USB Type-C and PD Source Controller

1. FEATURES

- USB PD3.2 and Type-C 1.3
- Support up to Five FPDOs
  - Typical 5V, 9V, 12V, 15V and 20V FPDOs
- Support up to three APDOs
  - Support 9-20V SPR AVS
  - Support 5V-Prog, 9V-Prog, 15V-Prog and 20V-Prog PPS
  - 20mV LSB Voltage Regulation and 50mA LSB for Current Regulation
  - Constant power limit
- Support QC2.0/QC3.0, BC1.2 DCP protocols
  - Apple 5V, 2.4A mode
  - BC1.2 DCP mode
  - QC2.0 5V/9V/12V and 20V
  - QC3.0 3.6V~20V continuous model voltage mode with 200mV step adjustment
  - Support Fast Charging Protocol, FCP
  - Support Adaptive Fast Charging, AFC
- Constant Voltage (CV) and Constant Current Limit (CC) Regulation
  - Integrated secondary side compensation circuit, such as TL431
- Built-in VIN and VBUS pins fast discharge scheme
- Small Current Sensing Resistor (5mΩ) for High Efficiency application
- CC1/CC2 Pin Protection up to 28V
- Support cable drop compensation with 0, 50m, 100m/200mΩ selection
- Support Smart Power Derating function at two ports USB application (USB-C or USB-A)
- Integrated VCONN power and eMarker detection
- Built-in adaptive UVP, adaptive OVP, I_OTP, E_OTP, CC_OVP and VCONN_OCP Fault Detections

2. APPLICATIONS

- AC-DC PD Compliant power adapters
- DC-DC Car chargers
- USB-PD converter

3. GENERAL DESCRIPTION

The HT5350 is a highly integrated PD source controller that support USB PD3.2, AVS, PPS, QC2.0/3.0, FCP, AFC, BC1.2 DCP etc.

The HT5350 incorporates various protections, such as Under Voltage Protection (UVP), Over Voltage Protection (OVP), Over Current Protection (OCP), CC1 and CC2 Over Voltage Protection (CC_OVP), VCONN Over Current Protection (VCONN_OCP), and internal and external Over Temperature protection (I_OTP and E_OTP). With a 10−bit A/D converter, output voltage, output current, IC internal temperature and external temperature via an NTC resistor can be monitored. The HT5350 provides the smart power derating function for dual-port charger application.

The HT5350 is designed to operate with general ACDC, DCDC controller or I²C interface ACDC, DCDC controller.

4. PART NUMBER INFORMATION

PART NO.	PACKAGE
HT5350	QFN16

5. TYPICAL APPLICATION

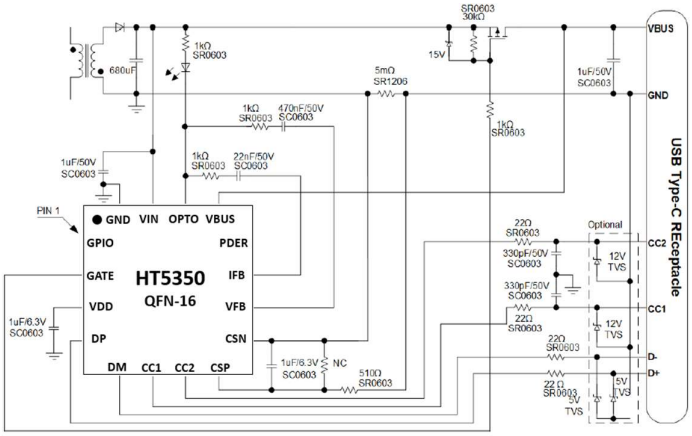


Figure 1. Typical Application Circuit of HT5350

6. PIN CONFIGURATION AND DESCRIPTIONS

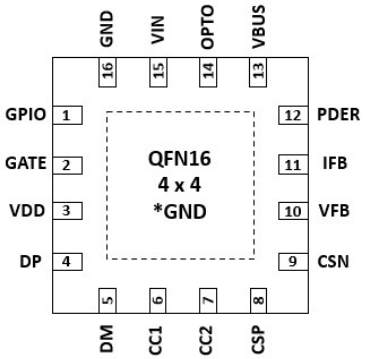


Figure 2. HT5350 Pin Diagram (Bottom View)

Pin Descriptions

Pin No.	Pin Name	Pin Type	Voltage Type	Pin Description
1	GPIO	Open Drain IO	LV	General purpose IO
2	GATE	Open Drain IO	HV	Open drain gate driver to the gate of PMOS load switch
3	VDD	Supply	LV	Internal LDO output voltage. Connect this pin to GND via an 1uF ceramic capacitor
4	DP	Analog IO	HV	USB D+ line
5	DM	Analog IO	HV	USB D- line
6	CC1	Analog IO	HV	USB Type-C Configuration Channel1
7	CC2	Analog IO	HV	USB Type-C Configuration Channel2
8	CSP	Analog I	LV	Positive input of the current sense amplifier
9	CSN	Analog I	LV	Negative input of the current sense amplifier. Provide a low ohmic connection to GND
10	VFB	Analog I	LV	Voltage loop feedback & compensation.
11	IFB	Analog I	LV	Current loop feedback & compensation.
12	PDER	Analog I	LV	Power derating control pin. It is pulled high internally. Connect different resistors to GND to achieve power derating
13	VBUS	Analog I	HV	VBUS sense and discharge
14	OPTO	Analog I	HV	Opto-coupler cathode pin on the secondary side provides feedback signal to the primary side PWM controller.
15	VIN	Supply	HV	Supply input voltage. Connect this pin to GND via an 1uF ceramic capacitor
16	GND	Ground	HV	Power ground
17	-	Ground	-	Exposed ground if available

*Exposed pad is connected to GND if available

Typical Application

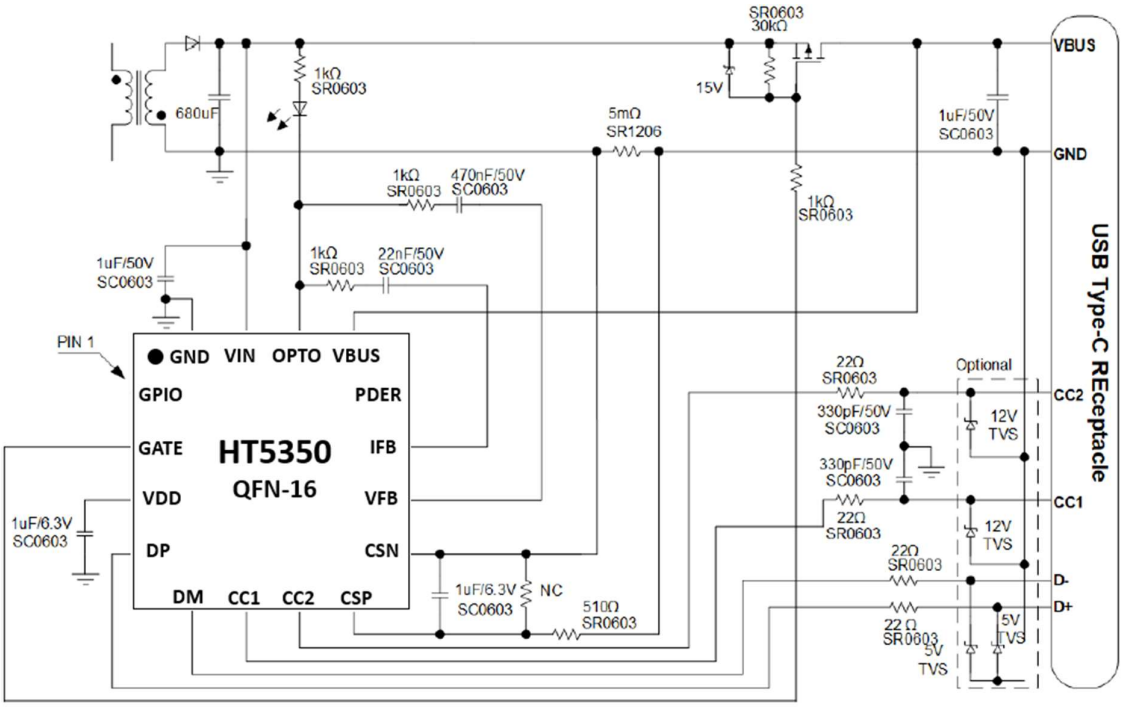


Figure 3. Application circuits where the HT5350 drives an opto-coupler

Block Diagram

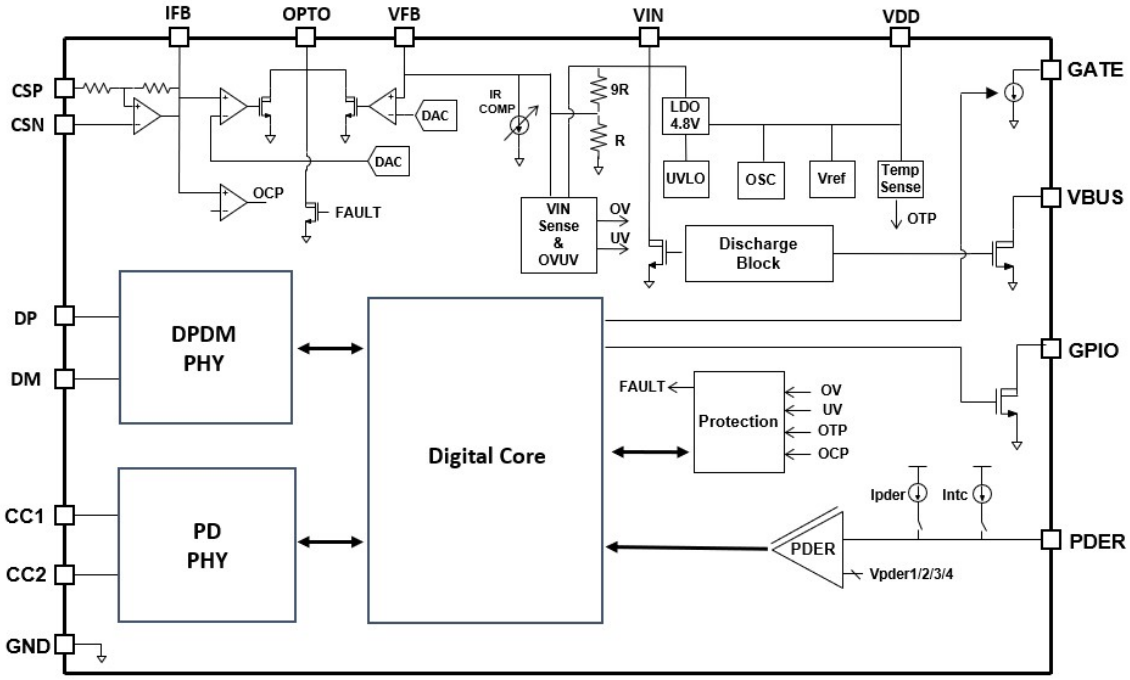


Figure 4. HT5350 Block Diagram

7. SPECIFICATIONS

7.1. Absolute Maximum Ratings

Rating	Symbol	Value	Unit
VIN, VBUS, GATE, OPTO, CC1, CC2, DP, DM	V_{IN}	-0.3 to 28	V
PDER, GPIO, CSP, CSN, VFB, IFB	$V_{I/O}$	-0.3 to 6	V
VDD	V_{DD}	-0.3 to 6	V
Operating Junction temperature range	T_J	-40 to +140	°C
Storage temperature range	T_{STG}	-40 to +150	°C

Remarks: 1) All voltages are with respect to GND unless otherwise noted.

7.2. ESD Ratings

Rating		VALUE	Unit
HT5350 (QFN-16 package)			
ESD HBM JEDEC JS-001	CC1, CC2	±8	kV
	Others	±2	kV

7.3. Recommended Operating Conditions

Rating	Symbol	Value	Unit
Input Voltage	V_{IN}	3.3 to 25	V
Output Current Through Load Switch	I_{OUT}	5	A
Adjustable Type-C Connector VBUS Output Voltage	VBUS	3.3 to 21	V
Ambient Temperature	T_A	-40 to 125	°C

7.4. Electrical Characteristics

VIN = 5 V, TA =25°C unless otherwise specified

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
VDD SECTION						
LDO output voltage	VIN = 6V, I_{OUT}= 0A	VDD	4.65	4.8	4.95	V
Output Current Limit	VIN = 6V, Rout = 50ohm	$Ivdd_{limit}$	40	50		mA
VIN SECTION						
Operating voltage		VIN_{op}	3.3		25	V
Standby operating current	VIN = 5V, V_{CS} = 0mV	I_{stby}		0.9		mA
Operating current	VIN = 5V, R_{CS} = 5mΩ	Iq_{5V}		1.2		mA
Turn-on voltage	VIN increasing	VIN_{on}		2.9		V
Turn-off voltage	VIN decreasing after VIN ≥ VIN_{on}	VIN_{off}		2.4		V
Turn-off to Turn-off Hysteresis	VIN decreasing after VIN ≥ VIN_{on}	VIN_{off_HYS}		0.5		V
VIN UVP & OVP SECTION						
Ratio of VIN UVP to target VIN		K_{VIN_UVP}		75		%
Ratio of VIN OVP to target VIN		K_{VIN_OVP}		120		%
OVER CURRENT PROTECTION SECTION						
Programmable Current sense amplifier gain	R_{CS} = 5mΩ (default)	A_{V_CS}		40		V/V
OCP threshold on R_{CS} between CSP and CSN	R_{CS} = 5mΩ, I_{OUT} = 1A	I_{OCP_1A}	1.15	1.2	1.25	A
	R_{CS} = 5mΩ, I_{OUT} = 3A	I_{OCP_3A}	3.42	3.6	3.78	A
	R_{CS} = 5mΩ, I_{OUT} = 5A	I_{OCP_5A}	5.7	6.0	6.3	A
CONSTANT CURRENT LIMIT CONTROL SECTION						
CC threshold on Rcs between CSP and CSN	VIN=5V, R_{CS} = 5mΩ, I_{OUT} = 1A	I_{CC_1A}	0.85	1.00	1.15	A
	VIN=5V, R_{CS} = 5mΩ, I_{OUT} = 3A	I_{CC_3A}	2.85	3.00	3.15	A
	VIN=5V, R_{CS} = 5mΩ, I_{OUT} = 5A	I_{CC_5A}	4.75	5.00	5.25	A
CC threshold on Rcs between CSP and CSN at ΔIout=50mA	VIN=5V, R_{CS} = 5mΩ	$I_{CC_STEP_50mA}$	48	50	52	mA
CONSTANT VOLTAGE CONTROL SECTION (VFB PIN)						
Voltage Sense Feedback Factor		K_{FB}		10		V/V
VFB Reference Voltage at 5V	VIN = 5.0V, Vcs = 0V	V_{CVR_5V}	0.48	0.5	0.52	V
VFB Reference Voltage at 9V	VIN = 9.0V, Vcs = 0V	V_{CVR_9V}	0.864	0.9	0.936	V
VFB Reference Voltage at 12V	VIN = 12V, Vcs = 0V	V_{CVR_12V}	1.152	1.2	1.248	V
VFB Reference Voltage at 20V	VIN = 20V, Vcs = 0V	V_{CVR_20V}	1.92	2.0	2.08	V
VFB Reference Voltage of 20mV step	ΔVIN = 20mV, Vcs = 0V	V_{CVR_STEP}	1.92	2.0	2.08	mV
DISCHARGE SECTION						
VIN bleeding current when discharging	Discharging current on VIN during voltage transition	I_{DCH_VIN}	200			mA
VBUS bleeding current when discharging	Discharging current on VBUS during voltage transition	I_{DCH_VBUS}	250			mA

Electrical Characteristics (continued)

VIN = 5 V, TA =25°C unless otherwise specified

Parameter	Conditions	Symbol	Min	Typ	Max	Unit
GATE SECTION						
GATE pin Sinking Current		I_{GATE}		23		mA
OPTO SECTION						
OPTO Max Sinking Current		I_{OPTO_MAX}		30		mA
PDER SECTION						
PDER source current	PDER mode	I_{PDER}		75		uA
PDER threshold input level1	PDER mode, Rpder = 30KΩ	V_{PDER1}		2.4		V
PDER threshold input level2	PDER mode, Rpder = 15KΩ	V_{PDER2}		1.2		V
PDER threshold input level3	PDER mode, Rpder = 10KΩ	V_{PDER3}		0.8		V
PDER threshold input level4	PDER mode, Rpder = 0 Ω	V_{PDER4}		0.4		V
OVER TEMPERATURE PROTECTION SECTION						
NTC source current at PDER pin	NTC mode, R_{NTC} = 47KΩ Low temperature range Medium temperature range High temperature range	I_{NTC}		15 60 240		uA
Thermal shutdown rise threshold		T_{OTP_r}		135		°C
Thermal shutdown fall threshold		T_{OTP_r}		115		°C
Thermal shutdown hysteresis		T_{OTP_hys}		20		°C
TYPE C SECTION						
Pullup Current Source at CC1/CC2	3.0A mode	$I_{PU_CC_330}$	304	330	356	uA
	1.5A mode	$I_{PU_CC_150}$	166	180	194	uA
	Default mode	$I_{PU_CC_DEF}$	64	80	96	uA
UFP Detecting threshold at CC1/CC2	3.0A mode	V_{TH_330}	2.46	2.6	2.74	V
	1.5A mode	V_{TH_150}	1.51	1.6	1.64	V
	Default mode	V_{TH_DEF}	1.51	1.6	1.64	V
Vconn Supply Voltage		V_{CONN}	3.0		5.0	V
Vconn OCP threshold		I_{VCONN_OCP}	50			mA
Vconn Supply Current	VDD=4.8, Vconn = 3V	I_{VCONN}	30			mA
OVP at CC1/CC2		V_{CC_OVP}	5.5	5.75	6.0	V
BMC TX SECTION						
Bit Rate		$f_{BitRate}$	270	300	330	Kbps
Logic High Voltage	IOH = -165uA or 293uA	V_{OH}	1.05	1.125	1.2	V
OVP at CC1/CC2	IOL = 763uA	V_{OL}			0.075	V
Rise Time	VDD=4.7uF	t_{RISE_TX}	300			ns
Fall Time	VDD=4.7uF	t_{FALL_TX}	300			ns
TX output impedance		Z_{BMC_TX}	33		75	Ω
BMC RX SECTION						
Time Window for Detecting BUS non-idle		t_{RX_WINDOW}	12		20	us
Number to Count to Detect Bus non-idle		n_{COUNT}	3			
Rx Bandwidth limiting filter		t_{RX_Filter}	100			ns
RX input impedance		Z_{BMC_RX}	1			MΩ
DPDM SECTION						
Divider Mode						
D+ and D- Output Voltage		V_{DPDM_2P7}		2.7		V
D+ and D- Output Impedance		R_{DPDM_2P7}	24	30	36	kΩ
HVDCP Mode						
Output Voltage Select Reference		V_{SEL_REF}	1.8	2.0	2.2	V
Output Voltage Data Reference		V_{DAT_REF}	0.25	0.325	0.4	V
D+ Leakage Resistance		R_{DAT_LKG}			1500	kΩ
D- Pulldown Resistance		R_{DM_DWN}		15		kΩ
D+, D- Short Resistance	DCP mode	R_{SHORT}		50		Ω
D+ High Glitch Filter Time		T_{BC_DONE}	1000	1250		ms
D- Low Glitch Filter Time		T_{DM_LOW}	1	2		ms
FCP Mode						
Unit Interval for FCP		FCP_UI	144	160	176	us
D- FCP Tx Valid Output High		V_{TX_VOH}	2.55		3.6	V
D- FCP Tx Valid Output High		V_{TX_VOL}			0.3	V
D- FCP Rx Valid Input High		V_{RX_VOH}	1.4		3.6	V
D- FCP Rx Valid Input High		V_{RX_VOL}			1.0	V
D- FCP Pulldown Resistance		R_{FCP_DWN}			600	Ω

8 Detailed Description

8.1 VIN AND VDD PINS

VIN Power System
VIN pin is the power supply input, which is derived from the output of the AC-DC or DC-DC converter. Connect a 1μF decoupling MLCC between VIN pin and GND pin, as closer so possible.

VIN Discharge
The VIN pin is also connected to an internal MOSFET and discharging resistor, which is used as a bleeder to help discharge the output capacitor to vSafe5V upon the detachment of a connected device, or to a lower desired output voltage level upon a UFP request, such as from 20V to 5V.

VIN Voltage Sense
See the Control Loop Compensation Circuit (VFB, CSP, CSN, IFB, OPTO Pins) section。

VDD System Supply
An internal LDO is used to provide 4.8V for system supply voltage. Connect a 1μF MLCC to VDD pin for decoupling, as closer as possible.

8.2 CONTROL LOOP COMPENSATION CIRCUIT (VFB, CSP, CN-, IFB, OPTO PINS)
In the HT5350, the constant voltage loop compensation (CV loop) and constant current loop (CC loop) compensation are implemented. The output of the compensator is used to drive the primary side of the opto-coupler and control the AC-DC power loop.

Constant Voltage Loop Compensation Circuit（CV Loop)
The input of CV loop is connected to VFB pin, which is derived from the internal 90kΩ and 10kΩ voltage divider. The voltage divider senses the VIN voltage. Therefore, the VFB voltage is 10% of VIN voltage. The CV loop compensator is implemented by the resistor and capacitor network between OPTO pin and VFB pin.

Constant Current Loop Compensation Circuit (CC Loop)
USB PD3.0 PPS defines current limit function clearly. In the HT5350, the CC loop input is derived from a 5mΩ current sense resistor. The current signal is filtered by an RC network and fed to the CSP and CSN differential inputs. The CC loop compensator is implemented by the resistor and capacitor network between OPTO pin and IFB pin

Voltage Shift Slew Rate
As PD proceeds for a voltage transition, to make sure the voltage shifts smoothly and to reduce inrush during voltage transition, the HT5350 has a fixed voltage shift slew rate setting.

Cable Voltage Drop Compensation（IR Compensation)
The cable voltage drop compensation is implemented in the HT5350. Once it is enabled, the output voltage increases with 0mV/A, 50mV/A, 100mV/A or 200mV/A according to the load current. It is equivalent to adding a negative resistance to cancel or reduce the cable resistance. The negative resistance can be programmed as 0mΩ, -50mΩ, -100mΩ or -200mΩ.
For example, for the 5V 3A condition with the 100mV/A compensation option, the actual output voltage is: 5V+3A*100mV/A=5.3V.

8.3 CC1 AND CC2 PINS

Type-C CC Function
CC1 and CC2 are the Configuration Channel pins used for connection and attachment detection, plug orientation determination and system configuration management across USB Type-C cable. CC1 and CC2 only support DFP mode with 500mA, 1.5A and 3A current advertising. CC1 and CC2 can support 28V high voltage. This is used for protection when the CC1 or CC2 is shorted to the VBUS pin.

BCM Driver
Through the Type-C detection, one of CC1or CC2 pins will be connect to the internal BMC block to achieve PD communication.

VCONN Power and eMarker Detection
The HT5350 supports VCONN power and USB eMarker detection function. The USB PD protocol defines that if an adapter is not with a captive cable, when the adapter has a PD output current more than 3A, it's PD controller must support VCONN power supply and eMarker detection function.

8.4 DP AND DM PINS
The HT5350 has DP, DM Pins, which can support the legacy charging modes as below:

Apple divider mode, 5V/2.4A charge mode (Divider 3 Mode)
The HT5350 support 5V/2.4A charge mode.

USB BC1.2 DCP charge mode
The HT5350 support USB BC1.2 DCP charge protocol.

HVDCP mode
The HVDCP mode includes multiple charging protocols, including QC2.0/QC3.0/FCP/AFC. HT5350 supports the QC2.0/3.0 Class A (5/9/12V), FCP (5/9V) and AFC (5/9/12V).
The control truth table is shown as below.

Table xx. HVDCP Voltage Mode

Signals from Portable Device		HVDCP
D+	D-	Adaptive Voltage
0.6V	0.6V	12V
3.3V	0.6V	9V
0.6V	3.3V	Continuous Mode
3.3V	3.3V	20V
0.6V	GND	5V

8.5 VBUS PIN
This pin is used to sense VBUS presence, monitor VBUS voltage and discharge VBUS on USB Type-C receptacle side. Connect directly to VBUS at the Type-C Receptacle.

vSafe0V Detection
When the HT5350 enter AttachWait.SRC for $t_{CCDebounce}$, it detects whether the VBUS voltage is within vSafe0V. If yes, the HT5350 pulls low GATE pin and enters Attached.SRC state. If no, it will stay at AttachWait.SRC state.

VBUS Discharge
The VBUS pin is also connected to an internal MOSFET and discharging resistor, which is used as a bleeder to help discharge the output capacitor to vSafe0V upon the detachment of a connected device, or to a lower desired output voltage level upon a UFP request, such as from 20V to 5V.

8.6 GATE PIN
The GATE pin is open–drain output allows to drive directly a PMOS load switch. When the HT5350 enters Type-C attached state (Attached.SRC), GATE pin is pulled low. When the HT5350 exits from Type-C attached state, the GATE pin is removed from being pulled low.

8.7 GPIO PIN
The GPIO pin is open-drain output which can be configured as 4 functions:

- Low VIN and Low Io indication: the GPIO pin is internally pulled down in default. When VIN is lower than 4.5V and load current is lower than 0.5A, GPIO becomes HIZ. An external pull-up resistor can be tied to this pin to get a high voltage signal.

- Low Io indication: the GPIO pin is internally pulled down in default. When load current is lower than 0.5A, GPIO becomes HIZ. An external pull-up resistor can be tied to this pin to get a high voltage signal.
- UFP indication: the GPIO pin is in HIZ status in default. When there is a sink attached at the CC pin, GPIO is pulled down.
- GPIO PDER: When PDER pin (Pin 12) is configured as OTP function. This GPIO pin can be re-configured as an additional Power Derating input by connecting this pin to an external pull-up DC voltage (VDD, etc.) via a resistor. With this setting, when GPIO is pulled down to be lower than $V_{GPIO_PDER_LOW}$, the advertised PDP of HT5350 is changed to be PDP-ΔP1. (See more details in the section of "PDER Pin").

8.8 PDER PIN

The HT5350 with QFN-16 package supports Smart Power Derating (SPD) function, which can optimize output power distribution when used in a USB-A + USB-C dual-port charger or USB-C +USB-C dual-port charger. The SPD is always enabled for HT5350. And the PDER pin is pulled up to an internal current source. With different resistors at PDER pin, HT5350 can re-advertise different pre-set power settings as shown in the table below:

Table xx. Recommended PDER Resistor

R_{PDER} (KΩ)	Advertised Power by HT5350
∞	**Default Power Setting (PDP)**
30	**Default Power Setting (PDP) – any power P1**
15	**Default Power Setting (PDP) – any power P1 - ΔP**
10	**Default Power Setting (PDP) – any power P1 - 2*ΔP**
0	**5V or 5/9V or 5/9/12V**

Any power P1 could be any power value which is lower than Default Power Settings (PDP). ΔP could be a pre-set value such as 10W, 12W, 15W or 18W. Once PDER pin is forced tie to GND, HT5350 can only advertise 5V or 5/9V or 5/9/12V.

PDER pin can also configured as Over-temperature protection. When this function is selected, connects a NTC of 47K resistance with BK=4108, with the increase of temperature, V_{PDER} falls and shut down the system after $V_{PDER}<V_{OTP_FALL}$.

9 PROTECTION FUNCTIONS

9.1 OVER-VOLTAGE PROTECTION (VIN_OV)

The HT5350 detects the VIN pin voltage to achieve over-voltage protection function. The threshold to trigger over-voltage protection is 120% of the V_{IN_REF}. When the over-voltage condition occurs, the HT5350 stops to pull the GATE pin low. When the over-voltage condition is removed, the HT5350 is reset to standby mode and will automatic recover again.

9.2 UNDER-VOLTAGE PROTECTION (VIN_UV)

The HT5350 detects the VIN pin voltage to achieve under-voltage protection function. The threshold to trigger under-voltage protection is 80% of the V_{IN_REF}. When the under-voltage condition occurs, the HT5350 stops to pull the GATE pin low. When the over-voltage condition is removed, the HT5350 is reset to standby mode and will automatic recover again.

According to PD protocol, under-voltage protection is turned off when it works in PPS mode.

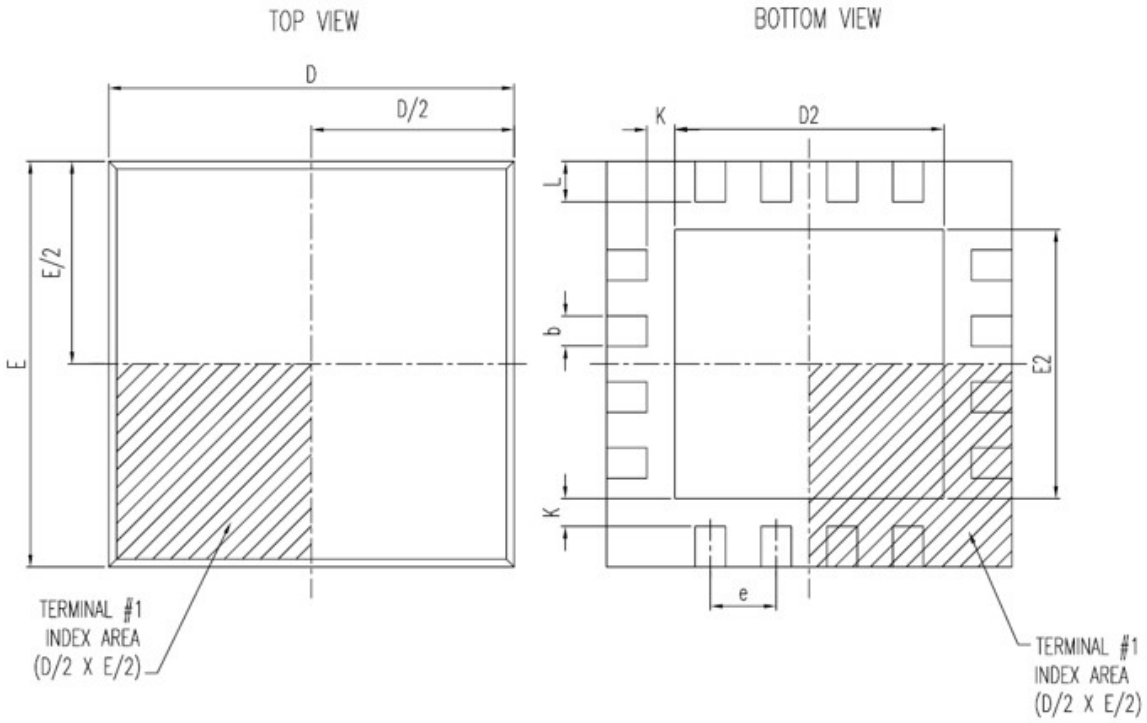
9.3 OVER-TEMPERATURE PROTECTION (OTP)

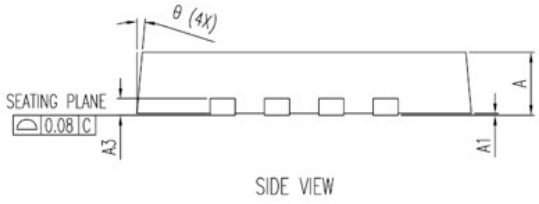
When the junction temperature rises across 135°C, over-temperature protection takes action and the load switch is turned off. When the junction temperature falls across 100°C, the HT5350 is reset to standby mode and will automatic recover again.

9.4 OVER-CURRENT PROTECTION (OCP)

When the current sensed by the sense resistor exceeds protection threshold, the over-current protection takes action and the load switch is turned off. When the over-current condition is removed, the HT5350 is reset to standby mode and will automatic recover again.

10 QFN-16 PACKAGE INFORMATION





SYMBOL	DIMENSION IN MM		
	MIN.	NOM.	MAX.
A	0.70	0.75	0.80
A1	0	0.02	0.05
A3		0.20 REF.	
D		4.00 BASIC	
D2	2.50	2.65	2.80
E		4.00 BASIC	
E2	2.50	2.65	2.80
e		0.65 BASIC	
b	0.25	0.30	0.35
L	0.35	0.40	0.45
K	0.20		
θ	0°		14°
JEDEC	MO-220 (Variation VGGC-2)		