | 2.9 | V |
| I_{CC} | supply current | unattached; $V_{CC} = 5\text{ V}$ | - | 1.8 | - | mA |
| | | nominal; $V_{CC} = 5\text{ V}$ | - | 3 | - | mA |
| $I_{CC(dch)}$ | discharge supply current | extra discharge current; $V_{CC} = 1.05 \times V_{O(\text{default})}$ | - | 20 | - | mA |
| | | discharge current of VCC during safe restart protection; depends on load conditions | - | 20 | - | mA |
| V_{os} | overshoot voltage | protection level voltage | - | $1.05 \times V_{O(\text{default})}$ | - | V |
| CC1/CC2 section (CC1 and CC2 pins) | | | | | | |
| Type C | | | | | | |
| I_{pu} | pull-up current | current source for DFP pull-up indication | | | | |
| | | default current | -96 | -80 | -64 | μA |
| | | 1.5 A mode | -194 | -180 | -166 | μA |
| | | 3 A mode | -356 | -330 | -304 | μA |
| V_{IH} | HIGH-level input voltage | with standard 5.1 k Ω pull-down resistance | | | | |
| | | default current | 1.5 | 1.6 | 1.7 | V |
| | | 1.5 A mode | 1.5 | 1.6 | 1.7 | V |
| | | 3 A mode | 2.45 | 2.60 | 2.75 | V |
| V_{IL} | LOW-level input voltage | with standard 5.1 k Ω pull-down resistance | | | | |
| | | default current | 0.15 | 0.20 | 0.25 | V |
| | | 1.5 A mode | 0.35 | 0.40 | 0.45 | V |
| | | 3 A mode | 0.75 | 0.80 | 0.85 | V |
| V_{ovp} | overvoltage protection voltage | | - | 4.5 | - | V |
| USB-PD normative specification | | | | | | |
| f_{bit} | bit rate | BMC bit rate | 270 | 300 | 330 | Kbps |
| USB-PD transmitter normative specification | | | | | | |
| t_{fall} | fall time | 10 % and 90 % amplitude points; minimum is underloaded condition | 300 | - | 650 | ns |

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|--|--------------------------------|--|-------|-------|-------|------------|
| t_{rise} | rise time | 10 % and 90 % amplitude points; minimum is underloaded condition | 300 | - | 650 | ns |
| V_o | output voltage | signal voltage swing | 1.050 | 1.125 | 1.200 | V |
| Z_o | output impedance | transmitter | - | 45 | - | Ω |
| USB-PD receiver normative specification | | | | | | |
| C_{in} | input capacitance | | - | 250 | - | pF |
| $t_{ftr(lim)}$ | time constant limiting filter | receiver bandwidth | 100 | - | - | ns |
| Z_i | input impedance | receiver | 10 | - | - | M Ω |
| V_i | input voltage | receiver comparator | | | | |
| | | low level | - | 0.55 | - | V |
| | | high level | - | 0.8 | - | V |
| | | hysteresis | - | 250 | - | mV |
| DP and DM pins | | | | | | |
| V_{ovp} | overvoltage protection voltage | | - | 4.5 | - | V |
| Qualcomm® QuickCharge™ QC2.0 and QC3.0 | | | | | | |
| R_{sw} | switch resistance | when DP and DM pins are shorted | - | - | 20 | Ω |
| V_i | input voltage | DM and DP comparator pins | | | | |
| | | high level | 1.8 | 2.0 | 2.2 | V |
| | | low level | 0.250 | 0.325 | 0.400 | V |
| R_{pd} | pull-down resistance | pin DP | 300 | 900 | 1500 | k Ω |
| | | pin DM | 14.25 | 19.53 | 24.80 | k Ω |
| Qualcomm® QuickCharge™ QC2.0 and QC3.0 | | | | | | |
| t_d | delay time | attach debounce time (BC1.2) | 1.0 | - | 1.5 | s |
| | | DM low debounce time after BC1.2 is completed | 1 | - | - | ms |
| | | signal detection debounce time | 20 | 40 | 60 | ms |
| Voltage control (VSNS pin) | | | | | | |
| V_{ref} | reference voltage | input voltage range on the VSNS pin to control the voltage loop | 0.3 | - | 2.4 | V |
| V_{acc} | voltage accuracy | voltage loop accuracy; $V_{CC} = 5\text{ V}$ | -2 | - | +2 | % |
| | | measurement voltage accuracy | -2 | - | +2 | % |

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|-----------------------------------|---|--|--------|--------|--------|--------------------|
| g_m | transconductance | VCC in; OPTO out | 4 | - | - | mA/mV |
| G_{max} | maximum gain | cable compensation | - | 8 | - | mV/mV |
| Current control (ISNS pin) | | | | | | |
| I_{ref} | reference current | parameter can be programmed in MTP 10 bits | 0 | - | 40 | mV |
| I_{out} | output current | current loop accuracy; $R_{sense} = 5\text{ m}\Omega$ | | | | |
| | | $0.5\text{ A} < I_{out} < 5\text{ A}$ | -100 | - | +100 | mA |
| | | $I_{out} > 5\text{ A}$ | -2 | - | +2 | % |
| | | measurement current accuracy; $R_{sense} = 5\text{ m}\Omega$ | | | | |
| | | $0.5\text{ A} < I_{out} < 5\text{ A}$ ^[1] | -100 | - | +100 | mA |
| | | $I_{out} > 5\text{ A}$ | -3 | - | +3 | % |
| GPIO1 and GPIO2 pins | | | | | | |
| $I_{O(GPIOX)}$ | output current on pins GPIOX | GPIO function = NTC (+OTP) | | | | |
| | | low temperatures (see Figure 6) | -15.75 | -15.00 | -14.25 | μA |
| | | medium temperatures (see Figure 6) | -63 | -60 | -57 | μA |
| | | high temperatures (see Figure 6) | -252 | -240 | -228 | μA |
| T_{acc} | temperature accuracy | 47 k Ω NTC (Beta = 4108) | -5 | - | +5 | $^{\circ}\text{C}$ |
| T_{res} | temperature resolution | temperature measurement | -1 | - | +1 | $^{\circ}\text{C}$ |
| V_I | input voltage | high level | 1.5 | - | - | V |
| | | low level | - | - | 0.9 | V |
| V_O | output voltage | GPIO function = supply | | | | |
| | | high level; no load | 2.7 | 3.0 | 3.3 | V |
| | | low level; no load | - | - | 0.3 | V |
| I_O | output current | GPIO function = supply | | | | |
| | | source; $V_O = 2.3\text{ V}$ | - | - | -1 | mA |
| | | sink; $V_O = 0.4\text{ V}$ | 1 | - | - | mA |
| Protections | | | | | | |
| V_{ovp} | overvoltage protection voltage | with control loop in voltage control mode | 3 | - | 25 | V |
| $V_{ovp(acc)}$ | overvoltage protection voltage accuracy | VCC pin; $V_{ovp} = 6\text{ V}$ | -3 | - | +3 | % |
| V_{ocp} | overcurrent protection voltage | | 6 | - | 40 | mV |

| Symbol | Parameter | Conditions | Min | Typ | Max | Unit |
|--|--|--|------|------|------|--------------|
| $V_{ocp(acc)}$ | overcurrent protection voltage accuracy | | -3 | - | +3 | % |
| V_{uvp} | undervoltage protection voltage | | 3 | - | 21 | V |
| $V_{uvp(acc)}$ | undervoltage protection voltage accuracy | | -3 | - | +3 | % |
| $I_{CC(dch)}$ | discharge supply current | during safe restart protection | - | 20 | - | mA |
| SW driver | | | | | | |
| R_O | output resistance | switch-on | - | 80 | - | k Ω |
| | | switch-off | - | 600 | - | Ω |
| DISCH part (DISCH pin) | | | | | | |
| R_{dch} | discharge resistance | | - | 3 | - | Ω |
| $V_{det(rst)}$ | reset detection voltage | hard reset | 0.65 | 0.70 | 0.75 | V |
| t_{act} | active time | maximum on-time during attached state | - | 100 | - | ms |
| OPTO pin | | | | | | |
| $I_{O(min)}$ | minimum output current | | - | 30 | - | μ A |
| $I_{O(max)}$ | maximum output current | | 3.75 | 5.00 | 6.25 | mA |
| Internal oscillator | | | | | | |
| f_{osc} | internal oscillator frequency | | - | 10 | - | MHz |
| Internal temperature protection | | | | | | |
| $T_{otp(acc)}$ | overtemperature protection trip accuracy | temperature regarding the trip level programmed in MTP | -10 | - | +10 | $^{\circ}$ C |

[1] The current sense pin can be used up to 40 mV. The result is a current range that depends on the programmed R_{sense} resistor. (e.g. with 10 m Ω , the value can be up to 4 A).