Application Note

Auxiliary Power Supply Design Based on LMR38020 Fly-Buck in Solar Micro Inverter

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ABSTRACT

Solar Micro Inverter is able to help the solar photovoltaic PV system to achieve per-panel level Maximum Power Point Tracking (MPPT) to improve power yield performance even in unideal conditions such as cloud or tree shades or bird drops and dust on the PV panels. Micro Inverter are once costly specialty products, but they are becoming more and more affordable thanks to technology advancement in recent years, and they are one of the fastest growing market segments in the solar industry. Usually installed under the PV panel, micro inverter is required to have high power conversion efficiency, good thermal performance, small size and long lifetime.

The conventional auxiliary power supply is usually a Flyback, either secondary side regulated (SSR) or primary side regulated (PSR). SSR design needs extra TL431+optocoupler that means extra costs. The optocoupler also introduces some reliability issue due to light attenuation when aging. The PSR design circuit is simpler and cost less but the conventional PSR flyback's output performance is relatively poorer. In addition, conventional PSR Flyback also requires an extra auxiliary winding which usually increases the transformer size and can be another issue for micro inverter application requiring small size.

This article presents a new auxiliary power supply design for micro inverter based on LMR38020 Fly-Buck™, with advantages of ease of design, low counts of components in BOM, low cost, small transformer size and well performance on efficiency, thermal and regulation.

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Trademarks

Fly-Buck™ is a trademark of Texas Instruments.
All trademarks are the property of their respective owners.

1 Introduction

The output characteristics of solar Photovoltaics (PV) cells reveals that the energy harvest can vary greatly depending on the light radiation intensity and ambient temperature. One basic requirement of PV system is always making each PV panel in the system to output the maximum power available. Hence, Maximum Power Point Tracking (MPPT) techniques are widely used to enhance the energy harvest to the maximum, hence getting the best return of the investment.

The conventional MPPT operation, which are widely used nowadays, is carried out at the PV string level, as shown in Figure 1-1. Since each PV string usually consists of multiple PV panels and each PV module consist of multiple PV cells, which are usually connected in series, it only achieves global string MPPT but not module level MPPT. Therefore, each PV module may not work at its own maximum power point, preventing the ultimate maximum energy harvest. To solve this issue, micro inverters are deployed beneath each PV panel, as shown in Figure 1-2, to achieve per-panel level MPPT thus improving the overall power yield performance. In such a configuration, the micro inverter converts each PV panel's DC power output to grid ac power rails.

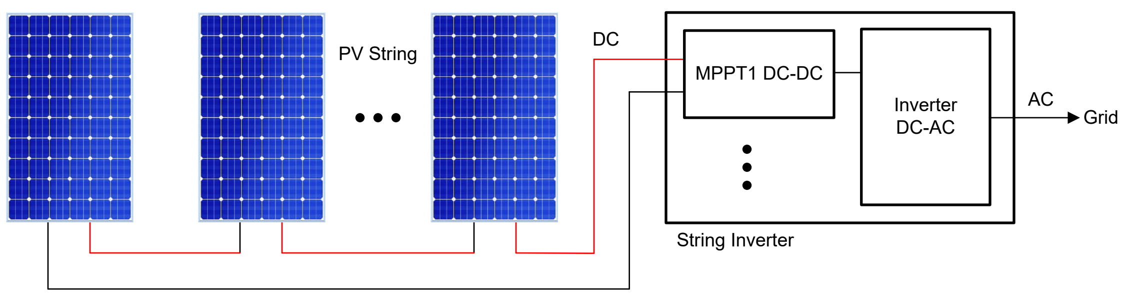

Figure 1-1. PV System Deployment with String Inverter

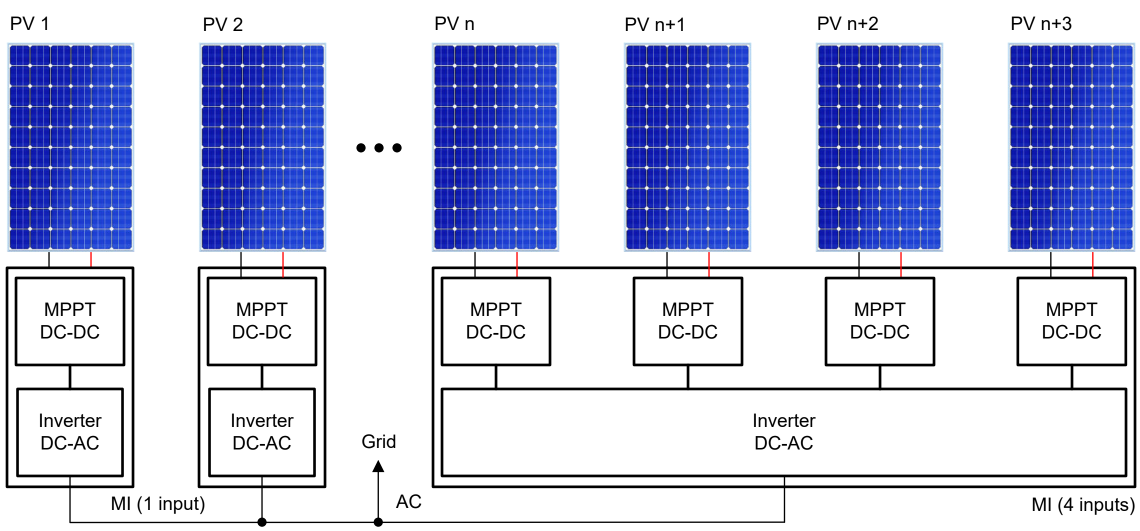

Figure 1-2. PV System Deployment with Micro Inverter

1.1 Micro Inverter System

Figure 1-3 shows a typical block diagram of micro inverter. There are two power stages in the micro inverter. The first power stage is DC/DC converter that converts the variable PV panels output voltage to a regulated high-voltage DC link suitable for the DC/AC inverter stage, and the first power stage also achieves the MPPT function. Commonly a micro inverter has 1, 2, or 4 DC/DC blocks allowing connected to 1, 2, or 4 PV panels, accordingly. Examples in Figure 1-2 show micro inverter with DC/DC blocks. The second power stage is the inverter that converts the high-voltage DC link to the grid ac voltage. It can be single phase or three phases inverter based on the targeted system configuration.

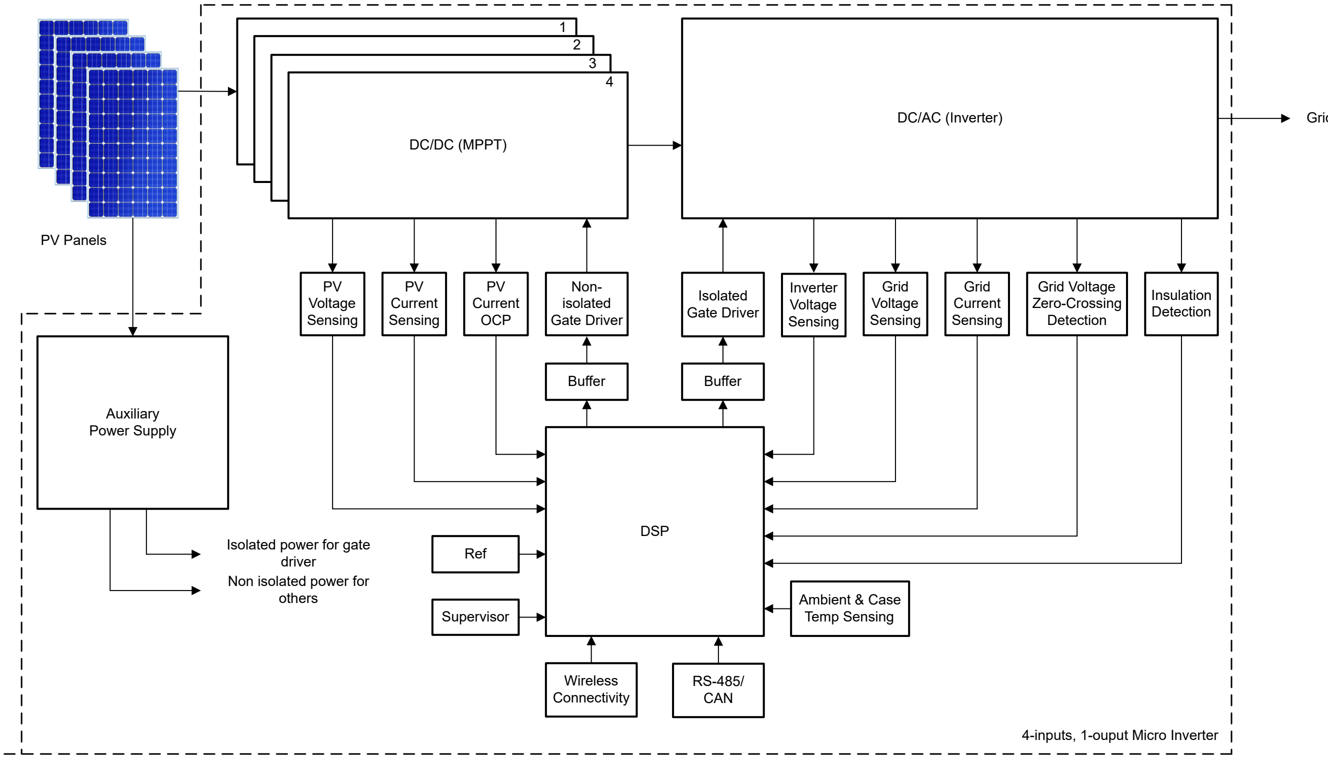

Figure 1-3. Block Diagram of Micro Inverter

Besides the two power stages, there are other function blocks, such as DSP control, gate driver, PV voltage and current sensing, inverter or grid voltage and current sensing, PV current OCP, grid voltage zero-crossing and Insulation detection, wire/wireless communication and temperature sensing, and importantly the bias supply which is critical for the entire system to function.

Generally, the DSP control system and related signal acquisition circuits operates in low voltage referenced to the DC side ground, which is also the PV panel return node. So, no isolation is required for these circuit. However, circuits in the DC/AC side, such as the inverter gate driver, need isolation. This requires the auxiliary bias supply, which takes power from the PV panel, to be able to produce both the non-isolated low voltage bias voltages for the DSP and signal acquisition circuit, and the isolate bias voltages for the inverter gate drivers' use.

1.2 Typical Power Tree and Design Requirements

Figure 1-4 shows a typical power tree of micro inverter.

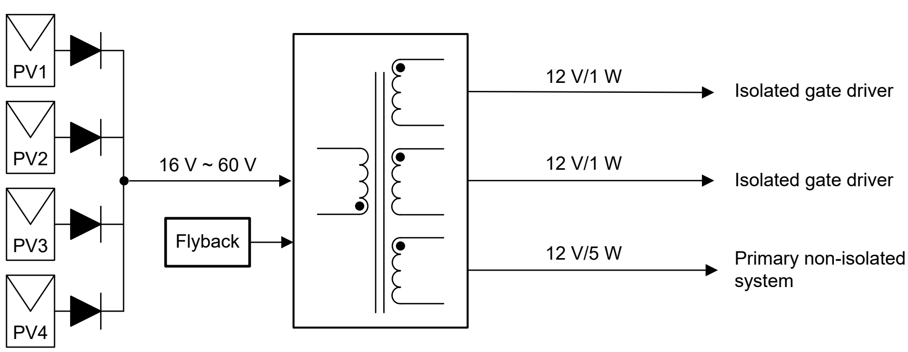

Figure 1-4. Typical Power Tree of Micro Inverters Auxiliary Power Supply

Outputs of all PV panels are connected together through the Oring diodes as the input source of the auxiliary power supply. Based on the voltage characteristics of the PV panel, the input voltage range is normally 16 to 60 volts.

Because the auxiliary power supply needs to provide multiple isolated voltages for the inverter gate drivers, the Flyback topology is commonly used, not only because it can easily realize multiple outputs, but also its counts of external components that can achieve competitive bill-of-materials (BOM) cost. For the single-phase inverter gate driver, the conventional flyback converter normally has one primary winding and three secondary windings, of which two windings for the upper and lower gate drivers, and one for the primary circuit use that includes MPPT dc-dc stage's non-isolated driver, relay and other system circuits.

Due to Flyback converter's cross regulation issue, other system circuits are not powered by the Flyback converter. Additional dc/dc converter or LDOs either on the primary side or secondary side are used to provide the required tightly regulated bias supply voltages to those circuits. Usually, a primary buck is used to produce 5 V for the buffer, amps, Comps and hall circuits etc. A secondary buck converter is used to produce 3.3 V and 1.2 V for the DSP. An LDO is used as well to provide 3.3 V output without switching noise for the wireless communication module (such as Sub-1G).

Table 1-1 lists a 7-watts design requirements example of the auxiliary power supply.

Table 1-1. Design Requirements Example of the Auxiliary Power Supply

Specifications	Requirements
Input Voltage Range	16 V approximately 60 V
Output 1	12 V/5 W (non-isolated)
Output 2	12 V/1 W (isolated)
Output 3	12 V/1 W (isolated)
Thermal	Allows max 30°C up above Ta (Ta max = 80°C).
Transformer Core	Prefer EP10 or smaller, accepts max EP13.
Frequency	Target around 300 KHz (250 approximately 400KHz).
Efficiency	> 85%
Cross Regulation	< 10%
Reliability	Solar products need high reliability and long-life time

The following section includes the conventional Flyback design based on the above design requirements.

2 Conventional Flyback Design Challenges

The Conventional Flyback design has two control schemes – primary-side regulation (PSR) and secondary-side regulation (SSR). Each method has its own set of advantages and widely used. However, both PSR and SSR Flyback bring some design challenges in micro inverter is discussed in the following sections.

2.1 SSR Design Challenges

Figure 2-1 shows a typical simplified SSR control schematic. The output voltage is sensed and fed back to the controller through an optocoupler. The optocoupler provides the isolated feedback path without breaking the isolation barrier between the primary and secondary sides. The advantage of SSR is good regulation performance, more accurate output voltage, and there are multiple outputs at the secondary side. This advantage is because cross-regulation between various secondary windings is much better than between the primary and secondary windings.

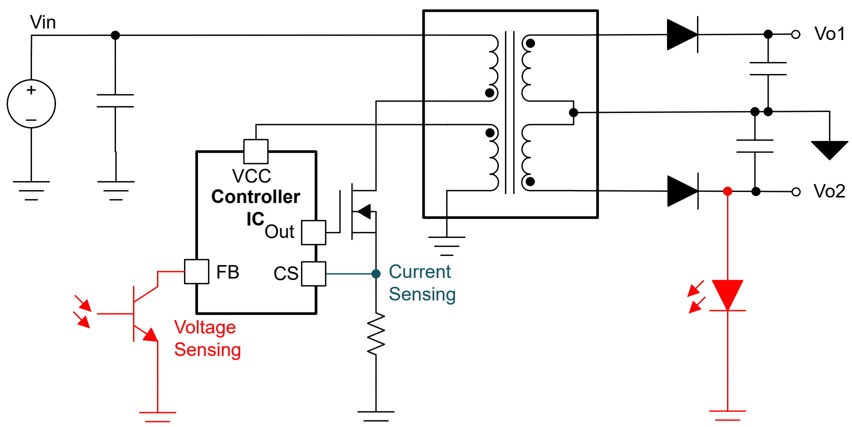

Figure 2-1. Simplified SSR Control Schematic

However, SSR control also has some drawbacks that are not negligible in the micro inverter application. As shown in Figure 2-2 SSR control loop requires a lot of components, including an optocoupler and a TL431, along with several resistors and capacitors, to constitute the feedback loop and error-amplifier-compensated circuit, when the voltage is compensated at the secondary side before being sent to the controller placed on the converter's primary side. This increases the converter's size and BoM cost.

Also, optocoupler has reliability issue due to light attenuation when aging. It may fail completely or degrade in performance with aging time. its Current-Transfer- Ratio (CTR) degrades with aging depending on the operating conditions. The application note *Lifetime of Optocouplers* from Würth Elektronik Group presents the optocoupler lifetime testing results, as shown in Figure 2-2. The average relative CTRs is given as a solid line and the average - 2σ relative CTRs is given as a dashed line. The 2σ curve shows the lowest expected relative CTR degradation will less than 87% beyond 25 years.

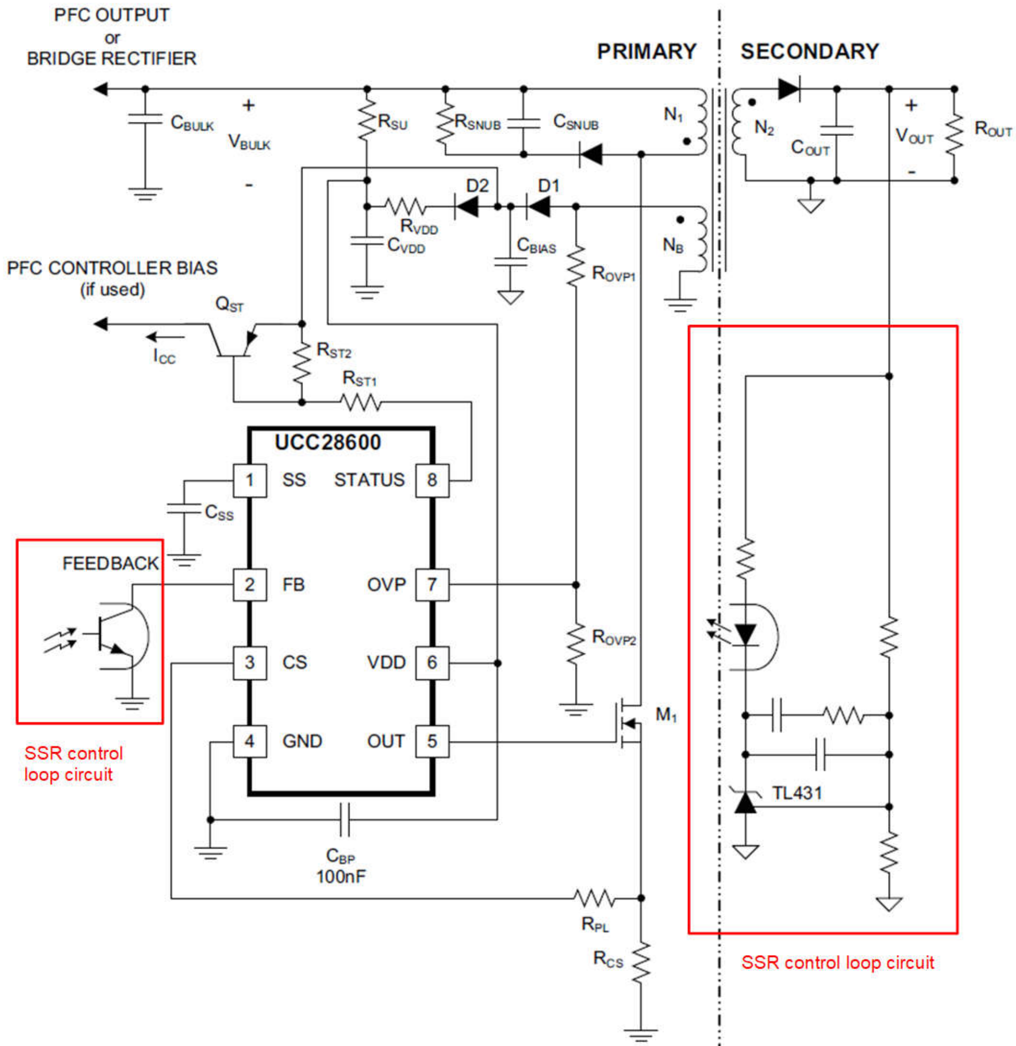

Figure 2-2. SSR Control Loop Example Circuit Based on UCC28600

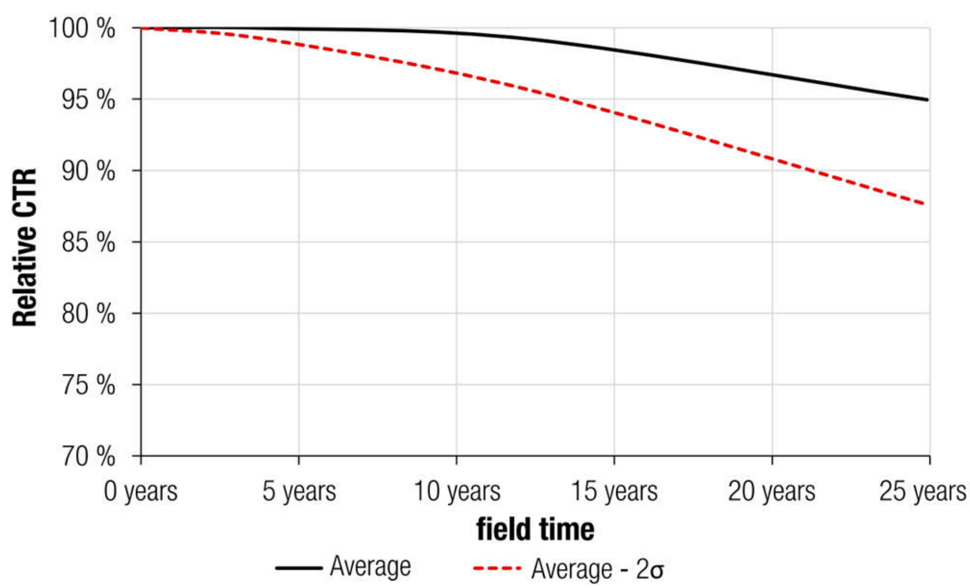

Figure 2-3. Optocouplers Expected CTR Degradation With Field Time

2.2 PSR Design Challenges

As shown in Figure 2-4, Compared to SSR control, the PSR control method is much simpler which eliminates the optocoupler, TL431, and related resistors and capacitors circuit.

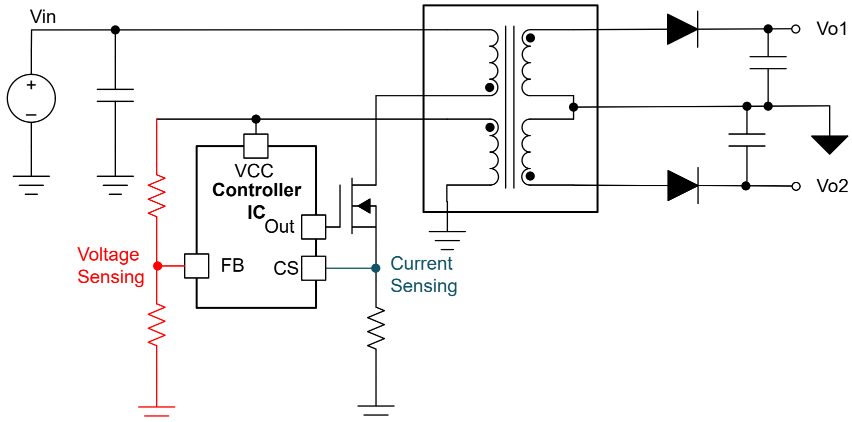

Figure 2-4. Simplified PSR Circuit Schematic

As shown in Figure 2-5, it saves BoM cost and PCB size, and the low counts of components increase mean time between failures (MTBF). In addition, for applications with high surge or isolation voltage requirements, reducing the number of components crossing the isolation barrier reduces the number of areas that could potentially break down, and also reduces the isolation voltage requirements of the components, which also has lowers total cost.

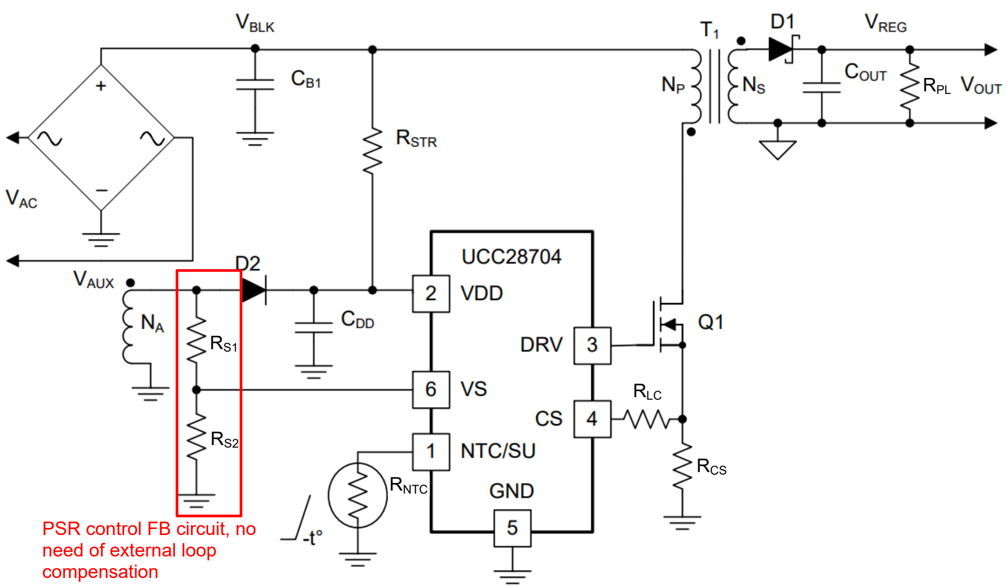

Figure 2-5. PSR Control Example Circuit Based on UCC28704

However, SSR control also has some drawbacks. Most PSR controllers use knee point sampling for feedback, which is a method that samples the voltage at the time when the inductor current is at its lowest value. So, the reflected output voltage sampling on the auxiliary winding occurs only once in each PWM cycle and in between switching cycles there is no monitoring of the voltage value. Therefore, transient response is slower than that of SSR control, where the output voltage is constantly monitored.

In addition, PSR has poorer cross regulation performance than that of SSR in multiple outputs application scenario, especially the loads attached to each winding vary significantly. Because for PSR controller's crossing regulation, the most heavily loaded output is typically chosen to implement the feedback and determines the control loop's response. The other outputs may be poorly regulated if lightly loaded.

In short, conventional Flyback designs, either SSR or PSR could bring some design challenges for micro inverter application. Moreover, for other issues in common, Flyback controller normally requires an extra auxiliary winding for controller powering and the switching frequency is usually less than 150KHz. So, the big transformer size could be challenging for micro inverter requiring small size. Fortunately, TI has an alternative design that can solve these challenges will be discussed in the following sections.

3 New Fly-Buck Design

A Fly-Buck™ converter is one of the best design options for low power applications. The Fly-Buck™ has the merits of low component count, simplified design, high efficiency, and good transient response when compared with the conventional isolated switch mode power supply topologies.

The Fly-Buck™ converter is based on the standard buck converter topology by replacing the regular inductor with a coupled inductor or transformer to produce one or multiple isolated secondary outputs. Figure 3-1 shows the simplified Fly-Buck™ circuit schematic, to produce a non-isolated output VOUT1 and an isolated output VOUT2. By adding more secondary winding, you are able to obtain additional isolated outputs.

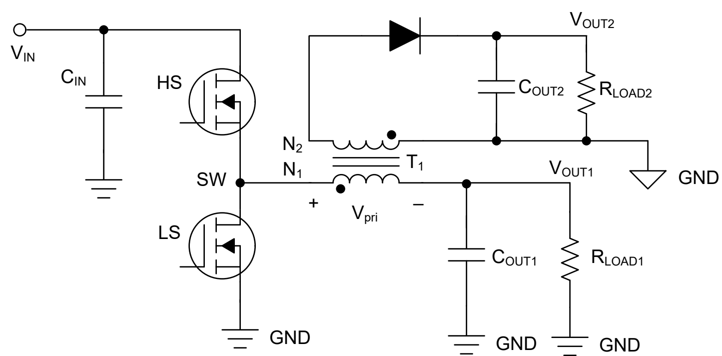

Figure 3-1. Simplified Fly-Buck™ Circuit Schematic

The Fly-Buck™ closed loop control is carried out as in a regular buck converter to regulate the primary voltage. The secondary output voltage has also been regulated through the coupling of the transformer that tracks the primary voltage regulation.

Fly-Buck™ produces a tightly regulated primary output, along with one or multiple electrically isolated secondary outputs without the need of using an optocoupler to regulate the secondary. This means that the design of a Fly-Buck™ converter is relatively straight forward and can be done similarly to the design of a typical buck converter with some minor variations. In the following a design example using the LMR38020 synchronous buck converter is presented.

3.1 LMR38020 Overview

The LMR38020 is a 4.2 V to 80 V, 2-A synchronous buck converter in HSOIC-8 package. The power MOSFETs as well as the loop compensation network are all integrated to reduce external component count making the LMR38020 designed for implementation of a Fly-Buck™ converter as the auxiliary bias supply in micro inverter applications.

The LMR38020's absolute maximum rating of VIN to PGND is 85 V, which is designed for micro inverter with PV panel having maximum 60 V output voltage (around 30% margin, which is adequate for long term reliability). The recommended maximum load current capability is 2 A, which is also enough for the auxiliary power of micro inverter which usually does not exceed 10 W power need.

3.2 Comparison with Conventional Flyback

The Fly-Buck™ is also known as the isolated buck converter, where the isolated output is generated by adding a coupled winding to the filter inductor of a buck converter. The circuit on the secondary side looks similar to a Flyback, but the primary side is a synchronous buck converter. This makes Fly-Buck™ naturally primary side regulation, and achieve isolated output regulation effortlessly via winding coupling. Comparing with the conventional PSR Flyback, Fly-Buck™ has the following key advantages and detailed differences comparison between Fly-Buck™ and Flyback are listed in Table 3-1.

- Fly-Buck™ eliminates the auxiliary sensing winding and provide an accurate primary output. This makes Fly-Buck™ have fewer components count, smaller design size and lower cost. Fly-Buck™ usually has high efficiency comparing with PSR Flyback.
- Fly-Buck™ has continuous current flow in the primary side due to the synchronous buck configuration, and the maximum voltage across MOSFET drain to source equals input voltage. Therefore, there is no need of snubber circuit. On the contrary, the primary side current in Flyback is discontinuous and the winding generates excessive voltage stress on the MOSFET and snubber is a must-have circuit.

Table 3-1. Comparison Between Fly-Buck and Flyback

Specifications	Fly-Buck	Flyback
Input	The minimum input voltage has to be larger than the primary output voltage, while the secondary output voltage can be higher or lower than input voltage (isolated buck topology).	The minimum input voltage can be smaller or larger than the output voltage (isolated buck-boost topology).
Output	Primary side output is a non-isolated output and can be only positive. Secondary side output is isolated, and can be positive or negative.	Primary side output is an non-isolated output for controller powering and also sensing in PSR. Secondary side dual outputs are isolated, and can be positive or negative.
Switch Stress	MOSFETs are rated at Vin_{max}.	Need consider flyback voltage on the primary low-side MOSFET, rated at Vin_{max} + (Vout / N) (where N = Ns / Np), which means higher switch stress.
Transformer	3-winding transformer, smaller, lower leakage.	4-winding transformer, bigger, larger leakage.
Size	Smaller design size, smaller transformer size (typically).	Larger design size, larger transformer size (typically).
Cost	Fewer components count, lower cost.	More components count, higher cost.
Performance	Good regulation achievable, +/-5% on both primary and secondary outputs. Relatively better power transfer efficiency.	PSR has poorer cross regulation performance. High output accuracy can be achieved if using SSR with optocoupler, but large deviation under light load condition. Less efficient as only utilizing off-time transferring power.

About the input specification of Fly-Buck™, it needs to be kept in mind that the minimum input voltage has to be higher than the targeted primary output voltage. Very often this results in a high duty cycle when the input voltage is low. That needs attention because high duty cycle results in very high peak current during power transferring to the secondary side.

For example, in micro inverter application, the output voltage of the PV panels (as input voltage of the auxiliary power) could be very low in dawn and dusk as the sun light is dim, or at some time the PV panels are under heavy shade. So, it needs more considerations on the switch MOSFET selection.

3.3 Design Considerations

Below are some tips that can be helpful to get started with a Fly-Buck™ converter design.

- To operate as a Fly-Buck™ converter, an IC that offers Forced Pulse Width Modulation (FPWM) needs to be selected to make sure that the part can handle negative inductor current. So, in this case, the LMR38020FADDA is selected.
- Most Buck converter devices specify the maximum output current, if a n-secondary output Fly-Buck™ converter is to be designed, the designer needs to choose a device with current rate no less than (Ipri + Nps1 × Isec1 + Nps2 × Isec2 + … + Npsn × Isecn), Npsn represents the turns ratio.
- Most Buck converter devices have positive and negative peak current limit. Check the $ipri_{pk}$ of Fly-Buck™ converter, both positive and negative, not to hit the peak current limit of the device.
- A small amount of preload might be needed for isolated outputs to prevent the output voltage from rising too high under light load conditions. The amount of preload depends on the leakage, frequency, and the current flowing in the windings to some extent. Usually the preload resistor is in the orders of magnitude of 1kΩ to 10kΩ. It is also possible to use a Zener based clamp instead of a preload resistor, which avoids power loss in the preload circuit under loaded conditions.
- The rule of thumb is keeping the duty cycle D_{max} < 0.5 because larger duty cycle may reduce the time to transfer energy to the secondary side, which may lead to lower output voltage at the secondary side. However, If D_{max} has to be > 0.5, monitoring the isolated output voltage regulation under Vin_{min} and full load

and making sure it can satisfy design requirements (lower L_{LK} and lower f_{sw} may help to achieve larger D_{max} upper limit).

- Do not short secondary output to ground for long time if the device does not have hiccup mode for negative overcurrent protection.

3.4 LMR38020 Fly-Buck Design Example

Figure 3-2 shows a typical application circuit for LMR38020 Fly-Buck™ with one non-isolated primary side output and dual secondary isolated outputs.

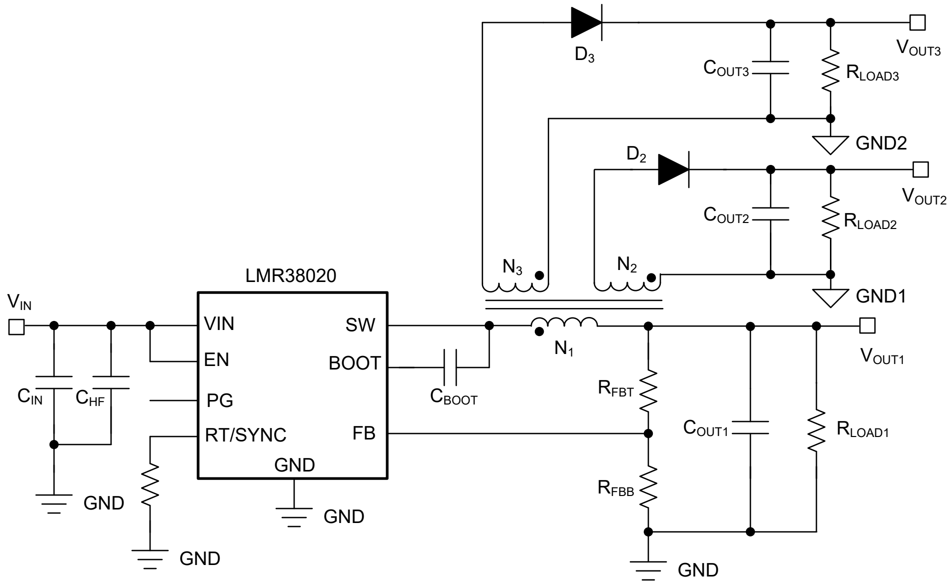

Figure 3-2. LMR38020 Fly-Buck Application Circuit Example

Referring to the design requirements of the 7-watts auxiliary power example in Table 1-1, the detailed design parameters of LMR38020 Fly-Buck™ for micro inverter application are listed in Table 3-2. The detailed design procedure are not discussed in this application note, please refer to *Designing an Isolated Buck (Fly-Buck™) Converter using the LMR38020* for more details.

Table 3-2. Detailed Design Parameters

Design Parameter	Example Value
Input voltage range (V_{IN})	16 V to 60 V
Primary output voltage (V_{OUT1})	12.6 V
Primary load current (I_{OUT1})	0.4 A
Isolated output voltage (V_{OUT2})	12 V
Isolated load current (I_{OUT2})	0.1 A
Isolated output voltage (V_{OUT3})	12 V
Isolated load current (I_{OUT3})	0.1 A
Switching frequency (f_{sw})	250 kHz

4 Bench Test and Result

Figure 4-1 shows the LMR38020 Fly-Buck™ application schematic for micro inverter and Figure 4-2 shows the demo board top view.

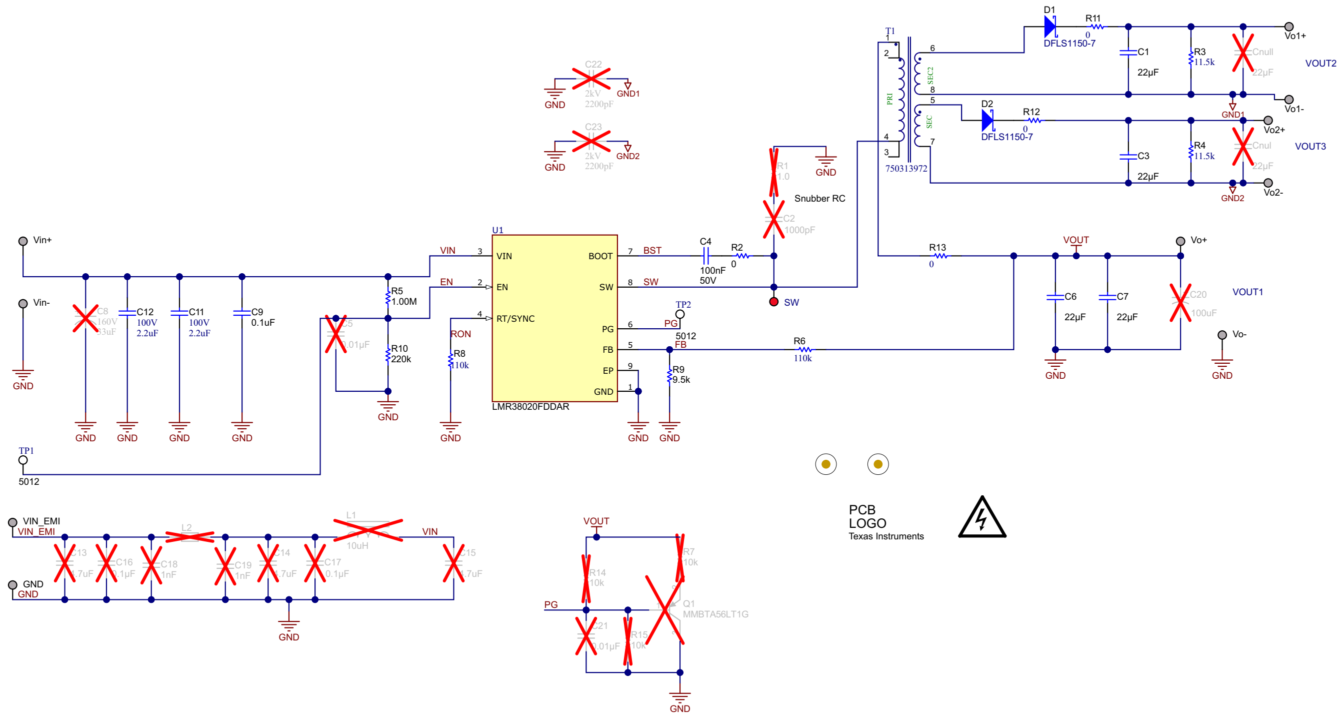

Figure 4-1. LMR38020 Fly-Buck Application Schematic for Micro Inverter

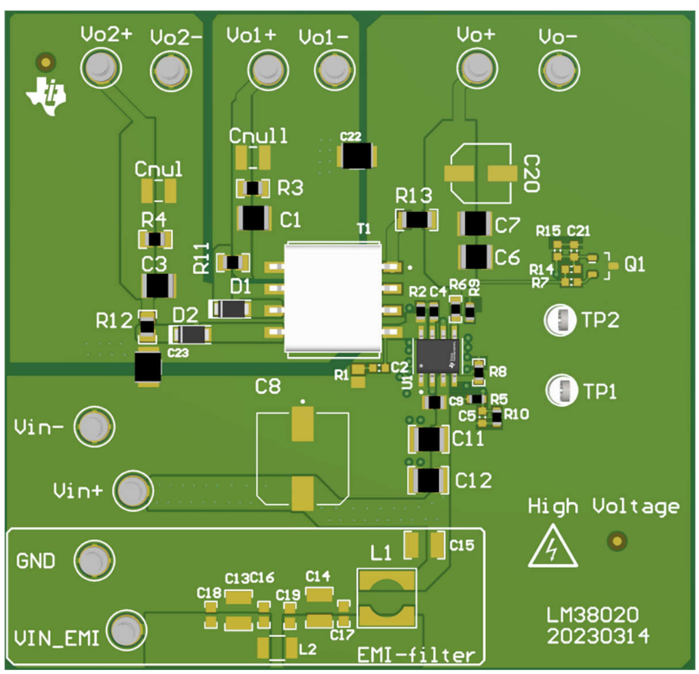

Figure 4-2. LMR38020 Fly-Buck Demo board for Micro Inverter

The demo board is tested almost over full-range line and load variation. In short, the efficiency can be up to 96% at VIN=24V and full load, as shown in Figure 4-9 and Figure 4-10. The regulation tolerance on the primary Vout is approximately 1% and the secondary Vout is <10% as shown in Figure 4-11 and Figure 4-12.

4.1 Start Up

The typical start-up behavior shows the secondary output voltage tracking the primary output voltage during the soft start sequence.

In the OCP blanking time (18 ms as stated in the data sheet), since the device operates in PFM mode during this period, there is a drop of the secondary output voltage. The heavier secondary load or lighter primary load brings more drop. The process is to add a small amount of preload on the primary side as hinted in Section 3.3

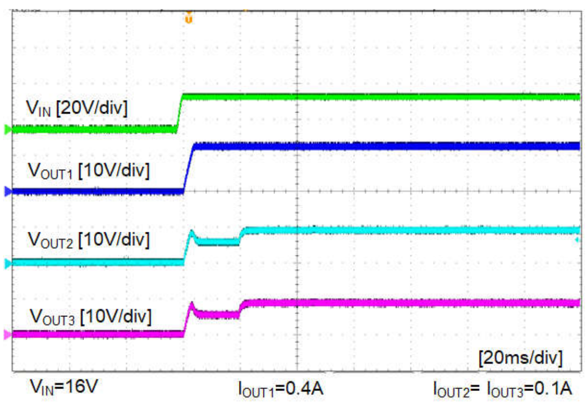

Figure 4-3. Start Up, Full Load, V_{IN}=16 V

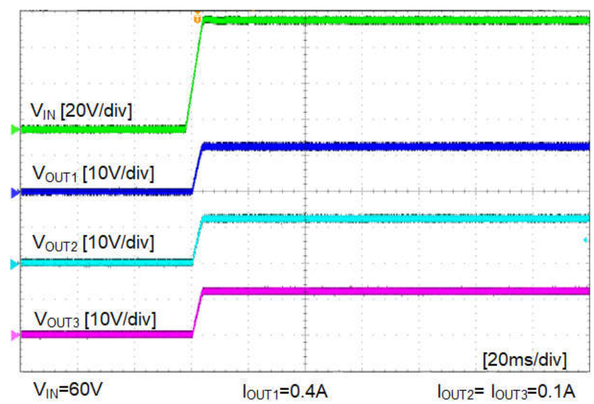

Figure 4-4. Start Up, Full Load, V_{IN}=60 V

4.2 Typical Switching Waveforms Under Steady State

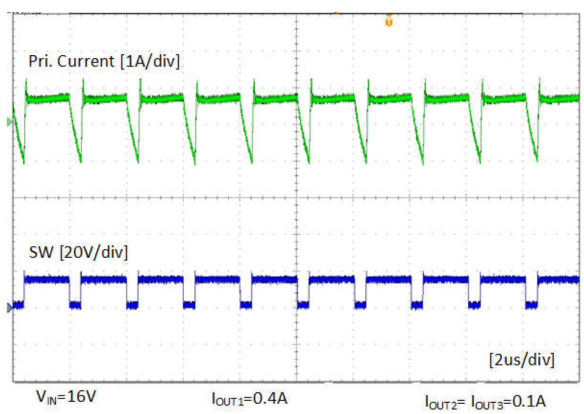

Figure 4-5. Steady State When V_{IN} = 16 V, I_{OUT1} = 0.4 A, I_{OUT2} = I_{OUT3} = 0.1 A

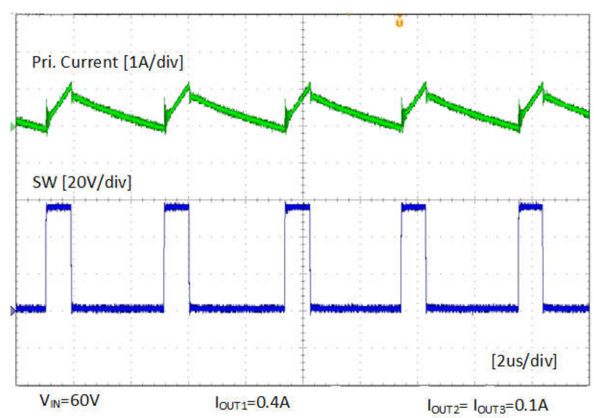

Figure 4-6. Steady State When V_{IN} = 60 V, I_{OUT1} = 0.4 A, I_{OUT2} = I_{OUT3} = 0.1 A

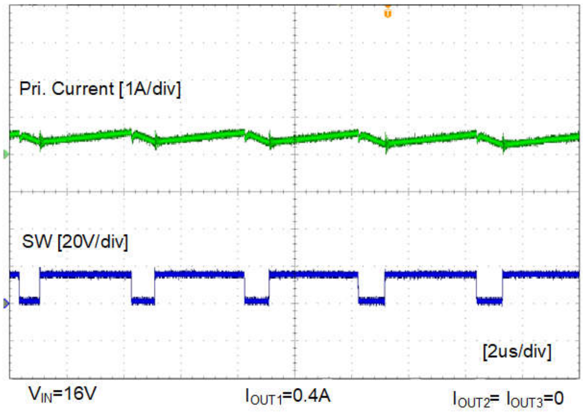

Figure 4-7. Steady State When V_{IN} = 16 V, I_{OUT1} = 0.4 A, I_{OUT2} = I_{OUT3} = 0 A

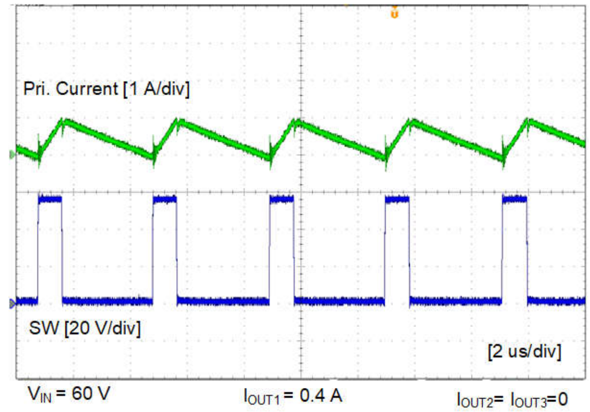

Figure 4-8. Steady State When V_{IN} = 60 V, I_{OUT1} = 0.4 A, I_{OUT2} = I_{OUT3} = 0 A

In Figure 4-7, the fsw is higher than in the typical operation. This normally happens when V_{IN} = V_{IN_MIN} and D > 0.5, where toff is small, the primary current will hit the negative peak current limit. The LMR38020 turns off the LS and start a new cycle. In this case, the output regulation when V_{IN} = V_{IN_MIN} need to be checked to make sure that satisfies the system requirement. The V_{OUT2} = V_{OUT3} = 10 V under this application.

4.3 Efficiency

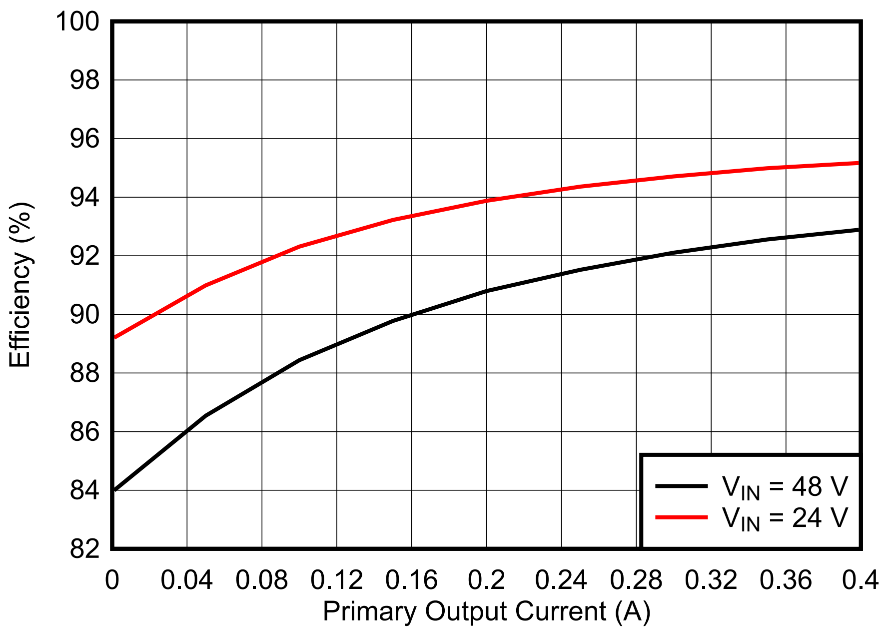

Figure 4-9. Efficiency: I_{OUT2} = I_{OUT3} = 0.1A

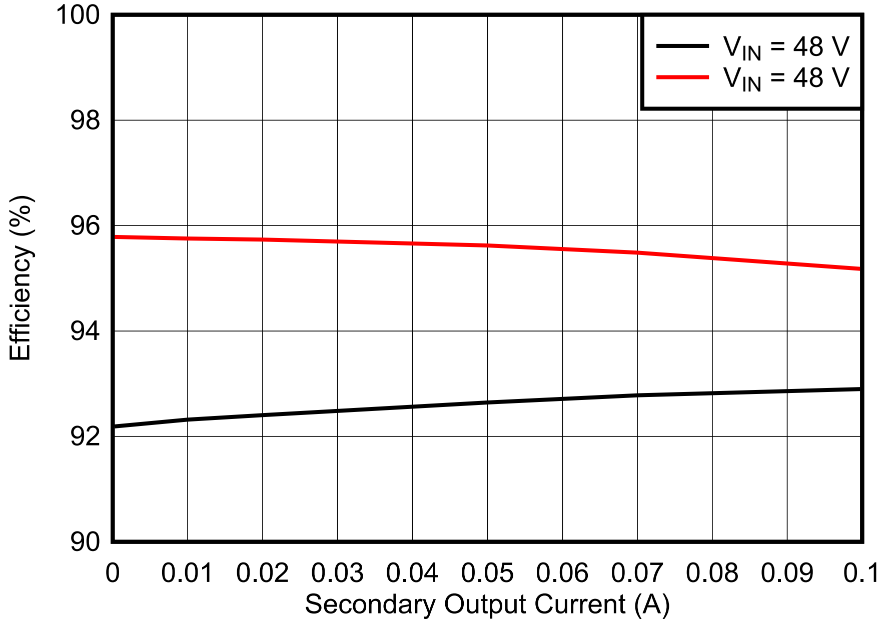

Figure 4-10. Efficiency: I_{OUT1} = 0.4A

4.4 Load Regulation

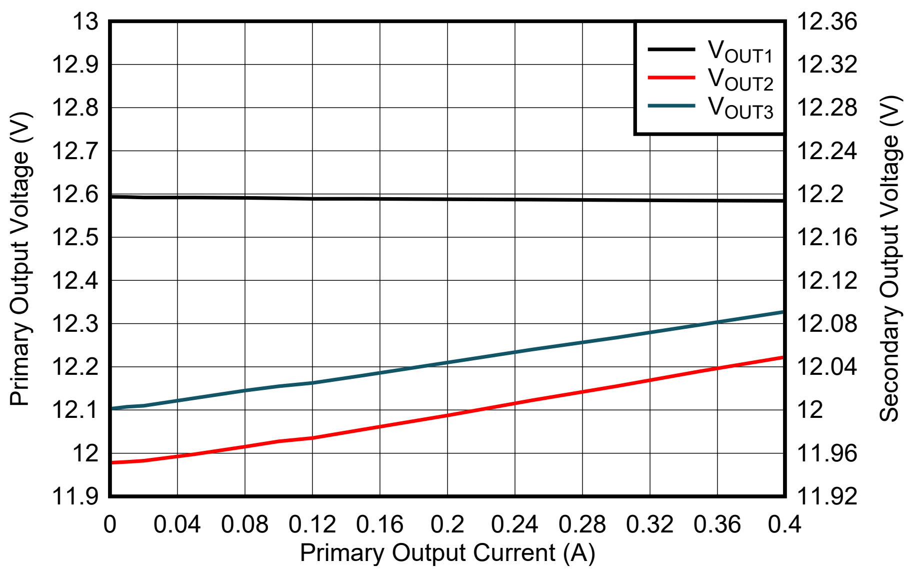

Figure 4-11. Load Regulation V.S. Primary Output Current: V_{IN} = 48 V

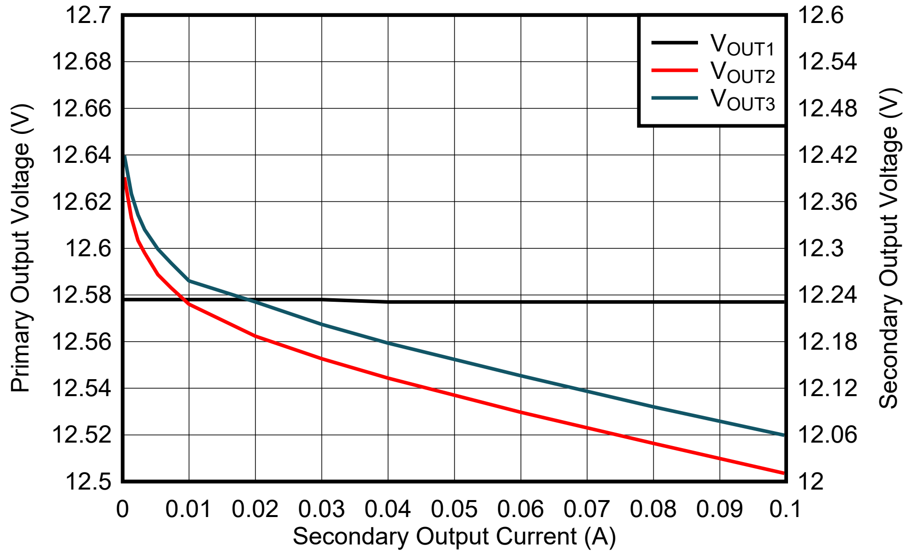

Figure 4-12. Load Regulation V.S. Secondary Output Current: V_{IN} = 48 V

4.5 Short Circuit

The LMR38020 enters hiccup protection mode when the primary side output is shorted to ground, as the waveform shown in Figure 4-13. When the short condition is removed, the converter auto-recovered.

However, when the secondary side output is shorted to ground, the device does not shutdown or enter hiccup mode. Due to the negative peak current protection mode (start a new cycle when the I_{L_NEG} is hit), the LMR38020 operates under very high f_{sw}, the inductor and the silicon can be hot. This needs to be avoided during normal operation as hinted in Section 3.3.

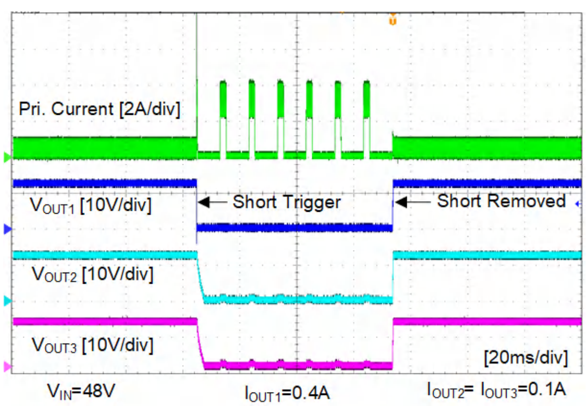

Figure 4-13. Short Circuit- Primary Output

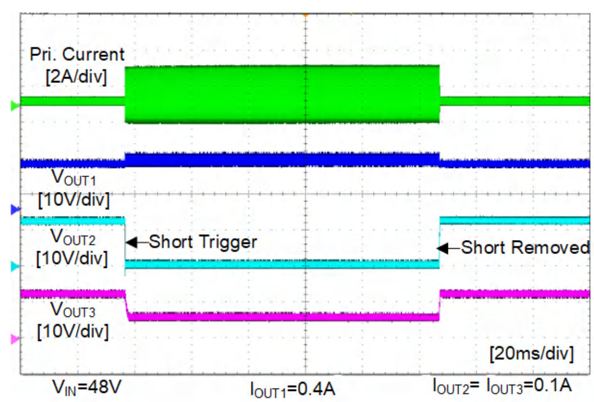

Figure 4-14. Short Circuit- Secondary Output

4.6 Thermal Performance

Figure 4-15 is the thermal performance when V_{IN} = 48 V, Full load (7.2 Watts). Ta = 26℃. Trise < 15℃.

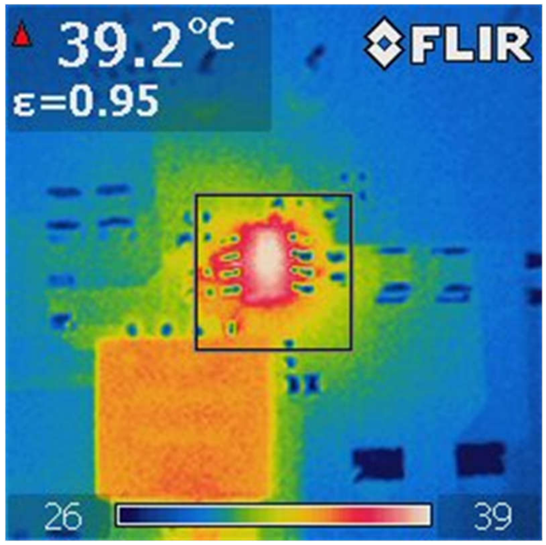

Figure 4-15. Thermal Performance When V_{IN} = 48 V, Full Load

5 Summary

The Fly-Buck™ converter is a versatile, isolated-power design. The converter offers a simple and cost-effective way to generate multiple isolated outputs. For low-power applications, it is an excellent candidate to replace the classic Flyback. This application note proposes a new auxiliary power supply solution based on LMR38020 Fly-Buck™, which is intended for the classic Flyback design for micro inverter application requiring high power conversion efficiency, good thermal performance, small size and long lifetime. The test results show the design has advantages of easy design to use few components, low cost, small transformer size and well performance on efficiency, thermal, and regulation.

6 References

- Texas Instruments, *LMR38020 SIMPLE SWITCHER® 4.2-V to 80-V, 2-A Synchronous Buck Converter with 40-µA IQ*, data sheet.
- Texas Instruments, *Designing an Isolated Buck (Fly-Buck™) Converter using the LMR38020*, application note.
- Texas Instruments, *UCC28600 8-Pin Quasi-Resonant Flyback Green-Mode Controller*, data sheet.
- Texas Instruments, *High-Efficiency Off-Line CV and CC Flyback Controller with Primary-Side Regulation (PSR)*, data sheet.
- Würth Elektronik, *Lifetime of Optocouplers*
- E2E, *Differences between PSR and SSR in bias power-supply design*
- IEEE, *Isolated Bias Power Supply for IGBT Gate Drives Using the Fly-Buck Converter*

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