Single-Stage 6.78 MHz Power-Amplifier Design Using High-Voltage GaN Power ICs for Wireless Charging Applications

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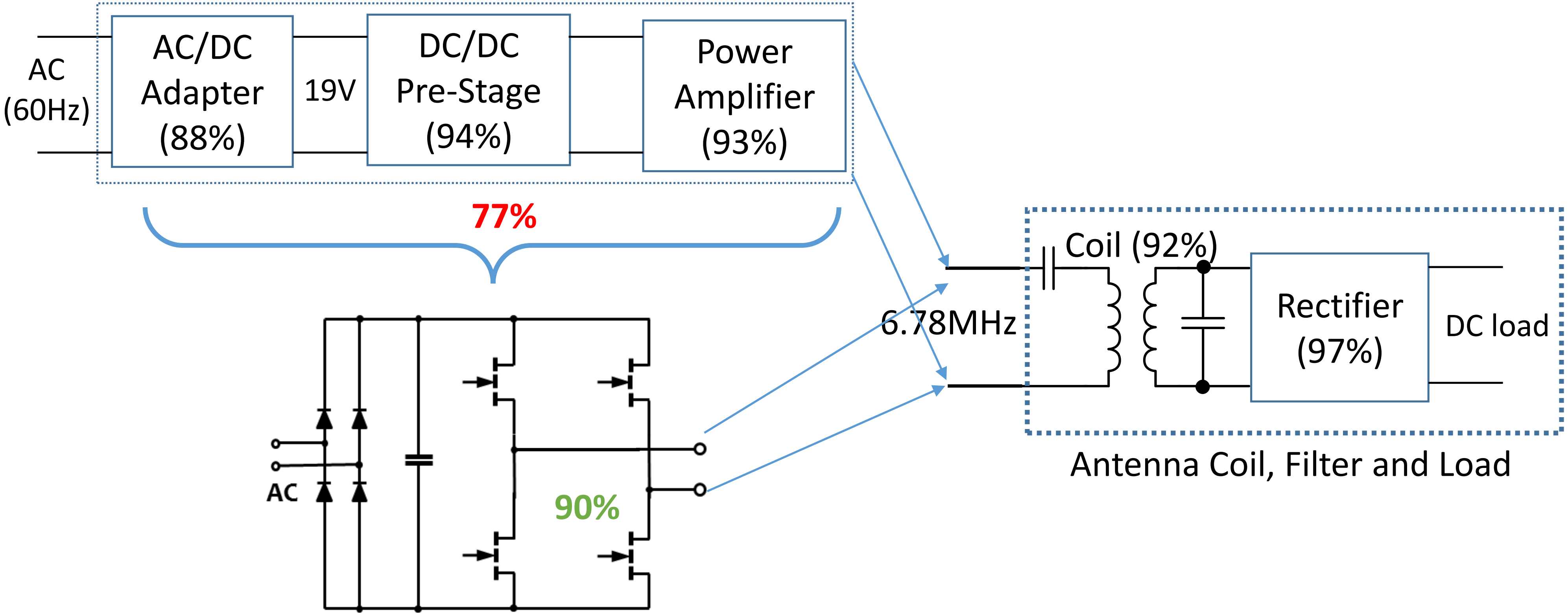
AirFuel Alliance Wireless Power Transfer

- 6.78MHz magnetic resonance
- Multi-device charging
- Large charging range
- Insensitive to metallic cases

Overall Wireless Power Transfer Efficiency is Low

Navitas

Benchmark multi-stage conversion efficiency: ~69% (AC to load)



Single-stage overall efficiency: 83% (AC to load)

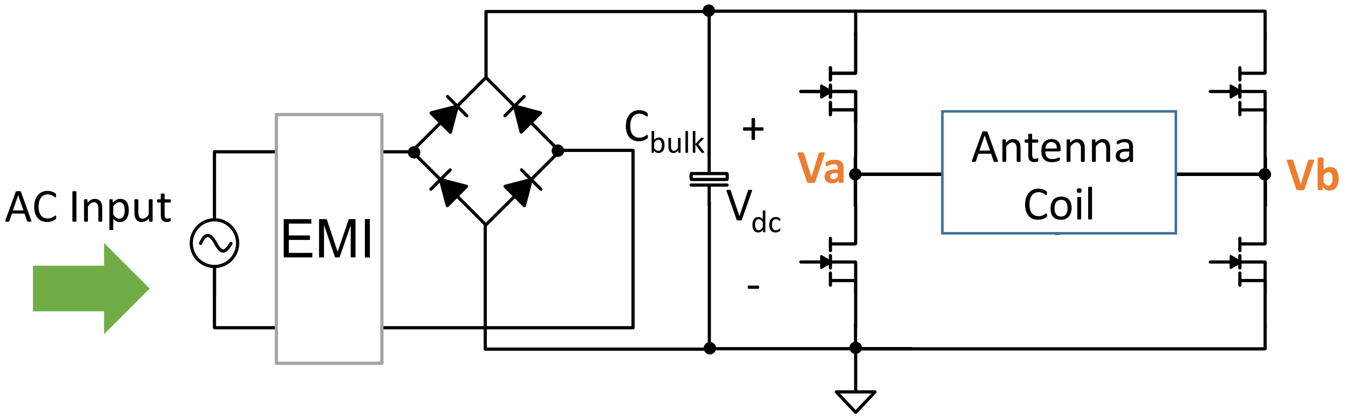
- Single stage high voltage transmitter improves system efficiency by more than 10%

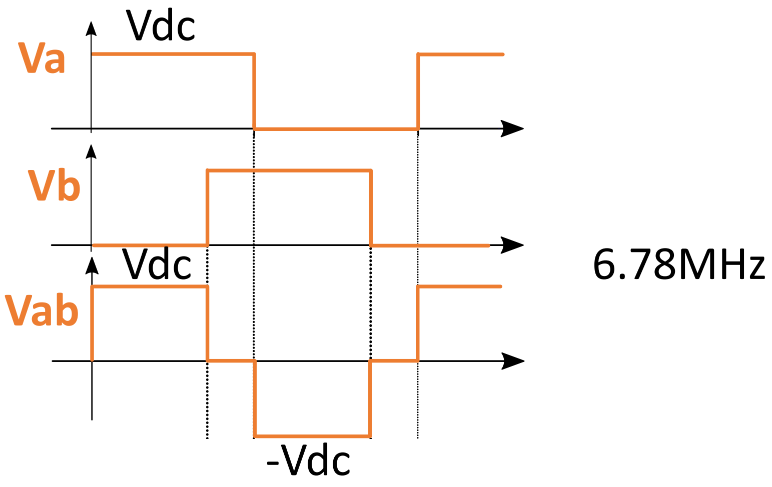
Outline

- Efficiency Issue of Multi-Stage Wireless Charging Architecture
- Single-Stage High voltage GaN Power Amplifier
- Optimization of Single Stage Wireless Transmitter
- Experimental Results and Conclusion

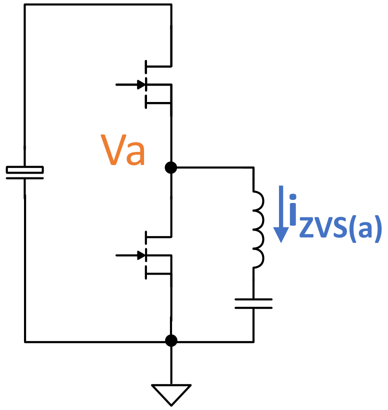
Single-Stage AC-RF Requires Fast Switches

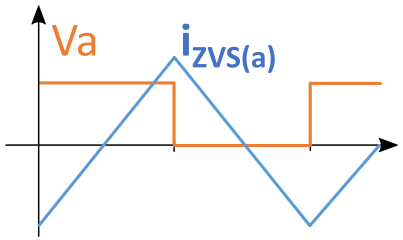
- Directly convert rectified AC into RF output (6.78MHz)
- Output power is adjusted by phase shift
- Zero-voltage switching is required at 6.78MHz and high bus voltage
- Switches need to be fast, low charge, high voltage with ideal "body diode"



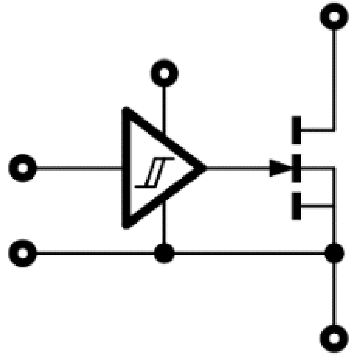


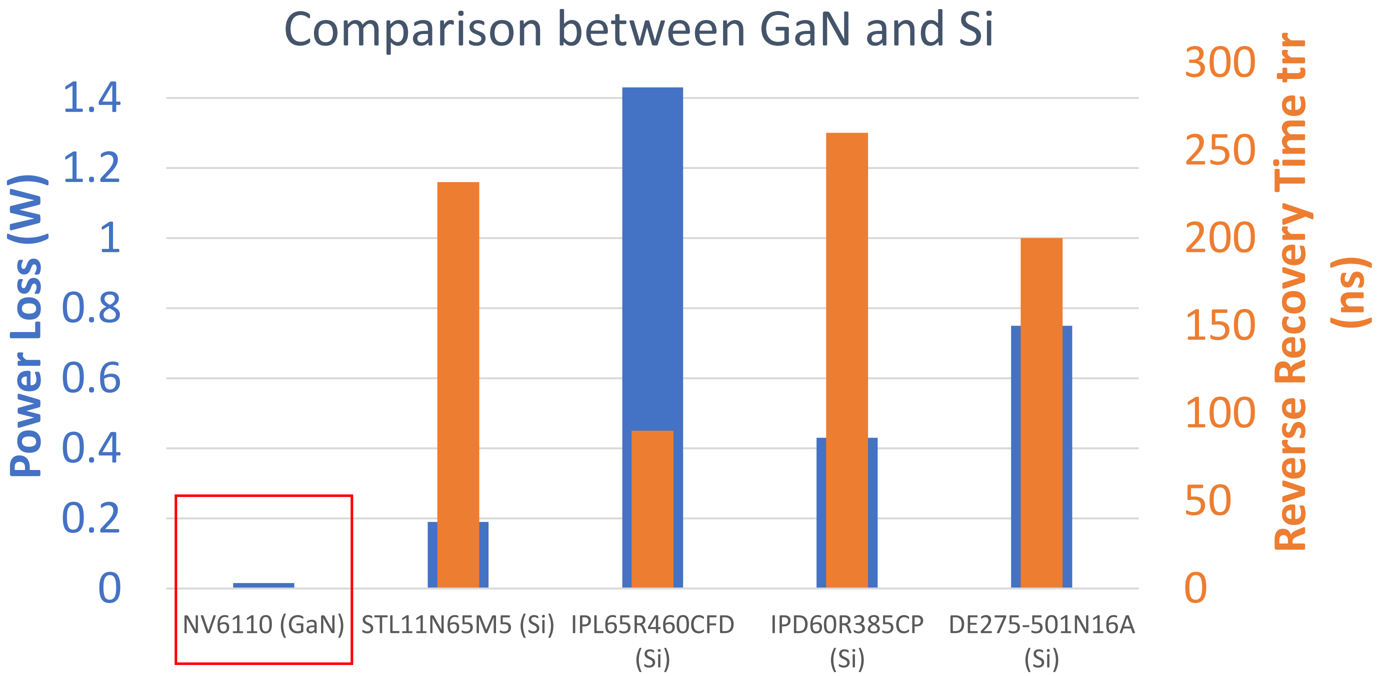
650V e-Mode GaN is a Perfect Fit





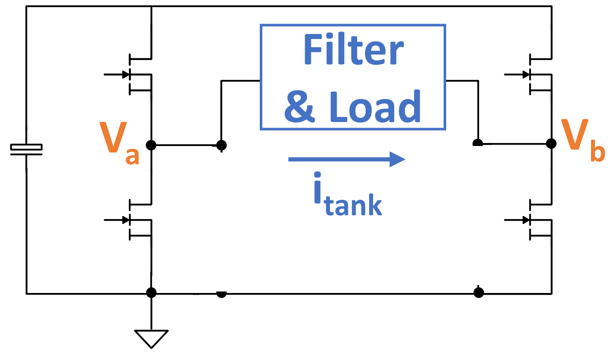
650V GaN IC with integrated gate driver

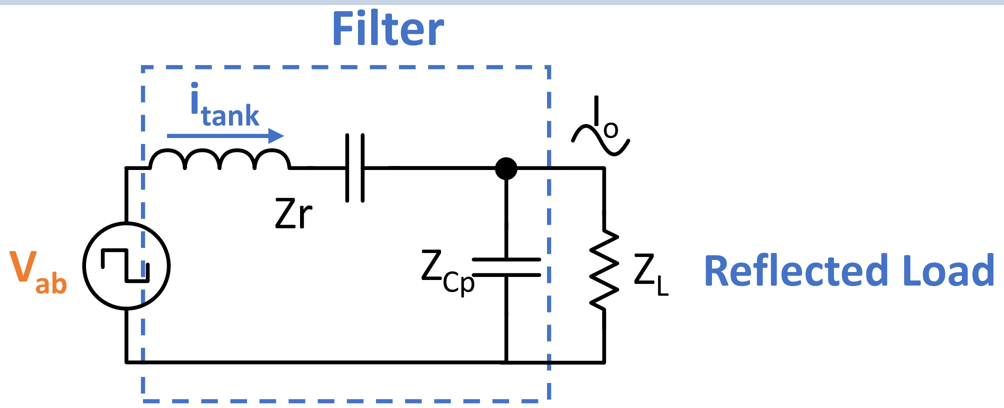




- GaN has 10x lower gate charge
- E-mode GaN has no reverse recovery loss
- Integrated driver simplifies system design

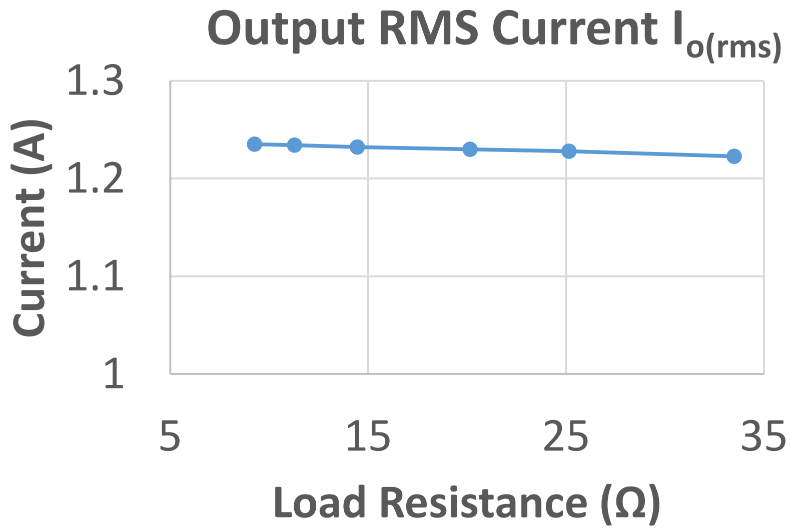
Antenna Filter Network Design





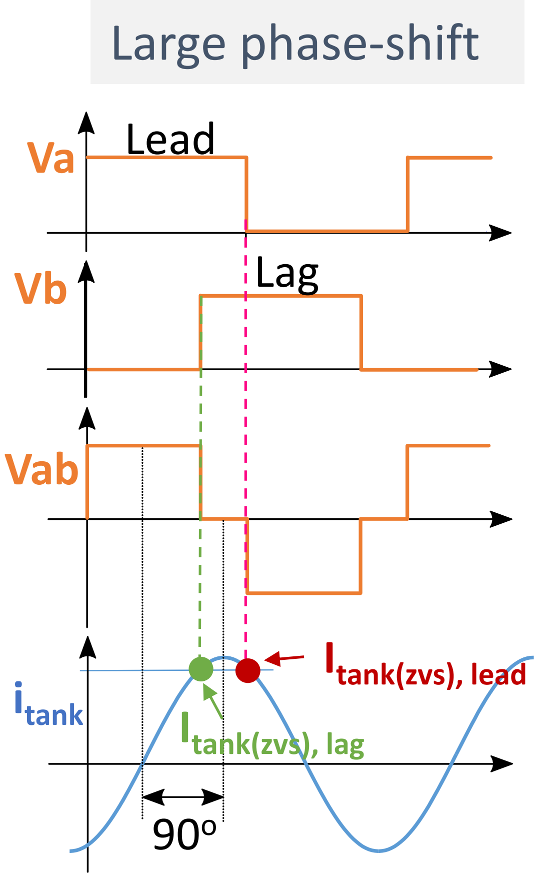
If Lr, Cr, and Cp are tuned so that $Z_r = -Z_{Cp}$

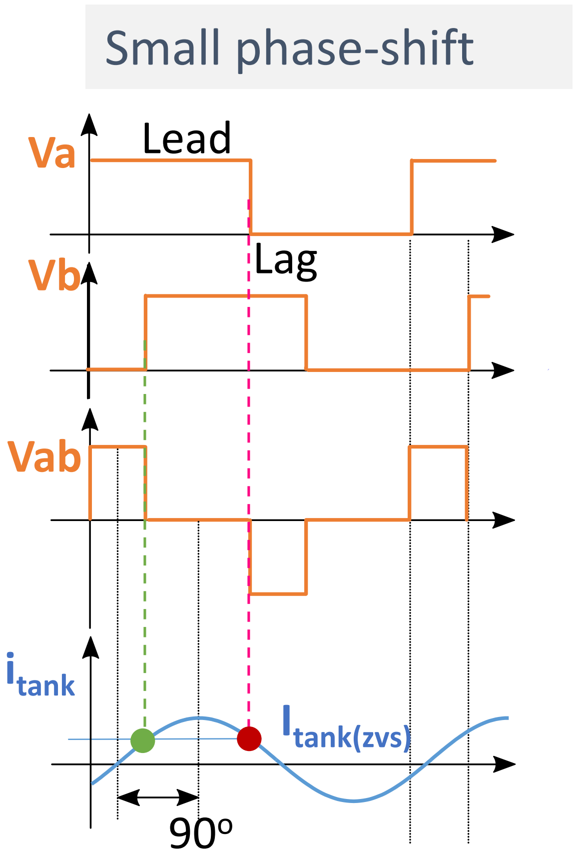
$$I_{o(rms)} \approx V_{ab(fs,rms)} \cdot \frac{1}{|Z_{Cp}|}$$

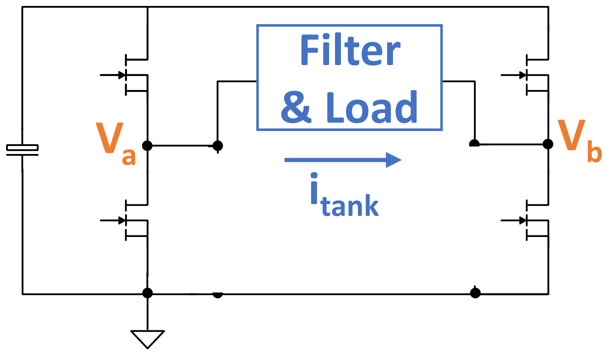


- Output RMS current independent of reflected load impedance Z_L
- Good load dynamic performance
- Output current adjustable by phase shift

Hard to Achieve ZVS with Tank Current



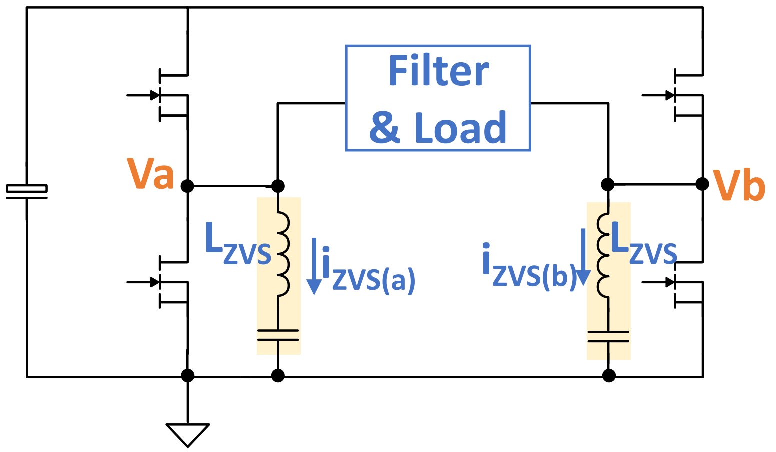


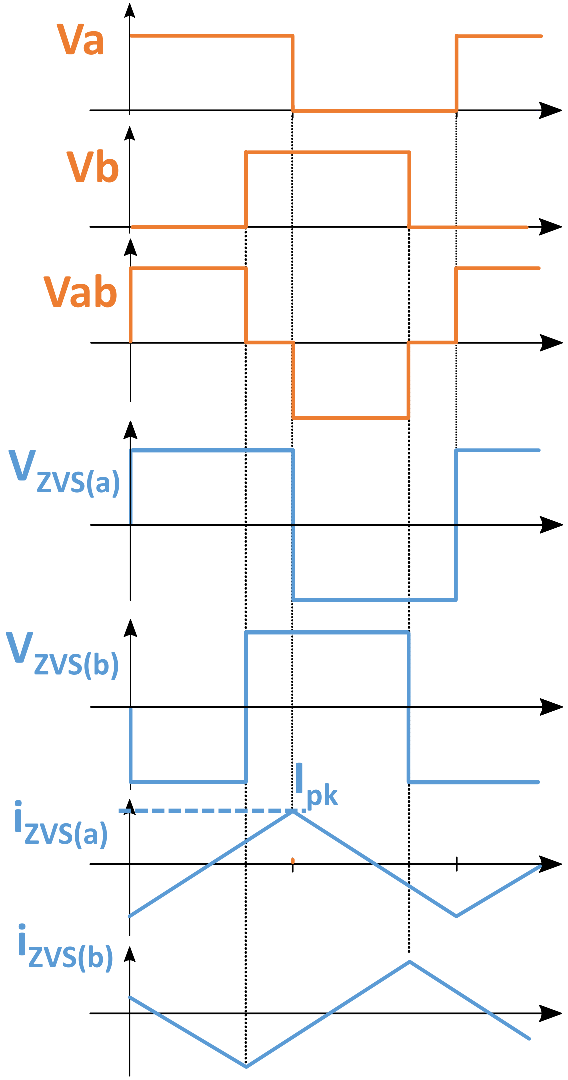


- Tank current assists ZVS for bridges
- ZVS current reduces at light load
- Load makes tank less inductive
- Hard to achieve ZVS with tank current

Ideal inductive tank

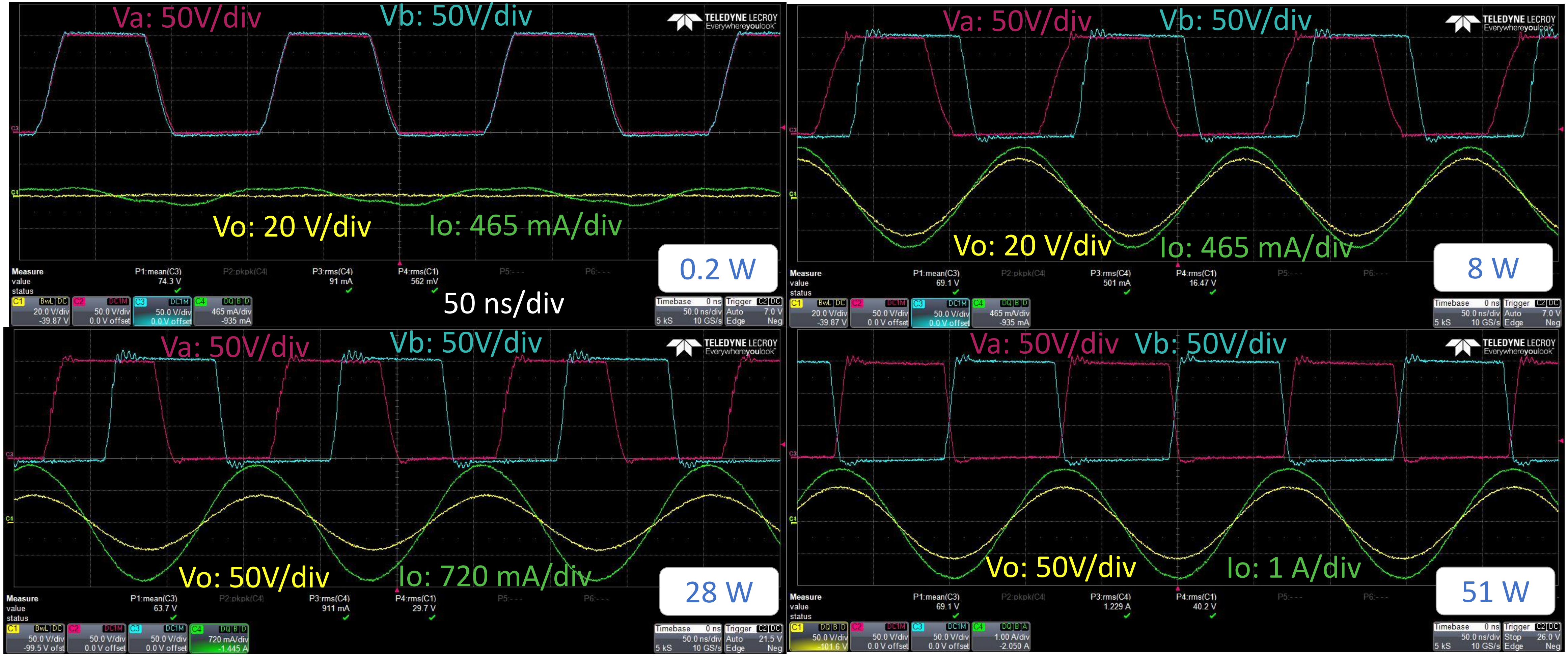
Auxiliary Tank Provides Extra ZVS Current





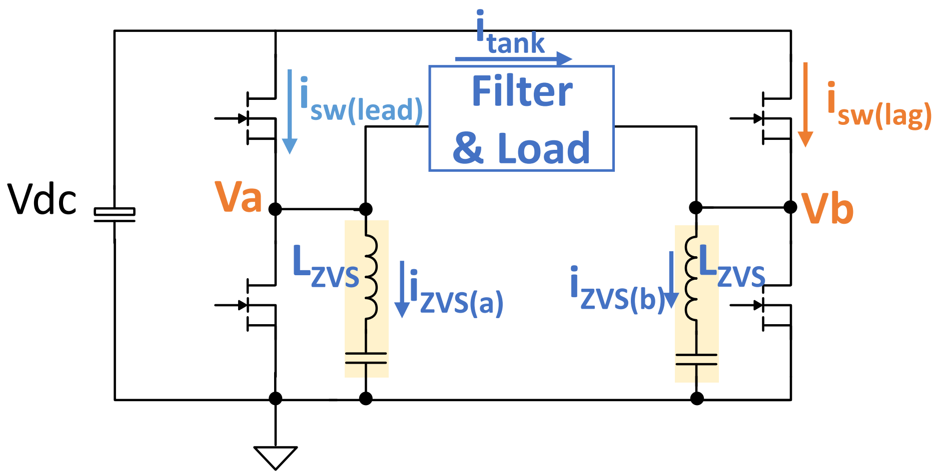
- Adding one LC tank for each half-bridge
- Fixed ZVS current independent of phase shift or load

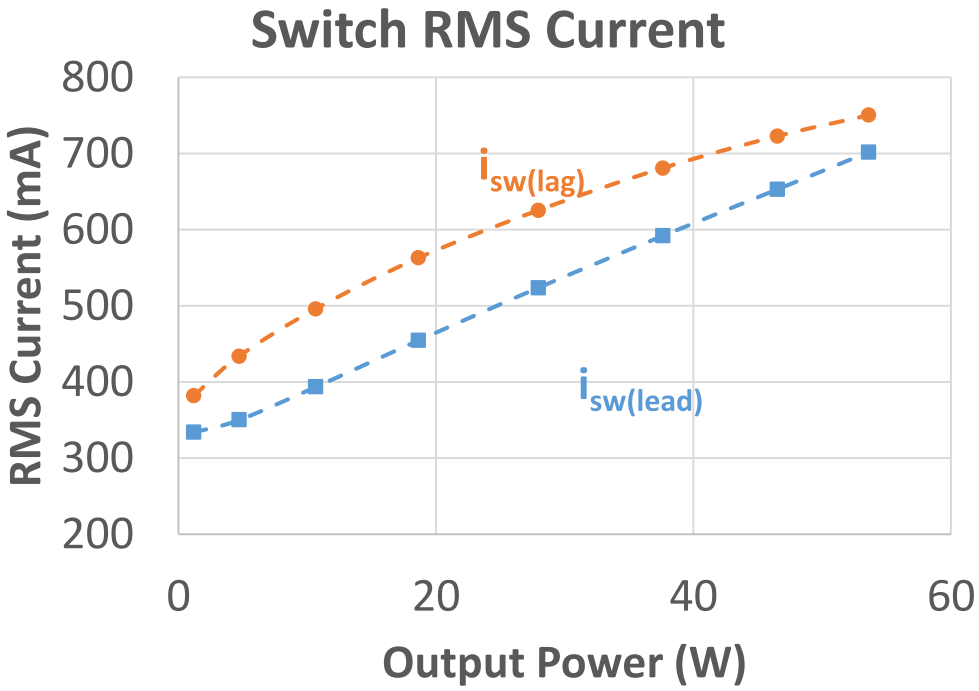
ZVS is Achieved Under All Load Conditions



ZVS achieved from 0° to 180° phase shift, i.e. 0.2W to 51W output power

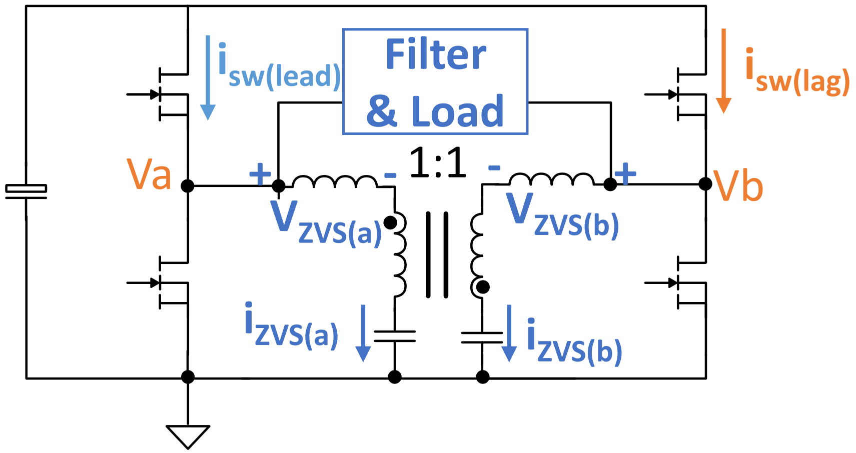
Issue: Too Much ZVS Current at Full Load

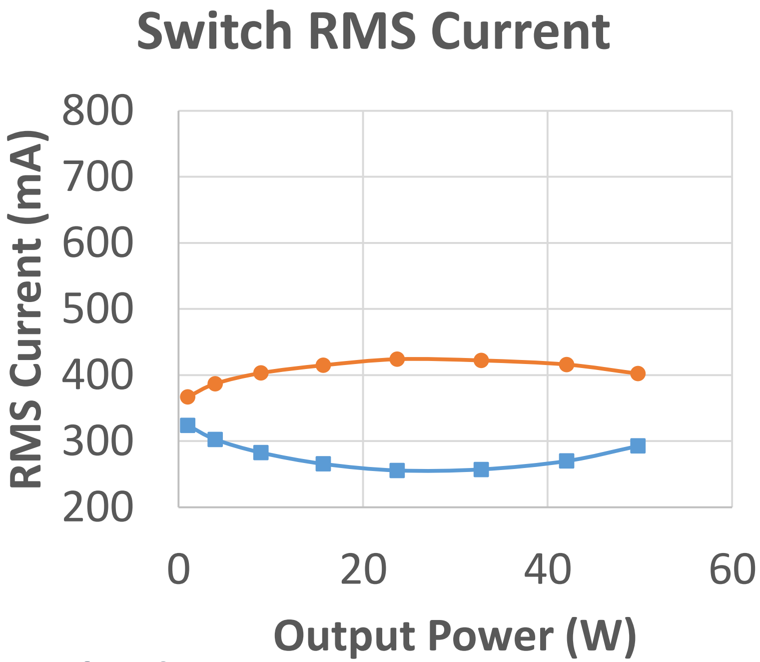


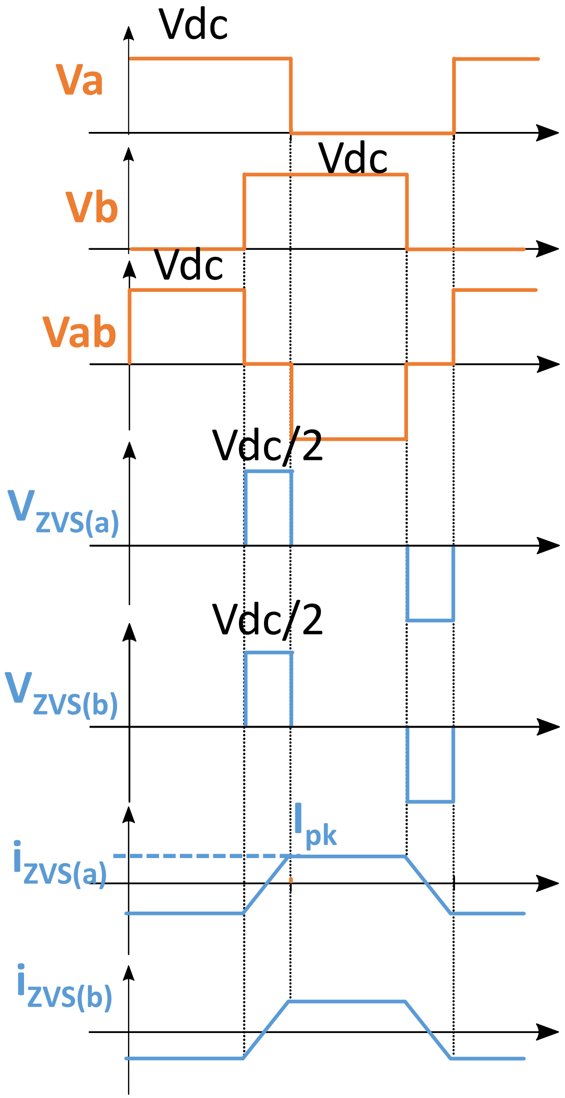


- Filter tank current i_{tank} increases with phase shift and output power
- ZVS tank currents i_{zvs} stay the same regardless of phase shift
- Switch current i_{sw} is the sum of the above, becoming too high at full load
- Need to reduce i_{zvs} at full load to improve efficiency

Solution: Coupled ZVS Tanks

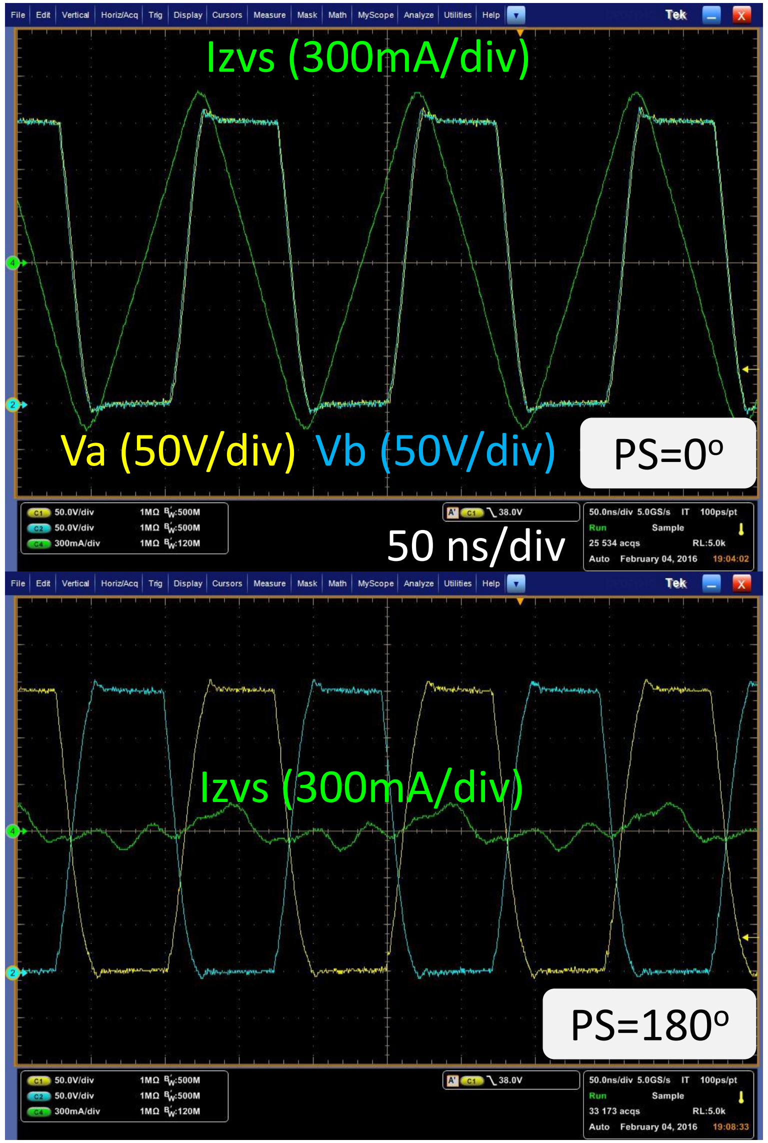


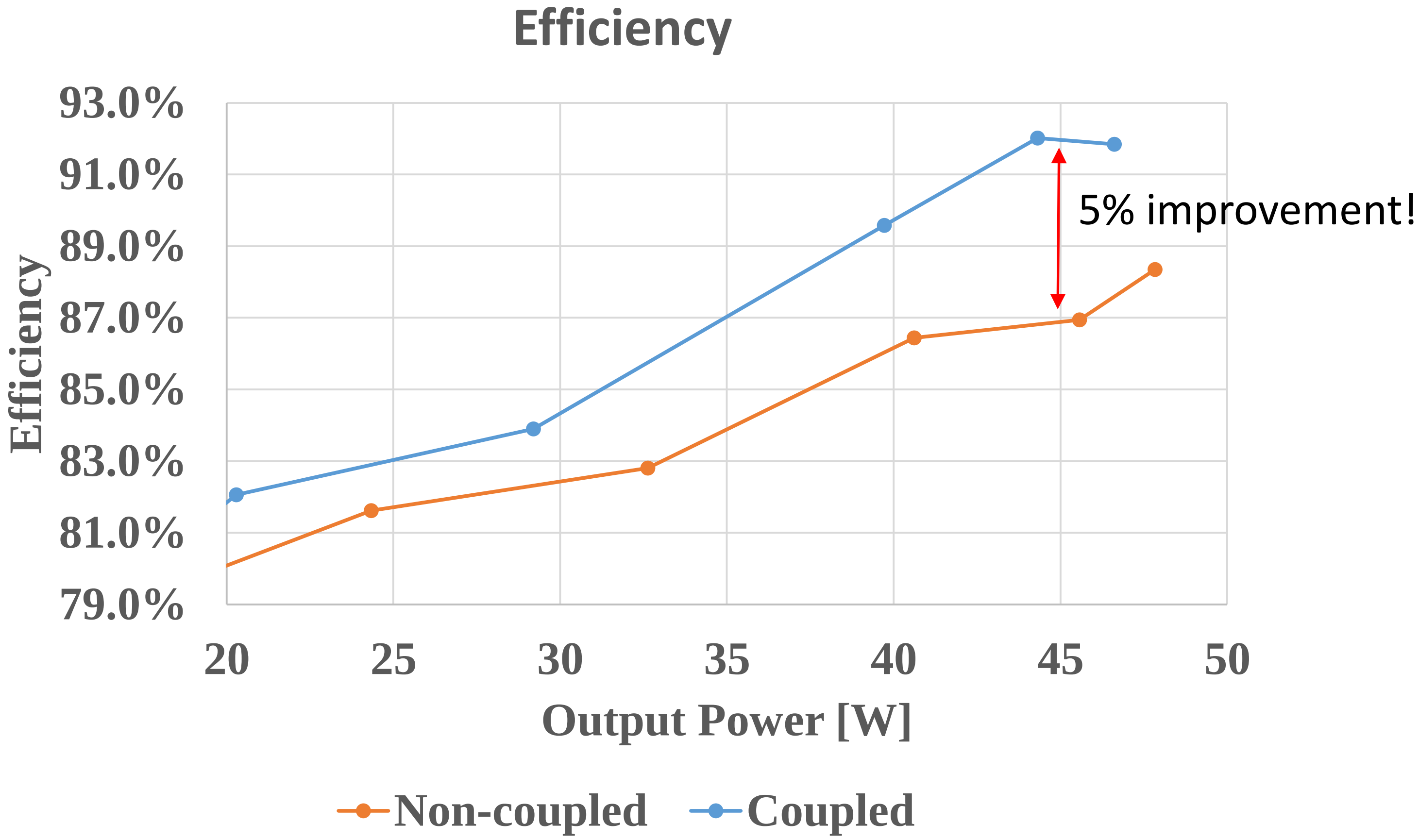




- Two ZVS tanks inversely coupled
- Auxiliary tank current reduces with large phase shift, i.e. full load
- Overall RMS current stays constant

Coupled ZVS Tank Improves Efficiency

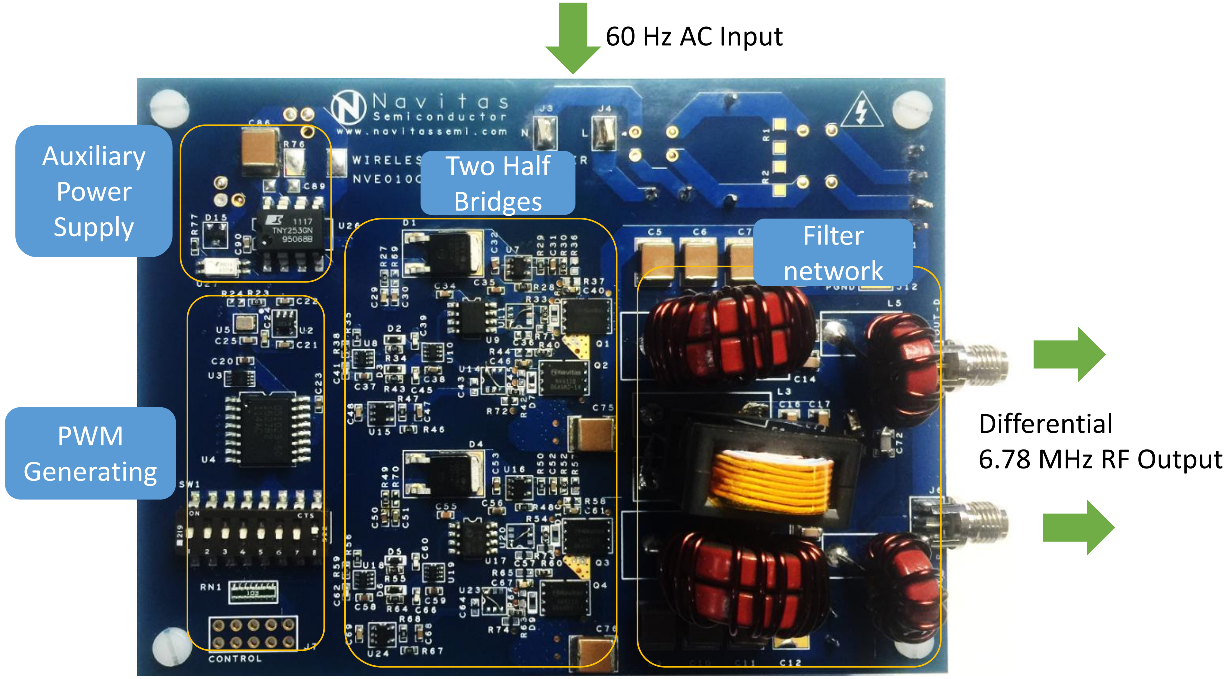


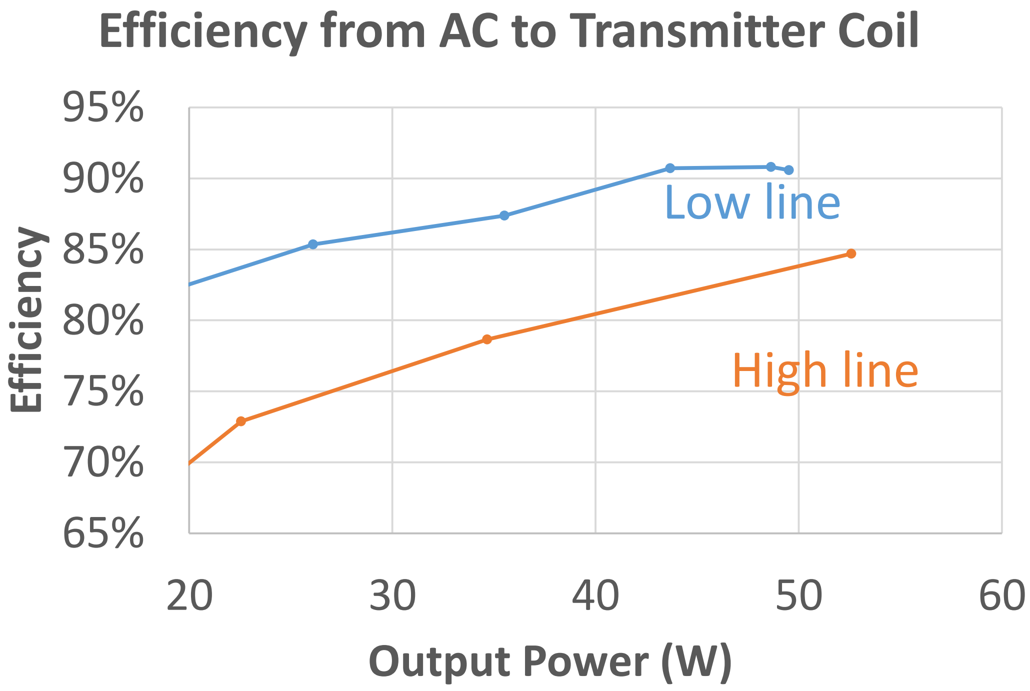


- 5% full load efficiency boost

PS: Phase Shift

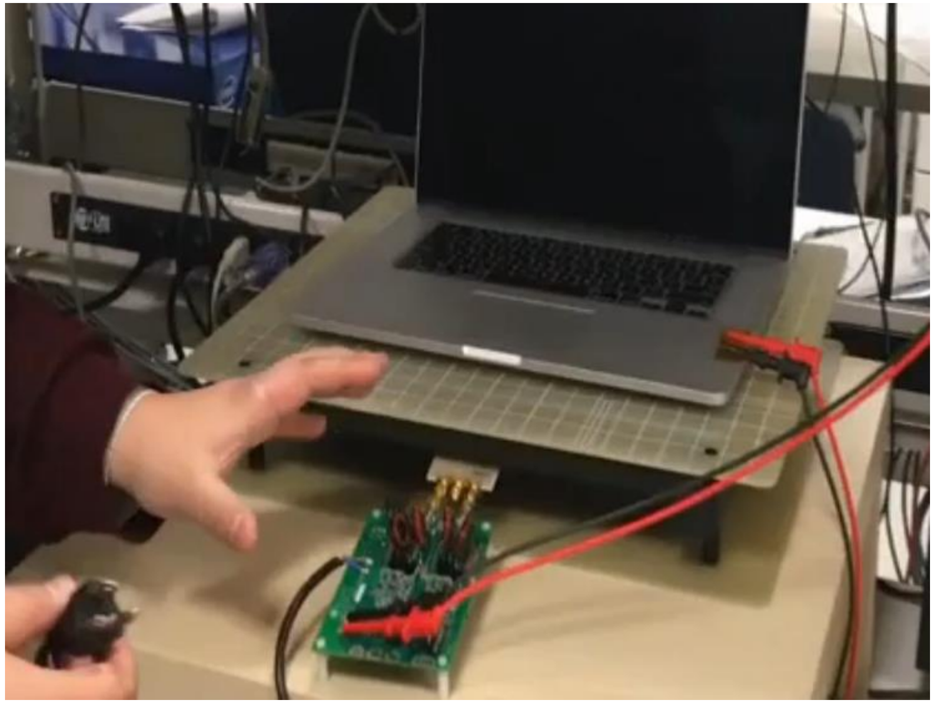
Single-Stage Amplifier Achieves 90% Efficiency

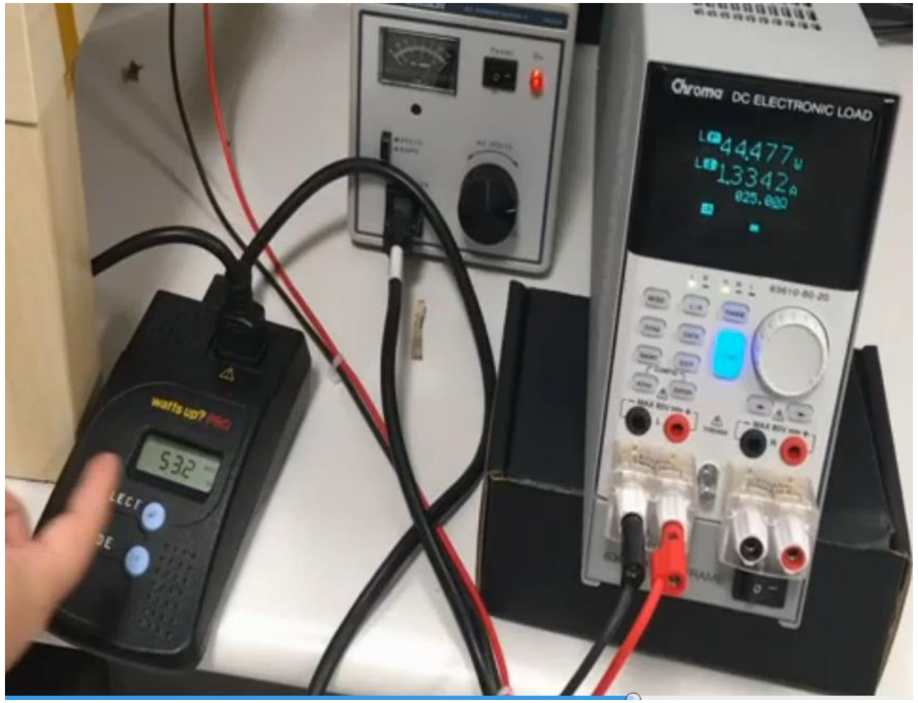




50W Full System Demonstration

- Powertrain:
  - Navitas AC-RF (phase-shifted full-bridge (4x NV6110))
  - Partner coils, receiver / rectifier
- Load: 50W Macbook Pro
- Complete AC to load efficiency = 83%





Conclusion

- Efficiency of multi-stage wireless charging architecture is too low
- High voltage GaN enables 6.78MHz single-stage power amplifier
- New coupled ZVS tank solution improves single stage transmitter efficiency above 90%
- A 50W system was built with GaN Power ICs, demonstrating 83% overall system efficiency, i.e. AC to laptop battery

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