Isolated Power Supplies for PLC I/O Modules

Tobias Puetz, Systems Engineer
Industrial Systems
Agenda

• PLC I/O Modules

• Isolated Power Topologies

• Fly-Buck

• Fly-Buck-Boost

• Design Examples and Resources
PLC I/O Modules

Types
Power Requirements
Why Isolation Is Necessary
PLC I/O Modules Types

Module Types
- Analog Input / Output
- Digital Input / Output
- Special Function
- Transducer
Example: Analog Input Module
Power consumption (isolated side) : < 1W

Typical voltage levels:
• MUX, AMP: ±12V
• ADC, REF, Data Isolation: 5V, 3.3V
PLC I/O Modules Why Isolation Is Necessary

• Protect equipment and humans from high voltage surges

• Handle ground loops / potential differences between electrical circuits that are connected over large distances

• Communicate reliably in systems with high side components (i.e. inverter / motor drive) or switches in general
Isolated Power Topologies for PLC I/O Modules

Push-Pull
Fly-Back
Fly-Buck
Isolated Power Topologies **Push-Pull**

**Advantages**

+ Simple to use
+ Little board space required
+ Low cost

**Disadvantages**

- No regulation
- High voltage stress for $Q_1$, $Q_2$

**Device Examples**

- SN6501
- SN6505

$$V_{out} = V_{in} \cdot \frac{N_s}{N_p}$$
Isolated Power Topologies **Fly-Back**

**Advantages**
+ Single primary switch
+ Wide $V_{in}$
+ Good regulation

**Disadvantages**
- Optocoupler needed
- High peak currents

**Device Examples**
- UCC28600
- LM5022
- LM5001

\[ \frac{V_{out}}{V_{in}} = D \cdot \sqrt{\frac{T \cdot V_{out}}{2 \cdot I_{out} \cdot L_p}} \]
Isolated Power Topologies Fly-Buck

**Advantages**
- Primary regulated
- Wide $V_{in}$
- Non-isolated + isolated output

**Disadvantages**
- Bad regulation ($\pm 5\%$)

**Device Examples**
- LM5017
- LM5160
- TPS55010

\[
V_{out} = V_{pri} \cdot \frac{N_s}{N_p} - V_D
\]
Fly-Buck

Topology
Working Principle
Things to Consider
Fly-Buck Topology

\[ V_{\text{pri}} = V_{\text{in}} \cdot D = V_{\text{in}} \cdot \frac{t_{\text{on}}}{t_{\text{on}} + t_{\text{off}}} \]

\[ V_{\text{out}} = V_{\text{pri}} \cdot N - V_D \]
Fly-Buck Working Principle

- **$t_{on}$** - $Q_1$ closed, $Q_2$ open:
  - Current flows through $L_{pri}$
  - Diode $D$ is reversed biased
  - No current flowing on sec. side

- **$t_{off}$** - $Q_1$ open, $Q_2$ closed:
  - Voltage across $L_{pri}$ and $L_{sec}$ reverses
  - Current flowing

$=>$ Device needs to support forced PWM mode!
**Fly-Buck Things to Consider – Duty Cycle**

- **High duty cycle** => short energy transfer time
- **Low duty cycle** => short energy charge time

\[
D = \frac{t_{on}}{t_{on} + t_{off}}
\]

\[
I_{pri} \cdot t_{on} = I_{sec} \cdot t_{off} \cdot N
\]

\[
I_{pri} = I_{sec} \cdot N \cdot \frac{1 - D}{D}
\]

- **Bad output voltage regulation** because of high peak currents on primary or secondary side

Choose \( D \) between 40% and 60%
Fly-Buck Things to Consider – Leakage Inductance

- Lower leakage inductance
  ⇒ Higher peak currents secondary side
  ⇒ Higher voltage drop across diode

- Higher leakage inductance
  ⇒ shorter energy charge times

Example 1:
Regulation of $V_{out}$ over duty cycle for increasing leakage inductance
Fly-Buck Things to Consider – Leakage Inductance

- Lower leakage inductance
  ⇒ Higher peak currents secondary side
  ⇒ Higher voltage drop across diode

- Higher leakage inductance
  ⇒ shorter energy charge times

Example 2:
Peak currents of $I_{sec}$ voltage for different leakage inductances
Fly-Buck-Boost

Topology
Fly-Buck Comparison
Fly-Buck-Boost Topology

\[ -V_{pri} = V_{in} \cdot \frac{t_{on}}{t_{off}} = V_{in} \cdot \frac{D}{1 - D} \]

\[ V_{out} = -V_{pri} \cdot N - V_D \]
Fly-Buck-Boost Fly-Buck Comparison

Advantages over Fly-Buck

- Easy generation of positive and negative supply rails
  Bipolar supplies needed for MUX, AMP

- Suited for bigger input voltage range
  Example: $V_{\text{in}} = 15V$, $V_{\text{out}} = 12V$
  Fly-Buck: $D = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{12V}{15V} = 80\%$
  Fly-Buck-Boost: $D = \frac{|V_{\text{out}}|}{V_{\text{in}} + |V_{\text{out}}|} = \frac{12V}{15V + 12V} = 44.4\%$

Disadvantage

- Switches need to withstand higher voltages
  $V_{Q1,\text{max}} = V_{\text{in,\text{max}}} + |V_{\text{pri}}|$
Fly-Buck-Boost Fly-Buck Comparison

**Example 3:** Duty cycle
- $N=1$
- $V_{out} = 12V$

**Example 4:** Output regulation
- $N=1$
- $V_{out} = 12V$

Source: https://www.pddnet.com/article/2015/03/inverting-fly-buck-design-simplifies-bipolar-rail-generation
Designs and Resources

TI Desings
PMPs
Application Notes
Links
<table>
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<tr>
<th><strong>TIDA-00237</strong></th>
<th>Ultra-Small 1W, 12V-36V Iso. Power Supply for Analog Prog. Logic Controller Modules Reference Design</th>
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<tr>
<td><strong>TIDA-00688</strong></td>
<td>1W Isolated Power Supply with Planar Transformer Reference Design</td>
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<td><strong>TIDA-00689</strong></td>
<td>Small Footprint Isolated Analog DC/DC Converter Reference Design</td>
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<td><strong>TIDA-00174</strong></td>
<td>IGBT Driver Bias for AC Motor Drive</td>
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<td>PMP7993</td>
<td>Flybuck Quad Isolated Output Power Supply</td>
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<td>PMP10491</td>
<td>9-36V Input, 5V/3A Output Synchronous Flyback Converter Reference Design</td>
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<td>PMP10532</td>
<td>Isolated Tri-output Fly-Buck Power Supply for Industrial PLC Applications</td>
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<tr>
<td>PMP10535</td>
<td>Low Profile, Quad Output, Isolated Fly-Buck Power Supply for Industrial Applications</td>
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Fly-Buck(TM) converter provides EMC and isolation in PLC applications

AN-2292 Designing an Isolated Buck (Fly-Buck) Converter (Rev. C)

Design a Flybuck Solution with Optocoupler to Improve Regulation Performance

Designing isolated rails on the fly with Fly-Buck™ converters
Designs and Resources Links

www.ti.com/automation

www.ti.com/flybuck

www.ti.com/flyback
Questions and Answers