Application Report
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Design a Flybuck Solution With Optocoupler to Improve Regulation Performance

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ABSTRACT

This paper presents an isolated flybuck design with synchronous buck regulator LM5160 using optocoupler for better regulation performance. Compared with typical isolated flyback solution, flybuck topology has outstanding features like higher frequency, smaller solution size, and better efficiency. Higher performance and reliability requires better input and load regulation. For typical flybuck design, the isolated output voltage is only controlled by primary output voltage and transformer. Therefore the input and load regulation cannot be ensured. Aiming at this, an optocoupler is added into the design as compensation to improve regulation performance. This paper includes application design and test results.

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1 Introduction

The LM5160 device is a 65-V, 1.5-A synchronous, COT control mode, step-down converter with integrated high- and low-side MOSFETs. The LM5160 can be applied in numerous end equipment systems requiring efficient step-down regulation. Flybuck solution is also a typical application for this device.

Compared with traditional isolated flyback solution, flybuck topology has outstanding features like higher frequency, smaller solution size, and better efficiency. In this kind of primary-side control, the secondary regulation is affected by the leakage inductance, diode drop, DCR, and so forth. Thus the flybuck solution results in poor regulation, especially in wide VIN, high IOUT application. Higher performance and reliability requires better input and load regulation. To improve regulation performance, an optocoupler is added into the design as compensation to increase regulation performance. This paper provides the application design and test result using the LM5160 with optocoupler.

2 Design Flybuck With LM5160

We start the design with a typical flybuck circuit using synchronous buck regulator LM5160, and calculate the component values. Table 1 is the design specification for the example. Figure 1 shows the LM5160 flybuck solution.

Table 1. Design Specification

Design Specifications	
Input voltage range (V_{IN})	33 V to 57 V
Isolated output voltage (V_{OUT2})	12 V
Primary load current (I_{OUT1})	0 A
Isolated load current (I_{OUT2})	1 A
Switching frequency (f)	340 kHz

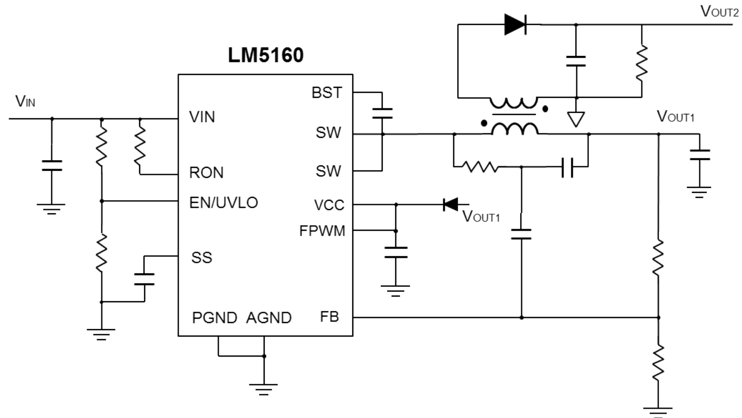

Figure 1. LM5160 Flybuck Solution

2.1 Selection of Primary Voltage and Turns Ratio

The primary output voltage in a flybuck converter should be no more than half of the minimum input voltage. For a minimum V_{IN} of 33 V, the primary output voltage (V_{OUT1}) should be less than 16 V. In this design, a transformer turns ratio (N_1:N_2) of 1:1 is selected. Using this turns ration, the primary output voltage V_{OUT1} is calculated to be:

$$V_{OUT1} = \frac{V_{OUT2} + 0.7\ V}{1} = 12.7\ V \qquad (1)$$

The 0.7 V subtracted from represents the forward voltage drop of the secondary rectifier diode.

2.2 Feedback Resistor

With the required primary output voltage set point at 12.7 V and V_{FB} = 2 V (typical), this parameter is selected by the user. V_{OUT1} is calculated as follows:

$$V_{OUT1} = V_{FB} \times \left(1 + \frac{R_{FB2}}{R_{FB1}}\right) \qquad (2)$$

Choose R_{FB1}=1.91 kΩ.

$$R_{FB2} = R_{FB1} \times \left(\frac{V_{OUT1}}{V_{FB}} - 1\right) = 10.2\ k\Omega \qquad (3)$$

Choose R_{FB2}=10 kΩ.

2.3 Secondary Rectifier Diode

The secondary rectifier diode must block the maximum input voltage multiplied by the transformer turns ratio. Equation 4 gives the minimum diode reverse voltage rating.

$$V_{R(diode)} = V_{IN(MAX)} \times \frac{N_2}{N_1} + V_{OUT2} = 69\ V \qquad (4)$$

Considering the margin and the voltage spike when high-side MOSFET turns on, a diode of 80 V or higher reverse voltage rating should be selected. If the input voltage has transients above the normal operating maximum input voltage of 57 V, then the worst-case transient input voltage should be used in the diode voltage calculation. A 100-V/3-A diode is selected in this design.

2.4 Transformer Calculation

A coupled inductor or a flyback-type transformer is required for flybuck topology. Energy is transferred from primary to secondary when the synchronous switch of the buck converter is on.

Peak current in high-side FET and primary winding,

$$I_{SW(PEAK)} = I_{L(PEAK)} = \frac{N_2}{N_1} I_{OUT2} + \frac{\Delta I_L}{2} \tag{5}$$

The maximum inductor current ripple that can be tolerated is given by,

$$\Delta I_L = \left(I_{SW(PEAK)} - \frac{N_2}{N_1} I_{OUT2} \right) \times 2 = (1.8\text{ A} - 1 \times 1.0\text{ A}) \times 2 = 1.6\text{ A} \tag{6}$$

Primary winding peak-to-peak current ripple,

$$\Delta I_L = \frac{V_{IN(MAX)} - V_{OUT1}}{L \times f} \times \frac{V_{OUT1}}{V_{IN(MAX)}} \tag{7}$$

The minimum inductor value is given by,

$$L = \frac{V_{IN(MAX)} - V_{OUT1}}{\Delta I_L \times f} \times \frac{V_{OUT1}}{V_{IN(MAX)}} = \frac{57\text{ V} - 12.7\text{ V}}{1.6\text{ A} \times 340\text{ kHz}} \times \frac{12.7\text{ V}}{57\text{ V}} = 18\ \mu\text{H} \tag{8}$$

We chose 33 μH for primary inductor, thus $\Delta I_L = 0.87$ A.

2.5 Input and Output Capacitor

An input capacitor should be large enough to limit the input voltage ripple.

$$C_{IN} \geq \frac{\Delta I_L}{8 \times f \times \Delta V_{IN}} = \frac{0.87\text{ A}}{8 \times 340\text{ kHz} \times 0.5\text{ V}} = 0.64\ \mu\text{F} \tag{9}$$

For better input ripple performance, an input capacitor with a standard value of 2.2 μF is selected.

The secondary output current is sourced by C_{OUT2} during on time. Ignoring the current transitions time in the secondary winding, the secondary output capacitor ripple voltage can be calculated as shown in Equation 10.

$$C_{OUT2} = \frac{I_{OUT2} \times D_{MAX}}{\Delta V_{OUT2} \times f} = \frac{1.0\ A \times 12.7\ V/33\ V}{0.12\ V \times 340\ kHz} = 9.4\ \mu F \tag{10}$$

Two 10-μF capacitors are selected for secondary output.

For primary-side output current, in this design, I_{OUT1} = 0 A,

$$\Delta V_{OUT1} = \frac{I_{OUT2} \times \frac{N_2}{N_1} \times T_{ON(MAX)}}{C_{OUT1}} \tag{11}$$

Set ΔV_{OUT1}= 100 mV,

$$C_{OUT1} = \frac{I_{OUT2} \times \frac{N_2}{N_1} \times T_{ON(MAX)}}{\Delta V_{OUT1}} = \frac{1A \times 1 \times \frac{12.7\ V}{33\ V}/340\ kHz}{100\ mV} = 11.3\ \mu F \tag{12}$$

Also two 10-μF capacitors are selected for primary side output to maintain a small ripple.

2.6 Ripple Injection Circuit

As introduced in LM5160 data sheet, Type I and Type II ripple circuits suffer from larger jitter as the reflected load current affects the feedback ripple. For a constant on-time converter to be stable, the injected phase matched ripple should be larger than the capacitive ripple on primary output capacitor. Type III ripple injection circuit is used in this design. New loop stability criteria for COT mode with ripple injection approach as follows:

$$\frac{L \times C_{OUT1}}{Rr \times Cr} > \frac{T_{ON}}{2} \tag{13}$$

$$Rr \times Cr < \frac{(V_{IN(MIN)} - V_{OUT1}) \times T_{ON}}{V_{inj\_RIPPLE}} \tag{14}$$

$$Cr > Cac > \frac{1}{2\pi \times f \times \left(\frac{R_{FB1}R_{FB2}}{R_{FB1} + R_{FB2}}\right)} \tag{15}$$

Calculation result follows:

$$Rr \times Cr < \frac{2 \times L \times C_{OUT1}}{T_{ON}} = \frac{2 \times 33\ \mu H \times 20\ \mu F \times 340\ kHz}{12.7\ V\ /\ 33\ V} = 1.17 \times 10^{-2} \tag{16}$$

$$Rr \times Cr < \frac{(V_{IN(MIN)} - V_{OUT1}) \times T_{ON}}{V_{RIPPLE}} = \frac{(33\ V - 12.7\ V) \times 12.7\ V\ /\ 33\ V}{25\ mV \times 340\ kHz} = 9.19 \times 10^{-4} \tag{17}$$

$$Cr > Cac > \frac{1}{2\pi \times f \times \left(\frac{R_{FB1}R_{FB2}}{R_{FB1} + R_{FB2}}\right)} = \frac{1}{2\pi \times 340kHz \times \left(\frac{1.91\ k\Omega \times 10\ k\Omega}{1.91\ k\Omega + 10\ k\Omega}\right)} = 292\ pF \tag{18}$$

For this design, select Rr = 51.1 kΩ, Cr = 1000 pF, Cac = 63 nF.

2.7 LM5160 Flybuck Schematic

Figure 2 shows the final schematic for isolated flybuck power supply. The regulator power loss can be reduced by supplying the VCC voltage externally from primary output. A preload of 1.63 kΩ is needed to prevent secondary output voltage from going too high at light load.

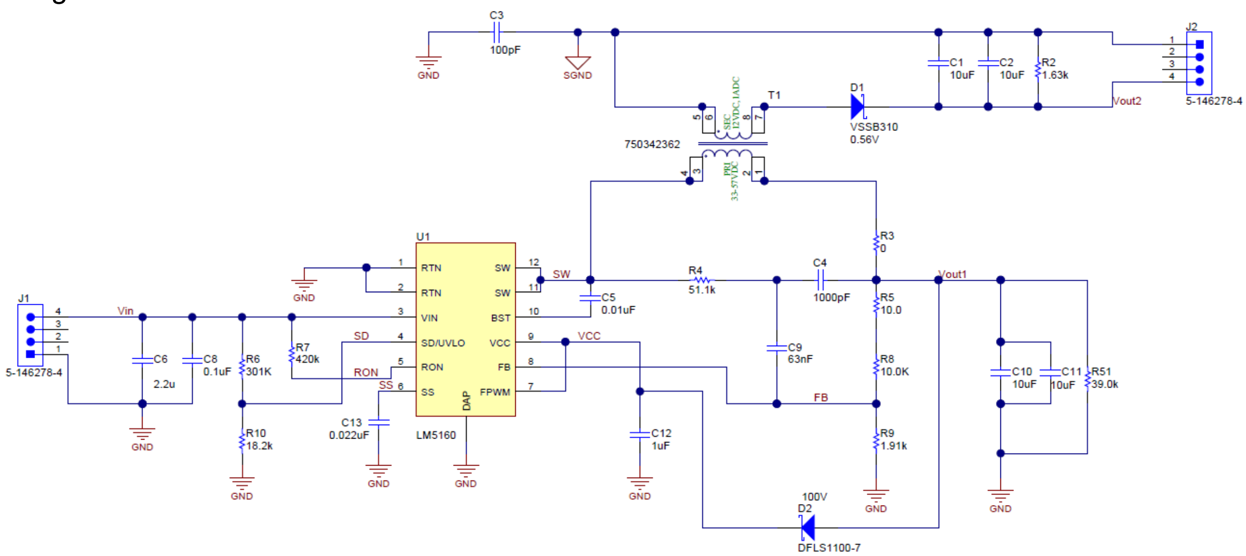

Figure 2. LM5160 Flybuck Schematic

3 Design Flybuck With Optocoupler

Normally for isolated flybuck, secondary output performance is controlled only by the primary output voltage and transformer, and it can achieve a 6% to 8% regulation performance. But for some applications, higher regulation is required, especially when output current is higher. An optocoupler can be used as a secondary-to-primary compensation to feedback voltage. Figure 3 shows the application circuit.

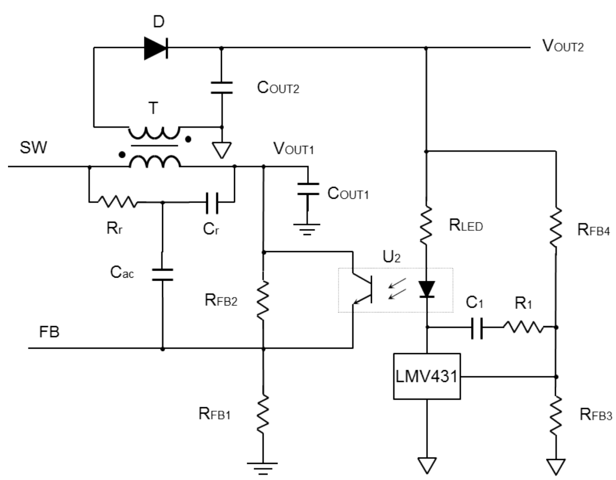

Figure 3. Optocoupler for Secondary Output Signal Transmission

LMV431 is regarded as a transconductance amplifier. Optocoupler is designed for signal transmission between two electrically separated circuits while maintaining a high degree of electrical isolation. Current transmission rate (CTR) is related to IF and temperature. Generally, typical CTR value is adopted in analysis.

In this application, optocoupler delivers the secondary side output voltage information to primary feedback. When V_{OUT2} rises, current flowing through primary forward LED increases, and then the output collector current also increases and raises the FB voltage; this extends OFF time and drives primary output voltage down, thus V_{OUT2} is pulled down.

3.1 Quiescent Operation Point

An LMV431 optocoupler is used to improve regulation performance, and quiescent operation point should be set first. Secondary side feedback resistors are calculated as in Equation 19.

$$V_{REF} = V_{OUT2} \times \frac{R_{FB3}}{R_{FB3} + R_{FB4}} \tag{19}$$

Choose R_{FB3} = 1.24 kΩ, then R_{FB4} = 10.8 kΩ.

R_{LED} can be calculated as in Equation 20.

$$I_{LED} = \frac{V_{OUT2} - V_{LMV431} - V_{LED}}{R_{LED}} \tag{20}$$

For primary side, FB voltage is determined by feedback resistors and optocoupler collector current.

$$V_{FB} = V_{OUT1} \times \frac{R_{FB1}}{R_{FB1} + R_{FB2}} + I_{LED} \times CTR \times \frac{R_{FB1}R_{FB2}}{R_{FB1} + R_{FB2}} \tag{21}$$

Choose R_{LED} = 7.5 kΩ, then R_{FB1} = 1.5 kΩ.

3.2 Loop Compensation Design

For this flybuck solution, the optocoupler secondary-side transistor current is compensation for LM5160 feedback signal. Type I compensation is chosen here for normal design.

Select R1 = 0, C1 = 6.8 μF, Figure 4 is loop test result. Cross-frequency is 4.83 kHz, phase margin is 52°. The cross-frequency is limited by ripple injection parameter, transformer and optocoupler response speed. Normally the performance can meet the requirements of most applications.

For design that requires higher cross-frequency, the basic method is to test loop with type I compensation as basic reference. The required gain can be read from loop test result. Then calculate the compensation demand according to design target as follows:

Phase compensation @required cross-frequency = current phase margin – phase @current cross-frequency – phase created by type I compensation

After confirming the gain and phase requirement of compensation, choose compensation network type and calculate required parameter to fit design target.

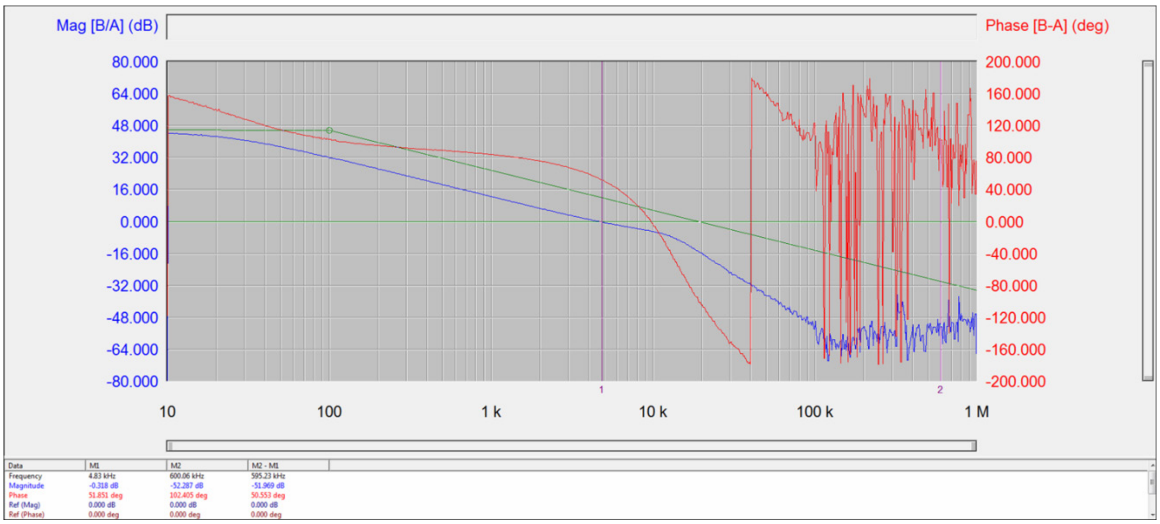

Figure 4. Loop Test Result With Type I Compensation Network

3.3 LM5160 Flybuck With Optocoupler Schematic

Figure 5 shows flybuck with optocoupler schematic. FODM121A optocoupler and LMV431A are used in this design. A 0.1-µF capacitor is added across LMV431A Ref and cathode pin to ensure normal work. No preload is needed here because of secondary output closed-loop control.

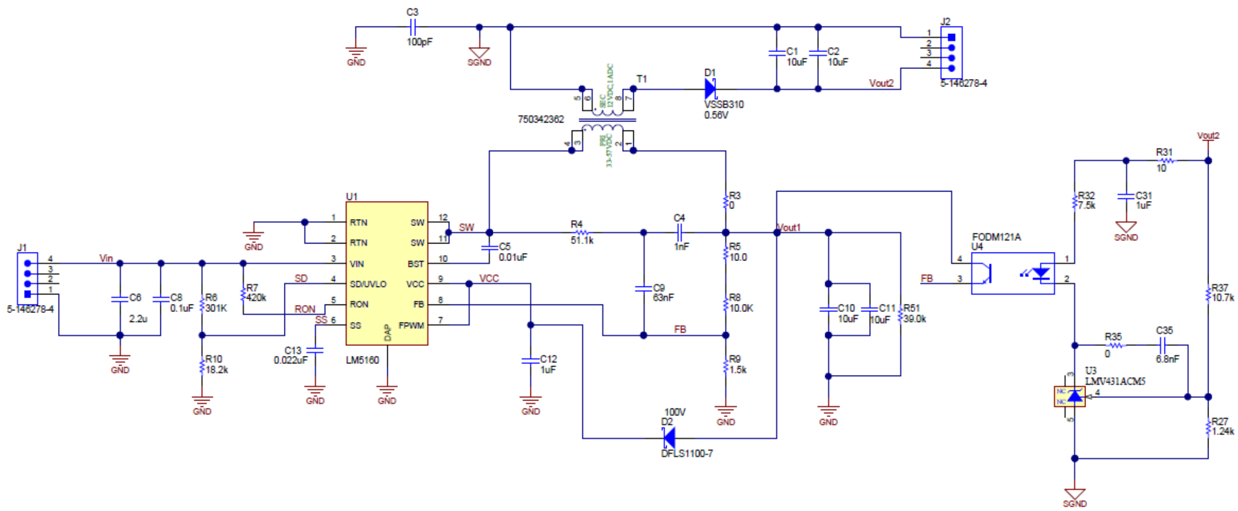

Figure 5. LM5160 Flybuck With Optocoupler Schematic

4 Test Result and Regulation Improvement

For better comparison of regulation performance, two boards are under evaluation, one without optocoupler and the other with optocoupler.

4.1 Regulation Performance Improvement

Figure 6 and Figure 7 show load regulation performance of non-optocoupler and optocoupler solution, respectively. Load regulation performance is improved significantly.

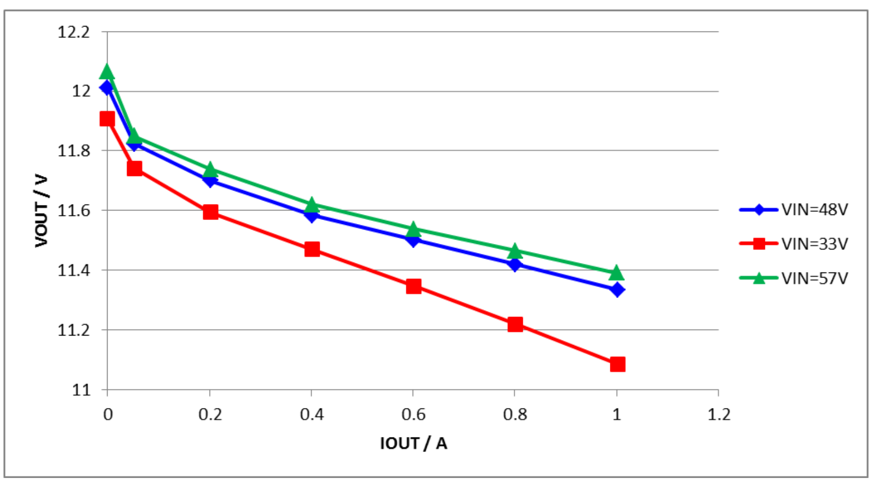

Figure 6. Load Regulation: LM5160 Flybuck Without Optocoupler

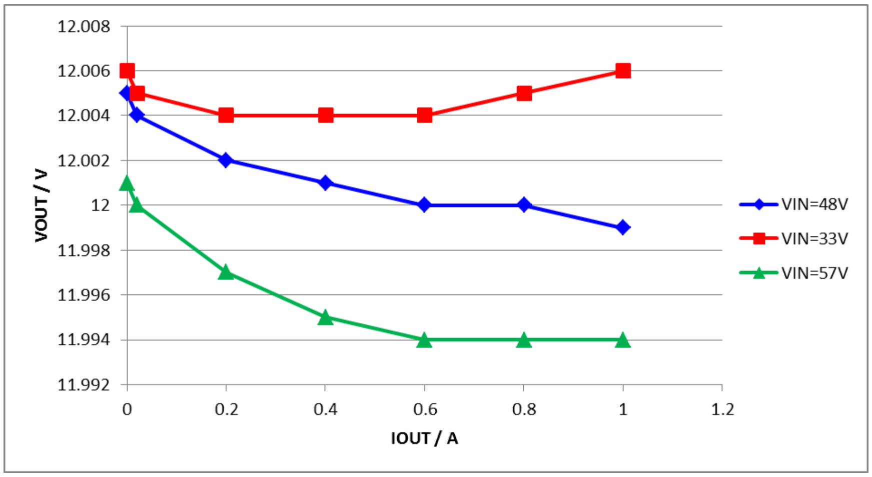

Figure 7. Load Regulation: LM5160 Flybuck With Optocoupler

Figure 8 and Figure 9 show input regulation performance of non-optocoupler and optocoupler solution, respectively. With optocoupler feedback, input regulation performance improves.

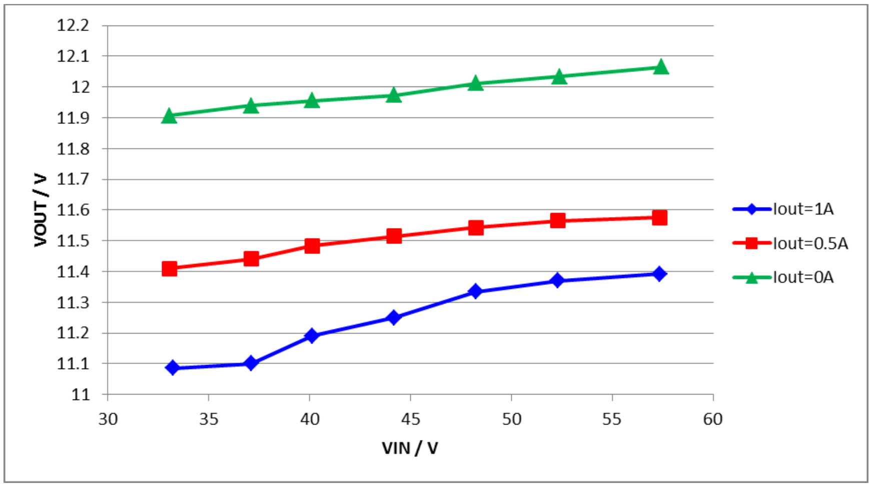

Figure 8. Input Regulation: LM5160 Flybuck Without Optocoupler

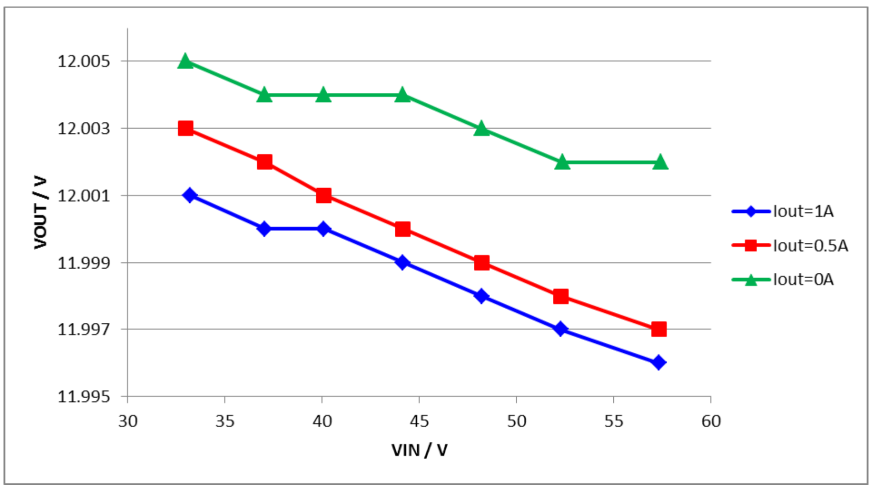

Figure 9. Input Regulation: LM5160 Flybuck With Optocoupler

4.2 Efficiency

For optocoupler solution, efficiency is shown in Figure 10. Up to 89.7% efficiency is achieved with flybuck solution and higher than typical flyback solution.

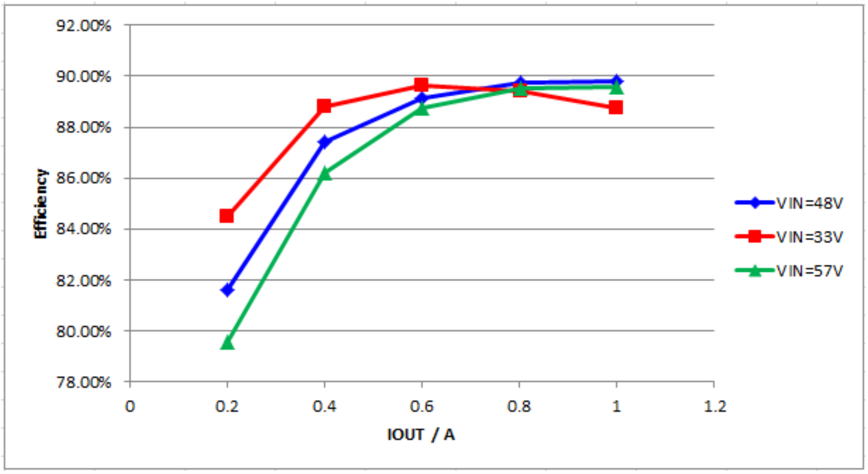

Figure 10. Efficiency

4.3 Ripple

Figure 11 shows the output ripple, approximately 140 mV when V_{IN} = 48 V, V_{OUT2} = 12 V, I_{OUT2} = 1 A. In this design, secondary output capacitor value is 20 µF, and ripple performance can be improved by increasing output capacitors to achieve higher requirement.

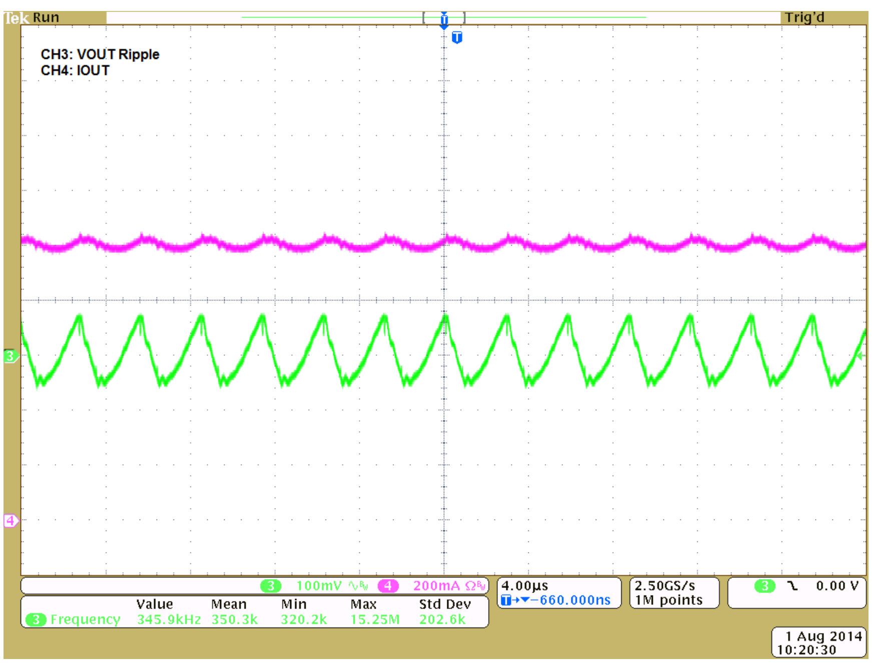

Figure 11. Output Voltage Ripple (V_{IN} = 48 V, V_{OUT2} = 12 V, I_{OUT2} = 1 A)

4.4 Transient Performance

Figure 12 shows the transient test result. Test condition is V_{IN} = 48 V, V_{OUT2} = 12 V, I_{OUT2} = 0.5-A to 1-A step with 0.1-A/us slew rate. In this design, loop analysis is not defined. Transient performance can also be optimized to achieve higher requirement.

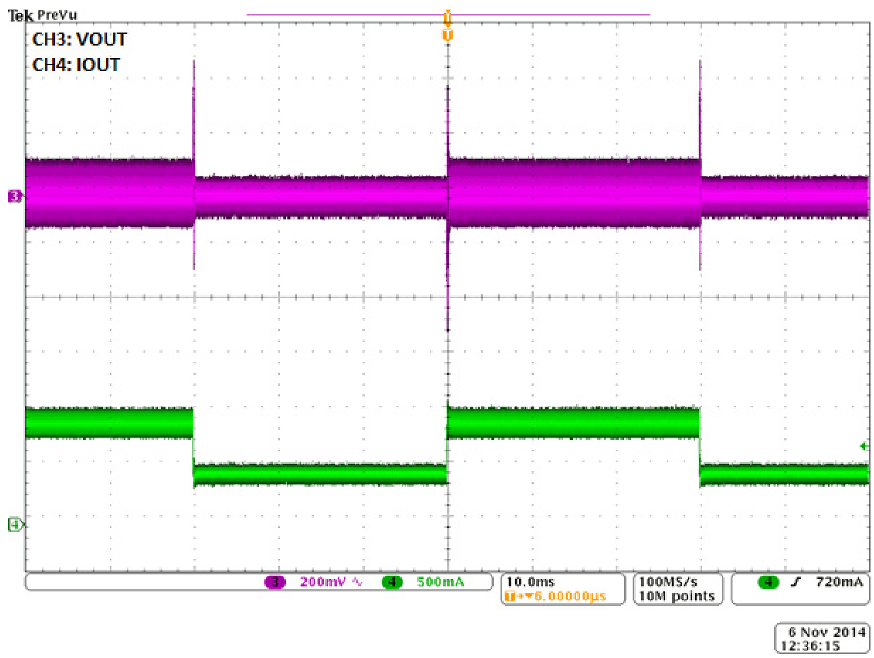

Figure 12. Transient Test (V_{IN} = 48 V, V_{OUT2} = 12 V, I_{OUT2} = 0.5 A to 1 A, 0.1 A/µs Slew Rate)

5 Conclusion

An isolated flybuck design with LM5160 using optocoupler can achieve better regulation performance. With optocoupler and compared with traditional isolated flyback solution, flybuck topology has features like good regulation, higher frequency, smaller solution size, and better efficiency. Experiment results verify that good regulation performance can be achieved by using optocoupler in flybuck topology.

Reference

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[3] *Designing an Isolated Buck (Flybuck) Converter*, Texas Instruments Application Report, SNVA674B, August 2012, revised May 2013
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