

## 60 W USB-PD and Quick Charge 3.0 Buck-Boost Reference Design Documentation Package



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### TECHNICAL NOTE

#### Overview

This reference design describes the operation and performance of the NCP81239. The design demonstrates the NCP81239 controller capabilities, as well as a fully qualified design for today's fast charging standards. This is a universal charger that is compliant to Qualcomm®, Samsung™, and USB™ fast-charging protocols.

The design depicts the typical non-inverting buck boost regulator which is optimal when the output voltage can be greater than or less than the input voltage. It is intended for the power supply designer to adopt the circuit directly into a typical system design, making only minimal component changes based on system requirements.

The design is meant to be a complete solution, but it also provides access to key features of the NCP81239. These include controlled slew rate voltage transitions, I<sup>2</sup>C interface, wide input range, over-voltage and over-current protection, and adaptive non-overlap drivers.

#### Key Features

- Compliant with USB Power Delivery 3.0 Specification
- Compliant with Qualcomm Quick Charge QC2.0 Specification
- Compliant with Qualcomm Quick Charge QC3.0 Specification
- Non-Inverting Buck Boost which Allows for Any Output Voltage 0.2 V to 25.5 V with 100 mV Resolution
- Type-C Receptacle for Easy Charging of All New Phones, Tablets, and Notebook Computers
- ON Semiconductor NCP81239 Synchronous Buck Boost Controller with Four MOSFETs
- Cypress® CCG2 CYPD2134 Port Control and Policy Manager
- Small Form Factor-Fits in Automotive Cigarette Lighter

#### Specifications

Table 1. SPECIFICATIONS TABLE

Device	NCP81239
Application	Car Adapter
Input Voltage	5 V to 24 V DC
Output Power	Up to 60 W
Topology	Non-inverting Buck Boost
Isolation	Non-isolated
Output Voltage	3.6 V – 20 V (USB-PD, QC2.0, QC3.0)
Nominal Current	3 A

#### Board

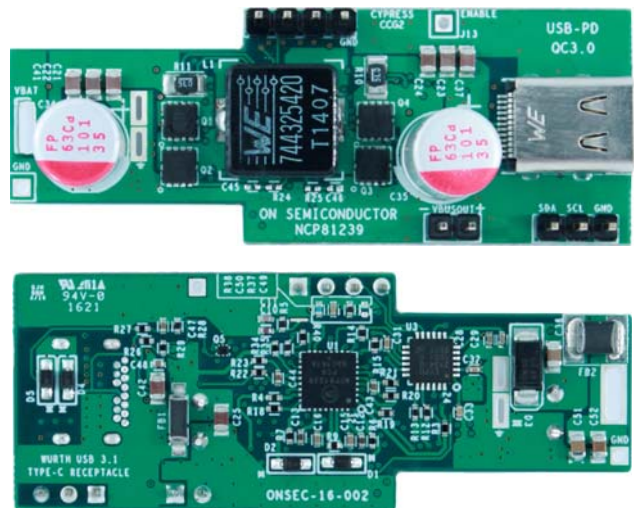


Figure 1. Reference Design Board Image

Schematics

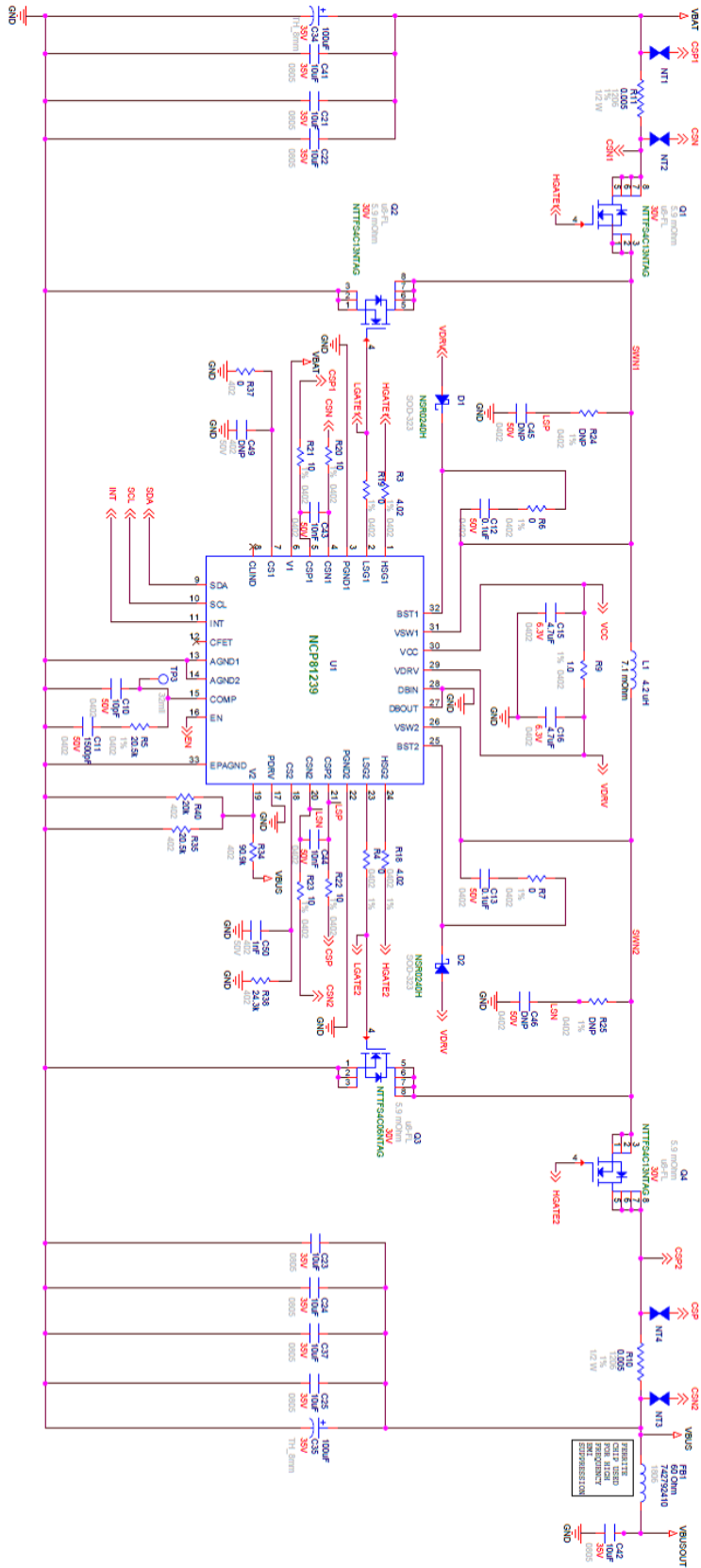


Figure 2. NCP81239 Buck-Boost Schematic

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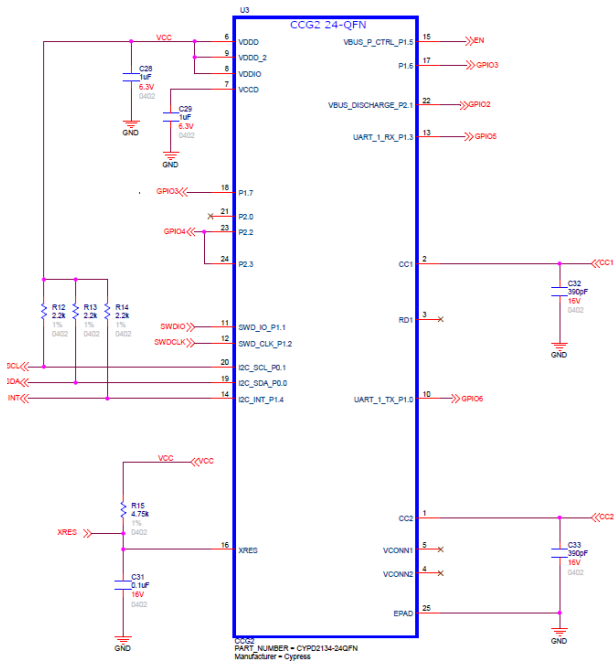


Figure 3. CCG2 QFN24 Package

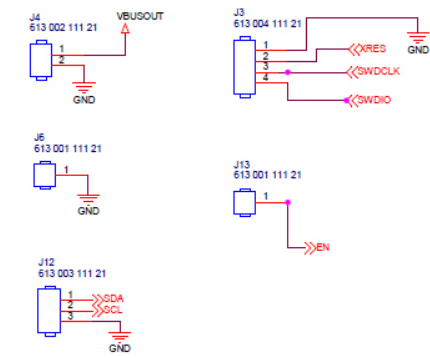


Figure 4. Connection Test Points

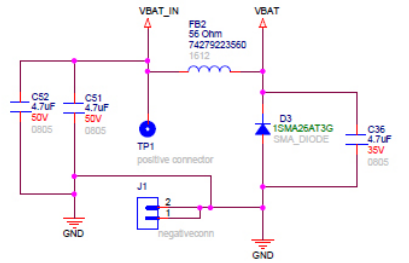


Figure 5. Input Protection Circuit

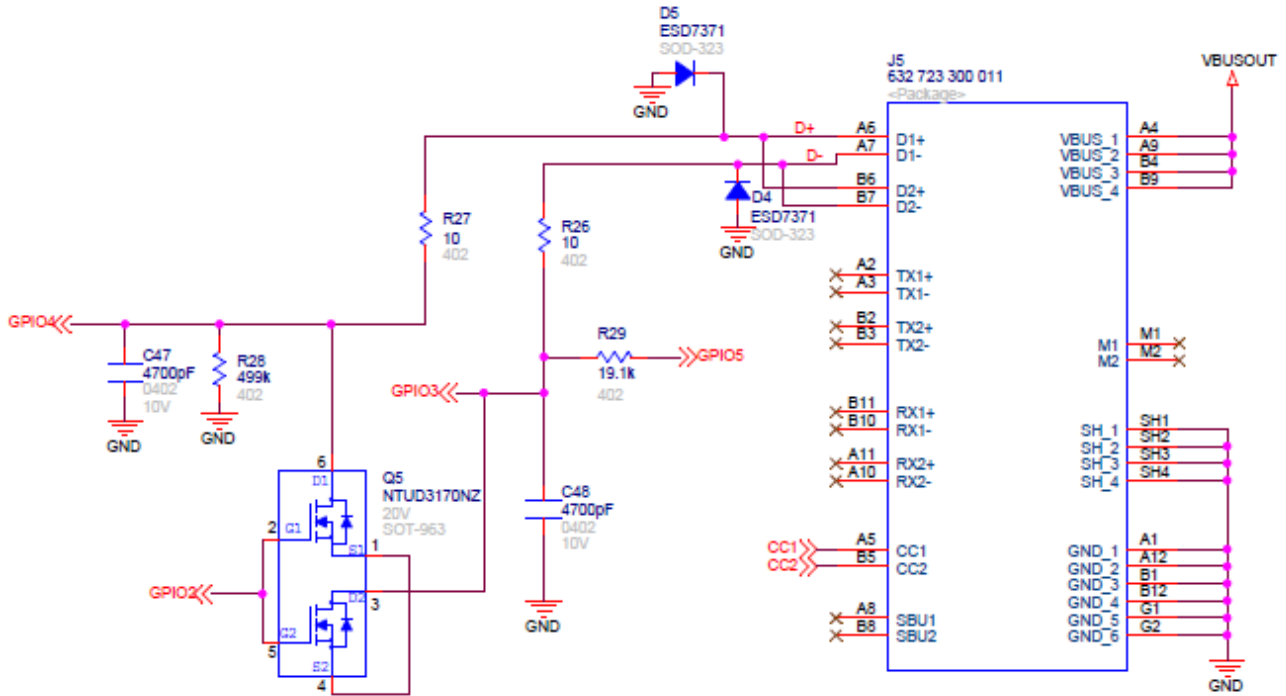


Figure 6. Type-C Receptacle and QC3.0/BC1.2 Implementation

Board Layout

Top Layer

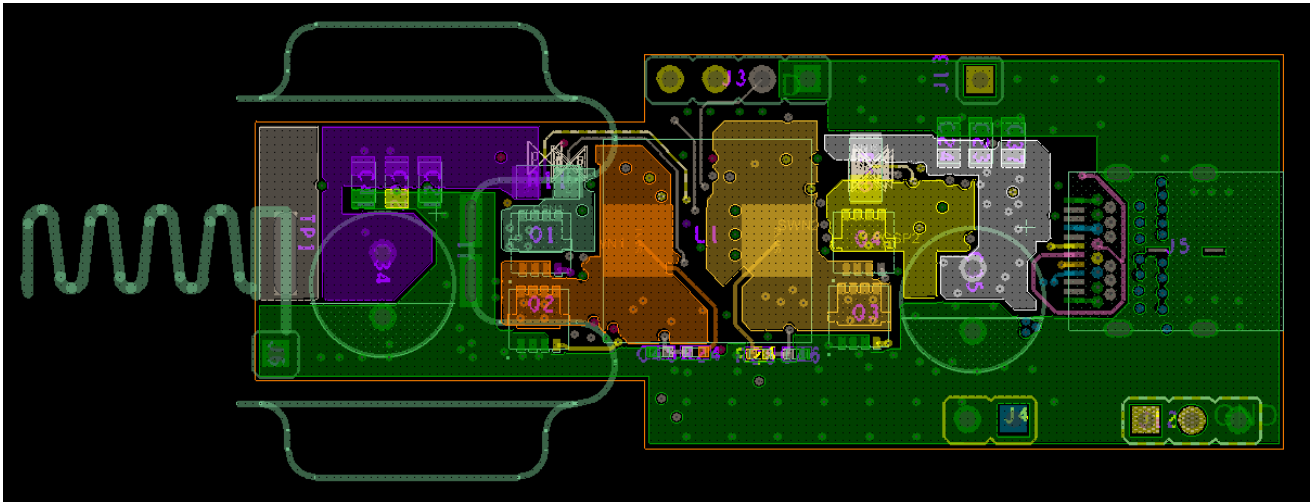


Figure 7. Top Layer

Bottom Layer

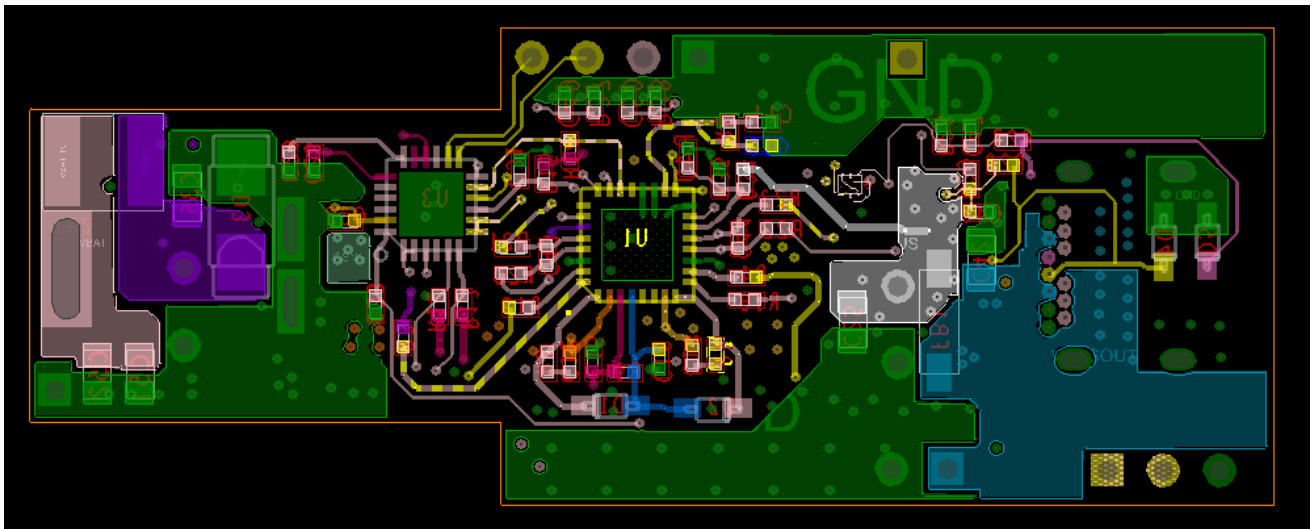


Figure 8. Bottom Layer

**Performance Summary**

*V-I Curve*

Below is a graph of output voltage vs. load current for each of the USB-PD profiles 5 V, 7 V, 8 V, 9 V, 12 V, 15 V, and 20 V. This shows that the output voltage is held constant

until the load reaches approximately 125% of the rated current of 3 A. At the heavy load, the design will enter a hiccup mode, where it tries to restart every 1.2 seconds. When it does power-up, it returns to 5 V.

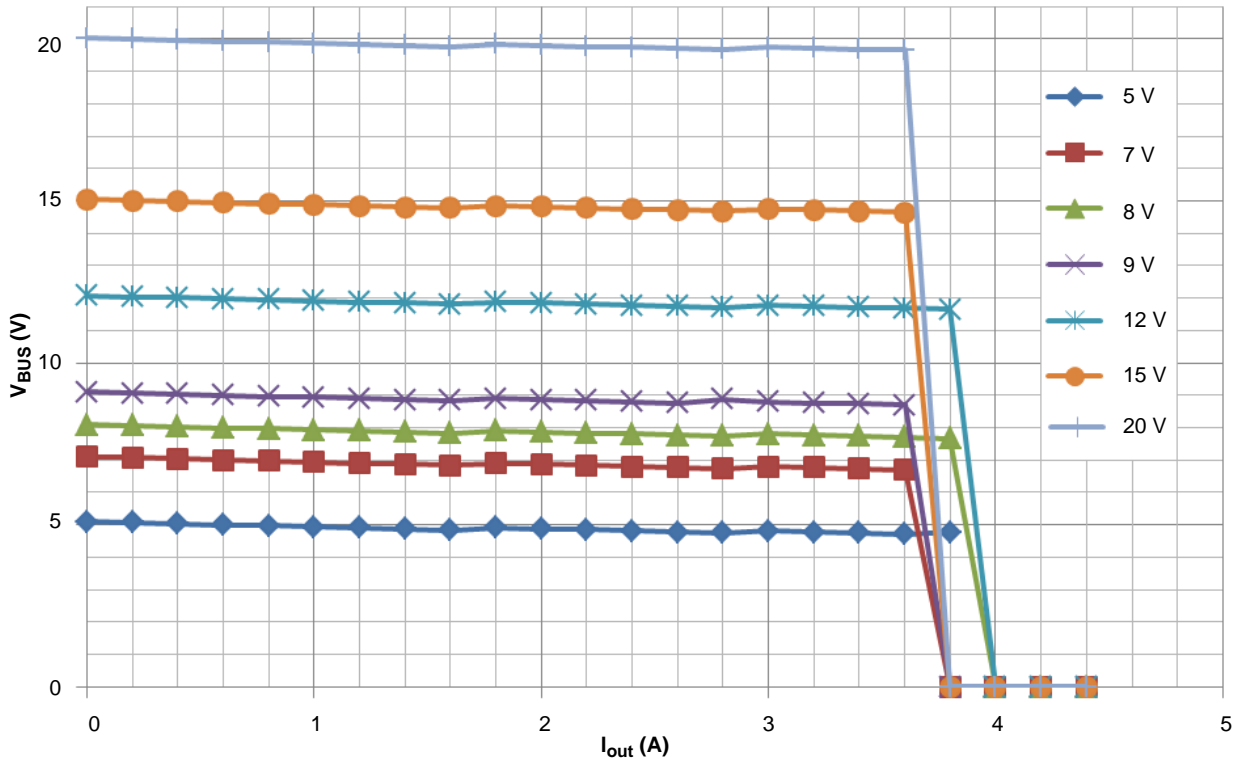


Figure 9. V-I Curve for USB-PB Profiles

Efficiency vs Load Current at 12 Vin

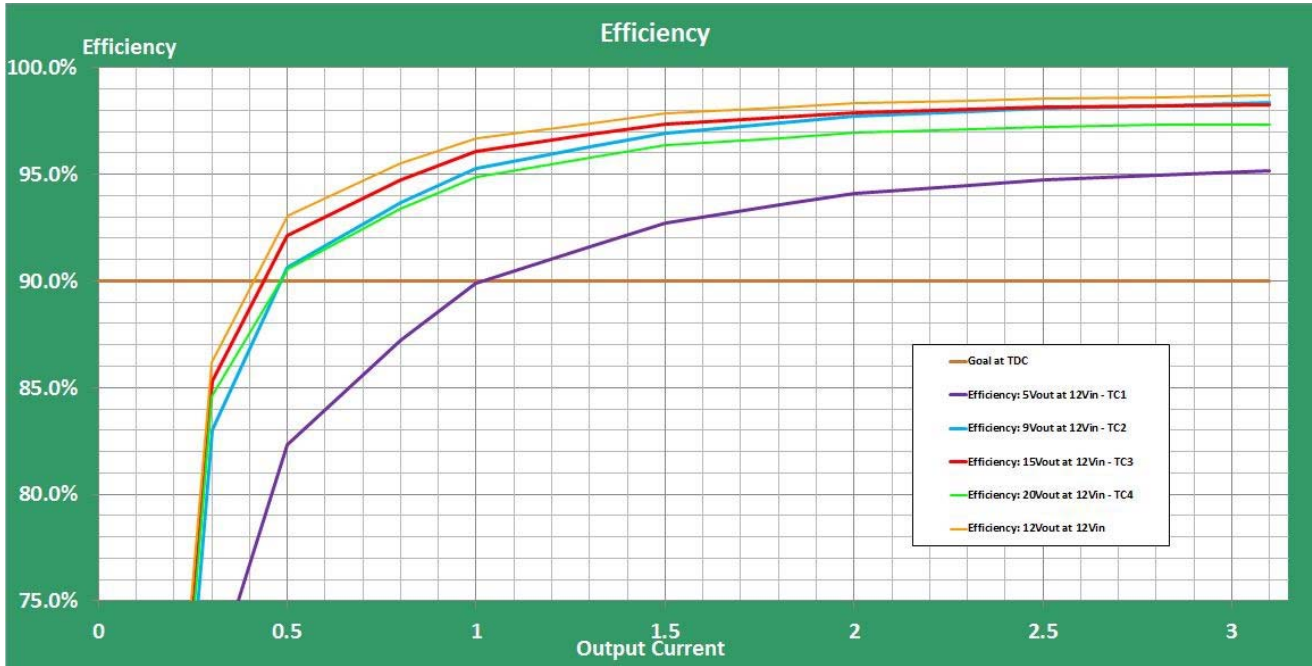


Figure 10. Efficiency vs Load Current at 12 Vin Graph

Table 2. EFFICIENCY VS LOAD CURRENT RESULTS TABLE

Results Summary					
	5 V Out at 12 V In – TC1	9 V Out at 12 V In – TC 2	15 V Out at 12 V In – TC 3	20 V Out at 12 V In – TC 4	12 V Out at 12 V In
Efficiency at TDC – POWERTRAIN	94.9%	98.2%	98.2%	97.2%	98.6%
Peak Efficiency – POWERTRAIN	95.2%	98.3%	98.2%	97.3%	98.7%
VR Power Loss at TDC	0.8 W	0.5 W	0.8 W	1.5 W	0.5 W

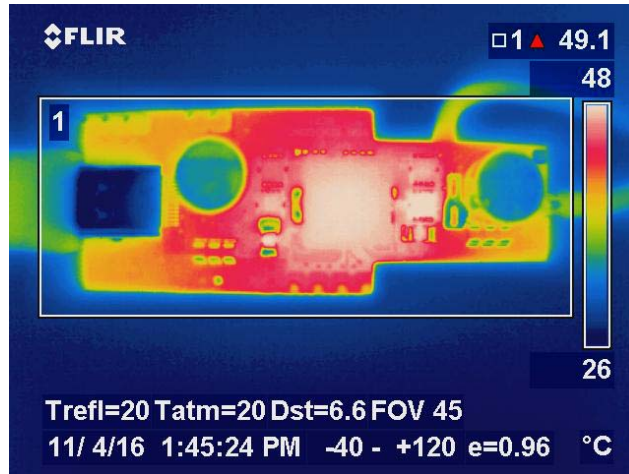


Figure 11. Thermal Measurements at 12 Vin, 5 Vout, 3 A (15 W)

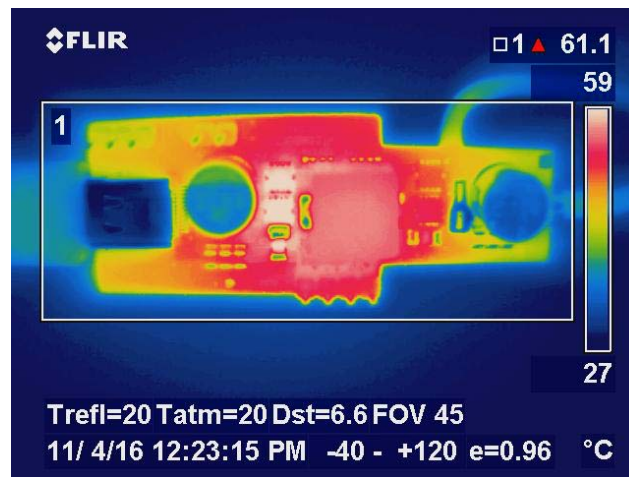


Figure 12. Thermal Measurements at 12 Vin, 15 Vout, 3 A (45 W)

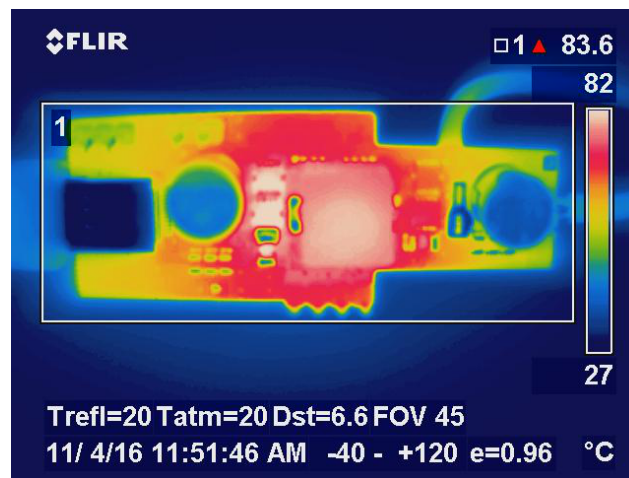


Figure 13. Thermal Measurements at 12 Vin, 20 Vout, 3 A (60 W)



*Startup and Shutdown Timings*

Startup and shutdown timings are shown below. These are initiated by driving the Enable pin high and low, respectively. By default the NCP81239 starts up at 5 V. Enable and Disable are controlled by CYPD2134 in the

application. The waveforms are shown here for reference only. When Enable goes low, the NCP81239 controls the output voltage so that it decays linearly to 0 V. It is required that a USB-PD adapter discharge VBUS to 800 mV or less in 650 ms following a detach event.

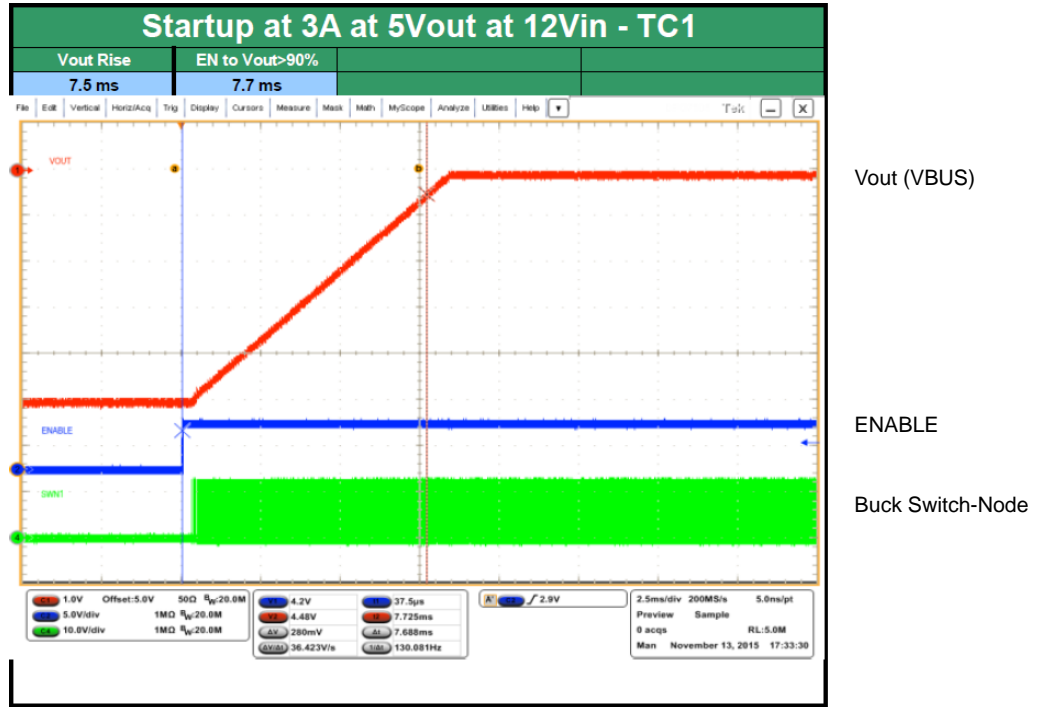


Figure 14. Startup at 3 A, 5 Vout, 12 V In Waveform

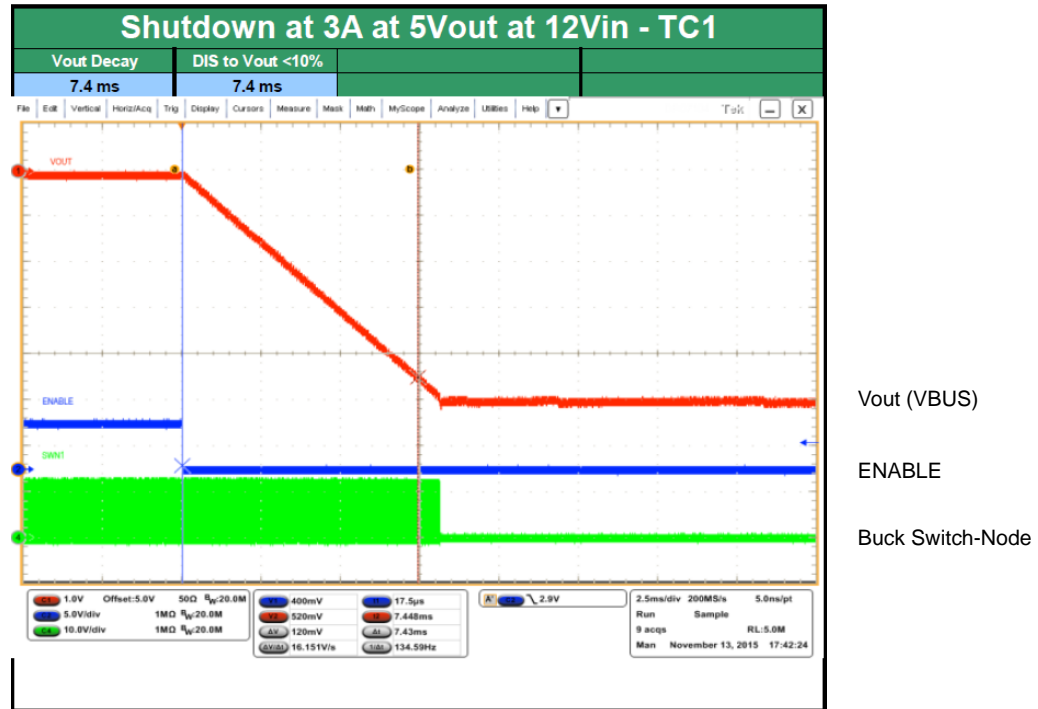


Figure 15. Shutdown at 3 A, 5 Vout, 12 V In Waveform



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## USB-PD Voltage Profile Transitions

After the reference design is powered and is plugged into a device, it will provide 5 V. From here, the device can request a higher voltage profile. Below is an example of a transition from 5 V to 20 V. The output (VBUS) rises

linearly with a slew rate which can be programmed over the I<sup>2</sup>C interface. In the image below, it can also be noted that the controller has a very smooth transition between buck and boost mode.

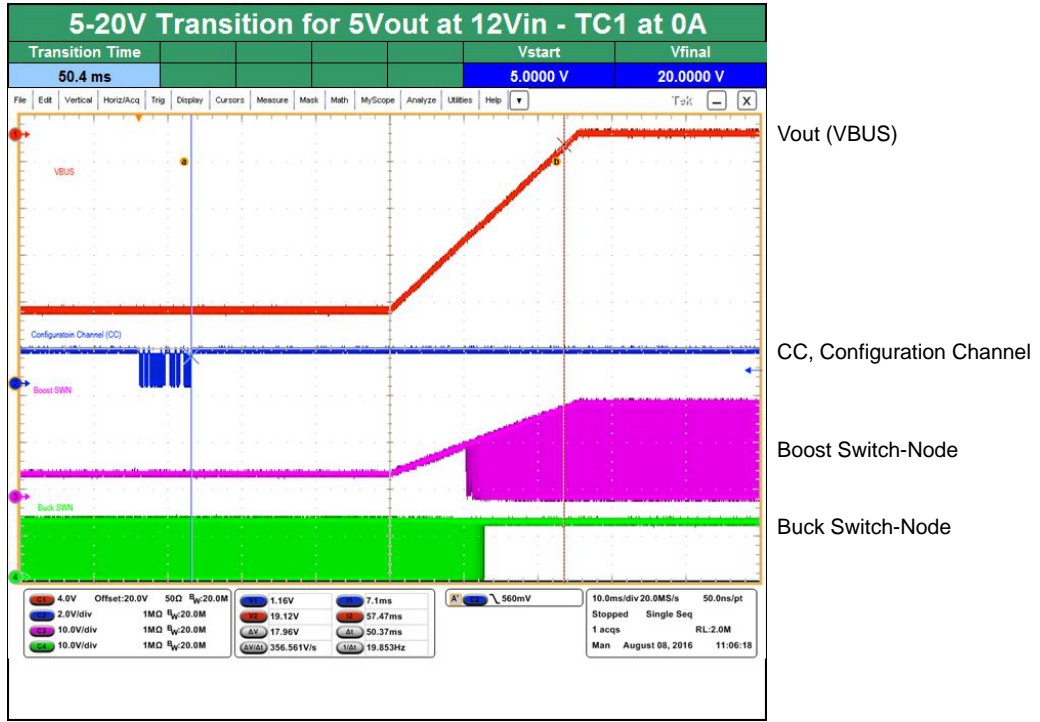


Figure 16. Transition Waveform from 5 V – 20 V

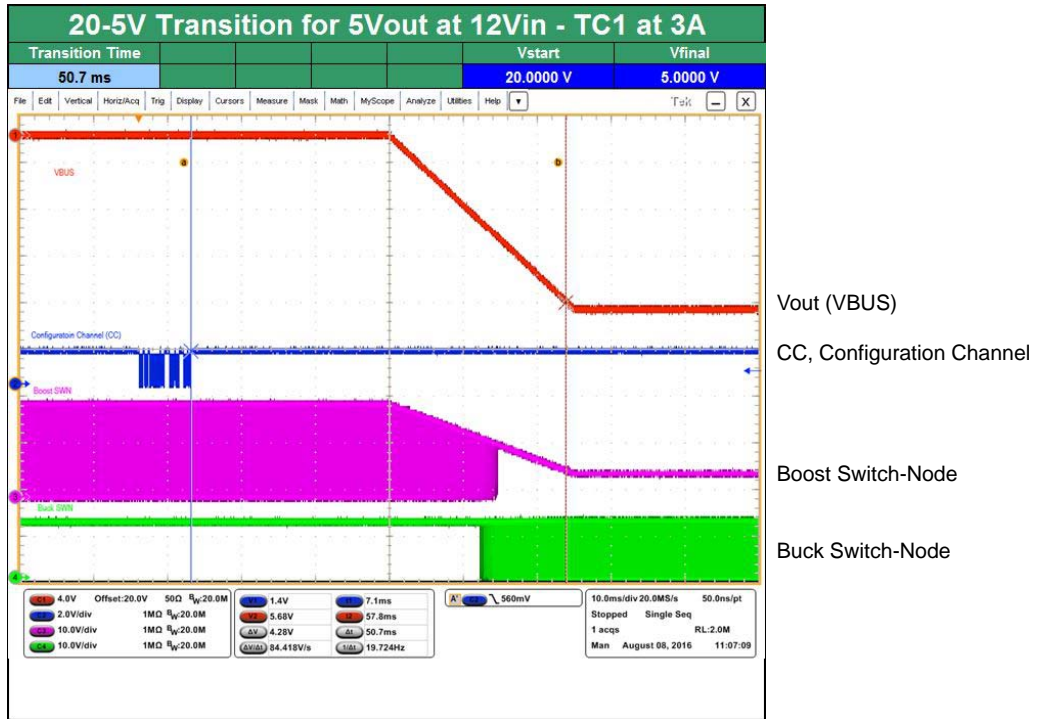


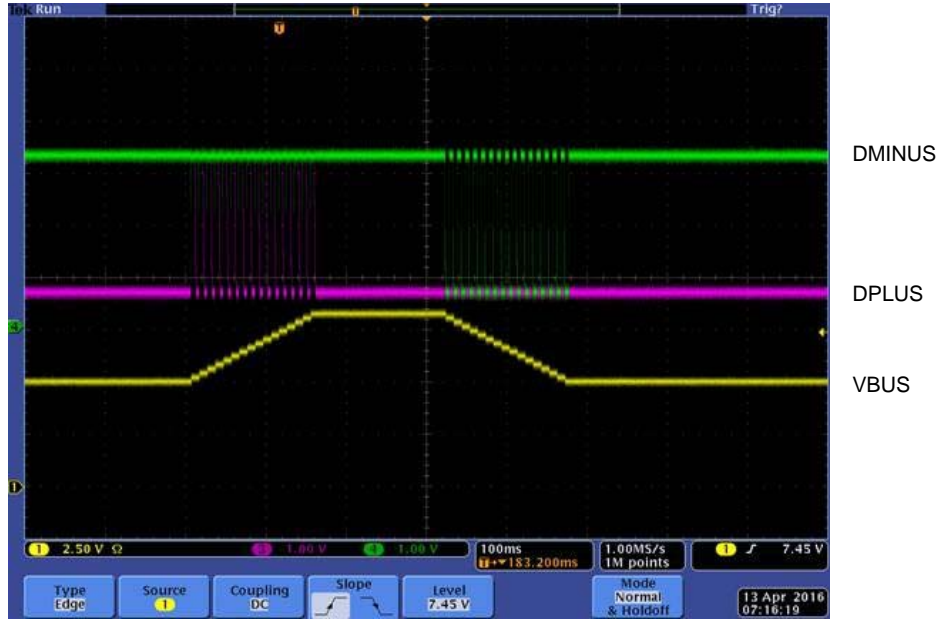
Figure 17. Transition Waveform from 20 V – 5 V

*Qualcomm Quick Charge Modes*

If a device with a Qualcomm processor is plugged into the reference design, the adapter will enter QC2.0 or QC3.0 mode. In QC3.0 mode the adapter will translate pulses on DPLUS into an increment on VBUS of 200 mV. It will translate pulses on DMINUS into a decrement on VBUS of 200 mV. In QC2.0 mode, the output voltage follows the table below.

**Table 3. QUALCOMM HIGH VOLTAGE DEDICATED CHARGING PORT (HVDCP) TABLE**

Portable Device		Adapter
DPLUS	DMINUS	Output Voltage
0.6 V	0.6 V	12 V
3.3 V	0.6 V	9 V
0.6 V	3.3 V	QC3.0
3.3 V	3.3 V	20 V
0.6 V	GND	5 V



**Figure 18. QC3.0 Voltage Increment and Decrement Waveform**

*Cable Compensation*

The USB-PD specification requires that VBUS must be regulated to  $\pm 5\%$  of the target profile, except at 5 V where it must be between 4.75 V and 5.5 V. The USB-PD specification also allows for up to 500 mV of drop across a USB-C to USB-C cable. In order to keep VBUS within these limits, cable compensation was implemented on this

design. When the current is greater than 1.6 A and less than 2.8 A, the output voltage is increased by 100 mV. When the output current is greater than 2.8 A, the output voltage is increased by another 100 mV. Below is a plot of the output voltage vs. load current on both sides of a 1 meter USB-C to USB-C cable.

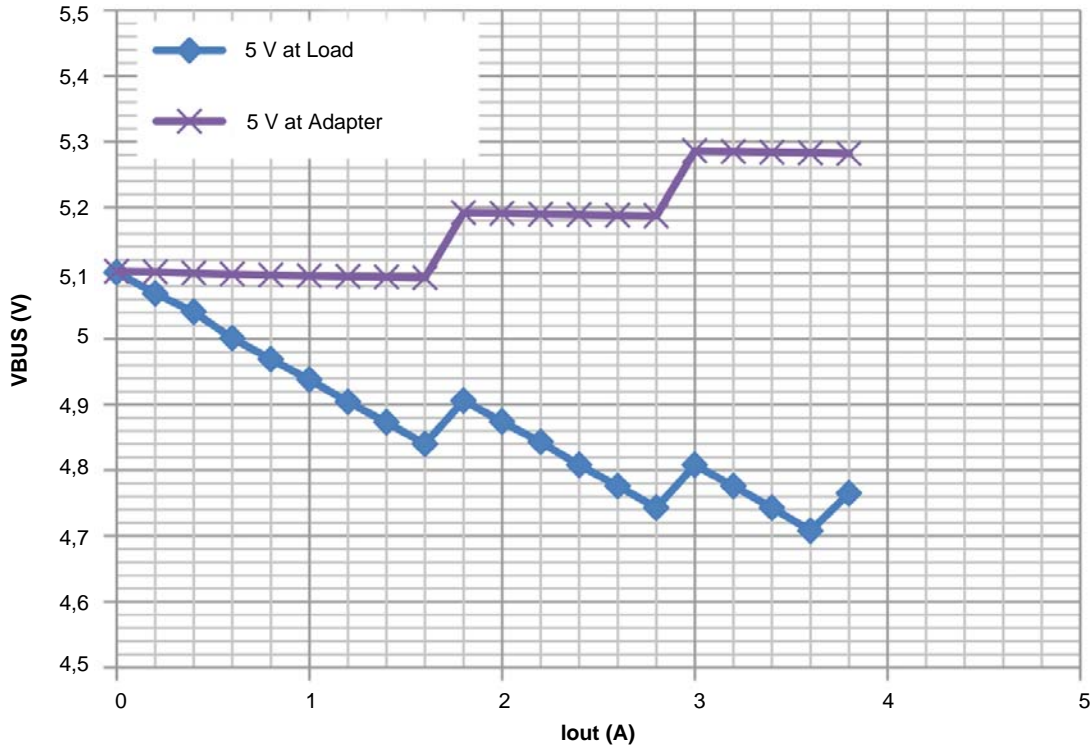


Figure 19. VBUS at Adapter and VBUS at the Load Graph

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## Bill of Materials (BOM)

**Table 4. BILL OF MATERIALS (Note 1)**

Designator	Qty	Description	Value	Tolerance	Footprint	Manufacturer	Manufacturer Part Number	Substitution Allowed
U1	1	USB POWER DELIVERY 4-SWITCH BUCK/BOOST			32QFN	ON Semiconductor	NCP81239	No
Q1,2,4	3	MOSFET N-CH 30 V 38 A U8FL	14 mΩ		u8-FL	ON Semiconductor	NTTFS4C13N	No
Q3	1	MOSFET N-CH 30 V 65 A U8FL	6.1 mΩ		u8-FL	ON Semiconductor	NTTFS4C06N	No
L1	1	4.2UH SHIELDED WIREWOUND INDUCTOR 11 A 7.1 mΩ	4.2 μH	20%	10x10x5mm	Würth Elektronik	744 325 420	No
C23,24,25,37,42	5	CAP CER 10 μF 35 V X5R 0805	10 μF	10%	0805	muRata	GRM21BR6YA106KE43L	Yes
C35	1	CAP ALUM POLY 100 μF 20% 35 V T/H	100 μF	20%	RTH 8 mm	Nichicon	RL81V101MDN1KX	Yes
C21,22,41	3	CAP CER 10μF 35 V X5R 0805	10 μF	10%	0805	muRata	GRM21BR6YA106KE43L	Yes
C34	1	CAP ALUM POLY 100 μF 20% 35 V T/H	100 μF	20%	RTH 8 mm	Nichicon	RL81V101MDN1KX	Yes
FB1	1	FERRITE BEAD 60 Ω 1806 1 LN	60 Ω		1806	Würth Elektronik	742 792 410	Yes
R6,7	2	RES SMD 0.0 Ω JUMPER 1/16 W 0402	0 Ω	Jumper	402	Vishay Dale	CRCW04020000Z0ED	Yes
C12,13	2	CAP CER 0.1 μF 50 V X5R 0402	0.1 μF	10%	0402	muRata	GRM155R61H104KE19D	Yes
C15,16	2	CAP CER 4.7 μF 6.3 V X5R 0402	4.7 μF	20%	0402	Würth Elektronik	885 012 105 008	Yes
R9	1	RES SMD 1 Ω 1% 1/16 W 0402	1 Ω	1%	0402	Vishay Dale	CRCW04021R00FKED	Yes
D1,2	2	DIODE SCHOTTKY 40 V 250 MA SOD323			SOD-323	ON Semiconductor	NSR0240H	No
R3,18	2	RES SMD 4.02 Ω 1% 1/16 W 0402	4.02 Ω	1%	0402	Vishay Dale	CRCW04024R02FKED	Yes
R4,19	2	RES SMD 0.0 Ω JUMPER 1/16W 0402	0 Ω	Jumper	0402	Vishay Dale	CRCW04020000Z0ED	Yes
C10	1	CAP CER 10 PF 50 V NP0 0402	10 pF	5%	0402	Würth Elektronik	885 012 005 055	Yes
C11	1	CAP CER 1500PF 50 V X7R 0402	1500 pF	10%	0402	Würth Elektronik	885 012 205 062	Yes
R5	1	RES SMD 20.5 kΩ 1% 1/16 W 0402	20.5 kΩ	1%	0402	Vishay Dale	CRCW040220K5FKED	Yes
R10,11	2	RES SMD 0.005 Ω 1% 1/2 W 1206	5 mΩ	1%	1206	Vishay Dale	WSL12065L000FEA18	Yes
C43,44	2	CAP CER 10000 PF 50 V X7R 0402	10 nF	10%	0402	Würth Elektronik	885 012 205 067	Yes
R20,21,22,23	4	RES SMD 10 Ω 1% 1/16 W 0402	10 Ω	1%	0402	Vishay Dale	CRCW040210R0FKED	Yes
FB2	1	FERRITE BEAD 56 Ω 1612 1LN	56 Ω		1612	Würth Elektronik	742 792 235 60	Yes
C36,51,52	3	CAP CER 4.7 μF 50 V X5R 0805	4.7 μF	10%	0805	muRata	GRM21BR61H475KE51L	Yes
D3	1	TVS DIODE 26 VWM 42.1 VC SMA			SMA	ON Semiconductor	1SMA26AT3G	No
Q5	1	DUAL MOSFET 2N-CH 20 V 0.22 A SOT-963			SOT-963	ON Semiconductor	NTUD3170NZ	No
U3	1	IC MCU 32 BIT 32 KB FLASH 24 QFN			24QFN	Cypress Semiconductor	CYPD2134-24QFN	No
C28,29	2	CAP CER 1 μF 6.3 V X5R 0402	1 μF	20%	0402	Würth Elektronik	885 012 105 006	Yes
R15	1	RES SMD 4.75 kΩ 1% 1/16 W 0402	4.75 kΩ	1%	0402	Vishay Dale	CRCW04024K75FKED	Yes
C32,33	2	CAP CER 330 PF 25 V X7R 0402	330 pF	10%	0402	Würth Elektronik	885 012 205 041	Yes
C31	1	CAP CER 0.1 μF 16 V X7R 0402	0.1 μF	10%	0402	Würth Elektronik	885 012 205 037	Yes
R24,25	0		DNP		0402			
C45,46	0		DNP		0402		DNP	
R12,13,14	3	RES SMD 2.2 kΩ 1% 1/16 W 0402	2.2 kΩ	1%	0402	Vishay Dale	CRCW04022K20FKED	Yes
J12	1	CONN HEADER 3 POS 2.54			-	Würth Elektronik	613 003 111 21	Yes
J3	1	CONN HEADER 4 POS 2.54			-	Würth Elektronik	613 004 111 21	Yes
J4	1	CONN HEADER 3 POS 2.54			-	Würth Elektronik	613 002 111 21	Yes
J5	1	USB TYPE-C RECEPTACLE			-	Würth Elektronik	632 723 300 011	Yes
R28	1	RES SMD 499 kΩ 1% 1/16 W 0402	499 kΩ	1%	0402	Vishay Dale	CRCW0402499KFKED	Yes
R26,27	2	RES SMD 10 Ω 1% 1/16 W 0402	10 Ω	1%	0402	Vishay Dale	CRCW040210R0FKED	Yes
R29	1	RES SMD 19.1 kΩ 1% 1/16 W 0402	19.1 kΩ	1%	0402	Vishay Dale	CRCW040219K1FKED	Yes
D4,5	2	TVS DIODE 5.3 VWM SOD-323			SOD-323	ON Semiconductor	ESD7371HT1G	No
R34	1	RES SMD 90.9 kΩ 1% 1/16 W 0402	90.9 kΩ	1%	0402	Vishay Dale	CRCW040290K9FKED	Yes
R40	1	RES SMD 20 kΩ 1% 1/16 W 0402	20 kΩ	1%	0402	Vishay Dale	CRCW040220K0FKED	Yes
R35	1	RES SMD 20.5 kΩ 1% 1/16 W 0402	20.5 kΩ	1%	0402	Vishay Dale	CRCW04220K5FKED	Yes
R37	1	RES SMD 0.0 Ω JUMPER 1/16 W 0402	0	Jumper	0402	Vishay Dale	CRCW04020000Z0ED	Yes
R38	1	RES SMD 24.3 kΩ 1% 1/16 W 0402	24.3 kΩ	1%	0402	Vishay Dale	CRCW040224K3FKED	Yes
C49	0		DNP		0402			
C50	1	CAP CER 1000 PF 50 V X7R 0402	1 nF	10%	0402	Würth Elektronik	885 012 205 061	Yes
C47,48	2	CAP CER 4700 PF 10 V X7R 0402	4700 pF	10%	0402	Würth Elektronik	885 012 205 010	Yes

1. All parts are Pb-Free

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