SEC-6K6W-CLLC-GEVK: 6.6/7.2 kW On Board Charger (OBC) CLLC Reference Design Kit Control Board (SEC-6K6W-CLLC-CTRL-GEVB)

TND6379/D

Use together with the *6.6/7.2 kW OBC CLLC Power Stage.*

SPECIFICATIONS

Device	Application	Input Voltage	Output Power	Topology	I/O Isolation
NLV74AC157DR2G NCV4390DR2G NLV74HC04ADR2G NCV33204DR2G NCP3170BDR2G …	On Board EV Charger	See document for *6.6/7.2 kW OBC CLLC Power Stage*	See document for *6.6/7.2 kW OBC CLLC Power Stage*	See document for *6.6/7.2 kW OBC CLLC Power Stage*	Yes

PHOTOGRAPH OF THE REFERENCE DESIGN BOARDS

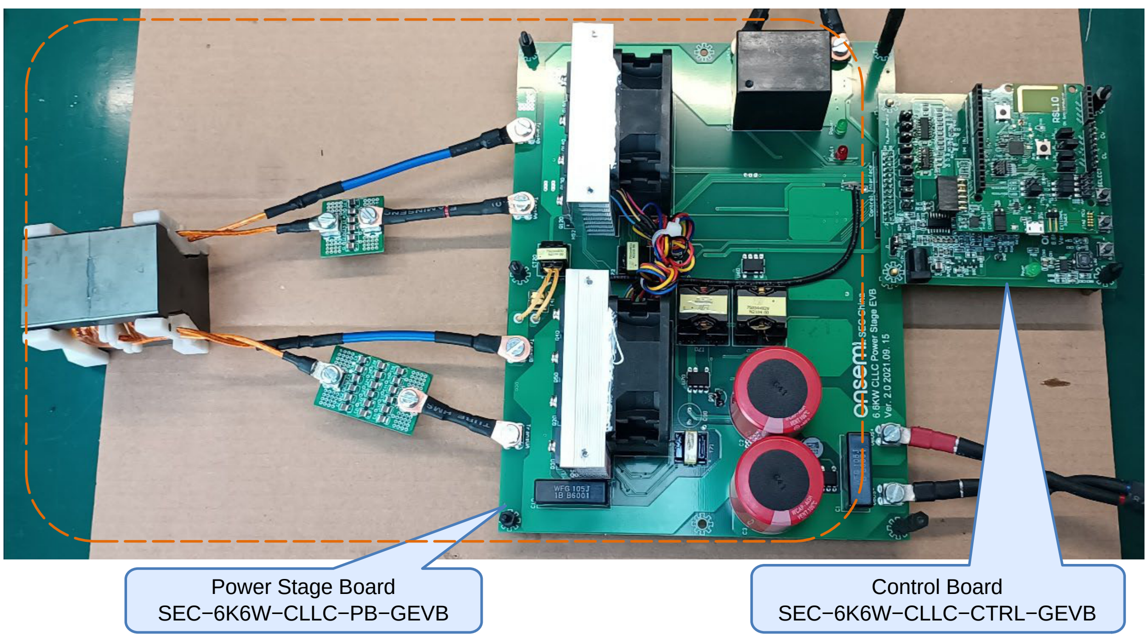

Figure 1. Full System – 7.2 kW CLLC Converter

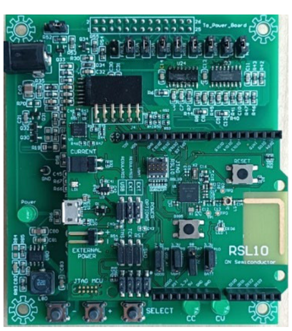

Figure 2. Top Side of the Control Board with the EVBUM2529/D Plug−in

Figure 3. Top Side of the Control Board without the RSL10 Board

Figure 4. Bottom Side of the Control Board

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TND6379/D

SYSTEM OVERVIEW

Key Features

- Hardware PFM, Sync−Rectifier control + software direction swap and CC/CV control. Provides both robustness and flexibility.
- Closed loop PFM + PWM hybrid operation on Grid to Battery mode and open loop under maximum efficiency point on Battery to Grid mode.

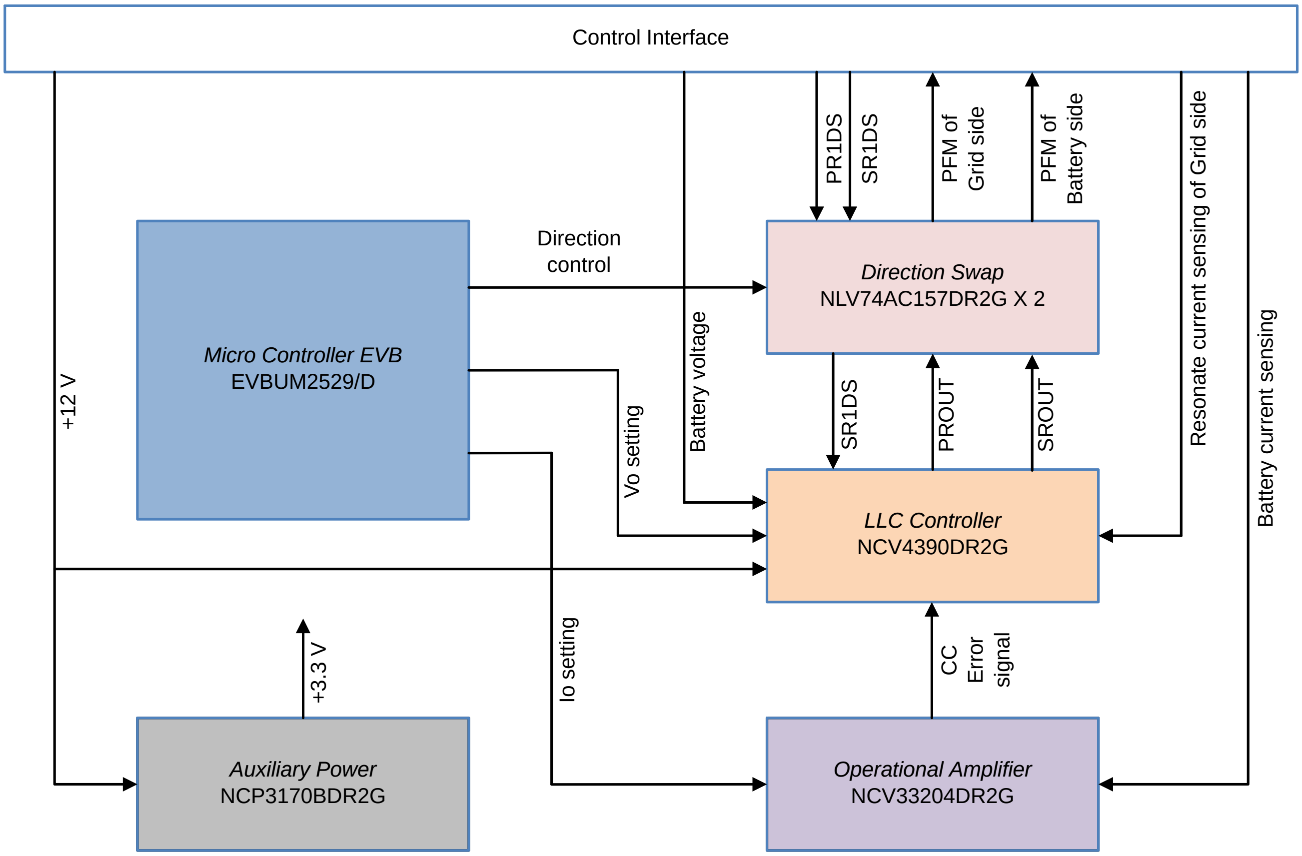

Figure 5. Block Diagram of Hardware

SCHEMATICS AND CIRCUIT DESCRIPTION

Hardware Description

Figure 6 shows the schematic of the control board. The core device of the board is the NCV4390DR2G (U30), an automotive advanced secondary side LLC controller with synchronous rectifier control. The key features and benefits of this device are listed in Table 1. More information such as the datasheet, application note and the demo board information about this device can be found on the website here. Originally, the NCV4390 was used for unidirectional LLC converter control, but this design expands the usage to operating as a bidirectional CLLC converter. This is achieved by swapping the gate drive outputs of the secondary side SR MOSFETs and the primary side switching MOSFETs, while at the same time swapping the SR edge signals between the secondary and the primary center point. The swapping is achieved by the automotive Quad 2−Input Multiplexer, NLV74AC157DR2G; controlled by the binary signal *DIREC* from the MCU.

In G to B mode, U30 operates under the normal closed loop. The upper resistors for the battery voltage divider are located on the power board, and this information is sent to the control board through the *VSAF* signal. The lower dividing resistor is R56. The output voltage setting PWM signal *CVPWM* is filtered by R20 and C25, then the dividing ratio is changed through R21. The output voltage varies according to the *CVPWM* duty cycle. The curve of the *CVPWM* duty cycle and the battery voltage is shown on Figure 7. R31 provides a little bit bias to make sure the voltage on the FB pin is higher than the SS pin before the converter power−up. Without R31, the COMP voltage may go high too fast at startup and trigger the OCP.

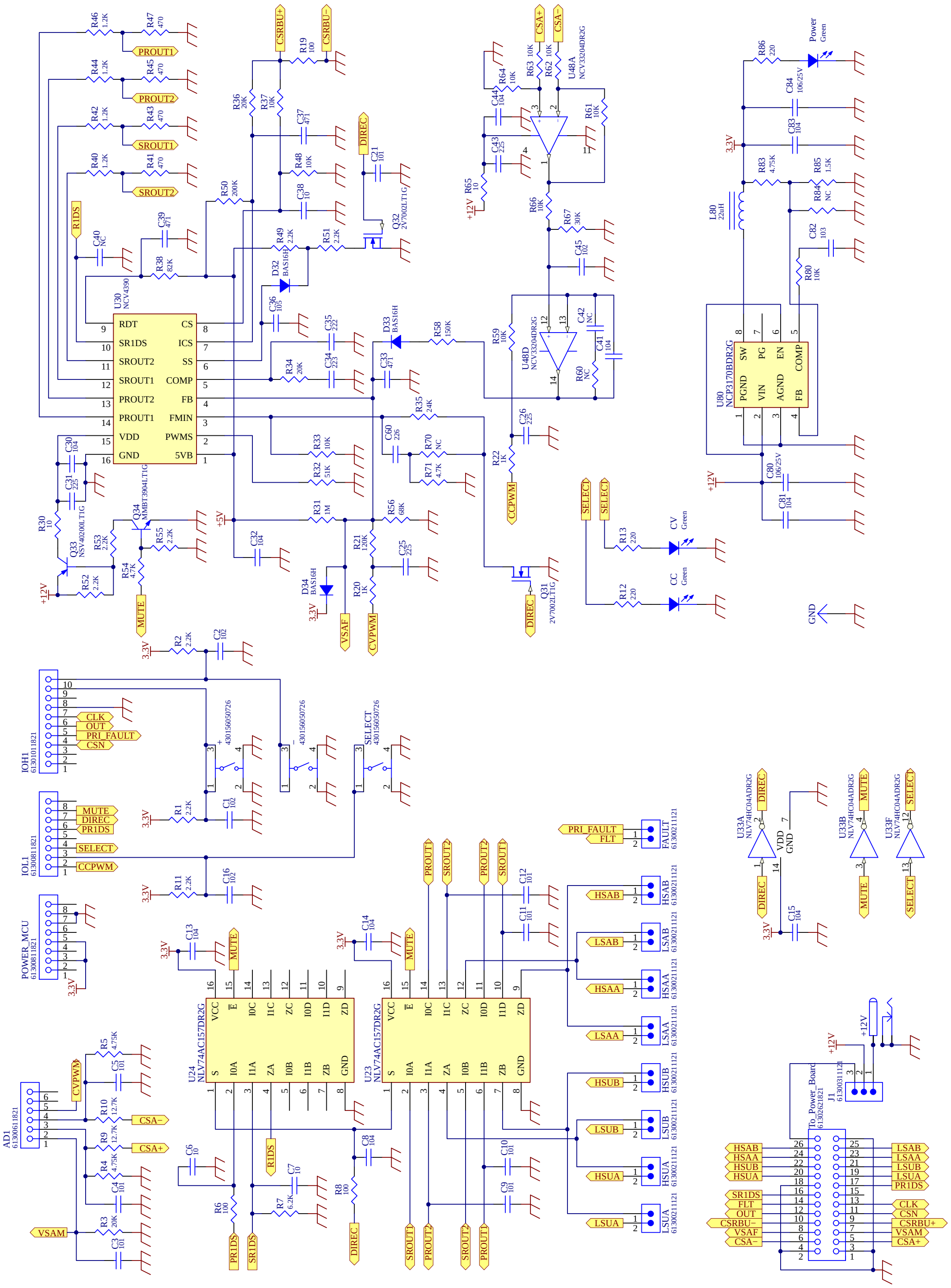

Figure 6. Schematic of the Control Board

Table 1. KEY FEATURES AND BENEFITS OF THE NCV4390DR2G

Features	Benefits
Charge Current Control	Excellent Transient response and Easy feedback Loop Design
Adaptive SR with Dual Edge Tracking	Best in Class Efficiency
Green Functions, provide wider PWM mode entry level including PWM disable	Improved Light Load Efficiency and output Voltage Ripple
Closed Loop Soft−Start	Monotonic Rising Output
Programmable Dead Times	Reliable and flexible design
Non−ZVS Protection	High system reliability
Protection Functions with Auto−Restart − Over−Current Protection (OCP) − Output Short Protection (OSP) − Power Limit by Compensation Cutback (Frequency Shift) − Overload Protection (OLP) with Programmable Shutdown Delay Time − Over−Temperature Protection (OTP)	Robust Design
Wide Operating Frequency (39 kHz~690 kHz)	
AEC Qualified	

The constant current operation is achieved by U48, the automotive rail to rail I/O operational amplifier NCV33204DR2G and the peripheral circuit. The output current is sensed and amplified on the power board and sent to the control board through the differential signal *CSA+* and *CSA−*. U48A converts the differential signal to a single−ended signal which is fed into a divider created by R66 and R67. This divider provides a scaled voltage of 0 − 3 V to correspond to the range of Vo = 0 − 20 A. The output current is controlled by the PWM signal *CCPWM*, which is filtered by R22 and C26 and sent to the minus input terminal of U48D by R59 as the reference of the CC loop. *CCPWM* duty cycle can vary from 0 to 90%, corresponding to Io from 0 to 20 A. If Io is less than the set point for current, U48D outputs a low voltage and the converter operates in CV mode. If Io is greater than the set point for current, U48D outputs a high voltage which is fed to the FB pin of U30 through the R58 and D33. This will pull down the output voltage until the Io = the set current. Then U48D outputs a proper voltage to keep the converter working in CC mode.

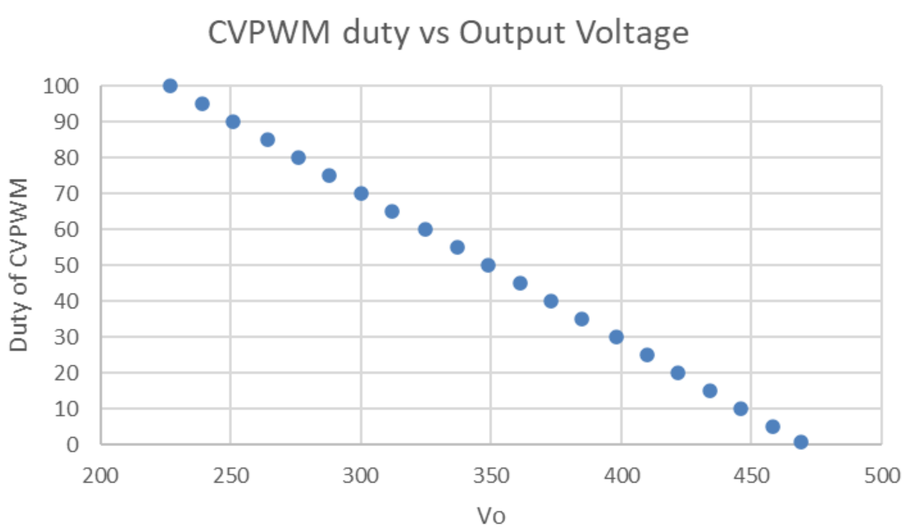

Figure 7. The Curve of the Output Voltage vs. the *CVPWM* Duty

Table 2 shows all signals of the connecter between the control board and the power board.

Table 2. SIGNALS OF THE CONTROL INTERFACE

Pin	Name	Type	Direction*	Description
1	CSRBU+	Analog	Output	Positive current of Resonant tank of Battery side.
2	CSRBU−	Analog	Output	Negative current of Resonant tank of Battery side.
3	CSA+	Analog	Output	Positive current on Battery terminal.
4	CSA−	Analog	Output	Negative current on Battery terminal (Reference).
5	VSAM	Analog	Output	Voltage of the Battery for Measurement.
6	VSAF	Analog	Output	Voltage of the Battery for Feedback.
7	CSRBA+	Analog	Output	Positive current of Resonant tank of Bus side.
8	CSRBA−	Analog	Output	Negative current of Resonant tank of Bus side.
9	CSN	Digital	Input	Chip select of the ADC (Read Vbus from battery side. Active low).
10	OUT	Digital	Output	Data output of the ADC (Read Vbus from battery side).
11	CLK	Digital	Input	Clock of the ADC (Read Vbus from battery side).
12	FLT	Digital	I/O	Fault output. Open drain with 2.2 kΩ pull high resistor. Active Low.
13	NC	−	−	
14	SR1DS	Digital	Output	Battery side switching edge. Clamp to 3.3 V.
15	PR1DS	Digital	Output	BUS side switching edge. Transferred to Battery side and clamped to 3.3 V.
16	GND	−	−	GND
17	LSUA	Digital	Input	Low side PWM signal of Bus side half bridge A.
18	HSUA	Digital	Input	High side PWM signal of Bus side half bridge A.
19	LSUB	Digital	Input	Low side PWM signal of Bus side half bridge B.
20	HSUB	Digital	Input	High side PWM signal of Bus side half bridge B.
21	LSAA	Digital	Input	Low side PWM signal of Battery side half bridge A.
22	HSAA	Digital	Input	High side PWM signal of Battery side half bridge A.
23	LSAB	Digital	Input	Low side PWM signal of Battery side half bridge B.
24	HSAB	Digital	Input	High side PWM signal of Battery side half bridge B.
25	GND	−	−	GND
26	+12V	Power	Output	±1 V; 0 − 0.2 A

On the B to G mode, U30 operates under open loop to simplify the BUS voltage sensing. To function properly, the following actions are taken with the circuit:

1. Parallel R35 to R33 by turning on Q31 to increase the minimum switching frequency from 100 kHz to 142 kHz (Resonant point).
2. Hold SS voltage below 3.2 V by D32, Q32, R49 and R51 avoiding the OLP trigger.
3. Set the *CVPWM* duty cycle targeting 1.5x of the battery voltage according to figure 7, to make sure the FB voltage is between 1.2 − 2.4 V.

The NCV4390DR2G has a built−in closed loop soft start function. The advantage of the closed loop soft start is that it makes sure the output voltage rise is monotonic during startup. Additionally, to avoid unforeseen circumstances that may cause oscillations at startup and trigger OCP, C60 and R71 were added.

Software Description

The software of this evaluation board is for internal board testing only. The code is not provided as part of this reference design.

The functions of the software are described below.

Voltage Monitor and Direction Setting

The MCU monitors the Battery voltage by the internal ADC and monitors the Bus voltage by the ADC IC located on the power board through a SPI interface and digital isolator. After power up, the MCU holds the *MUTE* signal low and reads the voltage of both Vbus and Vbattery and checks the voltages according to table 3. If the voltages meet the condition of G to B, set the *DIREC* signal to high and go to the G to B operation. If the voltages meet the condition of B to G, set the *DIREC* signal to low and go to the G to B operation. Otherwise, continue to read data to determine the operational mode.

Table 3. DIRECTION SETTING CONDITION

Vbus	Vbattery	Action
<350 V	<250 V	Read again
>750 V	X	Read again
X	>450 V	Read again
350 V < Vbus < 750 V	250 V < Vbattery < 450 V	Read again
350 V < Vbus < 750 V	<250 V	G to B
<350 V	250 V < Vbattery < 450 V	B to G

G to B Operating

(a) Load the *CCPWM* and *CVPWM* values from the internal memory and send to the corresponding pins.
(b) Pull high the *MUTE* signal in case of the time from power on > 3S.
(c) Set the indicating LEDs by pulling high or low the *SELECT* signal to indicate the active control mode is CV or CC.
(d) Scan the keys. If the SELECT key is pressed, swap the control mode. If the + or – key is pressed, increase, or decrease the PWM duty of the active control mode and update the data on the internal memory.

B to G Operating

(a) Set the *CVPWM* duty targeting 1.5x of the Vbattery according to Figure 2 to make sure the FB voltage between 1.2 − 2.4 V.
(b) Pull high the *MUTE* signal in case of the time from power on > 3S.

DESIGN FILES

PCB Layout

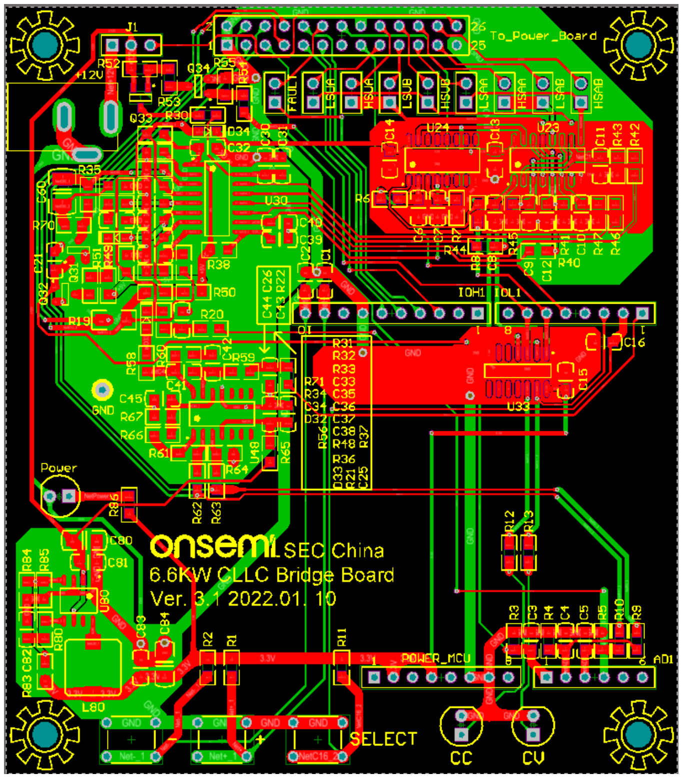

Figure 8. Top View, 88.9 x 101.6 x 1.6 mm

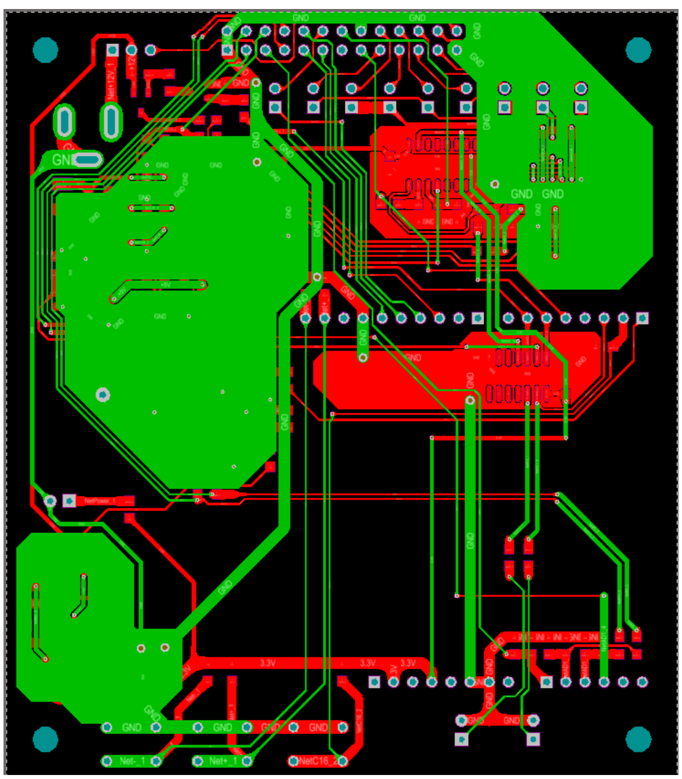

Figure 9. Top View, 88.9 x 101.6 x 1.6 mm

Table 4. BILL OF MATERIALS

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
IC, Secondary Side LLC Controller with SR Control, SOP16	NCV4390DR2G	**onsemi**	1	U30
IC, Quad Operational Amplifier, Rail to Rail I/O, SOP14	NCV33204DR2G	**onsemi**	1	U48
IC, Quad 2−Input Multiplexer, SOP16	NLV74AC157DR2G	**onsemi**	2	U23, U24
IC, Hex Inverter, SOP14	NLV74HC04ADR2G	**onsemi**	1	U33
IC, Buck Regulator, SOP8	NCP3170BDR2G	**onsemi**	1	U80
N−Channel Small Signal MOSFET 60 V, 7.5 Ω, SOT−23−3L	2V7002LT1G	**onsemi**	2	Q31, Q32
Transistor, PNP, −40 V, 2.0 A, SOT−23−3L	NSV40200LT1G	**onsemi**	1	Q33
Transistor, NPN, 40 V, 0.2 A, SOT−23−3L	MMBT3904LT1G	**onsemi**	1	Q34
Switching Diode 0.2 A 100 V, SOD323	BAS16H	**onsemi**	3	D32, D33, D34
LED D = 5 mm THT Green	151051VS04000	WURTH	3	CC, CV, Power
Chip resistor 0805 10 Ω−J	10	Any	2	R30, R65
Chip resistor 0805 100 Ω−J	100	Any	2	R6, R8
Chip resistor 0805 220 Ω−J	220	Any	3	R12, R13, R86
Chip resistor 0805 470 Ω−J	470	Any	4	R41, R43, R45, R47
Chip resistor 0805 1 kΩ−J	1K	Any	2	R20, R22
Chip resistor 0805 1.2 kΩ−J	1.2K	Any	4	R40, R42, R44, R46
Chip resistor 0805 1.5 kΩ−J	1.5K	Any	1	R85
Chip resistor 0805 2.2 kΩ−J	2.2K	Any	8	R1, R2, R11, R49, R51, R52, R53, R55
Chip resistor 0805 4.7 kΩ−J	4.7K	Any	2	R54, R71
Chip resistor 0805 4.75 kΩ−F	4.75K	Any	3	R4, R5, R83
Chip resistor 0805 6.2 kΩ−J	6.2K	Any	1	R7
Chip resistor 0805 10 kΩ−J	10K	Any	10	R33, R37, R48, R59, R61, R62, R63, R64, R66, R80
Chip resistor 0805 12.7 kΩ−F	12.7K	Any	2	R9, R10
Chip resistor 0805 20 kΩ−J	20K	Any	2	R3, R34, R36
Chip resistor 0805 24 kΩ−J	24K	Any	1	R35
Chip resistor 0805 30 kΩ−J	30K	Any	1	R67
Chip resistor 0805 51 kΩ−J	51K	Any	1	R32
Chip resistor 0805 68 kΩ−J	68K	Any	1	R56
Chip resistor 0805 82 kΩ−J	82K	Any	1	R38
Chip resistor 0805 120 kΩ−J	120K	Any	1	R21
Chip resistor 0805 150 kΩ−J	150K	Any	1	R58
Chip resistor 0805 200 kΩ−J	200K	Any	1	R50
Chip resistor 0805 1 MΩ−J	1M	Any	1	R31
Chip resistor 1206 100 Ω−J	100	Any	1	R19
MLCC 0805−50V−10pFJ−NP0	885012007051	WURTH	3	C6, C7, C38
MLCC 0805−250V−10pFJ−NP0	GCM21A5C2E100JX01	Muruta	3	C6, C7, C38

Table 4. BILL OF MATERIALS (continued)

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
MLCC 0805−450V−100pFJ−NP0	CGA4C4C0G2W101J	TDK	8	C3, C4, C5, C9, C10, C11, C12, C21
MLCC 0805−450V−100pFJ−NP0	GCM21A5C2J101JX01	Muruta	8	C3, C4, C5, C9, C10, C11, C12, C21
MLCC 0805−450V−471J−NP0	CGA4C4C0G2W471J	TDK	3	C33, C37, C39
MLCC 0805−450V−471J−NP0	GCM21A5C2J471JX01	Muruta	3	C33, C37, C39
MLCC 0805−100V−102J−NP0	CGA4C2C0G2A102J	TDK	4	C1, C2, C16, C45
MLCC 0805−50V−222J−NP0	CGA4C2C0G1H222J	TDK	1	C35
MLCC 0805−50V−103J−NP0	CGA4C2C0G1H103J	TDK	1	C82
MLCC 0805−250V−103J−NP0	GCM21B5C2E103JX0A	Muruta	1	C82
MLCC 0805−50V−223J−NP0	CGA4J2C0G1H223J125AA	TDK	1	C34
MLCC 0805−50V−223J−NP0	GCM21B5C1H223JA16	Muruta	1	C34
MLCC 0805−100V−104K−X7R	CGA4J2X7R2A104K	TDK	10	C8, C13, C14, C15, C30, C32, C41, C44, C81, C83
MLCC 0805−100V−104K−X7R	GCM21BR72A104KA37L	Muruta	10	C8, C13, C14, C15, C30, C32, C41, C44, C81, C83
MLCC 0805−50V−105K−X7R	CGA4J3X7R1H105K125AB	TDK	1	C36
MLCC 0805−50V−105K−X7R	GCM21BR71H105KA03L	Muruta	1	C36
MLCC 0805−25V−225K−X7R	CGA4J3X7R1E225K	TDK	4	C25, C26, C31, C43
MLCC 0805−25V−225K−X7R	GCM21BR71E225KA73L	Muruta	4	C25, C26, C31, C43
MLCC 1206−25V−106K−X7R	CGA5L1X7R1E106K	TDK	2	C80, C84
MLCC 1206−25V−106K−X7R	GCM31CC71E106KA03	Muruta	2	C80, C84
MLCC 1210−25V−226K−X7R	CGA6P3X7R1E226M250AB	TDK	1	C60
MLCC 1210−25V−226K−X7R	GCM32EC71E226KE36	Muruta	1	C60
SMD Inductor 7 X 7 X 3.5 mm−22 μH−1.6 A	784778220	WURTH	1	L80
SMD Inductor 7 X 7 X 4.5 mm−22 μH−1.7 A	SPM7045VT−220M−D	TDK	1	L80
SMD Inductor 7 X 7 X 4.5 mm−22 μH−2.9 A	ETQP4M220KFM	Panasonic	1	L80
SMD Inductor 7 X 6 X 2.8 mm−22 μH−2.5 A	AMP0603H220MT	Sunlord	1	L80
WR−PHD Socket Header, THT, pitch 2.54 mm, Single Row, Vertical, 10 pin	61301011821	WURTH	1	IOH1
WR−PHD Socket Header, THT, pitch 2.54 mm, Single Row, Vertical, 8 pin	61300811821	WURTH	2	IOL1, POWER_MCU
WR−PHD Socket Header, THT, pitch 2.54 mm, Single Row, Vertical, 6 pin	61300611821	WURTH	1	AD1
WR−PHD Pin Header, THT, pitch 2.54 mm, Single Row, Vertical, 3 pin	61300311121	WURTH	1	J1
WR−PHD Pin Header, THT, pitch 2.54 mm, Single Row, Vertical, 2 pin	61300211121	WURTH	9	FAULT, HSAA, HSAB, HSUA, HSUB, LSAA, LSAB, LSUA, LSUB
WR−PHD Socket Header, THT, pitch 2.54 mm, Dual Row, Vertical, 26 pin	61302621821	WURTH	1	To_Power_Board
WS−TATV THT Tact Switch 6 x 6 mm, height 5 mm, 260gf	430156050726	WURTH	3	+, −, SELECT
Low Voltage Power Supply Connector	PWR2.5	Any	1	+12V

*The adjacent items in same shadow are optional selections from different manufacturers.

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