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Chapter 1. Summary

1.1 General Description

The 120W Quad-Port USB Type-C® PD3.1 PPS Car Charger Module (EV1) is a reference design to demonstrate practical in-vehicle USB Type-C PD 3.1 PPS charging applications for 12V and 24V battery systems. It is composed of two main stages – the Buck-Boost (BB) and the PD3.1 PPS (PD) decoding stage. The BB stage adopts four TPS55289 chips, synchronous four-switch integrated buck-boost DC-DC controllers capable of regulating the output voltage at above or below the input voltage, covering the complete ranges of USB PD3.1 PPS voltage (3.3V~21V). The PD stage is implemented by two AP43776Q, dual-channel PD 3.1 PPS decoder IC, supporting compliance requirements for the USB PD3.1 PPS and Qualcomm® Quick Charge™ QC4/4+/5 protocols. The maximum 120W power input could be dynamically shared by four USB Type-C PD ports for predefined intelligent load sharing scheme. The quick charging status is indicated by the associated LED light indicator. Furthermore, Desirable Smart features such as low battery power management, thermal power management and charging status or fault indication by LED light could also be supported by AP43776Q through customizable built-in firmware.

1.2 Key Features

1.2.1 AP43776Q

- Dual-Channel independent USB Type-C PD3.1/PPS decoder
- Support PD3.1 / full range of PPS
- Support Qualcomm® QC4/4+/5 protocol operation
- Support USB Type-C PD Display Port (DP) Alternative mode
- Compliant with BC1.2 (SDP/CDP/DCP)
- Built-in MCU with 12KB OTP ROM
- Built-in ADC for voltage and temperature measurement
- Support e-Marker detection and VCONN switch with 30mA driving capability
- Support cable-loss compensations
- I2C interface for DC-DC control and status report
- OVP, OCP, UVP Protection
- Short protection of CC1 and CC2 pin to VBus pin (24V)
- Moisture Detection Protection
- QFN4x4-20L, 0.5mm pitch and Wettable Flank
- Automotive AEC-Q100 Grade 1 (-40ºC ~ +125ºC)

1.2.2 TPS55289

- Buck-Boost DC-DC converter with integrated four switch MOSFET
- 3.0~30V wide input range
- Support full PD3.1/PPS voltage control range (3.3V~21V 10mV/step), current control in 50mA/step up to 6.35A
- I2C interface for control and status report
- EMI mitigation with programmable spread spectrum
- Rich protection features
- 3.0-mm × 5.0-mm HotRod™ QFN package
- Search more details via: https://www.ti.com/product/TPS55289?keyMatch=TPS55289#features

1.3 Applications

- In-Vehicle Preinstalled Charger module
- Rechargeable Portable Devices
- USB Type-C PD Power Bank

1.4 Main Power Specifications

Parameter	Value
Input/Operating Voltage	3Vdc to 30Vdc
Output Power	120W maximum output power for 4 USB Type-C PD charging ports
Quick Charging protocol Support	Full-Range PD3.1 PPS QC 4/4+/5 Support
Smart Power Sharing Scheme	Single-Port in use – up to 60W Dual-Port in use – 60W+60W, Tri-Port in use – 60W+30W+30W Quad-Port in use – 4x30W Dynamic power allocation scheme
Low Battery Power De-Rating	Reduce power output for voltage below 11V, shutdown output for voltage below 9V
Thermal Power De-Rating	Output power reduction once threshold temperature is exceeded
LED Lighting Indicator	LED Lighting indication for quick charging states if each USB Type-C Port
Dimension	100mm * 50mm * 15mm

Table 1 Main Power Specifications

1.5 Evaluation Board Picture

Figure 1: Top View

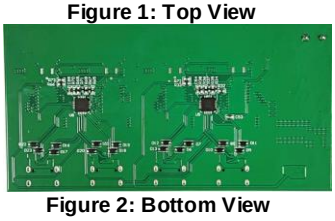


Figure 2: Bottom View

Chapter 2. Schematic and BOM

2.1 Evaluation Board Schematic

Schematic of 120W Quad-Port USB Type-C PD3.1 PPS In-Vehicle Charger Evaluation Board

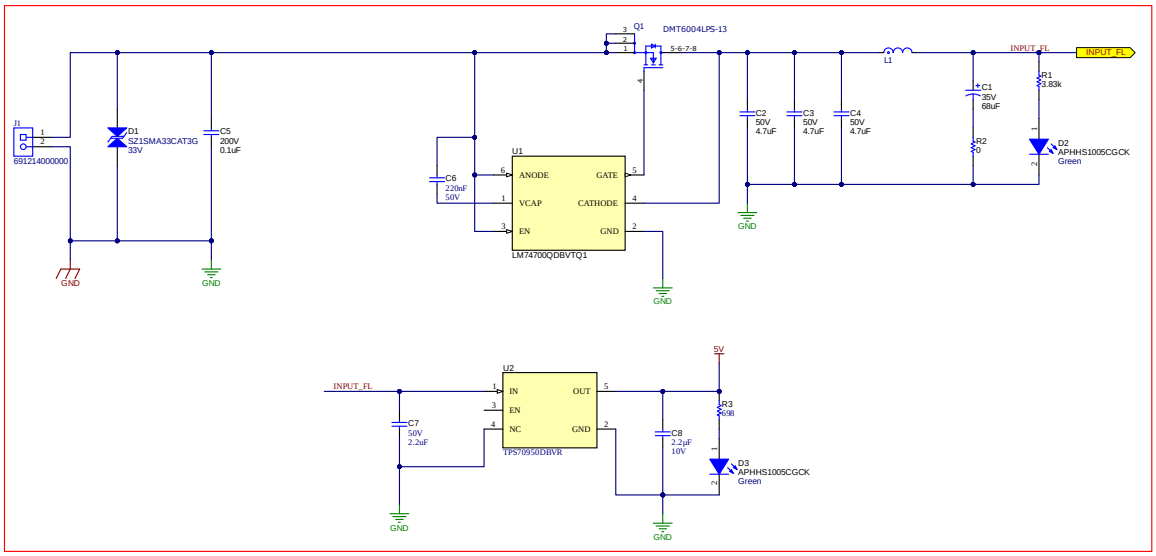
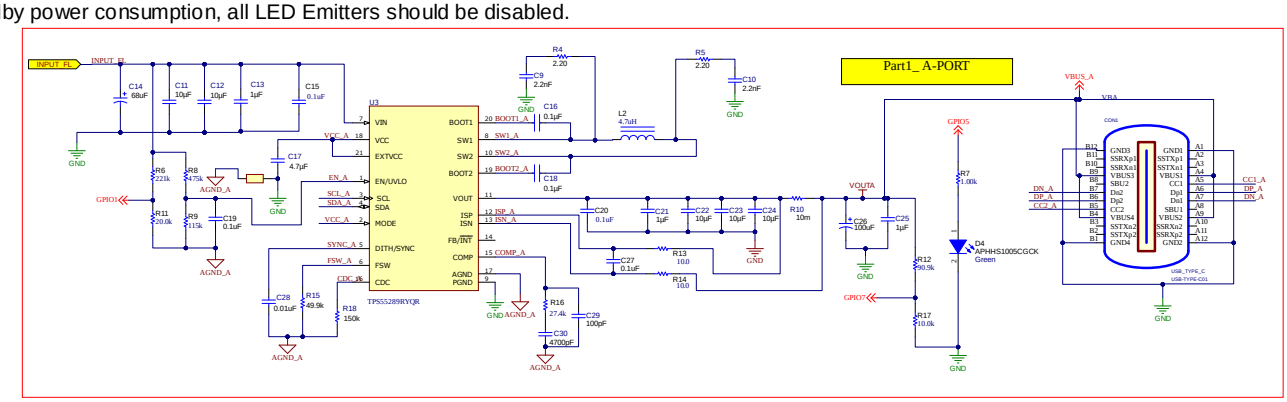


Figure 3: Input Protection Circuit

Note: Input Protection Circuit is used for the recovery battery protection. It is TI's additional Input Circuit, including LED Emitter. LM74700Q will bring additional power consumption of about 1.0mw.VCC Power is a LDO circuit for AP43776 power supply for lower standby power. For super lower standby power consumption, all LED Emitters should be disabled.



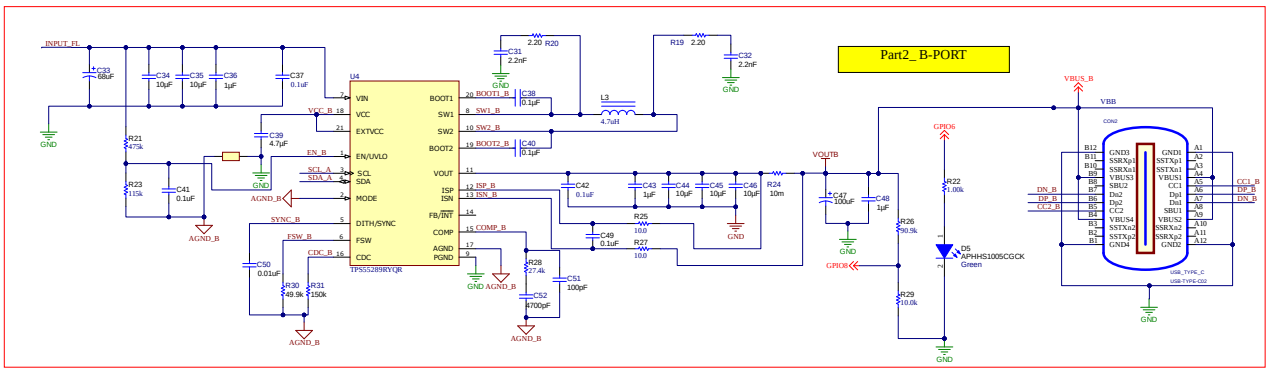


Figure 4: Port A and B Buck-Boost Circuit

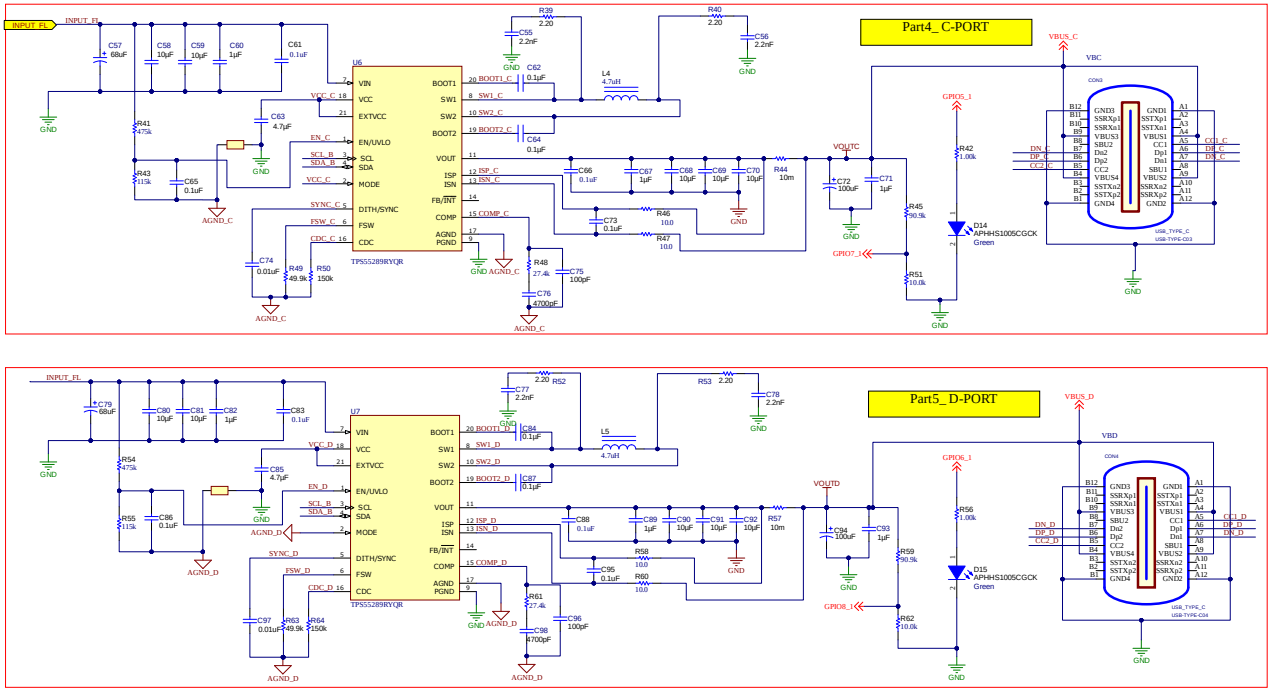


Figure 5: Port C and D Buck-Boost Circuit

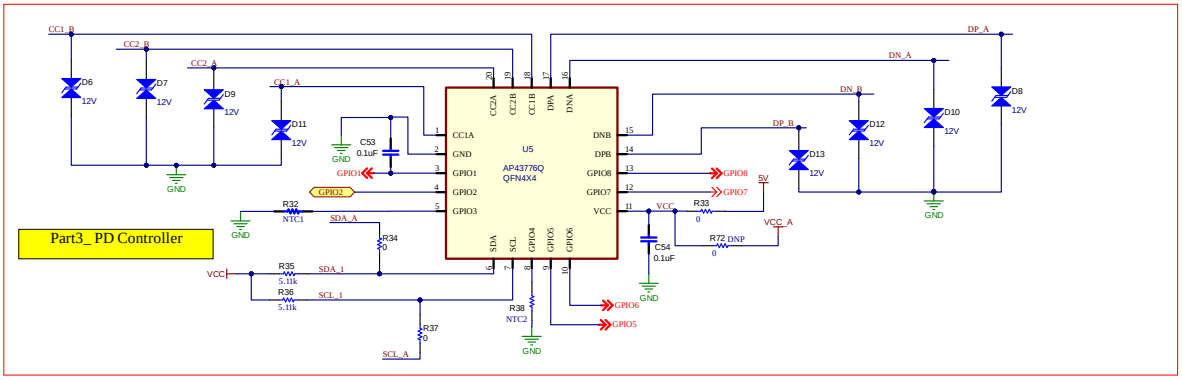


Figure 6:AP43776Q (Port A and Port B)

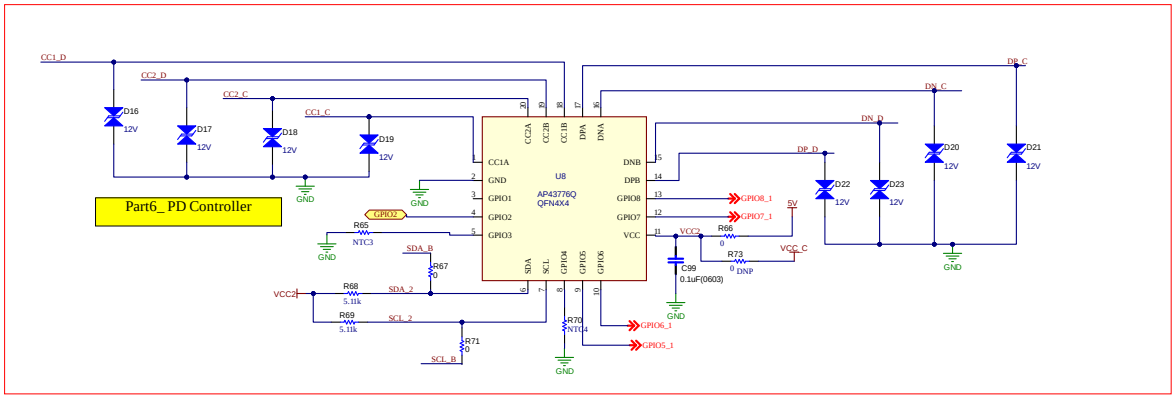


Figure 7: AP43776Q (Port C and Port D)

2.2 Bill of Material (BOM)

Item	Quantity	Designator	Description	Part Number	Manufactory
1	1	C1	68uF	EEE-FK1V680XP	Panasonic
2	3	C2, C3, C4	4.7uF	CGA6P3X7R1H475M250AB	TDK
3	1	C5	0.1uF	C2012X7T2E104M125AE	TDK
4	1	C6	0.22uF	CGA3E3X7R1H224K080AB	TDK
5	1	C7	2.2uF	GCM31CR71H225KA55L	MuRata
6	1	C8	2.2uF	GRM188R71A225KE15J	MuRata
7	20	C11, C12, C22, C23, C24, C34, C35, C44, C45, C46, C58, C59, C68, C69, C70, C80, C81, C90, C91, C92	10uF	CGA5L1X7R1H106K160AC	TDK
8	12	C13, C21, C25, C36, C43, C48, C60, C67, C71, C82, C89, C93	1uF	GRT188R61H105ME13D	MuRata
9	4	C14, C33, C57, C79	68uF	EEHZA1H680P	Panasonic
10	8	C15, C20, C37, C42, C61, C66, C83, C88	0.1uF	GRM155R71H104ME14D	MuRata
11	8	C16, C18, C38, C40, C62, C64, C84, C87	0.1uF	GCM188L81H104KA57D	Murata Electronics North America
12	4	C17, C39, C63, C85	4.7uF	GRT188R61C475KE13D	MuRata
13	11	C19, C27, C41, C49, C53, C54, C65, C73, C86, C95, C99	0.1uF	CGA2B3X7R1H104K050BB	TDK
14	4	C26, C47, C72, C94	100uF	EEHZK1V101XP	Panasonic
15	4	C28, C50, C74, C97	0.01uF	CGA2B3X7R1H103K050BB	TDK
16	4	C29, C51, C75, C96	100pF	CGA2B2C0G1H101J050BA	TDK
17	4	C30, C52, C76, C98	4700pF	CGA2B2X7R1H472K050BA	TDK
18	4	CON1, CON2, CON3, CON4		USB4105-GF-A	
19	1	D1	33V	SZ1SMA33CAT3G	Littelfuse
20	6	D2, D3, D4, D5, D14, D15	Green	APHHS1005CGCK	Kingbright
21	16	D6, D7, D8, D9, D10, D11, D12, D13, D16, D17, D18, D19, D20, D21, D22, D23	12V	D14V0S1U2WS	Diodes
22	1	J1		691216710002	Wurth Elektronik
23	1	L1	1uH	XAL7070-102MEC	Coilcraft
24	4	L2, L3, L4, L5	4.7uH	XAL7070-472MEB	Coilcraft
25	1	Q1	60V	DMT6004LPS-13	Diodes
26	1	R1	3.83k	CRCW04023K83FKED	Vishay-Dale
27	1	R2	0	RCA12060000ZSEA	Vishay-Dale
28	1	R3	698	CRCW0402698RFKED	Vishay-Dale
29	1	R6	221k	CRCW0402221KFKED	Vishay-Dale
30	4	R7, R22, R42, R56	1.00k	CRCW04021K00FKED	Vishay-Dale
31	4	R8, R21, R41, R54	475k	CRCW0402475KFKED	Vishay-Dale
32	4	R9, R23, R43, R55	115k	CRCW0402115KFKED	Vishay-Dale
33	4	R10, R24, R44, R57	10m	CRF1206-FZ-R010ELF	Bourns
34	1	R11	20.0k	CRCW040220K0FKED	Vishay-Dale
35	4	R12, R26, R45, R59	90.9k	CRCW040290K9FKED	Vishay-Dale
36	8	R13, R14, R25, R27, R46, R47, R58, R60	10	CRCW040210R0FKED	Vishay-Dale
37	4	R15, R30, R49, R63	56.0k	CRCW040249K9FKED	Vishay-Dale
38	4	R16, R28, R48, R61	27.4k	CRCW040227K4FKED	Vishay-Dale
39	4	R17, R29, R51, R62	10.0k	CRCW040210K0FKED	Vishay-Dale

40	4	R18, R31, R50, R64	150k	CRCW0402150KFKED	Vishay-Dale
41	4	R32, R38, R65, R70	10K	NCU15XH103F6SRC	MuRata
42	6	R33, R34, R37, R66, R67, R71	0	CRCW04020000Z0EDHP	Vishay-Dale
43	3	R35, R36, R68	5.11k	CRCW04025K11FKED	Vishay-Dale
44	1	R69	3.69k	CRCW04023K30FKED	Vishay-Dale
45	1	U1		LM74700QDBVTQ1	Texas Instruments
46	1	U2		TPS70950DBVR	Texas Instruments
47	4	U3, U4, U6, U7		TPS55289RYQR	Texas Instruments
48	2	U5, U8		AP43776Q	Diodes
49	0	C9, C10, C31, C32, C55, C56, C77, C78	2200pF	GRM21AR72E222KW01D	MuRata
50	0	R4, R5, R19, R20, R39, R40, R52, R53	2.2	ERJ-8RQF2R2V	Panasonic
	0	R72, R73	0	CRCW04020000Z0EDHP	Vishay-Dale

Table 2: BOM List

Chapter 3. The Evaluation Board Connections

3.1 Evaluation of PCB Board Layout

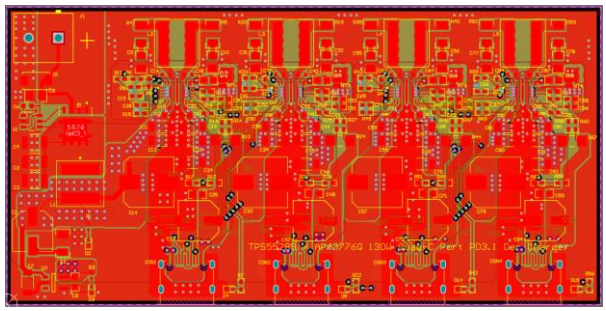


Figure 8: PCB Board Layout Top View

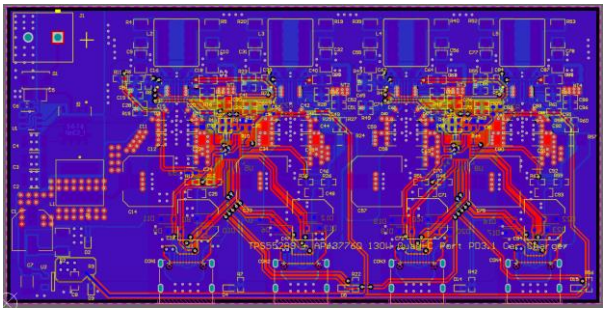


Figure 9: PCB Board Layout Bottom View

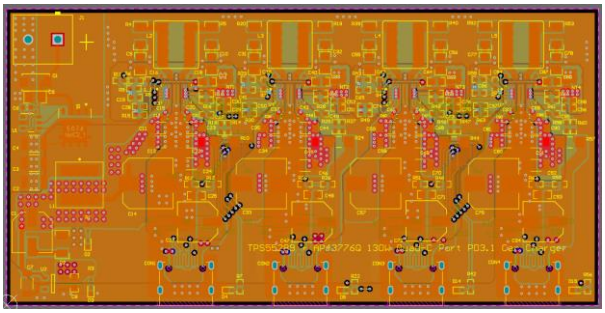


Figure 10: PCB Board Layout Signal Layer1

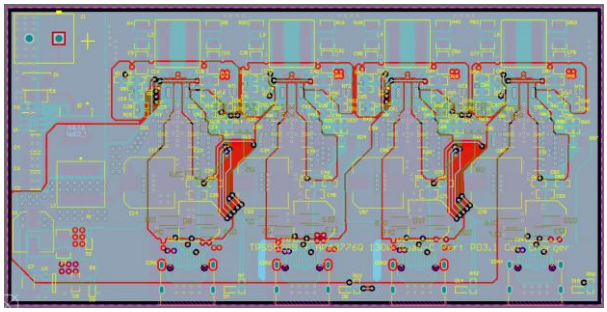


Figure 11: PCB Board Layout Signal Layer2

3.2 Quick Start Guide Before Connection

1) Before starting the 120W PD3.1 PPS Car Charger EVB test, the end user needs to prepare the following tool, software and manuals.

   For details, please contact DIODES Semiconductor local sales for further information.

   - USBCEE PD3.1 Test Kit: USBCEE Power Adapter Tester. https://www.usbcee.com/product-details/4

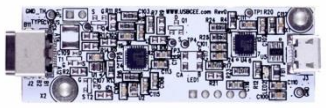
USBCEE PAT Tester	GUI Display	USB-A to Micro-B Cable	USB Type-C Cable
			

Figure 12: Test Kit / Test Cables

2) Prepare a certified three-foot USB Type-C cable and a Standard-A to Micro-B Cable.

3) Connect the input wires to DC power supply.

4) Ensure that the DC source is switched OFF or disconnected before the connection steps.

5) Use a USB Type-C cable for the connection between EV1 Board to USB Type-C receptacles.

6) Use 2 banana jack cables, one port of the cables is connected to E-load + & - terminals while the other port of the cables is connected to 120W PD3.1 PPS Car Charger unit's VBUS & GND holes.

7) A Standard-A to Micro-B cable to be connected to the test kit's Micro-B receptacle & PC Standard-A receptacle respectively.

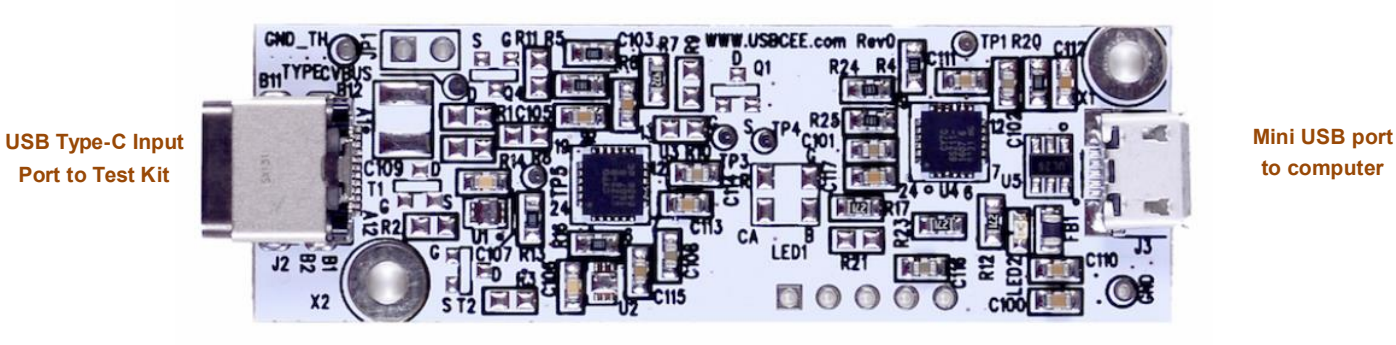


Figure 13: The Test Kit Input & Output and E-load Connections

3.3 Connection with E-Load

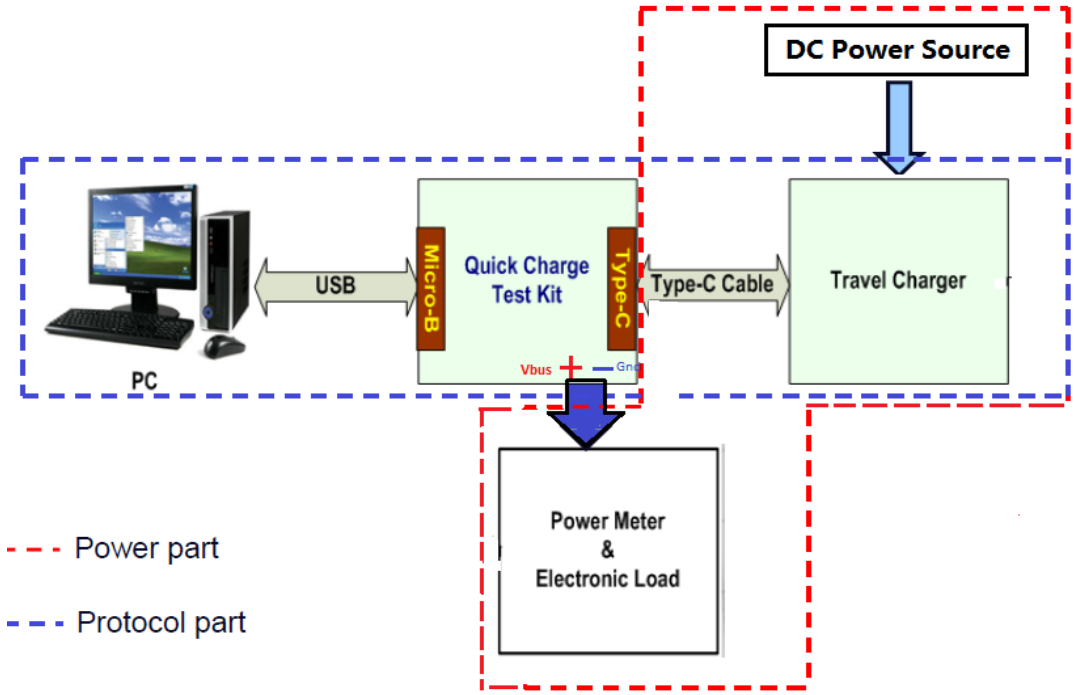


Figure 14: Diagram of Connections in the Sample Board

Chapter 4. Evaluation Board Testing Data

4.1 Multiple Output Efficiency at 12Vdc Line Input Voltage

A PORT						
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.00	5.30	63.65	20.00	3.00	60.10	94.42
12.00	3.95	47.43	20.00	2.25	45.08	95.04
12.00	2.63	31.54	20.00	1.50	30.07	95.35
12.00	1.33	15.97	20.00	0.75	15.04	94.18
12.00	0.57	6.81	20.00	0.30	6.02	88.41
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	3.90	46.87	15.00	3.00	45.07	96.16
12.00	2.92	35.05	15.00	2.25	33.80	96.46
12.01	1.95	23.38	15.00	1.50	22.56	96.47
12.01	0.99	11.84	15.00	0.75	11.28	95.24
12.01	0.41	4.97	15.00	0.30	4.51	90.75
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	2.36	28.31	9.00	3.00	27.04	95.52
12.00	1.77	21.18	9.00	2.25	20.28	95.75
12.01	1.18	14.18	9.00	1.50	13.53	95.43
12.01	0.60	7.24	9.00	0.75	6.77	93.46
12.01	0.26	3.11	9.00	0.30	2.71	87.10
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	1.36	16.33	5.00	3.00	15.02	92.00
12.00	1.02	12.21	5.00	2.25	11.27	92.28
12.01	0.68	8.20	5.00	1.50	7.52	91.69
12.01	0.36	4.28	5.00	0.75	3.76	87.90
12.01	0.16	1.95	5.00	0.30	1.51	77.39
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	0.90	10.76	3.30	2.90	9.56	88.82
12.00	0.69	8.29	3.30	2.25	7.43	89.59
12.01	0.46	5.57	3.30	1.50	4.96	89.05
12.00	0.24	2.93	3.30	0.75	2.48	84.74
12.00	0.11	1.37	3.30	0.30	0.99	72.25

B PORT						
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.00	5.32	63.89	20.11	3.00	60.42	94.57
12.01	3.96	47.60	20.10	2.25	45.31	95.18
12.01	2.64	31.70	20.10	1.50	30.22	95.34
12.00	1.34	16.08	20.10	0.75	15.11	93.96
12.01	0.57	6.87	20.09	0.30	6.05	88.07
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	3.93	47.14	15.08	3.00	45.30	96.09
12.00	2.94	35.24	15.08	2.25	33.98	96.42
12.01	1.96	23.52	15.07	1.50	22.67	96.38
12.01	0.99	11.90	15.07	0.75	11.33	95.28
12.01	0.42	4.98	15.07	0.30	4.54	91.00
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	2.37	28.43	9.05	3.00	27.20	95.66
12.00	1.77	21.27	9.05	2.25	20.40	95.91
12.01	1.19	14.24	9.05	1.50	13.61	95.63
12.01	0.61	7.27	9.05	0.75	6.81	93.65
12.01	0.26	3.11	9.05	0.30	2.72	87.50
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	1.37	16.39	5.00	3.00	15.02	91.64
12.00	1.02	12.26	5.00	2.25	11.27	91.91
12.01	0.69	8.24	5.00	1.50	7.52	91.24
12.01	0.36	4.29	5.00	0.75	3.76	87.73
12.01	0.16	1.94	5.00	0.30	1.51	77.49
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	0.90	10.81	3.33	2.90	9.65	89.35
12.00	0.70	8.37	3.33	2.25	7.50	89.62
12.01	0.47	5.62	3.33	1.50	5.01	89.05
12.00	0.25	2.96	3.33	0.75	2.51	84.66
12.01	0.12	1.39	3.33	0.30	1.00	71.97

Table 3: VBUS_A and VBUS_B: 12Vdc@3.3V/5V/9V/15V/20V_ 0%~100% Loading

C PORT						
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.00	5.31	63.77	20.02	3.00	60.17	94.34
12.01	3.96	47.54	20.02	2.25	45.12	94.91
12.01	2.63	31.63	20.02	1.50	30.10	95.19
12.00	1.33	16.01	20.02	0.75	15.05	94.03
12.01	0.57	6.80	20.02	0.30	6.02	88.52
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	3.92	47.02	15.01	3.00	45.11	95.94
12.00	2.93	35.16	15.01	2.25	33.84	96.25
12.01	1.95	23.44	15.01	1.50	22.58	96.31
12.01	0.99	11.86	15.01	0.75	11.29	95.15
12.01	0.41	4.97	15.01	0.30	4.52	90.84
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	2.37	28.43	9.04	3.00	27.17	95.55
12.00	1.77	21.27	9.04	2.25	20.38	95.80
12.01	1.19	14.24	9.04	1.50	13.60	95.52
12.01	0.61	7.27	9.04	0.75	6.80	93.55
12.01	0.26	3.11	9.04	0.30	2.72	87.41
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	1.36	16.36	5.00	3.00	15.02	91.82
12.00	1.02	12.24	5.00	2.25	11.27	92.05
12.01	0.68	8.22	5.00	1.50	7.52	91.49
12.01	0.36	4.28	5.00	0.75	3.76	87.78
12.01	0.16	1.94	5.00	0.30	1.51	77.58
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	0.90	10.82	3.32	2.90	9.63	88.93
12.00	0.70	8.38	3.32	2.25	7.48	89.27
12.01	0.47	5.62	3.32	1.50	4.99	88.83
12.00	0.25	2.95	3.32	0.75	2.50	84.55
12.01	0.12	1.38	3.32	0.30	1.00	72.02

D PORT						
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	5.33	64.02	20.07	3.00	60.30	94.18
12.01	3.97	47.66	20.06	2.25	45.21	94.86
12.00	2.64	31.69	20.06	1.50	30.16	95.19
12.00	1.34	16.04	20.05	0.75	15.08	94.01
12.00	0.57	6.81	20.05	0.30	6.03	88.55
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.00	3.93	47.16	15.04	3.00	45.20	95.85
12.00	2.94	35.23	15.04	2.25	33.90	96.22
12.00	1.96	23.48	15.04	1.50	22.62	96.32
12.00	0.99	11.87	15.04	0.75	11.31	95.29
12.00	0.41	4.97	15.04	0.30	4.53	91.07
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.00	2.37	28.42	9.02	3.00	27.11	95.41
12.00	1.77	21.27	9.03	2.25	20.35	95.65
12.00	1.19	14.22	9.03	1.50	13.58	95.48
12.00	0.61	7.27	9.03	0.75	6.79	93.47
12.00	0.26	3.11	9.04	0.30	2.72	87.37
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	1.37	16.41	5.03	3.00	15.10	92.00
12.00	1.02	12.27	5.03	2.25	11.33	92.28
12.00	0.69	8.23	5.03	1.50	7.56	91.85
12.00	0.36	4.27	5.03	0.75	3.78	88.56
12.01	0.16	1.93	5.03	0.30	1.51	78.26
Vin(V)	Iin(A)	Pi(W)	Vout(V)	Iout(A)	Po(W)	Eff(%)
12.01	0.90	10.82	3.32	2.90	9.63	88.95
12.00	0.70	8.38	3.32	2.25	7.48	89.34
12.01	0.47	5.62	3.32	1.50	4.99	88.88
12.00	0.25	2.95	3.32	0.75	2.50	84.72
12.01	0.11	1.38	3.32	0.30	1.00	72.34

Table 4: VBUS_C and VBUS_D: 12Vdc@3.3V/5V/9V/15V/20V_ 0%~100% Loading

4.2 Multiple Output Efficiency at Different DC Line Input Voltage

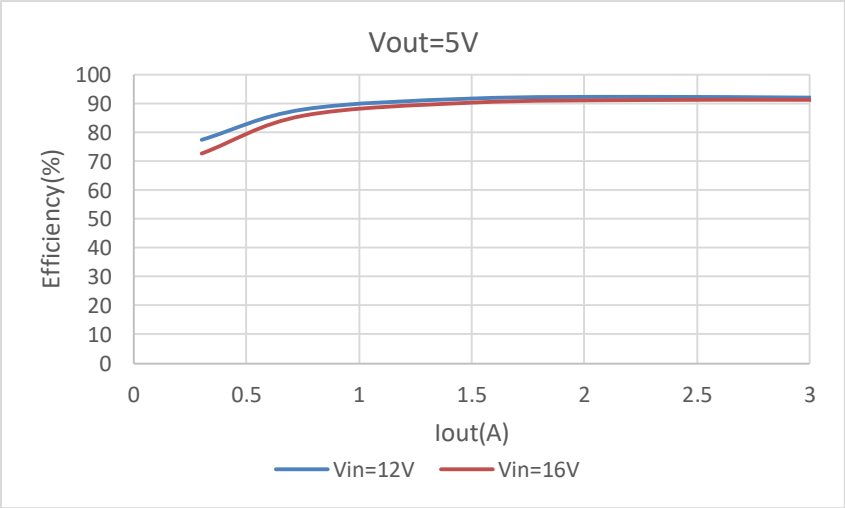


Figure 15: VBUS_A:12V/16V Vdc@5V/ 0%~100% Loading

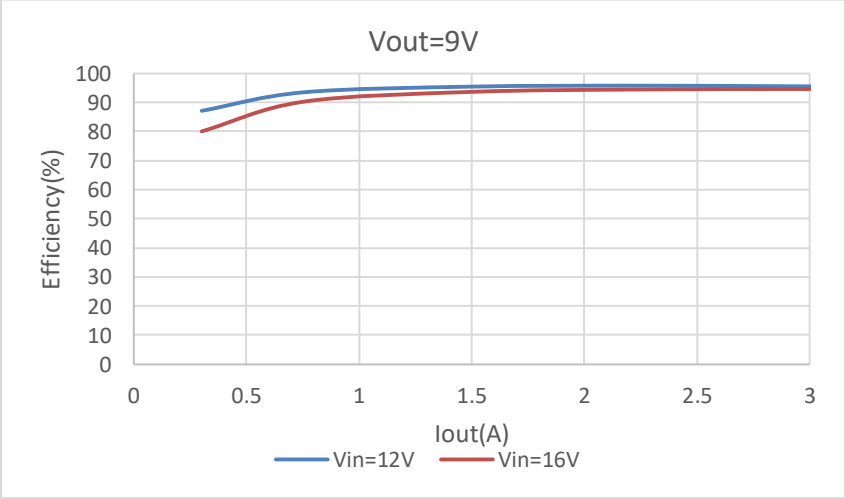


Figure 16: VBUS_A: 12V/16V Vdc@9V/ 0%~100% Loading

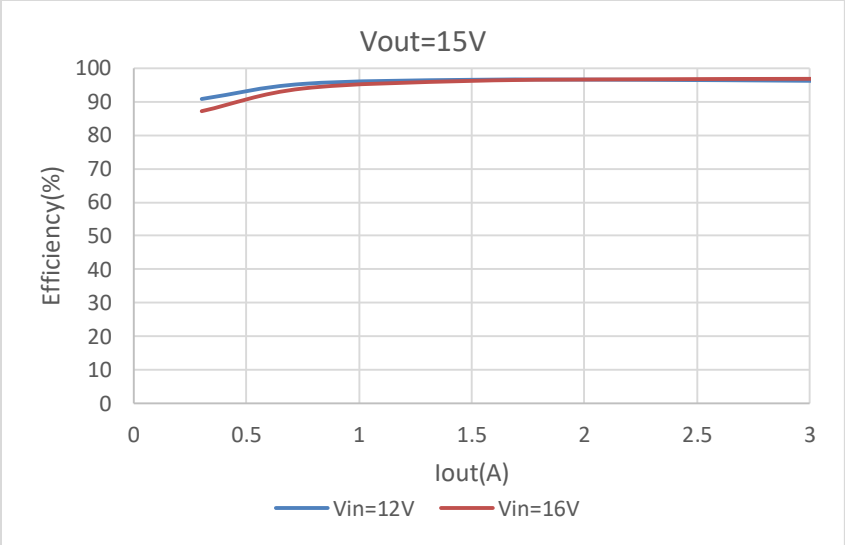


Figure 17: VBUS_A: 12V/16V Vdc@15V/ 0%~100% Loading

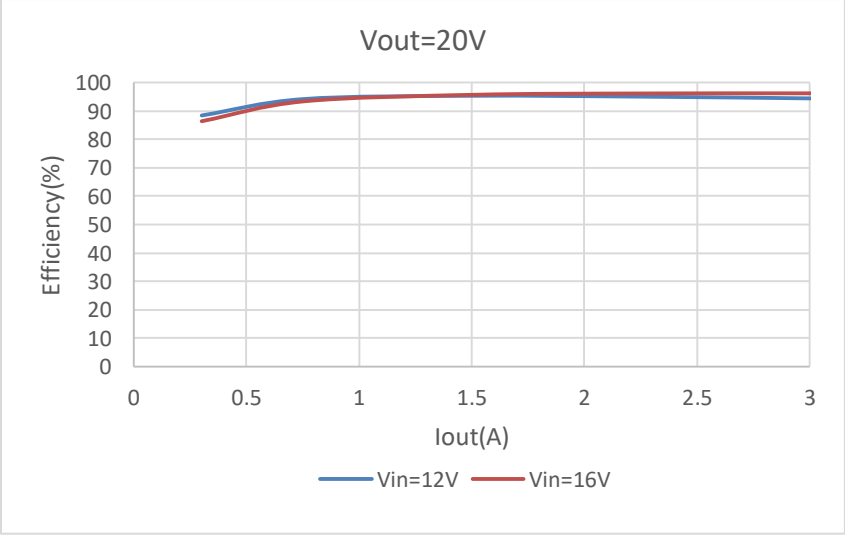


Figure 18: VBUS_A: 12V/16V Vdc@20V/ 0%~100% Loading

4.3 Input Standby Power

Vin(V)	Pi(mW)	4 Port
12	28.4	detach the jig
16	39.0	detach the jig

Table 5: Input Standby Power

NOTE: When system enters standby-power mode in this demo board, TPS55289 is still working and the working current is about 400uA. For super lower standby power consumption design, the system designers can control EN pin (Pin 2) of TPS55289 through a GPIO pin of AP43776Q for entrance and exit of standby power mode. When system detaches the jig, AP43776Q will pull down EN pin of TPS55289 via GPIO pin and make TPS55289 enter shut down mode (In this condition, the super lower standby power is only about 10mw). A simple schematic for low standby power is proposed in Figure 19.

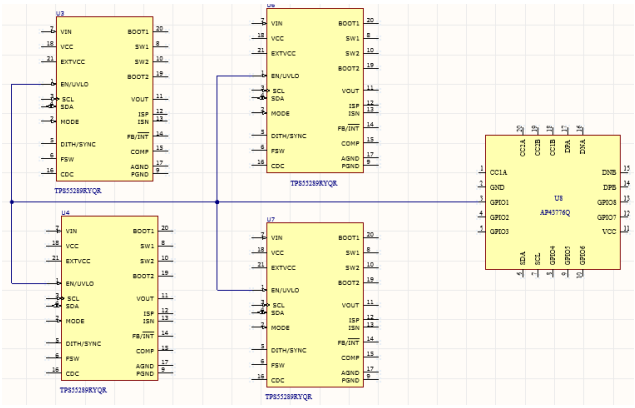


Figure 19: A simple schematics connection for super low standby power

4.4 Output Voltage Levels Transition

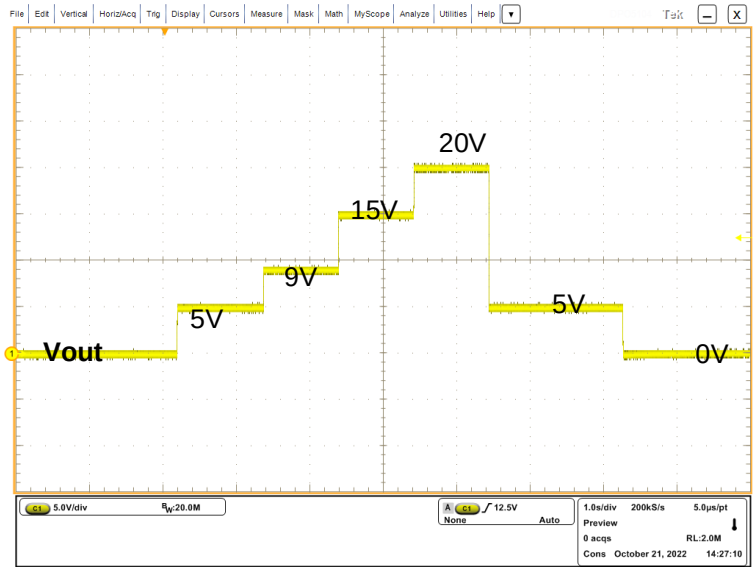


Figure 20: Output Voltage Levels Transition

4.5 Output voltage transition time

VBUS_A Voltage Transition Time

Port	Vin(V)	Vo(V)	Io(A)	Rising(ms)
A	12	5-->9	3	1.10
	12	9-->15	3	1.55
	12	15-->20	3	1.27
	Vin(V)	**Vo(V)**	**Io(A)**	**Falling(ms)**
	12	9-->5	3	1.12
	12	15-->9	3	1.57
	12	20-->15	3	1.24

Table 6: Transition Time

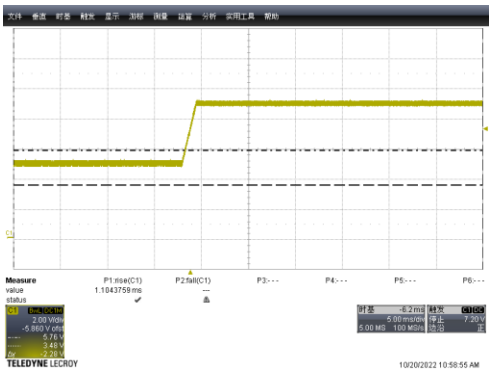


Figure 21: 12Vdc @5V/3A→9V/3A

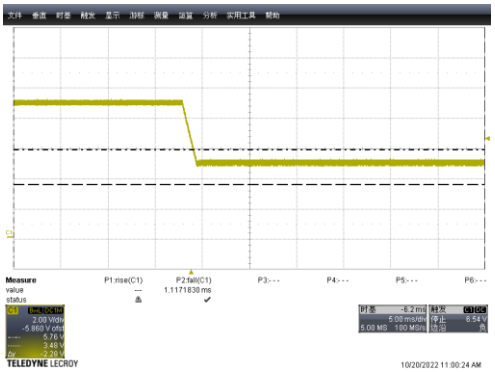


Figure 22: 12V @9V/3A→5V3A

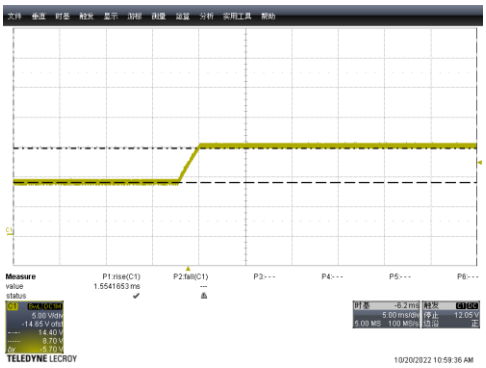


Figure 23: 12Vdc @9V/3A→15V/3A

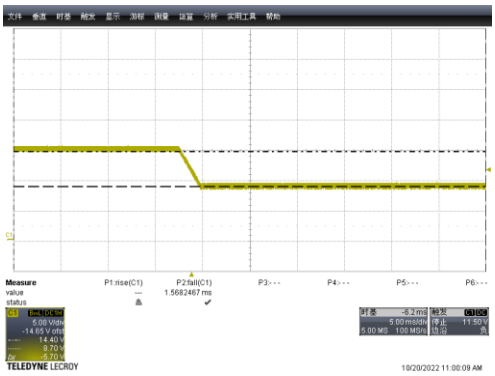


Figure 24: 12V @15V/3A→9V3A

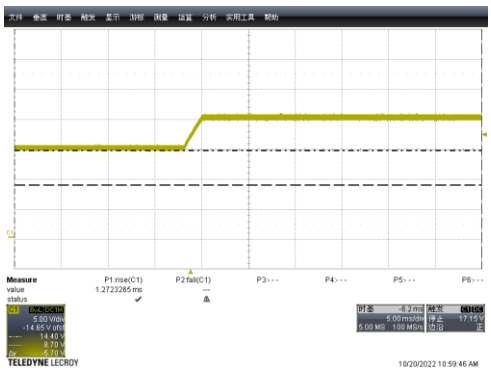


Figure 25: 12Vdc @15V/3A→20V/3A

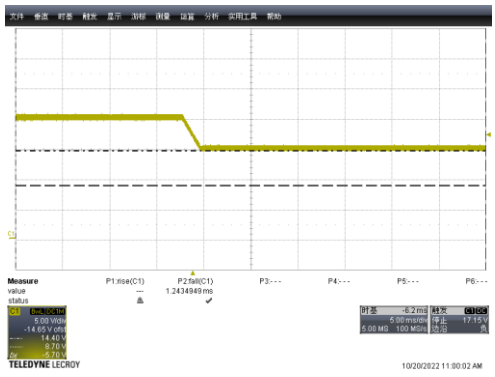


Figure 26: 12Vdc @20V/3A→15V3A

4.6 System Output Ripple & Noise at PCB End

VBUS_A Output Ripple

Port	Vin(V)	Vo(V)	Io(A)	Ripple (mV)
A	12	3.3	2.9	48
	12	5	3	39
	12	9	3	40.3
	12	15	3	77
	12	20	3	120
	16	3.3	2.9	57
	16	5	3	57
	16	9	3	60.8
	16	15	3	63.4
	16	20	3	56.3

Table 7: Output Ripple

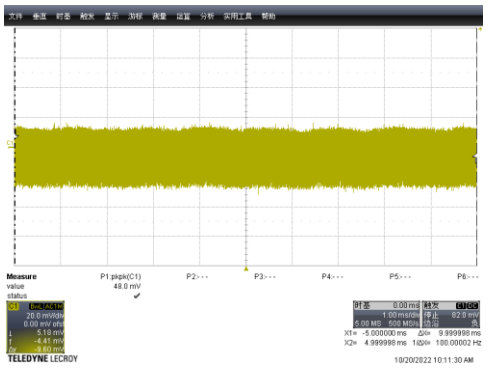


Figure 27: 12Vdc @ 3.3V/2.9A

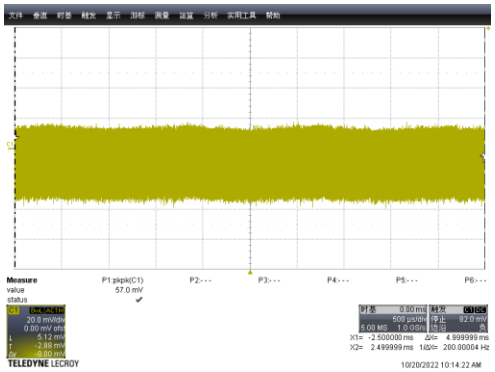


Figure 28: 16Vdc @ 3.3V/2.9A

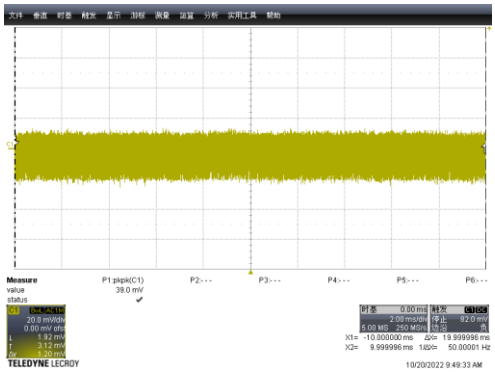


Figure 29: 12Vdc @ 5V/3A

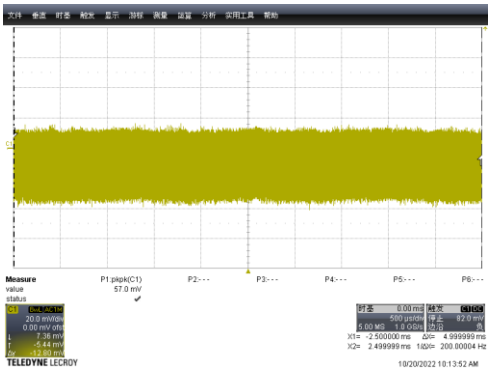


Figure 30: 16Vdc @ 5V/3A

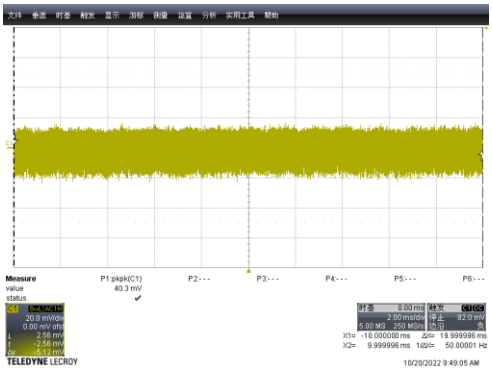


Figure 31:12Vdc @ 9V/3A

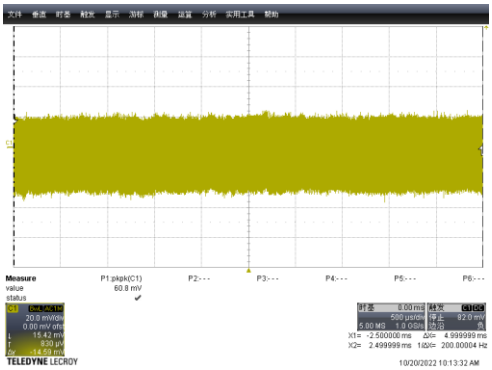


Figure 32: 16Vdc @ 9V/3A

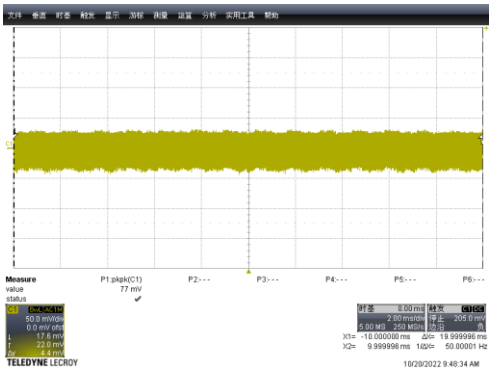


Figure 33: 12Vdc @ 15V/3A

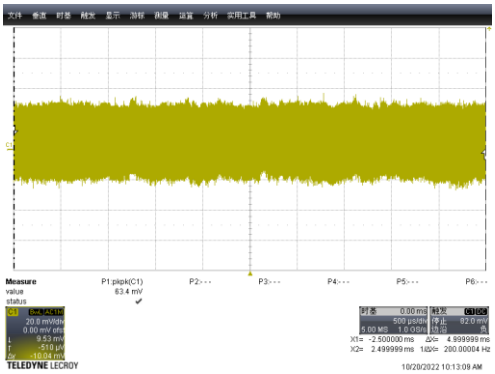


Figure 34: 16Vdc @ 15V/3A

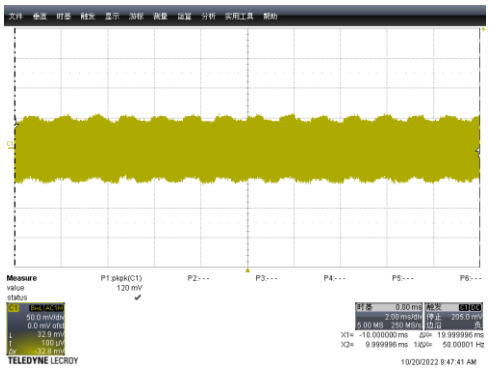


Figure 35: 12Vdc @ 20V/5A

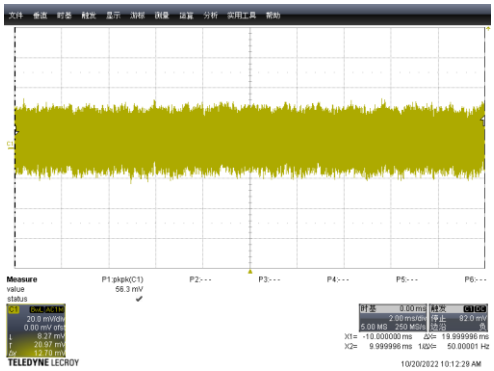


Figure 36: 16Vdc @ 20V/3A

4.7 Dynamic Load Test

VBUS_A Dynamic load ----0A to 3A,Tr=10mS, 100mA/Us

Port	Vin (V)	PDO (V)	Vout (V)	Iout (A)	VBUS	
					Overshoot(V)	Undershoot(V)
A	12	5	5.0	0<-->3	5.53	4.38
	12	9	9.0	0<-->3	9.5	8.35
	12	15	15.0	0<-->3	15.58	14.21
	12	20	20.0	0<-->3	20.78	19.02
	16	5	5.0	0<-->3	5.55	4.36
	16	9	9.0	0<-->3	9.48	8.35
	16	15	15.0	0<-->3	15.49	14.34
	16	20	20.0	0<-->3	20.49	19.34

Table 8: Dynamic Load Test

Figure 37: 12Vdc @ 5V_0A ~ 3A

Figure 38: 16Vdc @ 5V_0A ~ 3A

Figure 39: 12Vdc @ 9V_0A ~ 3A

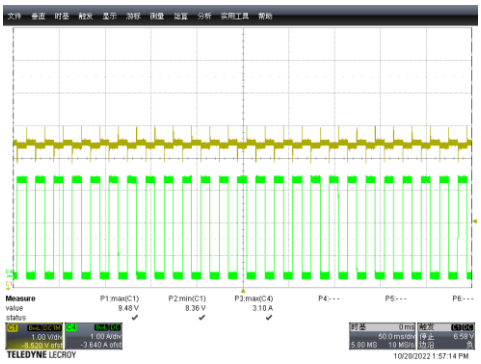


Figure 40: 16Vdc @ 9V_0A ~ 3A

Figure 41: 12Vdc @ 15V_0A ~ 3A

Figure 42: 16Vdc @ 15V_0A ~ 3A

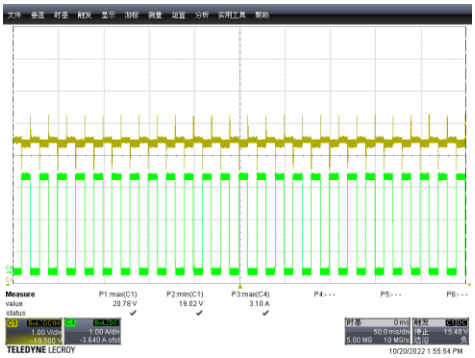


Figure 43: 12Vdc @ 20V_0A ~ 3A

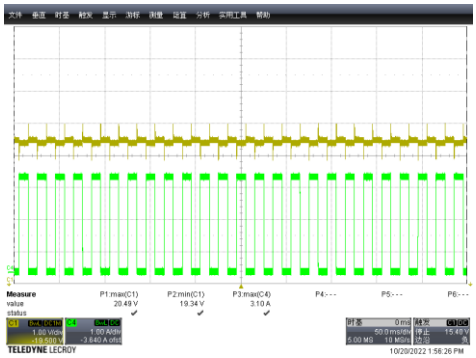


Figure 44: 16Vdc @ 20V_0A ~ 3A

4.8 Line Transient

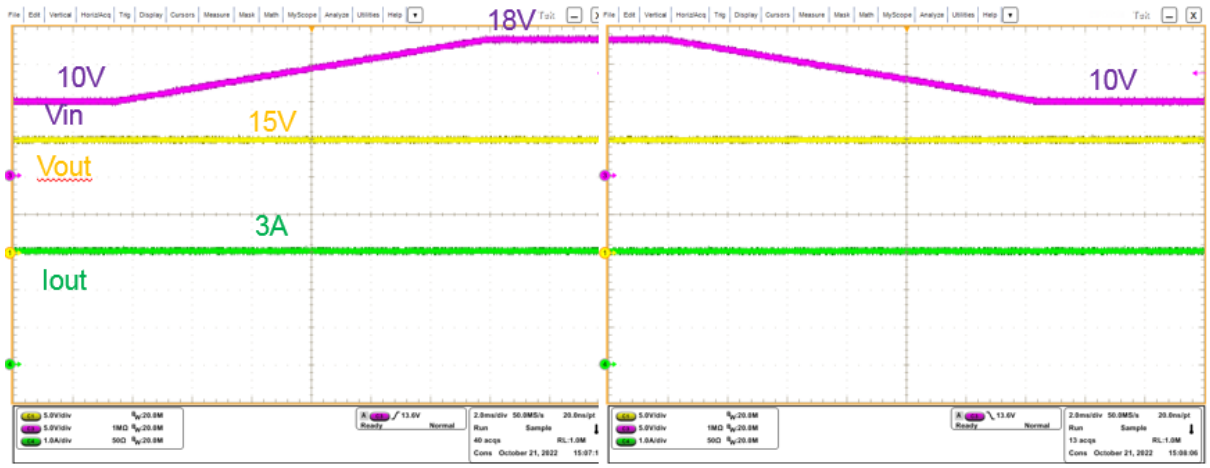


Figure 45: Vin: 10V <->18V, Vo=15V, Iout=3A

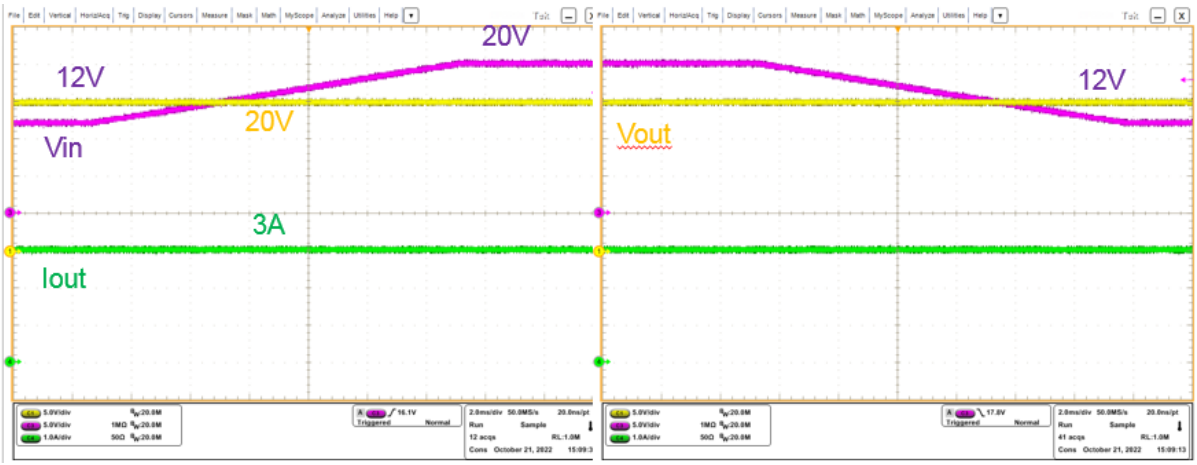


Figure 46: Vin: 12V <->20V, Vo=20V, Iout=3A

4.9 Output Current PPS Limit

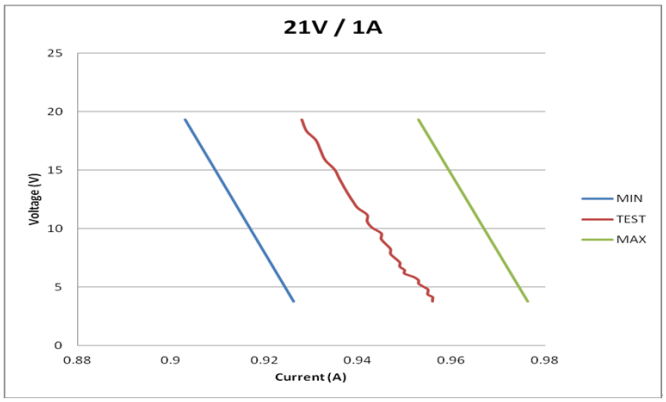


Figure 47: 21V /1A current limit test

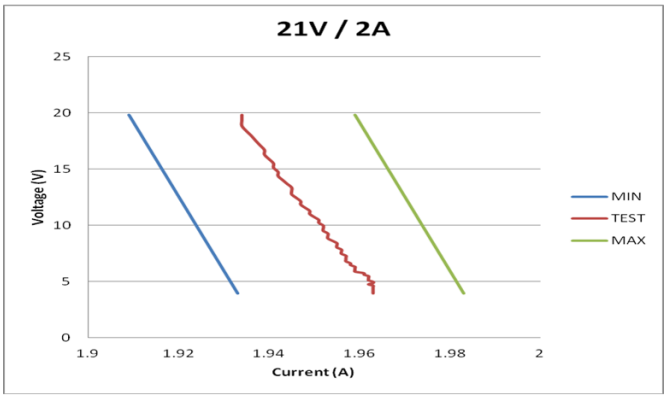


Figure 48: 21V /2A current limit test

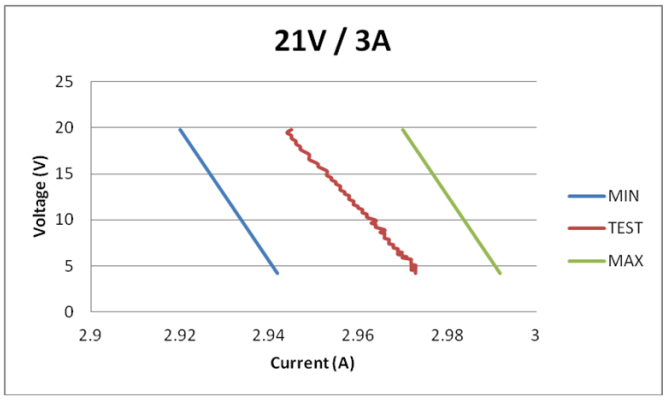


Figure 49: 21V /3A current limit test

4.10 Thermal Testing

4.10.1 Single Port Full Loading Test

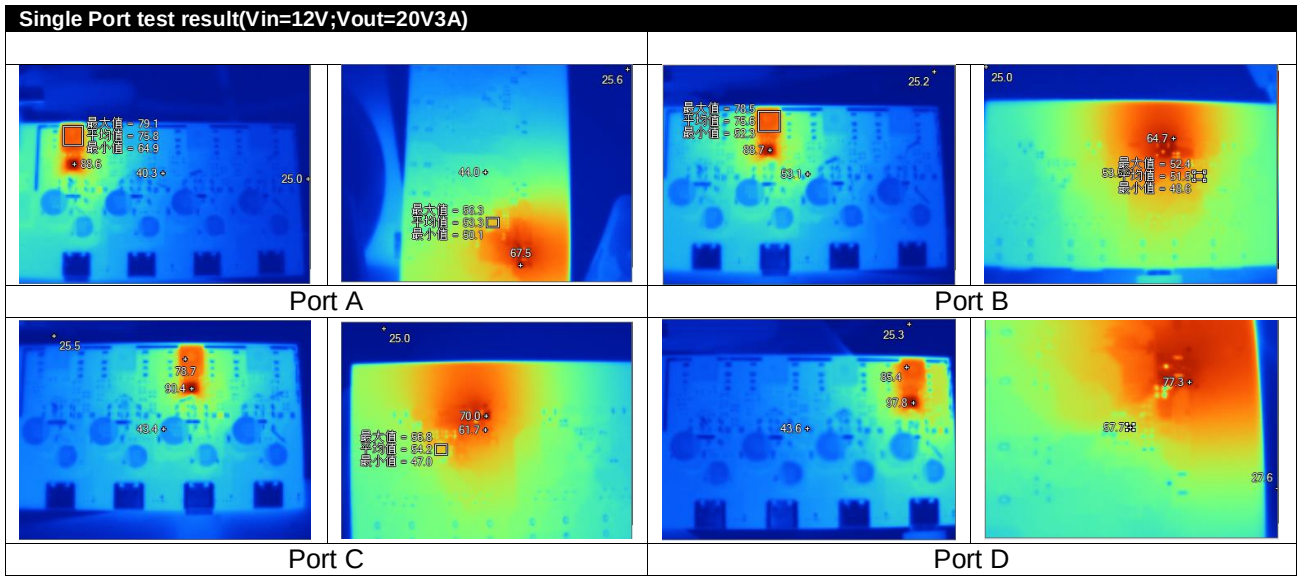


Figure 50: Single Port Thermal Test

	TPS55289	Inductor	AP43776Q
Port A(60W)	88.6°C	79.1°C	56.3°C
Port B(60W)	88.7°C	78.5°C	52.4°C
Port C(60W)	90.4°C	78.7°C	56.3°C
Port D(60W)	97.8°C	85.4°C	57.7°C

Table 9: Single Port Thermal Test

4.10.2 Port A and Port D dual Port Full Loading Test

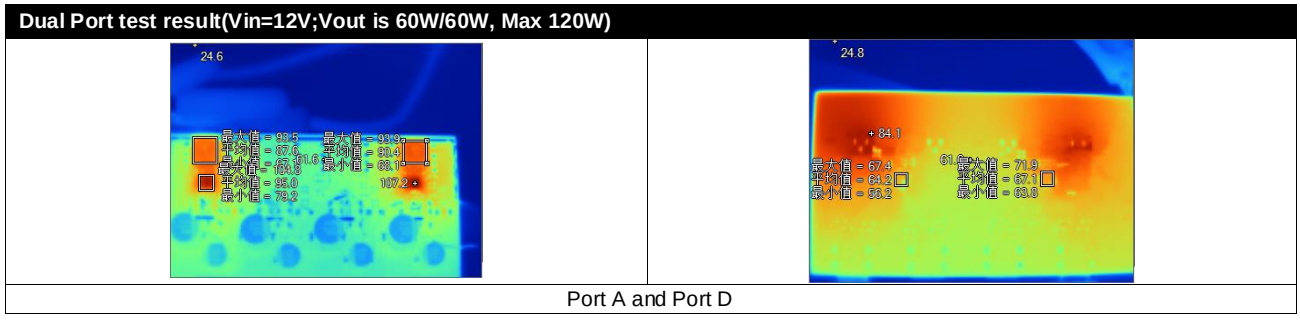


Figure 51: Dual Port Thermal Test

	TPS55289	Inductor	AP43776Q
Port A(60W)	104.8°C	93.5°C	67.4°C
Port D(60W)	107.2°C	93.9°C	71.9°C

Table 10: Dual Port Thermal Test

4.10.3 VBUS_ A, VBUS_B, VBUS_C and VBUS_D Four Port Full Loading Test

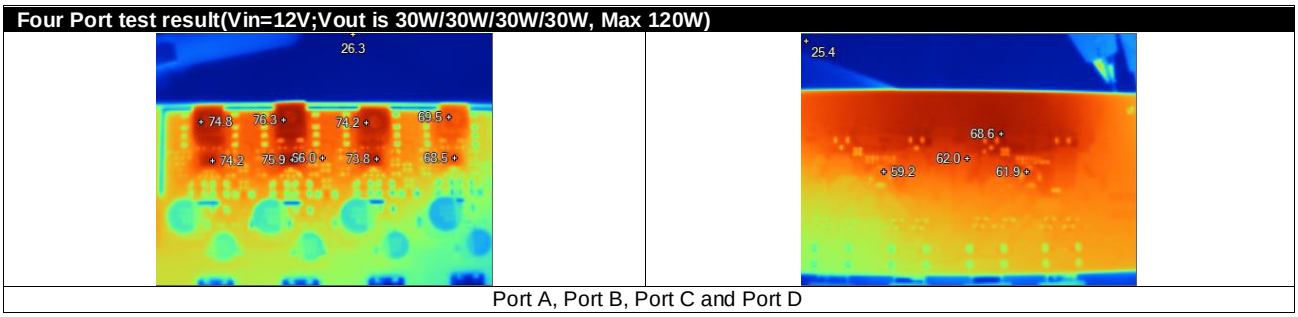


Figure 52: Four Port Thermal Test

	TPS55289	Inductor	AP43776Q
Port A(30W)	74.2°C	74.8°C	61.9°C
Port B(30W)	75.9°C	76.3°C	61.9°C
Port C(30W)	73.8°C	74.2°C	59.2°C
Port D(30W)	68.5°C	69.5°C	59.2°C

Table 10: Four Port Thermal Test

Chapter 5. Firmware Customization Performance Test

5.1 Power De-rating four Port table for Battery Status

12V 120W 4C Total Maximum Power for Allocation				
Output Power Allocation	Port #1	Port #2	Port #3	Port #4
Single Port Attached	60W			
		60W		
			60W	
				60W
Two Ports Attached	60W	60W		
	60W		60W	
	60W			60W
		60W	60W	
		60W		60W
			60W	60W
Three Port Attached	60W	30W	30W	
	60W	30W		30W
	60W		30W	30W
		60W	30W	30W
Four Port Attached	30W	30W	30W	30W

Table 11: Power De-rating four Port table for Battery Status

5.2 Battery Power De-Rating (Different Input Voltage)

Show the case of battery power de-rating

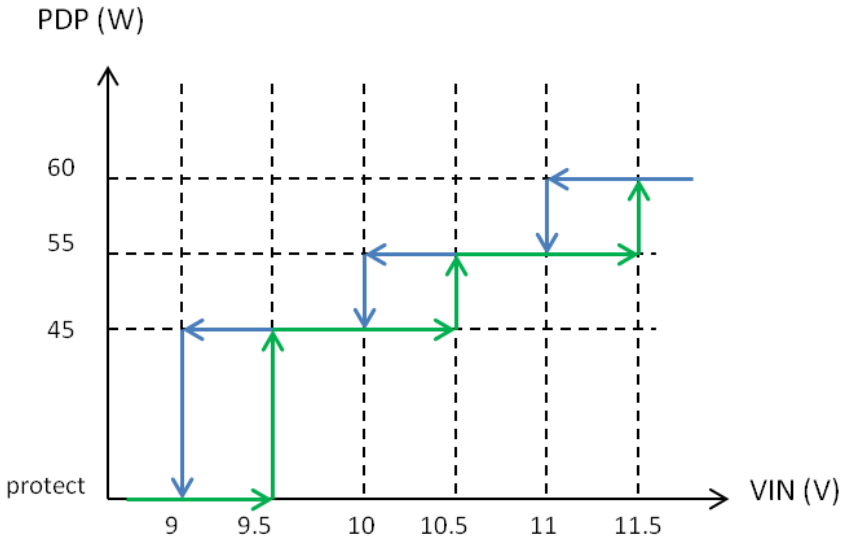


Figure 53: battery power de-rating

Battery Input Voltage Dependent Charging Power De-Rating Scheme				
	High(V)	**Low(V)**	**Power De-Rating (%)**	**COMMENT**
Battery Voltage (V)	**14.50**	**11**	**NONE**	Normal Typical Battery 12V Max power is 60W, 20V/3A
	11	**10**	**Decrease 5W**	Max power is 55W, 20V/2.75A
	10	**9**	**Decrease 15W**	Max power is 45W, 20V/2.25A
	9	-	**Shutdown Charging**	LED Indication of FAULT

Table 11: Battery Power De-Rating (Different Input Voltage)

5.3 Battery Power De-Rating (thermal)

Show the case of thermal de-rating.

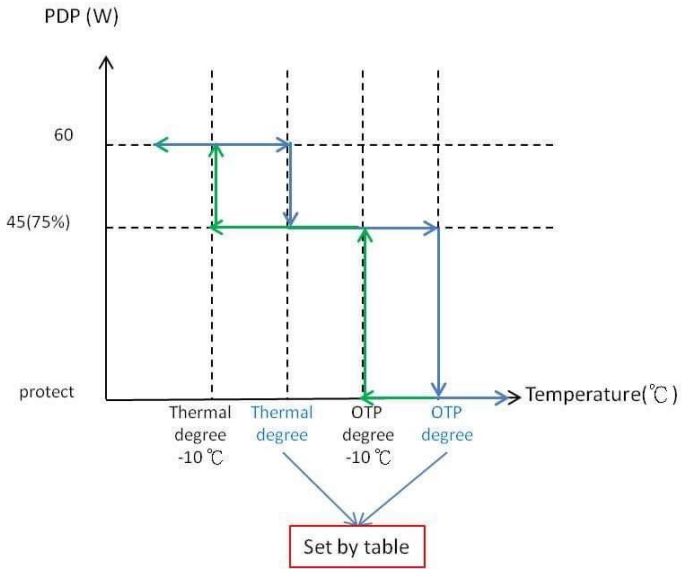


Figure 54: battery power de-rating(thermal)

Chapter 6. EMI Test

CE test result can pass the CISPR25_level5 limit with >6DB margin

(A) Conduction EMI test, 12V, Vo=5V/Io=3A

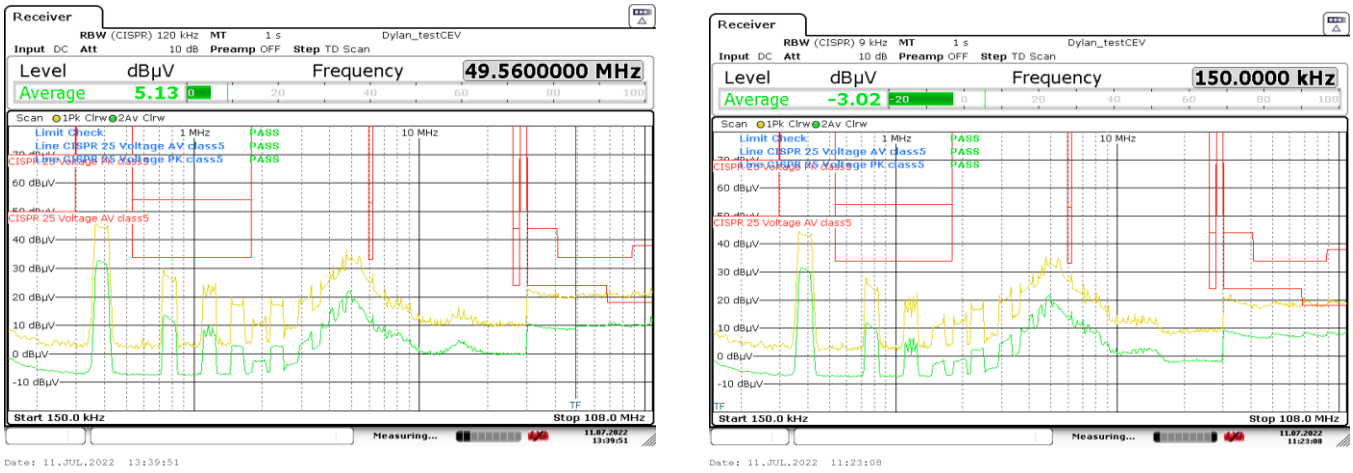


Figure 55: Vin=12V; Vout=5V/3A

(B) Conduction EMI test, 12V, Vo=9V/Io=3A

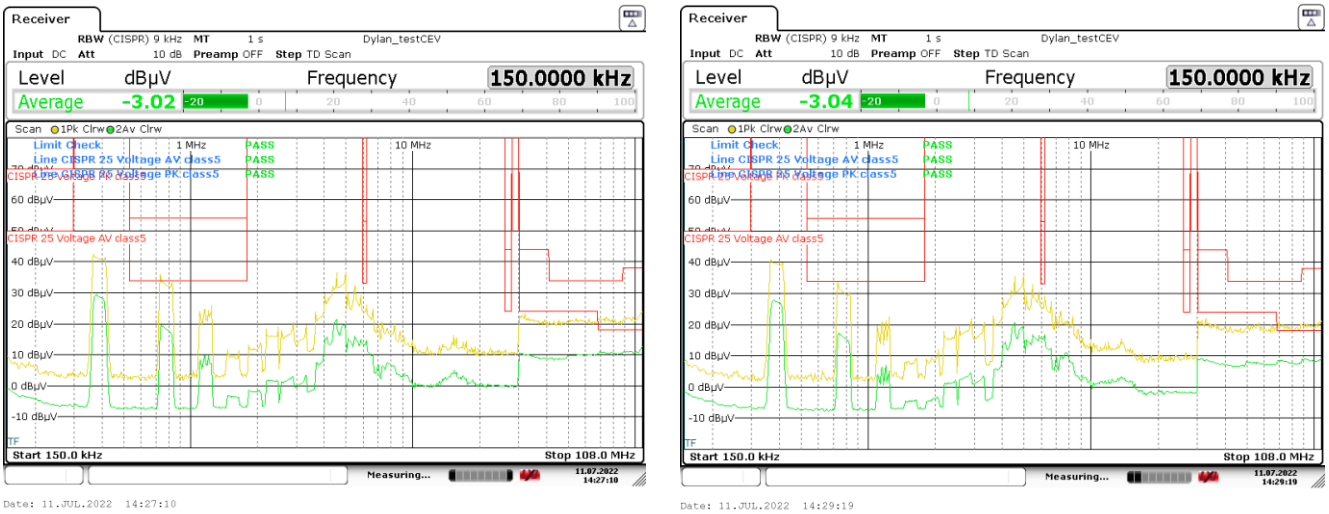


Figure 56: Vin=12V; Vout=9V/3A

(C) Conduction EMI test, 12V, Vo=15V/Io=3A

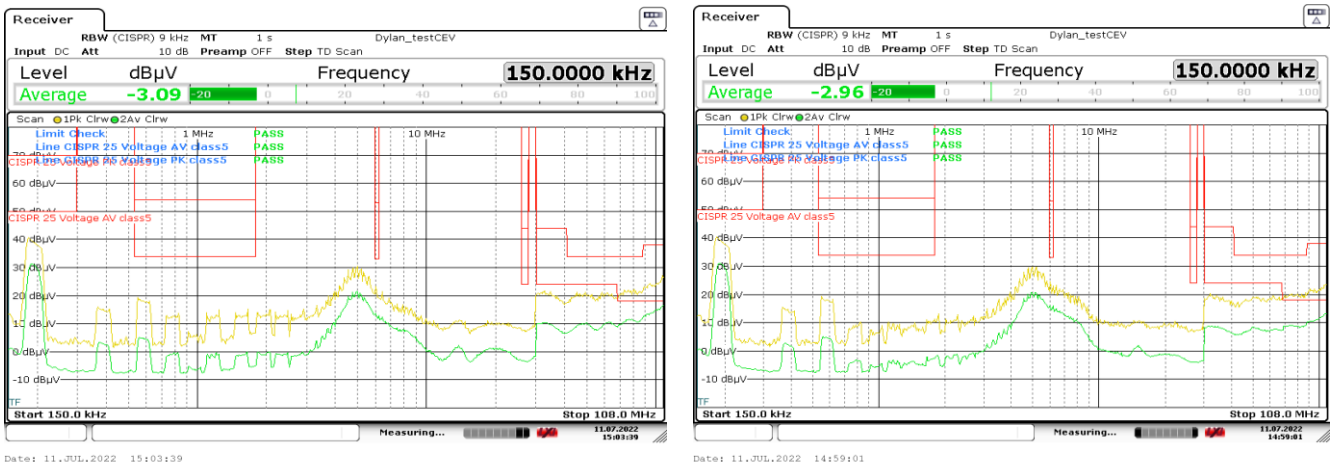


Figure 57: Vin=12V; Vout=5V/3A

(D) Conduction EMI test, 12V, Vo=20V/Io=3A

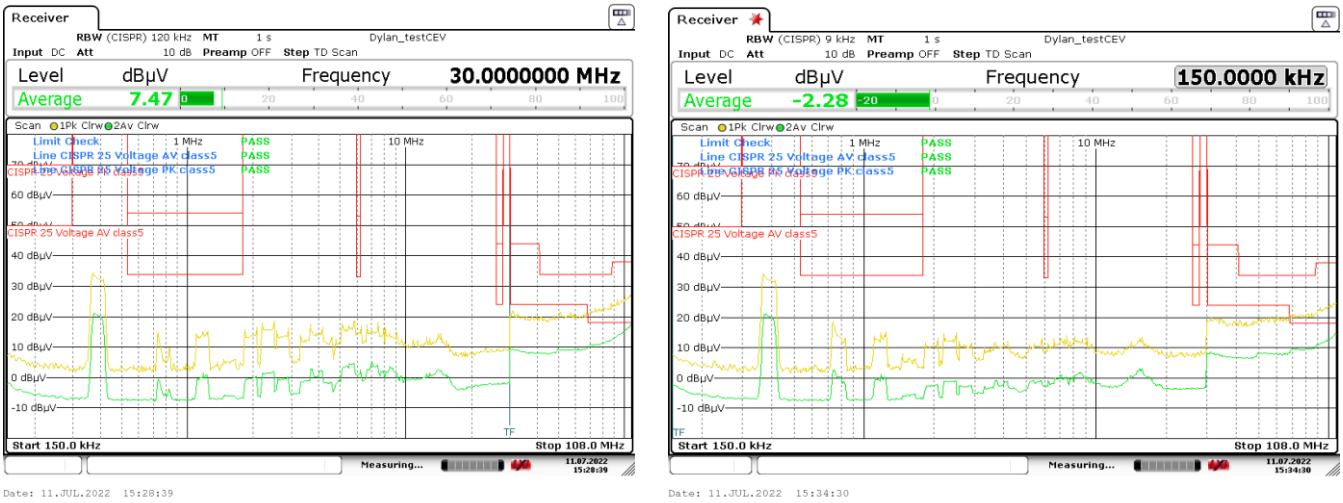


Figure 58: Vin=12V; Vout=5V/3A

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