Table of Contents

Chapter 1. Introduction

Growing popularity of standard USB PD3.0 chargers for mobile phone and notebook PC spurs the demand for leveraging standard PD 3.0 chargers to replace purposely and individually built chargers for any battery power electronic devices to reduce E-Waste.

AP33772 Evaluation Board (EVB) is intended to be used as an evaluation vehicle for charging applications between a Type C Connector-equipped Device (**TCD**, Energy Sink) and a Type C Connector-equipped PD3.0 compliance Charger or Adaptor (**PDC**, Energy Source).

Figure 1 illustrates a TCD, embedded with PD3.0 Sink controller IC (AP33772), is physically connected to PDC, embedded with USB PD3.0 decoder (AP43771), through a Type C-to-Type C cable. Based on built-in USB PD3.0 compliant firmware, The AP33772 and AP43771 pair would go through the USB PD3.0 standard attachment procedure to establish suitable PD3.0 charging state.

The AP33772 User's Guide of the Evaluation Board (EVB) explains a flexible I2C setting arrangement (I2C Interface Pin, I2C register Map and Operations) to request desired input voltage and input power for a typical TCD. Various system protection functions and system status checks could be also performance by accessing relevant I2C register contents by the host MCU device of the TCD so as to take proper system actions.

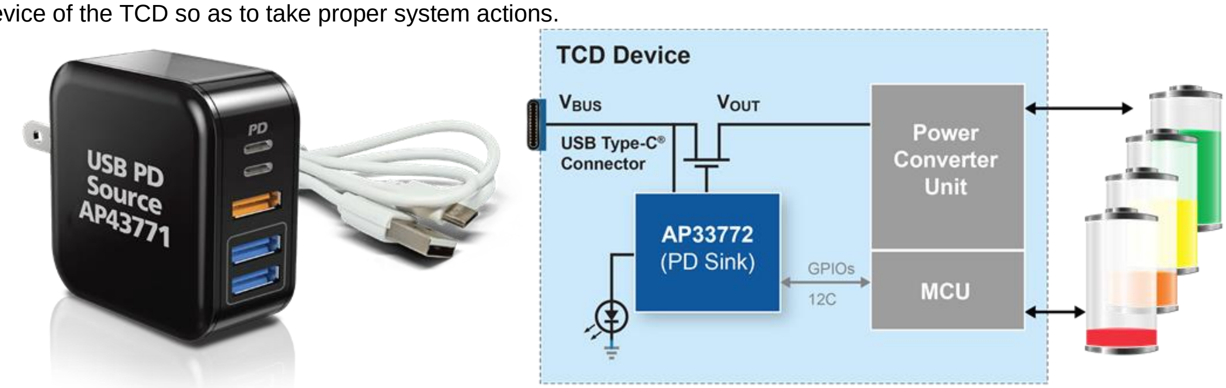


Figure 1 – A typical TCD uses AP33772 PD Sink Controller with I2C Interface to request power from an USB Type-C PD3.0/PPS Compliance Source Adapter

Chapter 2. AP33772 Sink Controller

2.1 Package Outline

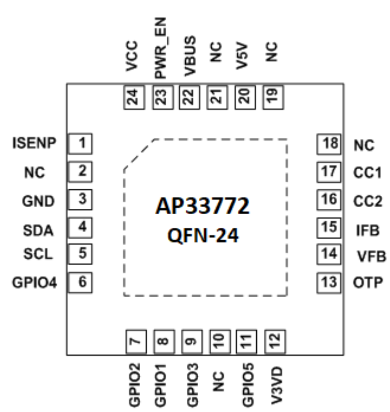


Figure 2 – Package Outline

2.2 Pin Descriptions

Pin No	Pin Name	Type (Note)	Pin Function
1	ISENP	AIO	Current Sense Positive Node.
2	NC	-	No Connection
3	GND	Ground	Ground
4	SDA	DIO	I2C Data
5	SCL	DIO	I2C Clock
6	GPIO4	DIO	General Purpose Input / Output, for LED usage
7	GPIO2	DIO	General Purpose Input / Output
8	GPIO1	DIO	General Purpose Input / Output
9	GPIO3	DIO	For Interrupt usage
10	NC	-	No Connection
11	GPIO5	DIO	General Purpose Input / Output
12	V3VD	DP	3.3V LDO Output. Power for Digital circuit and Digital I/O pins, with 0.1uF to Ground
13	OTP	AIO	Current source output. Can be connected to external NTC sensor for Over Temperature Protection.
14	VFB	AI	For Voltage Measurement.
15	IFB	AI	For Current Measurement, with 1nF to Ground
16	CC2	AIO	Type-C configuration channel 2
17	CC1	AIO	Type-C configuration channel 1
18	NC	-	No Connection
19	NC	-	No Connection
20	V5V	AP	5V LDO output. Power for Analog circuit and Analog I/O pins, with 0.1uF to Ground
21	NC	-	No Connection
22	VBUS	AHV	Terminal for Discharge Path.
23	PWR_EN	AHV	To control external NMOS switch ON (High) or OFF (Low).
24	VCC	AHV	The power supply of the IC, connected to a ceramic capacitor.
-	EP	GND	Exposed pad is connected to Ground

Note:
AHV– Analog High Voltage pin
AP – Power for Analog Circuit and Analog I/O pins, 5.0V operation
AI – Analog Input pin
DP – Power for Digital Circuit and I/O pins, 3.3V operation
AIO – Analog I/O pin.
DIO – Digital I/O pin.

Table 1 – AP33772 Pin Number, Name, Type, and Pin Function

Chapter 3. EVB Hardware Details

3.1 EVB TOP View

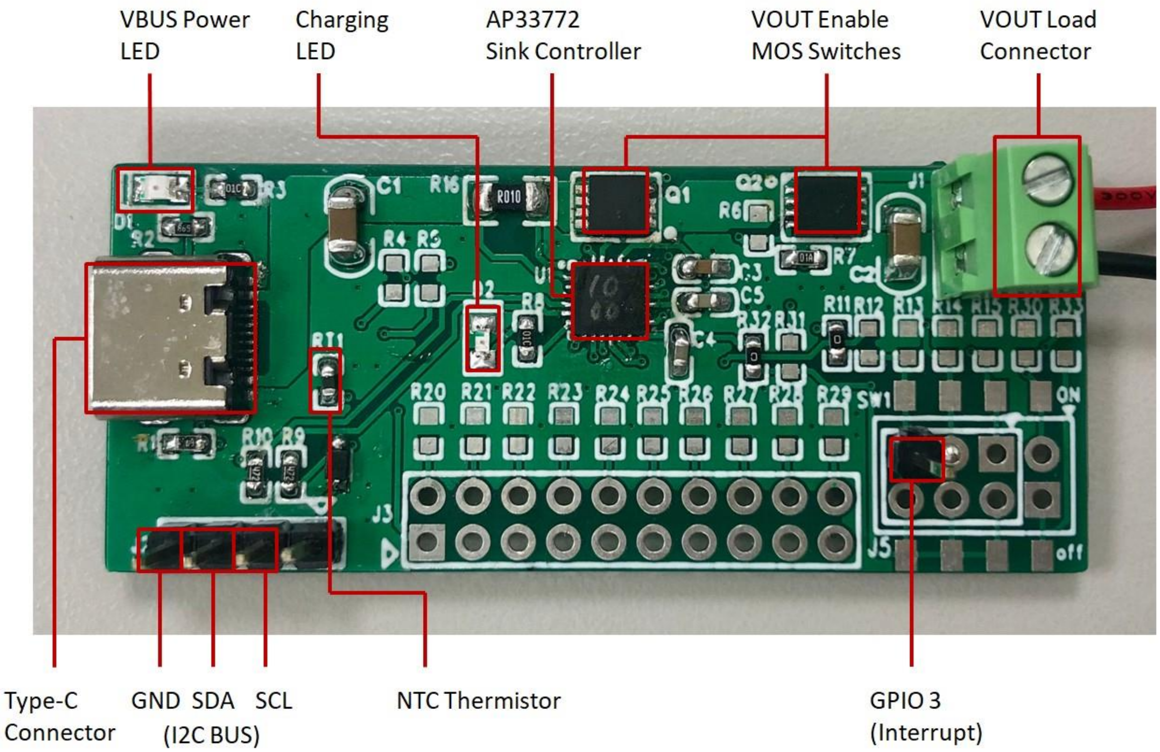


Figure 3 – AP33772 evaluation board top view and its key portions

3.2 EVB Block Diagram

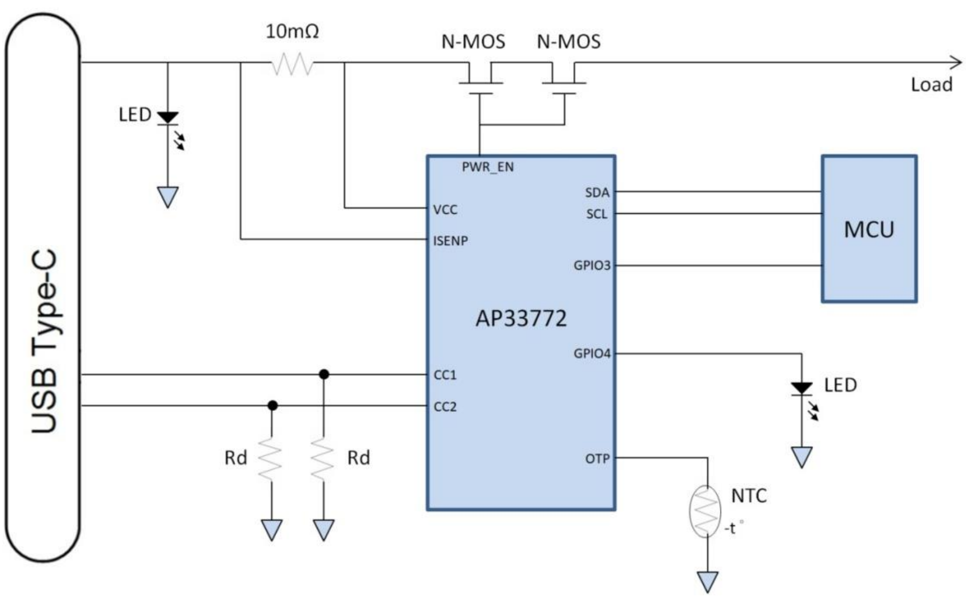


Figure 4 – Block diagram of the AP33772 evaluation board

3.3 EVB Schematics

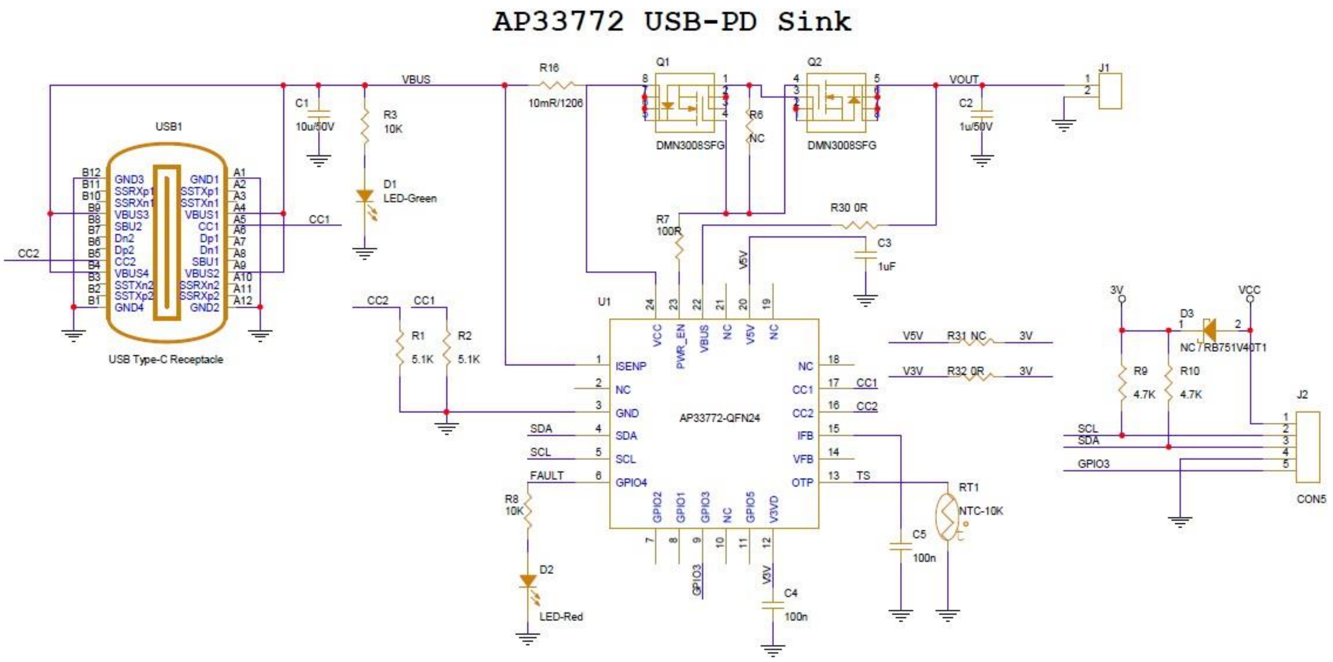


Figure 5 – Detailed schematics of the AP33772 evaluation board

3.4 EVB System BOM

Item	Quantity	Reference	Part
1	1	C1	10u/50V
2	1	C2	1u/50V
3	1	C3	1uF
4	1	C4	100n
5	1	C5	100n
6	2	D1, D2	LED
7	1	D3	RB751V40T1
8	2	Q1, Q2	DMN3008SFG
9	2	R1, R2	5.1K
10	1	R3	10K
11	1	R7	100
12	1	R8	10K
13	2	R9, R10	4.7K
14	1	R16	10mR/1206
15	2	R30, R32	0
16	1	RT1	NTC-10K
17	1	USB1	USB Type-C Receptacle
18	1	U1	AP33772-QFN24

Chapter 4. EVB Function Description

The AP33772 EVB provide users a convenient but flexible way of power profile setting as well as various status monitoring for proper actions by the host MCU in TCD through simple I2C interface pins (SCL and SDA).

4.1 Board Outline

The AP33772 EVB outline and floor plan is shown as Figure 6, where its connector and jumper location are listed in Table 2.

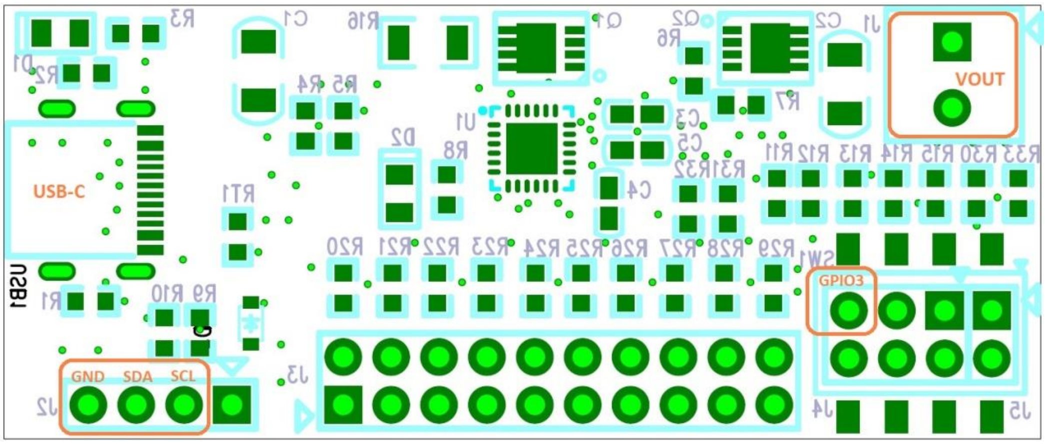


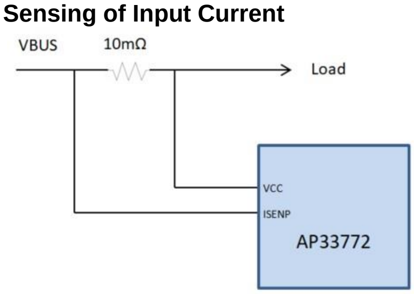
Figure 6 – Connector and jumper locations

Location	Function
J1	VOUT and Load Connector
J2	I2C Bus
GPIO3	Interrupt

Table 2 – Connectors and jumper names of the evaluation board

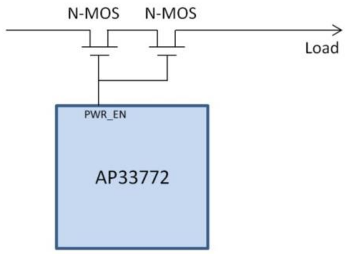
4.2 Application Circuit Description

Sensing of Input Current



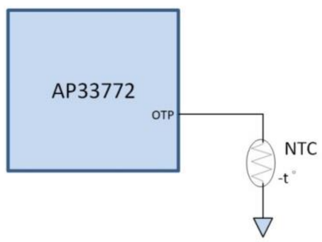
As shown in the figure above, the 10mΩ resistor is connected in series to detect the charging current. The ISENP pin is connected to the input side of the 10mΩ resistor, and the VCC pin is connected to the other side, AP33772 detects the current by measuring the voltage drop across the current sense resistor.

Use of Back-to-back N-MOS chips



The Common-Source Back-to-back N-MOSFET in the battery pack protection circuit module control charging and play a protective role in the occurrence of failures such as over-voltage, over-current and over-temperature that may damage the electrical appliances. The Back-to-back N-MOSFET control is also used to prevent current flows backward through the system when unplug the cable from PD Charger.

Temperature Sensing Circuitry



A 10kΩ NTC (Negative Temperature Coefficient) thermistor is connected to OTP pin and grounded nearby the potential hot spot. The characteristic data of temperature and resistance value of the NTC thermistor needs to set by the user through I2C. Then host MCU could read and calculate the temperature and enable OTP (Over Temperature Protection), De-rating function through I2C interface.

LED Light Indication Circuitry

The LED light and resistor is used to connect to GPIO4 pin and ground. The LED charging indication light starts to breathe at a speed to match quick charging pace for the battery.

I2C Support

The I2C Interface is supported in the AP33772, and used to communicate with the host MCU of TCD. I2C pins are listed as below Table 3. They are used to set the AP33772 register data like Initialization, PDO, APDO, OCP, OTP, temperature, de-rating, interrupt, and so on, Also, the AP33772 operating status can be monitored at the same time.

Meanwhile, GPIO3 is used as a fault report channel to the Interrupt input pin of the host MCU in case of any fault occur which deserves immediate action from the host MCU.

For the I2C commands and registers, please refer to Chapter 5.

Pin No	Pin Name	Pin Function
4	SDA	I2C Data
5	SCL	I2C Clock
9	GPIO3	For Interrupt usage

Table 3 – I2C interface pin list

4.3 Application Alert for Power Sequencing Requirement

When using a Host System (Single Board Computer, or MCU-based System) with I2C interface pins (SDA, SCL) to connect to AP33772 EVB, please make sure to power the AP33772 EVB board first before apply power to the Host System. The power-sequencing requirement for AP33772 EVB being powered up first is a MUST due to the I2C design for SDA and SCL pins.

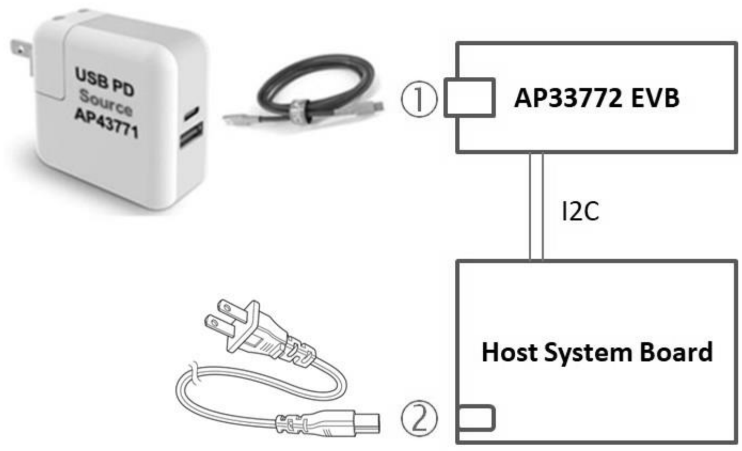


Figure 7 – AP33772 EVB power up sequence

If AP33772 EVB has been connect to the other I2C-based Host System already. The power up sequence MUST be followed:

1. AP33772 EVB should be “Powered Up” first.
2. Then apply power to the Host System Board.

Chapter 5. I2C Command/Register Summary

As an I2C slave device, the physical address of the AP33772 is 0x51.

The AP33772 supports I2C commands and registers, such as Initialization, PDO, APDO, OCP, OTP, temperature, de-rating, interrupt, status and so on. All AP33772 I2C related control operations and registers are summarized in this chapter.

5.1 I2C Command Format

Device Address Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
DevAddr6	DevAddr5	DevAddr4	DevAddr3	DevAddr2	DevAddr1	DevAddr0	R/W
1	0	1	0	0	0	1	0/1

Command Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
CmdBit7	CmdBit6	CmdBit5	CmdBit4	CmdBit3	CmdBit2	CmdBit1	CmdBit0

Data Format

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
DataBit7	DataBit6	DataBit5	DataBit4	DataBit3	DataBit2	DataBit1	DataBit0

5.2 I2C Operation

I2C Write Operation

Start	Device Address 7 Bits	W	A	Command 8 Bits	A	Data 0 8 Bits	A	Data ... 8 Bits	A	Data n 8 Bits	A	Stop

I2C Read Operation

Start	Device Address 7 Bits	W	A	Command 8 Bits	A	Restart	Device Address 7 Bits	R	A	Data 0 8 Bits	A	Data ... 8 Bits	A	Data n 8 Bits	NA	Stop

5.3 Register Summary

Register	Command	Length	Attribute	Pwr-on	Description
SRCPDO	0x00	28	RO	All 00h	Power Data Object (PDO) used to expose PD Source (SRC) power capabilities. Total length is 28 bytes
PDONUM	0x1C	1	RO	00h	Valid source PDO number
STATUS	0x1D	1	RC	00h	AP33772 status
MASK	0x1E	1	RW	01h	Interrupt enable mask
VOLTAGE	0x20	1	RO	00h	LSB 80mV
CURRENT	0x21	1	RO	00h	LSB 24mA
TEMP	0x22	1	RO	19h	Temperature, Unit: °C
OCPTHR	0x23	1	RW	00h	OCP threshold, LSB 50mA
OTPTHR	0x24	1	RW	78h	OTP threshold, Unit: °C
DRTHR	0x25	1	RW	78h	De-rating threshold, Unit: °C
TR25	0x28	2	RW	2710h	Thermal Resistance @25°C, Unit: Ω
TR50	0x2A	2	RW	1041h	Thermal Resistance @50°C, Unit: Ω
TR75	0x2C	2	RW	0788h	Thermal Resistance @75°C, Unit: Ω
TR100	0x2E	2	RW	03CEh	Thermal Resistance @100°C, Unit: Ω
RDO	0x30	4	WO	-	Request Data Object (RDO) is use to request power capabilities.
VID	0x34	2	RW	0000h	Vendor ID, reserved for future applications

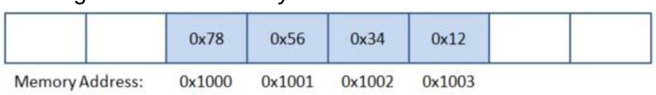
PID	0x36	2	RW	0000h	Product ID, reserved for future applications
RESERVED	0x38	4	-	-	Reserved for future applications

Attribute Convention
RW: Readable / Writable
RO: Read-Only
RC: Read-Clear
WO: Write-Only

Table 4 – AP33772 Register Summary

The memory representation of multibyte data types on AP33772 is Little Endian Byte Order. The least significant byte (the "little end") of the data is placed at the byte with the lowest address.

Suppose integer is stored as 4 bytes then a variable X with value 0x12345678 will be stored as following.

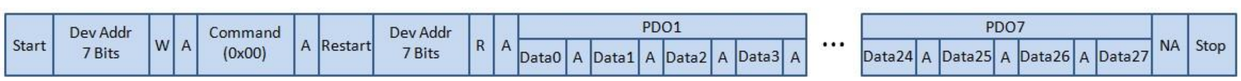


SRCPDO (0x00~0x1B)

SRCPDO is used to read source PDO data and the number of source PDO.

One PDO consists of 4 bytes, the maximum number of PDO is 7. The total length of SRCPDO register is 28 bytes. The initial value of SRCPDO is all 00h.

Format of I2C read SRCPDO register:



There are two types of Power Data Object (PDO) format, Fixed Supply Power Data Object (Fixed PDO) and Programmable Power Supply Augmented Power Device Object (PPS APDO)

Fixed PDO
Fixed Supply Power Data Object (Fixed PDO)

Bit(s)	Description
B31…30	00b - Fixed supply
B29…20	Reserved
B19…10	Voltage in 50mV units
B9…0	Maximum Current in 10mA units

Table 5 – Fixed Supply PDO

PPS APDO
Programmable Power Supply Augmented Power Device Object (PPS APDO)

Bit(s)	Description
B31…30	11b – Augmented Power Data Object (APDO)
B29…28	00b – Programmable Power Supply 01b…11b - Reserved
B27…25	Reserved
B24…17	Maximum Voltage in 100mV increments

B16	Reserved
B15…8	Minimum Voltage in 100mV increments
B7	Reserved
B6…0	Maximum Current in 50mA increments

Table 6 – Programmable Power Supply APDO

PDONUM (0x1C)

The PDONUM register contains the number of valid source PDO.
The default value for PDONUM is 00h, and shall be updated to 1~7 after negotiation with PD source successfully.

STATUS (0x1D)

The host MCU, working as I2C master, can access status of the AP33772 through the STATUS register.
The STATUS register will be reset to 0 after a read operation.

STATUS	Bit(s)	Attribute	Description
DR	B7	RC	De-rating(DR) start status
OTP	B6	RC	OTP status
OCP	B5	RC	OCP status
OVP	B4	RC	OVP status
	B3	RC	Reserved
NEWPDO	B2	RC	Source PDOs received
SUCCESS	B1	RC	1: success 0: unsuccess The negotiation result
READY	B0	RC	Status ready STATUS Bits [2:1] are valid when READY is set

Attribute Convention
RC: Read-Clear

Table 7 – STATUS Register

If Bit [0] =1. AP33772 has updated STATUS Bits [2:1].

If Bit [1] = 1. It indicates that the negotiation is successful.
If Bit [1] = 0. It indicates that the negotiation is unsuccessful.

If Bit [2] = 1. AP33772 has received the source PDOs and updated the value of SRCPDO register. The host MCU can access the updated content of SRCPDO register.

NEWPDO [B2]	SUCCESS [B1]	READY [B0]	Description
-	-	0	Status is invalid
0	0	1	The host MCU had written the RDO register but the negotiation is unsuccessful
0	1	1	The host MCU had written the RDO register and the negotiation is successful
1	0	1	The PD source advertise PDOs and the negotiation with RDO is unsuccessful
1	1	1	The PD source advertise PDOs and the negotiation with RDO is successful (Note)

Note:
On startup AP33772 requests 1st PDO (Fixed 5V) during the first negotiation (source-initiated)

Table 8 – Truth table of STATUS Bits [2:0]

If Bit [4] = 1. It indicates that OVP (Over Voltage Protection) has been triggered, Output Enable N-MOS switch has been turn off. The host MCU will have to starts a new RDO to initiate a new negotiation cycle.

If Bit [5] = 1. It indicates that OCP (Over Current Protection) has been triggered, Output Enable N-MOS switch has been turn off. The host MCU will have to starts a new RDO to initiate a new negotiation cycle.

If Bit [6] = 1. It indicates that OTP (Over Temperature Protection) has been triggered, Output Enable N-MOS switch has been turn off. The host MCU will have to starts a new RDO to initiate a new negotiation cycle.

If Bit [7] = 1. The AP33772 starts the Power DR (De-Rating) process and allow input current will be reduced by 50% through sending out a new RDO to negotiate with the PD source device (e.g. PD 3.0 compliance Charger).

MASK (0x1E)

The AP33772 supports a level-triggered interrupt signal through GPIO3 pin to the host MCU. The MASK register defines enable and disable of ON and OFF for various STATUS defined events. The default value for MASK is 01h.

MASK	Bit	Pwr-on	Description
DR_EN	B7	0b	DR start status enable
OTP_EN	B6	0b	OTP status enable
OCP_EN	B5	0b	OCP status enable
OVP_EN	B4	0b	OVP status enable
	B3	0b	Reserved
NEWPDO_EN	B2	0b	New PDO status enable
SUCCESS_EN	B1	0b	Negotiation success status enable
READY_EN	B0	1b	Status ready enable

Table 9 – MASK Register

VOLTAGE (0x20)

The VOLTAGE register contains the voltage of VOUT (connected to J1 jumper). The LSB (Least Significant Bit) is 80mV.
The default value for VOLTAGE is 00h (0mV).

CURRENT (0x21)

The CURRENT register contains the current of VBUS (refer to Section 4.2 Sensing of Input Current). The LSB (Least Significant Bit) is 24mA.
The default value for CURRENT is 00h (0mA).

TEMP (0x22)

The TEMP register contains the temperature near the NTC thermistor (refer to Section 4.2 Temperature Sensing Circuitry). The unit is °C.
The default value for TEMP is 19h (25°C).

OCPTHR (0x23)

The OCPTHR register defines the threshold of maximum OCP value triggers OCP protection function (Unit: mA). The LSB (Least Significant Bit) is 50mA.
The default value for OCPTHR is 00h, and shall be updated to the maximum current for chosen PDO after negotiation with PD source successfully.

OTPTHR (0x24)

The OTPTHR register defines the threshold of temperature value triggers OTP function. The unit is °C.
The default value for OTPTHR is 78h (120°C).

DRTHR (0x25)

The DRTHR register defines the threshold of temperature value triggers Power De-Rating procedure. The unit is °C.
The default value for DRTHR is 78h (120°C).

TR25 (0x28~0x29)

The TR25 register defines the resistance value of NTC thermistor at 25°C (Unit: Ω).
The default value for TR25 is 2710h (10000Ω).

Format of I2C read TR25 register:

Start	Dev Addr 7 Bits	W	A	Command (0x28)	A	Restart	Dev Addr 7 Bits	R	A	Data 0	A	Data 1	NA	Stop

TR50 (0x2A~0x2B)

The TR50 register defines the resistance value of NTC thermistor at 50°C (Unit: Ω).
The default value for TR50 is 1041h (4161Ω).

TR75 (0x2C~0x2D)

The TR75 register defines the resistance value of NTC thermistor at 75°C (Unit: Ω).
The default value for TR75 is 0788h (1928Ω).

TR100 (0x2E~0x2F)

The TR100 register defines the resistance value of NTC thermistor at 100°C (Unit: Ω).
The default value for TR100 is 03CEh (974Ω).

RDO (0x30~0x33)

The external host MCU could set a complete 4-Byte RDO (Request Data Object) register to initiate the PD3.0 negotiation procedure with an external USB PD3.0 compliant charger to obtain desired input voltage and current. Upon receiving PS_RDY message from the PD source after the RDO sent by the AP33772, the STATUS Bit [1] and Bit [0] will be set to 1. If RDO is rejected by PD Source, STATUS Bit [1] will be set to 0 and Bit [0] will be set to 1.

There are two formats for RDO, Fixed RDO and Programmable RDO.

Fixed Request Data Object (Fixed RDO)
If the chosen PDO format is Fixed PDO, RDO content will be loaded under Fixed RDO format.

Bit(s)	Description
B31	Reserved – Shall be set to zero
B30…28	Object position (000b is Reserved and Shall Not be used)
B27…20	Reserved - Shall be set to zero
B19…10	Operating Current in 10mA units
B9…0	Maximum Operating Current 10mA units

Table 10 – Fixed RDO

Programmable Request Data Object (Programmable RDO)
If the chosen PDO format is a PPS APDO, RDO content will be loaded under Programmable RDO format.
If Programmable RDO content is loaded properly, the AP33772 switches to PPS mode and automatically issue RDO to maintain PD Source VOUT supply. Under PPS mode, the host MCU could load the desired Output Voltage (B19….9) and Operating current (B6….B0) anytime and initiative a new cycle of PD3.0 negotiation cycle.

Bit(s)	Description
B31	Reserved – Shall be set to zero
B30…28	Object position (000b is Reserved and Shall Not be used)

B27…20	Reserved - Shall be set to zero
B19…9	Output Voltage in 20mV units
B8…7	Reserved - Shall be set to zero
B6…0	Operating Current 50mA units

Table 11 – Programmable RDO

Format of I2C write RDO register:

Start	Dev Addr 7 Bits	W	A	Command (0x30)	A	Data 0 B7...B0	A	Data 1 B15...B8	A	Data 2 B23...B16	A	Data 3 B31...B24	A	Stop

5.4 Reset Command

The AP33772 provides a Reset Command to the host MCU to initiate a hard reset by writing the following value to the RDO register.

Reset Command / RDO	
Bit(s)	Value
B31…24	0x00
B23…16	0x00
B15…8	0x00
B7…0	0x00

After AP33772 receives the Reset Command from the host MCU, it will send a hard reset signal to the PD source. Both the AP33772 and PD source will cause their power supplies to return to their default states after a hard reset. All AP33772 registers will be restored to their default values and the associated output Enable MOS switch will be turned off.

Chapter 6. Built-In Application Firmware Features

6.1 Firmware Overview and LED Indication

The AP33772 has built-in firmware, which can process I2C commands and protect the TCD during charging. Figure 8 shows the flowchart of AP33772 firmware.

The Host System in a Type C battery-powered device writes RDO (Request Data Object) to associated RDO register through I2C interface to indicate the desired profile. Based on the RDO, the AP33772 starts the PD3.0 negotiation procedure with the target PDC. After a successful negotiation, VOUT of the AP33772 enables desired RDO. If not, VOUT voltage remains the same.

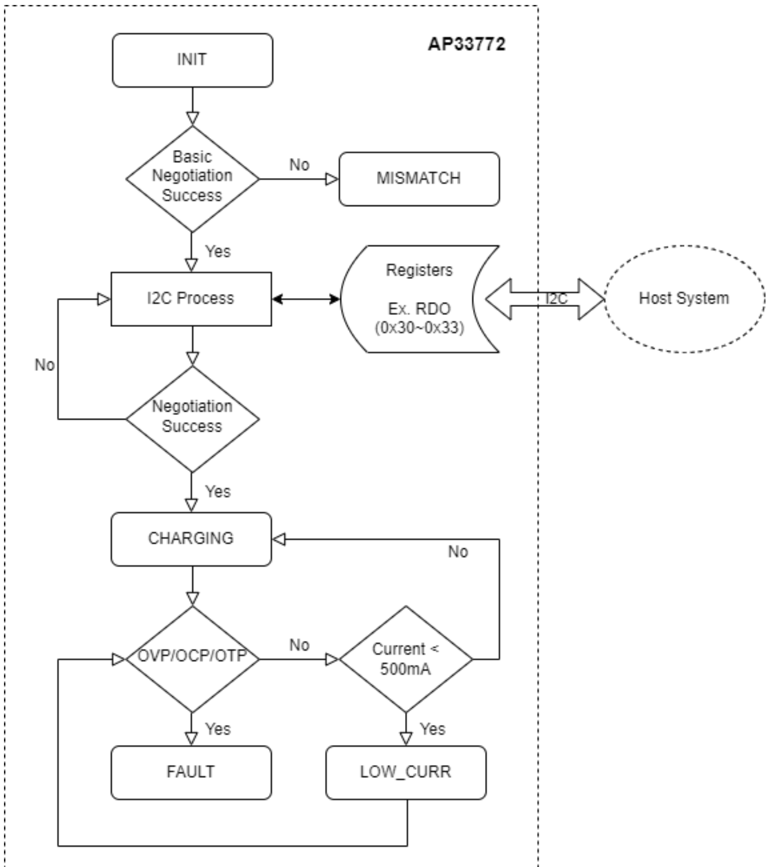


Figure 8 – AP33772 Firmware Flowchart

The AP33772 controls LED lighting through GPIO4. Table 12 summarizes LED indication and VOUT in each State.

State	LED Indication	VOUT	Comments
INIT	NA	OFF	VBUS/Rp attached and AP33772 initialization
CHARGING	4-sec Breathing	ON	Successful negotiation and start charging
LOW_CURR	Full Light	ON	Charging current < 500mA
NONPD	2-sec Flicker	OFF	Non-PD Source
FAULT	0.6-sec Flicker	OFF	OVP, OCP or OTP occurs

Table 12 – LED Indication Table

6.2 Interrupt

The AP33772 supports a level-triggered interrupt signal through GPIO3 pin to the host MCU. The MASK register defines enable and disable of options of ON and OFF for each interrupt-able event. Refer to Table 9 in Section 5.3 for the definition of the

MASK register

Interrupt Initialization is required before use. When defined interrupt-able event happens, the AP33772 will set the GPIO3 level high (1) if the relevant event of the MASK register is enabled.

For example, if the OVP_EN is set to be 1 (MASK = 0x11), GPIO3 is to be set at high when OVP event occurs.

MASK	Bit	Value
DR_EN	B7	0b
OTP_EN	B6	0b
OCP_EN	B5	0b
OVP_EN	B4	1b
	B3	0b
NEWPDO_EN	B2	0b
SUCCESS_EN	B1	0b
READY_EN	B0	1b

Table 13 – Example of MASK setting

6.3 Protection

Over Voltage Protection (OVP)

The AP33772 triggers the OVP protection when VBUS voltage is higher than OVP threshold Voltage. Table 14 shows the correspondence between Negotiated Voltage (V_{NEGO}) range and OVP Threshold setting.

Negotiated Voltage Range (V)	OVP Threshold Setting(V)
3.3 ~ 18	V_{NEGO} + 2
18.08 ~ 21	V_{NEGO} * 110%

Table 14 – Negotiated Voltage and OVP Threshold correspondence

Table 15 shows the example of the relationship between Negotiated Voltage (V_{NEGO}) and OVP Threshold Voltage (V_{OVPTH}).

Negotiated Voltage (V_{NEGO})	OVP Threshold Setting (V)	OVP Threshold Voltage (V_{OVPTH})
3.3	V_{NEGO} + 2	5.3
5		7
9		11
15		17
18		20
19	V_{NEGO} * 110%	20.9
20		22
21		23.1

Table 15 – Example of OVP Threshold Voltage

The OVP de-bounce time mechanism is to prevent mis-triggering by some unintended spurious noises. The default OVP de-bounce time is 30ms. If VBUS voltage is higher than V_{OVPTH} after the de bounce time limit (30ms), the STATUS Bit [4] will be set to 1. Subsequently, the associated output Enable MOS switch will be turned off. The host MCU needs to load new RDO to start a PD3.0 negotiation process to resume quick charging operation.

Over Current Protection (OCP)

The AP33772 triggers the OCP protection when the charging current is larger than OCP Threshold Current. Table 16 shows the correspondence between OCPTHR register value and OCP Threshold Current. The default value of the OCPTHR register is 00h.

After successful negotiation with the PD source, if the OCPTHR value is still 00h, the OCP Threshold Current should be updated to 110% of the maximum current (I_{MAX}) of the selected PDO/APDO.

If the OCPTHR value has been updated through I2C interface, the OCP Threshold Current should be updated to 110% of OCPTHR value.

State	OCPTHR Value	OCP Threshold Current
INIT	OCPTHR = 0	NA
CHARGING	OCPTHR = 0	I_{MAX} * 110% (Note)
CHARGING	OCPTHR != 0	OCPTHR * 110%

Note:
I_{MAX} : Maximum Current of PDO/APDO

Table 16 – OCPTHR and OCP Threshold correspondence

The default OCP de-bounce time is 30ms. If the charging current is larger than OCP Threshold Current after de-bounce time (30ms), the STATUS Bit [5] will be set to 1. Subsequently, the associated Output Enable MOS switch will be turned off. The host MCU will need to load new RDO to start a PD3.0 negotiation process to resume quick charging operation.

Over Temperature Protection (OTP) and De-rating

The host MCU could access the estimated temperature of a potential hot spot by accessing the TEMP register. A NTC thermistor is used to connect to OTP pin and ground nearby the potential hot spot. The host MCU must initialize the TR25, TR50, TR75 and TR100 registers before reading TEMP register or enabling OTP and power de-rating functions.

The default value of the OTPTHR register is 78h (120°C), which can be updated through I2C interface. If the TEMP value rises over the OTPTHR value after the de-bouncing time (30ms), the STATUS Bit [6] is to be set at 1. The associated Output Enable MOS switch will be turned off. The host MCU will need to load new RDO to start a PD3.0 negotiation process to resume quick charging operation.

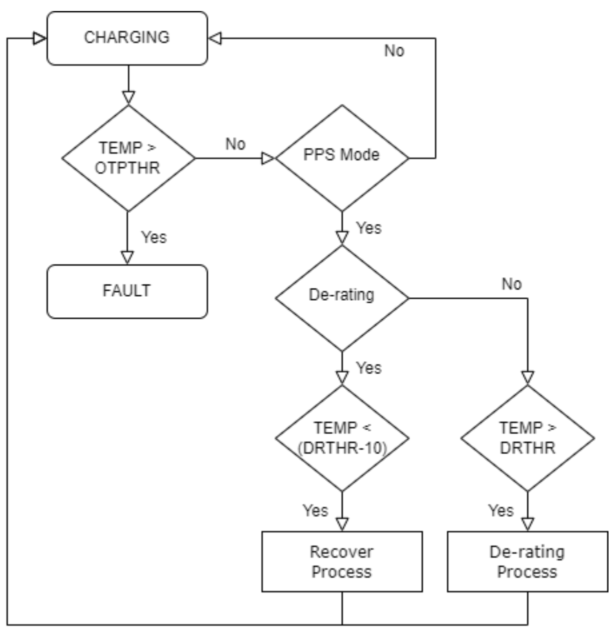


Figure 9 – OTP and De-rating Process Flowchart

Furthermore, the AP33772 defines DRTHR register as threshold temperature value to trigger the power de-rating functions. If Source PDO is PPS APDO, when TEMP value rises over DRTHR value after the de-bouncing time (30ms), the STATUS Bit [7] is to be set at 1. The input current will be reduced by 50% through sending out a new RDO to negotiate with the PD source device.

AP33772 monitors the temperate at the potential hot spot continuously. After some time duration, if TEMP value under DRTHR value more than 10°C will recovers the charging power.

6.4 Temperate Estimate

The AP33772 measures and estimates the temperature value based on 4 User-Entered NTC resistance value vs. temperature (TR25, TR50, TR75 and TR100) in the practical usage temperature range of the TCD.

AP33772 use Murata NTC NCP03XH103 as default. The NTC resistance value vs. temperature as the Table 17.

Register	Default Value	NTC Resistance (KΩ)	Temperature (°C)
TR25	2710h	10	25
TR50	1041h	4.161	50
TR75	0788h	1.928	75
TR100	03CEh	0.974	100

Table 17 – Default NTC resistance corresponds to temperature

If the calculated NTC resistance value is bounded by TR25 and TR100, the AP33772 uses the “LINEAR INTERPOLATION” of the two bounding TR values to estimate the temperature value and deposits this estimated temperature value in the I2C register TEMP.

If the calculated NTC resistance value is higher than TR25 value, the AP33772 uses the “LINEAR EXTRAPOLATION” of TR50 and TR25 to estimate the temperature below 25°C. Similarly, if the calculated resistance value is lower than TR100 value, the AP33772 uses the “LINEAR EXTRAPOLATION” of TR75 and TR100 to estimate the temperature above 100°C.

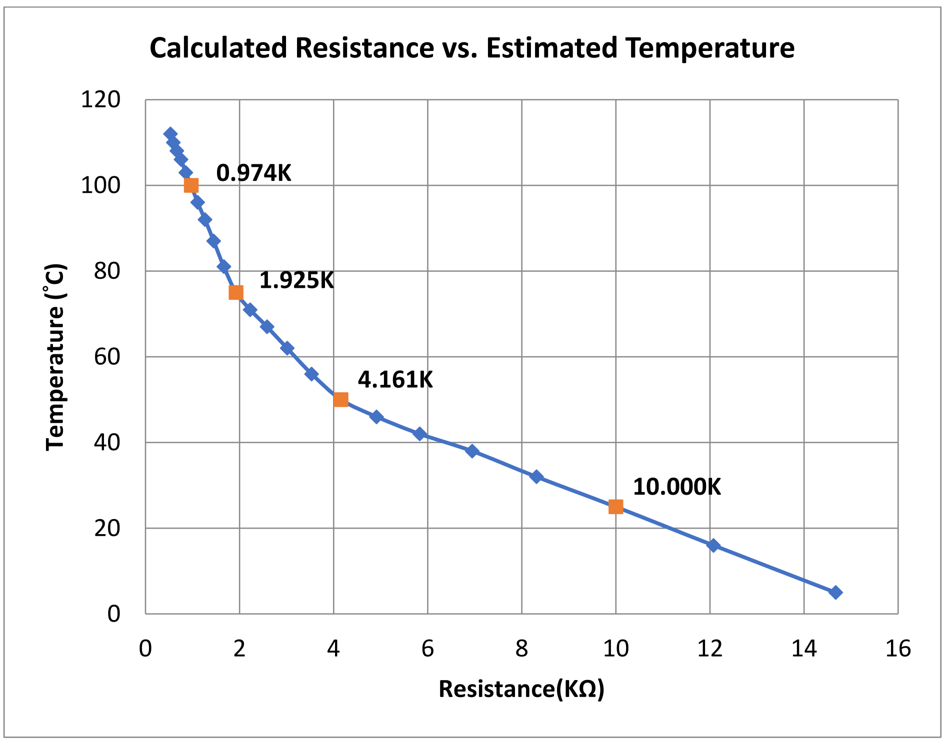


Figure 10 – Calculated Resistance vs. Estimated Temperature Plot (RED dot shows default setting values)

Ex. AP33772 calculates the resistance value of NTC is 2.250kΩ. The near boundary 50°C is 4.161kΩ, 75°C is 1.925kΩ. Therefore, 2.250kΩ corresponds to:

SLOPE = (1.925kΩ – 4.161kΩ) / (75°C – 50°C) = - 0.08944 kΩ/°C
Temperature = 50°C + (2.250kΩ - 4.161kΩ) / (- 0.08944 kΩ/°C) = 71.4°C

So, the TEMP register value is to be set at 47h (71°C).

Chapter 7. Practical Usage Example

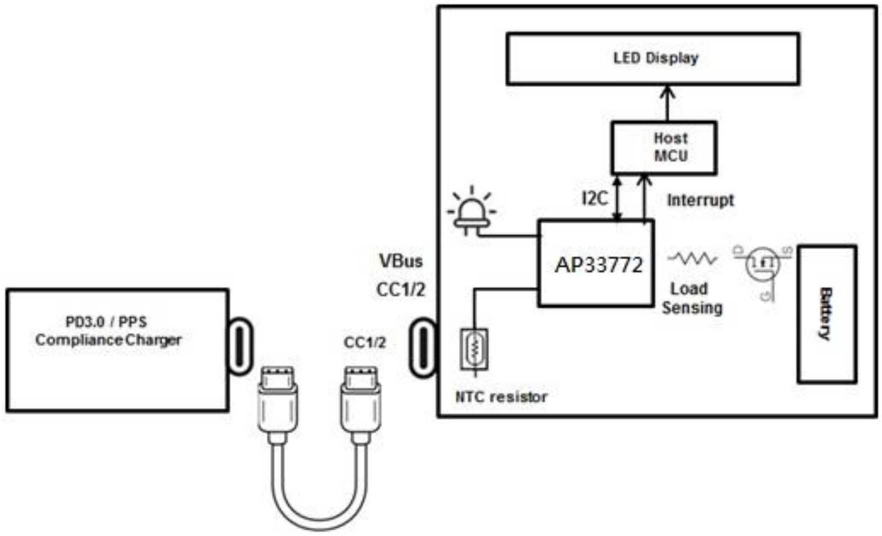


Figure 11 – Versatile USB Source and USB Sink Device Configuration I2C Interaction Example

7.1 System Description

Figure 11 shows a **TCD** connects to a **PD3.0 PPS** Charger for charging through a type C PD compliance cable.

For the energy sourcing side, the system uses a USB PD3.0 PPS compliance charger (PDC), rated at 60W output power (5V/9V/15V/20V@3A). For the energy sinking side, a battery-powered Type C mobile device adopts the AP33772 as the USB PD3.0 Sink compliance controller along with supporting circuitry to support various functions to ensure proper operations, protections and status reports.

It has host device has LED display to show status of the appliance (battery life, charging voltage, charging current, fault reporting, etc.). The system design includes load detection circuitry to monitor on-going charging voltage and current. It also has a NTC resistor attached to a designed pin of the AP33772 to measure a potential hot spot nearby the Type C connector. The host appliance has also charging light indicator.

There is also a fault report channel through GPIO3 of the AP33772 to the Interrupt input pin of the host MCU in case of any fault occur which deserves immediate action from the host MCU.

7.2 Desired Operations

After the connection of the TCD and the PDC, a Type C PD negotiation process starts. Given the charger advertises PDC capability up to 60W, and the host appliance request 45W power at 15V @ 3A input, the charging starts after successful negotiation. As the charging in progress, the LED charging indication light starts to breathe at a speed to match quick charging pace for the battery.

After some charging time, the AP33772 detects the temperate at the potential hot spot is rising to some threshold set by the host MCU. The AP33772 activates the designated power de-rating routine which updates new RDO profile with less charging energy power to ensure the measured temperature is within an acceptable upper limit.

The AP33772 monitors the temperature continuously to ensure to lower down to an acceptable level then recover the charging power. If the AP33772 detects the temperature at the potential hot spot keeps rising over the OTP threshold. AP33772 cuts off the charging process to put the entire system into sleep mode. After some predetermined time duration, the host MCU re-checks the temperature to ensure to lower down to an acceptable level.

As the voltage reaches some predetermined high voltage level, the host CPU cuts off the charging process to put the entire system into sleep mode until battery voltage drop to some predetermined voltage to start the charging process again.

7.3 Basic Request Power

Figure 12 shows the proposed host MCU flowchart. The host MCU could refer to the flowchart to implement its own functions.

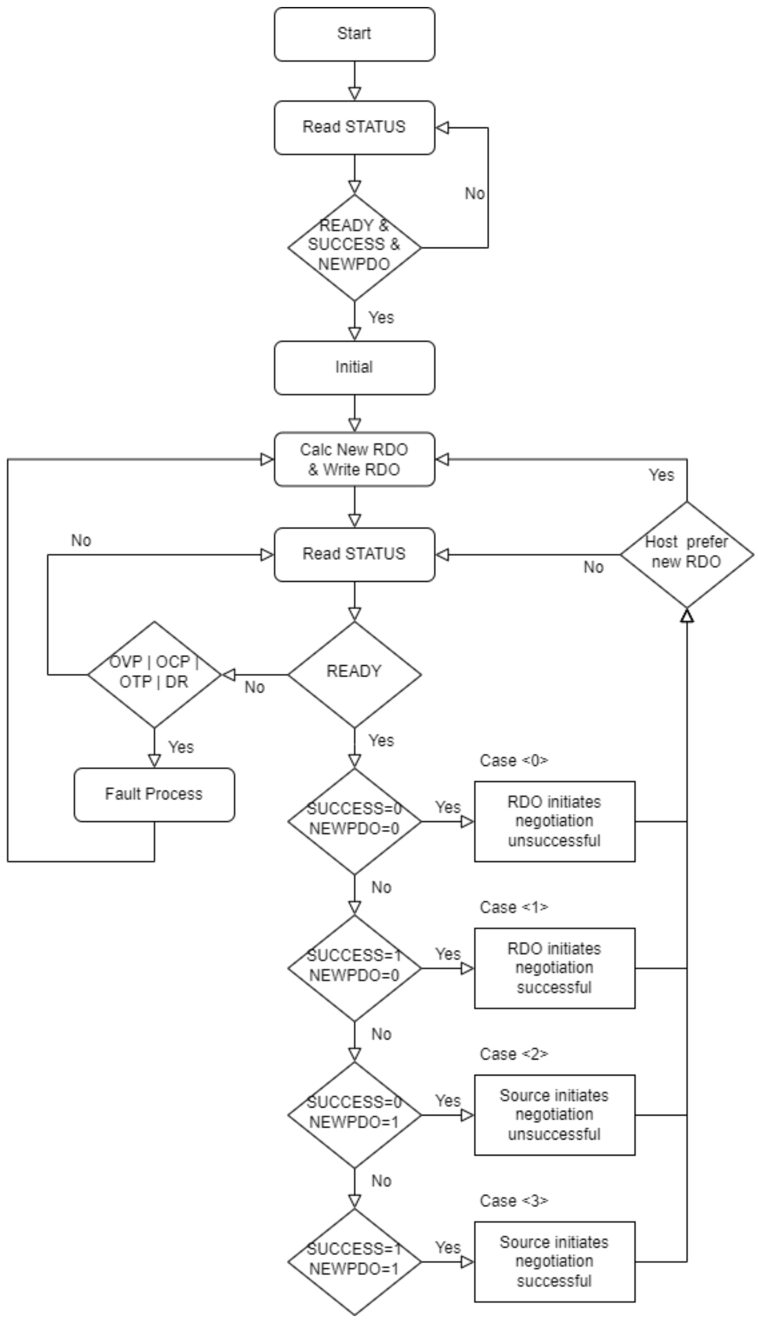


Figure 12 – The Proposed Host MCU Flowchart

The host MCU could implement basic request power function as following step.

1. The host MCU is **polling STATUS (0x1D)** every 10ms. In this case MCU did not use fault report interrupt.

2. If **READY = 1** and **SUCCESS = 1** and **NEWPDO = 1,** that means the AP33772 completes negotiation with the PD Source. Then the host MCU can **read SRCPDO (0x00)** and **PDONUM (0x1C).**

   Ex. **Read SRCPDO** (28 bytes), the result as following
   Byte 00~03 : **0x2C 0x91 0x01 0x0A** (PDO1)

Byte 04~07 : **0x2C 0xD1 0x02 0x00** (PDO2)
Byte 08~11 : **0x2C 0xB1 0x04 0x00** (PDO3)
Byte 12~15 : **0x2C 0x41 0x06 0x00** (PDO4)
Byte 16~19 : **0x3C 0x21 0xA4 0xC9** (PDO5)
Byte 20~23 : **0x00 0x00 0x00 0x00** (PDO6)
Byte 24~27 : **0x00 0x00 0x00 0x00** (PDO7)

Read PDONUM (1 byte),
Byte 00 : **0x05**

PDONUM = 0x05, that means PD source advertises 5 PDOs.

3. **Analyze the PDOs**

Ex. The PD source has 5 PDOs, as shown in the following table.

	PDO1	PDO2	PDO3	PDO4	PDO5
Value	0x0A01912C	0x0002D12C	0x0004B12C	0x0006412C	0xC9A4213C
Type	Fixed PDO	Fixed PDO	Fixed PDO	Fixed PDO	PPS APDO
(Maximum) Voltage	5V	9V	15V	20V	21V
Minimum Voltage	-	-	-	-	3.3V
Maximum Current	3A	3A	3A	3A	3A

4. **Find the suitable PDO** and **generate RDO**

Ex. The host MCU request 45W power at 15V @ 3A input.
The **Fixed PDO3** meets the requirements and generates RDO at 15V @ 3A. **RDO = 0x3004B12C.**
The RDO bitmap is shown in the following table.

Bit(s)	Field	Bitmap	Value	Meaning
B31	Reserved	0	0	-
B30…28	Object position	011b	3	PDO3
B27…20	Reserved	0000 0000b	0	-
B19…10	Operating Current in 10mA units	0100 1011 00b	300	3A
B9…0	Maximum Operating Current 10mA units	01 0010 1100b	300	3A

5. **Write RDO (0x30)** to request power

Ex. **Write RDO** (4 bytes)
Byte 00~03 : **0x2C 0xB1 0x04 0x30**

6. Read **STATUS.** If **READY = 1** and **SUCCESS = 1**. That means AP33772 had sent the RDO and PD Source accepted the RDO.

7. The charging starts at **15V @ 3A**

7.4 Implement OTP and De-rating

Assume the AP33772 has attached 10kΩ **NTC** (Negative Temperature Coefficient) thermistor, as Figure 11, to measure temperature of a potential hot spot nearby the Type C connector. There is also a fault report channel through GPIO3 of AP33772 to the Interrupt input pin of the host MCU.

The AP33772 attached the **Murata NTC NCP03XH103** (Reference 2) for example. The host MCU could implement OTP and de-rating function as following step.

1. Upon **receiving interrupt** request, the host MCU **read STATUS (0x1D)** and process the event.

2. If **READY = 1** and **SUCCESS = 1** and **NEWPDO = 1,** that means the AP33772 completes negotiation with the PD Source.

3. **Read SRCPDO (0x00)** and **analyze PDOs**, please refer to the step 2 and 3 in Section 7.3.

4. **Write MASK (0x1E).** MCU initializes the interrupt mask.

   Ex. Set MASK = 0xC7. The MASK bitmap is shown in the following table.

MASK	Bit	Value
DR_EN	B7	1
OTP_EN	B6	1
OCP_EN	B5	0
OVP_EN	B4	0
	B3	0
REJECT_EN	B2	1
COMPLETE_EN	B1	1
READY_EN	B0	1

   Write MASK (1 byte)
   Byte 00 : **0xC7**

5. **Write TR25 (0x28), TR50 (0x2A), TR75 (0x2C)** and **TR100 (0x2E).**
   MCU initializes the characteristic data of temperature and resistance value (TR25, TR50, TR75 and TR100) before read TEMP or enable de-rating and OTP function.

   Ex. Use Murata NTC NCP03XH103, the temperature vs. resistance and register show as table.

Register	Value	Resistance (Ω)	Temperature (°C)
TR25	2710h	10000	25
TR50	1041h	4161	50
TR75	0788h	1928	75
TR100	03CEh	0974	100

   Write TR25 (2 bytes)
   Byte 00~01 : **0x10 0x27**

   Write TR50 (2 bytes)
   Byte 00~01 : **0x41 0x10**

   Write TR75 (2 bytes)
   Byte 00~01 : **0x88 0x07**

   Write TR100 (2 bytes)
   Byte 00~01 : **0xCE 0x03**

6. **Write OTPTHR (0x24)** and **write DRTHR (0x25).** Set OTPTHR and DRTHR to enable OTP and de-rating function.

   Ex. Set OTPTHR = 0x50 (80°C), DRTHR = 0x3C (60°C). The host MCU need to enable power de-rating when temperate at the potential hot spot over 60°C and cut off the charging process when the temperate over 80°C.

   Write OTPTHR (1 byte)

Byte 00 : **0x50**

Write DRTHR (1 byte)
Byte 00 : **0x3C**

7. **Find the suitable PDO** and **generate RDO**

   Ex. MCU request **PPS PDO5** and generate RDO at 15V @ 3A. **RDO = 0x5005DC3C.**
   The RDO bitmap is shown in the following table.

Bit(s)	Field	Bitmap	Value	Meaning
B31	Reserved	0	0	-
B30…28	Object position	101b	5	PDO5
B27…20	Reserved	0000 0000b	0	-
B19…9	Output Voltage in 20mV units	0101 1101 110b	750	15V
B8…7	Reserved	0 0b	0	-
B6…0	Operating Current 50mA units	011 1100b	60	3A

8. **Write RDO (0x30)** to request power

   Ex. **Write RDO** (4 bytes)
   Byte 00~03 : **0x3C 0xDC 0x05 0x50**

8. If Interrupt occurred, read **STATUS**.
   If **READY = 1** and **SUCCESS = 1.** That means the AP33772 has sent the RDO and PD Source accept the RDO.

9. The charging starts at **15V @ 3A**.

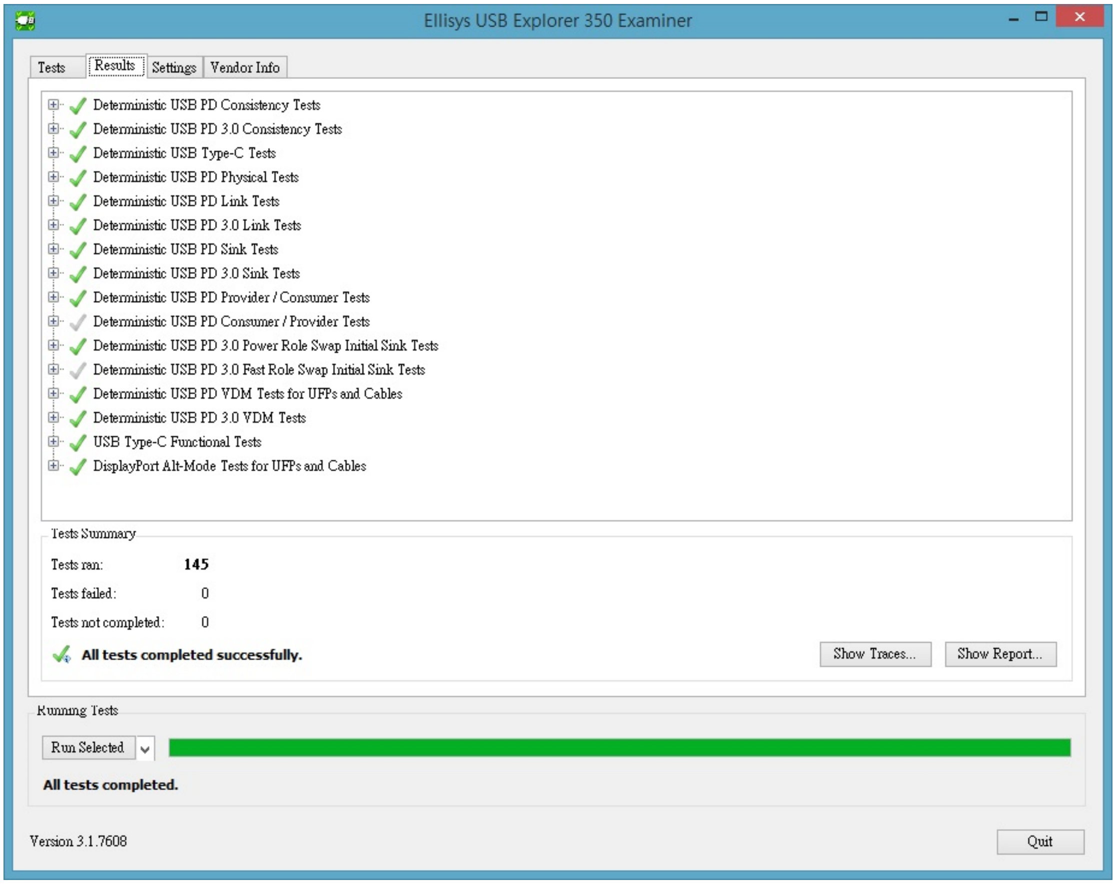
10. If a relevant Interrupt occurs during charging, the MCU reads **STATUS**.

    Ex. If **DR = 1.** That means the temperate at the potential hot spot over 60°C. The AP33772 detect the TEMP value over DRTHR and enable de-rating process. The host MCU shows a warning message on LED display.

11. After some time duration, if the temperate lower down under 50°C, the AP33772 recovers the charging power.

Chapter 8. Compliance test

AP33772 EVB passes all test items in Ellisys USB-PD Compliance test as below.



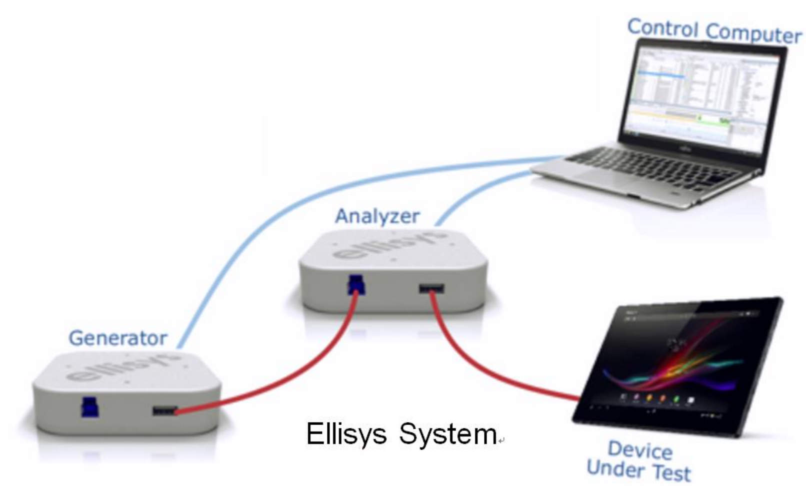


Figure 13 – Ellisys USB PD Test Environment and Test Item List

Chapter 9. Reference

1. AP33772 Datasheet (USB PD3.0 PPS Sink Controller) : https://www.diodes.com/products/power-management/ac-dc-converters/usb-pd-sink-controllers/
2. Murata Thermistor Specification NCP03 Family : https://www.murata.com/-/media/webrenewal/products/thermistor/ntc/ncp/ncp03.ashx?la=en-us&cvid=20201027045937000000)

Chapter 10. Revision History

Revision	Issue Date	Comment	Author
1.0	5/5/2022	Initial Release	Joseph Liang