Using the UCC24636EVM

User's Guide

Literature Number: SLUUBE7
March 2016

WARNING

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 the safety of those working around you. Contact TI's Product Information Center http://support/ti./com for further information.

Save all warnings and instructions for future reference.

Failure to follow warnings and instructions may result in personal injury, property damage, or death due to electrical shock and/or 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 suitably 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 50 V_{RMS}/75 V_{DC} must be electrically located within a protected Emergency Power Off (EPO) protected power strip.
   (e) Use a 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:**
   (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.

   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.
3. **Personal Safety:**
   (a) Wear personal protective equipment e.g. latex gloves and/or safety glasses with side shields or protect EVM in an adequate lucent plastic box with interlocks from accidental touch.
4. **Limitation for Safe Use:**
   (a) EVMs are not to be used as all or part of a production unit.

Secondary-Side Synchronous Rectifier Controller Diode-Replacement Demonstration Board

1 Introduction

The UCC24636EVM evaluation module (EVM) is used to convert the output rectifier of an off-line discontinuous mode (DCM) flyback converter from a diode to a MOSFET synchronous rectifier (SR) to investigate and evaluate the benefits of SR using volt-second balance control. This EVM senses the volt-second (V-s) product of the transformer magnetization during the primary switch on-time and controls the on-board SR MOSFET on-time to balance the V-s product during transformer demagnetization. The EVM is also compatible with transition-mode (TM) operation. SR conduction time can be maximized, regardless of $R_{DS(on)}$.

The SR-MOSFET can achieve very low conduction loss compared to that of a diode rectifier, significantly improving efficiency of the converter. Use this EVM to substitute for the diode in an existing DCM or TM flyback converter to evaluate and optimize the SR performance. It is ideally suited for converters with output voltages ranging from 5 V to 28 V at current levels up to 5 A, but may be adaptable to other conditions with special considerations. Photographs of the EVM can be seen in Figure 1 and Figure 2.

The UCC24636EVM is not compatible with flyback converters which can operate in continuous conduction mode (CCM) under any condition. For CCM flyback applications please refer to the UCC24630 SR controller and its associated UCC24630EVM-636.

Test points on the EVM provide input nodes for VDD bias voltage and ground (GND), VD and VS connections to the diode anode and cathode nodes, and an output voltage sensing node (VOUT). Two resistor positions are user programmable to scale the EVM parameters to the specific user application. These resistor values are calculated based on equations found in the UCC24636 datasheet or by using the Microsoft Excel®-based UCC24636 Calculator Tool. The UCC24636 controller drives the on-board SR MOSFET at the correct timing to maximize the SR conduction interval, independently of $R_{DS(on)}$.

The UCC24636EVM works best when substituting for a negative-referenced diode (also known as *low-side* diode) situated in the return leg of the flyback transformer secondary winding, as shown in Figure 3. In this arrangement, EVM bias voltage may be obtained directly from the converter output. It is also possible to use the EVM in a positive-referenced diode position (also known as *high-side* diode), but this arrangement requires some additional circuitry to provide bias voltage to the EVM. Figure 25 and Figure 26 show two methods to implement *high-side* SR with the EVM. It is not necessary to remove the diode for which the EVM will substitute; however, a comparison of SR-only losses to diode-only losses will be compromised.

Figure 1. Photograph of EVM (Top Side)

Figure 2. Photograph of EVM (Bottom Side)

2 Description

This evaluation module uses the TI UCC24636 Synchronous Rectifier Controller With Ultra-Low-Power Standby Current together with a TI CSD19531Q5A 100-V, 5.3-mΩ MOSFET and various configuration resistors to implement an SR demonstration board which the user can program to fit a specific application. This MOSFET can withstand up to 100 V during its off state, and can conduct up to 5 A_{RMS} current without special cooling. Higher currents may be accommodated, but the additional dissipation by the MOSFET may raise its case temperature above the safe handling level unless extra cooling is provided.

Seven test points and a terminal block provide access to several important nodes in the SR control circuit. Refer to the schematic diagram of the UCC24636EVM in Figure 4. In a *low-side* rectifier application, the EVM can connect directly to the converter's output, provided that the output voltage is in the range of 4 V to 28 V. For *high-side* rectifier applications, additional biasing circuitry and a special connection configuration are necessary which are discussed in Section 6.6 and Section 6.7 of this User's Guide. For applications where SR is required for converter output voltages lower than the minimum VDD voltage, a separate source for adequate VDD bias voltage must be provided.

The 2-position terminal block is used to connect the on-board MOSFET source and drain nodes to the application using user-supplied wires. Short lengths of bare wire, 20 AWG to 18 AWG (0.75 mm to 1 mm diameter), are best but other sizes with or without insulation can be used. The VDD, GND, and VOUT test points (TP3, TP4, and TP5, respectively) may be connected to the application using short jumpers with small spring-clip hooks, or with thinner wires soldered to the test points.

Resistor positions designated R1 and R4 are left unpopulated to allow the user to install those values which are appropriate to the application. These positions accept surface-mount resistors of 1206 size (metric 3216) for easier handling. The EVM will not function if resistors R1 and R4 are not properly populated.

For special applications requiring a different SR MOSFET, an empty DPAK foot-print, designated Q2, is provided on the back side of the EVM board to accommodate a user-selected device. The 5-mm × 6-mm SON package, Q1, on the front side should be removed if the back-side Q2 location is populated. In such a case, take care to ensure that the UCC24636 and other components on the EVM are used within their parametric limits.

This user's guide provides the schematic, component list, assembly drawing, art work, and installation instructions necessary to evaluate the UCC24636 in a typical DCM flyback converter SR application.

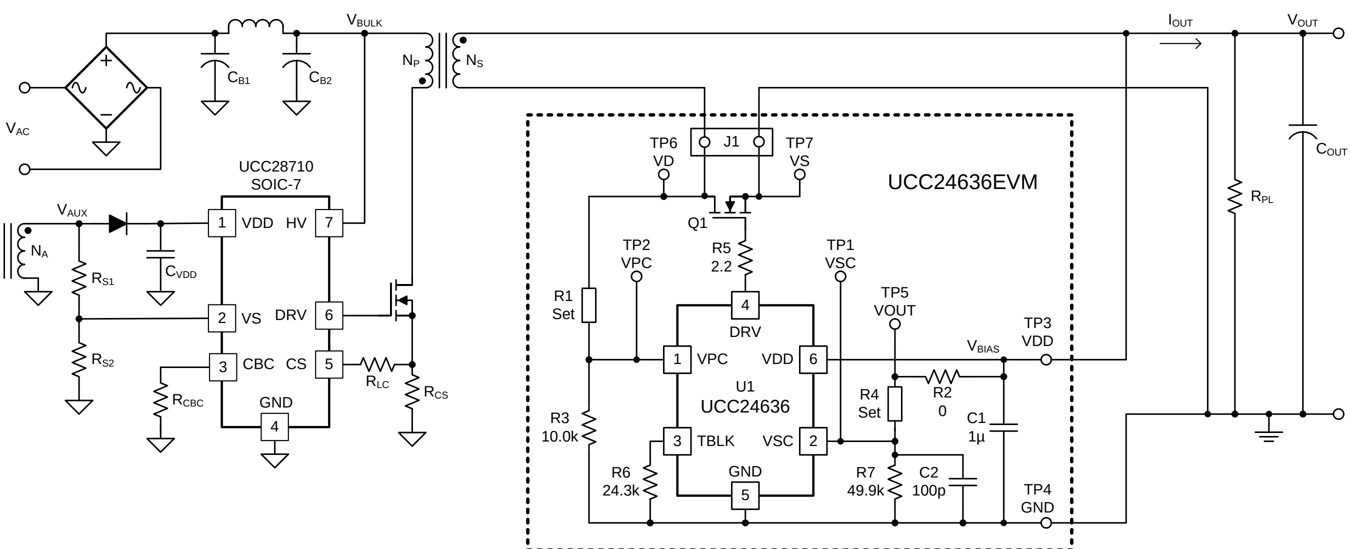

Figure 3. UCC24636EVM Used in *Low-Side* Rectifier Application

2.1 Applications

The UCC24636 synchronous rectifier controller is suited for use in isolated, off-line, discontinuous-conduction-mode (DCM) and transition mode (TM) flyback converters requiring high efficiency and minimal stand-by power; applications such as:

- USB-Compliant Adapters and Chargers for Consumer Electronics (such as smart phones, tablet computers, and cameras)
- Stand-By Supply for TV and Desktop
- White Goods

2.2 Features

The UCC24636EVM features include:

- Direct Connection of VDD to Converter Output Voltage Rail, 5 V to 28 V, in *Low-Side* Applications
- User-Programmable Divider Networks to Adapt the EVM to the Application
- Configured with 5.3-mΩ, 100-V SR MOSFET in SON 5 × 6 Package
- Terminal Block and Test Points for Wiring the SR MOSFET into the Application
- Available TO-252 Solder-Pad on Reverse Side for Alternate MOSFET

CAUTION

High voltage levels may be present on the evaluation module whenever it is energized, depending on the application in which it is installed. Proper precautions must be taken when working with the EVM. The voltage on VD test point TP6 and its associated connection wire may exceed 50 V while operating in the application. Power to the application must be removed and output voltage discharged before the EVM can be handled. Serious injury can occur if proper safety precautions are not followed.

High temperatures may be present on the evaluation module whenever it is energized, depending on the application in which it is installed. Proper precautions must be taken when working with the EVM. The temperature of the MOSFET case and copper heat-sink pad may exceed 50°C while operating in the application. Power to the application must be removed, output voltage discharged, and sufficient cool-down time provided before the EVM can be handled. Serious injury can occur if proper safety precautions are not followed.

3 Electrical Performance Specifications

Table 1. UCC24636EVM Electrical Specifications

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNITS
EVM CHARACTERISTICS						
V_{VDD}	Bias voltage range		4	5 to 24	28	V_{DC}
	VPC voltage range	R1 value calculated for the application	0.4		2.2	V_{DC}
	VSC voltage range	R4 value calculated for the application	0.3		2.2	V_{DC}
	Volt-second product	At VPC input			7	V-µs
	SR-MOSFET drain voltage				100 (1)	V_{DC}
	SR-MOSFET on resistance	T_J = 25°C, VDD ≥ 12 V		5.3	6.4 (1)	mΩ
SYSTEM CHARACTERISTICS						
	Maximum SR current	T_A = 25°C, TC < 50°C			5 (1)	A_{RMS}
f_{SW}	Switching frequency				130 (2)	kHz
T_A	Ambient operating temperature			25		ºC

(1) Other voltages, resistances and currents may be accommodated by removing the MOSFET at Q1 and installing a different MOSFET at Q1 or at Q2, bottom-side.
(2) Based on UCC24636 controller limitation.

4 UCC24636EVM Schematic

The UCC24636EVM schematic diagram indicates two resistor locations (R1 and R4) where the user must install 1206-size (3216 metric) surface-mount resistors. The values for these resistors are calculated using the UCC24636 Calculator Tool or from the UCC24636 datasheet equations corresponding to the VPC and VSC resistor-divider networks. Take care to match the R1 and R4 resistors on the EVM to the corresponding resistors of the calculator or datasheet, which use different reference designators than those in Figure 4.

The schematic diagram also indicates a position for an alternative MOSFET, located on the back side of the EVM board. If the user chooses to modify the EVM and install a MOSFET at Q2, the existing MOSFET at Q1 should be removed first.

A 0-Ω resistor, R2, connects VDD to VOUT (TP2 to TP3) so that the EVM can be biased by connecting VDD directly to the converter output voltage. To use this EVM in an application where VOUT may fall below the UVLO turn-off threshold of the UCC24636 controller, remove R2, connect VDD (TP2) to a separate bias source, and connect VOUT (TP3) to the converter output.

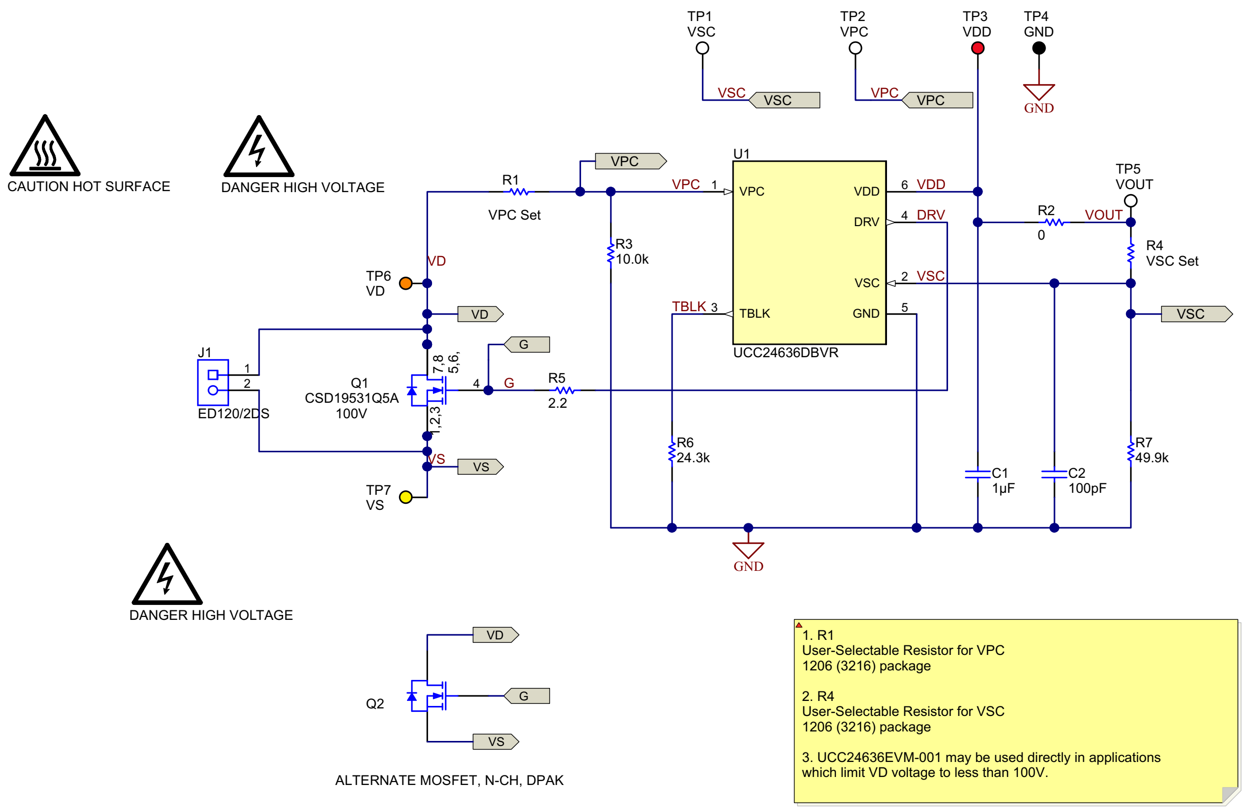

Figure 4. UCC24636EVM Schematic Diagram

5 Test Setup

Figure 5, Figure 6 and Figure 7 show the method to install the UCC24636EVM into an existing DCM flyback converter with a diode serving as the output rectifier. In this example, the converter is the UCC28740EVM-525 rated for 10-W output at 5 V. The output rectifier on this board consists of two SBR10U45SP5 Schottky diodes connected in parallel for low loss. These diodes are in the *high-side* configuration, but the UCC24636EVM is easiest to implement in the *low-side* configuration. Fortunately, the flyback transformer uses flying leads on the secondary winding, which allows insertion of the SR into the low side.

Figure 5 illustrates the top-side view of the UCC28740EVM-525 before modification. It is a straight-forward modification to disconnect the *low-side* lead from the converter board and insert the SR EVM in that path, and apply a short-circuit wire around the *high-side* diodes. Figure 6 shows the diodes on the bottom side shorted with wires. Figure 7 shows the UCC24636EVM attached on the top side in the negative leg of the transformer secondary winding. Figure 8 and Figure 9 show connections to a power source and load, and voltage and current probing with an oscilloscope. Similar modifications and probing arrangements can be done to other converters to compare diode versus SR, and to evaluate the converter's performance with the UCC24636EVM.

WARNING

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

5.1 Test Equipment

AC Voltage Source: The input source shall be an isolated variable AC source capable of supplying between 85 VAC and 265 VAC at no less than 20 W and connected as shown in Figure 8 and Figure 9.

Output Load: An isolated programmable electronic or resistive load capable of sinking beyond the converter output current rating shall be used. For current-limit testing of the converter, an electronic load should be set to constant resistance mode.

Recommended Wire Gauge: A minimum of 18 AWG (1-mm diameter) wire is recommended for high-current connections. The wire lengths between the AC source and the EVM and between the EVM and the load should not be excessive. Lengths of less than 24 inches (61 cm) long are suggested.

Multimeters: A DC voltmeter should be placed directly across the converter output terminals. A DC current meter should be placed in series with the converter output after the voltmeter for accurate output voltage measurements.

Oscilloscope: A high-bandwidth oscilloscope with high-bandwidth probes is recommended.

Fan: Forced-air cooling is not required for low current loads, but for SR current > 5 A_{RMS} additional cooling should be considered.

Power Analyzer: For accurate efficiency calculations and stand-by power measurements, a high quality power analyzer should be used; one capable of measuring very low currents. The analyzer's current measurement should be inserted in the Neutral or low-voltage path from AC source to the converter. Measure input power for average efficiency with the analyzer's voltage inputs across the converter input terminals. Use the readings from the voltage and current meters on the output to calculate the output power. To measure stand-by input power, connect the analyzer's voltage inputs at the AC source output terminals, and disconnect all other probes and meters from the converter to avoid affecting the measurement.

5.2 Example Test Setup

Figure 5 illustrates the 10-W host converter using *high-side* output diodes before being retrofitted with the UCC24636EVM SR module.

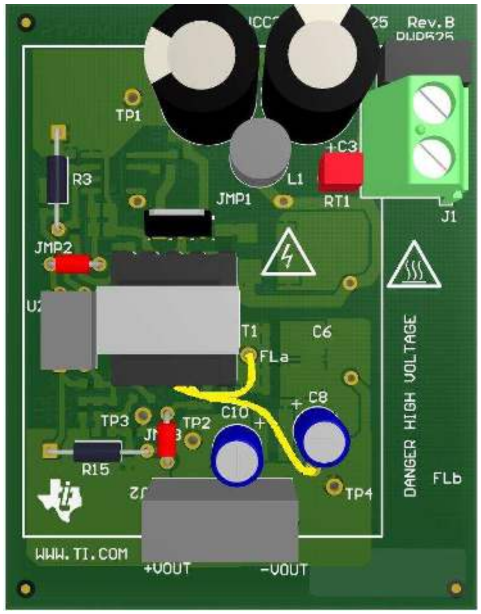

Figure 5. UCC28740EVM-525 with Normal Transformer Wiring Before Modification (Top View)

In preparation for installing the SR EVM, the *high-side* diodes are effectively removed by shorting them out with short pieces of wire soldered anodes to cathodes.

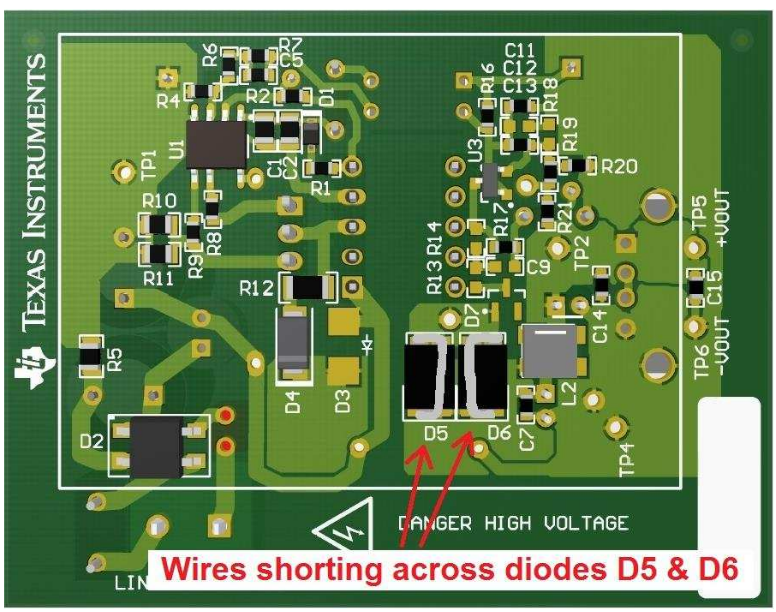

Figure 6. UCC28740EVM-525 Modified with Schottky Diodes Shorted (Bottom View)

Figure 7 shows the SR EVM installed on the top side of the converter EVM with suitable jumper wires at four locations. Smaller-gauge wires are used to connect VDD and GND (TP3 and TP4) to +VOUT and –VOUT, respectively, since the bias current to the EVM is low. Thicker wire connects VS and VD at the terminal block to the converter output ground and low side of the secondary winding, respectively, because the peak current in this path can be quite high. An additional loop of wire can be added to the VD path to accommodate a current probe if desired, but the length should be kept as short as possible to minimize additional leakage inductance. Ensure that the VD wiring connection does not contact the board or nearby components.

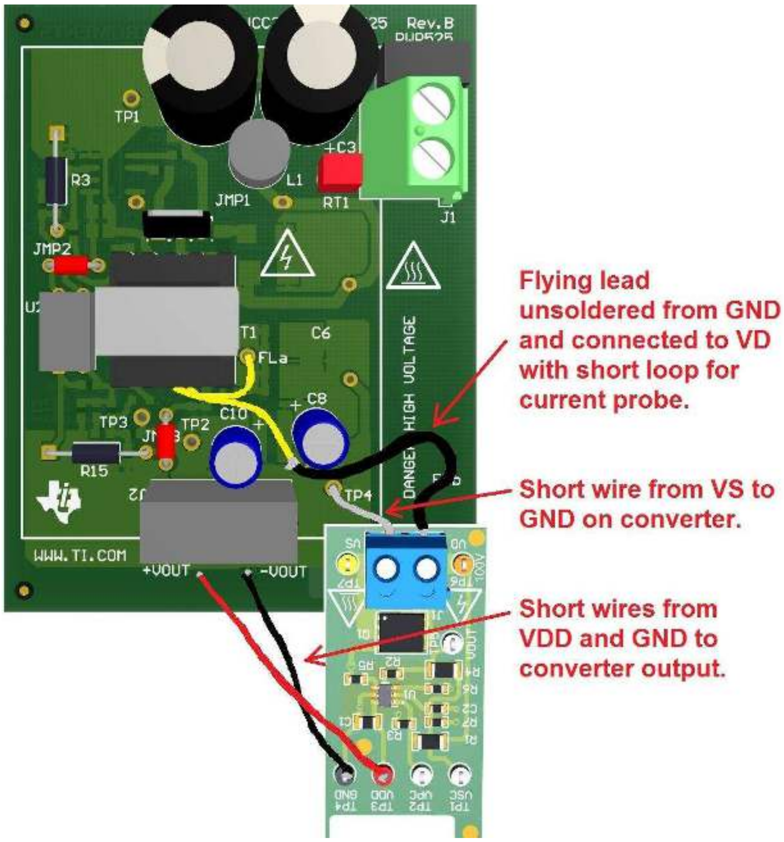

Figure 7. UCC28740EVM-525, Modified with UCC24636EVM Attached

Test points TP1 and TP2 (VSC and VPC) are never connected to any external network, but may serve as observation points for the VSC and VPC signals at the UCC24636 controller. Be careful to avoid injecting noise into these nodes when probing them. Probe capacitance on the VPC pin may increase the SR turn-on delay slightly.

Test point TP5 is used as the input for VOUT from the converter if VDD is sourced from a separate bias source rather than VOUT of the converter. To use this option, the zero-ohm resistor, R2, connecting TP3 to TP5 on the SR EVM must be removed.

Before the SR EVM is installed, Figure 8 illustrates a low-noise method to probe the output diodes on the UCC28740EVM-525 board to obtain forward voltage and current waveforms. Since this converter uses *high-side* diodes, the diode anode has a widely varying wave-shape, while the cathode is the output voltage. The oscilloscope probe ground ring should contact a test pin attached to the cathode node, and the probe tip should contact a test pin on the anode. Since this converter uses an isolation transformer, the oscilloscope ground effectively ties the output positive node to earth-ground.

WARNING

Do not connect other probe grounds to any other node.

A current probe is clamped around a short loop of wire inserted between the transformer negative flying lead and the lead's termination pad. The current probe polarity is oriented to show positive current during the DCM flyback demagnetization interval.

The diode voltage waveform should be displayed inverted in order to directly compare with the SR-MOSFET drain-to-source voltage obtained after the SR EVM is installed.

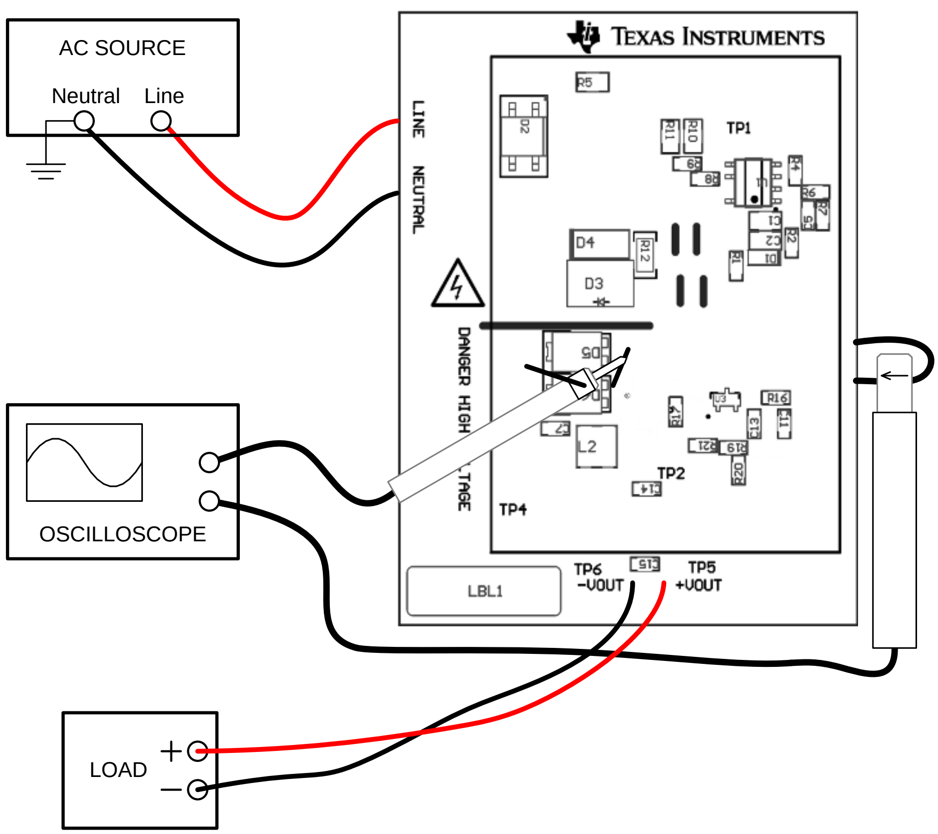

Figure 8. Method to Measure Diode Voltage and Current on the UCC28740EVM-525

After the SR EVM is installed, Figure 9 illustrates a low-noise method to probe the drain-to-source voltage, VDS, on the UCC24636EVM board to obtain forward voltage waveforms. Since this converter has been modified to *low-side* rectification, the drain node has a widely varying waveshape, while the source is the output ground return. The oscilloscope probe ground ring should contact a test pin attached to the VS node, and the probe tip should contact a test pin on the VD node. Since this converter uses an isolation transformer, the oscilloscope ground now effectively ties the output negative node to earth-ground.

A current probe is clamped around a short loop of wire inserted between the transformer negative flying lead and the SR EVM's VD input. The current probe polarity is oriented to show positive current during the DCM flyback demagnetization interval.

The SR VDS waveform should be displayed non-inverted in order to directly compare with the inverted anode-to-cathode diode voltage obtained before the SR EVM is installed.

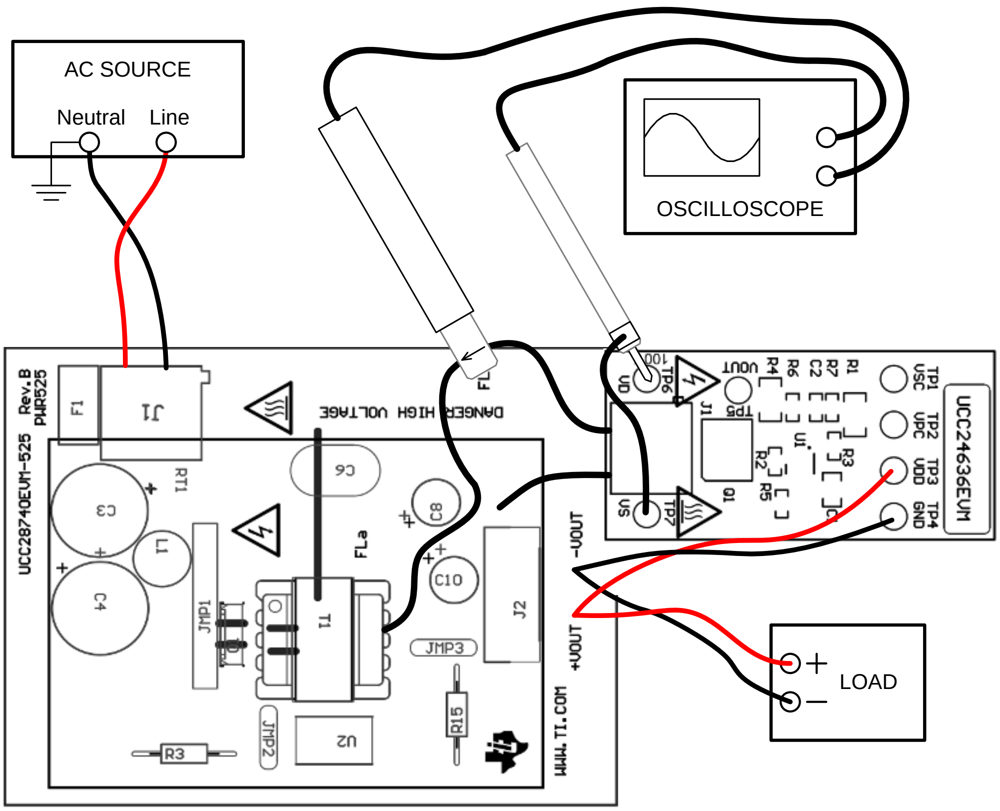

Figure 9. Method to Measure SR-MOSFET V_{DS} and Drain Current on UCC28740EVM-525

5.3 List of Test Points

Table 2. UCC24636EVM Test Point Functional Description

TEST POINT	NAME	DESCRIPTION
TP1	VSC	Monitor point for VSC signal, U1 pin 2
TP2	VPC	Monitor point for VPC signal, U1 pin 1
TP3	VDD	SR controller bias supply, U1 pin 6
TP4	GND	SR controller ground, U1 pin 5
TP5	VOUT	Connection for the converter output voltage
TP6	VD	Monitor point for drain of Q1 (also of Q2, if used)
TP7	VS	Monitor point for source of Q1 (also of Q2, if used)
J1-1	VD	Power connection to drain of Q1 (also of Q2, if used)
J1-2	VS	Power connection to source of Q1 (also of Q2, if used)

5.4 Applying Power to the Converter EVM

1. Set up the converter EVM as shown in . If testing for efficiency or stand-by power, set up the power analyzer per the manufacturer's recommendations.
2. If testing with an electronic load, set it to constant resistance mode.
3. Attach voltmeters, current meters, and oscilloscope probes as necessary to acquire the measurements desired. For safe operation, do not handle the EVMs after power is applied.
4. Set the AC source voltage to between 85 V_{AC} and 265 V_{AC}.
5. Vary the line and load as desired to evaluate SR operation over the full range of converter operation.
6. Refer to the UCC28740EVM-525 User's Guide for the power-up and test procedures for evaluation of the converter's performance on functional characteristics other than efficiency and stand-by input power consumption, such as start-up time, transient response, and fault protection, for example.

5.5 Equipment Shutdown

1. To quickly discharge the output capacitors, apply a load greater than 0.1 A on the converter EVM.
2. Turn off the AC source and wait for the primary bulk capacitance to discharge to a safe level before handling the EVM.

6 Waveform Comparisons and Typical Efficiency Curves

The primary purpose of a synchronous rectifier is to reduce losses compared to that of a diode rectifier and improve the efficiency of a converter. Various environmental and government agencies world-wide establish minimum efficiency requirements, with either voluntary or mandatory compliance requirements. Two notable agency standards are the European Union 2016 Tier-2 Code of Conduct and the United States Department of Energy 2016 Level-6 targets for minimum average efficiency. Although the requirements of these two standards are very similar, the Code of Conduct (CoC) is slightly more stringent and is used for the efficiency and stand-by power targets.

Figure 10 through Figure 13 present the typical current and voltage waveforms associated with the output rectifier diodes on an unmodified UCC28740EVM-525 board, all measured as shown in Figure 9. These waveforms correspond to high and low load conditions with low and high input voltages. Figure 14 through Figure 21 present detailed comparisons between the original diode waveforms and those of the SR when the UCC24636EVM is installed in place of the diode(s). It can be seen that the current waveforms do not change noticeably, but the voltage is reduced during the SR conduction time, which reduces losses and increases efficiency.

After the waveform comparison sections, efficiency and stand-by power loss measurements are compared in Figure 22 through Figure 24, to show the typical differences obtained when using an SR controlled by the UCC24636.

Other switching waveforms and system performance characteristics of the flyback converter are covered by the UCC28740EVM-525 User's Guide and are not repeated here.

6.1 Full-Load and Light-Load Waveforms of Converter with Output Diode at 85 V_{AC} and 265 V_{AC}

Figure 10 through Figure 13 show the switching waveforms associated with the output diodes on an unmodified converter UCC28740EVM-525 when operating near the extremes of the rated line and load conditions. All four figures have waveforms scaled to the same settings and time sweep for easy comparison. As can be seen, the current through the diode(s) does not change significantly when the input voltage is varied. However, the voltage stress on the diode (and consequently, on an SR-MOSFET) increases significantly as the input line voltage is raised from 85 V_{AC} to 265 V_{AC}. The same design considerations to limit peak voltage stress and dampen ringing on diodes apply to SR-MOSFETs as well.

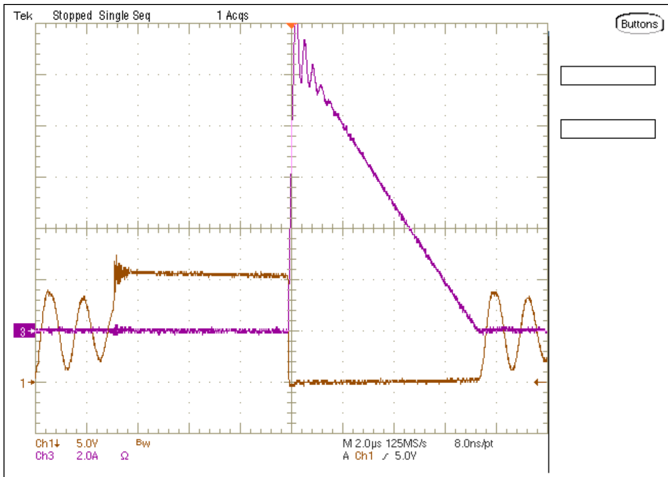

Figure 10. 100%-Load Diode Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

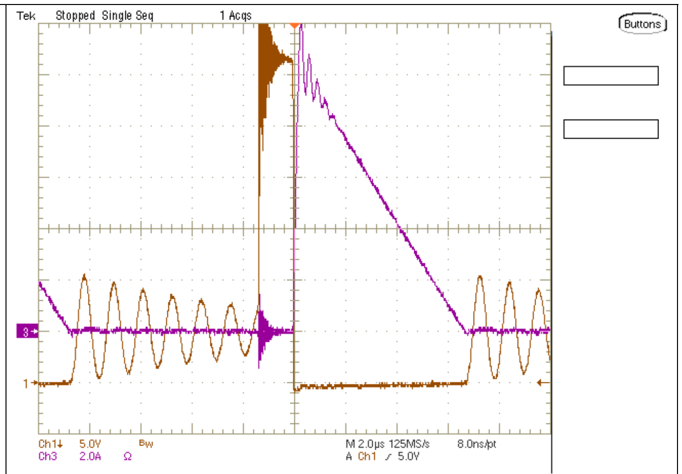

Figure 11. 100%-Load Diode Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

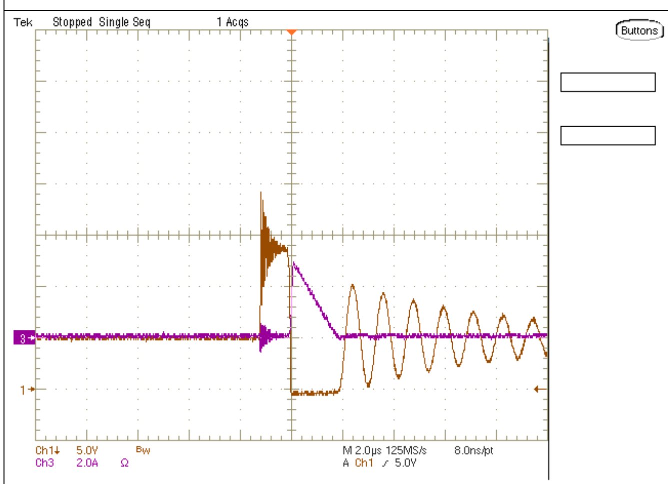

Figure 12. 1%-Load Diode Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

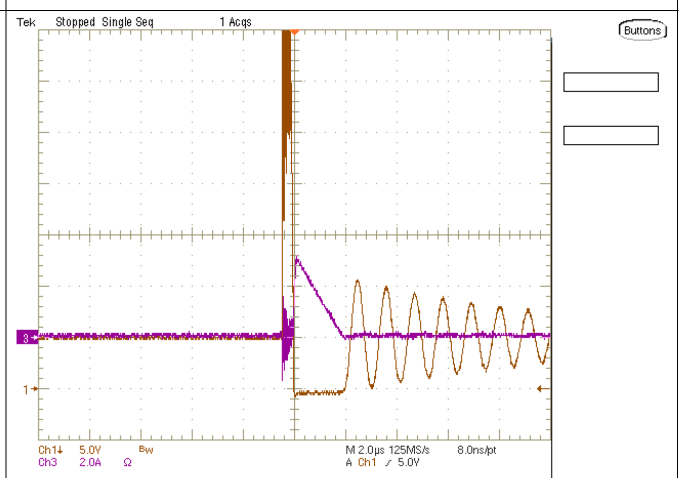

Figure 13. 1%-Load Diode Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

6.2 Detailed Comparison of Diode to SR Waveforms at 85-VAC and 265-VAC Inputs, 5.0-V 2.0-A Output

Figure 14 through Figure 17 use a faster time scale (1 µs/div) and expanded voltage scale (1 V/div) to emphasize the difference in power loss of the output rectifier. The secondary winding current (scaled at 2 A/div) drops linearly to zero from a peak of about 10 A (neglecting the ringing), as is characteristic of a DCM flyback converter. The forward voltage drop of the parallel diodes in Figure 14 and Figure 16 averages about 0.4 V during the diode conduction time. By contrast, the drain-to-source voltage of the SR-MOSFET in Figure 15 and Figure 17 is less than 0.1 V over most of the same interval. Notable exceptions are at the peak of the current and near the zero-crossing of the current. Peak current flows momentarily (about 100 ns) through the body-diode of the SR-MOSFET before the UCC24636 detects the negative SR voltage and turns on the MOSFET. Residual current also flows through the body-diode when the MOSFET is turned off prior to the current reaching zero. The durations of body-diode conduction at the beginning and end of the SR conduction interval may be different in each application and depend on the impedances at the controller's VPC and VSC inputs.

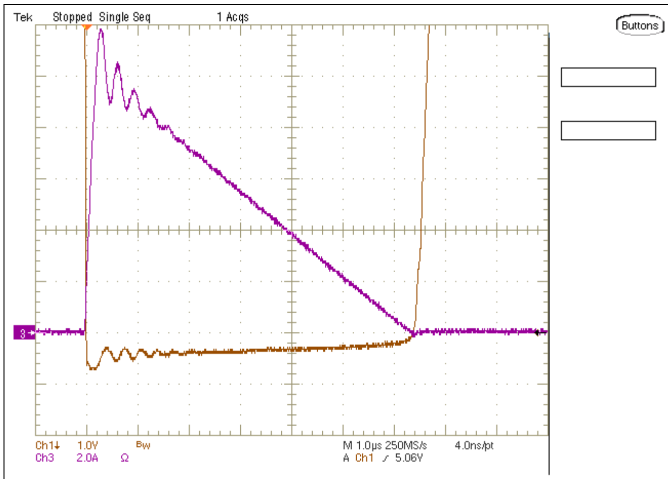

Figure 14. Diode Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

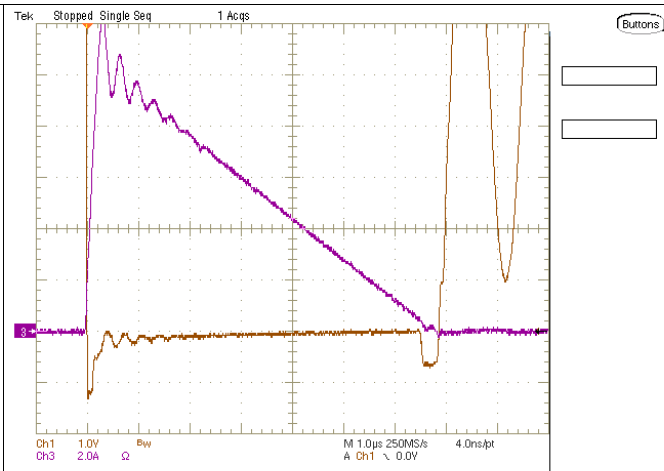

Figure 15. SR Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

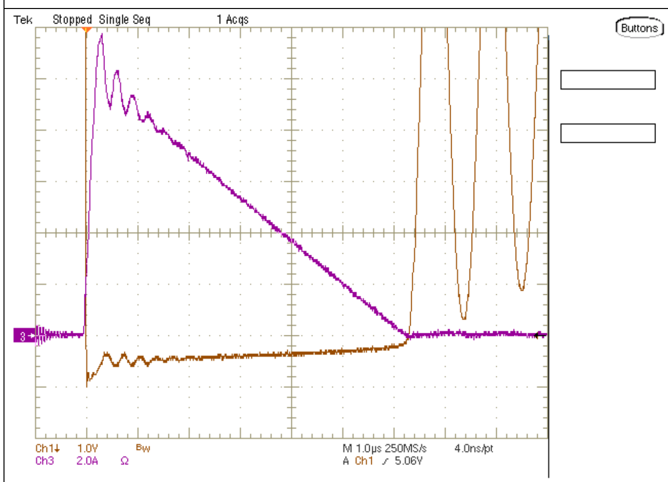

Figure 16. Diode Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

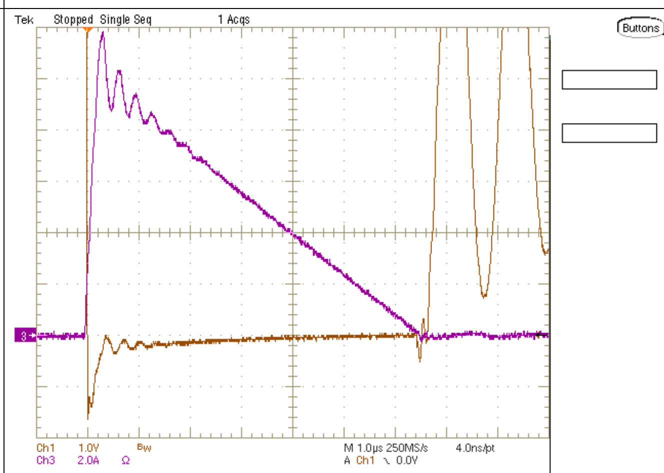

Figure 17. SR Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

6.3 Comparison of Diode to SR Waveforms at 85-V_{AC} and 265-V_{AC} Inputs, 5.0-V / 0.02-A Output

Figure 18 through Figure 21 illustrate the same waveforms characteristics as those of Figure 14 through Figure 17, except at a very light load (20 mA) on the output. The time scale has been increased to 400 ns/div to show more of the waveforms across the oscilloscope display. The secondary winding current now peaks at about 3 A but still drops linearly to zero. The forward voltage drop of the parallel diodes in Figure 18 and Figure 20 averages about 0.3 V during the diode conduction time. By contrast, the drain-to-source voltage of the SR-MOSFET in Figure 19 and Figure 21 is too low to measure over most of the same interval. The SR conduction voltage may be estimated using the $R_{DS(on)}$ rating of the MOSFET. Again, exceptions are at the peak of the current and near the zero-crossing of the current, where the SR-MOSFET is not turned on. The durations of body-diode conduction at the beginning and end of the SR conduction interval may be different in each application and depend on the impedances at the controller's VPC and VSC inputs.

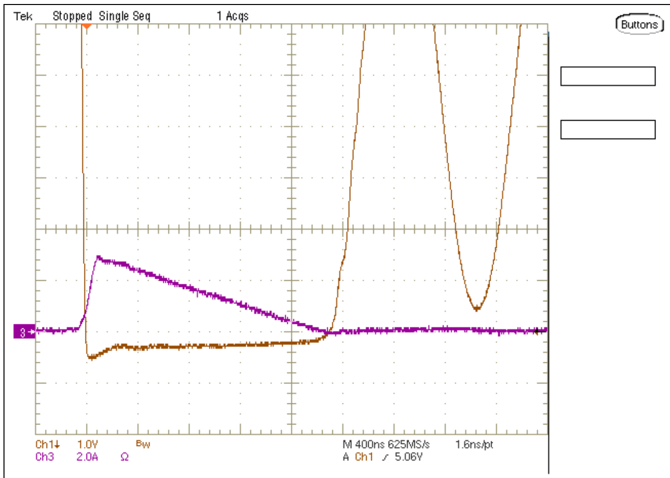

Figure 18. Diode Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

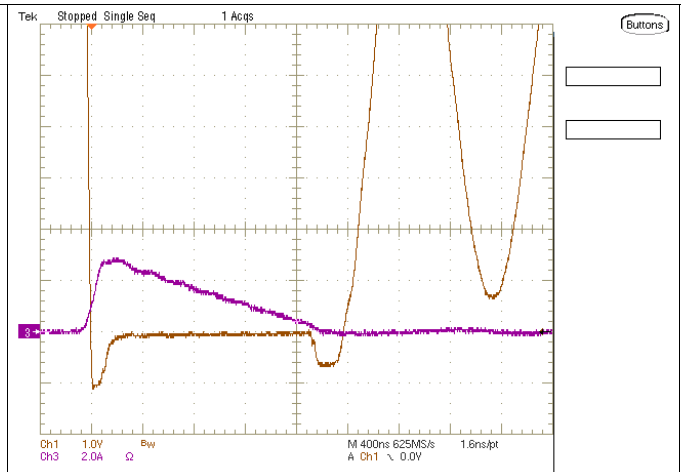

Figure 19. SR Current and Voltage on UCC28740EVM-525 at 85-V_{AC} Input

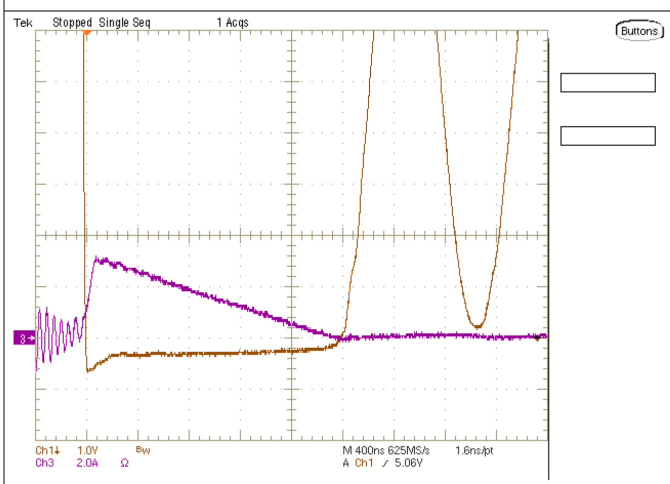

Figure 20. Diode Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

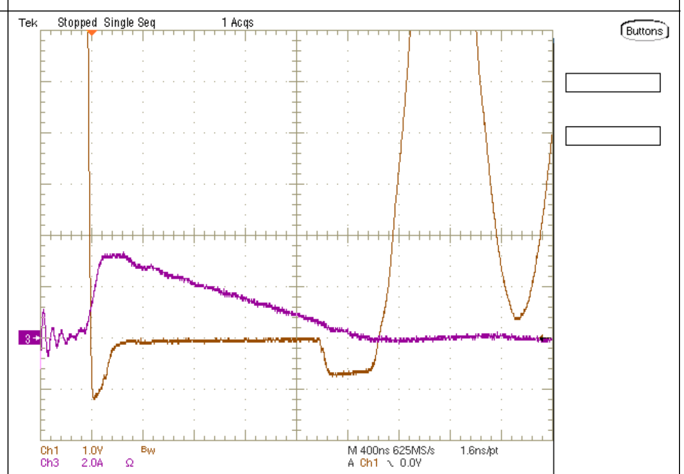

Figure 21. SR Current and Voltage on UCC28740EVM-525 at 265-V_{AC} Input

6.4 Comparison of Average Efficiency with Diode vs. SR

The average efficiency at 230 V_{AC}, 50 Hz exceeds the 0.79 design goal established to meet the 2016 Code of Conduct average efficiency target for low voltage outputs at a 10-W rating. The average efficiency at 115 V_{AC}, 60 Hz exceeds the 0.787 design goal established to meet the 2016 DoE Level-6 average efficiency requirement for low voltage EPS outputs at a 10-W rating. Figure 22 shows the actual measured efficiency with respect to load current.

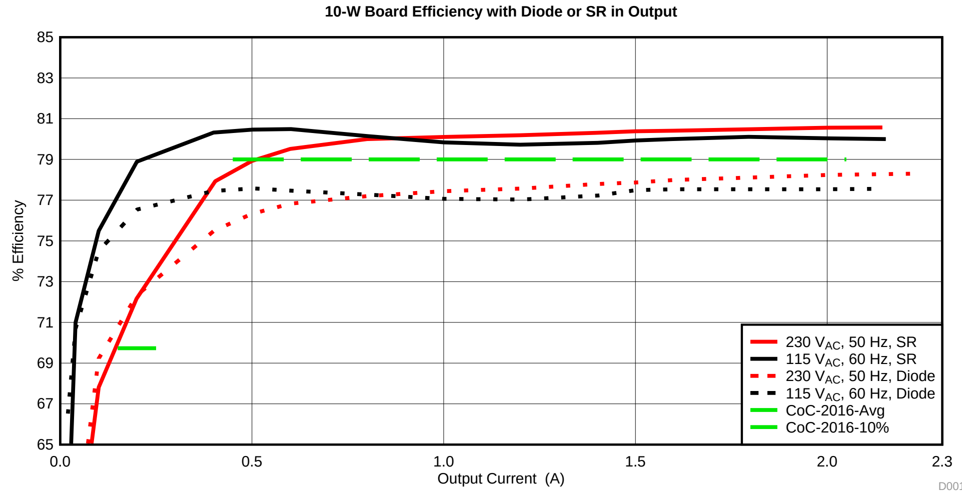

Figure 22. Comparison of UCC28740EVM-525 Efficiency Using SR vs. Diodes

Figure 23 highlights the overall efficiency improvement of the SR over that of parallel diodes.

Notably, there appears to be considerable loss of efficiency with SR at loads less 0.2 A (in this case, loads less than 10% of rated output). This is a mathematical result of the additional power needed to operate the SR circuit compared to the low power being delivered to the output. When load falls low enough to reduce the converter's average switching frequency to less than approximately 5 kHz, the UCC24636 operation goes into a stand-by mode to minimize stand-by power and the SR-MOSFET rectifies by body-diode conduction.

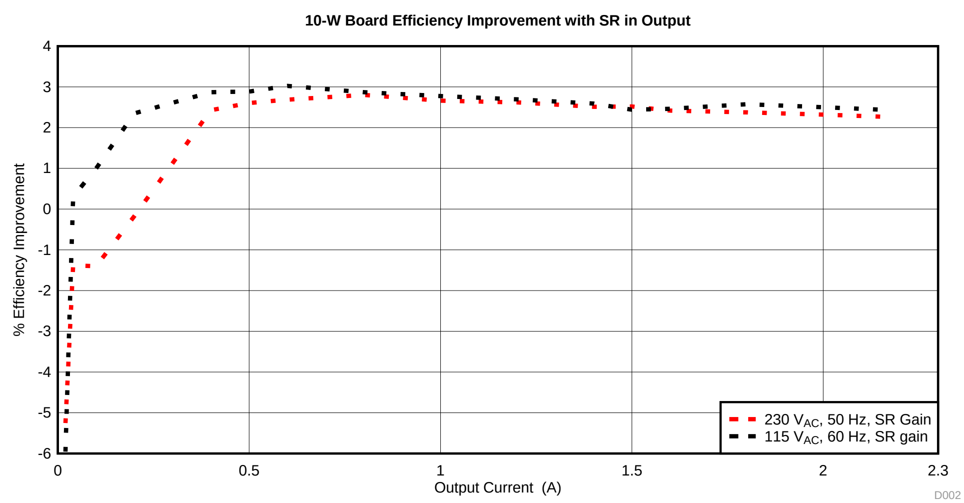

Figure 23. Improvement in Overall Efficiency with UCC24636EVM SR Installed

6.5 Comparison of No-Load Input Power Consumption with Diode vs. SR

Using the UCC24636EVM to implement SR increases the converter no-load input power consumption by less than 3 mW over the entire input line range.

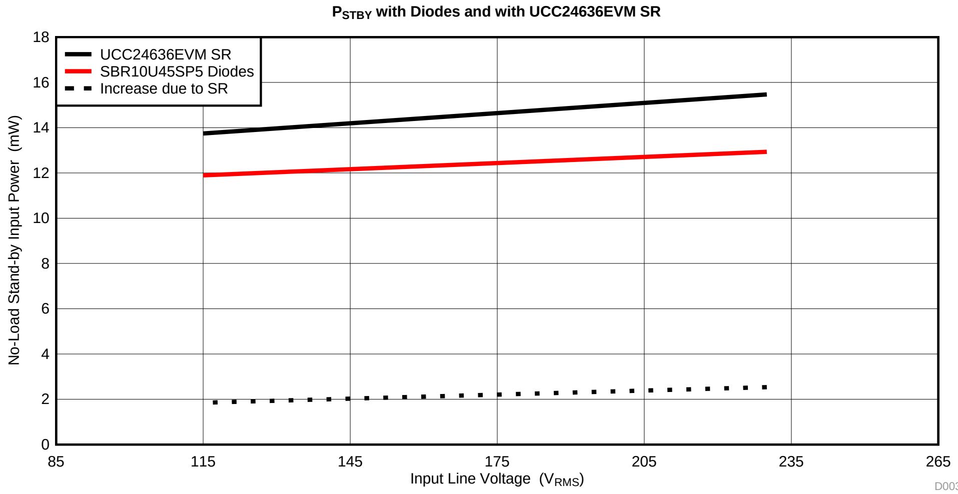

Figure 24. Comparison of No-Load Input Power Consumption

6.6 *High-Side* Diode Replacement with Bias Winding

Figure 25 shows the preferred method to implement a *high-side* SR application. A separate bias winding, N_B, provides power to VDD and reflects the output voltage to the VSC input divider network. Ideally, the turns-ratio of N_B to N_S would be 1:1 so that VDD tracks V_{OUT}, but this is not a strict requirement. If the output voltage is too low, such that N_B must have more turns to generate a higher VDD, the VSC divider network must compensate for the difference in voltage so that VSC tracks V_{OUT} as if the SR was in a *low-side* application.

The ground reference of the UCC24636EVM becomes a floating virtual ground, riding on the N_S secondary waveform. In this way, the pulsing voltage presented to the VPC input is recreated.

A standard-recovery diode (not fast or ultra-fast diode) used on the N_B winding helps to avoid peak-charging of VDD from leakage inductance effects.

Because the floating bias winding arrangement may be susceptible to noise injection into the VPC and VSC inputs, filter capacitors may be required to reject the noise. A relatively large value of capacitance may be applied to VSC, since VSC is proportional to V_{OUT} which is normally regulated. However, it should not be so large that it prevents VSC from closely tracking changes in V_{OUT}. Only a few picofarads of capacitance are appropriate to filter VPC. The SR-MOSFET is turned on when the voltage at VPC goes negative, and an excessive time constant on VPC will delay SR turn-on. Delayed turn-on results in higher losses and lower efficiency than expected.

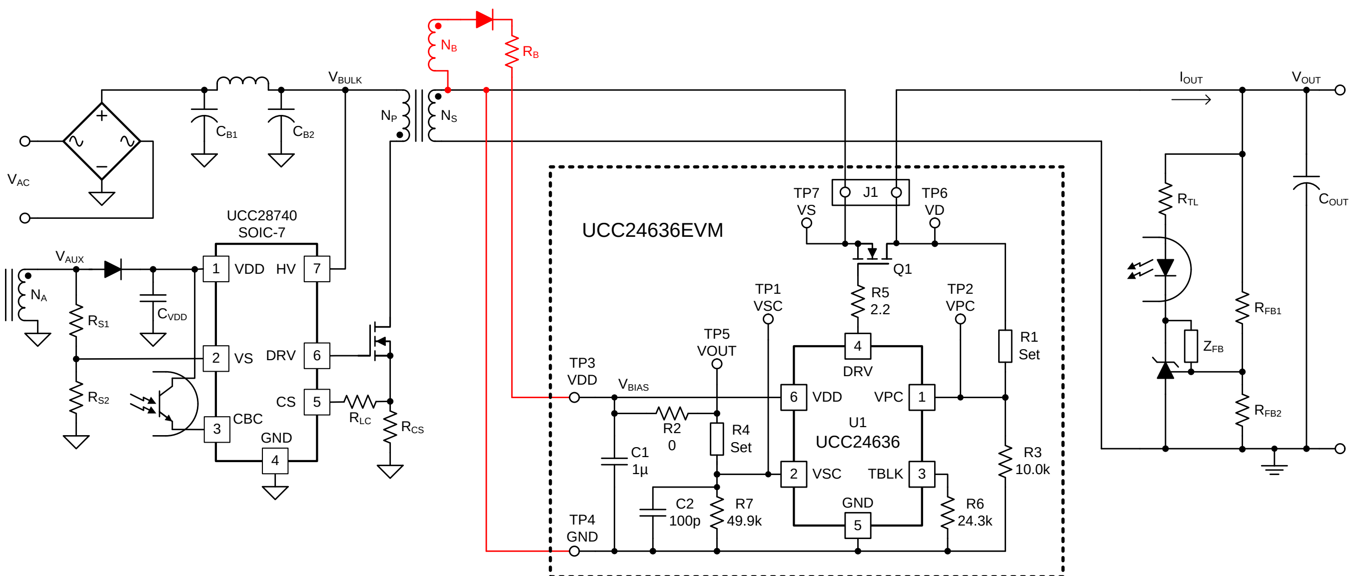

Figure 25. UCC24636EVM Used in the *High-Side* Rectifier Configuration

6.7 High-Side Diode Replacement without Bias Winding

Figure 26 shows an alternative method to implement a *high-side* SR application that does not require a separate bias winding. A major drawback to this method is that VSC does not track V_{OUT}. The UCC24636EVM operates on a floating virtual ground, again riding on the secondary winding voltage. Charge-pump action provides power to VDD, but this voltage varies with the primary-side bulk voltage. VDD does not track V_{OUT} and so the VSC input must be programmed from a fixed reference voltage corresponding to the highest value of V_{OUT}.

Because VSC cannot track V_{OUT}, there must be a compromise on SR timing to allow for V_{OUT} variations. The fixed reference voltage for VSC must accommodate the highest V_{OUT}. Consequently, the SR on-time becomes shorter when V_{OUT} becomes lower. The shorter on-time may result in higher losses and lower efficiency than expected.

In this implementation, just as in the previous case of Figure 25, the ground reference of the UCC24636EVM becomes a floating virtual ground, riding on the N_S secondary waveform. In this way, the pulsing voltage presented to the VPC input is recreated.

The drawbacks of this specific *high-side* SR configuration should be thoroughly considered before committing to its implementation, to ensure that the application is compatible with its limitations.

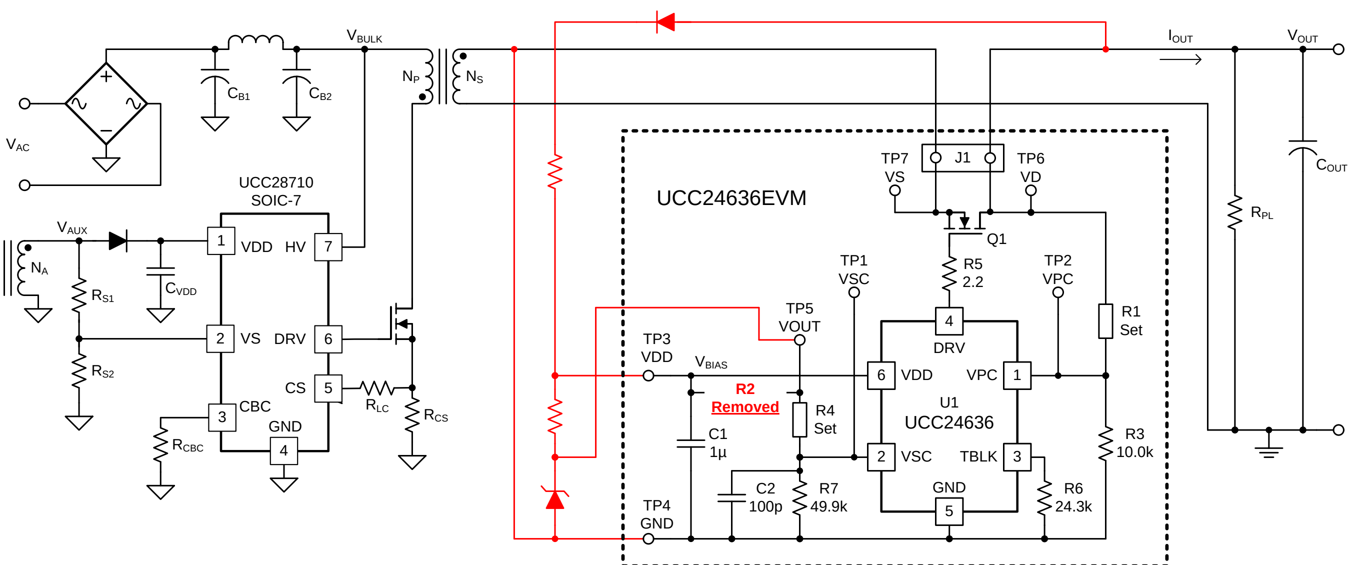

Figure 26. UCC24636EVM Used in the Alternate *High-Side* Rectifier Configuration

7 Assembly Drawing/Layout

Figure 27 and Figure 28 show the design of the UCC24636EVM printed circuit board. The final dimensions of the 2-layer circuit board measure 1.70 inches (43.2 mm) long by 0.82 inches (20.8 mm) wide.

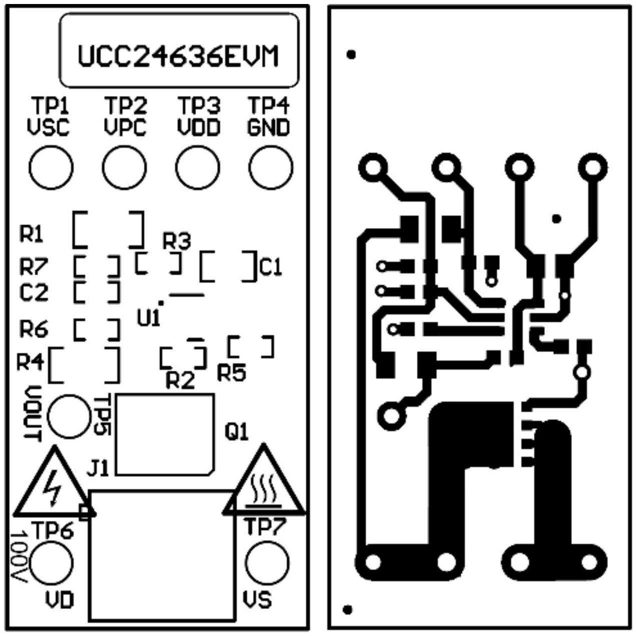

Figure 27. UCC24636EVM Assembly and Copper Drawings (Top View)

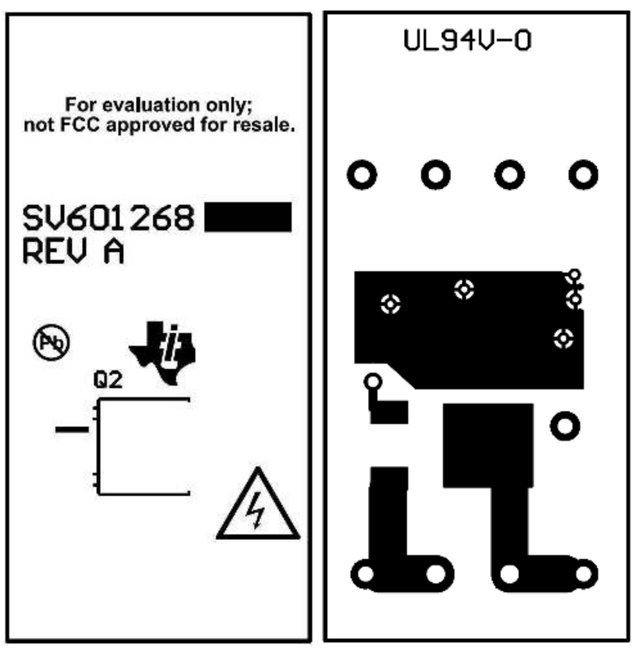

Figure 28. UCC24636EVM Assembly and Copper Drawings (Bottom View)

8 List of Materials

Table 3 EVM components list, corresponding to the schematic diagram of Figure 4.

Table 3. UCC24636EVM List of Materials

QTY	DES	DESCRIPTION	PART NUMBER	MANUFACTURER
1	PCB1	Printed circuit board	SV601268	Any
1	C1	Capacitor, ceramic, 1 µF, 50 V, ±10%, X7R, 0805	08055C105KAT2A	AVX
1	C2	Capacitor, ceramic, 100 pF, 50 V, ±5%, C0G/NP0, 0603	06035A101JAT2A	AVX
1	Q1	MOSFET, N-channel, 100 V, 16 A, SON 5 mm × 6 mm	CSD19531Q5A	Texas Instruments
1	R2	Resistor, 0 Ω, 5%, 0.1 W, 0603	CRCW06030000Z0EA	Vishay-Dale
1	R3	Resistor, 10.0 kΩ, 1%, 0.1 W, 0603	CRCW060310K0FKEA	Vishay-Dale
1	R5	Resistor, 2.2 Ω, 5%, 0.1 W, 0603	CRCW06032R20JNEA	Vishay-Dale
1	R6	Resistor, 24.3 kΩ, 1%, 0.1 W, 0603	CRCW060324K3FKEA	Vishay-Dale
1	R7	Resistor, 49.9 kΩ, 1%, 0.1 W, 0603	CRCW060349K9FKEA	Vishay-Dale
3	TP1, TP2, TP5	Test point, miniature, white, TH	5002	Keystone
1	TP3	Test point, miniature, red, TH	5000	Keystone
1	TP4	Test point, miniature, black, TH	5001	Keystone
1	TP6	Test point, miniature, orange, TH	5003	Keystone
1	TP7	Test point, miniature, yellow, TH	5004	Keystone
1	U1	Synchronous Rectifier Controller with Low Power Standby, DBV0006A	UCC24636DBVR	Texas Instruments

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- *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.*

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