开关电源基础

TI大学计划

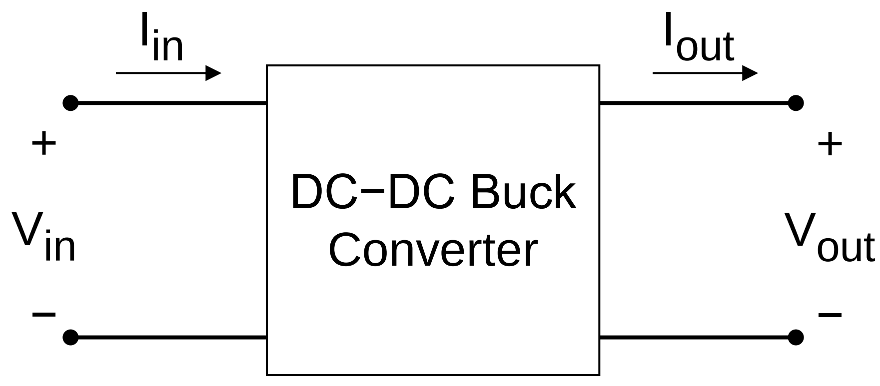
钟舒阳

shuyang-zhong@ti.com

Texas Instruments

Objective – to efficiently reduce DC voltage

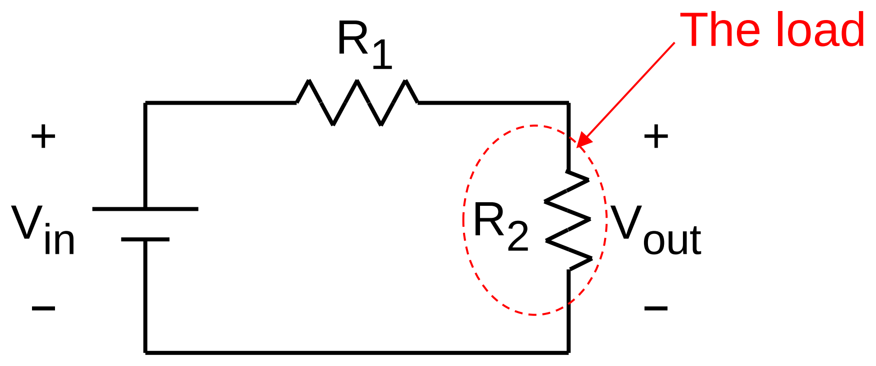
The DC equivalent of an AC transformer



Lossless objective: $P_{in} = P_{out}$, which means that $V_{in}I_{in} = V_{out}I_{out}$ and

$$\frac{V_{out}}{V_{in}} = \frac{I_{in}}{I_{out}}$$

Here is an example of an inefficient DC–DC converter



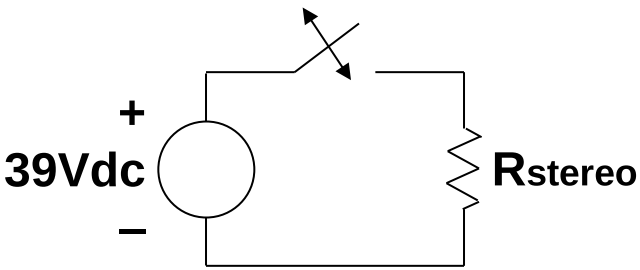
$$V_{out} = V_{in} \bullet \frac{R_2}{R_1 + R_2}$$

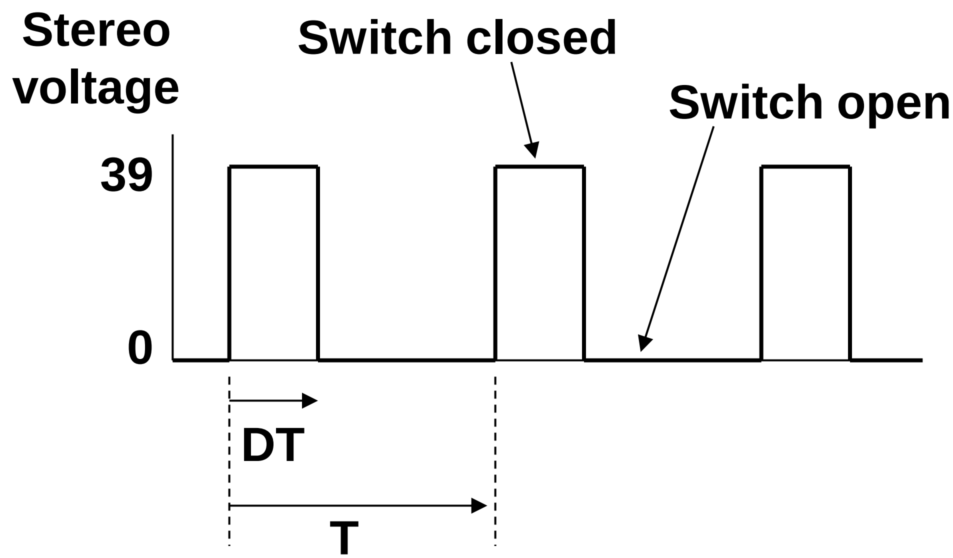
$$\eta = \frac{R_2}{R_1 + R_2} = \frac{V_{out}}{V_{in}}$$

If V_{in} = 39V, and V_{out} = 13V, efficiency η is only 0.33

Unacceptable except in very low power applications

Another method – lossless conversion of 39Vdc to average 13Vdc





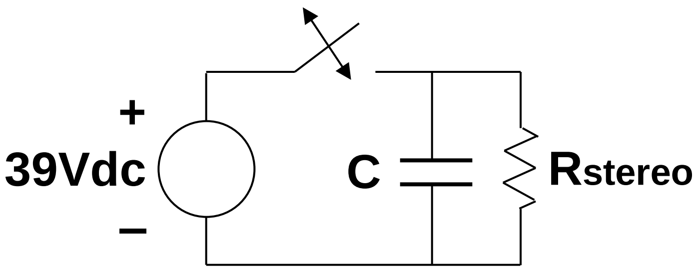
Switch state, Stereo voltage

Closed, 39Vdc

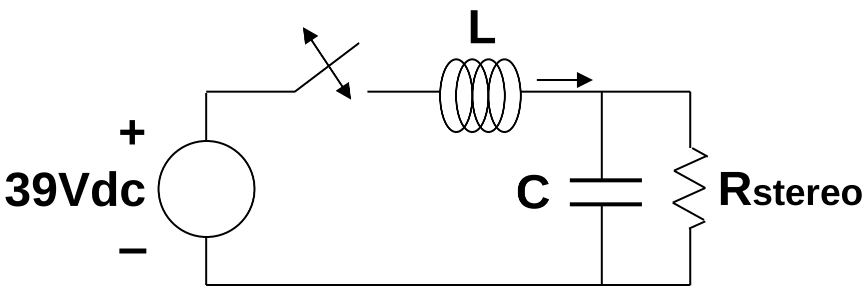
Open, 0Vdc

If the duty cycle D of the switch is 0.33, then the average voltage to the expensive car stereo is 39 • 0.33 = 13Vdc. This is lossless conversion, but is it acceptable?

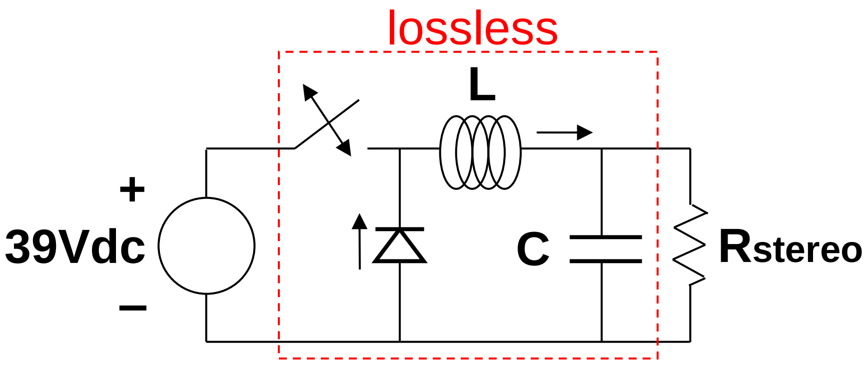
Convert 39Vdc to 13Vdc, cont.



Try adding a large C in parallel with the load to control ripple. But if the C has 13Vdc, then when the switch closes, the source current spikes to a huge value and burns out the switch.



Try adding an L to prevent the huge current spike. But now, if the L has current when the switch attempts to open, the inductor's current momentum and resulting Ldi/dt burns out the switch.

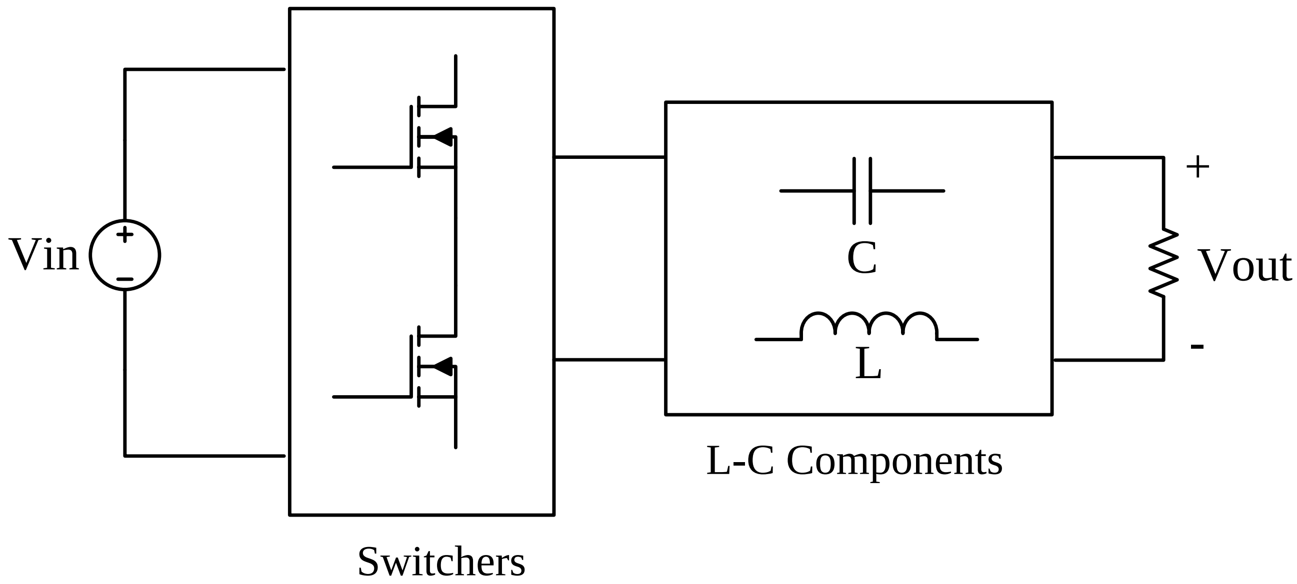


A DC-DC Buck Converter

By adding a "free wheeling" diode, the switch can open and the inductor current can continue to flow. With high-frequency switching, the load voltage ripple can be reduced to a small value.

What is a Switching Regulator?

- The switching regulator is a DC-DC converter that delivers power by using switcher components.
- It offers high power conversion efficiency and design flexibility



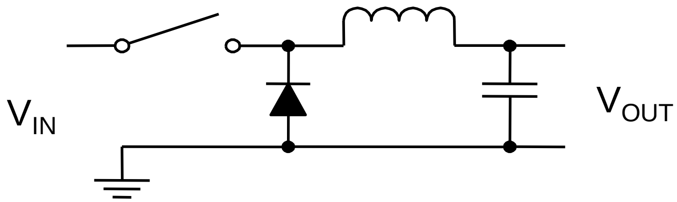
Pros and Cons

Advantages	Disadvantages
• High efficiency • Good thermal performance • High power density • Allow wide input voltage range • V_{out} can be smaller or larger than V_{in} • Isolation possible with transformer • Multiple outputs possible with transformer	• Switching produces higher output ripple & noise • Slow transient response • High complexity as more external components and design variables

Basic Topologies

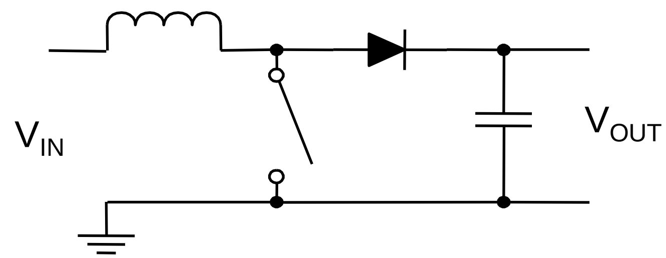
- Three basic types of switching converter topologies: Buck, Boost and Buck-boost

Buck



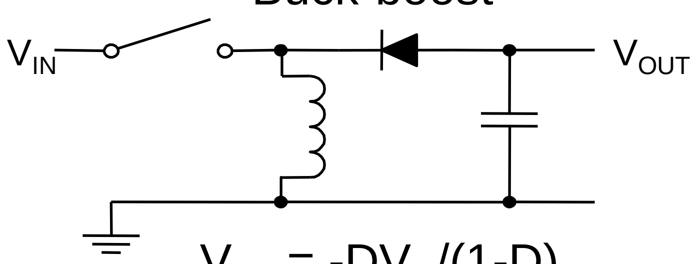
$$V_{out} = D*V_{in}$$

Boost



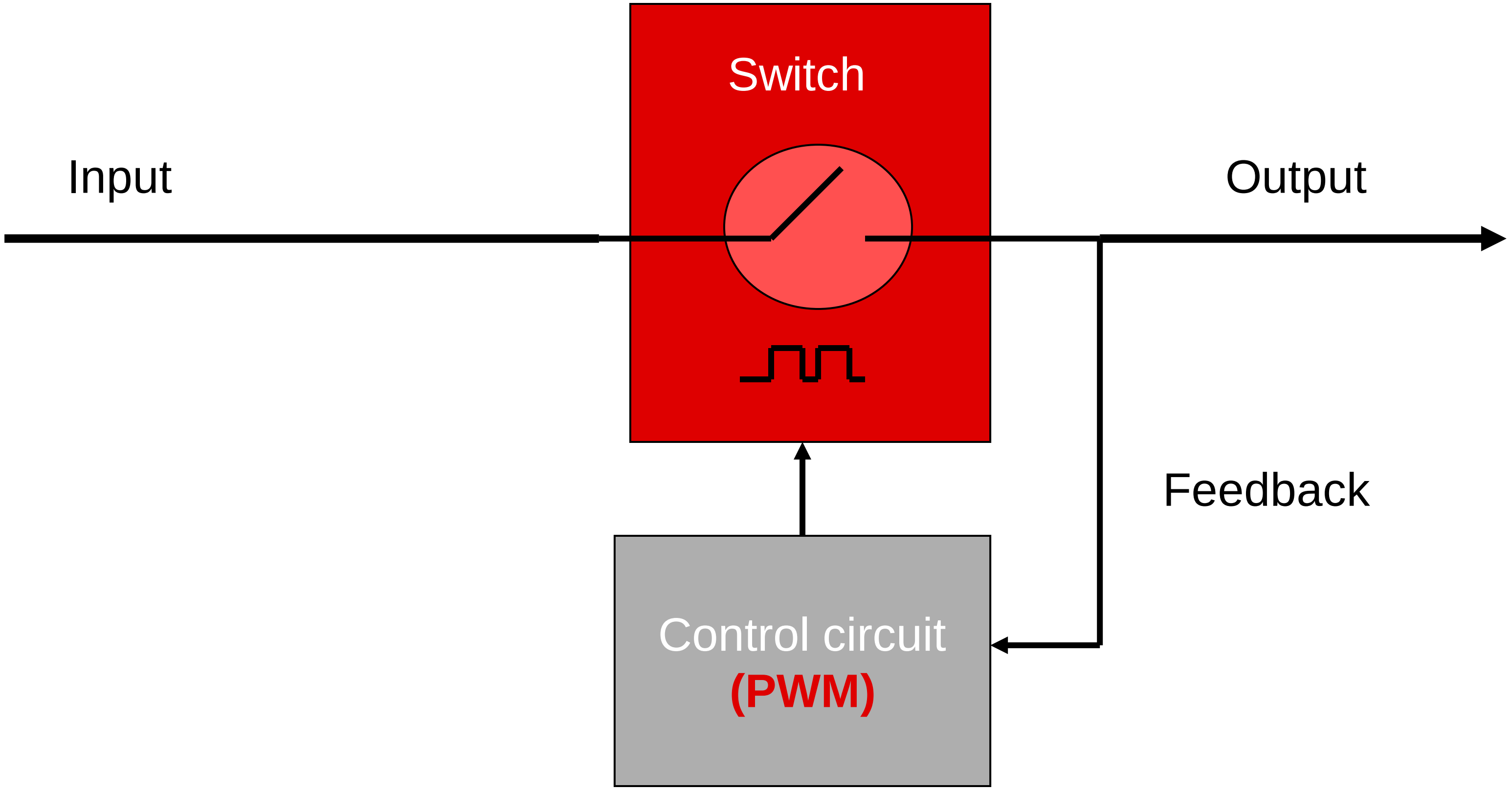
$$V_{out} = V_{in}/(1-D)$$

Buck-boost

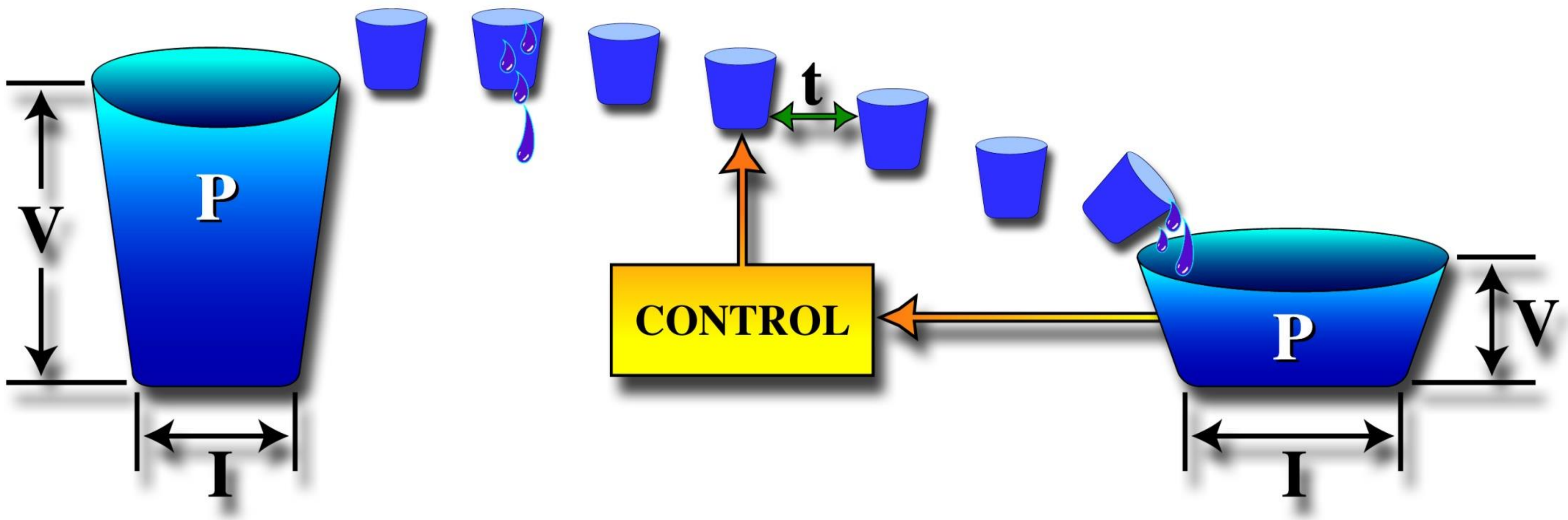


$$V_{out} = -DV_{in}/(1-D)$$

How A Switching Regulator Work?



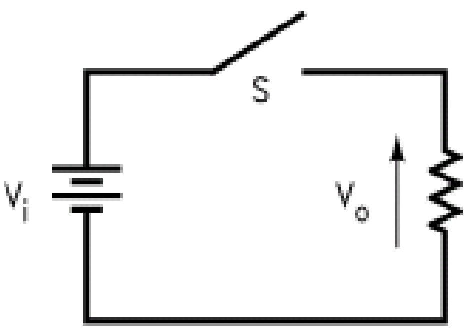
Buck Converter
Step-down Switching Regulator

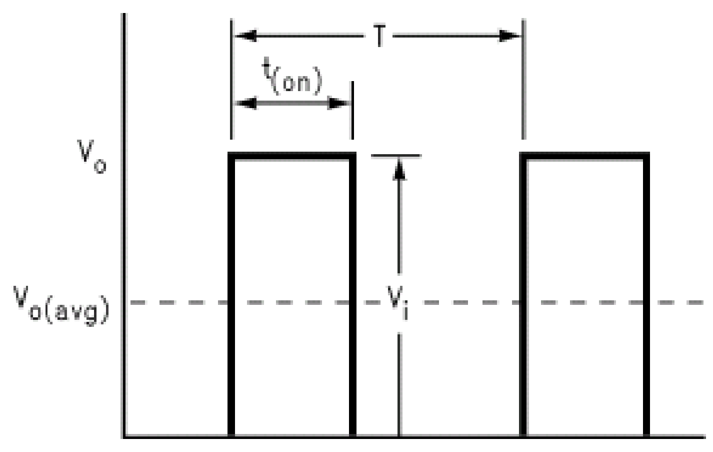


Input | Switching Regulator | Output

What is PWM?

- **P**ulse **W**idth **M**odulation
- Simple way to vary how much of the time the switch is on vs. off
- Duty Cycle (ratio of t_{ON} to T)
- But we can't use a pulsed output! Need a way to smooth the flow of energy

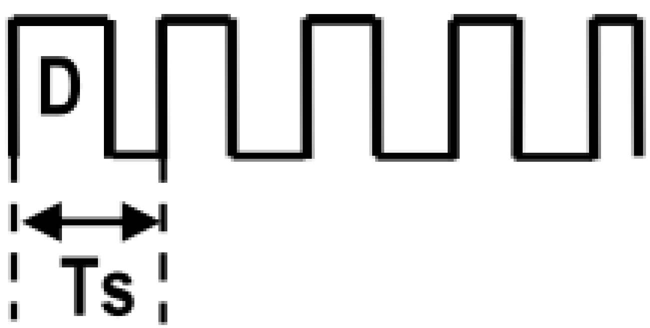




Definitions – PWM and PFM

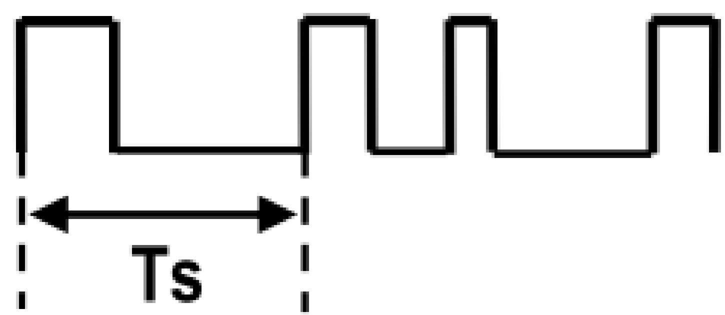
PWM Converter

- PWM = Pulse Width Modulation
- A converter architecture: Fixed-frequency oscillator
- The drive signal: Constant frequency, with variable duty cycle (ratio of power FET ON time to the total switching period)



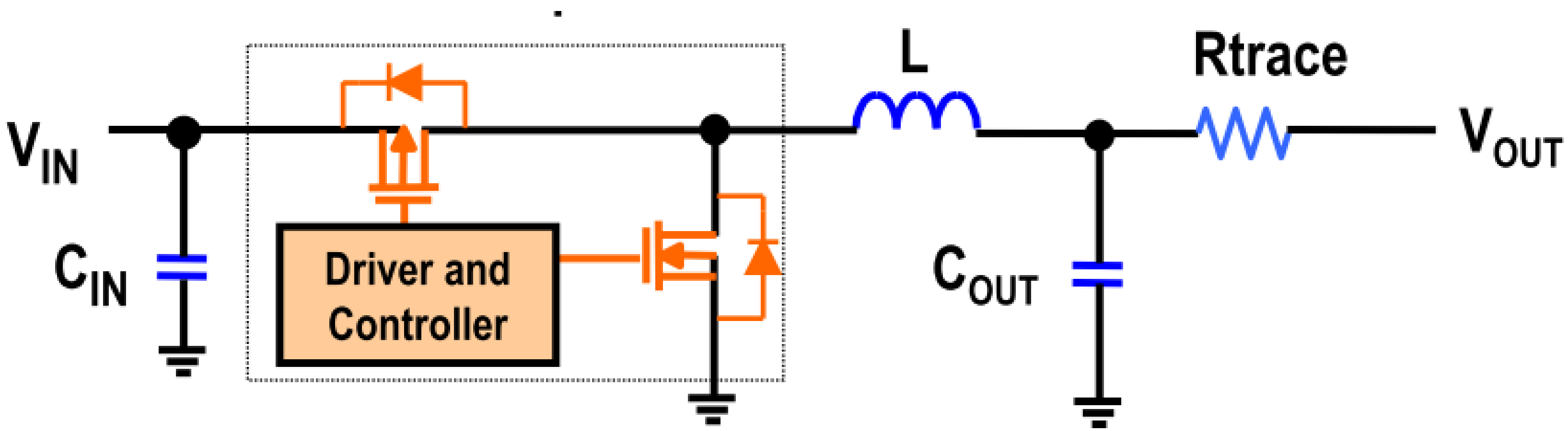
PFM Converter

- PFM = Pulse Frequency Modulation
- A variable-frequency clock is used
- PFM converter examples: “Constant ON-Time” or “Constant OFF-Time” control DC-DC converters.
- Several variations of PFM exist and the term is used to refer to other modes of operation as discussed later…



Converter Efficiency and Losses

- "Loss" = any energy that is drawn from the input without being transferred to the output



MOSFETs

- Switching Losses
- Gate Drive Losses
- Conduction losses

Passive Components

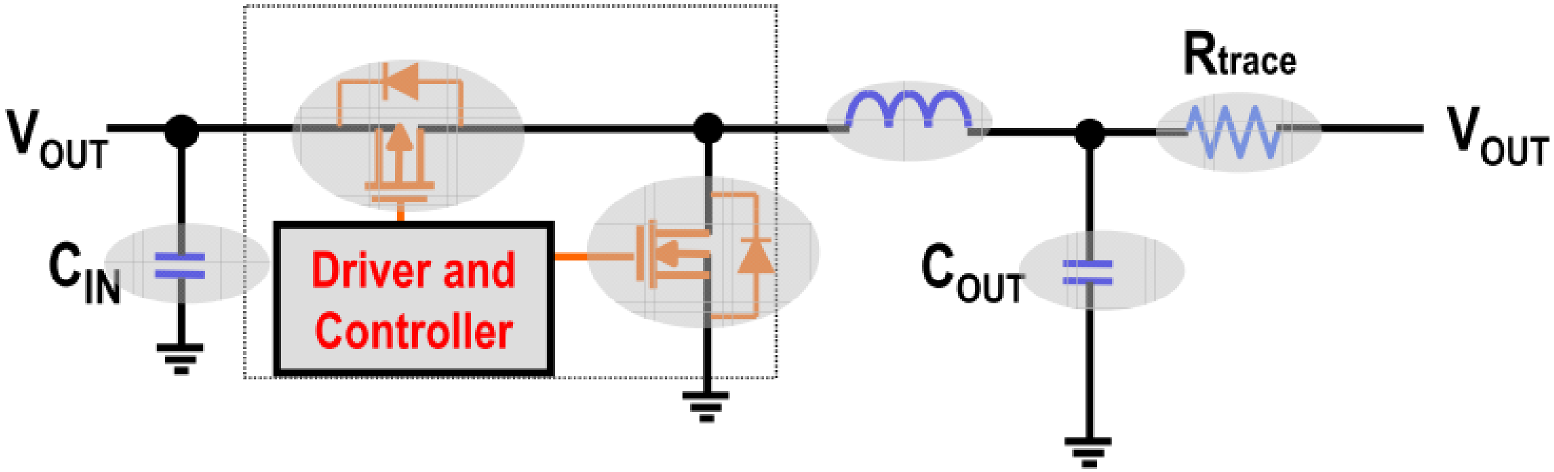
- L: Winding and Core Losses
- Resistive losses
- Cap ESR Losses

Converter IC

- Internal references
- Oscillator Circuit
- Gate Drive Circuits

Converter Efficiency and Losses

- As light load, passive components and FET losses decrease significantly
- IC internal currents are dominated by the oscillator
- At a fixed frequency, IC operating current does not decrease with load.

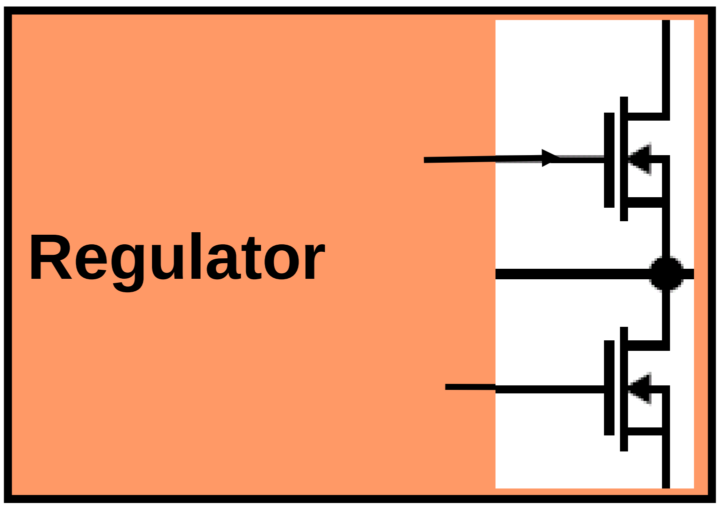


IC Operating Current Affects Light Load Efficiency

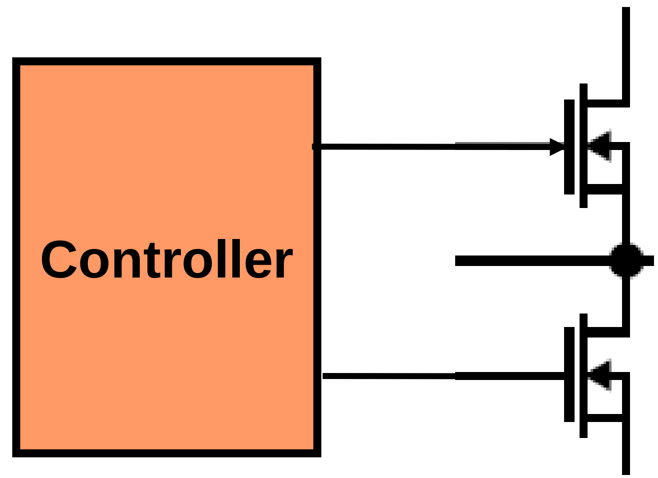
- If load current ~ 200 mA, IC internal current ~ 4 mA
  - “Best Case” efficiency > 90%
- If load current ~ 1 mA, IC internal current ~ 4 mA
  - “Best Case” efficiency < 20%

Controllers vs. Regulators

Regulator	Controller
• Includes switch(es) (sometimes the diode) in one package	• Has switch(es) and diode external to the IC package



- Best for < 3amp
- Low parts count, small footprint
- Thermal concerns



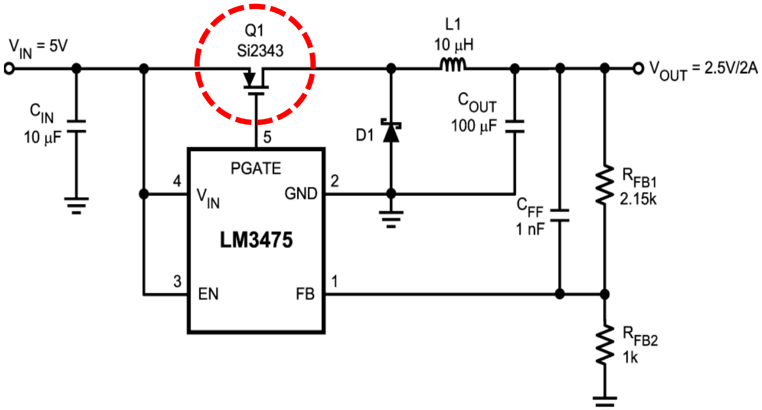
- High current control (>3amps)
- Scalable to load
- Increased component count

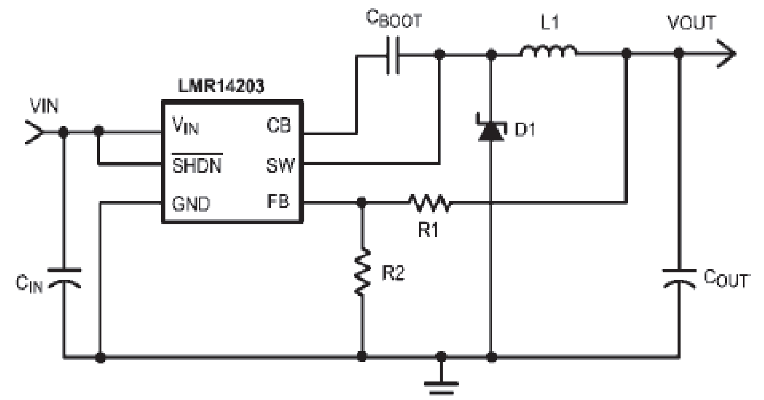
Example for Controller Vs. Regulator

Controller

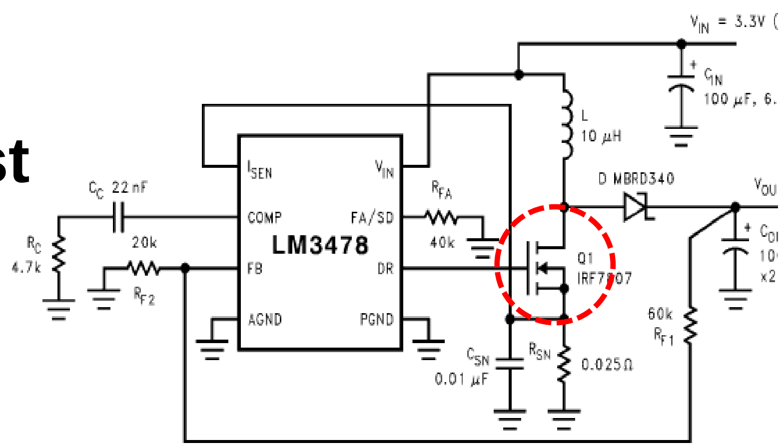
Regulator

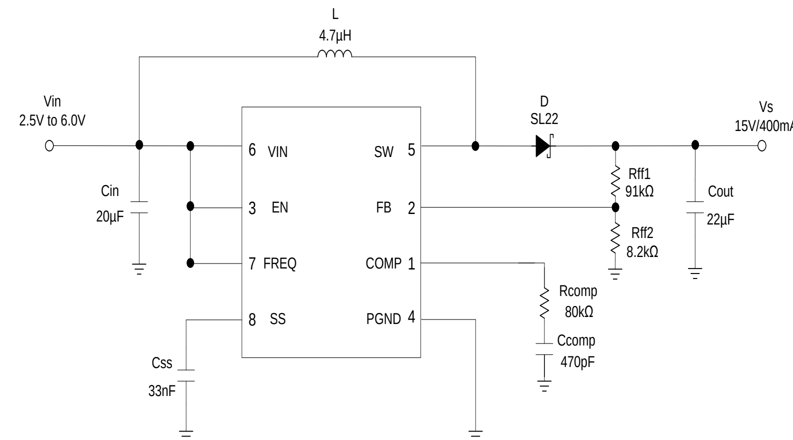
Buck





Boost

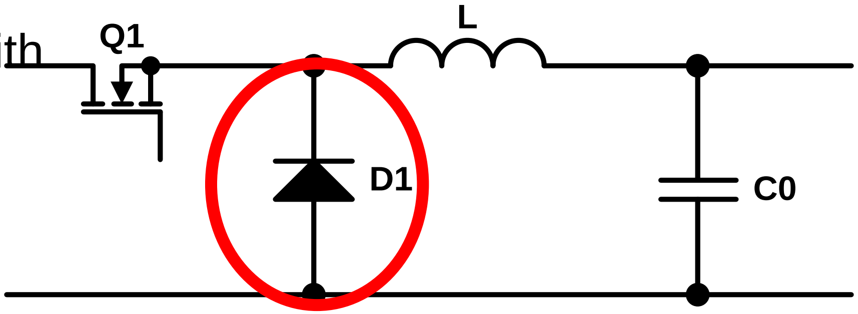




Synchronous vs. Non-Synchronous

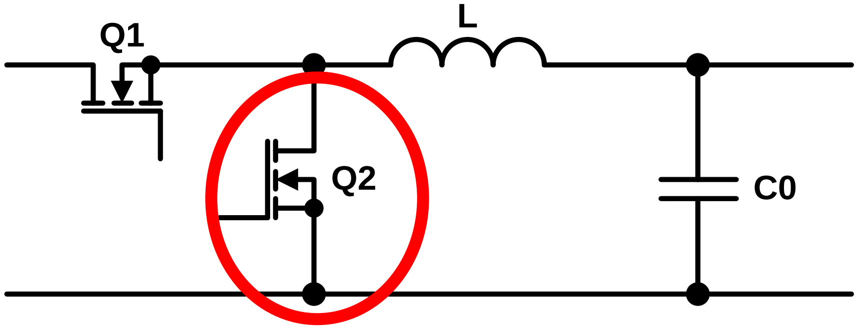
Non-Synchronous Buck

- Diode voltage drop is fairly constant with output current
- Less efficient
- Less expensive
- Used with higher output voltages



Synchronous Buck

- MOSFET has lower voltage drop
- More efficient
- Requires additional control circuitry
- Costs more



http://focus.ti.com/lit/an/slyt358/slyt358.pdf

Synchronous vs. Non-Synchronous

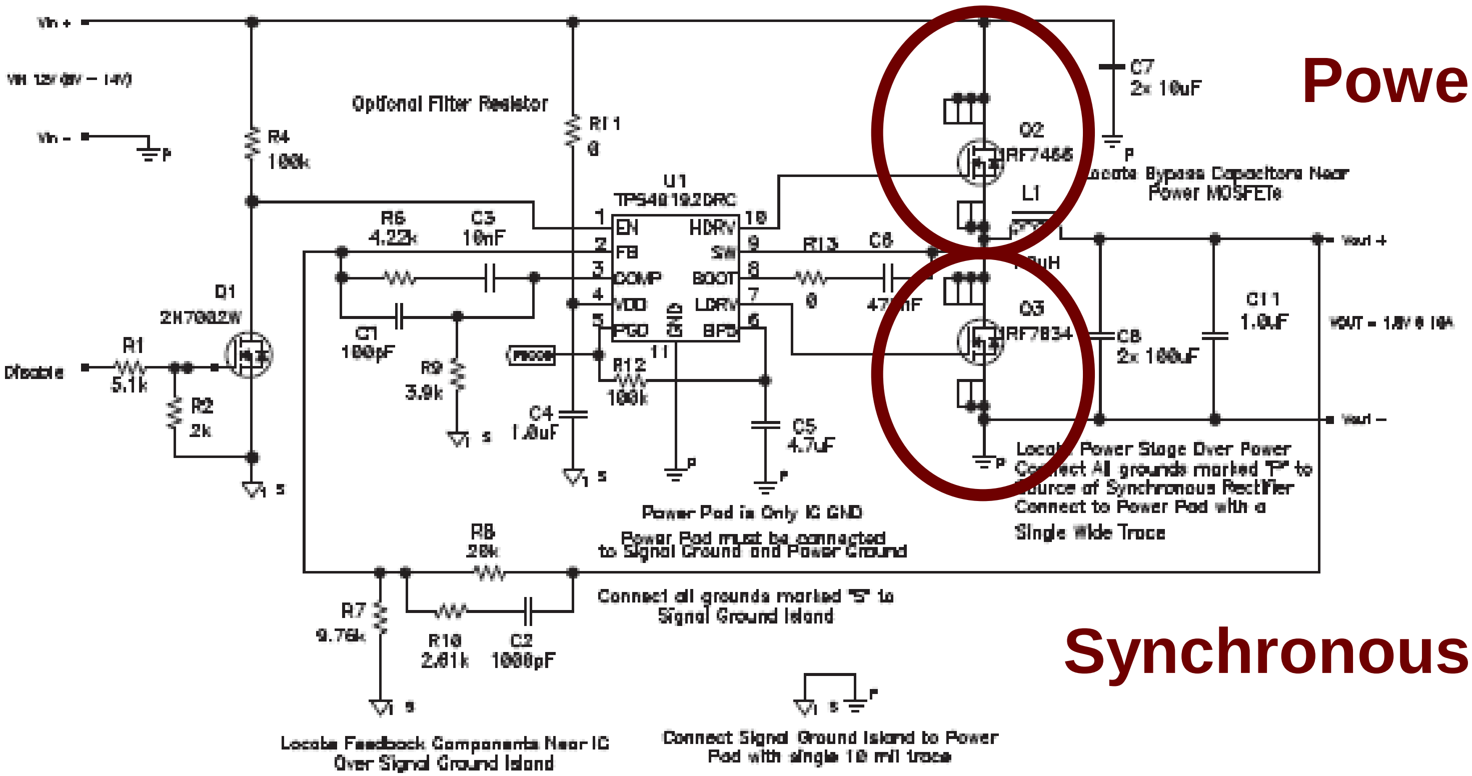
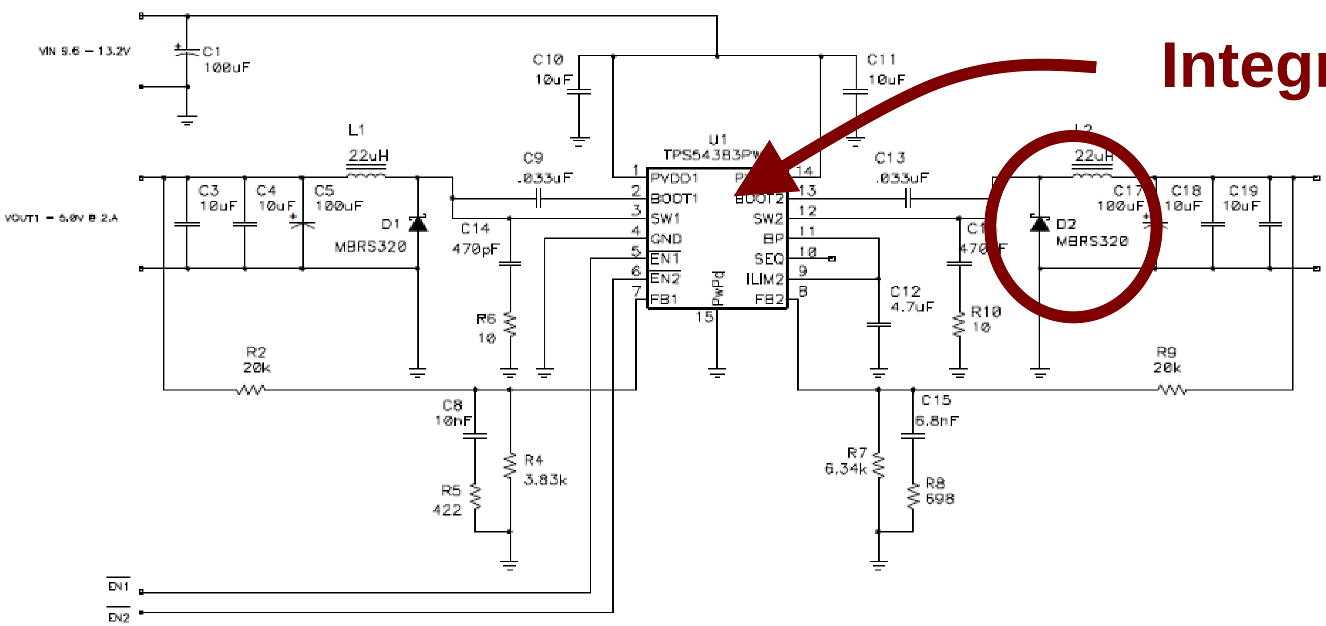


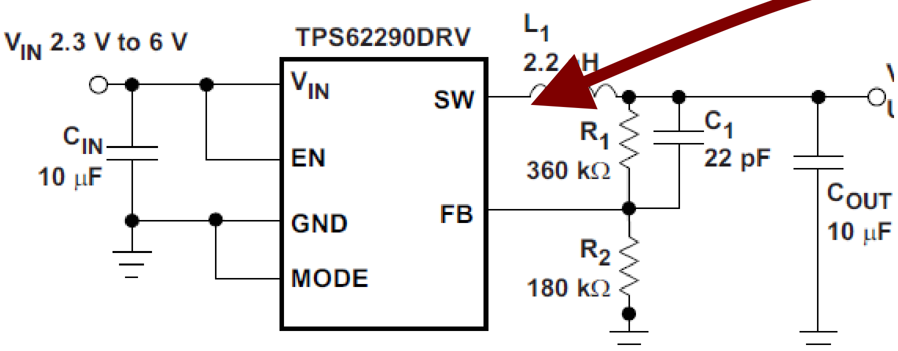
Figure 17. TPS40192 Sample Schematic

Synchronous vs. Non-Synchronous



Integrated Power FET

Catch Diode
Or
Rectifier Diode



Integrated Power FET
and synchronous FET

Synchronous vs. Non-Synchronous

V_{IN}=5V
V_{OUT}=1V R_{DSON_SYNC}=0.12ohm V_{F_DIODE}=0.5V
I_{OUT}=1A
R_{DSON}_PWR=0.2ohm

1V Output synchronous

$$P_{FET\_SYNC} = \left(I_{out}\cdot\sqrt{1-D}\right)^2\cdot R_{dson}$$

$$P_{FET\_SYNC} = \left(1A\cdot\sqrt{0.8}\right)^2\cdot 0.12\Omega$$

$$P_{FET\_SYNC} = 0.096W$$

$$\eta = 88\%$$

1V Output non-synchronous

$$P_{diode} = I_{diode\_avg}\cdot V_{diode}$$

$$P_{diode} = (1-D)\cdot I_{out}\cdot 0.5V$$

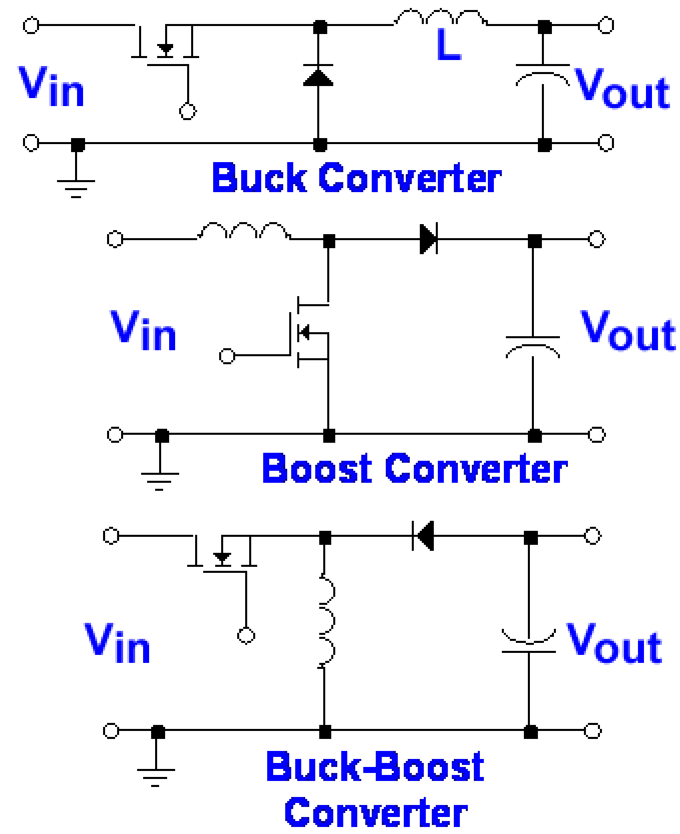
$$P_{diode} = 0.4W$$

$$\eta = 69.4\%$$

Sync vs. Non-sync is less of an issue with higher V_{OUT}
Higher duty cycles = less power dissipation in Sync FET or Catch Diode

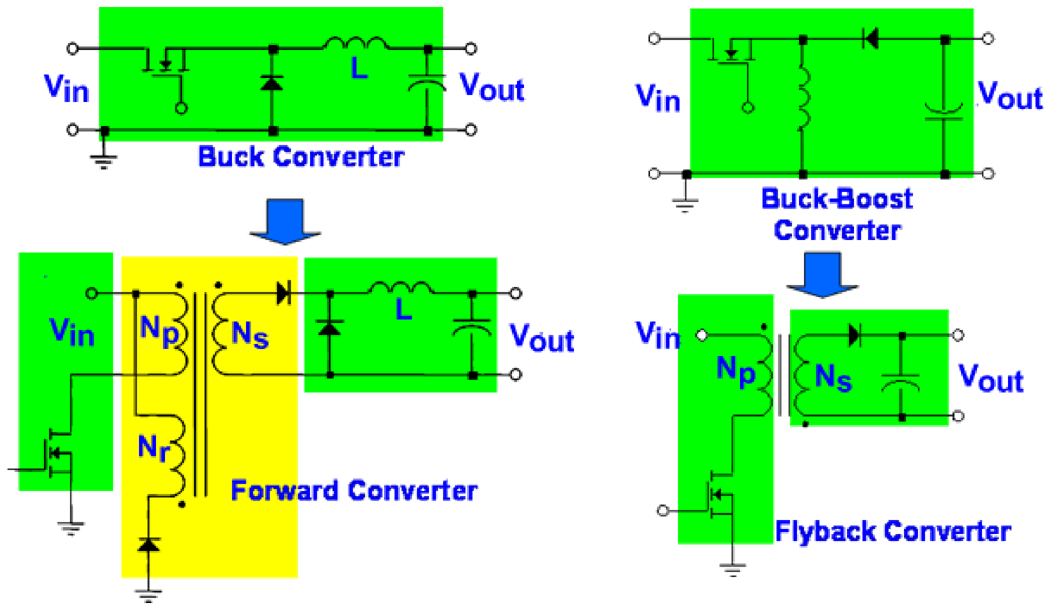
Isolated vs. Non-isolated

- Graphics show three fundamental DC-DC power converter topologies
- Major Limitation – they do not provide electrical isolation between the input and output
  - This is desirable in many applications
- Based on these, other popular topologies are derived:
  - Flyback
  - Forward
  - Push-pull
  - Half-bridge
  - Full bridge



Isolated Topologies

- Input/output isolation is required in many applications. Isolation breaks the propagation paths of unwanted signals and brings the following advantages:
- Protection of human and equipment against dangerous transient voltages induced on other side of isolation.



- Removal of the ground loop between the isolated circuits to improve noise immunity.
- Ease of output connections in the system without conflicting with the primary ground.
- These graphics show the two simplest isolated topologies: the forward and flyback. The parts in the yellow shaded area are additional parts to the fundamental topology.

Topology Selector