Application Report

Shunt Regulator Design Procedures for Secondary Feedback Loop in Isolated Converter

Dennis Oh

ABSTRACT

ATL43xLI device is a three-terminal adjustable shunt regulator and it consists of a voltage reference and internal error amplifier. with varying its form, it can be selected in many applications such as Adjustable voltage and current referencing, Zener diode replacement, Secondary side regulation in ACDC SMPS in closed-loop configuration and also, can be applicable to open-loop configuration as Comparator with integrated reference, Voltage monitoring extensions. This application note is to give developers design procedures for secondary feedback loop application and to definitize operating mechanism in the circuit. TI provides a family of 431 products and 432 as an alternative pin out of the 431. This document applies to a series of 431 products, including TL431LI, ATL431LI, and TLV431.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

1.1 TL431 as a Type-2 Amplifier

Figure 1-1 is a general current-mode control converter. This type of non-isolated converters integrate the EA (error amplifier) and Vref as parts of feedback control loop. And Type-2 amplifier network provides optimal compensation in the loop.

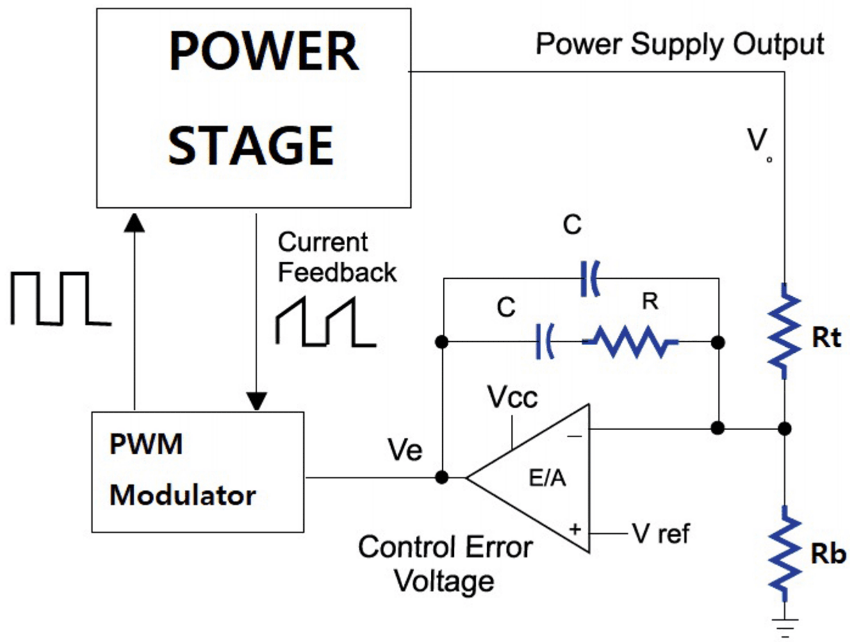

Figure 1-1. Feedback Loop in Non-Isolated Current-Mode Control Converter

On the basis of the composition of TL431, Figure 1-2 shows how it can be used as a standard EA.

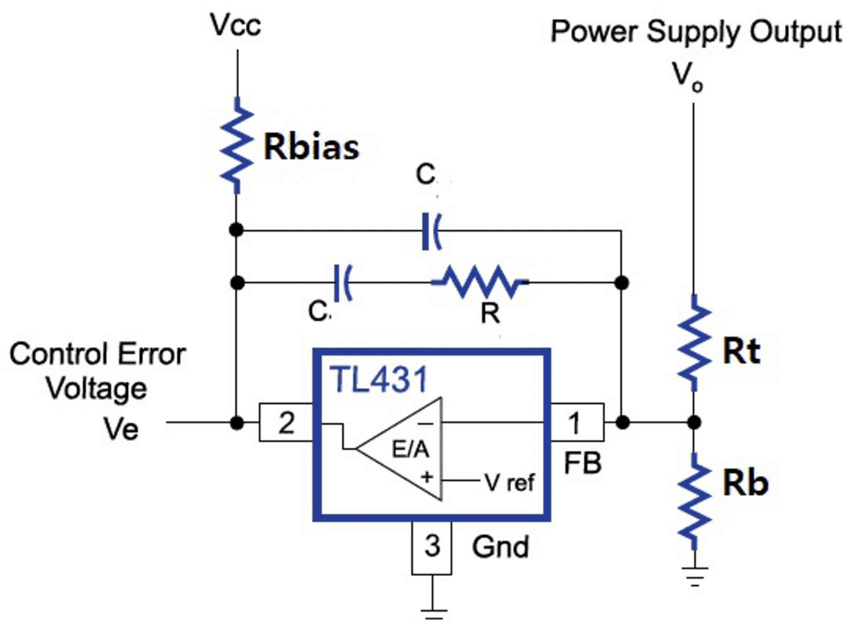

Figure 1-2. TL431 Used As A Type-2 Amplifier

The pullup resistor (Rbias) value should be chosen to meet the minimum cathode current requirement, this is to provide sufficient bias current to TL431 under all circuit conditions.

1.2 TL431 Solution with Isolation

TL431 has been used widely in isolated power supply applications and it provided design benefits of reducing the cost of feedback loop, taking up little board space within the performance tradeoff from the standard error amplifier and a precision reference.

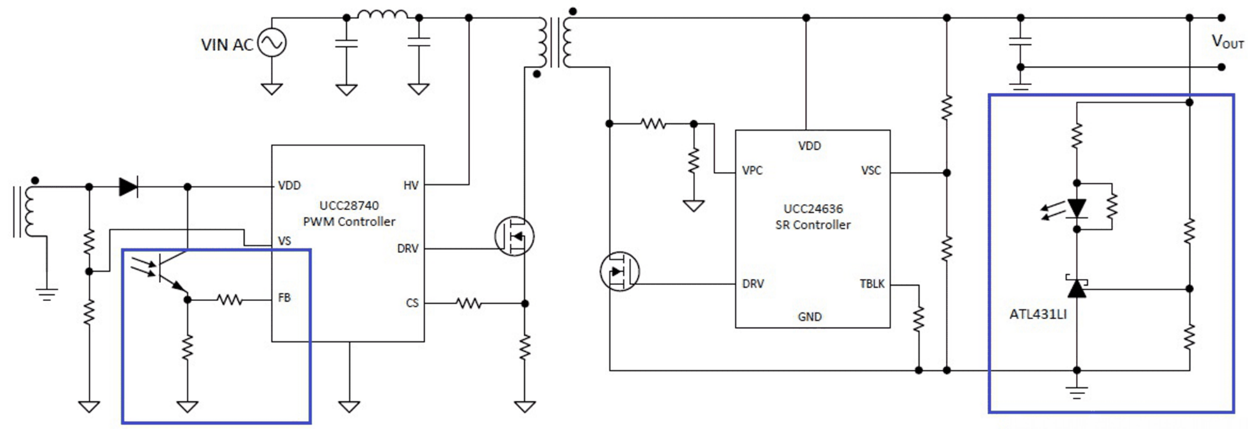

Figure 1-3. Flyback with Optocoupler Isolation with TL431

Further detail from Figure 1-3, we now understand TL431 is powered from output of converter. And the amount of current flowing through the Rbias and the optocoupler diode to the cathode of TL431 are driving the gain and operation of the circuit. Figure 1-4 shows typical TL431 in conjunction with optocoupler for isolated feedback control.

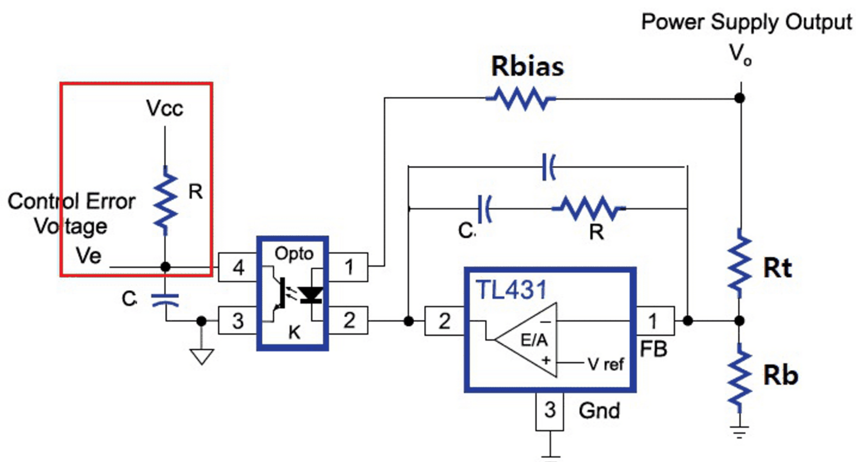

Figure 1-4. TL431 In Conjunction with Optocoupler for Isolated Feedback

As described, the bias current at both primary and secondary side are controlling the gain and frequency response of the circuit. However, it is very complicated analysis and even latest controllers have built the primary side bias, including current source and resistors, inside. Hence, we have options to follow design procedures for bias circuit of secondary side feedback.

2 Design Procedures

2.1 Design Considerations for Optocoupler

Optocoupler is an electronic component that transfers electrical signals between two isolated circuits by using light. It is common to find commercial products consist of an infrared emitting diode, optically coupled to a phototransistor detector. Basically the light from the diode acts like a base current to the transistor and the amount of light can be controlled by bias current into the diode.

Here we need to note one premise that the phototransistor should work in a linear region for normal condition wherein there is only a small change in the level of V_{out}. That means just a few tens of, or hundreds of change of u-volt or u-Amps in diode side can make the variation to the VCE. Extreme conditions such as high overvoltage, deep undershoot would require opto to work in saturation or cut-off region but, we assume that controller protects those extreme situation so no cases to consider into.

Step 1: Check the primary side controller's FB configuration. Maximum FB current.

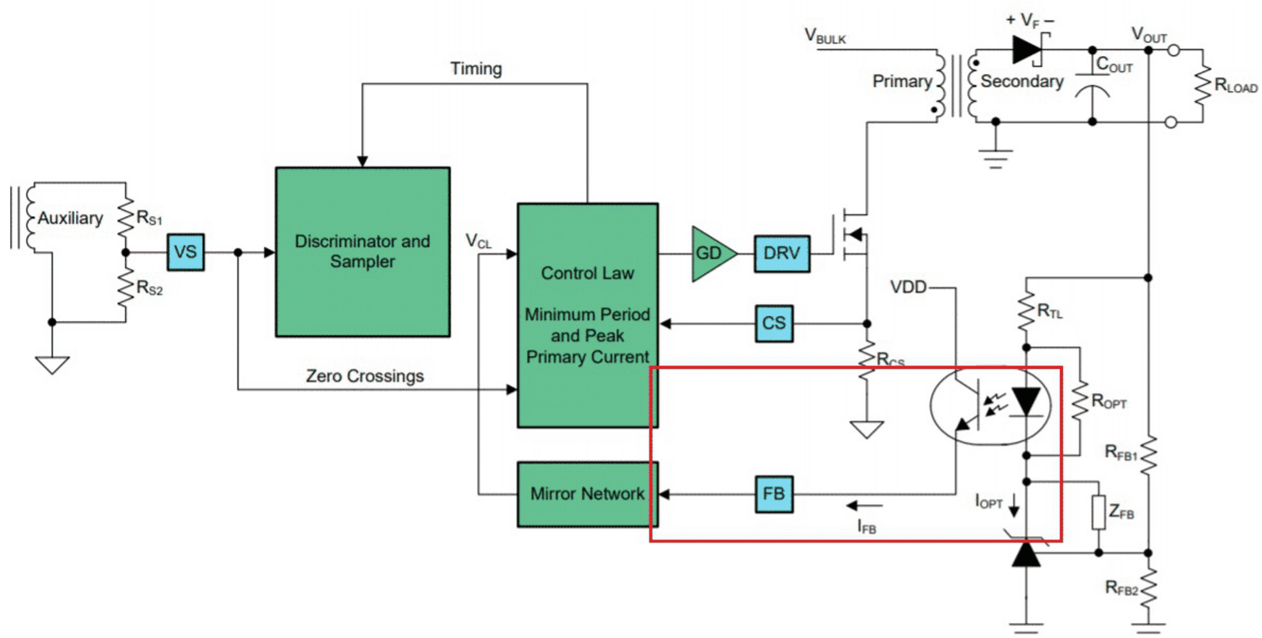

Figure 2-1. Example of UCC28740 (Low Side Current Sinking)

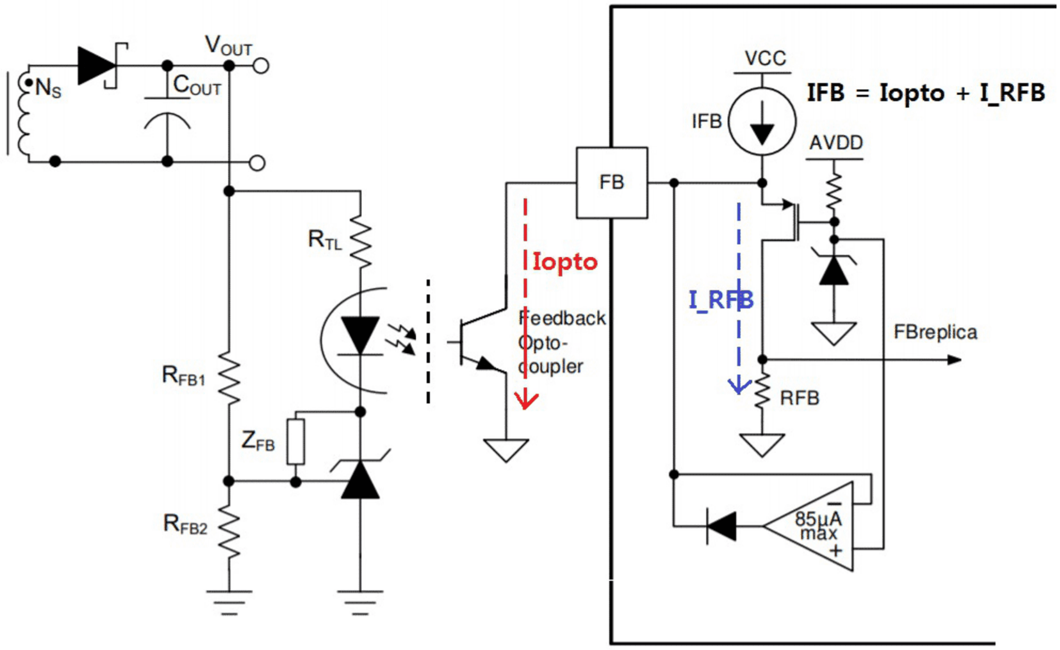

Figure 2-2. Example of UCC25640x (High Side Current Sourcing)

Step 2: High and Narrow variation CTR is essential.

As we focus on linear operation, a tight CTR will correspond to a smaller variation. Also, for higher design accuracy, designers should take ambient temperature, life cycle into account. Each vendor provides the information by the curve such as Relative CTR vs Temp, Operating hour in the data sheet.

Step 3: Users should understand how to bias optocoupler.

There are multiple, widely 4 variations configuration to bias optocoupler. As seen at Step1, we can choose the way depending on controller's requirement and should be able to analyze the circuit. We are not going to look into, but note that it is very easy KVL analysis based on the fact that the base of the photoTR is open (electrically isolated) and it makes the collector current and emitter current equal. Once we determine VDD, we set a proper diode current (IF) and can compute corresponding collector current (Ic).

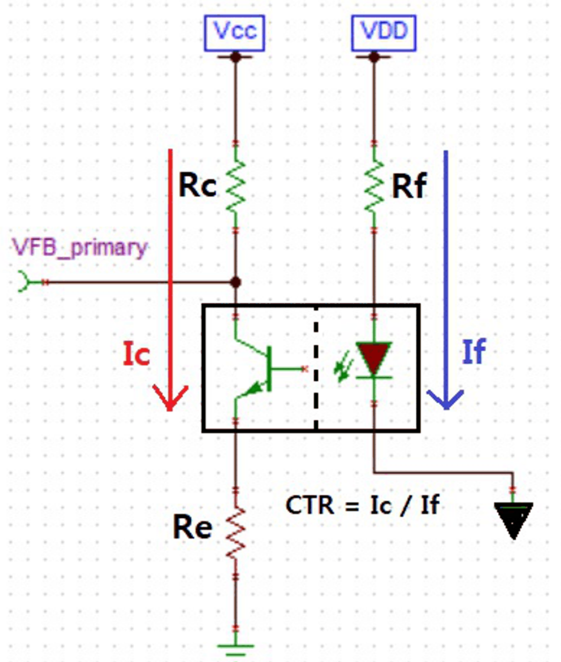

Figure 2-3. One Example of Biasing Optocoupler

2.2 Design Considerations for Biasing Circuit

We now understand how the feedback loop is configured and can categorize the current flow in the loop. Sufficient bias current would make a system stable but we know there are Standard Energy requirements to meet, such as DoE level VI in US and CoC tier 2 in EU. It means designers should take the limitations from total standby power consumption.

Before started, let's take one premise again that system accuracy by variation factors are fixed. We can find electrical parameters have error range and it would result in Vout error, current consumption error etc in the system. Regarding how managing those matters, see the *Designing with the Improved TL431LI* application note. Also, advanced product – ATL43xLI can be biased with lower cathode current (I_{KA}) and provide improved bandwidth compared to TL43x. Regarding the benefits detail, see the *Designing with the ATL431LI in Flyback Converters* application note.

Step 1: Check out standby Iq consumption from two paths, at a given power consumption budget.

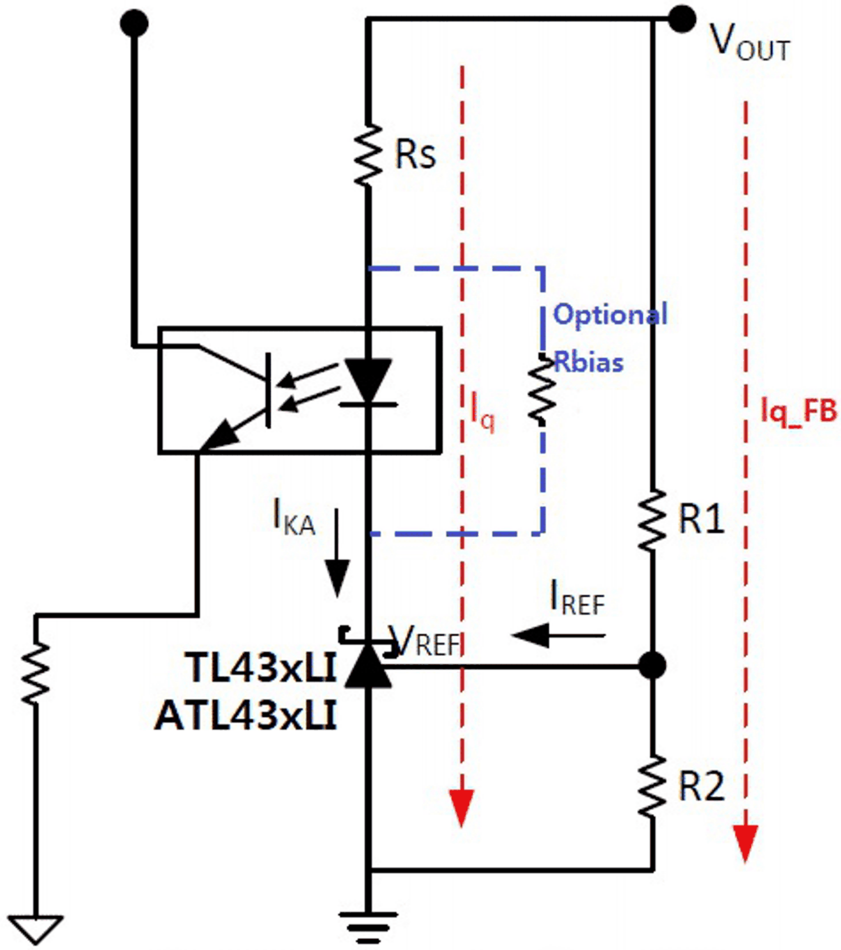

Figure 2-4. Quiescent Current Paths in the Feedback

Step 2: Compute required Rs. The I_{KA} bias current is limited by the value of Rs.

$$-Rs \approx \left(V_{OUT} - V_{OPTNL} - 2\ V\right) / I_{OPTNL}$$
$$\begin{cases} V_{OPTNL} = \text{Optocoupler voltage at No Load condition} \\ I_{OPTNL} = \text{Optocoupler voltage at No Load condition} \end{cases} \quad (1)$$

For further explanation, system designer should set a proper I_{OPTNL} first. We design it close to I_{KA}(min) * 1.5 at worst case which includes a margin. And then, we can find required V_{OPTNL} from the data sheet of optocoupler selected. Generally it will be about 1 V. Lastly, the factor of -2 V comes from the overvoltage condition of Vout. In other words, if we assume a fault situation where VREF much exceed 2.5 V (internal reference) the V_{ka} would drop low to a minimum of around 2 V. It is to compensate the worst case and allow designers to involve the margin into calculation. *Using the TL431 for Undervoltage and Overvoltage Detection* application note discusses the V_{ka} low.

Step 3: Set resistor feedback network

R1, R2 set the output voltage whereas it makes continuous leakage path. It's important to understand allowable current consumption on this node.

$$-R1 = \left(VOUT - VREF\right) / Iq\_FB \quad (2)$$

$$-R2 = VREF / (Iq\_FB - I_{REF}) \quad (3)$$

We might be able to increase the value ratio of R1- R2. However, system designers should consider noise immunity performance from the change and also, Compensation network will refer R1 into configuration.

Note, we will not discuss setting stability by compensation network. For detail information, see the *Compensation Design with TL431 for UCC28600* application note.

2.3 Schematic Analysis and Waveforms

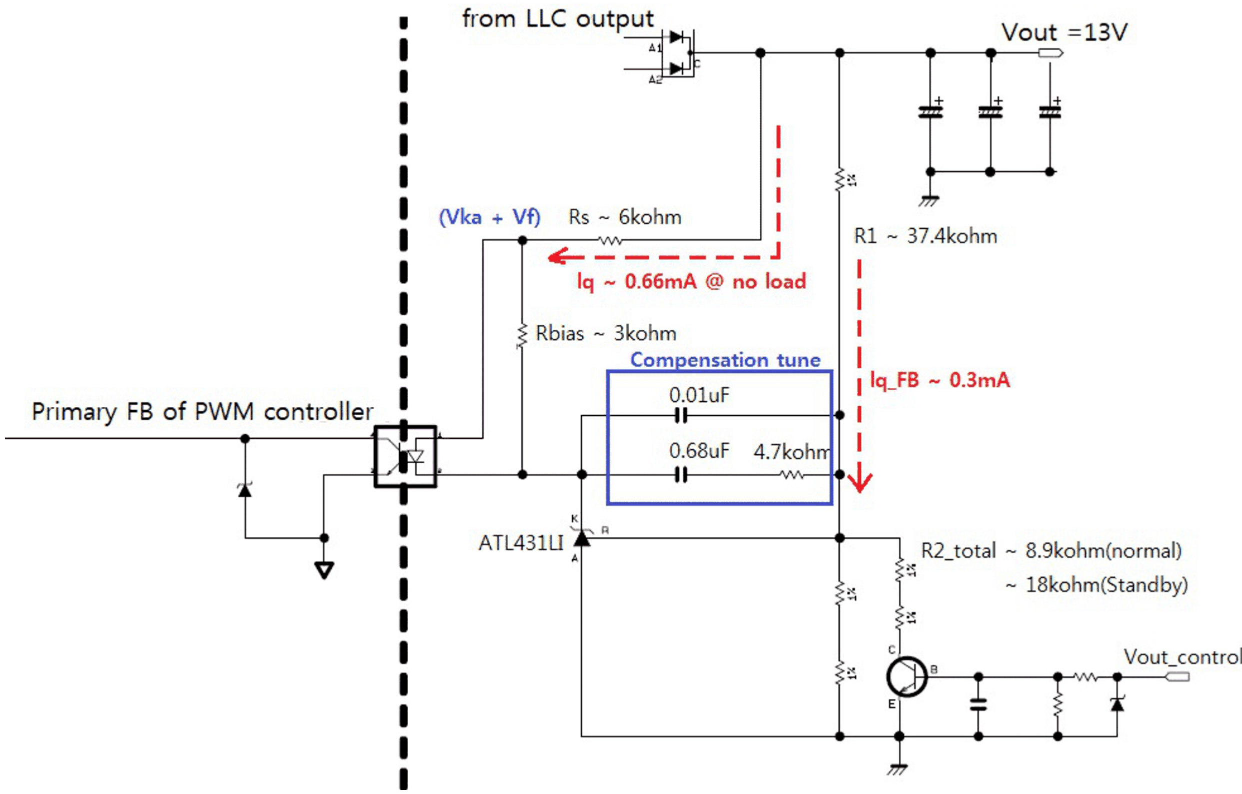

Figure 2-5. ATL431LI Design Review in LLC Schematic

Figure 2-5 shows a good starting value and it tells how much total power consumption in the feedback loop is consumed. We see about 1mA from two quiescent current paths. Probably designer would expect <15mW at beginning. However we still have more room to reduce it based on performance advantages of ATL43xLI. The optional Rbias also can contribute effort to minimize loss in tune. In case of system standby mode, which lowers the Vout level, the amount of consumption would decrease more. Let's define operating behaviors from measured waveforms.

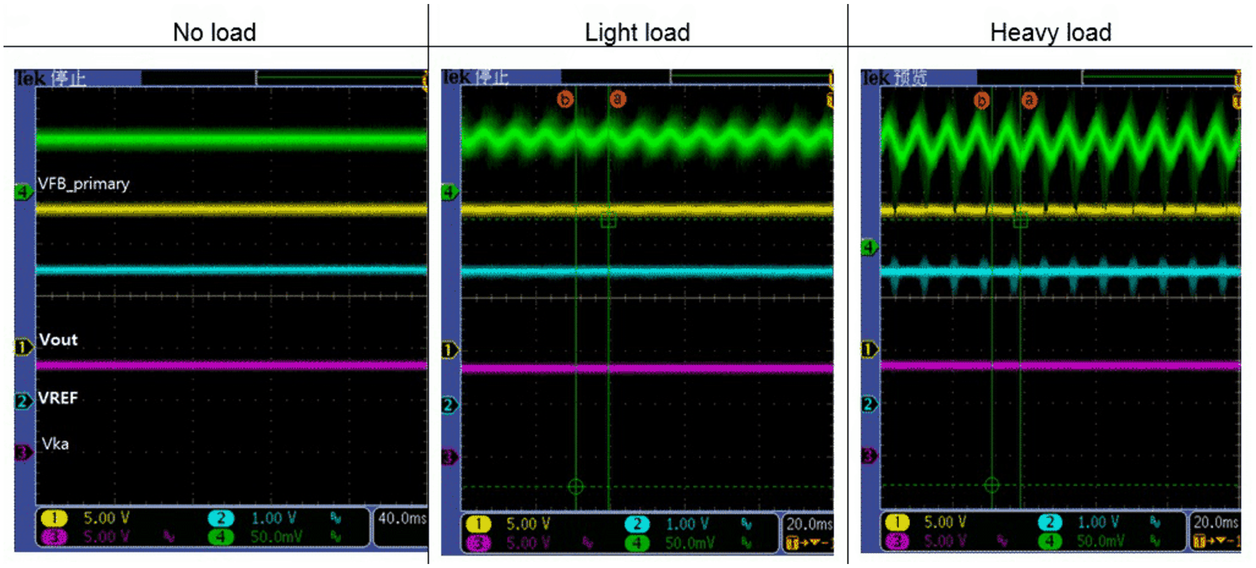

Figure 2-6. No Load, Light Load, and Heavy Load

Table 2-1 will give designers easy understanding to clarify how the system works. And it would request users to refer to block-diagram of shunt regulator. One note is that reflected VFB_primary are fully dependent on how PWM controller handles it. The V_{ka} is an error amplifier signal decided by feedback loop including compensation network and it also varies in a little change according to optocoupler's CTR and configuration of primary side.

Table 2-1. Operation of Vout Regulation by Shunt Regulator

Transient	NPN I_base	NPN I_sink	Vka(cathode)	I_{ka}	I_opto	PWM duty	
REF > VREF	Increased	Increased	Drop	Increased	Increased	Reduced	till VREF > REF
REF < VREF	Decreased	Decreased	Rise	Decreased	Decreased	Expand	till REF > VREF

3 Summary

We discussed step-by-step design procedures for shunt regulator in isolated converter system. And was able to review its basic configuration as error amplifier and how it works in actual operating schematic. System designers should understand Energy regulation requirements of where they release the system to. This application note is to help the way of biasing circuit, control scenario for Vout regulation, especially for those who are not familiar with isolated feedback control.

4 References

- *Using the TL431 in a Power Supply,* Dr. Ray Ridley, Ridley Engineering.
- Texas Instruments, *Designing with the ATL431LI in Flyback Converters* application report.
- Texas Instruments, *Compensation Design with TL431 for UCC28600* application report.
- Texas Instruments, *Setting the Shunt Voltage on an Adjustable Shunt Regulator* application report.
- *Electronicsbeliever.com* design analysis articles.
- Texas Instruments, *Designing with the Improved TL431LI* application report.
- Texas Instruments, *Using the TL431 for Undervoltage and Overvoltage Detection* application report.
- Texas Instruments, *UCC25640x LLC Resonant Controller with Ultra-Low Audible Noise and Standby Power* data sheet.
- Texas Instruments, *UCC28740-Q1 Ultra Low Standby, Flyback Controllerfor Automotive, with Integrated HV Startup and Optocoupler Feedback* data sheet.