Switching Power Supply Component Selection

7.1a Capacitor Selection – Overview

Capacitor Selection for DC/DC Converters

Design factors that are known before selecting capacitors:

Factor	Description
Switching frequency	Fsw : From 50KHz (High power) to 6MHz (Low power)
Input voltage range	V_{IN}
Output voltage	V_{OUT}
Switch duty factor	Duty Cycle (D) ~ V_{OUT}/V_{IN} (for Buck/Step Down)
Output current	I_{OUT}
Inductance	L is usually designed such that the ripple current is ~30-40% of I_{OUT} at the switching frequency
Topology	Chosen in architectural stage

Selection Process Summary
Electrical Specifications

Electrical Performance	Transient Requirements	Capacitor Impedance
• RMS Current in the capacitor – Look for RMS current equation in the chosen DC/DC topology • Applied voltage at the capacitor – De-rate the capacitor based on the chemistry	• Size bulk capacitance based upon voltage deviation requirements • Check that the selected capacitor meets stability requirements	• Does this capacitor chemistry look inductive at the frequency of interest?

Selection Process Summary

- Most designs use a combinations of technologies
  - Tantalums or Aluminum Electrolytics for bulk Capacitance
  - Ceramics for decoupling and bypass
- Depends on Mechanical Challenges
  - Vibration
  - Temperature
  - Cooling
- Lifetime comes into play
  - For longer life, improve the quality of the components
  - Ceramics and polymer have improved lifetime over electrolytic and tantalum. Large ceramics can crack due to vibration.
- Costs - Tradeoffs
  - Component cost vs. Total cost of ownership

Selection Process Summary

- Use Equations for selected topology
  - Calculate RMS Currents, Peak voltages, Minimum capacitance, Maximum ESR
- Select Chemistry based upon the designs needs
  - Remember to de-rate voltage by at least 20% for all chemistries
  - 50% for tantalum to improve reliability
  - 50% for class 2 ceramics to decrease capacitance lost to DC biasing
  - **Note**: Capacitor data sheet MUST include 100kHz data if the capacitor is to be applied in a switch mode power supply (SMPS). 120 Hz only versions are not suitable for SMPS
  - Consider NP0 (C0G), X7R, X5R and X7S ceramic dielectrics* - in this order.
    - DO NOT USE Y5V

Selection Process Summary

- Place additional units in parallel if one is not enough
  - Combine chemistries to benefit from their various advantages
    - Use polymer, electrolytic and tantalum for bulk
    - Use Ceramics as your primary decoupling capacitor

Capacitor RMS Current

- RMS current of a capacitor is one of the most important specifications for capacitor reliability

- It also effects the converters performance, and varies by topology
  - Self-Heating: Proportional to RMS Current and Internal Losses
  - Voltage Ripple: Higher RMS Current leads to larger voltage ripple

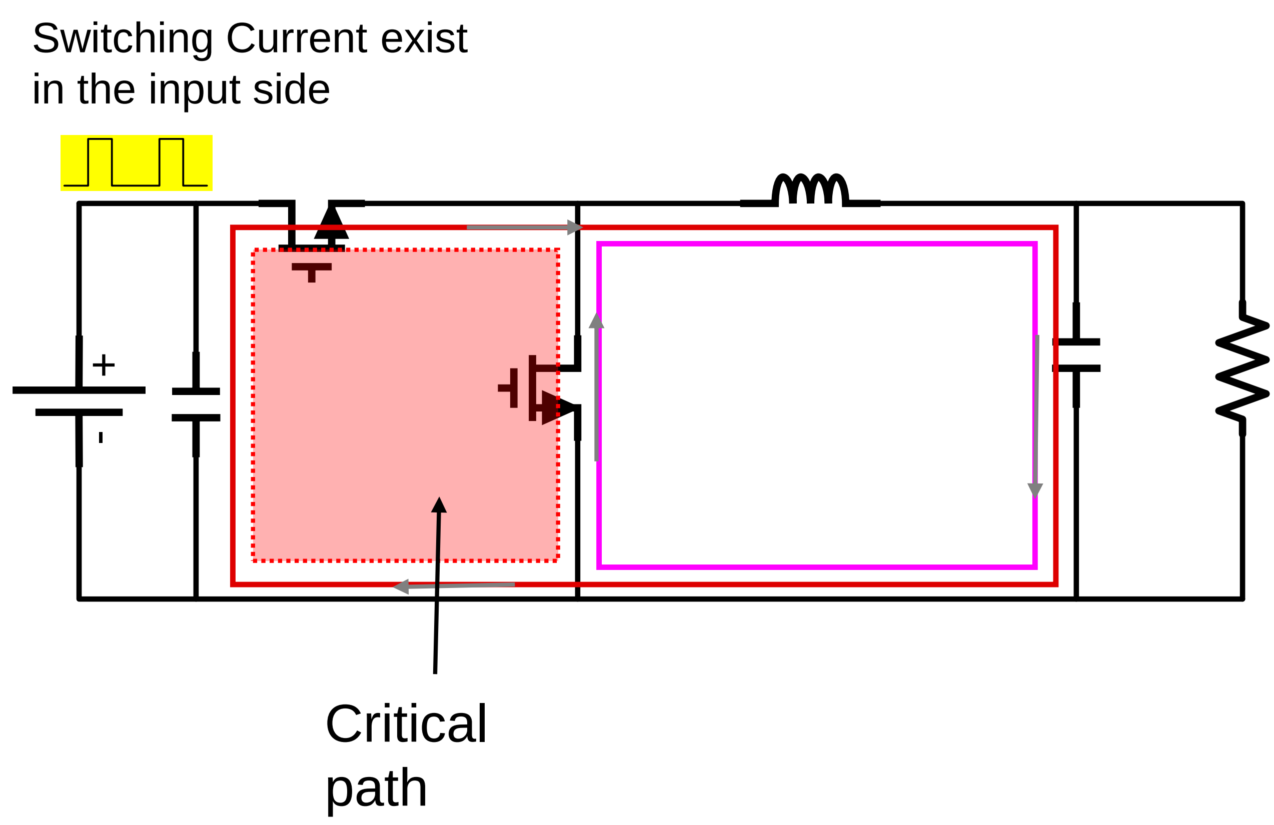
- Let’s calculate RMS current for different topologies

Common Topologies: BUCK

Buck Converter

Boost Converter

Buck-Boost Converter



Common Topologies: BUCK

Buck Converter

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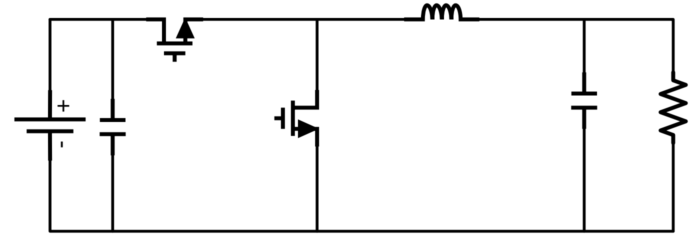
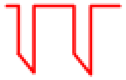


Input Capacitor RMS Current

$$I_{CIN\_RMS} \approx \sqrt{\left[I_{OUT}\times\left(1-\frac{V_{OUT}}{V_{IN}}\right)\times\sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2+\left[I_{OUT}\times\left(\frac{V_{OUT}}{V_{IN}}\right)^{\frac{3}{2}}\right]^2}$$



Output Capacitor RMS Current

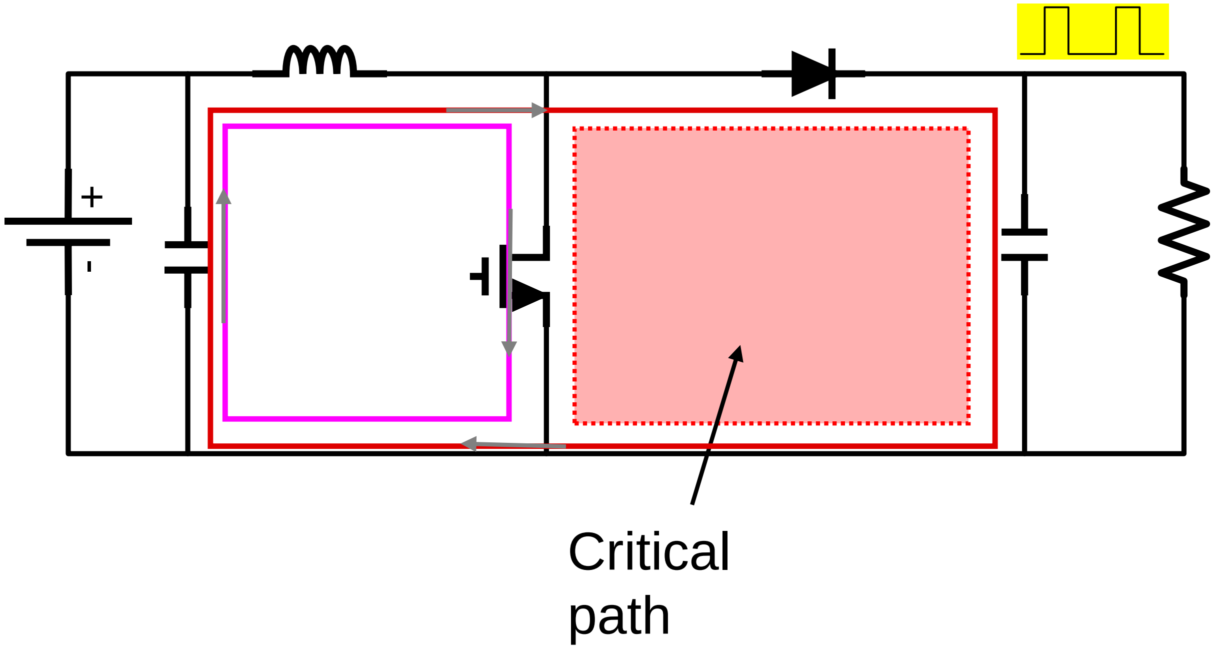
$$I_{COUT\_RMS} = \frac{(V_{IN}-V_{OUT})\times\frac{V_{OUT}}{V_{IN}}}{2\times L\times F_{SW}\times\sqrt{3}}$$

Common Topologies: BOOST

Buck Converter

Boost Converter

Buck-Boost Converter



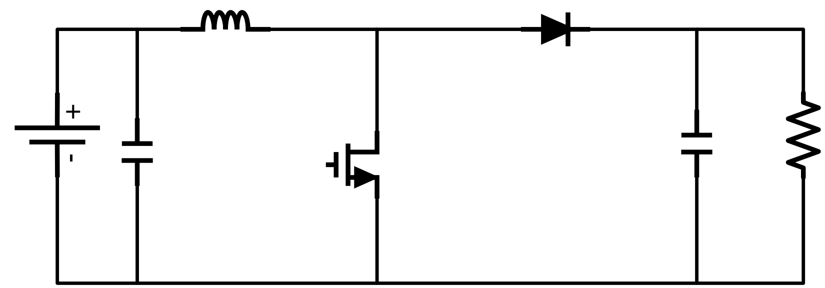
Texas Instruments

Common Topologies: BOOST

Buck Converter

Boost Converter

Buck-Boost Converter

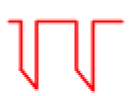


Input Capacitor RMS Current

$$I_{CIN\_RMS} = \frac{(V_{OUT} - V_{IN}) \times \frac{V_{IN}}{V_{OUT}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

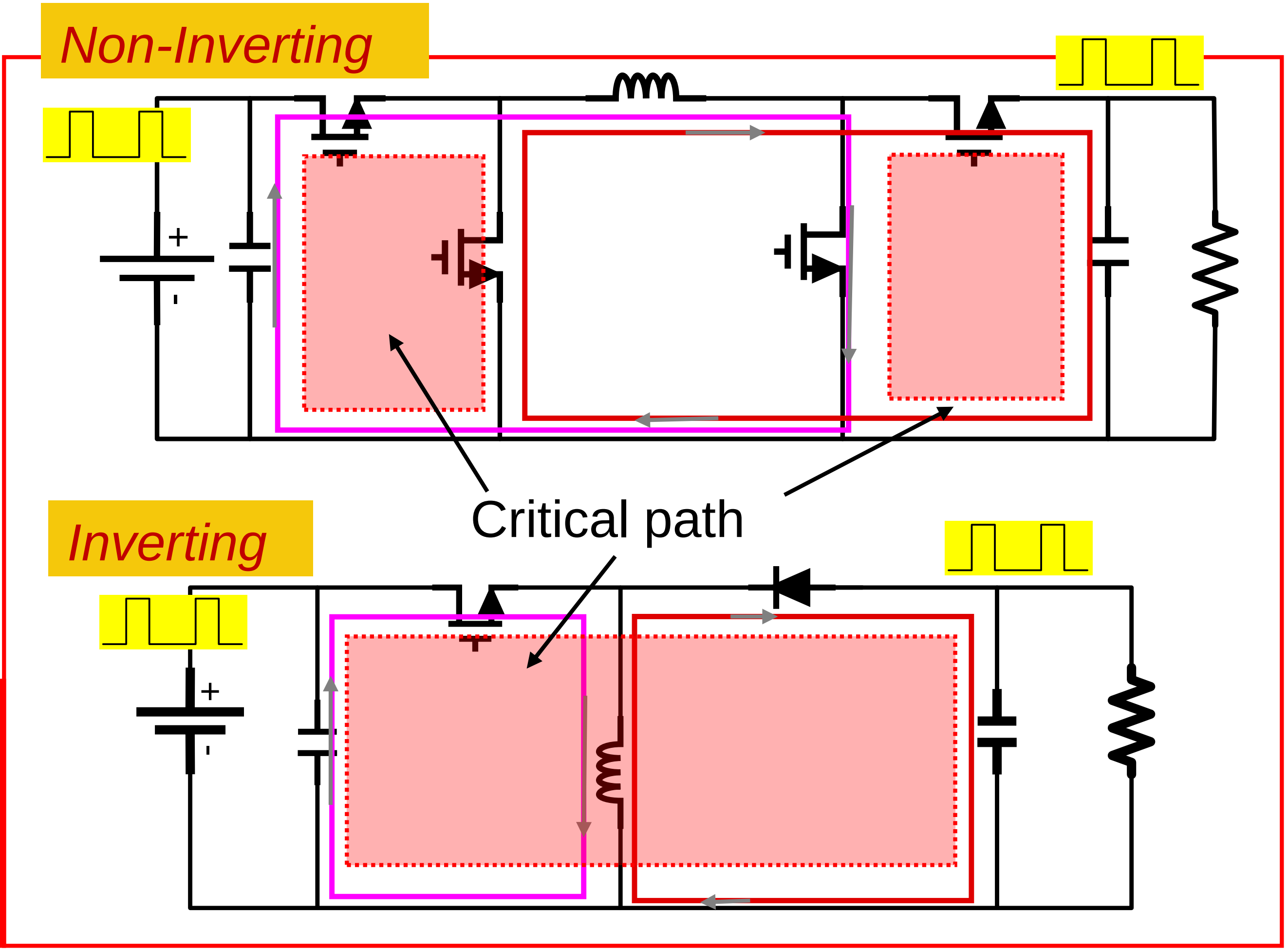
Output Capacitor RMS Current

$$I_{COUT\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{IN}}{V_{OUT}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \sqrt{\frac{V_{IN}}{V_{OUT}}}\right]^2}$$



Common Topologies: BUCK BOOST

- Buck Converter
- Boost Converter
- **Buck-Boost Converter**



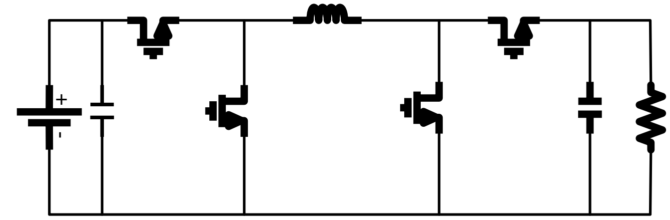
Common Topologies

Buck Converter

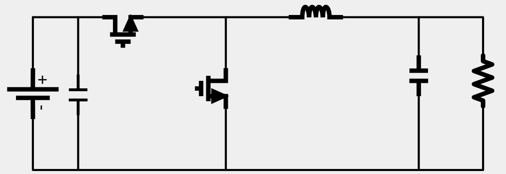
Boost Converter

Buck-Boost Converter

Non-Inverting



Mode 1 (Buck)



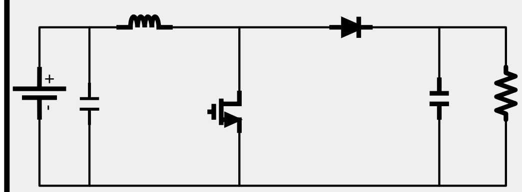
Input Cap RMS Current

$$I_{CIN\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{OUT}}{V_{IN}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \left(\frac{V_{OUT}}{V_{IN}}\right)^{\frac{3}{2}}\right]^2}$$

Output Cap RMS Current

$$I_{COUT\_RMS} = \frac{(V_{IN} - V_{OUT}) \times \frac{V_{OUT}}{V_{IN}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

Mode 2 (Boost)



Input Cap RMS Current

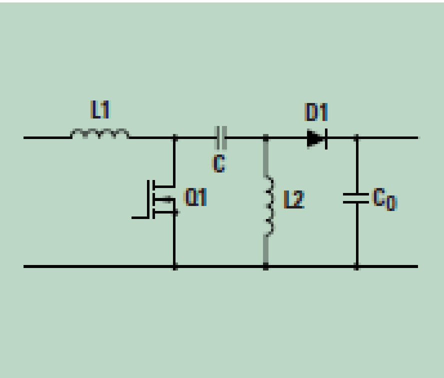
$$I_{CIN\_RMS} = \frac{(V_{OUT} - V_{IN}) \times \frac{V_{IN}}{V_{OUT}}}{2 \times L \times F_{SW} \times \sqrt{3}}$$

Output Cap RMS Current

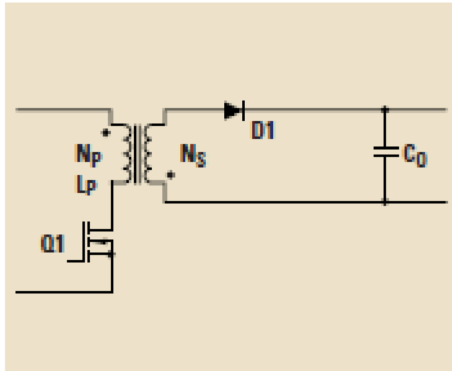
$$I_{COUT\_RMS} \approx \sqrt{\left[I_{OUT} \times \left(1 - \frac{V_{IN}}{V_{OUT}}\right) \times \sqrt{\frac{V_{OUT}}{V_{IN}}}\right]^2 + \left[I_{OUT} \times \sqrt{\frac{V_{IN}}{V_{OUT}}}\right]^2}$$

Additional Topologies

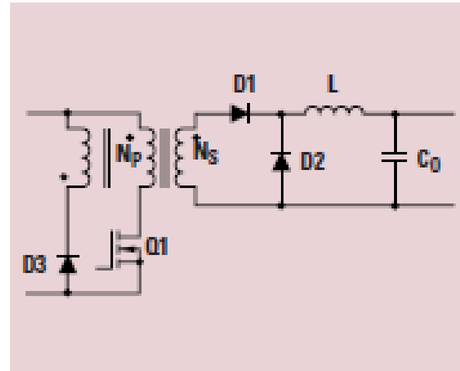
SEPIC



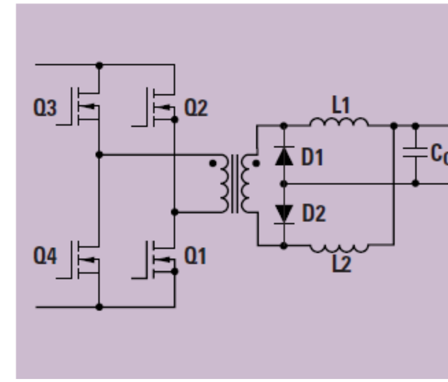
FLYBACK

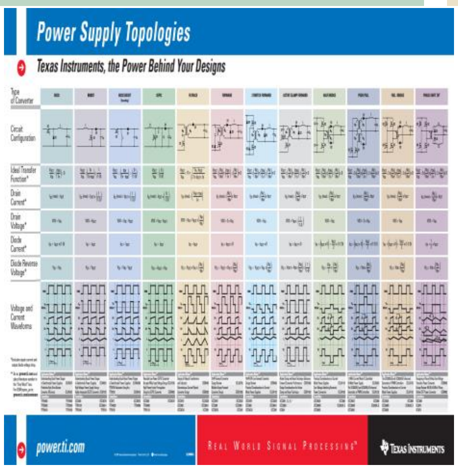


FORWARD



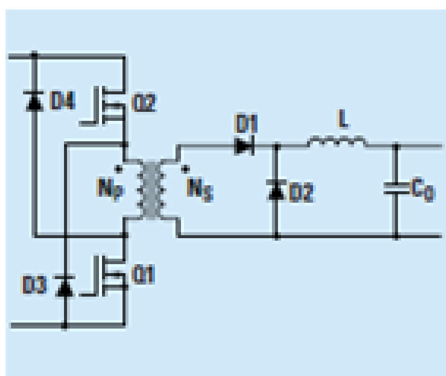
PHASE SHIFT ZVT



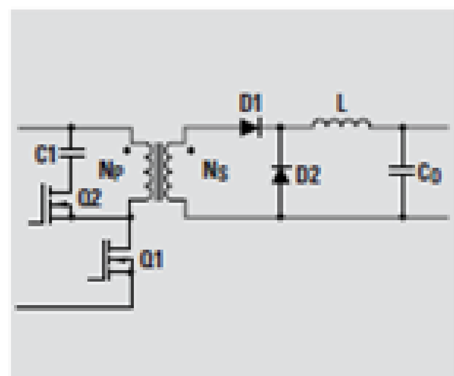


SLUW001A

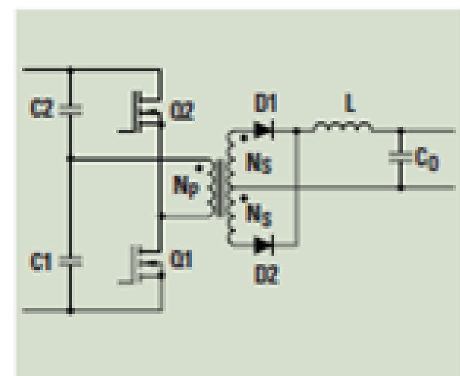
2 SWITCH FORWARD



ACTIVE CLAMP FORWARD



HALF BRIDGE



Thank you!