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14.5 W Auxiliary Power for White Goods and Industrial Equipment with FSL538HPG

Eval Board User's Manual

Table 1. GENERAL SPECIFICATIONS

| Devices | Applications | Input Voltage | Output Power | Topology | Board Size |
|----------------------------|---|--------------------------|-----------------------|-----------------------|---|
| FSL538HPG | White Goods and Industrial Power Supplies | 85–265 Vac | 14.5 W | Non-Isolated Flyback | 88 × 45 × 22 mm 2.73 W/inch ³ |
| Output Spec. | Turn on Time | Efficiency | Operating Temperature | Cooling | Standby Power |
| 12 V/1 A & 5 V/0.5 A | < 200 ms | Above 85% @ Full Load | 0–50 °C | Convection Open Frame | < 50 mW @ 230 Vac |

Description

This user manual provides elementary information about a Non-isolated dual output flyback with FSL538HPG, it performs high efficiency and smaller than 50 mW no-load power consumption. FSL538HPG is an integrated pulse width modulation (PWM) and 800 V power switch with SENSEFET®, it can help to save external MOSFET and sense resistor, increase power density and reliability. This application is targeting auxiliary power supply for white goods and industrial equipment, such as refrigerator, E-metering or similar types of equipment.

The PWM controller includes an integrated variable frequency oscillator, Under-Voltage Lockout (UVLO), Leading Edge Blanking (LEB), optimized gate driver, internal soft-start, and built-in error amplifier for feedback connection directly and self-protection circuitry. This design focuses mainly on the FSL538HPG current-mode PWM controller. Please refer to FSL538HPG's materials to get more information about this device.

The FSL538HPG is a current-mode PWM controller, it can have better response to handle dynamic operation. Controller combines line detection and burst-mode adjustment in one pin. It's easy to achieve these functionalities just need voltage divider and one Zener diode. Line detection includes brown-in, brown-out and line OVP, burst-mode adjustment is for fine tune audible noise and light load efficiency. Of course, it also provides frequency reduction with loading decreasing for gaining more design margin to improve light load efficiency.

Key Features

- Integrated Rugged 800 V Super Junction MOSFET with SENSEFET Technology
- Built-in HV Current Source for Start-up
- Peak-Current-Mode Control with Slope Compensation
- Line Compensation for Maximum Over-Power Limiting
- Advanced Soft-start for Low Electrical Stress
- Pulse-by-pulse Current Limit
- Line Brown-in, Brown-out, and Over-Voltage Protection (LOVP)
- Adjustable Burst-mode Operation
- Frequency Hopping for Better EMI
- Various Protections:
 - ◆ Auto Restart Mode: Brown-out, OLP, OVP, AOCV and TSD
 - ◆ Recovery Immediately by Triggering Level: LOVP

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DETAIL DEMO-BOARD SCHEMATIC DESCRIPTION

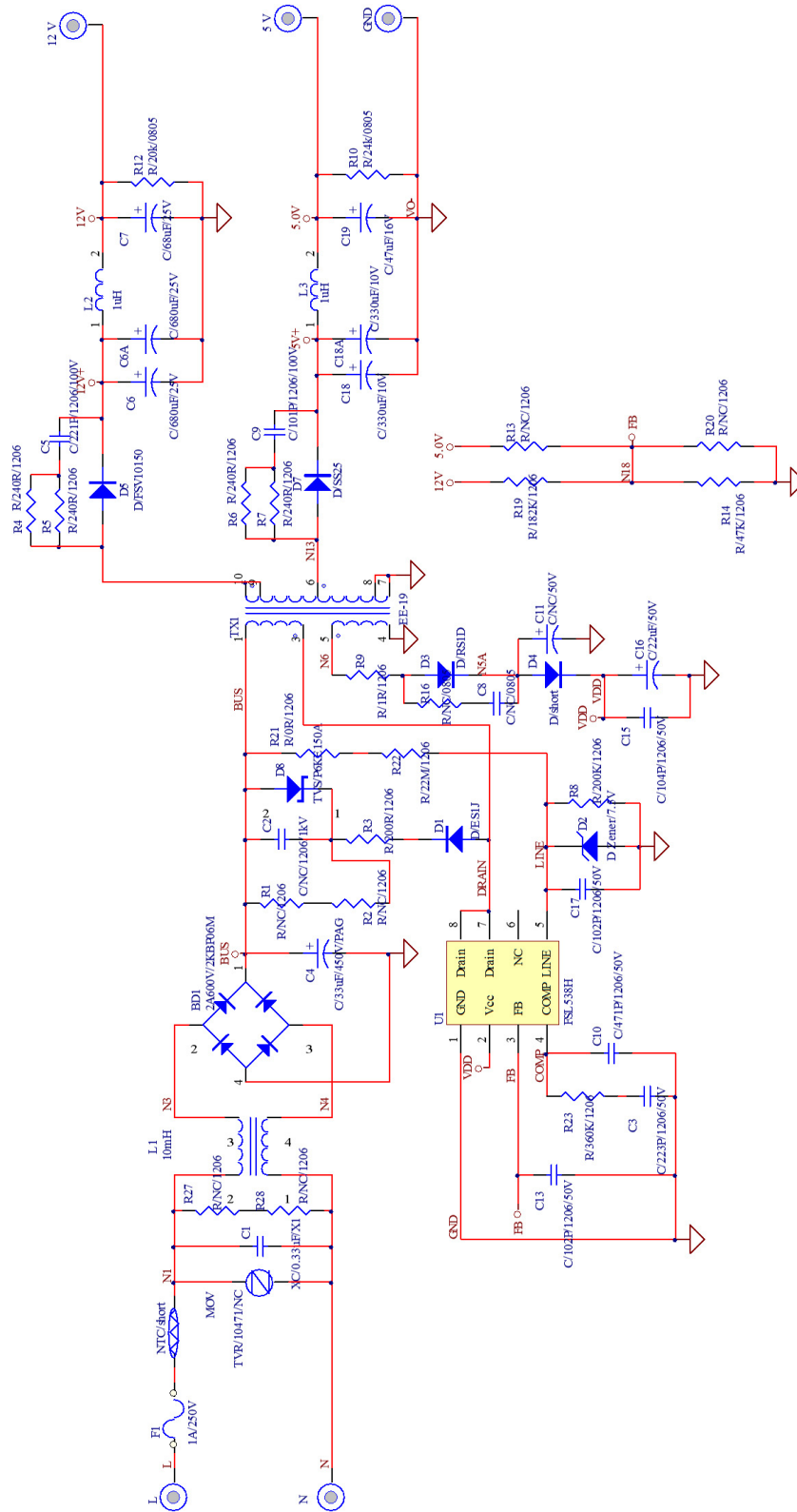


Figure 1. FSL538HFLYGEVB Demo-Board – Main Board Schematic

The input EMI filter is formed by components L1 and C1. Bleeder for X-cap, R27 and R28, are left not connected.

The primary side of flyback converter is composed of these devices; power transformer TX1, dc-link capacitor, TVS snubber, the integrated switcher U1(FSL538HPG) and related components. Meanwhile, the integrated switcher has a peak current mode PWM controller and 800 V super junction MOSFET. D1, R3 and D8 form TVS snubber to protect instant voltage spike produced by leakage inductance. R19 (or R13) and R14 (or R20) are a voltage divider to sense the output voltage, which needs a capacitor C13 optionally to avoid switching noise interference and stabilize FB pin voltage. COMP pin is the output of the internal error amplifier, where a compensation network, for example R23, C3 and C10 are connected and it generates a control voltage for PWM controller. LINE pin of U1 connects voltage divider from bulk capacitor to detect input voltage for some protections of brown-in, brown-out and LOVP. Besides, there is parallel-connected D2 on LINE pin to adjust burst threshold to fine tune audible noise and light load efficiency. C17 is used to avoid larger switching noise

interference, which is usually recommended around 1 nF~3.3 nF. Auxiliary winding shares same ground reference with U1. That is, reference ground is negative terminal of output of bridge rectifier BD1. Transformer winding is also used for providing VCC voltage in normal operation. R9 and D3 provide path to delivery energy when PWM is turned off. C16 can keep enough voltage if PWM is turned off for a while, and C15 is for better stability.

The secondary-side output is composed of two outputs. One is 12 V output terminal in which there are D5, C6 and C6A. The other is 5 V output terminal that composed of D7, C18 and C18A. When the MOSFET integrated in the switcher turns off, energy stored in the coupled inductor is transferred to the secondary side. At the time, there is switching noise on the output voltage, which can be, however, reduced by a LC filter on each output terminal formed by L2 and C7 (L3 and C19). R12 and R10 are used as dummy load to avoid V_{CC} self supply operation for better no load power consumption. The ground is same to reference ground of primary side.

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CIRCUIT LAYOUT

The PCB consists of a double layer FR4 board with 2 oz. copper cladding.

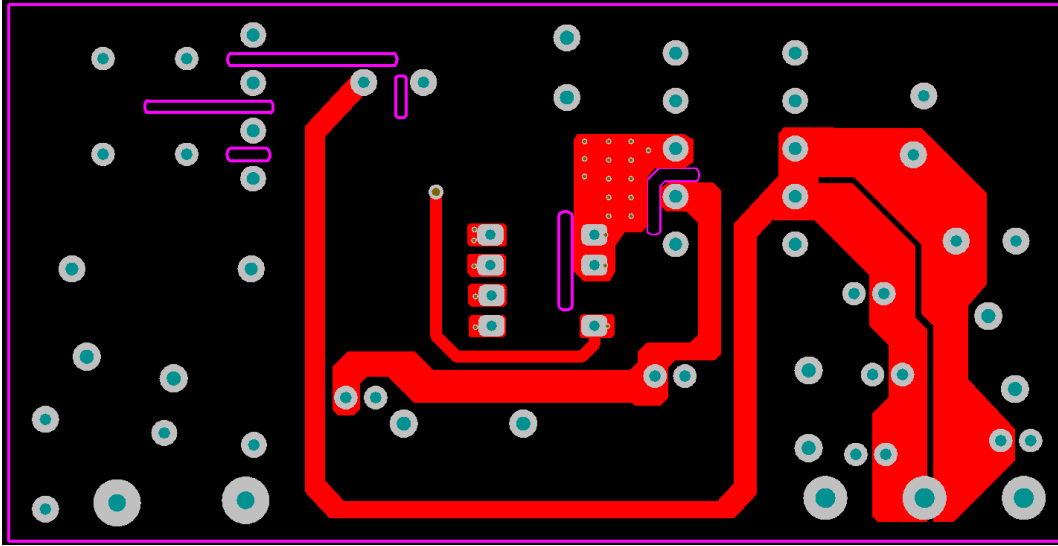


Figure 2. Main Board Top Layer

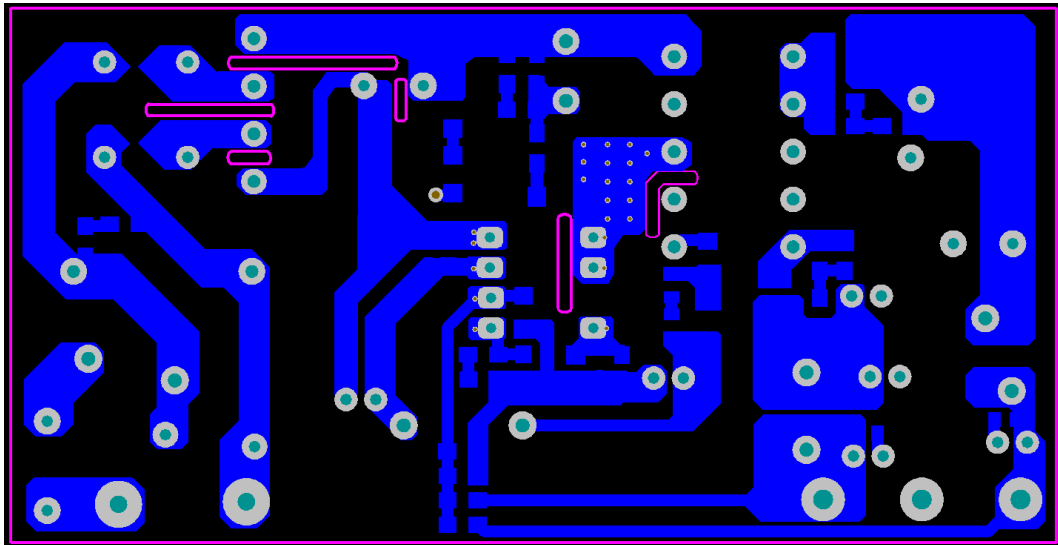


Figure 3. Main Board Bottom Layer

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CIRCUIT LAYOUT (Continued)

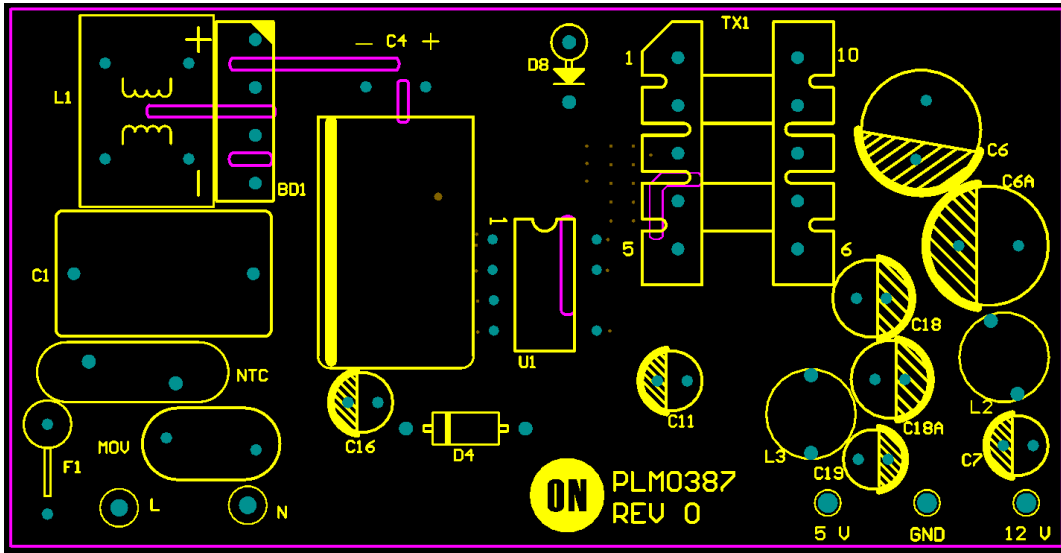


Figure 4. Main Board Top Side Components

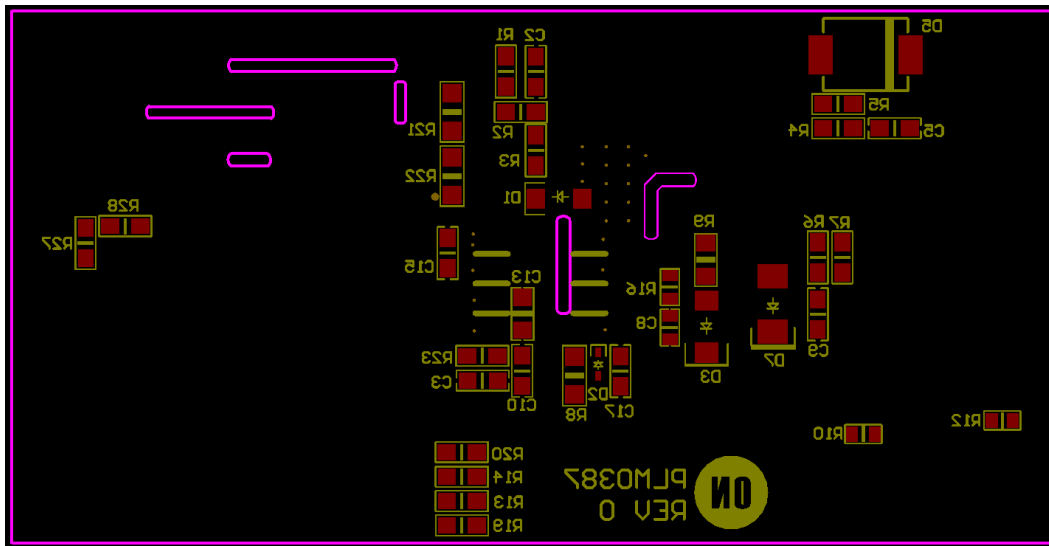


Figure 5. Main Board Bottom Side Components

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BOARD PICTURES



Figure 6. Main Board Photo – Top Side

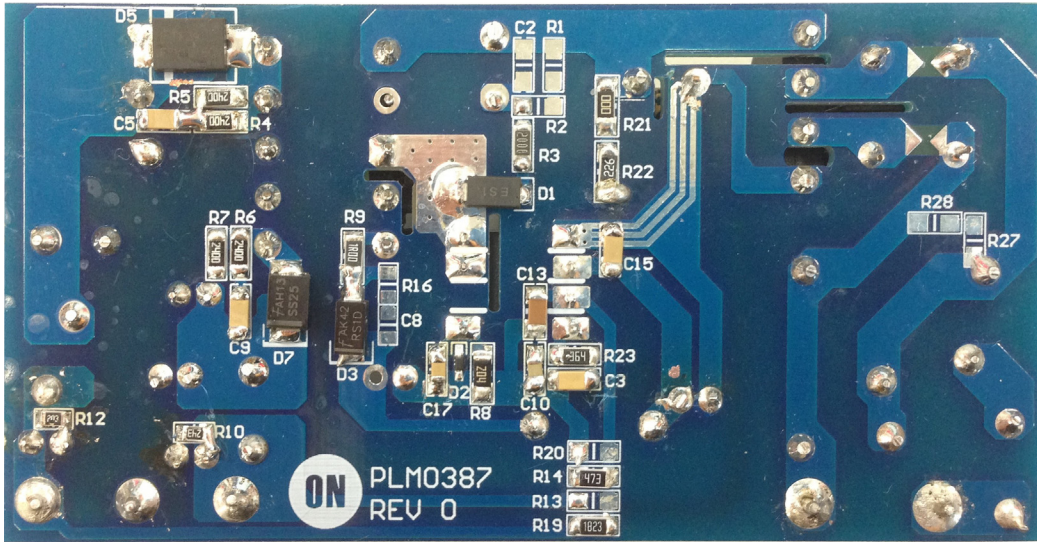


Figure 7. Main Board Photo – Bottom Side

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TRANSFORMER DATA

Bobbin & Core : EE-19

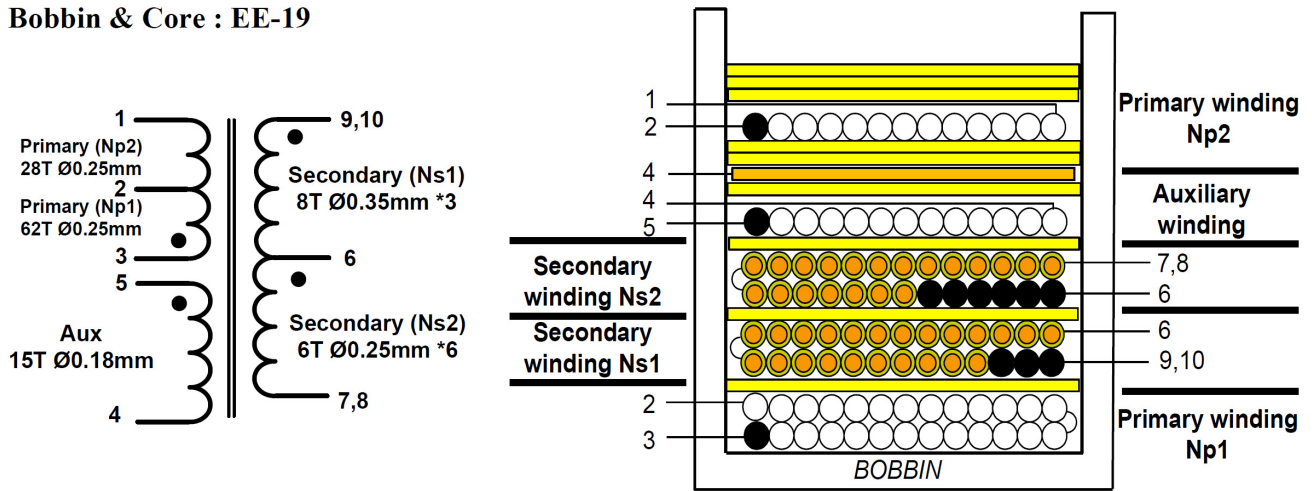


Table 2.

| | Pin | Specification | Remark |
|-------------------------|------------|--------------------|--------------|
| Primary-Side Inductance | Drain - B+ | 960 μ H (Typ.) | 100 kHz, 1 V |

Table 3.

| Layer | TERMINAL | | WIRE | Turns | Isolation Layer |
|-----------------------|-----------|---------|---------------|-------|-----------------|
| | Start Pin | End Pin | | | Turns |
| Primary Winding (Np1) | 3 | 2 | 2UEW 0.25 * 1 | 62 | 1 |
| Secondary (Ns1) | 9,10 | 6 | 0.35 * 3 | 8 | 1 |
| Secondary (Ns2) | 6 | 7,8 | 0.25 * 6 | 6 | 1 |
| AUX Winding | 5 | 4 | 2UEW0.18 * 1 | 15 | 1 |
| Copper Shield | 4 | - | | 1.2 | 1 |
| Primary Winding (Np2) | 2 | 1 | 2UEW 0.25 * 1 | 28 | 2 |

*Copper shield is open loop and connect to ground.

TEST DATA

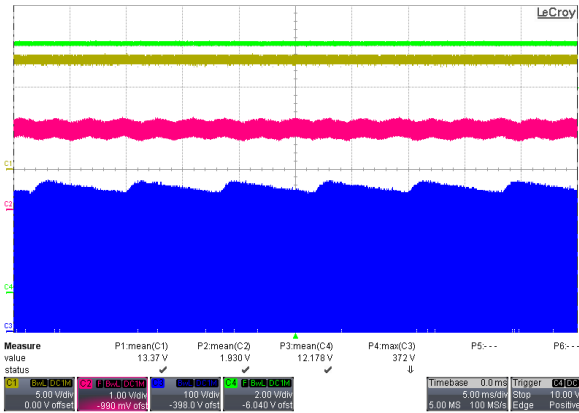


Figure 8. Operation, Full Load, 115 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

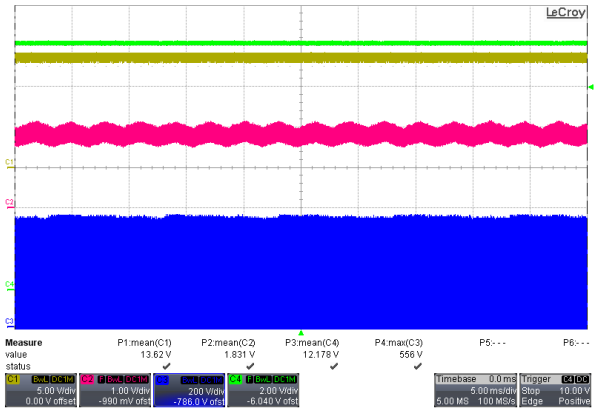


Figure 9. Operation, Full Load, 230 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

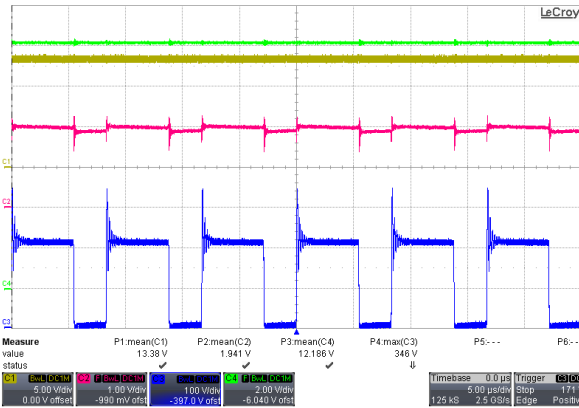


Figure 10. Zoom in Operation, Full Load, 115 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

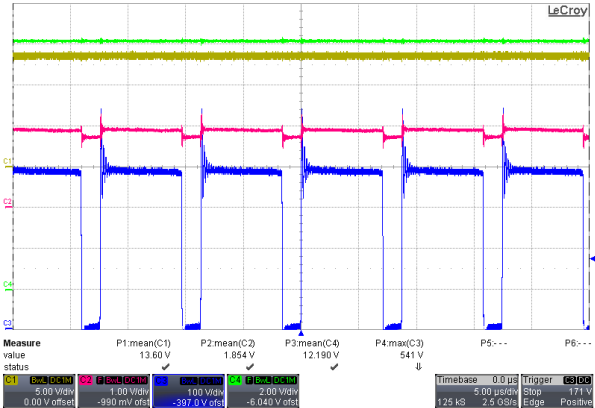


Figure 11. Zoom in Operation, Full Load, 230 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

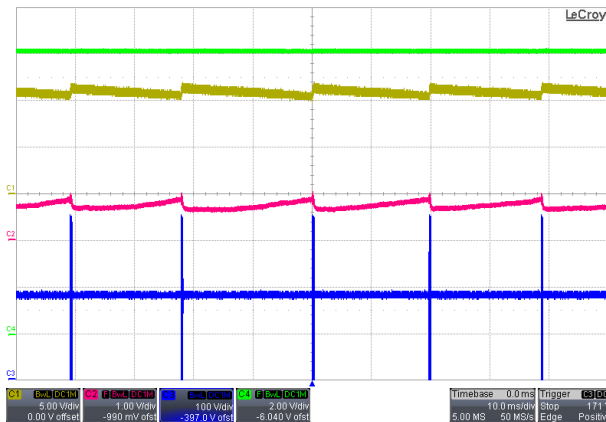


Figure 12. Operation, No Load, 115 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

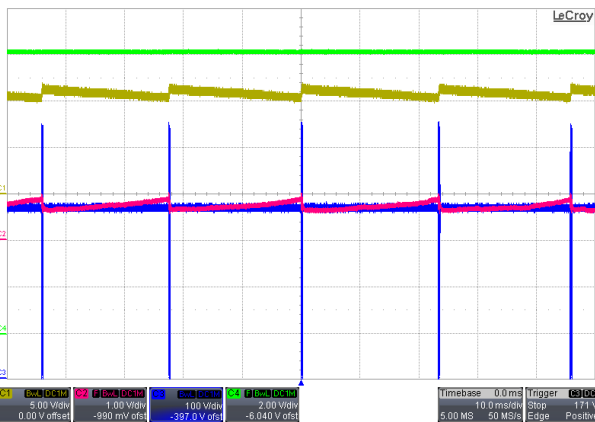


Figure 13. Operation, No Load, 230 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

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TEST DATA (Continued)

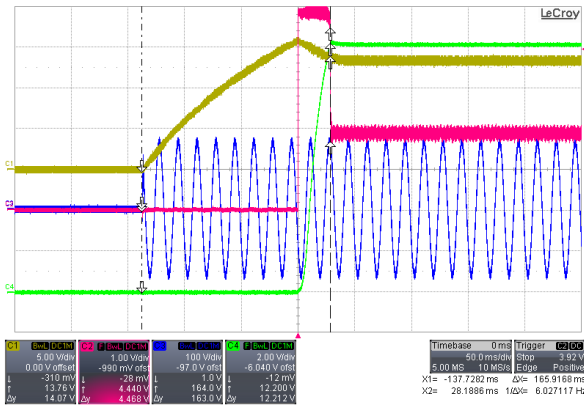


Figure 14. Ton On time, 115 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Vac, Ch4: Vo)

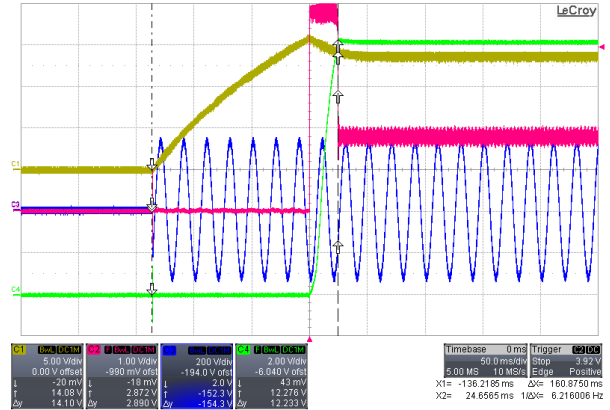


Figure 15. Ton on time, 230 Vac
(Ch1: V_{CC}, Ch2: COMP, Ch3: Vac, Ch4: Vo)

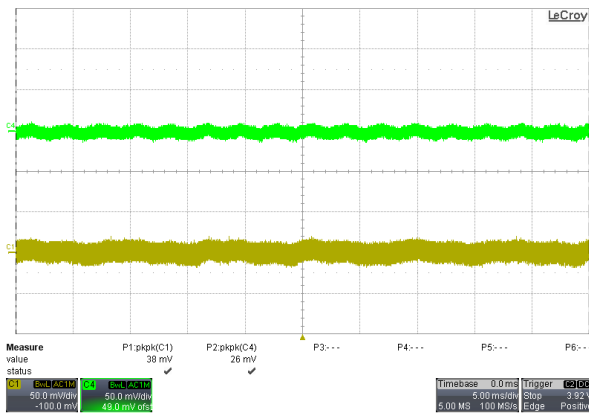


Figure 16. Output Ripple, Full Load, 115 Vac
(Ch1: Vo-5 V (AC), Ch4: Vo-12 V (AC))

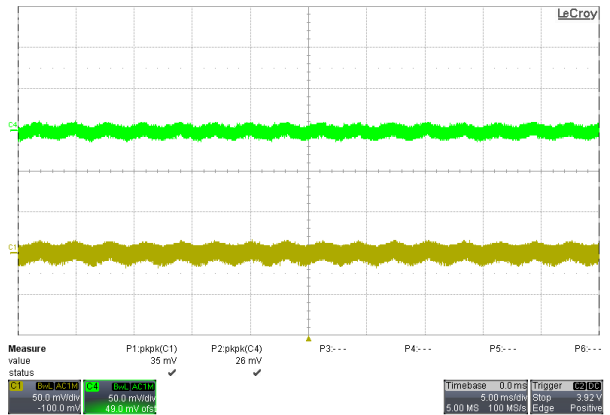


Figure 17. Output Ripple, Full Load, 230 Vac
(Ch1: Vo-5 V (AC), Ch4: Vo-12 V (AC))

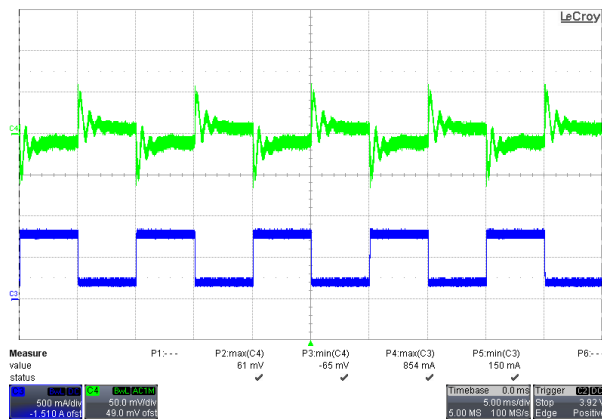


Figure 18. Dynamic operation
(20%~80% of the Full Load for 12 V Output, 5 ms Duty Cycle, 2.5 A/ μ s Rise/Fall Time), 115 Vac
(Ch3: Io, Ch4: Vo(AC))

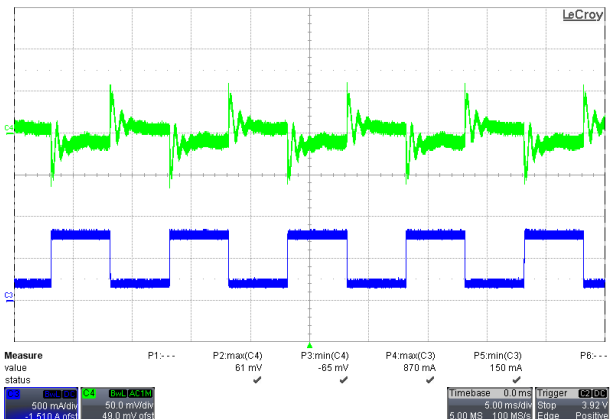


Figure 19. Dynamic Operation
(20%~80% of the Full Load for 12 V Output, 5 ms Duty Cycle, 2.5 A/ μ s Rise/Fall Time), 230 Vac
(Ch3: Io, Ch4: Vo(AC))

TEST DATA (Continued)

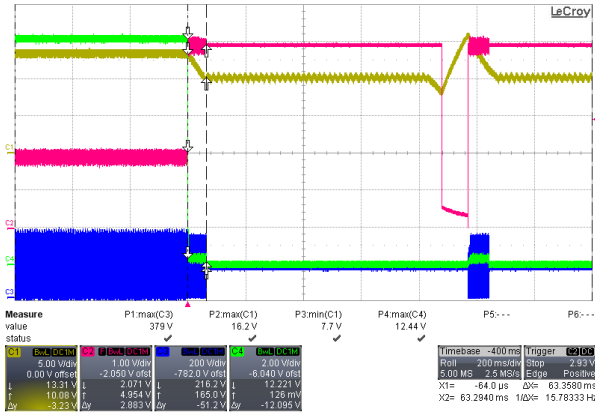


Figure 20. Output Short Triggers OLP, Full Load, 115 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

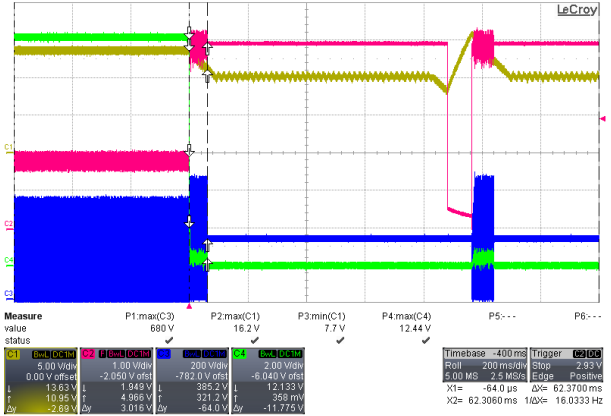


Figure 21. Output Short Triggers OLP, Full Load, 230 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

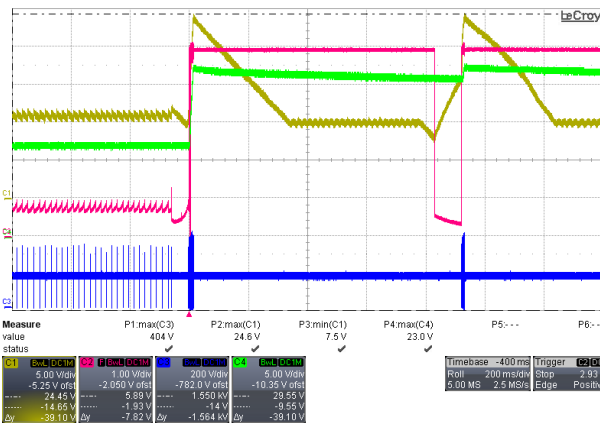


Figure 22. Short R14 to Trigger VCC OVP, No Load, 115 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

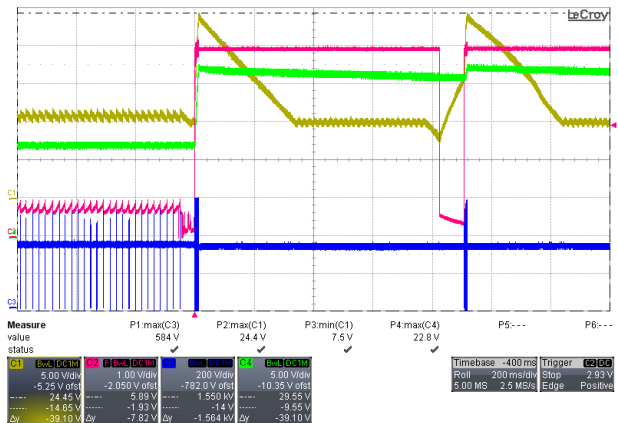


Figure 23. Short R14 to Trigger VCC OVP, No Load, 230 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

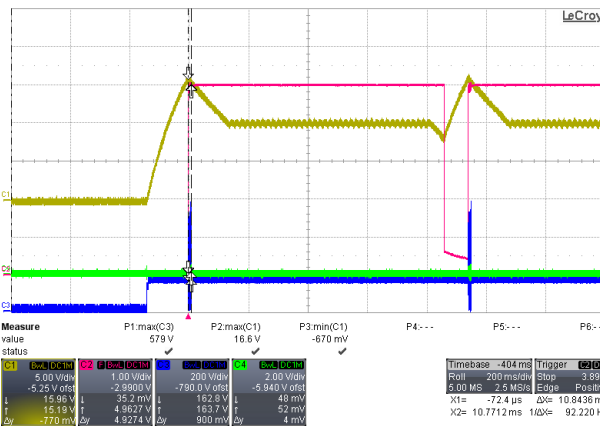


Figure 24. Short Output Schottky Diode to Trigger AOCV, Full Load, 115 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

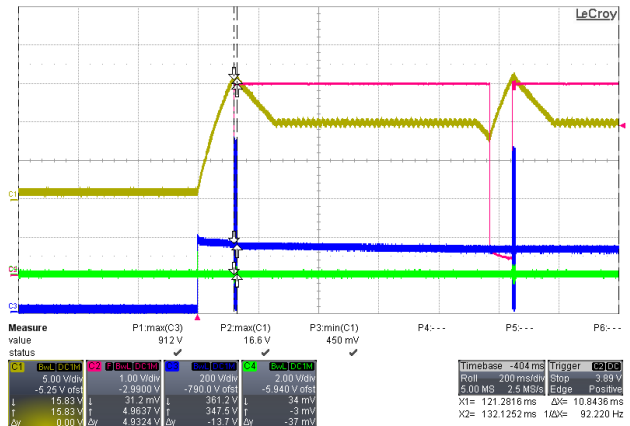


Figure 25. Short Output Schottky Diode to Trigger AOCV, Full Load, 230 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

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TEST DATA (Continued)

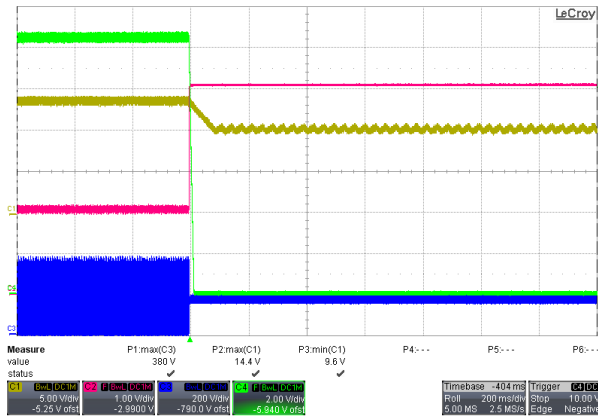


Figure 26. Heating on IC's Case to Trigger TSD, Full Load, 115 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

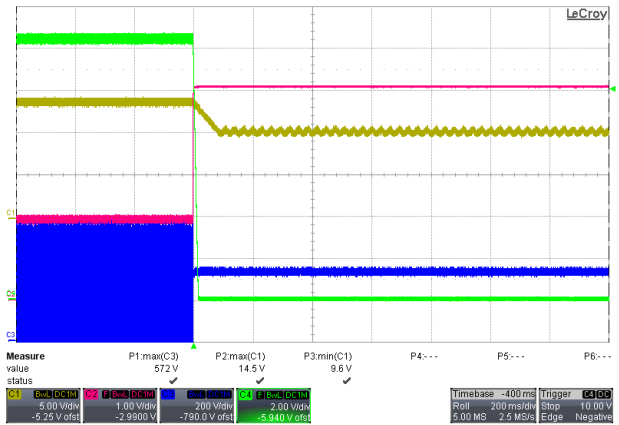


Figure 27. Heating on IC's Case to Trigger TSD, Full Load, 230 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

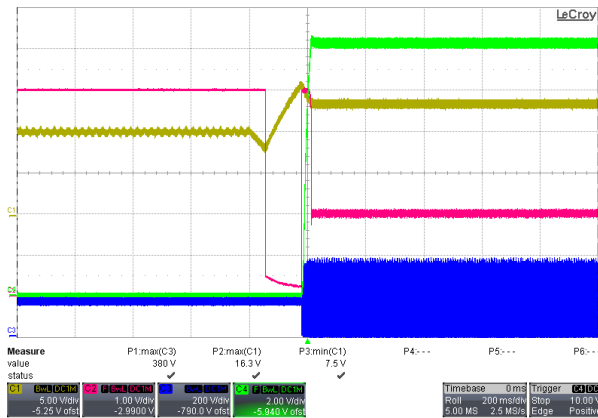


Figure 28. Remove Heating from IC's Case to Recover TSD Protection, Full Load, 115 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

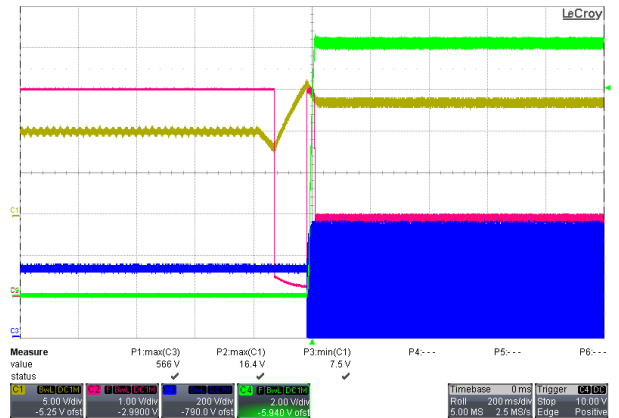


Figure 29. Remove Heating from IC's Case to Recover TSD Protection, Full Load, 230 Vac (Ch1: V_{CC}, Ch2: COMP, Ch3: Drain, Ch4: Vo)

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Table 4. BROWN IN/OUT

| Behavior | Vin (Vrms) |
|-----------|------------|
| Brown In | 77 |
| Brown Out | 64 |

NOTE: Test condition is full load.
Gradually increase/decrease input AC by 1 V/step.

Table 5. NO-LOAD INPUT POWER CONSUMPTION

| Input Voltage [Vac] | Power Consumption [mW] |
|---------------------|------------------------|
| 115 Vac | 24.2 |
| 230 Vac | 28.05 |

NOTE: Test condition: Outputs are connected to electronic load, but loading is not applied. Input power is integrated over three minutes.

Table 6. EFFICIENCY

| Input Voltage [Vac] | 25% Load | 50% Load | 75% Load | 100% Load | Avg. |
|---------------------|----------|----------|----------|-----------|--------|
| 115 Vac | 85.61% | 86.12% | 85.28% | 84.98% | 85.50% |
| 230 Vac | 81.99% | 84.46% | 84.94% | 84.84% | 84.06% |

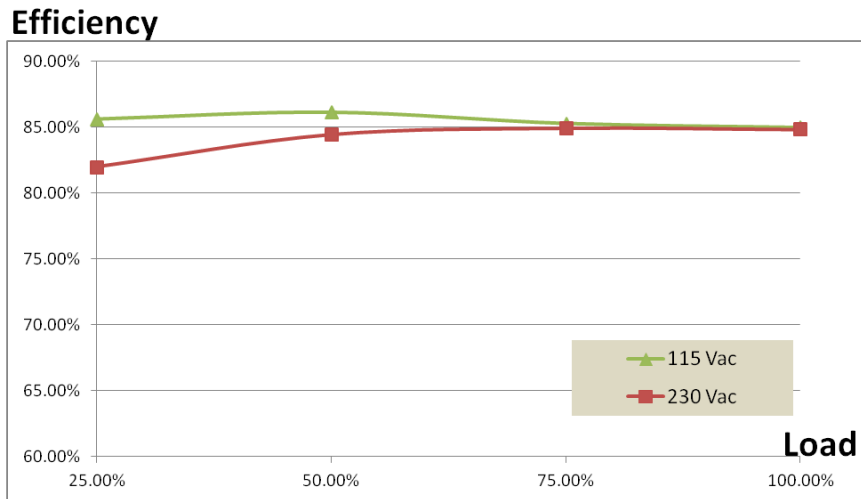


Figure 30. Board Efficiency

Table 7. LINE/LOAD REGULATION

| Input Voltage [Vac] | 85 Vac | | 115 Vac | | 230 Vac | | 265 Vac | | Line Regulation (±) | |
|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| | V _{O1} (V) | V _{O2} (V) | V _{O1} (V) | V _{O2} (V) | V _{O1} (V) | V _{O2} (V) | V _{O1} (V) | V _{O2} (V) | V _{O1} (V) | V _{O2} (V) |
| 0 W | 12.205 | 5.0955 | 12.2165 | 5.0955 | 12.211 | 5.0945 | 12.217 | 5.0915 | 0.05% | 0.04% |
| 0.25 W | 12.203 | 5.076 | 12.208 | 5.0765 | 12.206 | 5.071 | 12.211 | 5.07 | 0.03% | 0.06% |
| 0.5 W | 12.202 | 5.0795 | 12.204 | 5.08 | 12.205 | 5.075 | 12.208 | 5.073 | 0.02% | 0.07% |
| 25% | 12.1975 | 5.056 | 12.1995 | 5.059 | 12.203 | 5.058 | 12.205 | 5.059 | 0.03% | 0.03% |
| 50% | 12.196 | 5.0445 | 12.1955 | 5.045 | 12.2 | 5.059 | 12.2045 | 5.0505 | 0.04% | 0.14% |
| 75% | 12.195 | 5.0295 | 12.194 | 5.033 | 12.201 | 5.0405 | 12.2025 | 5.043 | 0.03% | 0.13% |
| 100% | 12.1955 | 5 | 12.194 | 5.0125 | 12.197 | 5.026 | 12.206 | 5.031 | 0.05% | 0.31% |
| Load Regulation (±) | 0.04% | 0.94% | 0.09% | 0.82% | 0.06% | 0.68% | 0.06% | 0.60% | | |

NOTE: Equation of line/load regulation is $\pm(\max - \min) / (\max + \min)$.
Measured within load range shown in specification.

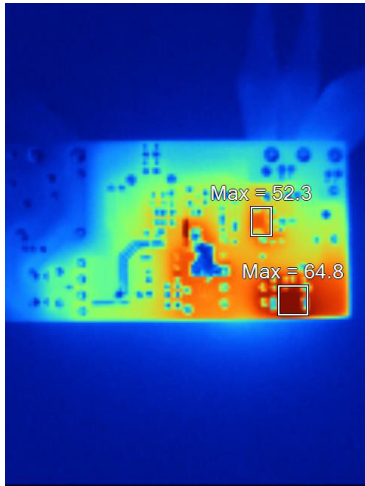


Figure 31. Temperature Checking on Bottom Side, Full Load, 115 Vac

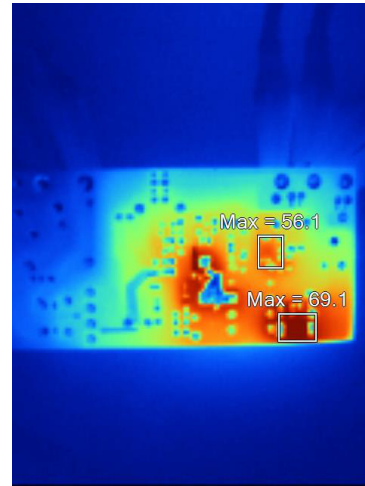


Figure 32. Temperature Checking on Bottom Side, Full Load, 230 Vac

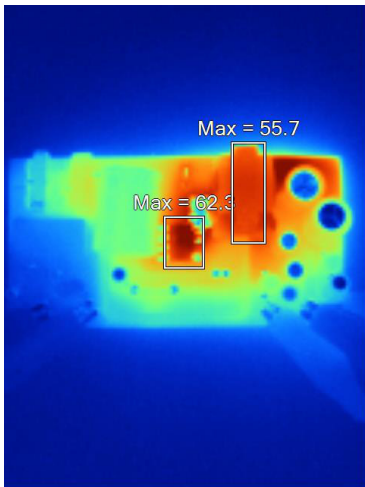


Figure 33. Temperature Checking on Top Side, Full Load, 115 Vac

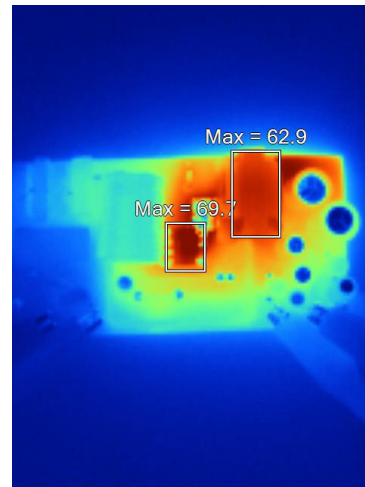


Figure 34. Temperature Checking on Top Side, Full Load, 230 Vac

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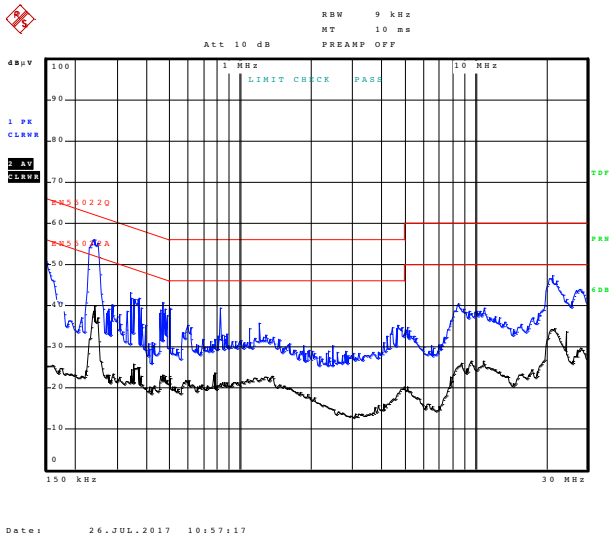


Figure 35. Conducted EMI, 115 Vac, LINE

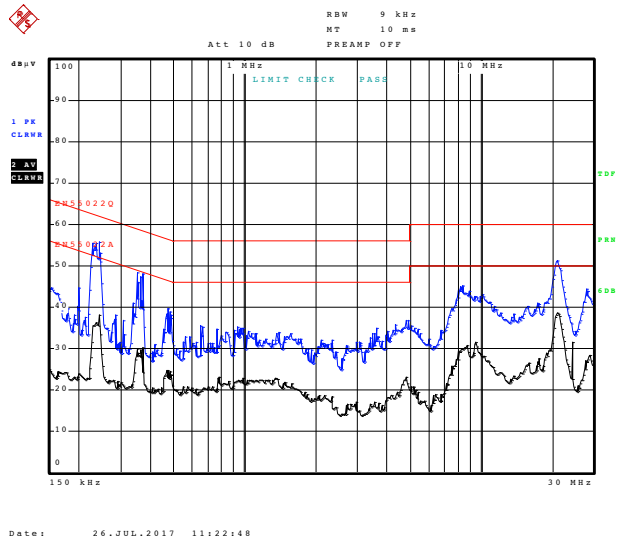


Figure 36. Conducted EMI, 230 Vac, LINE

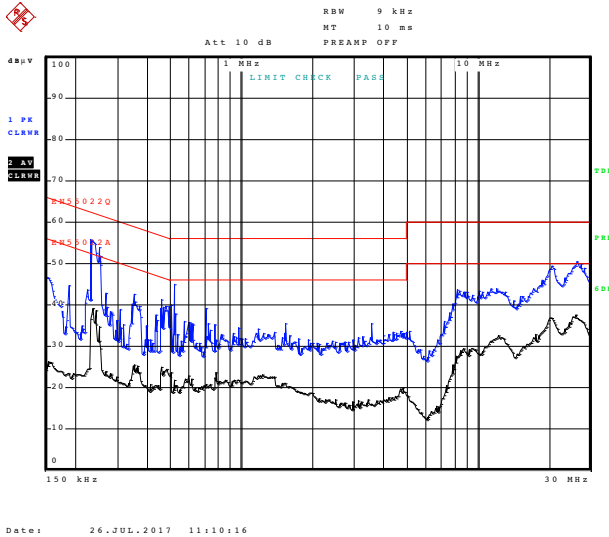


Figure 37. Conducted EMI, 115 Vac, Neutral

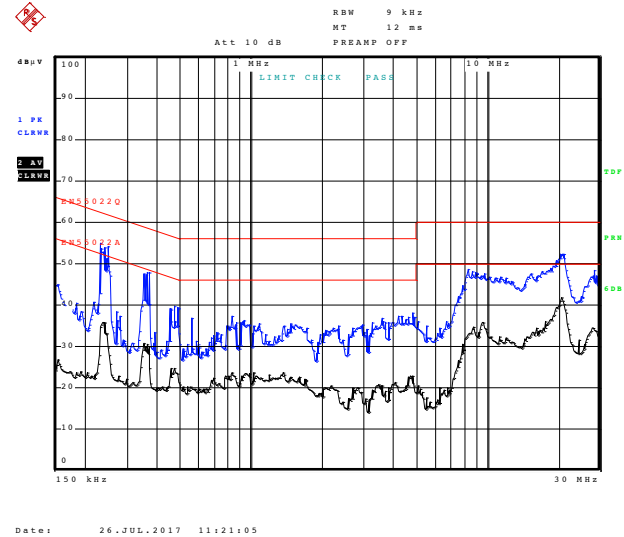


Figure 38. Conducted EMI, 230 Vac, Neutral

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BILL OF MATERIALS

Table 8. BILL OF MATERIALS

| Parts | Qty | Description | Value | Tolerance | Footprint | Manufacturer | Manufacturer Part Number | Substitution Allowed | Pb-Free |
|----------------------|-----|------------------------|--|-----------|---|------------------|--------------------------|----------------------|---------|
| C1 | 1 | X2 Capacitor | 0.33 μ F/275 V | \pm 10% | 17 \times 7.5 \times 15.5 mm Pitch = 15 mm | CARLI | PX334K3D1 | Yes | Yes |
| C3 | 1 | MLCC X7R Capacitor | 223 pF/100 V | \pm 10% | 1206 | Taiwan-Resister | CP223K100XRC | Yes | Yes |
| C4 | 1 | Electrolytic Capacitor | 33 μ F/450 V | \pm 10% | 18 \times 21 mm | SAMYOUNG | NHA | Yes | Yes |
| C5 | 1 | MLCC X7R Capacitor | 221 pF/100 V | \pm 10% | 1206 | Taiwan-Resister | CP221K100XRC | Yes | Yes |
| C6, C6A | 2 | Electrolytic Capacitor | 680 μ F/25 V | | 10 \times 20 mm | SAMYOUNG | SHL | Yes | Yes |
| C7 | 1 | Electrolytic Capacitor | 68 μ F/25 V | | 5 \times 11 mm | SAMYOUNG | KMG | Yes | Yes |
| C9 | 1 | MLCC X7R Capacitor | 101 pF/100 V | \pm 10% | 1206 | Taiwan-Resister | CP101K100XRC | Yes | Yes |
| C10 | 2 | MLCC X7R Capacitor | 471 pF/50 V | \pm 10% | 0805 | Taiwan-Resister | CP471K050XRB | Yes | Yes |
| C13, C17 | 1 | MLCC X7R Capacitor | 102 pF/50 V | \pm 10% | 0805 | Taiwan-Resister | CP102K050XRB | Yes | Yes |
| C15 | 1 | MLCC X7R Capacitor | 104 pF/50 V | \pm 10% | 0805 | Taiwan-Resister | CP104K050XRB | Yes | Yes |
| C16 | 1 | Electrolytic Capacitor | 22 μ F/50 V | | 5 \times 11 mm | SAMYOUNG | KMG | Yes | Yes |
| C18, C18A | 2 | Electrolytic Capacitor | 330 μ F/10 V | | 6.3 \times 11mm | SAMYOUNG | KMG | Yes | Yes |
| C19 | 1 | Electrolytic Capacitor | 47 μ F/16 V | | 5 \times 11 mm | SAMYOUNG | KMG | Yes | Yes |
| R3 | 1 | Resistor SMD | 200 Ω | \pm 5% | 1206 | Taiwan-Resister | RP12200RJR | Yes | Yes |
| R4, R5, R6, R7 | 4 | Resistor SMD | 240 Ω | \pm 5% | 1206 | Taiwan-Resister | RP12240RJR | Yes | Yes |
| R8 | 1 | Resistor SMD | 200 k Ω | \pm 5% | 1206 | Taiwan-Resister | RP12200KJR | Yes | Yes |
| R9 | 1 | Resistor SMD | 1 Ω | \pm 5% | 1206 | Taiwan-Resister | RP1201ROJR | Yes | Yes |
| R10 | 1 | Resistor SMD | 24 k Ω | \pm 5% | 0805 | Taiwan-Resister | RP0824KOJR | Yes | Yes |
| R12 | 1 | Resistor SMD | 20 k Ω | \pm 5% | 0805 | Taiwan-Resister | RP0820KOJR | Yes | Yes |
| R14 | 1 | Resistor SMD | 47 k Ω | \pm 5% | 1206 | Taiwan-Resister | RP1247KOJR | Yes | Yes |
| R19 | 1 | Resistor SMD | 182 k Ω | \pm 5% | 1206 | Taiwan-Resister | RP12182KJR | Yes | Yes |
| R21 | 1 | Resistor SMD | 0 Ω | \pm 5% | 1206 | Taiwan-Resister | RP12000JR | Yes | Yes |
| R22 | 1 | Resistor SMD | 22 M Ω | \pm 5% | 1206 | Taiwan-Resister | RP1222MOJR | Yes | Yes |
| R23 | 1 | Resistor SMD | 360 k Ω | \pm 5% | 1206 | Taiwan-Resister | RP12360KJR | Yes | Yes |
| D1 | 1 | Fast Rectifier | 600 V, 1 A | | DO-214AC | ON Semiconductor | ES1J | Yes | Yes |
| D2 | 1 | Zener Diode | 7.5 V, 0.2 W | | SOD-523F | ON Semiconductor | MM5Z7V5 | Yes | Yes |
| D3 | 1 | Fast Rectifier | 200 V, 1 A | | DO-214AC | ON Semiconductor | RS1D | Yes | Yes |
| D4 | 1 | Jumper Wire | short | | | | | Yes | Yes |
| D5 | 1 | Schottky Rectifier | 150 V, 10 A | | TO-277 | ON Semiconductor | FSV10150V | Yes | Yes |
| D7 | 1 | Schottky Rectifier | 50 V, 2 A | | DO-214AA | ON Semiconductor | SS25 | Yes | Yes |
| D8 | 1 | TVS | 150 V, 600 W | | DO-15 | ON Semiconductor | P6KE150A | Yes | Yes |
| 5 V, 12 V, GND, L, N | 5 | TEST PIN | Pin Ψ 2.2 \times 18.2 m m OEM-10 | | 2.2 \times 18.2 mm | KANG YANG | SG004-05 Pin | Yes | Yes |
| F1 | 1 | Fuse | FUSE CERAMIC 1 A/ 250 V SLOW | | 3.6 \times 10 mm | | 37SG | Yes | Yes |
| MOV | 1 | MOV | 470 V | \pm 10% | | THINKING | MOV-471KD10SBNL | Yes | Yes |
| NTC | 1 | Jumper wire | Short | | | | | Yes | Yes |

EVBUM2650/D

Table 8. BILL OF MATERIALS (continued)

| Parts | Qty | Description | Value | Tolerance | Footprint | Manufacturer | Manufacturer Part Number | Substitution Allowed | Pb-Free |
|---------------------|-----|-------------------------|--------------------|-----------|-----------------|------------------|--------------------------|----------------------|---------|
| BD1 | 1 | Bridge Rectifier | 600 V, 2 A | | KBPM | ON Semiconductor | 2KBP06M | Yes | Yes |
| L1 | 1 | Common-mode Choke | 10 mH | | UU9.8 | SEN HUEI | TRN0356 | Yes | Yes |
| L2, L3 | 2 | Inductor, Ferrite Core | 1 μ H | | DR 6 \times 8 | WURTH | 744772010 | Yes | Yes |
| TX1 | 1 | Transformer | 960 μ H | \pm 10% | EE-19 | SEN HUEI | | No | Yes |
| U1 | 1 | PWM with Power SENSEFET | | | 7DIP | ON Semiconductor | FSL538HPG | No | Yes |
| | 1 | PCB | | | | | PLM0387V0 | No | Yes |
| NTC, D4, F1, C4, D8 | 5 | Teflon Tube | 17L \times 305 m | | | | | Yes | Yes |

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