EMI Reduction by Spread Spectrum Clocking with Ripple Suppression for LLC Resonant Converter

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Outline

1. Research Background
2. LLC Resonant Converter
3. EMI Reduction
   for LLC Resonant Converter
4. Output Ripple Compensation
5. Simulation Verification
6. Conclusion

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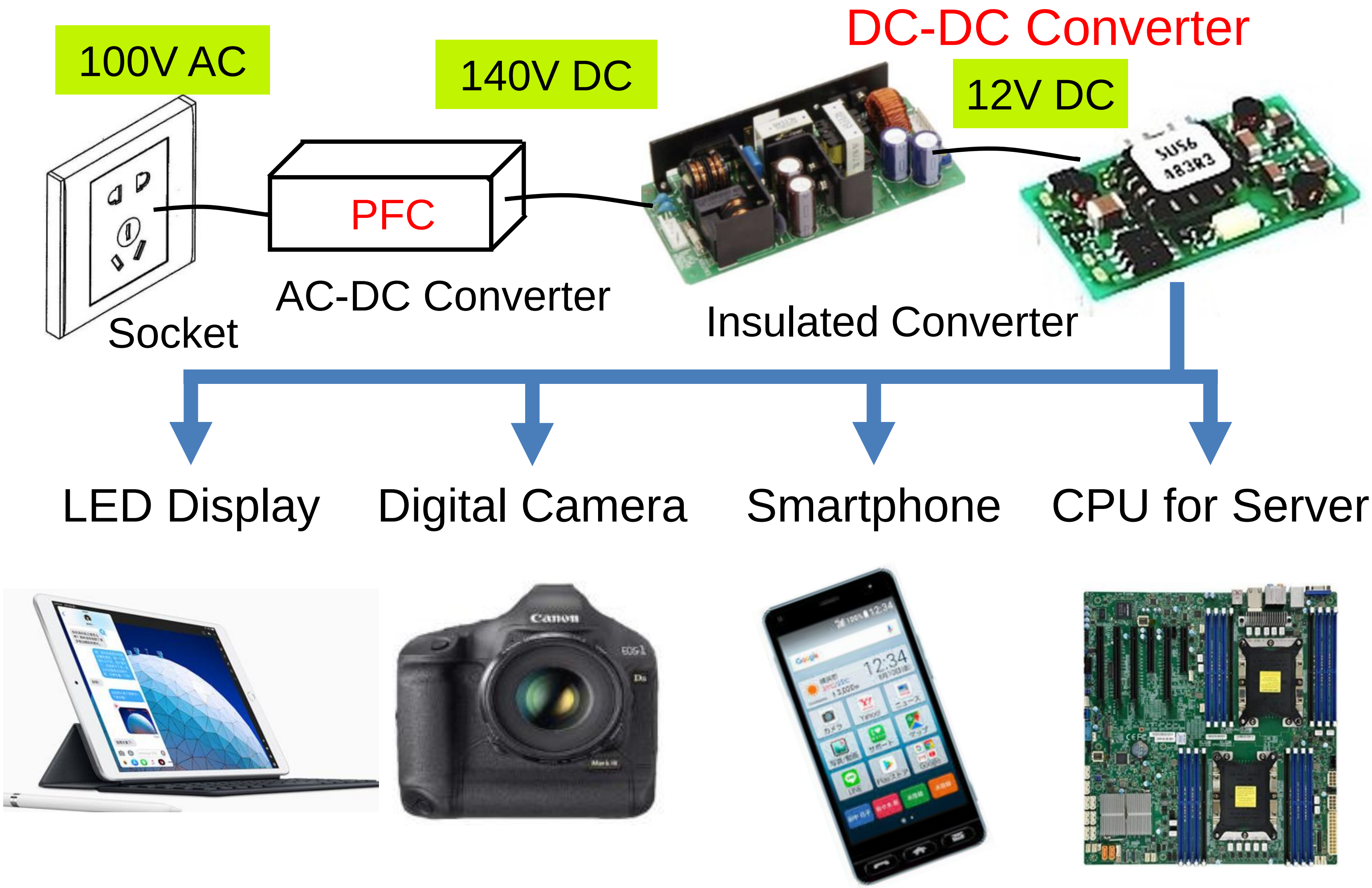
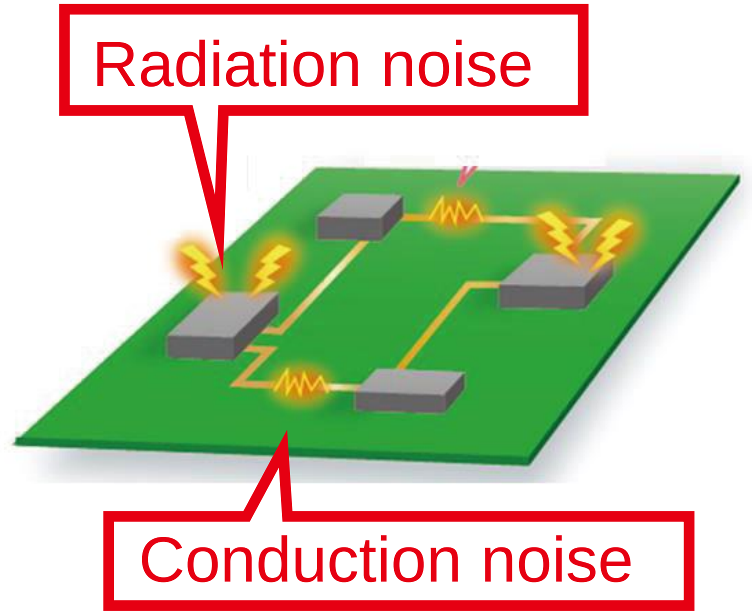
Research Background



PFC: **P**ower **F**actor **C**orrection

EMI Noise Emission of Switching Converter



Output current: Increase
Switching frequency: Higher

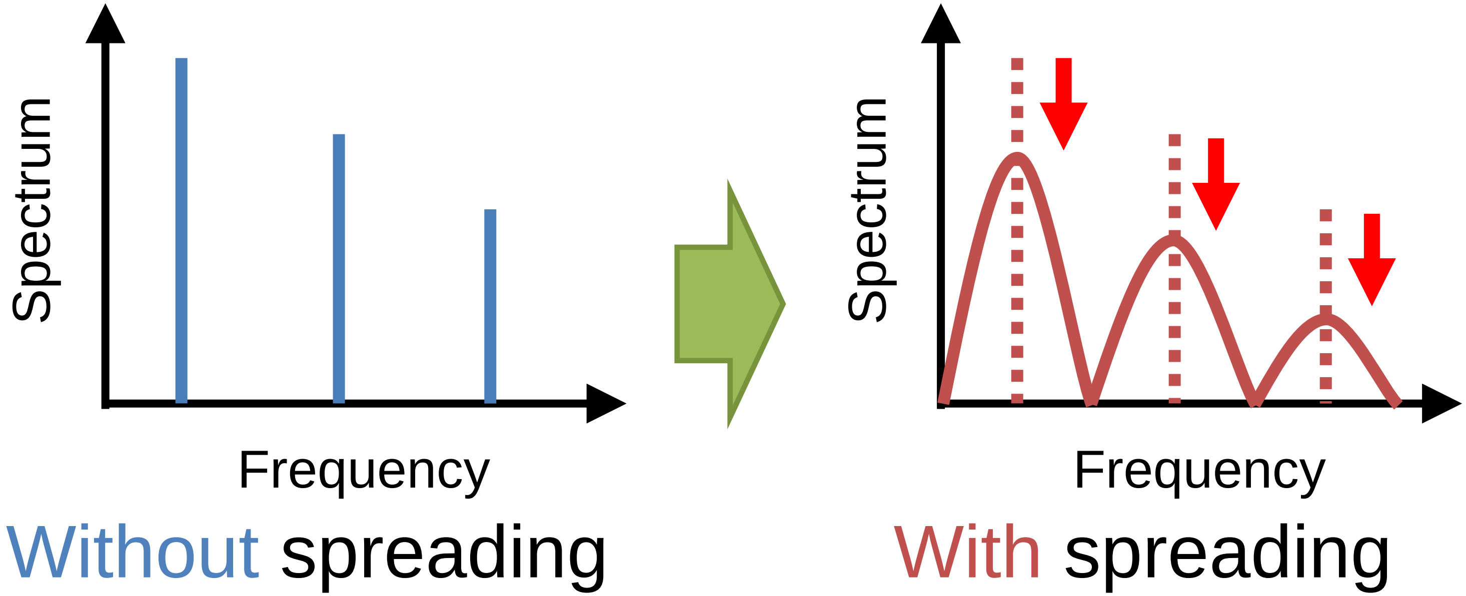
EMI noise generation by current flow

EMI: **E**lectro-**M**agnetic **I**nterference

Conventional EMI noise reduction
- Analog filter
- Shield case

Large size
High cost

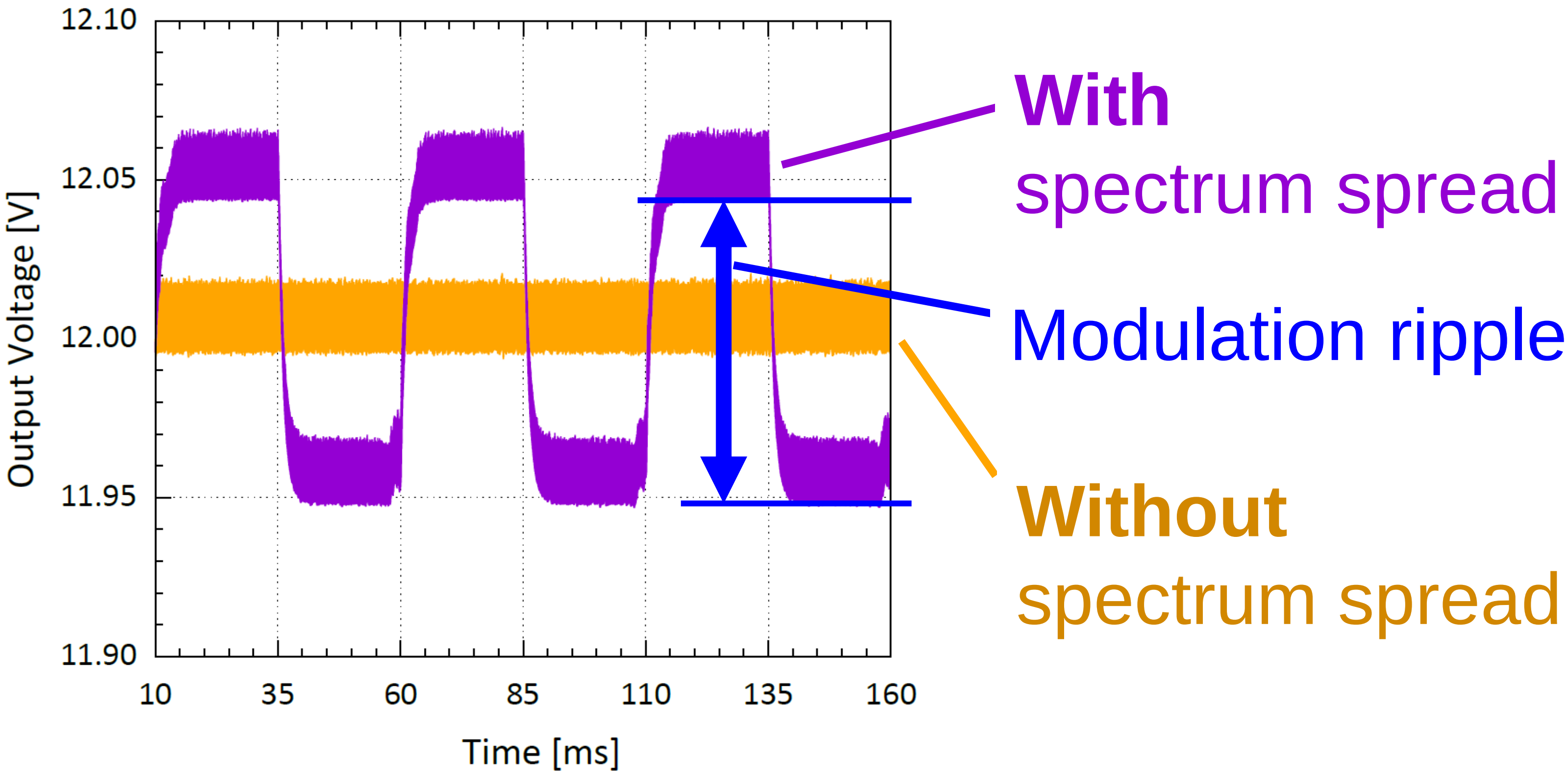
EMI Reduction by Noise Spectrum Spread



Switching frequency modulation

Noise spectrum peak ➡ Reduced

Problem of Spectrum Spread



Switching frequency modulation
Output voltage ripple ➡ Increase

This research target: Ripple suppression

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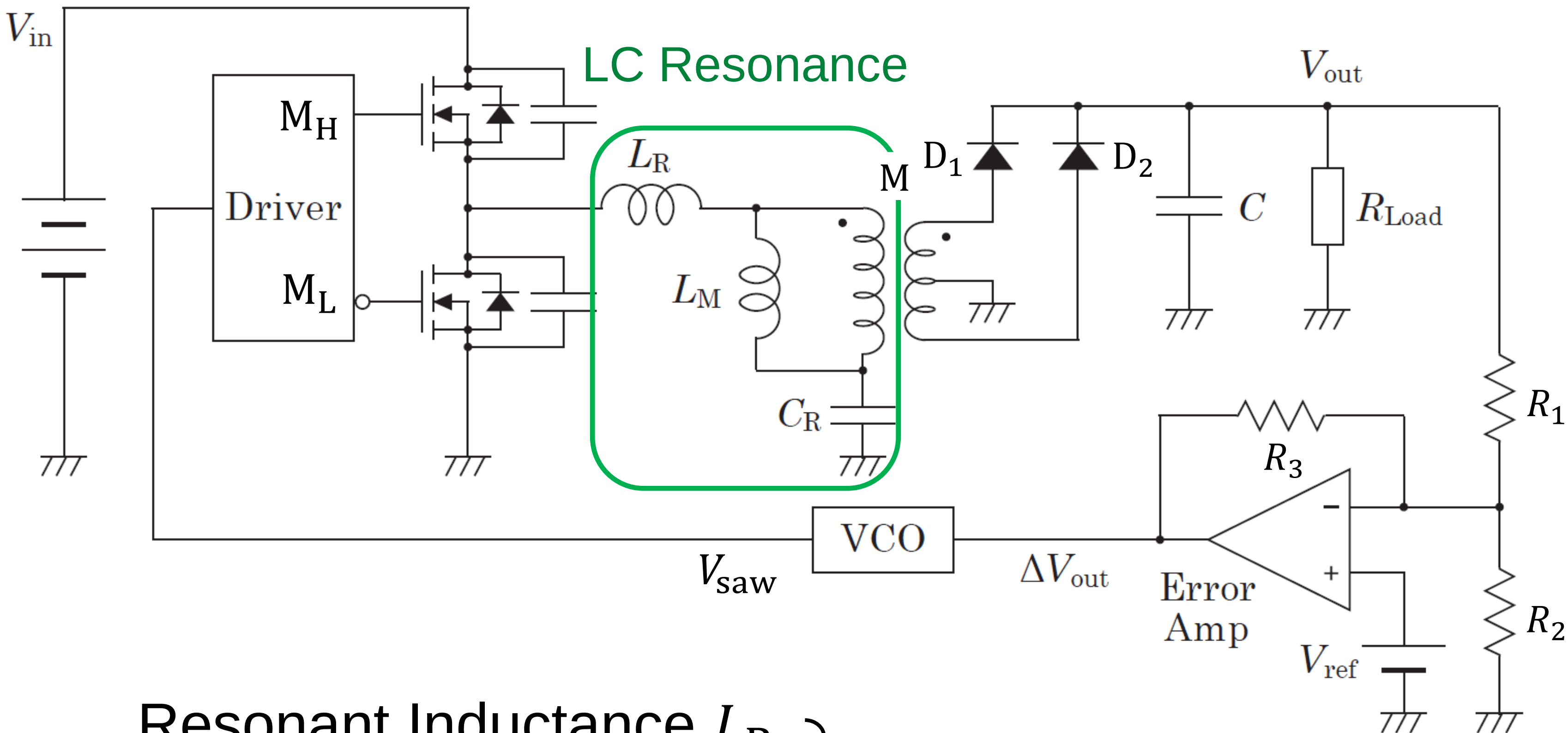
LLC Resonant Converter Circuit



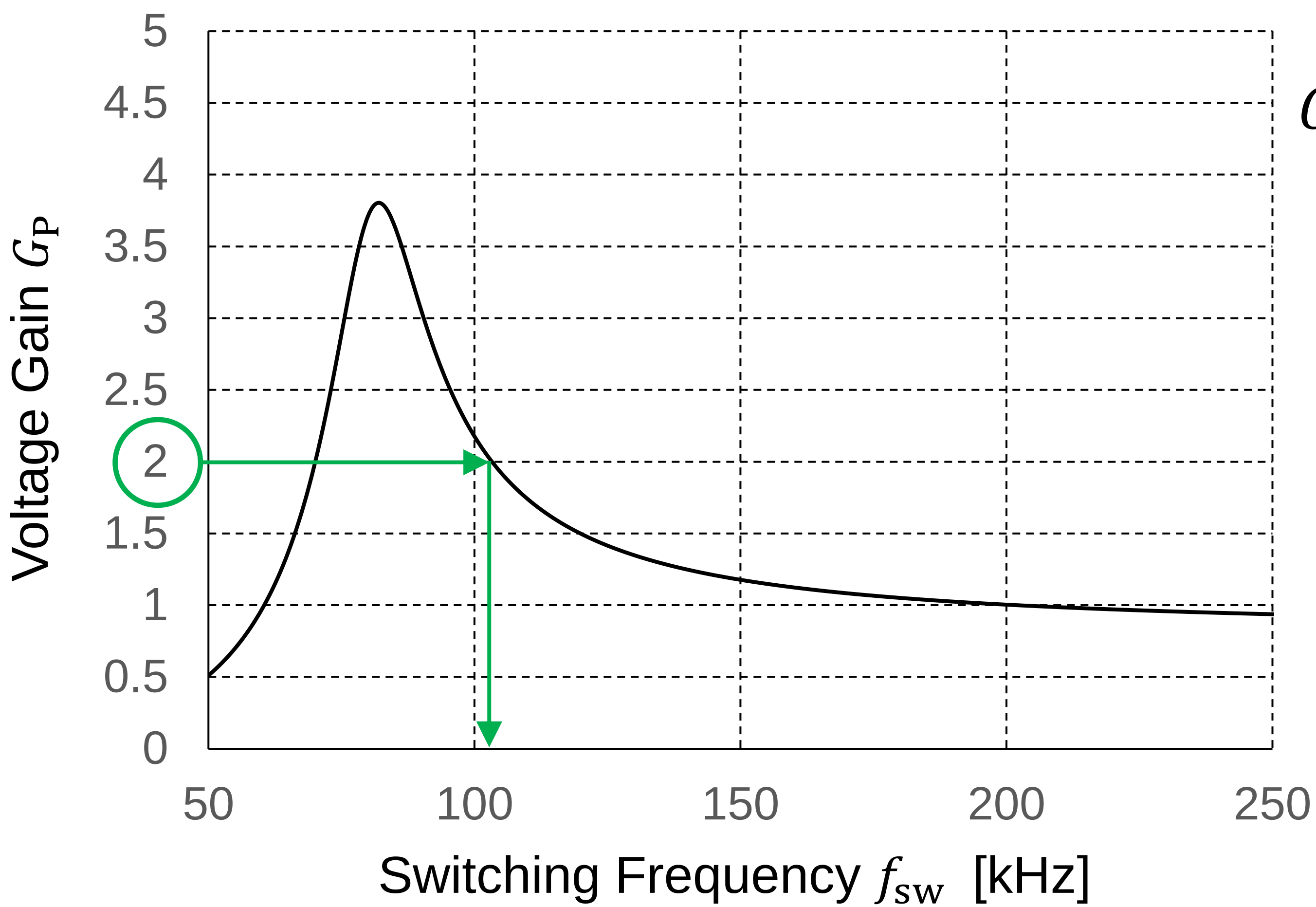
Resonant Inductance L_R
Excitation Inductance L_M
Resonant Capacitor C_R

LC Resonance

Small EMI noise
for server, TV usage

This research ⇒ further EMI reduction

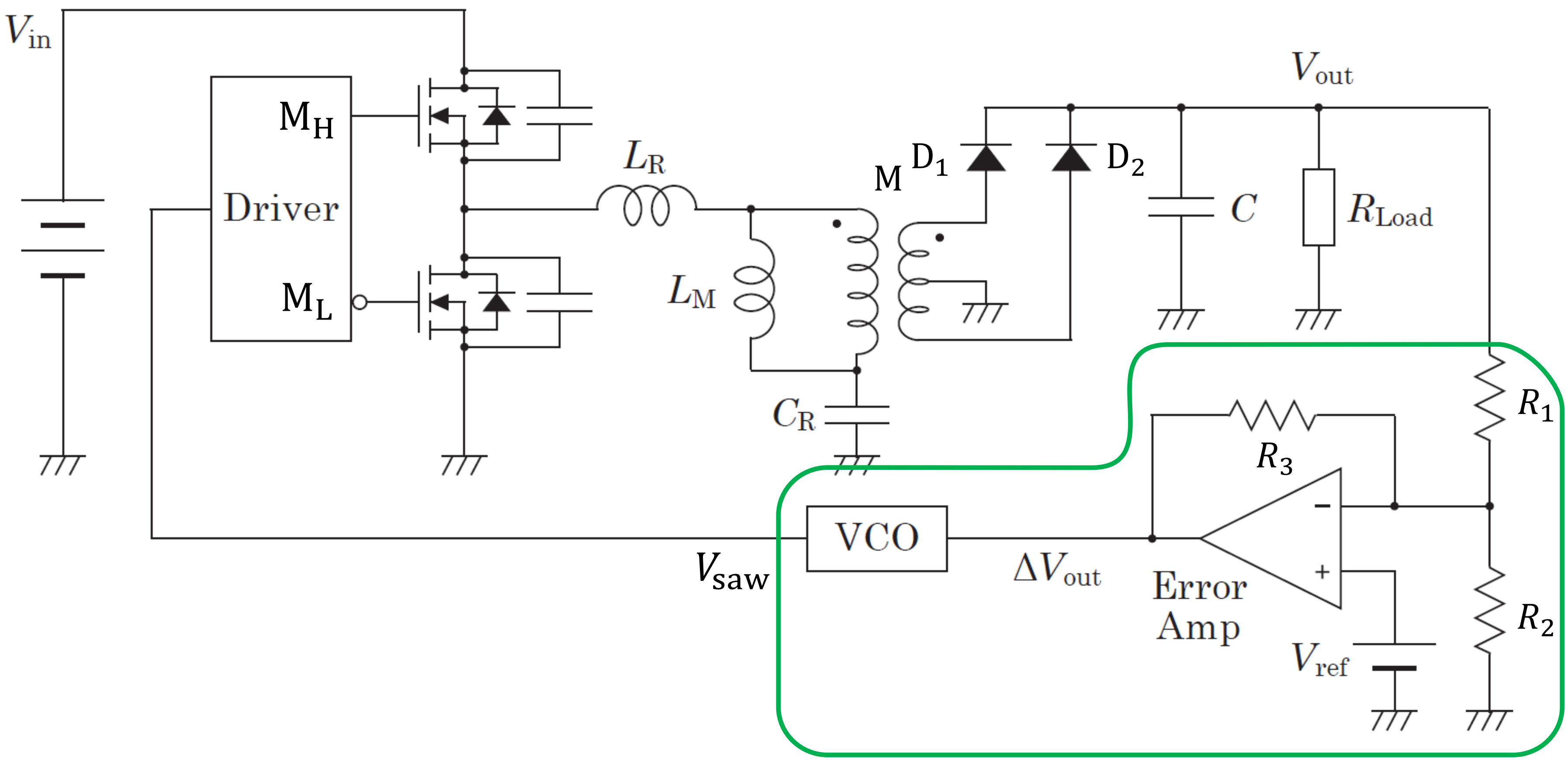
Output Voltage Control of LLC Resonant Converter



$$G_{\mathrm{P}} = \frac{V_{\mathrm{out}}}{V_{\mathrm{in}}}$$

Desired voltage gain G_{P} ➡ Switching frequency f_{sw}

Control Circuit of LLC Resonant Converter



- Desired voltage gain G_P ➡ Switching frequency f_{sw}

- Feedback control: Input error amp. output to VCO
- Without external clock

VCO: **V**oltage **C**ontrol **O**scillator

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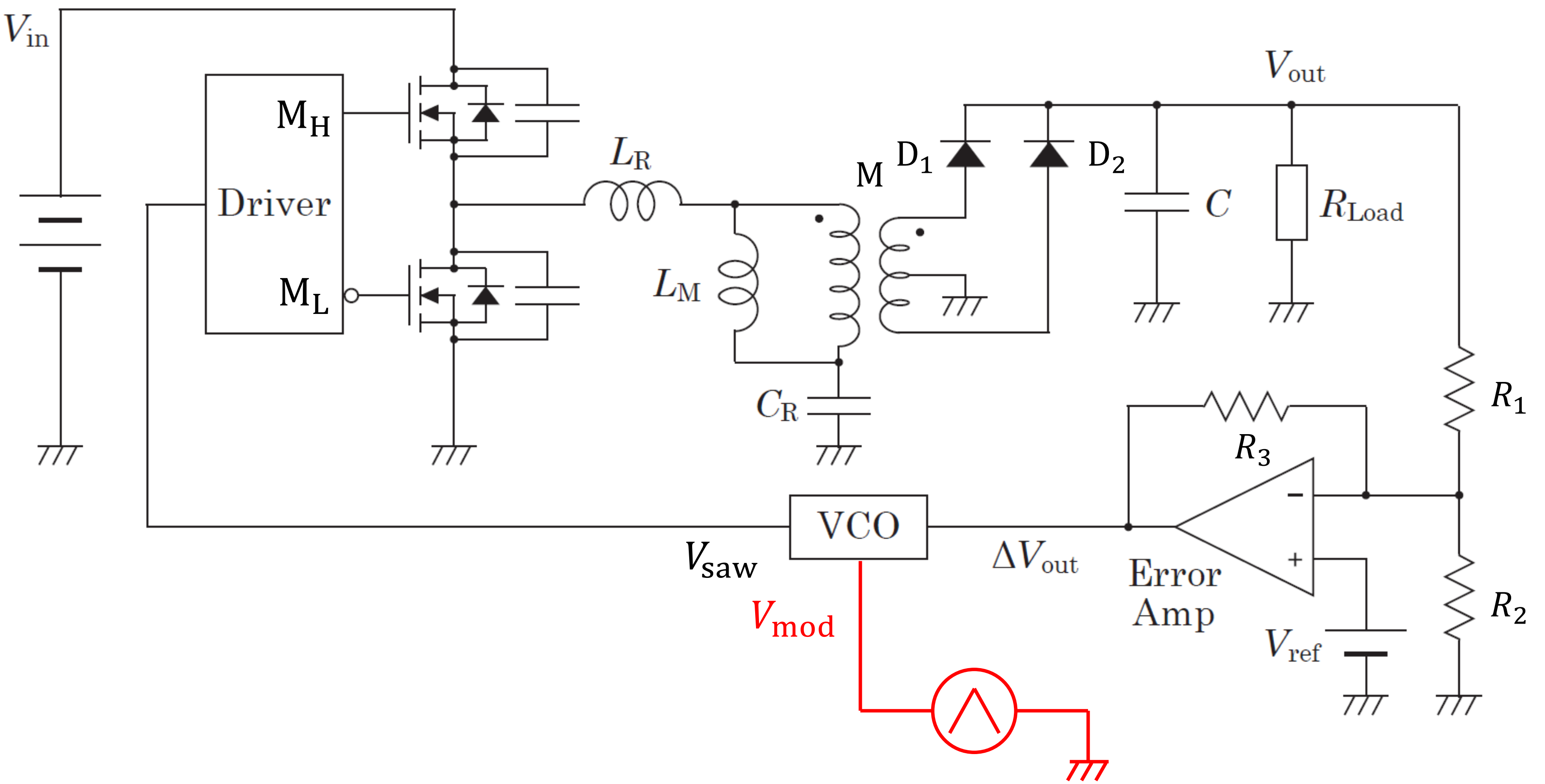
Spectrum Spread for LLC Resonant Converter



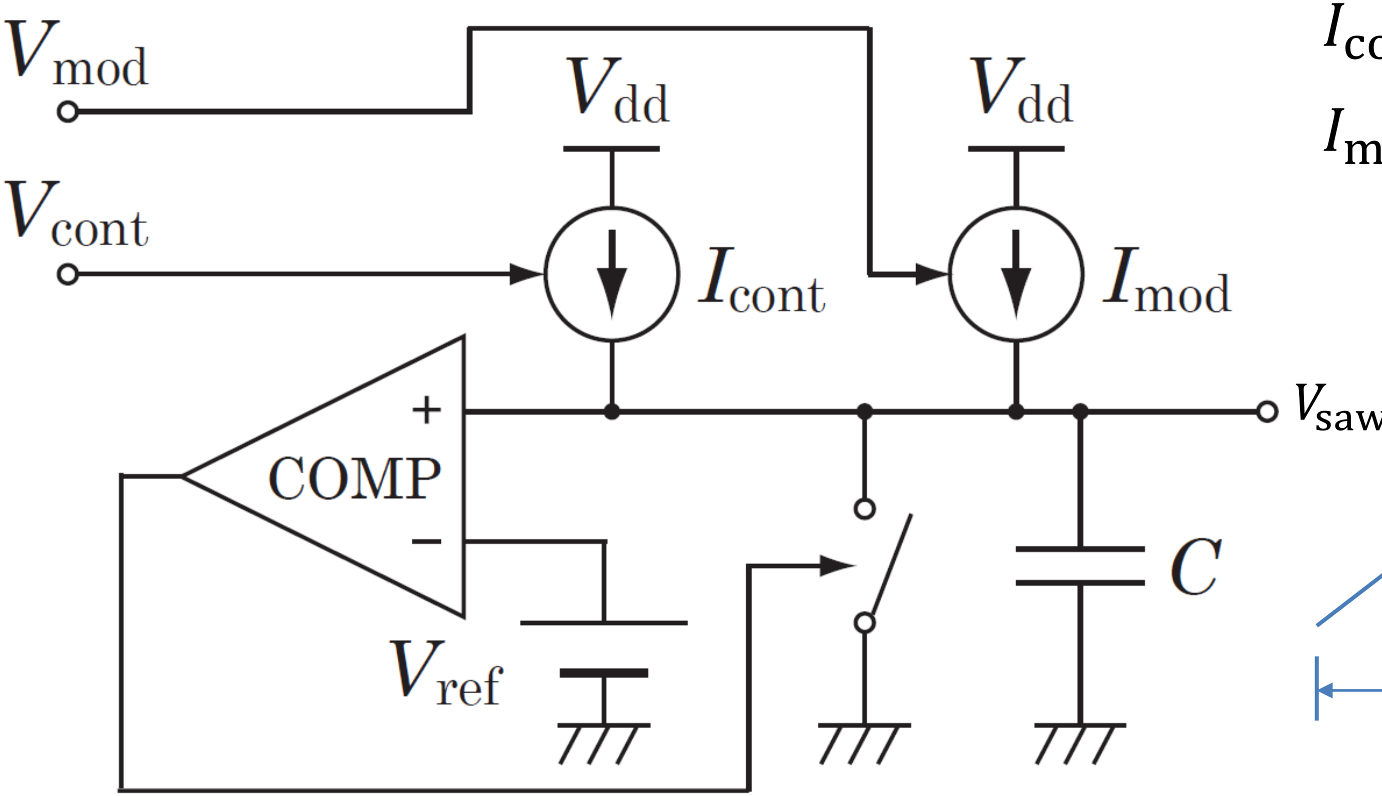
Input triangular wave to VCO

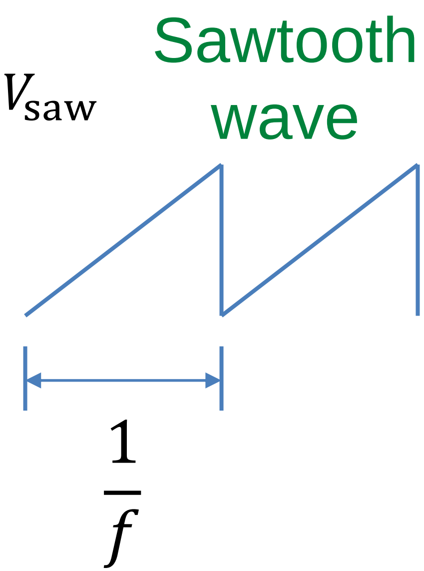
Modulate SW frequency from ΔV_{out}

VCO in Control Circuit

$I_{\mathrm{cont}} \propto V_{\mathrm{cont}}$

$I_{\mathrm{mod}} \propto V_{\mathrm{mod}}$

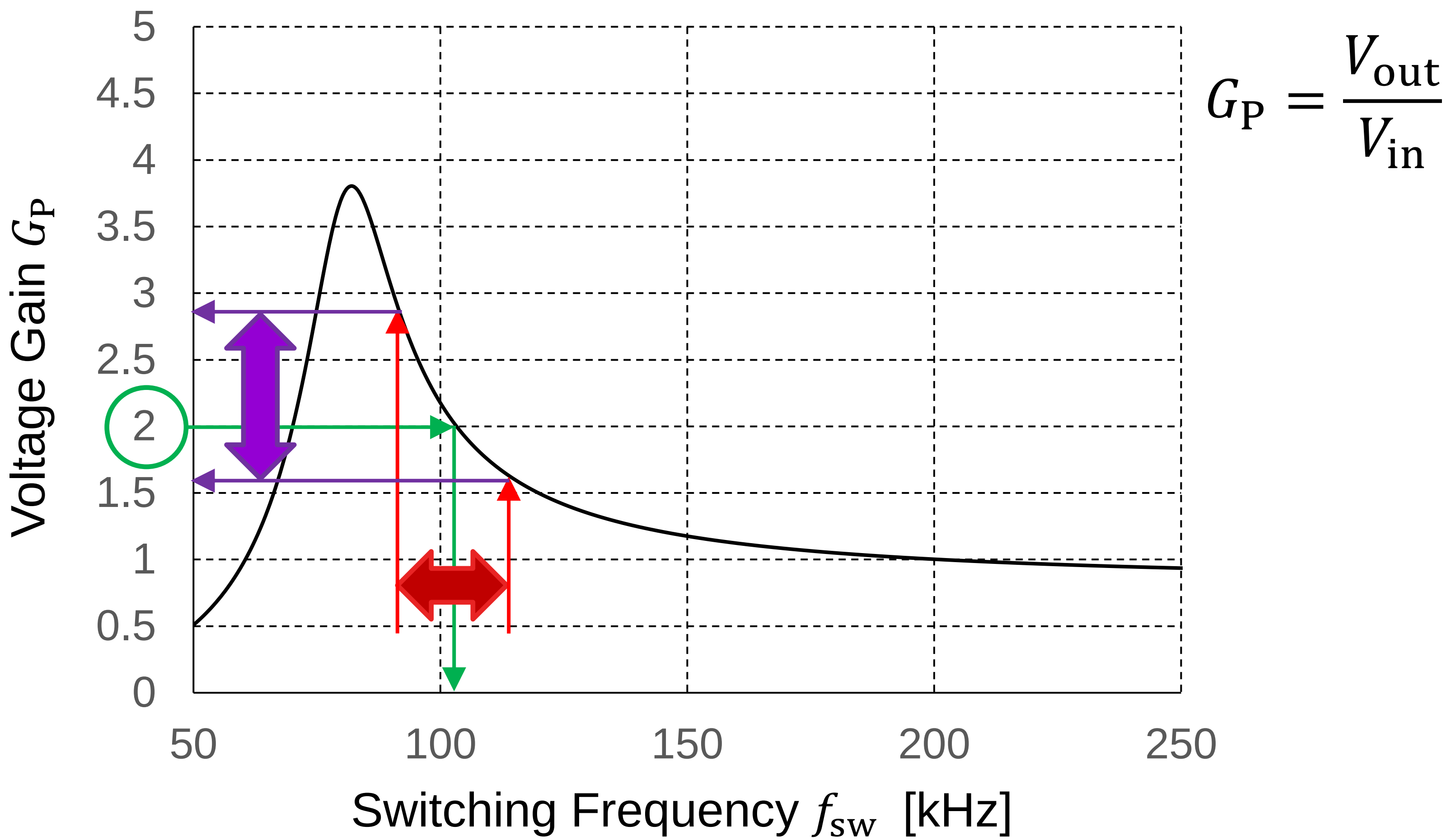




Frequency of sawtooth wave

$$f \propto V_{\mathrm{cont}} + V_{\mathrm{mod}}$$

Output Voltage Ripple with Spectrum Spread



Modulate SW frequency f_{sw} ➡ Modulating output voltage

Modulating output voltage ➡ Output voltage ripple

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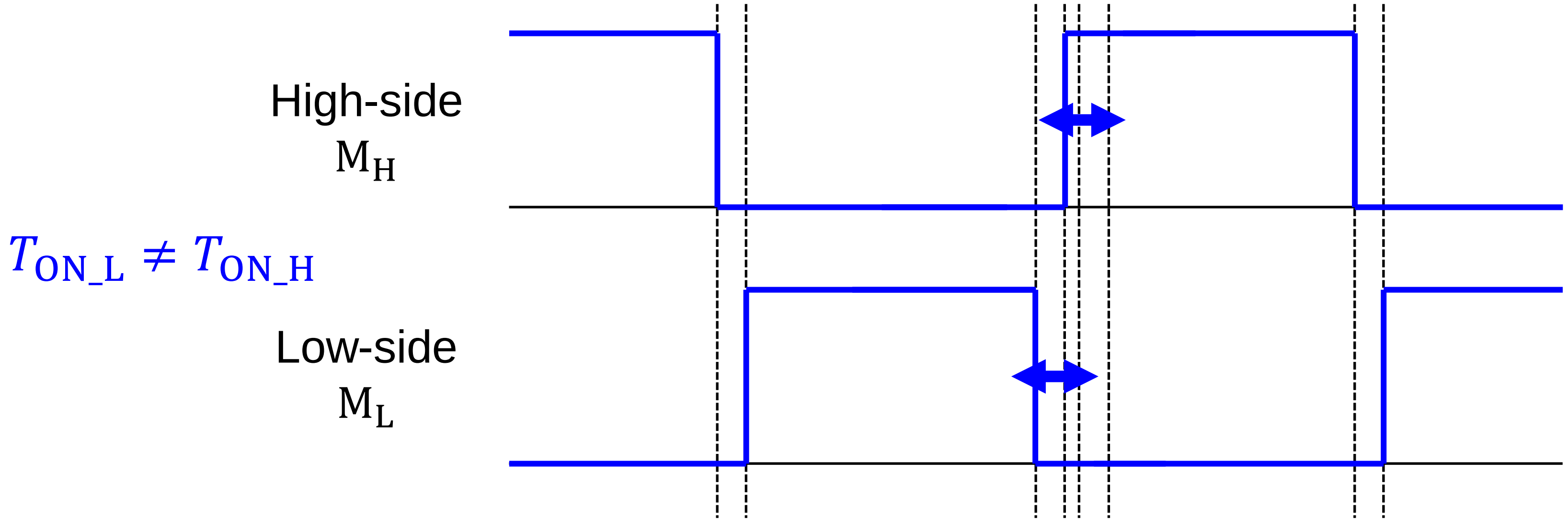
Conventional Duty Ratio Compensation Method

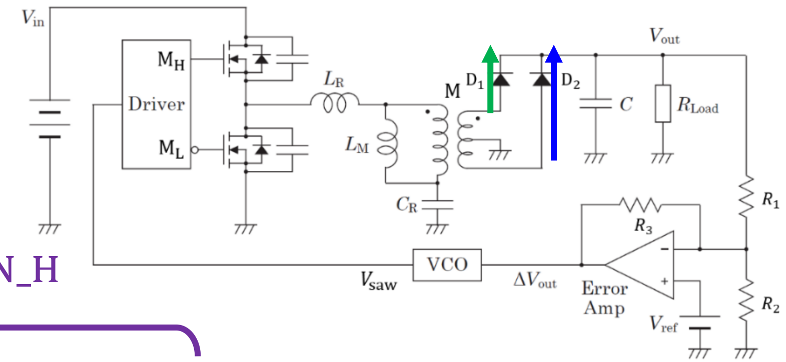


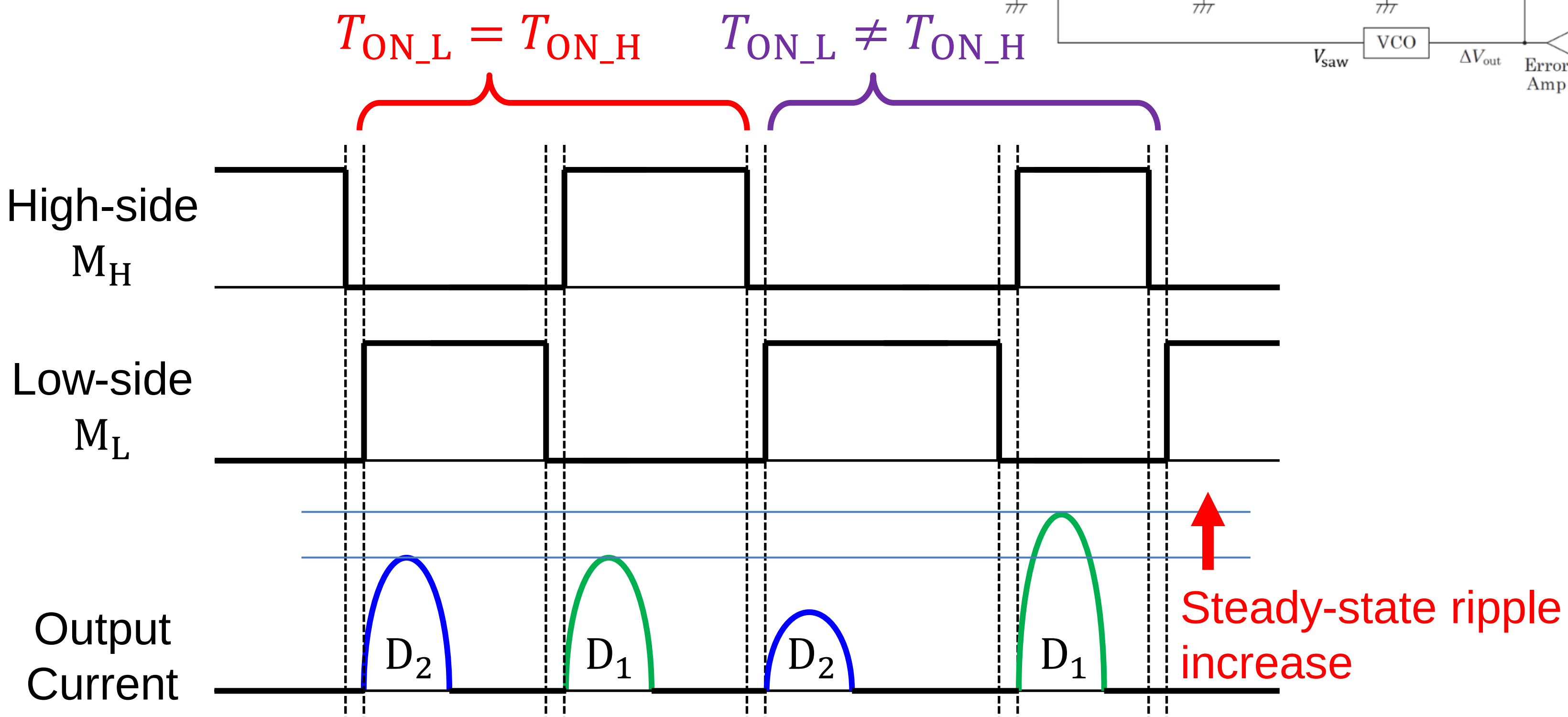
Conventional method:

- Duty ratio modulation
- Synchronization to SW frequency f_{sw} modulation
- Voltage gain: Constant

$$\text{Duty ratio: } \frac{\text{ON time of High side}}{\text{SW period}}$$

Problem of Duty Ratio Compensation





Output current : D_1-side, D_2-side Unbalance

Steady-state ripple increase ➡ Not effective to ripple suppression

Proposal: Deadtime Compensation

Conventional:

Duty ratio compensation

High-side M_H

$T_{ON\_L} \neq T_{ON\_H}$

Low-side M_L

Proposed:

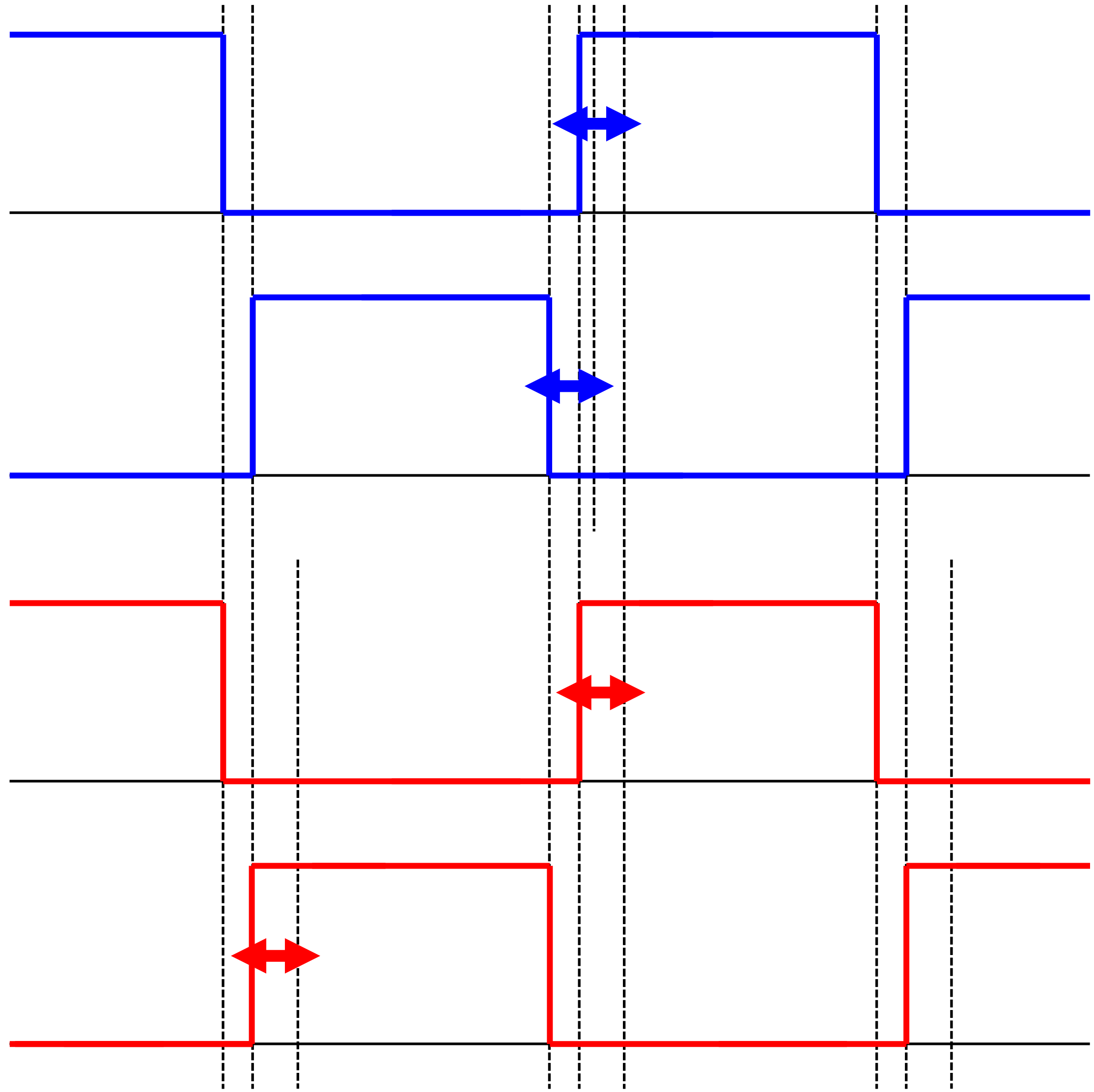
Deadtime compensation

High-side M_H

Always

$T_{ON\_L} = T_{ON\_H}$

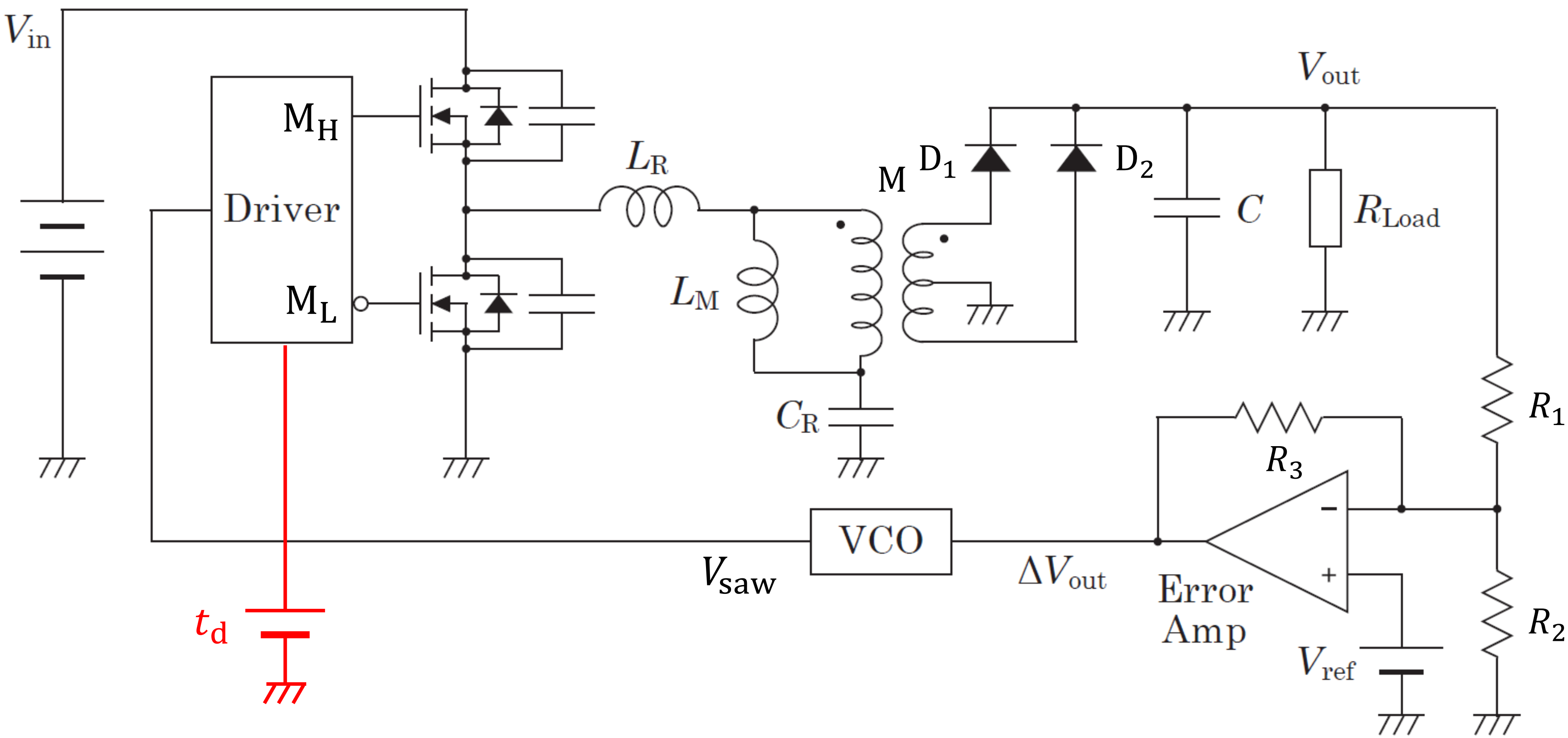
Low-side M_L



Deadtime:

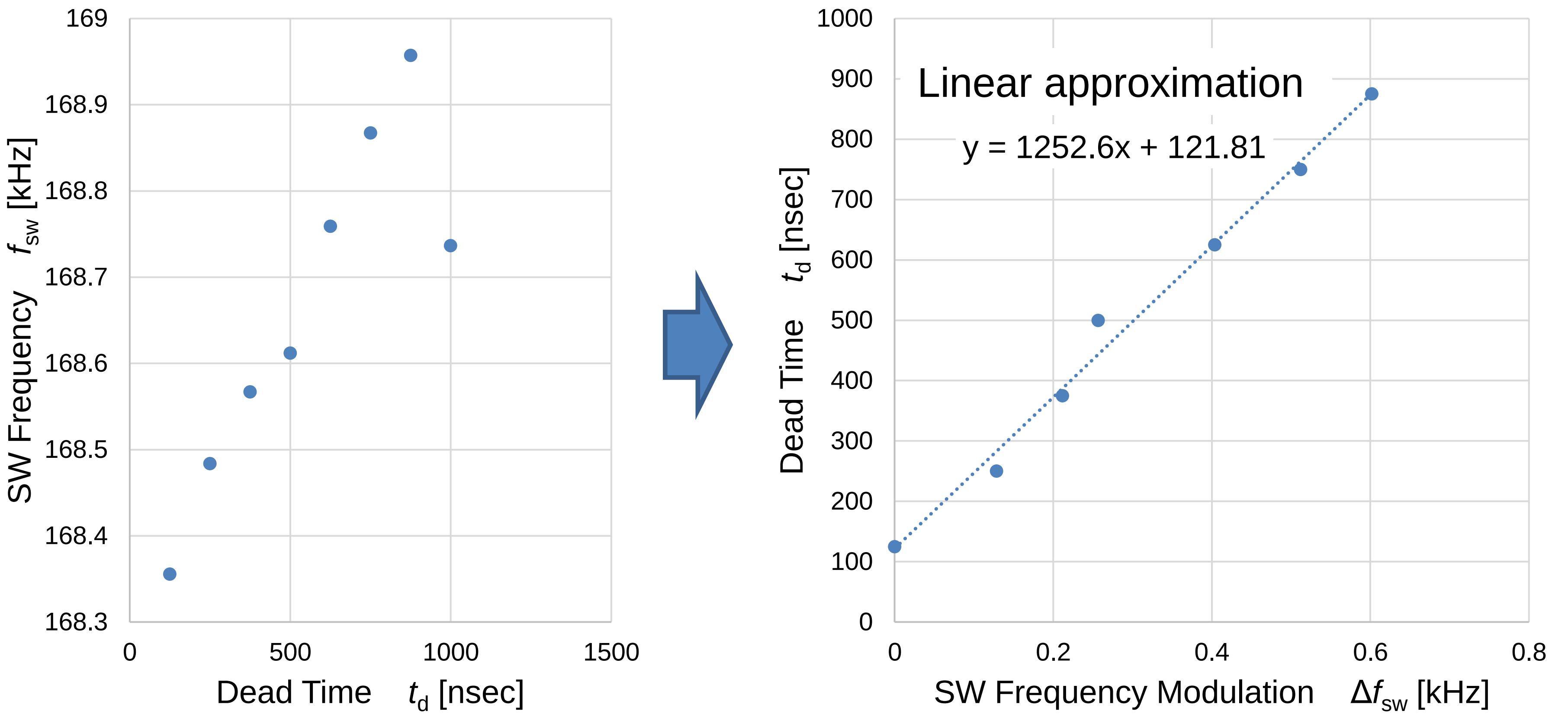
ON-time between High-Side and Low-side

Creation of Deadtime Compensation Function



- Simulate with parameter of dead-time
- Obtain SW frequency
  from steady state error amp. output ΔV_{out}

Deadtime Compensation Function



SW frequency modulation Δf_{SW}

Δf_{SW} - t_d relationship ➡ Deadtime compensation function

$$t_d = 1252.6\Delta f_{SW} + 121.81 \quad [\text{nsec}]$$

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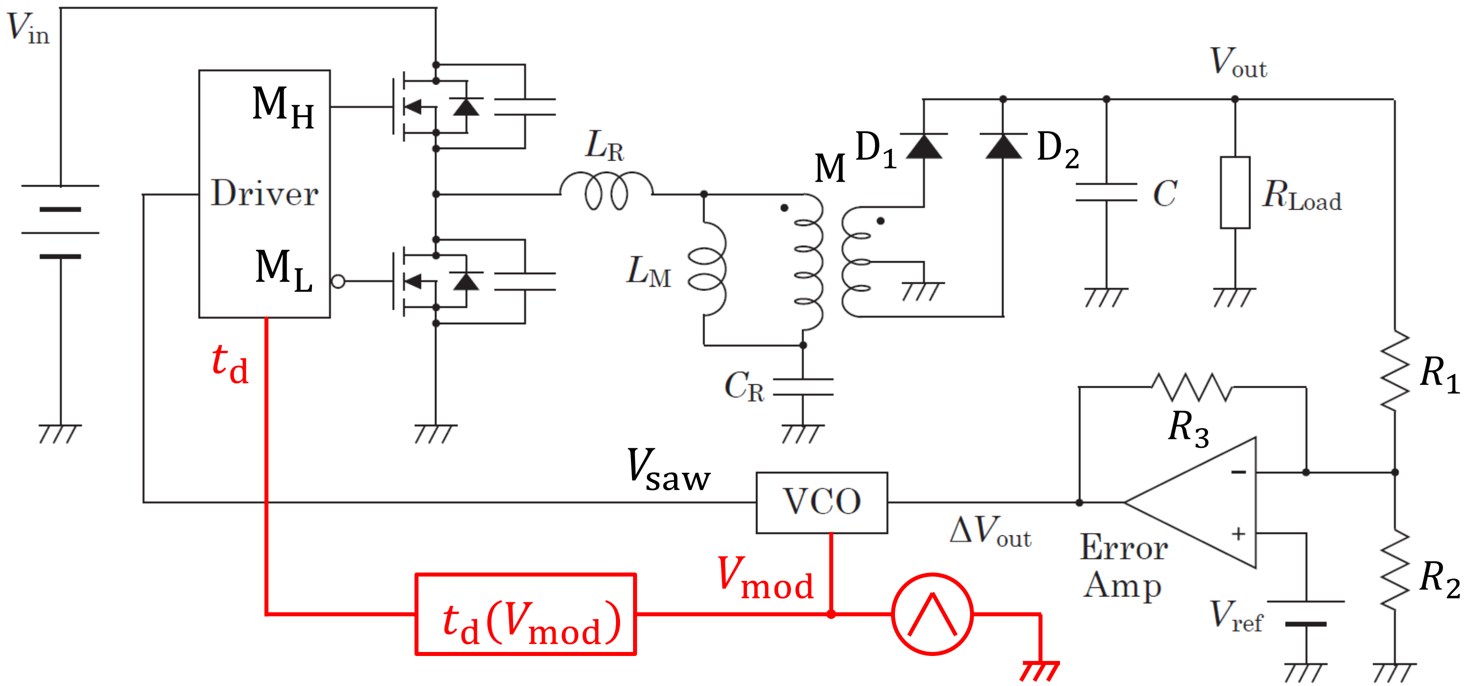
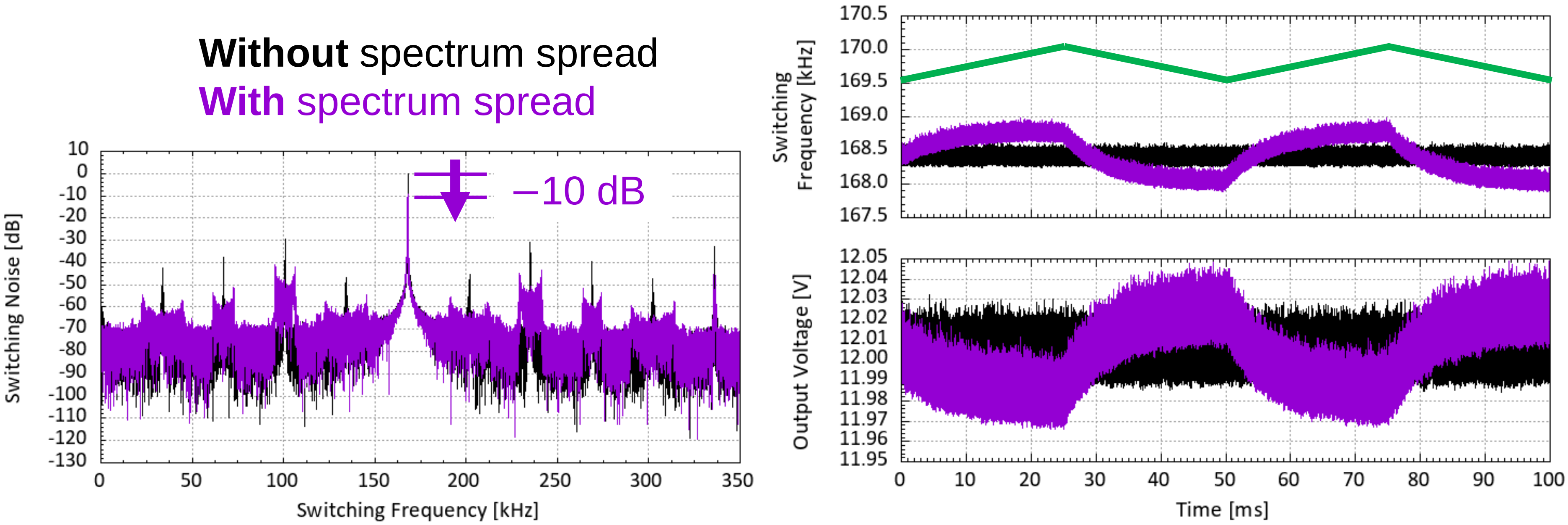
Simulation Circuit and Condition



Parameter	Value	Parameter	Value
Input Voltage V_{in}	DC 400 V	Excitation Inductance L_M	250 μH
Output Voltage V_{out}	12 V	Resonant Inductance L_R	48 μH
Load Resistance R_{Load}	6 Ω	Resonant Capacitor C_R	13 nF
Modulation Sensitivity	1 kHz/V	Transformer Ratio	12 : 1

Simulation Result (Spectrum Spread)



SW frequency modulating: 700 Hz   SW noise spectrum: −10 dB
Modulation signal: Triangular wave 2.14 V

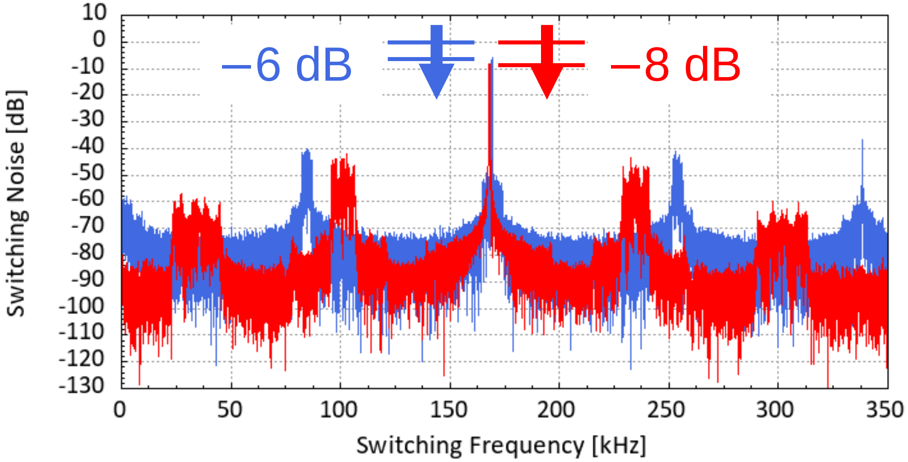
Output voltage ripple

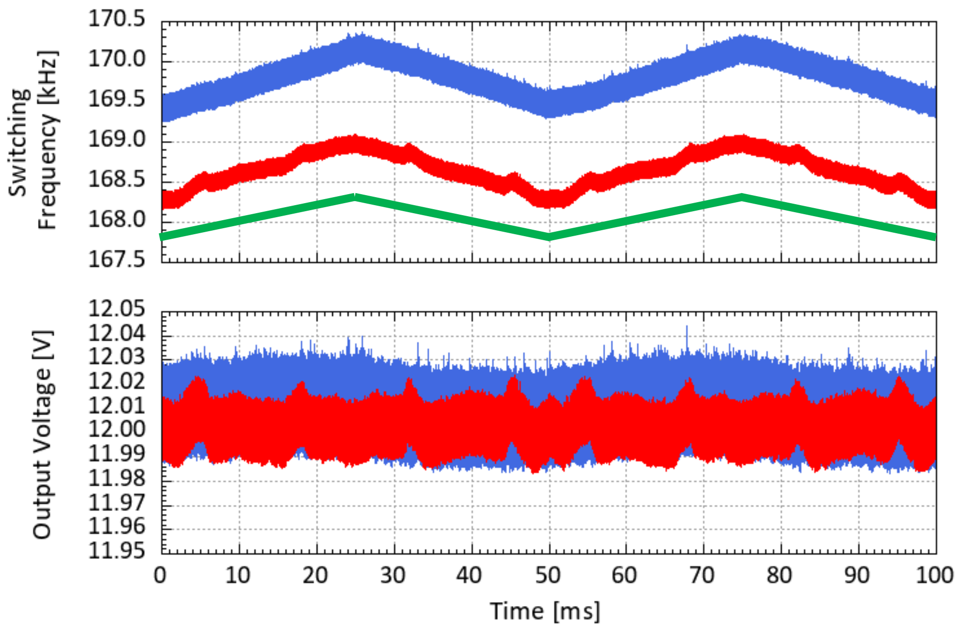
Without spread: 40 mV steady state
With spread: 35 mV steady state + 45 mV modulation

Spectrum spread ⇒ Ripple increase

Simulation Result (Ripple Compensation)

Duty ratio compensation
Deadtime compensation





SW frequency modulating: 700 Hz SW noise spectrum: –6 dB, –8 dB
Modulation signal: Triangular wave 0.495 V, 0.72 V

Output voltage ripple

Duty ratio compensation: 40 mV steady state + 12 mV modulation

Deadtime compensation: 28 mV steady state + 12 mV modulation

Deadtime compensation ⇒ further suppression

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Conclusion

EMI reduction with spread spectrum
for LLC resonant converter

- Output voltage ripple reduction

Conventional:
Duty ratio compensation
Proposed method:
Deadtime compensation

- Simulation verification

SW noise spectrum reduction: –10 dB
Modulation ripple:
Only spectrum spread 35 mV + 45 mV
With duty ratio compensation 40 mV + 12 mV
With deadtime compensation 28 mV + 12 mV

Final Statement

Two problems (EMI, ripple) are solved simultaneously.

Thank you for your kind attention