Using Leakage Energy to Achieve Zero-Voltage Switching

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Energy Management - Are You Throwing Energy Away? Don't, or Recover it!

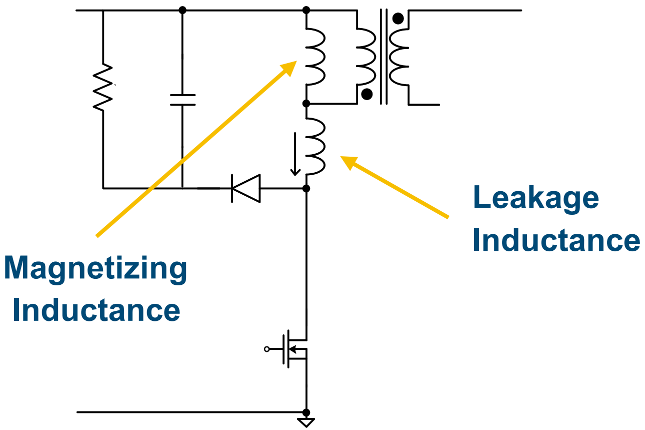
APEC 2022

Houston, Texas – March 24, 2022

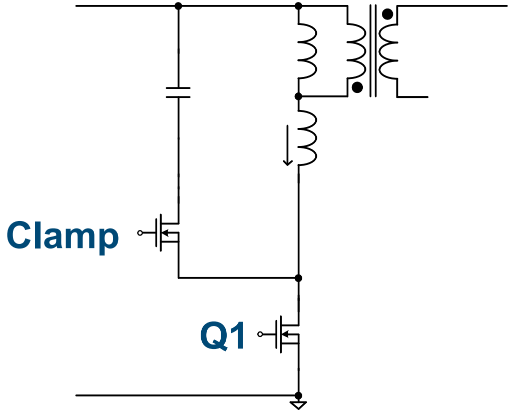
Agenda

- Recycling leakage energy improves efficiency
  - RCD clamp vs. active clamp
- How an active clamp works
- Benefits of active clamp operation
- Performance data for different designs
- What handles can we turn to achieve zero voltage switching (ZVS)
- Power range and target applications

Recycling Leakage Energy Improves Efficiency



RCD Clamp

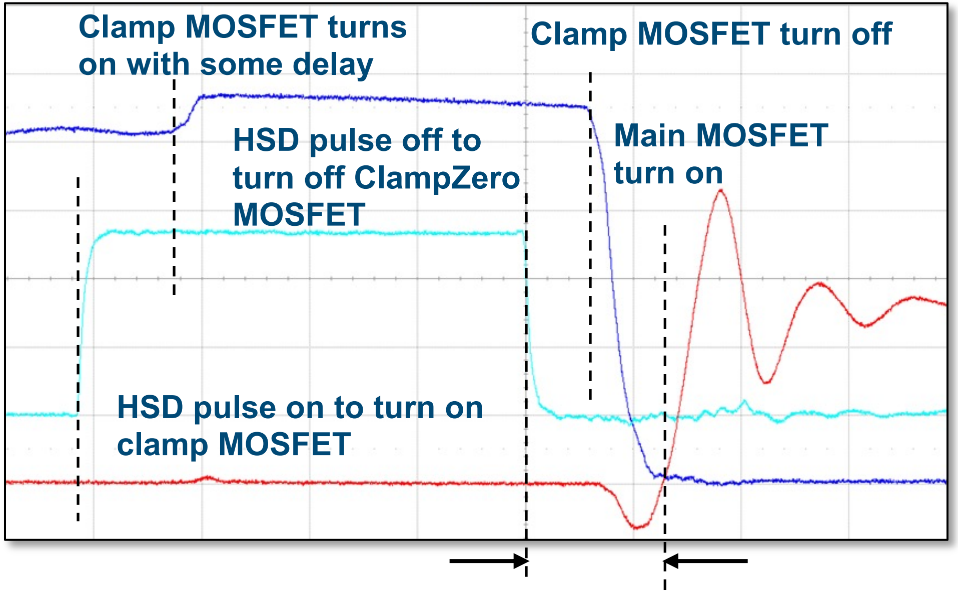


Active Clamp

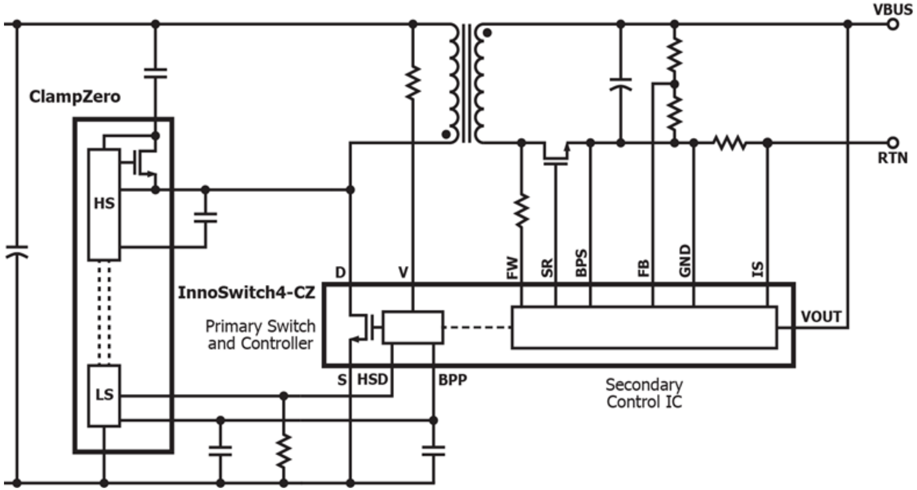
- Leakage energy dissipated in snubber resistor reduces efficiency
  - Thermal management issue
- Limits power supply to lower switching frequency regardless of power switch performance

- Leakage energy recycled through clamp FET
- ZVS on flyback MOSFET
  - Reduces switching losses
- Increased efficiency means lower temperatures
- Permits high frequency PSU operation

Active Clamp Operation



Programmable Delay



Simplified Integrated Active Clamp Flyback Power Supply

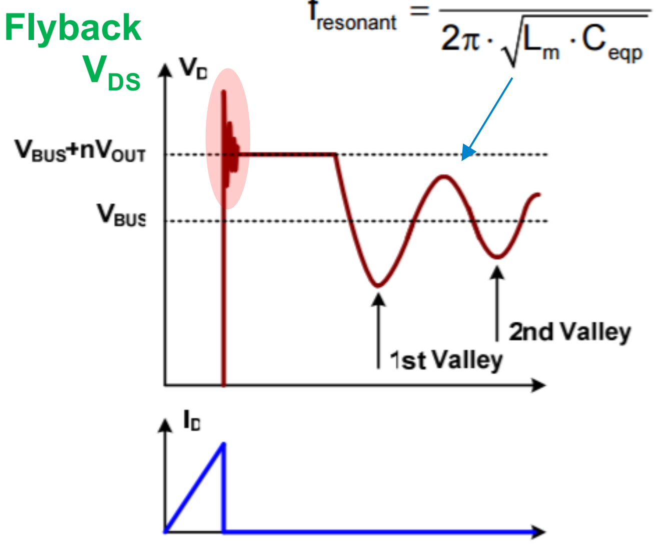
Benefits of Active Clamp When Compared to Quasi-Resonant Operation

Quasi-Resonant Flyback	Active Clamp Flyback
Valley switching only available in DCM operation mode	ZVS can be achieved both in CCM and DCM operation
Higher RMS currents if designed to retain valley switching benefit at low line	Lower RMS current because of CCM operation
Larger magnetics due to lower switching frequency (max. f_{SW} = 100 kHz)	Smaller magnetics (max. f_{SW} = 140 kHz)
Moderate power density	Very high power density
Thermal management challenge due to dissipative snubber and non ZV switching	Better thermal management
Leakage inductance should be minimized	Leakage inductance aids in achieving ZVS, also less common-mode emission as an added benefit due to increased leakage inductance
Higher leakage spike on the main FET	No leakage spike due to large clamp capacitor – allows larger VORs in order to reduce the SR voltage stress

Valley Switching vs. Active Clamp Flyback

Valley Switching

$$f_{resonant} = \frac{1}{2\pi \cdot \sqrt{L_m \cdot C_{eqp}}}$$

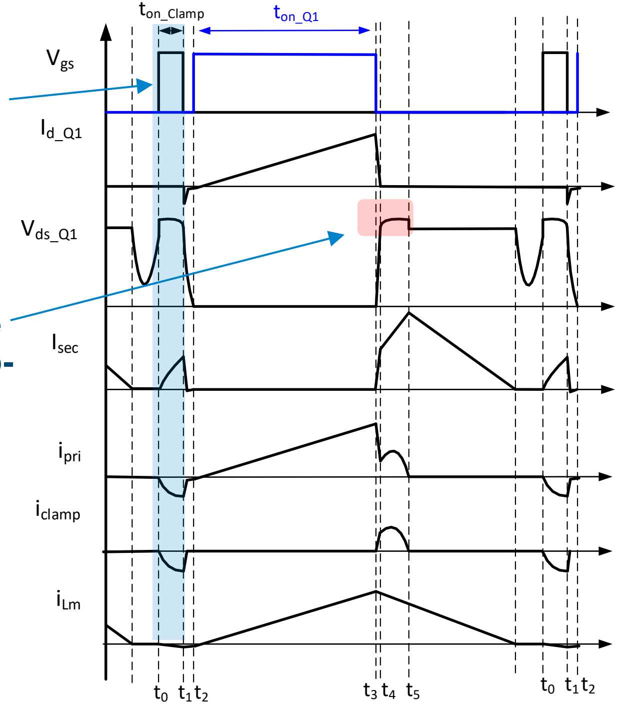


QR Flyback, V_{DS} Valley Switching for Minimum Switching Loss

Active Clamp

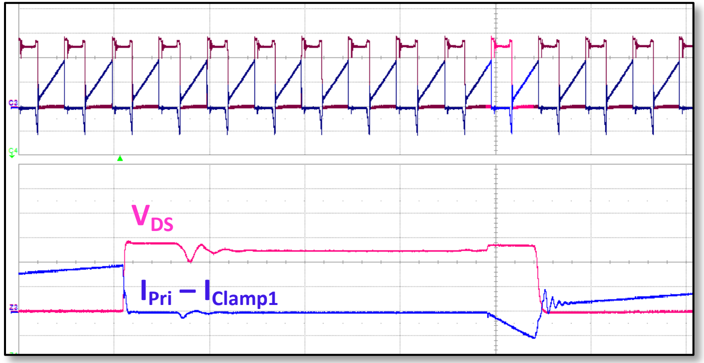
Clamp FET turns on at V_{DS} peak to reduce switching stress on clamp FET in DCM operation

There is no excess leakage spike seen on active clamp-based designs because of larger clamp capacitance values

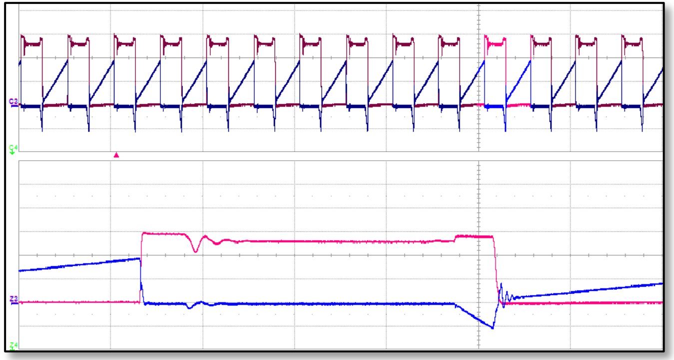


Non-Complementary Mode

ZVS at Different Line Voltages

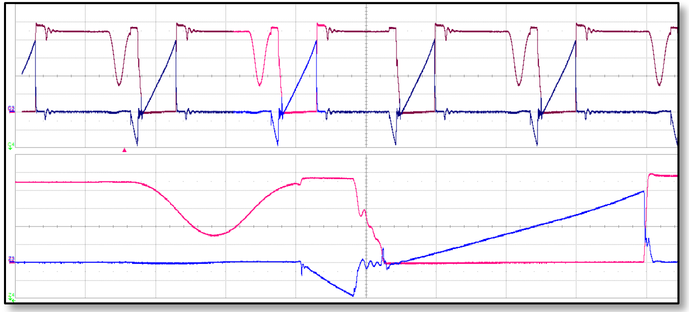


90 VAC

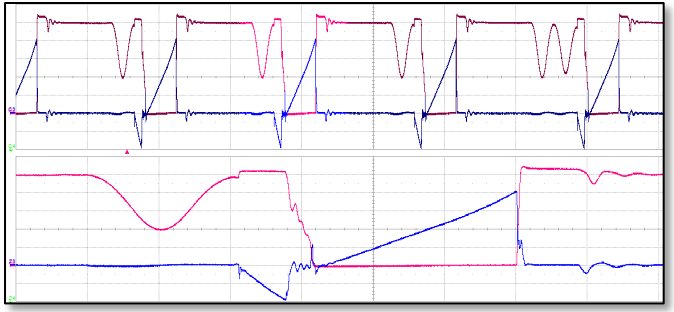


115 VAC

Uses leakage energy in CCM operation



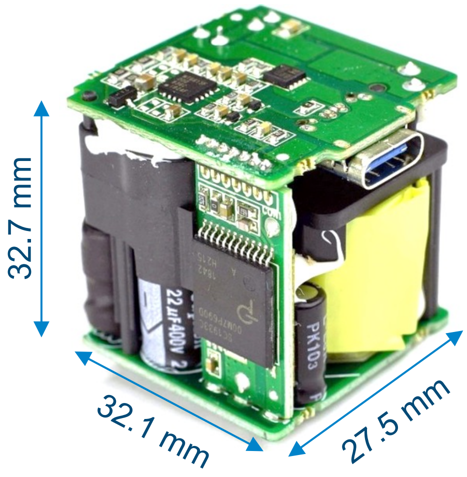
230 VAC



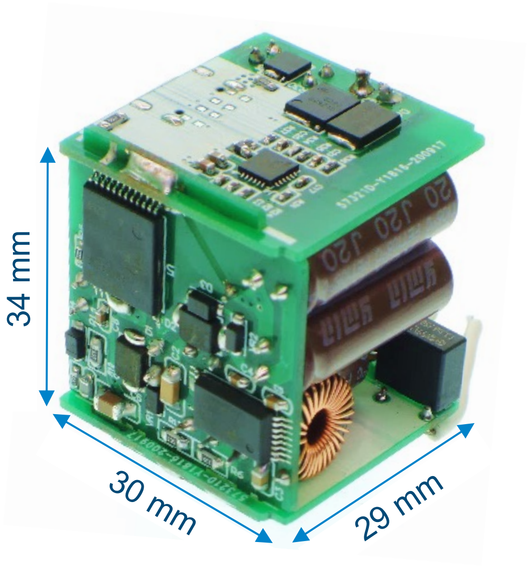
265 VAC

Uses both leakage and magnetizing energy in DCM operation

Significant Increase in Power Density

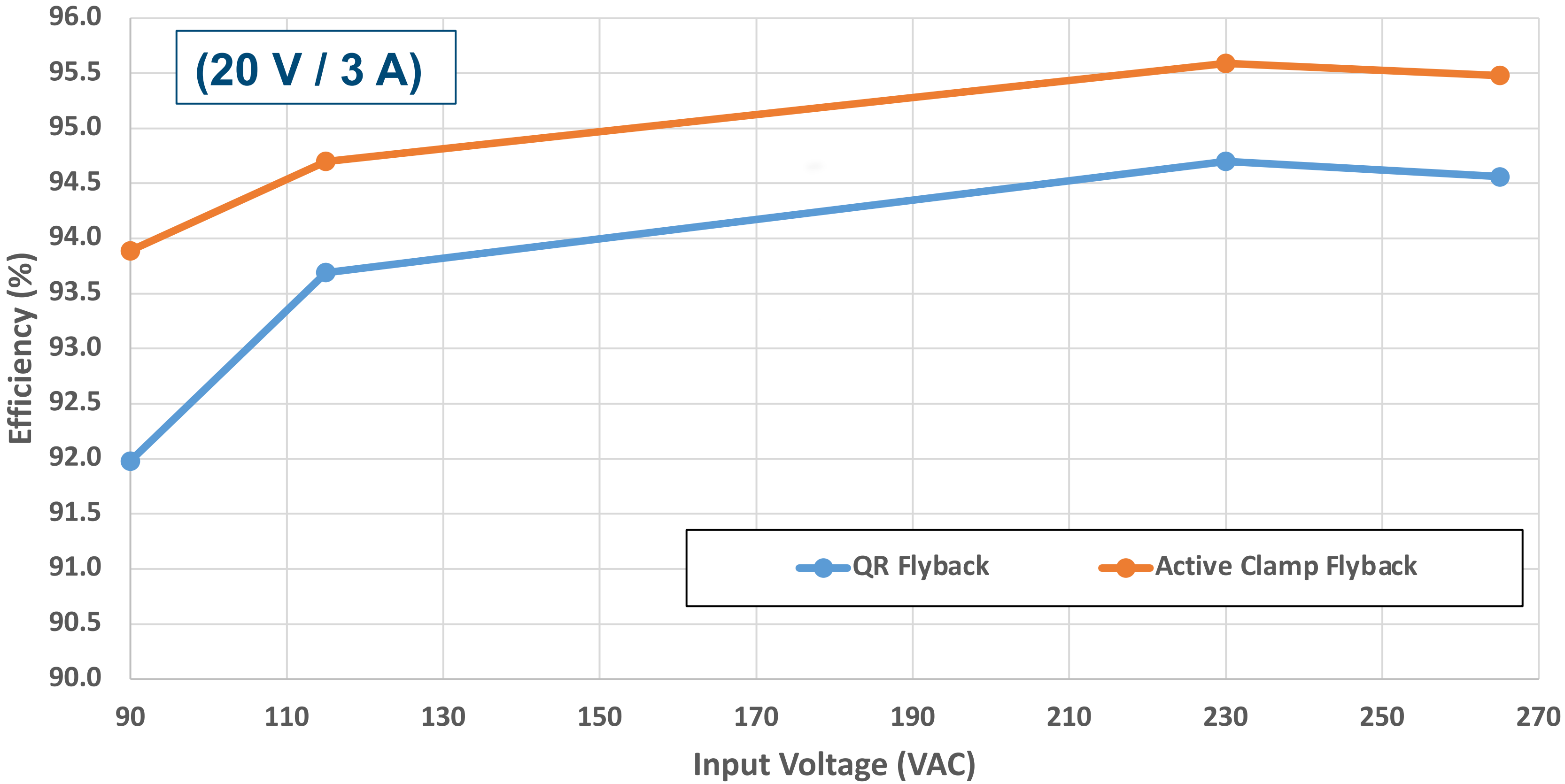


30 W PD Adapter Design,
17 W / Inch³ (QR)

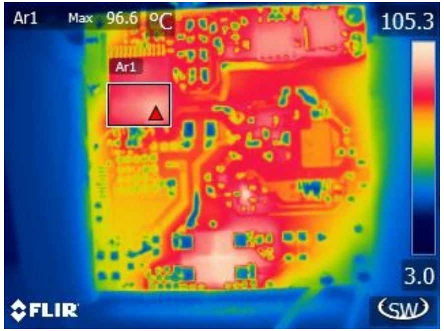


65 W PD Adapter Design,
36 W / Inch³ (ACF)

Makes a Significant Difference in Efficiency



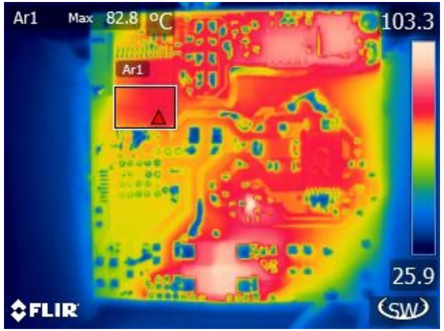
Thermal Comparison: Hard Switching vs. Active Clamp



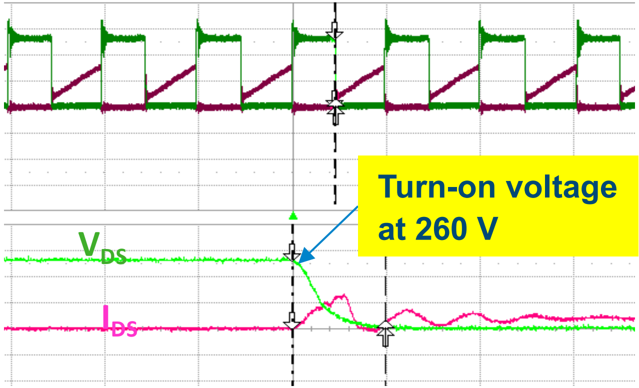
Primary main switch temperature = 96.6 °C

Measured at 20 V output (60 W design):

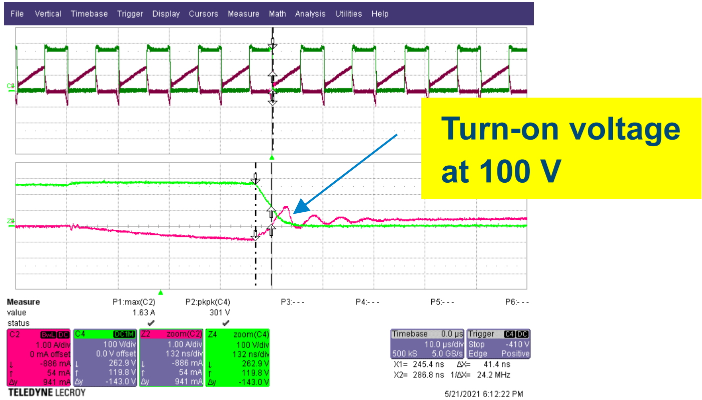
- 90 VAC input
- Full-load
- ~105 kHz average switching frequency



Primary main switch temperature = 82.8 °C

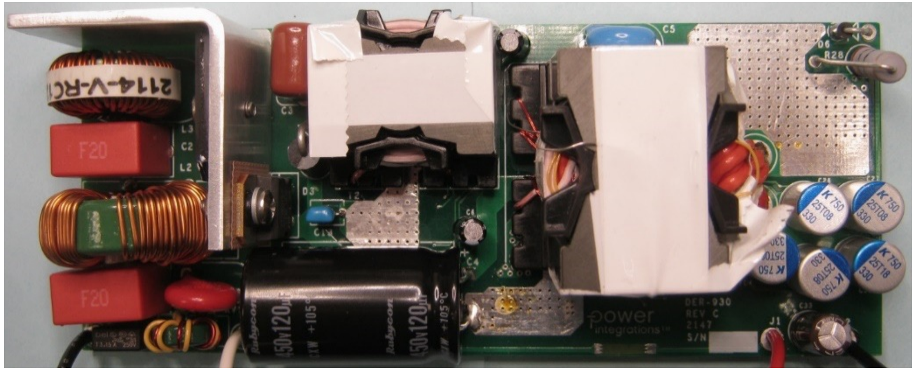


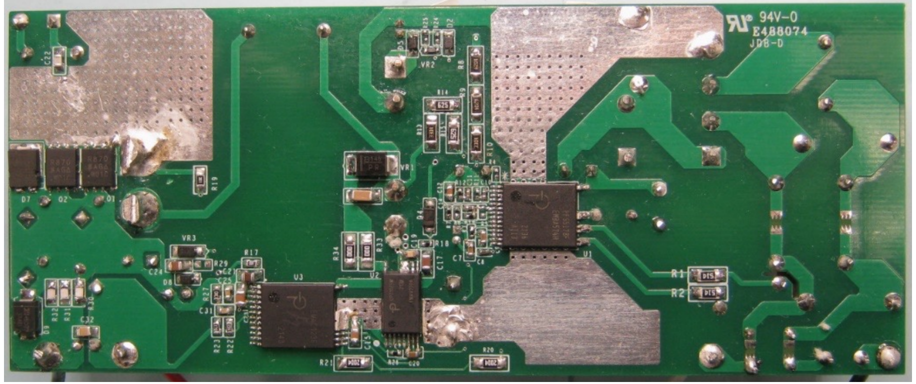
Hard Switching with RCD Clamp



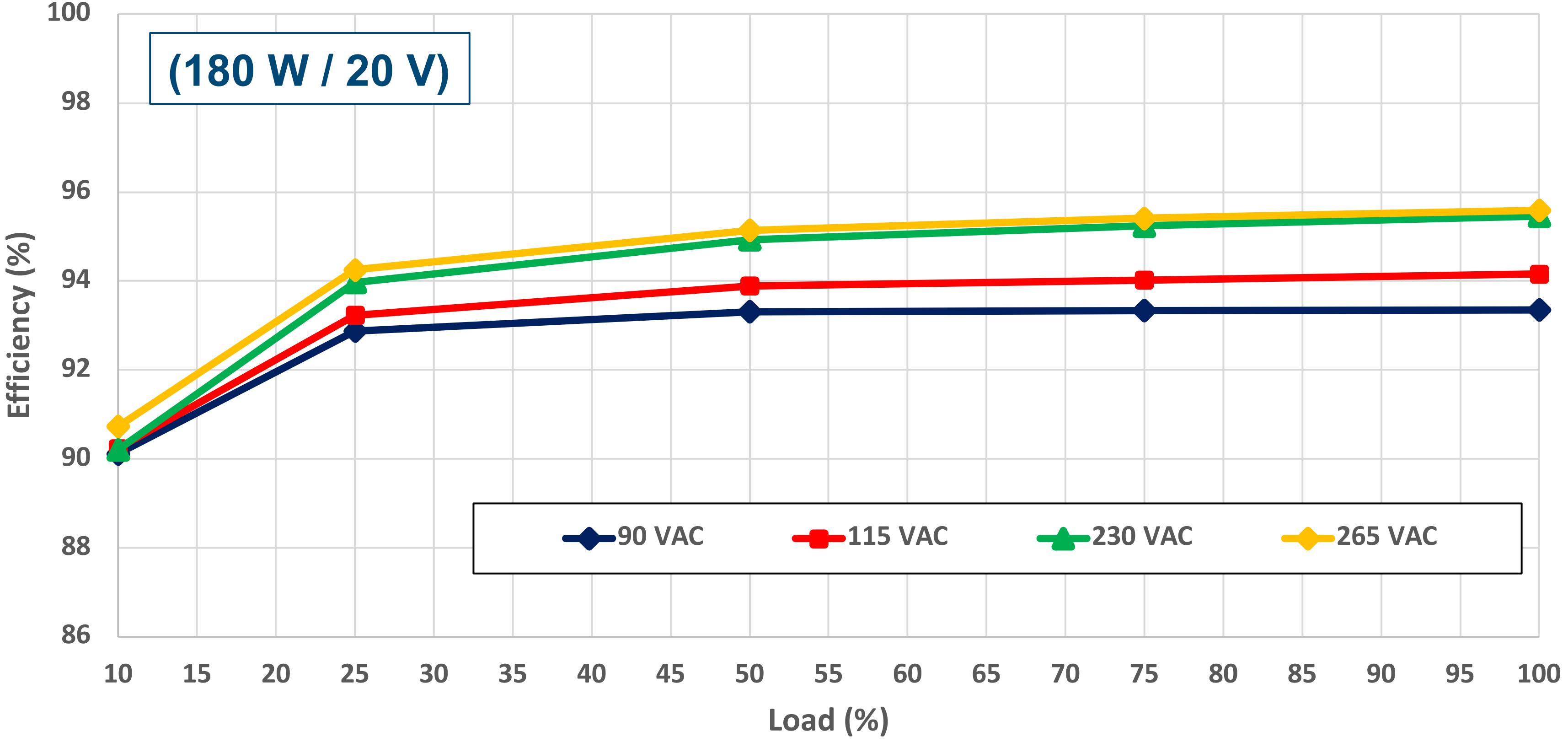
Soft Switching with Active Clamp

180 W PFC + Active Clamp Flyback





High Efficiency Across the Load Range



How to Achieve ZVS – Handles to Turn

1. Transformer leakage inductance
2. Clamp capacitor value
3. Primary current limit of the device
4. Resonant delay period
5. Pulse width of active clamp switch

Active Clamp Increases Flyback Power Delivery

- Active clamp and ZVS eliminate turn-off loss and recycle leakage energy
  - Useful when high efficiency and/or thermal performance is important
- Significantly reduces voltage stress on power switches
  - Both on primary switch and secondary SR
- With PFC input, active clamp flyback can deliver up to 200 W
  - Offers increased power density and range
- Target applications
  - Compact USB PD adapters
  - AIO PC
  - eBikes
  - Power tools
  - Game consoles

Thank you for your interest.

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APEC 2022 Industry Session IS18.6

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