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Synchronous Buck Converter Enables Multiple Bias Rails And Input Voltage Sensing For Isolated Applications

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Telecommunications power converters are increasingly using secondary-side controllers because of the performance advantages that secondary-side control provides. This, however, brings up the challenge of creating bias power needed to provide power to the controller and drivers on the secondary side. A traditional flyback-based solution typically uses an asymmetric transformer turns ratio, an optocoupler, and an elaborate compensation design. This results in a more expensive and bulky isolated bias supply. Another challenge in isolated supplies is to provide the input-voltage measurement to the secondary-side controller for control and telemetry.

A synchronous buck converter can be used in an isolated (Fly-Buck) configuration, as presented in this article, to create multiple power rails on both the primary and secondary sides of the isolation barrier. The isolated outputs do not need any optocoupler-based feedback for regulation. The primary output is controlled directly and the additional outputs are regulated based on the transformer turns ratio. Therefore, a Fly-Buck converter is simpler to design and results in smaller and cheaper isolated bias power solutions. Additionally, a Fly-Buck-based solution can be easily modified to transfer input-voltage information to the secondary side, thereby providing a compact, relatively accurate, and cost-effective sensing and power solution.

Fly-Buck Converter Topology

A synchronous buck converter (see Fig. 1) can be used with a coupled inductor or flyback-type transformer to generate additional, isolated outputs. This configuration is known as an isolated buck converter, or Fly-Buck converter. A synchronous buck converter used in Fly-Buck configuration with one primary output and two isolated outputs is shown in Fig. 2. There is one winding per output and each isolated output requires a diode/capacitor pair.

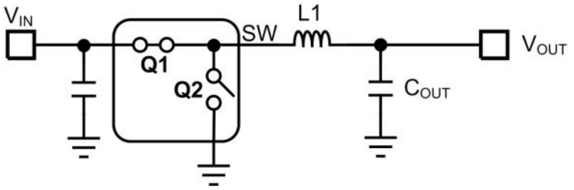


Fig. 1. Simplified diagram of a synchronous buck converter.

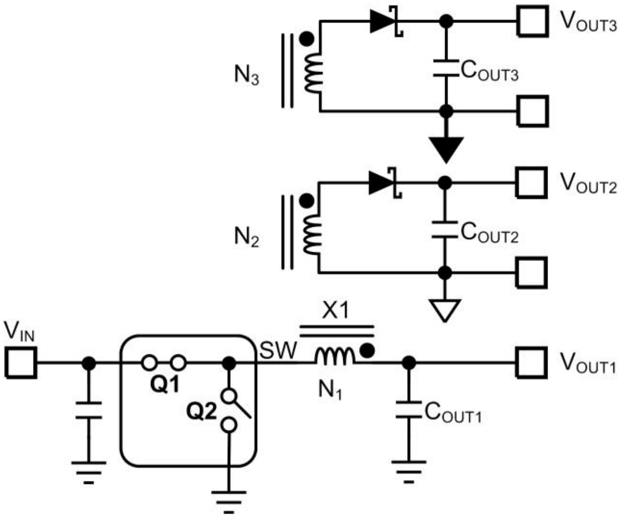


Fig. 2. Simplified diagram of a three-output Fly-Buck converter.

The operating principle of a Fly-Buck converter is explained in Figs. 3 and 4. The operating waveforms are shown in Fig. 5. For simplicity a two-output converter is shown, but the results can be expanded to any number of outputs. As shown in Fig. 3, during T_{ON}, the buck switch Q1 is on and the synchronous switch Q2 is off. The secondary diode is reversed and the primary winding carries the magnetizing current (I_M) just like in a buck converter.

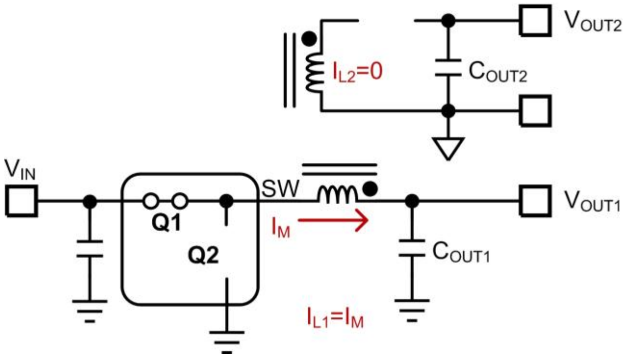


Fig. 3. Fly-Buck converter operation during T_{ON} subinterval.

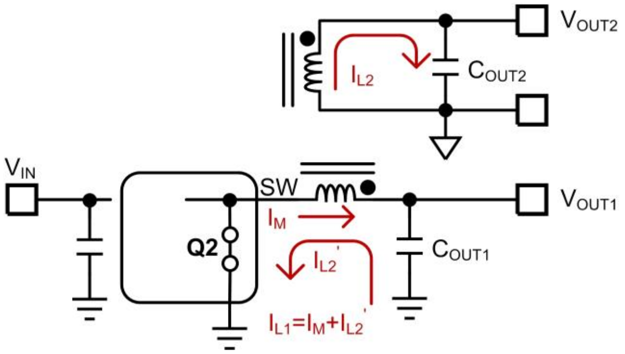


Fig. 4. Fly-Buck converter operation during T_{OFF} subinterval.

During T_{OFF} (Fig. 4), the reflected output voltage ($N2/N1*V_{OUT1}$) appears across the secondary winding. The primary output capacitor charges the secondary output capacitor (C_{OUT2}) through the leakage inductance of the coupled inductor. This charging profile in the secondary winding during T_{OFF} is shown in Fig. 5 and is similar to an LC circuit. During this time, the primary winding and the synchronous switch Q2 carry two current components—the magnetizing current (I_M) and the reflected secondary current (I_{L2}').

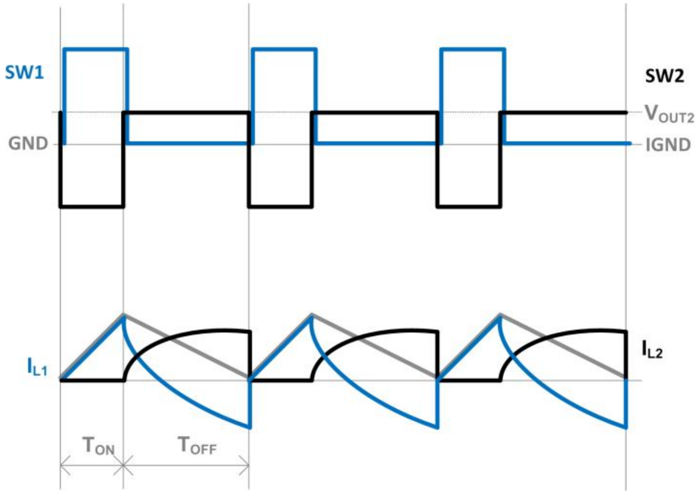


Fig. 5. Fly-Buck converter operating waveforms.

The output voltage and current relationships are listed in Table 1 for the three-output Fly-Buck converter shown in Fig. 2. Extension to a higher number of outputs is straight forward.

Table 1. Design equations for a three-output Fly-Buck converter.

Description	Equation Number	Equation
Output voltages	Eqn. 1	$V_{OUT1} = \frac{T_{ON}}{T_{ON} + T_{OFF}} V_{IN} = D \times V_{IN}$
	Eqn. 2	$V_{OUT2} = \frac{N2}{N1} V_{OUT1} - V_F$
	Eqn. 3	$V_{OUT3} = \frac{N3}{N1} V_{OUT1} - V_F$
Cycle-by-cycle average quantities	Eqn. 4	$I_{L1} = I_{OUT1}$
	Eqn. 5	$I_{L2} = I_{OUT2}$
	Eqn. 6	$I_{L3} = I_{OUT3}$
Peak currents in high-side FET and primary winding	Eqn. 7	$i_{sw(peak)} = i_{L1(peak)} = I_{OUT1} + \frac{N2}{N1} I_{OUT2} + \frac{N3}{N1} I_{OUT3} + \frac{\Delta I_{L1}}{2}$
Primary winding peak-to-peak current ripple	Eqn. 8	$\Delta I_{L1} = \frac{\left(V_{IN(MAX)} - V_{OUT}\right)}{L1 \times f_{sw}} \frac{V_{OUT}}{V_{IN(MAX)}}$

Simple Three-Output Fly-Buck Converter

In this section, a design example for a three-output Fly-Buck converter for communication infrastructure bias applications is presented. The output voltage and current specifications are listed in Table 2. The 10-V rails are used for powering the primary and the secondary drivers, and the 5-V isolated rail is used for the controller and other logic circuits on the secondary side.

Table 2. Three-output Fly-Buck converter specifications.

Input voltage range (V_{IN})	36 V to 75 V
Primary output voltage (V_{OUT1})	10 V/40 mA
Isolated Output (V_{OUT2})	10 V/120 mA
Isolated Output (V_{OUT3})	5 V/80 mA
Switching frequency (fsw)	750 kHz

A 100-V synchronous buck regulator IC with integrated high- and low-side switches, such as the LM5017 from Texas Instruments, is used in this design. Based on the required output voltages, a three-winding coupled inductor with a turns ratio of 2:2:1 is needed for this application. This results in nominal output voltages given by Equations 1 through 3:

$$V_{OUT1} = 10V \qquad \text{Equation 1}$$

$$V_{OUT2} = \frac{N2}{N1} V_{OUT1} - V_F = 9.3V \qquad \text{Equation 2}$$

$$V_{OUT3} = \frac{N3}{N1} V_{OUT1} - V_F = 4.3V \qquad \text{Equation 3}$$

where a diode drop of V_F = 0.7 V is assumed.

In practice a V_{OUT1} of slightly higher than 10 V is selected to get isolated output voltages closer to the target voltages. A three-winding transformer (Part Number: 750312924 from WE-Midcom) is selected. The peak inductor current is determined by Equations 7 and 8 to be $i_{L1(peak)} = 420mA$. This is well within the saturation current rating (550 mA) of the chosen transformer. The complete schematic for the specification of Table 2 is shown in Fig. 6. The load and line regulation results for the circuit are presented in Table 3.

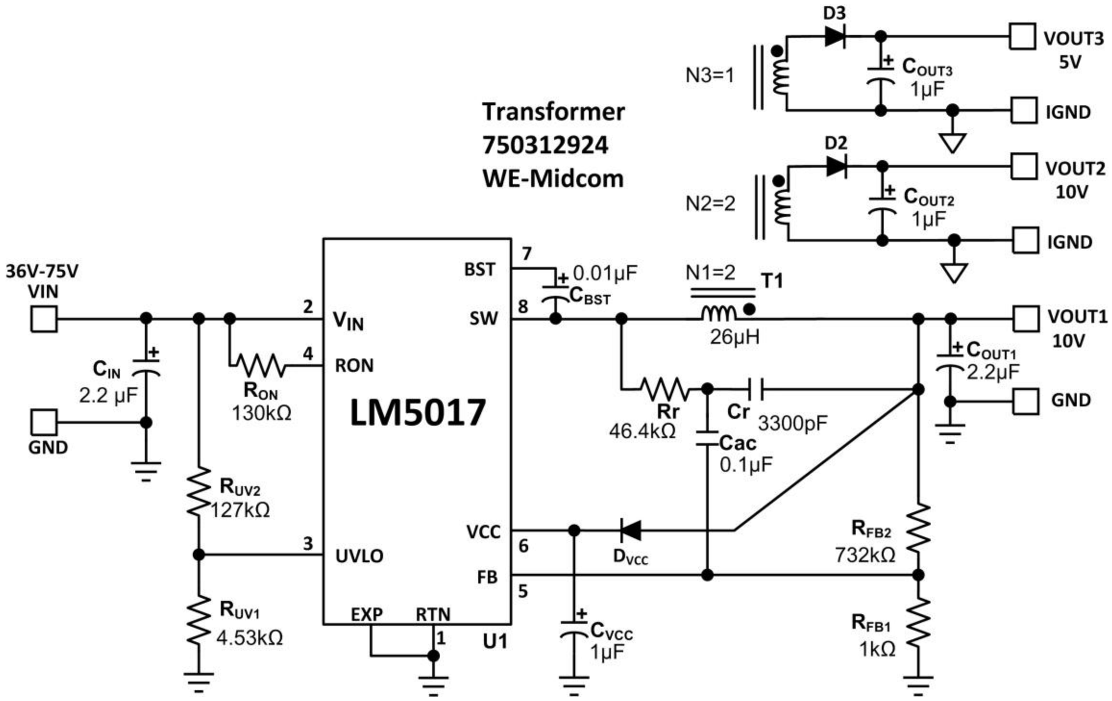


Fig. 6. Three output Fly-Buck converter schematic.

Table 3. Load and line regulation.

V_{IN}	I_{OUT1}	I_{OUT2}	I_{OUT3}	V_{OUT1}	V_{OUT2}	V_{OUT3}
36 V	-	-	-	10.21 V	9.80 V	4.75 V
48 V	-	-	-	10.33 V	9.96 V	4.83 V
72 V	-	-	-	10.63 V	10.37 V	5.01 V
48 V	50 mA	-	-	10.29 V	9.95 V	4.82 V
48 V	-	120 mA	-	10.31 V	9.57 V	4.82 V
48 V	-	-	80 mA	10.34 V	9.95 V	4.63 V

Input-Voltage Sensing Using Fly-Buck Sensing Scheme

Isolated dc-dc converters with secondary-side control need input-voltage information for input-voltage feed forward as well as for telemetry. Isolated sensing is usually done with optocouplers or transformers. Optocouplers are either used in a closed-loop system, or for transferring threshold (on/off) information across the secondary.

The example in Fig. 7 shows an optocoupler used in association with a shunt regulator, or LM431-based reference. This enables the controller on the secondary side when the primary-side supply voltage is higher than a set threshold. Optocouplers don’t have good linearity and, thus, are not suited for analog voltage transfer across the isolation boundary in an open-loop manner.

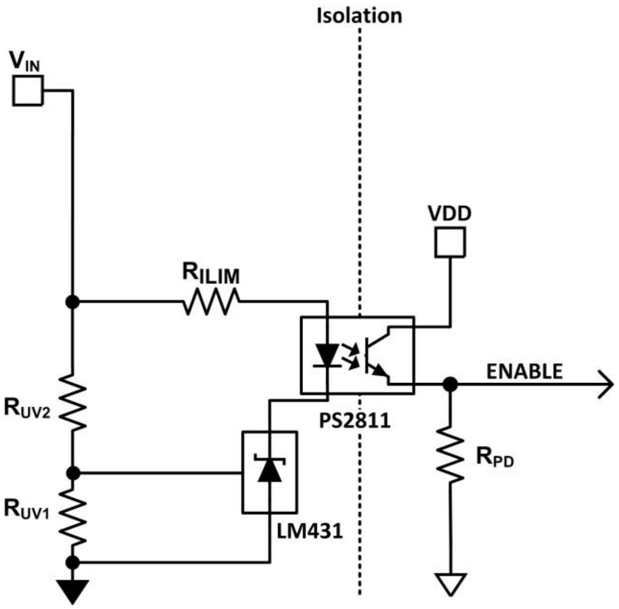


Fig. 7. An optocoupler-based UVLO sensing circuit for a secondary-side control dc-dc converter.

Another technique is to use the rectified secondary-winding signal as an estimate of input voltage (Fig. 8.) This sensing usually is slow, and in the case of half-bridge converters, the voltage applied across the primary winding is not equal to the input voltage, but is the voltage of the capacitor divider. This signal, when used for duty cycle modulation, has the potential of destabilizing the converter as it is inherently similar to current-mode control. Traditionally, pulse transformer-based input-voltage sensing is used in isolated power supplies where input voltage information is needed. However, the pulse transformer-based input-voltage-sensing schemes are complicated as the pulse transformers need a driving circuit.

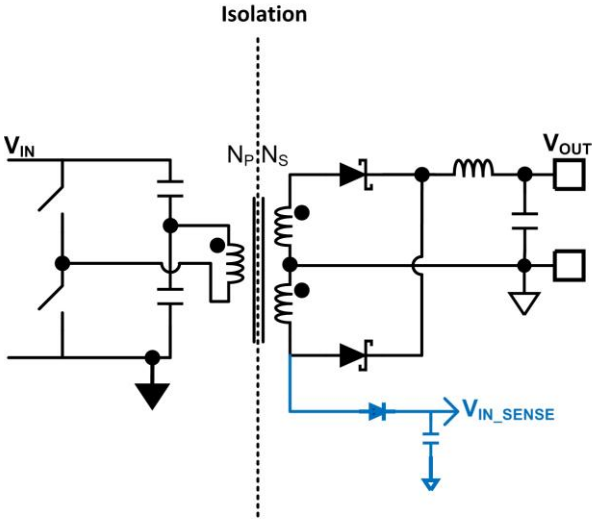


Fig. 8. Rectification of secondary winding in a half-bridge to sense input voltage.

In this article, we present a totally self-contained isolated V_{IN} sensing circuit based on the LM5017, an integrated synchronous buck converter. A simplified diagram (Fig. 9) shows how this regulator is on the primary side and sends both (V_{IN}-V_{OUT}) and V_{OUT} information to the secondary side through a transformer during T_{ON} and T_{OFF}, respectively (Fig. 10.) The input voltage is then reconstructed on the secondary side by adding these two voltages. Since this circuit can operate at a frequency higher than the main power stage, it can transfer V_{IN} information faster than a method based on sensing the main power stage transformer winding as described above for the case of a half-bridge converter.

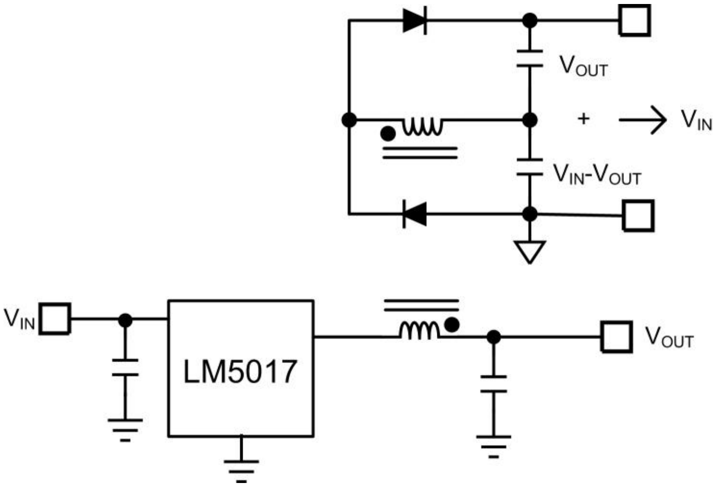
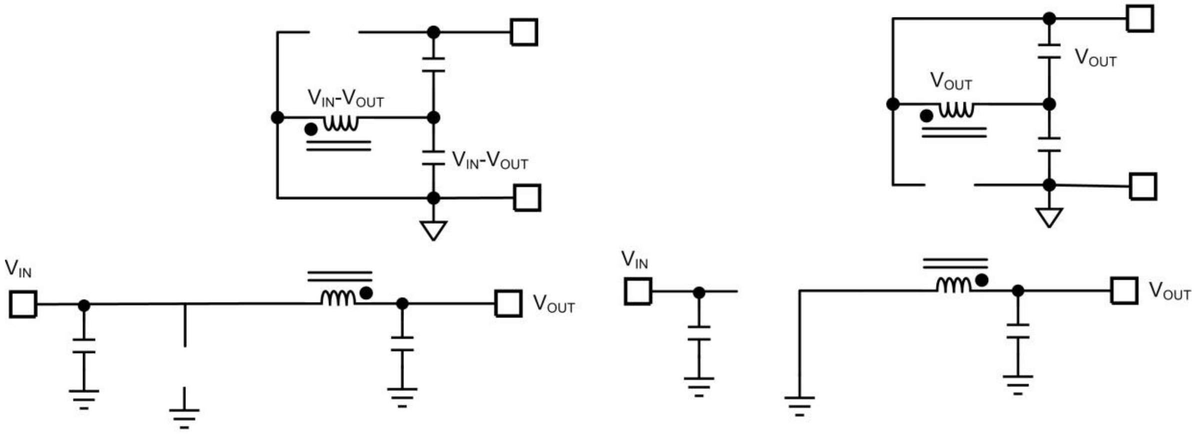


Fig. 9. Synchronous buck regulator-based V_{IN} sensing concept.



(a) (b)

Fig. 10. V_{IN} sensing mechanism during T_{ON} and T_{OFF}. During T_{ON}, the high-side switch is on (a), while during T_{OFF}, the low-side switch is on.

In most secondary-side-controlled isolated dc-dc converters, both the primary and secondary sides need bias power, which often is generated by a small isolated regulator, such as an auxiliary flyback regulator. You can configure this synchronous buck regulator to provide both the primary- and secondary-side bias power, and simultaneously double down as an input-voltage-sensing circuit.

Fig. 11 shows an input-voltage-sensing circuit schematic added to a Fly-Buck configuration. This single circuit provides bias power to the primary and secondary side of the isolation boundary. Additionally, it provides an estimate of input voltage on the secondary side. Fig. 12 shows the sensed input voltage on the secondary side as the primary input voltage varies from 0 V to 60 V. The sense circuit tracks the input voltage accurately.

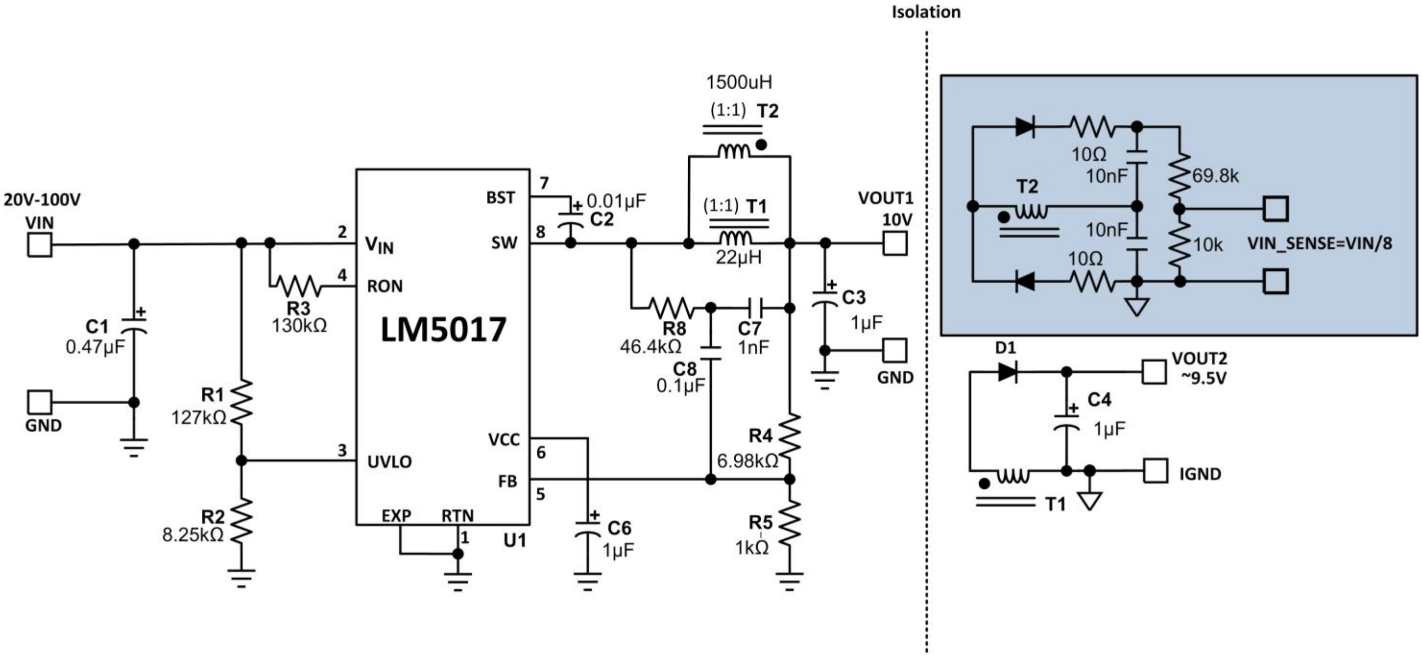


Fig. 11. V_{IN} sensing concept (V_{IN} sensing coupled with bias power).

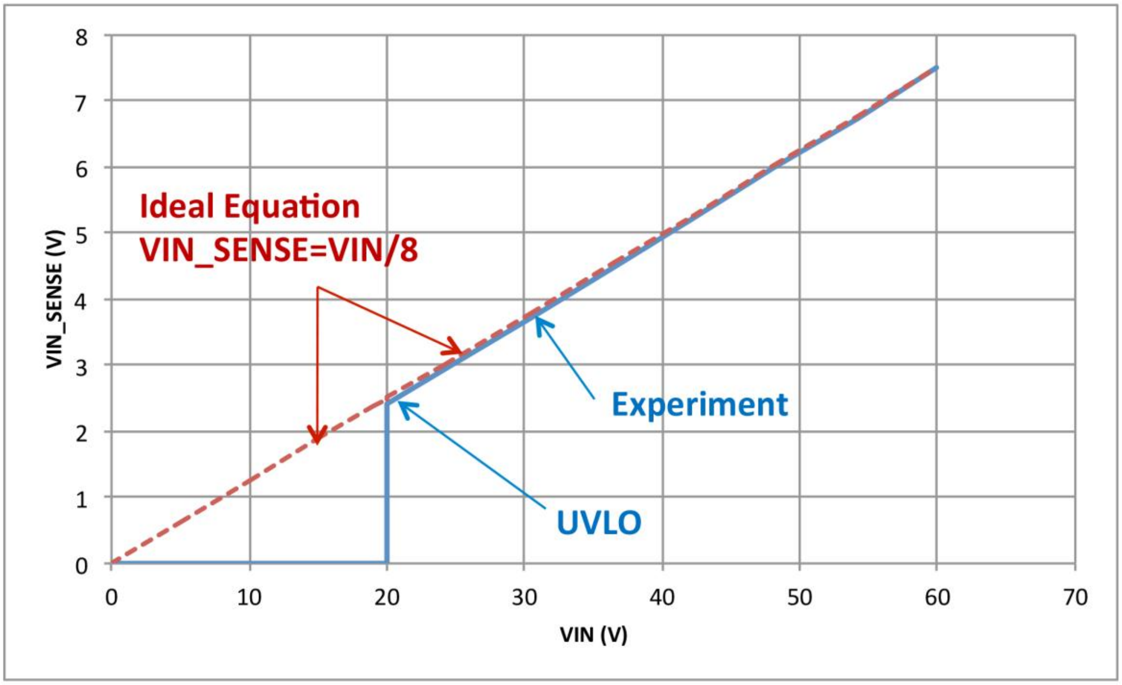


Fig. 12. V_{IN} sensing: V_{IN} vs V_{IN_SENSE} ($V_{IN\_SENSE} = V_{IN/8}$).

Conclusion

A multi-output Fly-Buck converter having isolated and nonisolated outputs is presented based on a synchronous buck regulator IC that provides power to both the primary- and secondary-side circuits in isolated systems. This solution is simple to design and results in a compact, cost-effective bias power solution.

A simple input-voltage-sensing scheme for isolated dc-dc converters is also presented and the limitations of existing isolated sensing schemes discussed. The Fly-Buck-based input-voltage-sensing scheme is simple to design, uses fewer components than other solutions, and provides an accurate estimate of input voltage on the secondary side. Moreover, this solution provides bias power to both the primary and secondary-side circuits with a single design.

Reference

LM5017 datasheet.

About The Author

Vijay Choudhary is an applications engineer for TI's Power Products group where he is responsible for new applications, product development, and customer support. Vijay has more than a decade of power management engineering experience and has written various journal papers, articles, and application notes. Vijay received his Master of Science and PhD from Arizona State University, Tempe, Arizona, and has three patents pending. Vijay can be reached at ti_vijaychoudhary@list.ti.com.

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