Designing isolated rails on the fly with Fly-Buck™ converters

TEXAS INSTRUMENTS

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Fly-Buck™ or coupled inductor buck converters provide isolated and bipolar bias rails in a smaller solution size at a reduced cost, and are simple to design.

Isolated bias rails are common in test and measurement equipment, process control, telecommunications systems, building infrastructure, and industrial automation systems. Traditionally, isolated supply design has been a tedious process involving loop compensation, optocouplers, extra windings, and/or pre-regulated primary rails. The effort, complexity, solution size, and cost involved are not really justified at relatively low power levels. This white paper presents Fly-Buck converters as a simple, easy, and cost-effective way of generating multiple isolated rails. Actual examples from different application areas are presented to illustrate the usefulness of the Fly-Buck-based approach for low-power isolated designs up to 15W. These examples can help identify potential solutions close to specific bias power requirements. References to sample designs and resources are provided to get designers up and running with isolated power solutions for their systems.

Isolated rails in modern electronic systems

Modern electronics systems consist of a number of distributed rails to provide power to a variety of digital and analog circuitry. Many systems or subsystems, particularly those requiring human intervention, need to be isolated from the main power source for safety. These systems include industrial process control, building automation, telecommunication infrastructure systems, and medical equipment, to name a few. Figures 1 through 6 provide a few examples of systems with isolated rails. The Fly-Buck converter approach is a simple way of generating the bias rails in these and other similar applications.

One common application area is factory automation where a 24V DC rail or a custom power over Ethernet (PoE) forms part of the distributed power backbone of the system (Figure 1). Control and sensor blocks distributed throughout the system
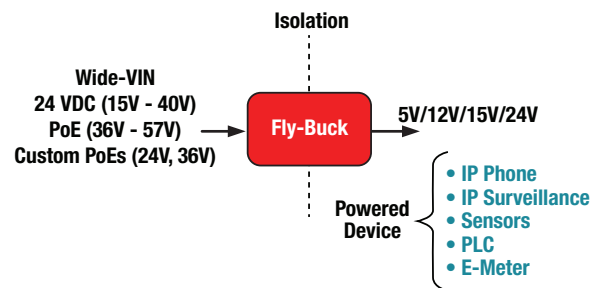

Figure 1. Isolated rails in industrial applications

require bias power that needs to be isolated from the main power bus. Reference 1 contains a full design for powering a programmable logic controller (PLC) I/O module.

Another common application area is gate drive bias power in isolated DC/DC converters or in motor control. MOSFETs, IGBTs, or silicon carbide (SiC) based power stages require isolated rails for powering the drivers as well as the control circuit that may be sitting on the different side of the isolation boundary than the power source. The high-side drivers also require floating bias rails separated

from the low-side rail by up to hundreds of volts (Figure 2). Reference 2 is a complete Fly-Buck bias power design for a three-phase motor control system.
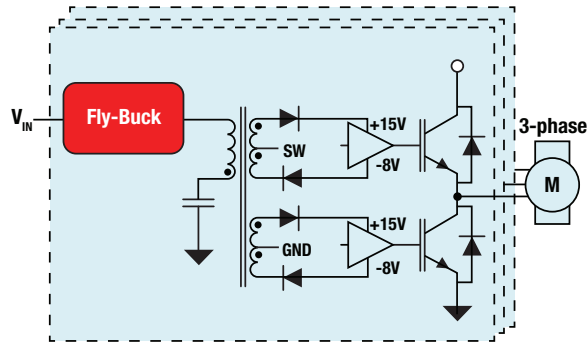

Figure 2. IGBT/SiC/MOSFET gate drive bias rails

Figure 3 shows a telecommunications DC/DC converter with primary and secondary driver bias power. The secondary side controller power is derived from a single Fly-Buck converter. Reference 3 has a complete reference design for this bias supply.
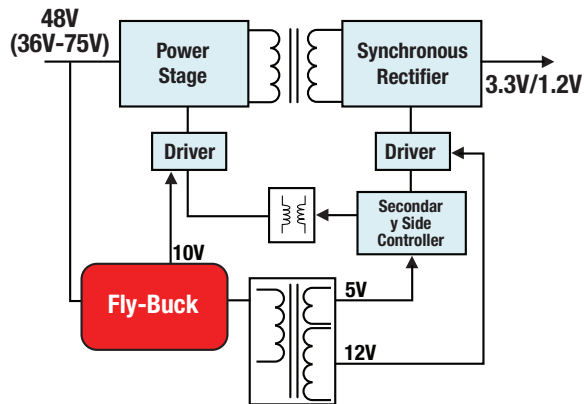

Figure 3. Telecommunication DC/DC converter bias supply

Medical equipment typically requires isolation for patient and operator safety. Another area where isolated converters are used is in the generation of a bipolar (±) supply for analog front end circuitry of many high performance operational amplifiers (op amps) and other types of amplifiers. The isolated output is often used to generate one of the ± rails (Figure 4).
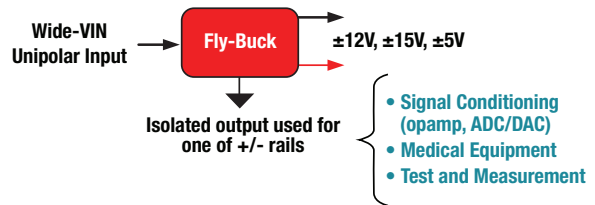

Figure 4. Bipolar (±) rails for instrumentation

Another common scenario where transformer isolation is used is in buck-boost applications or voltage stabilizers. In these applications, the input voltage deviates considerably above and below the nominal rail voltage. Using a transformer simplifies the regulator design because the transformer is used to step up the voltage whereas the switching DC/DC converter can be used to regulate the voltage. It is simpler to generate low-power, buck-boost converters using a transformer-based topology than with non-isolated converters (Figure 5).
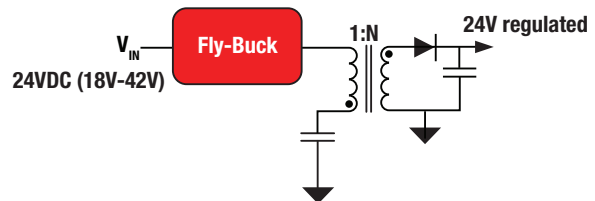

Figure 5. Low-power buck-boost converter/rail stabilizer

Figure 6 shows a telecom system with –48V rail. A 5V/500 mA rail is needed with reference not to the system return rail (–48V) but with respect to ground. An isolated supply is an easy way of generating a positive (or negative) level-shifted rail from –48V input rail.
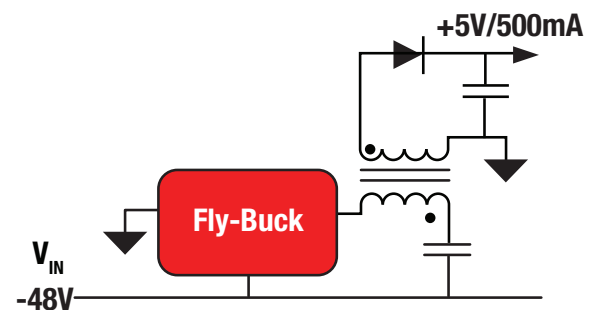

Figure 6. Level-shifting rails

Creating isolated rails

This section describes a few commonly used methods to generate isolated rails along with advantages are disadvantages for each.

One method of creating an isolated rail is to use a flyback converter. Flyback is indeed a cost-effective way to create an isolated power supply in the 10-100 W range. The flyback topology design, however, is relatively complex. It often requires complex design procedures involving compensation design for stability. It also requires isolated feedback for voltage regulation which necessitates an extra transformer winding or optocoupler. The power stage itself is very sensitive to transformer leakage inductance. This requires careful snubber design to limit the switch node spikes to a reasonable value. As a result, for a relatively low-power rail often needed in electronic systems, a flyback solution is usually too complex. In short, flyback is not a suitable topology for low-power bias supply designs (10 W or less).

Another common approach for generating an isolated bias rail is to use a driver and transformer circuit, for example, a push/pull driver with a center-tapped transformer. This is an open-loop approach that works when the input power supply is regulated and the power requirement is really low (1-2 W). For input rails that vary or for higher power levels, the transformer driver approach is not attractive in terms of circuit complexity and/or performance.

For systems with main power stages, auxiliary bias supplies can be created using auxiliary windings off the main power conversion stage. This procedure has long been used by experienced power designer. This can result in cost-effective solutions, but it complicates the main power stage design by mixing bias design with the main power design. Furthermore, this approach is only useful in generating bias for and/or around the main power supply.

What is Fly-Buck™ converter?

The Fly-Buck converter is a synchronous buck converter with the inductor replaced by a coupled inductor or flyback-type transformer. The secondary output voltage (V_{OUT2}) is generated by a diode rectifying the secondary winding. The secondary output capacitor (C_{OUT2}) is charged from the primary output capacitor (C_{OUT1}) every switching cycle when the synchronous switch (Q2) is on, as in Figure 7.
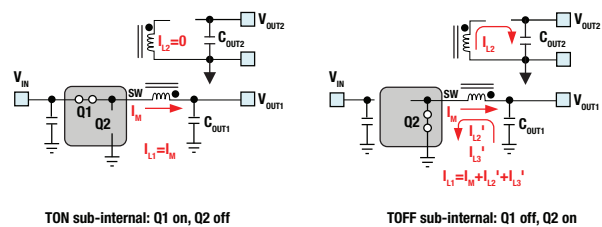

Figure 7. Operation of a Fly-Buck converter

For detailed description and operating principle of a Fly-Buck converter, see Reference 4.

Fly-Buck converter advantages

The Fly-Buck converter is a primary-side regulated (PSR) topology. There is no isolated output sensing required, obviating the need for an extra transformer winding or an optocoupler. With the availability of a 65V/100V Fly-Buck family of regulators with both high- and low-side switches integrated as seen in Table 1, isolated bias design using Fly-Buck topology tends to be simpler and smaller.

Fly-Buck topology is a cost-effective solution, if the application requires both isolated and non-isolated rails. The primary output of the Fly-Buck converter, which is essentially a buck converter, can be used without extra overhead.

For systems requiring multiple isolated rails, the Fly-Buck is a suitable choice as extra outputs can be created using additional windings in the transformer without any change in the overall design procedure. For multiple isolated outputs the advantages of a dedicated isolated feedback loop tends to fade away as the isolated loop only improves the regulation of one output. References 1 – 3 contain a complete Fly-Buck solution with 3, 4, and 8 rails.

Fly-Buck transformers often use close to symmetric turns ratios. Often transformers with a 1:1 or 1:1.5 turns ratio can be used. Transformers with matching turns ratios are often smaller. Flyback designs, by contrast, often have hugely mismatched turns ratios.

For all its advantages and simplicity, Fly-Buck converter performance tends to deteriorate as power levels increase. Because of the passive secondary side regulation, the Fly-Buck application is limited to relatively low power levels. Figure 8 shows where a Fly-Buck solution is likely to be more attractive than alternate methods.
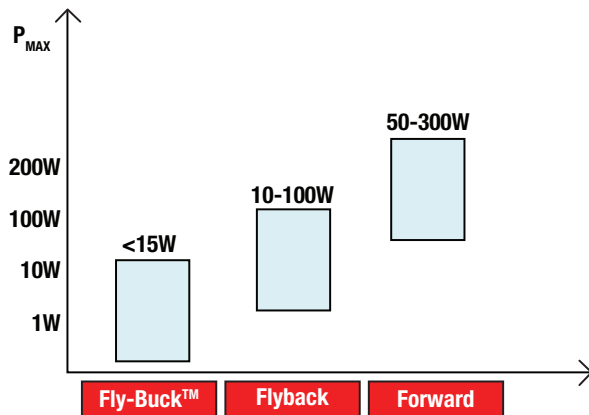

Figure 8. Isolated converter types recommended for different power levels

Factors affecting Fly-Buck regulation

Fly-Buck converters regulate primary output voltage (V_{OUT1}) using a closed-loop controller. The secondary output (V_{OUT2}) is regulated indirectly from the primary output utilizing transformer (magnetic) coupling.

The secondary output regulation is passive or open loop. The following circuit parameters affect the secondary output regulation:

- winding leakage inductances
- winding resistances
- synchronous switch RDSON

To achieve better secondary output (V_{OUT2}) regulation, select a low-leakage (higher coupling) transformer. A reasonable design target is 1% or lower leakage inductance.

Fly-Buck transformers or coupled inductors

The transformer used in the Fly-Buck topology is a coupled inductor or a Flyback type transformer. It stores energy just like an inductor in a buck converter. Transformers used in forward, half-bridge, or full-bridge topologies store no or negligible amount of energy and are not suitable for a Fly-Buck topology.

The most straight-forward way of designing or selecting Fly-Buck magnetics is to treat it as an inductor. Typically (coupled) inductors are selected based on inductance, turns ratio, and saturation current rating, whereas the transformer design or selection uses parameters like volt-second product, flux density, number of turns, core-volume, to a name a few. Most electrical engineers are more comfortable with electrical quantities such as inductance and peak-current rating than with magnetic quantities. Treating the Fly-Buck transformer as a coupled inductor helps the designer focus on the electrical circuit. The details of the transformer design are only needed if a custom transformer is required.

Many magnetics suppliers provide Fly-Buck transformers. Reference 5 contains a list of recommended transformer part numbers and

reference designs that us them. Additionally, a large number of off-the-shelf-coupled inductors are available that can be used in Fly-Buck designs. Any flyback-type transformer with suitable turns ratio also can be used in Fly-Buck designs.

How much power can a Fly-Buck converter manage?

The Fly-Buck topology transfers power to the secondary when the low-side switch (synchronous rectifier) is conducting. As the duty cycle of the control switch (D=TON/T) increases, the duty cycle of the synchronous switch decreases (1-D). For a given average secondary current, the peak current in the secondary winding, and the peak reflected current in the primary winding and the synchronous rectifier increase. Regulation suffers due to the high current flowing into the transformer and switch impedance. This impedance consists of resistance and leakage inductance of the windings, and the resistance of the synchronous switch.

To maintain good regulation, the duty cycle of Fly-Buck converters should be kept below 50 percent (D < ½). This places a maximum output power limit for practical use of Fly-Buck converters. At lower input voltages, the available power increases linearly with the input voltage. At higher input voltage, the power output is limited by the maximum current capability of the part and the output voltage. A maximum output voltage on the primary side (V_{OUT1}) of 15V usually covers most practical applications. Figure 9 serves as a guide for selecting the maximum output power as a function of minimum operating input voltage for TI's Fly-Buck converters.
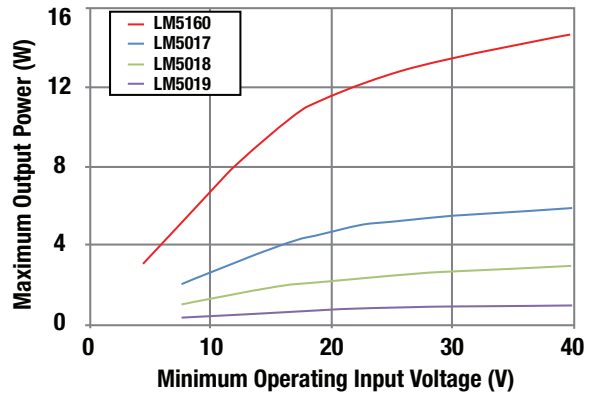

Figure 9. Maximum output power of Fly-Buck converters

Conclusion

The Fly-Buck topology is a simple and easy approach to create isolated, bipolar, or multi-rail bias supplies. Potential applications include industrial automation, building infrastructure, telecom equipment, medical equipment, and test and measurement systems. The Fly-Buck topology has several advantages over other design methods involving flyback or discrete transformer driver or push-pull approaches for low-power bias designs. TI's wide offering of Fly-Buck regulator ICs cover industrial and telecommunication rails up to 100V. Additionally, there are several ready-to-use designs that can reduce the time, effort, and expertise needed to come up with isolated bias solutions.

References

1. Reference Design PMP7993.1: Powering PLC I/O module with LM5017 Fly-Buck reference design

2. Reference design TIDA-00199: Wide-input isolated IGBT gate-drive Fly-Buck power supply for three-phase inverters

3. Reference design PMP7798.1: Wide V_{IN} Fly-Buck™ power converter with two isolated bias supplies + one non-isolated power

4. Choudhary, Vijay. AN-2292 Designing an isolated buck (Fly-Buck) converter, Texas Instruments Application Report, December 2014

5. Kollman, Robert. Pick the right turns ratio for a Fly-Buck converter, EETimes, February 18, 2014

6. Download these datasheets: LM5160A, LM5017, LM5018, LM5019

7. Choudhary, Vijay. Fly-Buck converter PCB layout tips, TI Power House, April 1, 2014

8. Choudhary, Vijay. When is Fly-Buck the right choice for your isolated power needs? ECN, August 4, 2014

9. Xiang Fang and Wei Liu, Product How to: Fly-Buck adds well-regulated isolated outputs to a buck without optocouplers, EDN, April 6, 2014

10. Ready-to-use Fly-Buck reference designs

11. Here's more information on Fly-Buck and Wide V$_{IN}$-Solutions

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