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# TND6320/D

## 6.6 kW On Board EV Charger Reference Design



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### REFERENCE DESIGN

#### SPECIFICATION

Device Series	Application	Input Voltage	Output Power	Topology	I/O Isolation
FAN9673Q, NCV4390DR2G, NCV3843BVD1R2G, FAN3224TUMX-F085, NCV890100PDR2G, NCV51460SN33T1G, NCV210SQT2G, NCV2003SN2T1G, FODM8801C, ...	On Board EV Charger	90 ~ 264 Vac	6.6 kW	3CH Interleave PFC + Full Bridge LLC	Yes

#### OTHER SPECIFICATION

	Output 1	Output 2
Output Voltage	250 – 450 Vdc	12 Vdc
Ripple	5% (Meet QCT 895 2011)	5%
Max Current	16 A	0.6 A
Min Current	0	0
PFC (Yes/No)	Yes	
Typical Efficiency	94%	
Inrush Limiting	48 A	
Operating Temperature Range	-20 – 85°C	
Cooling Method	Force Air or Liquid cooling: Depends on the Heatsink	
Signal Level Control	On/Off, CC, CV, Bus Voltage	
Dimension	254 x 198 x 70 mm + Heatsink	

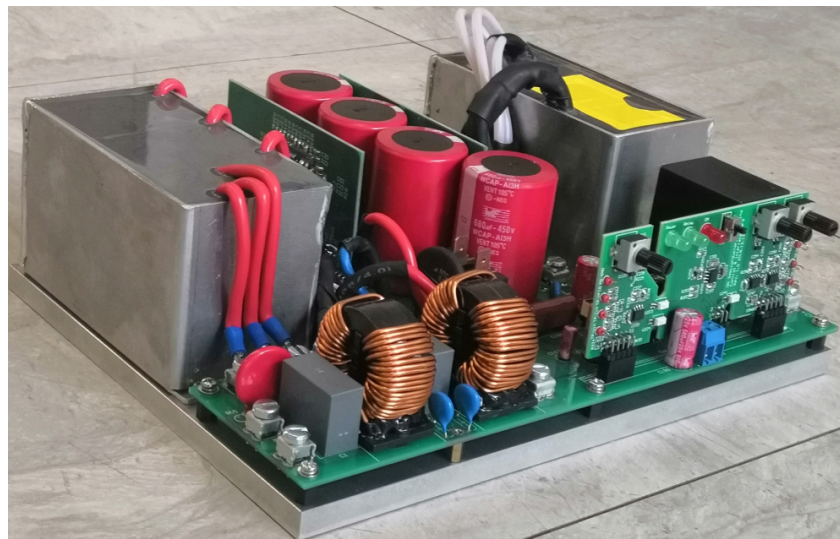


Figure 1. Photograph of the Evaluation Board

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## KEY FEATURES

### Whole Solution

- 3CH Interleave PFC to get high efficiency and power density. Decrease the current ripple at mean time
- Full bridge LLC to boost efficiency by high bus voltage usage
- Hardware PFC and LLC control approach for easily designing and less malfunction.
- Active inrush current limit circuit to decrease the PCB footprint
- Full functional solution including input/output current/voltage sensing and CC/CV PWM control interface.
- Bus voltage adjustable to optima the efficiency according to the output voltage.

### PFC Controller FAN9673

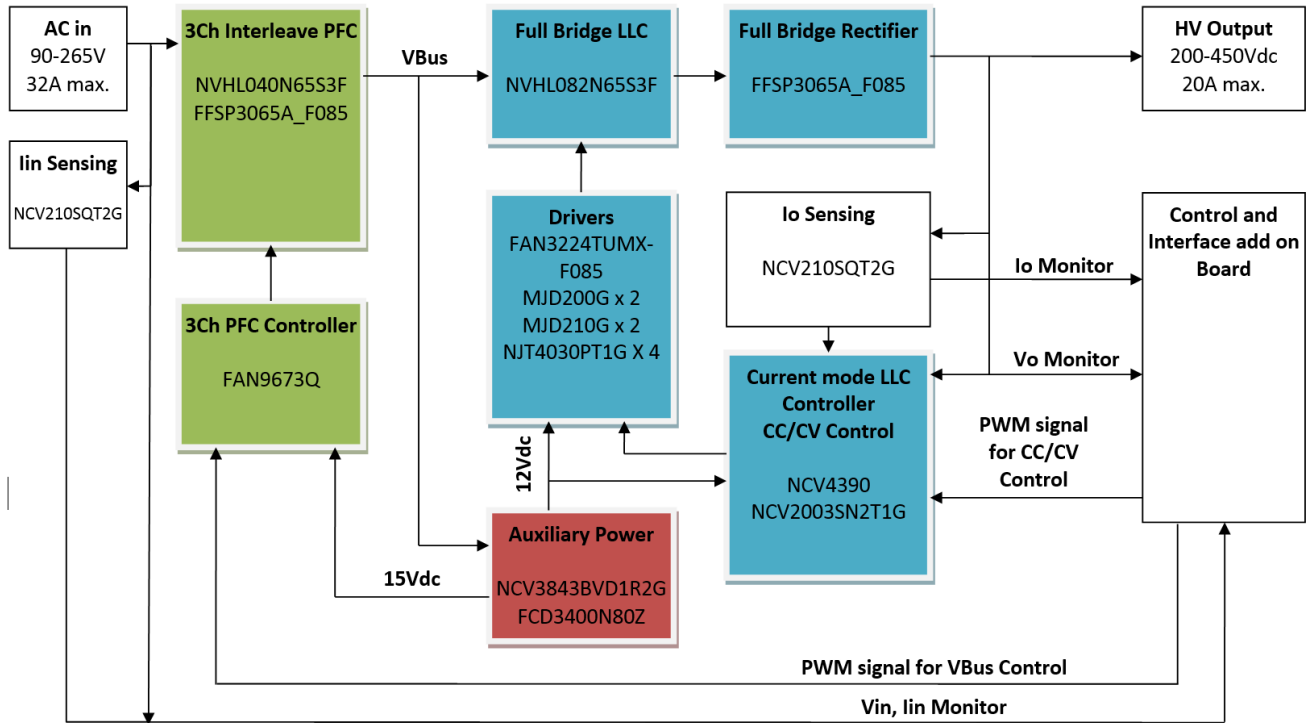
- Continuous Conduction Mode with Average Current Mode Control
- Three-Channel Interleave Operation
- Programmable Operation Frequency Range: 18 kHz ~ 40 kHz or 55 kHz ~ 75 kHz
- Programmable PFC Output Voltage
- Two Current-Limit Functions
- TriFault Detect Protects Against Feedback Loop Failure
- SAG Protection
- Programmable Soft-Start
- Under-Voltage Lockout (UVLO)
- Differential Current Sensing

### LLC Controller NCV4390DR2G(AEC Qualified version of FAN7688)

- Secondary Side PFM Controller for LLC Resonant Converter with Synchronous Rectifier Control
- Charge Current Control for Better Transient Response and Easy Feedback Loop Design
- Adaptive Synchronous Rectification Control with Dual Edge Tracking
- Closed Loop Soft-Start for Monotonic Rising Output
- Wide Operating Frequency (39 kHz ~ 690 kHz)
- Green Functions to Improve Light-Load Efficiency
- Symmetric PWM Control at Light-Load to Limit the Switching Frequency while Reducing Switching Losses
- Protection Functions with Auto-Restart
  - ◆ Over-Current Protection (OCP)
  - ◆ Output Short Protection (OSP)
  - ◆ NON Zero-Voltage Switching Prevention (NZS) by Compensation Cutback (Frequency Shift)
  - ◆ Power Limit by Compensation Cutback (Frequency Shift)
  - ◆ Overload Protection (OLP) with Programmable Shutdown Delay Time
  - ◆ Over-Temperature Protection (OTP)
- Programmable Dead Times for Primary Side Switches and Secondary Side Synchronous Rectifiers
- VDD Under-Voltage Lockout (UVLO)
- Wide Operating Temperature Range -40°C to +125°C
- Automotive Qualification

**SCHEMATICS AND CIRCUIT DESCRIPTION**

The system diagram is on Figure 2. The key elements of the OBC are marked in the color blocks.



**Figure 2. System Diagram of the 6.6 kW OBC**

Following the AC input is the PFC stage. It's marked in light green. The detail schematic is shown on Figure 2. The key elements of the PFC stage are the controller FAN9673 and the triple boost power devices. They are in the right hand of the Figure 2. More details of the FAN9673 please refer the datasheet and the application notes of the device on the web site <https://www.onsemi.com/PowerSolutions/product.do?id=FAN9673>. Among others, to avoid the CS+ signals are short circuit equivalent by C48, C49 and C50, we placed the decouple inductors L21, L31 and L41 on the Vcc of the Totem poles. The PFC inductors and the Bridge rectifier locate out of the PCB and are mounted on the heatsink directly for better thermal control.

U10 is the input current sensing amplifier. It is a 200X fix-gain current sense amplifier. Co-operate with the R7

and R8, the voltage on pin6 of U10 will be  $200 \times 0.001 \times I_{in}$ . If  $I_{in} = 32$  Arms, at peak point of the sin wave, the output of U10 is 9.0496 V.

The bus voltage is adjustable by the duty of the PWM signal BSPWM. This function allow the system designer optima the system efficiency according to the input and output condition. For example, if  $V_{in} = 220ac$ ,  $V_o = 250Vdc$ . PFCO set to 330Vdc will get higher efficiency in both of PFC and LLC stage than set to 390Vdc. The adjusting range is: When duty = 100%, the PFCO =  $2.5 \times [R_{24}+R_{25}+(R_{14}+R_{15})/R_{26}] / [(R_{14}+R_{15})/R_{26}] = 412.45$  Vdc. When the duty = 0%, the PFCO =  $2.5 \times (R_{24}+R_{25}+R_{26}) / R_{26} = 210.83$  Vdc.

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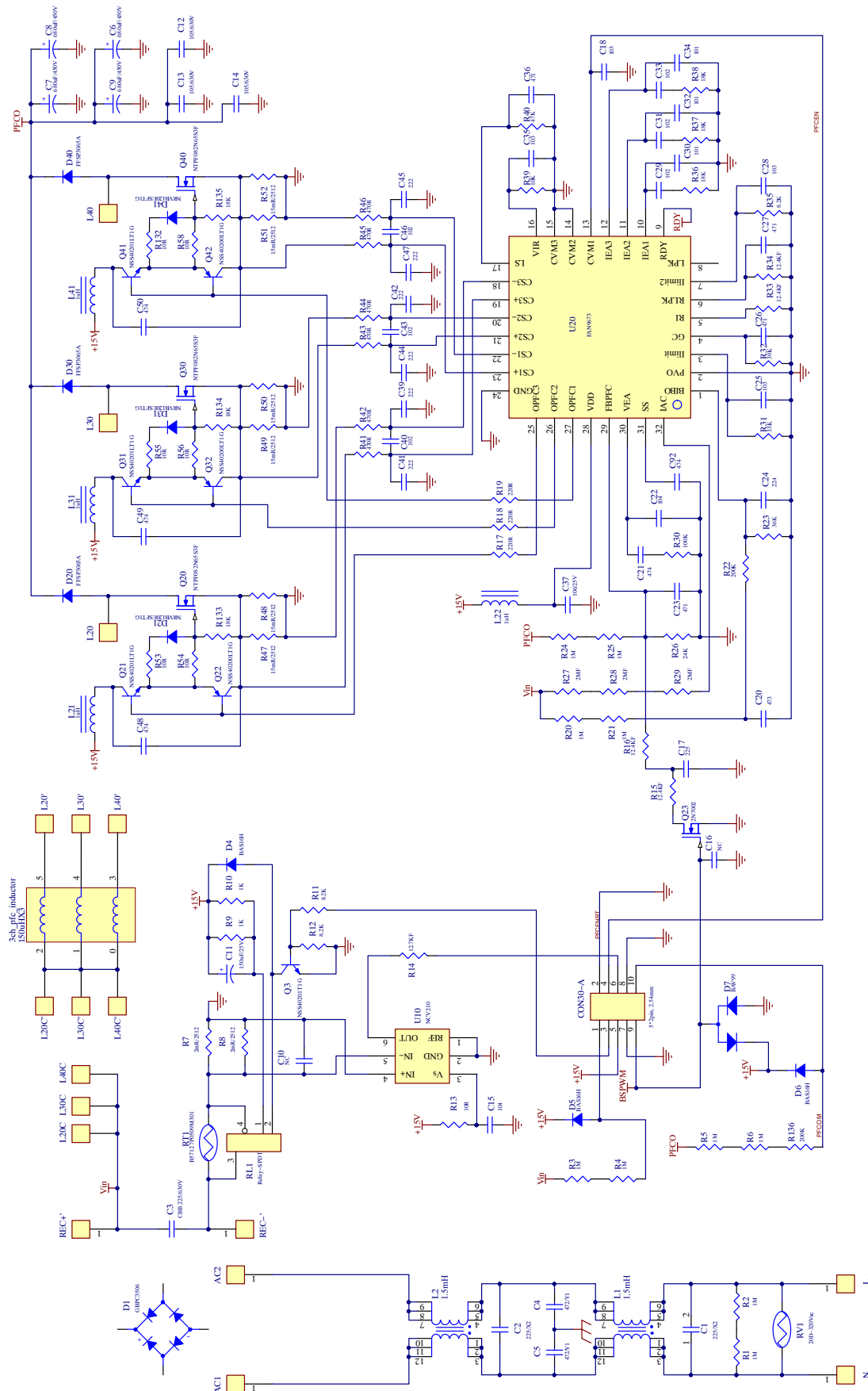


Figure 3. Schematic of the PFC

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The connector CON30–A connects the PFC stage to the interface board. The table 1 shows the signals.

**Table 1. SIGNALS OF THE CON30–A**

Pin No.	Direction	Description
1	Output	Input voltage sensing.
2	–	Return of PFC enable signal. Connect to GND of FAN9673 in differential path with Pin5.
3	Input	Relay Control signal.
4	Input	PFC enable signal. Control CM1 of FAN9673.
5	Output	+15V. Vcc of the circuits in primary side on the interface board.
6	Output	Input current sensing signal.
7	–	GND
8	–	GND
9	Input	BSPWM. PWM signal to control the bus voltage PFCO.
10	Output	PFC output voltage sensing.

Another key element of the OBC is the DCDC stage. It was marked in blue in Figure 2. The schematic of the DCDC stage is shown in Figure 4. We adopt the single full bridge LLC topology to get the high efficiency and suitable cost. It composed by U60 and Q60, Q62, Q70, Q72 etc. The NCV4390DR2G (U60) is a current mode advanced LLC controller. It is a pin to pin compatible device of the FAN7688. If you cannot find the device on the website, you can refer the description of FAN7688. More details of the

part please refer the datasheet and the application notes. Because of the high output voltage (250 – 450 Vdc), the Synchronous Rectifier cannot help too much on the rectifier conduction loss. So we omitted the SR function of the NCV4390DR2G. The transformer with integrated resonate inductor (please refer the datasheet of the transformer at below) and the resonate capacitor are glued on the aluminum box for better heat sink.

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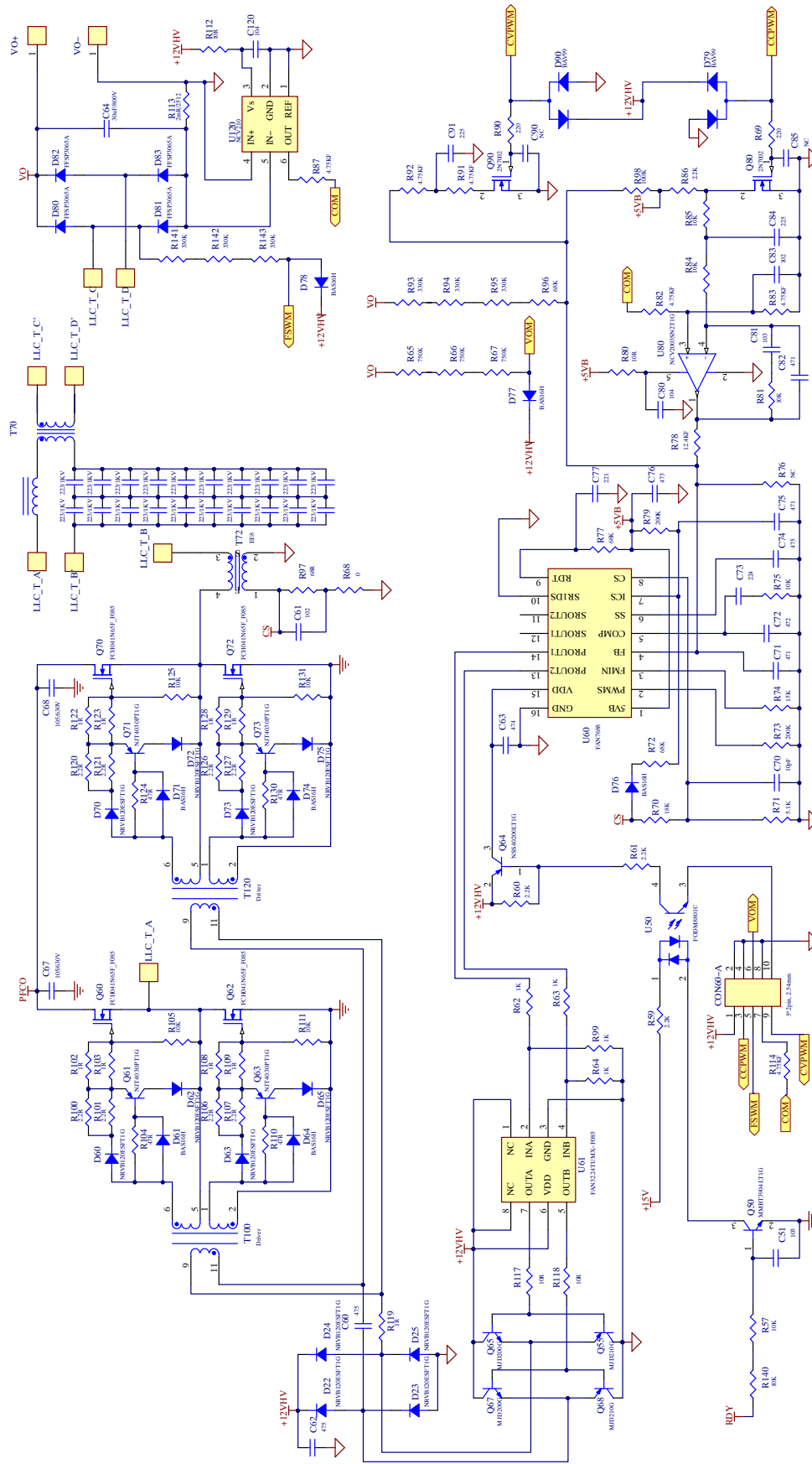


Figure 4. Schematic of the DCDC

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CN60 is the interface of the DCDC stage. The Table 2 shows the signals on the CON60.

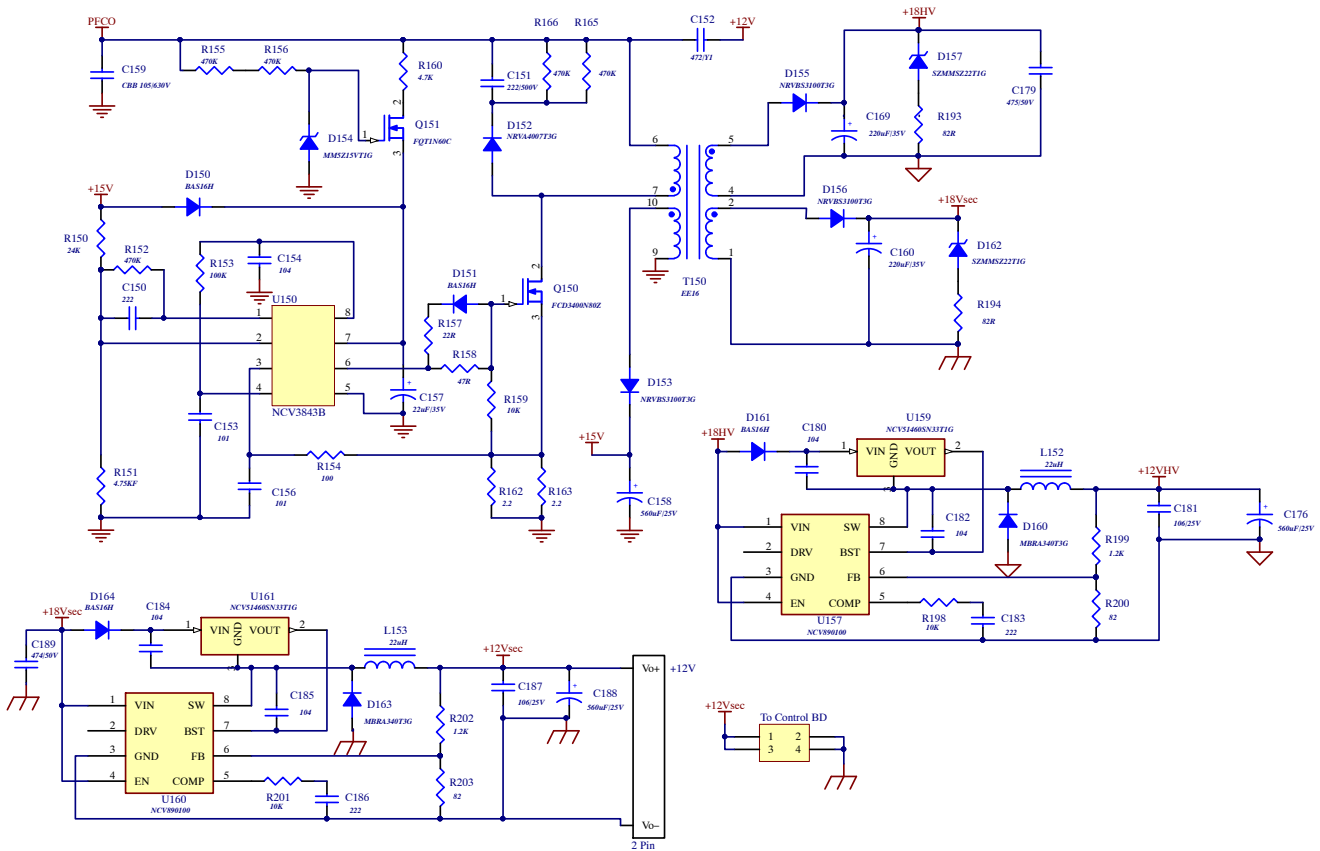
The NCV4390DR2G get VDD when both of the PFC RDY and the LLC enable signal are active.

**Table 2. SIGNALS OF THE CON60**

Pin No.	Direction	Description
1	Output	+12VHV.
2	–	GND
3	Input	CCPWM. PWM signal for constant current setting.
4	–	GND
5	Output	FSWM. Signal for switching frequency measurement.
6	Output	VOM. Output voltage sensing.
7	Output	COM. Output current sensing.
8	–	GND
9	Input	CVPWM. PWM signal for content voltage setting.
10	Input	LLC enable signal.

Except the main stages of PFC and DCDC, we also need an auxiliary power on the OBC to supply the Vcc/Vdd to the

controller and driver circuits. Figure 5 shows the schematic of the auxiliary power of this reference design.



**Figure 5. Schematic of the Auxiliary Power**

The main topology of the auxiliary power is the fly-back which controlled by the AEC qualified PWM controller NCV3843BVD1R2G. The detail of the device please refer the datasheet on the web site: <https://www.onsemi.cn/pub/Collateral/NCV3843BV-D.PDF>.

This OBC has 3 separate GNDs. They are primary GND, Secondary GND, and HV GND. These GNDs are isolating each other. The auxiliary power supplies 3 insulating outputs according to the 3 separate GNDs. The +15V output powers of the PFC controller, PFC MOSFETs driver and the Relay; the +12Vsec powers the circuits on the control board and the



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off-board devices such as cooling FANs; the +12VHV powers the LLC controller and drivers. The controller of the auxiliary power feedback the output of the primary side +15V to save the optical coupler. Then the outputs of the secondary side and HV side will not be regulate due to the cross-regulation phenomena. So we inserted 2 Buck mode DCDC to the transformer outputs and the Loads. They are achieved by two pieces of NCV890100PDR2G. This device is a non-SR buck switching regulator with SO8-EP package. The switching frequency is up to 2 MHz. The performance cost ratio is high and easy for application.

On the typical application circuit of NCV890100, the Bootstrap is powered by the internal 3.3V regulator. This method has a problem on this OBC design. In case of the load of +15V is very light, the voltage of 18Vsec and +18VHV will drop and close to +12Vsec and +12VHV. The off-period of the buck converter will be very small. Then the bootstrap cap has no enough time to be charged. The voltage of the BST pins will drop below the DRV POR Stop Threshold and the device stop working. To save this problem we connect the bootstrap diodes (D161, D164) to Vin of the buck converters instead of the DRV pin. And insert a 3.3V LDO (U159, U161) from the bootstrap voltage to BST pin.

This way extends the maxima duty range of the converter. And if the device stops working by Vin drop, once the Vin-Vo goes up to 3.3V, the device will re-work again. But in the typical application circuit, if the device stops working, it will keep stop until the Vo drop to 0V.

In this design, we put the interface circuits on an add-on board for the flexibility. The features of the full function interface board could include the (1) Can communication with the BMS system to report the information like: Input voltage, Input current, Output voltage, Output current, Bus voltage, Output miss-connection, Temperature of the key components. (2) Can communication with the BMS to receive the following command: Power-up, Output voltage, Output current, Power off. (3) Output the CC, CV PWM signals and the power-on and relay-on signals to the main board. (4) Setting the Bus voltage according to the Vin, Vo and LLC switching frequency to get the maximum system efficiency. (5) Connect to Strata Developer Studio for evaluate the solution easily. But, the full function interface board is not ready so far. We use a simple manual control board instead of the full function one. Figure 6 shows the schematic of the manual control interface board.

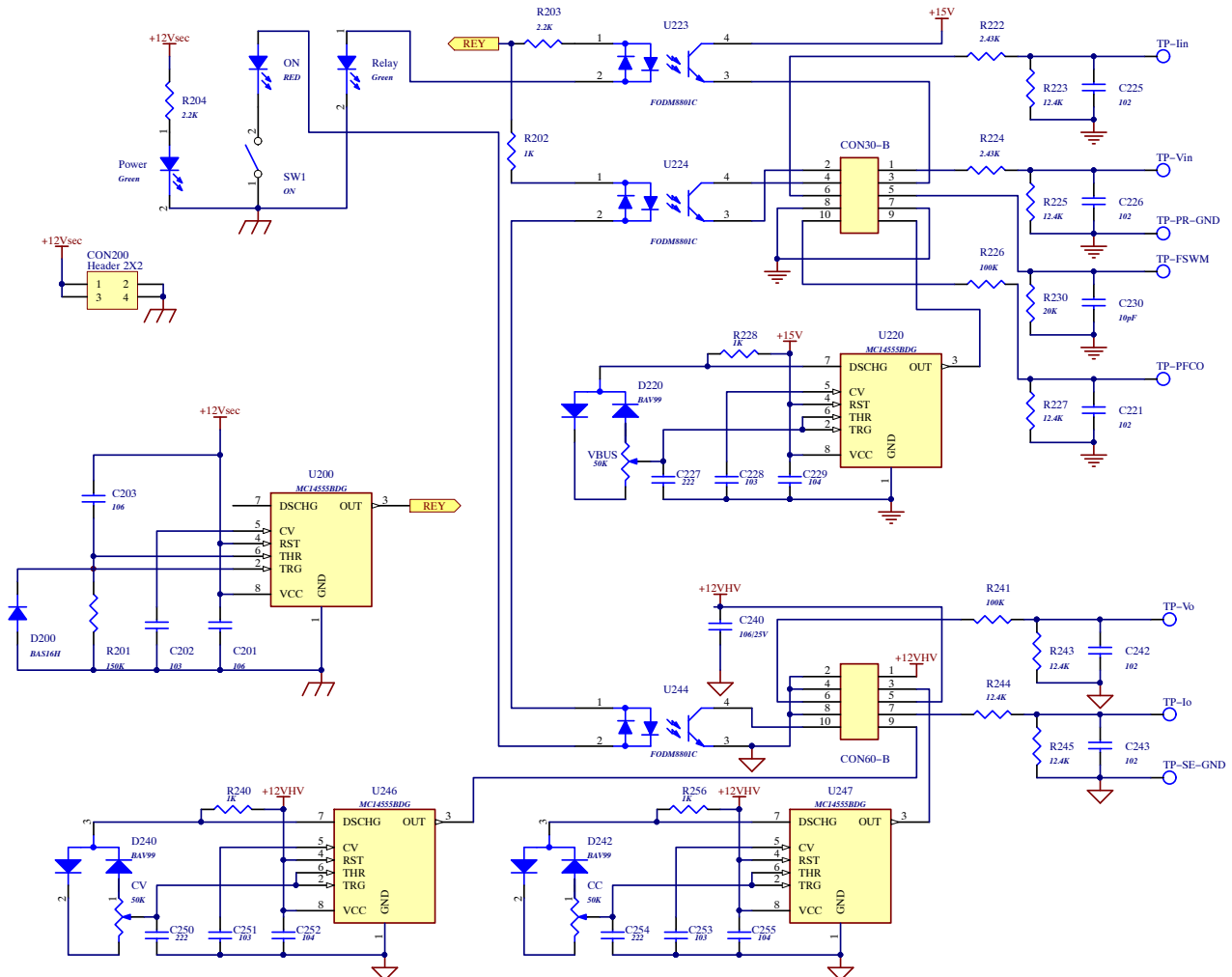


Figure 6. Schematic of the Manual Control Interface Board

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The SW1 powers ON/OFF the PFC and LLC stage in the secondary side for safety. It is delivery to the primary and HV stage by U224 and U244. The Vcc of the U223 and U224 is powered by the REY signal, thus the power-up will be AND with the relay active. The REY signal is 3 second delayed by U200 from the 12V LV active moment to guarantee the Bus Caps is full charged. The BSPWM, CC

and CV PWM signals are generated by the U220, U246 and U247 and the peripherals components. The variable resistors VBUS, CC and CV control the duty of the PWM signals. The sensing signals like Vin, Iin, Vbus, Vo and Io was connected to the test points for customer testing by the voltage meter.

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## MEGNATICS DESIGN DATA SHEET

PFC Inductors: 3pcs. Fill in aluminum box. Monte to heat sink.



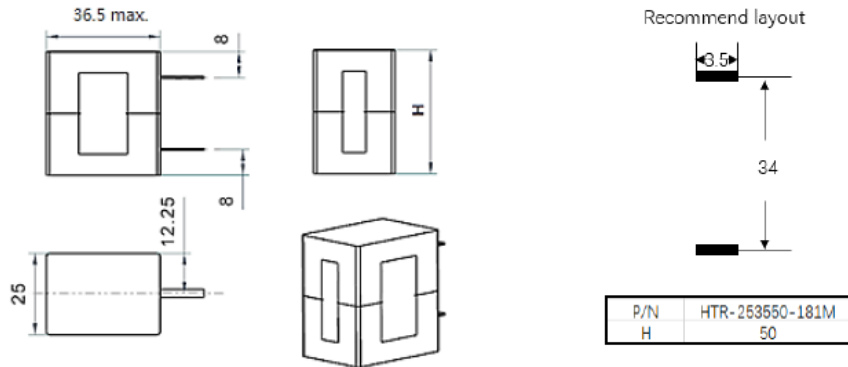
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墨尚电子技术(上海)有限公司

P/N:HTR-253550-181M

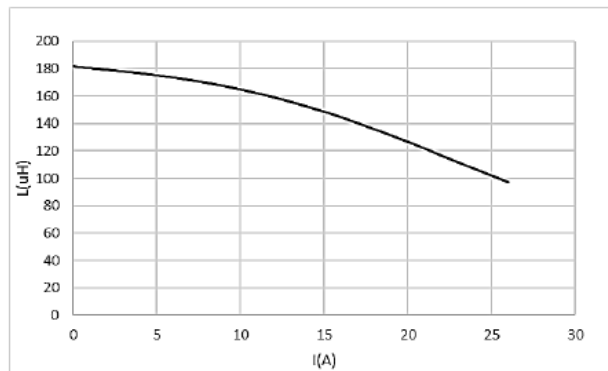
### Dimension (mm, ±0.5mm tol.)



### Electrical Characteristics at 25°C

HTR: Dimension		$L_0(\mu\text{H})$	$R_{dc}(m\Omega)$		$I_{sat}(A)$
Overall size (mm)	P/N	±20%	TYP.	MAX.	TYP.
25*35*50	HTR-253550-181M	180	18.5	20.0	26A for 45% rolloff

### Typical DC-bias curve



### Test instruments & Test condition

Items	Testing Condition	Testing Point	Specification
Inductance	100KHz, 1V HP4284 or Equivalent	L: Terminal-Terminal	as L-I Curve
Dielectric Strength	LK7122 or Equivalent	Coil-Core/Housing	2.5KV AC, 50Hz, 1Min < 2mA
Insulation Resistance	LK7122 or Equivalent	Coil-Core/Housing	>100MΩ, 0.5KV, DC
Operating Temperature	Class F Insulation, -25 °C~155 °C		
Storage Temperature	-25 °C~75 °C		
Dimension (mm)	See Spec.detail		

Figure 7.

Auxiliary Transformer: T150.

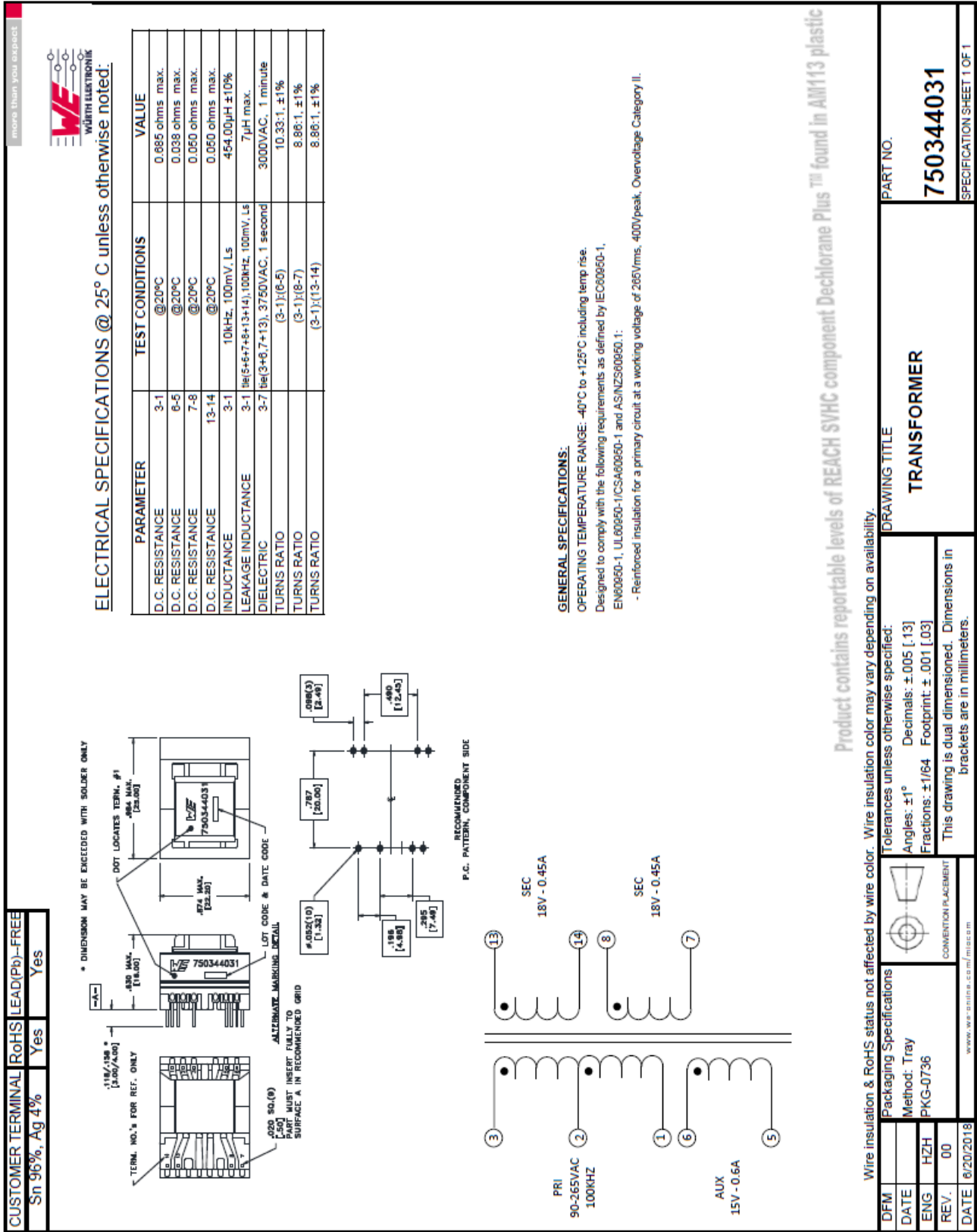
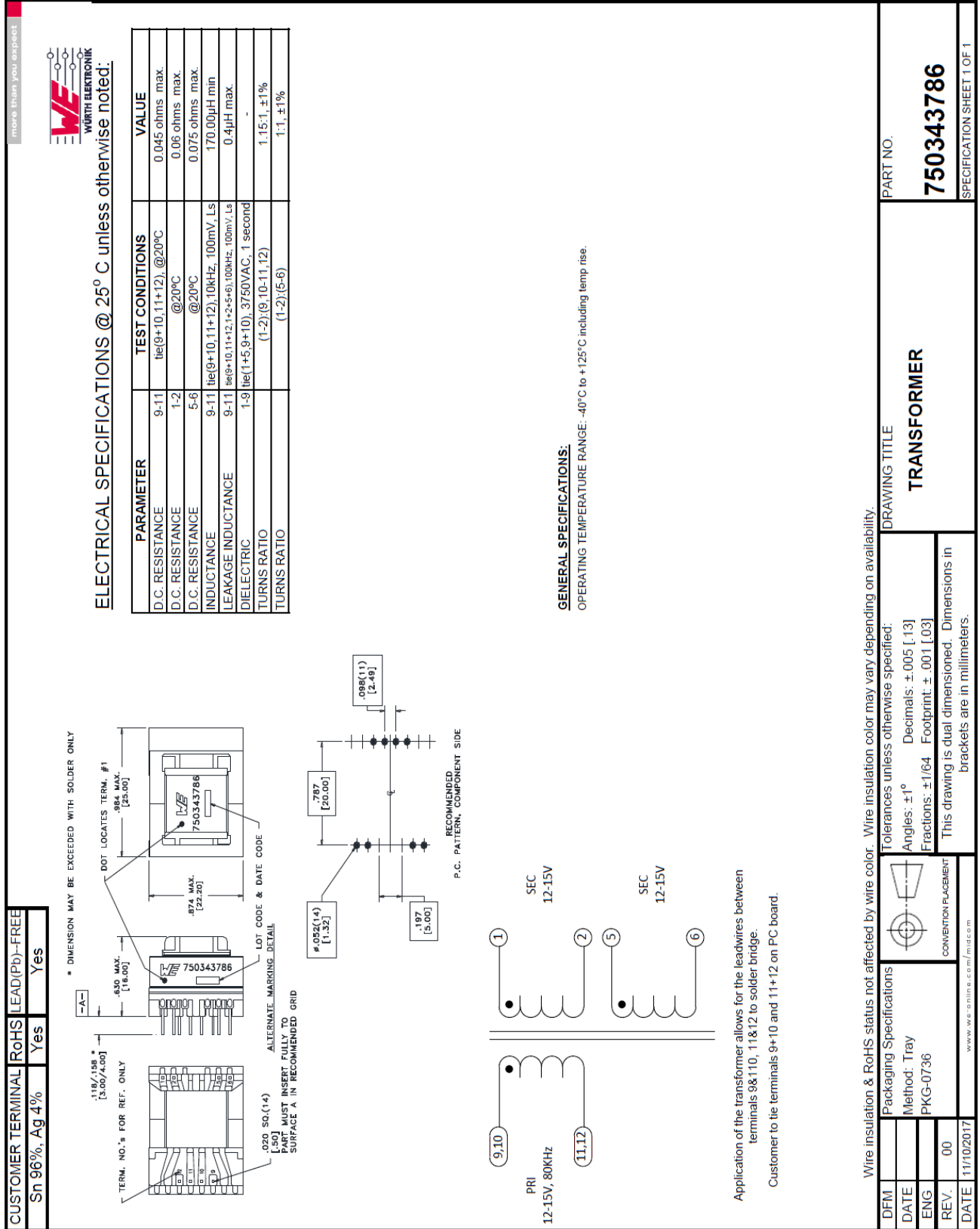


Figure 5.

Pulse Transformer: T73, T74..



Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability.		DRAWING TITLE		PART NO.	
Tolerances unless otherwise specified:		<b>TRANSFORMER</b>		<b>750343786</b>	
Angles: ±1°	Decimals: ±.005 [ .13]				
Fractions: ±1/64	Footprint: ±.001 [ .03]	This drawing is dual dimensioned. Dimensions in brackets are in millimeters.			
CONVENTION PLACEMENT					
DFM	Packaging Specifications	DATE		11/10/2017	
ENG	Method: Tray	REV.		00	
DATE	PKG-0736	www.wurth-elektronik.com		SPECIFICATION SHEET 1 OF 1	

Figure 9.

# TND6320/D

Current Transformer: T72.

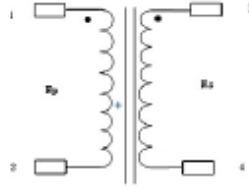


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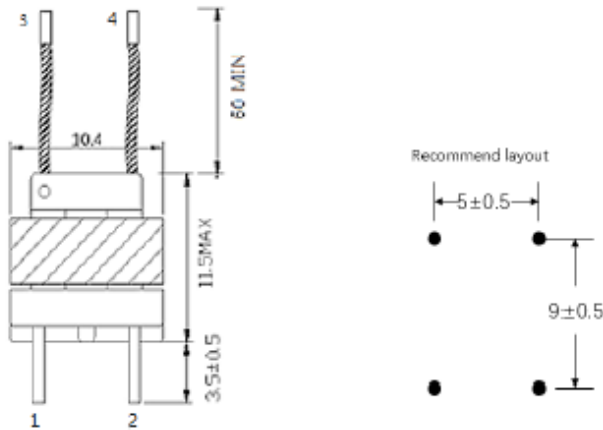
墨尚电子技术(上海)有限公司

P/N:MCTE10-1801

## SCHEMATIC



## DIMENSION(unit: mm)



## SPECIFICATION

Core Type: EE10

Inductance: 60mH(min)

Turns Ratio:  $N_p : N_s = 180:1$

Insulation Level : CLASS B

HI-POT: 2.5kVac/rms

Primary coils: Insulated Wire  $\Phi 0.1\text{mm}$

Secondary coils: TIW-B Wire  $\Phi 0.5\text{mm} \times 6\text{P}$

Figure 10.

# TND6320/D

LLC Transformers: Fill in aluminum box. Monte to heat sink.



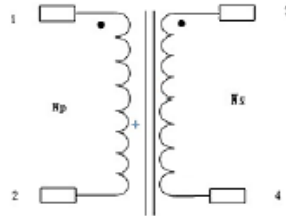
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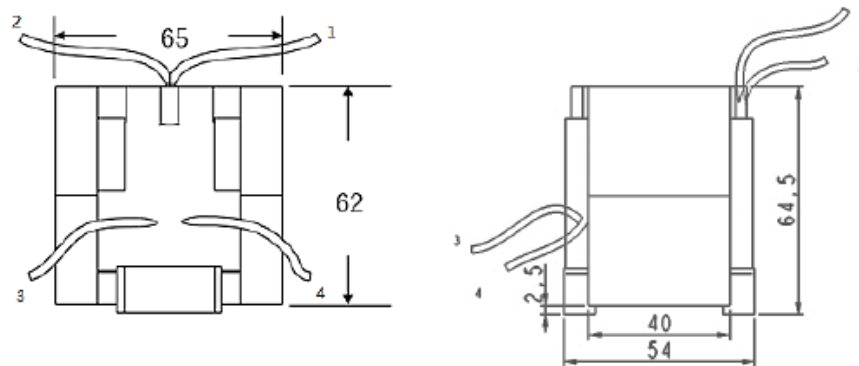
墨尚电子技术(上海)有限公司

P/N:PTX6R6K-17025

## SCHEMATIC



## DIMENSION(mm, ±1mm tol.)



## SPECIFICATION

Core Material: PC95 or equivalent

Type: PQ65/62

Self-Inductance  $L_P$  (1--2 test, 3--4 open):  $170\mu\text{H}\pm 10\%$

Leakage inductance  $L_K$  (1--2 test, 3--4 short):  $25\mu\text{H}\pm 10\%$

Turns Ratio:  $N_p : N_s = 13:13$

Insulation Level : CLASS F

HI-POT: 3.3kVac/rms

Primary coils: Litz Wire

Secondary coils: Litz Wire

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Figure 11.

# TND6320/D

## TEST RESULT

### Power Factor at Vin = 90 Vac

Input Current (A)	5	10	15	20	25	32
Vo=250Vdc	0.601	0.802	0.992	0.994	0.995	0.997
Vo=300Vdc	0.653	0.881	0.994	0.996	0.997	0.998
Vo=350Vdc	0.805	0.993	0.996	0.997	0.998	0.999
Vo=400Vdc	0.972	0.995	0.997	0.998	0.999	0.999

### Power Factor at Vin = 110 Vac

Input Current (A)	5	10	15	20	25	32
Vo=250Vdc	0.733	0.984	0.986	0.988	0.988	0.994
Vo=300Vdc	0.930	0.990	0.990	0.993	0.993	0.996
Vo=350Vdc	0.945	0.993	0.993	0.996	0.996	0.998
Vo=400Vdc	0.952	0.994	0.995	0.997	0.998	0.999

### Power Factor at Vin = 220 Vac

Input Current (A)	5	10	15	20	25	32
Vo=350Vdc	0.654	0.956	0.969	0.973	0.980	0.986
Vo=400Vdc	0.949	0.980	0.986	0.990	0.992	0.994

### Power Factor at Vin = 264 Vac

Input Current (A)	5	10	15	20	25	28
Vo=400Vdc	0.751	0.962	0.978	0.986	0.989	0.990

### Efficiency of PFC Stage at Vin = 90 Vac

Input Current (A)	5	10	15	20	25	32
Vo=250Vdc	90.49%	95.74%	95.18%	94.94%	94.66%	94.18%
Vo=300Vdc	89.43%	94.60%	95.10%	94.78%	94.59%	93.94%
Vo=350Vdc	86.57%	94.44%	94.63%	94.59%	94.33%	93.78%
Vo=400Vdc	85.16%	93.92%	94.55%	94.29%	94.16%	93.61%

### Efficiency of PFC Stage at Vin = 110 Vac

Input Current (A)	5	10	15	20	25	32
Vo=250Vdc	94.17%	95.87%	96.13%	95.78%	95.61%	95.09%
Vo=300Vdc	93.46%	95.56%	95.82%	95.62%	95.34%	94.91%
Vo=350Vdc	93.43%	95.32%	95.60%	95.56%	95.28%	94.76%
Vo=400Vdc	93.33%	94.94%	95.36%	95.33%	94.86%	94.66%

### Efficiency of PFC Stage at Vin = 220 Vac

Input Current (A)	5	10	15	20	25	32
Vo=350Vdc	96.42%	97.97%	97.86%	97.72%	97.52%	97.44%
Vo=400Vdc	96.06%	97.88%	97.73%	97.57%	97.39%	97.22%

### Efficiency of PFC Stage at Vin = 264 Vac

Input Current (A)	5	10	15	20	25	28
Vo=400Vdc	96.18%	98.26%	98.09%	98.01%	97.83%	97.78%



Waveforms of PFC stage. Yellow: Input Voltage; Green: Input Current; Cyan: Vds of CH1; Pink: Vds of CH3.

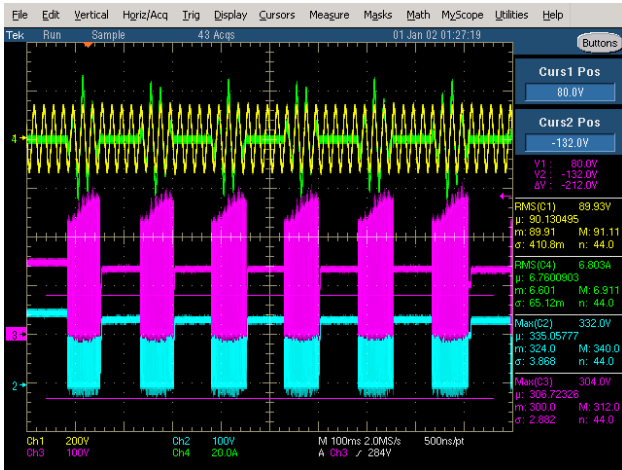


Figure 12. Vin = 90 Vac, Vo = 250 V, Iin = 5 A

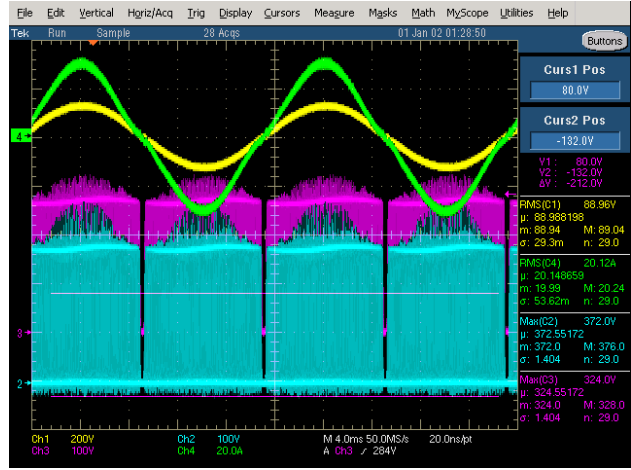


Figure 13. Vin = 90 Vac, Vo = 250 V, Iin = 20 A

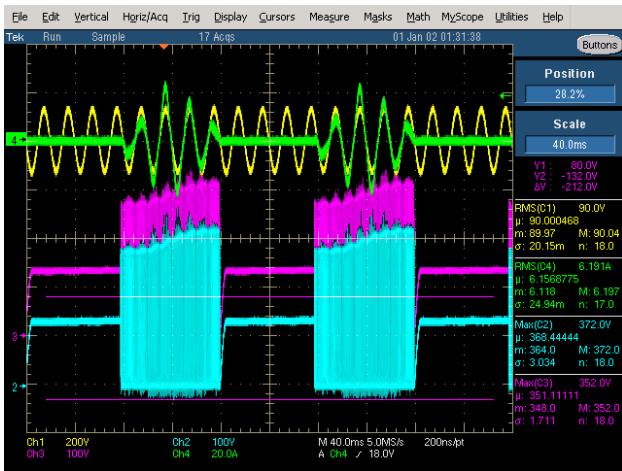


Figure 14. Vin = 90 Vac, Vo = 300 V, Iin = 5 A

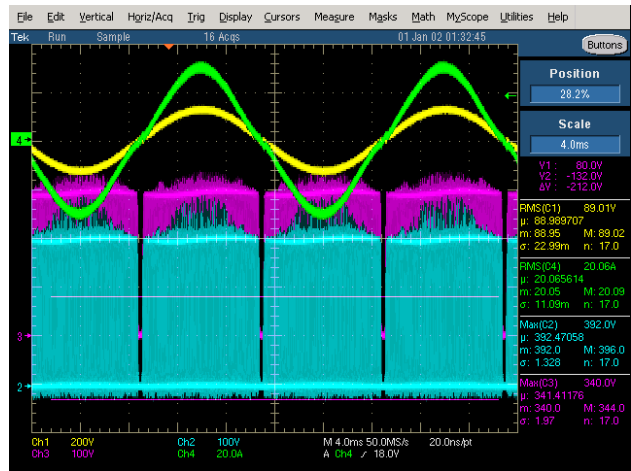


Figure 15. Vin = 90 Vac, Vo = 300 V, Iin = 20 A

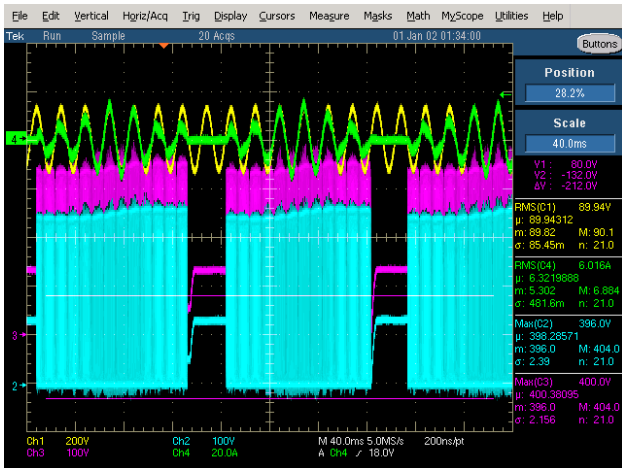


Figure 16. Vin = 90 Vac, Vo = 350 V, Iin = 5 A

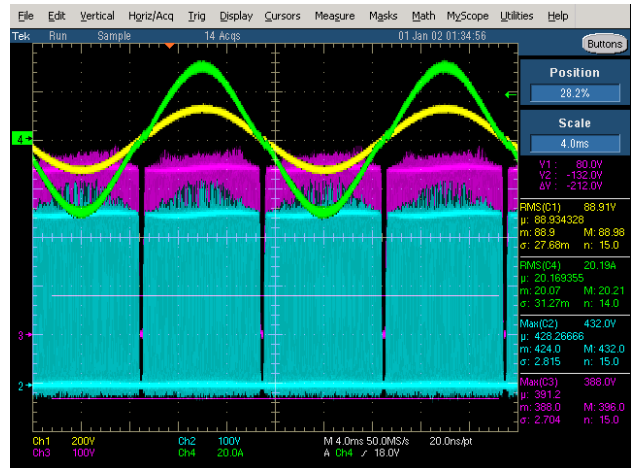


Figure 17. Vin = 90 Vac, Vo = 350 V, Iin = 20 A

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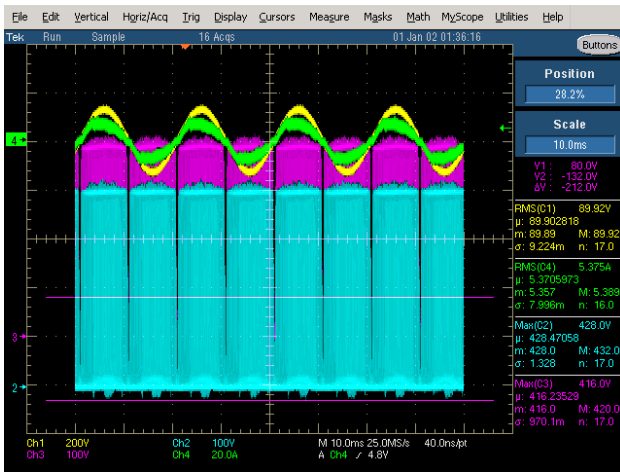


Figure 18. Vin = 90 Vac, Vo = 400 V, Iin = 5 A

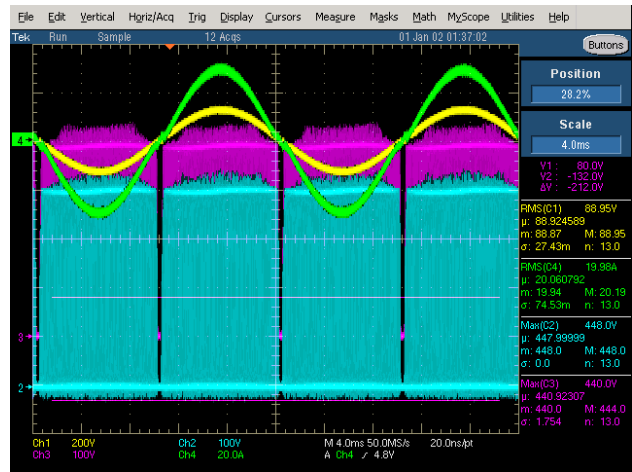


Figure 19. Vin = 90 Vac, Vo = 400 V, Iin = 20 A

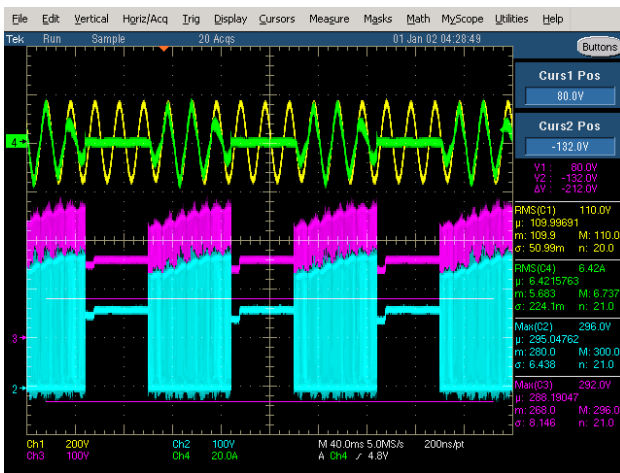


Figure 20. Vin = 110 Vac, Vo = 250 V, Iin = 5 A

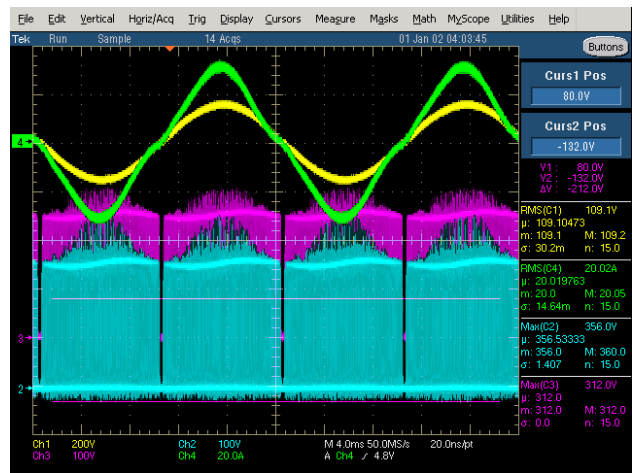


Figure 21. Vin = 110 Vac, Vo = 250 V, Iin = 20 A

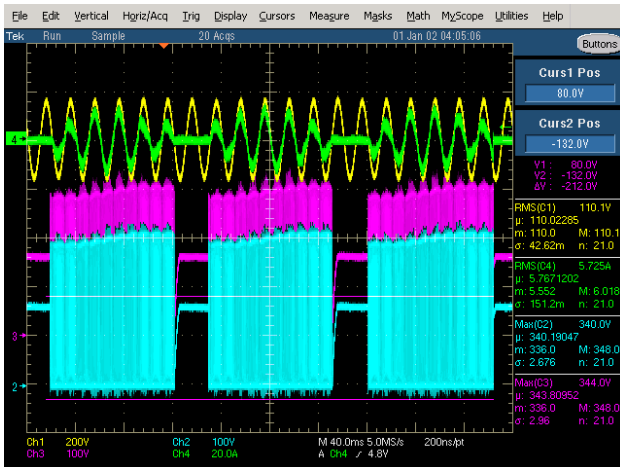


Figure 22. Vin = 110 Vac, Vo = 300 V, Iin = 5 A

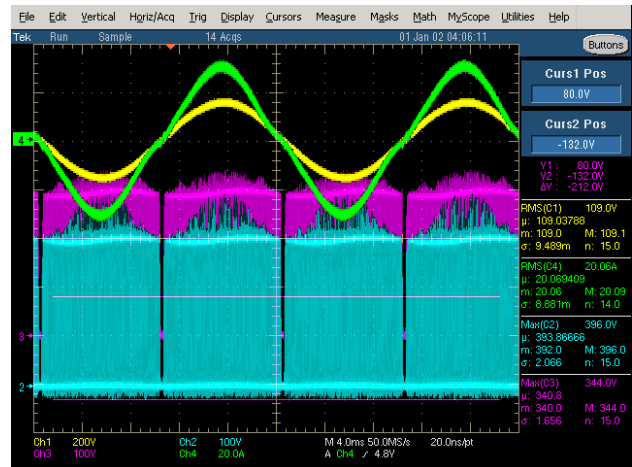


Figure 23. Vin = 110 Vac, Vo = 300 V, Iin = 20 A

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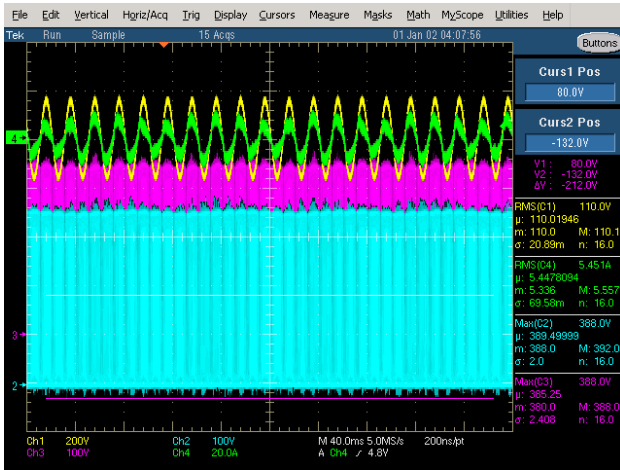


Figure 24. Vin = 110 Vac, Vo = 350 V, lin = 5 A

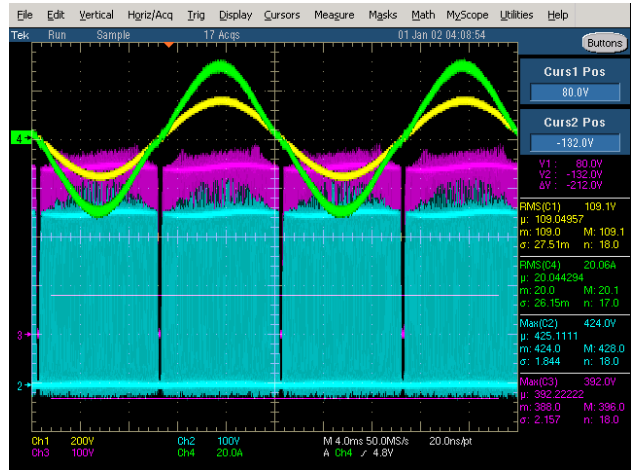


Figure 25. Vin = 110 Vac, Vo = 350 V, lin = 20 A

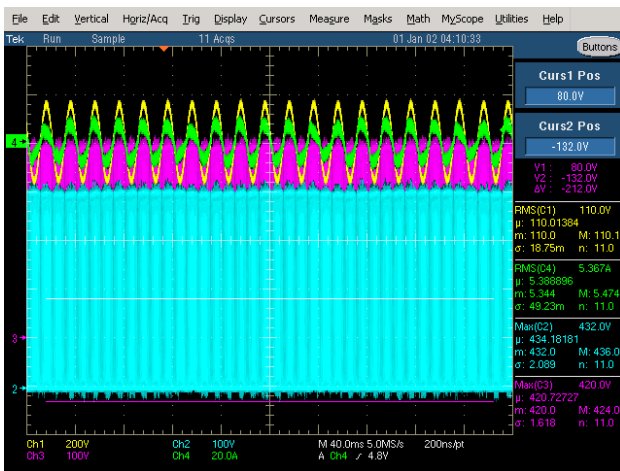


Figure 26. Vin = 110 Vac, Vo = 400 V, lin = 5 A

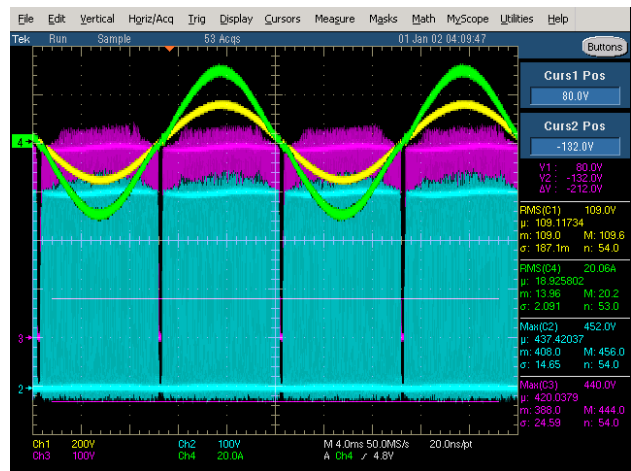


Figure 27. Vin = 110 Vac, Vo = 400 V, lin = 20 A

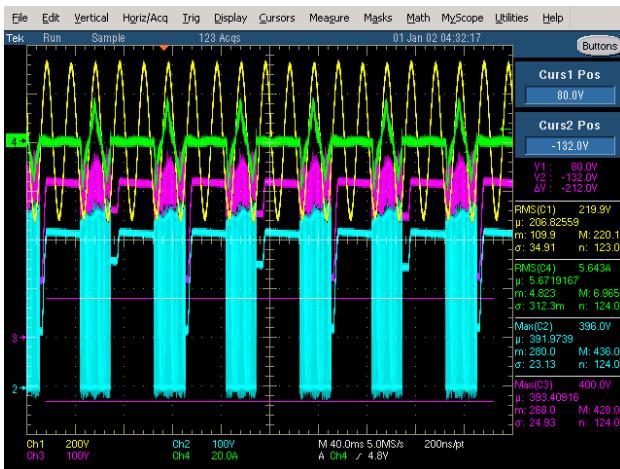


Figure 28. Vin = 220 Vac, Vo = 350 V, lin = 5 A

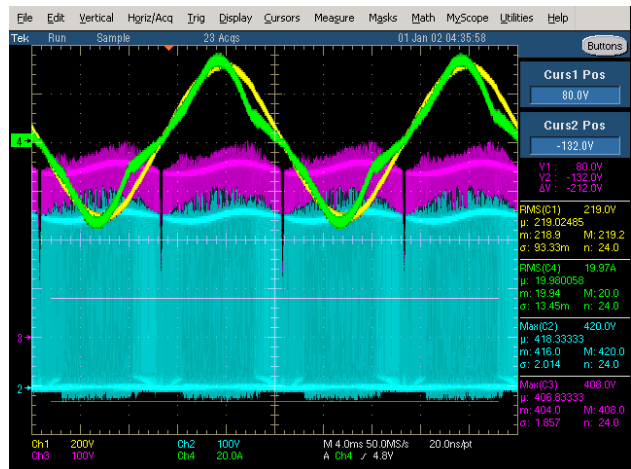


Figure 29. Vin = 220 Vac, Vo = 350 V, lin = 20 A

# TND6320/D

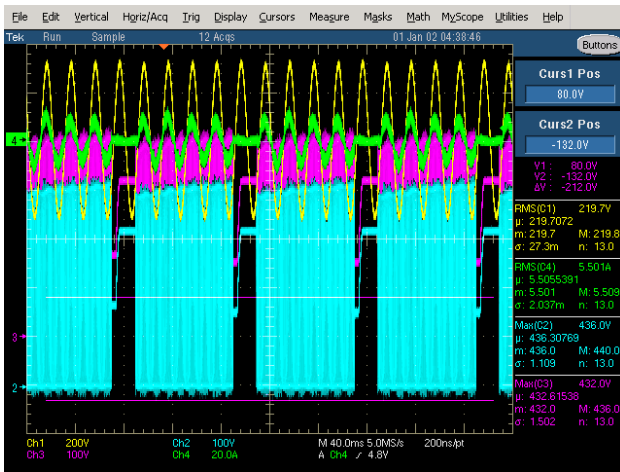


Figure 30. Vin = 220 Vac, Vo = 400 V, lin = 5 A

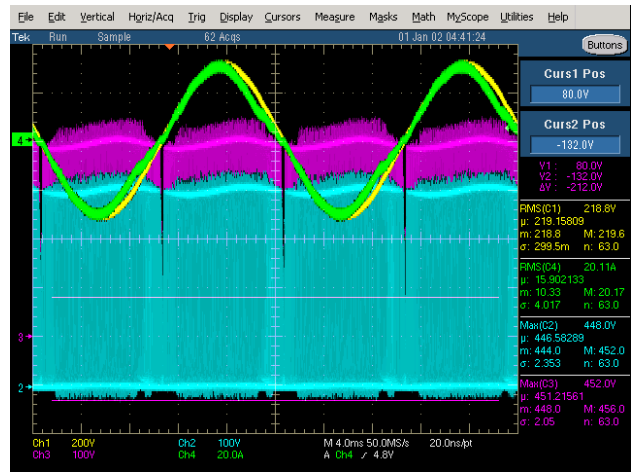


Figure 31. Vin = 220 Vac, Vo = 400 V, lin = 20 A

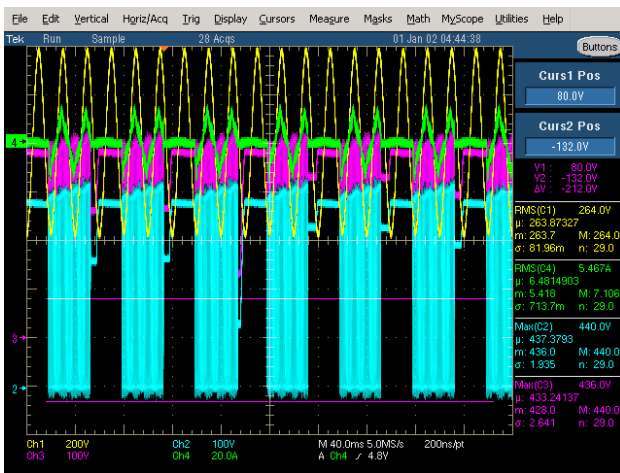


Figure 32. Vin = 264 Vac, Vo = 400 V, lin = 5 A

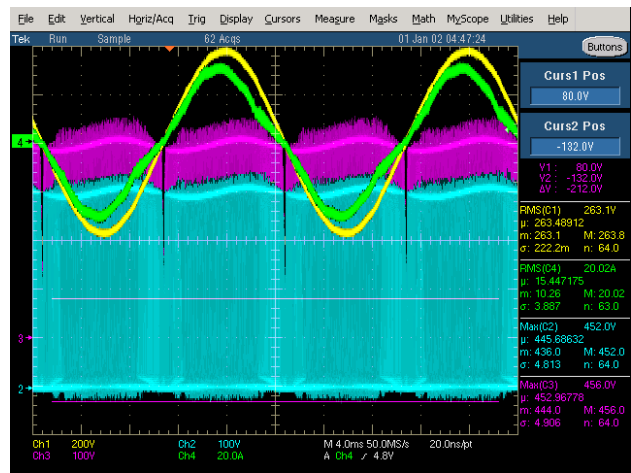


Figure 33. Vin = 264 Vac, Vo = 400 V, lin = 20 A

Efficiency of total set at different Vout under different Vbus. (Vin = 220 Vac).

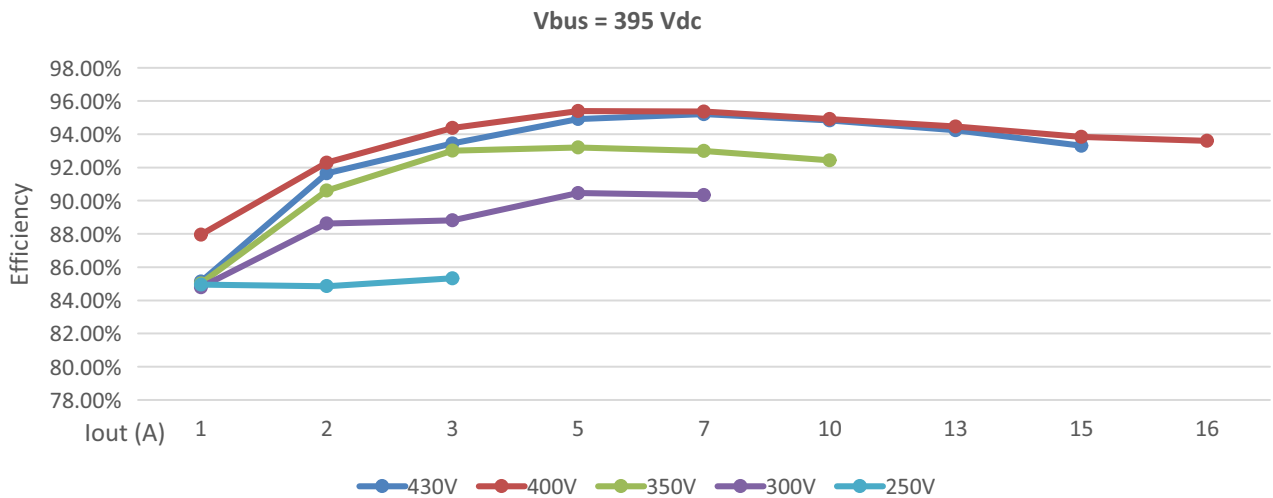


Figure 34.

# TND6320/D

Vbus = 350 Vdc

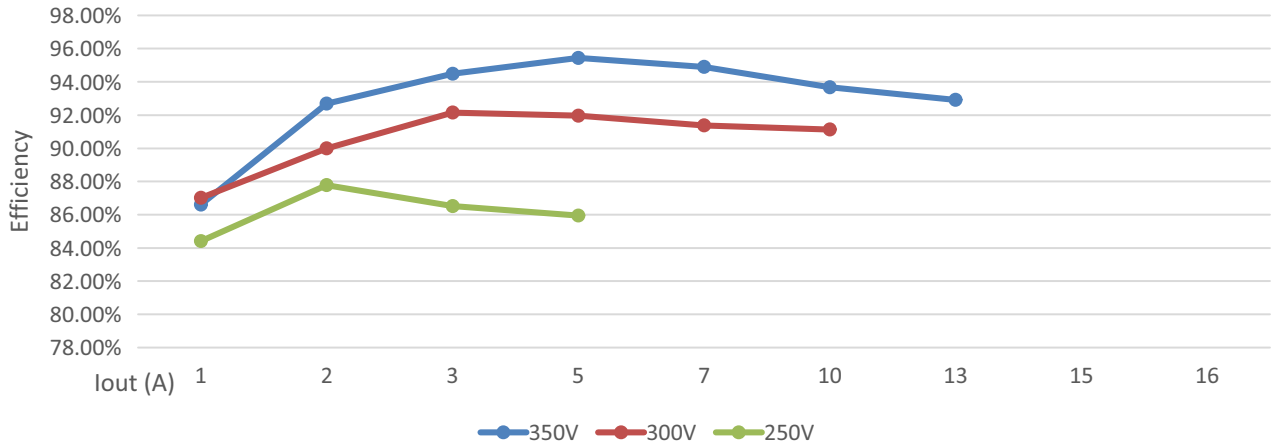


Figure 35.

Vbus = 320 Vdc

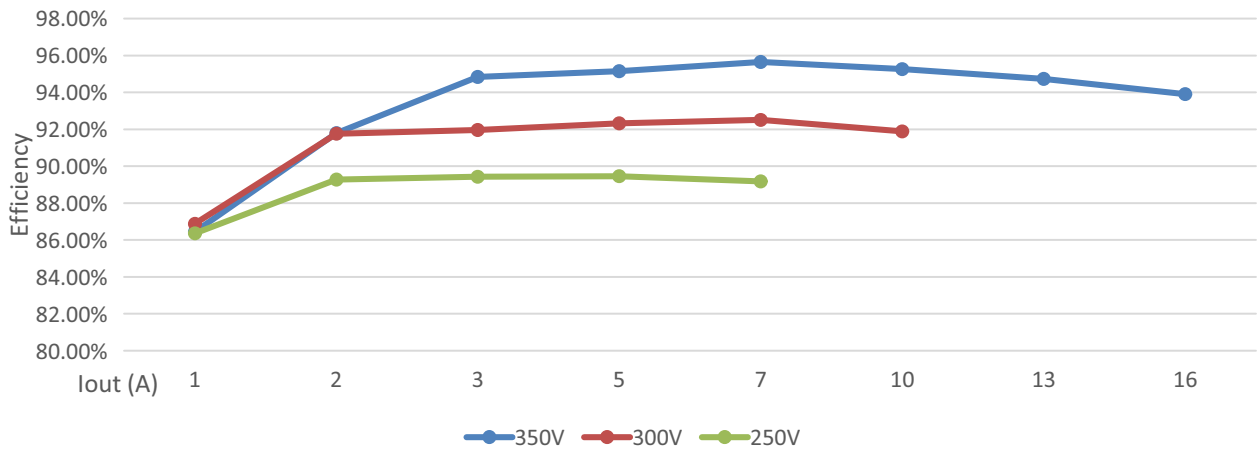


Figure 36.

Efficiency of total set at different Vbus under  
 Vout = 350 Vdc, Iout = 10 A. (Vin = 220 Vac).

Efficiency VS Bus Voltage

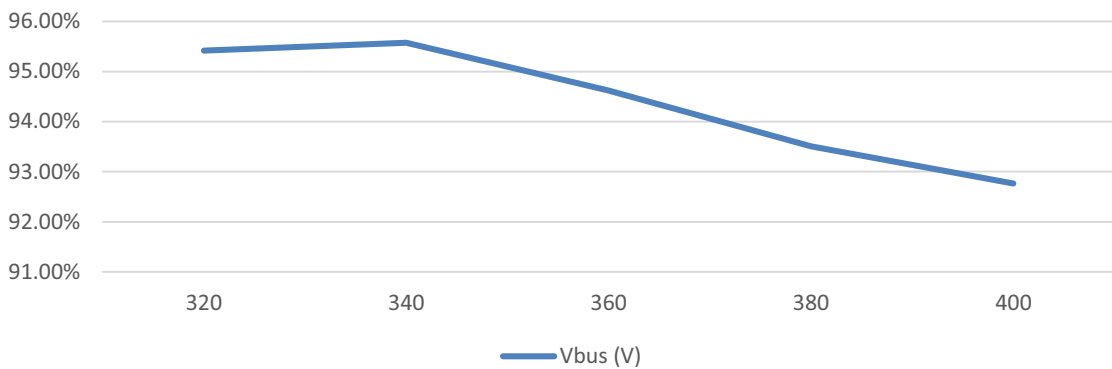


Figure 37. Efficiency vs. Bus Voltage

Waveforms of LLC stage. Yellow: Voltage between each center of the full bridge (Drain of Q62 to Drain of Q72); Green: Current of resonate tank; Cyan: Vgs of Q72.

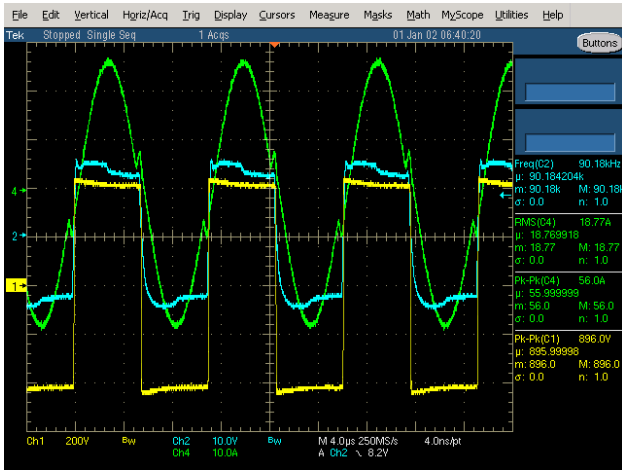


Figure 38. Vbus = 400 V, Vo = 430 V, Io = 15 A

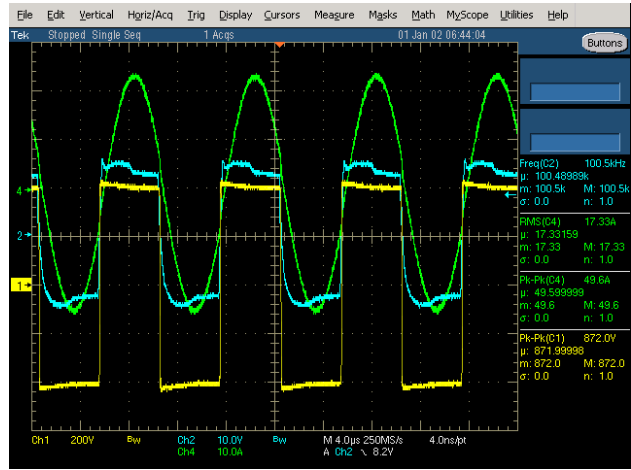


Figure 39. Vbus = 390 V, Vo = 400 V, Io = 15 A

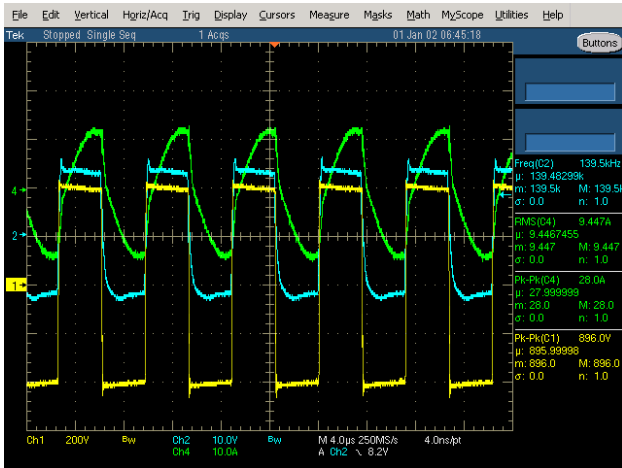


Figure 40. Vbus = 390 V, Vo = 350 V, Io = 8 A

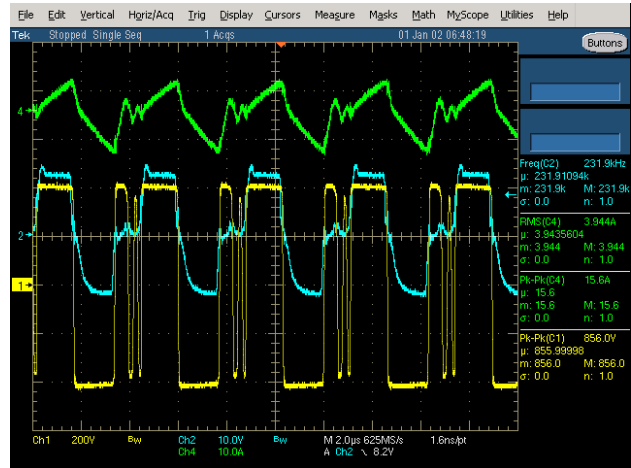


Figure 41. Vbus = 390 V, Vo = 250 V, Io = 3 A

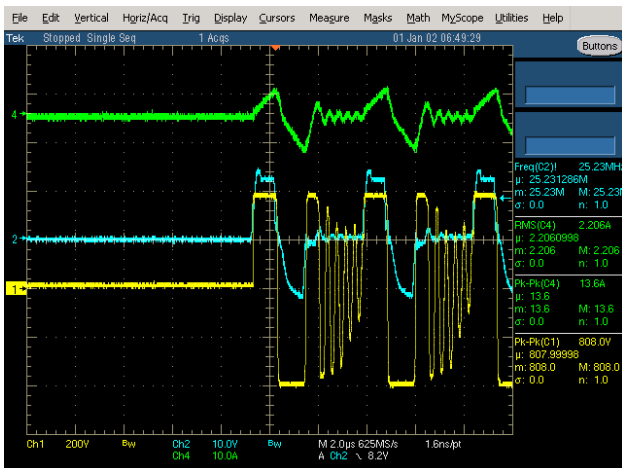


Figure 42. Vbus = 390 V, Vo = 250 V, Io = 1 A

Waveforms of Auxiliary Power. Cyan: +15V; Pink: Anode of D155. ; Green: Anode of D156; Yellow: Drain of Q150.

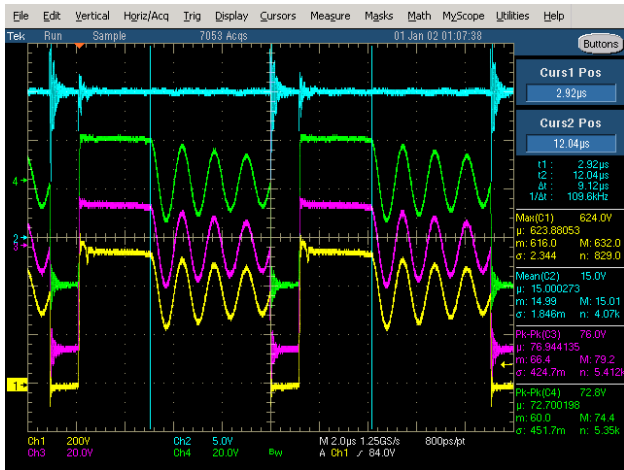


Figure 43.  $V_{in} = 275 \text{ Vac}$ , PFC off, +15V = 0.6 A, +12Vsec = 0.6 A, +12VHV = 0.75 A



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## PCB LAYOUT

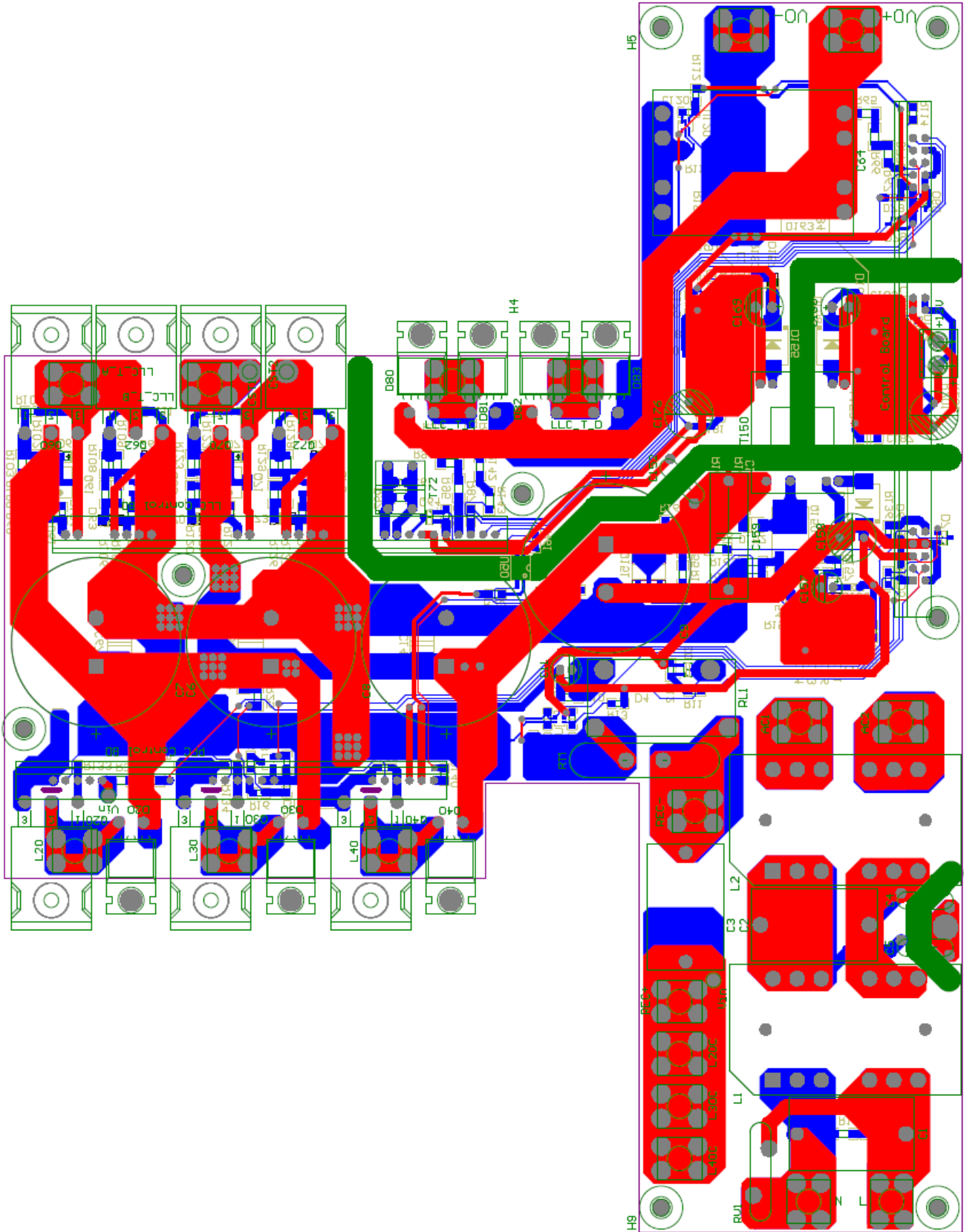


Figure 44. Top Side View of Main Board. 254 x 198 x 2 mm. 2 oz.



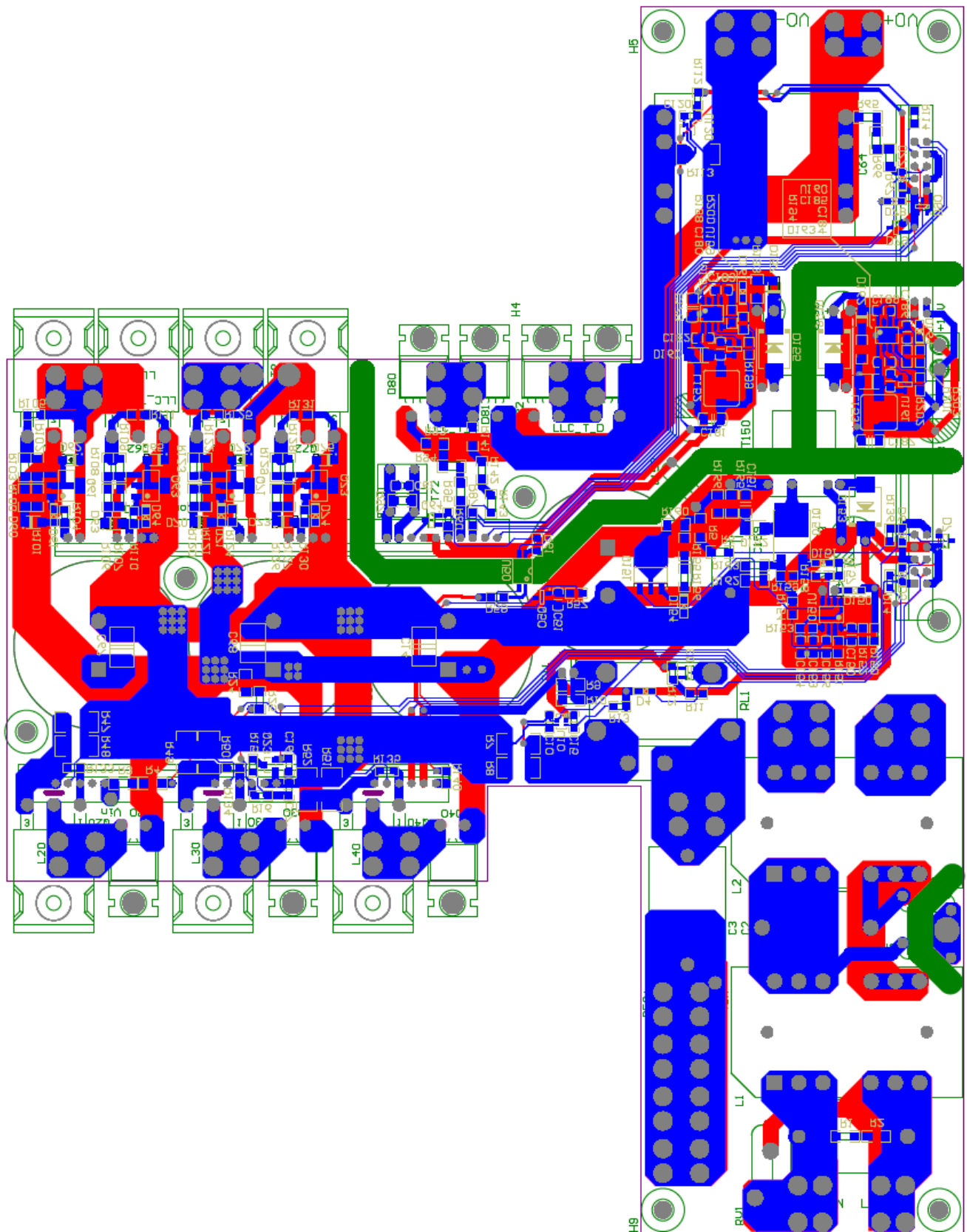


Figure 45. Bottom Side View of Main Board. 254 x 198 x 2 mm. 2 oz.

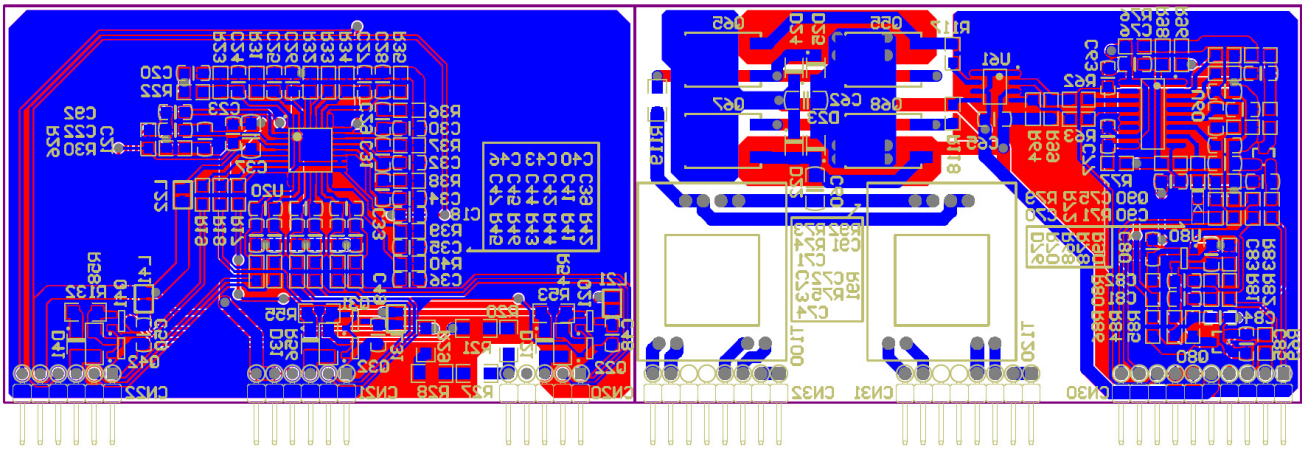


Figure 46. Top Side View of PFC Control Daughter Board (Left. 88.9 x 55.9 x 1.6 mm. 1 oz) and LLC Control Daughter Board (Right. 94 x 55.9 x 1.6 mm. 1 oz)

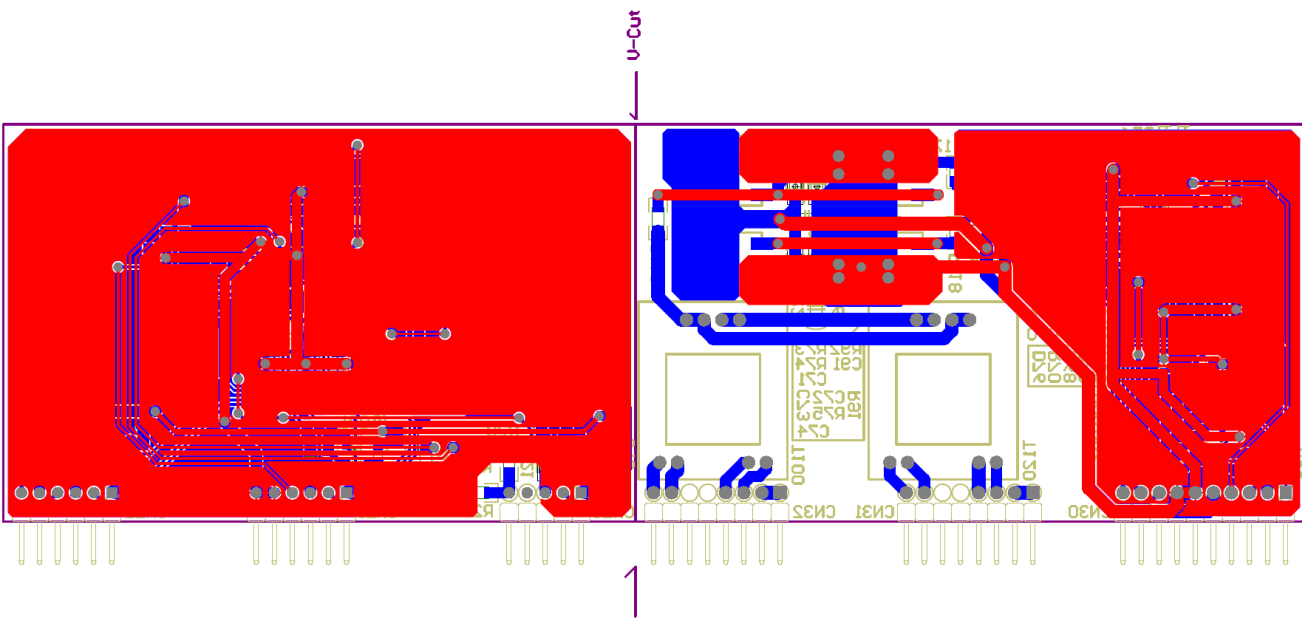


Figure 47. Bottom Side View of PFC Control Daughter Board (Left. 88.9 x 55.9 x 1.6 mm. 1 oz) and LLC Control Daughter Board (Right. 94 x 55.9 x 1.6 mm. 1 oz)

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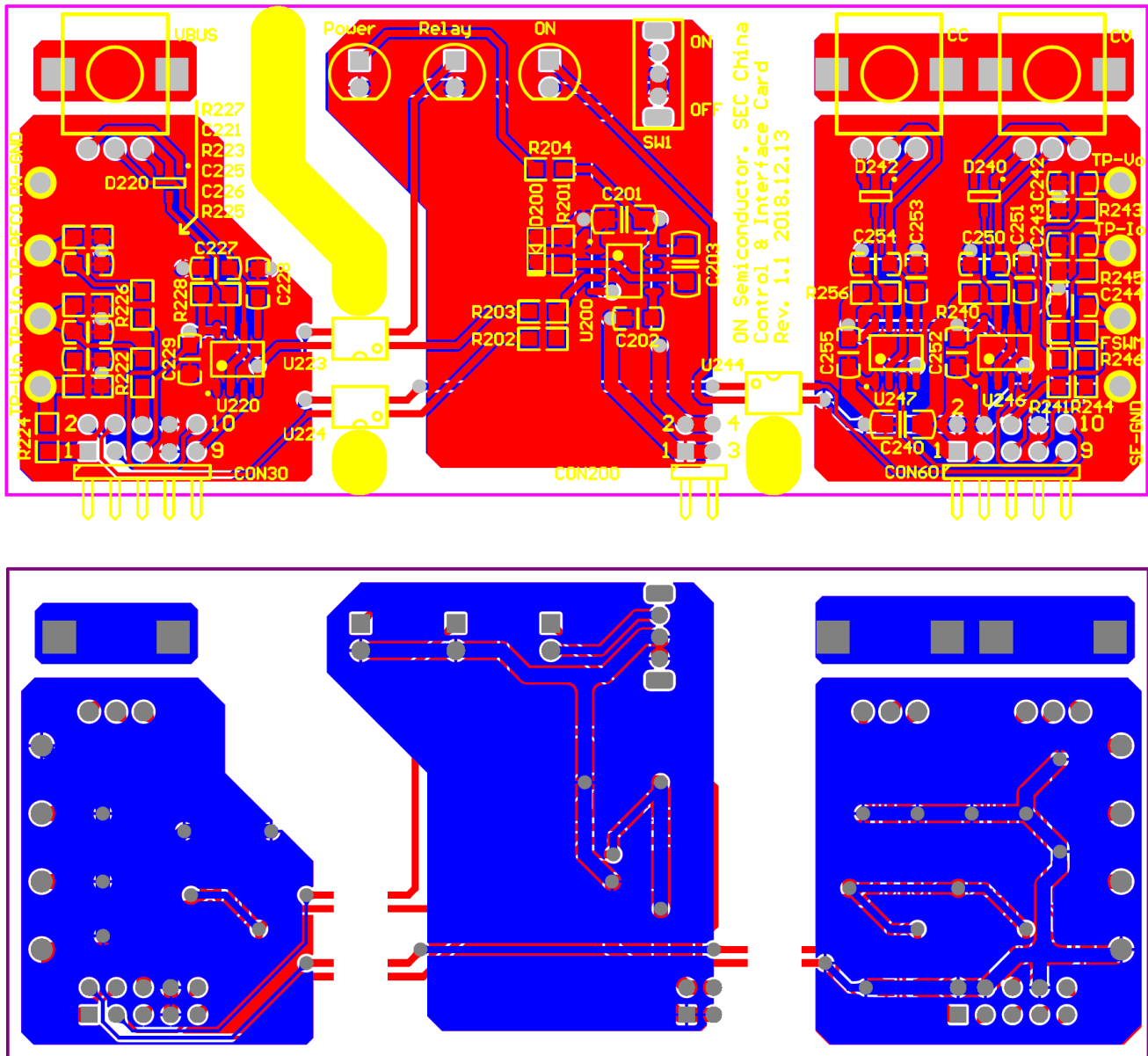


Figure 48. Top and Bottom Side View of Analog Control Daughter Board (106.7 x 45.7 x 1.6 mm. 1 oz)

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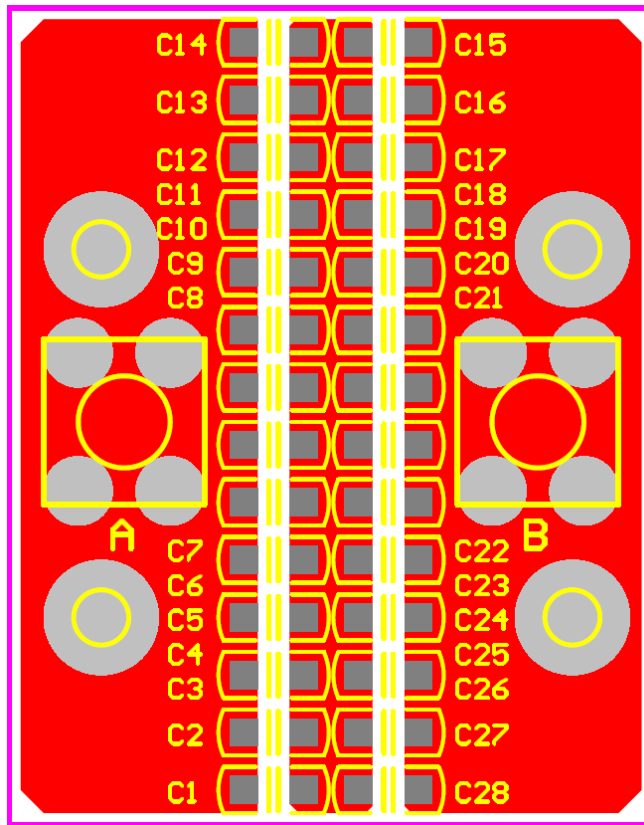


Figure 49. Resonate Capacitor Board (29.8 x 35.6 x 1.6 mm. Single Layer. 2 oz)

## TND6320/D

**Table 3. BILL OF MATERIALS – MAIN BOARD**

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
IC PWM Controller, SOIC8	NCV3843BVD1R2G	ON Semiconductor	1	U150,
IC Buck Switcher, 1.2 A, 2 MHz, SO8EP	NCV890100PDR2G	ON Semiconductor	2	U157, U160,
IC 3.3V Voltage Reference, SOT-23	NCV51460SN33T1G	ON Semiconductor	2	U159, U161,
IC Current Sense Amplifier, SC70-6	NCV210SQT2G	ON Semiconductor	2	U10, U120,
IC Photo Coupler High Temp, MFP-4L	FODM8801C	ON Semiconductor	1	U50,
MOSFET 2.75ohm 800V DPAK	FCD3400N80Z	ON Semiconductor	1	Q150,
MOSFET 82m ohm 650V TO-247	NVHL082N65S3F	ON Semiconductor	4	Q60, Q62, Q70, Q72,
MOSFET 11.5ohm 600V SOT223	FQT1N60CTF-WS	ON Semiconductor	1	Q151,
MOSFET 40mohm 650V TO-247	NVHL040N65S3F	ON Semiconductor	3	Q20, Q30, Q40,
Transistor 40 V, 3.0 A PNP, SOT223	NJT4030PT1G	ON Semiconductor	4	Q61, Q63, Q71, Q73,
Transistor 40V 2A PNP, SOT23	NSV40200LT1G	ON Semiconductor	1	Q64,
Transistor 40V 2A NPN, SOT23	NSV40201LT1G	ON Semiconductor	1	Q3,
Transistor 40V 0.2A NPN, SOT23	MMBT3904LT1G	ON Semiconductor	1	Q50,
MOSFET 60V 7.5Ω, SOT23	2V7002LT1G	ON Semiconductor	1	Q23,
Bridge Rectifier 50A 600V, GBPC-4L	GBPC5006	Any	1	Monte to Heat sink.
SIC Diode 30A 650V, TO220	FFSP3065A	ON Semiconductor	7	D20, D30, D40, D80, D81, D82, D83,
Diode 1A 1000V, SMA	NRVA4007T3G	ON Semiconductor	1	D152,
Schottky Diode 3A 100V, SMC	NRVBS3100T3G	ON Semiconductor	3	D153, D155, D156,
Schottky Diode 3A 40V, SMA	MBRA340T3G	ON Semiconductor	2	D160, D163,
Schottky Diode 1A 20V, SOD123	NRVB120ESFT1G	ON Semiconductor	8	D60, D62, D63, D65, D70, D72, D73, D75,
Switching Diode 0.2A 100V, SOD323	BAS16HT1G	ON Semiconductor	13	D4, D5, D6, D61, D64, D71, D74, D77, D78, D150, D151, D161, D164,
ZENER Diode 0.5W 15V, SOD523	MM5Z15VT1G	ON Semiconductor	1	D154,
ZENER Diode 0.5W 22V, SOD123	SZMMSZ22T1G	ON Semiconductor	2	D1576, D162,
Chip resistor 0805 10ohm-J		Any	2	R13, R112,
Chip resistor 0805 22ohm-J		Any	1	R157,
Chip resistor 0805 47ohm-J		Any	5	R104, R110, R124, R130, R158,
Chip resistor 0805 82ohm-J		Any	2	R200, R203,
Chip resistor 0805 100ohm-J		Any	1	R154,
Chip resistor 0805 1.2Kohm-J		Any	2	R199, R202,
Chip resistor 0805 2.2Kohm-J		Any	3	R59, R60, R61,
Chip resistor 0805 4.75Kohm-F		Any	3	R87, R114, R151,
Chip resistor 0805 8.2Kohm-J		Any	2	R11, R12,
Chip resistor 0805 10Kohm-J		Any	9	R57, R105, R111, R125, R131, R140, R159, R198, R201,
Chip resistor 0805 12.4Kohm-F		Any	2	R15, R16,
Chip resistor 0805 12.7Kohm-F		Any	1	R14,
Chip resistor 0805 18Kohm-J		Any	3	R133, R134, R135,
Chip resistor 0805 24Kohm-J		Any	1	R150,
Chip resistor 0805 100Kohm-J		Any	1	R153,

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**Table 3. BILL OF MATERIALS – MAIN BOARD** (continued)

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
Chip resistor 0805 200Kohm-J		Any	1	R136,
Chip resistor 0805 470Kohm-J		Any	1	R152,
Chip resistor 1206 1ohm-J		Any	8	R102, R103, R108, R109, R122, R123, R128, R129,
Chip resistor 1206 1.8ohm-J		Any	2	R162, R163,
Chip resistor 1206 2.2ohm-J		Any	8	R100, R101, R106, R107, R120, R121, R126, R127,
Chip resistor 1206 68ohm-J		Any	1	R97,
Chip resistor 1206 82ohm-J		Any	2	R193, R194,
Chip resistor 1206 1Kohm-J		Any	2	R9, R10,
Chip resistor 1206 4.7Kohm-J		Any	1	R160,
Chip resistor 1206 330Kohm-J		Any	6	R93, R94, R95, R141, R142, R143,
Chip resistor 1206 470Kohm-J		Any	4	R155, R156, R165, R166,
Chip resistor 1206 750Kohm-J		Any	3	R65, R66, R67,
Chip resistor 1206 1Mohm-J		Any	8	R1, R2, R3, R4, R5, R6, R24, R25,
Chip resistor 2512 2mohm-F	SMA25A2FR002T	SART	3	R7, R8, R113,
Chip resistor 2512 2mohm-F	ERJMS4SF2M0*	Panasonic	3	R7, R8, R113,
Chip resistor 2512 15mohm-J	SMF25M2FR015T	SART	6	R47, R48, R49, R50, R51, R52,
NTC 5ohm D31	B57127P0509M301	TDK	1	RT1,
Disk Varistor 320V D20	820423211	WURTH	1	RV1
Disk Varistor 320V D20	B72220P3321K101V87	TDK	1	RV1
Disk Varistor 320V D20	V20E300AUTO	Littelfuse	1	RV1
MLCC 0805-50V-100pFK-NP0	885012007057	WURTH	2	C153, C156,
MLCC 0805-450V-100pFK-NP0	CGA4C4C0G2W101J	TDK	2	C153, C156,
MLCC 0805-50V-102M-X7R	885012207086	WURTH	1	C61,
MLCC 0805-100V-102J-NP0	CGA4C2C0G2A102J	TDK	1	C61,
MLCC 0805-50V-222M-X7R	885012207088	WURTH	3	C150, C183, C186,
MLCC 0805-50V-222J-NP0	CGA4C2C0G1H222J	TDK	3	C150, C183, C186,
MLCC 0805-50V-103M-X7R	885012207092	WURTH	1	C51,
MLCC 0805-50V-103J-NP0	CGA4C2C0G1H103J	TDK	1	C51,
MLCC 0805-25V-104M-X7R	885012207072	WURTH	7	C15, C120, C154, C180, C182, C184, C185,
MLCC 0805-100V-104K-X7R	CGA4J2X7R2A104K	TDK	7	C15, C120, C154, C180, C182, C184, C185,
MLCC 0805-50V-105M-X7R	885012207103	WURTH	1	C189,
MLCC 0805-50V-105K-X7R	CGA4J3X7R1H105K125AB	TDK	1	C189,
MLCC 0805-25V-225M-X7R	885012207079	WURTH	1	C17,
MLCC 0805-25V-225K-X7R	CGA4J3X7R1E225K	TDK	1	C17,
MLCC 1206-25V-106M-X7R	885012208069	WURTH	2	C181, C187,
MLCC 1206-25V-106K-X7R	CGA5L1X7R1E106K	TDK	2	C181, C187,
MLCC 1206-50V-475M-X7R	885012208094	WURTH	1	C179,
MLCC 1206-50V-475K-X7R	CGA5L3X7R1H475K	TDK	1	C179,

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**Table 3. BILL OF MATERIALS – MAIN BOARD** (continued)

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
MLCC 1206-630V-222K-X7R	CGA5H4X7R2J222K	TDK	1	C151,
MLCC 2220-630V-105M-X7T	CAA572X7T2J105M	TDK	3	C14, C67, C68,
E-Cap 25V-150uF-105(6.3X11mm)	860020473010	WURTH	1	C11,
E-Cap 35V-22uF-105-10Kh(5X11mm)	860160572003	WURTH	1	C157,
E-Cap 35V-22uF-105-10Kh(5X11mm)	EEUFC1V220*	Panasonic	1	C157,
E-Cap 35V-220uF-105-LI(8X16mm)	86080574011	WURTH	2	C160, C169,
E-Cap 35V-220uF-105-LI(8X16mm)	EEUFC1V221L*	Panasonic	2	C160, C169,
E-Cap 25V-560uF-105-LI(10X20mm)	860080475017	WURTH	3	C158, C176, C188,
E-Cap 25V-560uF-105-LI(10X16mm)	EEUFC1E561*	Panasonic	3	C158, C176, C188,
E-Cap 450V-680uF-105 (35X57mm)	861141486026	WURTH	4	C6, C7, C8, C9,
E-Cap 450V-680uF-105 (35X55mm)	B43508A5687M062	TDK	4	C6, C7, C8, C9,
Film Cap 630V 1uF PP	ECWFD2J105K	Panasonic	1	C159,
Film Cap 630V 1uF PP	MEXPN41004JJ	Dura	1	C159,
Film Cap 630V 2.2uF PP	ECWFD2J225K	Panasonic	1	C3,
Film Cap 630V 2.2uF PP	MEXPN42204JJ	Dura	1	C3,
Film Cap 800V 30uF PP	EZPE80306MTA	Panasonic	1	C64,
X-Cap 275VAC 2.2uF X2	890324026034CS	WURTH	2	C1, C2,
X-Cap 275VAC 2.2uF X2	R46KN4220JHP0M	KEMET	2	C1, C2,
Y-Cap 400VAC 4700pF Y2	CD45-E2GA472M-NKA	TDK	3	C4, C5, C152,
Y-Cap 250VAC 4700pF Y2	JY14E472MY72N	JNC	3	C4, C5, C152,
Common Choke 1.5mH 38A	7448063801	WURTH	2	L1, L2
Aux. Transformer EF20, 14-Pin, THT.	750344031	WURTH	1	T150,
Integrated LLC Transformer	PTX6R6K-17025	Magsonder	1	Filled in aluminum box. Mounted to heat sink.
Current Transformer EE10	MCTE10-1801	Magsonder	1	T72,
PFC Inductor 180uH 26A	HTR-253550-181M	Magsonder	3	Filled in aluminum box. Mounted to heat sink.
SMD Inductor 7X7X3.5mm-22uH-1.6A	784778220	WURTH	2	L152, L153,
SMD Inductor 7X7X4.5mm-22uH-1.7A	SPM7045VT-220M-D	TDK	2	L152, L153,
Connector 5mm 2Pins Screw type	691101710002	WURTH	1	12V
Connector 5mm Screw type. 200X300mil	74760050	WURTH	18	AC1, AC2, LLC_T_A, LLC_T_B, LLC_T_C, LLC_T_D, L, N, REC+, REC-, VO+, VO-, L20, L20C, L30, L30C, L40, L40C,
Connector 2.54mm Dual Socket Header 4Pns	61300421821	WURTH	1	Control Board,
Connector 2.54mm Dual Socket Header 10Pns	61301021821	WURTH	2	Control Board,
Fly wire UL1015 22# 180mm		Any	1	Vin to Vin
RELAY 33A 250VAC	ALFG2PF121	Panasonic	1	RL1
Spacer Plastic, metric, internal/external, 8mm	971080365	WURTH	8	
Spacer Brass, metric, internal/external, 8mm	971080324	WURTH	1	

\* The adjacent items in same shadow are optional in different manufacturer.

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**Table 4. BILL OF MATERIALS – PFC CONTROL AND LLC CONTROL DAUGHTER BOARD**

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
IC 3CH ICCM PFC Controller, QFP32	FAN9673Q	ON Semiconductor	1	U20,
IC Current mode LLC Controller, SOP16	NCV4390DR2G	ON Semiconductor	1	U60,
IC Dual 4A Low-Side Gate Drivers, SO8	FAN3224TUMX-F085	ON Semiconductor	1	U61,
IC RRO OP Amplifier, SOT-23 5L	NCV2003SN2T1G	ON Semiconductor	1	U80,
Transistor 25 V 5A NPN, DPAK	MJD200G	ON Semiconductor	2	Q65, Q67,
Transistor 25 V 5A PNP, DPAK	MJD210G	ON Semiconductor	2	Q55, Q68,
Transistor 40V 2A PNP, SOT23	NSV40200LT1G	ON Semiconductor	3	Q22, Q32, Q42,
Transistor 40V 2A NPN, SOT23	NSV40201LT1G	ON Semiconductor	3	Q21, Q31, Q41,
MOSFET 60V 7.5Ω, SOT23	2V7002LT1G	ON Semiconductor	2	Q80, Q90,
Schottky Diode 1A 20V, SOD123	NRVB120ESFT1G	ON Semiconductor	7	D21, D22, D23, D24, D25, D31, D41,
Switching Diode 0.2A 100V, SOD323	BAS16HT1G	ON Semiconductor	1	D76,
Chip resistor 0805 0ohm-J		Any	1	R68,
Chip resistor 0805 10ohm-J		Any	3	R80, R117, R118,
Chip resistor 0805 220ohm-J		Any	5	R17, R18, R19, R69, R90,
Chip resistor 0805 470ohm-J		Any	6	R41, R42, R43, R44, R45, R46,
Chip resistor 0805 1Kohm-J		Any	4	R62, R63, R64, R99,
Chip resistor 0805 2.2Kohm-J		Any	1	R86,
Chip resistor 0805 4.75Kohm-F		Any	4	R82, R83, R91, R92,
Chip resistor 0805 5.1Kohm-J		Any	1	R71,
Chip resistor 0805 8.2Kohm-J		Any	1	R35,
Chip resistor 0805 10Kohm-J		Any	5	R39, R75, R81, R84, R85,
Chip resistor 0805 12.4Kohm-F		Any	3	R33, R34, R78,
Chip resistor 0805 15Kohm-J		Any	1	R74,
Chip resistor 0805 18Kohm-J		Any	4	R36, R37, R38, R70,
Chip resistor 0805 24Kohm-J		Any	1	R26,
Chip resistor 0805 33Kohm-J		Any	1	R31,
Chip resistor 0805 36Kohm-J		Any	1	R23,
Chip resistor 0805 39Kohm-J		Any	1	R32,
Chip resistor 0805 47Kohm-J		Any	1	R40,
Chip resistor 0805 68Kohm-J		Any	3	R72, R77, R96,
Chip resistor 0805 100Kohm-J		Any	2	R30, R98,
Chip resistor 0805 200Kohm-J		Any	3	R22, R73, R79,
Chip resistor 1206 1ohm-J		Any	1	R119,
Chip resistor 1206 10ohm-J		Any	6	R53, R54, R55, R56, R58, R132,
Chip resistor 1206 1Mohm-J		Any	2	R20, R21,
Chip resistor 1206 2Mohm-F		Any	3	R27, R28, R29,
MLCC 0805-50V-10pFK-NP0	885012007051	WURTH	1	C70,
MLCC 0805-50V-100pFJ-NP0	885012007057	WURTH	3	C30, C32, C34,
MLCC 0805-450V-100pFJ-NP0	CGA4C4C0G2W101J	TDK	3	C30, C32, C34,
MLCC 0805-50V-220pFK-NP0	885012007059	WURTH	1	C77,



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**Table 4. BILL OF MATERIALS – PFC CONTROL AND LLC CONTROL DAUGHTER BOARD** (continued)

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
MLCC 0805-450V-220pFJ-NP0	CGA4C4C0G2W221J	TDK	1	C77,
MLCC 0805-50V-471J-NP0	885012007061	WURTH	7	C23, C26, C27, C36, C71, C75, C82,
MLCC 0805-450V-471J-NP0	CGA4C4C0G2W471J	TDK	7	C23, C26, C27, C36, C71, C75, C82,
MLCC 0805-50V-102M-X7R	885012207086	WURTH	7	C29, C31, C33, C40, C43, C46, C83,
MLCC 0805-100V-102M-NP0	CGA4C2C0G2A102J	TDK	7	C29, C31, C33, C40, C43, C46, C83,
MLCC 0805-50V-222M-X7R	885012207088	WURTH	6	C39, C41, C42, C44, C45, C47,
MLCC 0805-50V-222J-NP0	CGA4C2C0G1H222J	TDK	6	C39, C41, C42, C44, C45, C47,
MLCC 0805-50V-472M-X7R	'885012207090	WURTH	1	C72,
MLCC 0805-50V-472J-NP0	CGA4C2C0G1H472J	TDK	1	C72,
MLCC 0805-50V-103M-X7R	885012207092	WURTH	5	C18, C25, C28, C35, C81,
MLCC 0805-50V-103J-NP0	CGA4C2C0G1H103J	TDK	5	C18, C25, C28, C35, C81,
MLCC 0805-50V-473M-X7R	885012207096	WURTH	2	C20, C76,
MLCC 0805-100V-473M-X7R	CGA4J2X7R2A473M	TDK	2	C20, C76,
MLCC 0805-25V-104M-X7R	885012207072	WURTH	2	C22, C80,
MLCC 0805-100V-104K-X7R	CGA4J2X7R2A104K	TDK	2	C22, C80,
MLCC 0805-25V-224M-X7R	885012207074	WURTH	2	C24, C73,
MLCC 0805-25V-224K-X7R	CGA4J2X7R1H224K	TDK	2	C24, C73,
MLCC 0805-25V-474M-X7R	885012207076	WURTH	7	C21, C48, C49, C50, C63, C65, C92,
MLCC 0805-25V-474K-X7R	CGA4J2X7R1E474K	TDK	7	C21, C48, C49, C50, C63, C65, C92,
MLCC 0805-25V-225M-X7R	885012207079	WURTH	2	C84, C91,
MLCC 0805-25V-225K-X7R	CGA4J3X7R1E225K	TDK	2	C84, C91,
MLCC 0805-16V-475M-X7R	885012207052	WURTH	1	C74,
MLCC 0805-16V-475K-X7R	CGA4J3X7R1C475K	TDK	1	C74,
MLCC 1206-25V-106M-X7R	885012208069	WURTH	1	C37,
MLCC 1206-25V-106K-X7R	CGA5L1X7R1E106K	TDK	1	C37,
MLCC 1206-50V-475M-X7R	885012208094	WURTH	2	C60, C62,
MLCC 1206-50V-475K-X7R	CGA5L3X7R1H475K	TDK	2	C60, C62,
Pulse Transformer EF20/10/6, THT	750343786	WURTH	2	T100, T120,
Chip Inductor 2016-1uH	74438343010	WURTH	4	L21, L22, L31, L41,
Chip Inductor 2016-1uH Automotive	TFM201610AL- MA1R0MTAA	TDK	4	L21, L22, L31, L41,
Connector 2.54mm THT Angled 5 Pin Header	61300511021	WURTH	1	CN20,
Connector 2.54mm THT Angled 6 Pin Header	61300611021	WURTH	2	CN21, CN22,
Connector 2.54mm THT Angled 8 Pin Header	61300811021	WURTH	2	CN31, CN32,
Connector 2.54mm THT Angled 10 Pin Header	61301011021	WURTH	1	CN30,

\* The adjacent items in same shadow are optional in different manufacturer.

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**Table 5. BILL OF MATERIALS – ANALOG CONTROL DAUGHTER BOARD**

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
IC Single Timer, SO8	NCV1455BDR2G	ON Semiconductor	4	U200, U220, U246, U247,
Photo Coupler High Temp MFP-4L	FODM8801C	ON Semiconductor	3	U223, U224, U244,
Switching Diode 0.2A 100V, SOD323	BAS16HT1G	ON Semiconductor	1	D200,
Schottky Diode 0.2A 100V, SOT23	SBAV99LT3G	ON Semiconductor	3	D220, D240, D242,
LED D=5mm THT Green	151051VS04000	WURTH	2	POWER, RELAY,
LED D=5mm THT Red	151051RS11000	WURTH	1	ON,
Chip resistor 0805 1Kohm-J		Any	4	R202, R228, R240, R256,
Chip resistor 0805 2.2Kohm-J		Any	2	R203, R204,
Chip resistor 0805 2.43Kohm-F		Any	2	R222, R224,
Chip resistor 0805 12.4Kohm-F		Any	6	R223, R225, R226, R243, R244, R245,
Chip resistor 0805 20Kohm-J		Any	1	R230,
Chip resistor 0805 100Kohm-J		Any	2	R226, R241,
Chip resistor 0805 150Kohm-J		Any	1	R201,
Potentiometer 50Kohm 10X11mm Vertical		Any	3	CC, CV, VBUS,
MLCC 0805-50V-10pFK-NP0	885012007051	WURTH	1	C230,
MLCC 0805-50V-102M-X7R	885012207086	WURTH	5	C221, C225, C226, C242, C243,
MLCC 0805-100V-102M-NP0	CGA4C2C0G2A102J	TDK	5	C221, C225, C226, C242, C243,
MLCC 0805-50V-222M-X7R	885012207088	WURTH	3	C227, C250, C254,
MLCC 0805-50V-222J-NP0	CGA4C2C0G1H222J	TDK	3	C227, C250, C254,
MLCC 0805-50V-103M-X7R	885012207092	WURTH	4	C202, C228, C251, C253,
MLCC 0805-50V-103J-NP0	CGA4C2C0G1H103J	TDK	4	C202, C228, C251, C253,
MLCC 0805-25V-104M-X7R	885012207072	WURTH	3	C229, C252, C255,
MLCC 0805-100V-104K-X7R	CGA4J2X7R2A104K	TDK	3	C229, C252, C255,
MLCC 1206-25V-106M-X7R	885012208069	WURTH	3	C201, C203, C240,
MLCC 1206-25V-106K-X7R	CGA5L1X7R1E106K	TDK	3	C201, C203, C240,
Connector 2.54 mm THT Angled Dual Pin Header 10Pns	61300421021	WURTH	1	CON200,
Connector 2.54 mm THT Angled Dual Pin Header 10Pns	61301021021	WURTH	2	CON30, CON60,
Test Pin		Any	8	TP_PFCO, TP_IIN, TP_VIN, TP_FSWM, TP_GND_PR, TP_GND_HV, TP_IO, TP_VO,
Switch 1 Connector 2 Position, 8.6X4.4mm		Any	1	SW1,


\* The adjacent items in same shadow are optional in different manufacturer.

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**Table 6. BILL OF MATERIALS – RESONATE CAPACITOR BOARD**

Description	Manufacturer Part Number	Manufacturer	Qty.	Designator
MLCC 1210-1000V-223J-NP0	CGA6P1C0G3A223JT0Y0N	TDK	20	C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26,
MLCC 1210-630V-223J-NP0	C1210C223JBGAxxx	KEMET	20	C3, C4, C5, C6, C7, C8, C9, C10, C11, C12, C17, C18, C19, C20, C21, C22, C23, C24, C25, C26,

\* The adjacent items in same shadow are optional in different manufacturer.

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