Application Report

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Using the TPS23753A (and family) with an External Error Amplifier

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Power Interface

ABSTRACT

The TPS23753A, TPS23754, TPS23756, and TPS23757 are intended for applications that have primary-secondary isolation, because of this they do not contain an internal (control loop) error amplifier. Despite the lack of an internal error amplifier, it may be advantageous to use these parts in applications which do not require isolation due to their mix of features. These features include adapter ORing support, 12V supply operation, wider duty cycle, and multiple gate drivers. This Application Report shows how to use the common TLV431 as an error amplifier in conjunction with the this family of parts in a non-isolated flyback converter application.

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1 Introduction

The TPS23753A and TPS23757 provide an IEEE 802.3-2008 (or IEEE 802.3at type 1) Power over Ethernet (PoE) interface and dc/dc controller for Powered Devices (PDs) that use up to 13 W. Examples of PDs are Voice-over-IP (VoIP) Phones and wireless access points (WAP). The TPS23754 and TPS23756 provide an IEEE 802.3at type 2 Power over Ethernet (PoE) interface and dc/dc controller for Powered Devices (PDs) that use up to 25.5 W. The most common dc/dc converter topologies used in PDs are the isolated flyback converter, and active-clamp forward converter.

Isolation between the Ethernet wiring and all other potentials is required by IEEE 802.3 (functional requirement), and isolation of customer accessible potentials from the Ethernet wiring is required by the IEC60950 standard (safety). Isolation is usually included to strictly meet the requirements, or for its implied added safety margin in cases where it is not certain. There are some applications that are clearly able to meet the requirements without isolation; an example would be an active-message sign that did not have any metallic I/O ports besides the Ethernet. Removing the isolation is perceived as reducing part count and thus cost. This application note shows how to use the TLV431 as an external error amplifier with this family of parts.

The TPS23753AEVM-001 (HPA304) board is used as a readily available tool to demonstrate the adaptation of an isolated topology to a non-isolated one. The stock EVM control is characterized, then modifications are made and the same characteristics are measured. We have selected load transient response, startup, and loop gain/phase as our criteria. The general technique applies to the whole family as they all use the same control (CTL) and pulse-width-modulation topology.

2 Converter Analysis

2.1 Isolated Converter

Figure 1 is the schematic for the TPS23753A-001 EVM. This design is a 250kHz, 7 W flyback converter with a diode output rectifier. It operates in both continuous and discontinuous modes depending on the output loading. The TPS23753A, U1, provides the pulse-width modulation (PWM), primary MOSFET current sense comparator, and slope compensation for current-mode stability. The TLV431, U3, acts a reference and error amplifier to provide the 5 V output regulation. The control-loop isolation is provided by U2, an optocoupler. Control loop compensation is provided by C11, C13, R16, R12, R11, R21, and C12. A softstart circuit comprised of R13, D9, C14 controls the turn-on rate and eliminates output voltage overshoot at turn-on.

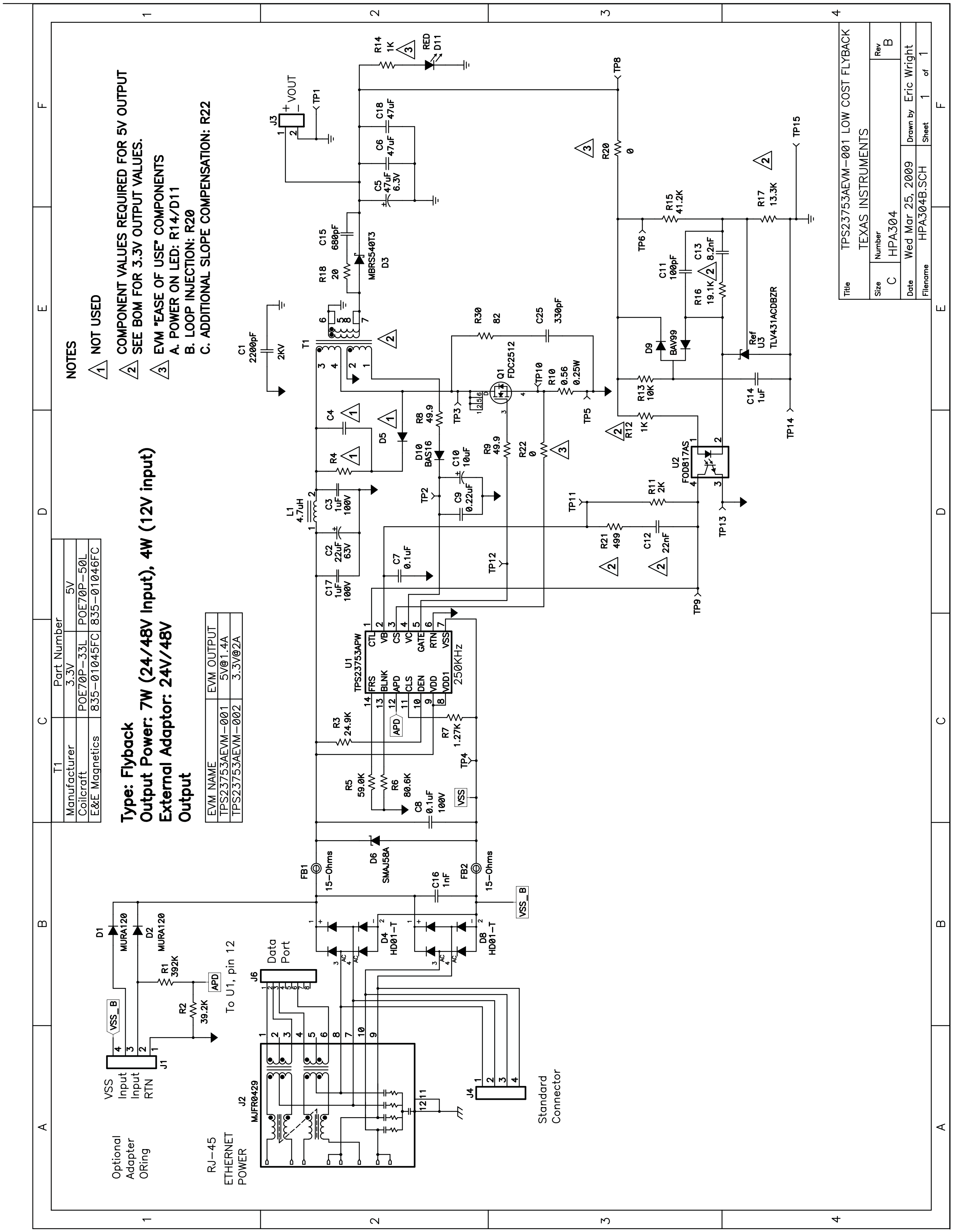

Figure 1. TPS23753AEVM-001 Schematic

Figure 2 shows the transient response of the isolated flyback converter with an input voltage of 57V and 200Hz pulsed load current (I_{LOAD}). The two cases are a 0.6 A to 1.4 A load step to show Continuous Conduction Mode (CCM) operation and 0.1 A to 0.6 A step to show the behavior of the circuit in and out of Discontinuous Conduction Mode (DCM).

As can be observed V_{OUT-PP}, is 240 mV in CCM and 220 mV in DCM about the desired output voltage for their respective I_{LOAD} changes. When I_{LOAD} steps up (down) V_{OUT} goes down (up) as a result of the ESR and ESL of the output capacitor, current-mode operating point, and loop response. V_{OUT} returns into regulation once the feedback loop responds and corrects the perturbation. Transient response is often used as an indication of loop stability.

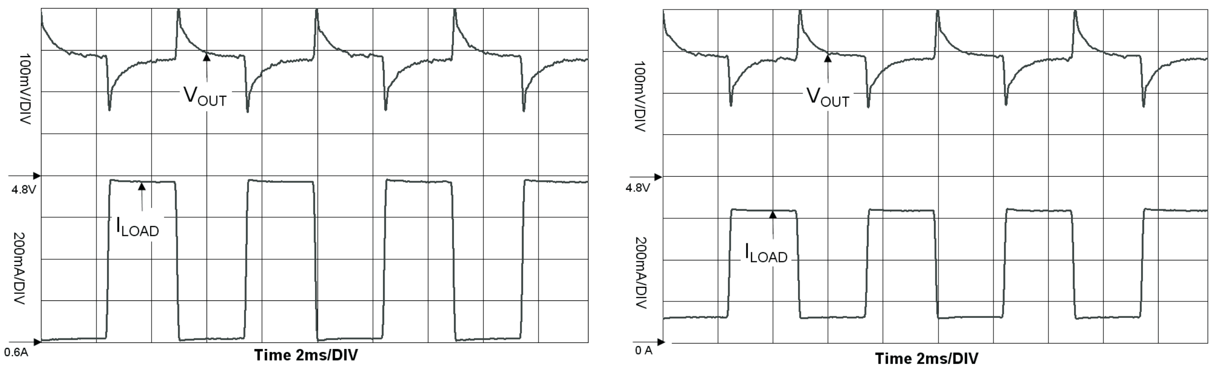

Figure 2. Isolated Circuit Transient Response

Figure 3 shows the converter output voltage during startup at 48 V in, for an I_{LOAD} of 1.4 A in the left hand side plot and at no-load in the right hand side plot. This test shows the ability of the error amplifier to control the output during startup and the action of the softstart circuit to avoid overshoots. Systems typically prefer monotonic rising supply voltages to avoid ambiguous states during startup. With maximum I_{LOAD} and with zero I_{LOAD} the circuit responds in a similar way and with the same speed (about 2 ms). The well controlled and smooth startup shows the system has adequate phase margin and controllability.

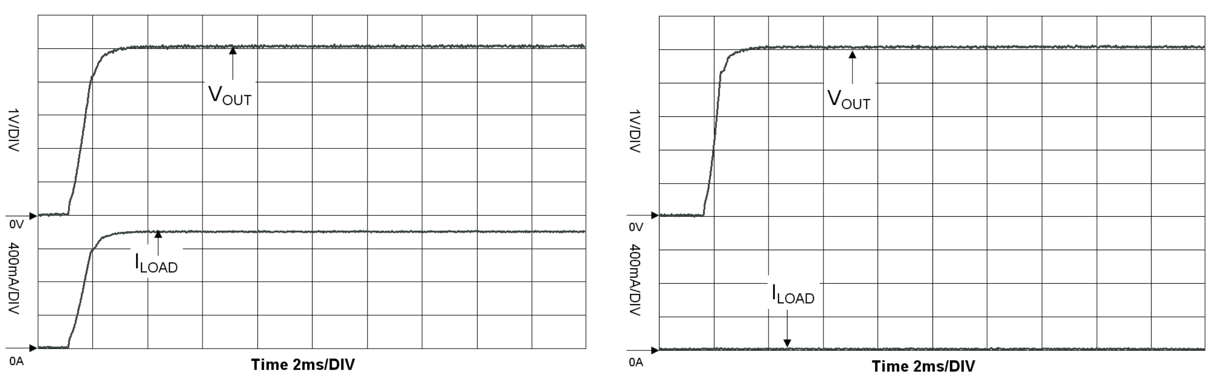

Figure 3. Isolated Circuit Startup

The Gain and Phase response of the Power Stage was obtained and is shown on Figure 4. Setup block diagrams used to perform these measurements are shown in Figure 5 and Figure 6. The box named "Power Stage" in Figure 6 includes part of the TPS23753A, input filter, flyback transformer, output filter, bias supply capacitors, and current sensing circuitry. The box named "PoE Interface" includes part of the TPS23753A, hotswap, Ethernet port, diode bridges, and PoE programming resistors. As shown in Figure 5, the gain/phase analyzer V1 input should be connected to TP9 and V2 to TP8. R20 is replaced by a 50Ω resistor and the two pins of the isolated oscillator interface are connected to TP8 and TP6 in order to add the test source oscillator. The ground of the primary and the secondary winding of the flyback transformer should be tied together as the test set voltage probes are referenced to the same ground.

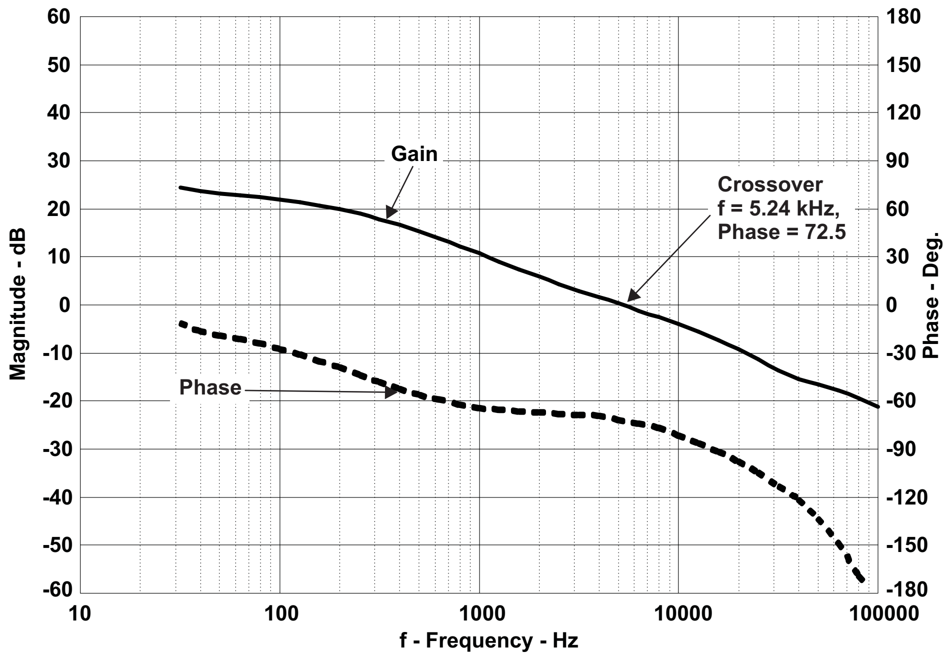

Figure 4. Power Stage Phase/Gain

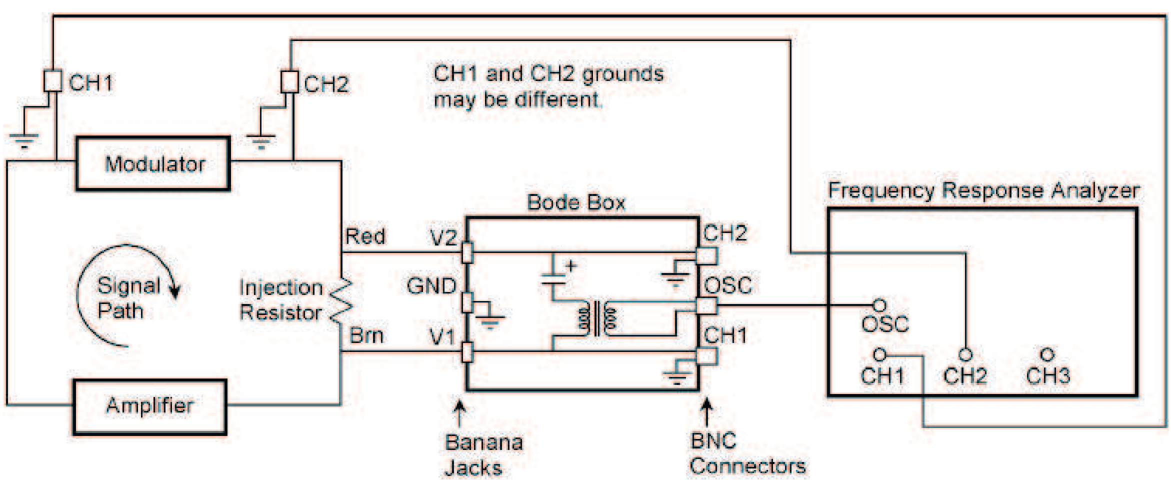

Figure 5. Set up for the Power Stage Phase/Gain Measurement Using the Venable Windows Software 4.0 For MODEL 3120, Venable Instruments®, 2006

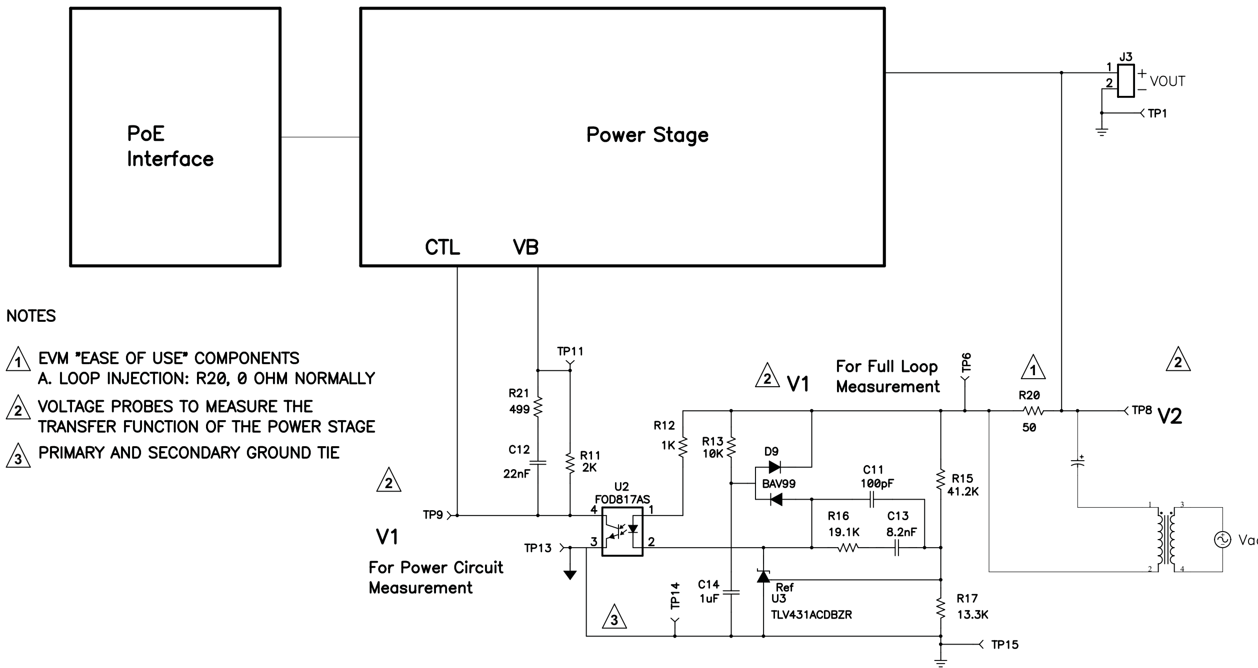

Figure 6. Setup for EVM Phase/Gain Measurement

Figure 7 shows the Gain and Phase response of the complete isolated converter with an input voltage of 57 V and a load current of 1 A. This was obtained with the setup of Figure 5 and Figure 6 by placing the analyzer V1 and V2 probes at TP6 and TP8 respectively. This plot is used to determine the crossover frequency and the stability of the circuit. The phase margin of the system at the gain crossover frequency (0 dB) is used as a measure of relative stability. This figure is a complement to the "quick" stability conclusions that can be made from the step response presented above. The designer should pick a phase margin that offers a good trade-off between speed and stability such as a critically damped 45° (second order system). In this case, the phase margin was 49.3° and the crossover frequency was 7.74 kHz. This means that the system is stable with a phase margin that is consistent with the step response.

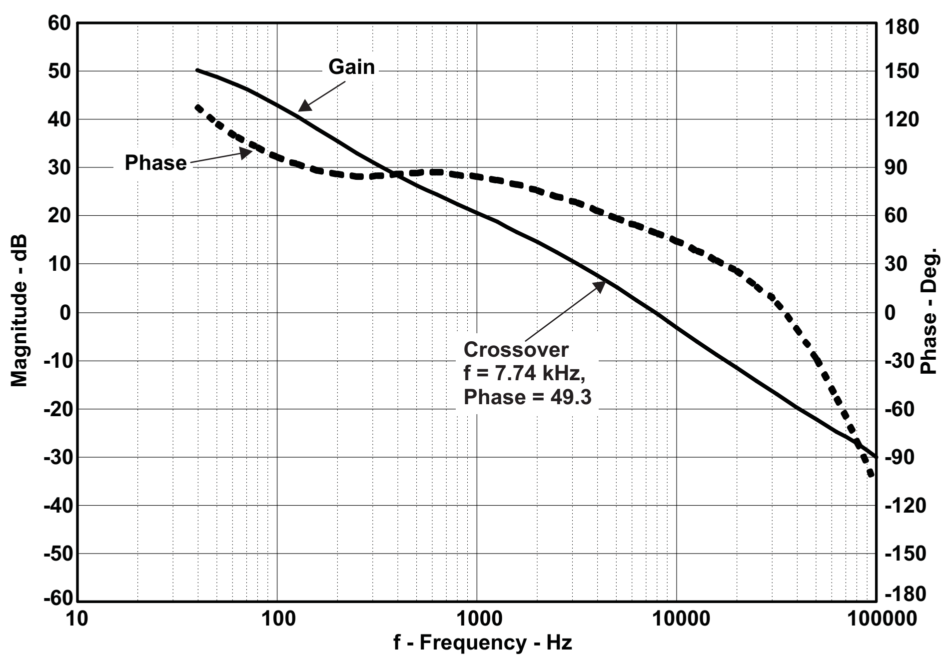

Figure 7. Isolated Circuit Phase/Gain

2.2 Non-Isolated Converter

In the non-isolated circuit, the error amplifier (U3) output is connected directly to the TPS23753A CTL input with no isolating optocoupler. This connection is shown in Figure 8. The optocoupler previously seen in the stock EVM has been removed, and the TLV431 has been directly interfaced to the TPS23753A.

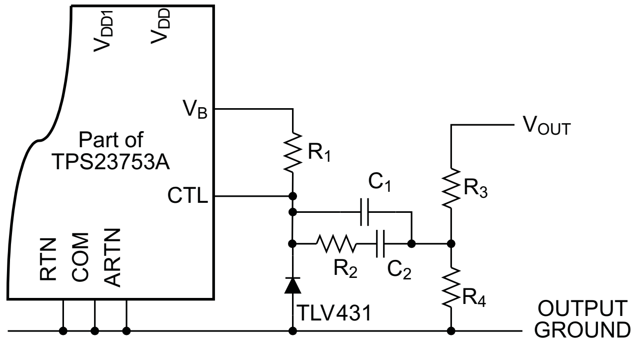

Figure 8. TL431 Error Amplifier Direct Interface

These modifications were made to the stock circuit of Figure 1, and are shown in Figure 9. The changes made are enclosed in the box to the lower right portion of the schematic. Q2 was added, and a number of part-type values were changed.

The new version of the softstart circuit includes Q2, D9, R13, and C14. This non-isolated topology allowed removal of R21 and C12 because the direct V_{OUT} to CTL signal feedback through the optocoupler has been eliminated. This simplifies the analysis and implementation of the compensation. The results of Figure 4 were used to select the compensation elements C11, R16, C13.

An important point in this implementation is that the TPS23753A minimum zero duty cycle threshold is 1.3V. The regulation voltage of the TLV431, when connected with the adjust pin to the output (cathode) is 1.25 V typical and 1.258 V maximum. This permits the TLV431 to apply the full range of control to the TPS23753A CTL input.

The softstart circuit was redesigned to be responsive to the output voltage rise. To accomplish this, Q2 and C14 were added. D19 is a fast discharge for C14 when the output collapses, ensuring rapid reset of the softstart circuit.

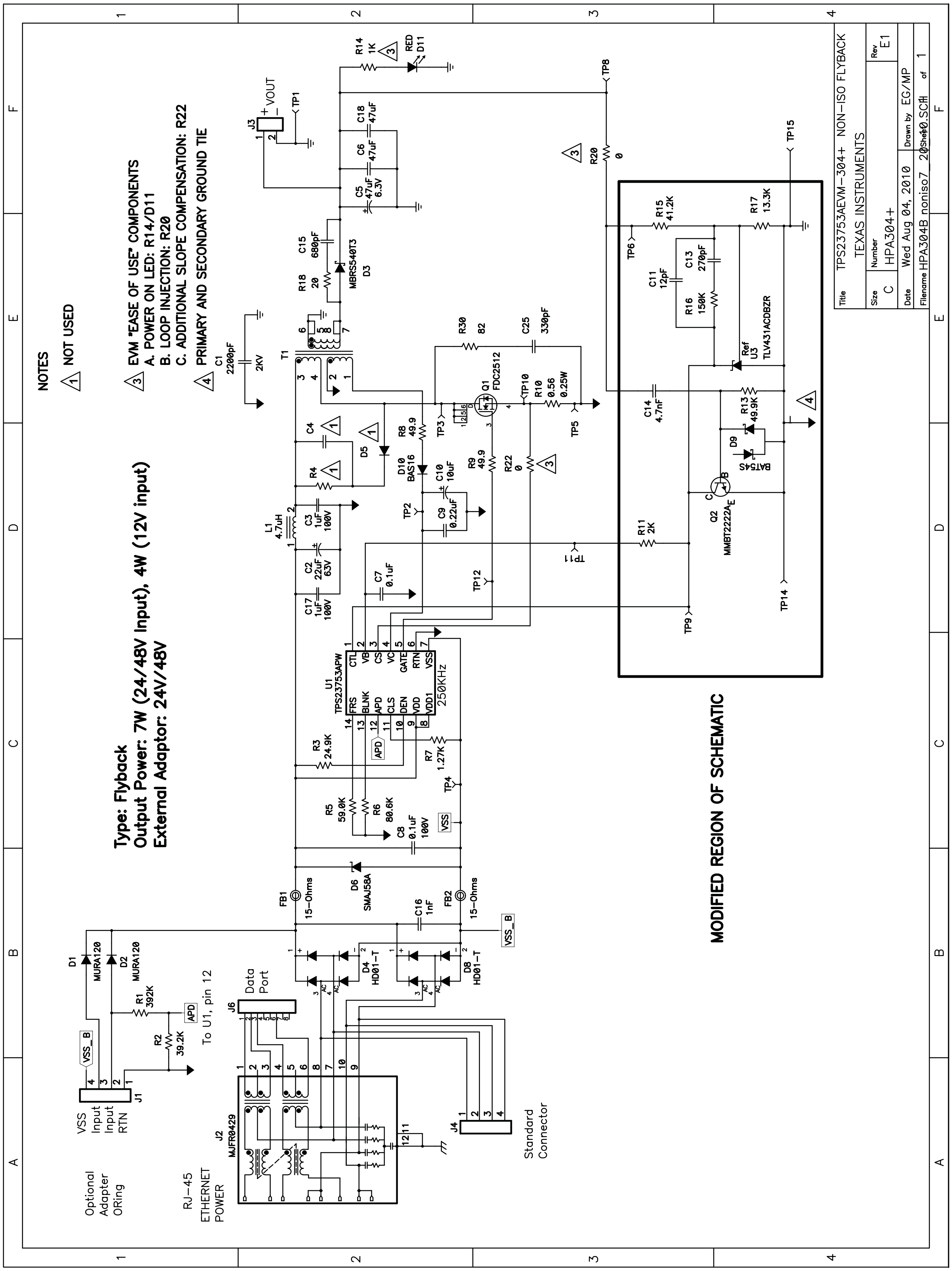

Figure 9. Modified TPS23753AEVM-001 Schematic

Figure 10 shows the transient response of the non-isolated flyback converter with an input voltage of 57 V and 200 Hz pulsed load current (I_{LOAD}). As in Figure 2, these measurements are done to show the behavior of the circuit in CCM and DCM. The figure on the left side shows a $V_{OUT\text{-}PP}$ of 45 mV for a 0.6 A to 1.4 A I_{LOAD} step in CCM while the right hand side plot shows a $V_{OUT\text{-}PP}$ of 40 mV for a 0.1 A to 0.6 A I_{LOAD} step.

The elimination of the isolating stage and its bandwidth limitations, along with somewhat more aggressive phase margin choices, results in substantially reduced transients from the isolated version of the preceding section.

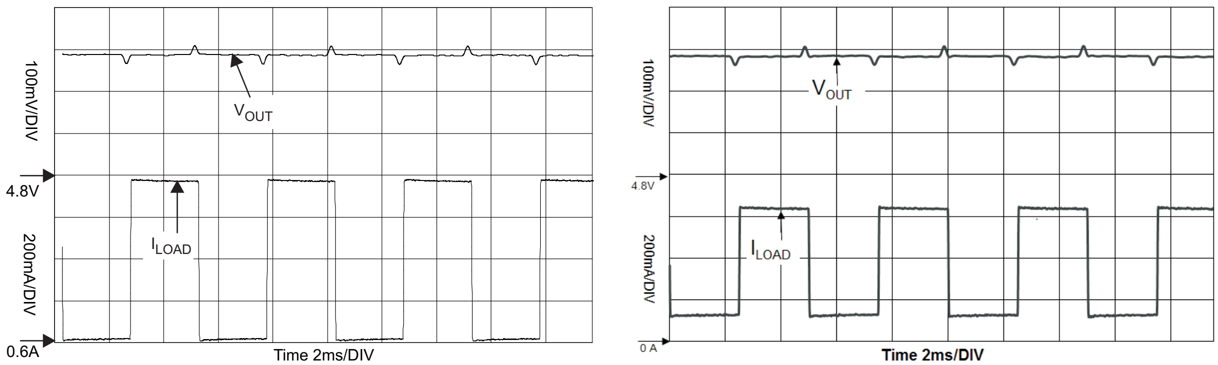

Figure 10. Non-isolated Circuit Transient Response

Figure 11 shows the converter output voltage during startup at 48 V in, for an I_{LOAD} of 1.4 A in the left hand side plot and at no-load in the right hand side plot. The results show a slightly faster rise of 1.5 ms vs. 2ms and sharper entry into regulation than those of Figure 3. The new compensation and the new start-up circuits improve the step response and start-up behavior.

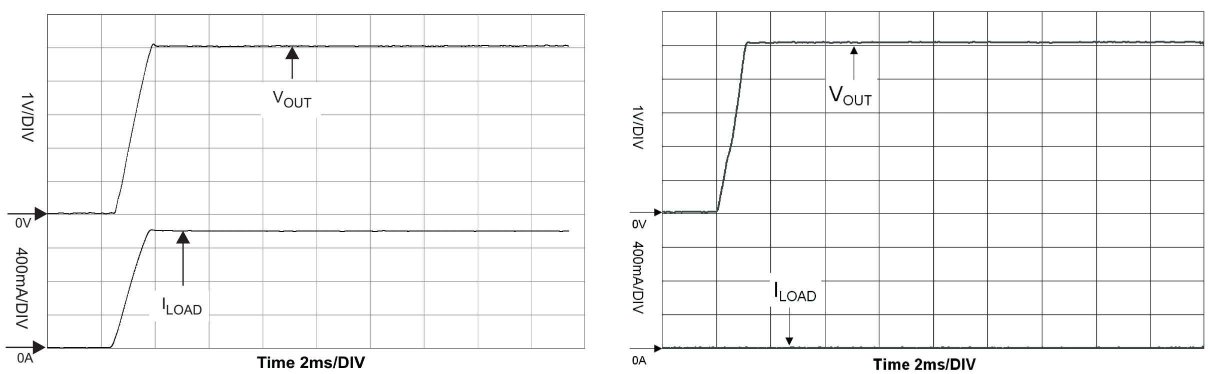

Figure 11. Non-isolated Circuit Startup

Figure 12 shows the Gain and Phase response of the system for an input voltage of 57 V and a load current of 1A. This plot is used to determine the crossover frequency and the stability of the circuit. In this case, the phase margin was 39.23° and the crossover frequency was 14.93 kHz. Notice that the crossover frequency is the double of the isolated case.

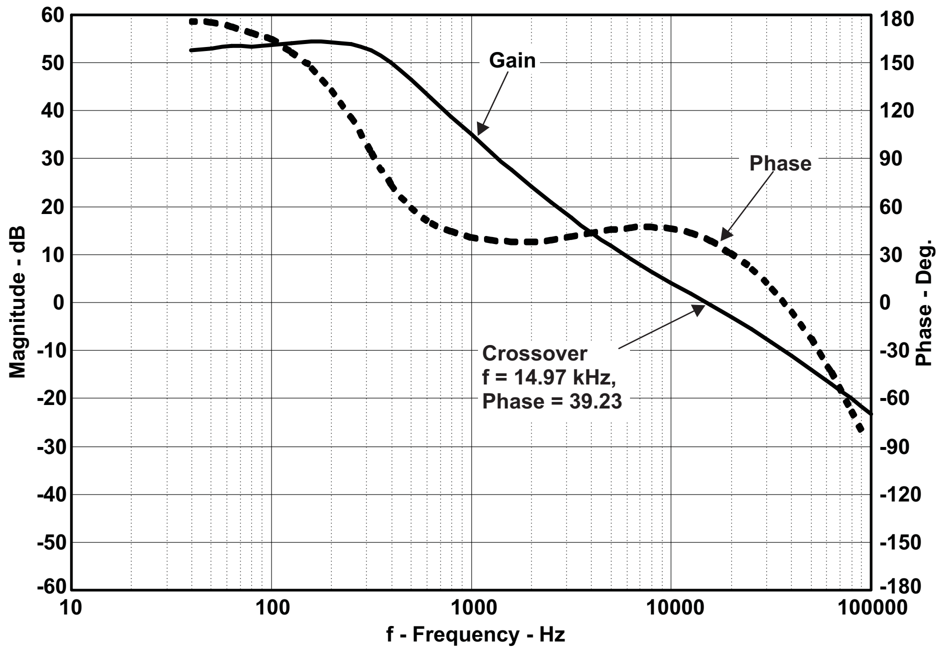

Figure 12. Non-isolated Circuit Phase/Gain

3 Isolated vs. Non-Isolated Comparison

This section compares the behavior of the circuit before (V_{OUT1}) and after (V_{OUT2}) the modifications applied to remove isolation.

Figure 13 shows the transient response with an input voltage of 57 V and 200 Hz pulsed load current (I_{LOAD}) from 0.6 A to 1.4 A (CCM) for the isolated (V_{OUT1}) and non-isolated (V_{OUT2}) converters in the left hand side plot. The plot on the right side shows the same response for I_{LOAD} pulsed from 0.1 A to 0.6 A (DCM).

Figure 14 shows the startup transient response (step response) for I_{LOAD} equal to 1.4 A for the isolated (V_{OUT1}) and non-isolated (V_{OUT2}) converters on the left side plot. The right-side plot shows the same response for the no load (I_{LOAD} equal to 0 A) case. Startup settling time is faster on the non-isolated circuit as can be expected from the wider bandwidth. This can be modified by tuning the startup circuit if desired.

A final recommendation is to make sure that the control block composed by the TLV431 and the associated components are isolated from any possible source of noise such as the drain of the switch or the anode of the output diode. When modifying the EVM, it became apparent that switching noise coupling into the TLV431 circuit was creating problems such as oscillations, dc offsets in the output, and erroneous phase/gain readings.

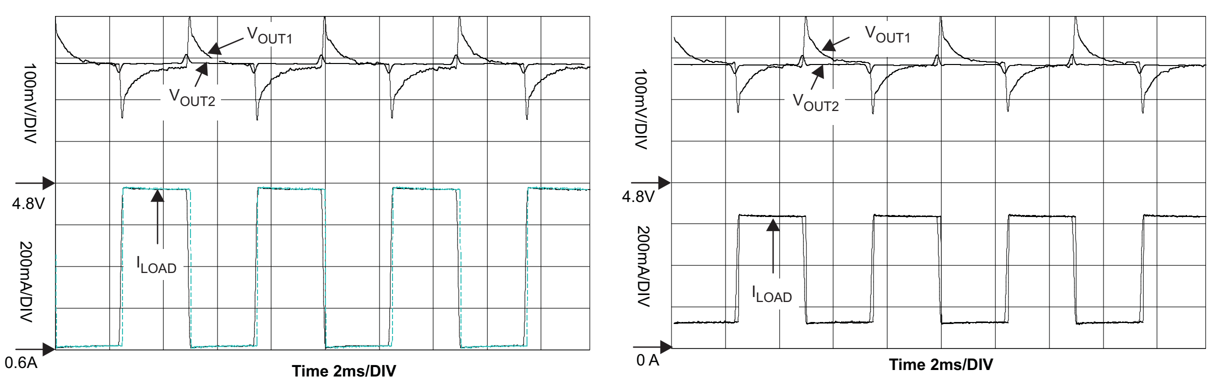

Figure 13. Isolated vs Non-isolated Transient Response

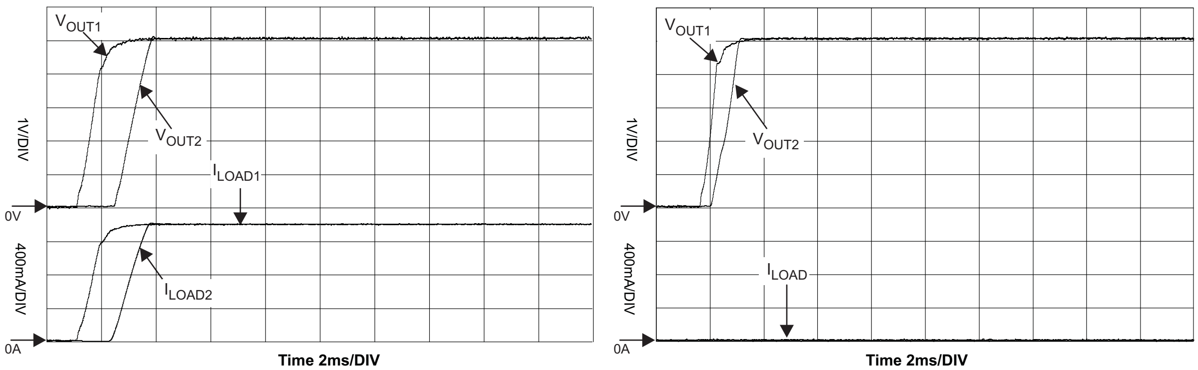

Figure 14. Isolated vs Non-isolated Circuit Startup

4 Conclusions

This application report demonstrates that the TLV431 can be used as an error amplifier for the family of parts including the TPS23753A. A comparison of the performance shows that a faster circuit is possible with the non-isolated configuration. In addition, a slightly different softstart circuit is demonstrated for use in the non-isolated design. This external error amplifier technique permits utilization of features unique to the TPS23753A, TPS23754, TPS23756, and TPS23757 such as adapter ORing support, 12V supply operation, wider duty cycle, and multiple gate drivers to be used in non-isolated converters.

5 References

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