Application Report

SNVA750–June 2016

Non-Isolated High-Side Buck Converter with UCC28910

David Ji

ABSTRACT

The non-isolated Buck topology is widely applied in the LED driver and low power products. A buck converter can obtain smaller size and fewer components compared to a flyback. This paper discusses the Buck converter design steps and theoretical analysis with wide input voltage range. It is practical to solve the limit of input voltage hysteresis by adding a few components. Electrical performance is tested and presented.

Contents

List of Figures

1 Introduction

This paper is based on a non-isolated high-side Buck design using the UCC28910. The UCC28910 integrates an internal 700-V MOSFET, which enables universal AC input operation. It is also easier to use fewer components through the internal, integrated control loop compensation. Fewer components make a low-cost solution possible. The UCC28910 uses peak current control and DCM mode operation only, which avoids the extra slope compensation requirement. Also, the IC integrates various protection features to meet more application requirements. This topology using an inductor can save size and lower cost compared to a flyback transformer. It can also achieve higher efficiency compared to HV LDO topology. Therefore, non-isolated high-side Buck is suitable for limited size and cost applications.

2 Design Parameters Consideration

Specifications

Input voltage: 85 Vac–265 Vac. Output voltage: 20 V, Output current: 100 mA
Requirements: When input voltage is in the brownout condition, output voltage will not bounce.
Output ripple voltage < 200 mV
Dynamic response requirements: < +1 V / –1 V

UCC28910 operation scheme in Buck mode:

As the input voltage increases, the UCC28910 internal high voltage current source charges the VDD capacitor and output capacitor. When the VDD reaches the startup threshold, the internal MOSFET turns on for three pulses. These three pulses detect the line brownout, output short circuit, and output over voltage conditions to prevent converter operation in a fault condition. The initial three current pulses keep the MOSFET running with one-third maximum current limit. Each switching cycle, when the integrated MOSFET turns off, freewheel diode forms the current flowing path for the output inductor.

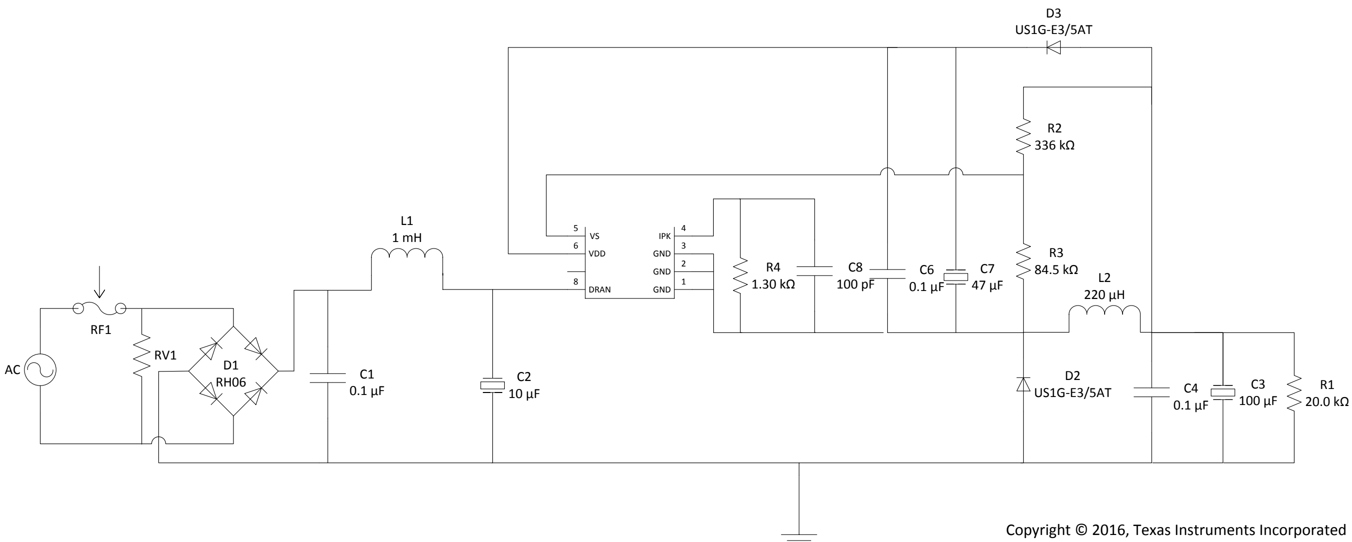


Figure 1. Schematic

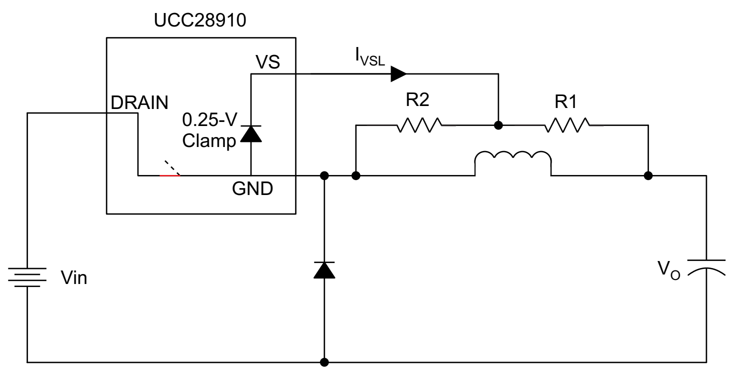


Figure 2. Buck Converter Function Diagram

2.1 Output Inductor

Considering the output inductor size and output capacitance, it is desired to set the controller switching frequency to 60 kHz. Discontinuous conduction mode (DCM) with valley switching is used to reduce switching losses. Assuming the converter is working in the boundary conduction mode at lowest input voltage and highest load condition, the output inductor value is designed by the following equations:

$$D = \frac{V_{out}}{V_{brownout}}$$

where

- $V_{brownin} = 72$ V
- $V_{brownout} = 43$ V (1)

$$V_{out} = L \times \frac{I_{pk}}{(1 - D)\,T}$$

where

- $L = 290$ µH (2)

To keep the converter working in DCM, TDK B82464P4224M000 is selected. The saturation current is 0.75 A.

2.2 Output Capacitor

Output capacitance is a key factor to transient response, output voltage ripple, and system stability. Due to the internal compensation of the UCC28910, the loop gain and phase cannot be obtained through measurements. However, the load transient test can be used to verify the loop stability. After verification, a 100-µF or more Aluminum capacitor is proved to allow stable operation.

2.3 VS pin: Divided Resistors

When MOSFET is off and inductor current comes to zero, the UCC28910 VS pin is used to detect the output voltage. Select the voltage divider ration to meet equation Equation 3:

$$V_{out} = V_{VSR} \times \frac{R_2 + R_3}{R_2}$$

where

- $V_{VSR} = 4.05$ V (3)

2.4 Startup Procedure

Through internal integrated high voltage current source, the current source charges the VDD capacitor and output capacitor. When the VDD reaches the startup threshold, the internal MOSFET turns on for three pulses. The controller sends out three pulses for detecting the UVLO, output short circuit, and output overvoltage protection. The initial three current pulses keep in one-third maximum current limit.

2.5 Current Limit

Use Equation 4 to calculate the current limit.

$$I_{pk} = \frac{V_{CCR}}{R_{pk}}$$

where

- $V_{CCR} = 540$ V (4)

To avoid the noise interference, the I_{pk} pin is preferred to be shorted to GND of the chip.

2.6 Cin

For lower system cost, the half-waveform rectifier is used. However, it needs more input bulk capacitor due to bigger ripple voltage on the bulk capacitor compared to the full wave rectifier. Regardless of whether the designer uses a half wave or full wave rectifier, the line under voltage protection hysteresis must be considered. During start up, the output voltage can bounce if the hysteresis is not enough. Equation 5 is used to calculate Cin.

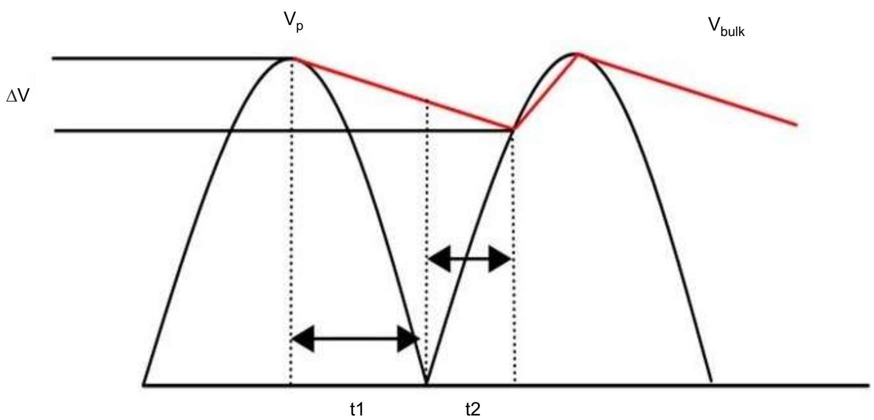


Figure 3. Bulk Capacitor Ripple Voltage

In the period: t1 + t2, the output power is provided by bulk capacitor Cin. To allow a 30-V line brownout protection hysteresis to work, the voltage ripple on Cin must meet Equation 5:

$$\frac{P_{out}}{eff}(t_1 + t_2) = \frac{1}{2}C_{min}\left[V_p^2 - (V_p - \Delta V)^2\right] \quad (5)$$

where

- Eff = 0.75
- V_p = 76 V
- ΔV = 30 V

The minimum input capacitor is calculated as 10 µF. The line brownout protection is calculated based on Equation 6 and Equation 7:

$$V_{brownin} = I_{VSL(run)} \times R_2 \quad (6)$$

$$V_{brownout} = I_{VSL(stop)} \times R_2 + V_{out} \quad (7)$$

Considering the IC parameter tolerances, two methods can be used to achieve wider line brownout protection to allow the system to use smaller input capacitors.

2.6.1 Add a Resistor Between VS and Output Capacitor Negative Terminal

A resistor can be added between the UCC28910 VS pin and the output ground as Figure 4 shows. The UCC28910 measures the current flowing out of the VS pin to determine the input voltage. When the internal MOSFET turns on, the IC senses both the current flowing through R2 and R5 and this current is sensed as an indication of input voltage. During start up, output voltage is zero. After start up, the output voltage stays high. Keeping R5 to ground adds some offset to the line brownout protection hysteresis.

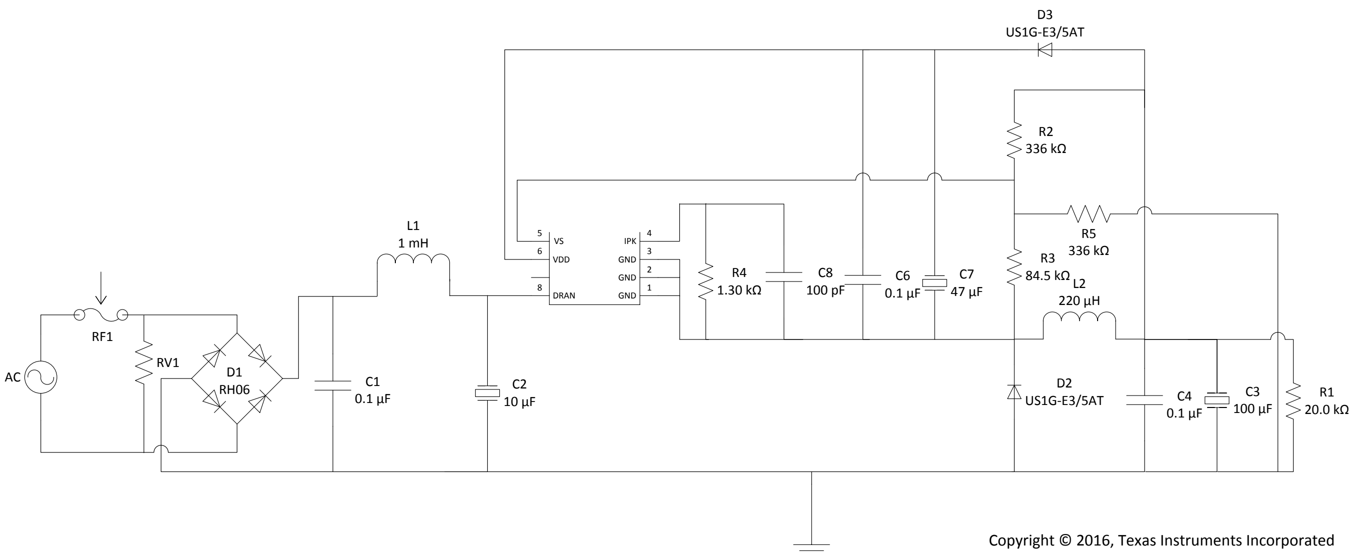


Figure 4. Add Resistor Solution Schematic

Equation 8 through Equation 10 show the new brownout protection and recovery point calculation equations:

$$V_{brownin} = I_{VSL(run)} \times (R_2 // R_5) \quad (8)$$

$$V_{brownout} = \left(I_{VSL(stop)} + \frac{V_{out}}{R_2} \right) \times (R_2 // R_5) \quad (9)$$

$$V_{out} = V_{VSR} \times \frac{R_2 + R_3 // R_5}{R_3 // R_5} \quad (10)$$

2.6.2 Add a Diode and a Resistor

Similar to adding s resistor, adding a diode and resistor separates the input voltage sensing and output voltage sensing as shown in Figure 5. When the internal MOSFET is turned on, the input voltage is sensed through R2 and R5 by the current flowing out of the VS pin. However, when the MOSFET is turned off, output voltage is sensed through the R2 and R3 voltage divider using diode D4. This way, the input voltage is always sensed without the influence of the output voltage.

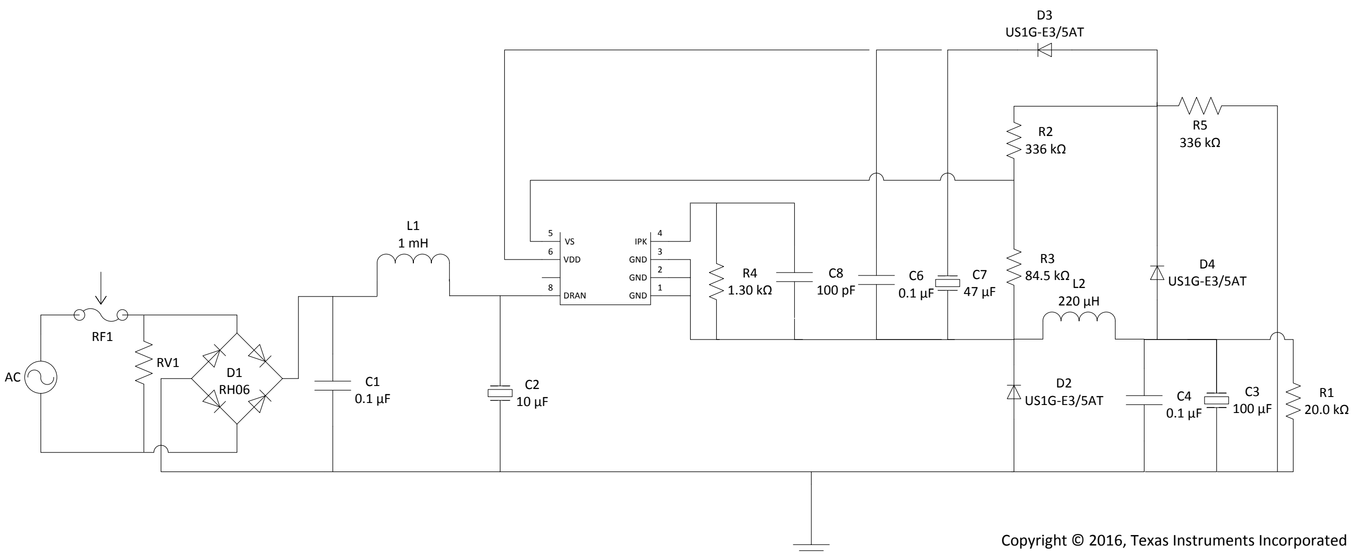


Figure 5. Add Diode and Resistor Schematic

Equation 11 and Equation 12 show the new brownout protection and recovery point calculation equations.

$$V_{brownin} = I_{VSL(run)} \times (R_2 + R_5) \tag{11}$$

$$V_{brownout} = I_{VSL(stop)} \times (R_2 + R_5) \tag{12}$$

From these two solutions, the operation principles are about the same. The purpose is to avoid the influence of the output voltage. The solution in Section 2.6.1 cannot fully eliminate the influence of the output voltage at startup. The solution in Section 2.6.2 can fully eliminate the influence of the output voltage at the startup.

3 Test Result Waveform

3.1 MOSFET Stress

Due to the Buck configuration, the MOSFET voltage stress is about the same as input voltage. No voltage spike is observed. Figure 6 illustrates MOSFET voltage stress.

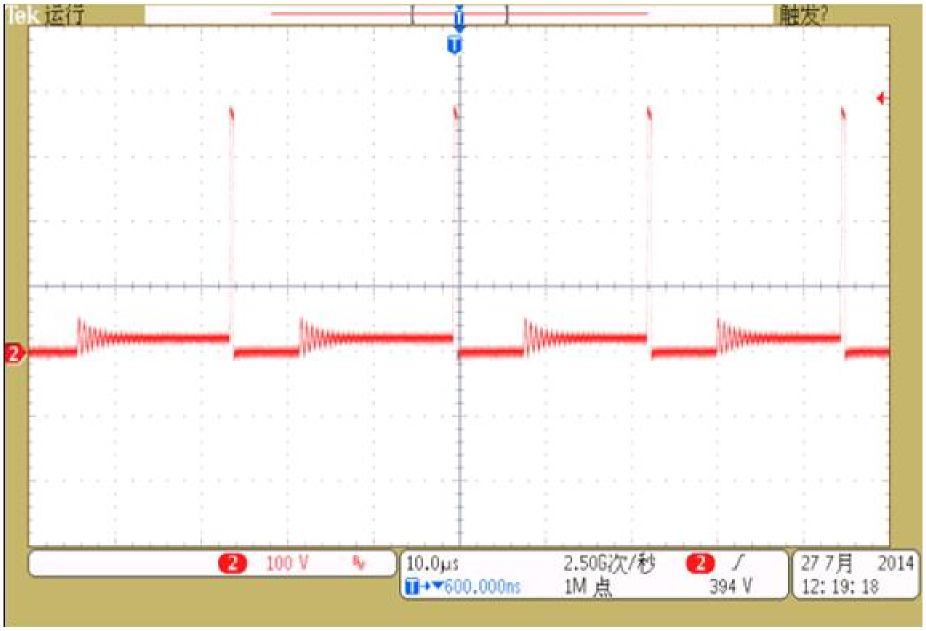


Figure 6. MOSFET Voltage Stress

3.2 Efficiency

Due to the nature of low duty cycle, the Buck converter is not able to achieve very high efficiency. However, the simple topology and few-external components still make it an attractive solution for certain applications. Figure 7 illustrates comparisons in efficiency.

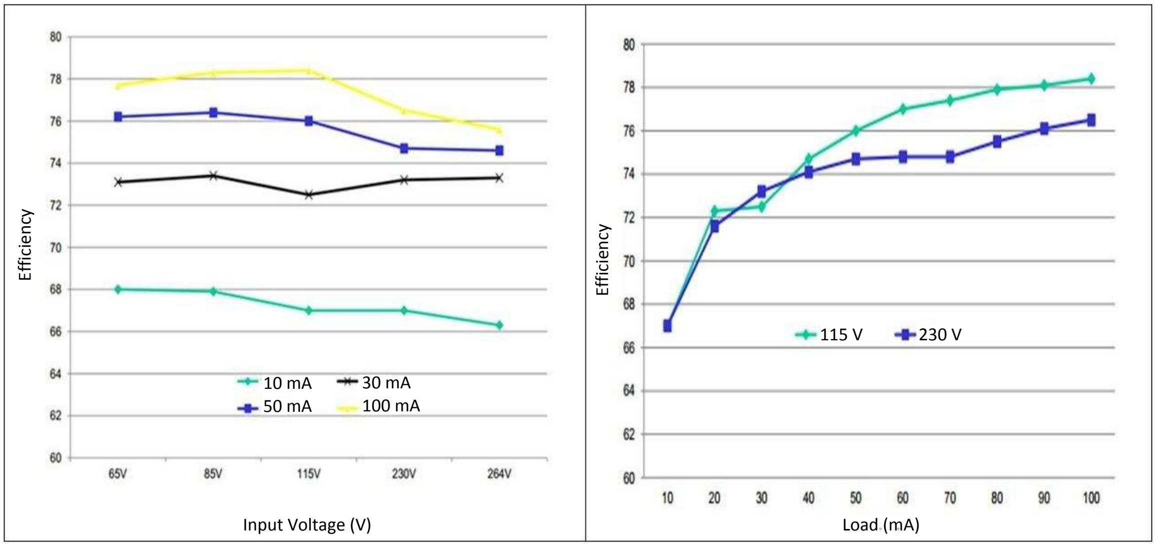


Figure 7. Efficiency Comparison

3.3 Standby Power

In a PLC application, the power supply works in standby mode most of the time. Achieving low standby power is critical. The UCC28910 is able to obtain low standby power through variable frequency control.

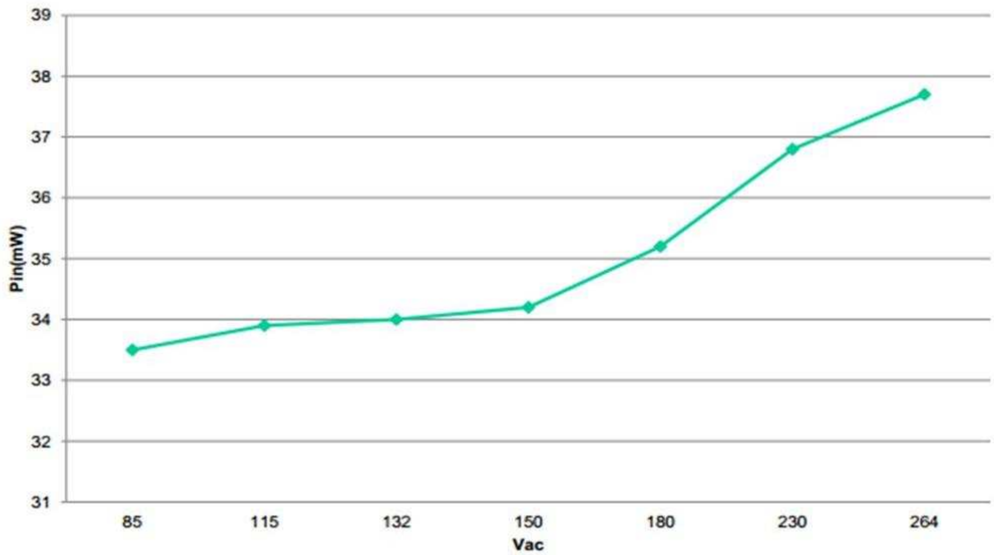


Figure 8. Standby Power

3.4 Dynamic Response

According to the +1V/–1V dynamic response requirement, the design meets the requirement, see Figure 9.

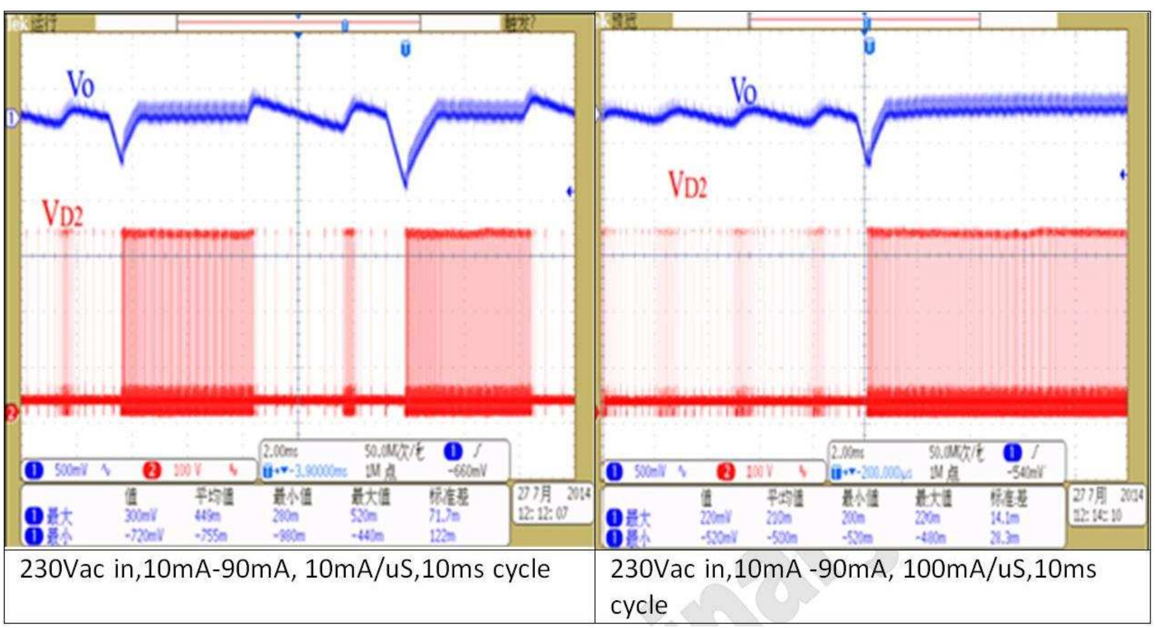


Figure 9. Dynamic Response

3.5 Output Ripple Voltage

According to 200-mV output voltage ripple requirement, the design meets the requirement.

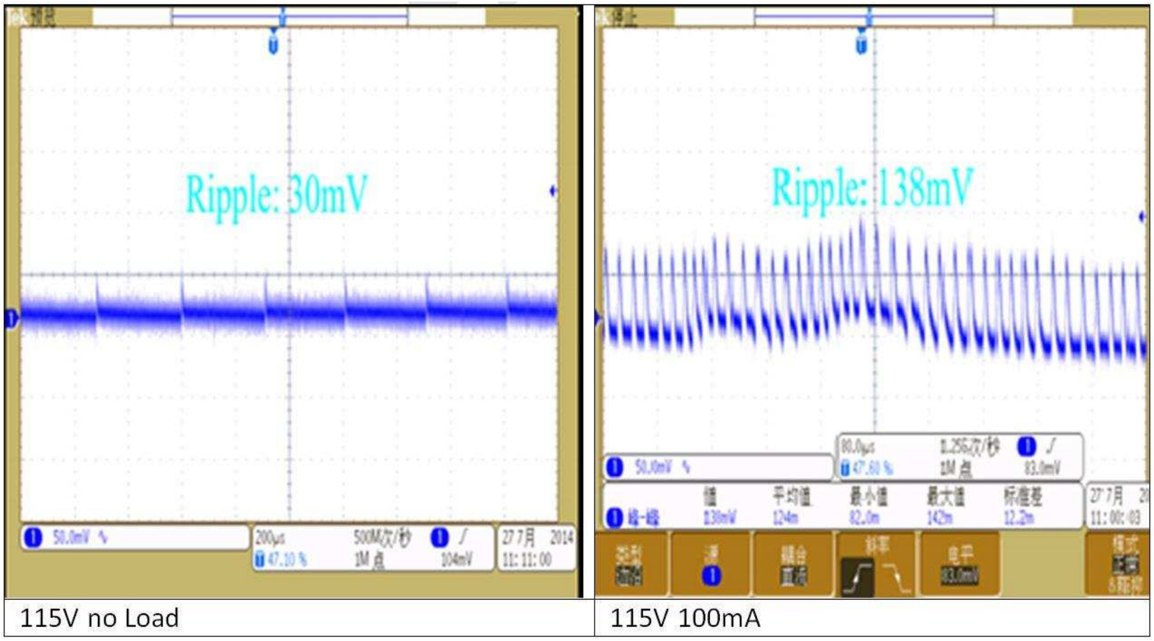


Figure 10. 115 Vin Output Ripple Voltage at No Load and Full Load

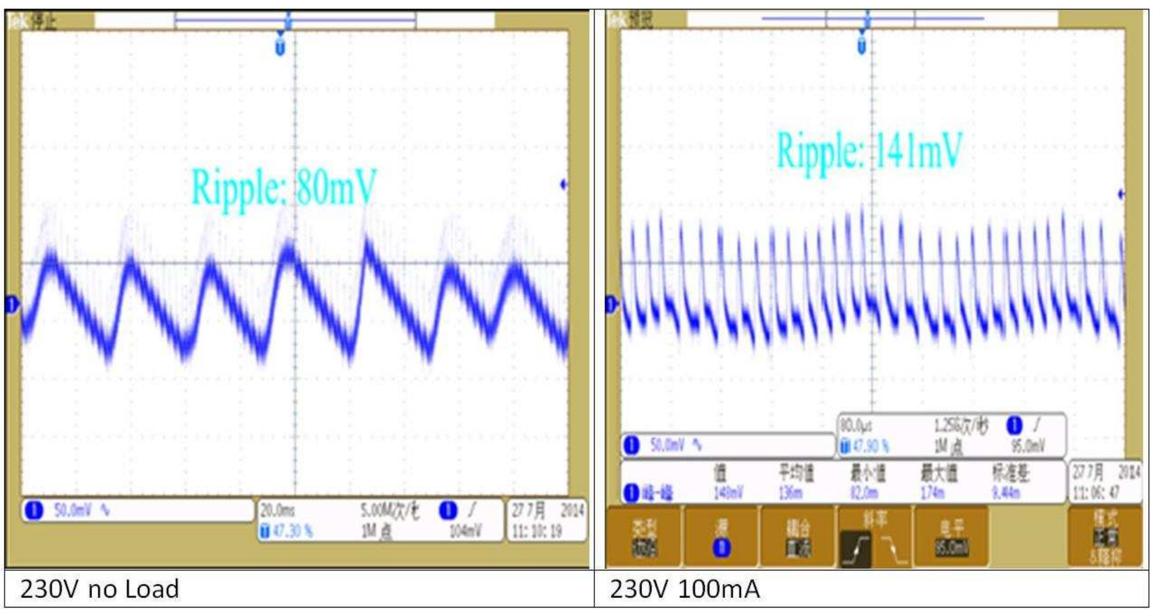


Figure 11. 230 Vin Output Ripple Voltage at No Load and Full Load

3.6 Thermal Test at 25°C

According to the 45° temperature rise requirement, the design meets the requirement.

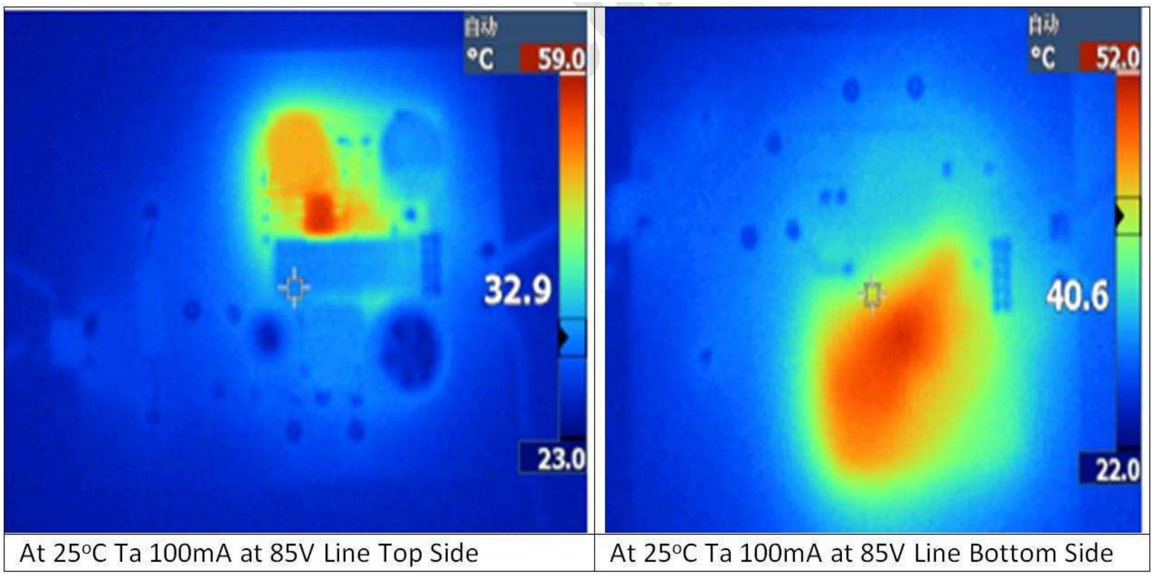


Figure 12. 85 Vin Thermal Performance

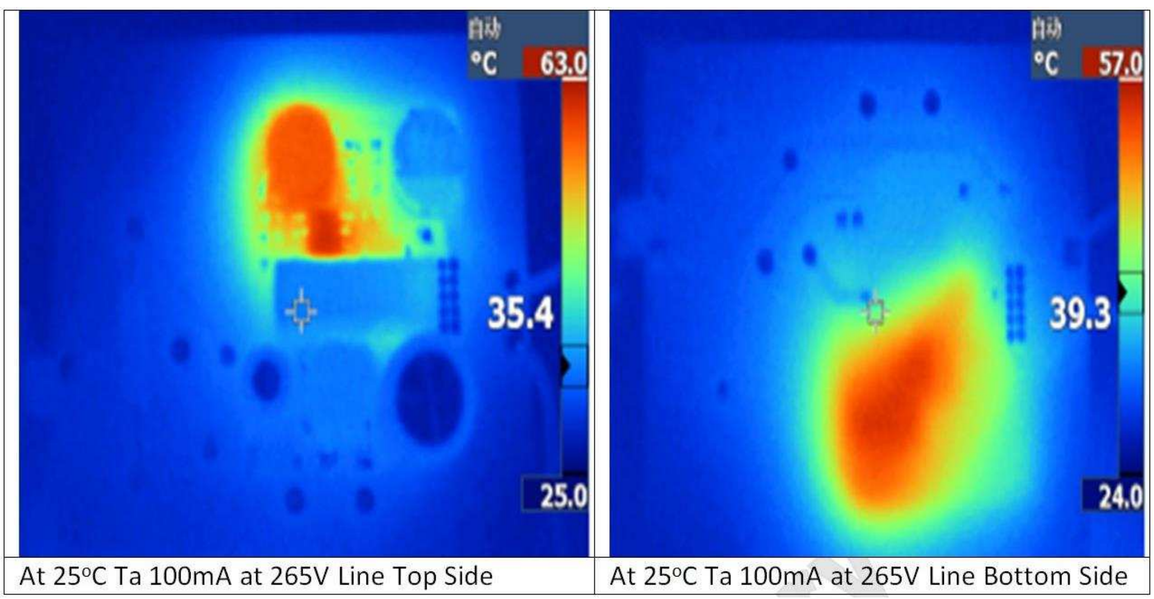
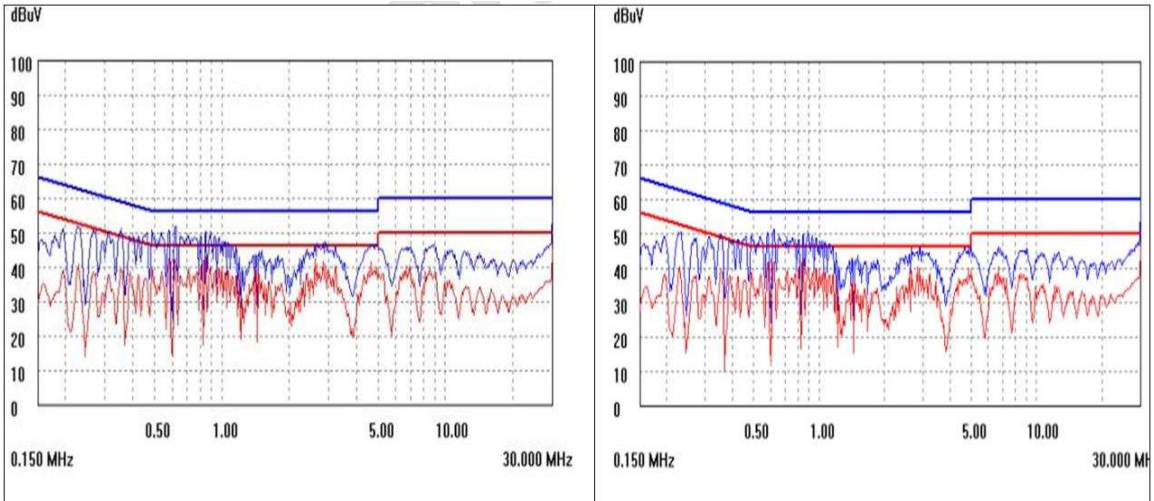


Figure 13. 230 Vin Thermal Performance

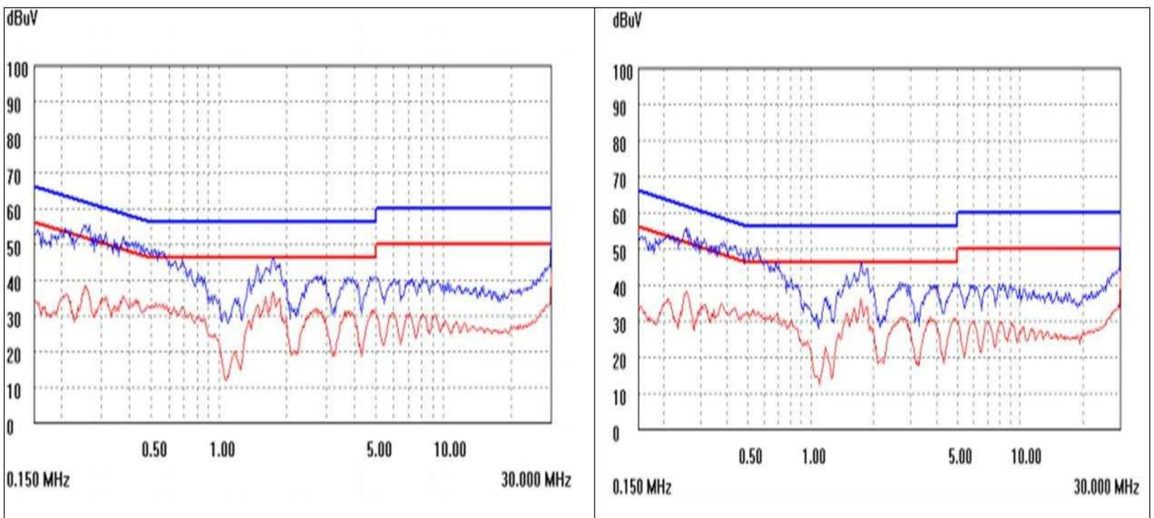
3.7 EMI Test

According to the EN55022B EMI limit, the design meets the requirement. **Note:** Output is not grounded.



Test condition: 200R resistor at 230V Line	Test condition: 200R resistor at 230V Natural

Figure 14. 230 Vin EMI Performance



Test condition: 200R resistor at 115V Line	Test condition: 200R resistor at 115V Natural

Figure 15. 115 Vin EMI Performance

4 Layout Suggestion

To increase the reliability and feasibility of the design, TI recommends the layout uses the following guidelines:

1. Place the Ripk resistor as close as possible to the UCC28910 with the shortest traces possible.
2. Try to minimize the area of DRAIN trace, this helps keep EMI disturbance low.
3. A copper area connected to the GND pins improves heat sinking thermal performance.
4. Place the auxiliary voltage sense resistor divider directly on the VS pin keeping traces as short as possible.

5 Conclusion

Through test and optimization, the non-isolated Buck converter achieves the performance meeting the specifications. This paper also details two methods for improving the hysteresis for line brownout protection. EMI standard EN55022B is also compliant. The non-isolated Buck converter is suitable for industrial and appliance applications.

6 Reference

1. *UCC28910: High-Voltage, Flyback Switcher with Primary-Side Regulation and Output Current Control* (SLUS769)
2. PMP4443: Universal AC input, 20V/100mA Non-isolated High-side Buck Converter