Application Note

Optimization of a Shunt Reference for Flyback Converters

Alex Noggle, Trailokya Rai, Jackson Wightman

ABSTRACT

Flyback converters are widely used in AC/DC power adapters and provide key advantages compared to other conventional AC/DC converters, such as isolation and competitive cost. Shunt references enable high-precision SSR (Secondary Side Regulation) in flyback converters and, when implemented properly, can make sure low standby power dissipation, high output accuracy, and quick transient responses to the flyback controller. When incorporating a shunt reference into a flyback feedback loop, designers must consider biasing, power dissipation, and transient response, and select their components accordingly. This application note outlines the key specs of shunt references in flyback design and explains how to effectively use these shunt references in the flyback control loop for SSR. Furthermore, these explanations are demonstrated with the implementation and comparison of the TL431, TLVH432, ATL431, TL431LI, and ATL431LI in the feedback loop of a flyback converter, which are some of the popular designs for SSR. This application note does not discuss the impacts of different types of compensation on the flyback feedback network.

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1 Introduction

Flyback converters are widely used in power adapters for personal electronics. These AC/DC or DC/DC converters provide the advantage of electrical isolation due to an isolation transformer, which protects end equipment from voltage surges and ground loops. The key elements of a flyback converter include a feedback network, PWM controller, gate driver IC, and switching MOSFETs. A flyback converter uses either primary-side regulation (PSR) or secondary-side regulation (SSR) to provide feedback to the PWM controller to set the output voltage. SSR provides the advantages of a quick transient response, reduced noise coupling between the primary and secondary sides, and improved accuracy across all load conditions with the disadvantage of an increased component count. SSR implementation requires an optocoupler and a shunt reference acting as an error amplifier in the feedback network of the flyback converter. When selecting this shunt reference for the feedback network, designers must balance accuracy, power dissipation, and transient response requirements. Once this shunt reference is selected, the flyback converter must be configured as an error amplifier to set the flyback converter's output voltage properly. This shunt references performance, and proper biasing can optimize power dissipation. Figure 1-1 shows a list of popular shunt references for designer needs.

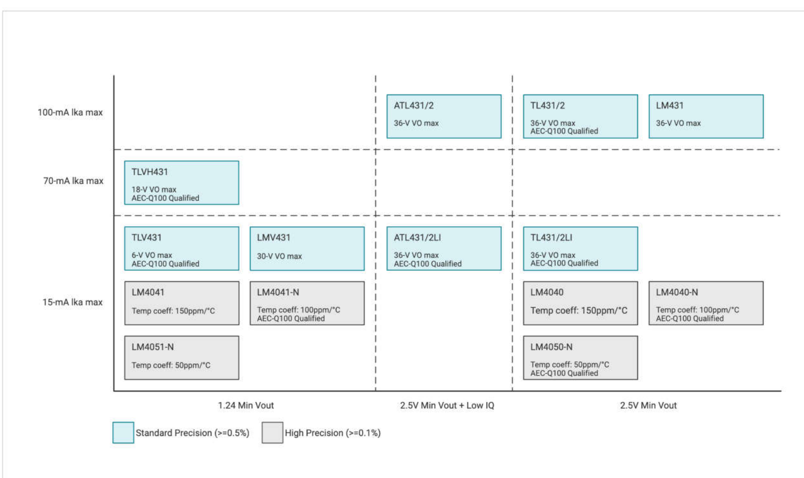

Figure 1-1. Shunt Reference Chart

2 Designing for SSR With a Shunt Reference

The design of a SSR feedback loop utilizes a shunt reference and optocoupler to send a continuous feedback signal from the secondary side of the flyback converter to a PWM controller on the primary side. The optocoupler allows for this feedback signal to be transferred while maintaining electrical isolation between the primary and secondary sides. The flyback converters output voltage is sampled through a resistor divider, which is compared to the internal reference voltage of a shunt reference. This reference voltage controls the current being shunted to ground through the shunt references cathode. This current being shunted to ground is pulled through the optocoupler LED, which activates the phototransistor on the primary side of the feedback loop. This phototransistor is connected to the flyback PWM controller, which allows a feedback signal from the secondary side to be received on the primary side. This feedback signal being received by the PWM controller increases and decrease proportionally with the current being shunted to ground through the shunt reference, meaning that this feedback signal changes with the output voltage. The PWM controller responds to these feedback signals by regulating the output voltage to the programmed value.

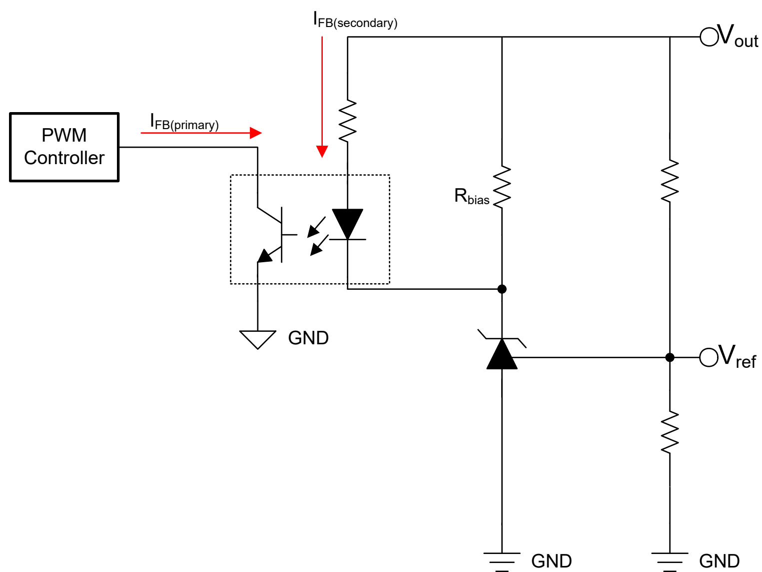

Figure 2-1. Typical SSR Feedback Loop (Without Compensation)

When designing a SSR feedback loop of a flyback converter the implementation of the chosen shunt reference is critical to the performance of the flyback converter. The performance of this chosen shunt reference can be optimized by properly setting the output voltage of the flyback converter, meeting the shunt references biasing requirements, and selecting a shunt reference that can meet transient requirements. When selecting a shunt reference for SSR, a designer also needs to balance the requirements of power dissipation, transient response, and accuracy.

2.1 Setting the Output Voltage

The three-terminal shunt references that this paper focuses on shunt current through their cathode pins, and this current increases dramatically as the voltage at the V_{ref} pins exceeds the internal voltage reference. This allows these shunt references to act as error amplifiers. An output voltage can be programmed using a resistor divider to set V_{ref} equal to the internal reference voltage. By doing this, the shunt reference cathode current, I_{KA}, rapidly increases as soon as the output voltage, V_{out}, exceeds the programmed value or decreases as V_{out} falls below the programmed voltage. This current being shunted to ground through the shunt reference passes through an optocoupler, acting as a feedback signal. Because the flyback feedback loop requires a continuous signal to be sent through an optocoupler via a current, the shunt reference can be partially on so the current can sink through. Figure 2-2 provides some insight into the workings of a shunt reference by demonstrating that when V_{out} is at the programmed value, REF is equivalent to the internal V_{ref}, which causes some feedback current to flow through the cathode from the optocoupler's internal LED.

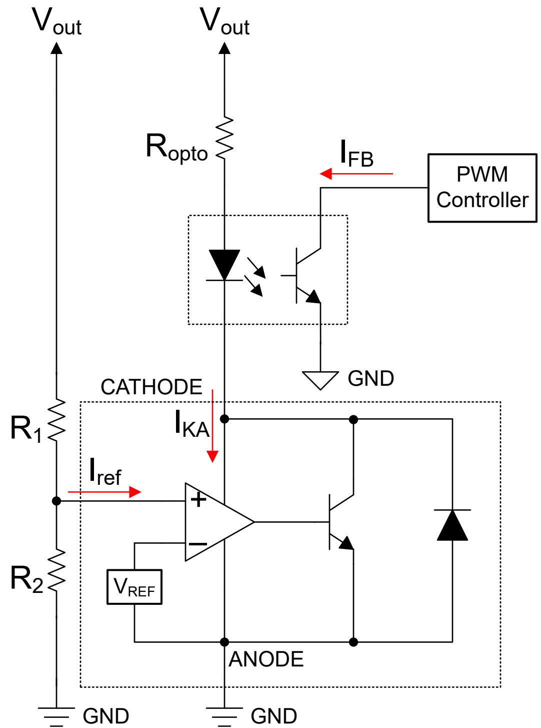

Figure 2-2. Basic Shunt Reference Configuration with Optocoupler

$$V_{out} = V_{REF} \times \left(1 + \frac{R_1}{R_2}\right) + R_1 \times I_{ref} \quad (1)$$

The formula to set the output voltage is shown in Equation 1, where V_{ref} is the internal voltage reference of the shunt reference, I_{ref} is a small current being sunk through the REF pin, and the resistors R_1 and R_2 are used as a resistor divider to program the output. These parameters vary from device to device, and designers can use this formula to set the output voltage of their SSR flyback converters.

Equation 1 is used to solve for the programmed output voltage of the flyback converter; however, each parameter in this formula has a tolerance, which is determined by the accuracy grade of that component. Therefore, the accuracy grade of the internal voltage reference of the shunt reference and the accuracy grades of resistors R_1 and R_2 directly impact the accuracy of the flyback converters' output voltage. While the initial tolerance of V_{ref} can be selected as low as 0.5%, I_{ref} can vary largely with temperature. The effects of I_{ref} on the accuracy can be minimized by selecting a device with a lower nominal I_{ref} value.

2.2 Biasing a Shunt Reference

Shunt references require a minimum cathode current to function properly. This current is provided in each device's data sheet and can vary widely between devices. A biasing resistor is used to verify that these shunt references operate properly so that a biasing current flows into the shunt reference cathode without affecting the feedback signal through the optocoupler. There are two common topologies for biasing a shunt reference for SSR; one places a biasing resistor in parallel with the optocoupler diode, while the other places this biasing resistance directly from the system output to the shunt reference cathode.

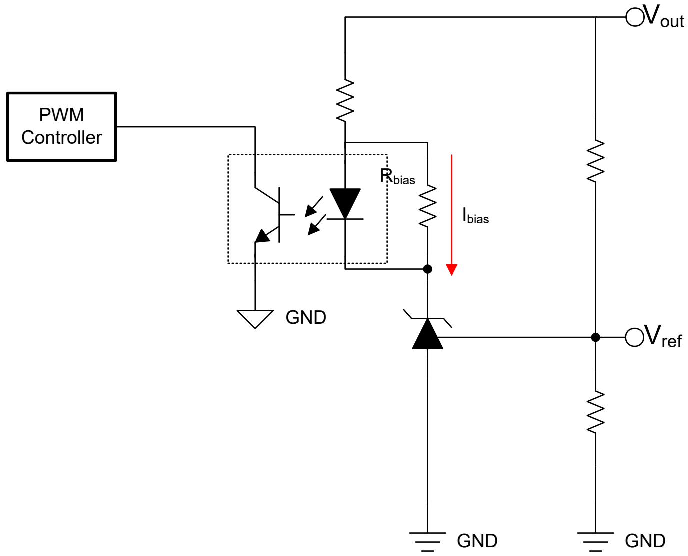

Figure 2-3. Biasing a Shunt Reference Topology 1

When the biasing resistor, R_{bias}, is placed in parallel with the optocoupler diode, as shown in Figure 2-4, the minimum biasing resistance can be generally solved with Equation 2 where $V_{F(drop)}$ is the expected forward voltage drop of the diode, and $I_{KA(min)}$ is the minimum cathode current of the chosen shunt reference.

$$R_{bias} = \frac{V_{F(drop)}}{I_{KA(min)}} \tag{2}$$

The forward voltage drop across the optocoupler diode is non-linear and varies with forward current and temperature. When a flyback converter is subjected to the max load condition, the steady state forward current of the optocoupler is at the minimum value (due to the requirement of higher power output from the PWM controller), which decreases the forward voltage drop of the optocoupler diode. This shows that under max load conditions, the biasing current being provided to the shunt reference is minimized, meaning that when selecting R_{bias}, the minimum expected forward voltage drop, $V_{F(drop)}$, can used in Equation 2 to prevent accidental under-basing for a flyback converter under max-load conditions. This can maintain that the shunt reference is properly biased under all load conditions.

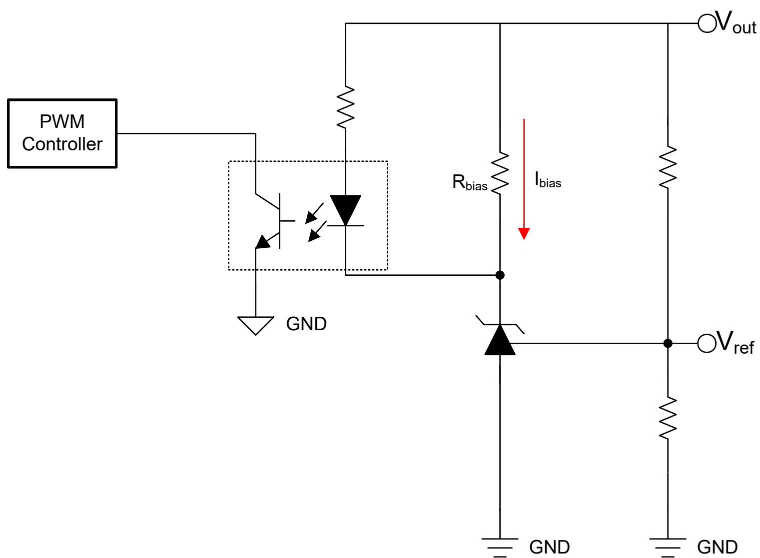

Figure 2-4. Biasing a Shunt Reference Topology 2

In the second topology shown in Figure 2-4, the biasing resistance between the flyback output and the shunt references cathode pin is established. The shunt reference controls the optocoupler current and acts as an error amplifier. Choosing a biasing resistance for this topology is similar to the previous topology; however, the expected voltage drop across this biasing resistance varies more under different load conditions due to an additional voltage drop across the optocoupler resistance that must be considered.

$$R_{bias} = \frac{V_{out} - V_{KA}}{I_{KA(min)}} \tag{3}$$

Equation 3 shows the formula for calculating the max biasing resistance, R_{bias}. The cathode voltage, V_{KA}, is determined by the expected feedback current through the optocoupler diode on the secondary side and can be calculated as the output voltage, V_{out}, minus the voltage drop of the optocoupler diode and resistance on the secondary side. Decreasing the biasing resistance below this calculated value increases the biasing current above $I_{KA(min)}$, which dissipates extra power with no clear improvements in performance. Under max-load conditions, expect the feedback current flowing through the optocoupler diode, IFB (secondary), to be lower than this current under a no-load condition (standby mode).This shows a reduced voltage drop across these components, increasing the cathode voltage, V_{KA}, at the shunt reference. Therefore, similarly to the first topology, the bias current, I_{bias}, varies under different load conditions, where when the flyback converter is subjected to the max-load condition, the biasing current is at the minimum value. Choose the bias resistance, R_{bias}, to provide the minimum cathode current, $I_{KA(min)}$, to the shunt reference under the desired max-load conditions so that this reference is properly biased across the entire load range.

In both topologies, the current flowing into the cathode of the shunt reference, I_{KA}, is the sum of the current flowing through the optocoupler diode, $I_{F(drop)}$, and the biasing current I_{bias}. The voltage applied to the REF pin determines the amount of cathode current the shunt reference shunts to the ground. One can think that because of this, increasing I_{bias} decreases the current through the optocoupler diode, $I_{F(drop)}$, thus impacting the feedback loop; however, this is not the case. This is due to the near-infinite transconductance of the shunt reference when the REF voltage is near the internal reference, which is shown in Figure 2-5.

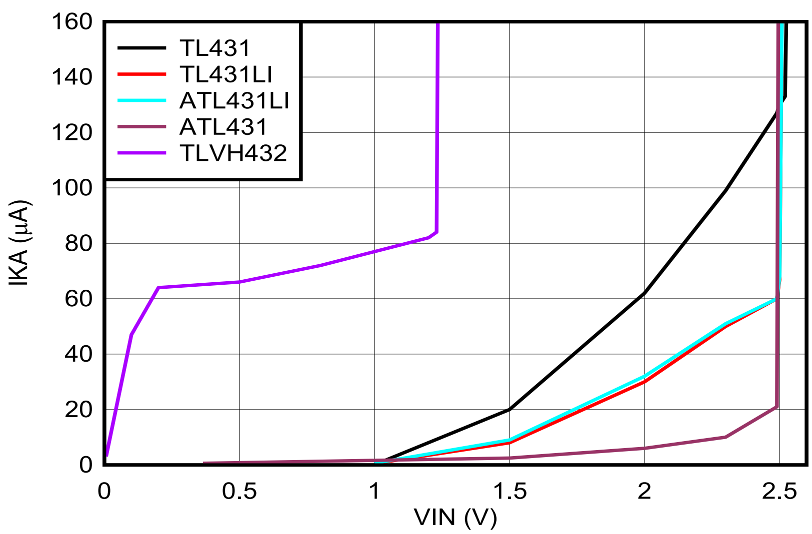

Figure 2-5. V_{ref} Gain Comparison

Figure 2-5 shows that if excess bias current is provided to a shunt reference, the REF voltage does not need to increase by any notable amount to allow this extra current to be shunted to ground. It is biased close to the ON current. This shows that overbiasing the shunt reference won't have any notable impact on the feedback current through the optocoupler diode, $I_{FB(secondary)}$.

2.3 Designing for Transient Response

In flyback converters a transient response is the feedback loops response to a sudden change at the flyback output. This sudden change at the output is likely due to a switching load or high noise across the flyback output. A feedback loop with a good transient response will respond quickly to any changes in the output condition by modifying its feedback signal, $I_{FB(secondary)}$, through the optocoupler diode accordingly. The PWM controller will respond to this new signal by regulating the output voltage back to its programmed value. In applications with a switching load, it's desirable to have a quick transient response, and the speed of this response will be determined by the gain of the shunt reference, which will vary from device to device. The larger this transconductance gain of the chosen shunt reference is, the quicker the cathode current, and thus the optocoupler feedback current, will change. Figure 2-5 shows the transconductance gains of several shunt references that will be explored in greater detail in Section 4.4.

3 Power Considerations

Flyback converters are often used in common household power adapters, meaning many of these converters must follow national and global power consumption standards. The most popular standard designers must follow is the DoE Level VI standard, which specifies maximum standby power consumption based on the normal output power.

Table 3-1. Standby Energy Requirements

Output Power	Standby Power
US DoE Level VI (≤ 49 W)	< 100 mW
US DoE Level VI (50W to 249 W)	< 210 mW
US DoE Level VI (> 249 W)	< 500 mW

Minimizing the power dissipation of the shunt reference in the control loop is critical for meeting global power consumption standards. The power dissipation of the control loop can be calculated as the voltage being applied to this control system multiplied by the current flowing through. The voltage applied to the control system is the output voltage of the flyback converter, which is set to a desired value; therefore, minimizing the current through the control network is the key to reducing power dissipation.

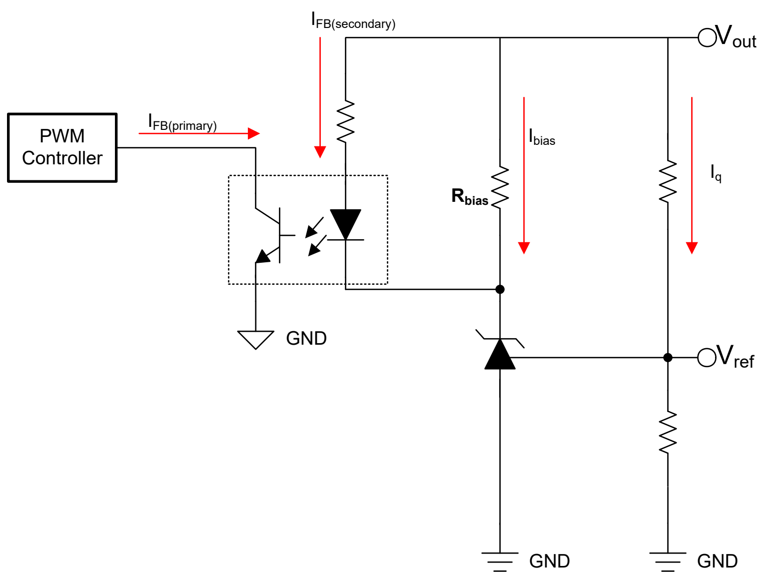

Figure 3-1. Current Through an SSR Feedback Network

Figure 3-1 shows that the total current that flows through the control loop is the sum of the I_q current through the resistor divider, the feedback current through the optocoupler diode, $I_{FB(secondary)}$, and the biasing current, I_{bias}.

$$P_{dissipation} = V_{out} \times \left(I_{FB(secondary)} + I_{bias} + I_q\right) \quad (4)$$

Equation 4 shows the formula for calculating the power dissipation of a feedback network with SSR (for the second biasing topology). Choosing an optocoupler with a higher CTR (current transfer ratio) allows the secondary side feedback current, $I_{FB(secondary)}$, to be reduced via a larger optocoupler resistance. Increasing the resistances on the resistor ladder while maintaining the same ratio can reduce I_q; however, this can come at the expense of increasing the output voltage reliance on I_{ref}, which can vary widely under different conditions. The most common design choice for reducing power dissipation in the feedback network is to reduce the biasing current, I_{bias}. This biasing current can only be reduced to $I_{KA(min)}$ without negatively impacting the performance of the flyback converter. In applications requiring reduced power consumption, selecting a shunt reference with a lower minimum IKA (min) is the best practice.

Table 3-2. Device Critical Spec Comparison

Device	Bandgap Reference	Nominal Iref Current	Minimum Cathode Current
TL431	V_{ref} = 2.495 V	I_{ref} = 2 µA	$I_{KA(min)}$ = 1 mA
TLVH432	V_{ref} = 1.24 V	I_{ref} = 0.1 µA	$I_{KA(min)}$ = 100 µA
ATL431	V_{ref} = 2.5 V	I_{ref} = 30 nA	$I_{KA(min)}$ = 35 µA
TL431LI	V_{ref} = 2.495 V	I_{ref} = 0.2 µA	$I_{KA(min)}$ = 1 mA
ATL431LI	V_{ref} = 2.5 V	I_{ref} = 0.2 µA	$I_{KA(min)}$ = 80 µA

Table 3-2 shows some of the key specs when selecting a shunt reference, where a lower $I_{KA(min)}$ allows for reduced power dissipation, and a lower nominal I_{ref} allows for improved accuracy reliability at the flyback output. These specs make the ATL431 an excellent design for minimizing power dissipation to meet global regulations.

4 Methodology

To prove the performance improvements of some shunt references over others, the TL431, TLVH432, ATL431, TL431LI, and ATL431LI were all separately tested with their own required bias currents on the UCC28780EVM-021, which is a flyback EVM (Evaluation Module) with SSR. This flyback EVM uses the biasing topology shown in Figure 2-4. This experiment connected an E-load to the flyback output to test each shunt reference under a no-load condition (standby mode), a 20-W load, and a 40W load. The EVM was powered with an isolated 120 V 60 Hz source via an isolation transformer and a virac. The biasing resistance was determined by following the steps in Section 2.2, where this resistance set I_{bias} = $I_{KA(min)}$ under a 40W load. Several test points were soldered onto the EVM to properly analyze the results to determine the optocoupler diode feedback current, $I_{FB(secondary)}$, the biasing current, I_{bias}, and the output voltage, V_{out}. This test setup is shown in Figure 4-1, which shows the actual EVM being tested, and in Figure 4-2, which shows the full feedback network, including the test points and compensation capacitors.

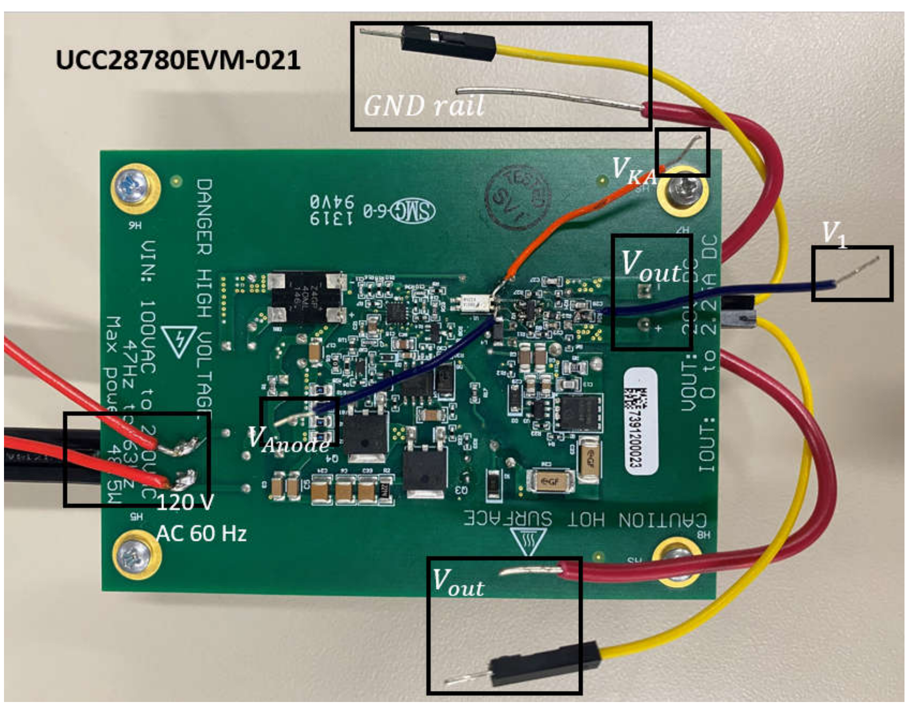

Figure 4-1. EVM Test Board Setup

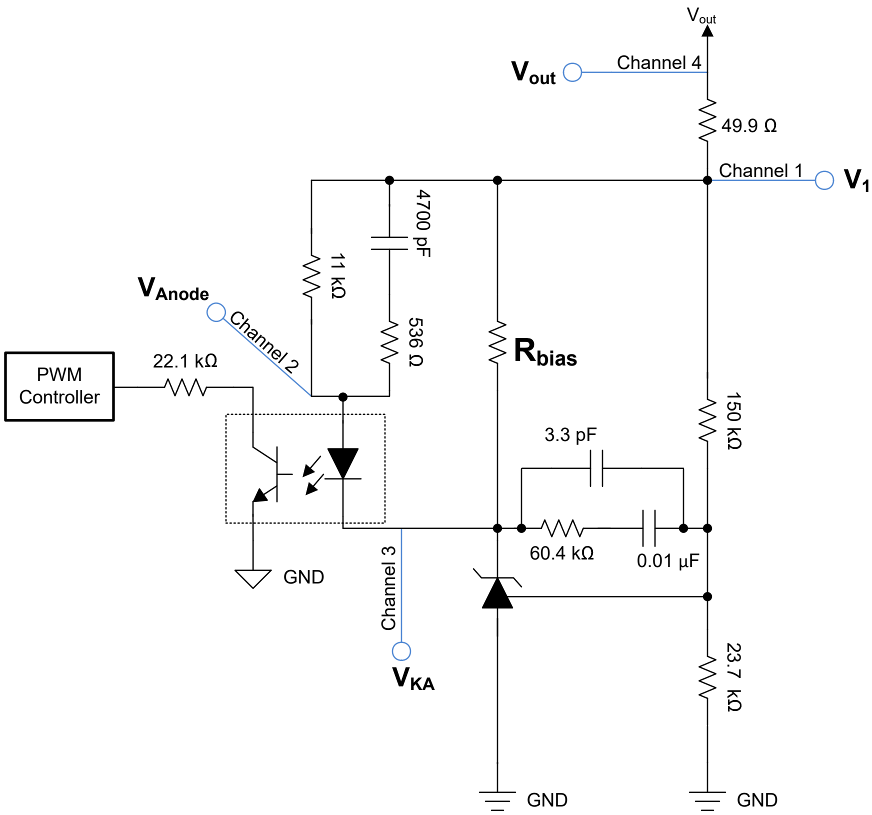

Figure 4-2. Control Network Probe Connections

4.1 Shunt Reference Implementation

The UCC28780EVM-021 EVM that was used to perform this experiment originally had an ATL431 shunt reference with a biasing resistance of 34 kΩ. Once test probes were installed, the average cathode voltage, V_{KA}, under a 40 W load was measured to be 16.9 V. When a new shunt reference was soldered onto the board for testing, a new bias current had to be established. Equation 3 was used to calculate the new required biasing resistance, R_{bias}, where 16.9 V was assumed as the cathode voltage V_{KA} for simplicity. $I_{KA(min)}$ was pulled from the new devices data sheet, and V_{out} was found using Equation 1. The cathode voltage, $V_{KA,}$ changes according to the programmed output voltage due to the required feedback current to set that output voltage. The TLVH432 has a lower internal reference of 1.24V, meaning that the programmed output voltage is much lower, so R_2 was decreased to 10 kΩ to change the programmed output voltage to 19.855 V. The TLVH432's cathode voltage, V_{KA}, was measured at 18.27 V under a 40 W load, which was then used in Equation 3 to calculate the bias resistance, R_{bias}. The biasing resistance and biasing current provided for each shunt reference for a 40 W load are shown in Table 4-1.

Table 4-1. Shunt Reference Biasing Data

Component	R_{bias}	I_{bias} (40 W load)	$I_{KA(min)}$	V_{out} (expected)
TL431	1.5 kΩ	0.99 mA	1 mA	18.59 V
TLVH432	14 kΩ	105.9 µA	100 µA	9.10 V
ATL431	34 kΩ	44 µA	35 µA	18.33 V
TL431LI	1.5 kΩ	0.99 mA	1 mA	18.32 V
ATL431LI	19.1 kΩ	77.96 µA	80 µA	8.35 V

The following scope images show the steady state performance of each shunt reference under the three-load conditions.

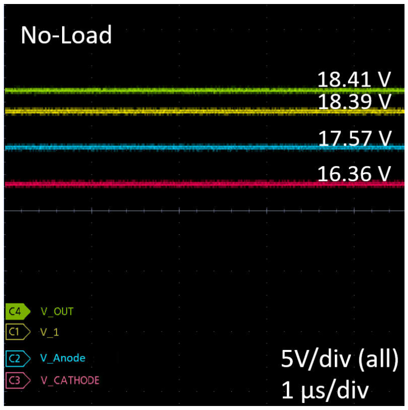

Figure 4-3. TL431 No-Load

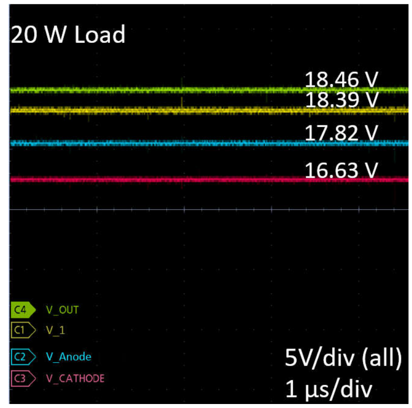

Figure 4-4. TL431 20 W Load

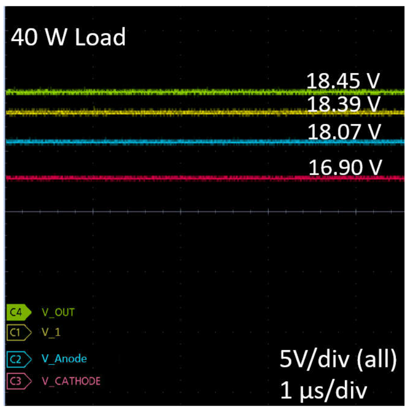

Figure 4-5. TL431 40 W Load

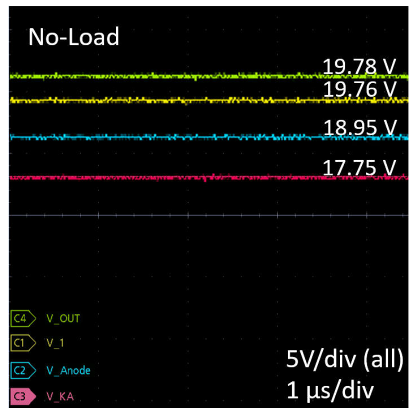

Figure 4-6. TLVH432 No-Load

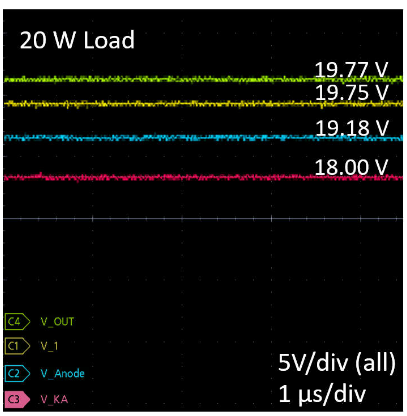

Figure 4-7. TLVH432 20 W Load

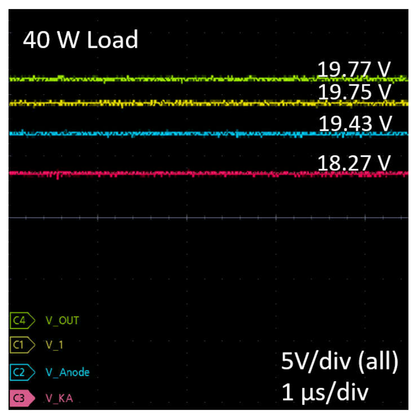

Figure 4-8. TLVH432 40 W Load

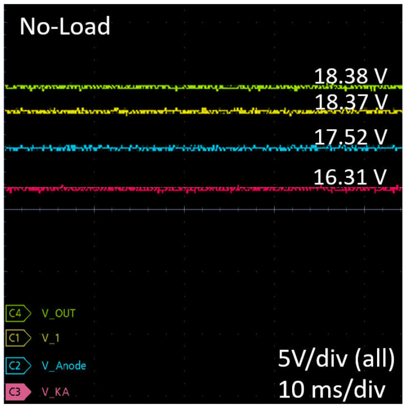

Figure 4-9. ATL431 No-Load

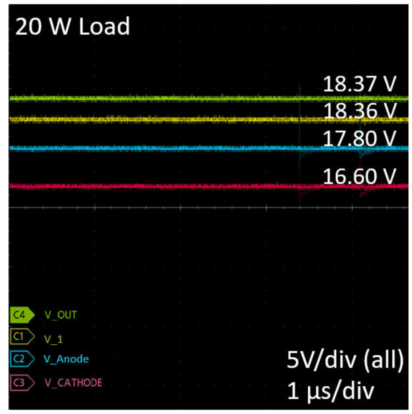

Figure 4-10. ATL431 20 W Load

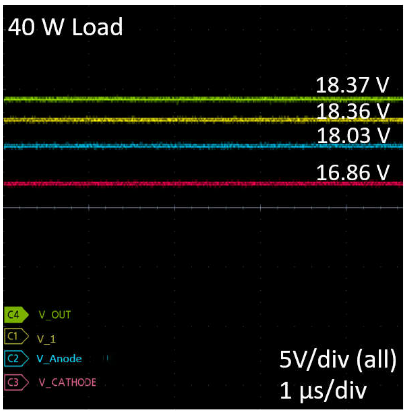

Figure 4-11. ATL431 40 W Load

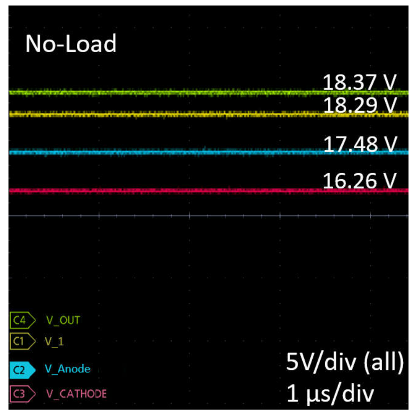

Figure 4-12. TL431LI No-Load

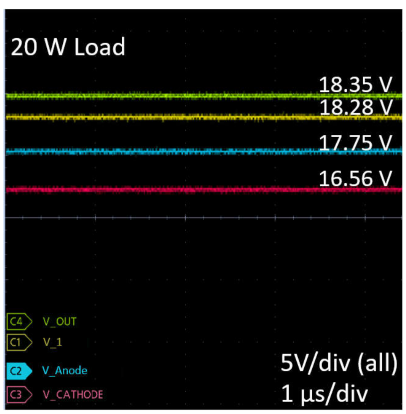

Figure 4-13. TL431LI 20 W Load

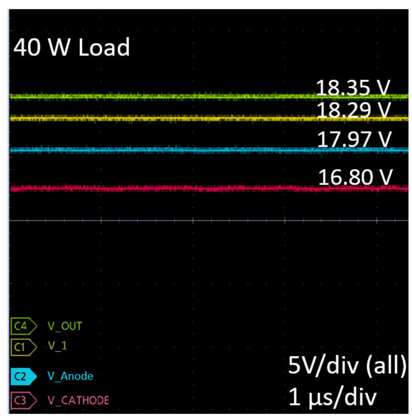

Figure 4-14. TL431LI 20 W Load

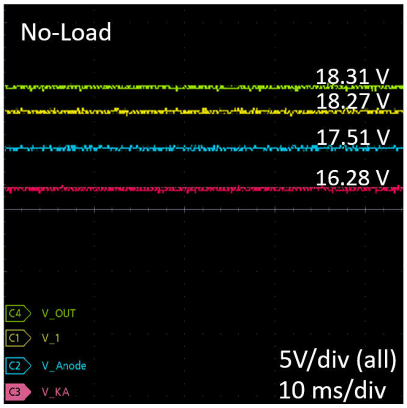

Figure 4-15. ATL431LI No-Load

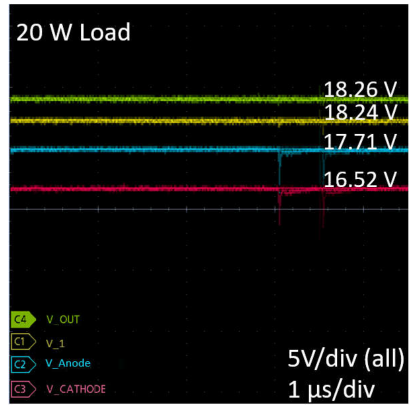

Figure 4-16. ATL431LI 20 W Load

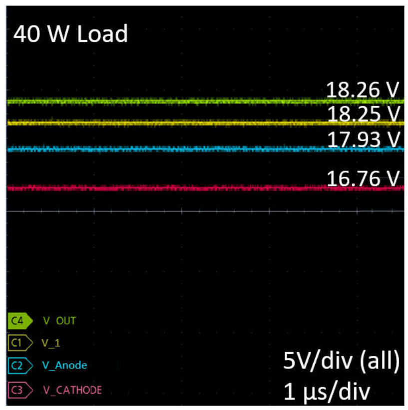

Figure 4-17. ATL431LI 40 W Load

Vout was measured as the expected programmed value for each of the plots shownand V_1 was measured as a slightly lower value than V_{out}. V_{Anode} and V_{KA} change under different load conditions to modify the secondary side feedback current, $I_{FB(secondary)}$, through the optocoupler diode. This change in V_{KA} also decreases the biasing current, I_{bias}, being provided to the shunt reference under larger loads, which is why I_{bias} was established as $I_{KA(min)}$ at the full-load condition.

4.2 Accuracy Comparison

The expected output voltage of the flyback converter for each shunt reference was calculated using Eq. 1, where I_{ref} was chosen as the nominal value provided in each component data sheet, V_{ref} was selected as the typical value for each component, and R_1 and R_2 were constant at 150 kΩ and 23.7 kΩ respectively, both with a 1% tolerance for each shunt reference except the TLVH432. The TLVH432's R_1 and R_2 values were constant at 150 kΩ and 10 kΩ, with a 1% tolerance. Table 4-2 shows the actual flyback output voltages measured for each shunt reference at the three load conditions. Table 4-2 also shows the standby-mode accuracy, which was calculated using Equation 5.

$$\text{accuracy (\%)} = \frac{|V_{out(expected)} - V_{out(measured)}|}{V_{out(expected)}} \tag{5}$$

Table 4-2. Accuracy Comparison Chart

Device	Expected Output Voltage (V)	Measured Output Voltage (V) - Standby Mode	Accuracy (%)	Measured Output Voltage (V) - 20 W Load	Measured Output Voltage (V) - 40 W Load
TL431	V_{out} = 18.586 V	V_{out} = 18.414 V	0.926 %	V_{out} = 18.459 V	V_{out} = 18.448 V
TLVH432	V_{out} = 19.855 V	V_{out} = 19.777 V	0.393 %	V_{out} = 19.770 V	V_{out} = 19.770 V
ATL431	V_{out} = 18.327 V	V_{out} = 18.377 V	0.271%	V_{out} = 18.369 V	V_{out} = 18.370 V
TL431LI	V_{out} = 18.316 V	V_{out} = 18.374 V	0.316 %	V_{out} = 18.350 V	V_{out} = 18.349 V

Table 4-2. Accuracy Comparison Chart (continued)

Device	Expected Output Voltage (V)	Measured Output Voltage (V) - Standby Mode	Accuracy (%)	Measured Output Voltage (V) - 20 W Load	Measured Output Voltage (V) - 40 W Load
ATL431LI	V_{out} = 18.353 V	V_{out} = 18.313 V	0.217%	V_{out} = 18.256 V	V_{out} = 18.260 V

Table 4-2 goes to show that when properly biased, the flyback converters' output accuracy never deviated by more than 1% for any of the shunt references used under any of the three load conditions. Note that the flyback output for the TL431 had a slightly worse accuracy than the other devices, likely due to the larger nominal I_{ref} value, which deviates largely under different conditions. The ATL431/LI provided the lowest nominal I_{ref}, which can maintain accuracy in applications that require very high precision.

4.3 Power Consumption Comparison

As explained in Section 3: the power dissipation of the feedback network can be calculated as the total output voltage multiplied by the total current flowing through this feedback network, which is shown in Equation 4. The currents in these equations were calculated by measuring the voltage drop across the optocoupler resistance (11 kΩ), biasing resistance (changed from device to device), and R_1 (150 kΩ) and then dividing these voltage drops by their respective resistances. This is shown in Equation 6, where the reference voltage is assumed to be the internal reference of the shunt reference for simplicity.

$$P_{dissipation} = V_{out} \times \left(\frac{V_1 - V_{Anode}}{11\ k\Omega} + \frac{V_1 - V_{KA}}{R_{bias}} + \frac{V_1 - V_{REF}}{150\ k\Omega} \right) \quad (6)$$

Using Equation 6 and the sampled data, Table 4-3 below was constructed to compare the power dissipation of the feedback network with different shunt references under each of the three load conditions.

Table 4-3. Feedback Network Power Consumption

Component	$I_{KA(min)}$	Standby Mode Power Consumption	20 W Load Power Consumption	40 W Load Power Consumption
TL431	1 mA	28.29 mW	24.65 mW	20.82 mW
TLVH432	100 µA	6.74 mW	5.96 mW	5.12 mW
ATL431	35 µA	4.45 mW	3.83 mW	3.30 mW
TL431LI	1 mA	28.11 mW	23.78 mW	20.59 mW
ATL431LI	80 µA	5.31 mW	4.44 mW	3.87 mW

Table 4-3 confirms that a lower bias current, I_{bias}, reduces the power dissipation across the feedback network. This reduction also shows that the feedback network consistently dissipates more power in standby mode than when the flyback converter is at max load condition. This is due to the lower feedback current, $I_{FB(secondary)}$, flowing through the optocoupler diode when a load is applied to the output. The ATL431 is an excellent choice for meeting strict power consumption requirements.

4.4 Transient Response Comparison

The transient response of each shunt reference was observed by switching a 40 W load on and off while observing the instantaneous reactions of the output voltage, V_{out}, and the feedback current, $I_{FB(secondary)}$. When an electrical load is applied, the output voltage can suddenly drop due to voltage losses caused by the current flow through the flyback converter. The larger the load applied, the larger the voltage losses. A sudden drop in the output voltage results in a drop in the reference voltage, thus decreasing the cathode current, I_{KA}, being shunted through the shunt reference. This reduced current flow decreases the feedback current through the optocoupler, $I_{FB(secondary)}$, thus decreasing the signal being received by the PWM controller. Some shunt references had a quicker transient response than others due to the gain of these shunt references, which isn't provided in any of these devices' data sheets. The following images show the observed transient response for each shunt reference.

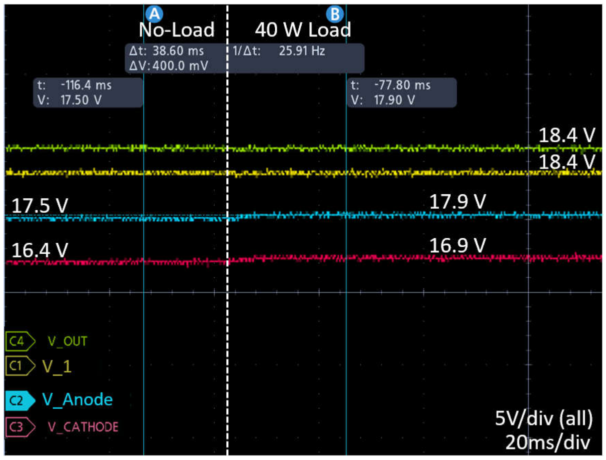

Figure 4-18. TL431 Transient Response

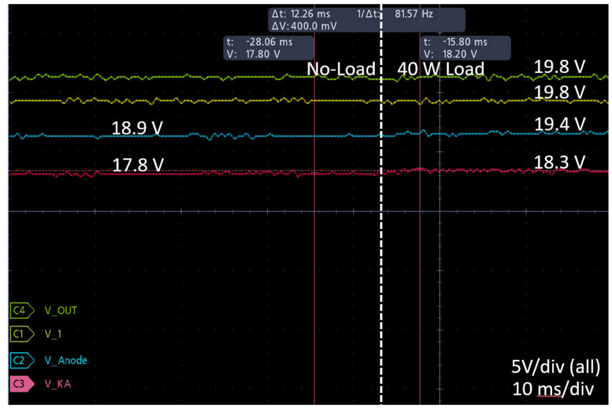

Figure 4-19. TLVH432 Transient Response

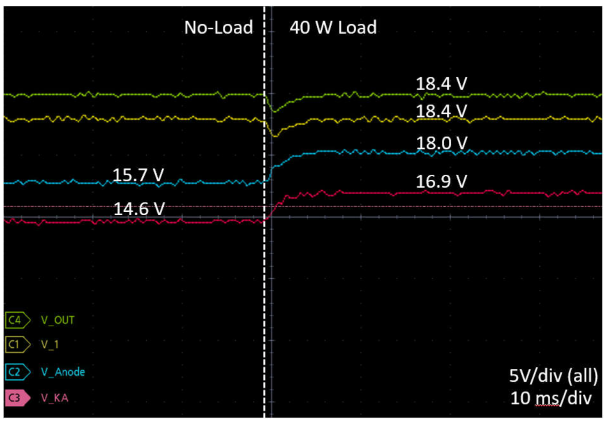

Figure 4-20. ATL431 Transient Response

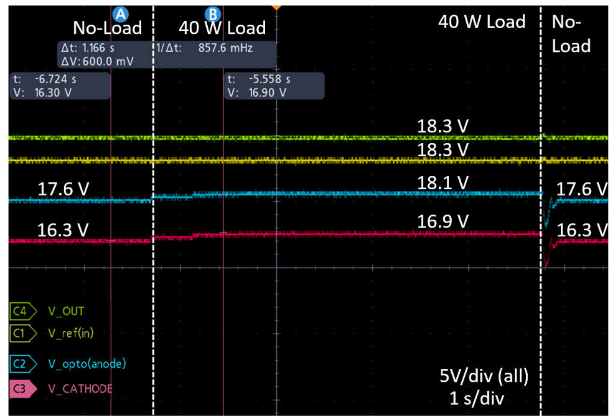

Figure 4-21. TL431LI Transient Response

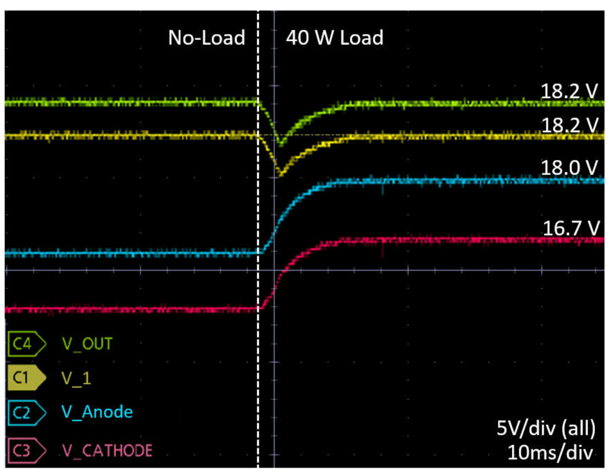

Figure 4-22. ATL431LI Transient Response

These plots show the transient response of each shunt reference when a 40 W load is switched on. The TL431/LI and the TLVH432 performed well, with no noticeable change in the output voltage, while the ATL431/LI performed noticeably slower. The ATL431/LI's cathode voltage, V_{KA}, and anode voltage, V_{Anode}, fall significantly below their steady-state values once a load is turned off and then take considerable time to stabilize. While this does not impact the accuracy of the flyback output voltage, the time increased for their transient responses to occur and resulted in extra power dissipation while these voltages were steadying out. The scope shots for the ATL431/LI in Figure 4-20 and Figure 4-22 , both show the transient response of switching a 40 W load on shortly after that same load was switched off.

5 Results

Once the components had each been individually tested and the data analyzed, the results concluded that the ATL431 was the best design for a low-power dissipation and reliable accuracy, with the TLVH432, and the ATL431LI close behind. The TL431, TLVH432, and TL431LI each had a quick transient response, while the ATL431/LI had a noticeably slower transient response. The test results supported the idea that a lower nominal Iref improved the output voltage accuracy; however, without additional testing, this cannot be confirmed. The results from the previous section are compiled on Table 5-1 for an overall comparison of the tested shunt references.

Table 5-1. Shunt Reference Performance Comparison

Shunt References	Power Dissipation (standby mode)	Output Accuracy (standby mode)	Transient Response Performance
TL431	28.29 mW	0.926 %	Best
TLVH432	6.74 mW	0.392 %	Best
ATL431	4.45 mW	0.271 %	Good
TL431LI	28.11 mW	0.316 %	Best
ATL431LI	14.77 mW	0.217 %	Good

6 Summary

This application note explained the key shunt reference specs and their impacts on the performance of SSR in a flyback converter. The process for implementing a shunt reference into the SSR feedback network was explained in detail, including how one can set the flyback converters output voltage, and bias the shunt reference. The performance of the TL431, TLVH432, ATL431,TL431LI, and the ATL431LI were analyzed, and a conclusion was created for which shunt reference had the best performance for accuracy, power dissipation, and transient response.

7 References

- Texas Instruments, *Using the TL431 for Undervoltage and Overvoltage Detection* application note.
- Texas Instruments, *Designing with the ATL431LI in Flyback Converters* application note.
- Texas Instruments, *Compensation Design With TL431 for UCC28600* application note.
- Texas Instruments, *Under the Hood of Flyback SMPS Designs* power supply design seminar.
- Texas Instruments, *Shunt Reference Considerations for Flyback Converters with Optocoupler Feedback* YouTube tutorial.