# Active Clamp Flyback Using GaN Power IC for Power Adapter Applications

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# How to Improve Power Adapter Density?

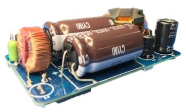
Navitas

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

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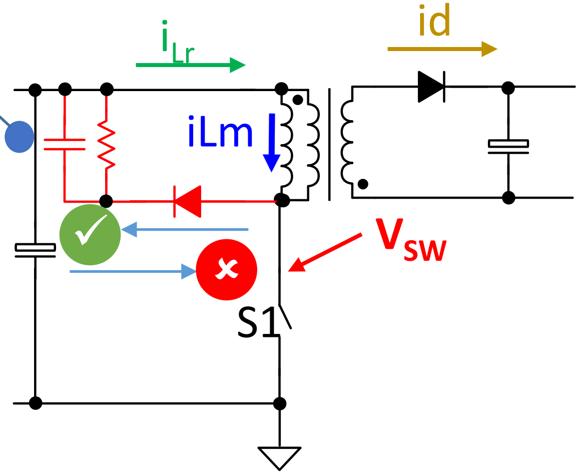
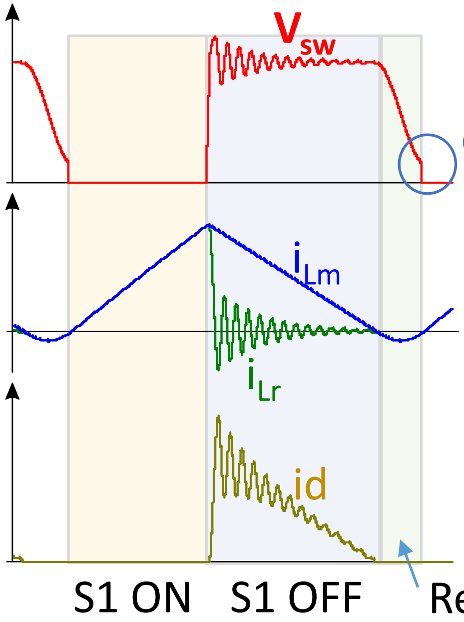
Lossy RCD clamp




Lossy hard switching

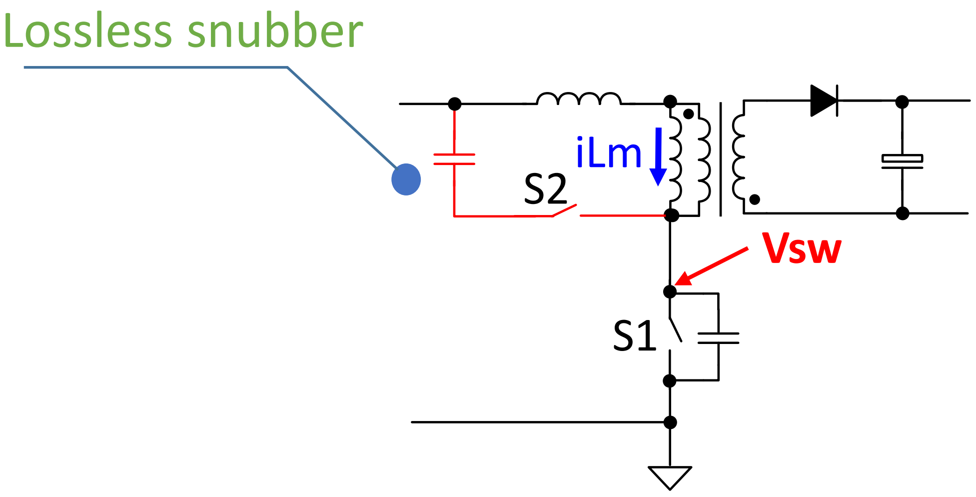
这个时刻开通的话，其实电压已经降低不少了

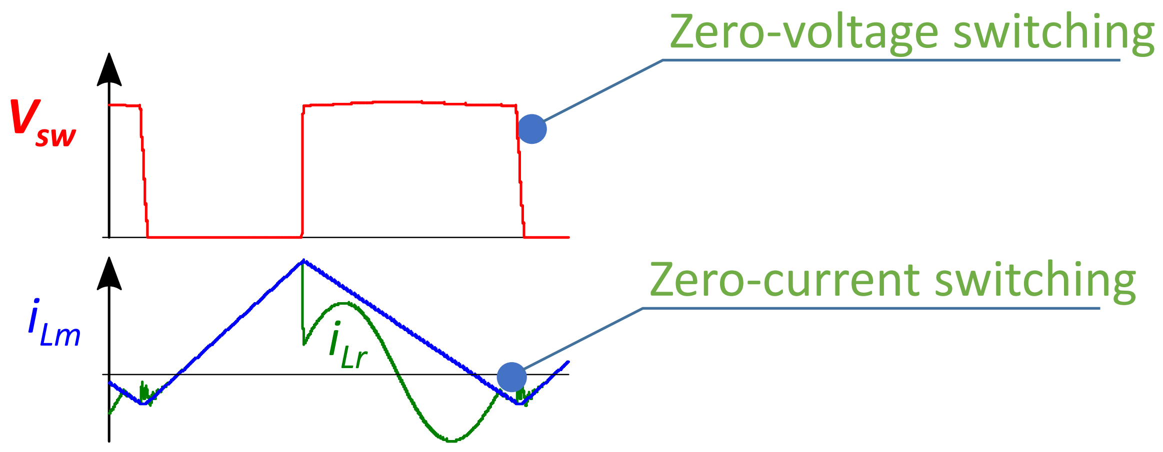
Resonant for valley switching

- 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

DCM，这里应该是Lr+Lm和S1的等效电容之间的震荡

# ACF Enables ZVS and High Frequency Switching

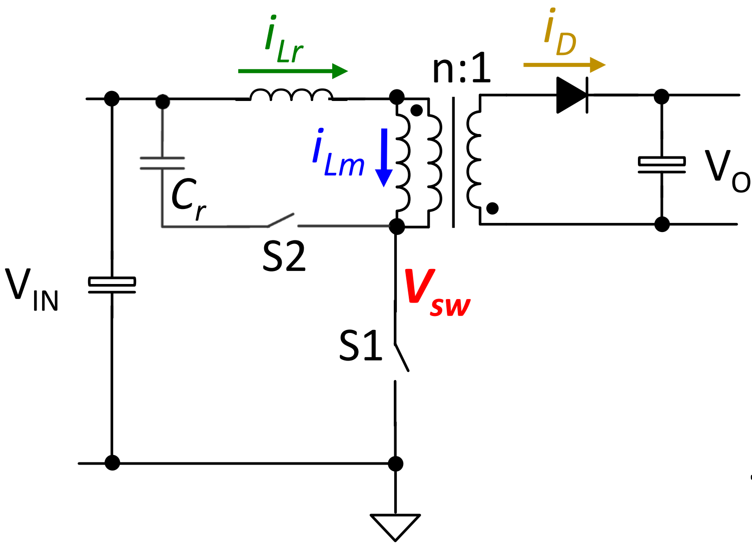


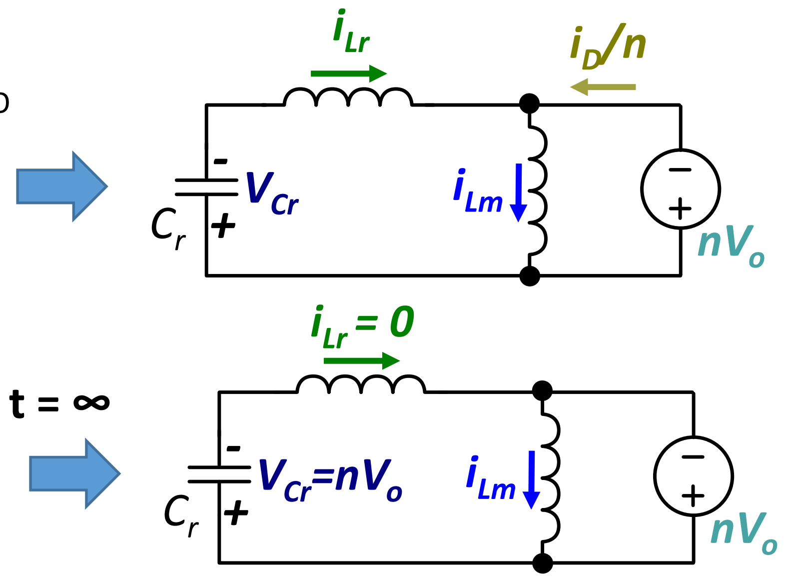



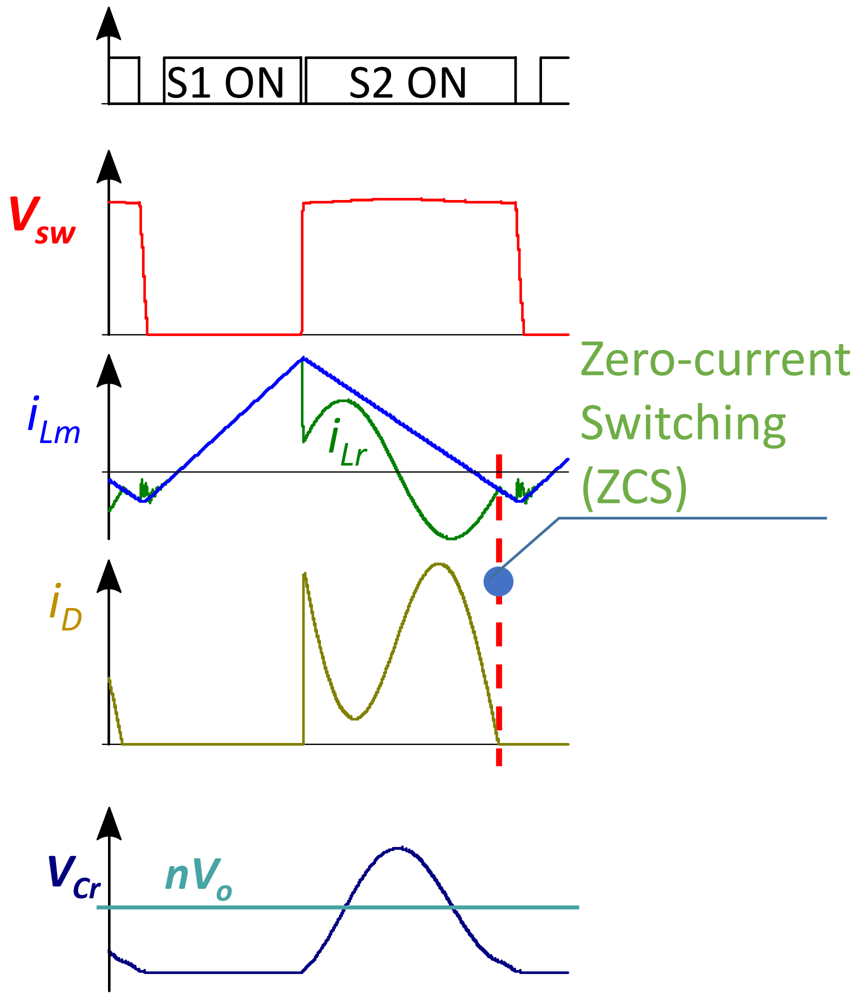

- No snubber losses, all leakage energy is recovered
- ZVS soft switching over entire operation range
- ZCS soft turn-off for output rectifier
- Clean waveforms reduce EMI
- Enable small adapter design with high-frequency switching

# ACF Operation

这个过程中S1的结电容会不会参与进来?



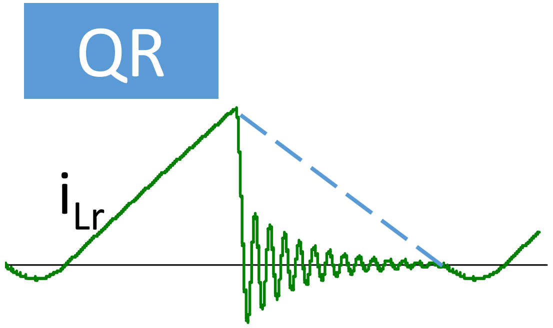



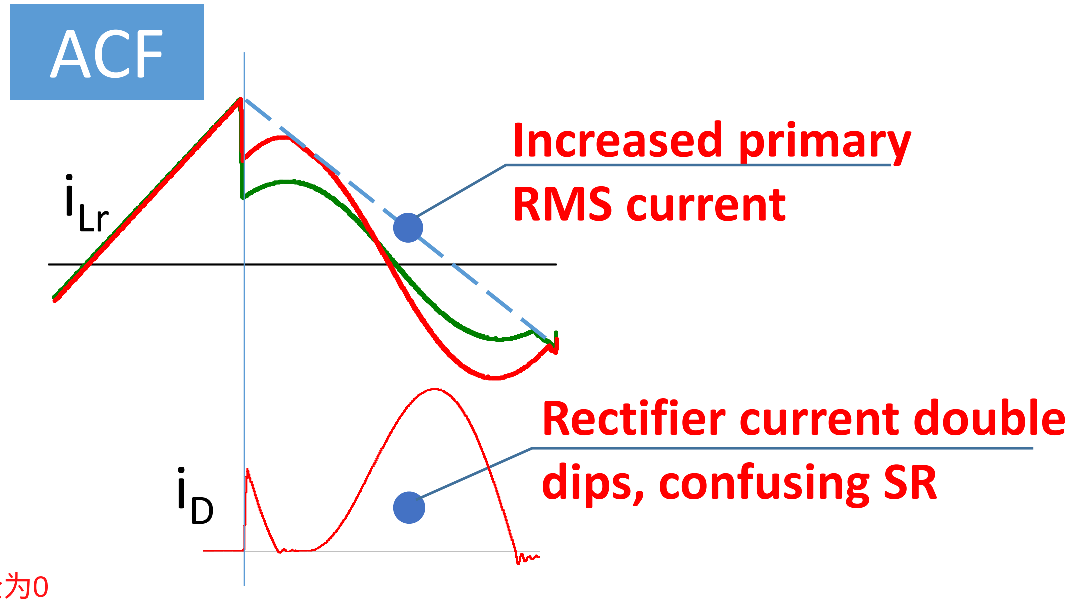




- Lr resonates with Cr during S2 ON interval
- ZVS is achieved by magnetizing inductance current
- Rectifier current is the difference between $i_{Lm}$ and $i_{Lr}$
- $i_{Lr}$ returns to $i_{Lm}$ by the end of S2 ON interval for rectifier ZCS

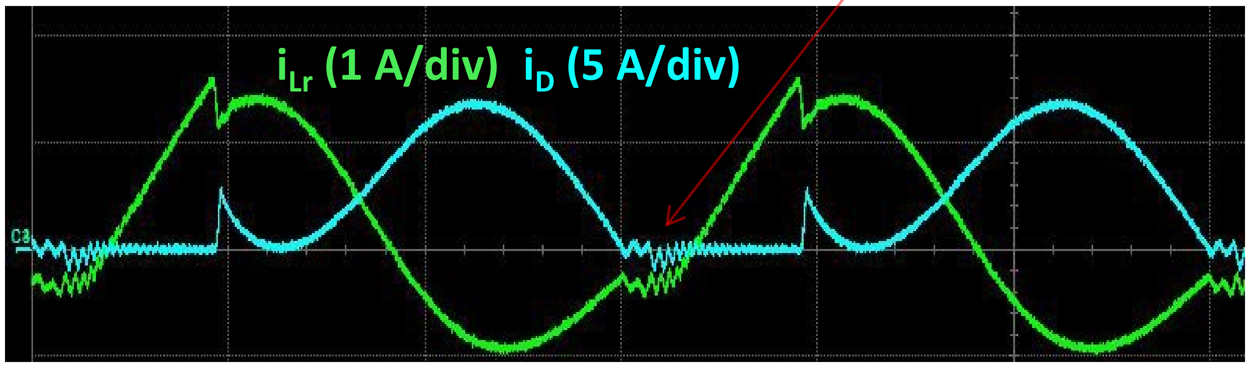
这里指的是二极管

# Drawbacks of Traditional ACF



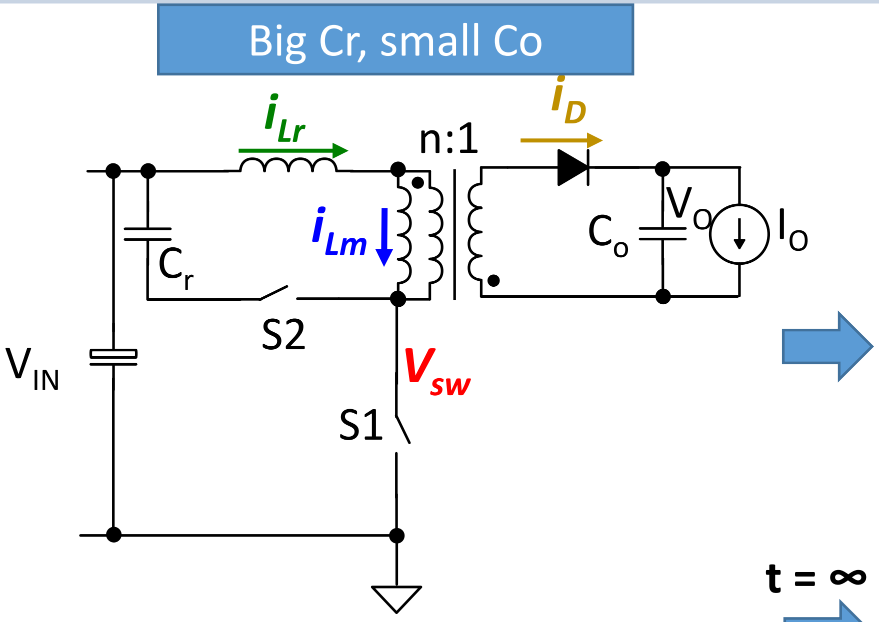



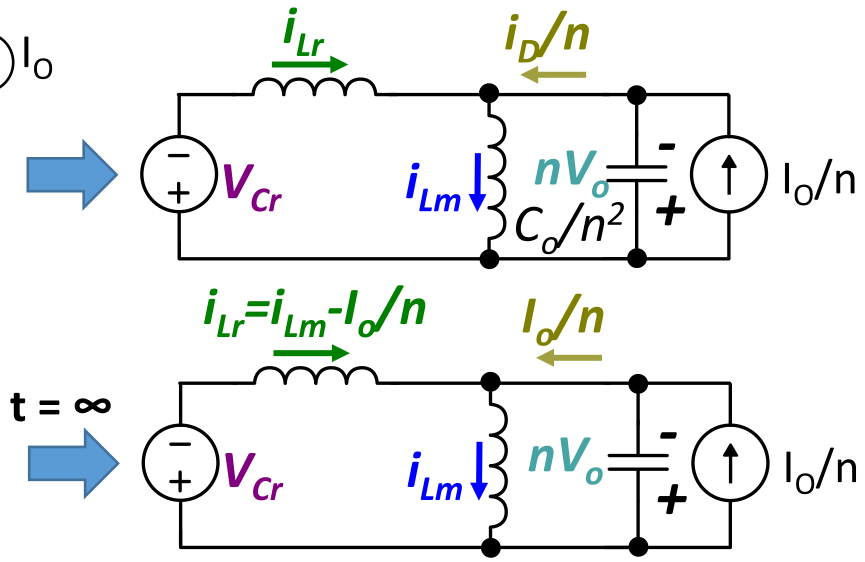

这里还是有点震荡，并没有电流完全为0

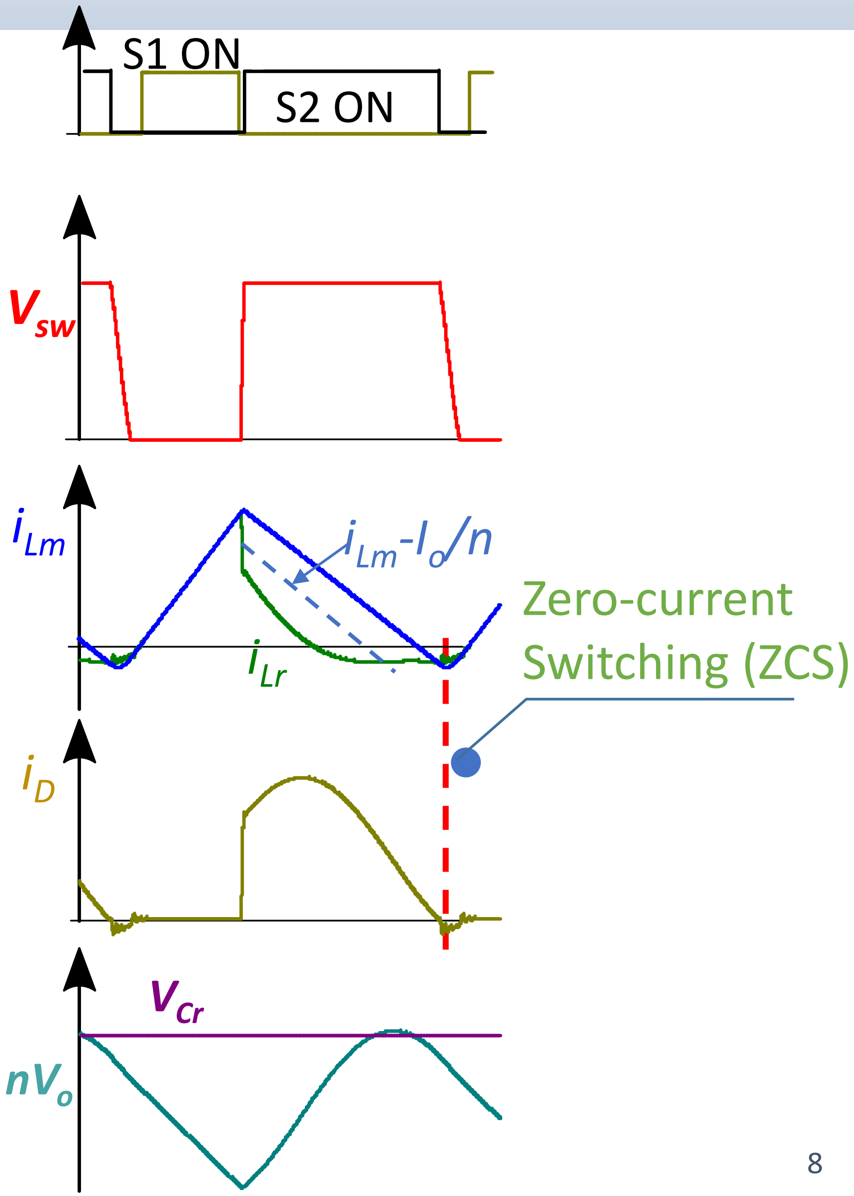



- Difficult to shape the current to achieve ZCS and minimize rms current
- Conduction loss is high
- Not compatible with SR controllers

# New ACF Using Secondary Resonance

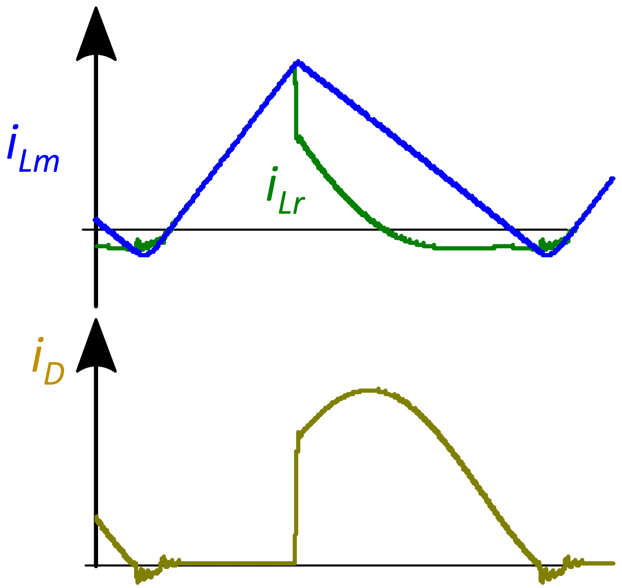


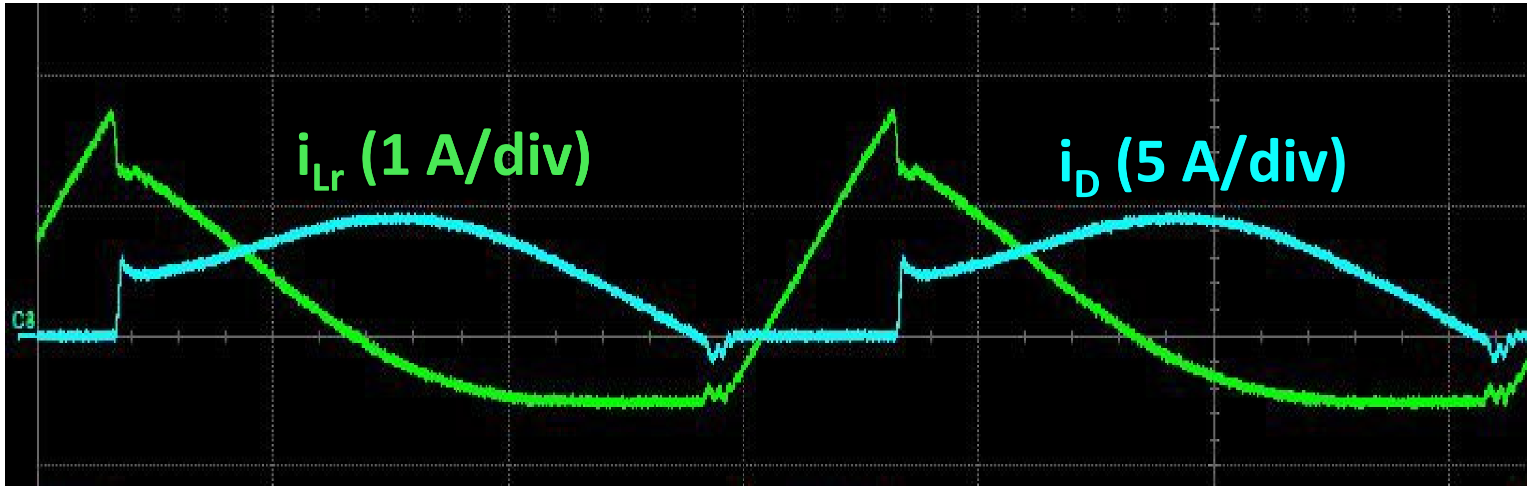




- S1 ON interval is the same as primary resonant
- In S2 ON interval
  - $C_o/n^2 << C_r$, Co resonates with Lr
  - $i_{Lr}$ centers around a line lower but in parallel with $i_{Lm}$
  - ZCS is easily achieved. No rectifier current double dipping

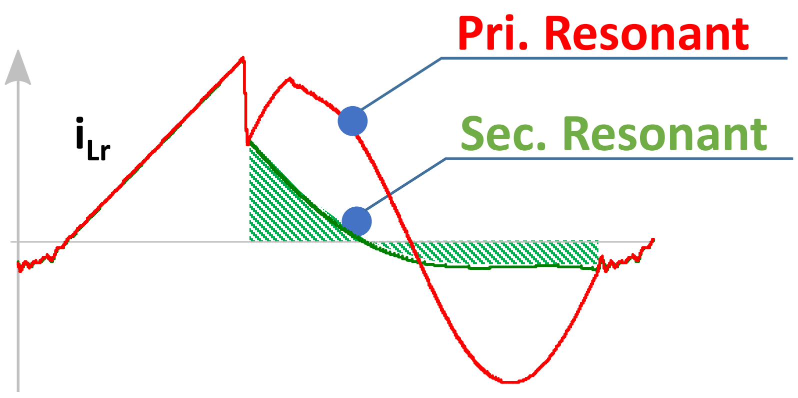
# New ACF Simplifies SR and Reduces Current RMS

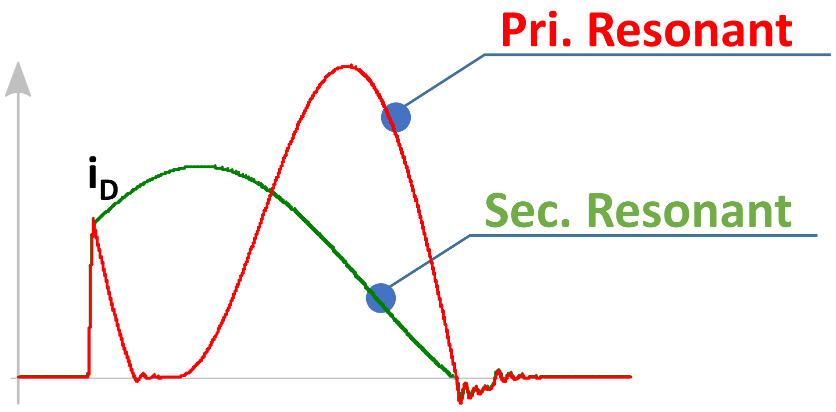


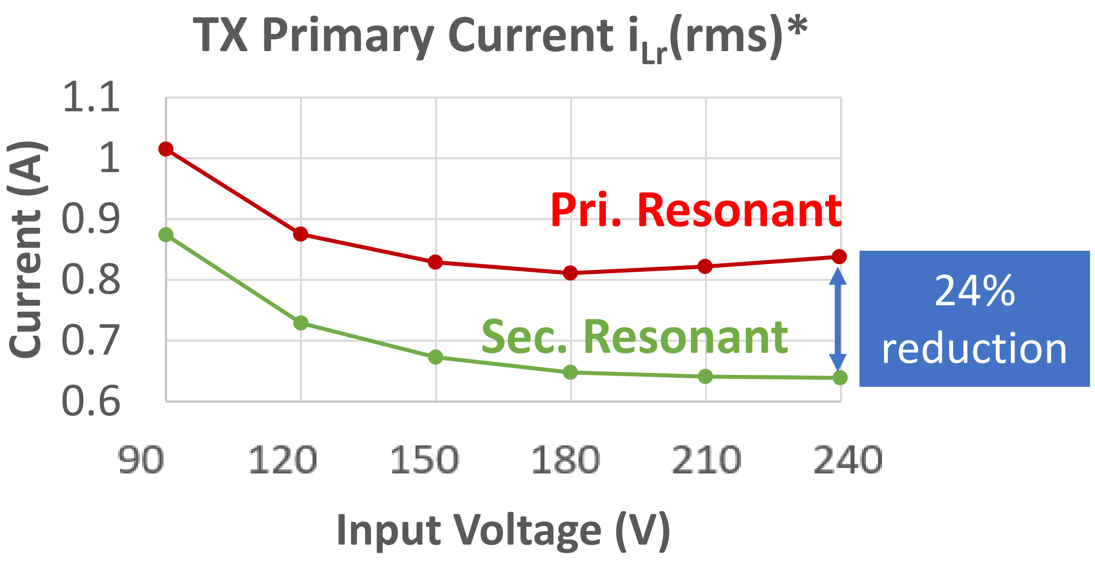



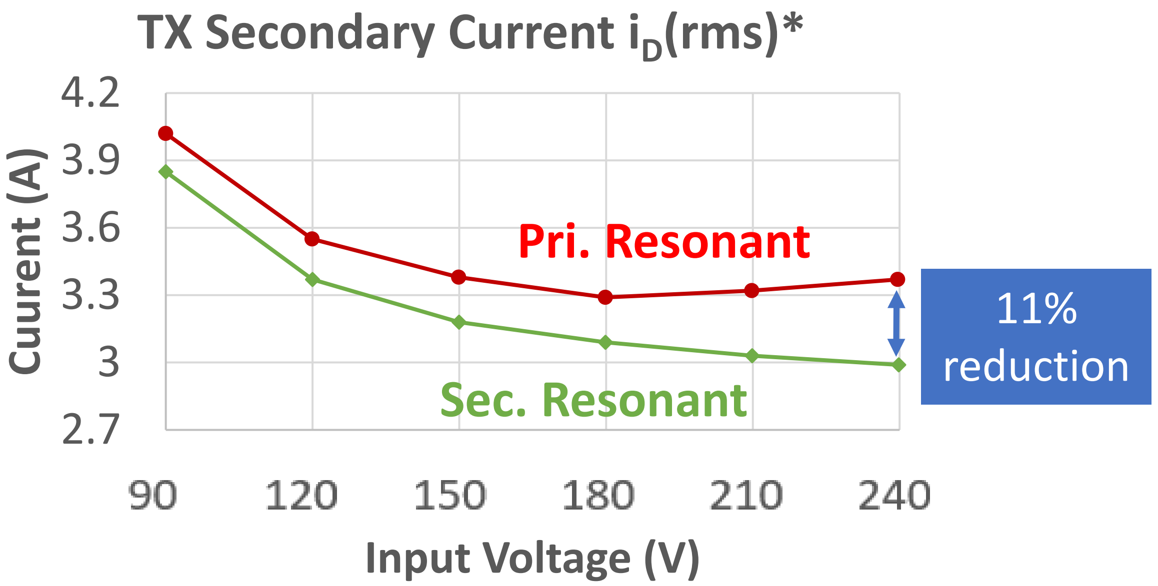

- $i_{Lr}$ current can be easily shaped
- No rectifier current dipping issue. Simplifies SR
- Reduced rms current and conduction loss

# Experimental Result of RMS Reduction



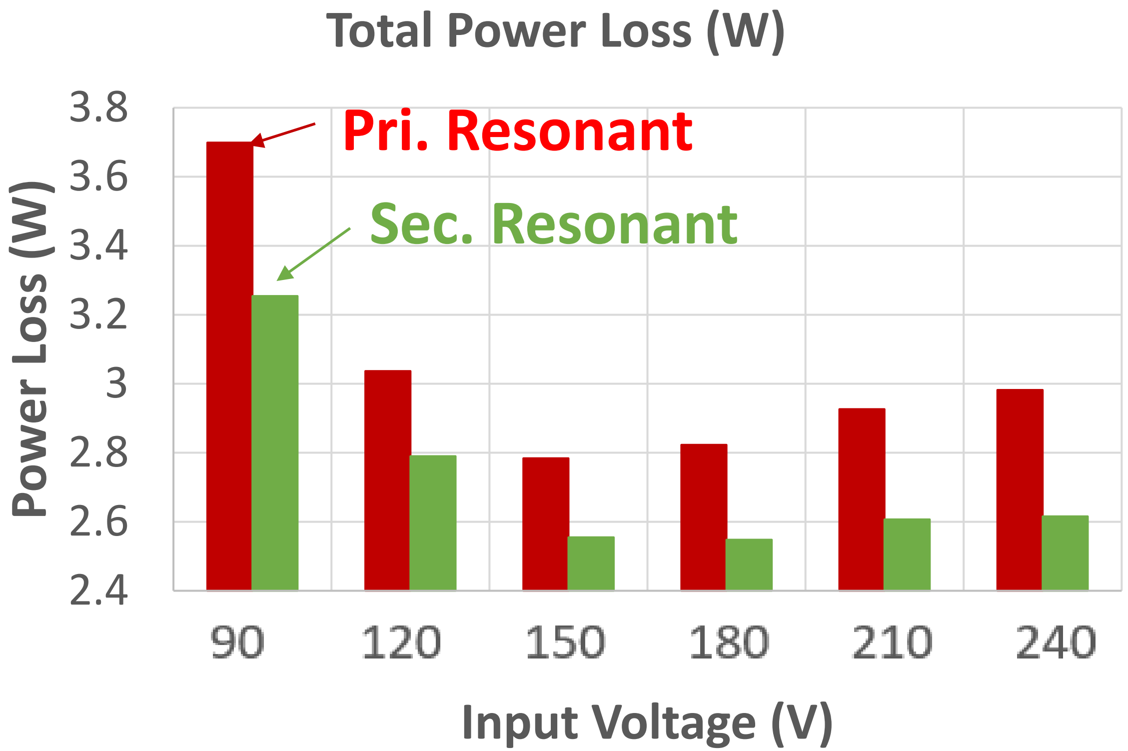



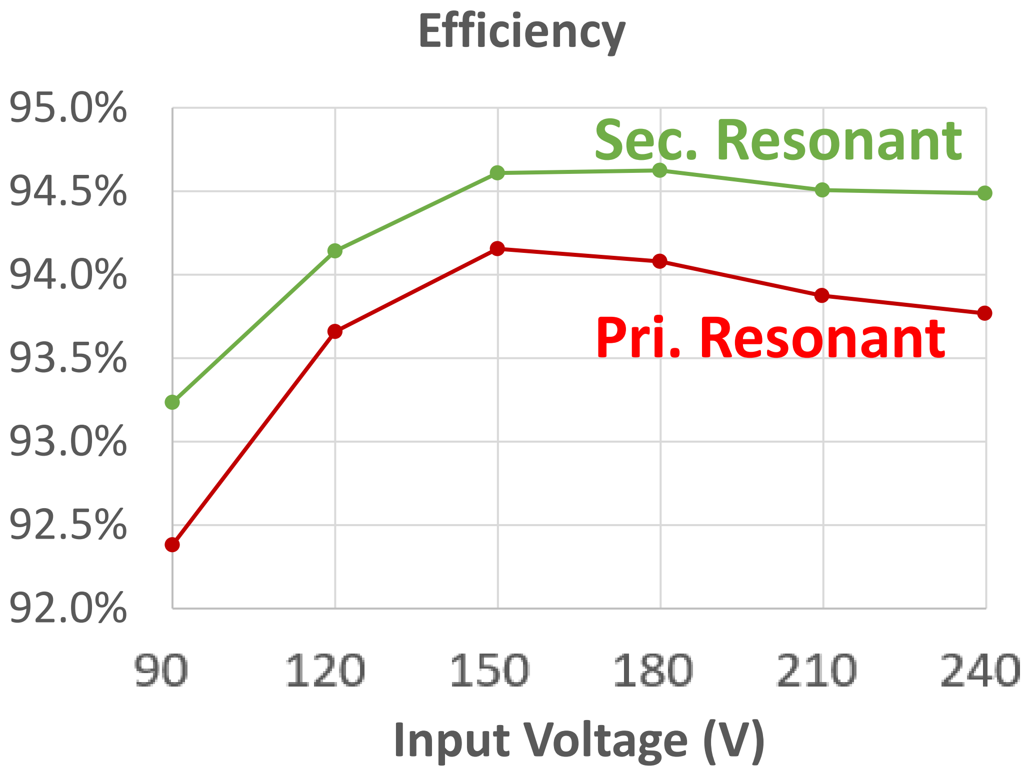




*Measured results of 45W ACF

# Efficiency Benefit of New ACF

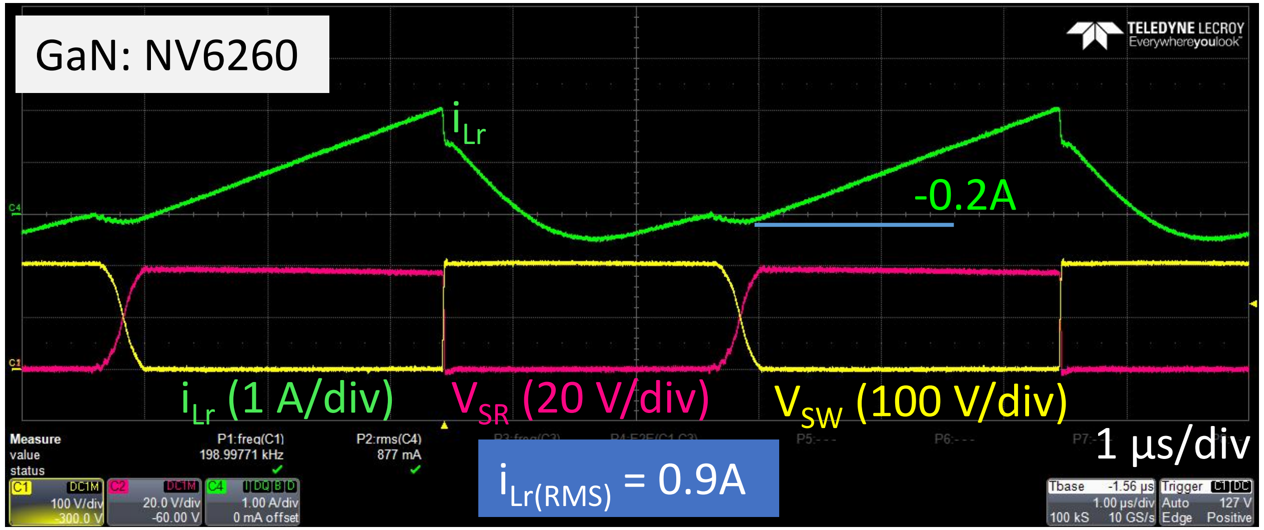


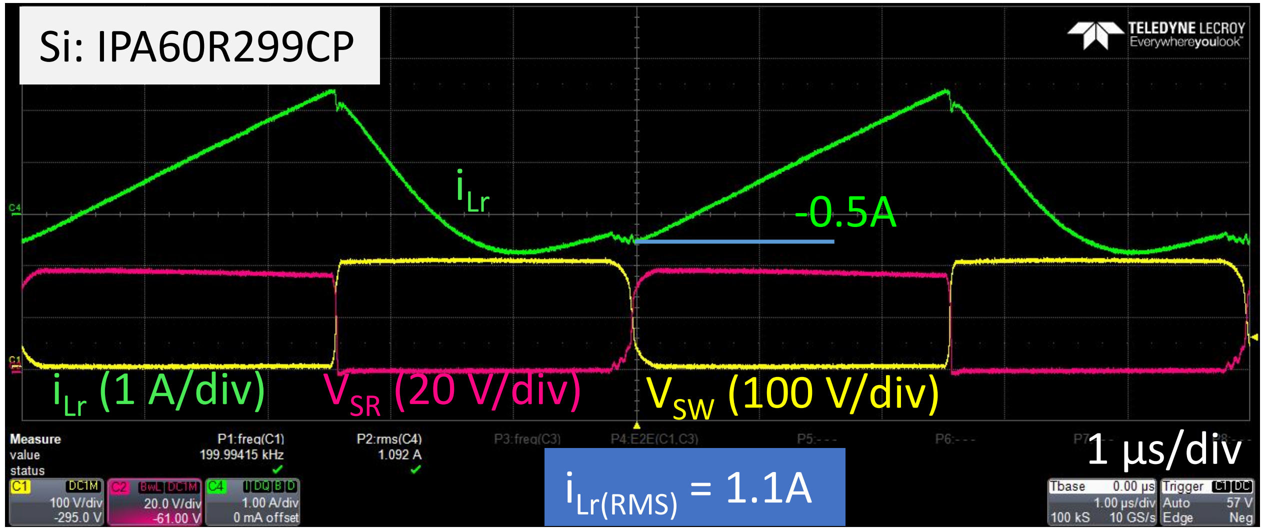




- 0.4 W power loss reduction
- ~0.8% efficiency improvement

*Measured results of 45W ACF

# Advantages of Using GaN in ACF



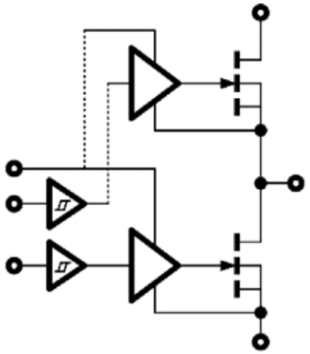




| | IPA60R299CP | NV6260 (per FET) |
|---|---|---|
| Voltage Rating (V) | 650 | 650 |
| $R_{DS(ON)}$ | 270 | 160 |
| $C_o$(tr) (pF) | 120 | 50 |
| $Q_g$ (nC) | 22 | 2.5 |
| $Q_{rr}$ (nC) | 3900 | 0 |

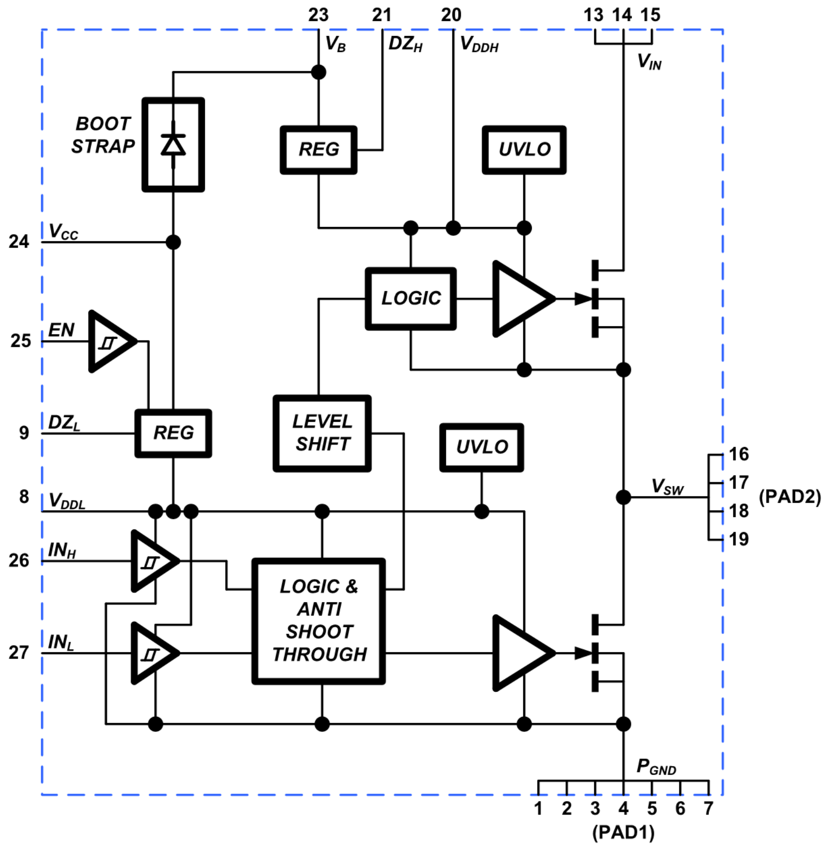
- GaN ACF needs only 0.2A negative current for ZVS vs. Si's 0.5A
- GaN ACF RMS is only 0.9A vs. Si's 1.1A
- GaN has **no** body diode loss
- Low high-frequency gate-charge loss

# Half-Bridge iDrive GaN Power IC


PQFN 6x8 mm

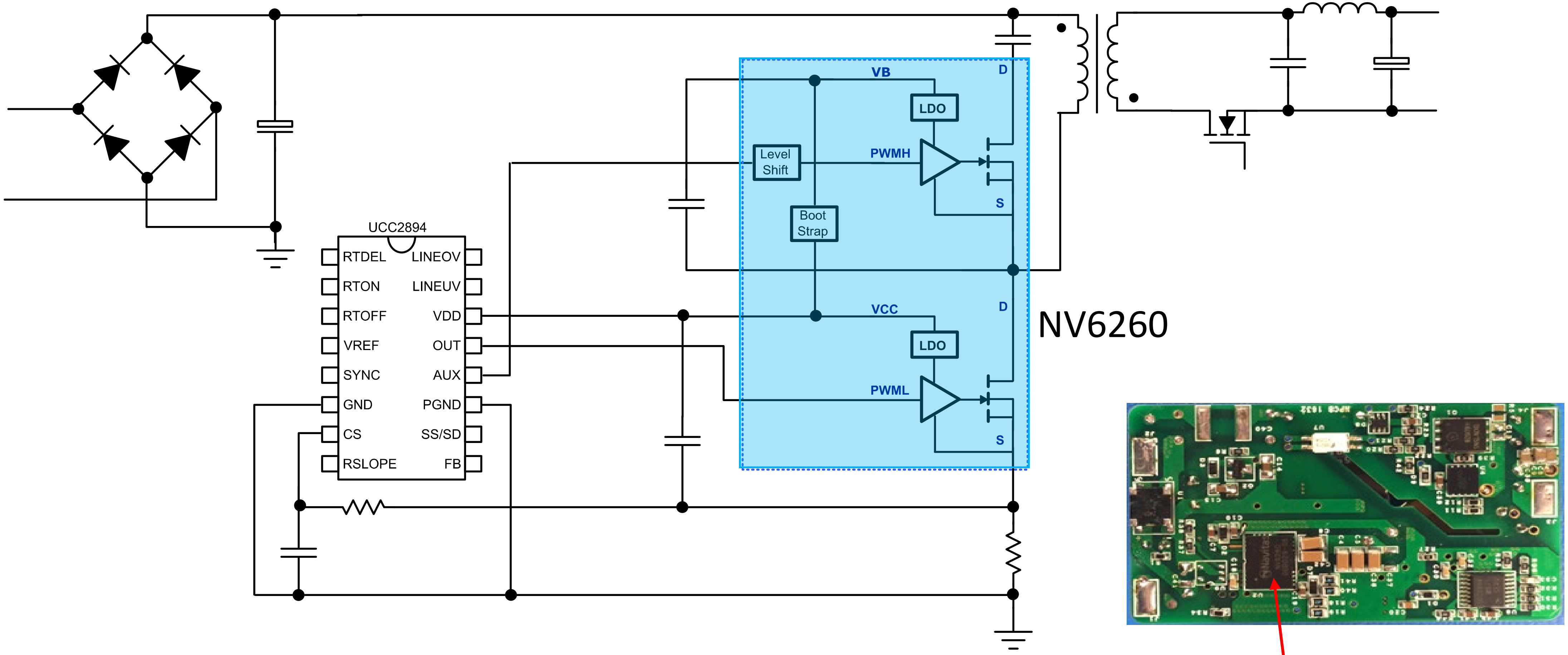


Simplified Schematic



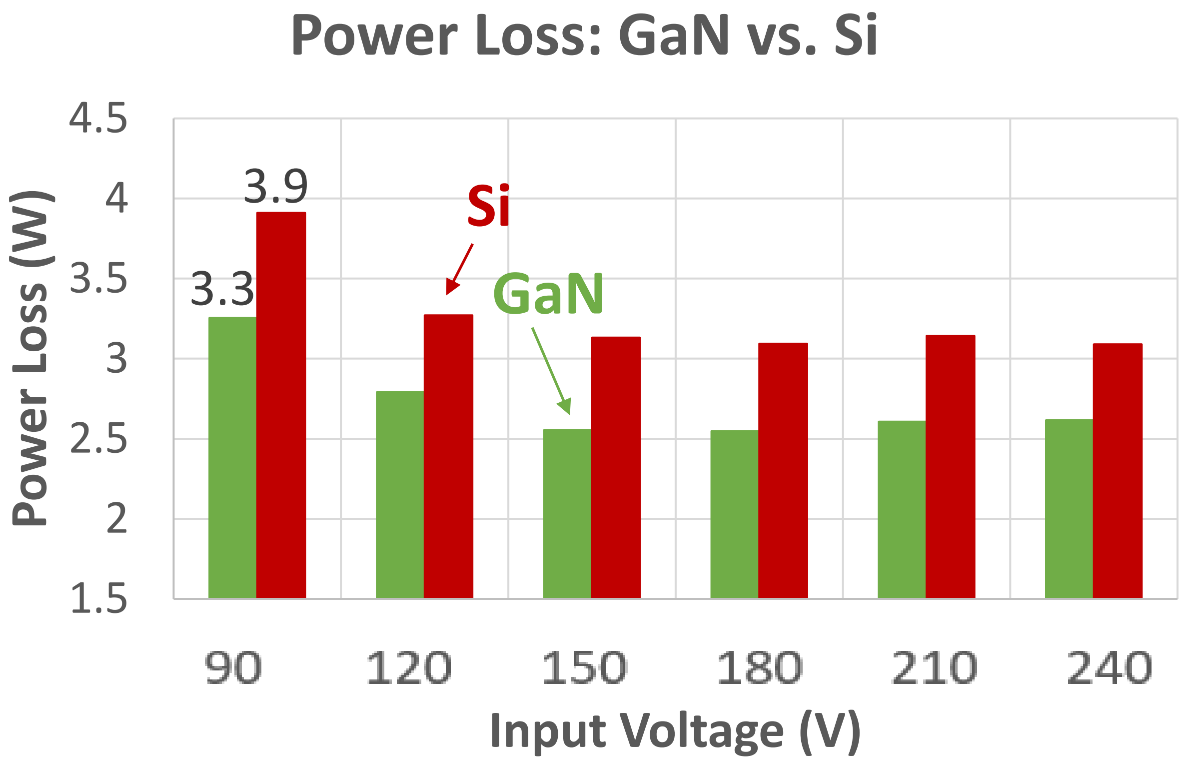

- Internal level-shift, bootstrap
- Range from 150-600 mOhm (650V)
- Single component
- Ground-referenced PWM signals
- Active Clamp Flyback, Half-Bridge, LLC, etc.

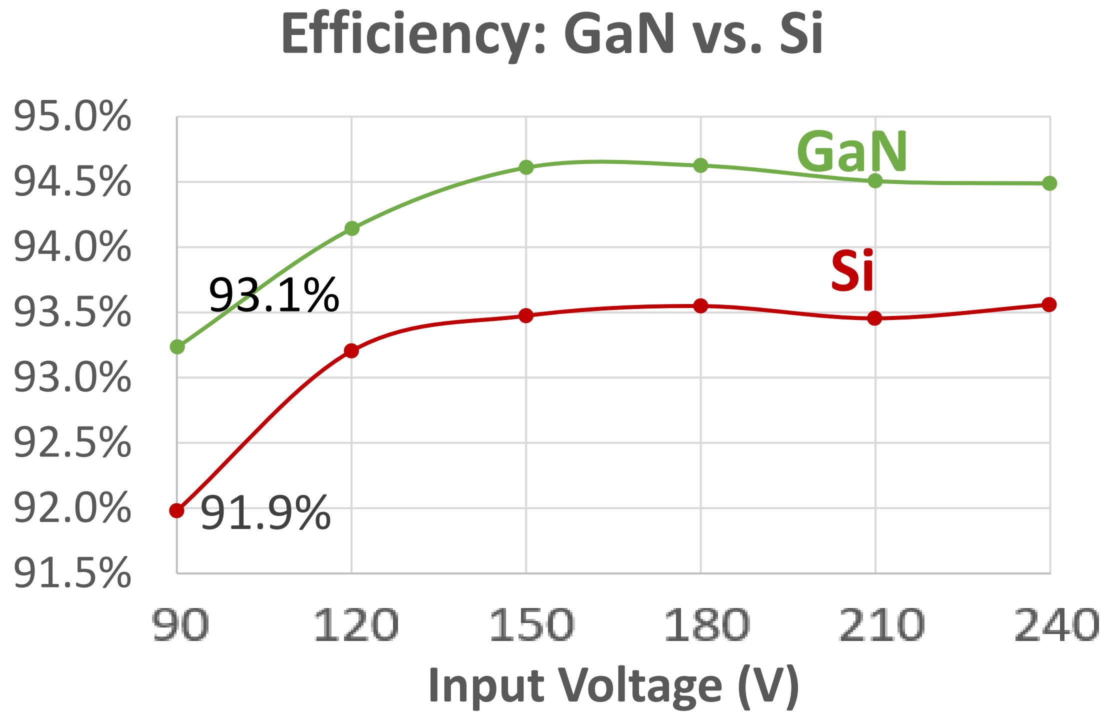
# GaN Power IC Simplifies ACF




GaN IC

# GaN Power IC Efficiency Advantage



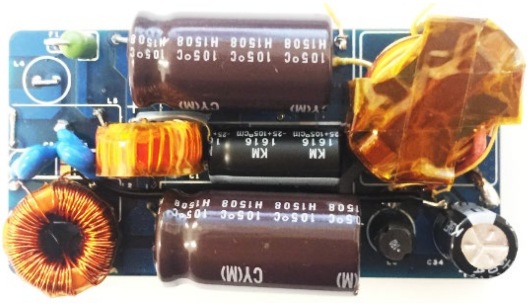

- GaN reduces power loss by 0.6W
- GaN boosts efficiency by 1.2%

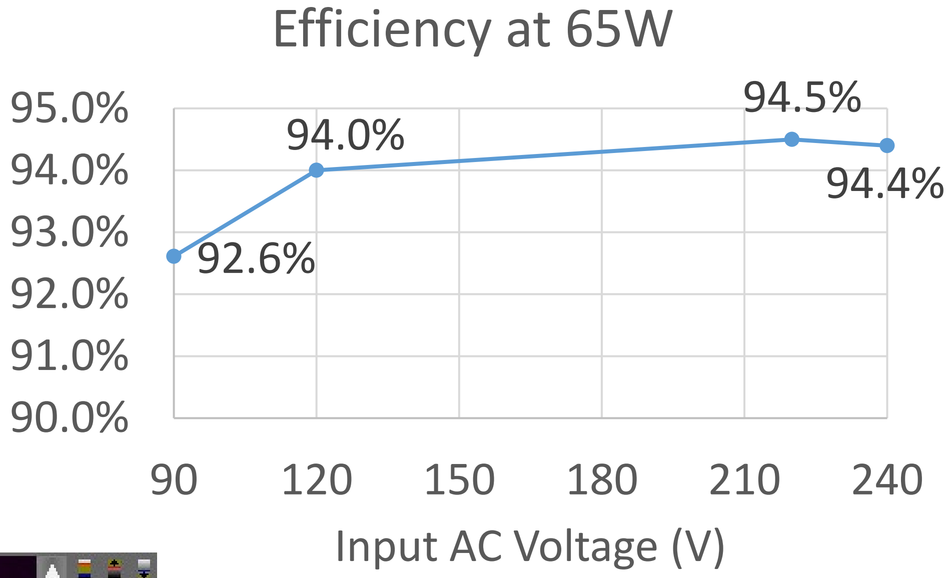
*Measured results of 45W ACF

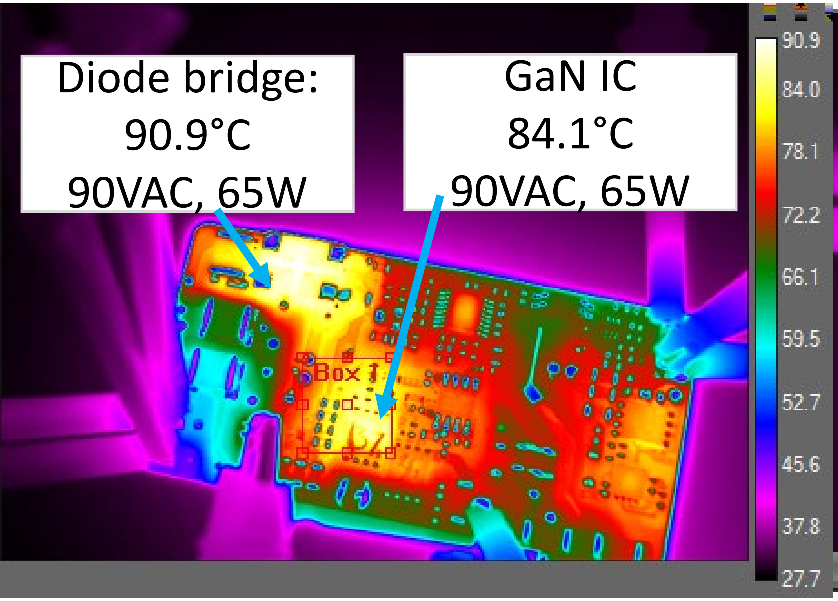
# High Density 65W Adapter Using ACF and GaN

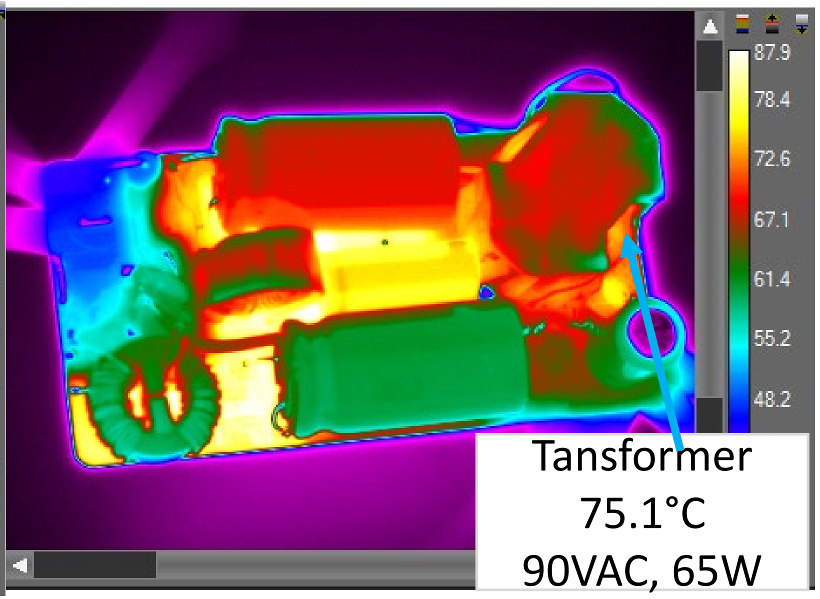
**2.63 x 1.32 x 0.62 in**

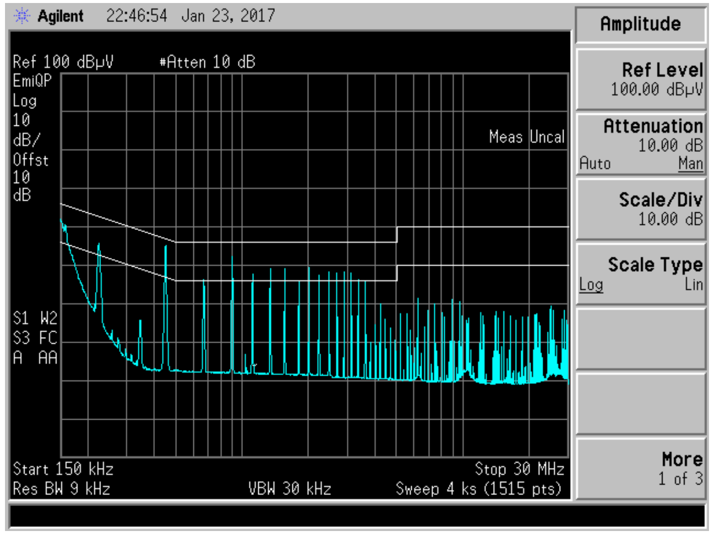
**Power density 22 W/in$^3$ (including case)**





# 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


# Active Clamp Flyback Using GaN Power IC for Power Adapter Applications

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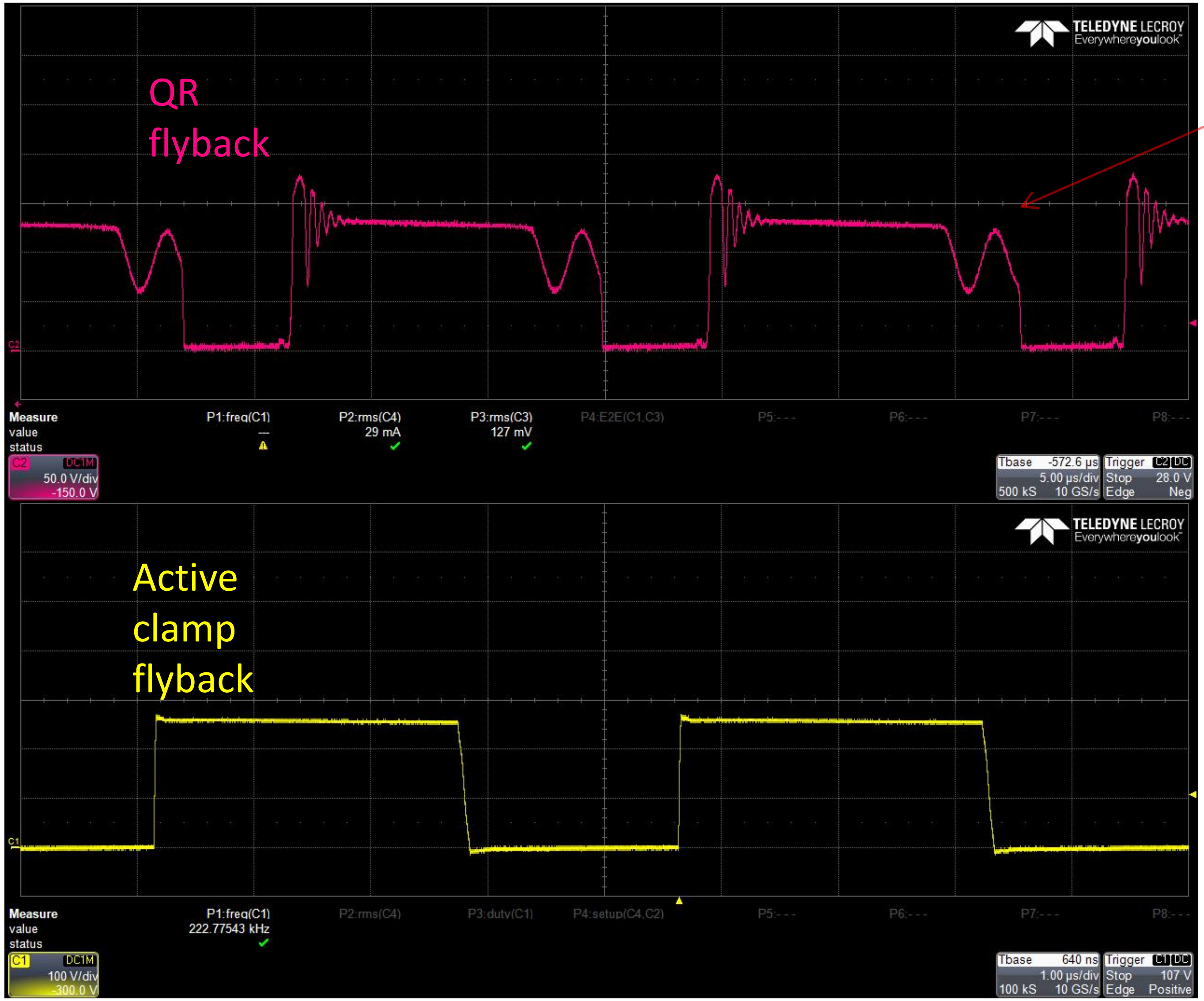
# Backup

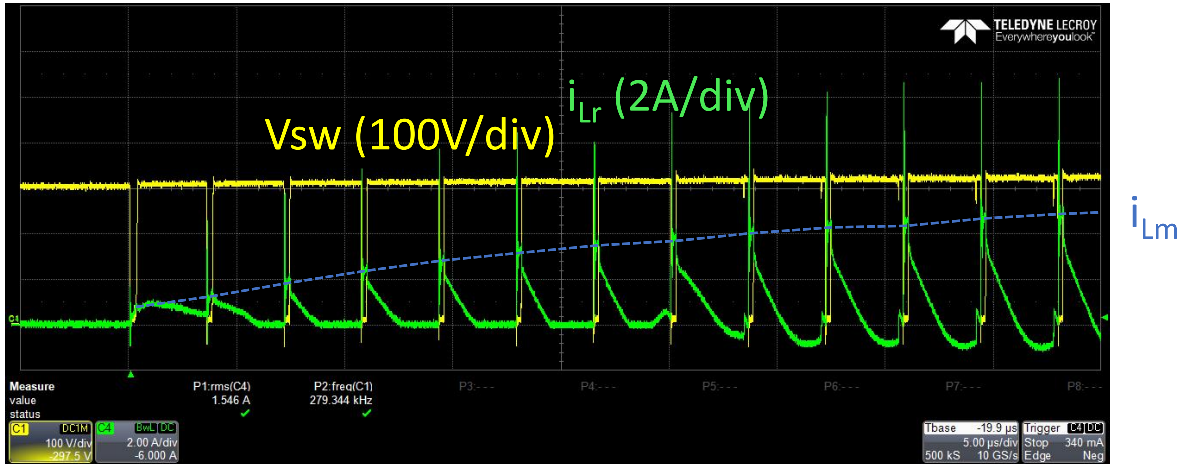
# Waveform: QR vs. ACF

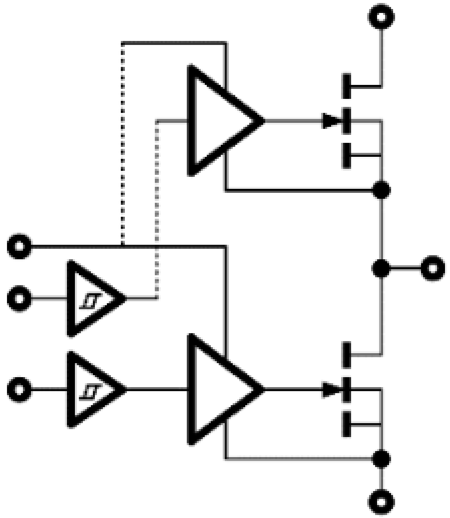



DCM发生了震荡，这里称为QR

# Startup in CCM and Hard-Switching

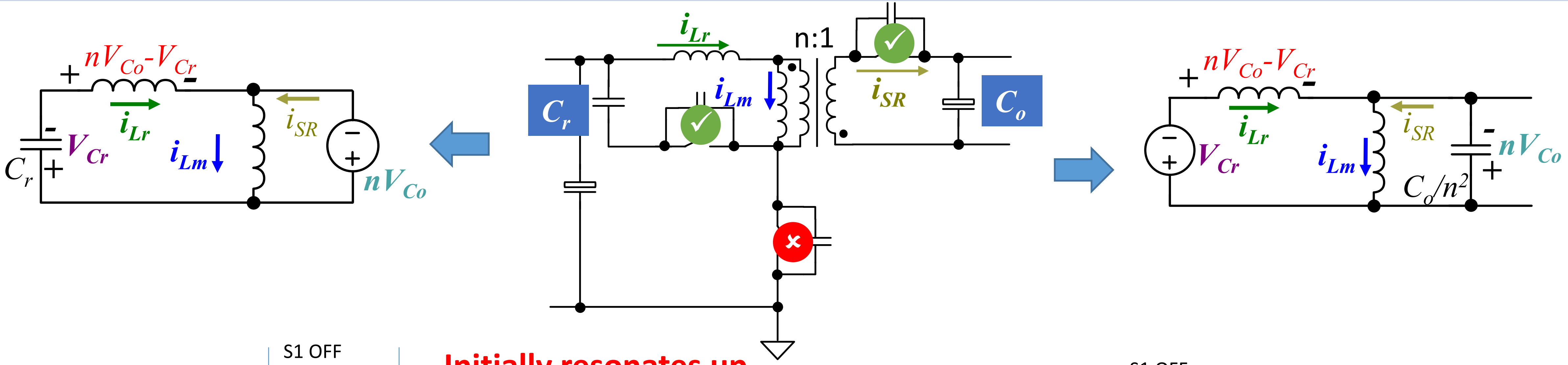
- Start-up in CCM: hard-switched, body diode reverse recovery..

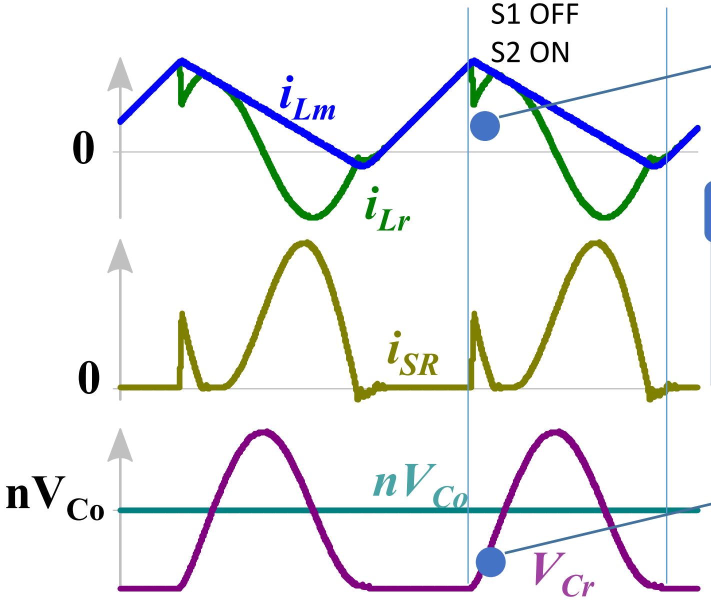



Navitas GaN
Half Bridge IC

# Lr Resonant Interval



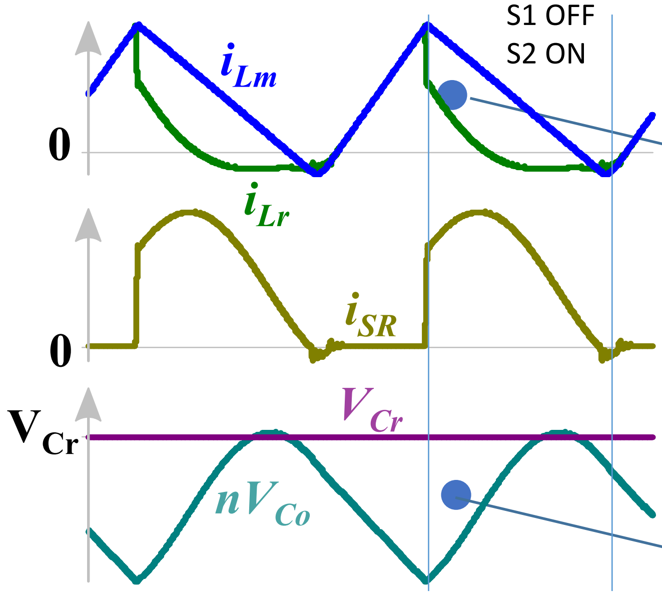




**Initially resonates up**

**Primary Resonant**

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

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



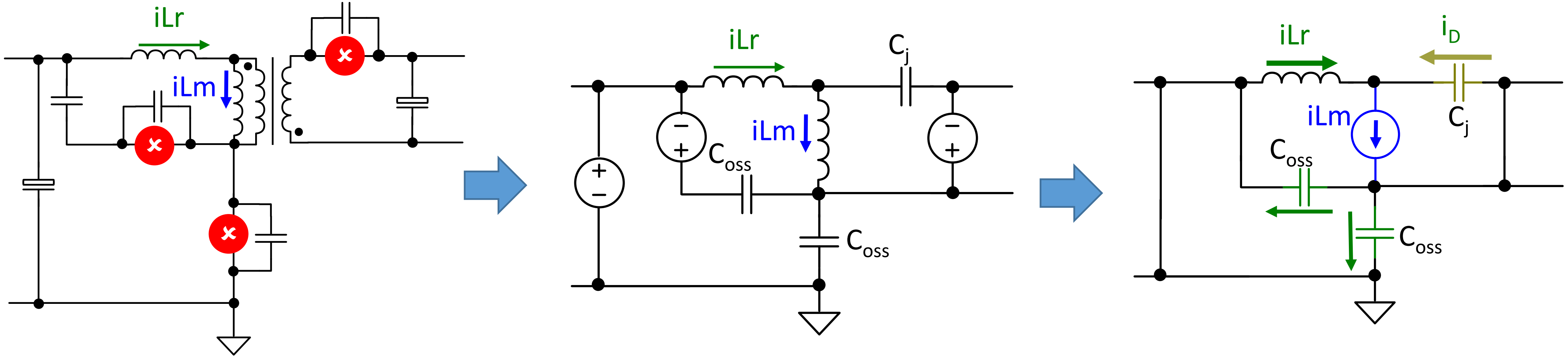

**Initially resonates down**

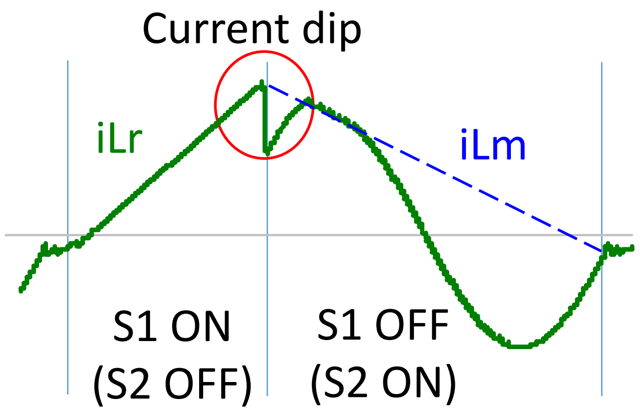
**Secondary Resonant**

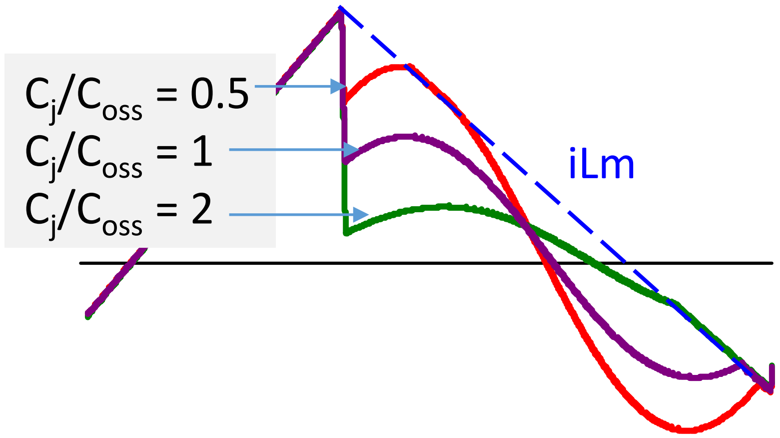
- $C_r >> C_o/n^2$
- No SR double turn-on

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

# ACF Primary Current Dip



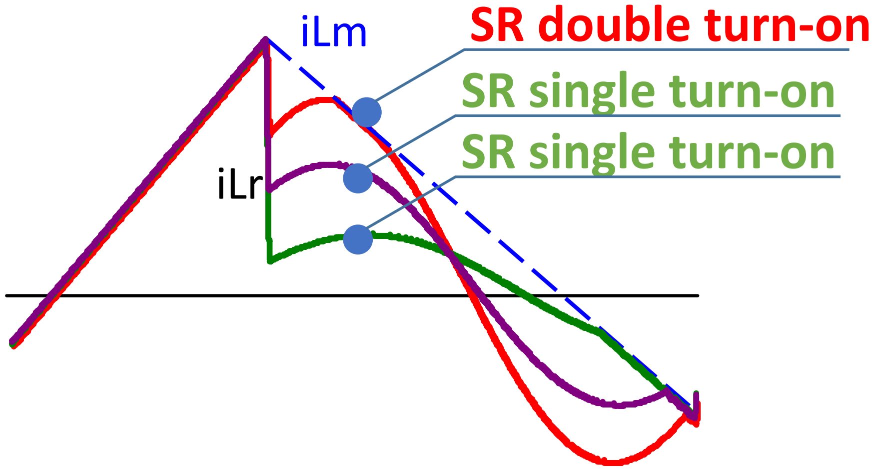



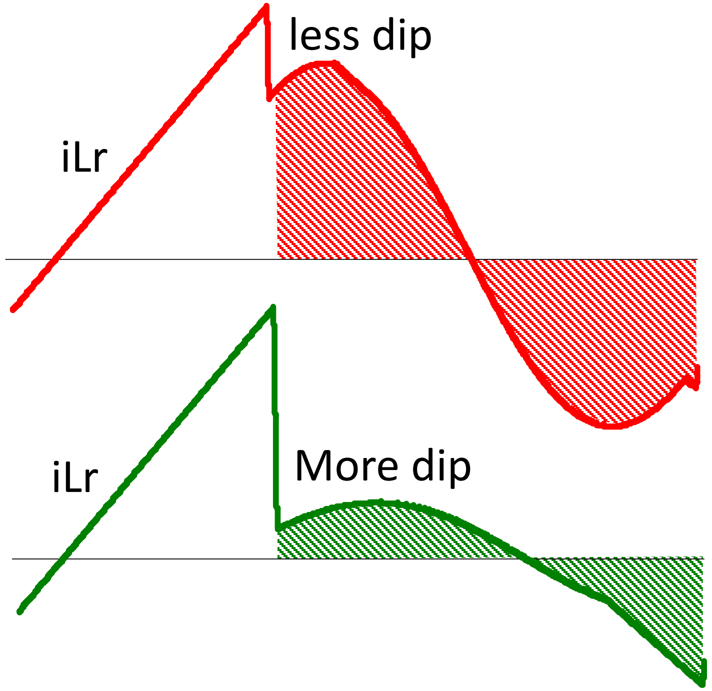



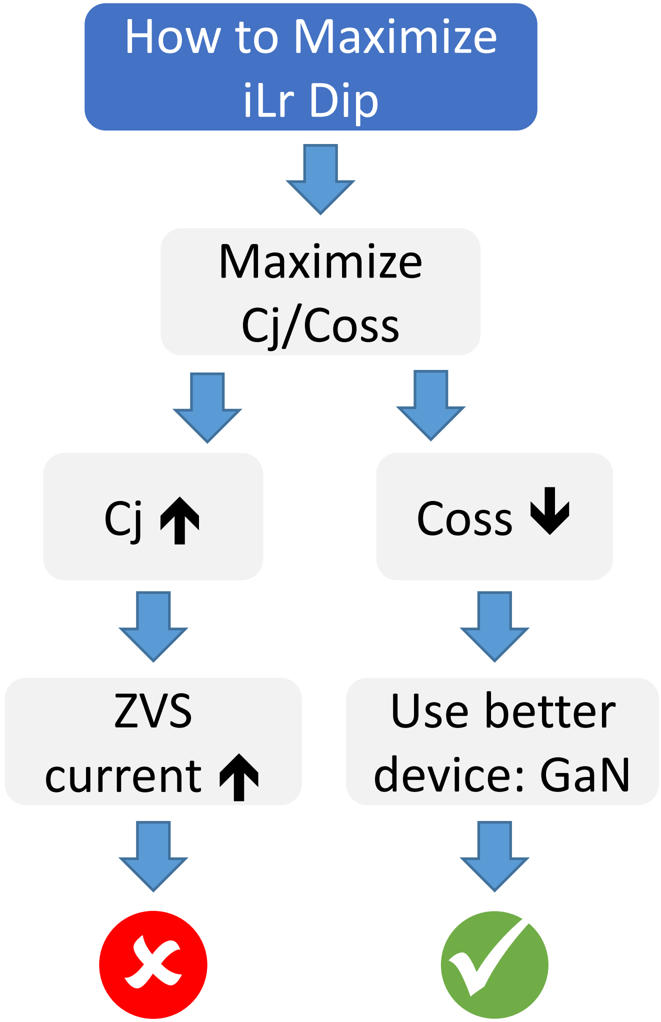

- Bigger $C_j/C_{oss}$
  →bigger current dip
- Why is current dip important?

# Current Dip Benefits






- Current dip ↑
  SR double turn-on ↓

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

# Current Dip: Adding 2.2nF Cj