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

Linqxiao (Lincoln) Xue, Staff Applications Engineer, linxiao.xue@navitassemi.com
Jason Zhang, VP Applications, jason.zhang@navitassemi.com
March 30th 2017
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

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

- GaN has 10x lower gate charge
- E-mode GaN has no reverse recovery loss
- Integrated driver simplifies system design
If $L_r$, $C_r$, and $C_p$ are tuned so that $Z_r = -Z_{cp}$,

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

**Output RMS Current $I_{o(rms)}$**

- 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

50 ns/div

Efficiency

Efficiency

Output Power [W]

PS: Phase Shift

Non-coupled  • Coupled

5% improvement!
Single-Stage Amplifier Achieves 90% Efficiency

- 60 Hz AC Input
- Two Half Bridges
- Filter network
- Differential 6.78 MHz RF Output
- Efficiency from AC to Transmitter Coil
- Output Power (W)
- Efficiency
- Low line
- High line
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
Single-Stage 6.78 MHz Power-Amplifier Design Using High-Voltage GaN Power ICs for Wireless Charging Applications

Linqxiao (Lincoln) Xue, Staff Applications Engineer, linxiao.xue@navitassemi.com
Jason Zhang, VP Applications, jason.zhang@navitassemi.com
March 30th 2017