*Application Note*

# *Zero Current Switching Issues with Burst Mode in LLC Controllers*

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**ABSTRACT**

TV and Monitor Switch-Mode Power Supplies (SMPS) commonly employ the LLC topology for the isolated DC/DC power conversion stage. The reasons for this are due to the very high efficiencies and high-power density that can be achieved with this resonant topology. One challenge with any LLC operating in burst mode is minimizing audible noise. Another is preventing Zero-Current Switching (ZCS) from occurring when entering or exiting burst-mode. This can show an example of how to improve burst-mode operation with the UCC256404.

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## Trademarks

# 1 Introduction

At the time of writing this application note, the current requirement for TV's to meet DoE Level Vi and CoC Tier 2 standards is to consume less than 500mW of standby power when the TV is off. Because the LLC topology has a limited frequency range where it can achieve resonance, at light load the best option is to enter into burst mode to minimize power consumption. The UCC256404 employs a soft-in and soft-out of burst mode to help minimize audible noise. The challenge with entering into and out of burst mode is to ensure that under all conditions that Zero Current Switching (ZCS) is avoided. ZCS or hard switching is an unwanted operating mode for an LLC and may result in circuit failures. The purpose of this application note is to show how to dynamically adjust standby power performance in burst mode.

# 2 Theory of LLC Topology Design

The LLC resonant converter is based on the series resonant converter (SRC). By using the transformer magnetizing inductor, zero-voltage switching can be achieved over a wide range of input voltage and load. Because, the LLC topology operates in resonance, it is always running at a 50% duty cycle. Therefore, the only way to control power to the load is by changing the resonant frequency. This frequency range is limited by the resonant tank defined by Lm, Lr, and Cr as shown in Figure 2-1. An LLC controller achieves the best efficiency when operating at resonant frequency at a nominal input voltage. As the switching frequency is lowered, the voltage gain is significantly increased. This behavior allows the converter to maintain regulation when the input voltage is reduced. For example, if the PFC is disabled to further minimize power at light load. Due to the nature of resonant converter, all the voltages and currents on the resonant components are approximately sinusoidal. The gain characteristic of the LLC resonant converter is analyzed based on the first harmonic approximation (FHA), which means all the voltages and currents are treated as a sinusoidal shape with the frequency the same as the switching frequency. FHA models the LLC power stage as a sinusoidal input voltage (V**S**) driving an effective load resistance R**L** as shown in figure 2-1 below.

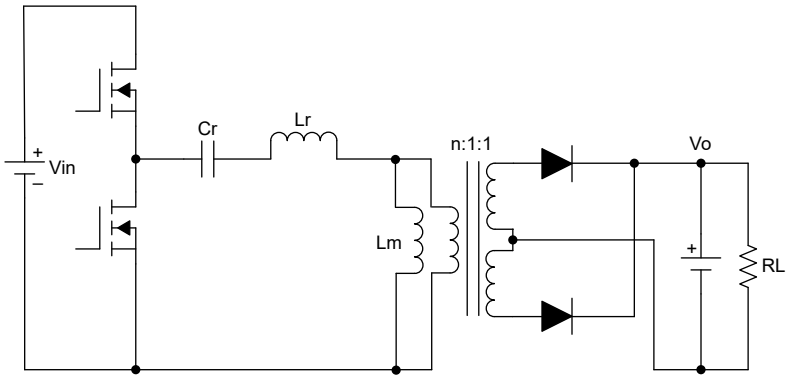


**Figure 2-1. LLC Resonant Converter**

## 3 Burst Mode Operating Control Mechanism

Like any power converter the efficiency of the LLC converter power stage drops rapidly with output power To maintain reasonable light-load efficiency, the LLC converter operates in burst mode. In this mode the LLC converter operates at relatively high power for a short burst period and then switching is stopped for a time period. During burst period excess charge is transferred to and stored in the output capacitor. During the burst off period this stored charge is used to supply the load current. Burst mode operation is critical to meet strict standby power consumption requirements. One challenge presented by burst mode operation can be the audible noise performance. Due to the need to stop switching for a certain time, there is a pattern of switching pulses with frequencies that fall within the 20Hz to 20kHz audible frequency range. Some device variants of UCC25640x include a burst mode with soft-on and soft-off periods at the first and last few switching pulses, minimizing the audible noise during standby operation. Two burst mode thresholds are used to control entering and exiting burst-mode. BMTL stands for Burst-Mode Threshold Low and this is used as the threshold for entering into burst mode. BMTH stands for Burst-Mode Threshold High and this is the threshold to exit burst mode. Figure 3-1 shows has the internal feedback signal named FBreplica is compared with the two thresholds and determines burst mode operation

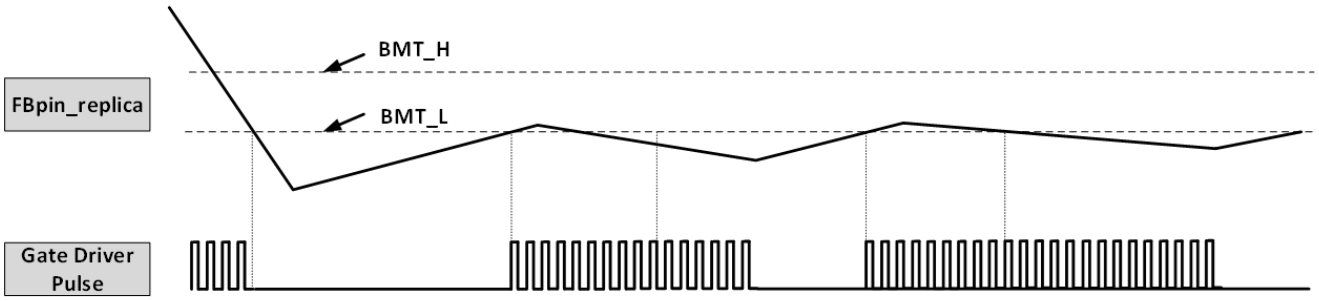


**Figure 3-1. Burst Mode Switching Pattern With UCC256404**

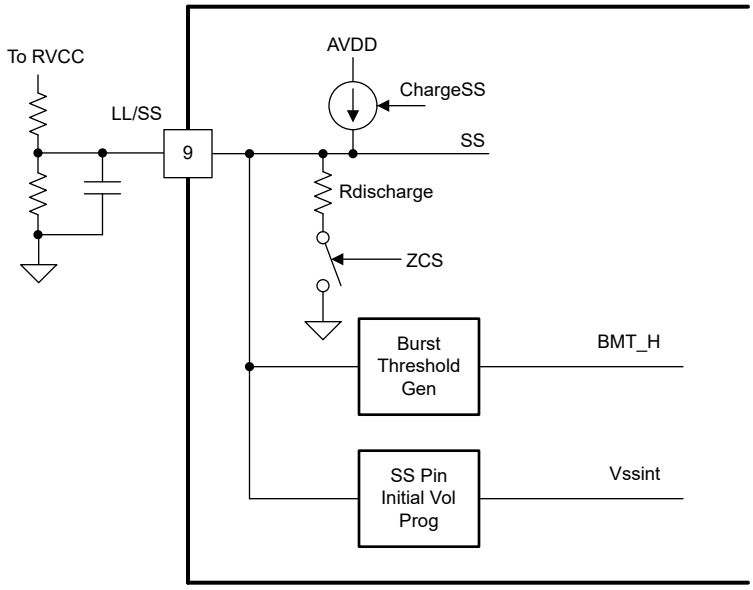


**Figure 3-2. Internal Block of Burst Mode Control With UCC256404**

## 4 Potential ZCS Issue When Exiting Burst Mode

The ZCS happening can occur when the burst packets are too close to each other. This is can happen when there is less off time before coming out of burst mode and the switching node is still ringing which can cause the low side to turn on with current spikes. Figure 4-1 shows how the ZCS problem occurs as burst packets get closer to each other.

1. When burst off period is small, the first pulse of the burst packet can turn on under ZCS condition
2. Minimum burst off can be designed for switching node to be damped and when first pulse of the burst packet can turn on without ZCS

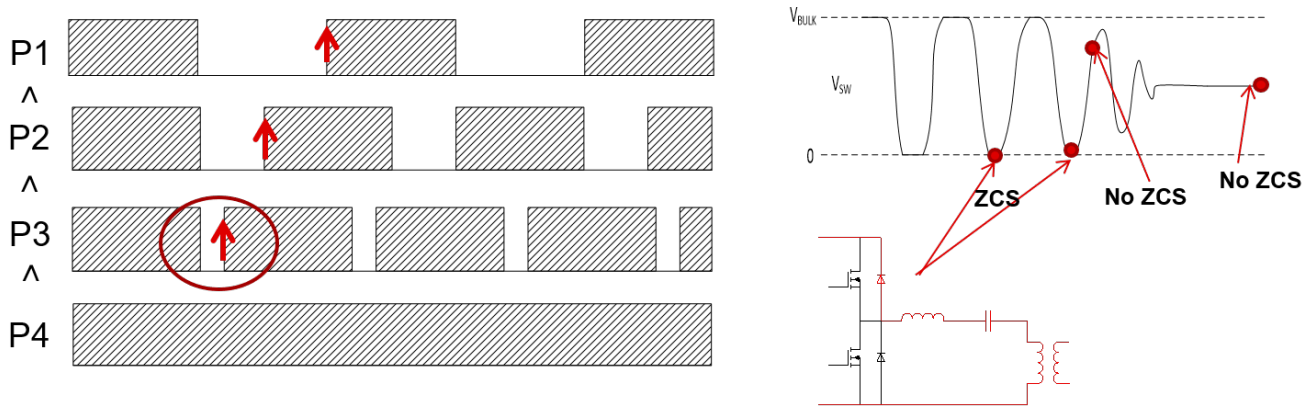


**Figure 4-1. ZCS Issue Mechanism at Burst Operating Condition**

# 5 Design to External Circuit for Solving ZCS Issue at Burst Transition Period

The auto standby circuitry below makes sure that the minimum burst off is 200µs when the switching node is damped, and the first pulse of the burst packet turns on without ZCS. Figure 5-1 shows how to minimize the ZCS issue at burst transition period with auto standby external circuit.

**The following list details the operating mechanism for external auto standby circuit with the UCC256404.**

1. Use circuit to automatically turn on PFC and disable burst mode at higher load condition.
2. INA boosts voltage across current sense on output power rail
3. Comparator output is high when INA output is greater than reference voltage, Small FET turn on sends fault signal to primary side at LL/SS pin.
4. Disables burst mode as load gets larger to make sure minimum time is kept between burst packets

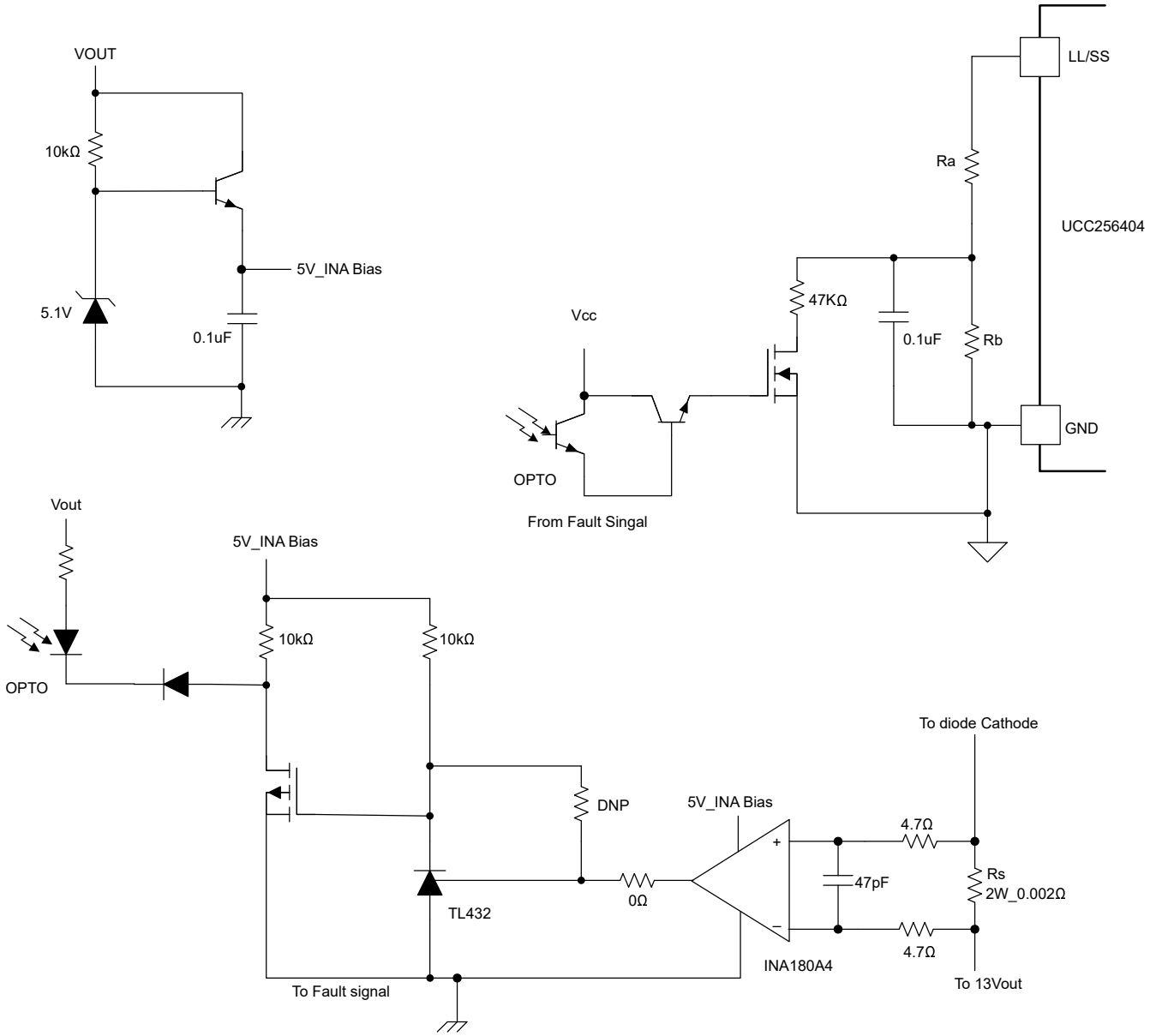


**Figure 5-1. External Auto Standby Circuit With UCC256404**

# 6 Design to Accurate External Circuit for Solving ZCS Issue at Burst Transition Period_(Option)

This is necessary to design the external circuit in more detail for the accurate operation of the auto standby function. We changed the circuit as follows so that the circuit can operate precisely in all AC voltage range conditions (90Vac to 264Vac). The fault signal output circuit was designed as shown in Figure 6-1 to improve the ZCS operation in the burst transition period by changing the small signal FET and shunt regulator configuration to an op amp configuration for more accurate auto standby operation.

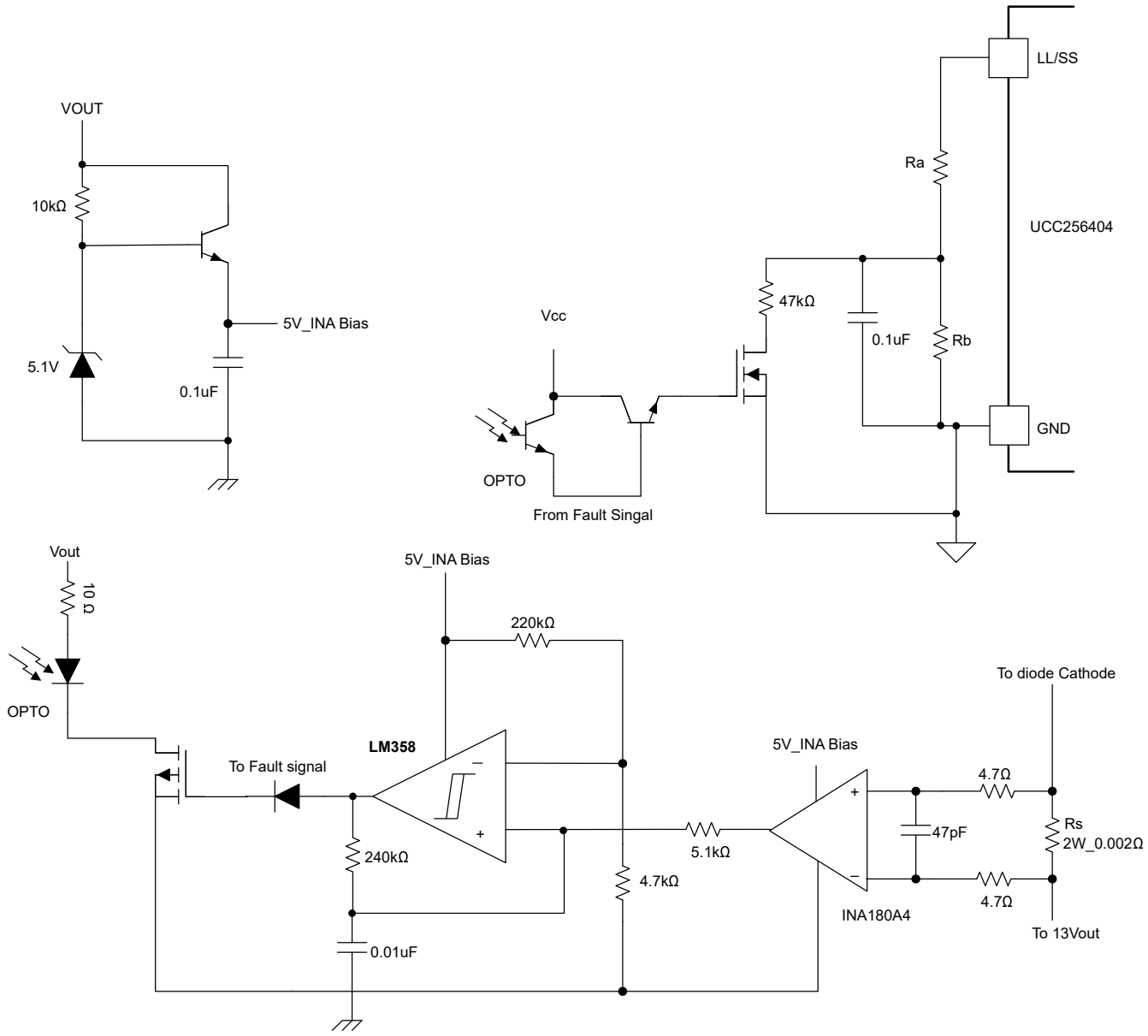


**Figure 6-1. Accurate External Auto Standby Circuit With UCC256404**

## 6.1 Test Result of External Circuit for Solving ZCS Issue at Burst Transition Period

Table 6-1 shows setting external circuit components value for auto standby output current level

**Table 6-1. Auto Standby Output Current Level**

| Load Condition | Burst Mode Setting | Burst Off Period |
|---|---|---|
| > 0.25A | No burst | 0 |
| < 0.25A | Burst with higher power than 0.25A | Large |

The following waveforms show without external auto standby circuit and with external auto standby circuit

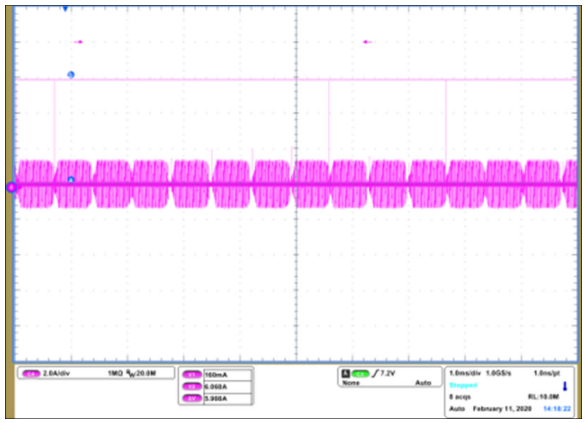

**Figure 6-2. Waveform of Low Side Current (Without Circuit)**

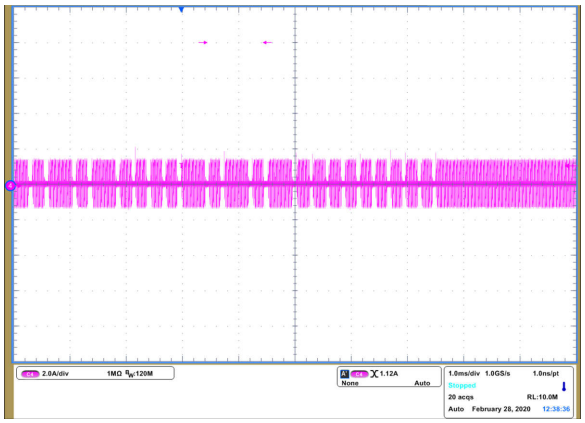

**Figure 6-3. Waveform of Low Side Current Zoom (Without Circuit)**

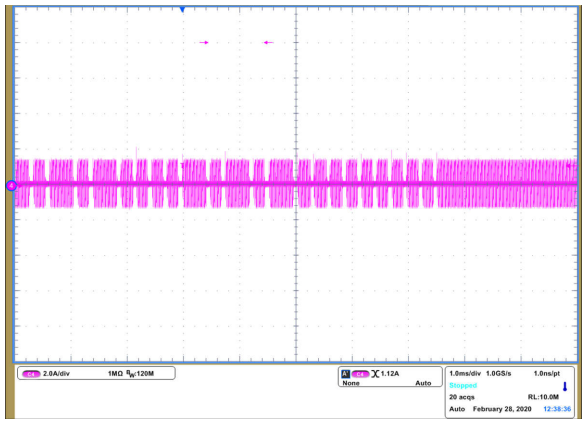

**Figure 6-4. Waveform of Low Side Current (With Circuit)**

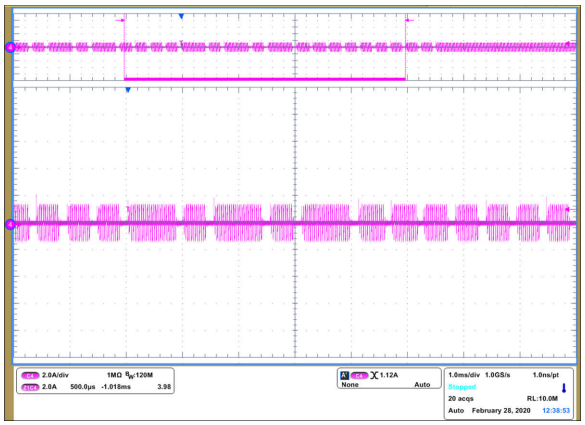

**Figure 6-5. Waveform of Low Side Current Zoom (With Circuit)**

## 7 Summary

As a result of testing and measuring waveforms after applying the auto-standby external circuit design as described in this document, this circuit operates so that the ZCS problem does not occur in the burst mode transition period condition where two switching burst packets are close, and additionally, the output current. Also shown is that the automatic standby level can be adjusted according to the rated value. Therefore, this can be seen that in all test conditions from 90Vac to 264Vac, normal operating performance is achieved with the auto-standby external circuit.

## 8 References

- Texas Instruments, *UCC25640x LLC Resonant Controller with Ultra-Low Audible Noise and Standby Power*, data sheet.

# 9 Revision History

| Changes from Revision * (September 2024) to Revision A (April 2025) | Page |
|---|---|
| • Updated the numbering format for tables, figures, and cross-references throughout the document | 1 |
| • Changed *External Auto Standby Circuit With UCC256404* image | 5 |
| • Changed *Accurate External Auto Standby Circuit With UCC256404* image | 6 |

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