

Practical Feedback Loop Design Considerations for Flyback Converter Using UCC28740

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ABSTRACT

The flyback converter is the isolated version of the buck-boost converter. The circuit that has become very widespread is where the TL431 is used in conjunction with an optocoupler to provide feedback loop isolation. Although the TL431 is advertised as a transconductance amplifier, it can be used as a standard Type II error amplifier if it is connected properly. The TL431 and an optocoupler play an important role for stable feedback and control loop, and this application report describes the design considerations to make the entire loop stable for achieving proper operations on flyback converter.

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1 Introduction

The flyback converter represents very popular structure found in the market due to its simplicity, ease of design and low cost. And, the flyback operated in current mode is the most widely used converter having first-order behavior in the low-frequency portion. The UCC28740 is a flyback power-supply controller which combines frequency with primary peak-current amplitude modulation to provide high conversion efficiency across the load range.

Figure 1 shows the typical application circuit of the UCC28740. The circuit that has become very widespread is where the TL431 is used in conjunction with an optocoupler to provide feedback loop isolation. Note that several of the components including the TL431, an optocoupler, C_{FB} , C_{FB3} , R_{TL} , R_{FB3} and R_{FB4} are involved in making the loop stable. In this circuit, the output of the TL431 is powered through the resistor R_{TL} and the optocoupler diode, connected in series with the power supply output.

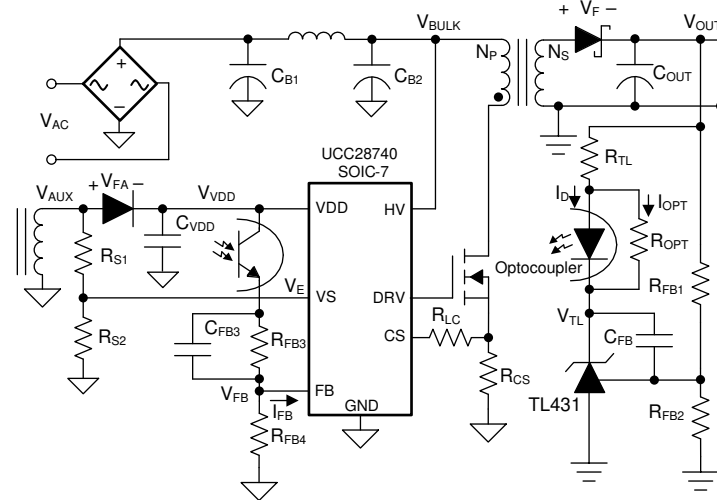


Figure 1. Typical Application Circuit of the UCC28740

The main effect is that the gain of the circuit is now driven by the current into the output of the TL431, not by its output voltage. This current is determined by the voltage gain of the TL431, the supply voltage to the top of R_{TL} and the value of R_{TL} itself.

2 Design Considerations for the Stability

Figure 2 shows the schematic highlighting elements around the TL431 and an optocoupler. At low frequencies, the gain of the TL431 amplifier acts like an integrator with feedback capacitor C_{FB} and resistor R_{FB1} . And, resistor R_{FB2} provides the correct DC regulation level, but due to the virtual ground at the input of the error amplifier, it does not appear in any of the gain equations.

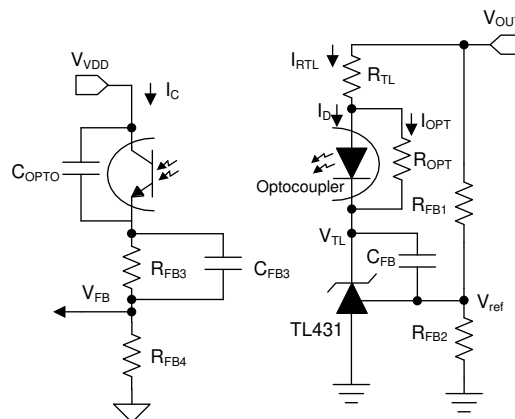


Figure 2. Main Feedback and Control Loop

At mid frequency, the gain of the integrator around the TL431 amplifier reaches unity, and beyond this point, the output voltage signal from the amplifier is attenuated. However, there is always gain from the output voltage to optocoupler diode current due to the connection of the resistor R_{TL} to the power supply output, this is the dominant feedback path in the midband frequencies.

Figure 3 shows the open loop voltage gains of the TL431A (SOT23-3 Package) with different bias conditions, and it's important to choose a proper pullup resistor since the gain of the TL431A is significantly changed by the pullup resistor. The value of this resistor must be chosen to provide sufficient bias current to the cathode of the TL431A under all operating conditions. Also, notice that the output of the TL431A must be kept above a minimum value required to provide the bias.

Voltage loop stability compensation is applied at the shunt-regulator which drives the opto-coupled feedback signal. The tolerances chosen for the shunt-regulator reference and the sense resistors determine the regulation accuracy.

The TL431A usually requires a minimum bias current of 1 mA to maintain regulation accuracy. Together with the UCC28740 primary-side controller, careful biasing is important to meet standby power loss requirements. The output voltage (V_{OUT}) is set with a resistor divider by R_{FB1} and R_{FB2} , and it is recommended to use 1% tolerance or better divider resistors. To improve efficiency at light loads consider using larger value resistors. However, if the values are too high, the converter is more susceptible to noise and voltage errors from the V_{ref} input current are noticeable.

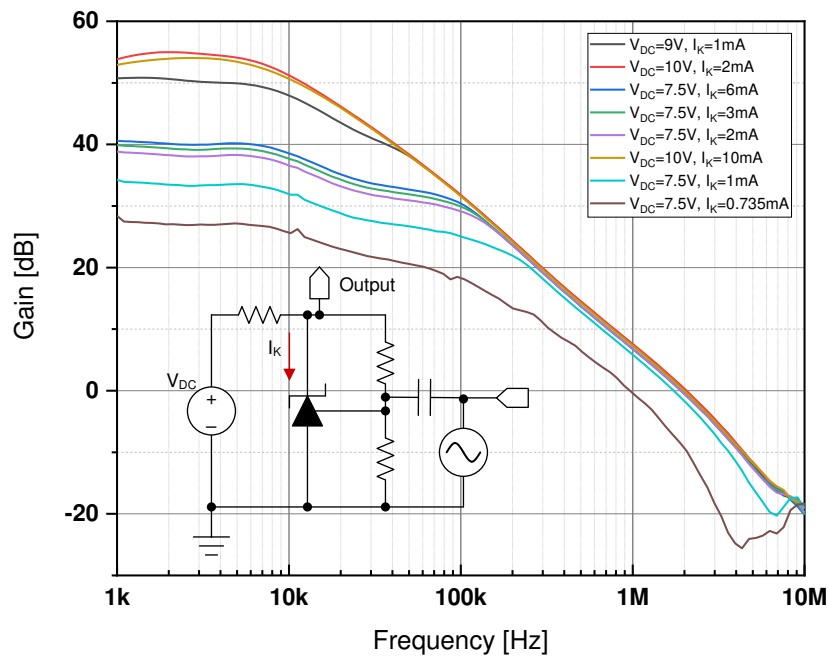


Figure 3. AC Test Results of the TL431A with Different Bias Conditions

Figure 4 shows the way the optocoupler can be wired to unveil its pole position. The optocoupler chosen for the EVM (Evaluation Module) design is a LTV-817A of Lite-on, and the V2 source fixes the DC operation point of this common-emitter configuration. For the proper frequency response measurement, 3-kΩ resistor (R2) is used for the DC bias until the collector of the optocoupler measured around 2.5 V, and this is to ensure enough voltage dynamics when the AC sweep will begin. A similar resistor value (15 kΩ) is used for the both R_{pullup} and R1 to bring the low frequency AC gain to the CTR value in this case.

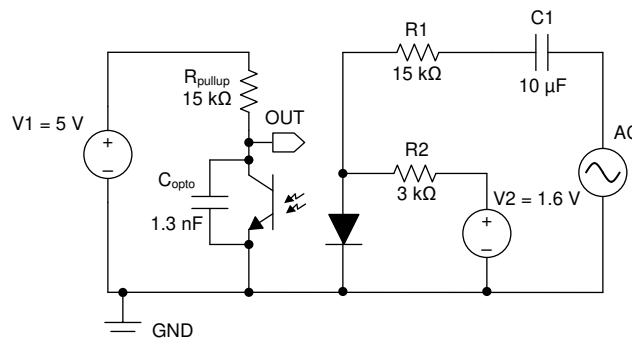


Figure 4. Optocoupler Frequency Response Analysis Test Circuit

The transfer function for this optocoupler frequency response circuit is obtained by calculating the impedance offered by the network placed in the optocoupler diode path, CTR and the common-emitter configuration with R_{pullup} and C_{opto} .

$$H(s) = \frac{V_{out}(s)}{V_{ac}(s)} = - \frac{CTR \times C1 \times R2 \times R_{pullup} \times s}{(R1 + R2) \times C_{opto} \times C1 \times R_{pullup} \times s^2 + (C_{opto} \times R_{pullup} + C1 \times R2 + C1 \times R1) \times s + 1} \quad (1)$$

Developing and arranging Equation 1:

$$H(s) = - \frac{CTR \times C1 \times R2 \times R_{pullup}}{(R1 + R2) \times C_{opto} \times C1 \times R_{pullup}} \times \frac{s}{s^2 + \frac{C_{opto} \times R_{pullup} + C1 \times R1 + C1 \times R2}{(R1 + R2) \times C_{opto} \times C1 \times R_{pullup}} \times s + \frac{1}{(R1 + R2) \times C_{opto} \times C1 \times R_{pullup}}} \quad (2)$$

Factoring and rearranging Equation 2, we have:

$$H(s) = - CTR \times C1 \times R2 \times R_{pullup} \times \frac{s}{(C_{opto} \times R_{pullup} \times s + 1) \times ((R1 + R2) \times C1 \times s + 1)} \quad (3)$$

The locations of the poles are:

$$f_{p1(opto)} = \frac{1}{2 \times \pi \times (R1 + R2) \times C1} = 0.88 \text{ Hz} \quad (4)$$

$$f_{p2(opto)} = \frac{1}{2 \times \pi \times C_{opto} \times R_{pullup}} = 8.12 \text{ kHz} \quad (5)$$

When the optocoupler is connected to FB pin of the UCC28740, it will introduce a pole ($f_{p2(opto)}$) due to C_{opto} coupling with the pull-up resistor (or the pull down in a common-collector configuration). $f_{p2(opto)}$ will affect the total system stability, and the contribution of C_{opto} should be considered for the stable operation. Also, note that changing the DC operating point (different V_{ce} of the optocoupler) does not affect the pole position. Figure 5 shows the frequency response of LTV-817A (Lite-on) optocoupler, and $f_{p2(opto)}$ measured to be 8.12 kHz at -3 dB gain attenuation as it is calculated in Equation 5.

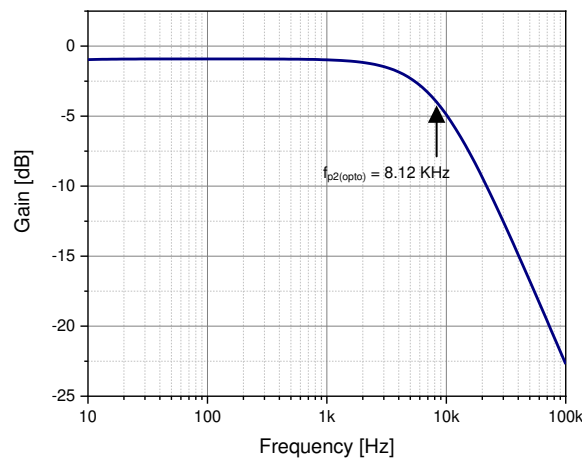


Figure 5. Frequency Response of LTV-817A Optocoupler

A capacitor (C_p) can be added in parallel with the optocoupler in the primary side to adjust the location of $f_{p2(opto)}$. When the optocoupler capacitor couples to a capacitor (C_p), the new pole is shifted to

$$f_{p2(opto,Cp)} = \frac{1}{2 \times \pi \times (C_{opto} + C_p) \times R_{pullup}} \quad (6)$$

Therefore, once a capacitor (C_p) is known, it is needed to calculate the new pole frequency, and the new pole frequency will be lower compared to $f_{p2(opto)}$ with this approach. The solution is to explore a new pole for the proper gain and phase margins.

The control law of the UCC28740 combines frequency with primary peak-current amplitude modulation and provides a wide dynamic operating range of output power which allows the power supply designer to easily achieve less than 30 mW standby power dissipation using a standard shunt-regulator and optocoupler. For a target of less than 10 mW standby power, careful loss-management design with a low power regulator and high CTR optocoupler is required.

In [Figure 2](#), the transfer function from V_{TL} to V_{FB} is obtained by calculating the impedance offered by the network placed in the optocoupler diode path on the primary side with CTR.

$$H(s) = \frac{V_{FB}(s)}{V_{TL}(s)} = \frac{C_{FB3} \times CTR \times R_{FB3} \times R_{FB4} \times s + CTR \times R_{FB4}}{C_{FB3} \times C_{opto} \times R_{FB3} \times R_{FB4} \times s^2 + (C_{FB3} \times R_{FB3} + C_{opto} \times R_{FB3} + C_{opto} \times R_{FB4}) \times s + 1} \quad (7)$$

The location of the zero is determined by:

$$C_{FB3} \times CTR \times R_{FB3} \times R_{FB4} \times s + CTR \times R_{FB4} = 0 \quad (8)$$

f_z can be extracted from [Equation 8](#) to obtain (considering $C_{FB3}=47$ nF, $R_{FB3}=196$ k Ω , $R_{FB4}=22$ k Ω)

$$f_z = \frac{CTR \times R_{FB4}}{2 \times \pi \times C_{FB3} \times CTR \times R_{FB3} \times R_{FB4}} = 17.28 \text{ Hz} \quad (9)$$

Also, the locations of the first pole and the second pole are determined by:

$$C_{FB3} \times C_{opto} \times R_{FB3} \times R_{FB4} \times s^2 + (C_{FB3} \times R_{FB3} + C_{opto} \times R_{FB3} + C_{opto} \times R_{FB4}) \times s + 1 = 0 \quad (10)$$

f_{p1} and f_{p2} can be extracted from [Equation 10](#) (considering $C_{opto}=1.3$ nF)

$$f_{p1} = \frac{105.62 \text{ Hz}}{2 \times \pi} = 16.81 \text{ Hz} \quad (11)$$

$$f_{p2} = \frac{35.94 \text{ kHz}}{2 \times \pi} = 5.72 \text{ kHz} \quad (12)$$

Since the location of the both f_z and f_{p1} is about 17 Hz as shown in [Equation 9](#) and [Equation 11](#), f_{p2} plays the role of the dominant pole in the system. To make the system stable, the crossover frequency should be less than f_{p2} . If f_{p2} is less than the crossover frequency, the gain falls at a rate of -40 dB/decade, and the system will be unstable in this case.

3 Experimental Results

The components including C_{opto} , C_{FB3} , R_{FB3} and R_{FB4} are important to determine the dominant pole position properly, and the value of R_{FB4} is usually in the range from 10 k Ω to 100 k Ω . A tradeoff must be made between a lower value for faster transient response and a higher value for lower standby power

[Figure 6](#) shows the loop gain and the phase margin of applying C_{FB3} , R_{FB3} , R_{FB4} , C_{opto} values to a flyback converter example. And, the UCC28740 EVM-525 is used for this measurement. As shown in [Figure 6](#), the crossover frequency, with a 110 V_{AC}, 60 Hz input and load current of 1 A, is limited to about 1.5 kHz passing it through with -1 gain slope (-20 dB/decade), and the phase margin measured to be 70 degrees at this crossover frequency. The actual location of the dominant pole (f_{p2}) is about 5.72 kHz as it is already calculated in [Equation 12](#).

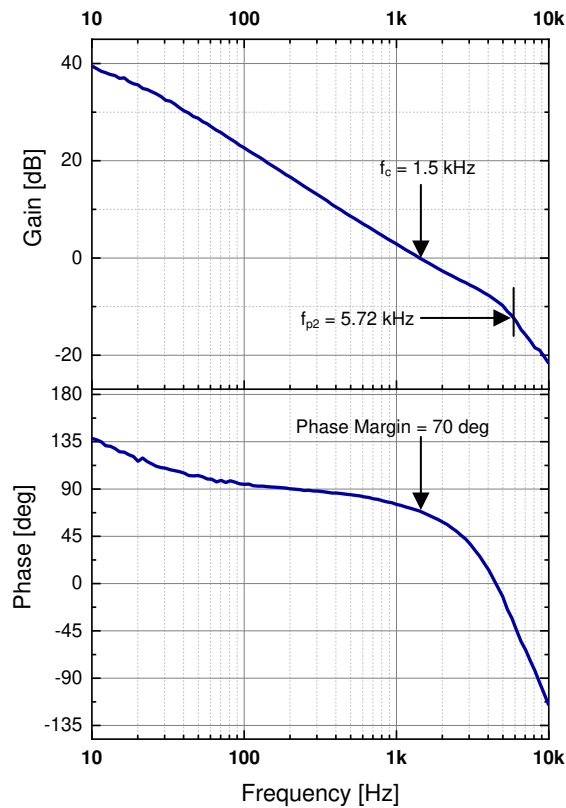


Figure 6. Loop Gain and Phase Margin

The gain drops off rapidly with -2 gain slope (-40 dB/decade) after this pole frequency, and the gain margin measured to be -8 dB when the phase is zero degrees.

4 Summary

The TL431 and an optocoupler play an important role for the stable feedback and control loop. The open loop gain of the TL431 is significantly changed by the pullup resistor, and the value of this resistor must be chosen to provide sufficient bias current to the cathode of the TL431 under all operating conditions. When the optocoupler is connected to FB pin of the UCC28740, it will introduce a pole ($f_{p2(\text{opto})}$) due to C_{opto} . $f_{p2(\text{opto})}$ will affect the total system stability, and the contribution of C_{opto} should be considered for the stable operation. The components including C_{opto} , C_{FB3} , R_{FB3} and R_{FB4} are important to determine the dominant pole position (f_{p2}) properly, and f_{p2} is calculated applying these components in this application report. The location of f_{p2} has been confirmed by measuring the loop gain and the phase margin using the UCC28740 EVM-525.

5 References

- Texas Instruments, [UCC28740 Constant-Voltage Constant-Current Flyback Controller Using Optocoupled Feedback Data Sheet](#)
- Texas Instruments, [UCC28740, Using the UCC28740EVM-525 10 W Constant-Voltage, Constant-Current Charger Adaptor Module, User Guide](#)
- Texas Instruments, [TL431A Precision Programmable Data Sheet](#)

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