# 240 W UHD Power Supply - CrM Totempole PFC and Current Mode LLC HB Solution

# TND6457/D

| onsemi's Devices | Applications | Input Voltage | Output Power | Topology | I/O Isolation |
|---|---|---|---|---|---|
| NCP1680<br>NCP13994<br>2*NCP51530BMNTWG<br>2*NCP4306DAHZZAASNT1G<br>2*NCP58921<br>2*NCP58922<br>2*NTMT064N65S3H<br>2*FDMS4D0N12C | PD3.1 multi−port adapter, industrial and other applications | 90 Vac to 264 VAc | 240 W | TPPFC + LLC | Isolated |

| | Output Specification |
|---|---|
| Output Voltage | 48 V |
| Max Current | 5 A |
| Min Current | zero |

| | |
|---|---|
| Efficiency | 95.75% & 96.49% @ 115 Vac & 230 Vac and 48 V 5 A |
| Protection | OVP, OCP, SCP, OTP |
| PCBA | 89 mm × 53 mm × 21 mm |

### Circuit Description

This reference design describes a 240 W **U**ltra **H**igh **D**ensity(**UHD**) power supply solution using NCP1680, NCP13994 and NCP4306 with TPPFC pluses LLC power supply with 48 V 5 A for multi−port super charger, and general power supply supporting 240 W with high efficiency and compact profile.

The featured PFC solution uses NCP1680 totem pole PFC controller with CRM and VSFF control, HF current mode LLC controller NCP13994 and syn. controller NCP4306 for 48 V 5 A. 2 SJ FETs are used for PFC slow leg SW and 2 drive GaN NCP58921 are used for PFC fast leg SW and 2 drive GaN NCP58922 for LLC converter.

This reference design provides a total solution which has the whole circuit schematic details, PCB layout, EVM photo, inductor, transformer specification and BOM for 240 W UHD power supply solution, also some key waveforms for reference.

A dual layer PCB is designed in order to reduce cost for a demonstration although totem pole PFC has more component and complex replacement, also consider easy to test, only 1 daughter card with some filtering components is used.

LLC controller has a high startup current source and PFC controller has a low operation current, so LLC startup current source should supply PFC and LLC Vcc during startup, PFC controller has a low Vcc_on threshold so PFC will start first then LLC Vcc continues to rise to Vcc_on threshold, PFC has completed startup and PFCOK signal has a high level output while Vcc reaches Vcc_on, a capacitor with large capacitance is used for LLC Vcc to maintain enough voltage to ensure PFC operation until LLC operation then LLC's auxiliary winding supplies all Vcc voltage.

The PFCOK pin is intended to control operation of a downstream DC−DC converter by acting as an enable or UVLO signal. The pin output of the pin is a current source proportional to the FB pin voltage with a gain of 10 _A/V. A resistor to ground placed at the pin will give the downstream converter an image of the bulk voltage for use as a UVLO or brown out for LLC converter, this will reduce the power loss on bulk voltage resistor divider.

Two auxiliary windings are used for primary and secondary. 2 pcs NCP4306 with TSOP6 dedicated for LLC are used for secondary rectified controller, compared with dual channel syn. controller, the PCB replacement and layout can be optimized.

**Key Features**

- AC input from 90 V to 264 V
- TPPFC + LLC topology
- High Frequency operation with GaN, 50 mΩ for TPPFC and 78 mΩ for LLC
- Output voltage and current: 48 V and 5 A
- Max Output power: 240 W
- Low standby power: <300 mW in universal
- Ripple&Noise: <150 mV
  AVG efficiency: 94.25% & 94.76%
  at 115 Vac & 230 Vac and 48 V
- Full load efficiency: 95.75% & 96.49%
  at 115 Vac & 230 Vac and 48 V 5 A
- OVP, OCP and SCP protection
- Open loop protection
- 2 layers PCB used and name card size with compact design
- PCBA size: 89 mm × 53 mm × 21 mm
- Power Density: 39.7 W/in^3

## BOARD PHOTOS

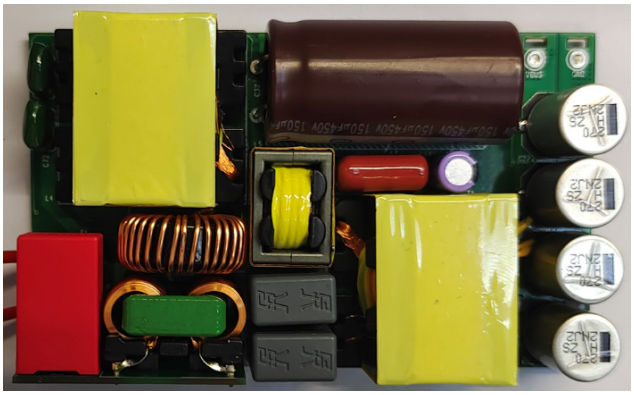

**Figure 1. The Front View of 240 W EVM**

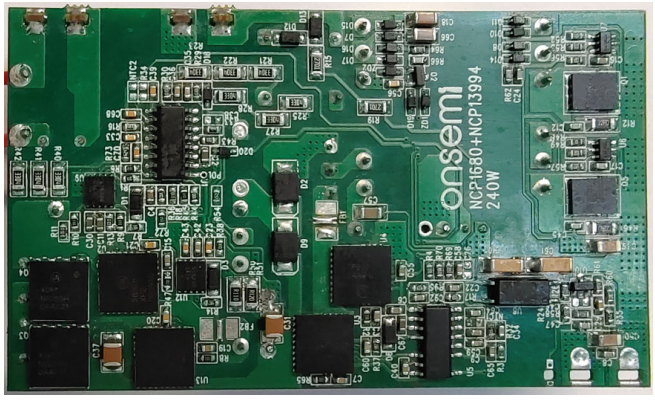


**Figure 2. Reverse Side of 240 W EVM**

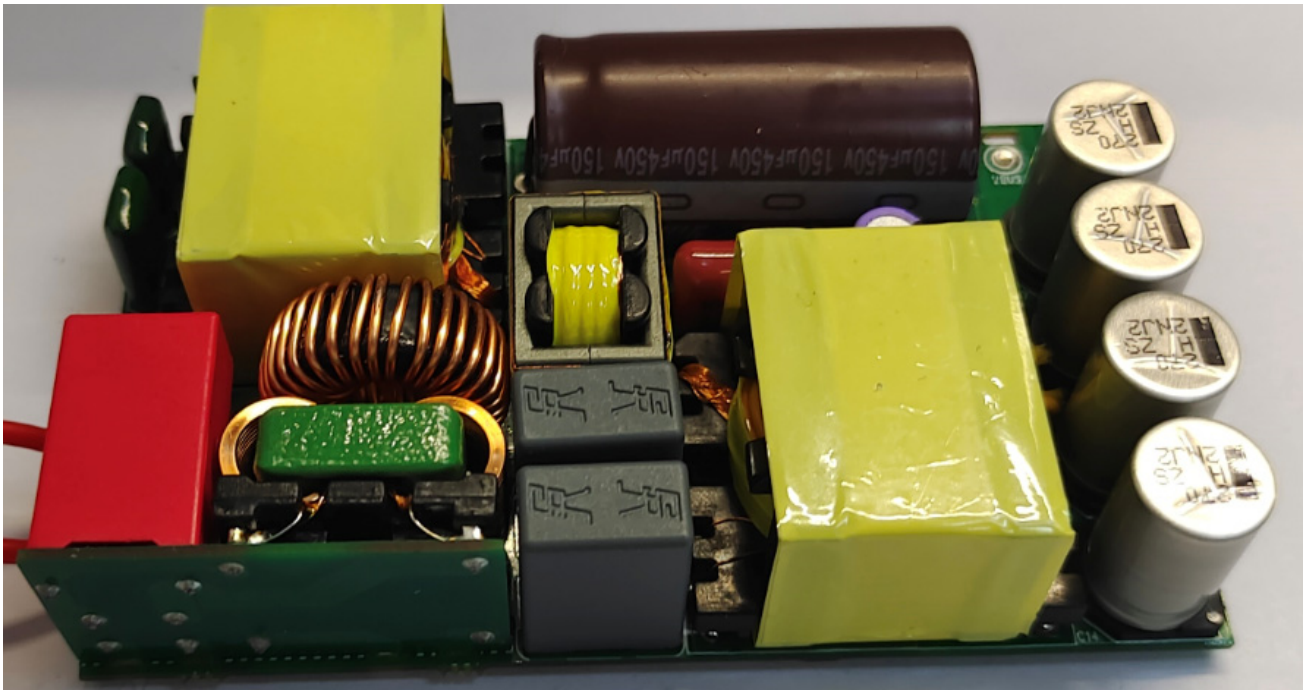

**Figure 3. Profile of 240 W EVM**

## CIRCUIT SCHEMATIC (TPPFC PORTION)

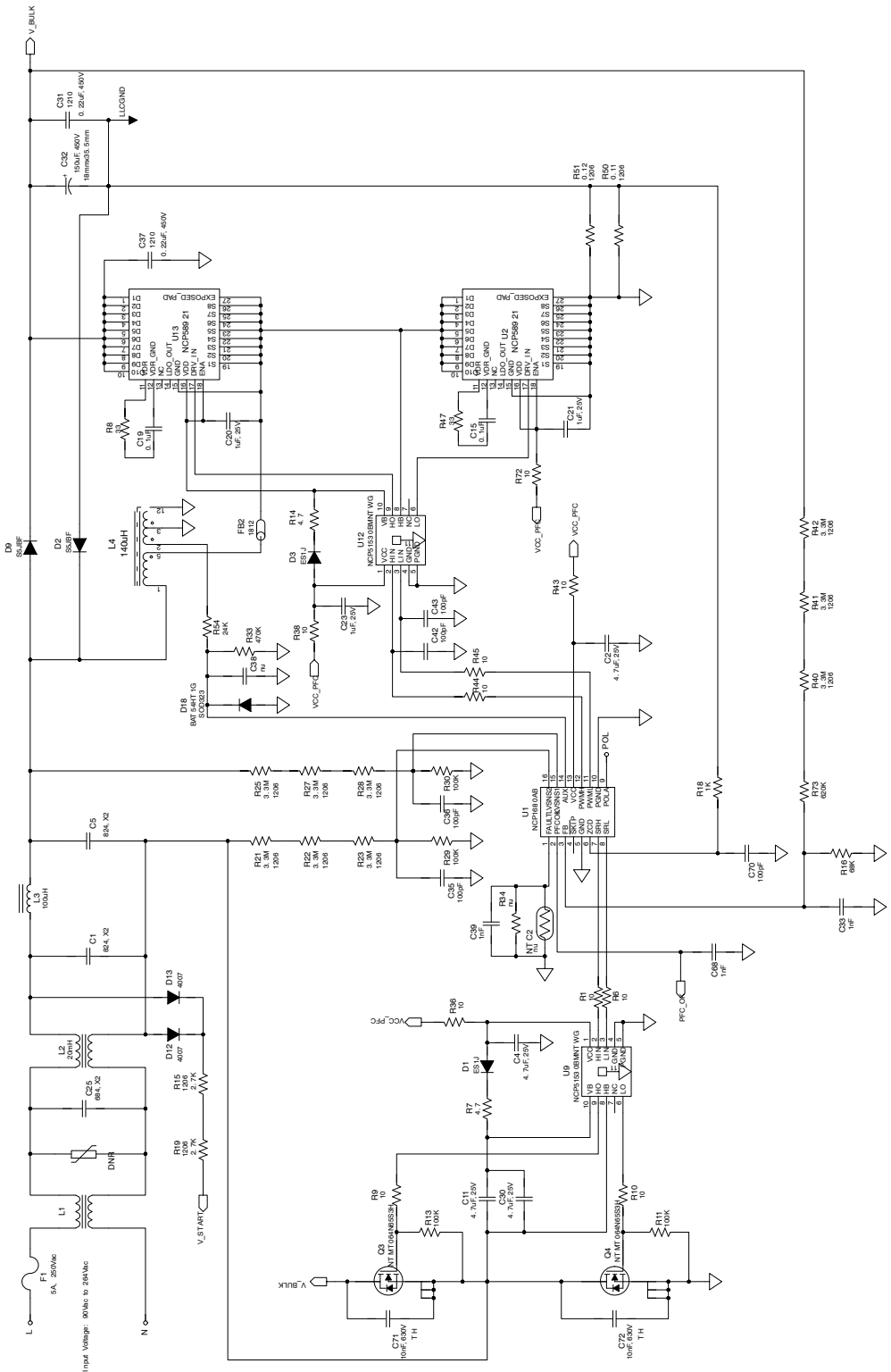

**Figure 4. Schematic for TPPFC Portion**

## CIRCUIT SCHEMATIC (LLC PORTION)

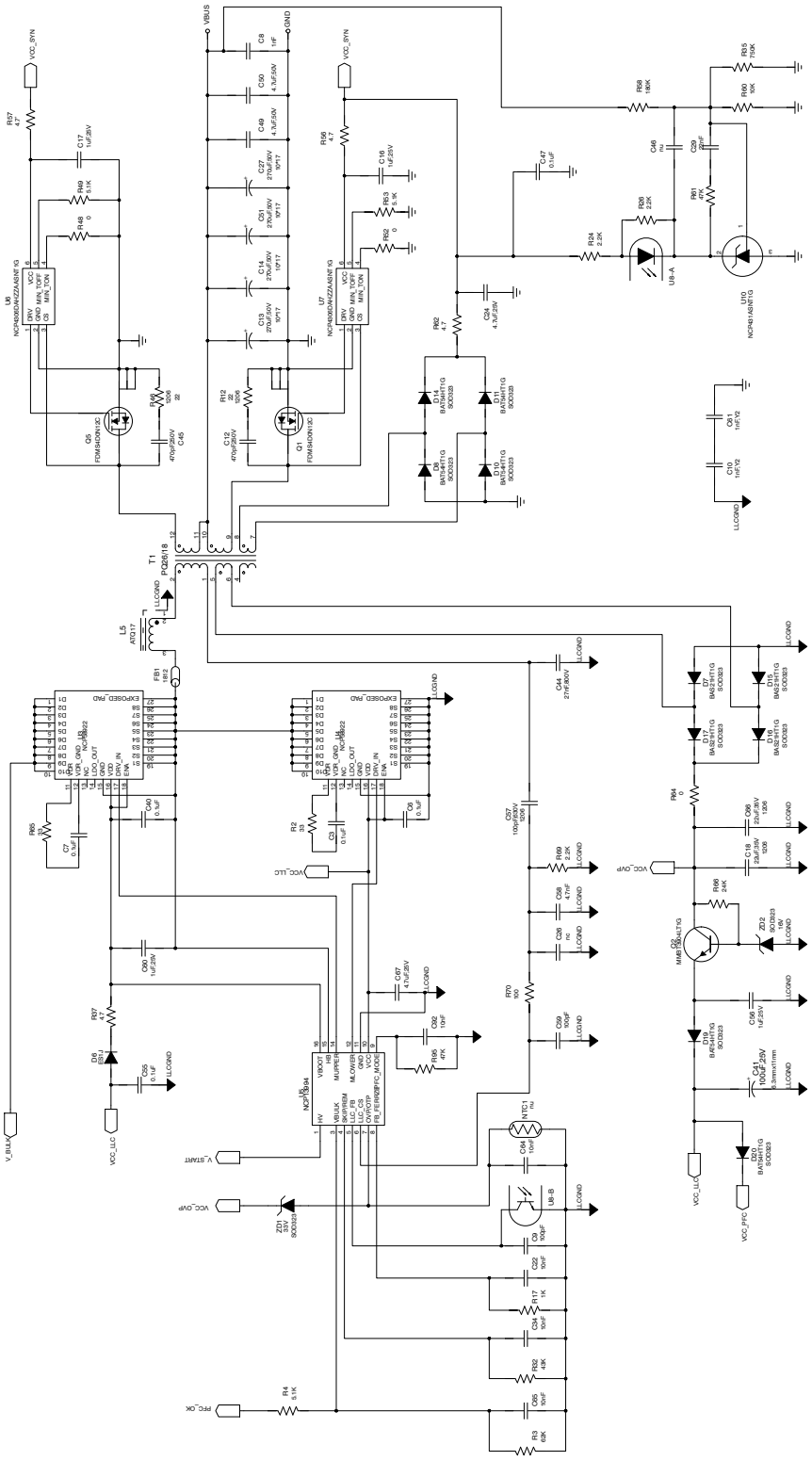

**Figure 5. Schematic for LLC**

## PCB LAYOUT

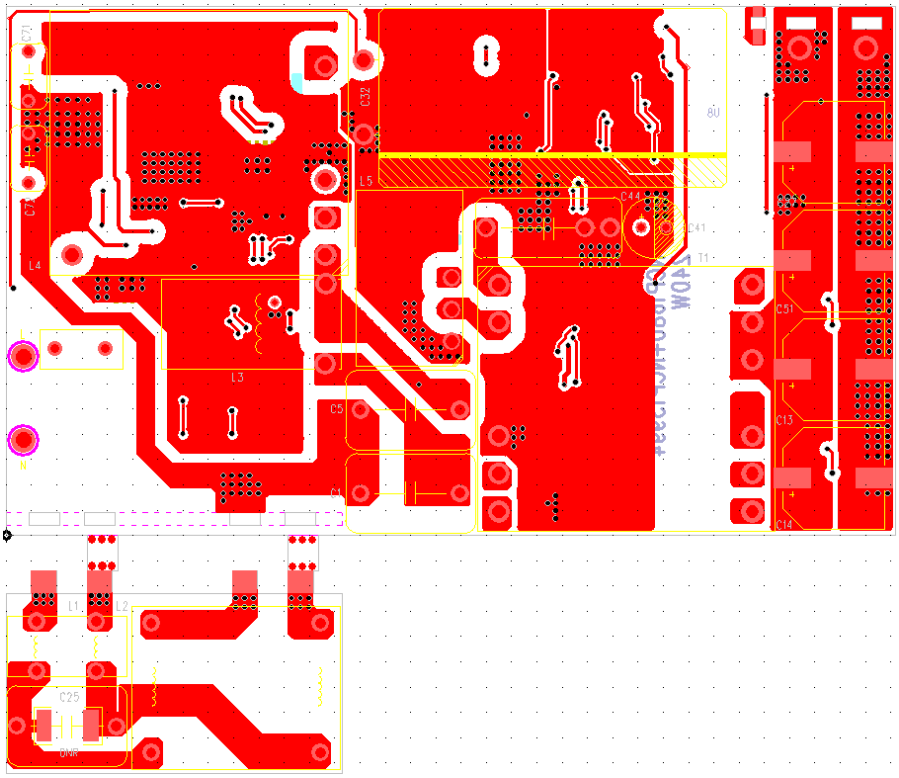

Figure 6. Top View

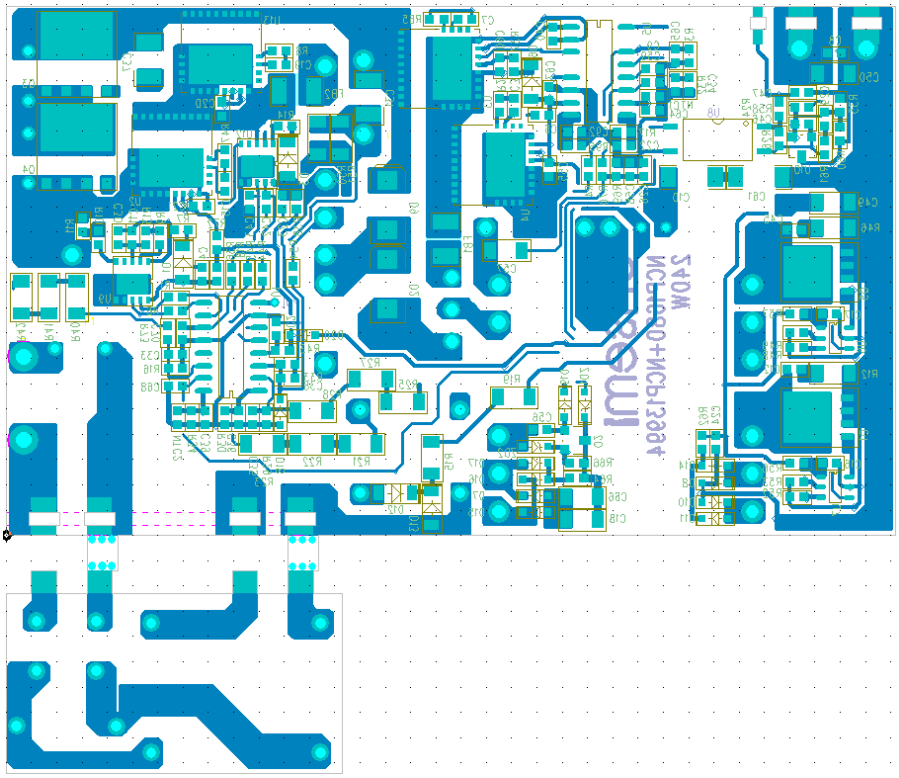

Figure 7. Bottom View

## PFC INDUCTORS DESIGNS

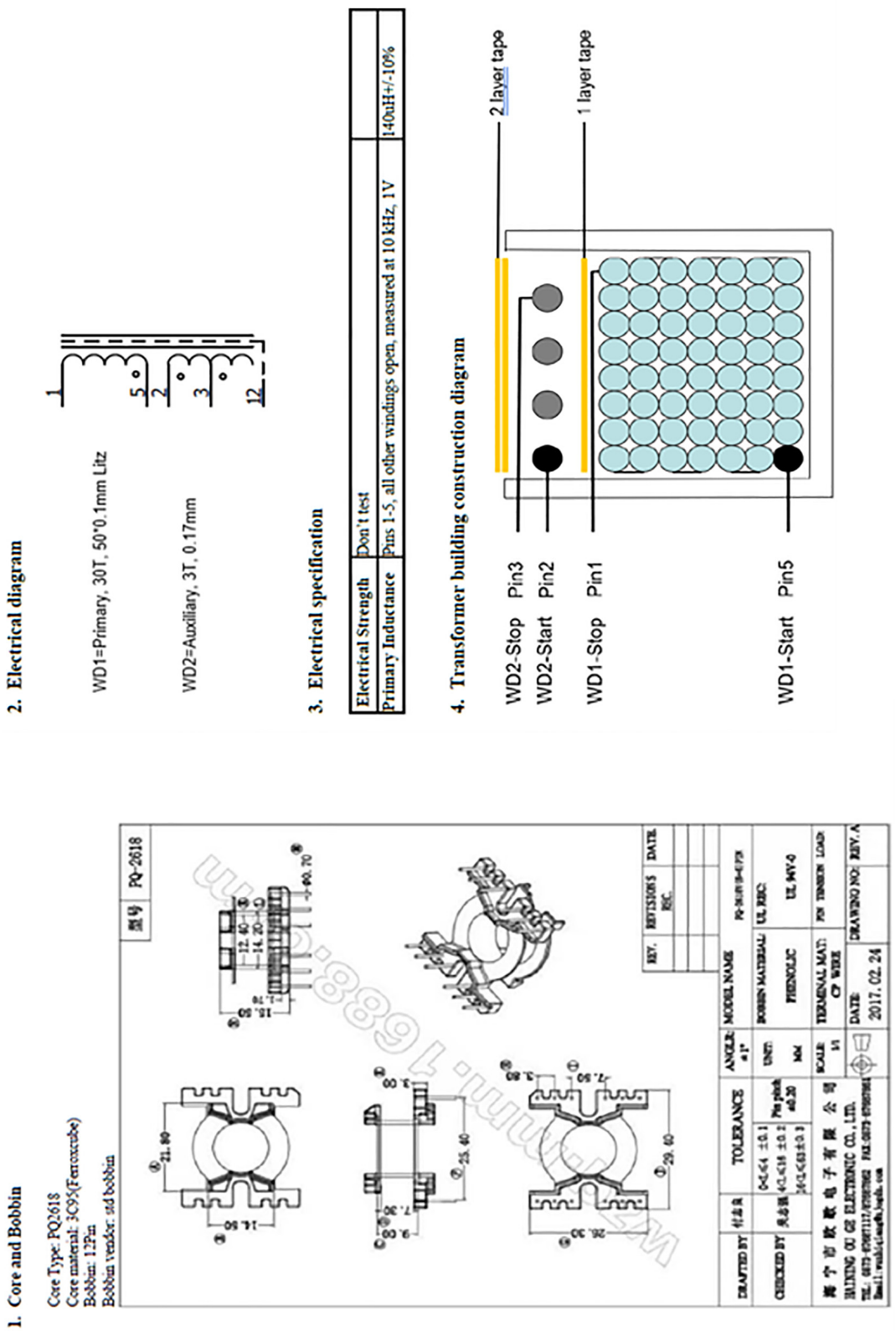


**Figure 8. PFC Inductor Specification**

## LLC RESONANT INDUCTORS DESIGNS

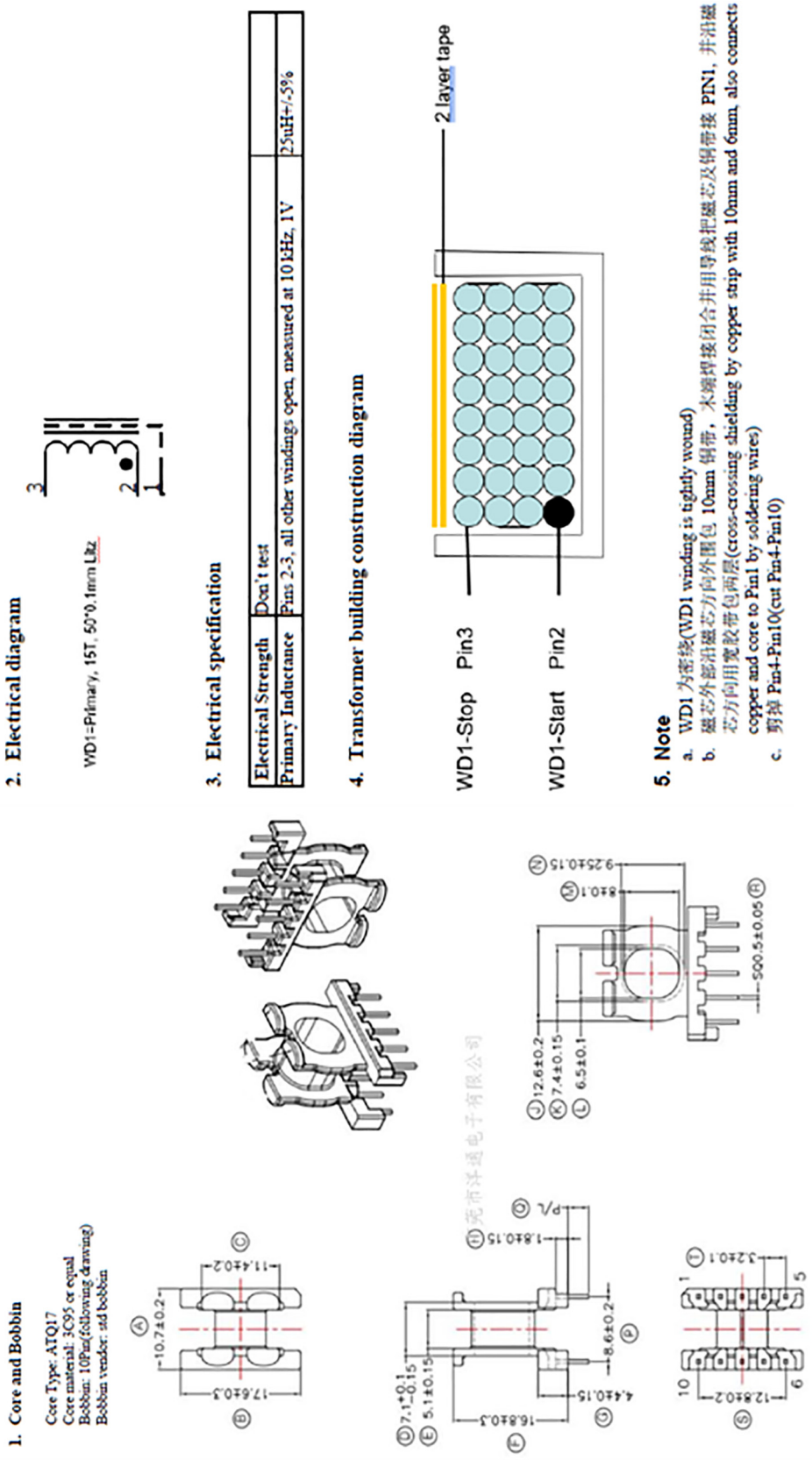


Figure 9. LLC Resonant Inductor Specification

## LLC TRANSFORMER DESIGNS

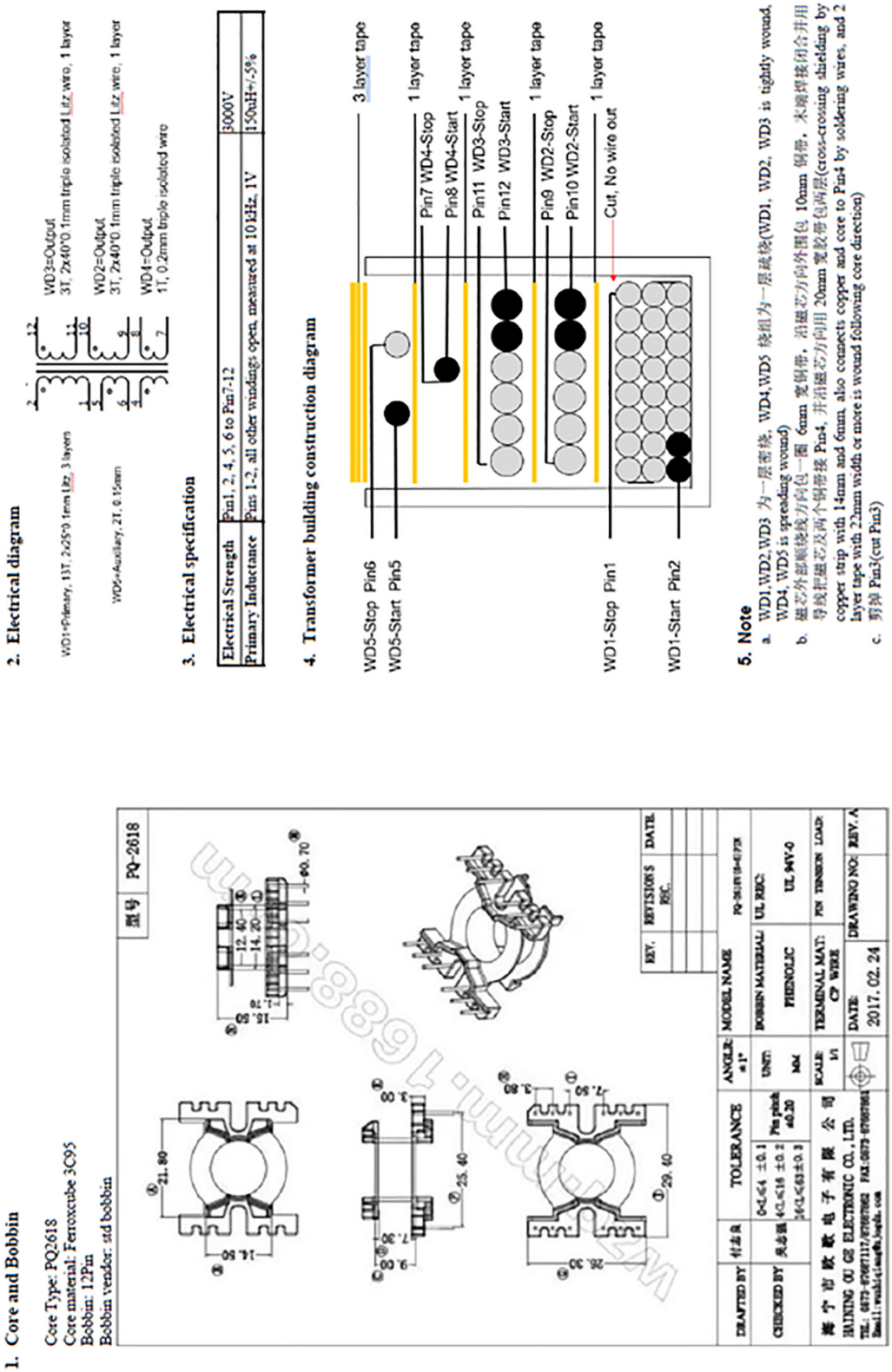


**Figure 10. LLC Transformer Specification**

## Standby Power and PF

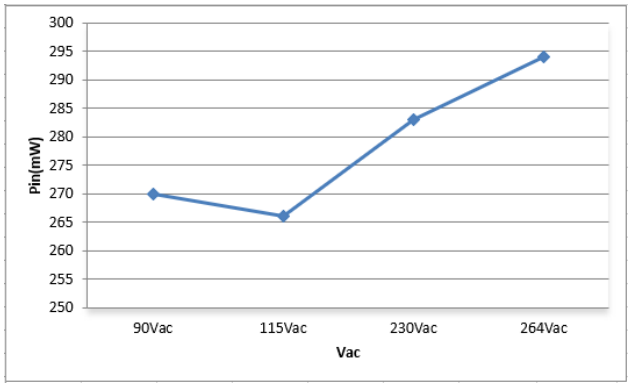


Figure 11. Standby Power

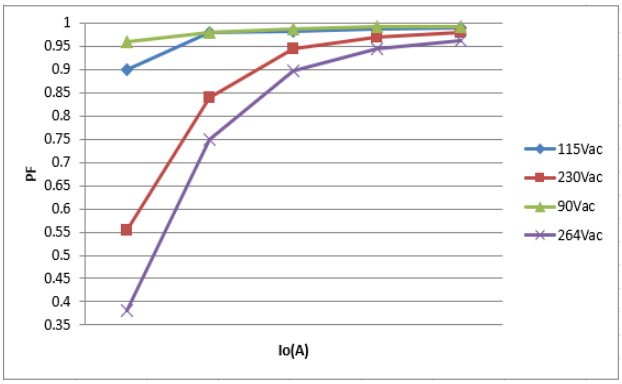


Figure 12. PF

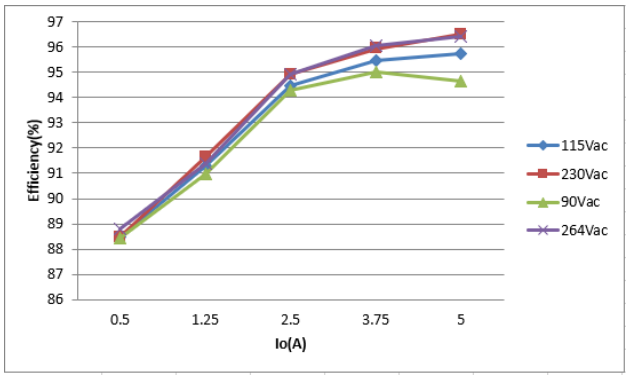


Figure 13. Efficiency vs. Load

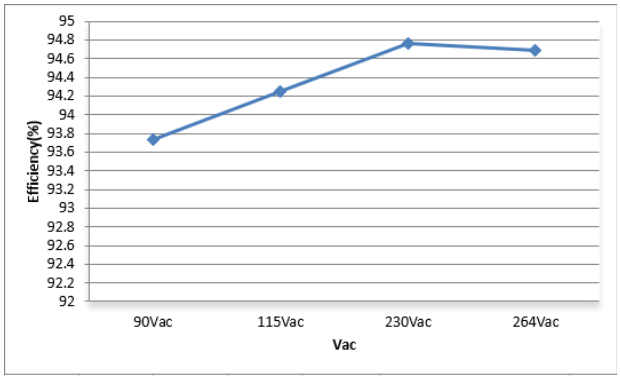


Figure 14. AVG Efficiency

**PFC Waveform at 90 Vac and Full Load**

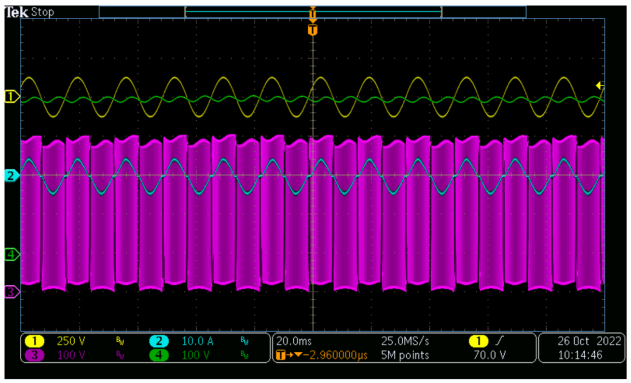


**Figure 15. 90 Vac and Full Load (ch1−Vin, ch2−Iin, ch3−fast leg SW, ch4−Vbulk)**

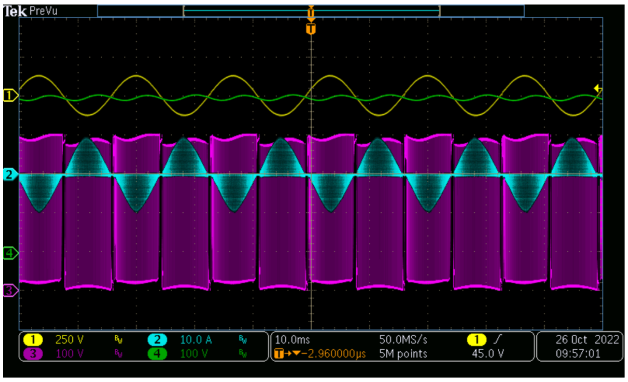


**Figure 16. 90 Vac and Full Load (ch1−Vin, ch2−IL, ch3−fast leg SW, ch4−Vbulk)**

**PFC Waveform at 90 Vac and Full Load**

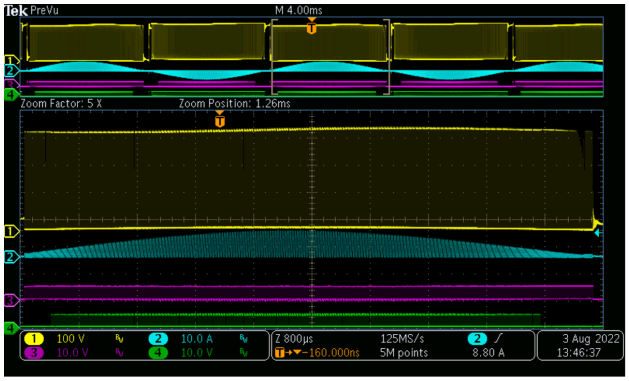


**Figure 17. 90 Vac and Full Load (ch1−Vfastleg, ch2−IL, ch3−Vpwml, ch4−Vpwmh)**

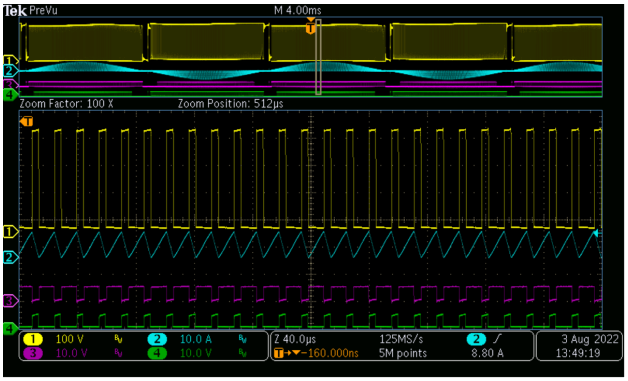


**Figure 18. 90 Vac and Full Load (ch1−Vfastleg, ch2−IL, ch3−Vpwml, ch4−Vpwmh)**

**Load Transition**

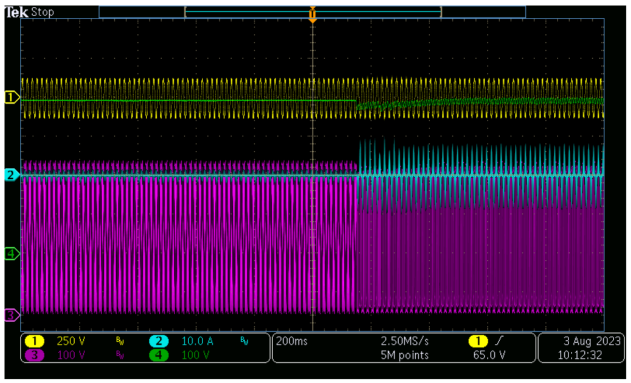


**Figure 19. 0 to Full Load Transition at 90 Vac (ch1−Vin, ch2−IL, ch3−Vfast leg SW, ch4−Vbulk)**

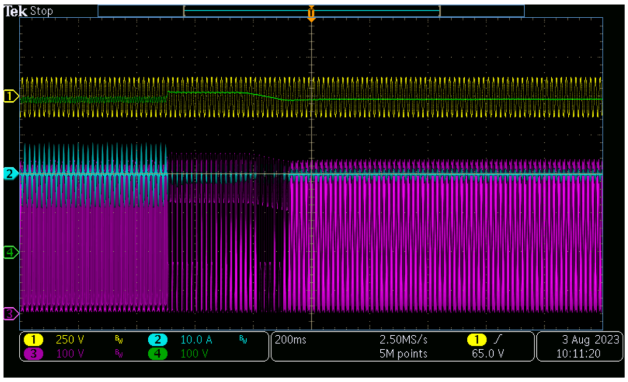


**Figure 20. Full Load to 0 Transition at 90 Vac (ch1−Vin, ch2−IL, ch3−Vfast leg SW, ch4−Vbulk)**

### Line Transition

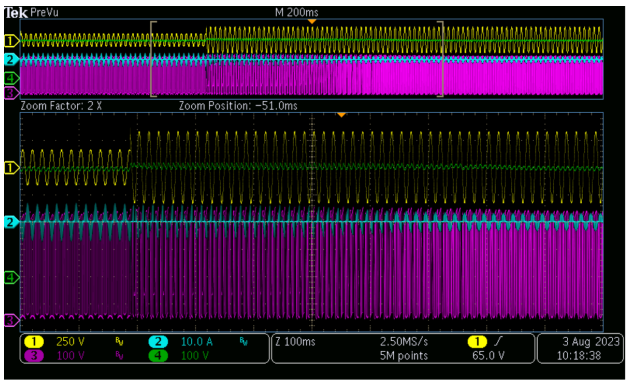


**Figure 21. 115 Vac to 230 Vac Transition at Full Load (ch1−Vin, ch2−IL, ch3−Vfast leg SW, ch4−Vbulk)**

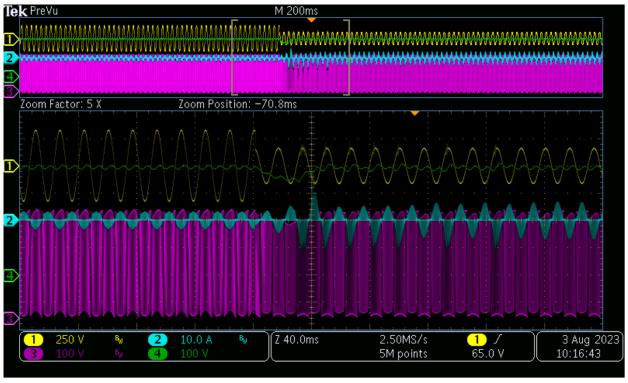


**Figure 22. 230 Vac to 115 Vac Transition at Full Load (ch1−Vin, ch2−IL, ch3−Vfast leg SW, ch4−Vbulk)**

### LLC Startup Waveform at No Load and Full Load

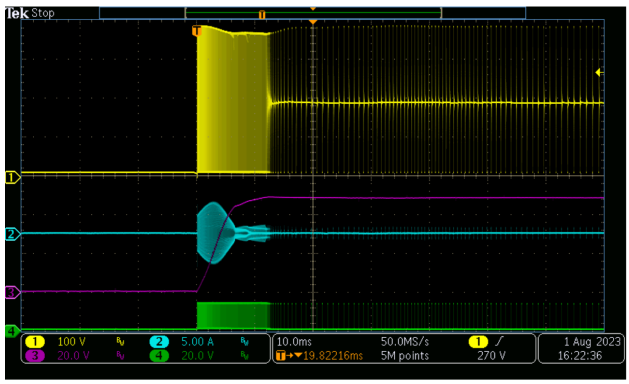


**Figure 23. Power on at 115Vac and 48 V 0 A (ch1−Vllcsw, ch2−Ip, ch3−Vo, ch4−Vmlower)**

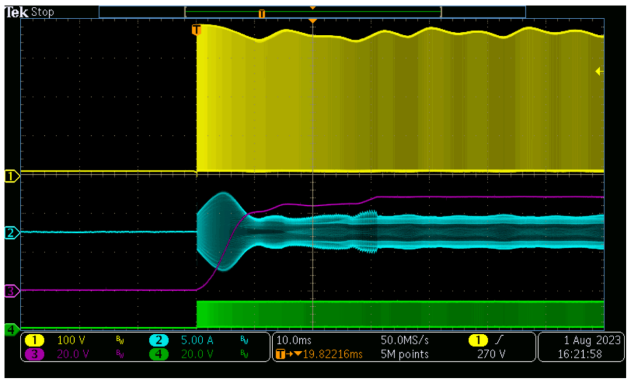


**Figure 24. Power on at 115Vac and 48 V 5 A (ch1−Vllcsw, ch2−Ip, ch3−Vo, ch4−Vmlower)**

### LLC Operation Waveform and Max Dead Time

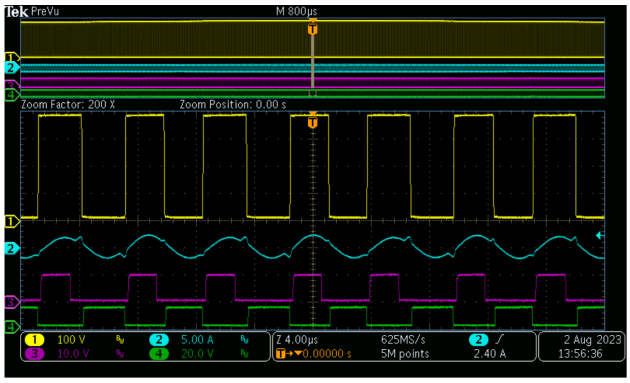


**Figure 25. Stable Operation at 115 Vac and 48 V 5 A (ch1−Vllcsw, ch2−Ip, ch3−Vsyn−drv, ch4−Vmlower)**

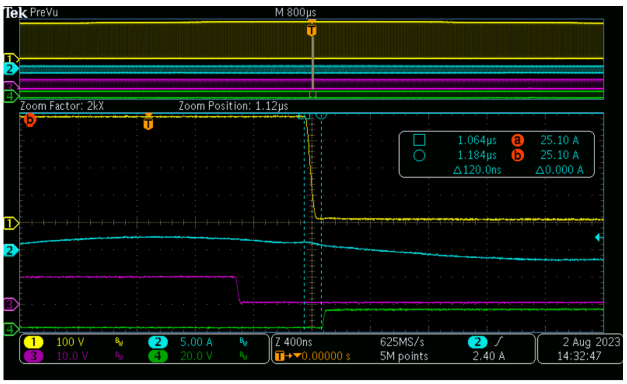


**Figure 26. Stable Operation at 115 Vac and 48 V 5 A (ch1−Vllcsw, ch2−Ip, ch3−Vsyn−drv, ch4−Vmlower)**

### Secondary Stress

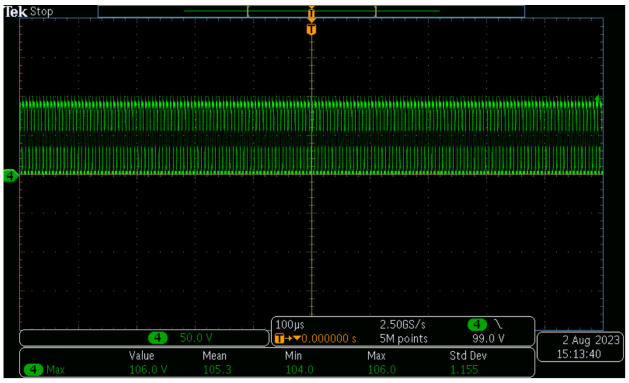


Figure 27. Normal operation at 115 Vac and 48 V & 5 A (ch4−Vsecondary−vds)

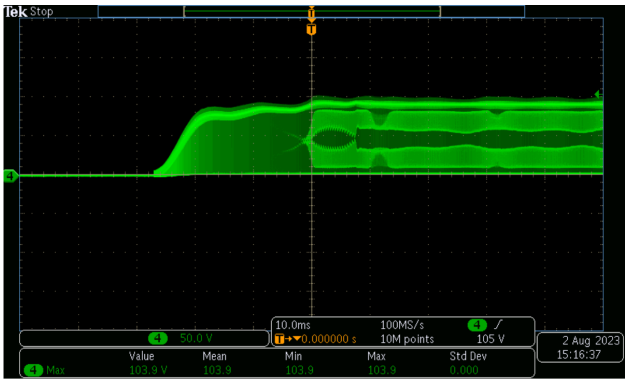


Figure 28. Startup at 115 Vac and 48 V & 5 A (ch4−Vsecondary−vds)

### LLC Operation Waveform During Load Transition

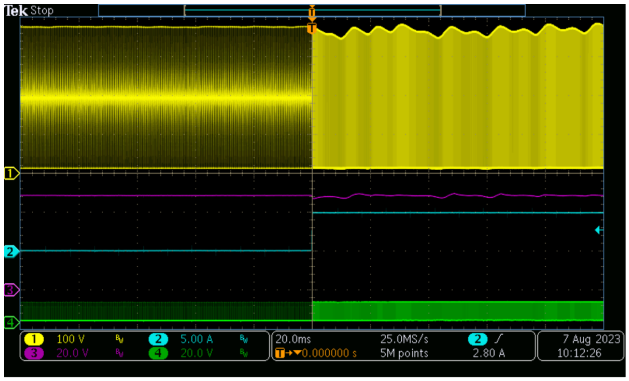


Figure 29. 0−5 A Load Transition at 48 V (ch1−Vllc−sw, ch2−Io, ch3−Vo, ch4−Vsyn−drv)

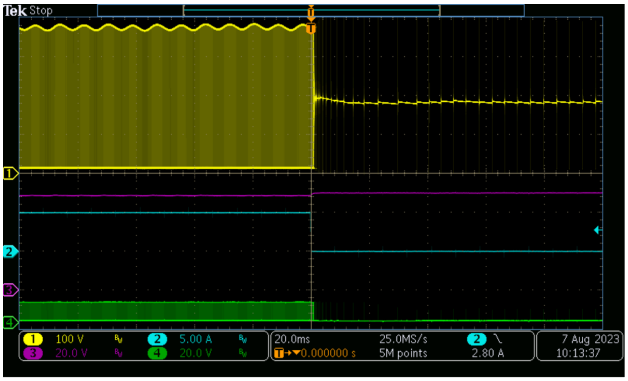


Figure 30. 5 A−0 Load Transition at 48 V (ch1−Vllc−sw, ch2−Io, ch3−Vo, ch4−Vsyn−drv)

### LLC Operation Waveform at Skip Mode

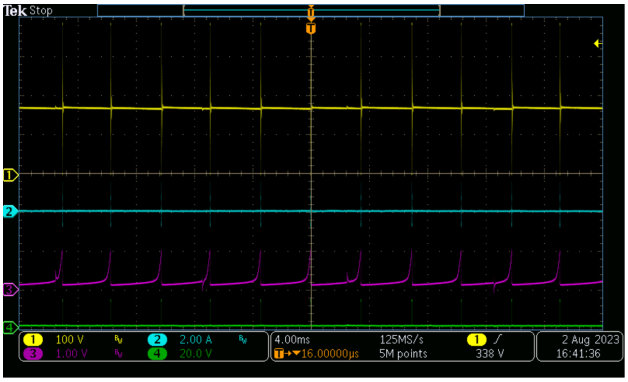


Figure 31. Waveform at 115 Vac and 48 V 0 A (ch1−Vllc−sw, ch2−Ip, ch3−Vfb, ch4−Vldrv)

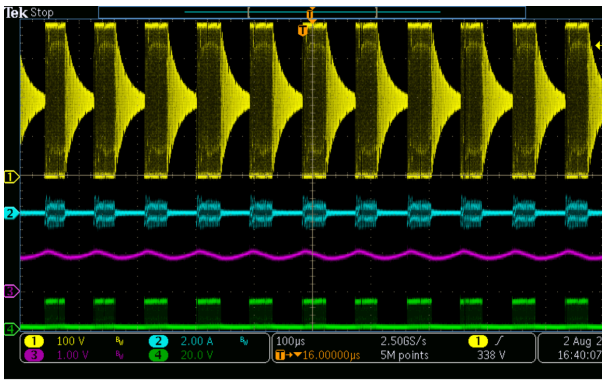


Figure 32. Waveform at 115 Vac and 48 V 0.5 A (ch1−Vllc−sw, ch2−Ip, ch3−Vfb, ch4−Vldrv)

### Startup Timing at No Load and Full Load

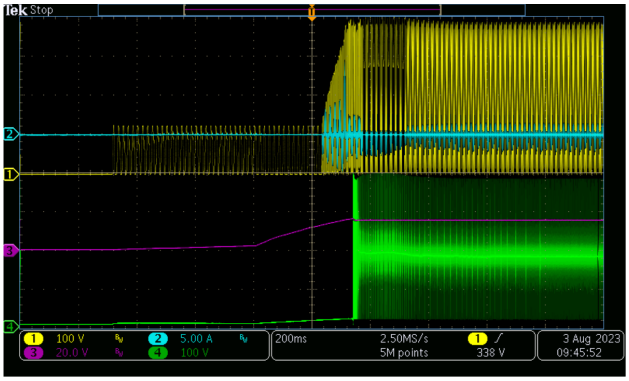


**Figure 33. Startup at 115 Vac and 48 V 0 A (Ch1−Vpfc−fastleg, ch2−pfc−ILch3−Vcc_llc, ch4−Vsw−llc)**

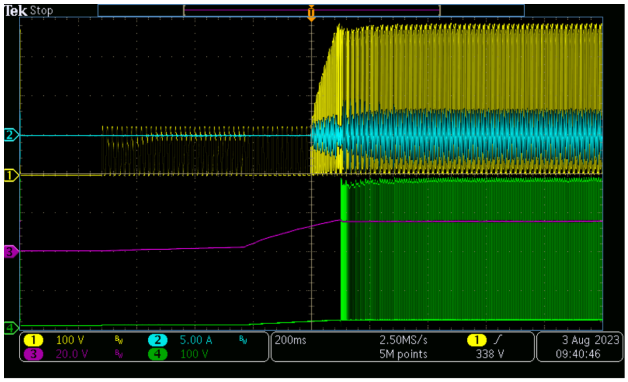


**Figure 34. Startup at 115 Vac and 48 V 5 A (Ch1−Vpfc−fastleg, ch2−pfc−ILch3−Vcc_llc, ch4−Vsw−llc)**

### Ripple Test

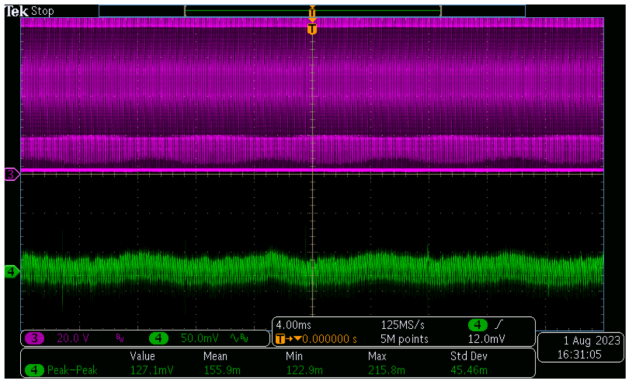


**Figure 35. 115 V and 48 V 0.9 A (ch3−Vds−sec, ch4−Vripple)**

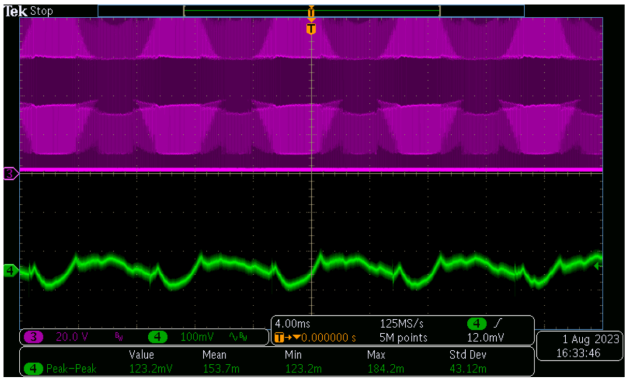


**Figure 36. 115 Vac and 48 V 5 A (ch3−Vds−sec, ch4−Vripple)**

### Load Dynamic Response

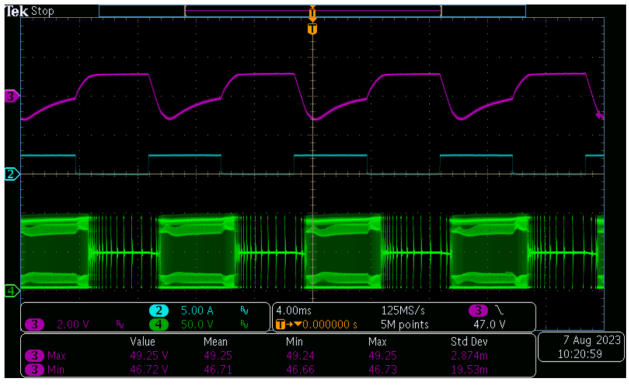


**Figure 37. 0−2.5 A, 10 mS Cycle, 0.25 A/μs (ch2−Io, ch3−V0, ch4−Vsecds−llc)**

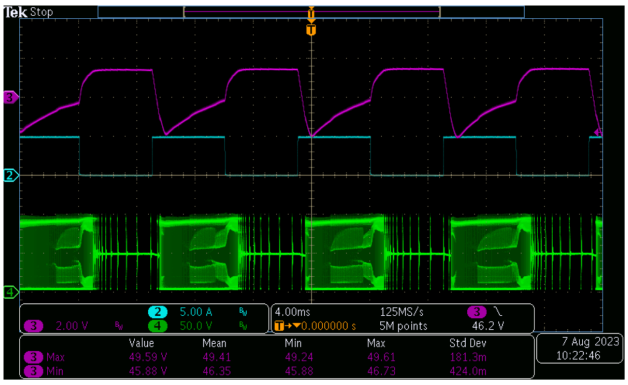


**Figure 38. 0−5 A, 10 mS Cycle, 0.25 A/μs (ch3−Vds−sec, ch4−Vripple)**

**OCP Waveform**

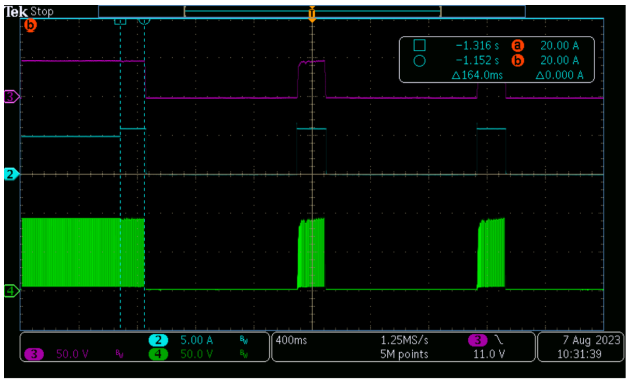


**Figure 39. OCP at 115 Vac and 48 V 5.8 A to 6 A Transition (ch2−Io, ch3−Vo, ch4−Vds−sec)**

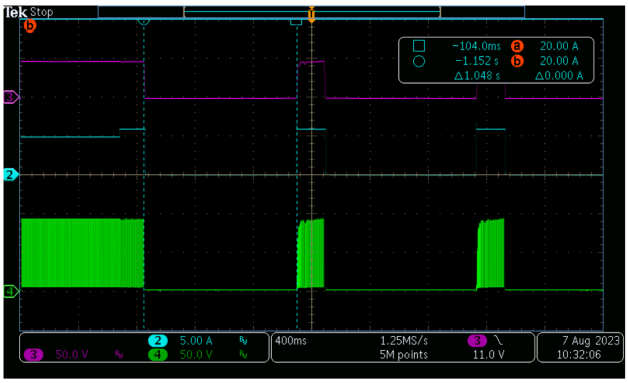


**Figure 40. OCP at 115 Vac and 48 V 5.8 A to 6 A Transition (ch2−Io, ch3−Vo, ch4−Vds−sec)**

**Thermal Camera Image (Tested after 30 min Operation)**

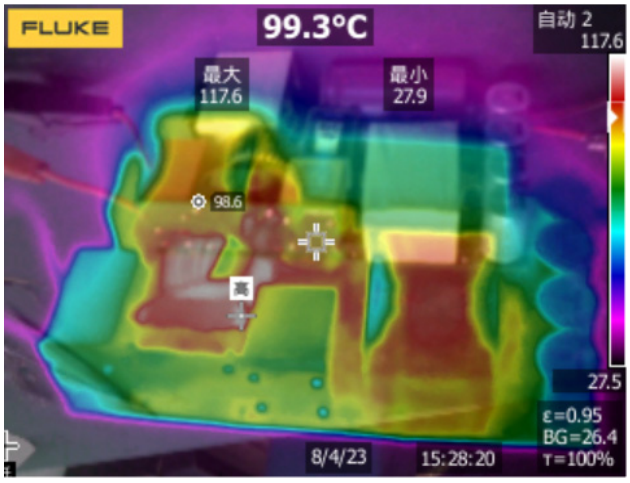


**Figure 41. 90 Vac & 48 V 5 A, Front Side**

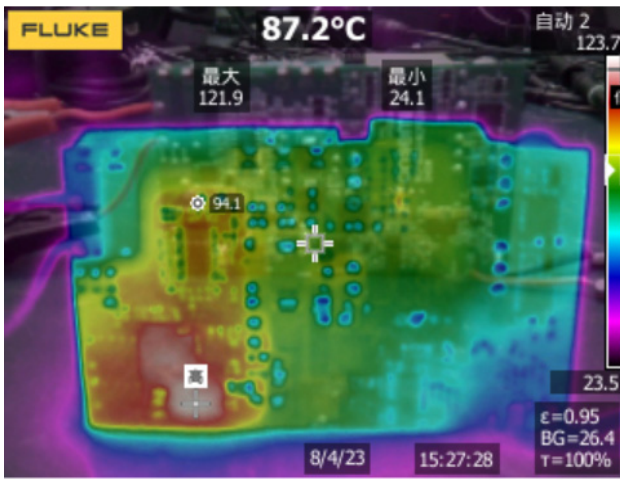


**Figure 42. 90 Vac & 48 V 5 A, Reverse Side**

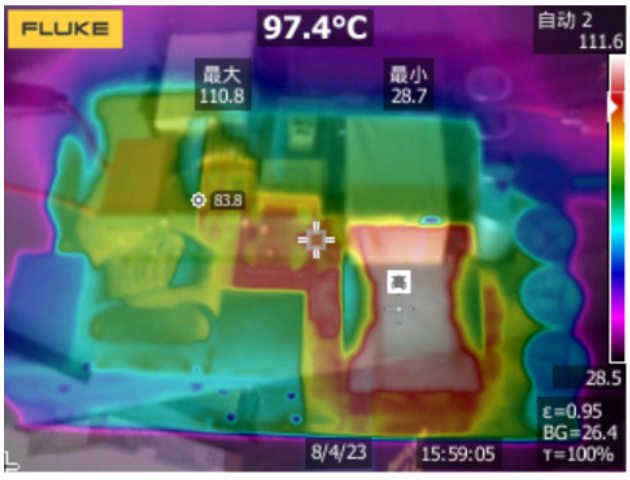


**Figure 43. 115 Vac & 48 V 5 A, Front Side**

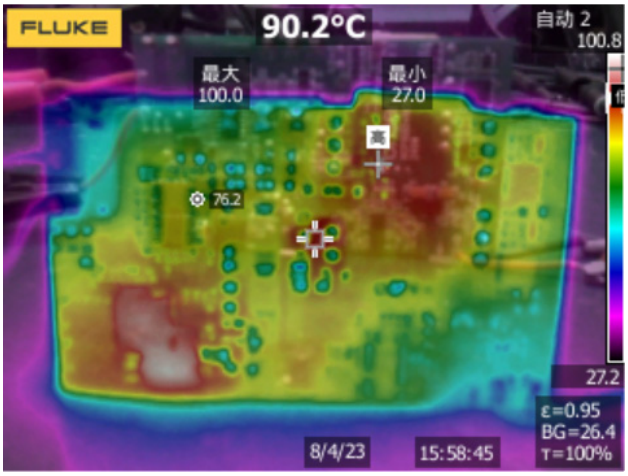


**Figure 44. 115 Vac & 48 V 5 A, Reverse Side**

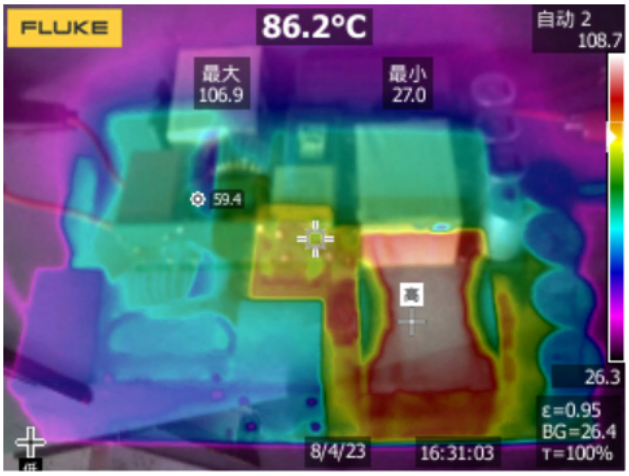


Figure 45. 230 Vac & 48 V 5 A, Front Side

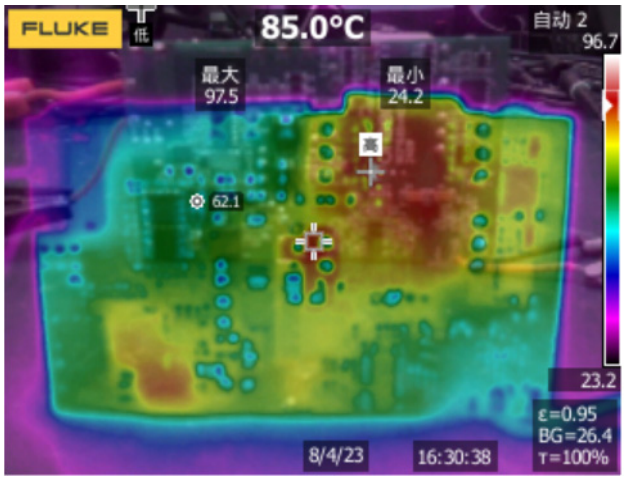


Figure 46. 230 Vac & 48 V 5 A, Reverse Side

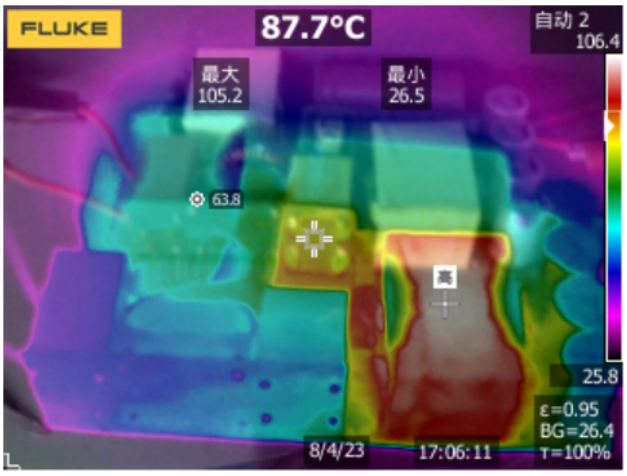


Figure 47. 264 Vac & 48 V 5 A, Front Side

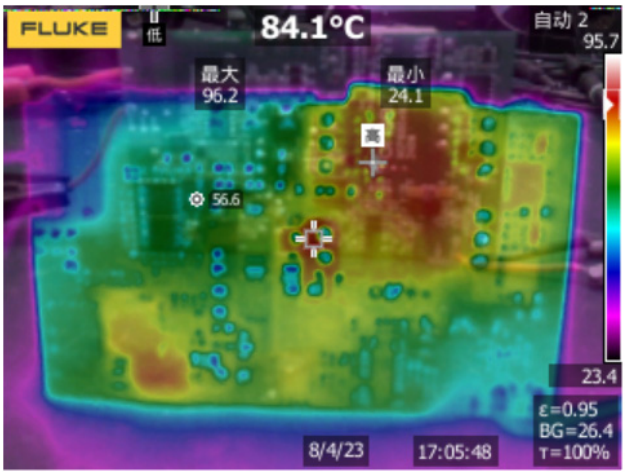


Figure 48. 264 Vac & 48 V 5 A, Reverse Side

**Table 1. BOM**

| Item | Qty | Reference | Type | Part Name | Package | MFR | Value | Description |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | L5 | Inductor | ATQ17 | TH type | Std | 25 μH | ATQ17, 10Pin |
| 2 | 8 | C3 C6−7 C15 C19 C40 C47 C55 | Ceramic Capacitor | /885012206095 | 603 | Wurth | 0.1 μF | Capacitor, Ceramic, 50 V, 10% |
| 3 | 2 | C31 C37 | Ceramic Capacitor | C3225X7T2W224K | 1210 | TDK | 0.22 μF, 450 V | Capacitor, Ceramic, Chip, 10% |
| 4 | 7 | C9 C35−36 C42−43 C59 C70 | Ceramic Capacitor | /885012206077 | 603 | Wurth | 100 pF | Capacitor, Ceramic, 50 V, 10% |
| 5 | 1 | C57 | Ceramic Capacitor | /885342008004 | 1206 | Wurth | 100 pF, 630 V | Capacitor, Ceramic, SMD, 5% |
| 6 | 5 | C22 C34 C64−65 C92 | Ceramic Capacitor | /885012206089 | 603 | Wurth | 10 nF | Capacitor, Ceramic, 50 V, 10% |
| 7 | 2 | C71−72 | Ceramic Capacitor | CL112J103J050 | TH | KYET | 10 nF, 630 V | Capacitor, Ceramic, TH, 5% |
| 8 | 4 | C8 C33 C39 C68 | Ceramic Capacitor | /885012206083 | 603 | Wurth | 1 nF | Capacitor, Ceramic, 50 V, 10% |
| 9 | 2 | C10 C61 | Ceramic Capacitor | /8853522100131 | 1808 | Wurth | 1 nF, Y2 | HV Ceramic Capacitor, safety standard approved, 10% |
| 10 | 7 | C16−17 C20−21 C23 C56 C60 | Ceramic Capacitor | /885012206076 | 603 | Wurth | 1 μF, 25 V | Capacitor, Ceramic, 25 V, 10% |
| 11 | 1 | C29 | Ceramic Capacitor | /885012206091 | 603 | Wurth | 22 nF | Capacitor, Ceramic, 50 V, 10% |
| 12 | 2 | C18 C66 | Ceramic Capacitor | C3216X5R1V226MTJ00E | 1206 | TDK | 22 μF, 35 V | Capacitor, Ceramic, 35 V, 20% |
| 13 | 1 | C44 | Film Capacitor | ECWH8273HA | THT, 12.5 mm, 15 mm × 6 mm × 12 mm | Panasonic | 27 nF, 800 V | Film capacitor |
| 14 | 1 | C58 | Ceramic Capacitor | /885012206087 | 603 | Wurth | 4.7 nF | Capacitor, Ceramic, 50 V, 10% |
| 15 | 6 | C2 C4 C11 C24 C30 C67 | Ceramic Capacitor | C1608X5R1E475K080AC | 603 | TDK | 4.7 μF, 25 V | Capacitor, Ceramic, 25 V, 10% |
| 16 | 2 | C49−50 | Ceramic Capacitor | GRM31CR71H475KA12L | 1206 | Murata | 4.7 μF, 50 V | Capacitor, Ceramic, 50 V, 10% |
| 17 | 2 | C12 C45 | Ceramic Capacitor | /885342006005 | 603 | Wurth | 470 pF, 250 V | Capacitor, Ceramic, SMD, 5% |
| 18 | 2 | C1 C5 | X2 Capacitor | SP2824K32CKR6LC | THT, 10 mm, 12.5 mm × 6 mm × 16 mm | SRD | 824, X2 | X2 capacitor, Safety standard approved, 10% |
| 19 | 1 | C25 | X2 Capacitor | X2 684K310V | THT, 10 mm, 12.5 mm × 6 mm × 20 mm | JURCC | 684, X2 | X2 capacitor, Safety standard approved, 10% |
| 20 | 1 | C26 | Ceramic Capacitor | /885012206087 | 603 | Wurth | nc | nc |
| 21 | 2 | C38 C46 | Ceramic Capacitor | /885012206095 | 603 | Wurth | nc | nc |
| 22 | 2 | D2 D9 | Rectifier | S5JBF | SMBF | SHIKUES | 5 A, 600 V | General Rectifier |
| 23 | 1 | DNR | Varistor | SVMH4532KA301PT401 | 3225 | Shunlord | 470 V | Varistor, 471 V |
| 24 | 2 | D12−13 | Standard rectifier | 4007 | SOD123FL | Std | 0.8 A, 600 V | General Rectifier, 0.8 A, 600 V |
| 25 | 3 | D1 D3 D6 | Ultrafast rectifier | ES1JFL | SOD123FL | **onsemi** | 1 A, 600 V | Ultrafast Rectifier, 1 A, 600 V |
| 26 | 4 | D7 D15−17 | Switching diode | BAS21HT1G | SOD323 | **onsemi** | 0.2 A, 250 V | Switching diode, SMD |
| 27 | 7 | D8 D10−11 D14 D18−20 | Switching diode | BAT54HT1G | SOD323 | **onsemi** | 0.2 A, 30 V | Switching diode, SMD |

**Table 1. BOM** (continued)

| Item | Qty | Reference | Type | Part Name | Package | MFR | Value | Description |
|---|---|---|---|---|---|---|---|---|
| 28 | 2 | FB1−2 | Ferrite bead | PZ3216U600−4R0TF | 1206 | Shunlord | nc | nc |
| 29 | 1 | L1 | Common filter | Toroidal CM filter | TH | Std | 500 μH | T type, 10*6*5 MnZn core, 7T, 0.7 mm wire |
| 30 | 1 | L2 | Common filter | SQ1515 | TH, 17 mm × 13 mm | Std | 20 mH | CM Filter, SQ1515, 17*13, 60 mΩ |
| 31 | 1 | F1 | Fuse | 39215000000 | Axial lead | Littlefuse | 5 A, 250 Vac | Micro Fuse, 5 A/250 V |
| 32 | 1 | Q2 | NPN Transistor | MMBT3904LT1G | SOT23 | **onsemi** | | GENERAL PURPOSE NPN SILICON TRANSISTOR |
| 33 | 1 | U10 | Voltage reference | NCP431ACSNT1G | SOT23 | **onsemi** | | PROGRAMMABLE PRECISION REFERENCE |
| 34 | 1 | U1 | TPPFC controller | NCP1680AB | SO16 | **onsemi** | | TPPFC controller |
| 35 | 1 | U5 | LLC controller | NCP13994 | SO16 | **onsemi** | | |
| 36 | 2 | U2 U13 | Drive GaN | NCP58921 | QFN26 | **onsemi** | 50 mΩ | |
| 37 | 2 | U3−4 | Drive GaN | NCP58922 | QFN26 | **onsemi** | 78mohm | |
| 38 | 2 | U6−7 | Syn. rectified controller | NCP4306DAHZZAAS-NT1G | TSOP6 | **onsemi** | | |
| 39 | 2 | U9 U12 | HB Drive | NCP51530BMNTWG | DFN10 | **onsemi** | | |
| 40 | 2 | Q1 Q5 | MOSFET | FDMS4D0N12C | SO8FL | **onsemi** | | MOSFET, NChan, 120 V |
| 41 | 2 | Q3−4 | MOSFET | NTMT064N65S3H | Power88 | **onsemi** | | MOSFET, NChan, 650 V |
| 42 | 2 | NTC1−2 | NTC | SD-NT1608X104J4250HTF | 603 | Sunloard | nc | |
| 43 | 1 | U8 | Optical coupler | FODM1009 | LSOP4 | **onsemi** | | optical coupler, standard SOP package |
| 44 | 1 | L3 | Toroidal Line Choke | T065125−100uH−0.9 | TH type | Std | 100 μH | FeSiAl Toroidal, 65125, 0.9 mm wire |
| 45 | 1 | L4 | Inductor | PQ2618 | TH type | Std | 140 μH | PQ2618, Ferroxcube 3C95 core,12 Pin Bobbin |
| 46 | 1 | T1 | Transformer | PQ2618 | TH type | Std | 150 μH | PQ2618, Ferroxcube 3C95 core,12 Pin Bobbin |
| 47 | 3 | R48 R52 R64 | Resistor | Std | 603 | Std | 0 | Resistor, Chip, 1/10 W, 1% |
| 48 | 10 | R1 R6 R9−10 R36 R38 R43−45 R72 | Resistor | Std | 603 | Std | 10 | Resistor, Chip, 1/10 W, 1% |
| 49 | 1 | R70 | Resistor | Std | 603 | Std | 100 | Resistor, Chip, 1/10 W, 1% |
| 50 | 4 | R11 R13 R29−30 | Resistor | Std | 603 | Std | 100 K | Resistor, Chip, 1/10 W, 1% |
| 51 | 1 | R60 | Resistor | Std | 603 | Std | 10 K | Resistor, Chip, 1/10 W, 1% |
| 52 | 1 | R58 | Resistor | Std | 603 | Std | 180 K | Resistor, Chip, 1/10 W, 1% |
| 53 | 2 | R17−18 | Resistor | Std | 603 | Std | 1 K | Resistor, Chip, 1/10 W, 1% |
| 54 | 3 | R24 R26 R69 | Resistor | Std | 603 | Std | 2.2 K | Resistor, Chip, 1/10 W, 1% |
| 55 | 2 | R54 R66 | Resistor | Std | 603 | Std | 24 K | Resistor, Chip, 1/10 W, 1% |
| 56 | 4 | R2 R8 R47 R65 | Resistor | Std | 603 | Std | 33 | Resistor, Chip, 1/10 W, 1% |
| 57 | 6 | R7 R14 R37 R56 R57 R62 | Resistor | Std | 603 | Std | 4.7 | Resistor, Chip, 1/10 W, 1% |
| 58 | 1 | R32 | Resistor | Std | 603 | Std | 43 K | Resistor, Chip, 1/10 W, 1% |
| 59 | 1 | R33 | Resistor | Std | 603 | Std | 470 K | Resistor, Chip, 1/10W, 1% |

**Table 1. BOM** (continued)

| Item | Qty | Reference | Type | Part Name | Package | MFR | Value | Description |
|---|---|---|---|---|---|---|---|---|
| 60 | 2 | R61 R95 | Resistor | Std | 603 | Std | 47 K | Resistor, Chip, 1/10 W, 1% |
| 61 | 3 | R4 R49 R53 | Resistor | Std | 603 | Std | 5.1 K | Resistor, Chip, 1/10 W, 1% |
| 62 | 1 | R73 | Resistor | Std | 603 | Std | 620 K | Resistor, Chip, 1/10 W, 1% |
| 63 | 1 | R3 | Resistor | Std | 603 | Std | 62 K | Resistor, Chip, 1/10 W, 1% |
| 64 | 1 | R16 | Resistor | Std | 603 | Std | 68 K | Resistor, Chip, 1/10 W, 1% |
| 65 | 1 | R35 | Resistor | Std | 603 | Std | 750 K | Resistor, Chip, 1/10 W, 1% |
| 66 | 1 | R34 | Resistor | Std | 603 | Std | nc | Resistor, Chip, 1/10 W, 1% |
| 67 | 1 | R50 | Resistor | ERJ8BSFR11V | 1206 | Panasonic | 0.11 | Resistor, Chip, 1/2 W, 1% |
| 68 | 1 | R51 | Resistor | ERJ8BSFR12V | 1206 | Panasonic | 0.12 | Resistor, Chip, 1/2 W, 1% |
| 69 | 2 | R15 R19 | Resistor | Std | 1206 | Std | 2.7 K | Resistor, Chip, 1/4 W, 1% |
| 70 | 2 | R12 R46 | Resistor | Std | 1206 | Std | 22 | Resistor, Chip, 1/4 W, 1% |
| 71 | 9 | R21−23 R25 R27−28 R40−42 | Resistor | Std | 1206 | Std | 3.3 M | Resistor, Chip, 1/4 W, 1% |
| 72 | 1 | C41 | Electrolytic capacitor | KF470M025C110A | 6.3 mm × 11 mm | CapXon | 100 μF, 25 V | size:5 mm × 11 mm |
| 73 | 1 | C32 | Electrolytic capacitor | OLKJ3552W151MF | 18 mm × 35.5 mm | YMIN | 150 μF, 450 V | size:18 mm × 35.5 mm |
| 74 | 4 | C13−14 C27 C51 | Hybrid Electrolytic capacitor | VHTE1701H271MVCG | 10*17 | YMIN | 270 μF, 50 V | size: SMD10*17, ESR 15 mΩ |
| 75 | 1 | ZD2 | Zener | MM3Z16VT1G | SOD323 | **onsemi** | 16 V | GENERIC ZENER−DIODE |
| 76 | 1 | ZD1 | Zener | MM3Z33VT1G | SOD323 | **onsemi** | 33 V | GENERIC ZENER−DIODE |

## References

[1] **onsemi** datasheet for NCP1680, NCP13994, NCP51530, NCP4306, NCP58921, NCP58922, FDMS4D0N12C, NTMT064N65S3H

[2] **onsemi** Design Notes TND6412



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