Active Clamp Flyback Using GaN Power IC for Power Adapter Applications

Linqxiao (Lincoln) Xue, Staff Applications Engineer, lingxiao.xue@navitassemi.com
Jason Zhang, VP Applications, jason.zhang@navitassemi.com
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How to Improve Power Adapter Density?

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Traditional Travel Adapter and Chargers

5 W/in^3
Samsung 25 W

7 W/in^3
Apple 45 W

USB PD and Quick Charge

CERTIFIED USB™ CHARGER 45W

Qualcomm® Quick Charge™

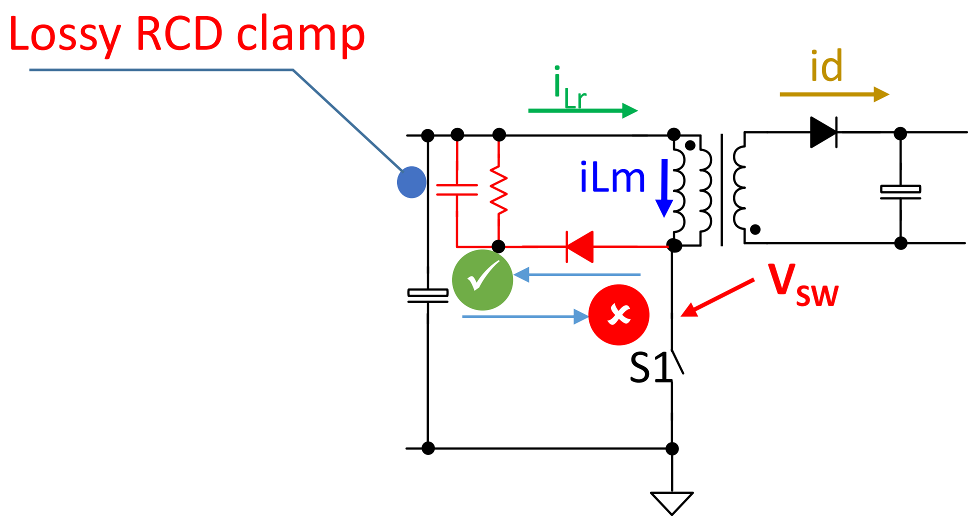
> 20 W/in^3

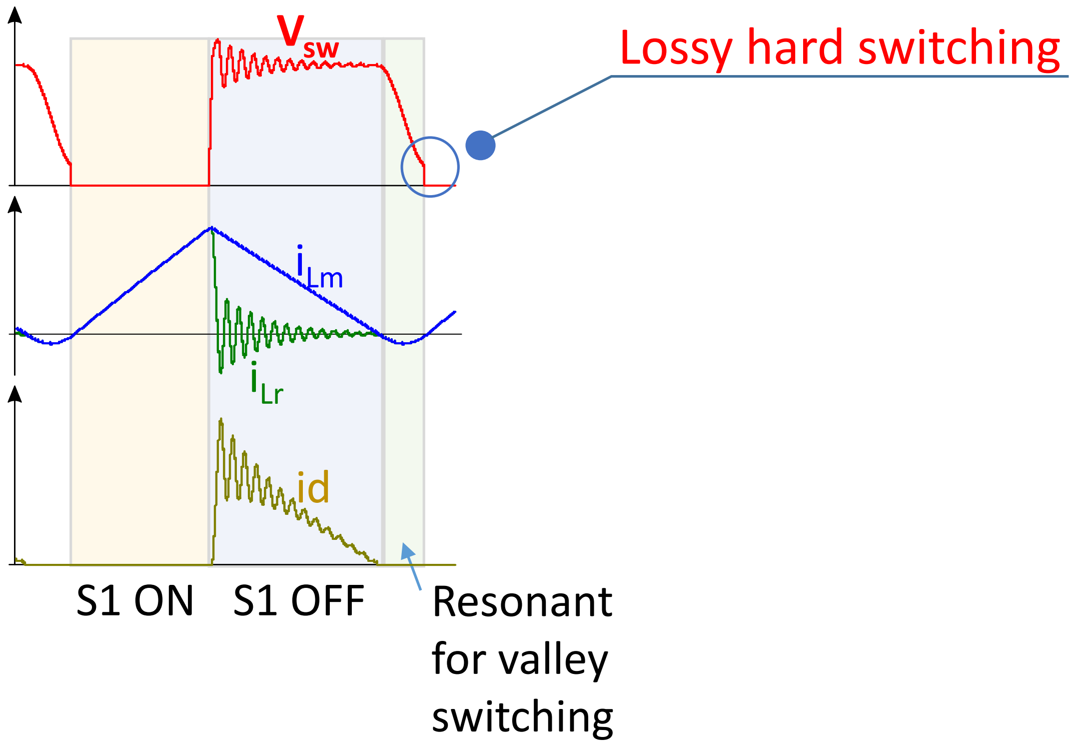
- Added power in USB PD and Quick Charge requires dramatically higher power density (>20 W/in^3)
- Higher efficiency and lower power loss are required in high density adapters
- How to dramatically improve the power density?

Outline

- Limitations of standard flyback
- Active clamp flyback's benefits and drawbacks
- Improvement of active clamp flyback (ACF)
- GaN half-bridge power IC enables high density ACF
- Experimental results and conclusion

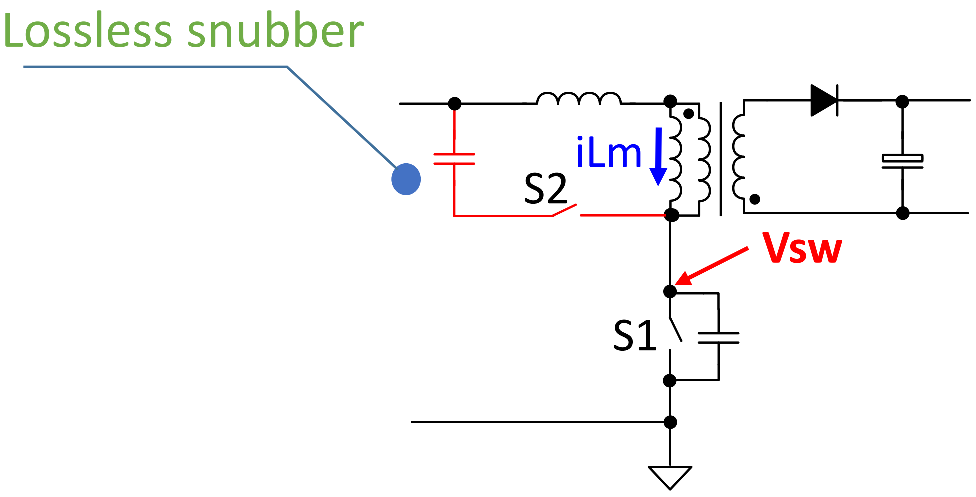
QR Flyback Hits Performance Ceiling

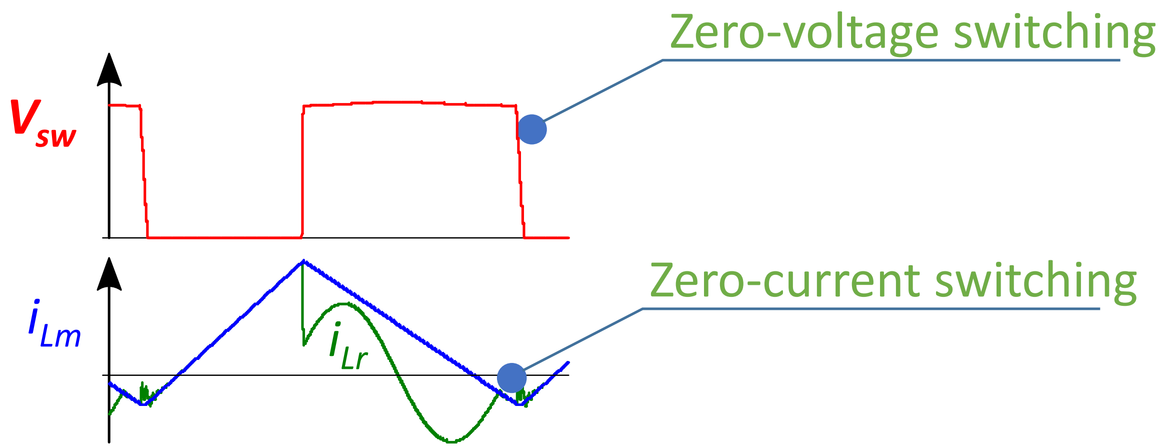




- Frequency-dependent losses
  - Leakage inductance loss
  - Snubber/clamp losses
  - Partial hard-switching loss at high line
  - Slow turn-on loss to minimize EMI
- Difficult to improve efficiency at high frequency

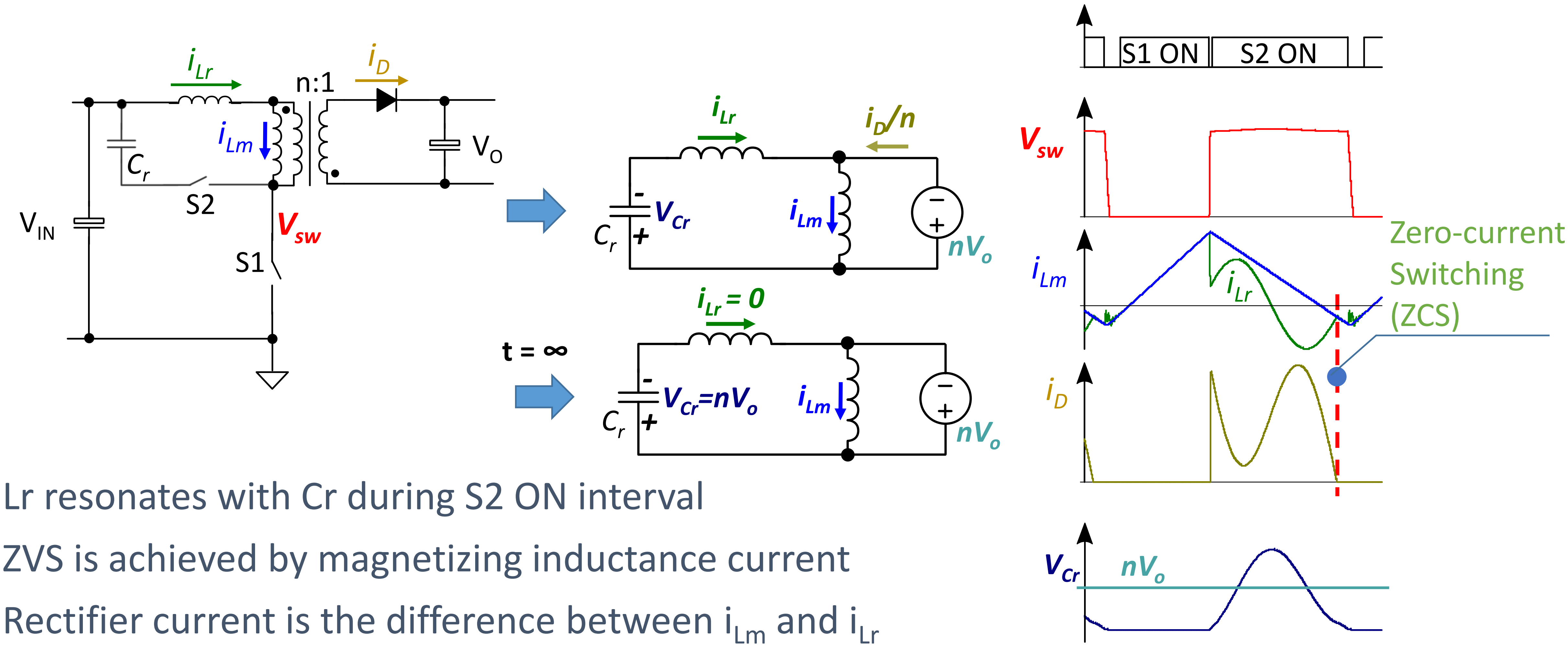
ACF Enables ZVS and High Frequency Switching





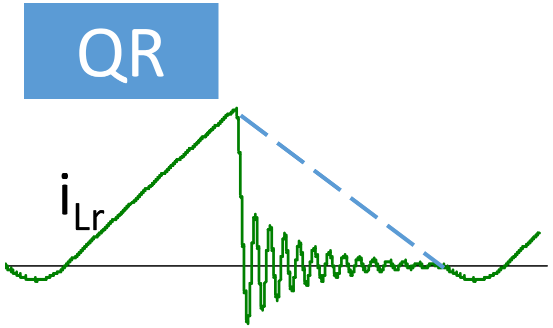
- No snubber losses, all leakage energy is recovered
- ZVS soft switching over entire operation range
- ZCS soft turn-off for output rectifier
- Clean waveforms reduce EMI
- Enable small adapter design with high-frequency switching

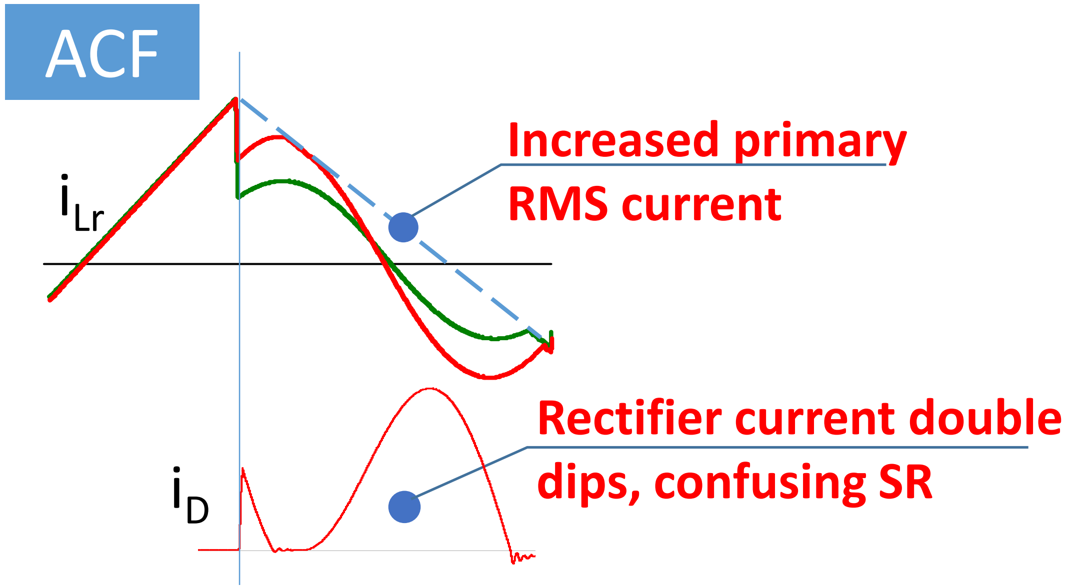
ACF Operation

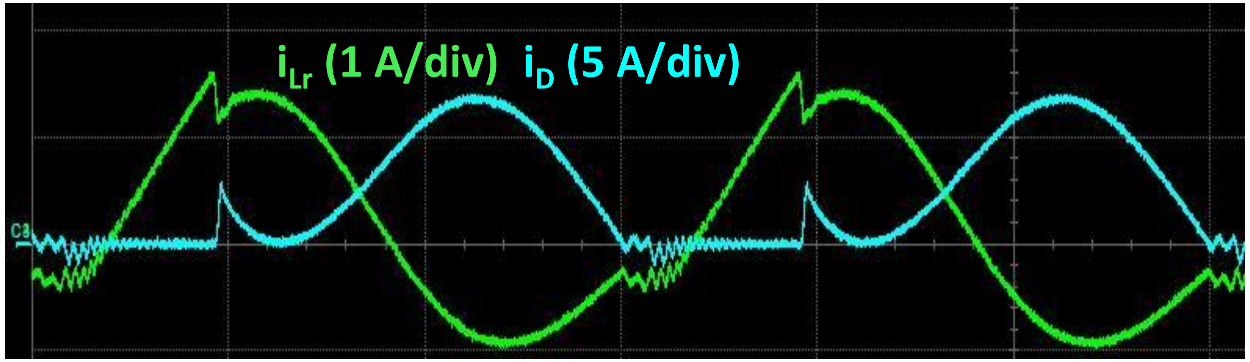


- Lr resonates with Cr during S2 ON interval
- ZVS is achieved by magnetizing inductance current
- Rectifier current is the difference between i_{Lm} and i_{Lr}
- i_{Lr} returns to i_{Lm} by the end of S2 ON interval for rectifier ZCS

Drawbacks of Traditional ACF

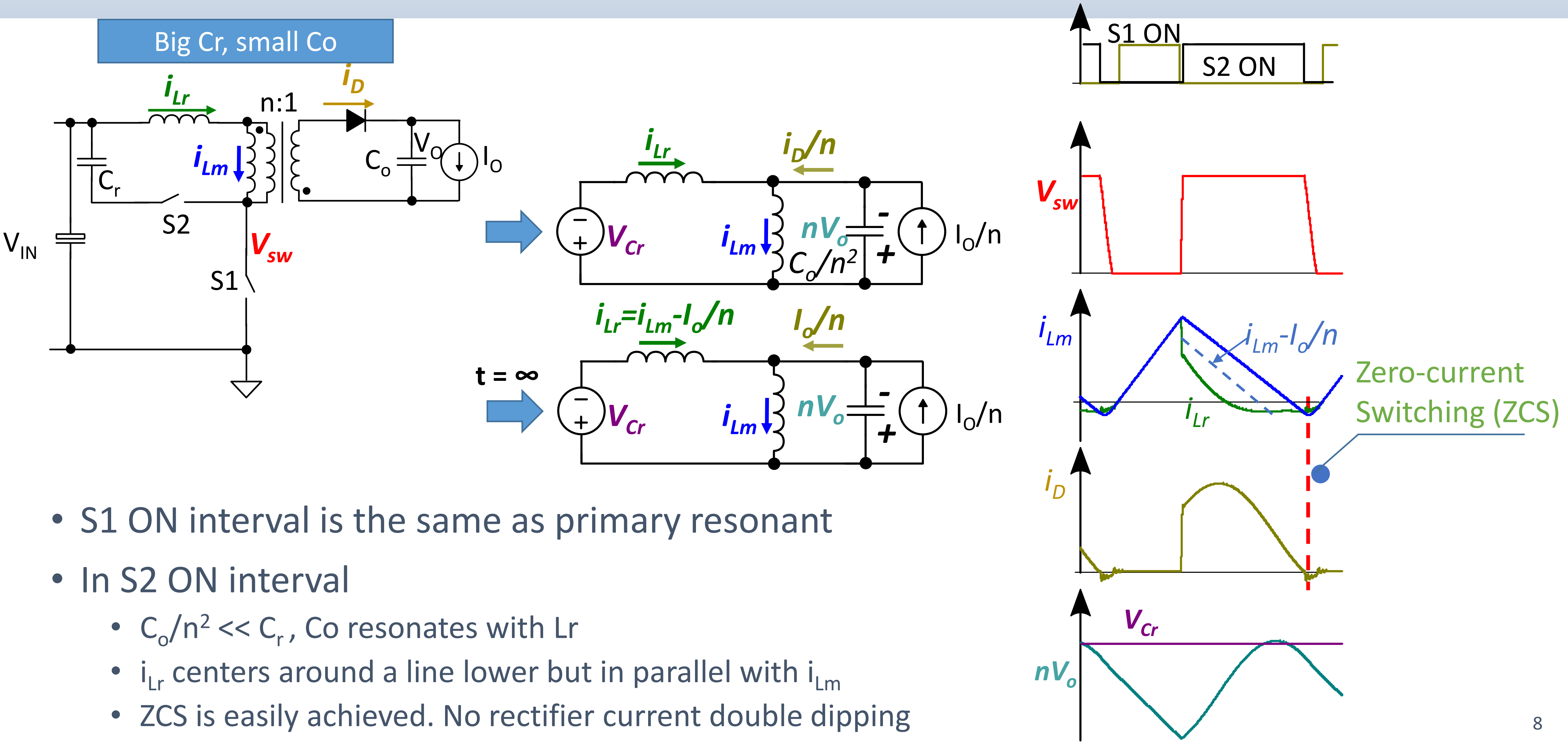






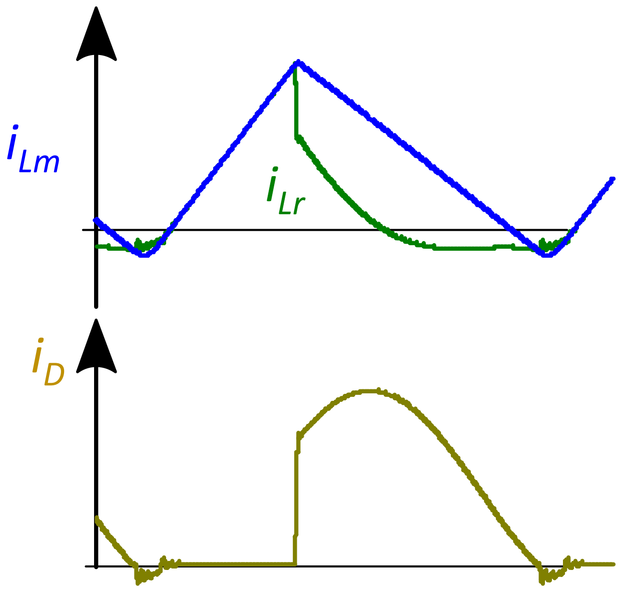
- Difficult to shape the current to achieve ZCS and minimize rms current
- Conduction loss is high
- Not compatible with SR controllers

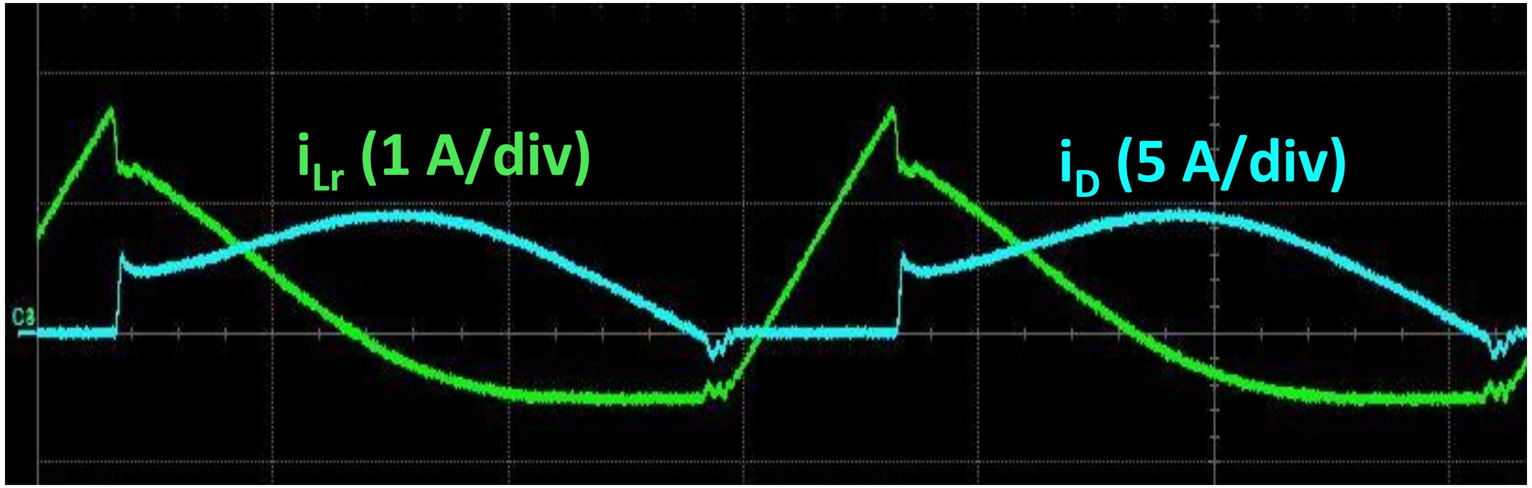
New ACF Using Secondary Resonance



- S1 ON interval is the same as primary resonant
- In S2 ON interval
  - $C_o/n^2 << C_r$, Co resonates with Lr
  - i_{Lr} centers around a line lower but in parallel with i_{Lm}
  - ZCS is easily achieved. No rectifier current double dipping

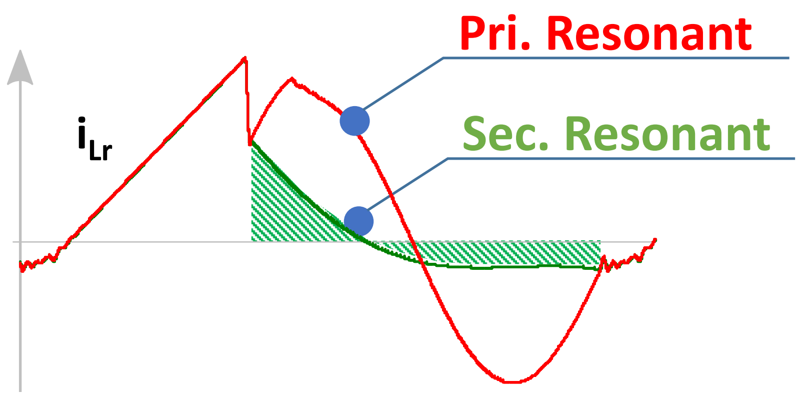
New ACF Simplifies SR and Reduces Current RMS

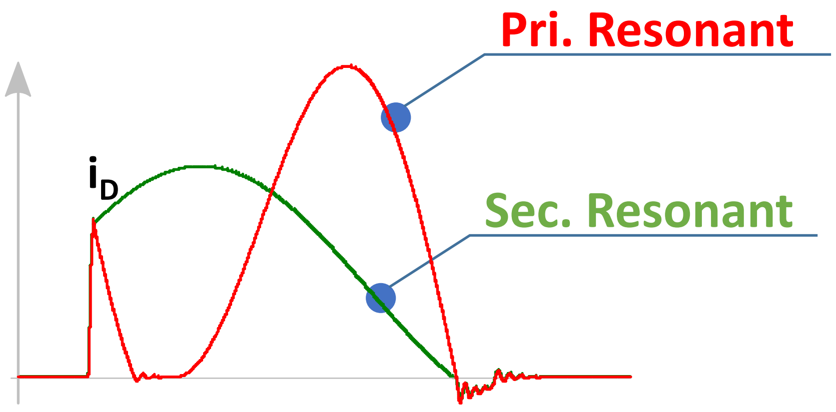


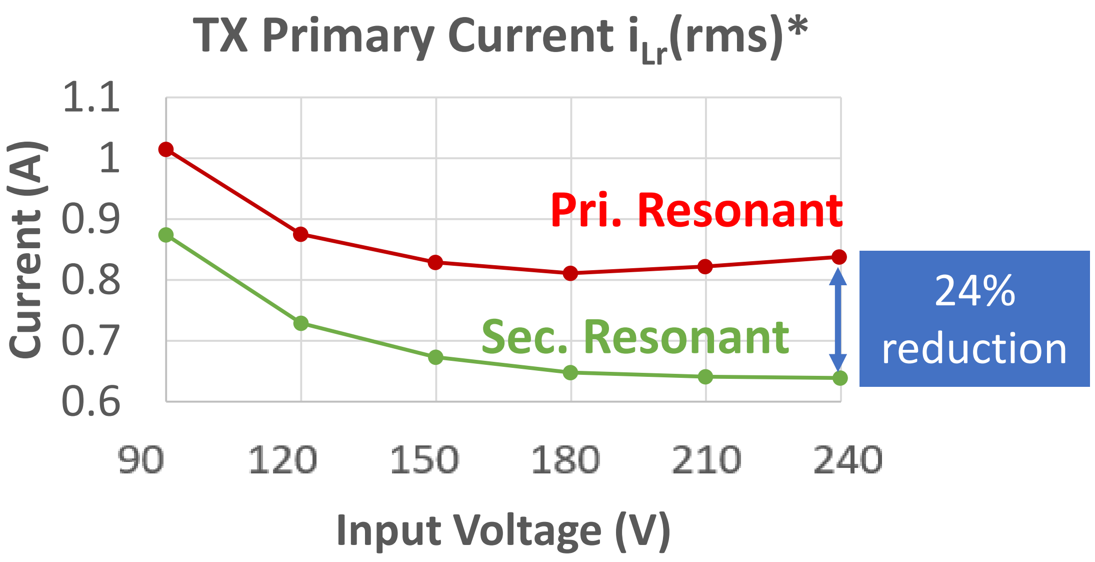


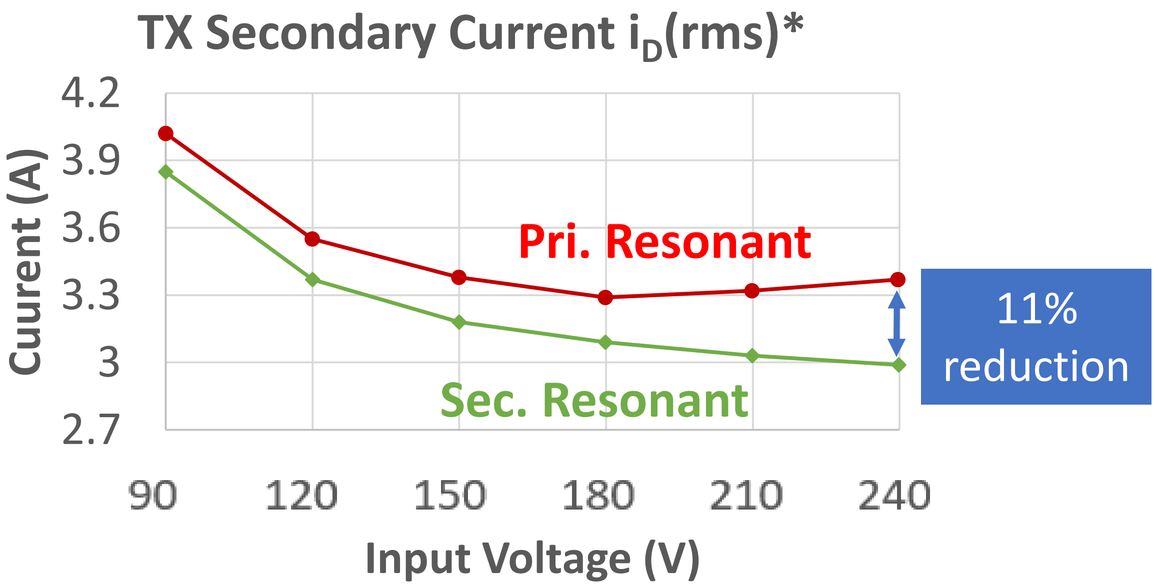
- i_{Lr} current can be easily shaped
- No rectifier current dipping issue. Simplifies SR
- Reduced rms current and conduction loss

Experimental Result of RMS Reduction



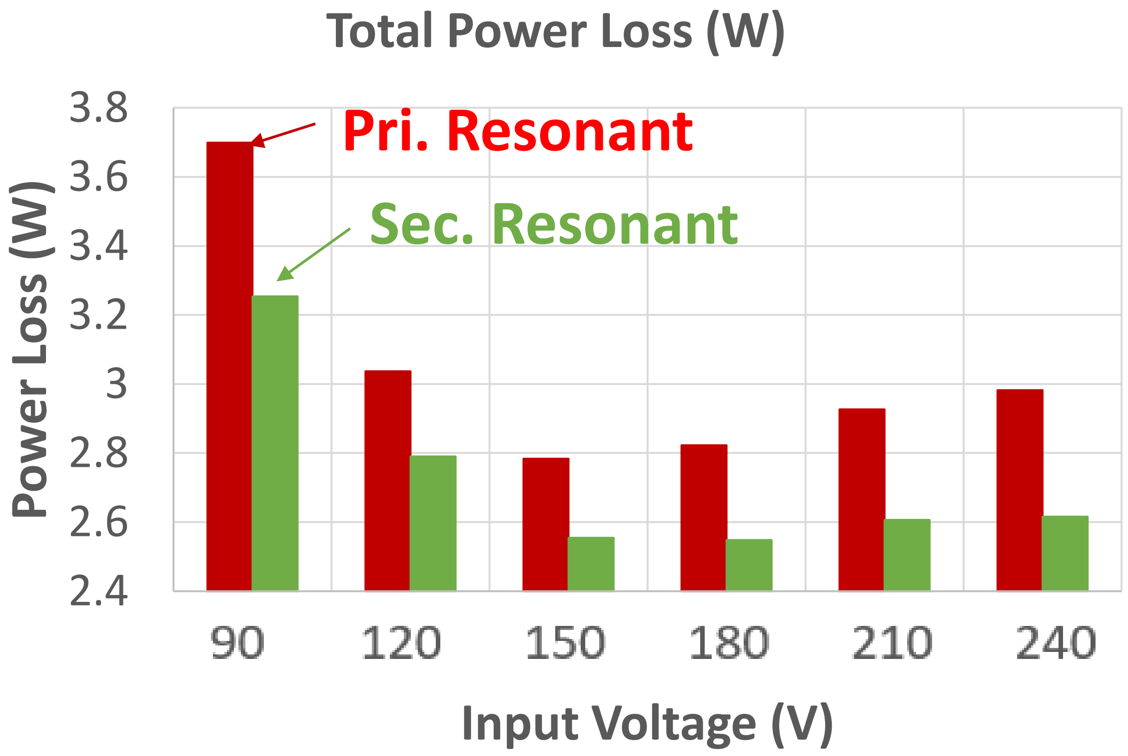


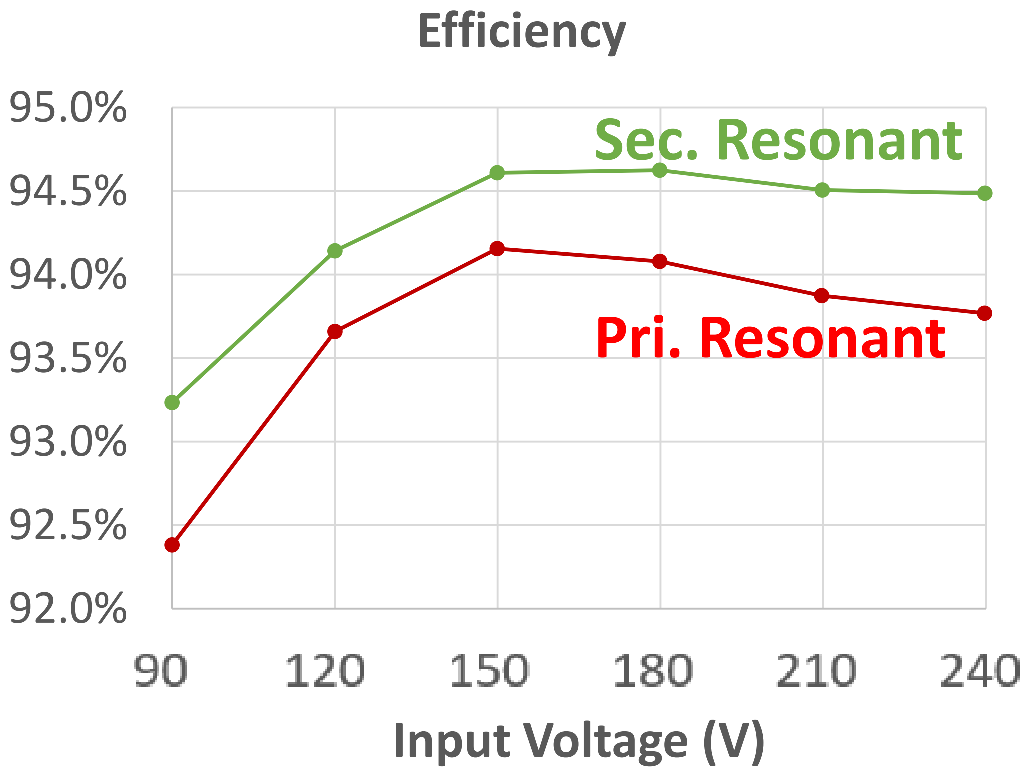




*Measured results of 45W ACF

Efficiency Benefit of New ACF

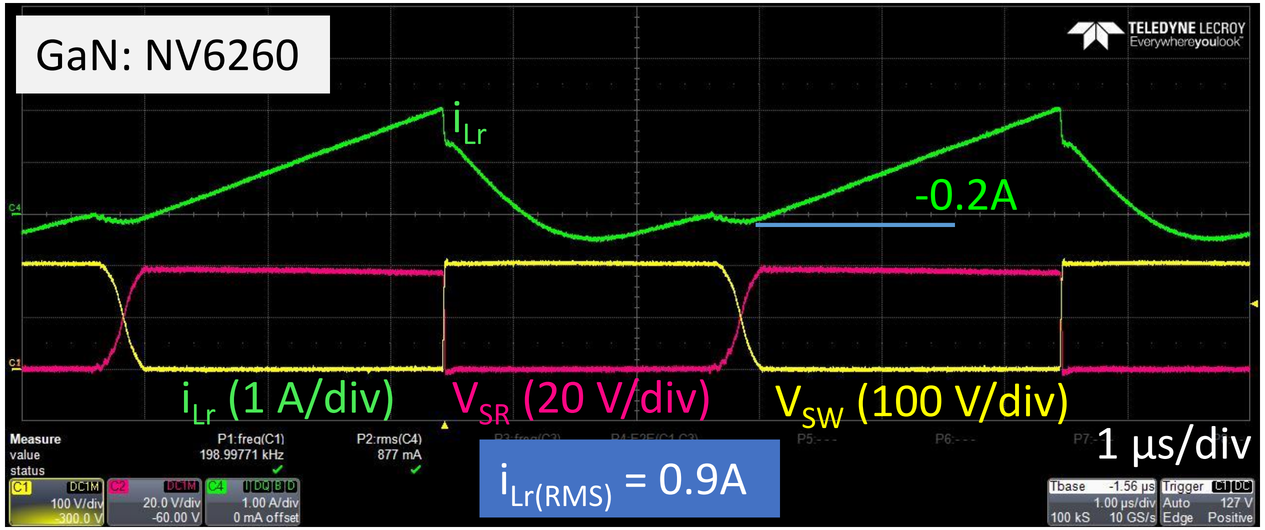


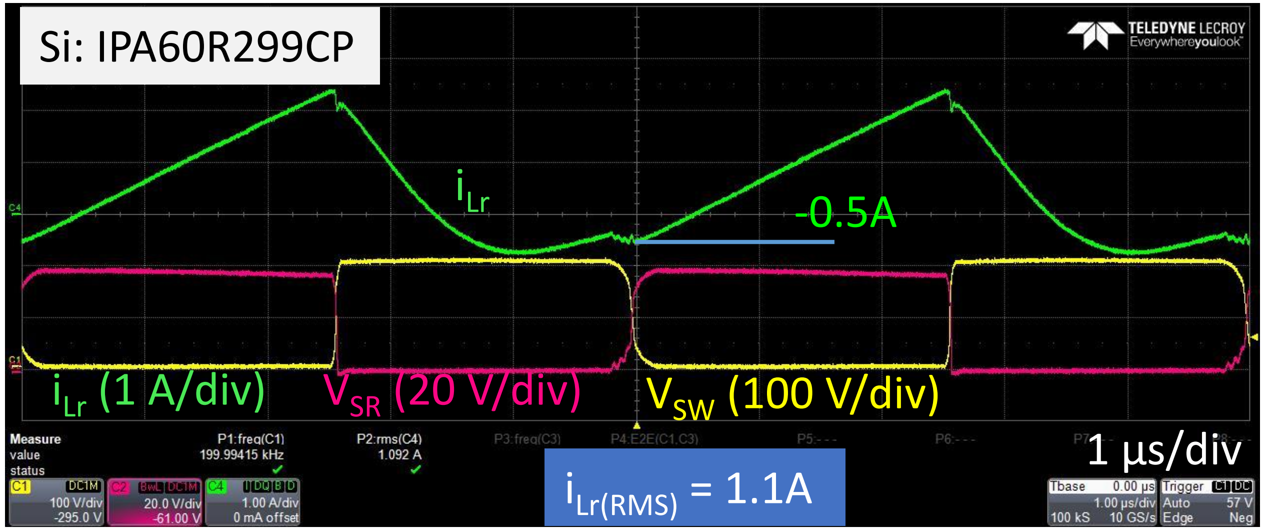


- 0.4 W power loss reduction
- ~0.8% efficiency improvement

*Measured results of 45W ACF

Advantages of Using GaN in ACF





	IPA60R299CP	NV6260 (per FET)
Voltage Rating (V)	650	650
$R_{DS(ON)}$	270	160
C_o(tr) (pF)	120	50
Q_g (nC)	22	2.5
Q_{rr} (nC)	3900	0

- GaN ACF needs only 0.2A negative current for ZVS vs. Si's 0.5A
- GaN ACF RMS is only 0.9A vs. Si's 1.1A
- GaN has **no** body diode loss
- Low high-frequency gate-charge loss

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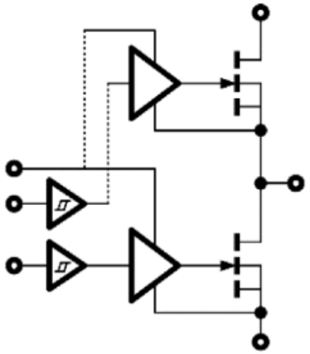
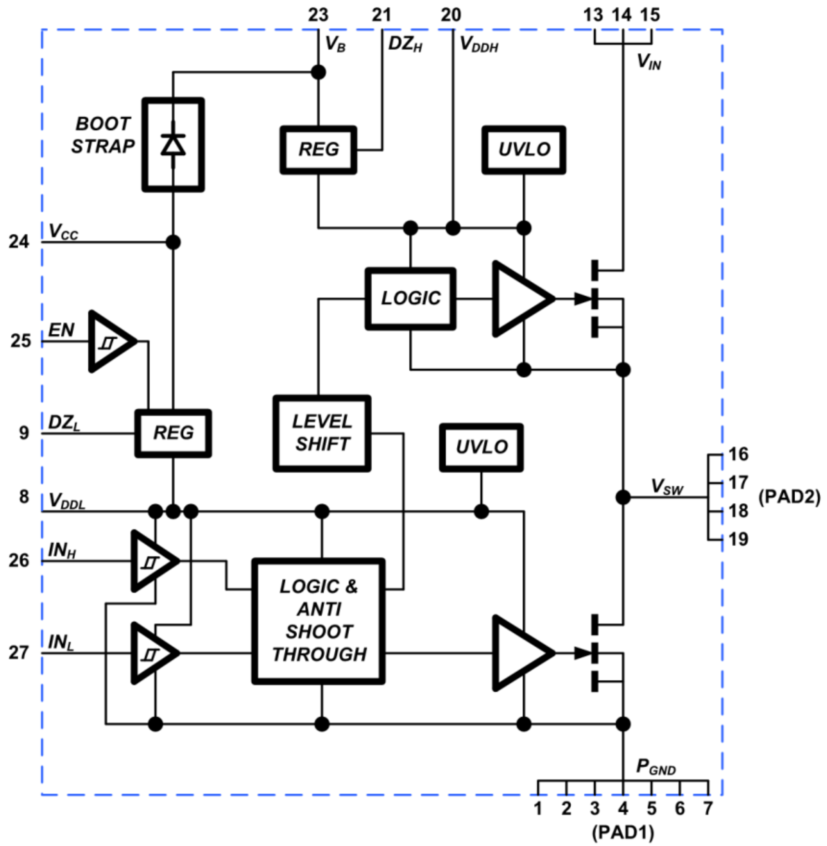
Half-Bridge iDrive GaN Power IC

PQFN 6x8 mm

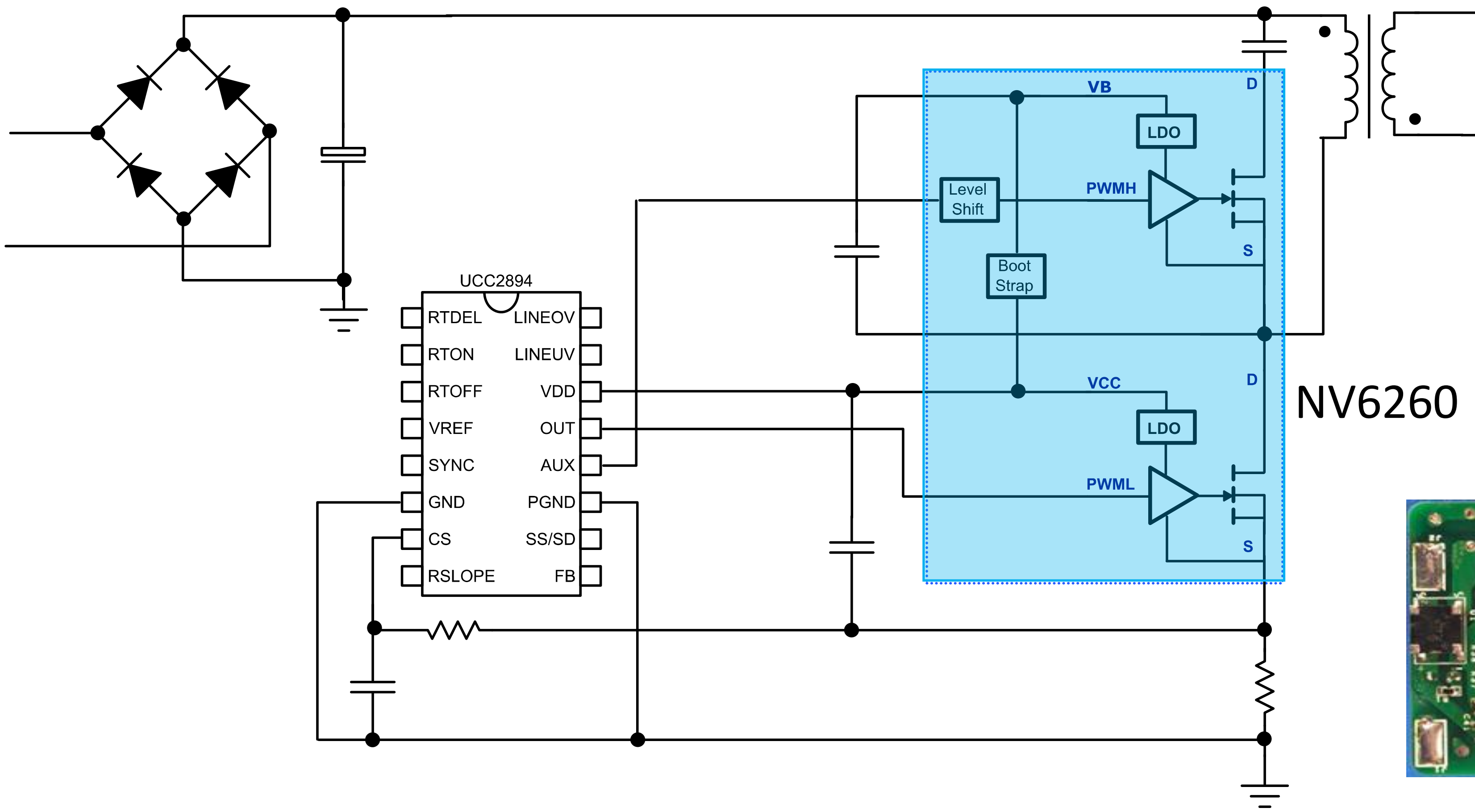


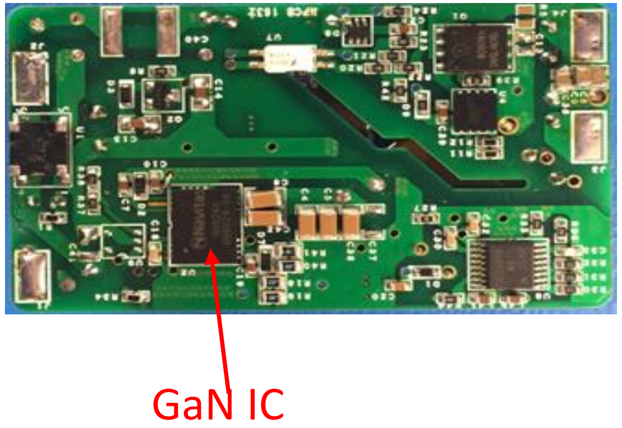
Simplified Schematic



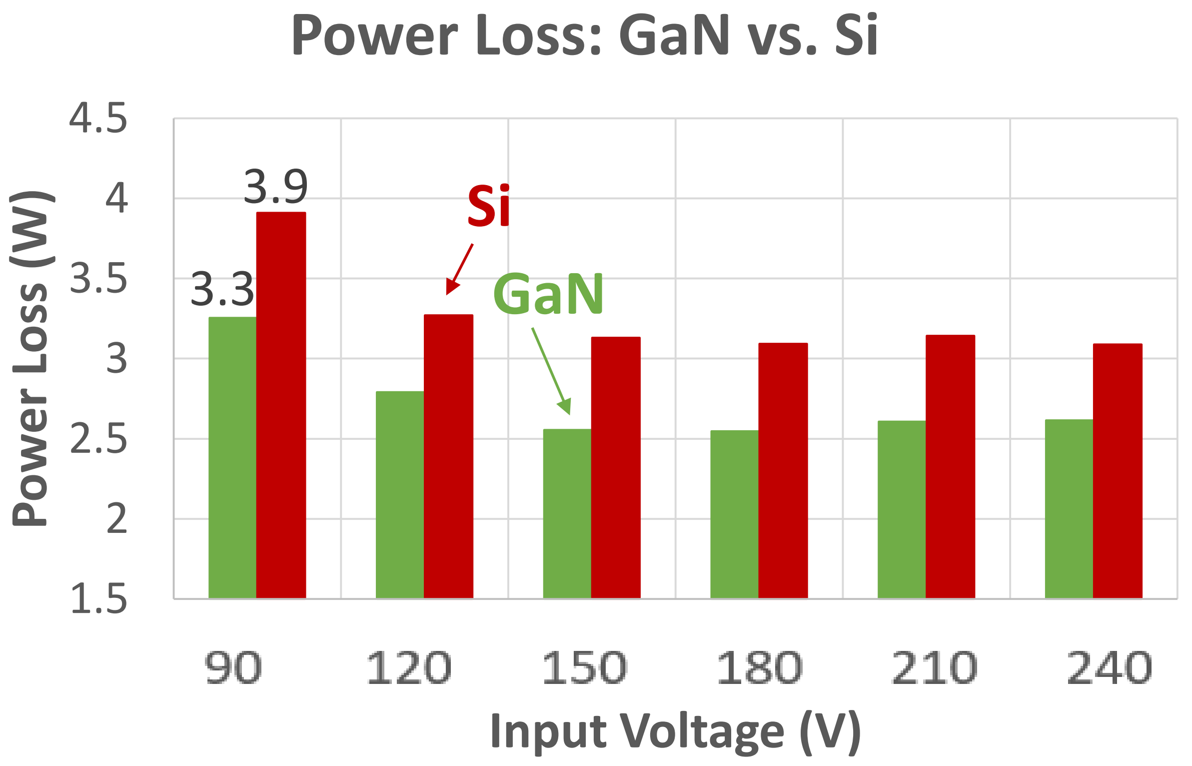
- Internal level-shift, bootstrap
- Range from 150-600 mOhm (650V)
- Single component
- Ground-referenced PWM signals
- Active Clamp Flyback, Half-Bridge, LLC, etc.

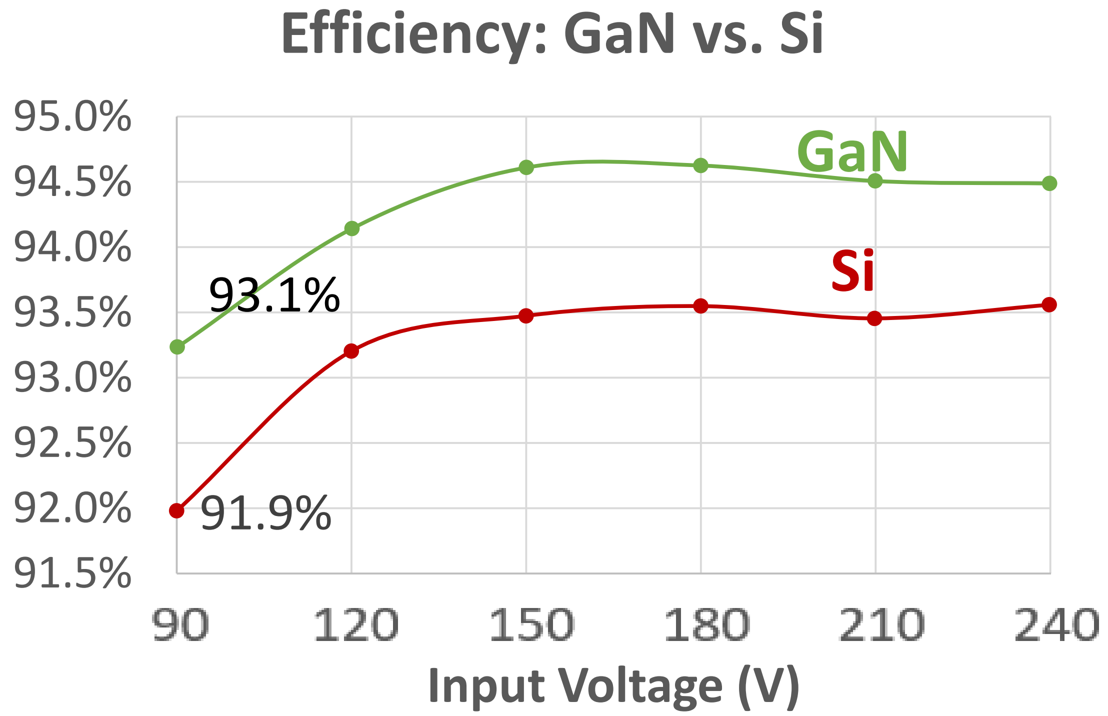
GaN Power IC Simplifies ACF





GaN Power IC Efficiency Advantage





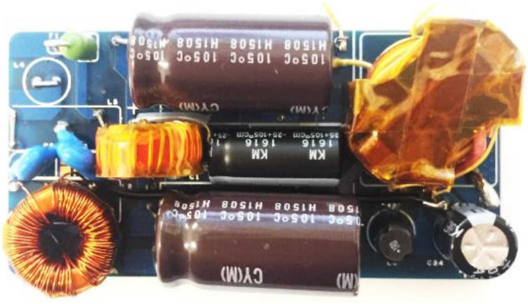
- GaN reduces power loss by 0.6W
- GaN boosts efficiency by 1.2%

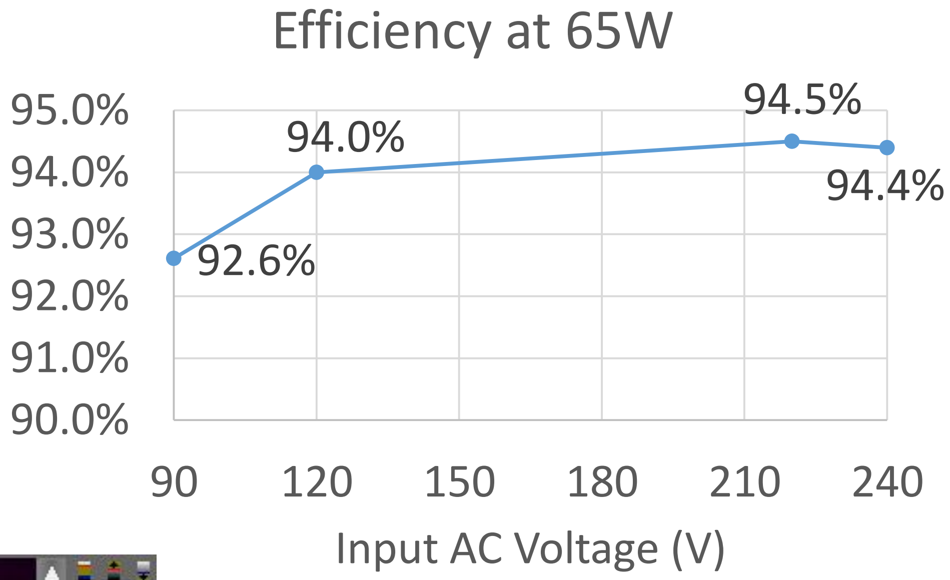
*Measured results of 45W ACF

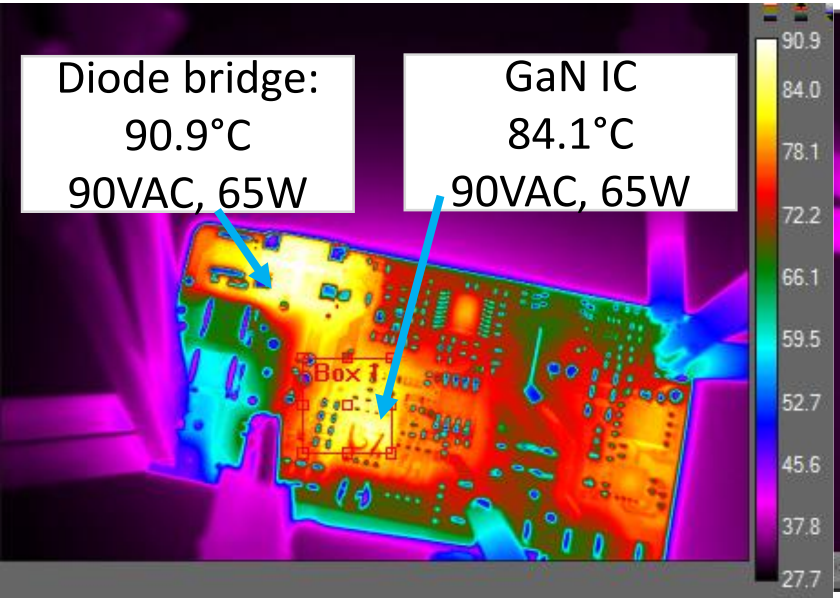
High Density 65W Adapter Using ACF and GaN

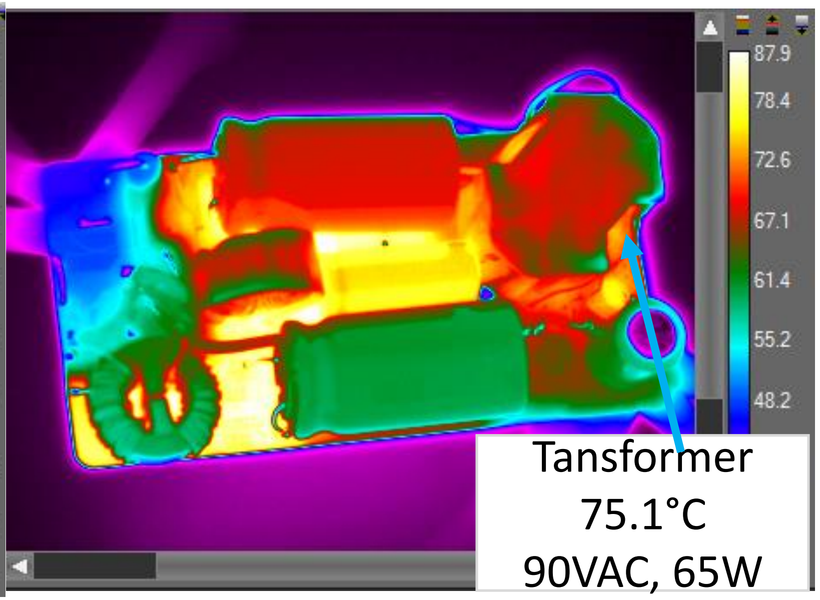
2.63 x 1.32 x 0.62 in

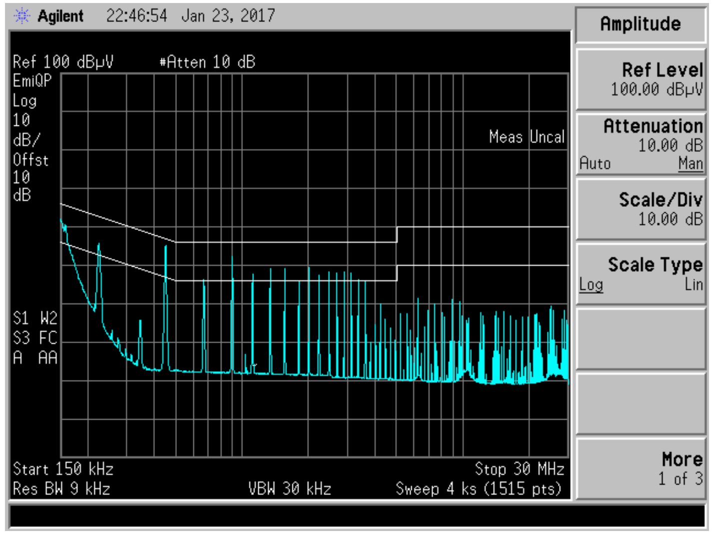
Power density 22 W/in³ (including case)











Conclusion

- USB-PD and QC demand high density solutions
- QR flyback hits performance ceiling
- ACF overcomes QR limitations and enables high frequency operation
- New ACF using secondary resonance improves ACF's operation and efficiency
- GaN is uniquely suitable for high frequency operation
- Half-Bridge GaN Power IC simplifies ACF design and improves density
- An example of 65W ACF adapter using GaN and secondary resonance achieves 22W/in^3 density, while meeting thermal and EMI requirement

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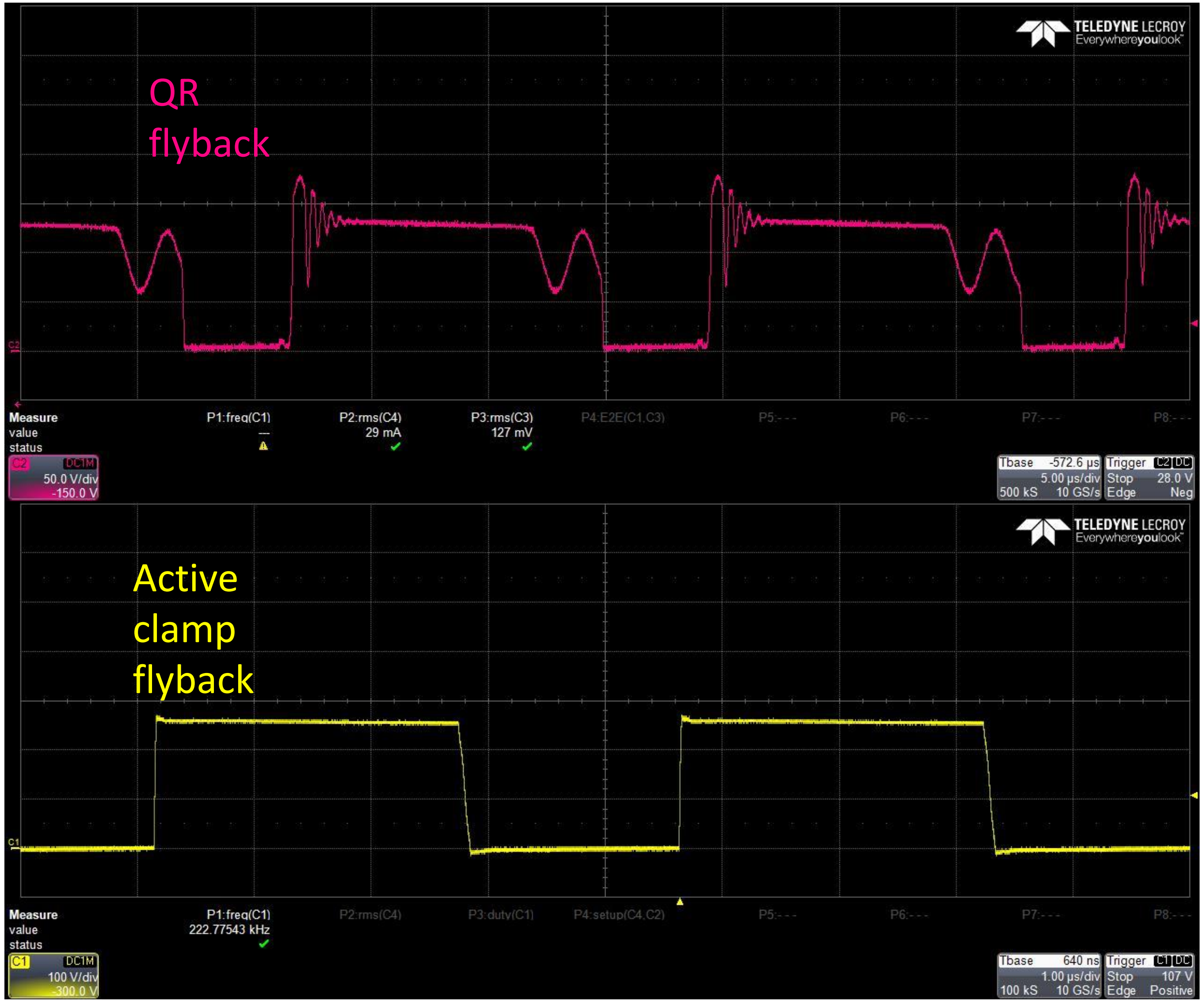
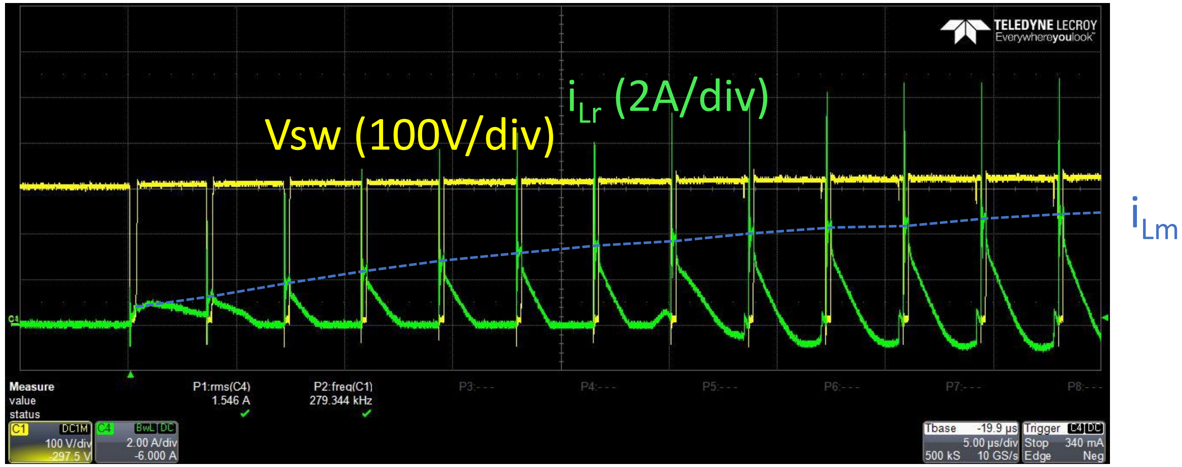
Backup

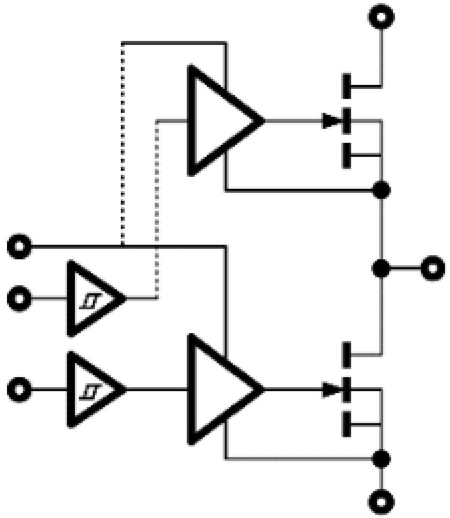
Waveform: QR vs. ACF



Startup in CCM and Hard-Switching

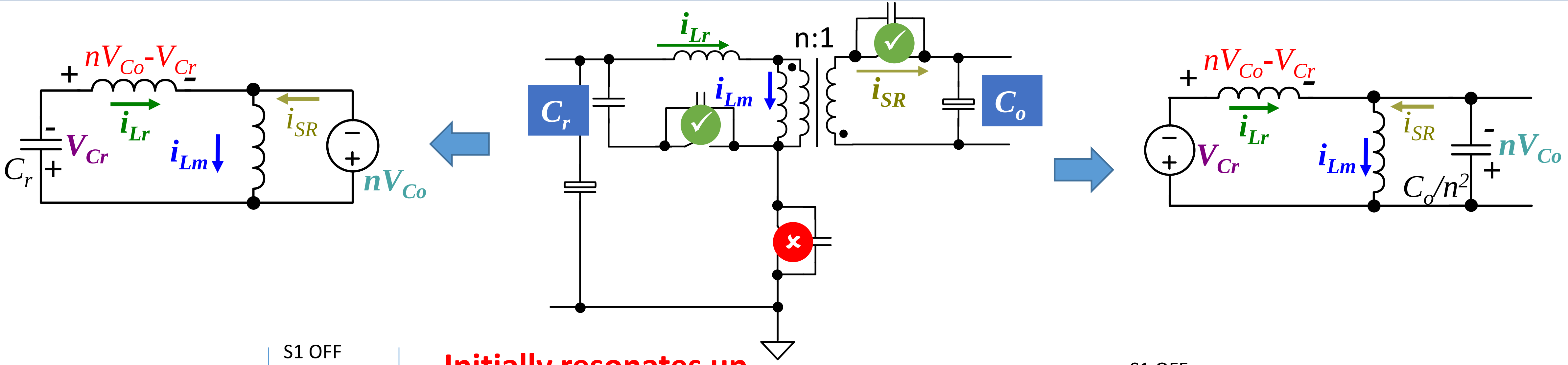
- Start-up in CCM: hard-switched, body diode reverse recovery..

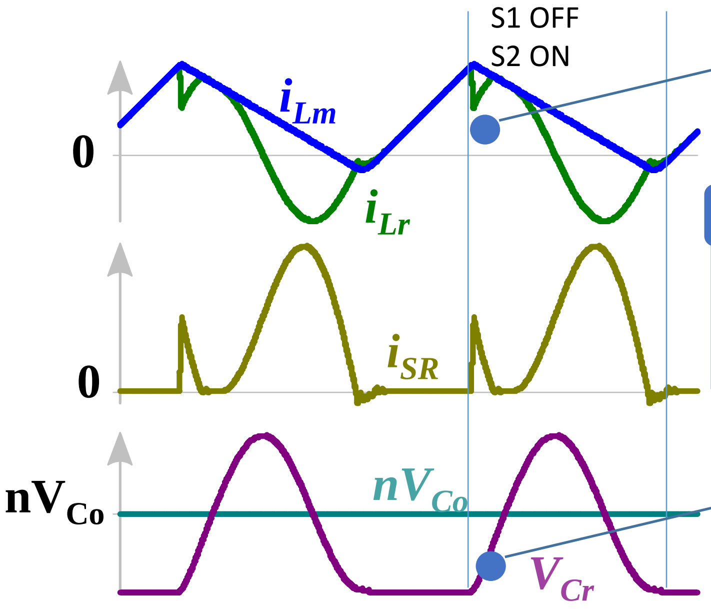




Navitas GaN
Half Bridge IC

Lr Resonant Interval



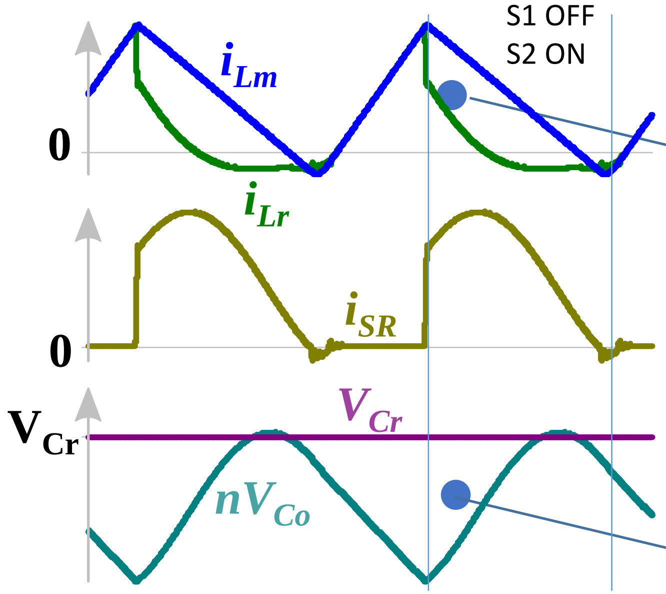


Initially resonates up

Primary Resonant

- $C_r << C_o/n^2$
- SR double turn-on

Initially $nV_{Co} > V_{Cr}$



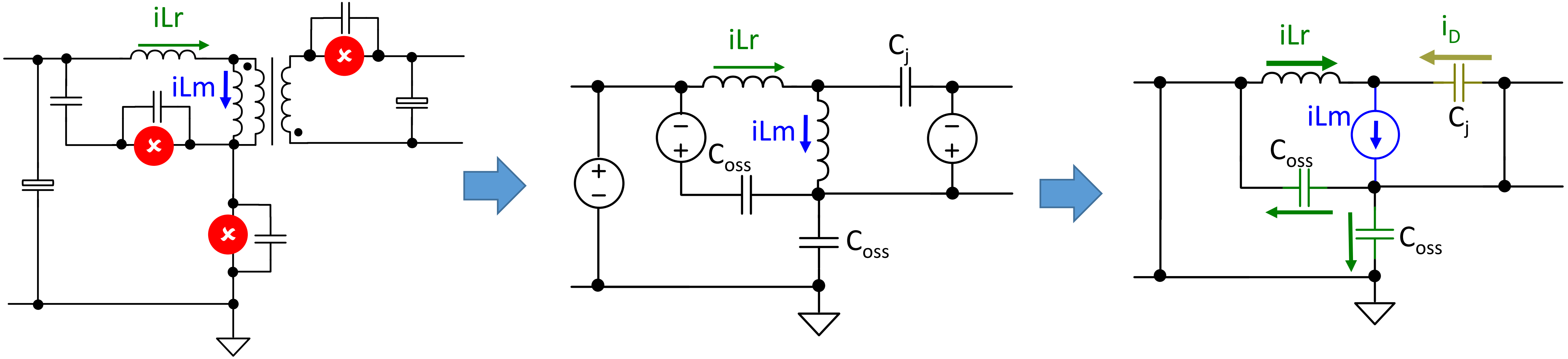
Initially resonates down

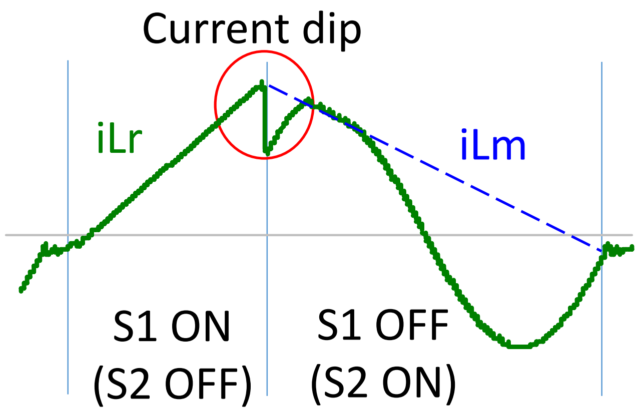
Secondary Resonant

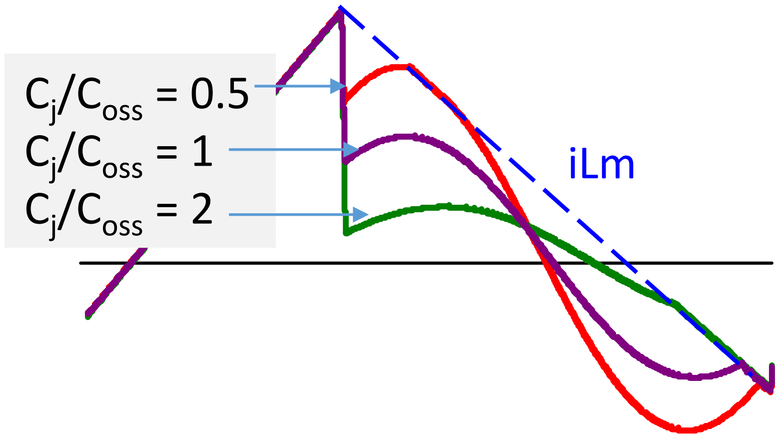
- $C_r >> C_o/n^2$
- No SR double turn-on

Initially $nV_{Co} < V_{Cr}$

ACF Primary Current Dip



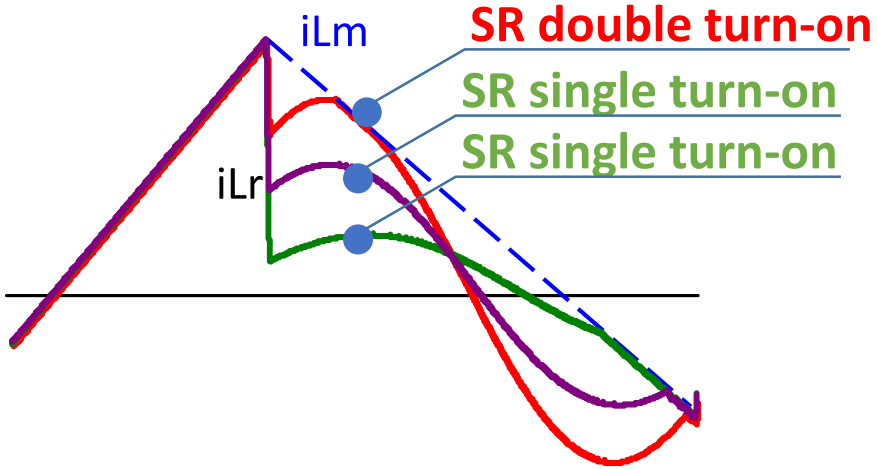


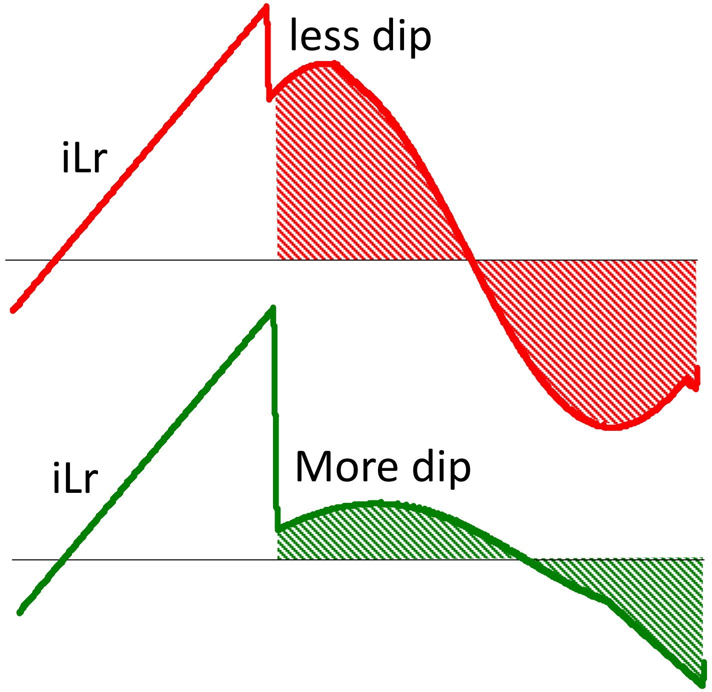


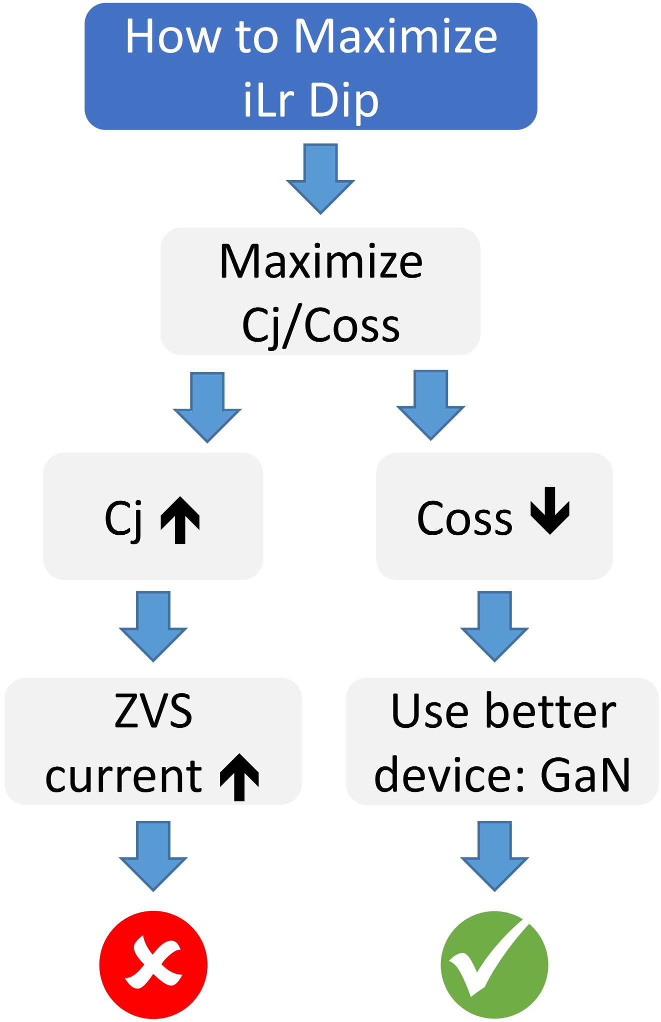
- Bigger C_j/C_{oss}

  → bigger current dip
- Why is current dip important?

Current Dip Benefits







- Current dip ↑
  SR double turn-on ↓

- Current dip ↑
  RMS value $i_{Lr(RMS)}$ ↓

Current Dip: Adding 2.2nF Cj