Isolated Power Supplies for PLC I/O Modules

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Industrial Systems

Agenda

- PLC I/O Modules
- Isolated Power Topologies
- Fly-Buck
- Fly-Buck-Boost
- Design Examples and Resources

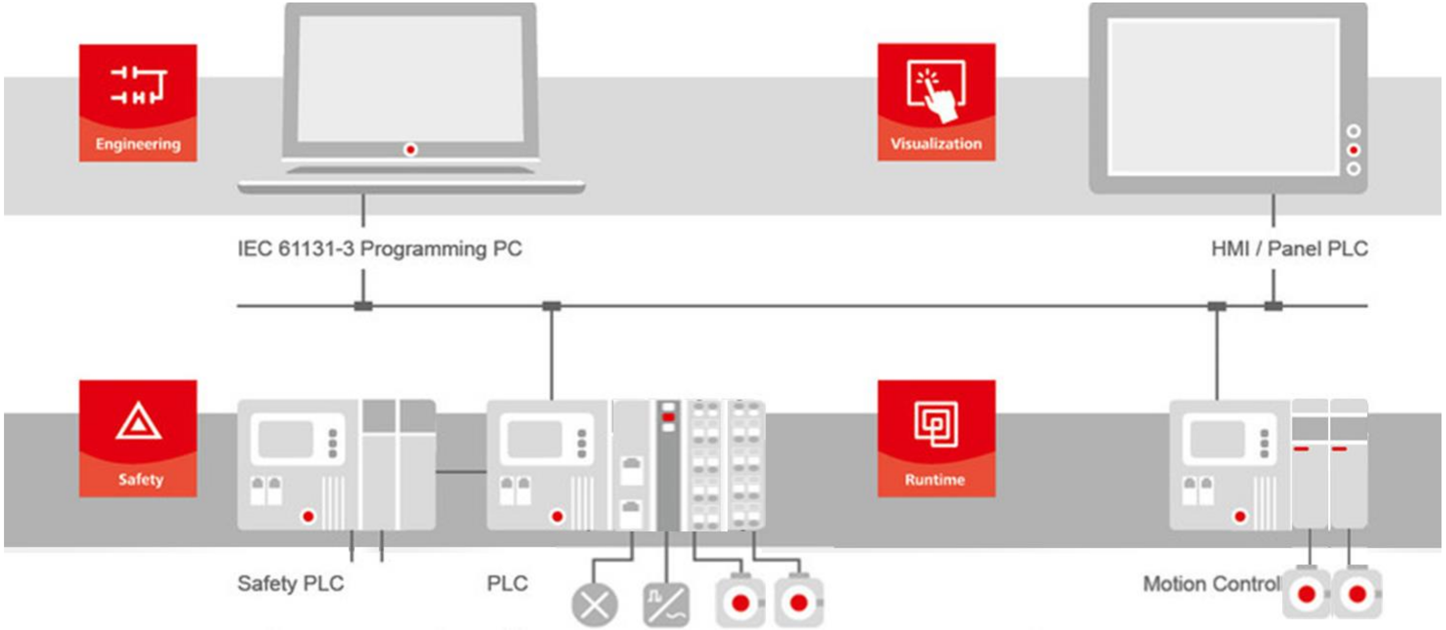
PLC I/O Modules

Types

Power Requirements

Why Isolation Is Necessary

PLC I/O Modules Types



Module Types

- Analog Input / Output
- Digital Input / Output
- Special Function
- Transducer

PLC I/O Modules Power Requirements

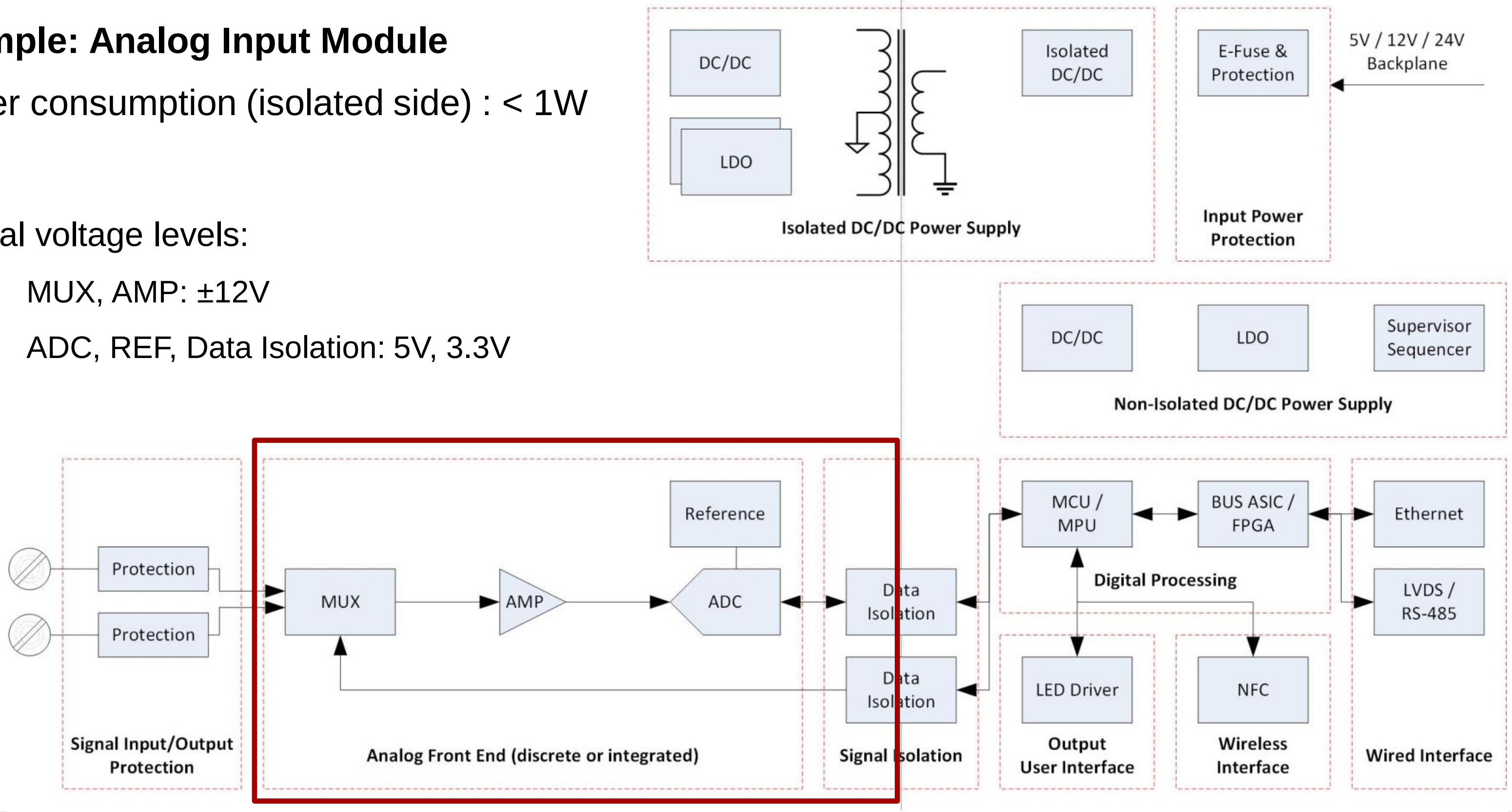
Example: Analog Input Module

Power consumption (isolated side) : < 1W

Typical voltage levels:

- MUX, AMP: ±12V
- ADC, REF, Data Isolation: 5V, 3.3V

±10V



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

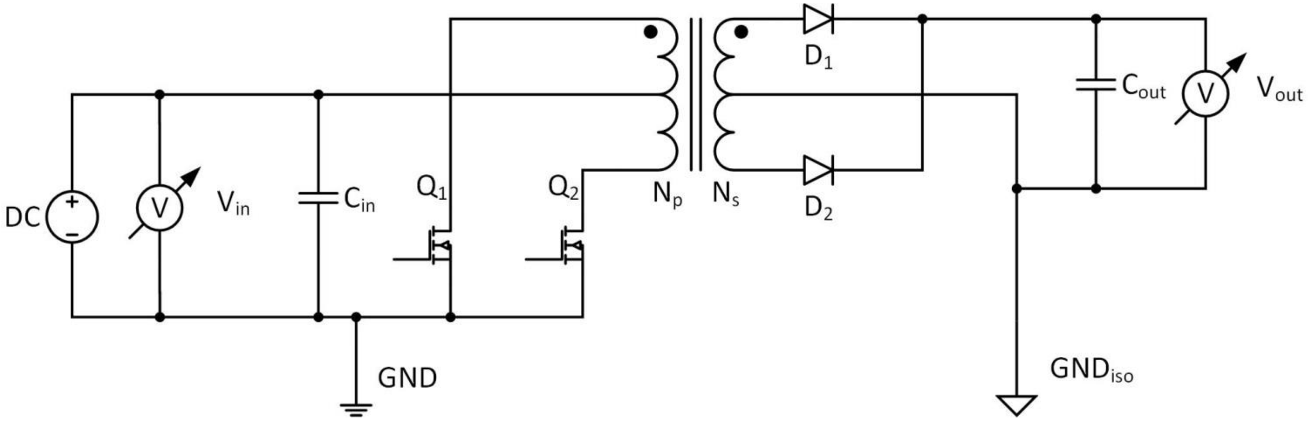
Disadvantages

- 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

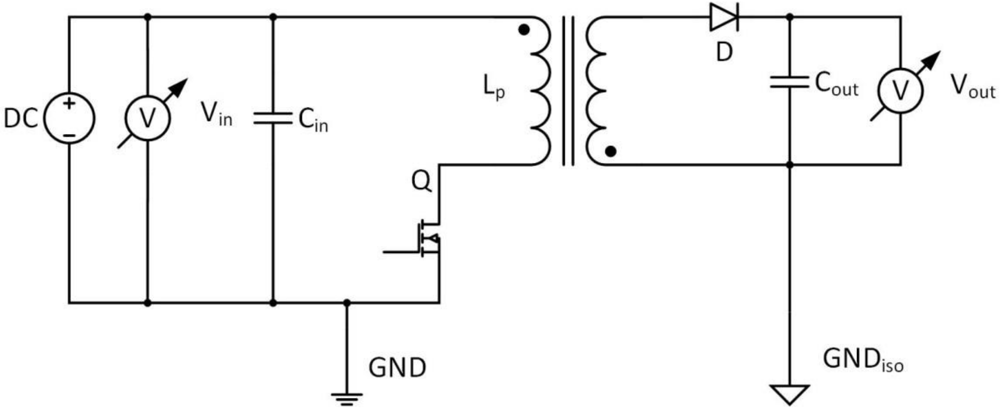
- Optocoupler needed
- High peak currents

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

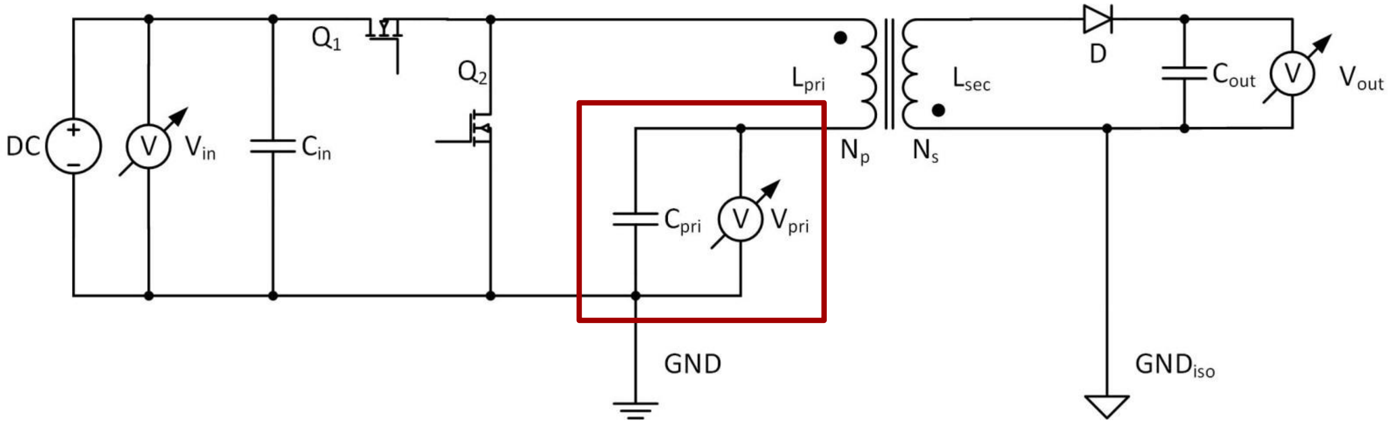
+ Primary regulated
+ Wide V_{in}
+ Non-isolated + isolated output

Disadvantages

- Bad regulation (±5%)

Device Examples

LM5017
LM5160
TPS55010



$$V_{out} = V_{pri} \cdot \frac{N_s}{N_p} - V_D$$

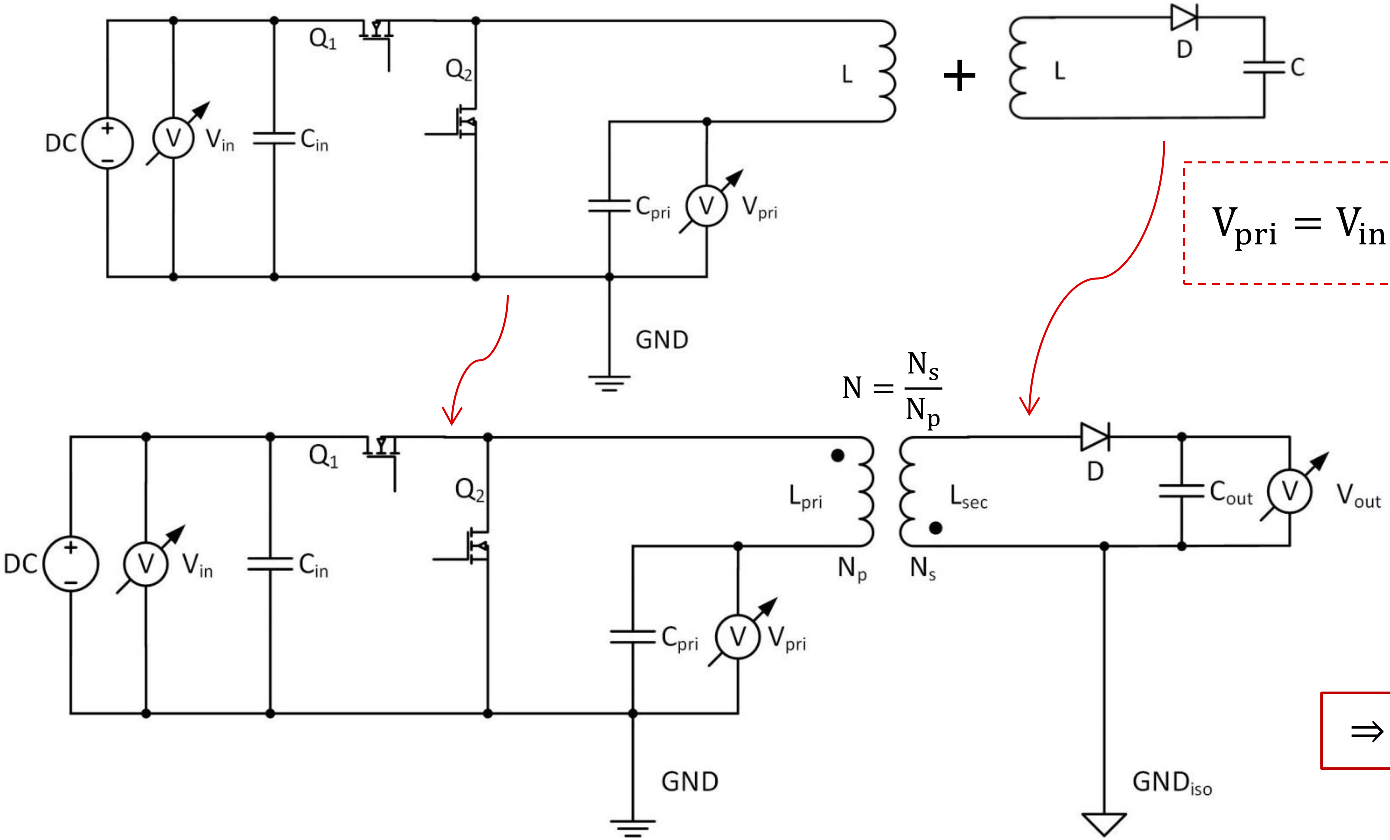
Fly-Buck

Topology

Working Principle

Things to Consider

Fly-Buck Topology



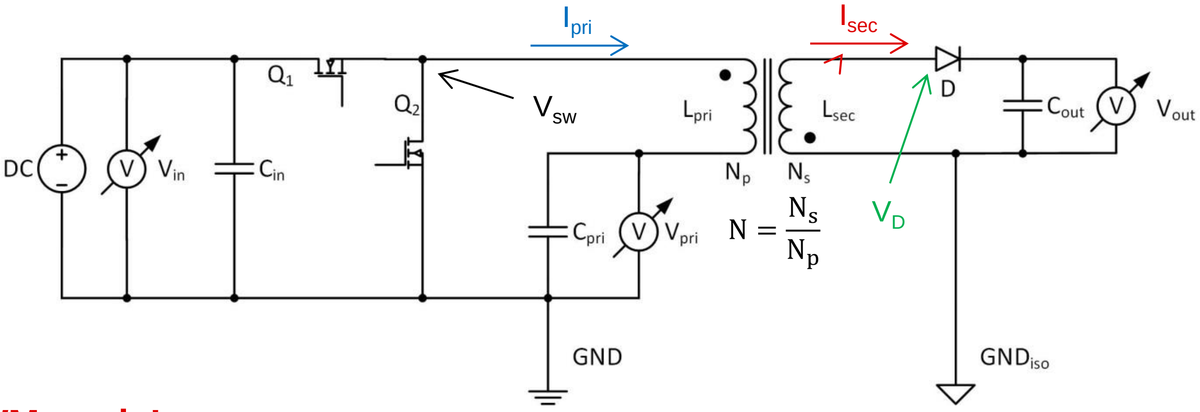
$$V_{pri} = V_{in} \cdot D = V_{in} \cdot \frac{t_{on}}{t_{on} + t_{off}}$$

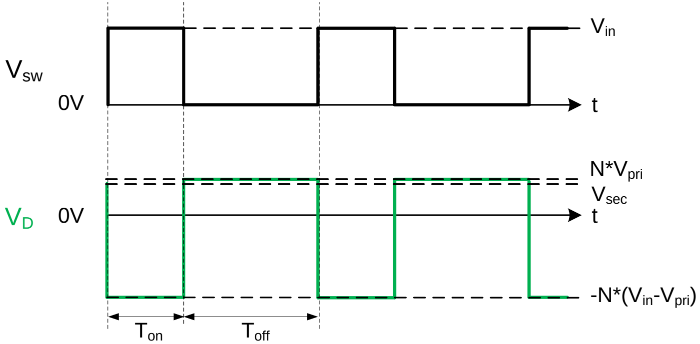
$$\Rightarrow V_{out} = V_{pri} \cdot N - V_D$$

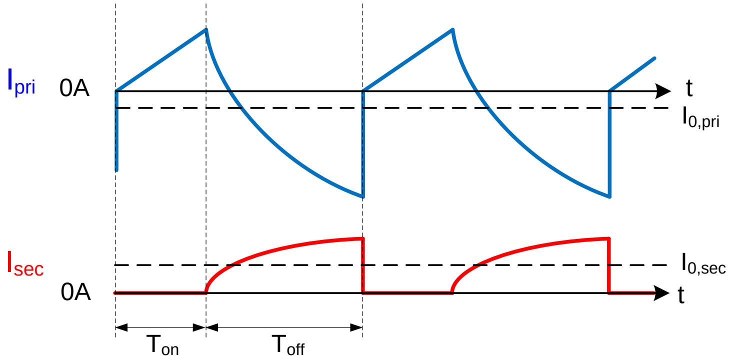
Fly-Buck Working Principle

- 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

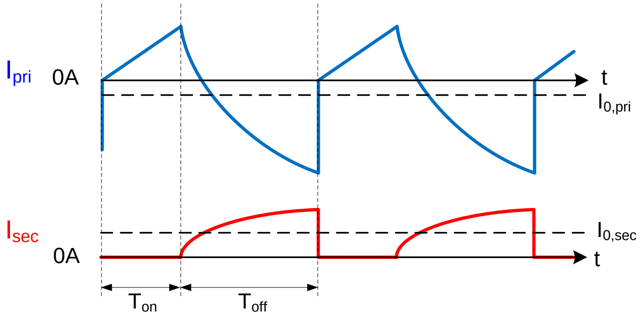
=> Device needs to support forced PWM mode!

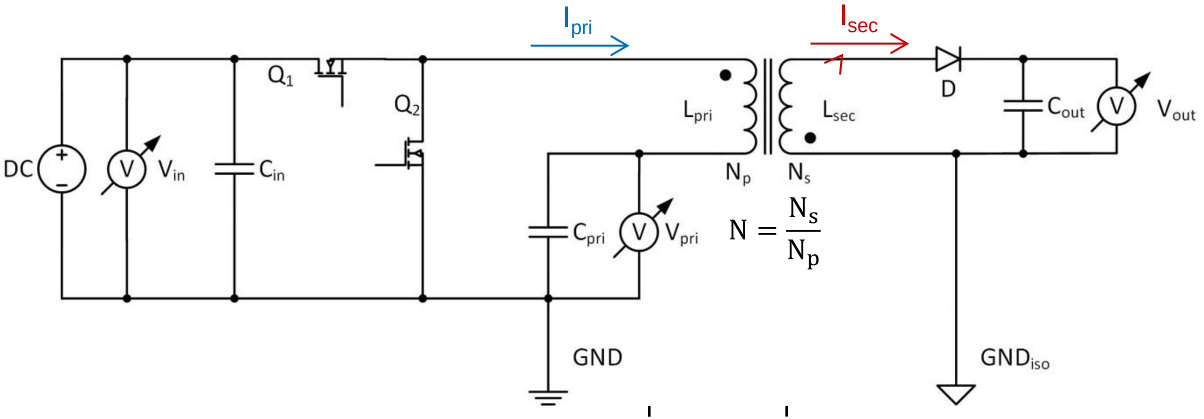






Fly-Buck Things to Consider – Duty Cycle





$$N = \frac{N_s}{N_p}$$

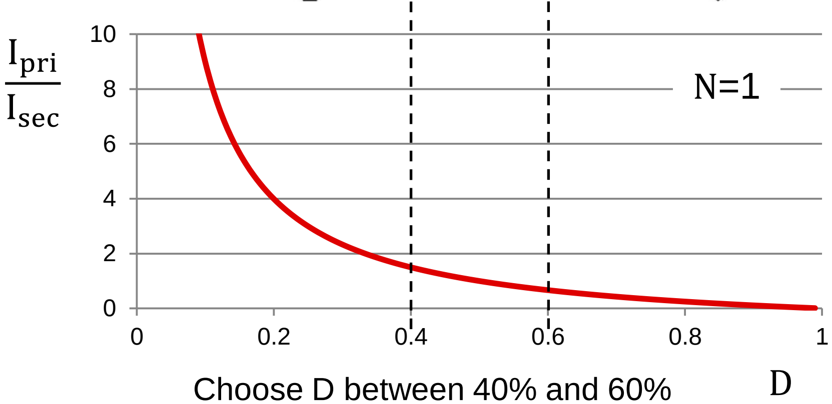
$$D = \frac{t_{on}}{t_{on} + t_{off}}$$

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

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

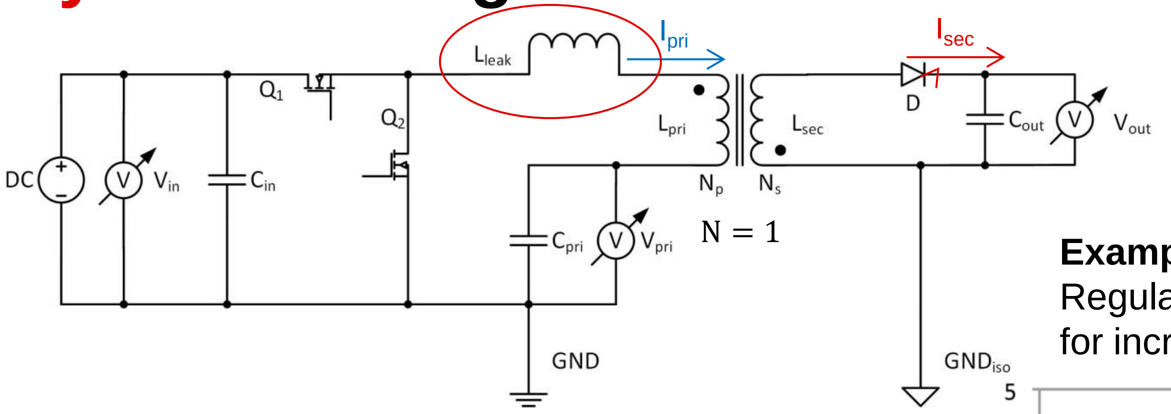
High duty cycle => short energy transfer time
Low duty cycle => short energy charge time

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

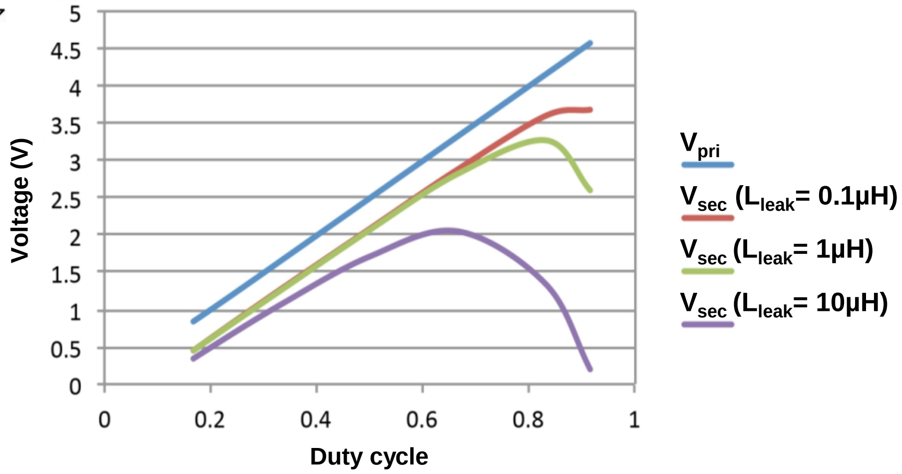


Choose D between 40% and 60%

Fly-Buck Things to Consider – Leakage Inductance

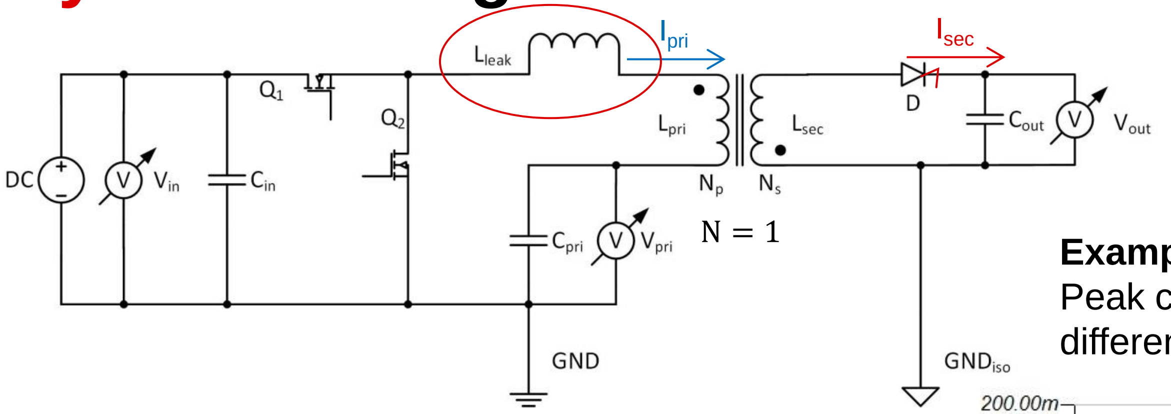


Example 1:
Regulation of V_{out} over duty cycle for increasing leakage inductance

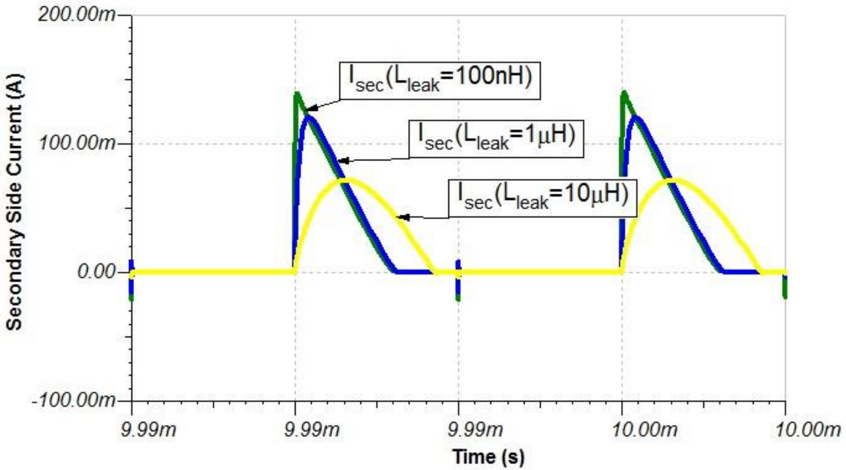


- Lower leakage inductance
  - ⇒ Higher peak currents secondary side
  - ⇒ Higher voltage drop across diode
- Higher leakage inductance
  - ⇒ shorter energy charge times

Fly-Buck Things to Consider – Leakage Inductance



Example 2:
Peak currents of I_{sec} voltage for different leakage inductances



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

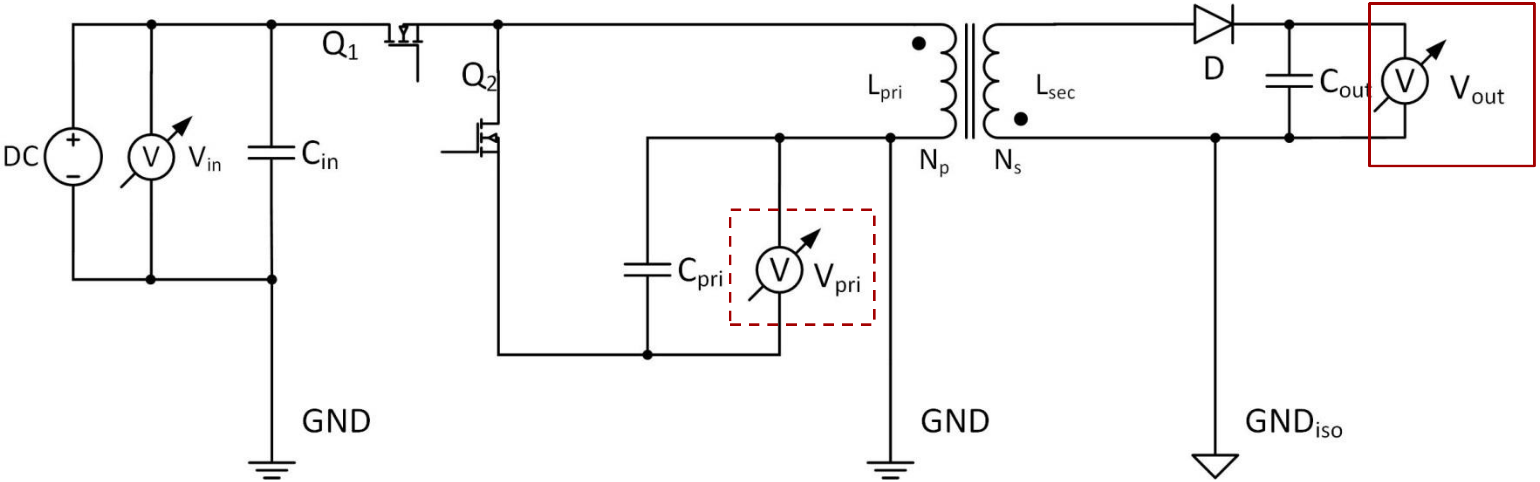
- Higher leakage inductance
  - ⇒ shorter energy charge times

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

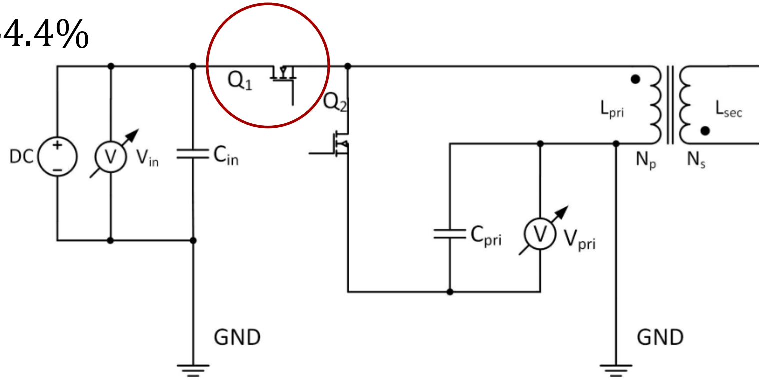
  Bipolar supplies needed for MUX, AMP

- Suited for bigger input voltage range

  Example: V_{in} = 15V, V_{out} = 12V

  Fly-Buck: $D = \frac{V_{out}}{V_{in}} = \frac{12V}{15V} = 80\%$

  Fly-Buck-Boost: $D = \frac{|V_{out}|}{V_{in}+|V_{out}|} = \frac{12V}{15V+12V} = 44.4\%$



Disadvantage

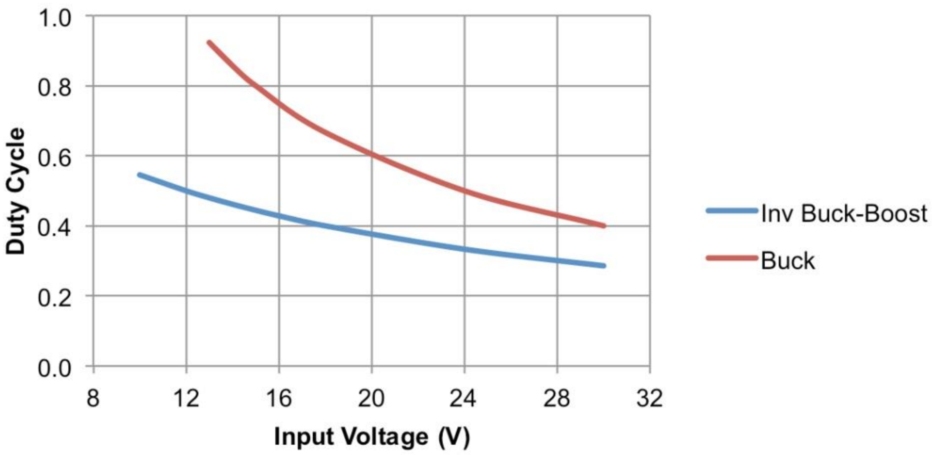
- Switches need to withstand higher voltages

$$\mathbf{V_{Q_1,max} = V_{in,max} + |V_{pri}|}$$

Fly-Buck-Boost Fly-Buck Comparison

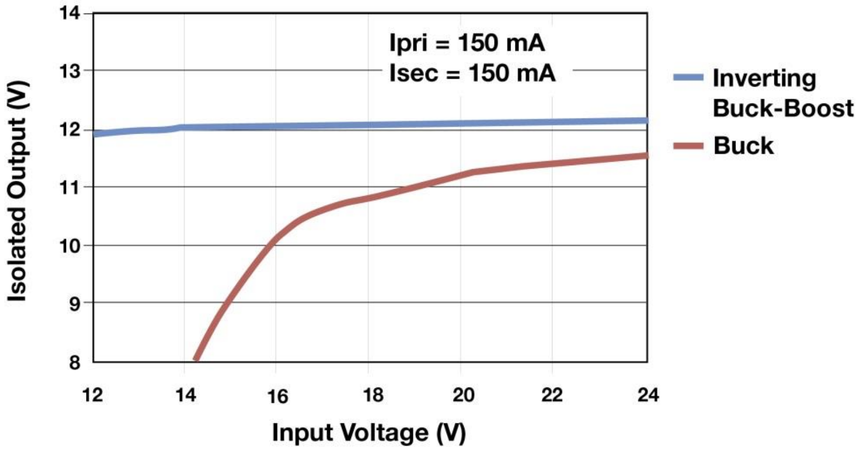
Example 3: Duty cycle

- 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

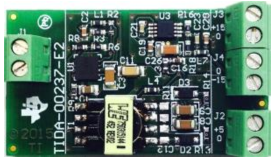
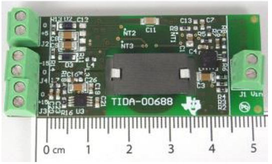
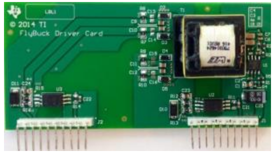
TI Desings

PMPs

Application Notes

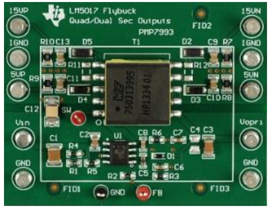
Links

Designs and Resources TIDesigns

TIDA-00237	Ultra-Small 1W, 12V-36V Iso. Power Supply for Analog Prog. Logic Controller Modules Reference Design	
TIDA-00688	1W Isolated Power Supply with Planar Transformer Reference Design	
TIDA-00689	Small Footprint Isolated Analog DC/DC Converter Reference Design	
TIDA-00174	IGBT Driver Bias for AC Motor Drive	

Designs and Resources PMPs

PMP7993 — Flybuck Quad Isolated Output Power Supply



PMP10491 — 9-36V Input, 5V/3A Output Synchronous Flyback Converter Reference Design

PMP10532 — Isolated Tri-output Fly-Buck Power Supply for Industrial PLC Applications

PMP10535 — Low Profile, Quad Output, Isolated Fly-Buck Power Supply for Industrial Applications

Designs and Resources Application Notes

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