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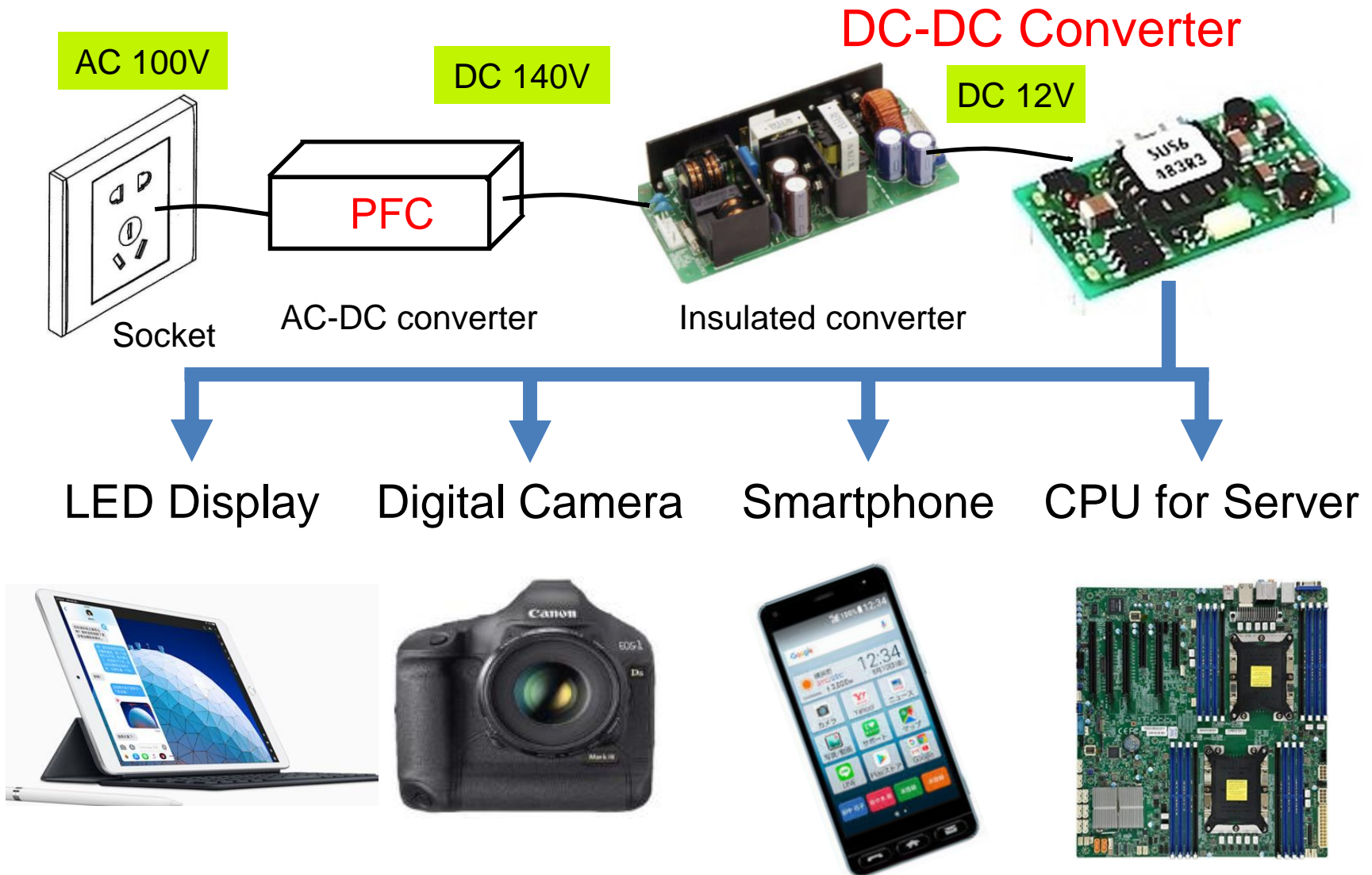
Output Voltage Ripple Reduction with Noise Spectrum Spread for Dual-Phase LLC Resonant Converter

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Outline

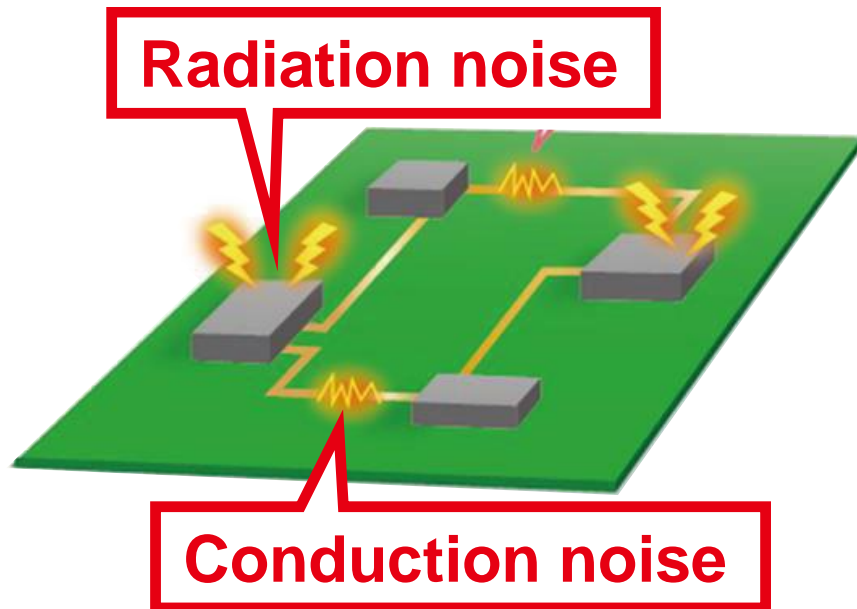
1. Research Background
2. LLC Resonant Converter
3. EMI Reduction Method for LLC Resonant Converter
4. Modulation Ripple Suppression Method
5. Simulation Verification
6. Conclusion

Research Background

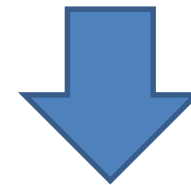


PFC: Power Factor Correction

Switching Converter Emits EMI Noise



Output current: **Increase**
Switching frequency: **Higher**



EMI noise generation
by current flow

EMI: Electro-Magnetic Interference

Conventional EMI noise reduction

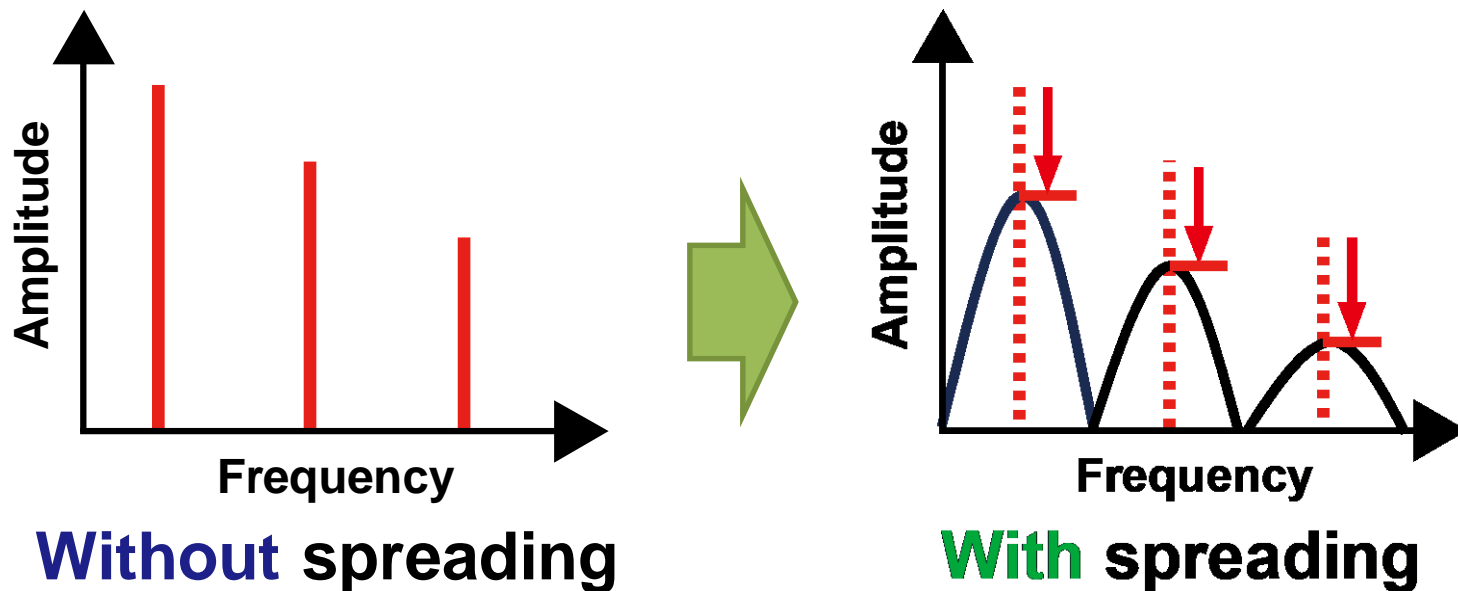
Analog filter
Shield case



Large scale
High cost

EMI Reduction by Frequency Spreading

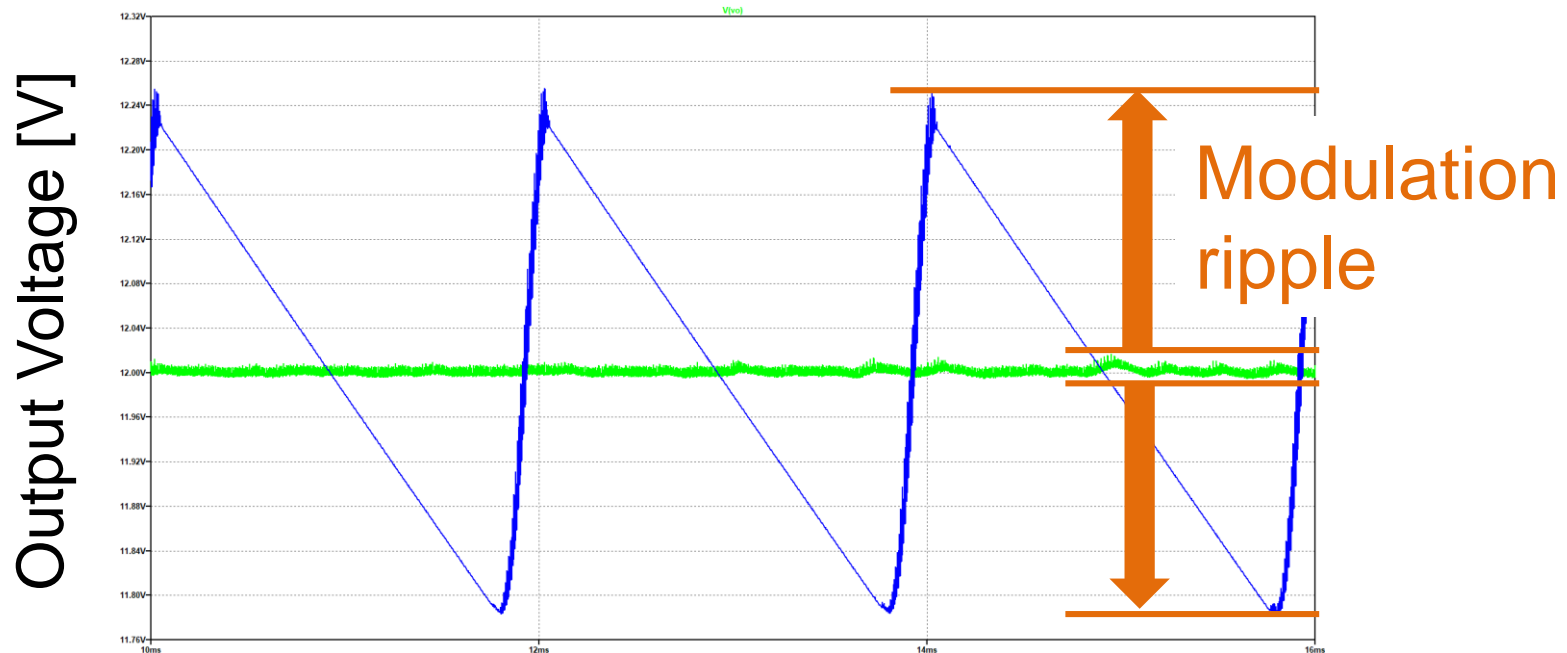
Proposed EMI noise reduction
Noise spectrum spread



Modulating switching frequency
Noise spectrum peak → Decrease

Problem of Frequency Spreading

Proposed EMI noise reduction
Noise spectrum spread

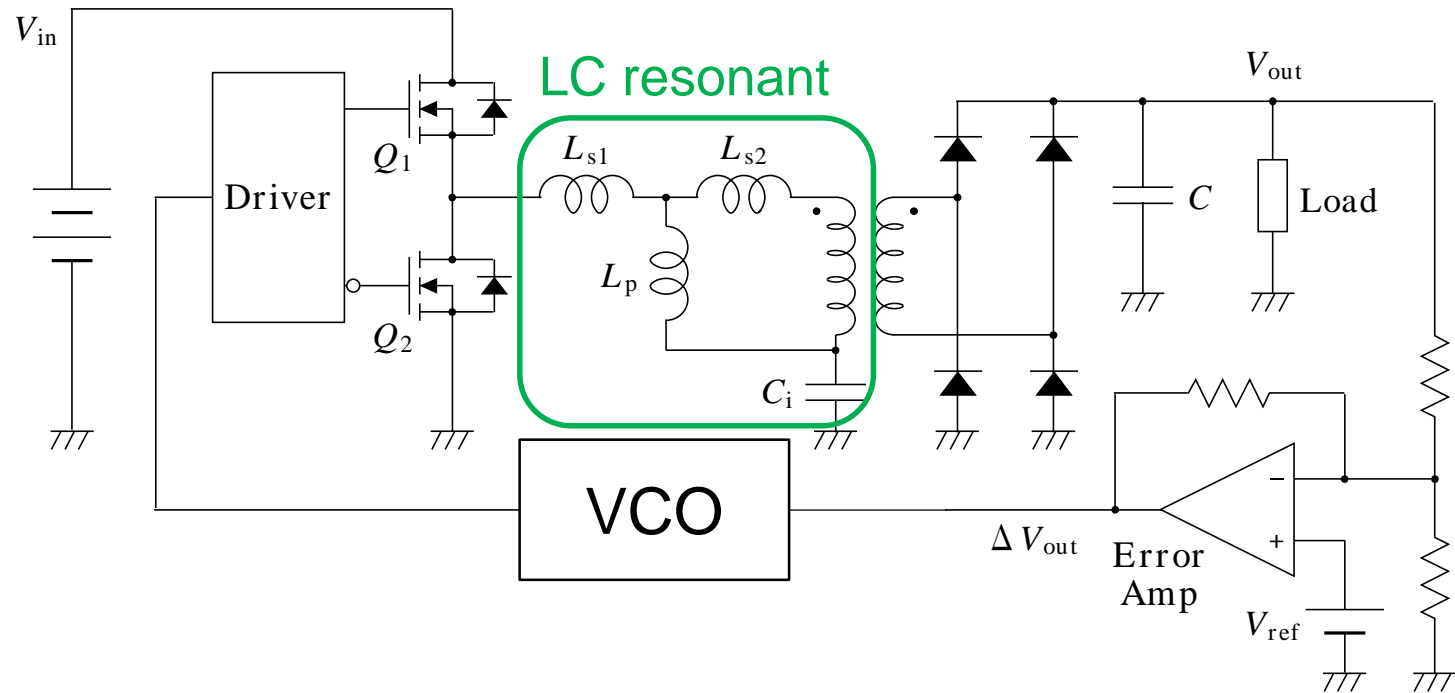


Modulating switching frequency
Output voltage ripple → Increase

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LLC Resonant Converter



Resonant the capacitor and primary-side of transformer

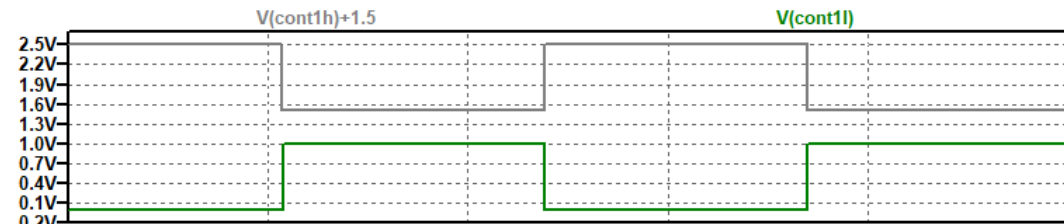
- Primary-side voltage: Substantially sinusoidal waveform
 ➡ Reduce EMI noise
- This study: **More reduction**

Waveform of LLC Resonant Converter

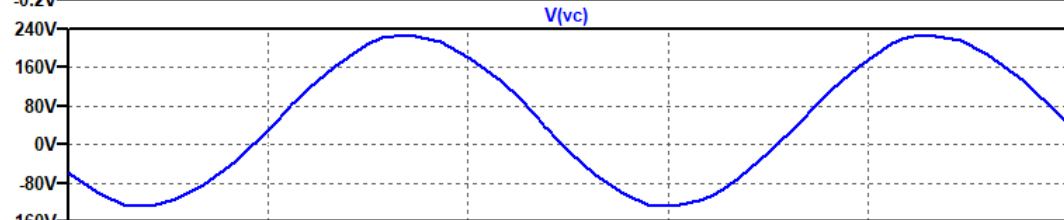
Switching pulse

High-side

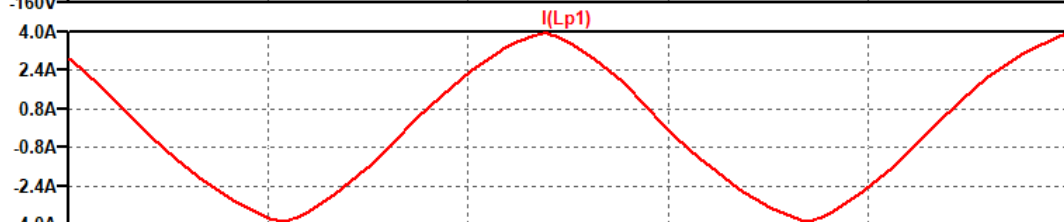
Low-side



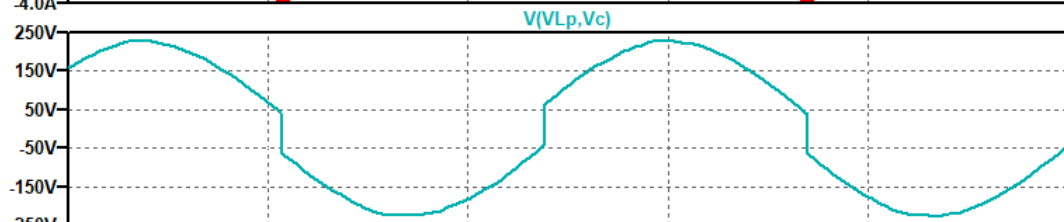
Resonant Capacitor Voltage



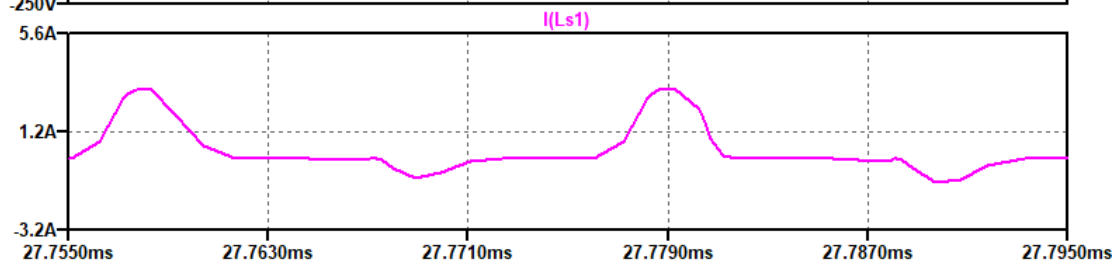
Primary-side Current



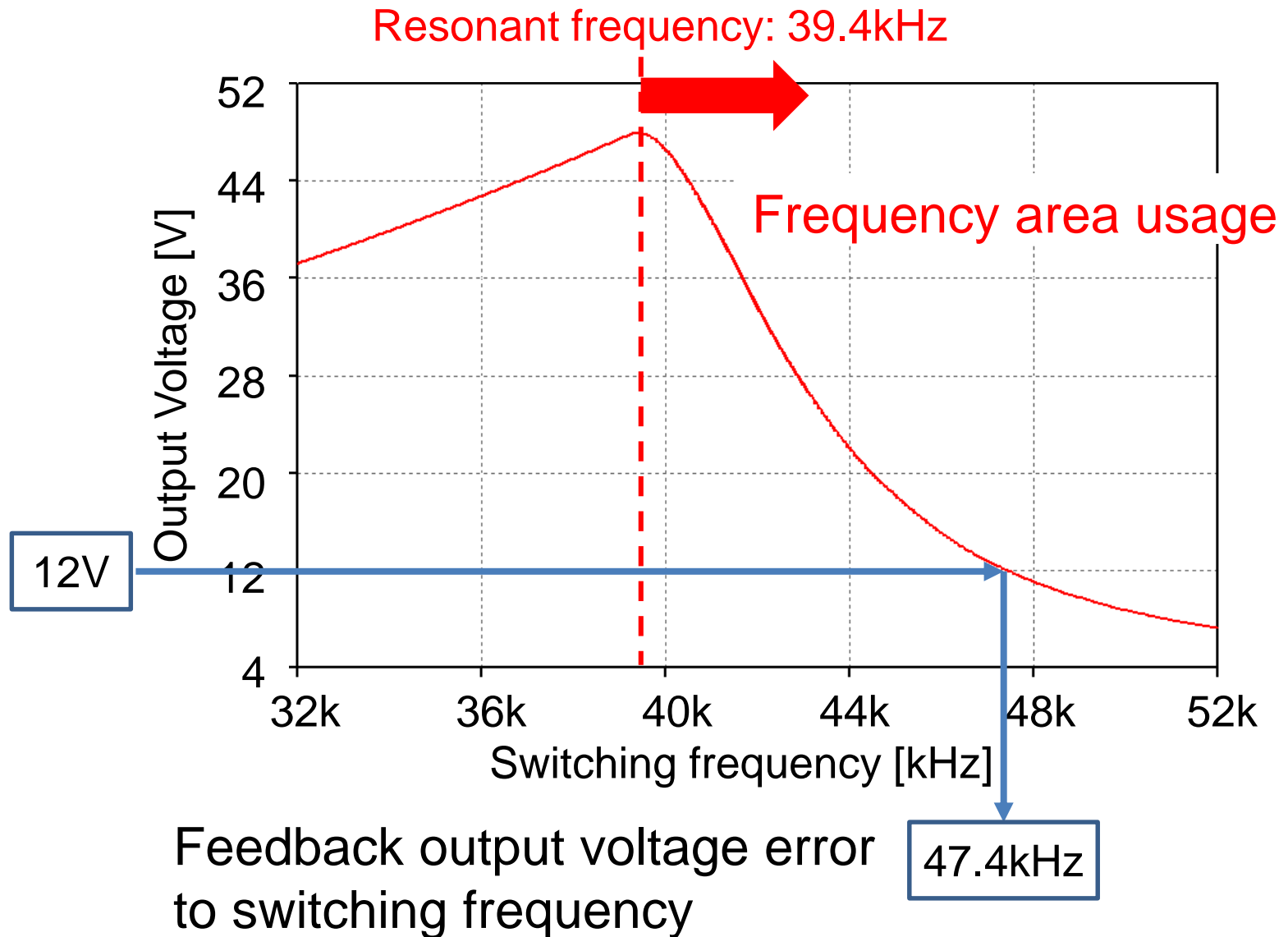
Primary-side Inductor Voltage



Secondary-side Current



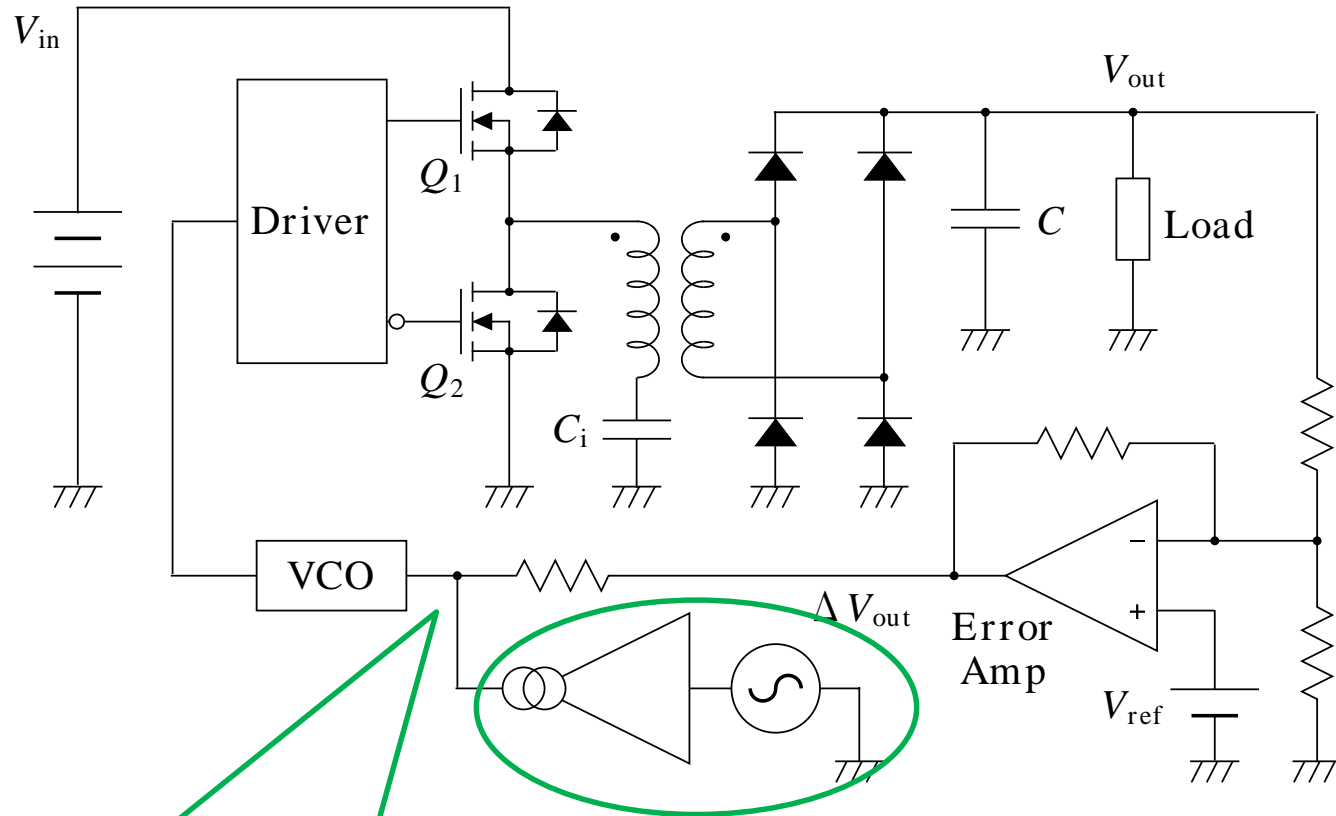
Voltage Control of LLC Resonant Converter



Outline

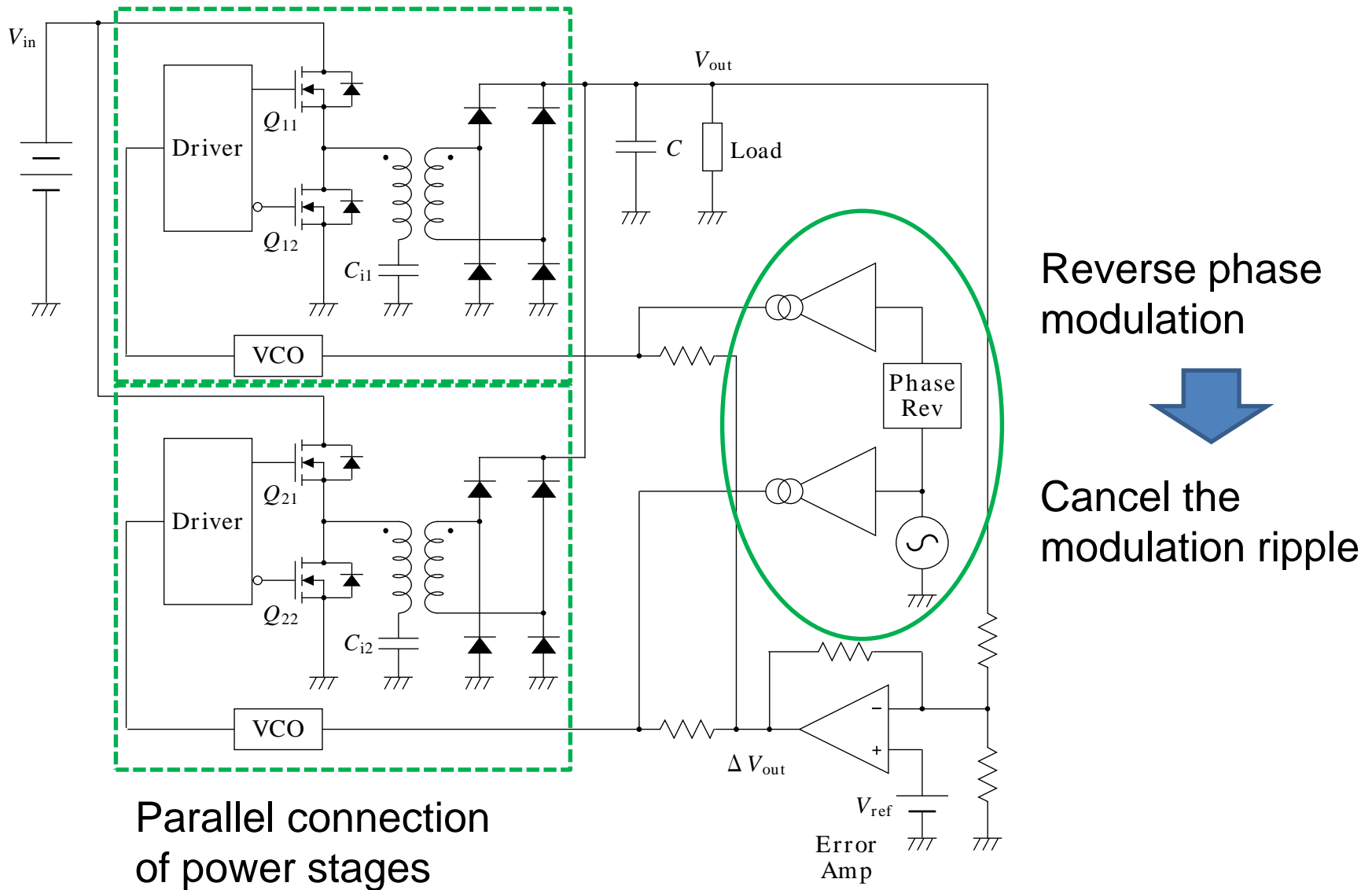
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EMI Reduction for LLC Resonant Converter



Modulating switching frequency

Modulation Ripple Suppression



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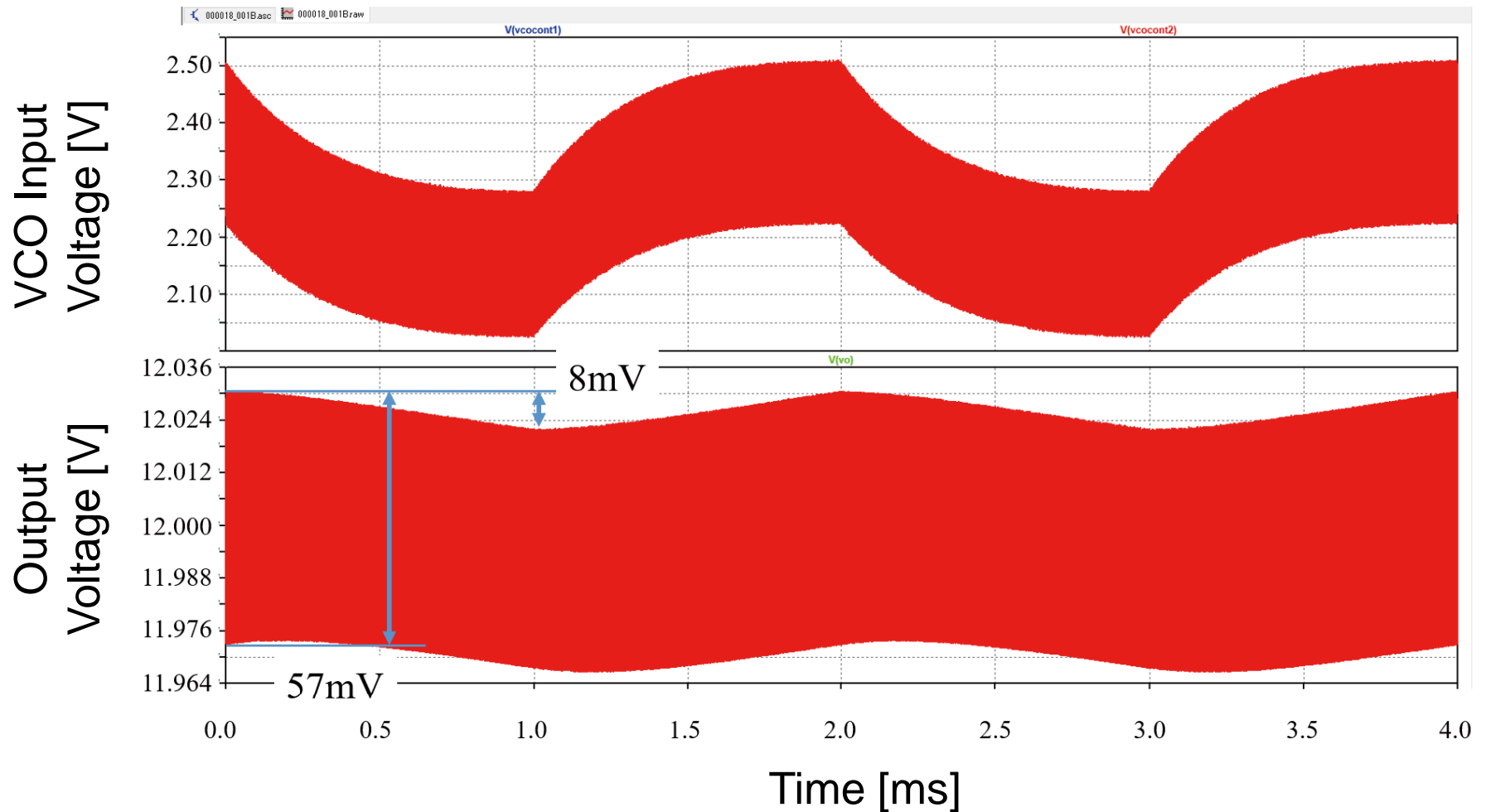
Simulation Conditions

Parameter	Value
Primary-side Inductance L_p	100 μ H
Leakage inductance L_{s1}	18 μ H
Resonant Capacitor C_i	39nF
Input Voltage	100V DC
Output Voltage	12V DC

Resonant frequency:

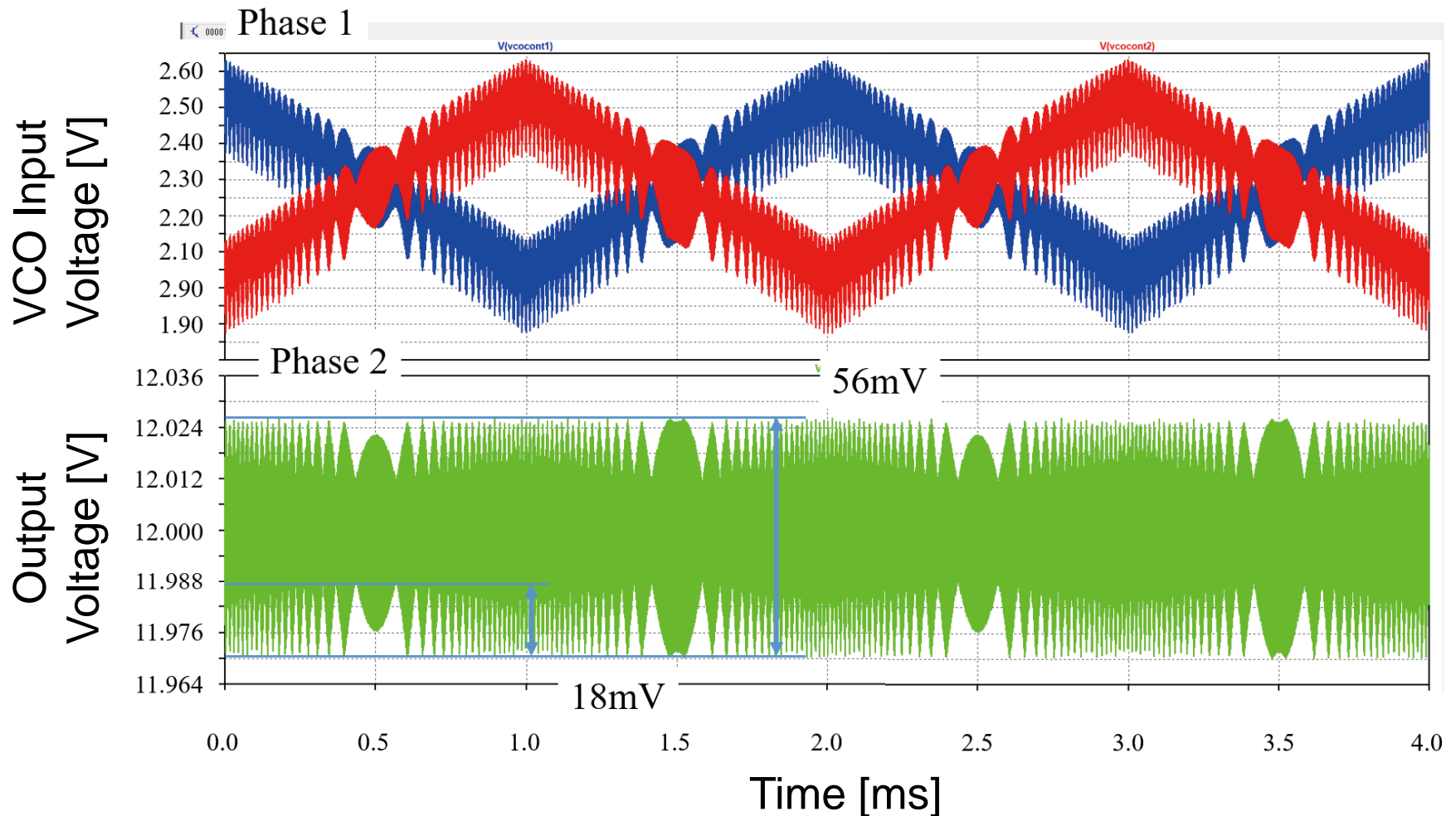
$$f = \frac{1}{2\pi\sqrt{(L_p+L_{s1})C_i}} = 52.1\text{kHz}$$

Simulation Result (Without Ripple Suppression)



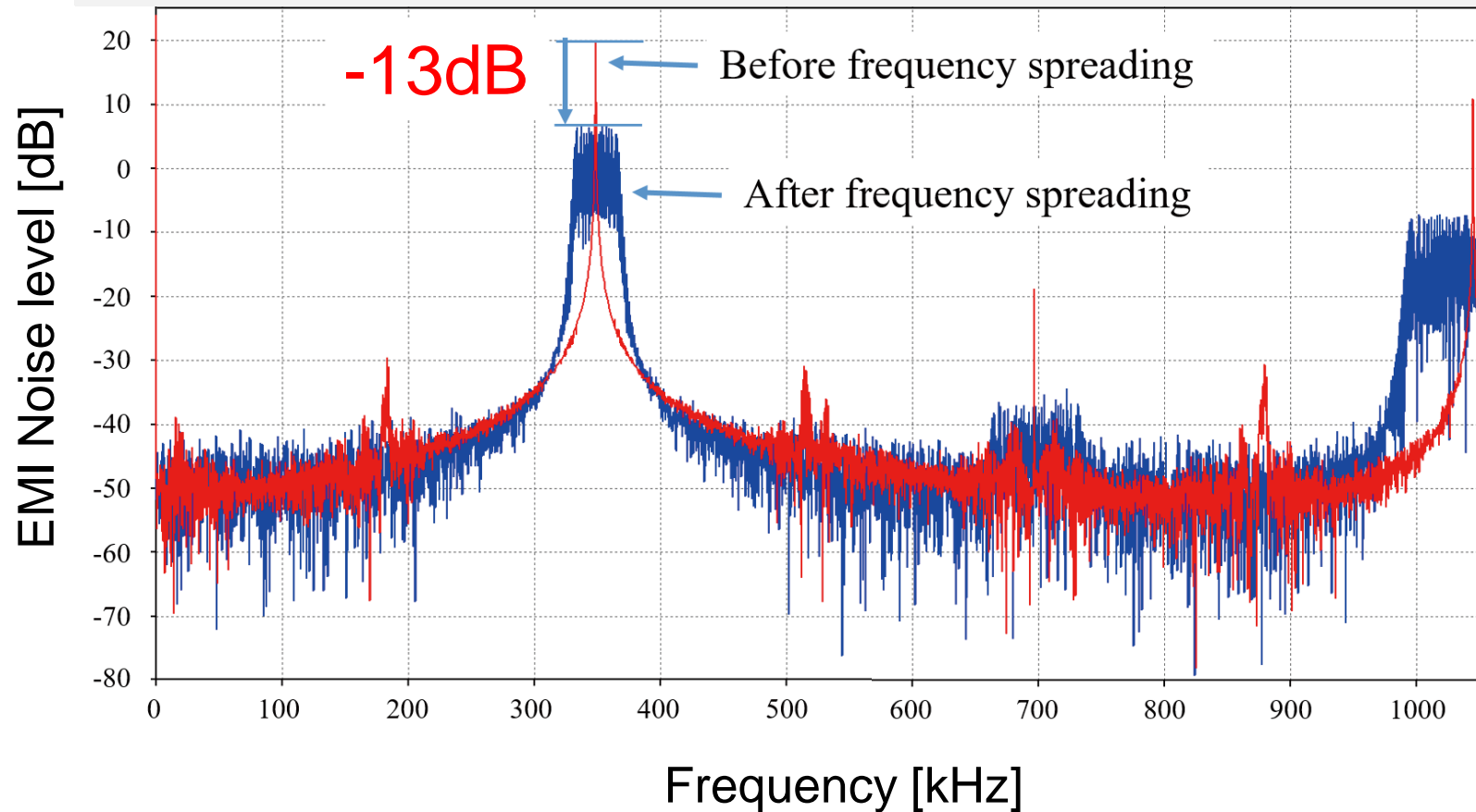
Steady state ripple: 57mV
Modulation ripple: 8mV

Simulation Result (With Ripple Suppression)



Steady state ripple: 20mV-56mV
Modulation ripple: **0mV**

Simulation Result (Spectrum Spreading)



Spectrum peak reduction by frequency spreading

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Conclusion

◆ EMI noise reduction for LLC resonant converter

 **Frequency spreading**

◆ Modulation ripple Suppression

 **Multi-Phase configuration**
Ripple canceling with reverse phase modulation

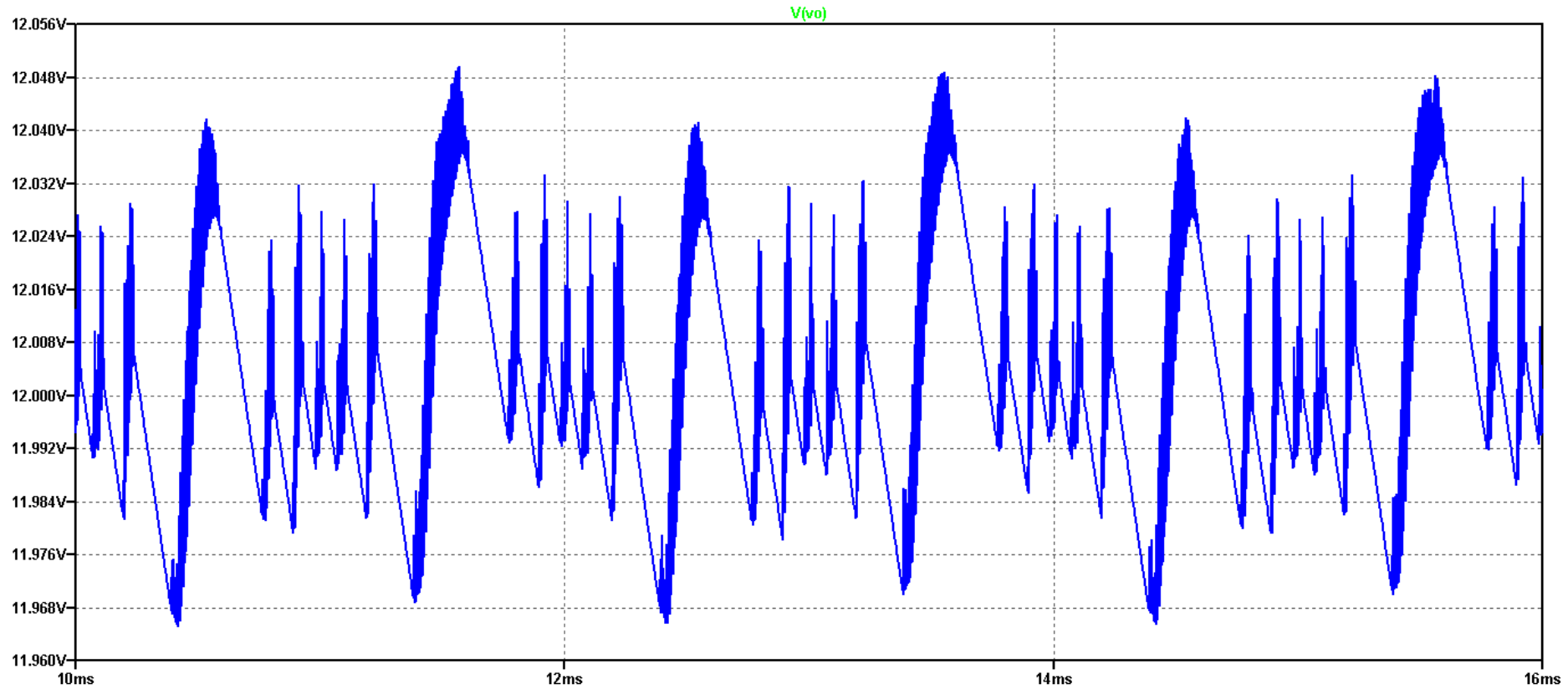
◆ Simulation

 **Switching frequency spreading: -13dB**
Modulation ripple reduction: 8mV  0mV

Thank you for your attention

謝謝

Simulation Result



Simulation Result

