*Product Overview*

# ***Isolated Power Topologies for PLC I/O Modules and Other Low-Power Applications***

*Juergen Schneider, Brian King*

*Systems Engineering and Marketing*

Designers of programmable logic controller (PLC) I/O modules or other industrial low-power applications have to find a reliable design for proper and safe operation of their designed circuits under the conditions of a harsh industrial environment. Isolated power converters are frequently found in such applications and help in the following:

- Avoiding or breaking potential ground loops
- Avoiding coupling between adjacent channels or modules
- Providing electrical safety

Common design requirements for such isolated power converters used specifically in PLC I/O module applications include the following, which are also similarly applicable to other industrial low-power applications:

- Input voltage: Field power voltages, often 24 V ±20% to 30% (a wide range of up to 17 V to 36 V, sometimes even wider) or lower voltages like 4.5 V to 6 V (for example, from the backplane or generated as an intermediate supply rail from the 24 V)
- Output voltages: typical voltages like 3.3 V, 5 V, 12 V, or even 24 V, but also split rails like ±5 V, ±15 V , ±18 V
- Output voltage accuracy: better than 3% to 5% desired, optocoupler-less designs preferred to reduce complexity and improve reliability
- Output power: up to 4 W to 5 W, sometimes up to 10 W or above
- Size: small size designs needed, height often limited to a range of 4 mm to 8 mm
- Type of isolation: in most cases, functional isolation for breaking ground loops (1 kV to 2.5 kV for a 1-second to 1-minute test), but also more stringent ones ranging from basic, up to reinforced insulation in cases when electrical safety is required
- Power efficiency: needs usually to be very high (80 to 90% or higher desired) to provide the lowest full-power losses due to the following reasons:
  - Small plastic housing, no forced air flow
  - Maximum ambient temperature of application in the range of 50°C to 70°C, expected ambient board temperature level in the range of 85°C to 105°C
  - Total power consumption per PLC module is often limited to 2 W to 4 W due to thermal restrictions based on the previously-listed items. The majority of this power is targeted for the payload. Additional power losses in the isolated power converters; therefore, need to be minimized.

Table 1 provides an overview of usable isolated power topologies and proposed TI devices addressing the aforementioned requirements.

All of the listed topologies are optocoupler-less approaches – although the underlying traditional topologies which are found in higher power designs are known to use optocoupler feedback.

The table groups the proposed topologies into the following categories:

- Non-regulated
- $V_{IN}$ controlled
- Quasi-regulated
- Regulated

The provided minimum and maximum input voltage values ($V_{IN}$ minimum, $V_{IN}$ maximum) of the devices represent the best-case values of all the listed devices supporting a specific topology. The 2.95 V given as

$V_{IN}$ minimum for the fly-buck topology is related to the minimum $V_{IN}$ of the TPS55010, whereas the 120 V given as $V_{IN}$ maximum for this topology represents the maximum $V_{IN}$ of the LM5168 and LM5169. Specific topologies like fly-buck-boost and primary side regulated flyback[(3)] require an additional margin to be applied.

The given maximum output power (maximum $P_{OUT}$) is representing the capability of the most powerful device given for a specific topology and depends furthermore on the ratio $V_{OUT}/V_{IN}$ and the turns ratio of the used transformer.

V_ISO stands for the isolation voltage of the used transformer and is often related to specific technical standards.

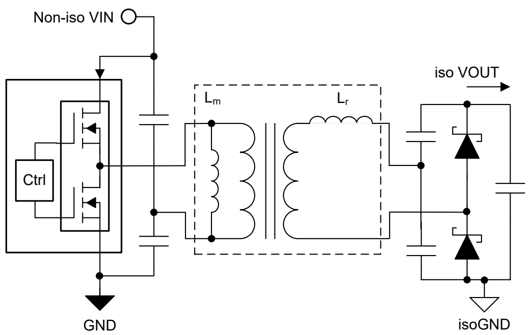


**Figure 1. Open-Loop LLC**

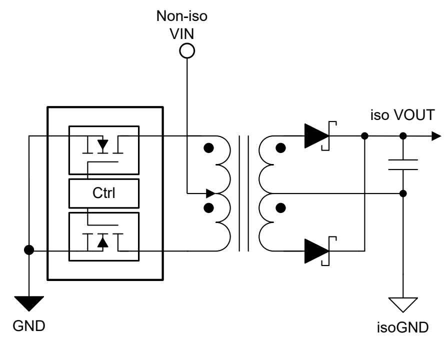


**Figure 2. Open-Loop Push-Pull**

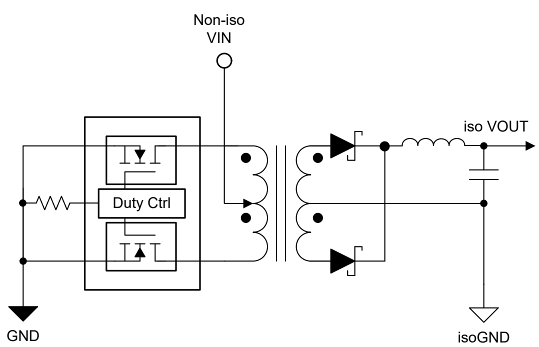


**Figure 3. Duty Cycle Controlled Push-Pull**

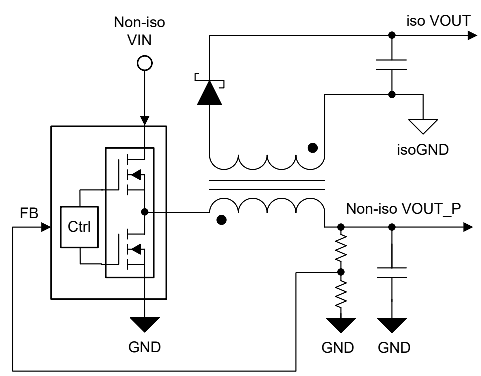


**Figure 4. Fly-Buck**

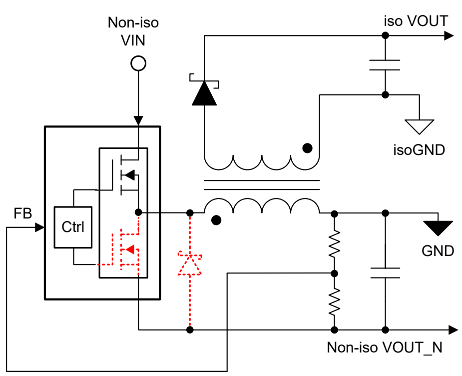


**Figure 5. Fly-Buck- Boost**

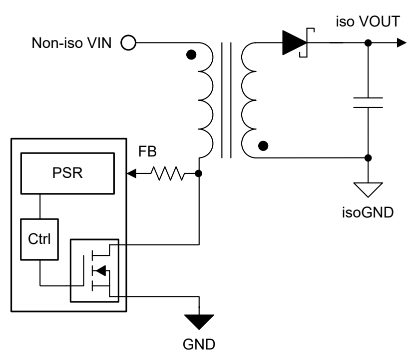


**Figure 6. Primary Side Regulated Flyback**

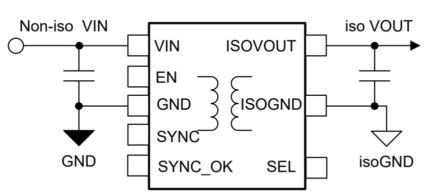


**Figure 7. Fully-Integrated Modules**

### Table 1. Usable Isolated Power Topologies and Proposed TI Devices

| Parameter | Open-Loop LLC (see Figure 1) | Open-Loop Push-Pull (see Figure 2) | Duty Control Push-Pull (see Figure 3) | Fly-Buck (see Figure 4) | Fly-Buck Boost (see Figure 5) | Primary-Side Regulated Flyback (see Figure 6) | Fully-Integrated Modules (see Figure 7) |
|---|---|---|---|---|---|---|---|
| $V_{IN\ (MIN,\ MAX)}$ | 9 V, 34 V | 2.25 V, 36 V | 3 V, 36 V | 2.95 V, 120 V | 2.95 V,<br>120 V – \|Non-iso $V_{OUT\_N}$\| | 4.5 V, 65 V(3) | 4.5 V, 26.4 V |
| MAX $P_{OUT}$ | Up to 9 W | Up to 10 W | Up to 5 W | Up to 15 W | Up to 10 W | Up to 15 W | Up to 2 W |
| $V_{OUT}$ Regulation | Non-regulated | | $V_{IN}$ controlled | Quasi-regulated | | Regulated | Regulated and non-regulated |
| V_ISO | Depends on used transformer | | | | | Up to 5 $kV_{RMS}$ | |
| Type of Isolation | | | | | | Up to reinforced | |
| EMI | Best | Good | Good | Better | Better | Good | (4) |
| Supporting Devices | UCC25800-Q1 | SN6501,<br>SN6505A, SN6505B<br>SN6505D-Q1,<br>SN6507 | SN6507 | LM5017, LM5018, LM5019,<br>LM25017, LM25018, LM25019,<br>LM5160, LM5160A, LM5161,<br>TPS55010,<br>LM5168-Q1, LM5169-Q1<br>(1)<br>LMR50410XF, TPS560430XF,<br>TPS560430X3F TPS560430YF,<br>LMR23630F, LMR23630AF,<br>LM73605 , LM73606,<br>LMR36015FB, LMR36503RF,<br>LMR36503MSC-Q1,<br>LMR36520FA | (2)<br>LM5017, LM5018,<br>LM5019, LM5160,<br>LM5168-Q1, LM5169-Q1 | LM5180, LM5181,<br>LM25180, LM25183,<br>LM25184 | UCC12050, UCC12040,<br>UCC12051-Q1, UCC12041-Q1,<br>UCC14240-Q1, ISOW784x,<br>ISOW7841A-Q1, ISOW774x,<br>DCH01, DCPA1, DCP01B,<br>DCR01, DCV01, DCP02,<br>DCR02 |
| Reference Designs (Examples) | PMP23061,<br>PMP23216,<br>PMP23209 | TIDA-01576,<br>PMP22992,<br>PMP21561 | SN6507DGQEVM | TIDA-00688,<br>TIDA-00689,<br>PMP15006,<br>PMP10532,<br>PMP9298 | PMP10545,<br>PMP10733,<br>PMP10571 | TIDA-010048,<br>TIDA-010006,<br>TIDA-01535,<br>PMP30750,<br>PMP22760 | TIDA-01434 |
| Additional Collateral | SLUAAB9 | SLLA587,<br>SLLA436,<br>SLLA566 | SLLA587,<br>SLLA566 | SLYT615,<br>SLPY004,<br>SNVA790,<br>FLYBUCK FLYBACK Design Calculator | E2E™ forum blog post,<br>FLYBUCK FLYBACK Design Calculator | SNVAA28,<br>SNVA900,<br>SLYT800<br>PSR Flyback Design Tool | SLUA977,<br>SLLA553,<br>SLYY202,<br>SLLA561 |

(1) Basically any synchronous buck which can be forced to operate in CCM or in forced PWM and for which a negative current limit is large enough and specified can work in low-power, fly-buck configuration. Select the appropriate device version out of a device family. Cross-check negative current limit and loop stability - see data sheets and additional collateral.
(2) Basically any buck converter, even non-synchronous buck. Cross-check loop stability and consult collateral for inverting buck boost such as SNVA856, SLVA933, SLVA910, SLYT286, SLVAE10, SLVA317.
(3) Additional limitation of 65 V or 100 V exists for switch-node voltage; see the specific data sheet especially regarding the reflected output voltage and the needed clamp circuit.
(4) Depends on specific module and used topology

# IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265