Isolated Power Feedback Loop Design with Isolated Amplifier

1 Introduction

As an important element in switching power supply design, error amplifier is used as the output voltage's error signal amplification and generates feedback control based on the error signal. The performance of error amplifier directly affects the output accuracy and transient response of the switching power supply. In the traditional isolated power supply design, usually uses an optocoupler to perform the isolated error signal transmission, as shown in Figure 2. This application note compares the optocoupler-based solution with the isolated amplifier-based solution (CA-IS310x), and discusses the advantages of the CA-IS310x in the isolated switching power supply design, also provides the feedback loop analyses and design suggestions in typical applications.

2 Isolated Power Supply Operation

2.1 Overview

A simplified block diagram of the isolated power supply is shown in Figure 1, which is composed of PWM controller and feedback loop, transformer, power module, input and output network.

In Figure 1, the error amplifier compares the divider voltage of the output Vo with the reference voltage REFOUT2, and amplifies the generated error signal. The amplified signal is sent output via COMP, then drives the controller to generate a PWM control signal whose duty cycle is proportional to the error signal. The PWM control signal put the MOSFET on or off and controls the transformer to transmit energy to secondary side or store energy in the core, to maintain a stable output voltage Vo, also the transformer provides the power isolation between the primary side and the secondary side. To ensure the stability of the isolated power supply feedback loop, the error amplifier usually require type II or type III compensation circuit. This system also includes a signal isolation channel as shown in Figure 1, the error signal needs to be transmitted from the secondary side to the primary side controller through the isolation channel. In the traditional isolated power supply design, usually an optocoupler isolation is used, as shown in Figure 2. However, considering the advantages of isolation amplifier compared with optocoupler, more and more power supply designs begin to select isolation amplifier. Next, we will discuss more details and compare these two isolation technologies.

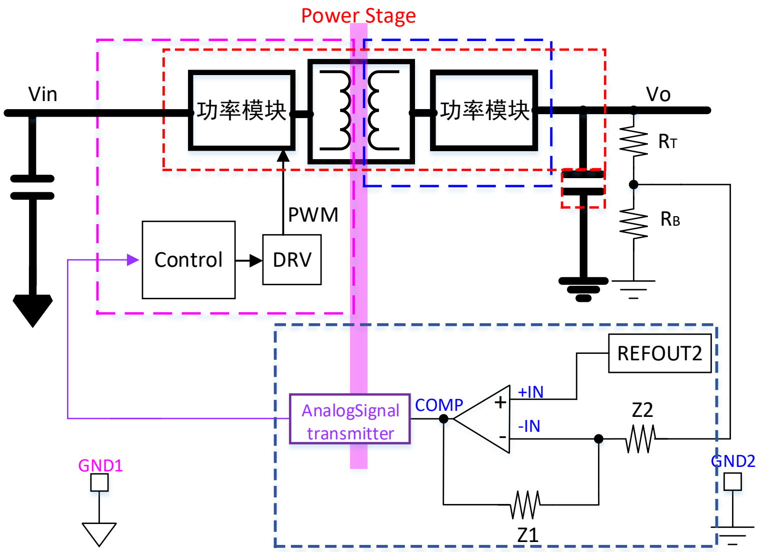

Figure 1. Isolated Power Supply Block Diagram

2.2 Optocoupler-based solution

Figure 2 shows a typical application circuit of optocoupler-based isolated power supply. The two main elements of the voltage feedback circuit are the TL431 shunt regulator and the optocoupler. Several manufacturers produce this reference part, and it comes in various grades of accuracy. The internal reference voltage of the shunt regulator is 2.5V typical. An external voltage divider is used, and it consists of R_T, R_B for the regulated output voltage V_{OUT} setup. This feedback-circuit configuration is very common in the traditional switching power supplies and is used widely. This circuit has two feedback paths from the output. One path is through the shunt regulator, providing the low-frequency gain for good output-voltage regulation, whereas the second path is through the optocoupler itself to the cathode terminal of the shunt regulator. To visualize this latter loop, it suffices to replace the shunt regulator with a virtual constant voltage source. In this arrangement, any increase in output voltage will result in a higher current i_1 flowing through the LED of the optocoupler, and increase i_2 on the primary side, forcing the collector voltage of the coupled phototransistor to fall and thus reduce the duty cycle. This results in a negative feedback loop that has the tendency to keep the output voltage constant. Therefore, care must be exercised when trying to stabilize this loop. R_C, C_C can be used for the loop compensation. The easiest method is to rely on the ESR of the output capacitors for proper compensation of this latter feedback path. However, this puts a constraint on the minimum value of the ESR, in order to get the required ripple at the output, one or more capacitors may have to be paralleled at output network.

Since a minimum operating current must be provided for the optocoupler, in Figure 2, R1 resistance can not be too large as the current limiting control. The maximum value is dependent on the minimum operating current. So the optocoupler isolation solution needs to consume more power in the system.

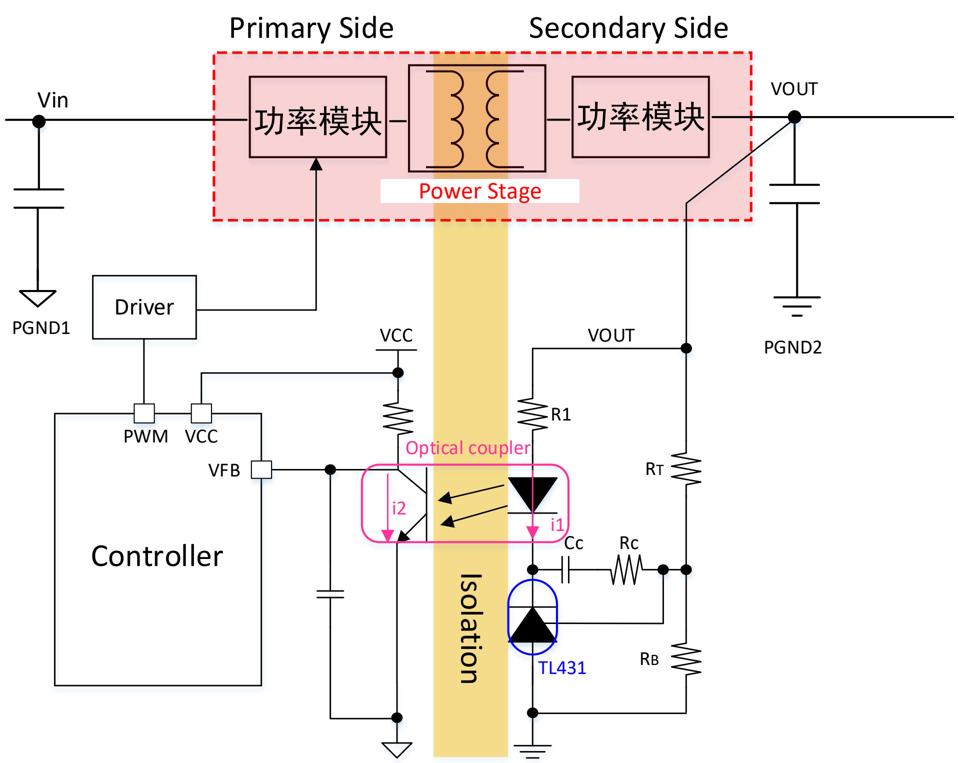

Figure 2. Block Diagram of the Optocoupler-based Isolated Power Supply

2.3 Isolated amplifier-based solution

Figure 3 sows the isolated op amp-based solution. In Figure 3, the CA-IS3101/CA-IS3102 isolated amplifier is used as the error amplifier for the feedback of the output voltage V_O, to regulate the output voltage, using a resistor divider to the inverting −IN pin of the amplifier to setup the output voltage. This configuration inverts the output signal at the COMP pin when compared to the amplifier's noninverting input +IN pin, which is connected to the internal 1.225 V reference (REFOUT2). For example, when the output voltage, falls due to a load step or other reasons, the divider voltage at the −IN pin falls below the +IN reference voltage, causing the COMP pin output signal increased. The COMP output is modulated as OOK, and then demodulated on the primary side by the capacitive isolator, recover to an increased analog output at EAOUT/EAOUT2 or IOUT. The output of the CA-IS310x drives the feedback input of the PWM controller to produce a PWM duty cycle output. This PWM duty cycle output drives the power stage to increase the V_O voltage until it returns to the regulated level. Also, the amplifier output COMP and inverting −IN pins are used to attach resistor and capacitor components (Z1, Z2) in a compensation network. The CA-IS310x devices are compatible with Type I, Type II or Type III compensation networks, calculating compensation components based on the application requirements and ensure the feedback loop stability.

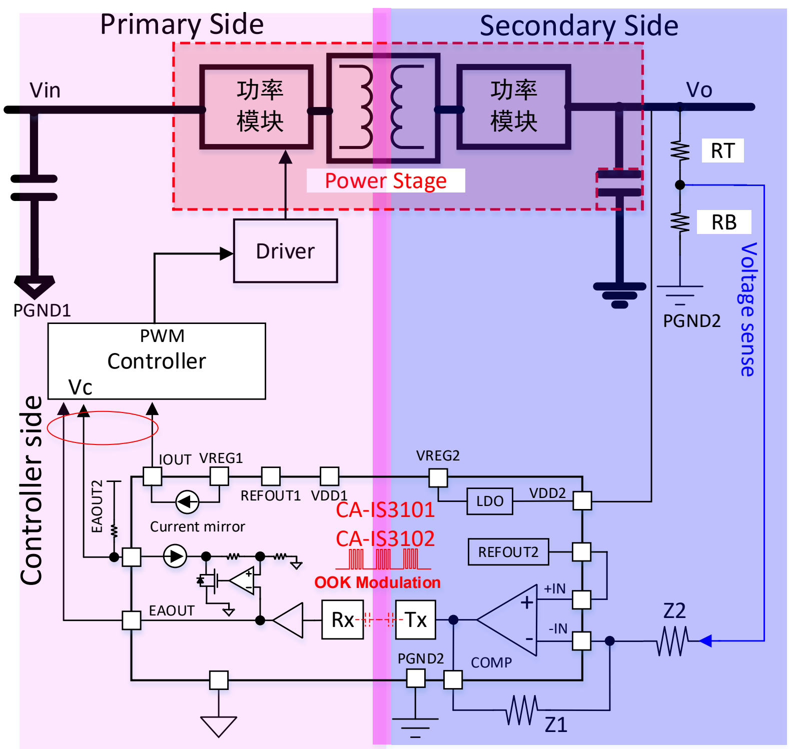

Figure 3. Block Diagram of the Isolated Power Supply with Isolated Amplifier

2.4 Optocoupler-based solution vs. isolated amplifier-based solution

Unlike optocoupler-based solutions, which have an uncertain current transfer ratio over lifetime and wide temperature range, the CA-IS310x isolated amplifier transfer function does not change over the lifetime and is stable over −40°C to +125°C wide temperature range. Table 1 shows the comparison between "optocoupler + TL431" solution and the CA-IS3101/CA-IS3102 solution. Also, the CA-IS310x devices feature wideband operation, can be used for a variety of power supply loop compensation techniques. These isolated error amplifiers are fast enough to allow a feedback loop to react to fast transient conditions and overcurrent conditions. Also offer a high accuracy 1.225V reference to compare with the supply output set-point, it helps to improve the output stability and reduce the external components.

Table 1. Capacitive Isolation vs. Optocoupler

Features	CA-IS310x	TL431 + Opto
Insulation barrier	SiO_2	Opto
Voltage Reference: Stability	High	Low
Voltage Reference: Accuracy	<1%	< 2%
Operating Temperature Range	-40°C ~ 125°C	< 85°C
Bandwidth	400kHz	< 80kHz
Response Speed	Fast (< 0.5µs)	Slow (~ 5µs)
Gain Stability	Stable	Short because of Light attenuation
Power Consumption	Low	High
Life Time	> 40years	Short
Design Complexity	Simple	Complex, lot of external components

3 Isolated Op Amplifier Compensation Design

3.1 EAOUT/EAOUT2 output control

When the isolated operational amplifier is used in the isolated power supply feedback loop, the compensation design for the error amplifier is a key factor to ensure the system operation normally. Z1 and Z2 in Figure 4 compose the compensation network of CA-IS310x. The transfer function from FB to comp is as below,

$$\mathrm{Gain(s)} = -\frac{\mathrm{Z1(s)}}{\mathrm{Z2(s)}}$$

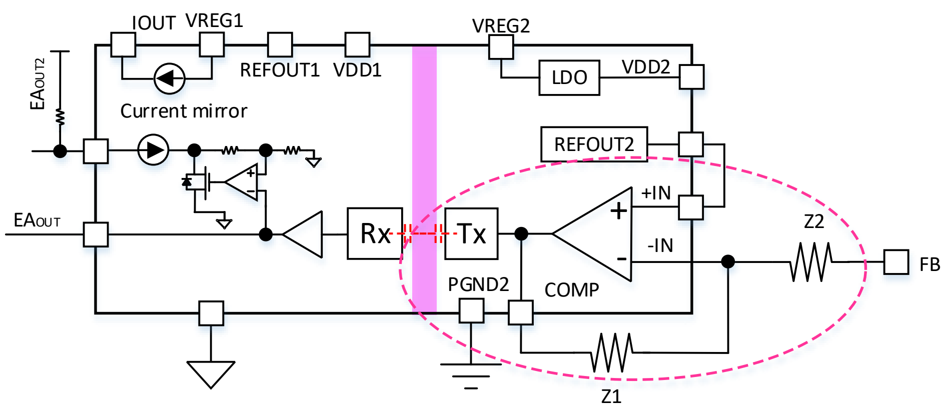

Figure 4. Loop Compensation for the CA-IS310x Isolated Error Amplifier

Changing Z1 and Z2 resistor/capacitor networks, get different compensation circuits. The CA-IS310x devices employ a high-bandwidth error amplifier. This op-amp voltage-error amplifier can work with type I, type II or type III compensation to fully utilize the bandwidth of the high-frequency switching to obtain fast transient response, see Figure 5 to Figure 8 for the compensation circuits for the CA-IS310x.

Figure 5 sows the Type I compensation circuit. Type I compensation possesses one pole and one zero, frequency locations are given as follows:

$$f_{P1}=0\mathrm{Hz},\ f_{Z1}=\frac{1}{2\pi R1*C1};\quad \mathrm{Gain\_Comp(s)} = \frac{1+R1*C1*s}{s*C1*R2}$$

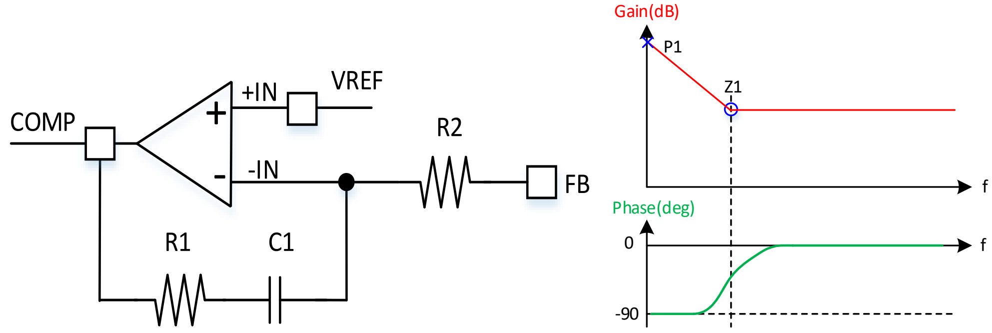

Figure 5. Type I Compensation Network and Frequency Response

Figure 6 sows the Type II compensation circuit. It has a double pole and one zero. The double pole and zero frequencies are given as follows:

$$f_{P1} = 0Hz,\ f_{Z1} = \frac{1}{2\pi R1*C1},\ f_{P2} = \frac{1}{2\pi R1*C2},\ C2<<C1;$$

$$Gain\_Comp(s) = \frac{1+R1*C1*s}{s*R2(C1+C2)*(1+s*\frac{C1*C2}{C1+C2}*R1)},\ s = 2*\pi*f*j$$

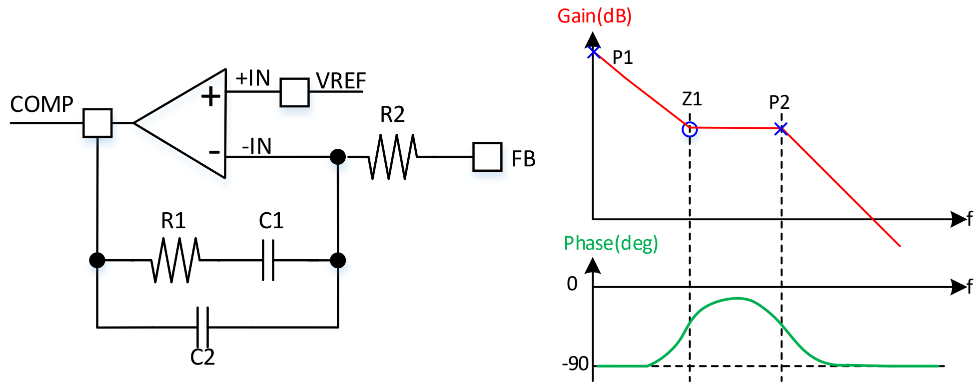

Figure 6. Type II Compensation Network and Frequency Response

The Type III compensation circuit is shown in Figure 7 and Figure 8, the transfer function consists of three poles and one double zero introduced by the resistors (R1/R2/R3) and capacitors(C1/C2/C3):

$$f_{P1}=0Hz,\ f_{Z1} = \frac{1}{2\pi R1*C1},\ f_{Z2} = \frac{1}{2\pi(R2+R3)*C3};\ f_{P2} = \frac{1}{2\pi R1*(\frac{C1*C2}{C1+C2})},\ f_{P3} = \frac{1}{2\pi R3*C3},\ C2<<C1。$$

$$Gain\_Comp(s) = \frac{R3+R2}{R2*R3*C2} * \frac{1+R1*C1*s}{s*(s+\frac{C1+C2}{R1*C1*C2})} * \frac{s+\frac{1}{C3*(R2+R3)}}{s+\frac{1}{C3*R3}},\ s = 2*\pi*f*j$$

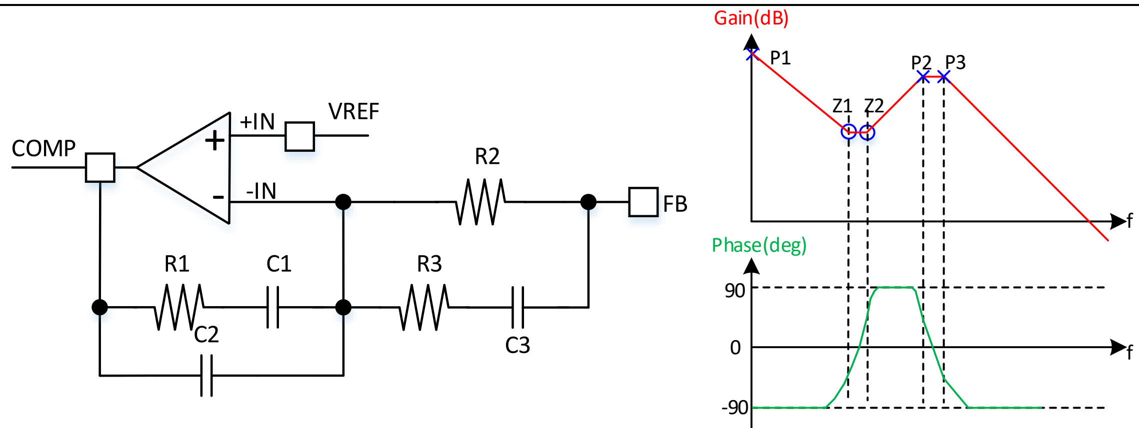

Figure 1. Type III Compensation Network and Frequency Response (1)

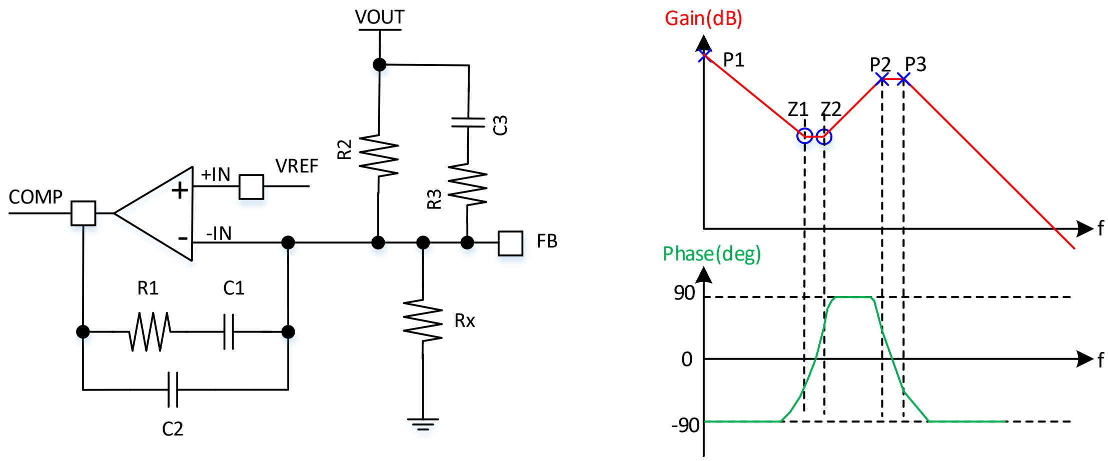

Figure 8. Type III Compensation Network and Frequency Response (2)

The 400 kHz bandwidth of the CA-IS310x error amplifier output offers faster loop response for better transient response than the typical shunt regulator and optocoupler solution, and allow the PWM controller to operate at high switching speeds. However, to enable smaller values for the output filter components, the DC-DC converter has to operate at higher switching frequency. In this case, need to consider of the CA-IS310x's -3dB bandwidth from COMP to EAOUT/EAOUT2. This frequency response must be added to the compensation loop when calculating the loop components, see Figure 9.

$$\text{Gain\_op}(s) = \frac{1}{1+\frac{s}{400000*2*\pi}}, \quad s = 2*\pi*f*j$$

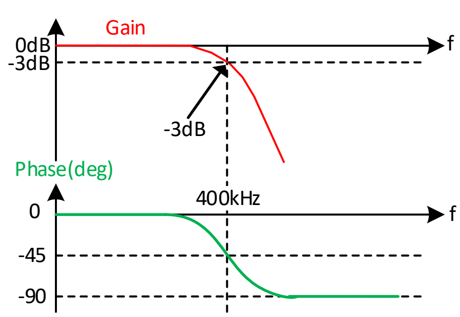

Figure 9. Error Amplifier Frequency Response

From the output VOUT to the compensation input FB, the common feedback network is shown in Figure 10, in which the transfer function of the circuit on the left is H(s)=1; and the transfer function of the circuit on the right is $H(s) = \frac{RB}{RB+RT}$.

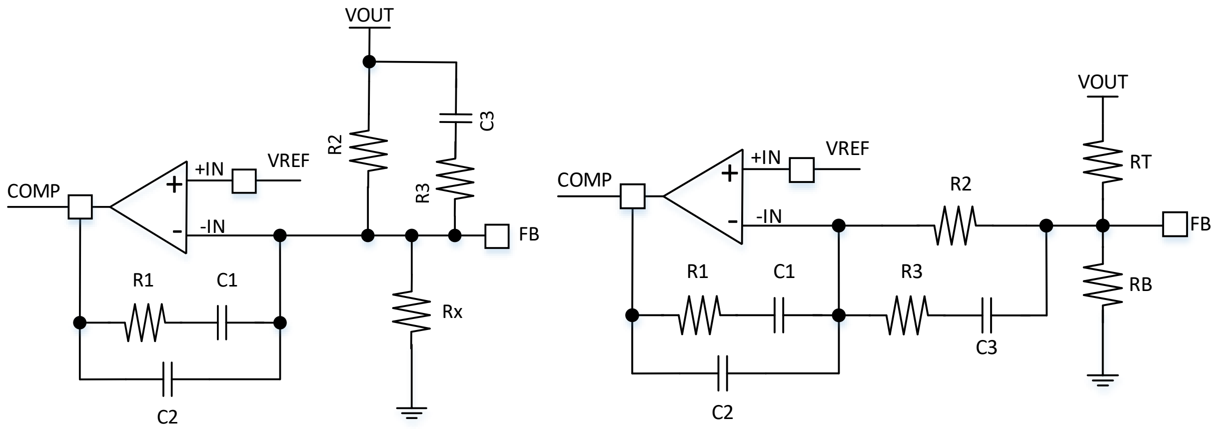

Figure 10. Two Types of Feedback Network

Then, from VOUT to EAOUT, the signal transfer function is given as below,

$$\text{Gain\_total\_1(s)} = \text{Gain\_op(s)} * \text{Gain\_Comp(s)} * \text{H(s)};$$

From VOUT to EAOUT2, the signal transfer function is given as,

$$\text{Gain\_total\_2(s)} = 2.6 * \text{Gain\_op(s)} * \text{Gain\_Comp(s)} * \text{H(s)}$$

Combined with the above calculation and the transfer function of the power stage, the frequency response characteristics and compensation components of the whole system loop can be calculated.

3.2 IOUT Control

The CA-IS3101/CA-IS3102 features a current output IOUT. IOUT is the mirror current of EAOUT2, it can be used to drive COMP pin of the PWM controller as the replacement of optocoupler transistor, see Figure 11.

In Figure 11, $Ix = \frac{VDD-EAOUT2}{Rx}$; $IOUT = \frac{VDD-EAOUT2}{Rx} * 2 - 40(uA)$

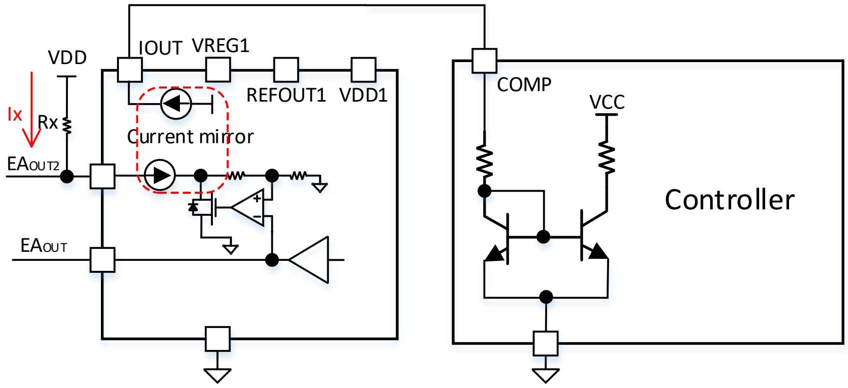

Figure 11. IOUT Control

Thus, the current signal transfer function from EAOUT2 to IOUT can be calculated as: $\mathrm{Gm\_vi(s)} = -\frac{2}{\mathrm{Rx}}$; The overall small signal transfer function from the power supply output voltage VOUT to IOUT is as below,

$$\mathrm{Gain\_total\_3(s)} = 2.6 * \mathrm{Gain\_op(s)} * \mathrm{Gain\_Comp(s)} * \mathrm{H(s)} * \mathrm{Gm\_vi(s)}$$

4 Conclusion

This article discusses the application of CA-IS3101/CA-IS3102 in the design of isolated power supply, analyzes several common compensation networks for the isolated error amplifier, and provide the transfer functions for the different compensation networks.

5 Revision History

Revision Number	Description	Page Changed	Revision Date
Version 1.00	**Initial version**	All	Dec. 2021
Version 1.01	Updated Figure 1 and Description for each Sections.	N/A	2022-01-18

6 Important Statement

The above information is for reference only and used for helping Chipanalog customers with design, research and development. Chipanalog reserves the rights to change the above information due to technological innovation without advance notice.

All Chipanalog products pass ex-factory test. As for specific practical applications, customers need to be responsible for evaluating and determining whether the products are applicable or not by themselves. Chipanalog's authorization for customers to use the resources are only limited to development of the related applications of the Chipanalog products. In addition to this, the resources cannot be copied or shown, and Chipanalog is not responsible for any claims, compensations, costs, losses, liabilities and the like arising from the use of the resources.

Trademark information

Chipanalog Inc.® and Chipanalog® are registered trademarks of Chipanalog.

http://www.chipanalog.com