# 30 W high-efficiency auxiliary SMPS for refrigerator using ICE5QR1680BG

## REF_5QR1680BG_30W1

## About this document

### Scope and purpose

This document is a reference design for a high-efficiency 30 W auxiliary SMPS for a refrigerator with the latest fifth-generation Infineon QR CoolSET™ **ICE5QR1680BG**. The power supply is designed with a universal input compatible with most geographic regions and three outputs (isolated +12 V/2.2 A, +5 V/0.2 A and non-isolated 15 V/0.15 A) as typically employed in most home appliances.

Highlights of this auxiliary power supply for a refrigerator:

- Overall high efficiency to meet energy efficiency requirements
- Simplified circuitry with good integration of power and protection features
- Auto restart protection scheme to minimize interruption to enhance end user experience
- Add-in AC zero-crossing detection (ZCD) circuit
- Add-in LDO enable circuit to reduce standby loss

### Intended audience

This document is intended for power supply design or application engineers, etc. who want to design auxiliary power supplies for refrigerators that are efficient, reliable and easy to design.

## Table of contents

# 1 System introduction

With the growing household trend for internet-connected devices, the new generation of home appliances such as refrigerators are equipped with advanced features which often include communication capability, such as wireless communication, touchscreen display and sensors. These will transform a static product into an interactive and intelligent home appliance, capable of adapting to the smart-home theme. Infineon has introduced the latest fifth-generation QR CoolSET™ to address this need in an efficient and cost-effective manner.

An auxiliary SMPS is needed to power the various modules and sensors, which typically operate from a stable DC voltage source. The Infineon CoolSET™ (as shown in **Figure 1**) forms the heart of the system, providing the necessary protection and AC-DC conversion from the mains to multiple regulated DC voltages to power the various blocks.

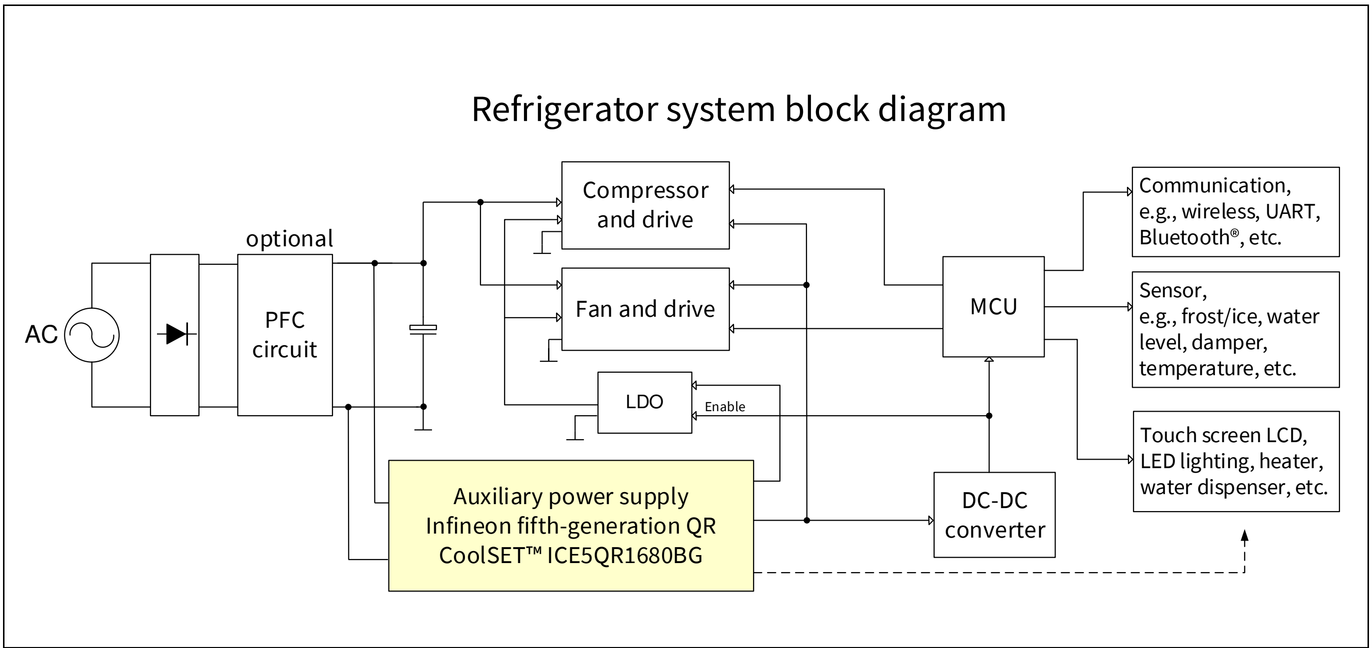



**Figure 1 Simplified refrigerator system block diagram**

**Table 1** lists the system requirements for a refrigerator, and the corresponding Infineon solution is shown in the right-hand column.

**Table 1 System requirements and reference board solutions**

| | System requirement for a refrigerator | Reference board solution – ICE5QR1680BG |
|---|---|---|
| 1 | High efficiency to meet various energy efficiency requirements | Primary QR control and secondary synchronous rectifier control |
| 2 | Simplified circuitry with good integration of power and protection features | Embedded 800 V MOSFET and controller in DSO-12 package |
| 3 | Auto restart protection scheme to minimize interruption to enhance end user experience | All abnormal protections are in auto restart mode |

## 1.1 High efficiency under light-load conditions to meet ENERGY STAR requirements

During typical refrigerator operation, the power requirement fluctuates according to various use cases. However, in most cases, the refrigerator will reside in an idle state in which the loading toward the auxiliary power supply is low. It is crucial that the auxiliary power supply operates as efficiently as possible, because it will be in this particular state for a prolonged period. Under light-load conditions, losses incurred with the power switch are usually dominated by the switching operation. The choice of switching scheme and frequency play a crucial role in ensuring high conversion efficiency.

In this reference design, ICE5QR1680BG was primarily chosen due to its QR switching scheme. Compared with a traditional flyback switching scheme, the CoolSET™ will attempt to turn on its integrated high-voltage (HV) MOSFET in the valley of the resonant period, thereby minimizing switching losses. Additionally, the fifth-generation QR series suports up to 10 valleys, thereby lowering the switching frequency further along with a reduction in load. Therefore, an efficiency of more than 80 percent is achievable under 25 percent loading conditions.

## 1.2 Simplified circuitry with good integration of power and protection features

To relieve the designer of the complexity of PCB layout and circuit design, CoolSET™ is a highly integrated device with both a controller and a HV MOSFET integrated in a single, space-saving DSO-12 package. These certainly help the designer to reduce component count as well as simplifying the layout into a single-layer PCB design for ease of manufacturing, using the traditional, cost-effective wave-soldering process.

To counter abnormal line input conditions, CoolSET™ has integrated line input overvoltage (OV) as well as brown-out protection to increase the robustness of the auxiliary power. In the event of such faults, the controller within the CoolSET™ will halt the switching operation of the integrated HV MOSFET, thereby preventing permanent damage. These features allow the designer to reduce the complexity of introducing additional external circuitry and yield a saving of many components.

## 1.3 Auto restart protection scheme to minimize interruption to enhance end user experience

For a refrigerator it would be annoying to both the end user and the manufacturer if the system were to halt and latch after protection. To minimize interruption, the CoolSET™ implements auto restart mode for all protections.

# 2 Reference board

This document provides complete design details including specifications, schematics, bill of materials (BOM), and PCB layout and transformer design and construction information. This information includes performance results pertaining to line/load regulation, efficiency, transient load, thermal conditions, conducted EMI scans, etc.

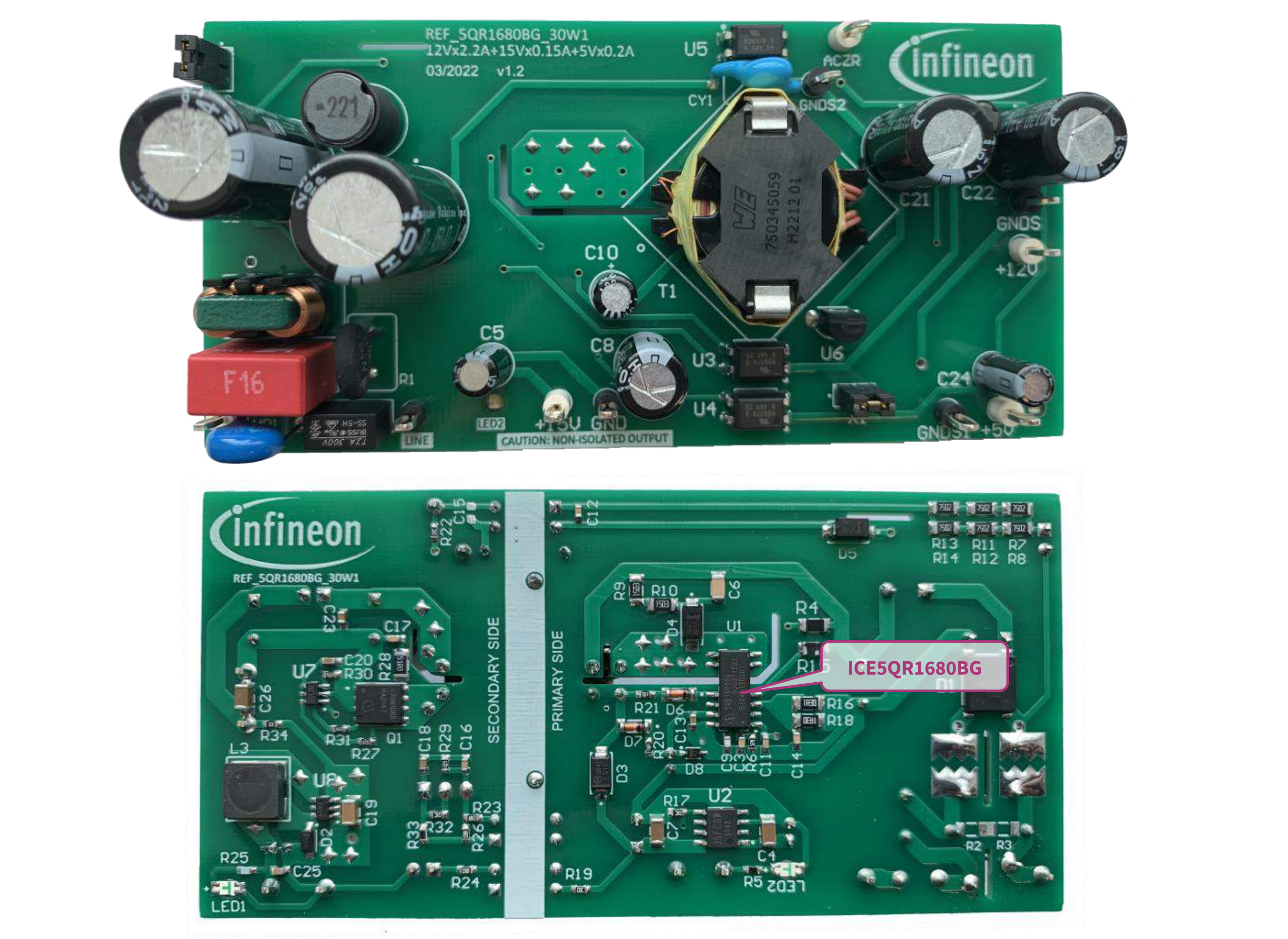



**Figure 2** **REF_5QR1680BG_30W1**

# 3 Power supply specifications

The table below represents the minimum acceptance performance of the design. The actual performance is listed in the measurements section.

**Table 2 Specifications of REF_5QR1680BG_30W1**

| Description | Symbol | Min. | Typ. | Max. | Units | Comments |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 85 | – | 264 | V AC | Two wires (no P.E.) |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 64 | Hz | |
| No-load input power | $P_{stby\_NL}$ | – | 0.5 | – | W | Enabled LDO at 230 V AC |
| Line OV | $V_{IN\_OVP}$ | – | 300 | – | V AC | |
| **Output** | | | | | | |
| Output voltage 1 | $V_{OUT1}$ | – | 12 | – | V | ±1 percent |
| Output current 1 | $I_{OUT1}$ | – | 2.2 | – | A | |
| Output voltage ripple 1 | $V_{RIPPLE1}$ | – | – | 120 | mV | |
| Output voltage 2 | $V_{OUT2}$ | – | 5 | – | V | Tapped from 12 V output via DC-DC converter |
| Output current 2 | $I_{OUT2}$ | – | 0.2 | – | A | |
| Output voltage 3 | $V_{OUT3}$ | – | 15 | – | V | Tapped from 18 V output via LDO |
| Output current 3 | $I_{OUT3}$ | – | 0.15 | – | A | |
| Overcurrent protection (12 V) | $I_{OCP}$ | – | – | 3.3 | A | With full load on other outputs |
| **Efficiency** | | | | | | |
| Maximum load efficiency | $\eta$ | – | 84 | – | % | 115 V AC/230 V AC |
| Average efficiency | $\eta_{avg}$ | – | 83 | – | % | 115 V AC/230 V AC |
| Average efficiency for single output configuration | $\eta_{avg\_s}$ | – | 89 | – | % | 115 V AC/230 V AC |
| **Environmental** | | | | | | |
| Conducted EMI | | | 10 | | dB | Margin, CISPR 22 class B |
| ESD | | | | | | EN 61000-4-2 |
| Contact discharge | | | ±6 | | kV | |
| Air discharge | | | ±8 | | kV | |
| Surge immunity | | | | | | EN 61000-4-5 |
| Differential mode | | | ±1 | | kV | |
| Common mode | | | ±2 | | kV | |
| PCBA form factor | | | 110 x 54 x 30 | | $mm^3$ | L x W x H |

# 4 Circuit diagram

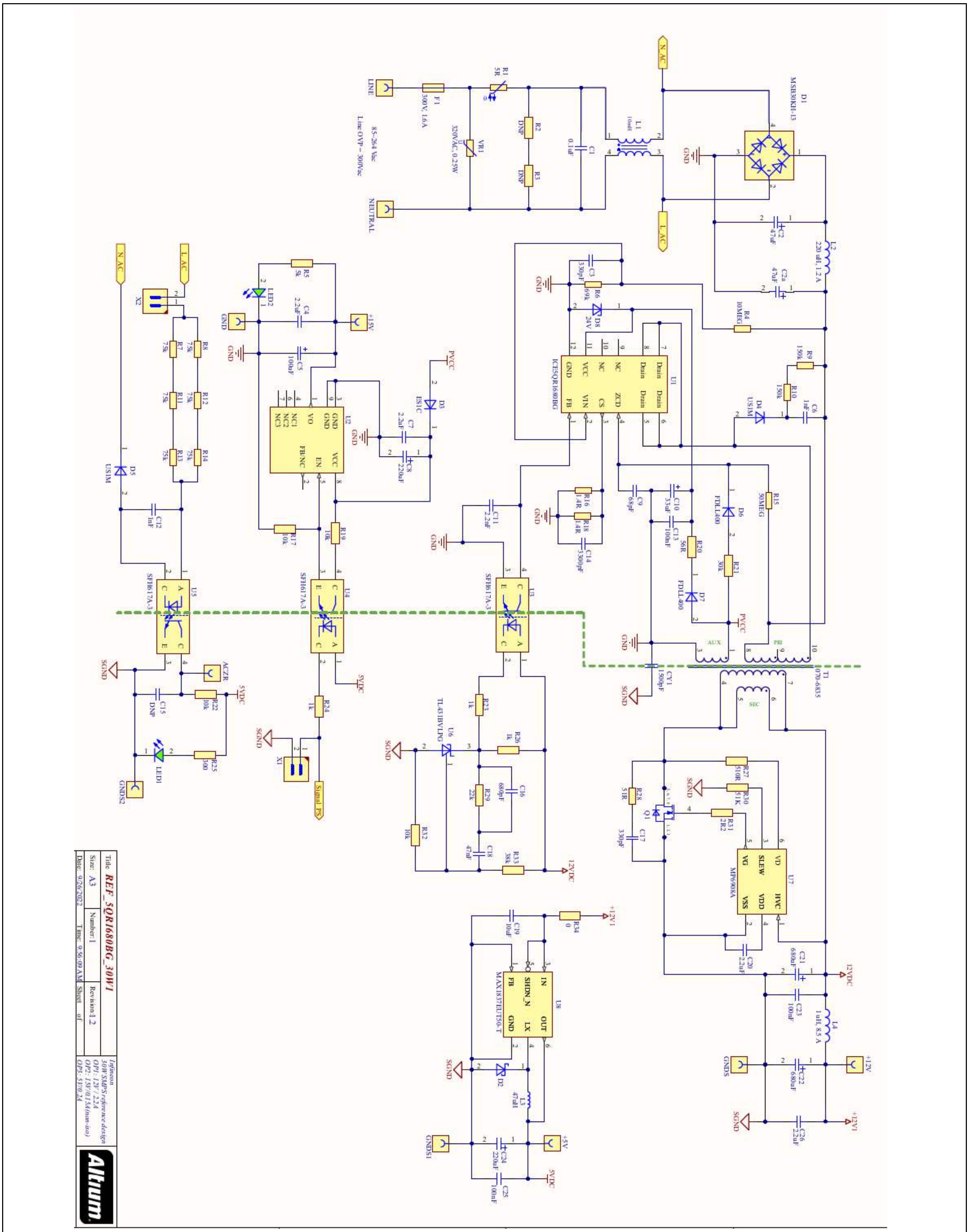



**Figure 3 Schematic of REF_5QR1680BG_30W1**

# 5 Circuit description

In this section, the reference design circuit for refrigerator auxiliary power will be briefly described by the different functional blocks. For details of the design procedure and component selection for the flyback circuitry please refer to the IC design guide [2] and calculation tool [3].

## 5.1 EMI filtering and line rectification

The input of the refrigerator auxiliary power unit is taken from the AC power grid, which is in the range of 85 V AC ~ 264 V AC. The fuse F1 is right at the entrance to protect the system in case of excess current entering the system circuit due to any fault. Following is the varistor VR1, which is connected across L and N to absorb the line surge transient. Common mode (CM) choke L1 and X-capacitor C1 form a basic filter to attenuate the DM and CM conducted EMI noise. The bridge rectifier D1 rectifies the AC input into DC voltage, filtered by the π filter (capacitor C2, C2a and L2). The above is not applicable if the power-factor correction (PFC) circuit is used as shown in **Figure 1**.

## 5.2 Flyback converter power stage

The flyback converter power stage consists of transformer T1, a primary HV MOSFET (integrated into ICE5QR1680BG), secondary synchronous rectifier (SR) MOSFET Q1, secondary output capacitors and filtering component (C21, C22 and L4).

When the integrated CoolMOS™ turns on, some energy is stored in the transformer. When it turns off, the stored energy would release to the output capacitors and the output loading through the output SR MOSFET Q1.

Sandwich winding structure for the transformer T1 is used to reduce the leakage inductance, and so the loss in the clamper circuit is reduced. T1 has two output windings; one primarily for the $V_{OUT1}$ (12 V) and the other for the $V_{OUT3}$ (15 V). All the secondary output capacitors should be the low-ESR type, which can effectively reduce the switching ripple. Together with the Y-capacitor CY1 across the primary and secondary side, the EMI noise can be further reduced to comply with CISPR 22 specifications.

## 5.3 Control of flyback converter through fifth-generation QR CoolSET™ ICE5QR1680BG

### 5.3.1 Integrated HV power MOSFET

The ICE5QR1680BG CoolSET™ is a 12-pin device in a DSO-12 package. It has been integrated with the new QR PWM controller and all necessary features and protections, and most importantly the 800 V power MOSFET, Infineon superjunction CoolMOS™. Hence, the schematic is much simplified and the circuit design becomes much easier.

### 5.3.2 Current sensing

The ICE5QR1680BG is a CM controller. The peak current is controlled cycle-by-cycle through the current sensing (CS) resistors R16 and R18 in the CS pin (pin 3), so transformer saturation can be avoided and the system is more robust and reliable.

### 5.3.3 Feedback and compensation network

Resistors R32 and R33 are used to sense the $V_{OUT1}$ and send reference voltage to the feedback (FB) pin (pin 2) via error amplifier TL431 (U6) and optocoupler (U3). A Type II compensation network (C16, C18 and R29) is implemented to stabilize the system.

The FB pin of ICE5QR1680BG is a multifunction pin which is used to select the entry burst power level (there are two levels available) through $R_{sel}$ and also the burst-on/burst-off sense input during active burst mode (ABM).

## 5.4 Unique features of the fifth-generation QR CoolSET™ ICE5QR1680BG to support the requirements of refrigerator auxiliary power

### 5.4.1 Fast self-start-up and sustaining of $V_{CC}$

The IC uses a cascode structure to fast-charge the $V_{CC}$ capacitor. The zero-crossing detection (ZCD) pin (pin 4) is a multifunction pin and it serves as the start-up pin with the connection of pull-up resistors R15, which has the other end connecting to the bus voltage during the start-up phase. At first, $I_{VCC\_Charge1}$ is used to charge the $V_{CC}$ capacitor from 0 V to $V_{CC\_SCP}$. This is a protection which reduces the power dissipation of the power MOSFET during $V_{CC}$ short-to-GND condition. Thereafter, a much higher charging current of $I_{VCC\_Charge2}$ will charge the $V_{CC}$ capacitor until the $V_{CC\_ON}$ is reached.

After start-up, the IC $V_{CC}$ supply is sustained by the auxiliary winding of transformer T1, which needs to support the $V_{CC}$ to be above undervoltage lockout (UVLO) voltage (10 V typ.). In this reference board, the $V_{CC}$ supply is tapped from the +18 V winding.

### 5.4.2 QR switching with valley sensing

ICE5QR1680BG is a QR flyback controller, which always turns on at the lowest valley point of the drain voltage. The IC senses the valley point through the ZCD pin (pin 4), which monitors auxiliary winding voltage by R21, D6 and C9 to the ZCD pin (pin 4) together with the internal resistor $R_{ZCD}$. The IC detects the valley crossing signal. When the ZCD voltage drops below 100 mV (typ.), the CoolMOS™ is allowed to switch on. With QR switching, the lowest switching losses can be achieved for good efficiency.

### 5.4.3 System robustness and reliability through protection features

#### 5.4.3.1 Input voltage monitoring and protection

To avoid system damage due to the high AC input transient, refrigerator auxiliary power requires the input line overvoltage protection (LOVP) to stop the flyback converter switching whenever the $V_{Bus}$ voltage exceeds the operating range. The IC has a $V_{IN}$ pin (pin 2), which can sense $V_{Bus}$ voltage through voltage dividers R4 and R6. When the $V_{IN}$ pin exceeds the protection threshold 2.9 V (typ.), the IC stops switching. With the same $V_{IN}$ sensing, ICE5QR1680BG also implements input undervoltage (UV) protection (brown-in/brown-out) to prevent the overcurrent (OC) stress of the power stage components when the input voltage is too low.

#### 5.4.3.2 Other protections with auto restart

Besides input OV and UV protection, ICE5QR1680BG has more comprehensive protection features to protect the system, such as $V_{CC}$ OV, $V_{CC}$ UV, overload, open-loop protection, output OV, overtemperature, $V_{CC}$ short-to-GND, etc.

## 5.5 Clamper circuit

A clamper network (D4, C6 and R9, R10) is used to reduce the switching spikes on the drain pin, which are generated from the leakage inductance of the transformer T1. This is a dissipative circuit and the selection of the R9, R10 needs to be fine-tuned.

## 5.6 AC zero-crossing detection and LDO enable circuit

A ZCD circuit is usually required in home appliances that supply power from an AC outlet to detect the zero-cross point (which is the 0 V point of the AC waveform) in order to efficiently control motors. Thus, a conventional ZCD circuit was built in here to output a zero-cross signal from 85 V AC to 264 V AC input at the ACZR pin. This circuit can be disabled by removing jumper X2.
The LDO enable function is controlled via an optocoupler U4 by 5 V output, which can reduce standby power loss if LDO output is not required. By removing jumper X1, LDO can be disabled.

## 5.7 PCB design tips

For a good PCB design layout, there are several points to highlight.

- The power loop needs to be as small as possible (see **Figure 4**). There are two power loops in the reference design; one from the primary side and the other from the secondary side. For the primary side, it starts from the bulk capacitor (C2a) positive to the bulk capacitor negative. The power loop components include C2a, the main primary transformer winding (pin 8 and pin 10 of T1), the drain pin and CS pin of the CoolSET™ U1 and CS resistors R16 and R18. For the secondary side, the 12 V output starts from the secondary transformer windings (pin 6 and 7 of T1), SR MOSFET Q1 and output capacitors C21 and C22.
- Star-ground concept should be used to avoid unexpected HF noise coupling to affect the proper control. The ground of the small-signal components, e.g., C3, C9, C11, C13 and R6, and emitter of optocoupler (pin 3 of U3) etc. should connect directly to the IC ground (pin 12 of U1). Then it connects to the negative terminal of the C2a capacitor directly.

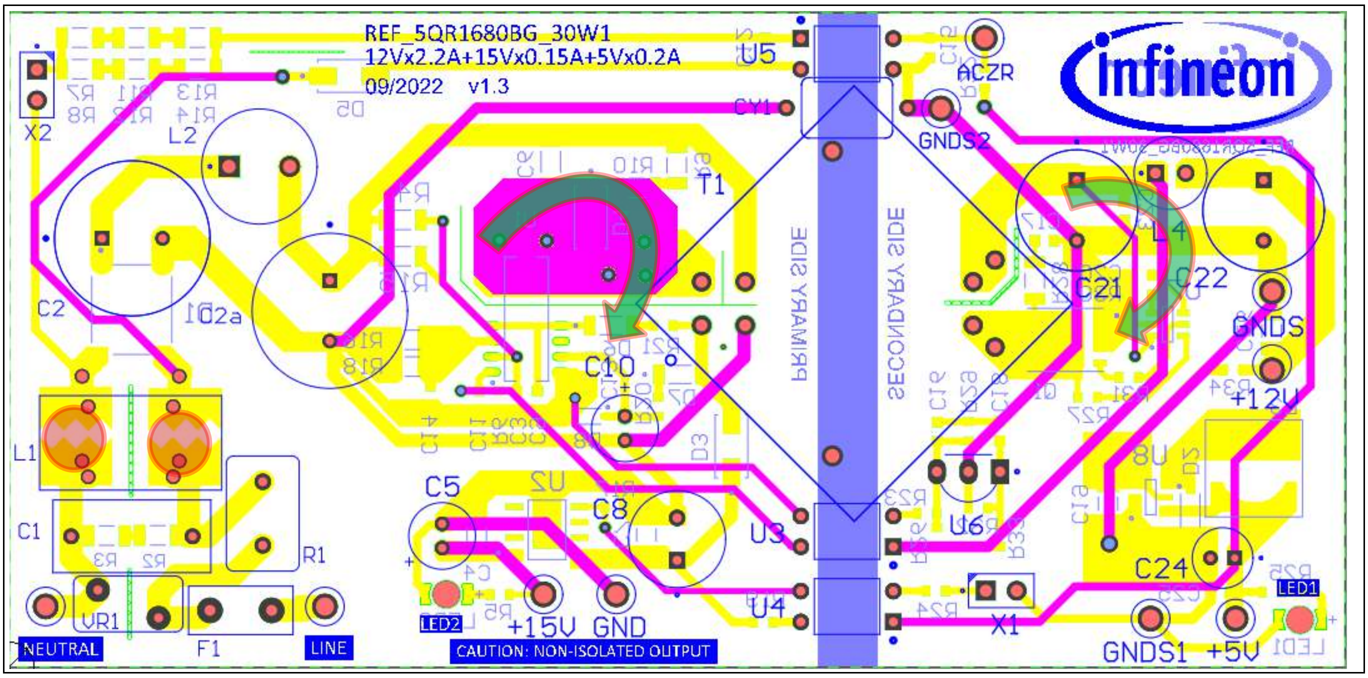



**Figure 4** **PCB layout tips**

- Adding a certain amount of drain PCB copper area can increase the margin of power capability of the CoolSET™.
- Adding spark-gap (PCB sawtooth, 0.5 mm separation) pattern under the input CM choke L1 can improve system input line surge and ESD immunity.

## 5.8 EMI reduction tips

EMI compliance is always a challenge for a power supply. There are several critical points to consider in order to achieve satisfactory EMI performance.

- Good transformer winding coupling is very important. Without this it would lead to high leakage inductance and incur a lot of switching spike and high-frequency (HF) noise. The most effective method is to adopt sandwich winding (refer to **Figure 8**) where the secondary winding is in the middle of the winding and covered by the primary winding on the bottom and top layer. Shielding the transformer can reduce the HF noise. The outermost shield wrapped around the transformer cores with copper foil can help to reduce leakage flux and reduce the noise coupling to nearby components. The inner shield (copper foil or copper wire winding) between the transformer windings can help to reduce the parasitic capacitance and reduce the HF noise coupling. Both shields need to tie to the negative of C2a to achieve the best performance, but note that the inner shield approach would result in more energy loss.
- Short power loop design in the PCB (as described in section **5.6**) and terminating to the low ESR capacitor such as C2 and C2a for primary-side loop and C21 and C22 for the secondary-side loop can help to reduce the switching ripple, which comes out to the input terminals $V_{IN}$. In addition, adding a low-ESR ceramic capacitor in parallel may help to further reduce the switching ripple.
- Sufficient input filter (C1, L1, L2, C2 and C2a) design is important to pass the EMI requirement.
- The Y-capacitor CY1 has a function to return the HF noise to the source (negative of C2a) and reduce the overall HF noise going out to the input terminals. The greater capacitance is more effective. However, a higher value would introduce more leakage current and may fail the safety requirement.

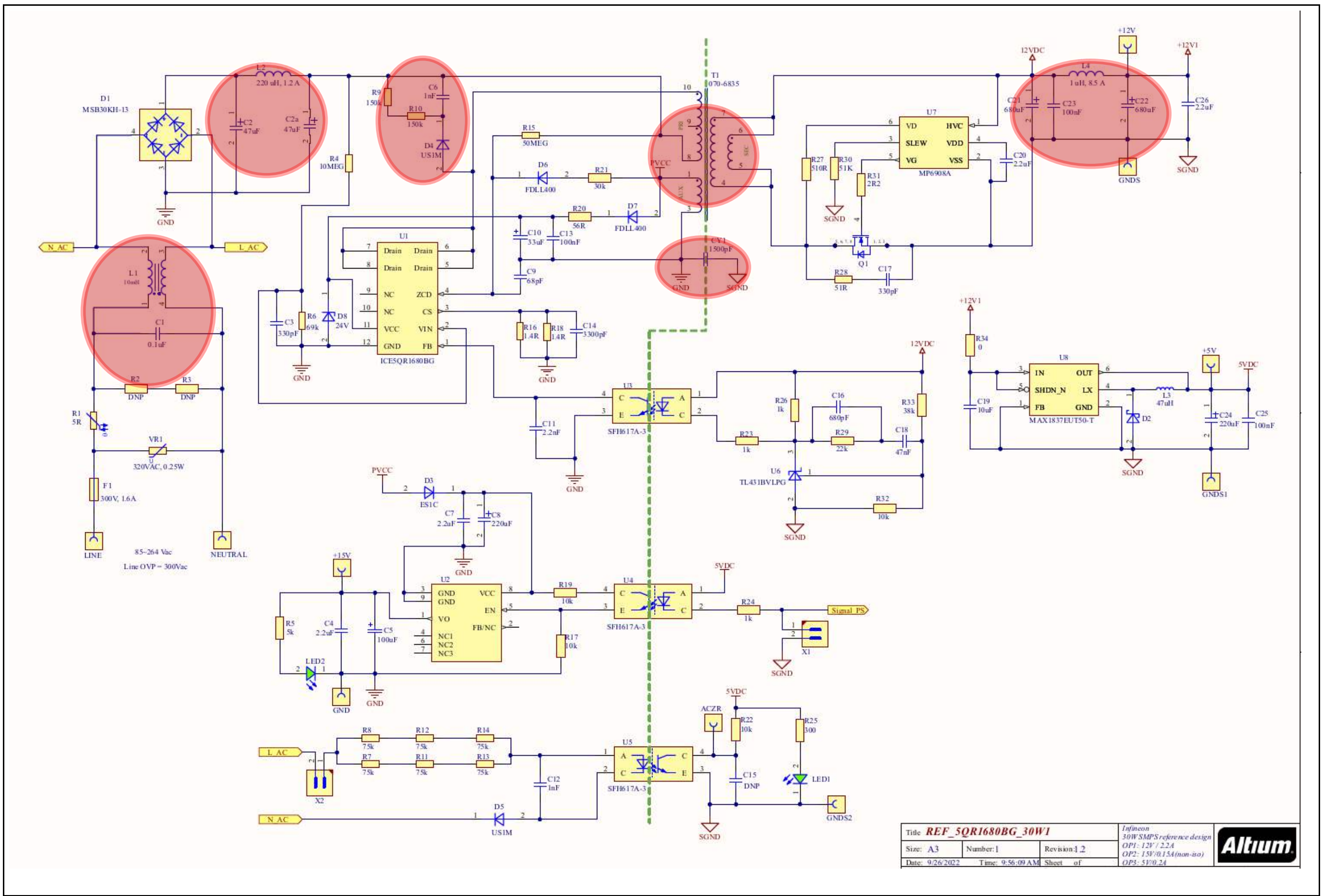


**Figure 5** **EMI reduction tips**

# 6 PCB layout

## 6.1 Top side

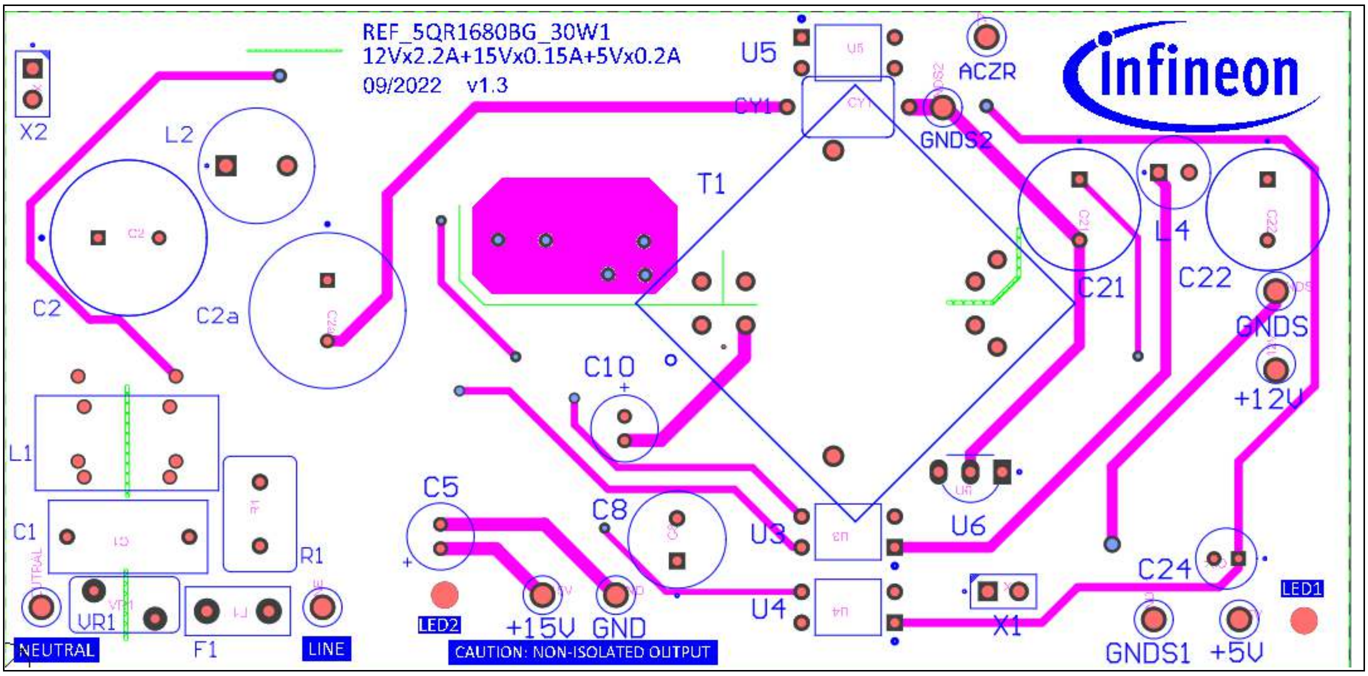



**Figure 6** Top-side component legend

## 6.2 Bottom side

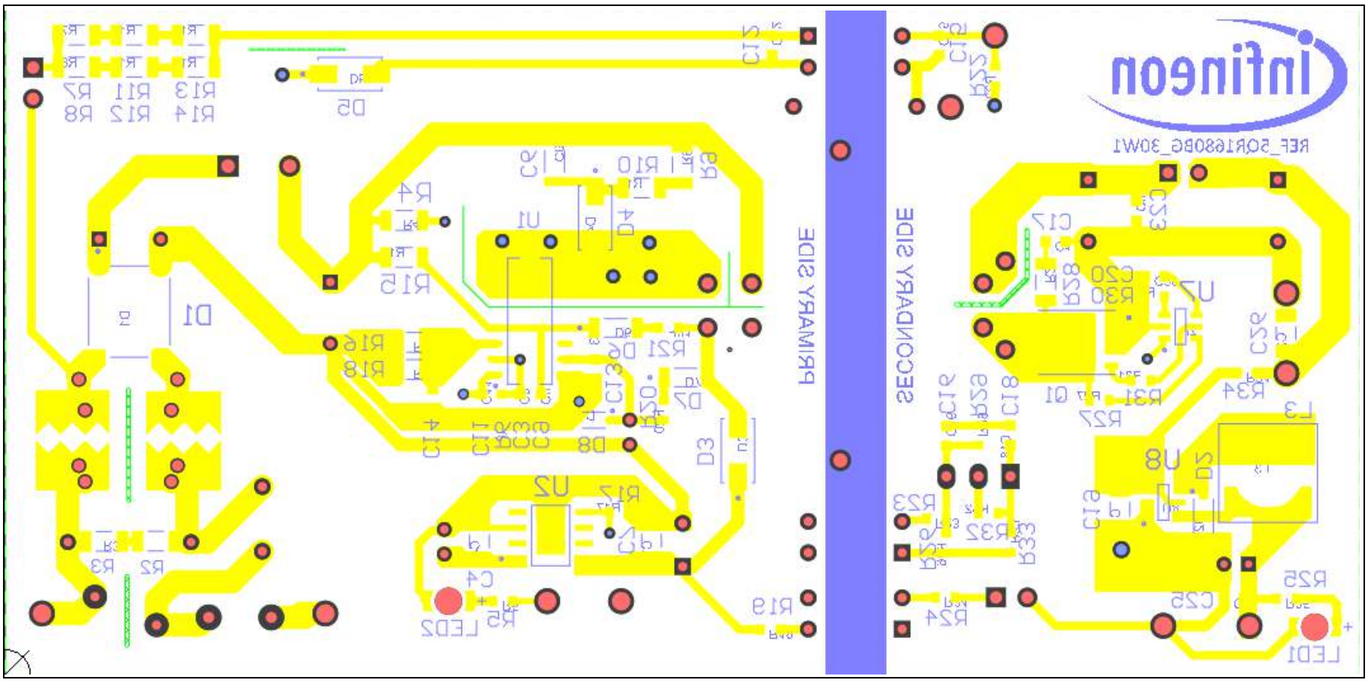



**Figure 7** Bottom-side component legend

# 7 Bill of materials

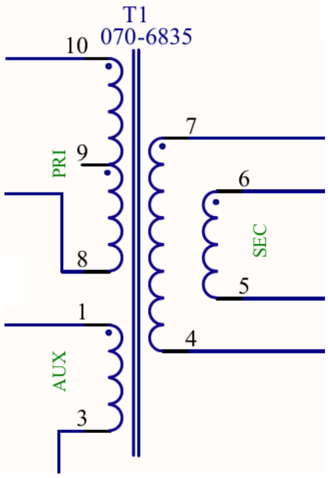
**Table 3 BOM**

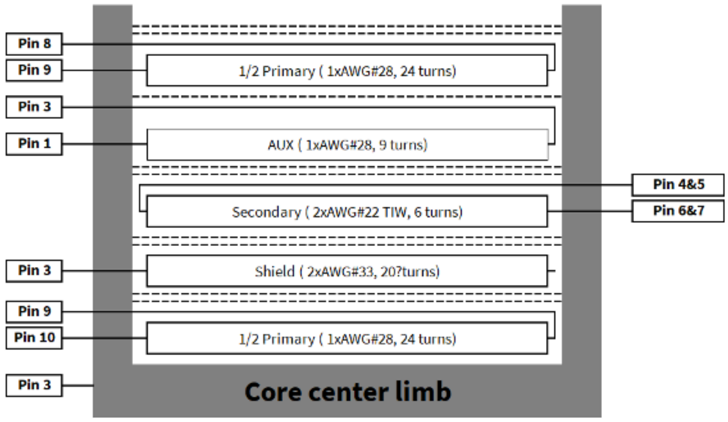
| No. | Designator | Description | Manufacturer | Part number | Quantity |
|---|---|---|---|---|---|
| 1 | C1 | Safety capacitors 0.1 µF 310 V 10% | Würth Elektronik | 890334023023 | 1 |
| 2 | C2, C2a | Aluminum capacitor 47 µF 10% 450 V radial | Rubycon | 450HXW47MEFR12.5X25 | 2 |
| 3 | C3, C17 | Ceramic capacitor 330 pF 100 V CH 0603 | AVX | 06031C331KAZ2A | 3 |
| 4 | C4, C7, C26 | Ceramic capacitor 2.2 µF 50 V X7R 1206 | | | 3 |
| 5 | C13, C23, C25 | Ceramic capacitor 100 nF 50 V X7R 0603 | | | 3 |
| 6 | C5 | Aluminum capacitor 100 µF 20% 25 V radial | Rubycon | 25YXJ100M5X11 | 1 |
| 7 | C6 | Ceramic capacitor 1206 1 nF 500 V X7R 10% FL | Kemet | C1206X102KCRACAUTO | 1 |
| 8 | C8 | Aluminum capacitor 220 µF 20% 35 V radial | United Chemi-Con | EKZE350ELL221MH15D | 1 |
| 9 | C9 | Ceramic capacitor 68 pF 50 V X7R 0603 | | | 1 |
| 10 | C10 | Aluminum capacitor 33 µF 20% 35 V radial | | | 1 |
| 11 | C11 | Ceramic capacitor 0603 2.2 nF 16 V X7R 10% | | | 1 |
| 12 | C12 | Ceramic capacitor 0603 1 nF 50 V X7R 10% | | | 1 |
| 13 | C14 | Ceramic capacitor 0603 3.3 nF 50 V X7R 10% | | | 1 |
| 14 | C16 | Ceramic capacitor 680 pF 50 V X7R 0603 | | | 1 |
| 15 | C18 | Ceramic capacitor 0603 47 nF 16 V X7R 10% | | | 1 |
| 16 | C19 | Ceramic capacitor 10 µF 25 V X7R 1206 | | | 1 |
| 17 | C20 | Ceramic capacitor 2.2 µF 10 V X7R 0603 | | | 1 |
| 18 | C21, C22 | Aluminum capacitor 680 µF 20% 25 V radial | Rubycon | 25ZLH680MEFC10X16 | 2 |
| 19 | C24 | Aluminum capacitor 220 µF 20% 10 V radial | Rubycon | 10YXJ220M5X11 | 1 |
| 20 | CY1 | Ceramic capacitor 1500 pF 250 V radial | Murata | DE1E3KX152MA4BN01F | 1 |
| 21 | D1 | Bridge rectifier single-phase 800 V 3 A 4MSBL | Diodes Inc | MSB30KH-13 | 1 |
| 22 | D2 | Schottky diode 30 V 1 A SOD-123 | ON Semiconductor | MBR130T3G | 1 |
| 23 | D3 | General-purpose diode 150 V 1 A SMA | ON Semiconductor | ES1C | 1 |
| 24 | D6, D7 | General-purpose diode 150 V 200 mA SOD-80 | ON Semiconductor | FDLL400 | 2 |
| 25 | D4, D5 | General-purpose diode 1 kV 1 A SMA | ON Semiconductor | US1M | 2 |
| 26 | D8 | Zener diode 24 V 300 mW SOD-323 | Nexperia | BZX384-C24,115 | 1 |
| 27 | F1 | Time-lag fuse 300 V 1.6A | Littelfuse | 36911600000 | 1 |
| 28 | L1 | CMC 10 mH 2LN TH | Tengda | TD1010-10.0mH | 1 |
| 29 | L2 | Fixed inductor 220 µ H 1.2A 290 mΩ TH | Würth Elektronik | 7447452221 | 1 |
| 30 | L3 | Fixed inductor 47µH 730 mA 280 mΩ SMD | Würth Elektronik | 744062470 | 1 |
| 31 | L4 | Inductor WE-TI size 5075 1 µH 8.5 A | Würth Elektronik | 7447462010 | 1 |
| 32 | LED1, LED2 | Clear green LED two SMD bottom entry | Würth Elektronik | 156120VS82500 | 2 |
| 33 | Q1 | MOSFET N-channel 100 V 80 A TDSON-8 | Infineon | BSC070N10NS5 | 1 |
| 34 | R1 | ICL 5 Ω 20% 4.2 A 9.5 mm | TDK | B57235S0509M000 | 1 |
| 35 | R4 | SMD resistor 10 mΩ 1% 1206 | Vishay | RCV120610M0FKEA | 1 |
| 36 | R5 | SMD resistor 5 kΩ 1% 1/10 W 0603 | | | 1 |
| 37 | R6 | SMD resistor 69 kΩ 1% 1/10 W 0603 | | | 1 |
| 38 | R7, R8, R11, R12, R13, R14 | SMD resistor 75 kΩ 1% 1/4 W 1206 | | | 6 |
| 39 | R9, R10 | SMD resistor 150 kΩ 1% 1/4 W 1206 | | | 2 |
| 40 | R15 | SMD resistor 50 mΩ 1% 1206 | Vishay | CRHA1206AF50M0FKEF | 1 |
| 41 | R16, R18 | SMD resistor 1.3 Ω 1% 1/4 W 1206 | | | 2 |
| 42 | R17, R19, R22, R32 | SMD resistor 10 kΩ 1% 1/10 W 0603 | | | 4 |
| 43 | R20 | SMD resistor 56 Ω 1% 1/10 W 0603 | | | 1 |
| 44 | R21 | SMD resistor 30 kΩ 1% 1/10 W 0603 | | | 1 |
| 45 | R23, R24, R26 | SMD resistor 1 kΩ 1% 1/10 W 0603 | | | 3 |

| No. | Designator | Description | Manufacturer | Part number | Quantity |
|---|---|---|---|---|---|
| 46 | R25 | Resistor 300 Ω 1% 1/8 W 0603 | | | 1 |
| 47 | R27 | SMD resistor 510 Ω 1% 1/10 W 0603 | | | 1 |
| 48 | R28 | SMD resistor 51 Ω 5% 1/4 W 1206 | | | 1 |
| 49 | R29 | SMD resistor 22 kΩ 1% 1/10 W 0603 | | | 1 |
| 50 | R30 | SMD resistor 51 kΩ 1% 1/10 W 0603 | | | 1 |
| 51 | R31 | SMD resistor 2.2 Ω 1% 1/10 W 0603 | | | 1 |
| 52 | R33 | SMD resistor 38 kΩ 1% 1/10 W 0603 | | | 1 |
| 53 | R34 | SMD resistor 0 Ω 1% 1/10 W 0603 | | | 1 |
| 54 | T1 | Transformer RM style, RM8, Rev01 | Würth Elektronik | 750345059 | 1 |
| 55 | U1 | QR 800 V CoolSET™ | Infineon | ICE5QR1680BG | 1 |
| 56 | U2 | 35 V withstand voltage 1 A LDO regulators | Rohm | BDJ5FC0WEFJ-E2 | 1 |
| 57 | U3, U4, U5 | Opto-isolator 5.3 kV transformer 4DIP | Vishay | SFH617A-3 | 3 |
| 58 | U6 | IC $V_{REF}$ shunt ADJ 0.4% TO92-3 | | TL431BVLPG | 1 |
| 59 | U7 | Synchronous rectifier controller | MPS | MP6908A | 1 |
| 60 | U8 | Step-down converter | Maxim Integrated | MAX1837EUT50-T | 1 |
| 61 | VR1 | Varistor 510 V 1.75 kA disc 7 mm | Epcos | B72207S2321K101 | 1 |
| 62 | X1, X2 | Vertical header connector two-position 2.54 mm | Samtec | TSW-102-08-G-S | 2 |
| 63 | X1, X2 | Shunt connector two-position | Samtec | SNT-100-BK-G | 2 |
| 64 | +5 V, +12 V, +15 V, NEUTRAL, ACZR | Test-point multipurpose THT, white | Keystone | 5012 | 5 |
| 65 | GND, LINE, GNDS, GNDS1, GNDS2 | Test-point multipurpose THT, black | Keystone | 5011 | 5 |

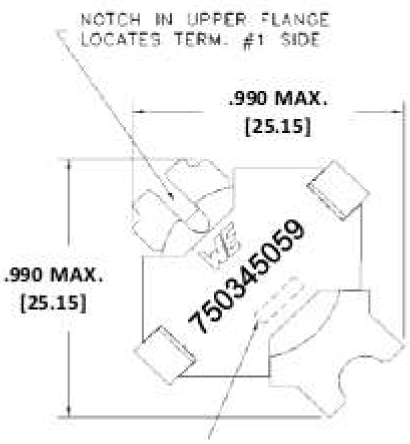
# 8 Transformer specification

- Core and materials: RM8, TP4A (TDG)
- Bobbin: 070-6835 (10-pin, THT, horizontal version)
- Primary inductance: $L_p$ = 450 µH (±10 percent), measured between pin 8 and pin 10
- Manufacturer and part number: Würth Elektronik Midcom (750345059)
- Refer to Appendix A for transformer design and Appendix B for WE transformer specification




Notes:
(1) === 2 layers of tape
(2) core is shielded with a copper foil wrap around it and connected to pin 3 (core and foil shorted)




Top view

**Wire size requirement :**

| Start | Stop | No. of turns | Wire size | Layer |
|---|---|---|---|---|
| Pin 10 | Pin 9 | 24 | 1 x AWG#27 | 1/2 Primary |
| Pin 3 | NC | | 2 x AWG#33 | Shield |
| Pin 6&7 | Pin 4&5 | 6 | 2 x AWG#22 TIW | Secondary |
| Pin 1 | Pin 3 | 9 | 1 x AWG#28 | AUX |
| Pin 9 | Pin 8 | 24 | 1 x AWG#27 | 1/2 Primary |

**Figure 8 Transformer specification**

# 9 Measurement data and graphs

**Table 4 Efficiency data**

| Input (V AC/Hz) | Load percentage | $P_{IN}$ (W) | $V_{O1}$ (V) | $I_{O1}$ (A) | $V_{O2}$ (V) | $I_{O2}$ (A) | $V_{O3}$ (V) | $I_{O3}$ (A) | $P_{OUT}$ (W) | Efficiency (%) | Average efficiency (%) | OLP $P_{IN}$ (W) | OLP $I_{O1}$ (A) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 85 V AC/60 Hz | 25% | 8.92 | 12.000 | 0.545 | 4.96 | 0.045 | 15.06 | 0.038 | 7.335 | 82.24 | 82.74 | 38.34 | 2.40 |
| | 50% | 17.73 | 12.000 | 1.096 | 4.94 | 0.090 | 15.05 | 0.078 | 14.771 | 83.31 | | | |
| | 75% | 26.75 | 11.984 | 1.644 | 4.91 | 0.148 | 15.04 | 0.119 | 22.218 | 83.06 | | | |
| | 100% | 35.81 | 11.984 | 2.195 | 4.88 | 0.193 | 15.03 | 0.149 | 29.486 | 82.34 | | | |
| 115 V AC/60 Hz | 25% | 8.88 | 12.000 | 0.545 | 4.96 | 0.045 | 15.06 | 0.038 | 7.335 | 82.61 | 83.81 | 43.34 | 2.75 |
| | 50% | 17.54 | 12.000 | 1.096 | 4.94 | 0.090 | 15.05 | 0.078 | 14.771 | 84.21 | | | |
| | 75% | 26.41 | 11.984 | 1.644 | 4.91 | 0.148 | 15.04 | 0.119 | 22.218 | 84.13 | | | |
| | 100% | 34.99 | 11.984 | 2.195 | 4.89 | 0.193 | 15.03 | 0.149 | 29.488 | 84.28 | | | |
| 230 V AC/50 Hz | 25% | 8.96 | 12.000 | 0.545 | 4.96 | 0.045 | 15.06 | 0.038 | 7.335 | 81.87 | 84.20 | 44.89 | 2.96 |
| | 50% | 17.45 | 12.000 | 1.096 | 4.94 | 0.090 | 15.05 | 0.078 | 14.771 | 84.64 | | | |
| | 75% | 26.19 | 11.984 | 1.644 | 4.91 | 0.148 | 15.04 | 0.118 | 22.203 | 84.78 | | | |
| | 100% | 34.48 | 11.984 | 2.195 | 4.89 | 0.193 | 15.03 | 0.149 | 29.488 | 85.52 | | | |
| 263 V AC/50 Hz | 25% | 9.07 | 12.000 | 0.545 | 4.96 | 0.045 | 15.06 | 0.038 | 7.335 | 80.88 | 83.79 | 46.21 | 3.05 |
| | 50% | 17.54 | 12.000 | 1.096 | 4.94 | 0.090 | 15.05 | 0.078 | 14.771 | 84.21 | | | |
| | 75% | 26.26 | 12.000 | 1.644 | 4.91 | 0.148 | 15.04 | 0.118 | 22.229 | 84.65 | | | |
| | 100% | 34.52 | 11.984 | 2.195 | 4.89 | 0.193 | 15.03 | 0.149 | 29.488 | 85.42 | | | |

*Note: AC ZCD circuit was disabled (open X2) during efficiency test.*

**Table 5 Single-output (+12 V) configuration efficiency data**

| Input (V AC/Hz) | Load percentage | $P_{IN}$ (W) | $V_{O1}$ (V) | $I_{O1}$ (A) | $P_{OUT}$ (W) | Efficiency (%) | Average efficiency (%) |
|---|---|---|---|---|---|---|---|
| 85 V AC/60 Hz | 0 | 0.038 | 12.000 | 0.000 | 0.000 | | |
| | 10% | 3.020 | 12.000 | 0.216 | 2.592 | 85.83 | |
| | 25% | 7.331 | 12.000 | 0.545 | 6.540 | 89.21 | 88.66 |
| | 50% | 14.772 | 12.000 | 1.096 | 13.152 | 89.03 | |
| | 75% | 22.210 | 12.000 | 1.644 | 19.728 | 88.82 | |
| | 100% | 30.040 | 11.984 | 2.195 | 26.305 | 87.57 | |
| 115 V AC/60 Hz | 0 | 0.041 | 12.000 | 0.000 | 0.000 | | |
| | 10% | 3.050 | 12.000 | 0.216 | 2.592 | 84.98 | |
| | 25% | 7.290 | 12.000 | 0.544 | 6.528 | 89.55 | 89.90 |
| | 50% | 14.590 | 12.000 | 1.096 | 13.152 | 90.14 | |
| | 75% | 21.910 | 12.000 | 1.644 | 19.728 | 90.04 | |
| | 100% | 29.310 | 12.000 | 2.195 | 26.340 | 89.87 | |
| 230 V AC/50 Hz | 0 | 0.053 | 12.000 | 0.000 | 0.000 | | |
| | 10% | 3.048 | 12.000 | 0.216 | 2.592 | 85.04 | |
| | 25% | 7.436 | 12.000 | 0.544 | 6.528 | 87.79 | 89.67 |
| | 50% | 14.630 | 12.000 | 1.096 | 13.152 | 89.90 | |
| | 75% | 21.860 | 12.000 | 1.644 | 19.728 | 90.25 | |
| | 100% | 29.020 | 12.000 | 2.195 | 26.340 | 90.76 | |
| 264 V AC/50 Hz | 0 | 0.057 | 12.000 | 0.000 | 0.000 | | |
| | 10% | 3.085 | 12.000 | 0.216 | 2.592 | 84.02 | |
| | 25% | 7.510 | 12.000 | 0.544 | 6.528 | 86.92 | 89.23 |
| | 50% | 14.690 | 12.000 | 1.096 | 13.152 | 89.53 | |
| | 75% | 21.920 | 12.000 | 1.644 | 19.728 | 90.00 | |
| | 100% | 29.120 | 12.000 | 2.195 | 26.340 | 90.45 | |

*Note:* *Single-output (+12 V) configuration efficiency measurement was done by removing the LDO circuit (open X1) and DC-DC circuit (remove R34), and also shorting R20 on board. The overall circuit is not optimized for single-output configuration; the above efficiency data is for illustration only.*

**Table 6 Standby power measurement**

<table>
<tr><th rowspan="2">Test condition</th><th>Input condition</th><th>$P_{IN}$</th><th>$V_{O1}$ (+12 V)</th><th>$V_{O2}$ (+5 V)</th><th>$V_{O3}$ (+15 V)</th><th>AC_ZR detection circuit</th></tr>
<tr><th>(V AC/Hz)</th><th>(W)</th><th>(V)</th><th>(V)</th><th>(V)</th><th>(On/Off)</th></tr>
<tr><td rowspan="4">Condition 1</td><td>85 V AC/60 Hz</td><td>0.341</td><td>12.000</td><td>4.963</td><td>15.097</td><td rowspan="4">On</td></tr>
<tr><td>115 V AC/60 Hz</td><td>0.368</td><td>12.000</td><td>4.965</td><td>15.097</td></tr>
<tr><td>230 V AC/50 Hz</td><td>0.566</td><td>12.000</td><td>4.963</td><td>15.100</td></tr>
<tr><td>264 V AC/50 Hz</td><td>0.649</td><td>12.000</td><td>4.965</td><td>15.100</td></tr>
<tr><td rowspan="4">Condition 2</td><td>85 V AC/60 Hz</td><td>0.304</td><td>12.000</td><td>4.963</td><td>15.100</td><td rowspan="12">Off</td></tr>
<tr><td>115 V AC/60 Hz</td><td>0.306</td><td>12.000</td><td>4.963</td><td>15.100</td></tr>
<tr><td>230 V AC/50 Hz</td><td>0.323</td><td>12.000</td><td>4.963</td><td>15.100</td></tr>
<tr><td>264 V AC/50 Hz</td><td>0.335</td><td>12.000</td><td>4.965</td><td>15.100</td></tr>
<tr><td rowspan="4">Condition 3</td><td>85 V AC/60 Hz</td><td>0.169</td><td>12.000</td><td>4.965</td><td rowspan="8">Disabled</td></tr>
<tr><td>115 V AC/60 Hz</td><td>0.172</td><td>12.000</td><td>4.968</td></tr>
<tr><td>230 V AC/50 Hz</td><td>0.186</td><td>12.000</td><td>4.968</td></tr>
<tr><td>264 V AC/50 Hz</td><td>0.191</td><td>12.000</td><td>4.968</td></tr>
<tr><td rowspan="4">Condition 4</td><td>85 V AC/60 Hz</td><td>0.038</td><td>12.000</td><td rowspan="4">Disabled</td></tr>
<tr><td>115 V AC/60 Hz</td><td>0.041</td><td>12.000</td></tr>
<tr><td>230 V AC/50 Hz</td><td>0.053</td><td>12.000</td></tr>
<tr><td>264 V AC/50 Hz</td><td>0.057</td><td>12.000</td></tr>
</table>

*Note: Standby power was measured under four different test conditions, below; there is no load at any output throughout testing:*

- Condition 1: power on as per original board delivered with all features and outputs enabled;
- Condition 2: disable AC ZCD circuit, enable 12 V, 5 V and 15 V outputs;
- Condition 3: disable AC ZCD circuit and 15 V LDO circuit, enable 12 V and 5 V outputs;
- Condition 4: test under single output (+12 V) configuration.

### 9.1 Efficiency curve

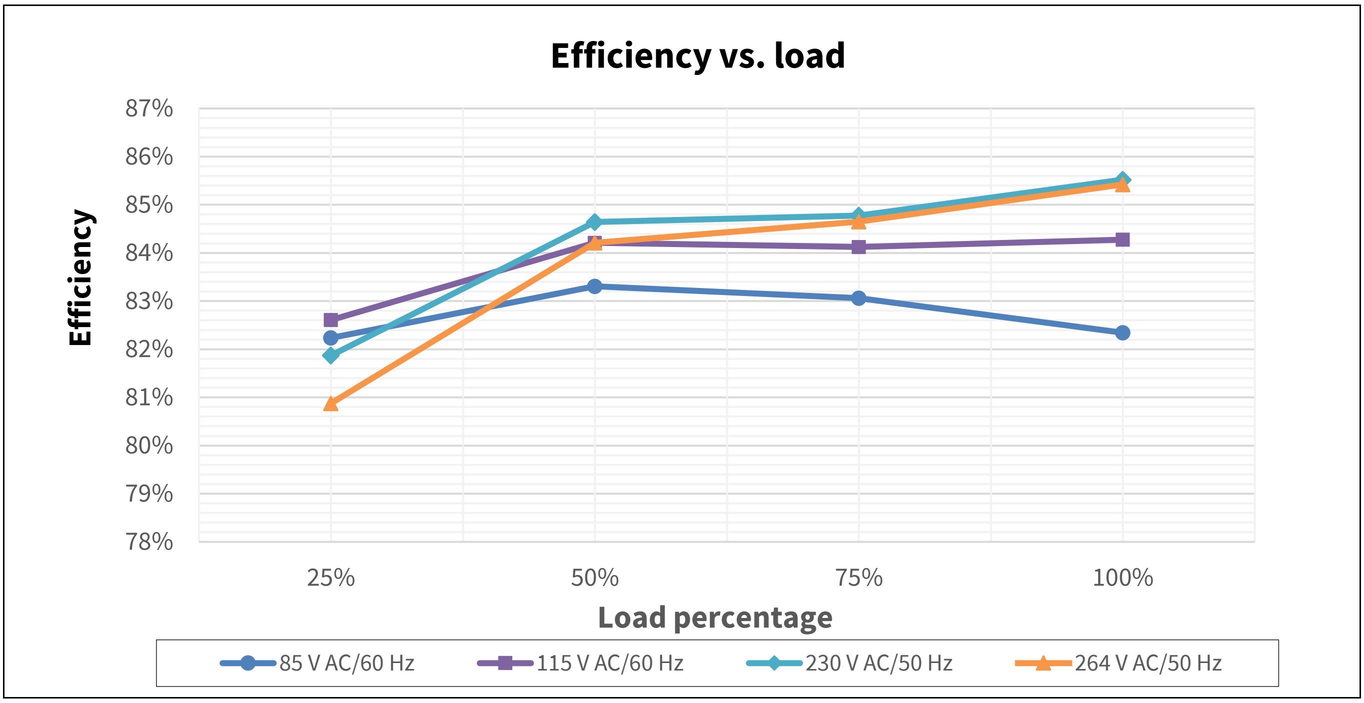



**Figure 9** Efficiency curve

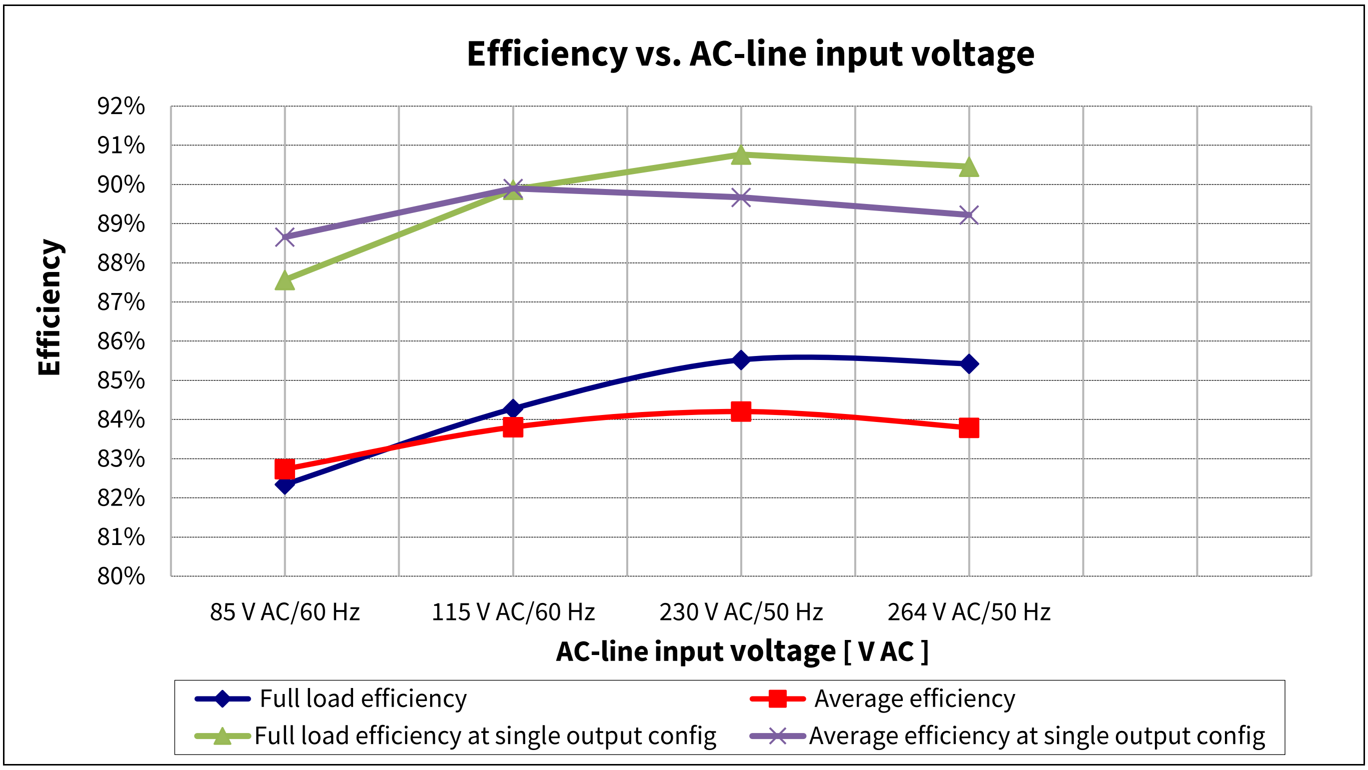



**Figure 10** Efficiency vs. AC-line input voltage

## 9.2 Line and load regulation

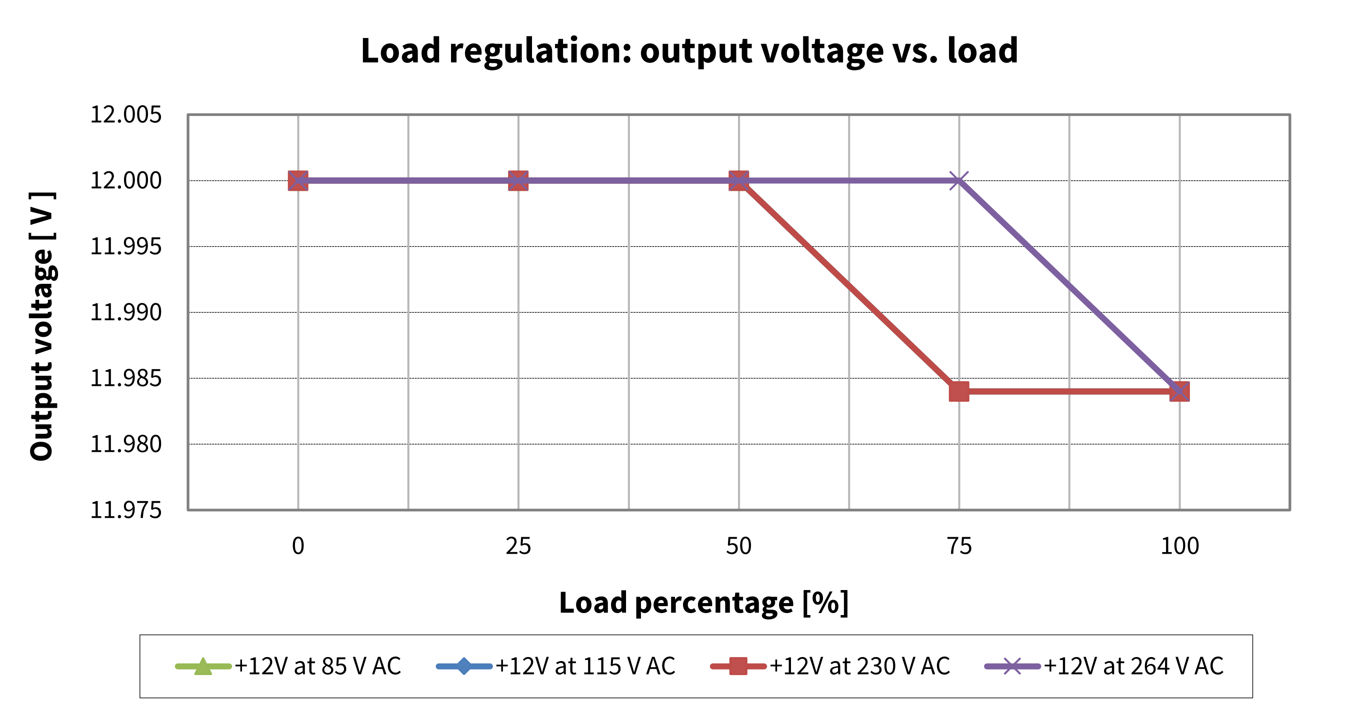



**Figure 11** Line and load regulation (+12 V output)

## 9.3 Standby power

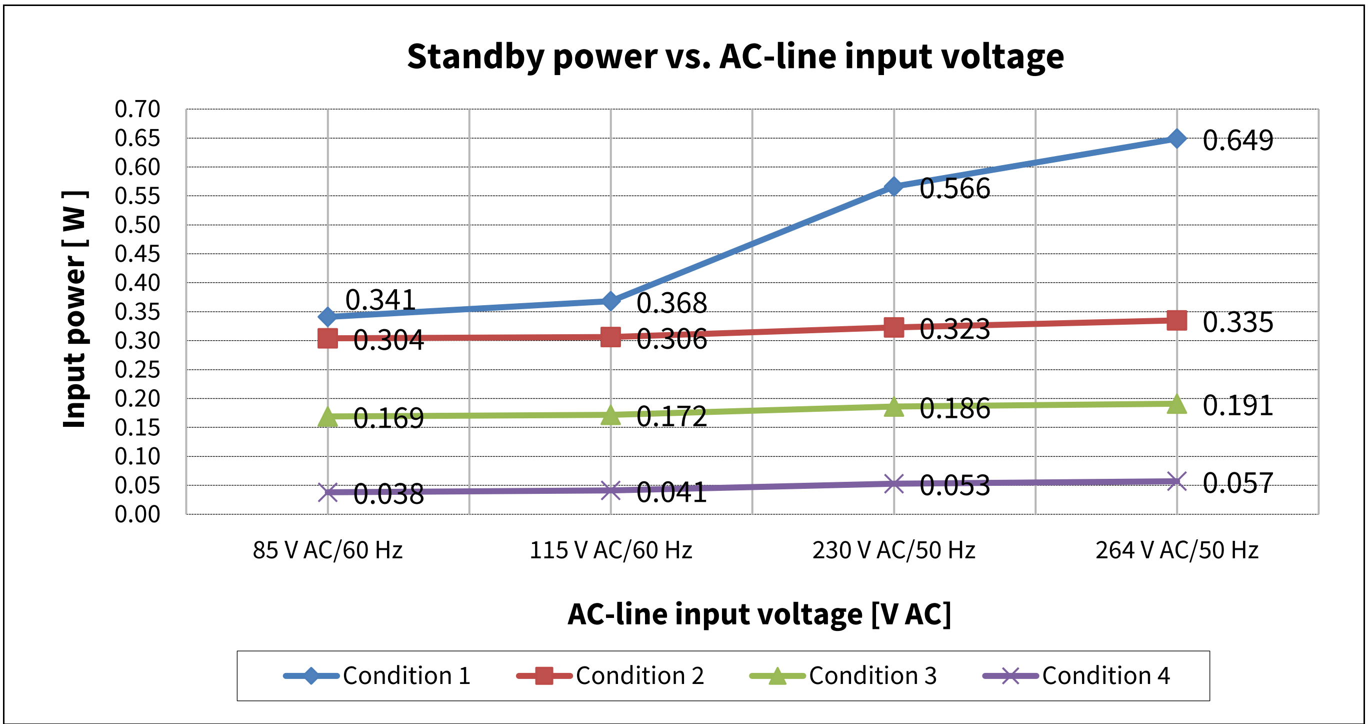



**Figure 12** Standby power vs. AC-line input voltage (refer to page 18 for all conditions)

## 9.4 Maximum input power

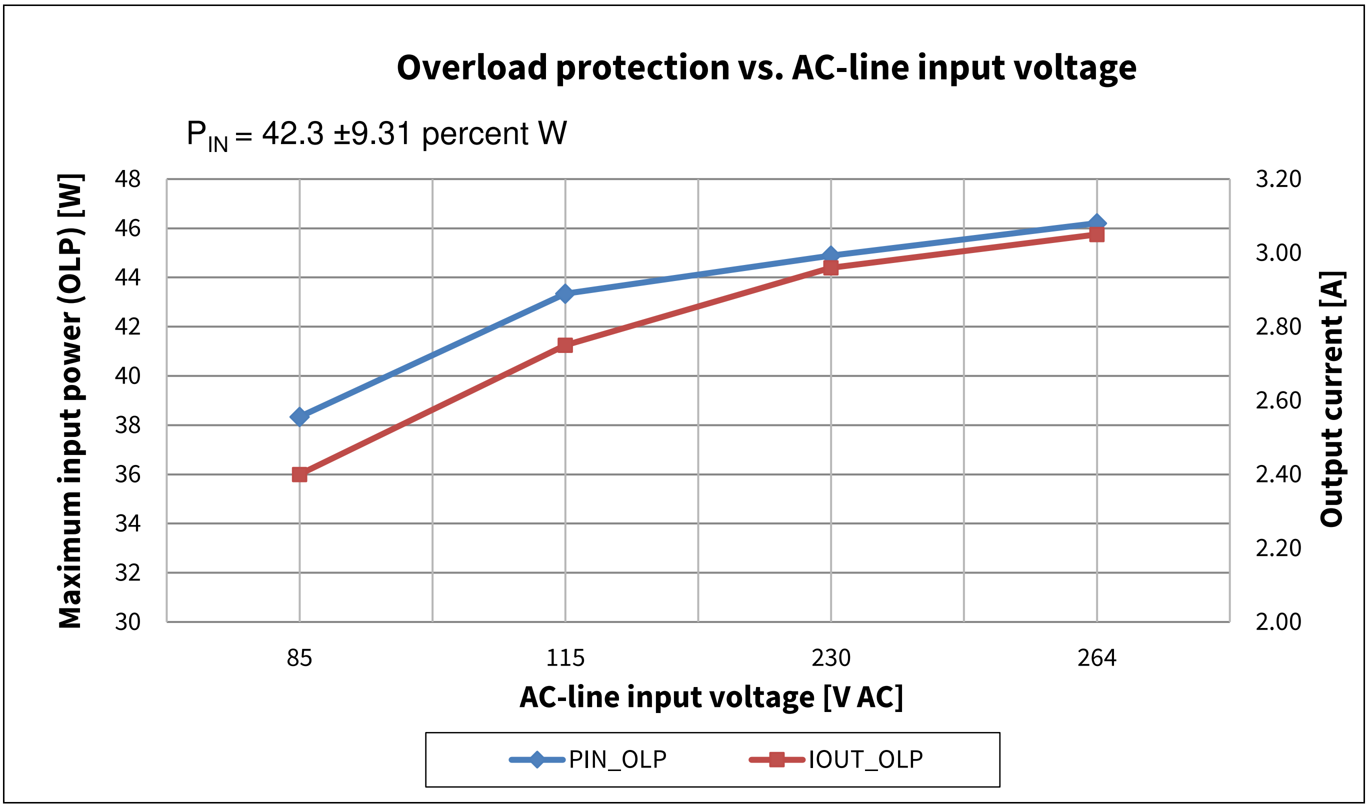



**Figure 13** Maximum input power (before overload protection) vs. AC-line input voltage

## 9.5 ESD immunity (EN 61000-4-2)

This system was subjected to ESD testing according to EN 61000-4-2 level 3 (±6 kV contact and ±8 kV air discharge). It was tested at full load (resistive load). A test failure was defined as non-recoverable.

**Table 7** System ESD test result

| Description | ESD test | Level | Number of strikes | | Test result |
|---|---|---|---|---|---|
| | | | $V_{OUT1}$ | Com | |
| 115/230 V AC, 30 W | Contact | ±6 kV | 10 | 10 | Pass |
| | Air | ±8 kV | 10 | 10 | Pass |

## 9.6 Surge immunity (EN 61000-4-5)

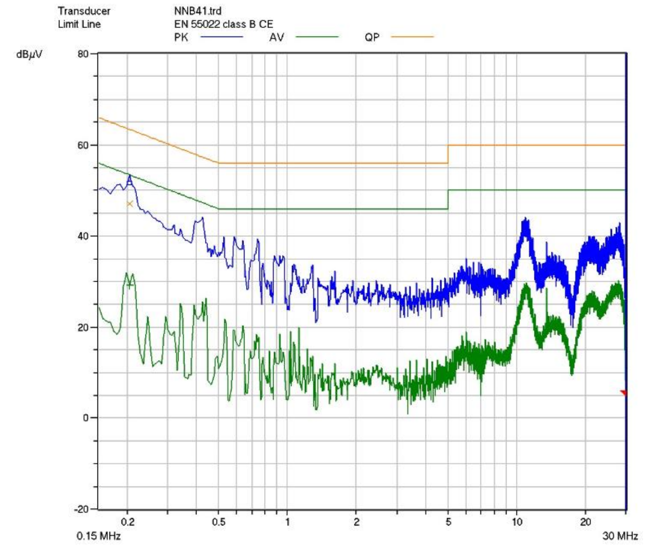
The reference board was subjected to a surge immunity test (±2 kV DM and ±4 kV CM) according to EN 61000-4-5. It was tested at full load (resistive load). A test failure was defined as non-recoverable.

**Table 8** System lightning surge immunity test result

| Description | Test | Level | | Number of strikes | | | | Test result |
|---|---|---|---|---|---|---|---|---|
| | | | | 0° | 90° | 180° | 270° | |
| 115/230 V AC, 30 W | DM | ±2 kV | L → N | 3 | 3 | 3 | 3 | Pass |
| | CM | ±4 kV | L → G | 3 | 3 | 3 | 3 | Pass |
| | | ±4 kV | N → G | 3 | 3 | 3 | 3 | Pass |

## 9.7 Conducted emissions (EN 55022 class B)

The conducted EMI was measured by Schaffner (SMR4503) and followed the test standard of EN 55022 (CISPR 22) class B. The reference board was tested at full load (resistive load) at input voltages of 115 V AC and 230 V AC.




Final Measurement Results: * = Limit exceeded

| Frequency | | Level Pk | | Level AV | | Level QP | Limit AV | Limit QP |
|---|---|---|---|---|---|---|---|---|
| 0.2040 | L | 51.8 | L | 29.2 | L | 47.2 | 53.4 | 63.4 |

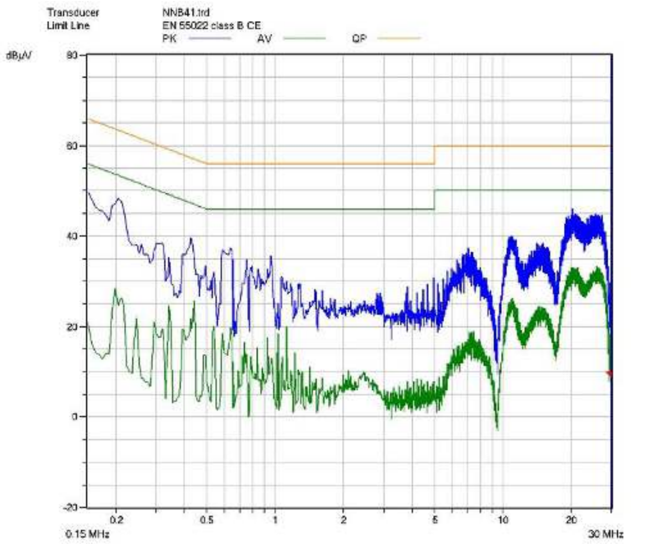
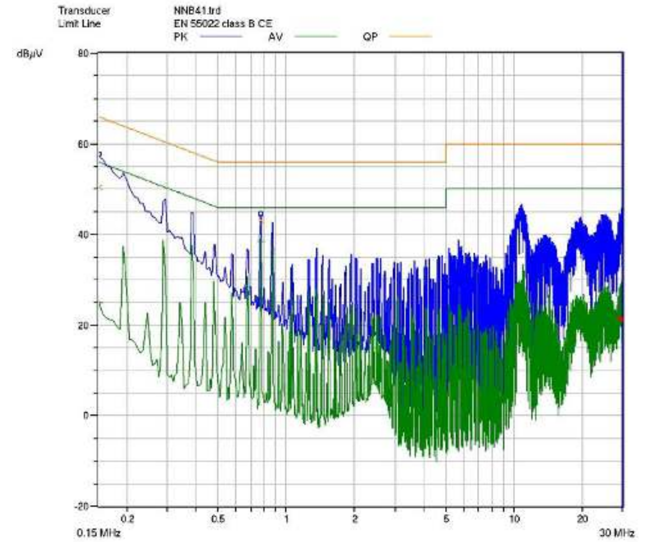
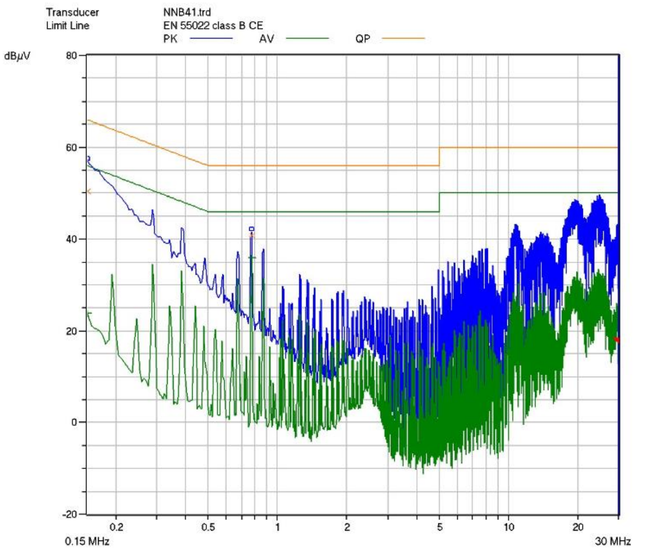



**Figure 14 Conducted emissions at 115 V AC and full load on line (left) and neutral (right)**




Final Measurement Results: * = Limit exceeded

| Frequency | | Level Pk | | Level AV | | Level QP | Limit AV | Limit QP |
|---|---|---|---|---|---|---|---|---|
| 0.1500 | L | 57.8 | L | 24.8 | L | 50.4 | 56.0 | 66.0 |
| 0.7680 | L | 44.5 | L | 38.5 | L | 43.2 | 46.0 | 56.0 |




Final Measurement Results: * = Limit exceeded

| Frequency | | Level Pk | | Level AV | | Level QP | Limit AV | Limit QP |
|---|---|---|---|---|---|---|---|---|
| 0.1500 | L | 57.6 | L | 23.9 | L | 50.4 | 56.0 | 66.0 |
| 0.7680 | L | 42.1 | L | 36.0 | L | 40.8 | 46.0 | 56.0 |

**Figure 15 Conducted emissions at 230 V AC and full load on line (left) and neutral (right)**

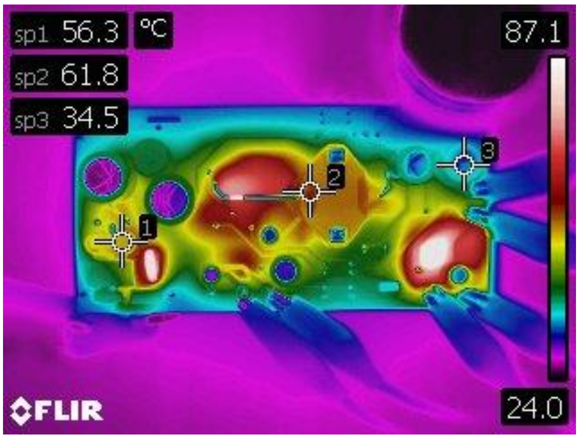
## 9.8 Thermal measurement

The thermal testing of the reference board was done in the open air without forced ventilation at an ambient temperature of 25°C. An infrared thermography camera (FLIR-T62101) was used to capture the thermal reading of particular components. The measurements were taken at the maximum load running for one hour. The tested input voltages were 85 V AC and 264 V AC.

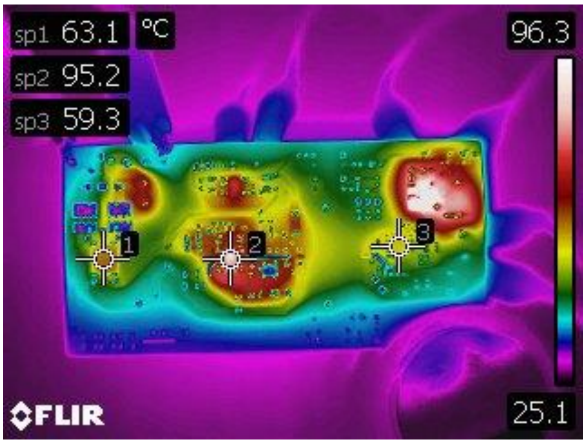
**Table 9 Component temperature at full load under $T_{amb}$ = 25°C**

| Circuit code | Major component | 85 V AC (°C) | 264 V AC (°C) |
|---|---|---|---|
| L1 | Input CMC choke | 56.3 | 38.5 |
| TR1 | Main transformer | 61.8 | 70.5 |
| D1 | Bridge diode | 63.1 | 45.9 |
| U1 | ICE5QR1680BG | 95.2 | 82.6 |
| Q1 | SR MOSFET | 59.3 | 63.5 |

**85 V AC maximum load and 25°C ambient**

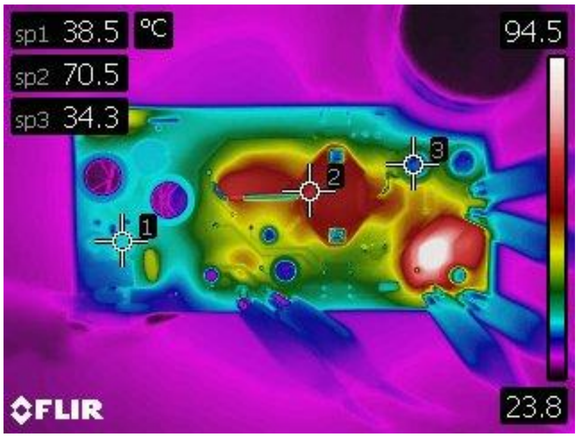



Top side




Bottom side

**264 V AC maximum load and 25°C ambient**




Top side


Bottom side

**Figure 16 Infrared thermal image of REF_5QR1680BG_30W1**

# 10 Waveforms and scope plots

All waveforms and scope plots were recorded with a Teledyne LeCroy 44Xi oscilloscope.

## 10.1 Start-up at full load

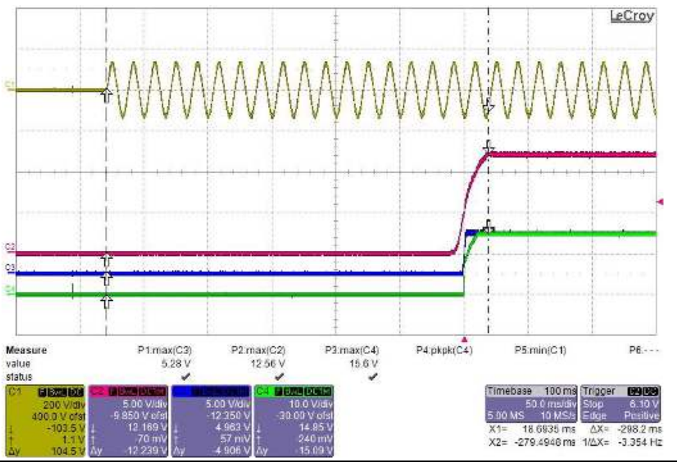
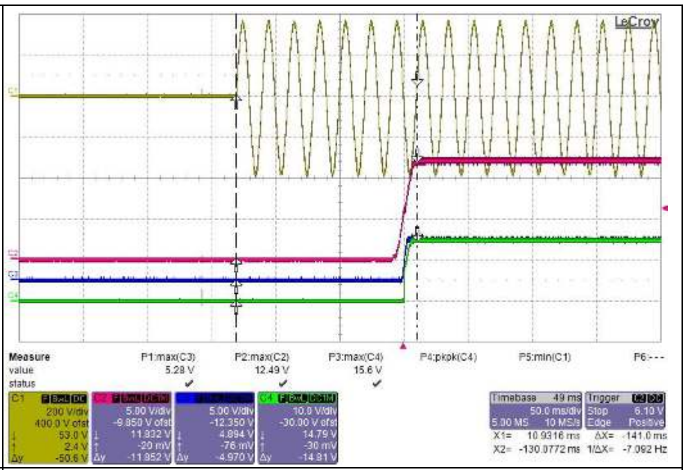
| | |
|---|---|
|  |  |
| C1 (yellow) : AC-line voltage<br>C2 (purple) : +12 V output voltage<br>C3 (blue) : +5 V output voltage<br>C4 (green) : +15 V output voltage | C1 (yellow) : AC-line voltage<br>C2 (purple) : +12 V output voltage<br>C3 (blue) : +5 V output voltage<br>C4 (green) : +15 V output voltage |
| 85 V AC start-up time at full load is around 298 ms | 264 V AC start-up time at full load is around 141 ms |

**Figure 17 Start-up at full load**

## 10.2 Soft-start at full load

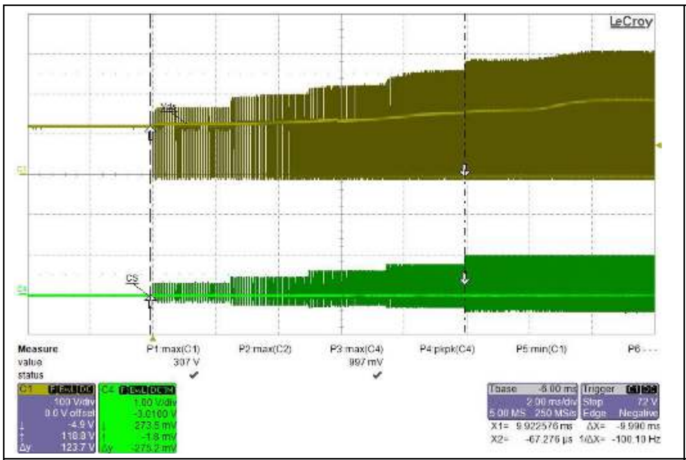
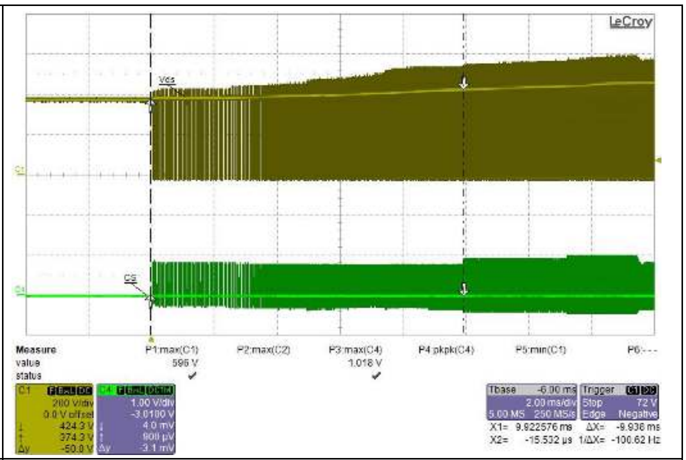
| | |
|---|---|
|  |  |
| C1 (yellow) : Drain voltage<br>C4 (green) : CS voltage | C1 (yellow) : Drain voltage<br>C4 (green) : CS voltage |
| 85 V AC soft-start at full load within ~10 ms | 264 V AC soft-start time at full load within ~10 ms |

**Figure 18 Soft-start at full load**

## 10.3 Switching waveform at full load

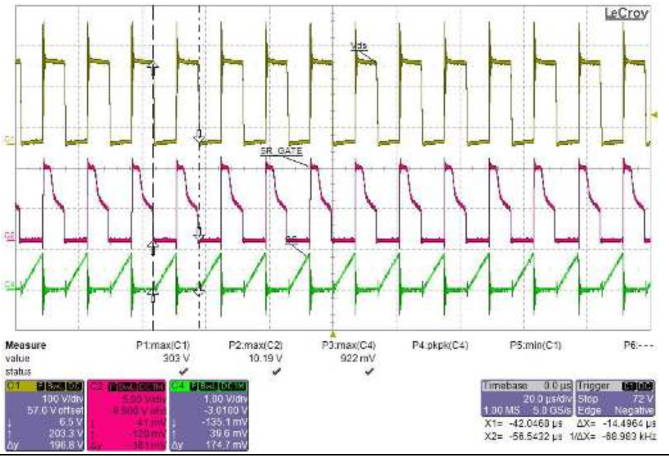
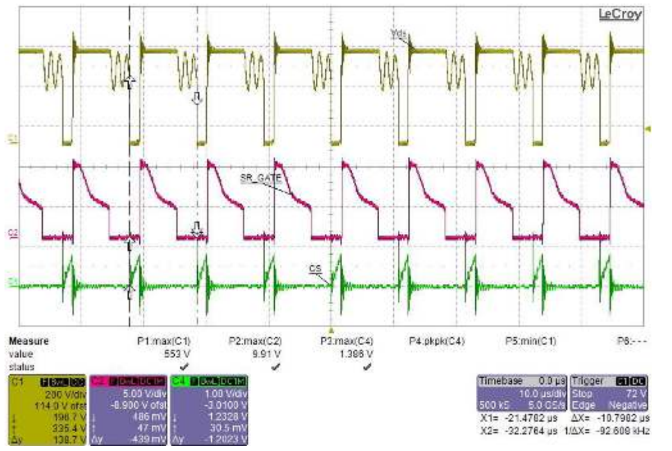
| | |
|---|---|
|  |  |
| C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : SR gate signal<br>C4 (green) : CS voltage ($V_{CS}$) | C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : SR gate signal<br>C4 (green) : CS voltage ($V_{CS}$) |
| $V_{IN}$ = 85 V AC, full load; the first ZC is measured (highest ZC at low-line)<br>Switching frequency is around 69 kHz | $V_{IN}$ = 264 V AC, full load; the third ZC is measured (highest ZC at high-line)<br>Switching frequency is around 92 kHz |

**Figure 19 Switching waveform at full load**

## 10.4 Output ripple voltage at full load

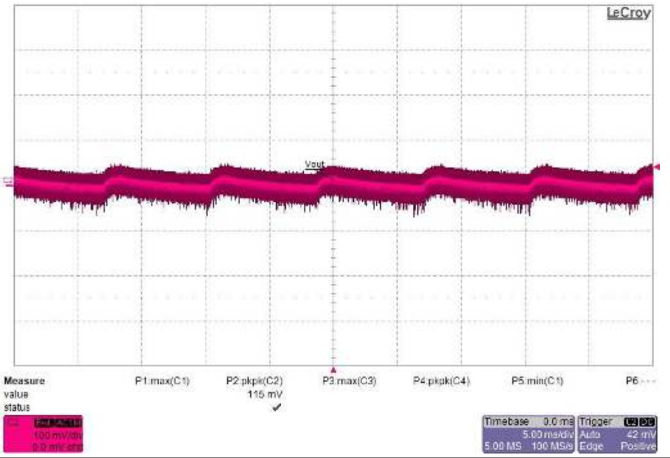
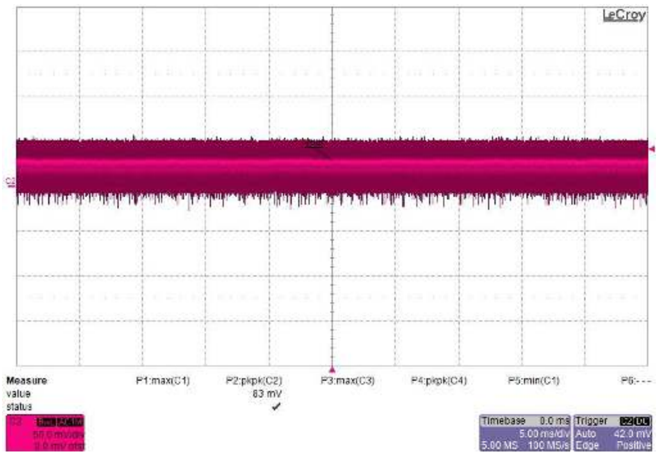
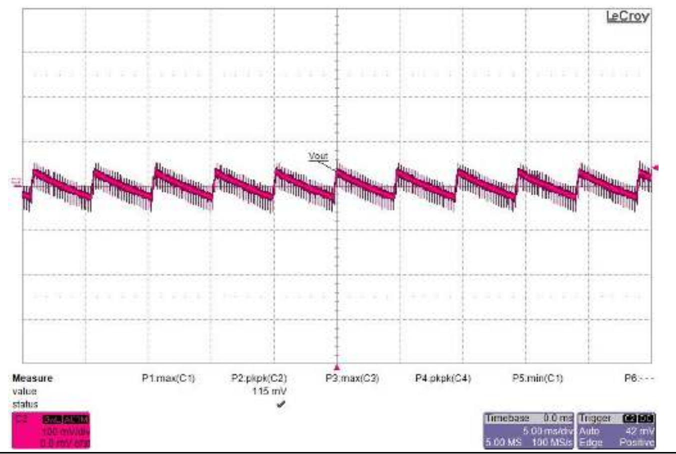
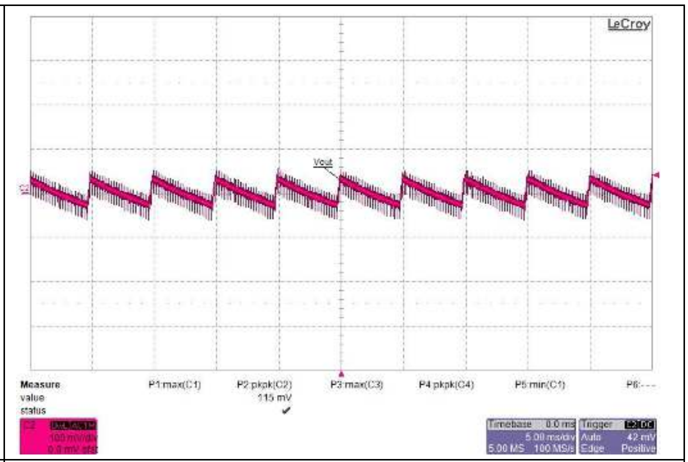
| | |
|---|---|
|  |  |
| C2 (purple) : +12 V output ripple voltage | C2 (purple) : +12 V output ripple voltage |
| Input 85 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 115 mV | Input 264 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 83 mV |

**Figure 20 Output ripple voltage at full load (20 MHz bandwidth and 10 µF electrolytic capacitor in parallel with 0.1 µF ceramic capacitor)**

## 10.5 Output ripple voltage in ABM

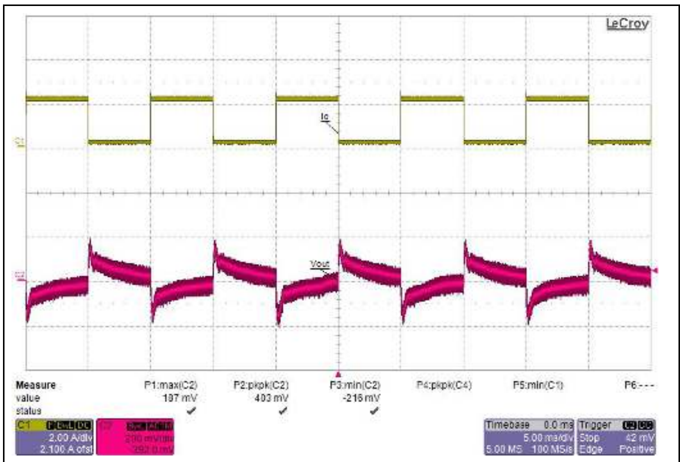


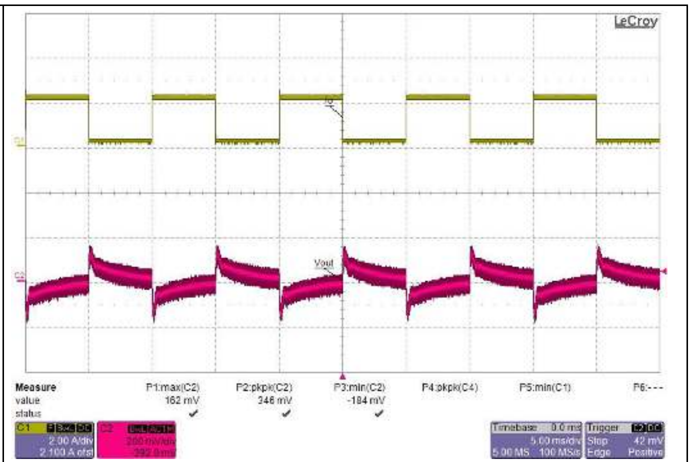




| | |
|---|---|
| C2 (purple) : +12 V output ripple voltage | C2 (purple) : +12 V output ripple voltage |
| Input 85 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 115 mV | Input 264 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 115 mV |

**Figure 21 Output ripple voltage in ABM (20 MHz bandwidth and 10 µF electrolytic capacitor in parallel with 0.1 µF ceramic capacitor)**

## 10.6 Load-transient response




| | |
|---|---|
| C4 (yellow) : Load current<br>C2 (purple) : +12 V output voltage | C4 (yellow) : Load current<br>C2 (purple) : +12 V output voltage |
| Input 85 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 216 mV | Input 264 V AC<br>$V_{ripple\_pk\_pk}$ for +12 V output voltage: 184 mV |

**Figure 22 Load-transient response (+12 V output load change from 10 percent to 100 percent at 0.4 A/µs slew rate, 100 Hz, +15 V output and +5 V output load are fixed at full load; 20 MHz bandwidth and 10 µF electrolytic capacitor in parallel with 0.1 µF ceramic capacitor)**

## 10.7 Entering ABM

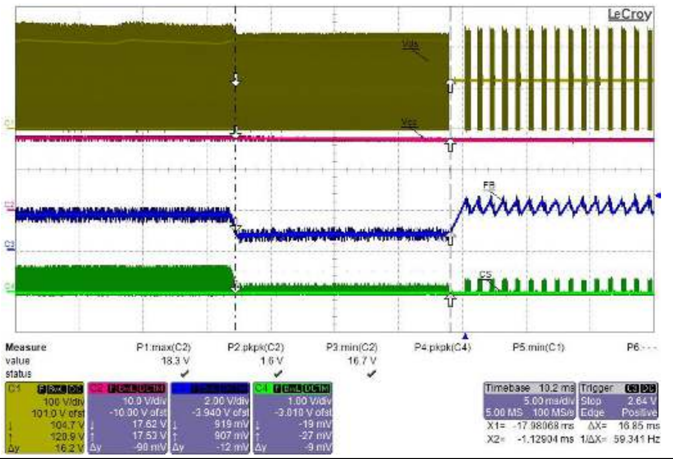
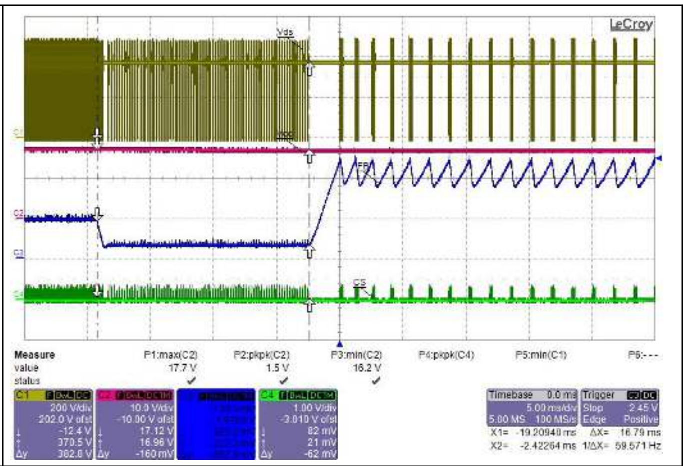
| | |
|---|---|
|   |   |
| C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) | C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) |
| Condition to enter ABM level 1: $V_{FB}$ less than 0.9 V, $N_{ZC}$ = 8 and $t_{blanking}$ = ~20 ms<br>(load change from 5 W to 0.5 W at 85 V AC) | Condition to enter ABM level 1: $V_{FB}$ less than 0.9 V, $N_{ZC}$ = 10 and $t_{blanking}$ = ~20 ms<br>(load change from 5 W to 0.5 W at 264 V AC) |

**Figure 23 Entering ABM**

## 10.8 During ABM

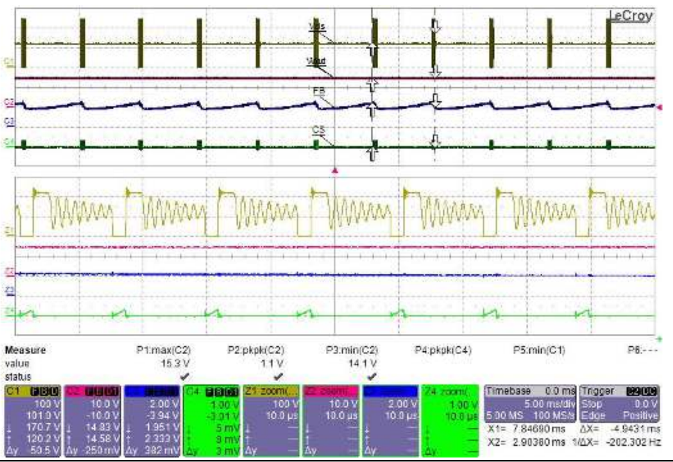
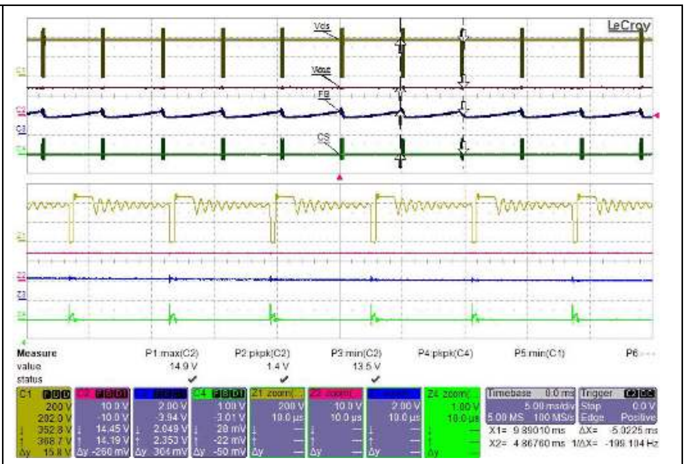
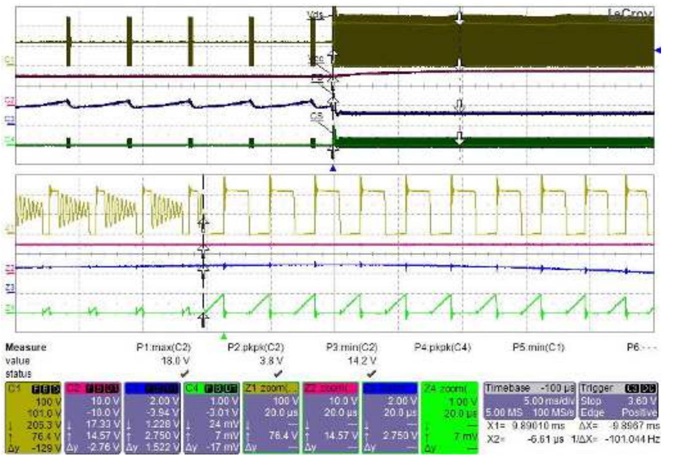
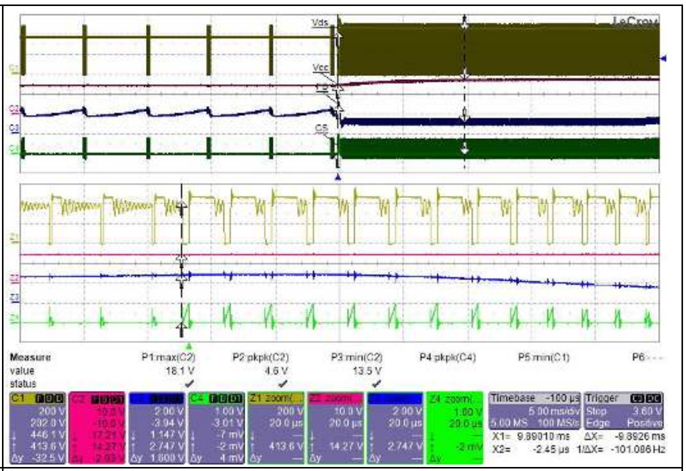
| | |
|---|---|
|   |   |
| C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) | C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) |
| During ABM level 1: $V_{FB\_Bon}$ = 2.4 V<br>$V_{FB\_BOff}$ = 2.0 V, $V_{CSBLP}$ = 0.31 V, $N_{ZC}$ = 8<br>(no load at 85 V AC) | During ABM level 1: $V_{FB\_Bon}$ = 2.4 V<br>$V_{FB\_BOff}$ = 2.0 V, $V_{CSBLP}$ = 0.31 V, $N_{ZC}$ = 10<br>(no load at 264 V AC) |

**Figure 24 During ABM**

## 10.9 Leaving ABM

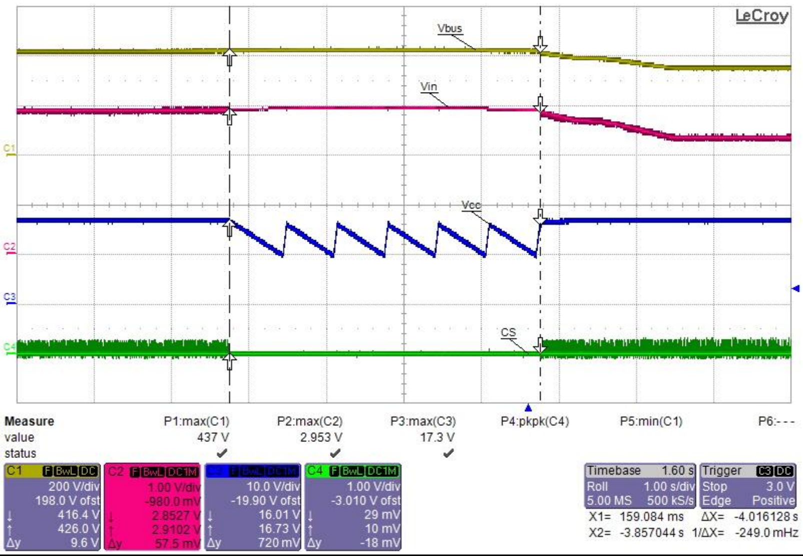





| | |
|---|---|
| C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) | C1 (yellow) : Drain voltage ($V_D$)<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : Feedback voltage ($V_{FB}$)<br>C4 (green) : CS voltage ($V_{CS}$) |
| Condition to leave ABM: $V_{FB}$ more than 2.75 V<br>(load change from no load to full load at 85 V AC) | Condition to leave ABM: $V_{FB}$ more than 2.75 V<br>(load change from no load to full load at 264 V AC) |

**Figure 25** **Leaving ABM**

## 10.10 LOVP

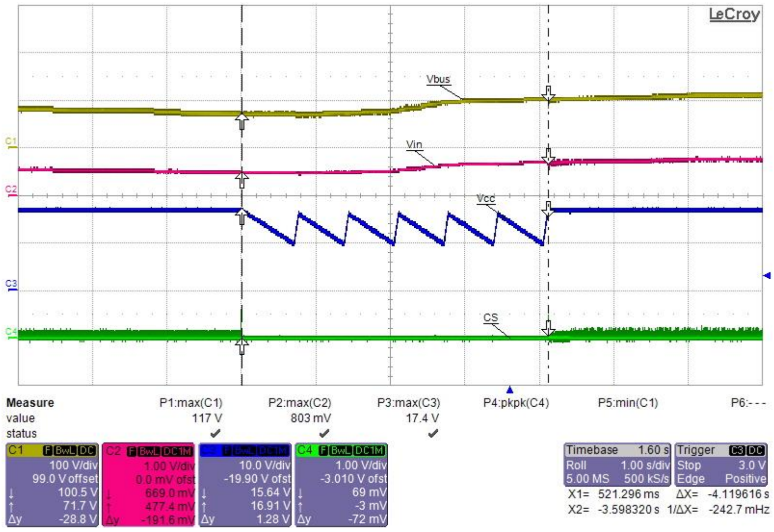



C1 (yellow) : Bulk capacitor voltage ($V_{Bulk}$)
C2 (purple) : $V_{IN}$ voltage ($V_{VIN}$)
C3 (blue) : Supply voltage ($V_{VCC}$)
C4 (green) : CS voltage ($V_{CS}$)

Condition to detect LOVP: $V_{VIN}$ more than 2.9 V
Condition to reset LOVP: $V_{VIN}$ less than 2.9 V

**Figure 26** **LOVP**

## 10.11 Brown-out protection

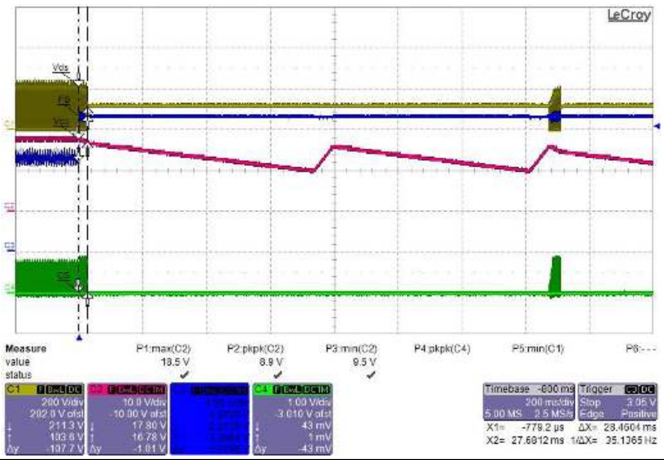


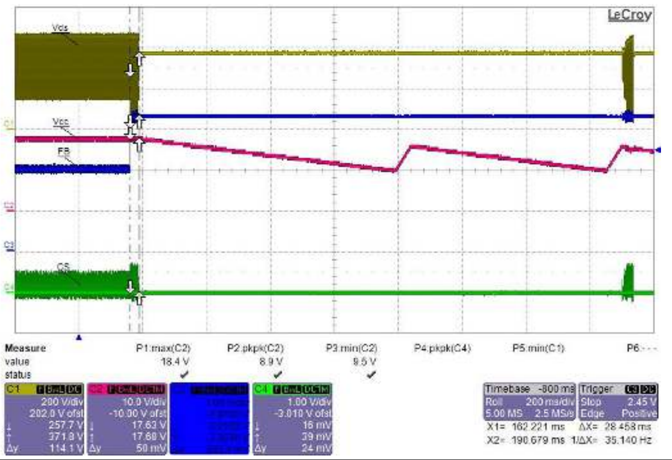

C1 (yellow) : Bulk capacitor voltage ($V_{Bulk}$)
C2 (purple) : $V_{IN}$ pin voltage ($V_{VIN}$)
C3 (blue) : Supply voltage ($V_{VCC}$)
C4 (green) : CS voltage ($V_{CS}$)

Condition to reset brown-out protection (brown-in): $V_{VIN}$ more than 0.66 V
Condition to detect brown-out protection: $V_{VIN}$ less than 0.4 V and $t_{blanking}$ = ~250 µs

**Figure 27 Brown-out protection**

## 10.12 Overload protection

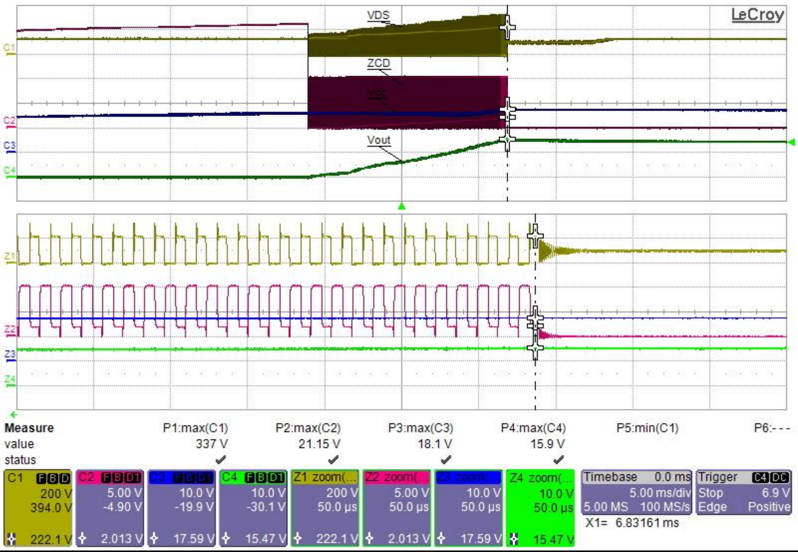



| | |
|---|---|
| C1 (yellow) : Drain voltage<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : FB pin voltage<br>C4 (green) : CS voltage | C1 (yellow) : Drain voltage<br>C2 (purple) : Supply voltage ($V_{VCC}$)<br>C3 (blue) : FB pin voltage<br>C4 (green) : CS voltage |
| 85 V AC<br>Trigger protection at FB pin voltage greater than 2.75 V ($V_{FB\_OLP}$) for approximate 30 ms ($t_{FB\_OLP\_B}$) | 264 V AC<br>Trigger protection at FB pin voltage greater than 2.75 V ($V_{FB\_OLP}$) for approximate 30 ms ($t_{FB\_OLP\_B}$) |

**Figure 28 OLP**

## 10.13 Output OV protection

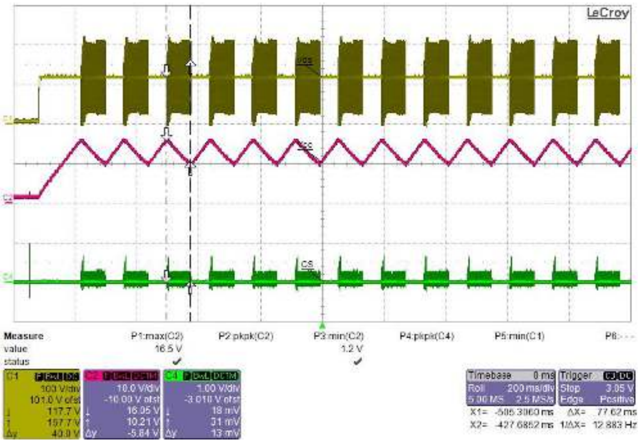



C1 (yellow) : Drain voltage ($V_D$)
C2 (purple) : ZCD voltage ($V_{ZCD}$)
C3 (blue) : Supply voltage ($V_{VCC}$)
C4 (green) : +12 V output voltage ($V_{O1}$)

Condition to enter output OVP: $V_{ZCD}$ more than 2 V for 10 consecutive pulses ($V_{O1}$ more than ~15 V)
(85 V AC, short R32 during system operation at no load)

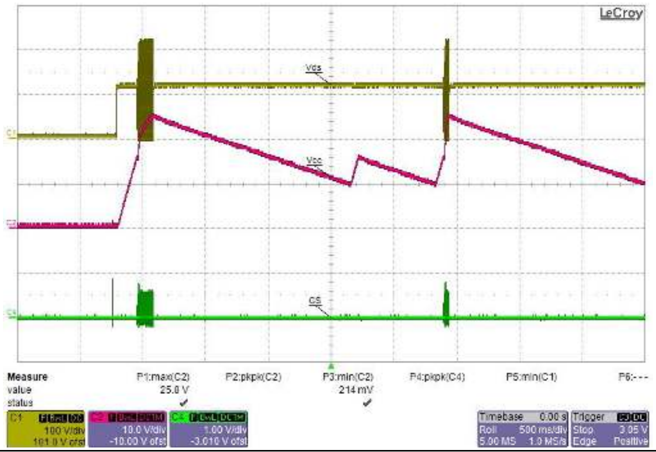
**Figure 29 Output OVP**

## 10.14 $V_{CC}$ OV/UV protection




C1 (yellow) : Drain voltage
C2 (purple) : Supply voltage ($V_{VCC}$)
C4 (green) : CS voltage

85 V AC at full load
Trigger $V_{CC}$ UVP at $V_{CC}$ voltage less than 10 V ($V_{VCC\_OFF}$)
Auto restart mode
(open R20)




C1 (yellow) : Drain voltage
C2 (purple) : Supply voltage ($V_{VCC}$)
C4 (green) : CS voltage

85 V AC start-up at full load
Trigger $V_{CC}$ OVP at $V_{CC}$ voltage greater than 25.5 V ($V_{VCC\_OVP}$), odd-skip auto restart mode
(short R20 and remove D8)

**Figure 30 $V_{CC}$ OVP/UVP**

## 10.15 ZCD

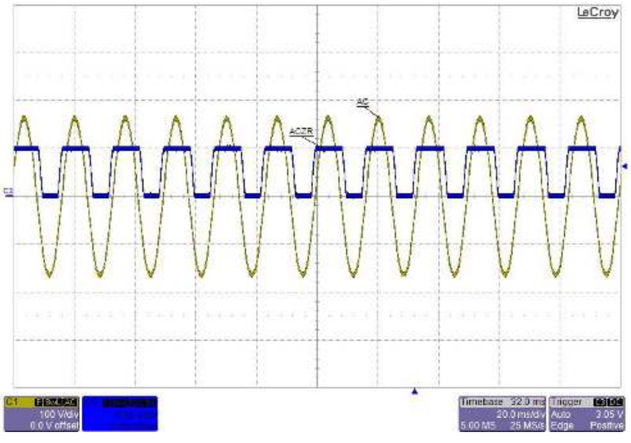
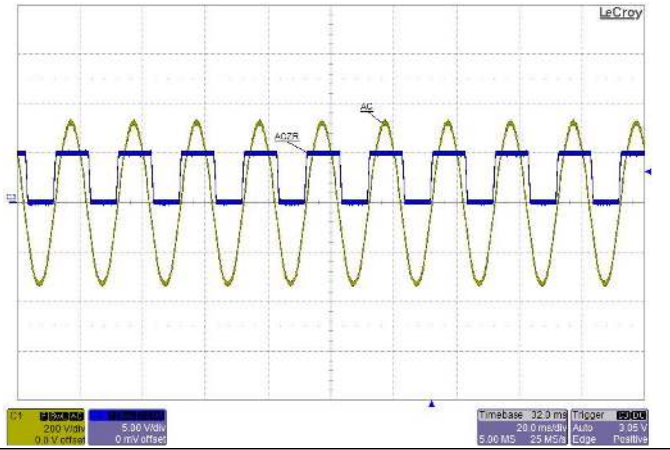
<table>
<tr><td>
</td><td>
</td></tr>
<tr><td>C1 (yellow) : AC input<br>C2 (purple) : ACZR</td><td>C1 (yellow) : AC input<br>C2 (purple) : ACZR</td></tr>
<tr><td>Input 115 V AC</td><td>Input 230 V AC</td></tr>
<tr><td colspan="2">AC ZCD circuit is an optional circuit, which can be disabled by removing X2</td></tr>
</table>

**Figure 31 AC zero-crossing signal**

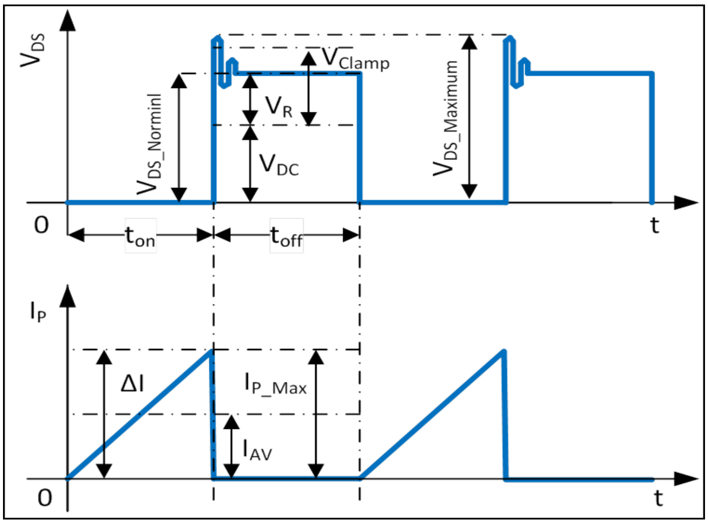
# 11 Appendix A: Transformer design and spreadsheet [2]

**Design procedure for QR flyback converter using Q5 CoolSET™ 5QRxxxxAx (version 1.1)**

| | |
|---|---|
| Project: | ICE5QR1680BG |
| Application: | 30 W aux SMPS for refrigerator application |
| CoolSET™: | ICE5QR1680BG |
| Date: | Feb. 22, 2022 |
| Revision: | 1.0 |
| Note: | AC zero-crossing circuit, LDO-related circuit and DC-DC circuit are not taken into consideration in this spreadsheet |

Enter design variables in orange-colored cells
Read design results in green-colored cells
Equation numbers are according to the application note; some changes are made for this specified design

| | | | Unit | Value |
|---|---|---|---|---|
| Input | Minimum AC input voltage | $V_{ACMin}$ | [V] | 85 |
| Input | Maximum AC input voltage | $V_{ACMax}$ | [V] | 264 |
| Input | Line frequency | $f_{AC}$ | [Hz] | 60 |
| Input | Bus capacitor (C13) DC ripple voltage | $V_{DCRIPPLE}$ | [V] | 25 |
| Input | Output voltage 1 | $V_{OUT1}$ | [V] | 12 |
| Input | Output current 1 | $I_{OUT1}$ | [A] | 2.2 |
| Input | Output ripple voltage | $V_{OUT\ Ripple}$ | [V] | 0.12 |
| Input | Maximum output power for start-up, transient response and OLP | $P_{OUTMax}$ | [W] | 33 |
| Input | Nominal output power | $P_{OUTNor}$ | [W] | 29.10 |
| Input | Minimum output power | $P_{OUTMin}$ | [W] | 0.5 |
| Input | Efficency | η | | 0.87 |
| *Result* | Drain-to-source capacitance of MOSFET (including $Co_{(er)}$ of MOSFET) | $C_{DS}+Co_{(er)}$ | [pF] | 8.00 |




| | | | | |
|---|---|---|---|---|
| Input | Reflection voltage | $V_R$ | [V] | 96 |
| Input | $V_{CC}$ voltage | $V_{VCC}$ | [V] | 18 |
| Input | Forward voltage of $V_{CC}$ diode (D12) | $V_{FDiodeVCC}$ | [V] | 0.3 |
| Input | CoolSET™ -Q5 | CoolSET™ -Q5 | | ICE5QR1680BG |
| Input | Low-line min. switching frequency | $f_S$ | [Hz] | 65000 |
| Input | Targeted max. drain-source voltage | $V_{DSMax}$ | [V] | 700 |
| Input | Max. ambient temperature | $T_a$ | [°C] | 50 |
| **Diode bridge (BR1)** | | | | |
| *Result* | Eq 1 | $P_{INMax}$ | [W] | 37.93 |
| *Result* | Eq 2 | $I_{AC\_RMS}$ | [A] | 0.744 |
| *Result* | Eq 3 | $V\ DC_{Max\_Pk}$ | [V] | 373.35 |
| *Result* | Eq 4 | $V\ DC_{Min\_Pk}$ | [V] | 120.21 |
| *Result* | Eq 10 | $V\ DC_{Min}$ | [V] | 95.55 |

| | | | | |
|---|---|---|---|---|
| *Result* | Eq 6 | $T_D$ | [ms] | 6.59 |
| *Result* | Eq 7 | $W_{IN}$ | [Ws] | 0.25 |
| *Result* | Eq11 | $D_{Max}$ | | 0.5012 |
| **Input capacitor (C13)** | | | | |
| *Result* | Eq 8 | $C_{IN}$ (C13) | [µF] | 92.85 |
| Input | Select input capacitor | $C_{IN}$ (C13) | [µF] | 94 |
| **Transformer (TR1)** | | | | |
| *Result* | Eq 12 | $L_P$ | [H] | 4.537E-04 |
| *Result* | Eq 13 | $I_{AV}$ | [A] | 0.79 |
| *Result* | Eq 14 | ΔI | [A] | 1.624 |
| *Result* | Eq 15 | $I_{P\_Max}$ | [A] | 1.60 |
| *Result* | Eq 16 | $I_{Valley}$ | [A] | 0.0 |
| *Result* | Eq 17 | $I_{P\_RMS}$ | [A] | 0.65 |
| **Select core type** | | | | |
| Input | Select core type | | | 10 |
| | | Core type | | User-defined core |
| | | Core material | | 0 |
| | Maximum flux density | $B_{Max}$ | [T] | 0.3 |
| | Effective magnetic cross-section | $A_e$ | [mm²] | 52 |
| | Bobbin width | BW | [mm] | 9.14 |
| | Winding cross-section | $A_N$ | [mm²] | 31.35 |
| | Average length of turn | $l_N$ | [mm] | 44.6 |
| **Winding calculation** | | | | |
| *Result* | Eq 18 | $N_P$ | Turns | 46.65 |
| Input | Choose number of primary turns | $N_P$ | Turns | 48 |
| *Result* | Eq 19 | $N_{S1}$ | Turns | 6.00 |
| Input | Choose number of secondary turns | $N_{S1}$ | Turns | 6 |
| *Result* | Eq 20 | $N_{VCC}$ | Turns | 9.15 |
| Input | Choose number of auxiliary turns | $N_{VCC}$ | Turns | 9 |
| *Result* | Auxiliary supply voltage (Eq 21) | $V_{VCC}$ | [V] | 17.70 |
| **Post calculation** | | | | |
| *Result* | Eq 23 | $V_R$ | [V] | 96.0 |
| *Result* | Eq 24 | $D_{Max}$ | | 0.50 |
| *Result* | Eq 25 | $D_{Max}'$ | | 0.49 |
| *Result* | Eq 26 | $B_{Max}$ | [T] | 0.292 |
| **CS resistor** | | | | |
| Input | CS threshold value from datasheet | $V_{csth}$ | [V] | 1 |
| *Result* | Eq 21 | $R_{Sense}$ | [Ω] | 0.62 |
| *Result* | Eq 22 | $P_{SR}$ | [W] | 0.26 |
| Input | PWM-OP gain from datasheet | $G_{PWM}$ | | 2.05 |
| *Result* | Eq 94 | $Z_{PWM}$ | [V/A] | 1.3 |
| **Transformer winding design** | | | | |
| Input | Margin according to safety standard | M | [mm] | 0 |
| Input | Copper space factor | $f_{Cu}$ | | 0.4 |
| **Primary** | | | | |
| Input | Insulation thickness | INS | [mm] | 0.02 |
| *Result* | Eq 32 | $A_p$ (area of primary wire) | [mm²] | 0.13 |
| *Result* | Eq 36 | Dia. (diameter of primary wire) | [mm] | 0.41 |
| *Result* | Eq 35 | AWG | | 26 |
| Input | Selected wire size | AWG | | 27 |
| Input | Number of parallel wires | Np | | 1 |
| *Result* | Eq 37 | Dia. (diameter of primary wire) | [mm] | 0.36 |
| *Result* | Eq 38 | (Eff. copper area of primary) | [mm²] | 0.1034 |
| *Result* | Eq 39 | Sp (primary current density) | [A/mm²] | 6.30 |
| *Result* | Eq 30 | $BW_e$ (effective bobbin width) | [mm] | 9.1 |
| *Result* | Eq 40 | $Od_p$ (diameter of primary wire including insulation) | [mm] | 0.40 |
| *Result* | Eq 41 | $NL_P$ (max. primary turns/layer) | Turns/layer | 22 |
| *Result* | Eq 42 | $Ln_P$ (primary layers) | Layers | 3 |

| | | | | |
|---|---|---|---|---|
| **Secondary** | | | | |
| Input | Insulation thickness | INS | [mm] | 0.02 |
| *Result* | Eq 33 | $A_S$ (area of secondary wire) | [mm²] | 0.94 |
| *Result* | Eq 36 | Dia. (diameter of secondary wire) | [mm] | 1.09 |
| *Result* | Eq 35 | AWG | | 17 |
| Input | Selected wire size | AWG | | 22 |
| Input | Number of parallel wires | Np | | 2 |
| *Result* | Eq 37 | Dia. (diameter of secondary wire) | [mm] | 0.65 |
| *Result* | Eq 38 | (Eff. copper area of secondary) | [mm²] | 0.6564 |
| *Result* | Eq 39 | $S_S$ (secondary current density) | [A/mm²] | 7.92 |
| *Result* | Eq 30 | $BW_E$ (effective bobbin width) | [mm] | 9.1 |
| *Result* | Eq 40 | $Od_S$ (diameter of secondary wire including insulation) | [mm] | 0.69 |
| *Result* | Eq 41 | $NL_S$ (max. secondary turns/layer) | Turns/layer | 6 |
| *Result* | Eq 42 | $Ln_S$ (secondary layers) | Layers | 1 |
| **Leakage inductance** | | | | |
| Input | | Leakage inductance as percentage of $L_P$ | [%] | 1 |
| *Result* | Eq 45 | $L_{LK}$ | [H] | 4.54E-06 |
| **RCD clamper circuit** | | | | |
| *Result* | Eq 44 | $V_{clamp}$ | [V] | 230.65 |
| *Result* | Eq 46 | $C_{clamp}$ (C15) | [nF] | 0.2 |
| Input | Selected $C_{clamp}$ capacitor value | $C_{clamp}$ (C15) | [nF] | 1 |
| *Result* | Eq 47 | $R_{clamp}$ (R11) | [kΩ] | 257 |
| Input | Selected $R_{clamp}$ value | $R_{clamp}$ (R11) | [kΩ] | 300 |
| **Output and $V_{CC}$ diodes** | | | | |
| *Result* | Eq 43a | $V_{SR\_MOS}$ (for output SR MOSFET) | [V] | 58.67 |
| *Result* | Eq 28 | $I_{S\_Max1}$ | [A] | 12.83 |
| *Result* | Eq 29 | $I_{S\_RMS1}$ | [A] | 5.20 |
| *Result* | Eq 43b | $V_{RDiode}$ (for $V_{CC}$ diode) | [V] | 88.00 |
| **Output capacitors** | | | | |
| Input | Max. voltage overshoot at output capacitor (C22, C23) | $\Delta V_{OUT1}$ | [V] | 0.5 |
| Input | Number of clock periods | $n_{cp}$ | | 20 |
| *Result* | Eq 49 | $I_{RIPPLE1}$ | [A] | 4.71 |
| *Result* | Eq 50 | $C_{OUT1}$ | [µF] | 1354 |
| Input | Selected output capacitor value | C22 | [µF] | 1360 |
| Input | Number of parallel capacitors | $n_c$ | | 2 |
| **Soft-start time** | | | | |
| Input | Selected soft-start time from datasheet | $t_{softstart}$ | [ms] | 12 |
| **$V_{CC}$ capacitor (C16) and start-up time** | | | | |
| Input | Selected $I_{VCC,Charge3}$ from datasheet | $I_{VCC,Charge3}$ | [mA] | 3 |
| Input | Selected $V_{VCChys}$ from datasheet | $V_{VCChys}$ | [mV] | 6 |
| *Result* | Eq 56A | $C_{VCC}$ | [µF] | 6.00 |
| Input | Selected $V_{CC}$ capacitor | $C_{VCC}$ (C16) | [µF] | 22 |
| Input | Selected $V_{VCC,STG}$ from datasheet | $V_{VCC,STG}$ | [V] | 1.1 |
| Input | Selected $I_{VCC,Charge1}$ from datasheet | $I_{VCC,Charge1}$ | [mA] | 0.2 |
| Input | Selected $V_{VCC,ON}$ from datasheet | $V_{VCC,ON}$ | [V] | 16 |
| *Result* | Eq 56B | $t_{StartUp}$ | [ms] | 238.33 |
| **Calculation of losses** | | | | |
| **Input diode bridge** | | | | |
| Input | Select $V_{F\_Bridge}$ from datasheet | $V_{F\_Bridge}$ | [V] | 1 |
| *Result* | Eq 57 | $P_{DIN}$ | [W] | 1.49 |
| **Transformer copper losses** | | | | |
| *Result* | Eq 58 | $R_{PCu}$ | [mΩ] | 355.99 |
| *Result* | Eq 58 | $R_{SCu1}$ | [mΩ] | 7.01 |
| *Result* | Eq 58 | $R_{SCu2}$ | [mΩ] | 151.14 |
| *Result* | Eq 59 | $P_{PCu}$ | [mW] | 189.63 |
| *Result* | Eq 60 | $P_{SCu1}$ | [mW] | 0.3408 |
| **Output rectifier MOSFET** | | | | |
| Input | $R_{DSON}$ from datasheet | $R_{DSON}$ at $T_J$ = 125°C | [Ω] | 0.02 |

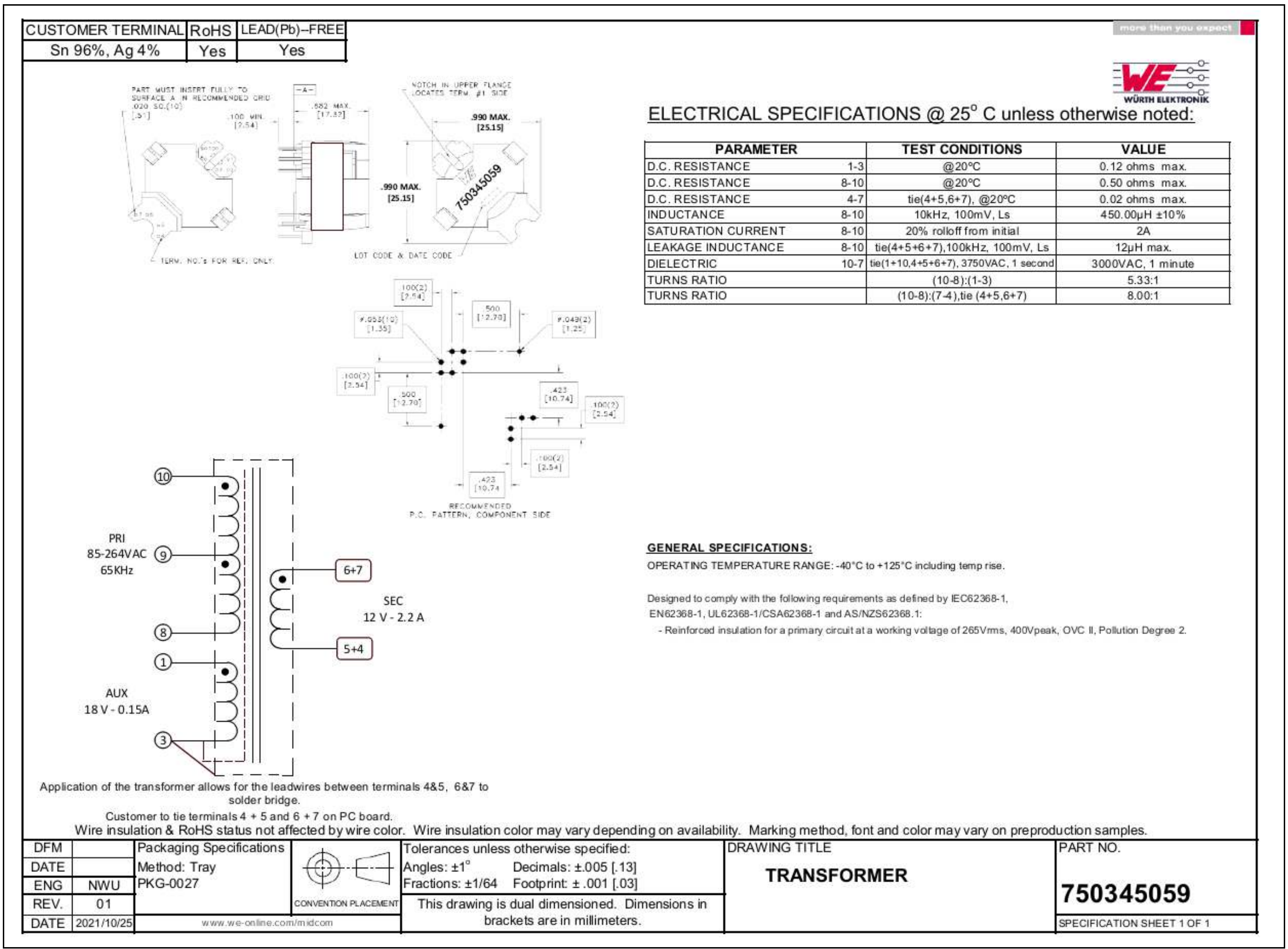
| | | | | |
|---|---|---|---|---|
| *Result* | | $P_{OUT\_MOSFET}$ | [W] | 0.54 |
| **RCD clamper circuit** | | | | |
| *Result* | Eq 63 | $P_{clamp}$ | [W] | 0.54 |
| **MOSFET** | | | | |
| Input | $R_{DSON}$ from datasheet | $R_{DSON}$ at $T_J$ = 90°C ($T_J$ by measurement) | [Ω] | 3.01 |
| Input | $C_{O(er)}$ from datasheet | $C_{O(er)}$ | [pF] | 7 |
| Input | External drain-to-source capacitance of MOSFET | $C_{DS}$ | [pF] | 0 |
| **MOSFET losses at V $AC_{Min}$ + $P_{Max}$** | | | | |
| *Result* | Eq 65 | $P_{SON}$ | [W] | 0.000000045 |
| *Result* | Eq 66 | $P_{cond}$ | [W] | 1.2779 |
| *Result* | Eq 67 | MOSFET losses | [W] | 1.2779 |
| **MOSFET losses at V $AC_{Max}$ + $P_{Max}$** | | | | |
| *Result* | Eq 68 | $P_{SON}$ | [W] | 0.0228 |
| *Result* | Eq 69 | $P_{cond}$ | [W] | 0.4252 |
| *Result* | Eq 70 | MOSFET losses | [W] | 0.4479 |
| **Temperature calculation** | | | | |
| Input | Enter MOSFET losses | MOSFET losses | [W] | 1.28 |
| Input | Enter thermal resistance junction – ambient | $R_{th}$ | [°K/W] | 75 |
| *Result* | Eq 74 | ΔT | [°K] | 95.8 |
| *Result* | Eq 75 | $T_{jmax}$ | [°C] | 145.8 |
| *Note: estimated $T_{jmax}$ is based on maximum drain-source turn-on resistance; actual thermal measurement will be needed.* | | | | |
| **Controller** | | | | |
| *Result* | $I_{VCC,Normal}$X$V_{VCC}$ | Controller losses | [W] | 0.0157 |
| **Sum of losses (excluding LDO circuit-related loss and DC-DC loss)** | | | | |
| *Result* | Eq 77 | $P_{Losses}$ | [W] | 4.20 |
| **Efficiency after losses (NOT considering LDO and DC-DC related circuit)** | | | | |
| *Result* | Eq 78 | $\eta_L$ | | 0.8871 |
| **Calculation of the regulation loop** | | | | |
| Input | Minimum current for TL431 reference | $I_{KAmin}$ | [mA] | 1 |
| Input | Optocoupler gain | $G_C$ (200%) | | 2 |
| Input | Maximum current for optocoupler diode | $I_{Fmax}$ | [mA] | 10 |
| Input | Second resistor of TL431 voltage divider | R26 | [kΩ] | 10 |
| Input | 0 dB crossover frequency | fg | [kHz] | 3 |
| Input | Eq 81 | R25 | [kΩ] | 38.00 |
| Input | Selected value of R25 | R25 | [kΩ] | 38 |
| Input | Eq 82 | R22 | [kΩ] | 0.8250 |
| *Result* | Selected value of R22 | R22 | [kΩ] | 1 |
| Input | $V_{REF}$ from datasheet | $V_{REF}$ | [V] | 3.3 |
| *Result* | $V_{FB,OLP}$ from datasheet (overload/open-loop detection limit at FB pin) | $V_{FB,OLP}$ | [V] | 2.75 |
| Input | $R_{FB}$ from datasheet | $R_{FB}$ | [kΩ] | 3 |
| *Result* | Eq 83 | R23 | [kΩ] | 1.34 |
| Input | Selected value of R23 | R23 | [kΩ] | 1 |
| *Result* | Eq 84 | $V_{Out\_RL}$ | [V] | 12.0 |
| Input | Eq 85 | $K_{FB}$ | | 6.00 |
| Input | Eq 86 | $G_{FB}$ | [dB] | 15.56 |
| Input | Eq 87 | $K_{VD}$ | | 0.21 |
| Input | Eq 88 | $G_{VD}$ | [dB] | -13.62 |
| *Result* | Eq 89 | $R_{LH}$ | [Ω] | 4.36 |
| Input | Eq 90 | $R_{LL}$ | [Ω] | 1440.00 |
| *Result* | Eq 91 | $f_{OH}$ | [Hz] | 26.82 |
| *Result* | Eq 92 | $f_{OL}$ | [Hz] | 0.08 |
| *Result* | Eq 93 | $f_{OM}$ | [Hz] | 1.48 |
| *Result* | Eq 95 | $\lvert F_{PWR}(fg)\rvert$ | | 0.052 |
| *Result* | Eq 96 | $G_{PWR}(fg)$ | [dB] | -25.62 |
| *Result* | Eq 99 | Gr | [dB] | 23.687 |
| *Result* | Eq 100 | R24 | [kΩ] | 121.03 |
| *Result* | Selected value of R24 | R24 | [kΩ] | 22 |
| *Result* | Eq 101 | C26 | [nF] | 2.411 |

| | | | | |
|---|---|---|---|---|
| *Result* | Selected value of C26 | C26 | [nF] | 1 |
| *Result* | Eq 102 | C25 | [nF] | 4899.29 |
| *Result* | Selected value of C25 | C25 | [nF] | 47 |
| **ZCD and output OVP calculation** | | | | |
| Input | Designed $V_{OUT\_OVP}$ | $V_{OUT\_OVP}$ | [V] | 15 |
| Input | $V_{ZC\_OVP\_MIN}$ from datasheet | $V_{ZC\_OVP\_MIN}$ | [V] | 1.9 |
| Input | $R_{ZCD\_MIN}$ from datasheet | $R_{ZCD}$ | [kΩ] | 3 |
| *Result* | Eq 103 | $R_{ZC}$(R15) | [kΩ] | 32.53 |
| Input | Selected value of R15 | $R_{ZC}$ (R15) | [kΩ] | 30 |
| Input | $f_{OSC2}$ by measurement | $f_{OSC2}$ | [kHz] | 900 |
| *Result* | Eq 104 | $C_{ZC}$ (C19) | [pF] | 101 |
| *Input* | Selected value of $C_{ZC}$ (C19) | $C_{ZC}$ (C19) | [pF] | 68 |
| **LOVP is the first priority and its associated brown-out, brown-in and line selection** | | | | |
| Input | | $R_{l1}$ (R18) | [Ω] | 10,000,000 |
| Input | | LOV ($V_{OVP\_AC}$) | [V AC] | 300 |
| Input | | V $DC_{RIPPLE}$ | [V] | 25 |
| *Result* | Eq 105A | $R_{l2}$ (R19) | [Ω] | 68,824 |
| Input | Selected value of R19 ($R_{l2}$) | $R_{l2}$ (R19) | [Ω] | 69,000 |
| *Result* | Eq 106 | Brown-in voltage ($V_{Brownin\_AC}$) | [V AC] | 68 |
| *Result* | Eq 107 | Brown-out voltage for full load which considers V $DC_{RIPPLE}$ ($V_{Brownout\_AC}$) | [V AC] | 59 |
| *Result* | Eq 107 | Brown-out voltage for light load which neglects V $DC_{RIPPLE}$ ($V_{Brownout\_AC}$) | [V AC] | 41 |
| *Result* | Eq 108 | Line selection threshold with V $DC_{RIPPLE}$ ($V_{VIN}$ = 1.52 V) | [V AC] | 175 |
| *Result* | Eq 108 | Line selection threshold without V $DC_{RIPPLE}$ ($V_{VIN}$ = 1.52 V) | [V AC] | 157 |

| **Electrical** | | | |
|---|---|---|---|
| Minimum AC voltage | | [V] | 85 |
| Maximum AC voltage | | [V] | 264 |
| Maximum input current | | [A] | 0.45 |
| Minimum DC voltage | | [V] | 96 |
| Maximum DC voltage | | [V] | 373 |
| Maximum output power | | [W] | 33.0 |
| Output voltage | | [V] | 12.0 |
| Inductor peak current | | [A] | 1.60 |
| Maximum duty cycle | | | 0.50 |
| Reflected output voltage | | [V] | 96 |
| Copper losses | | [W] | 0.34 |
| MOSFET losses | | [W] | 1.28 |
| Sum losses | | [W] | 4.20 |
| Efficiency | | | 0.89 |

| **Transformer** | | | |
|---|---|---|---|
| Core type | | | RM8 |
| Core material | | | 0 |
| Effective core area | | [mm²] | 52 |
| Maximum flux density | | [mT] | 292 |
| Inductance | | [uH] | 454 |
| Margin | | [mm] | 0 |
| Primary turns | | Turns | 48 |
| Primary copper wire size | | AWG | 27 |
| Secondary turns ($N_{S1}$) | | Turns | 6 |
| Secondary copper wire size | | AWG | 22 |
| Number of parallel secondary wires | | | 2 |
| Secondary turns ($N_{S2}$) | | Turns | 0 |
| Auxiliary turns | | Turns | 9 |
| Leakage inductance | | [µH] | 4.5 |
| Turns ratio | | | 8.00 |
| Primary layers | | Layer | 3 |
| Secondary layers | | Layer | 1 |

# 12 Appendix B: WE transformer specification



| CUSTOMER TERMINAL | RoHS | LEAD(Pb)–FREE |
|---|---|---|
| Sn 96%, Ag 4% | Yes | Yes |

ELECTRICAL SPECIFICATIONS @ 25° C unless otherwise noted:

| PARAMETER | | TEST CONDITIONS | VALUE |
|---|---|---|---|
| D.C. RESISTANCE | 1-3 | @20°C | 0.12 ohms max. |
| D.C. RESISTANCE | 8-10 | @20°C | 0.50 ohms max. |
| D.C. RESISTANCE | 4-7 | tie(4+5,6+7), @20°C | 0.02 ohms max. |
| INDUCTANCE | 8-10 | 10kHz, 100mV, Ls | 450.00µH ±10% |
| SATURATION CURRENT | 8-10 | 20% rolloff from initial | 2A |
| LEAKAGE INDUCTANCE | 8-10 | tie(4+5+6+7),100kHz, 100mV, Ls | 12µH max. |
| DIELECTRIC | 10-7 | tie(1+10,4+5+6+7), 3750VAC, 1 second | 3000VAC, 1 minute |
| TURNS RATIO | | (10-8):(1-3) | 5.33:1 |
| TURNS RATIO | | (10-8):(7-4),tie (4+5,6+7) | 8.00:1 |

GENERAL SPECIFICATIONS:

OPERATING TEMPERATURE RANGE: -40°C to +125°C including temp rise.

Designed to comply with the following requirements as defined by IEC62368-1, EN62368-1, UL62368-1/CSA62368-1 and AS/NZS62368.1:

- Reinforced insulation for a primary circuit at a working voltage of 265Vrms, 400Vpeak, OVC II, Pollution Degree 2.



Application of the transformer allows for the leadwires between terminals 4&5, 6&7 to solder bridge.

Customer to tie terminals 4 + 5 and 6 + 7 on PC board.

Wire insulation & RoHS status not affected by wire color. Wire insulation color may vary depending on availability. Marking method, font and color may vary on preproduction samples.

| DFM | | Packaging Specifications | Tolerances unless otherwise specified: | DRAWING TITLE | PART NO. |
|---|---|---|---|---|---|
| DATE | | Method: Tray | Angles: ±1° Decimals: ±.005 [.13] | TRANSFORMER | 750345059 |
| ENG | NWU | PKG-0027 | Fractions: ±1/64 Footprint: ± .001 [.03] | | |
| REV. | 01 | CONVENTION PLACEMENT | This drawing is dual dimensioned. Dimensions in brackets are in millimeters. | | SPECIFICATION SHEET 1 OF 1 |
| DATE | 2021/10/25 | www.we-online.com/midcom | | | |

**Figure 32** WE transformer specification

# 13 References

[1] **ICE5QRxxxxBG datasheet, Infineon Technologies AG**

[2] **Design Guide Quasi Resonant CoolSET™ Generation 5**

[3] **Calculation Tool Quasi Resonant CoolSET™ Generation 5**

# Revision history

| Document version | Date of release | Description of changes |
|---|---|---|
| V 1.0 | 2022-07-27 | Initial release |
| V 1.1 | 2022-10-19 | Schematic and PCB layout updated |
| | | |

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