UCC25640EVM-020 Evaluation Module

User's Guide

Texas Instruments

General Texas Instruments High Voltage Evaluation (TI HV EMV) User Safety Guidelines

Always follow TI's set-up and application instructions, including use of all interface components within their recommended electrical rated voltage and power limits. Always use electrical safety precautions to help ensure your personal safety and those working around you. Contact TI's Product Information Center http://ti.com/customer support for further information.

Save all warnings and instructions for future reference.

> ## <u>WARNING</u>
>
> Failure to follow warnings and instructions may result in personal injury, property damage or death due to electrical shock and burn hazards.

The term TI HV EVM refers to an electronic device typically provided as an open framed, unenclosed printed circuit board assembly. It is *intended strictly for use in development laboratory environments, solely for qualified professional users having training, expertise and knowledge of electrical safety risks in development and application of high voltage electrical circuits. Any other use and/or application are strictly prohibited by Texas Instruments.* If you are not suitable qualified, you should immediately stop from further use of the HV EVM.

1. Work Area Safety:

   a. Keep work area clean and orderly.

   b. Qualified observer(s) must be present anytime circuits are energized.

   c. Effective barriers and signage must be present in the area where the TI HV EVM and its interface electronics are energized, indicating operation of accessible high voltages may be present, for the purpose of protecting inadvertent access.

   d. All interface circuits, power supplies, evaluation modules, instruments, meters, scopes, and other related apparatus used in a development environment exceeding 50Vrms/75VDC must be electrically located within a protected Emergency Power Off EPO protected power strip.

   e. Use stable and non-conductive work surface.

   f. Use adequately insulated clamps and wires to attach measurement probes and instruments. No freehand testing whenever possible.

2. Electrical Safety:

   As a precautionary measure, it is always good engineering practice to assume that the entire EVM may have fully accessible and active high voltages.

   a. De-energize the TI HV EVM and all its inputs, outputs and electrical loads before performing any electrical or other diagnostic measurements. Revalidate that TI HV EVM power has been safely de-energized.

   b. With the EVM confirmed de-energized, proceed with required electrical circuit configurations, wiring, measurement equipment hook-ups and other application needs, while still assuming the EVM circuit and measuring instruments are electrically live.

   c. Once EVM readiness is complete, energize the EVM as intended.

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WARNING

While the EVM is energized, never touch the EVM or its electrical circuits, as they could be at high voltages capable of causing electrical shock hazard.

</div>

3. Personal Safety

    a. Wear personal protective equipment e.g. latex gloves or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.

Limitation for safe use:

EVMs are not to be used as all or part of a production unit.

UCC25640EVM-020 Evaluation Module

1 Introduction

The purpose of the UCC25640EVM-020 (EVM) is to aid in evaluation of the UCC256403 and UCC256404 LLC resonant controller. The EVM is a stand-alone LLC resonant half-bridge DC-DC power converter designed to operate with DC input from 365 VDC to 410 VDC, AC input from 85 to 265 V_{RMS}, 47 to 63 Hz, and a nominal output of 12 VDC up to 180-W. The EVM is delivered using a diode rectifier at the output. The user has the option to evaluate this converter with a synchronous rectifier (SR) by populating the UCC24624 and SR FETs. This user's guide provides basic evaluation instruction from a viewpoint of system operation of the stand-alone LLC resonant power converter.
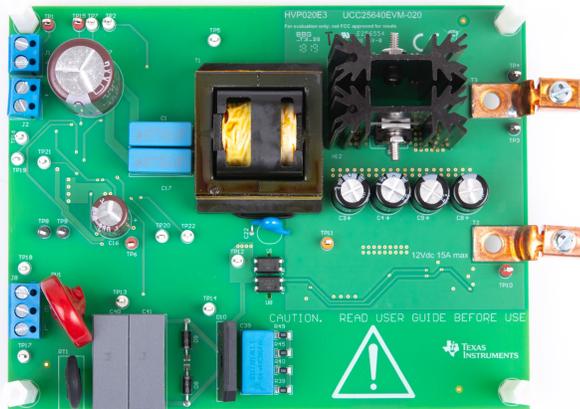
Figure 1. UCC25640EVM-020 Top View
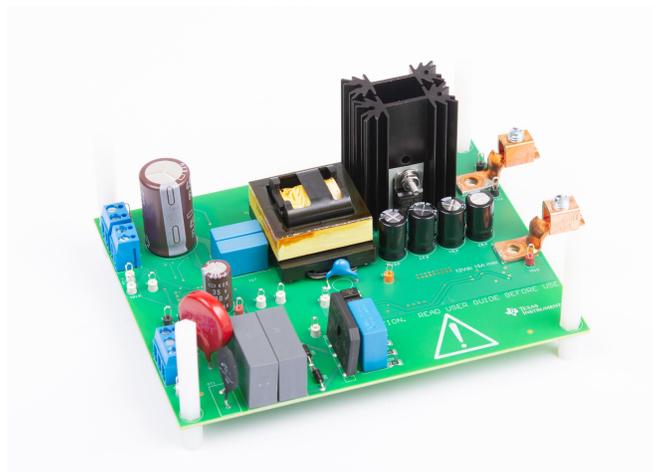
Figure 2. UCC25640EVM-020 Side View

2   Description

2.1   Typical Applications

- SMPS power supply for TV
- Industrial AC-DC adapters
- Power tools
- Medical power supply
- Multi-functional printer
- Enterprise and cinema projector
- PC power supply
- Gaming console power supply
- Lighting

2.2   Features

- Hybrid hysteretic controlled LLC resonant half-bridge DC-DC power conversion
- DC line Input from 365 VDC to 410 VDC
- AC Input voltage from 85 VDC to 265 VAC
- Regulated 12-VDC typical output
- Regulated 9.75-VDC low power mode output
- Full-load power of 180 W, or full-load current of 15 A
- High efficiency
- Optimized low power features enable extremely low standby power
- Advanced burst mode with burst soft-on and soft-off for minimized audible noise
- Adaptive dead-time
- X-capacitor discharge
- Over temperature, output over voltage, and three level over current protections
- Test points to facilitate device and topology evaluation

2.3   Using the EVM with UCC256402

- Replace U4 with UCC256402
- Replace R37 with 124kΩ
- Connect TP1 to TP14
- Disconnect the AC voltage source

2.4   Using the EVM with UCC256403

UCC25640EVM-020 comes populated with UCC256404. To use this EVM with UCC256403:

- Replace U4 with UCC256403
- Remove R5 and R28
- Replace R37 with 124 kΩ
- Remove C25
- Replace R57 with 1.07kΩ
- Replace C46 with 2.2nF
- Replace C36 with 33 nF
- Connect a 15 V DC source to TP6
- Disconnect the AC voltage source

2.5   *Using the EVM with UCC24624 Synchronous Rectifier Controller*

UCC25640EVM-020 is delivered using the diode rectifier at the output. The option to evaluate the converter with synchronous rectification (SR) is available to the user. SR is often used to increase efficiency by replacing the freewheeling diode with a lower loss FET.

To use this EVM with UCC24624:

- Remove D2 and D5
- Populate R31 and R32 with 0Ω
- Populate R35 with 10Ω
- Populate R53 and R54 with 532Ω
- Populate R55 with 39.2Ω
- Populate R2 and R7 with 10Ω
- Populate C2 and C19 with 1.2nF

3   Performance Specifications

Table 1. UCC25640EVM-020 Specifications

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNITS
	INPUT CHARACTERISTICS					
	DC voltage range		365	390	410	VDC
	AC voltage range		85		265	VAC
	AC voltage frequency		47		63	Hz
	Input DC UVLO On			365		VDC
	Input DC UVLO Off			330		VDC
	OUTPUT CHARACTERISTICS					
V_{OUT}	Output voltage - Normal mode	Burst mode threshold to full load = 15 A		12		VDC
V_{OUT}	Output voltage - Standby mode	No load to burst mode threshold		9.75		VDC
	Burst mode threshold output current limit (rising)			240		mA
	Burst mode threshold output current limit (falling)			110		mA
I_{OUT}	Output load current	365 to 410 VDC			15	A
	Output voltage ripple	390 VDC and full load = 15 A		120		mVpp
	SYSTEM CHARACTERISTICS					
	Resonant frequency			100		kHz
	Peak efficiency	390 VDC, load = 8 A		93%		
	Operating temperature	Natural convection		25		ºC

4 Schematic Diagram

Figure 3. UCC25640EVM-020 Power Stage Schematic
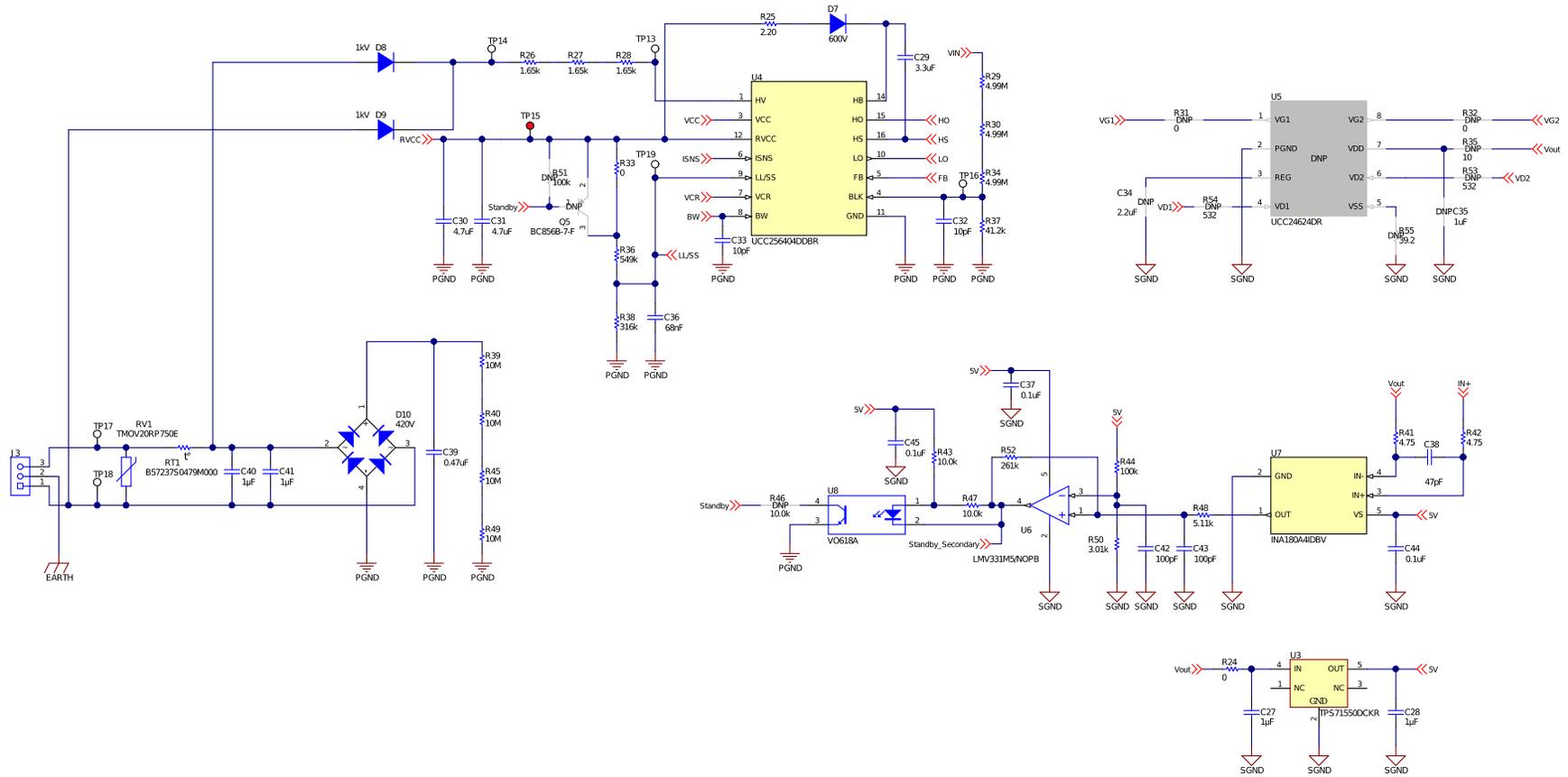
**Figure 4. UCC25640EVM-020 Control Schematic**

5   Test Setup

5.1   *Test Equipment*

DC Voltage Source: Capable of 365 VDC to 410 VDC, adjustable, with minimum power rating 500 W, or current rating not less than 1 A, with current limit function. The DC voltage source to be used should meet IEC 60950 reinforced insulation requirement.

AC Voltage Source: Capable of single-phase output AC voltage 85 to 265 VAC, 47 to 63 Hz, adjustable, with minimum power rating 100 W and current limit function. The AC voltage source to be used should meet IEC 60950 reinforced insulation requirement.

DC Digital Multimeter: One unit capable of 0-VDC to 450-VDC input range, four digit display preferred; and one unit capable of 0-VDC to 20-VDC input range, four digit display preferred.

Output Load: : DC load capable of receiving 0 VDC to 20 VDC, 0 A to 15 A, and 0 W to 300 W or greater, with the capability to display information such as load current and load power.

Oscilloscope: Capable of 500-MHz full bandwidth, digital or analog: if digital, 5 Gsps, or better.

Fan: 200 to 400 LFM forced air cooling is recommended, but not required.

Recommended Wire Gauge: Capable of 25 A, or better than #14 AWG, with the total length of wire less than 8 feet (4 feet input and 4 feet return).

## 5.2 Recommended Test Setup
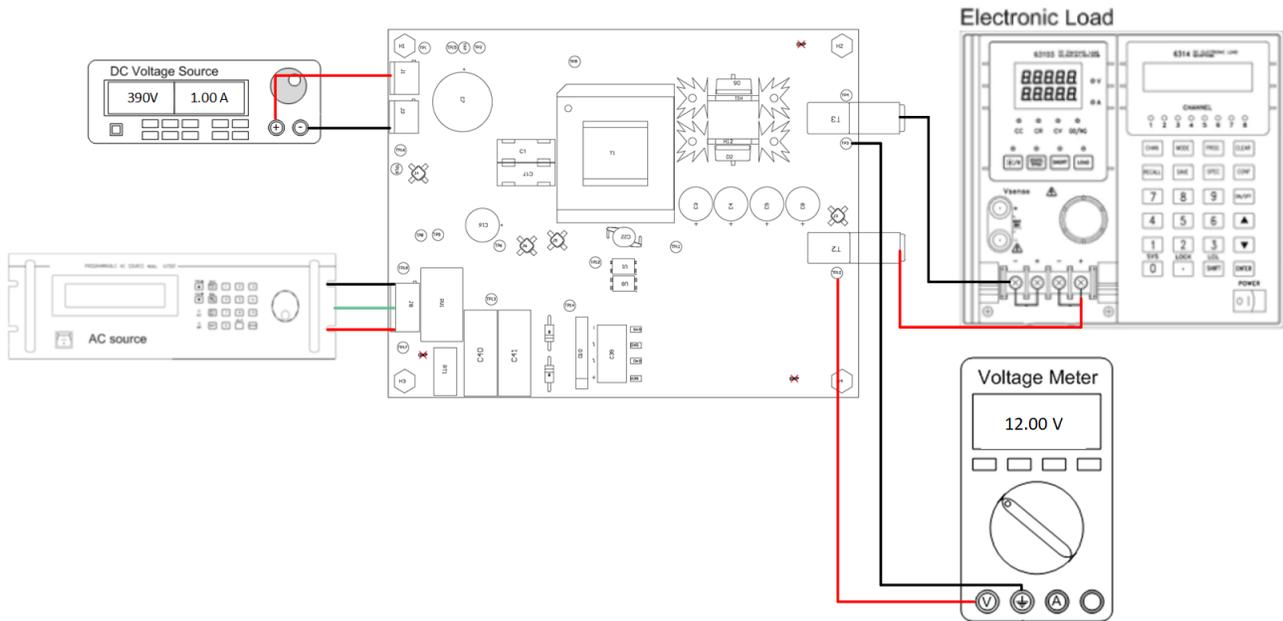
Figure 5. UCC25640EVM-020 Test Setup Diagram

WARNING

High voltages that may cause injury exist on this evaluation module (EVM). Please ensure all safety procedures are followed when working on this EVM. Never leave a powered EVM unattended.

5.3 *Power Factor Correction (PFC) Boost Front End Setup*

UCC25640EVM-020 is typical for a two stage AC/DC power supply with a PFC boost converter in front of it. The following steps and schematic describe how to connect the UCC28056EVM-296 or UCC28064EVM-004, Transition-Mode (TM) PFC Controllers, to this EVM.

1. Remove D8 and D9 from UCC25640EVM-020.
2. Connect the anode of D8 to AC Line and the anode of D9 to AC Neutral on UCC28056EVM-296 or UCC28064EVM-004.
3. Connect both the cathodes of D8 and D9 to TP14 on UCC25640EVM-020.
4. Connect TP15 (RVCC) on UCC25640EVM-020 to TP9 (VCC) on UCC28056EVM-296 or J1-1 (VCC) on UCC28064EVM-004.

Figure 6 is a diagram of the PFC LLC setup used for testing.
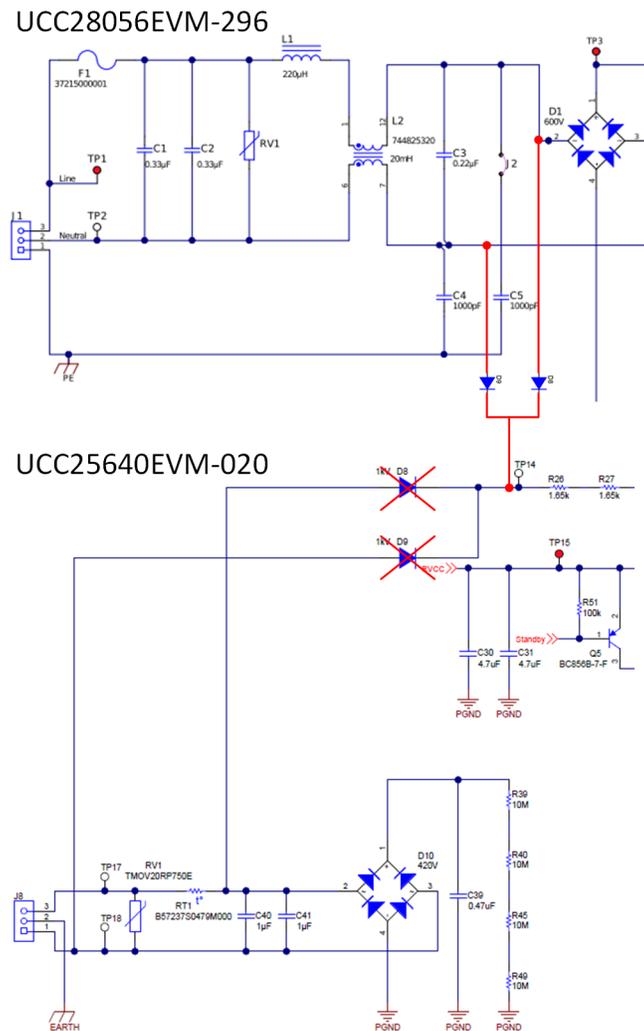
Figure 6. UCC28056EVM-296/UCC28064EVM-004 PFC to UCC25640EVM-020 LLC Test Setup

6 Test Points

Table 2 lists the EVM test points.

Table 2. Test Points

Test Points	Name	Description
TP1	VIN	Input voltage positive terminal
TP2	HO	Primary-side high side MOSFET gate, Q1
TP3	SGND	Secondary-side ground
TP4	SGND	Secondary-side ground
TP5	HS	Primary-side switch node, or the intersection of Q1 and Q3
TP6	VCC	Supply input
TP7	LO	Primary-side low side MOSFET gate, Q3
TP8	PGND	Primary-side ground
TP9	PGND	Primary-side ground
TP10	VOUT	Output voltage positive terminal
TP11	INJECT	Small signal injection terminal
TP12	FB_Current	Feedback current measurement
TP13	HV	High-voltage start pin
TP14	AC_Rect	Rectified AC input
TP15	RVCC	Regulated 12-V supply
TP16	BLK	Input voltage sensing
TP17	AC_L	AC line
TP18	AC_N	AC neutral
TP19	LL/SS	Soft-start and light-load burst mode threshold
TP20	ISNS	Resonant current sense
TP21	BW	Bias winding voltage sense
TP22	VCR	Resonant capacitor voltage sense

7 Terminals

Table 3 lists the EVM terminals.

Table 3. List of Terminals

Terminal	Name	Description
J1	VIN	Input voltage positive terminal
J2	PGND	Input voltage return terminal
J8	AC Input	3-pin, AC power input, 85–265 V_{RMS}
T2	VOUT	Output voltage positive terminal
T3	SGND	Output voltage ground terminal

8   Test Procedure

Use the following steps for the test procedure:

1. Refer to Section 5.2 for basic setup. The required equipment for this measurement is listed in Section 5.1.

2. Before making electrical connections, visually check the board to make sure there are no suspected spots of damage.

3. Keep the DC voltage source output off. Connect the DC source to J1 (+) and J2 (-). The DC voltage source should be isolated and meet the IEC 60950 requirement. Set the DC output voltage within the range specified in Table 1, between 365 VDC and 410 VDC; set the DC source current limit to 1 A.

CAUTION

The board has no fuse installed and relies on the external voltage source current limit to ensure circuit protection.

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4. Keep the AC voltage source output off. Connect the source with AC_neutral to J8-1, AC_earth to J8-2, and AC_line to J8-3. Isolate the AC voltage source and meet the IEC 60950 requirement. Set the AC output voltage and frequency within the range specified in Table 1, between 85 and 265 VAC and 47 to 63 Hz. Set the AC source current limit to 200 mA.

5. Connect an electronic load set to either constant-current mode or constant-resistance mode. The load range is from 0 to 15 A.

6. If the load does not have a current or a power display, TI recommends inserting a current meter between the output voltage and the electronic load.

7. Connect a voltage meter to TP10 and TP3/TP4 to monitor the output voltage.

8. Turn on the AC source output.

9. Turn on the DC source output.

8.1   Equipment Shutdown

Shut down the equipment using the following steps:

1. Shut down the AC voltage source.

2. Shut down the DC voltage source.

3. Shut down the electronic load.

WARNING

High voltage may still be present on the resonant capacitors after turning off the DC source.

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9 Performance Data and Typical Characteristic Curves

9.1 UCC25640EVM-020 Standalone Standby and Light Load Power

Table 4 lists the total standby and light load power measurement for the standalone EVM. The average input power is measured over a two minute interval.

Table 4. Standalone Standby Power

I_{OUT} (mA)	V_{OUT} (V)	P_{OUT} (mW)	V_{IN} (V)	I_{IN} (mA)	P_{IN} (mW)
0	9.740	0.000	389.826	0.115	44.666
10	9.739	97.392	389.823	0.393	153.093
20	9.739	194.772	389.820	0.672	261.815
50	9.739	486.925	389.814	1.514	590.186
100	9.738	973.820	389.807	2.914	1135.799

9.2 PFC Boost Front End Standby Power

9.2.1 Overview

UCC256404 includes a high voltage startup feature. This feature enables the controller to be powered by a wide AC input, eliminating the need for an external supply to power both the PFC and LLC. When AC power is applied to UCC256404, a JFET initially charges the VCC capacitor to provide the energy needed to start the PFC and LLC power system. Once running, power for the PFC and LLC controllers is derived from a bias winding on the LLC transformer. Figure 7 illustrates the described startup sequence. UCC256403 does not include the high voltage startup feature and requires an external power supply as described in Section 5.3.
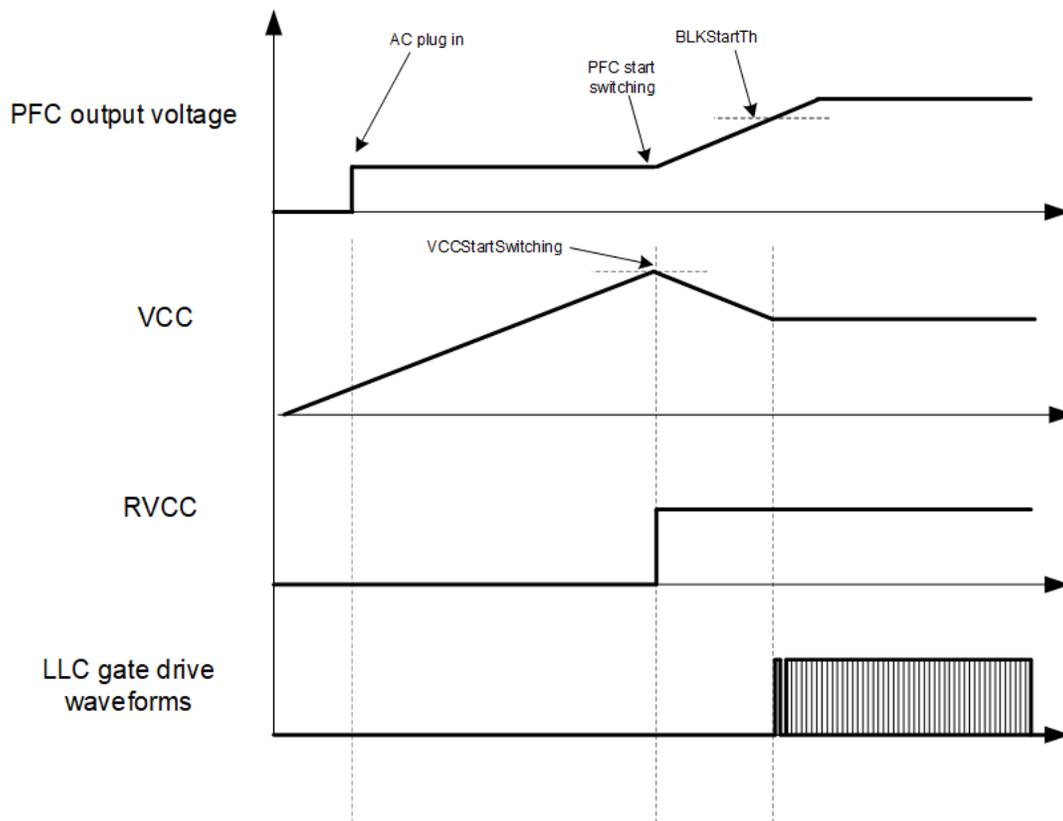

Figure 7. PFC LLC Startup Sequence

9.2.2 PFC LLC Standby Power and Light Load Efficiency

PFC LLC system standby power for UCC25640EVM-020 is measured with both UCC28056EVM-296 and UCC28064EVM-004. Refer to Section 5.3 for test setup and procedure. The WT310 power analyzer is used for PFC LLC standby and light load measurements.

Table 5. Total Standby Power with UCC28056EVM-296 (PFC) and UCC25640EVM-020 (LLC)

V_{IN} (V)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)
90	0.218	9.697	0.0124	0.120	54.94
115	0.216	9.697	0.0124	0.120	55.44
230	0.223	9.697	0.0124	0.120	53.70
265	0.227	9.697	0.0124	0.120	52.76
90	0.361	9.697	0.0248	0.240	66.56
115	0.360	9.696	0.0248	0.240	66.74
230	0.364	9.697	0.0248	0.240	66.01
265	0.365	9.697	0.0248	0.240	65.83

Table 6. Total Standby Power with UCC28064EVM-004 (PFC) and UCC25640EVM-020 (LLC)

V_{IN} (V)	P_{IN} (W)	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	Efficiency (%)
90	0.229	9.697	0.0124	0.120	52.29
115	0.228	9.696	0.0124	0.120	52.52
230	0.250	9.697	0.0124	0.120	47.90
265	0.260	9.697	0.0124	0.120	46.06
90	0.374	9.696	0.0248	0.240	64.24
115	0.370	9.696	0.0248	0.240	64.94
230	0.391	9.696	0.0248	0.240	61.45
265	0.400	9.696	0.0248	0.240	60.07

9.3 Efficiency

Figure 8 illustrates the standalone EVM efficiency graph.
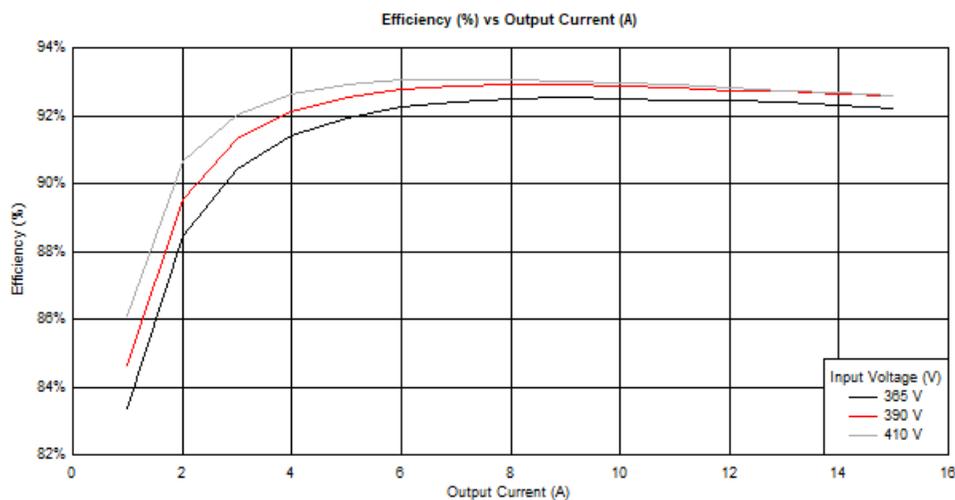
Figure 8. Efficiency vs Output Current

9.4 Load Regulation

Figure 9 illustrates the load regulation versus output current graph.
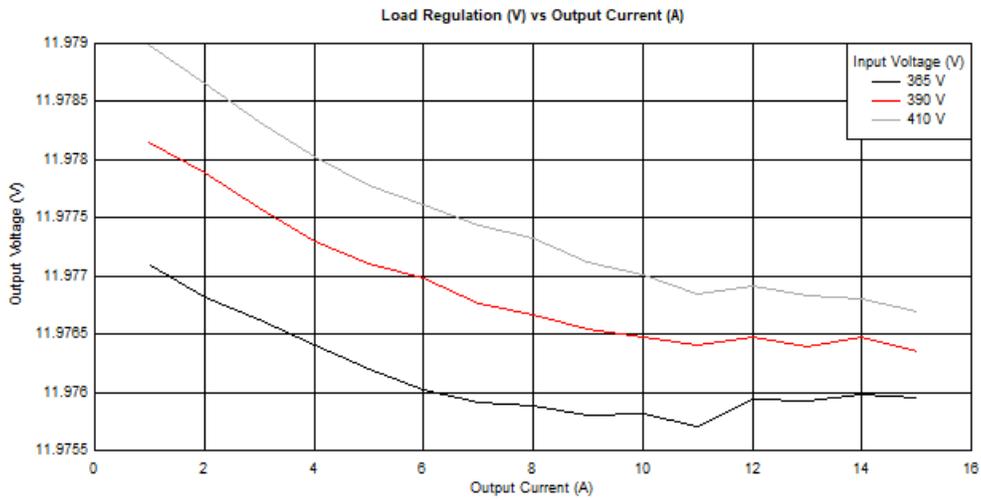
Figure 9. Load Regulation vs Output Current

9.5 Switching Frequency

Figure 10 illustrates the converter switching frequency versus output current.
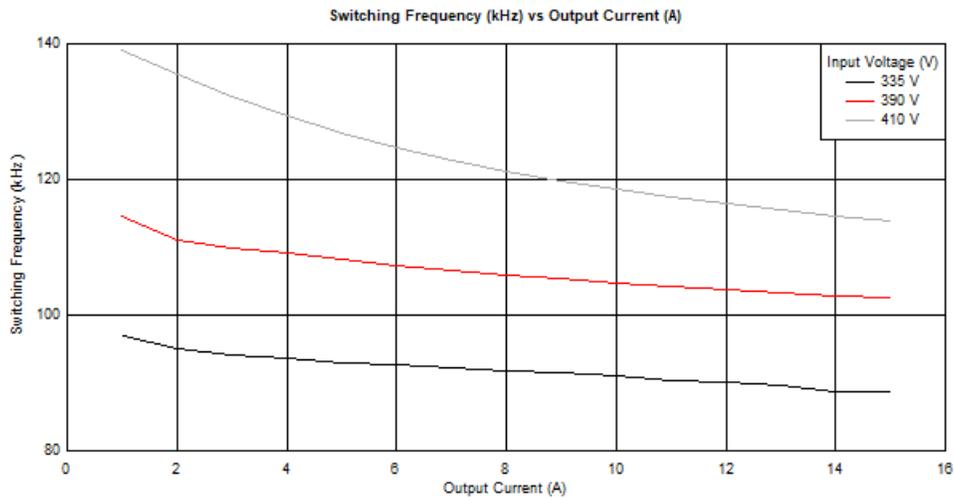

Figure 10. Switching Frequency vs Output Current

9.6 Audible Noise

Figure 11 and Figure 12 show the audible noise measurements during light load standby operation. The measurements are performed in a soundproof container with the microphone 5 mm above the transformer.
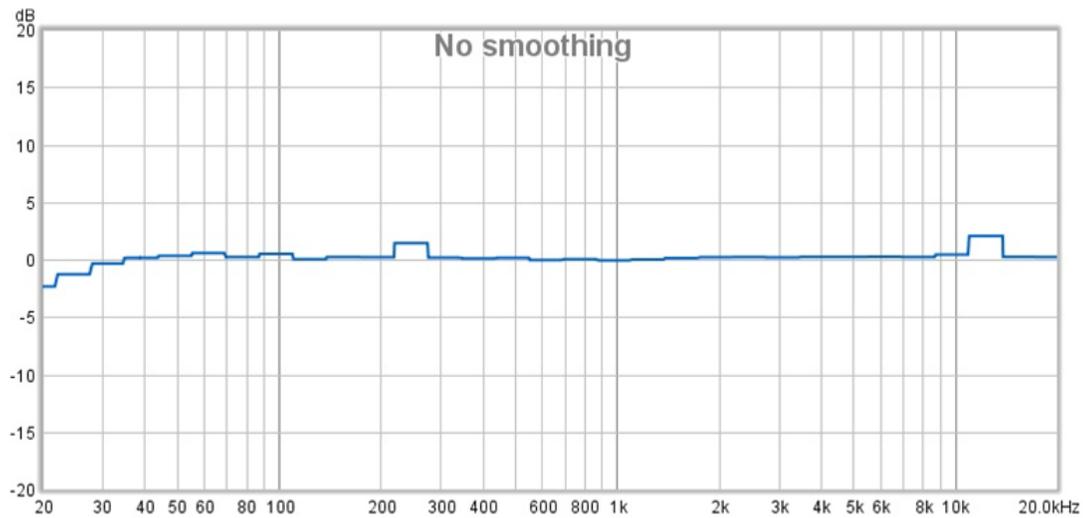
Figure 11. Audible Noise Measurement at 10 mA Load
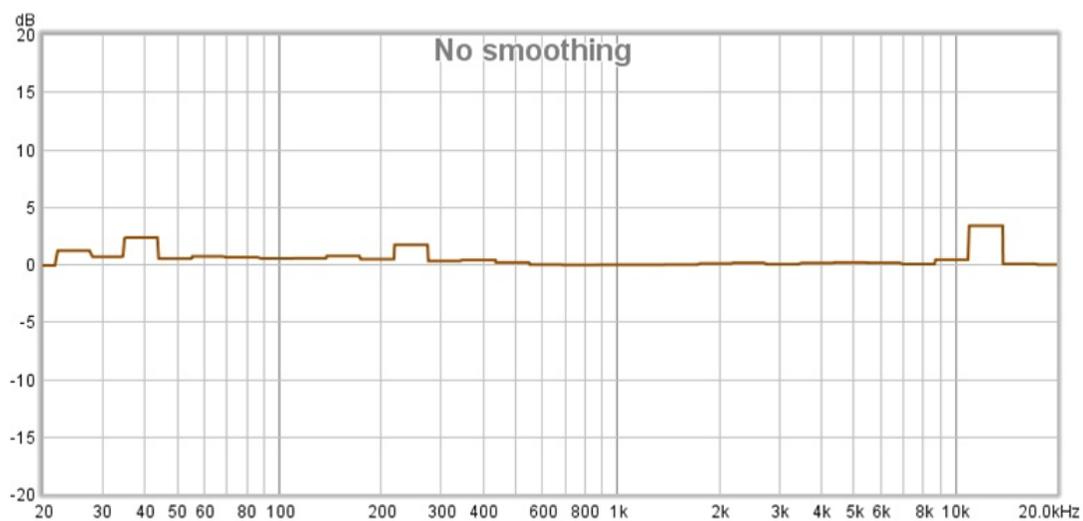
Figure 12. Audible Noise Measurement at 20 mA Load

9.7   *Startup*

The following waveforms show the output voltage and low side gate behavior. 115 VAC, 60 Hz is applied initially to the AC input, then the 390 VDC input is applied to the DC input
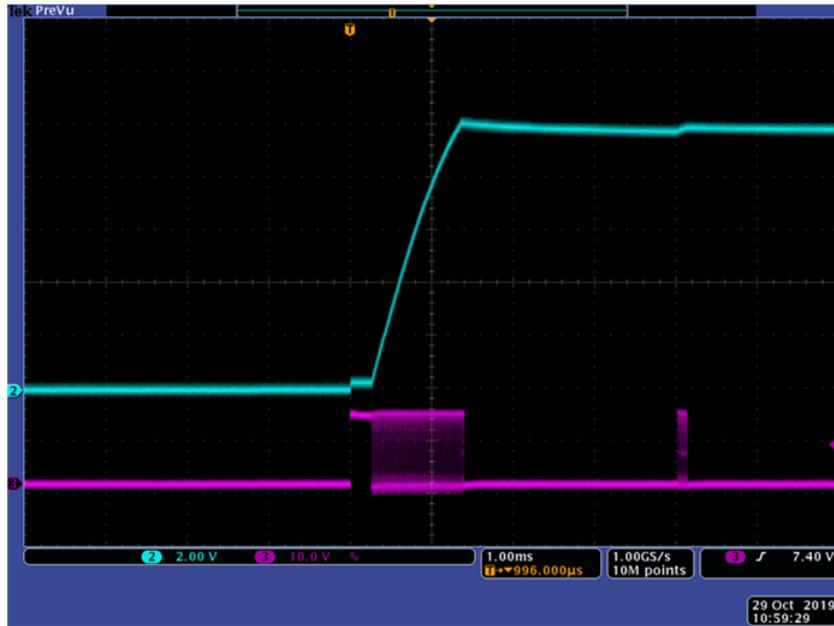

**Figure 13. No Load (0 A) Startup (Ch2 = V$_{OUT}$; Ch3 = LO)**
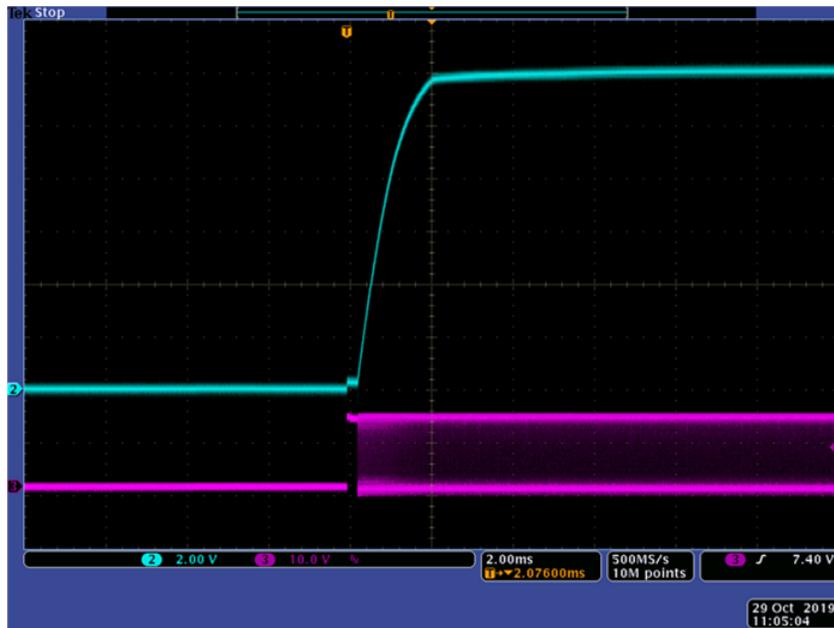
Figure 14. Full Load (15 A) Startup (Ch2 = V$_{OUT}$; Ch3 = LO)

9.8   Thermal Image

The following images show the EVM temperature after 20min soak at full load, no forced air and 390Vdc input applied to the DC input.


Figure 15. Thermal Image Top

Table 7. Component Temperature

Component	Temperature (°C)
T1 (Bx1)	74.9°C
D2 (Bx2)	90.2°C
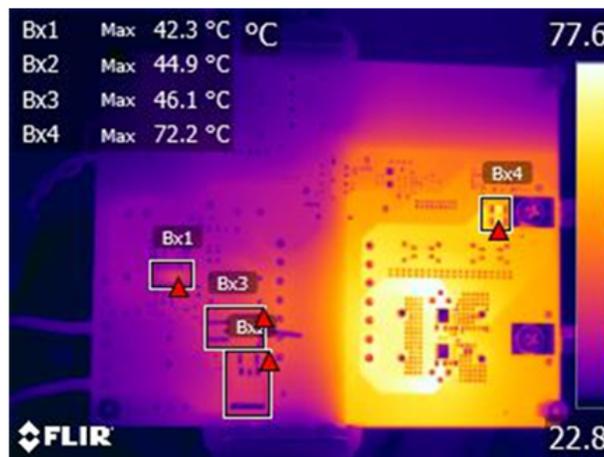
Figure 16. Thermal Image Bottom

Table 8. Component Temperature

Component	Temperature (°C)
U4 (Bx1)	42.3°C
Q1 (Bx2)	44.9°C
Q3 (Bx3)	46.1°C
R9, R12 (Bx4)	72.2°C

9.9 *Output Voltage Ripple*

The following waveforms show the output voltage ripple with 115 VAC, 60 Hz applied to the AC input and 390 VDC applied to the DC input. The oscilloscope probe is AC coupled.
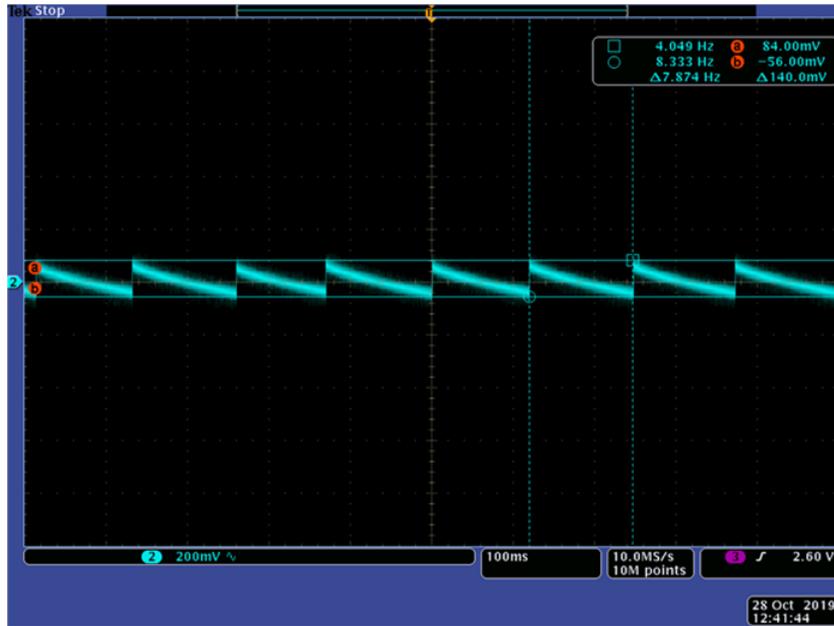
**Figure 17. No Load (0 A) Output Ripple (Ch2 = V$_{OUT}$)**
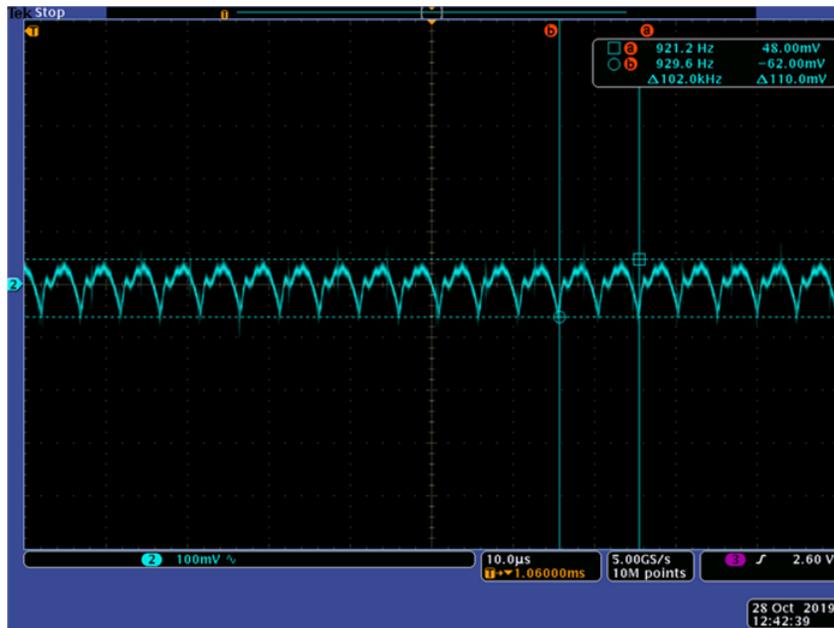
Figure 18. Full Load (15 A) Output Ripple (Ch2 = V$_{OUT}$)

9.10 Load Transient Response

The following waveforms show the output voltage with 115 VAC, 60 Hz applied to the AC input and 390 VDC applied to the DC input. Figure 20 illustrates the dynamic voltage scaling through the entry and exit of burst mode. The output voltage immediately exits standby mode, increasing to 12 V, when the BMT is exceeded. It then drops to the 9.75 V standby output voltage level when the load falls below the BMT. This behavior is due to the circuit explained in Section 10.2.


Figure 19. 300 mA to 15 A Transient (Ch2 = V$_{OUT}$ AC Coupled; Ch4 = I$_{OUT}$)

Figure 20. 10 mA to 15 A Transient (Ch2 = V$_{OUT}$ DC Coupled; Ch4 = I$_{OUT}$)

9.11 Loop Response

The following plot shows the loop response with 115 VAC, 60 Hz applied to the AC input and 390 VDC applied to the DC input at full load condition.
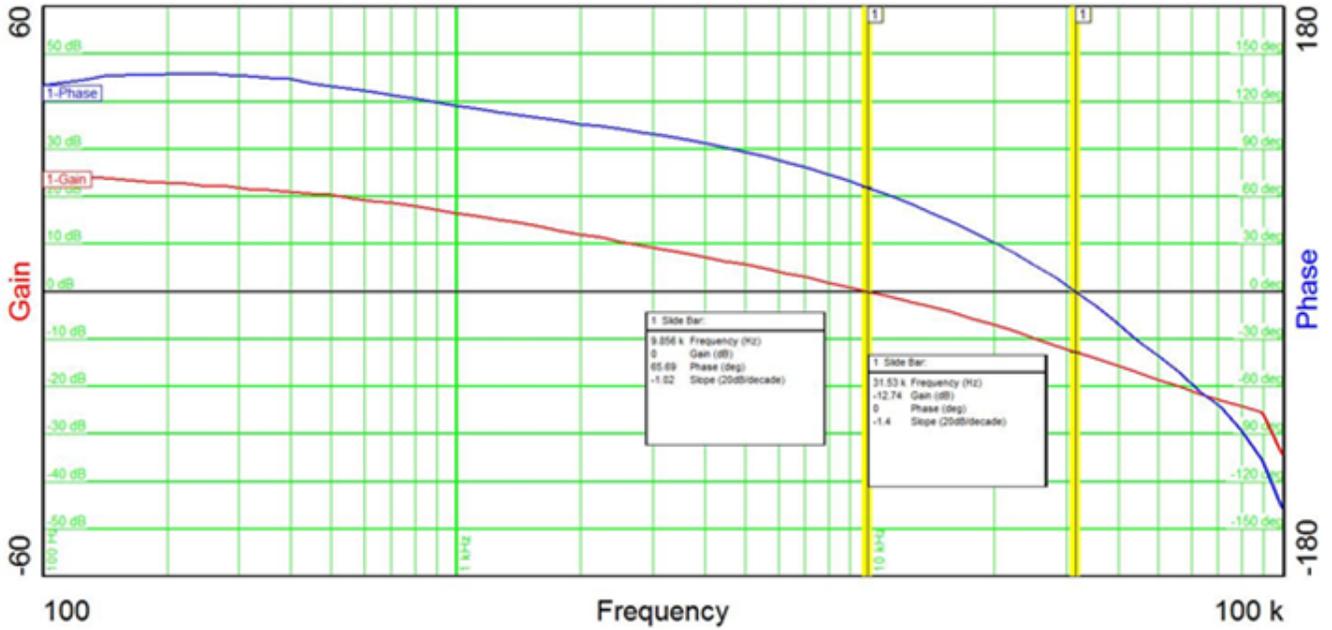

Figure 21. Bode Plot at 15 A Load

9.12 Steady State

The following waveforms show the sampled resonant capacitor voltage (VCR), resonant current, and low side gate voltage (LO) with 115 VAC, 60 Hz applied to the AC input and 390 VDC applied to the DC input. Figure 22 and Table 7 show the waveforms during burst mode.
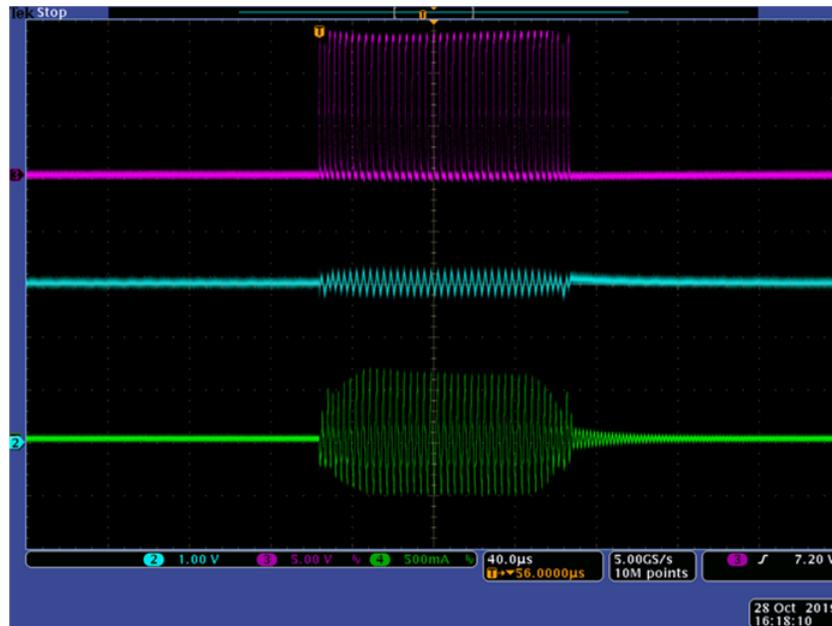

Figure 22. Steady State Waveforms at No Load (Ch2 = VCR; Ch3 = LO; Ch4 = IResonant)
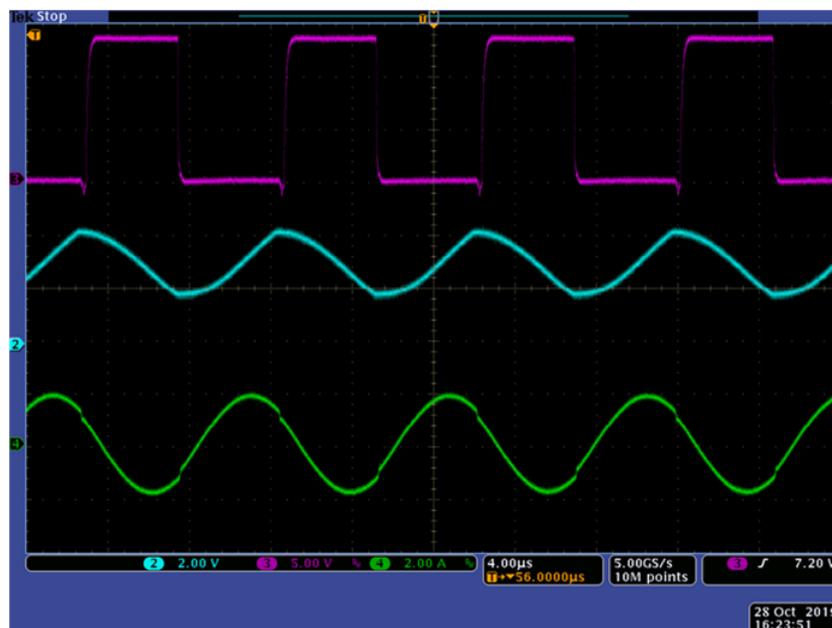

Figure 23. Steady State Waveforms at 15 A Load (Ch2 = VCR; Ch3 = LO; Ch4 = IResonant)

9.13 *X-Capacitor Discharge*

The following waveform shows the X-Capacitor discharge after the AC input is disconnected at the peak of a 265 VAC input. 390 VDC is applied to the DC input and the output is unloaded.
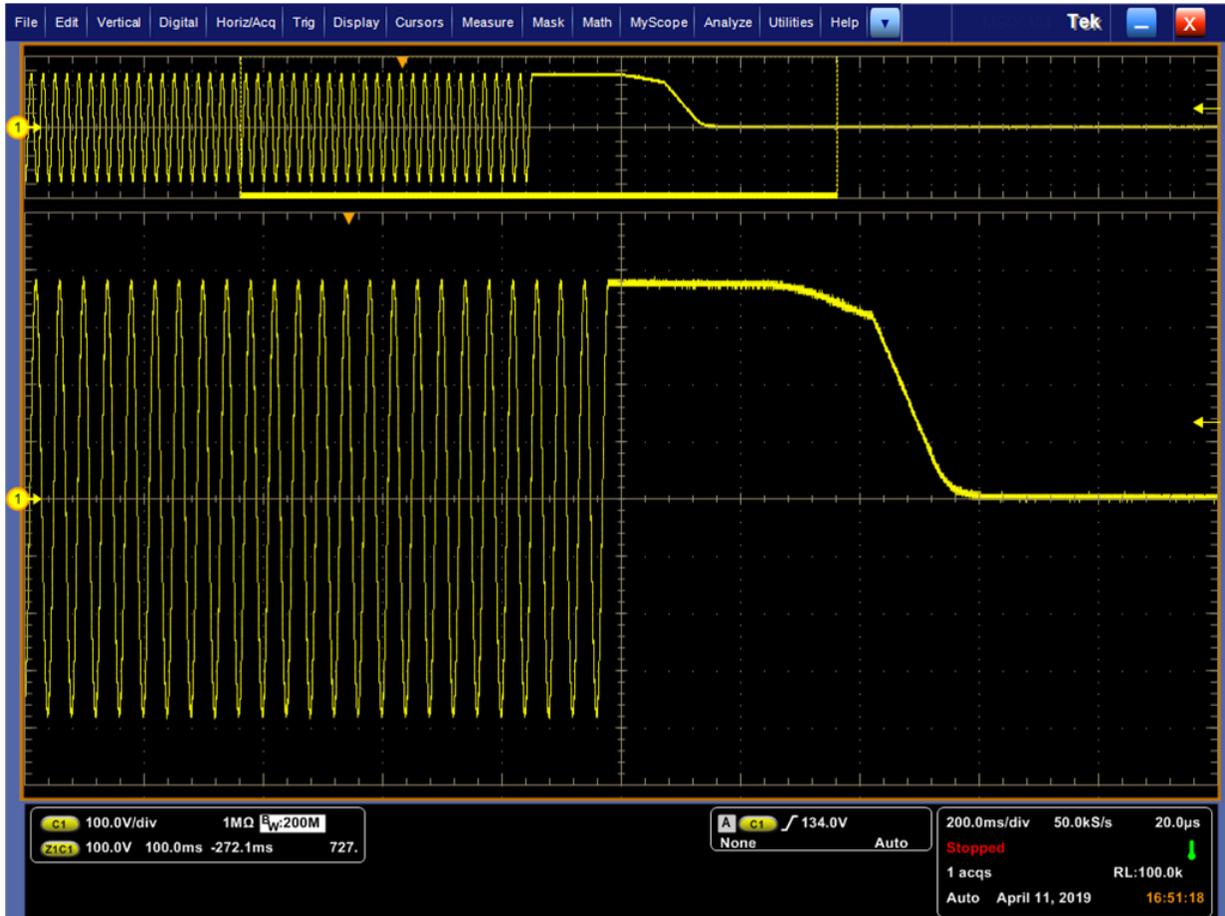
Figure 24. X-Cap Discharge (Ch1 = Voltage across X-Cap, C40 and C41)

10   Assembly Drawing and List of Materials

10.1   Assembly Drawing
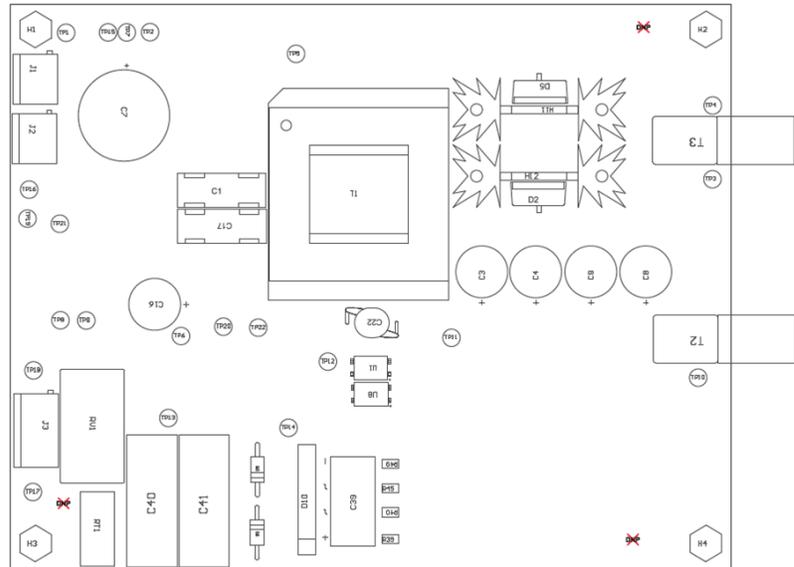
Figure 25. UCC25640EVM-020 Top Layer Assembly Drawing (Top view)
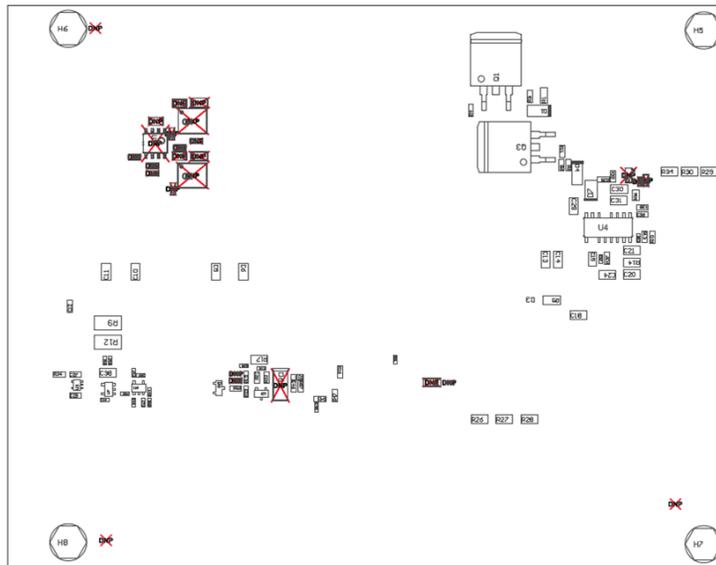
Figure 26. UCC25640EVM-020 Bottom Layer Assembly Drawing (Top view)

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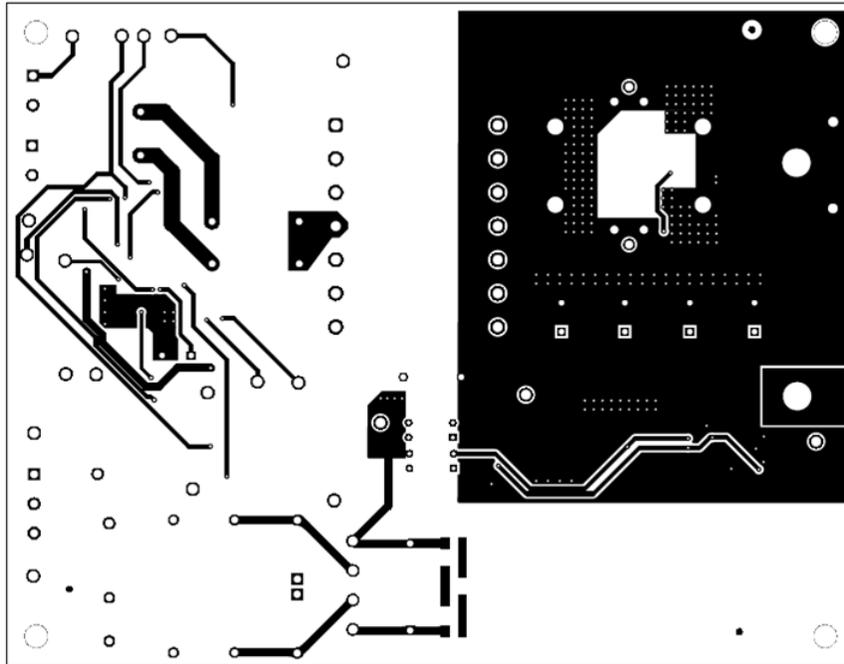
Figure 27. UCC25640EVM-020 Top Copper Assembly Drawing (Top view)
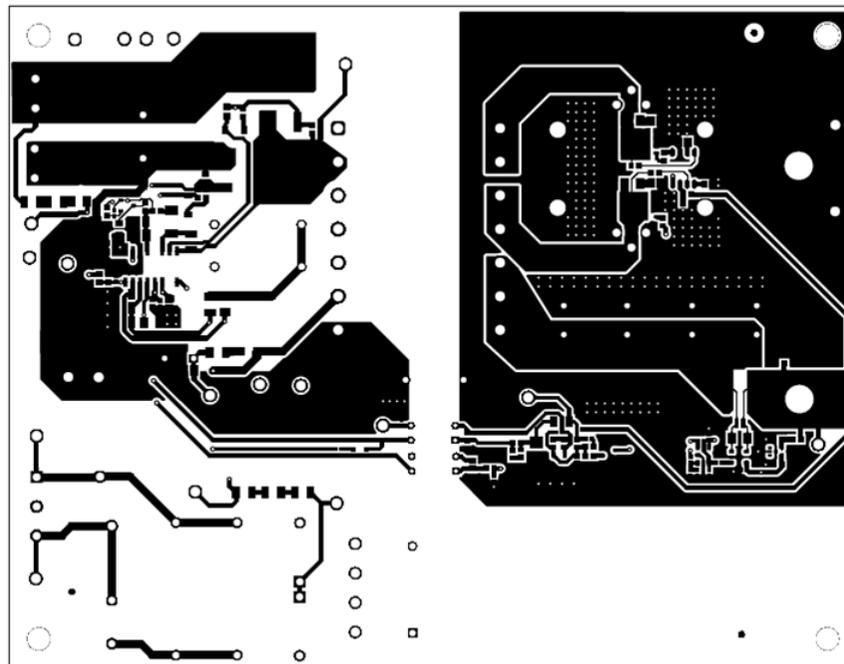
Figure 28. UCC25640EVM-020 Bottom Copper Assembly Drawing (Top view)

10.2 Standby Mode Circuit for TV Applications

For some applications such as LED or OLED TV, the AC/DC power supply is placed into a standby power mode to meet light load efficiency requirements. In this mode, the output voltage is reduced and the LLC converter is configured to operate in burst mode to minimize input power. A central control circuit communicates with the AC/DC power supply to enter or exit standby mode as needed. In order to mimic this system level behavior, an external standby circuit was added to this design. This external standby circuit adjusts both the burst mode threshold setting and output voltage set point depending on the magnitude of the output current.

This is accomplished by sensing the voltage across a current sense resistor.
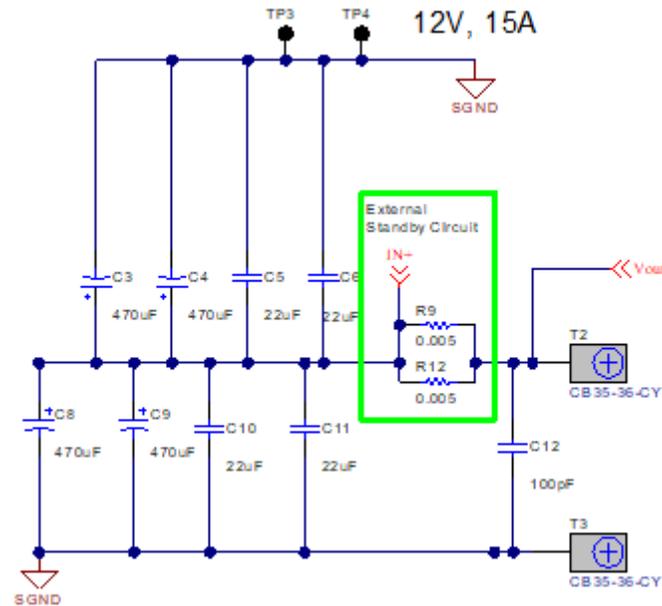
Figure 29. High Side Current Sense in Series with Output

The resulting voltage is fed to a current sense amplifier with a 200V/V gain. The amplifier output is compared to a set reference voltage to determine when to enter or exit standby mode. Hysteresis is implemented on the comparator using R52 and R48.
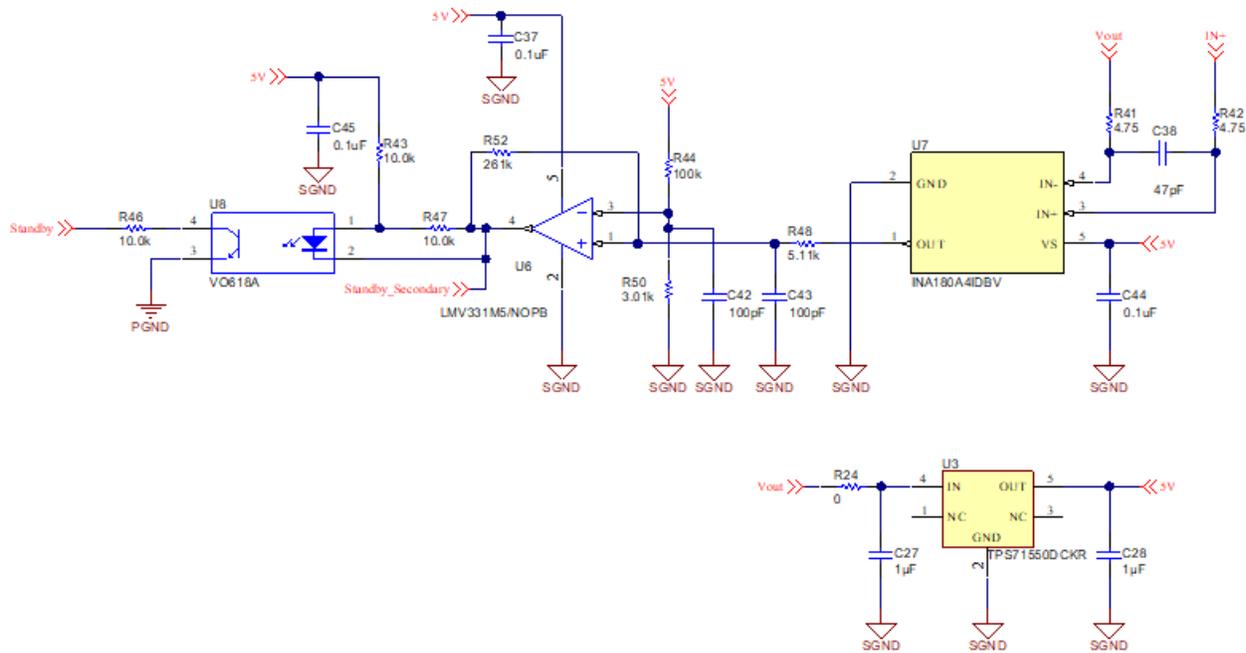
Figure 30. External Standby Circuit Current Sense Gain and Comparator

The standby circuit adjusts the output voltage set point by changing the feedback resistor divider ratio through Q6 and R56. When in standby mode, the gate of Q6 is held low. When out of standby mode, Q6 is turned on to put R56 in parallel to R23.
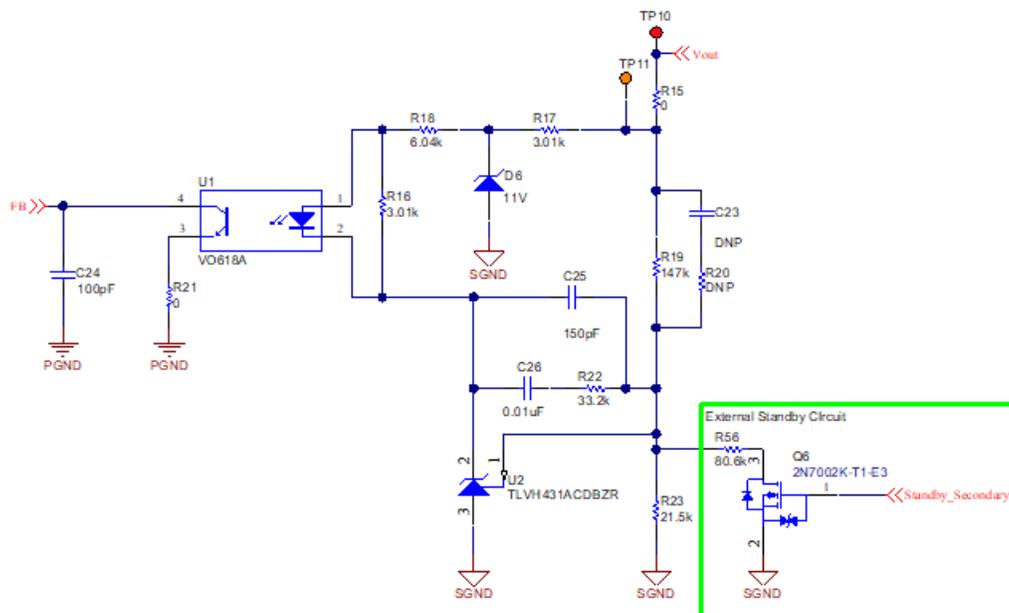
Figure 31. Output Voltage Set Point Adjustment

The burst mode threshold is controlled by the standby circuit using transistor Q5. When in standby mode, the base of Q5 is pulled low, connecting the top of the LL/SS resistor divider to RVCC. When out of standby mode, Q5 is turned off, changing the burst mode threshold to the minimum burst threshold (0.2V). For applications where the output voltage set point is decreased when in standby mode, it is possible to get in and out of burst mode by changing the output voltage regulation set point. This is because the change in necessary peak to peak voltage on the VCR waveform to regulate at the higher output voltage is greater than the programmed burst threshold. For these applications, the burst threshold adjustment circuit on the primary may not be necessary.
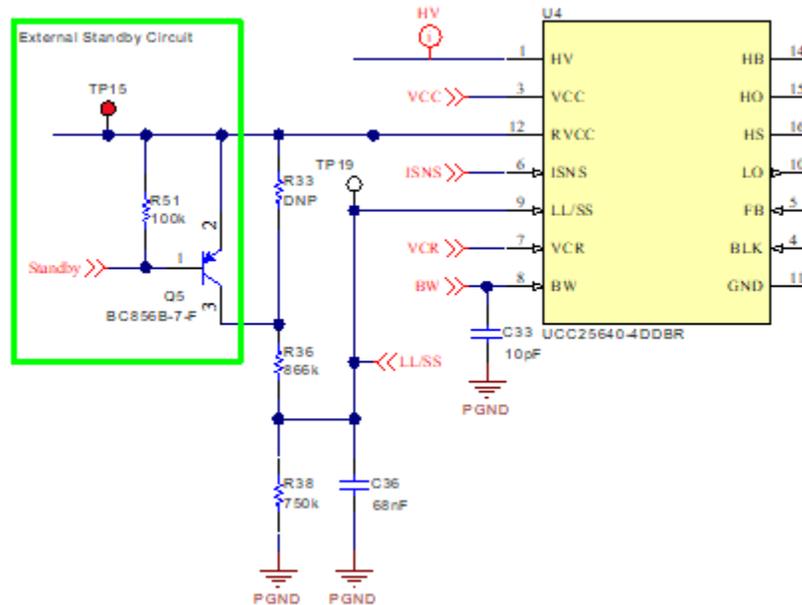
Figure 32. Burst Mode Threshold Adjustment

Please note that this external standby circuit was added to evaluation module only to mimic system level behavior. This circuit is not required in order to design with UCC25640x.

10.3 List of Materials

Table 9. List of Materials

| Designator	QTY	Description	Part Number
PCB1	1	Printed Circuit Board	HVP020
C1, C17	2	Capacitor, Film, 0.015 uF, 1250 V, +/- 5%, AEC-Q200 Grade 3, TH	B32652A7153J000
C3, C4, C8, C9	4	Capacitor, aluminum, 470 uF, 35 V, +/- 20%, 0.03 ohm, TH	UHW1V471MPD
C5, C6, C10, C11	4	Capacitor, ceramic, 22 uF, 25 V, +/- 20%, X5R, 1206_190	C3216X5R1E226M160AB
C7	1	Capacitor, aluminum, 68 uF, 450 V, +/- 20%, TH	EKXG451ELL680MMN3S
C12	1	Capacitor, ceramic, 100 pF, 50 V, +/- 1%, C0G/NP0, 0603	06035A101FAT2A
C13	1	Capacitor, ceramic, 68 pF, 1 kV, +/- 5%, C0G/NP0, 1206	CC1206JKNPOCBN680
C14	1	Capacitor, ceramic, 150 pF, 630 V, +/- 5%, C0G/NP0, 1206	GRM31A5C2J151JW01D
C15	1	Capacitor, ceramic, 2.2 uF, 35 V, +/- 10%, X7R, 0805	C2012X7R1V225K085AC
C16	1	Capacitor, aluminum, 330 uF, 35 V, +/- 20%, TH	EKZE350ELL331MJ16S
C18	1	Capacitor, ceramic, 10 uF, 35 V, +/- 10%, X7R, 1206	C3216X7R1V106K160AC
C20, C24	2	Capacitor, ceramic, 100 pF, 100 V, +/- 5%, C0G/NP0, 1206	12061A101JAT2A
C21	1	Capacitor, ceramic, 8200 pF, 50 V, +/- 10%, X7R, 1206	CC1206KRX7R9BB822
C22	1	Capacitor, ceramic, 1000 pF, 440V, +/- 20%, E, D7xT6mm	CD45-E2GA102M-NKA
C25	1	Capacitor, ceramic, 150 pF, 50 V,+/- 5%, C0G/NP0, 0402	885012005062
C26	1	Capacitor, ceramic, 0.01 uF, 100 V, +/- 5%, X7R, 0603	06031C103JAT2A
C27, C28	2	Capacitor, ceramic, 1 uF, 16 V, +/- 10%, X7R, 0603	EMK107B7105KA-T
C29	1	Capacitor, ceramic, 2.2 uF, 16 V, +/- 10%, X7R, 1206	C1206C225K4RACTU
C30, C31	2	Capacitor, ceramic, 4.7 uF, 25 V, +/- 10%, X7R, 1206	C3216X7R1E475K085AB
C32, C33	2	Capacitor, ceramic, 10 pF, 16 V,+/- 10%, C0G, 0402	C0402C100K4GACTU
C36	1	Capacitor, ceramic, 0.068 µF, 25 V,+/- 10%, X7R, 0603	885012206070
C37, C45	2	Capacitor, ceramic, 0.1 uF, 16 V, +/- 10%, X5R, 0402	GRM155R61C104KA88D
C38	1	Capacitor, ceramic, 47 pF, 500 V, +/- 5%, C0G/NP0, 1206	12067A470JAT2A
C39	1	Capacitor, film, 0.47 uF, 630 V, +/- 10%, TH	B32922C3474K
C40, C41	2	Capacitor, film, 1 µF, X2 275 VAC, +/- 20%, TH	R46KN410000P0M
C42, C43	2	Capacitor, ceramic, 100 pF, 50 V, +/- 5%, C0G/NP0, 0402	GRM1555C1H101JA01D
C44	1	Capacitor, ceramic, 0.1 uF, 25 V, +/- 10%, X5R, 0402	GRM155R61E104KA87D
C46	1	Capacitor, ceramic, 4700 pF, 100 V, +/-5%, C0G/NP0, 0603	C0603C472J1GAC7867
D1, D4	2	Diode, Ultrafast, 100 V, 0.15 A, SOD-123	1N4148W-7-F
D2, D5	2	Diode, Schottky, 100 V, 20 A, AEC-Q101, TH	STPS41H100CTY
D3	1	Diode, Schottky, 100 V, 2 A, AEC-Q101, SOD-123W	PMEG10020ELRX
D7	1	Diode, Ultrafast, 600 V, 1 A, AEC-Q101, SMAF	ES1JAF
D8, D9	2	Diode, P-N, 1000 V, 1 A, TH	1N4007-E3/73
D10	1	Diode, Switching-Bridge, 420 V, 8 A, TH	GBU8J-BP
H1, H2, H3, H4	4		4824
H5, H6, H7, H8	4		1903C
H9	1	TO-220 Mounting Kit	4880SG
H10	1	TO-247 Mounting Kit	4880SG
H11, H12	2		531202B02500G
J1, J2	2	Terminal Block, 5.08 mm, 2x1, Brass, TH	ED120/2DS
J8	1	Terminal Block, 5.08 mm, 3x1, Brass, TH	ED120/3DS
Q1, Q3	2	MOSFET, N-CH, 600 V, 20 A, DDPAK	AOB20S60L
Q5	1	Transistor, PNP, 65 V, 0.1 A, SOT-23	BC856B-7-F
Q6	1	MOSFET, N-CH, 60 V, 0.3 A, SOT-23	2N7002K-T1-E3
R1, R6	2	Resistor, 42.2, 1%, 0.1 W, 0603	RC0603FR-0742R2L

Table 9. List of Materials (continued)

Designator	QTY	Description	Part Number
R3, R8	2	Resistor, 1.00, 1%, 0.1 W, 0603	RC0603FR-071RL
R4, R11	2	Resistor, 51.0 k, 1%, 0.1 W, 0603	RC0603FR-0751KL
R5	1	Resistor, 0, 5%, 0.25 W, 1206	ERJ-8GEY0R00V
R9, R12	2	Resistor, 0.005, 1%, 1.5 W, 2010	CSNL2010FT5L00
R10	1	Resistor, 30.9 k, 1%, 0.1 W, 0603	RC0603FR-0730K9L
R13	1	Resistor, 5.36 k, 1%, 0.1 W, 0603	RC0603FR-075K36L
R14	1	Resistor, 133, 1%, 0.25 W, 1206	RC1206FR-07133RL
R15, R21	2	Resistor, 0, 5%, 0.063 W, 0402	RC0402JR-070RL
R16	1	Resistor, 2.05 k, 1%, 0.1 W, 0603	RC0603FR-072K05L
R17	1	Resistor, 0, 0.75 W, AEC-Q200 Grade 0, 1206	CRCW12060000Z0EAHP
R18	1	Resistor, 9.09 k, 1%, 0.1 W, 0603	RC0603FR-079K09L
R19	1	Resistor, 147 k, 1%, 0.1 W, 0603	RC0603FR-07147KL
R22	1	Resistor, 33.2 k, 1%, 0.1 W, 0603	RC0603FR-0733K2L
R23	1	Resistor, 21.5 k, 1%, 0.1 W, 0603	RC0603FR-0721K5L
R24, R33	1	Resistor, 0, 5%, 0.1 W, 0603	RC0603JR-070RL
R25	1	Resistor, 2.20, 1%, 0.1 W, 0603	ERJ-3RQF2R2V
R26, R27, R28	3	Resistor, 1.65 k, 1%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12061K65FKEA
R29, R30, R34	3	Resistor, 4.99 M, 1%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW12064M99FKEA
R36	1	Resistor, 549k, 1%, 0.125 W, AEC-Q200 Grade 0, 0805	ERJ-6ENF5493V
R37	1	Resistor, 41.2 k, 1%, 0.1 W, 0603	RC0603FR-0741K2L
R38	1	Resistor, 316k, 1%, 0.1 W, 0603	RC0603FR-07316KL
R39, R40, R45, R49	4	Resistor, 10 M, 5%, 0.25 W, AEC-Q200 Grade 0, 1206	CRCW120610M0JNEA
R41, R42	2	Resistor, 4.75, 1%, 0.063 W, AEC-Q200 Grade 0, 0402	CRCW04024R75FKED
R43, R47	3	Resistor, 10.0 k, 1%, 0.1 W, 0603	RC0603FR-0710KL
R44	1	Resistor, 100 k, 1%, 0.1 W, 0402	ERJ-2RKF1003X
R48	1	Resistor, 5.11 k, 1%, 0.063 W, 0402	CRCW04025K11FKED
R50	1	Resistor, 3.01 k, 1%, 0.063 W, 0402	CRCW04023K01FKED
R52	1	Resistor, 261 k, 1%, 0.063 W, 0402	CRCW0402261KFKED
R56	1	Resistor, 80.6 k, 1%, 0.1 W, 0603	RC0603FR-0780K6L
R57	1	Resistor, 1.21 k, 1%, 0.1 W, 0603	RC0603FR-071K21L
RT1	1	Thermistor NTC, 4.70 ohm, 20%, 15x7mm	B57237S0479M000
RV1	1	VARISTOR 1200V 10KA DISC 20MM	TMOV20RP750E
T1	1	Transformer, 510 uH, TH	750344018
T2, T3	2	Terminal 50A Lug	CB35-36-CY
TP1, TP6, TP10, TP15	4	Test Point, Multipurpose, Red, TH	5010
TP2, TP5, TP7, TP12, TP13, TP14, TP16, TP17, TP18, TP19, TP20, TP21, TP22	13	Test Point, Multipurpose, White, TH	5012
TP3, TP4, TP8, TP9	4	Test Point, Multipurpose, Black, TH	5011
TP11	1	Test Point, Multipurpose, Orange, TH	5013
U1, U8	2	Optocoupler, 5.3 kV, 50-600% CTR, TH	VO618A
U2	1	Low-Voltage Adjustable Precision Shunt Regulator, 129 ppm / degC, 80 mA, 0 to 70 degC, 3-pin SOT-23 (DBZ), Green (RoHS & no Sb/Br)	TLVH431ACDBZR
U3	1	Single Output LDO, 50 mA, Fixed 5 V Output, 3 to 24 V Input, 5-pin SC70 (DCK), -40 to 85 degC, Green (RoHS & no Sb/Br)	TPS71550DCKR

Table 9. List of Materials (continued)

Designator	QTY	Description	Part Number
U4	1	Wide Vin LLC Resonant Controller With High-Voltage Start Up Enabling Low Standby Power, DDB0014A (SOIC-14)	UCC25640-4DDBR
U6	1	Single General Purpose, Low Voltage, Tiny Pack Comparator, 5-pin SOT-23, Pb-Free	LMV331M5/NOPB
U7	1	Low- and High-Side Measurement, Multichannel, Voltage Output, Current-Sense Amplifier, DBV0005A (SOT-5)	INA180A4IDBV

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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WARNING

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User shall operate the Evaluation Kit within TI's recommended guidelines and any applicable legal or environmental requirements as well as reasonable and customary safeguards. Failure to set up and/or operate the Evaluation Kit within TI's recommended guidelines may result in personal injury or death or property damage. Proper set up entails following TI's instructions for electrical ratings of interface circuits such as input, output and electrical loads.

NOTE:
EXPOSURE TO ELECTROSTATIC DISCHARGE (ESD) MAY CAUSE DEGREDATION OR FAILURE OF THE EVALUATION KIT; TI RECOMMENDS STORAGE OF THE EVALUATION KIT IN A PROTECTIVE ESD BAG.

3 *Regulatory Notices:*

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FCC NOTICE: This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.

3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- *Reorient or relocate the receiving antenna.*
- *Increase the separation between the equipment and receiver.*
- *Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.*
- *Consult the dealer or an experienced radio/TV technician for help.*

3.2 *Canada*

3.2.1 *For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210 or RSS-247*

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSSs. Operation is subject to the following two conditions:

(1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur

3.3 *Japan*

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lsds/ti_ja/general/eStore/notice_01.page

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1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,

2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or

3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

【無線電波を送信する製品の開発キットをお使いになる際の注意事項】 開発キットの中には技術基準適合証明を受けて

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2. 実験局の免許を取得後ご使用いただく。

3. 技術基準適合証明を取得後ご使用いただく。

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3.4 *European Union*

3.4.1 *For EVMs subject to EU Directive 2014/30/EU (Electromagnetic Compatibility Directive)*:

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    4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

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        4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

        4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

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