Isolated Power Supplies for PLC I/O Modules

Industrial Systems - Factory Automation and Control
Agenda

• Where and why?

• What are my choices?

• Fly-Buck - How does it work, what is important?
  – Working principle
  – Why duty cycles of 40-60% should be chosen
  – Effects of leakage inductance
Where and why?

- Where: PLC modules where only limited power is required (1-4 W)
- Why: Isolated supplies for Multiplexer, Amplifier, ADC, Reference, Isolator

Example
Group Isolated Analog Input Module
What are my choices?

- **Push-Pull** (SN650x)
  - + Simple to use
  - + Low cost
  - - No regulation (especially critical for transformers with high turn ratios)

- **Flyback** (UCC28xxx)
  - + Mid power (5W-100W)
  - + Single primary switch
  - + Wide $V_{in}$ range
  - + Good regulation (if secondary side regulated)
  - - Needs optocoupler

- **Fly-Buck** (LM5xxx, TPS55010)
  - + Low power (<10W)
  - + Primary side regulation (no optocoupler)
  - + Non-isolated + isolated outputs
  - + Wide input range
  - - Bad regulation

Active Clamp, Half & Full Bridge oversized for power requirements (mostly used for >50W)
Fly-Buck – How does it work, what is important?
Topography

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

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

\[ N = \frac{N_{\text{sec}}}{N_{\text{pri}}} \]

\[ V_{\text{sec}} = V_{\text{pri}} \cdot N - V_{D1} \]
Working Principle

- **$t_{on}$ - $S_1$ closed, $S_2$ open:**
  - Current flows through $L_{pri}$, secondary side voltage / $D_1$ is reversed biased
  - No current flowing

- **$t_{off}$ - $S_1$ open, $S_2$ closed:**
  - Voltage across $L_{pri}$ and $L_{sec}$ reverses
  - Current flowing
Why duty cycles of 40-60% should be chosen

Too low or too high duty cycles lead to short energy charge or energy transfer times.

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

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

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

\[ \frac{I_{pri}}{I_{sec}} \]

Too low or too high duty cycles lead to short energy charge or energy transfer times.

\[
\begin{align*}
I_{pri} \cdot t_{on} &= I_{sec} \cdot t_{off} \cdot N \\
I_{pri} &= I_{sec} \cdot N \cdot \frac{1 - D}{D}
\end{align*}
\]

\[
\begin{align*}
D &= \frac{t_{on}}{t_{on} + t_{off}} \\
I_{pri} &= I_{sec} \cdot N \cdot \frac{1 - D}{D}
\end{align*}
\]

=> High peak currents on primary or secondary side

=> Transformer needs high saturation current rating
Effects of Leakage Inductance

- Lower leakage inductance
  ⇒ Higher peak currents
  ⇒ Higher voltage drop across D₁

- Higher leakage inductance
  ⇒ High currents increase effect of already high leakage inductance
  ⇒ Bad regulation

Example 1:
Output voltage over duty factor for different leakage inductance

Effects of Leakage Inductance

Example 2:
Peak currents for increasing leakage inductance
⇒ High leakage inductance leads to “too slow” system

Example 3:
Voltage drop across diode for increasing forward current


[http://www.diodes.com/_files/datasheets/ds30086.pdf](http://www.diodes.com/_files/datasheets/ds30086.pdf), Fig. 2
Resources
LM5017 Fly-Buck: Top Industrial Applications

**Factory Automation**
- PLCs and Motor Drives
  - Bias power from main bus
  - +/- bias voltage rails
  - Analog/digital I/O isolation

**Smart Grid**
- E-meters & Solar Inverters
  - Bias power for RS485
  - Bias power for PLC/Relay
  - Inverter system bias supply

**Other Industrial**
- Power Supplies & E-bikes
  - Power Modules: Digital PWM controller bias (UCD3k)
  - eBikes: system bias supply

**Further TI Designs**
- Ultra-Small 1W, 12V-36V Iso Power Supply for Analog Prog Logic Controller Modules Reference Design (TIDA-00237)
- 1W Isolated Power Supply with Planar Transformer Reference Design (TIDA-00688)
- Small Footprint Isolated Analog DC/DC Converter Reference Design (TIDA-00689)
LM5160A Fly-Buck Application-based TI Designs

**Industrial PLCs**
- **Application Needs**
  - 24V input bus typical
  - 18-32V Vin range
  - Isolated multiple outputs
  - Up to 15W total output
- **Reference Design**
  - Isolated triple output 5V@1A, +/-15V@200mA

**Industrial AC Motor Drive IGBT Bias**
- **Application Needs**
  - 24V input bus typical
  - 18-32V Vin range
  - Isolated multiple outputs
  - Up to 15W total output

**EV/HEV Bias**
- **Application Needs**
  - 12V battery, 6-16Vin range
  - Isolated single or multiple outputs
  - Up to 6W total output
- **Reference Design**
  - 3 designs: Isolated +15V@150mA, -9V/150mA, and 5V/200mA for CAN bus

**POE Powered IP Camera/IP Phone**
- **Application Needs**
  - 48Vin typical
  - 36-57V Vin range
  - Isolated or non isolated 12V or 5V output
  - Up to 12W output power
- **Reference Design**
  - 12W POE solution LM5160+TPS2378

**PMP10532**
**PMP10531**
**PMP10588**
**PMP10572**
www.ti.com/automation

www.ti.com/flybuck