Dual-Band Multi-Receiver Wireless Power Transfer: Architecture, Topology, and Control

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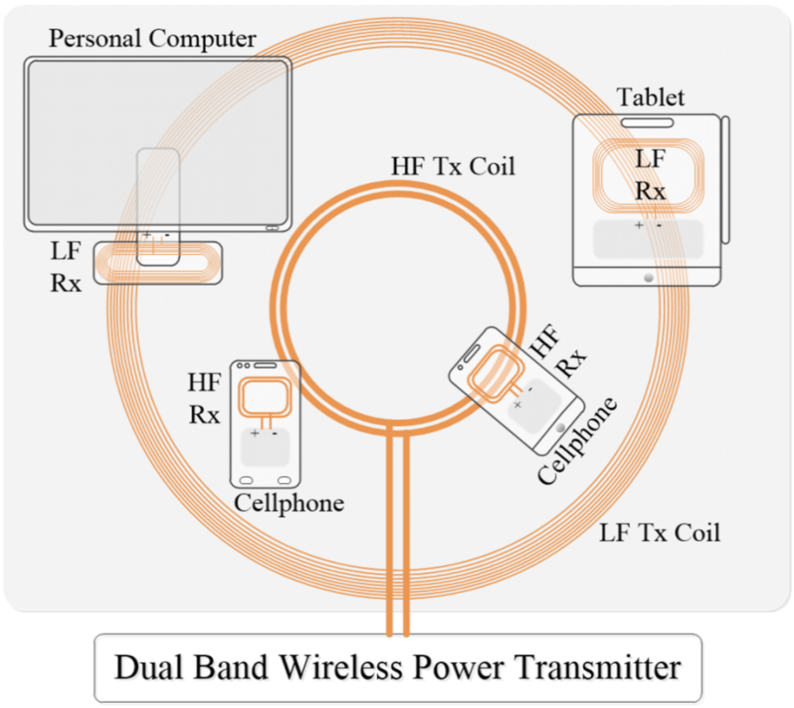
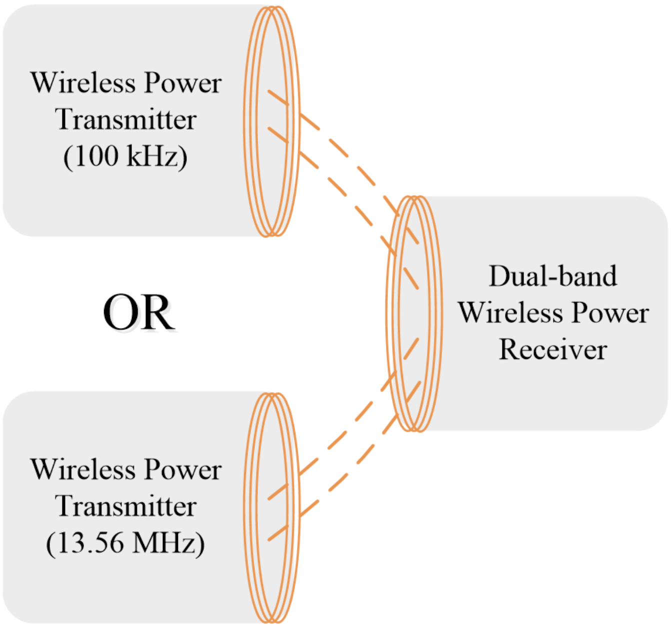
Dual-Band Wireless Power Transfer Applications

LF(kHz): High power, High efficiency; **HF(MHz):** High spatial freedom, Compact size;



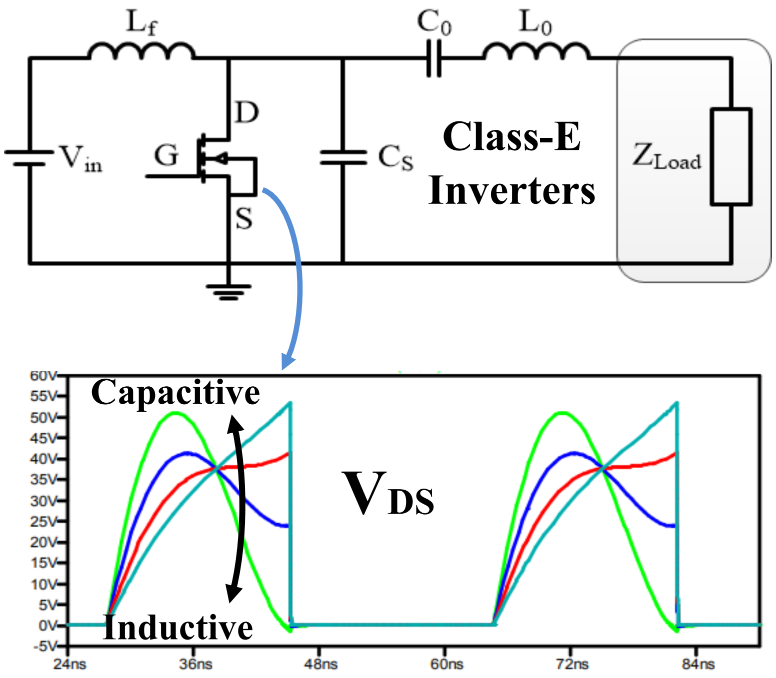
One transmitter can support LF/HF receivers

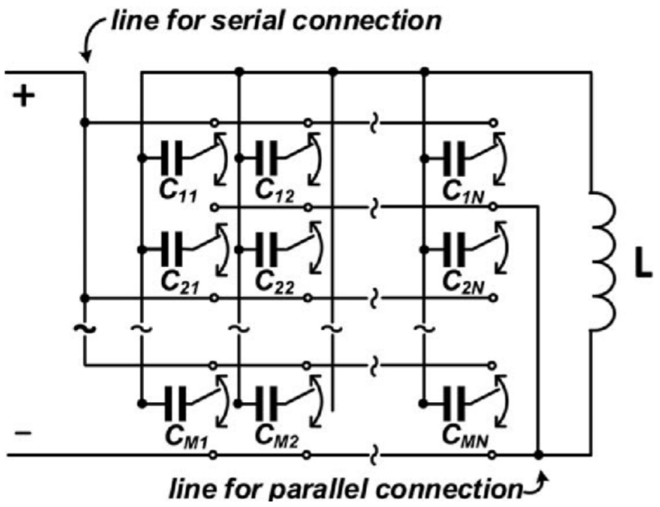


One receiver can pick up power from LF/HF transmitters

Challenges for Dual-Band Wireless Power Transfer

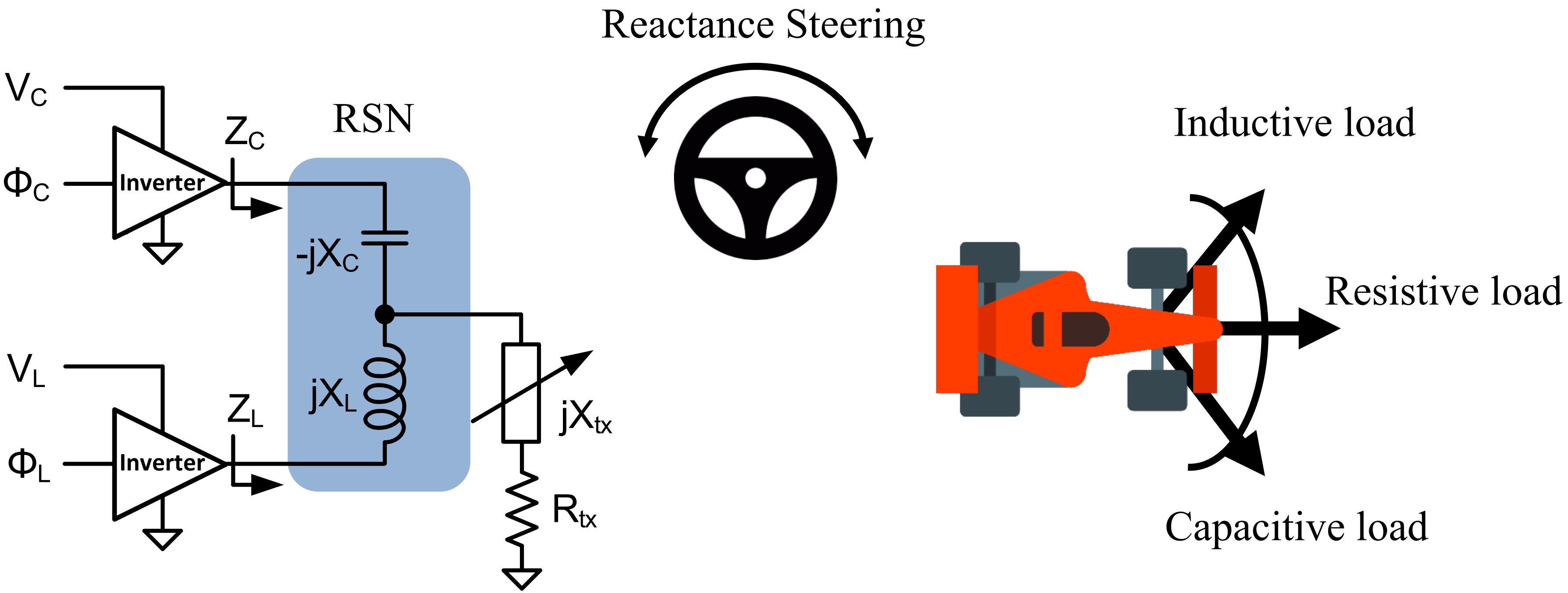
- Co-location of receivers induces large impedance variation
- HF inverters, e.g., Class-E, are usually sensitive to load impedance variation





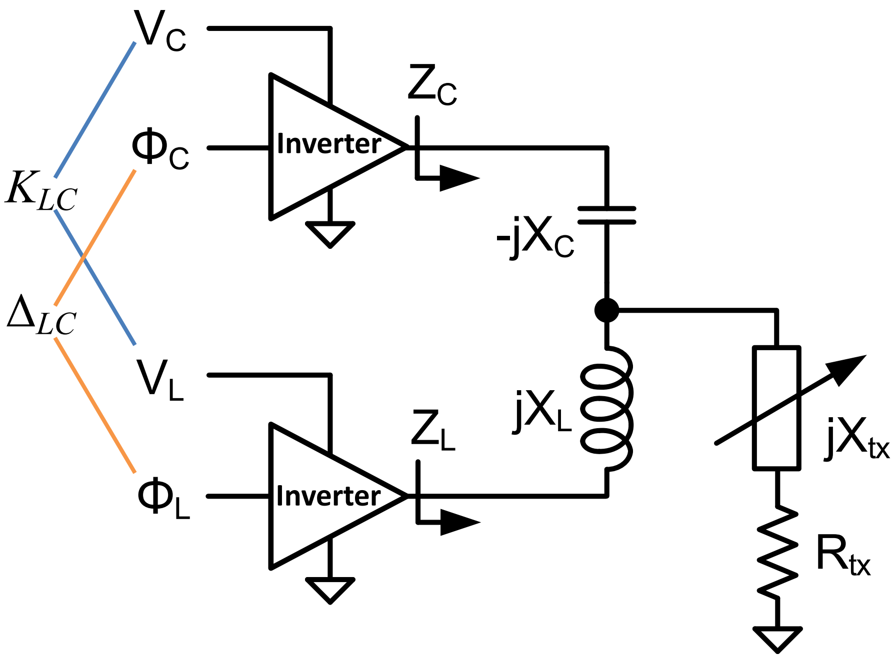
Existing compensation: switched capacitor tunable matching network

Operation Principles of Reactance Steering Network (RSN)



- Steering more power towards capacitive branch with inductive load.
- Steering more power towards inductive branch with capacitive load.
- Maintain pure resistive load for both inverters with wide reactance variation range.

Amplitude and Phase Modulation



Amplitude Ratio K_{LC}

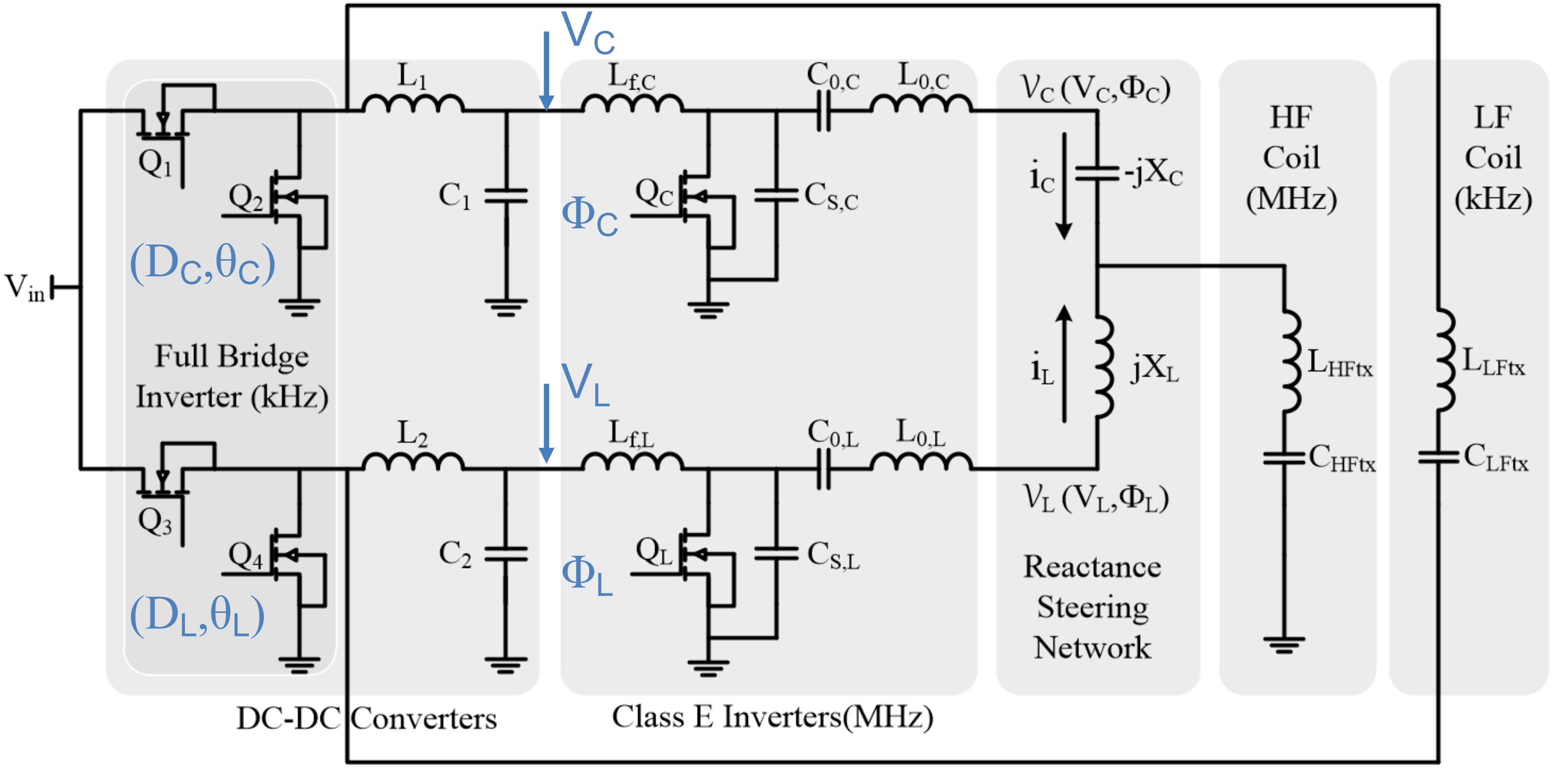
$$K_{LC} = \left|\frac{V_L}{V_C}\right| = \left|\frac{X_O + X_{tx}}{X_{tx}\cos(\Delta_{LC}) + R_{tx}\sin(\Delta_{LC})}\right|.$$

Phase Difference Δ_{LC}

$$\Delta_{LC} = \Phi_L - \Phi_C = \arcsin\sqrt{\frac{X_O^2}{X_{tx}^2 + R_{tx}^2}}.$$

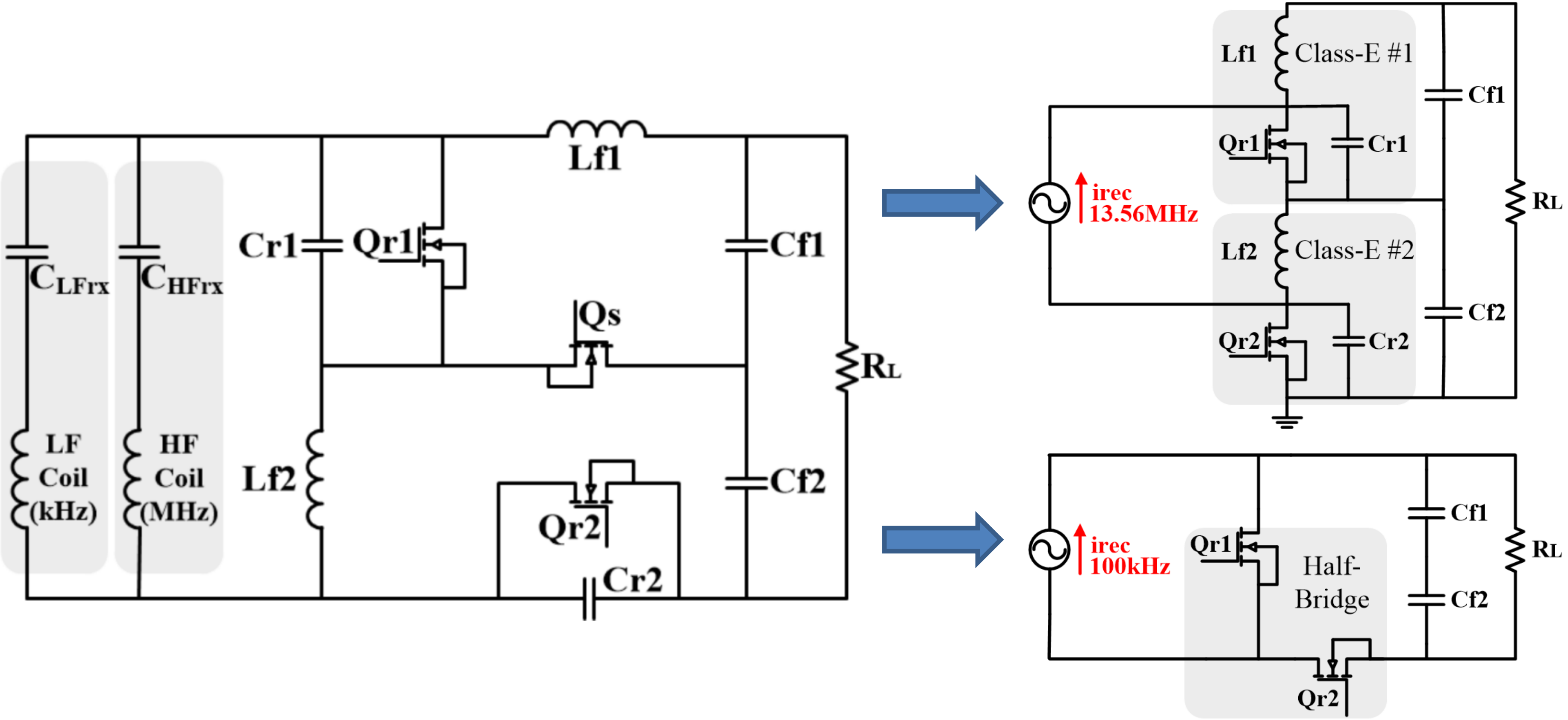
- Both inverters always see pure resistive load and adaptively split the power.

Schematic of the Dual-Band Transmitter



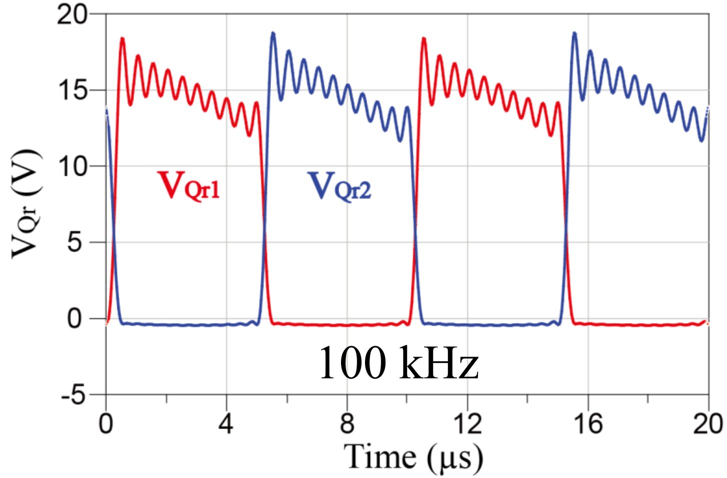
- LF and HF systems share the switches Q1, Q2, Q3, Q4.

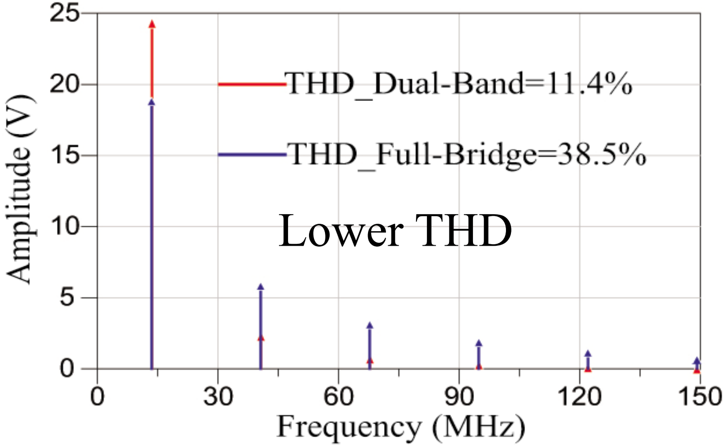
Dual-Band Reconfigurable Receiver with Low Switch Count

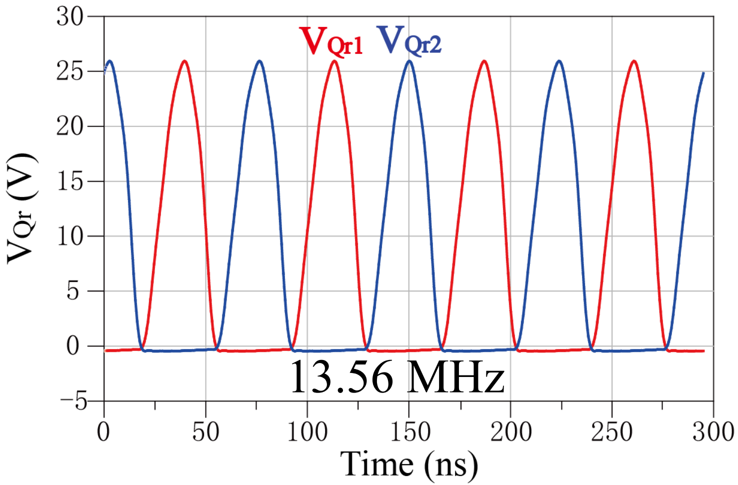


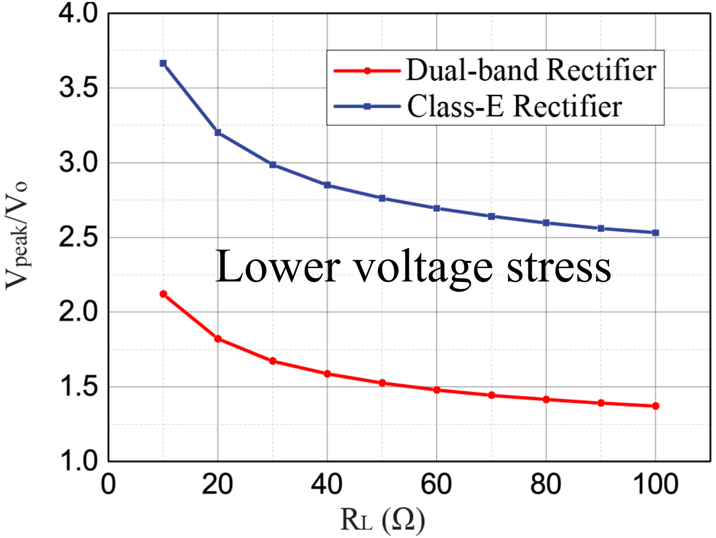
- Share the switches Qr1 and Qr2 at LF and HF, less switch count.

Performance Analysis of the Dual-Band Rectifier



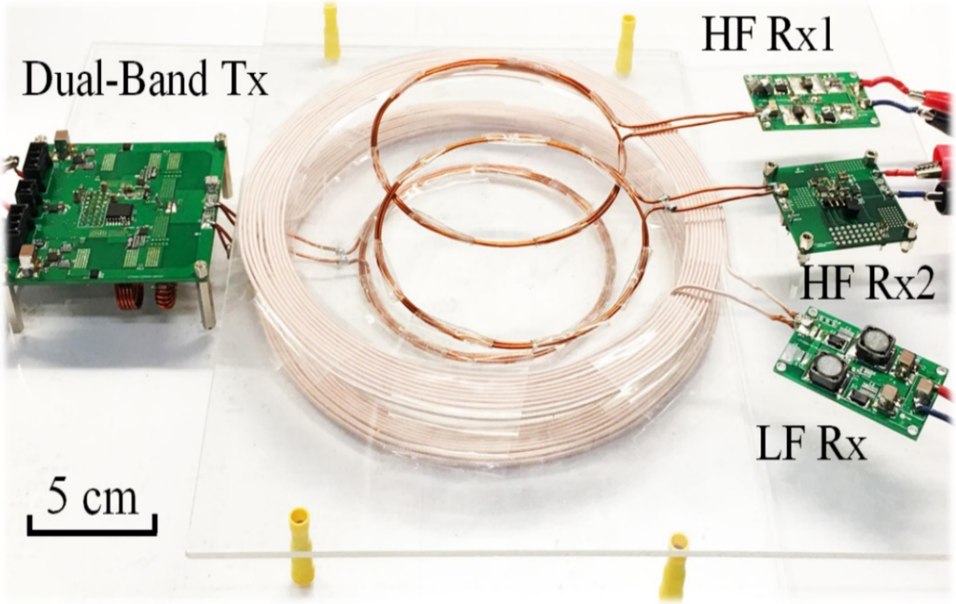


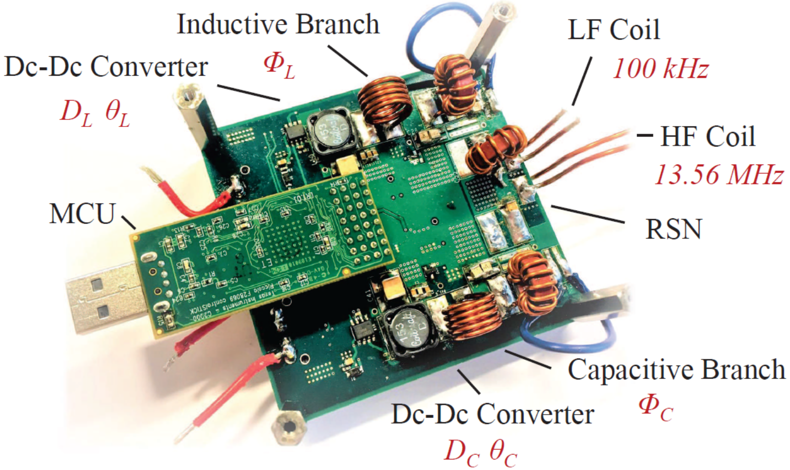


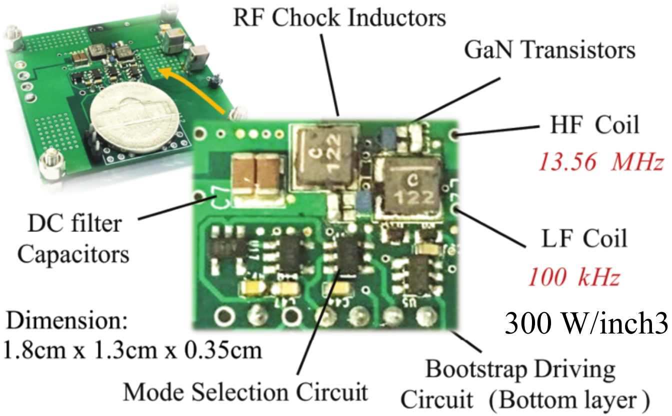


A Dual-Band Multi-Receiver WPT Prototype

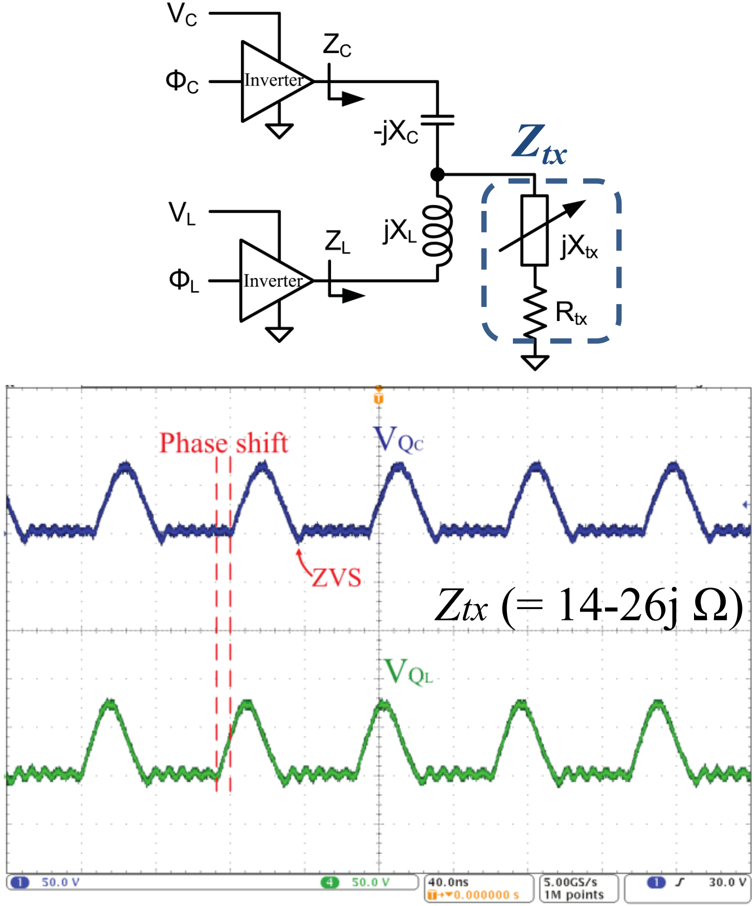
Dual Band Operation: 100 kHz and 13.56 MHz
Power Rating of TX: 65 W at both frequencies
Input/Output Voltage: 50V/20 V at both frequencies
Spacing: 2.8 cm distance, up to 5 cm misalignments



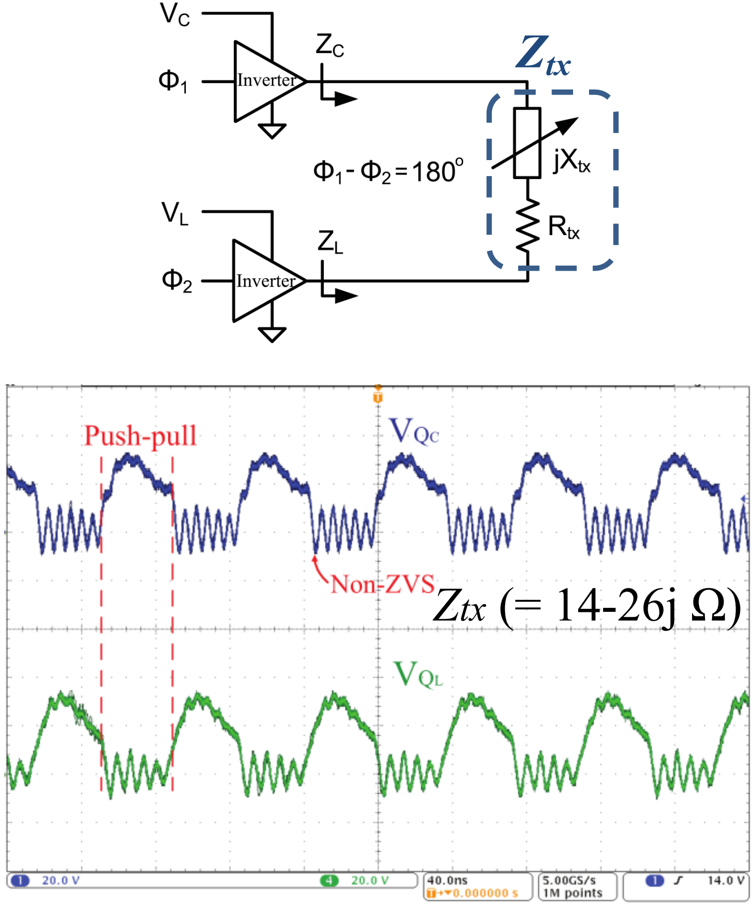




Experimental Waveforms of the Inverters



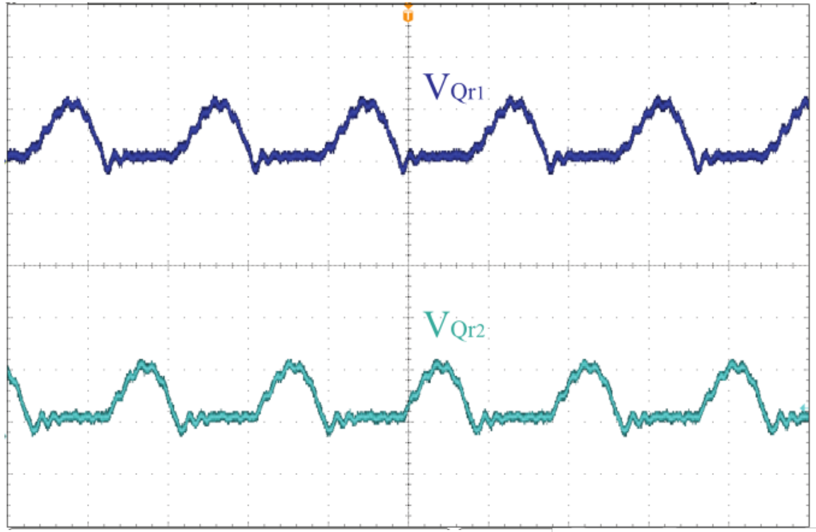
VDS of Class E Inverters with RSN



VDS of Class E Inverters without RSN

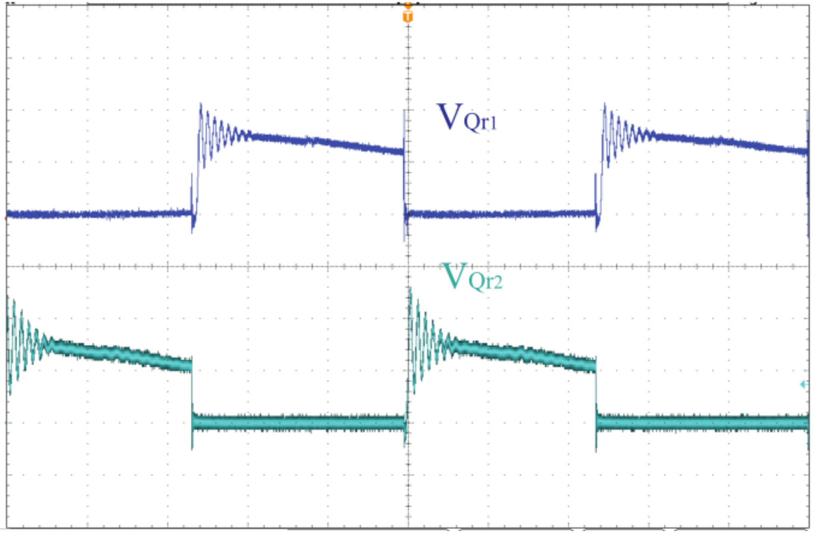
Experimental Waveforms of the Rectifier

V_{DS} at 13.56MHz

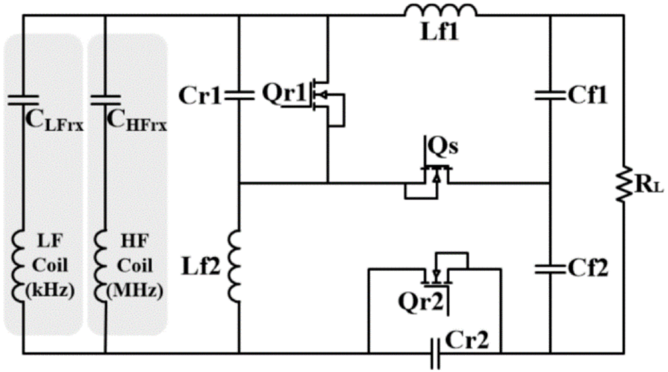


20V/div, 40ns/div

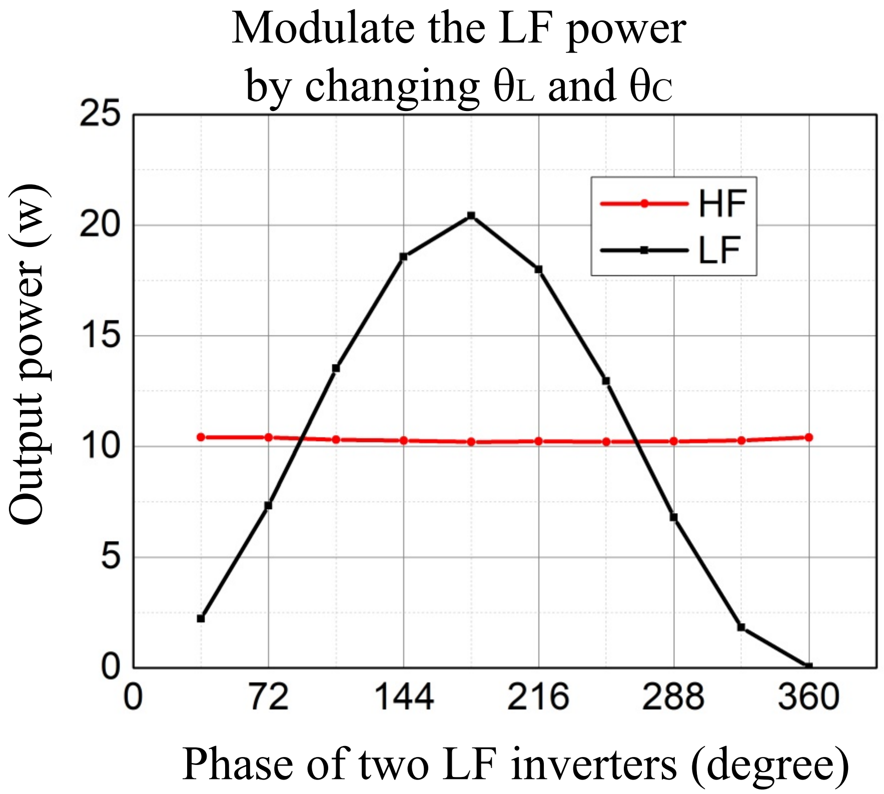
V_{DS} at 100kHz

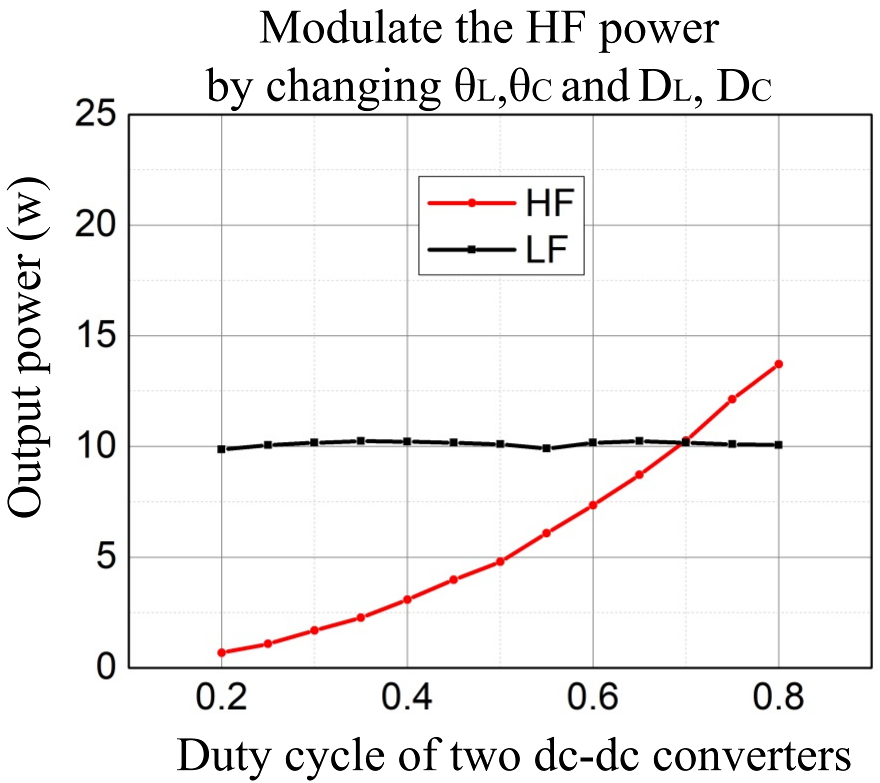


10V/div, 2μs/div



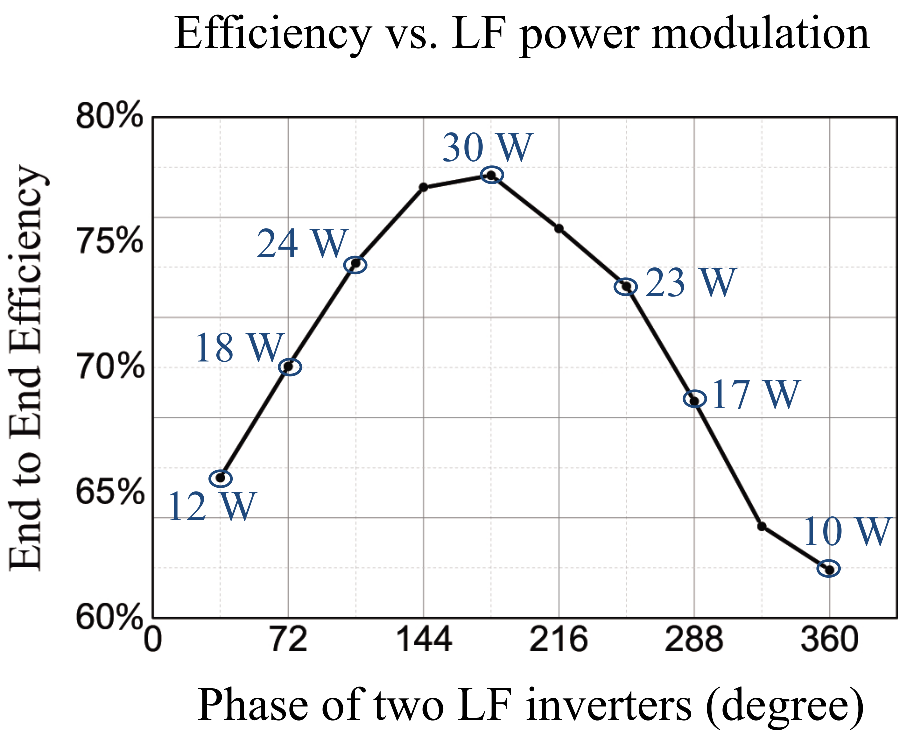
Decoupled Power Modulation of LF and HF Operation

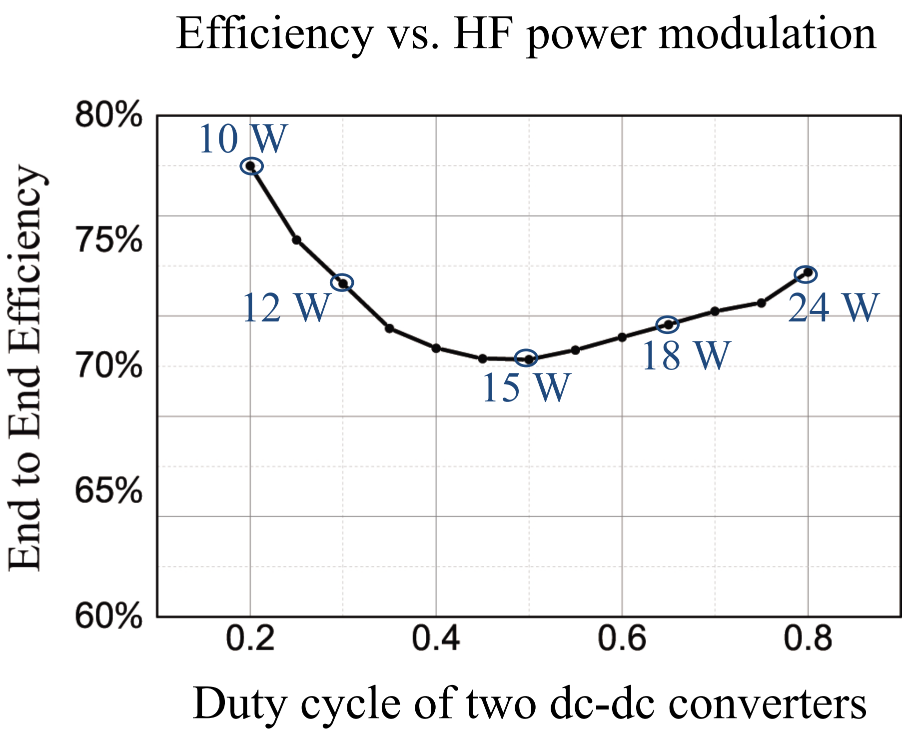




- In the power modulation, the reactance compensation is achieved at the same time.

Efficiencies with LF and HF Systems Working Together

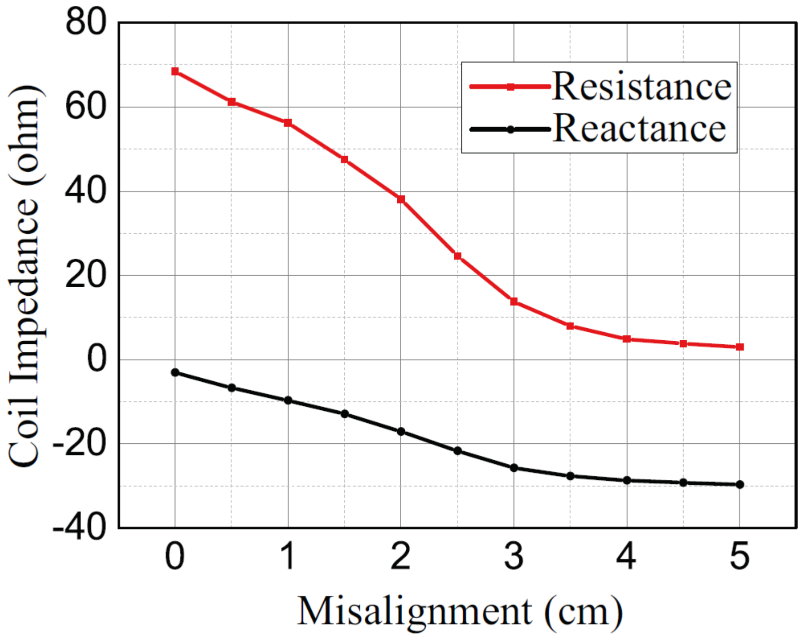




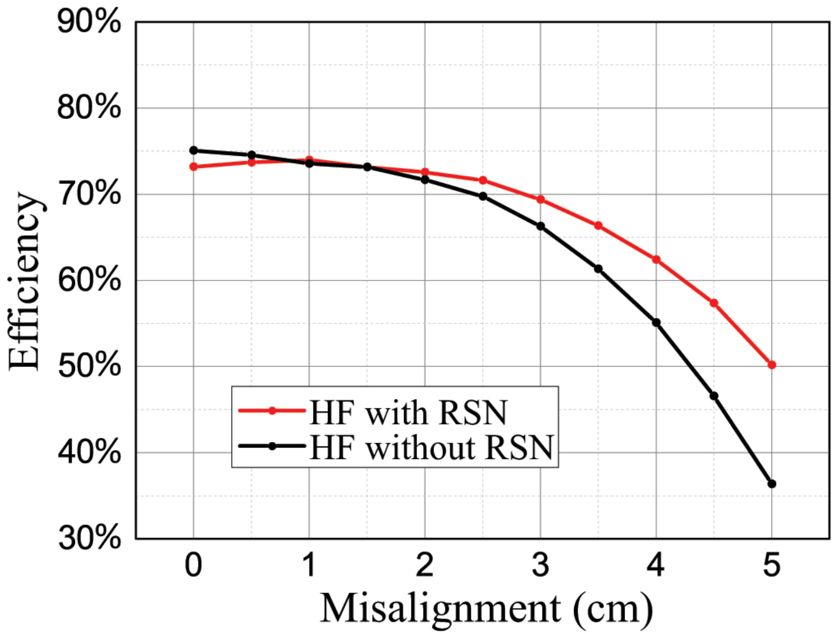
- Efficiency can be further improved by improving the quality factor of the coupling coils.

Impedance and Efficiency vs. Misalignment at MHz

Coil impedance vs. Misalignment at MHz



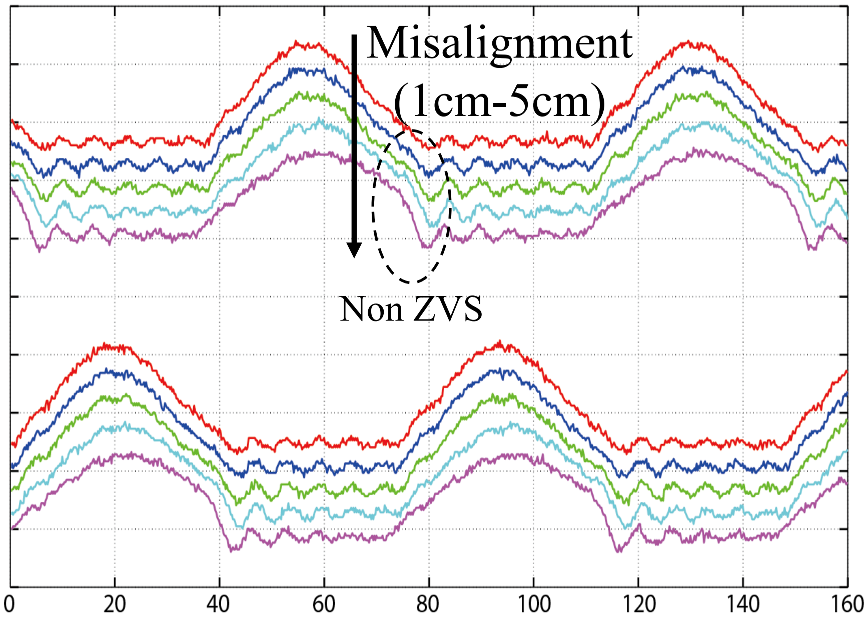
Efficiency vs. Misalignment at MHz



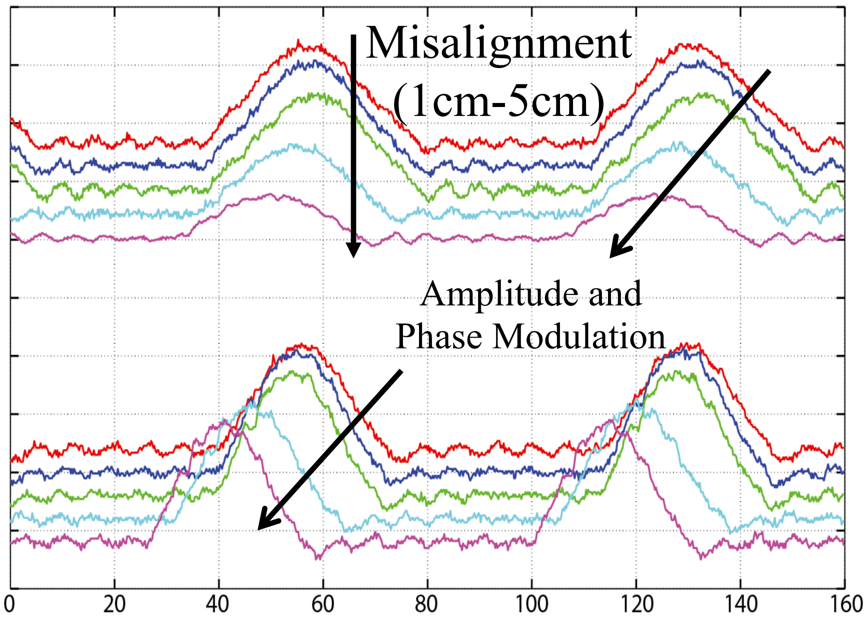
- Up to 13% of efficiency improvements with the high misalignment, (e.g., 5cm).

Measured Waveforms vs. Misalignment

V_{DS} of Class E Inverters without RSN control



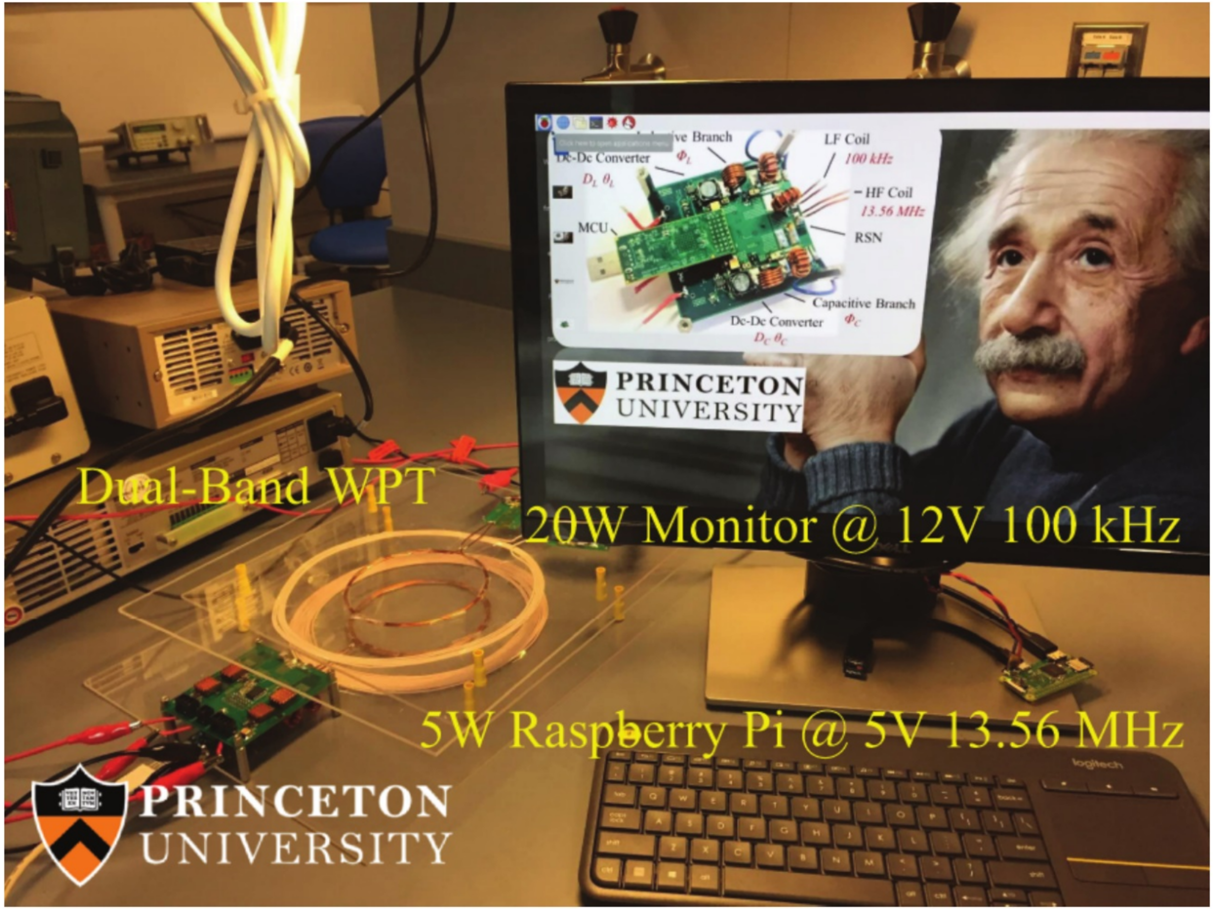
V_{DS} of Class E Inverters with RSN control



- In the close-loop control: K_{LC} and Δ_{LC}, are automatically selected from a look-up table according to the measured dc power ratio P_L/P_C of the HF inverters.

Conclusion

- A dual-band high performance transmitter with a reactance steering network which can maintain ZVS operation for the HF inverters across a wide load variation range;
- A dual-band reconfigurable receiver which functions as a half bridge rectifier at LF and functions as a Class-E rectifier at HF; This dual-band receiver has low component count and can achieve high power density;
- An online load impedance estimation algorithm and a look-up table based close loop control to maintain ZVS operation of the HF inverters;
- A complete demonstration of the dual-band WPT system with lower component count, higher efficiency, and higher power-density.


Dual-Band WPT
20W Monitor @ 12V 100 kHz
5W Raspberry Pi @ 5V 13.56 MHz
LF Coil
100 kHz
HF Coil
13.56 MHz
RSN
MCU
Capacitive Branch
Dc-Dc Converter
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Thank you!