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群馬大学
GUNMA UNIVERSITY

EMI Reduction and Output Ripple Improvement of Switching DC-DC Converters with Linear Swept Frequency Modulation

Minh Tri Tran*, Natsuko Miki, Yifei Sun
Yasunori Kobori and Haruo Kobayashi

Kobayashi Laboratory

Gunma University, Japan

Outline

1. Research Background
    - Applications of Switching Power Supply
    - Basic Switching Converter
2. Conventional EMI Reduction
    - EMI Reduction with Frequency Modulation
    - Enlargement of Output Ripple
3. Proposed EMI Reduction with Ripple Improvement
    - Linear Swept Frequency Modulation
    - Simulation Results
4. Conclusions

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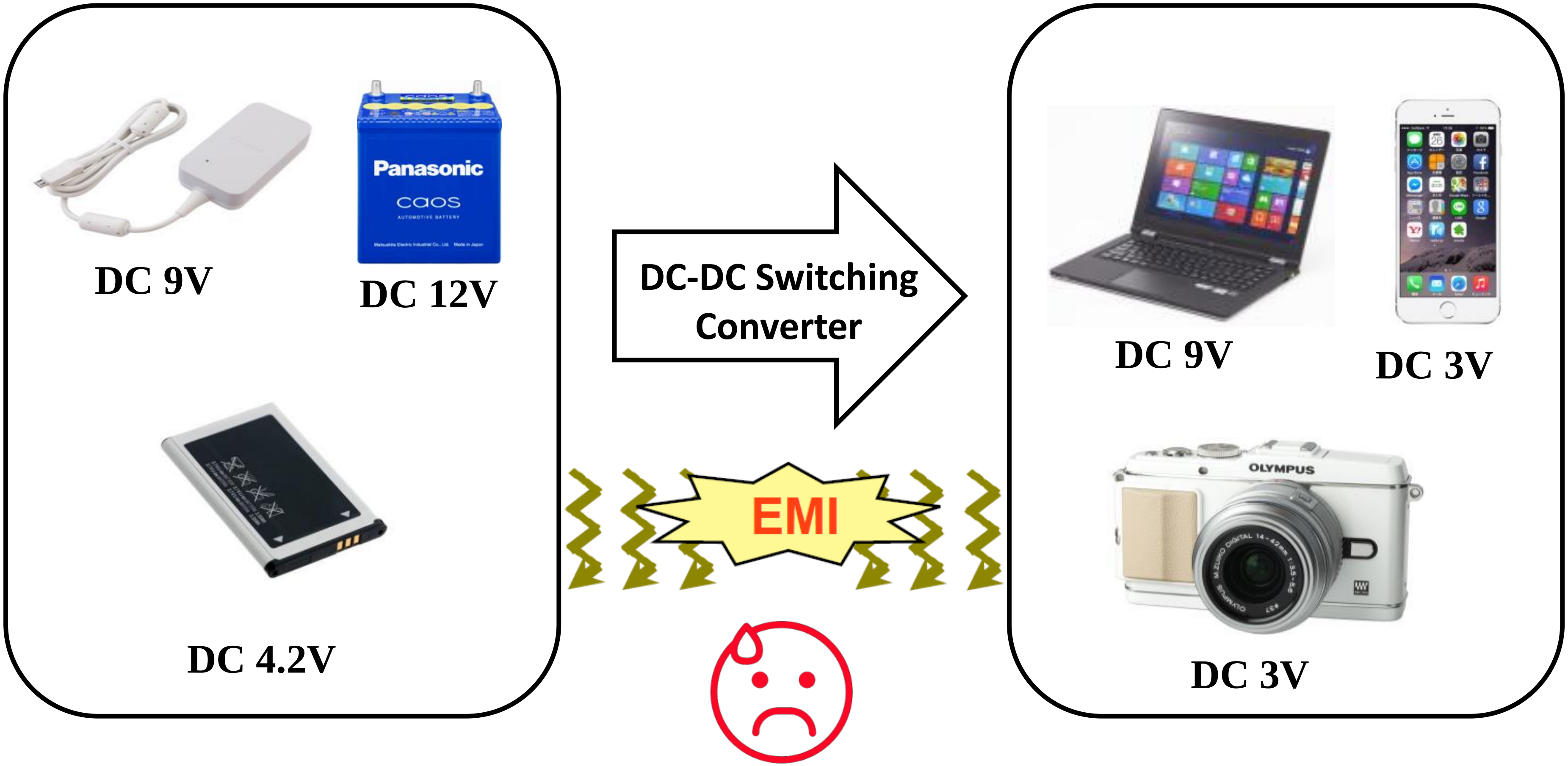
1. Research Background

Applications of Switching Power Supply



EMI: Electro Magnetic Interference

1. Research Background

Research Objective

Objective

Development of power supply with

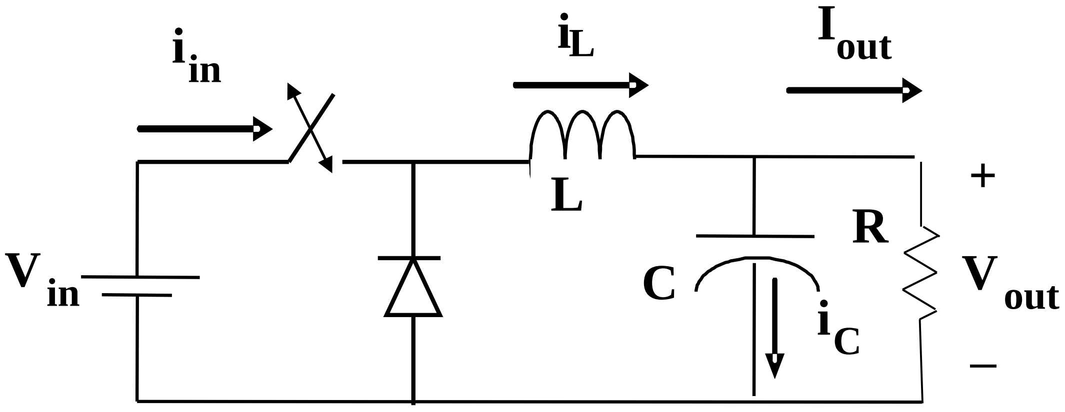
- ○ Fast Response & High Efficiency
- ○ Low EMI Noise
- ○ Small Output Ripple

Approach

- ○ EMI Noise Reduction with Frequency Modulation
- ○ PWM Duty Compensation in SAW Generator

1. Research Background

Basic Switching Converter



Basic Switching Converter

Merits
- Downsizing
- Light Weight
- High Efficiency

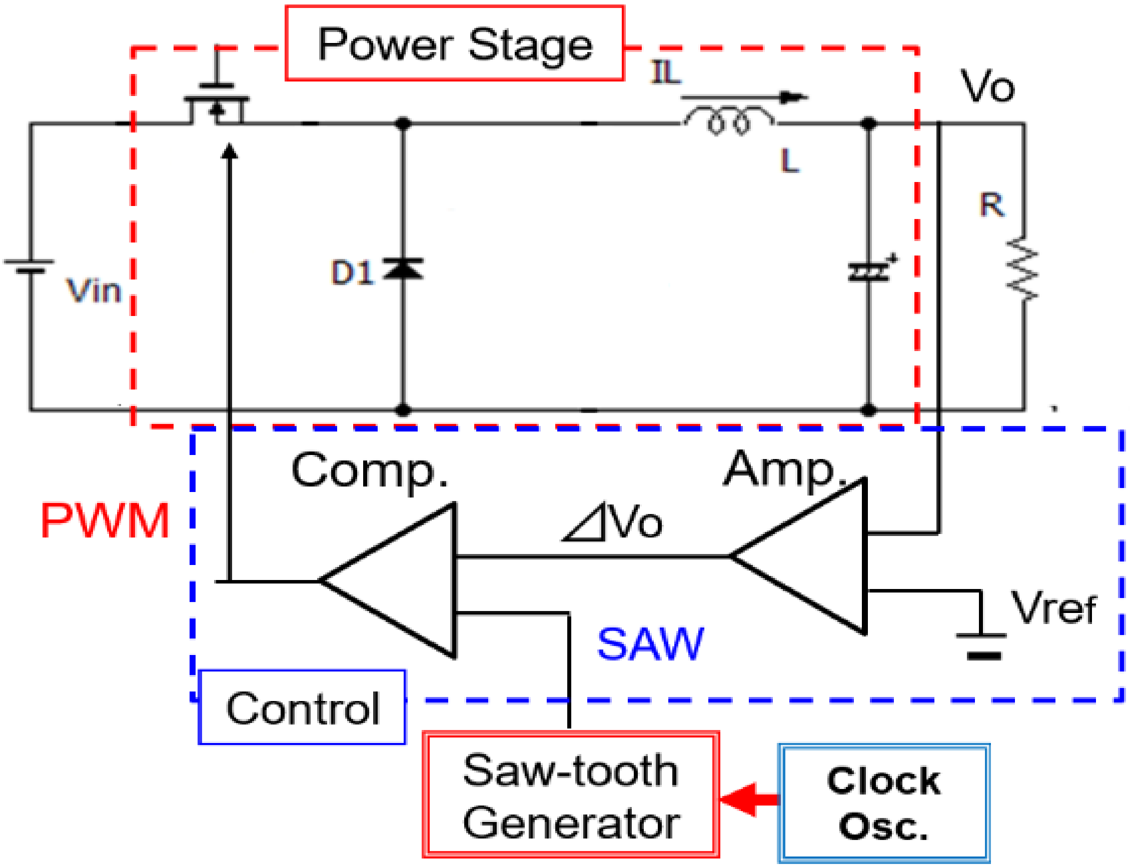
High Efficiency Switching
➔Reduce energy consumption
➔Extend battery operating time
➔Minimize costs of systems

Demerits
- Output Ripple
- Switching noise
- Harmonic noise

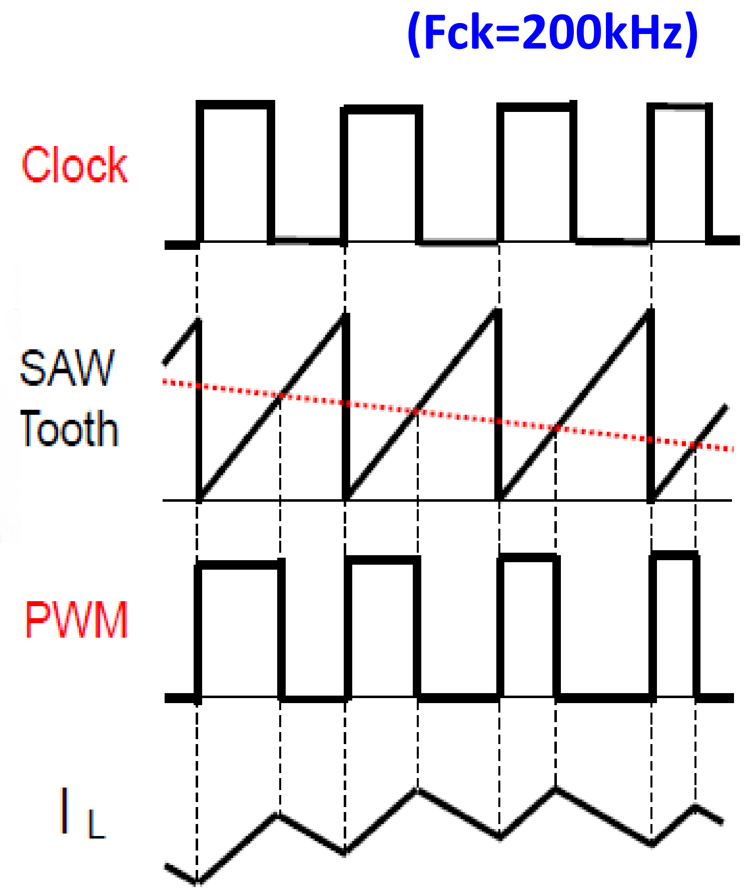
1. Research Background

Voltage Feedback Control

➔ **Small Output Ripple & Quick Response**



Switching Converter



Waveforms

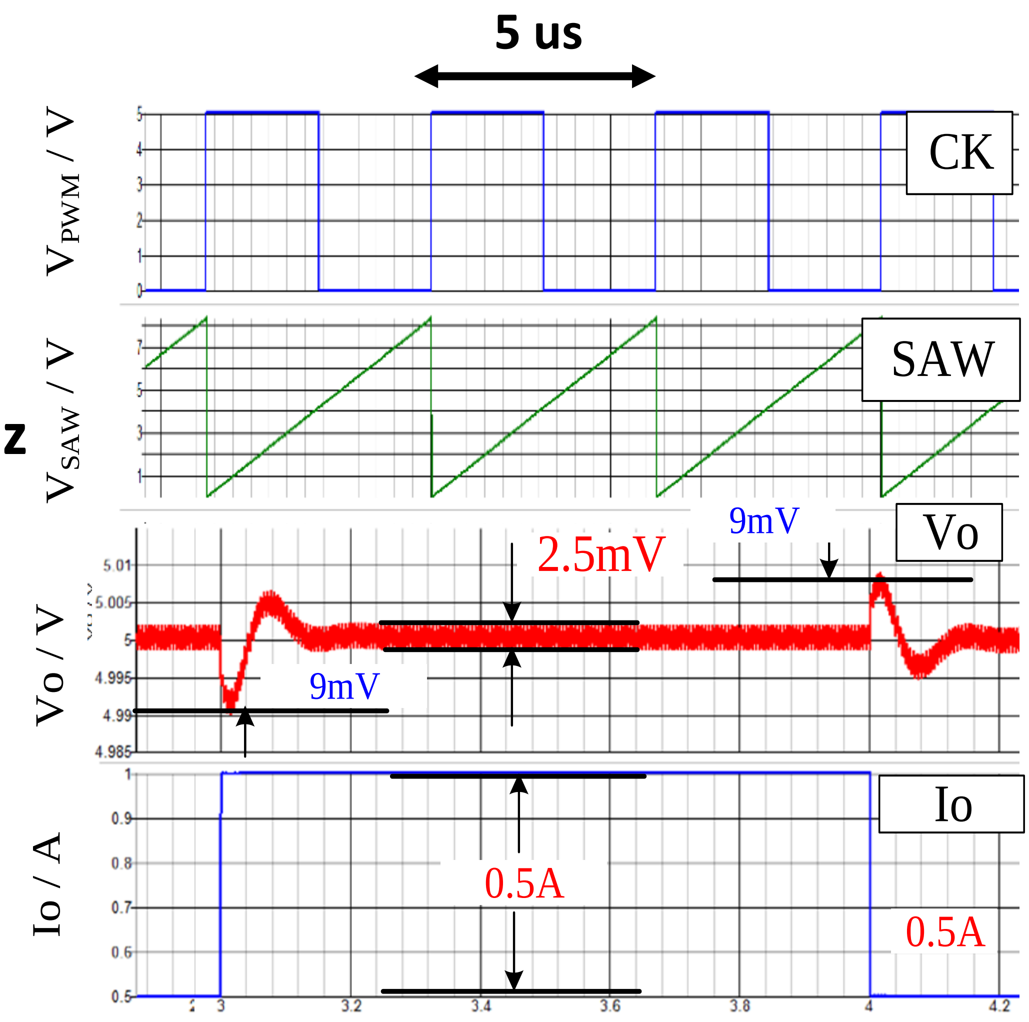
1. Research Background

Simulation Results of Basic Switching Converter

Operation conditions:

- Input Voltage (Vin): 12V
- Output Voltage (Vo): 5.0V
- Output Current (Io): 0.5A
- Clock Frequency (Fck): 200kHz
- Current Step (⊿Io) ： 0.5A

- Output Ripple: 2.5mV$_{pp}$
- Over-shoot: 9.0mV
- Under-shoot : 9.0mV



Simulation Results

1. Research Background

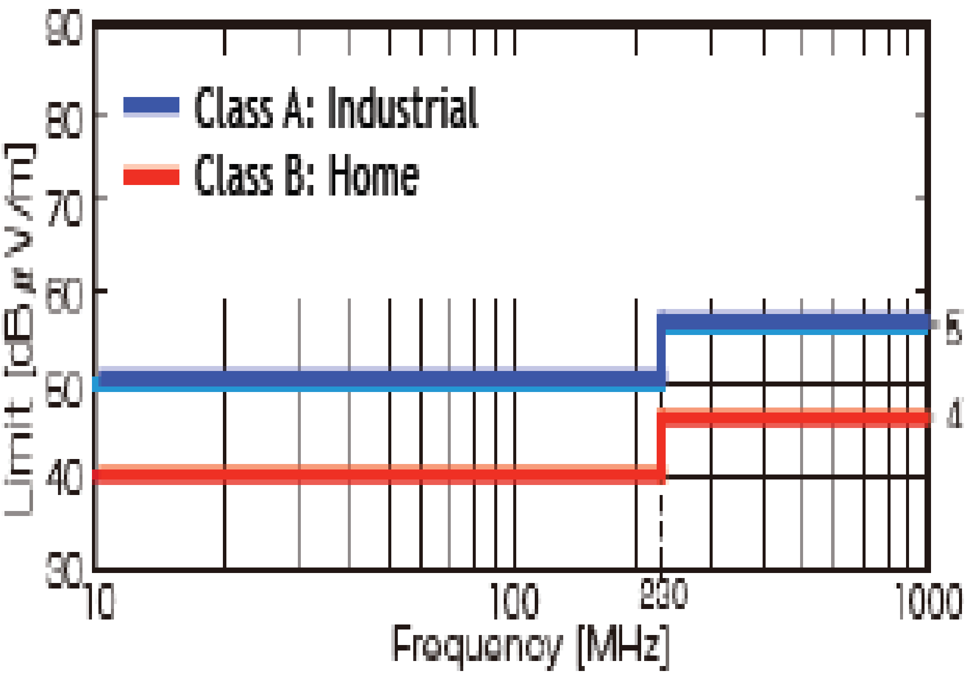
Spectrums of EMI Noise

○ **Spectrums of PWM pulse**

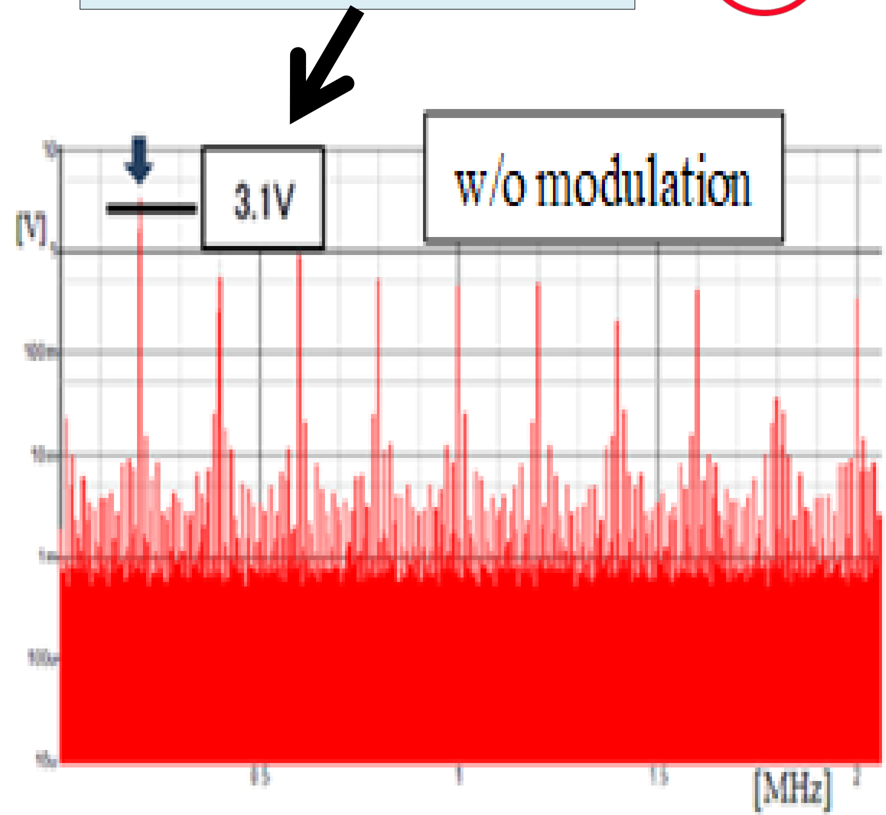
・**PWM noise ＞ Conduction noise**

➔ **Spectrum < Standard Level**

Spectrum: 3.1V



EMI Standard in Japan



Spectrums of PWM

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2. Conventional EMI Reduction

EMI Reduction with Frequency Modulation

VCO : Voltage Controlled Oscillator

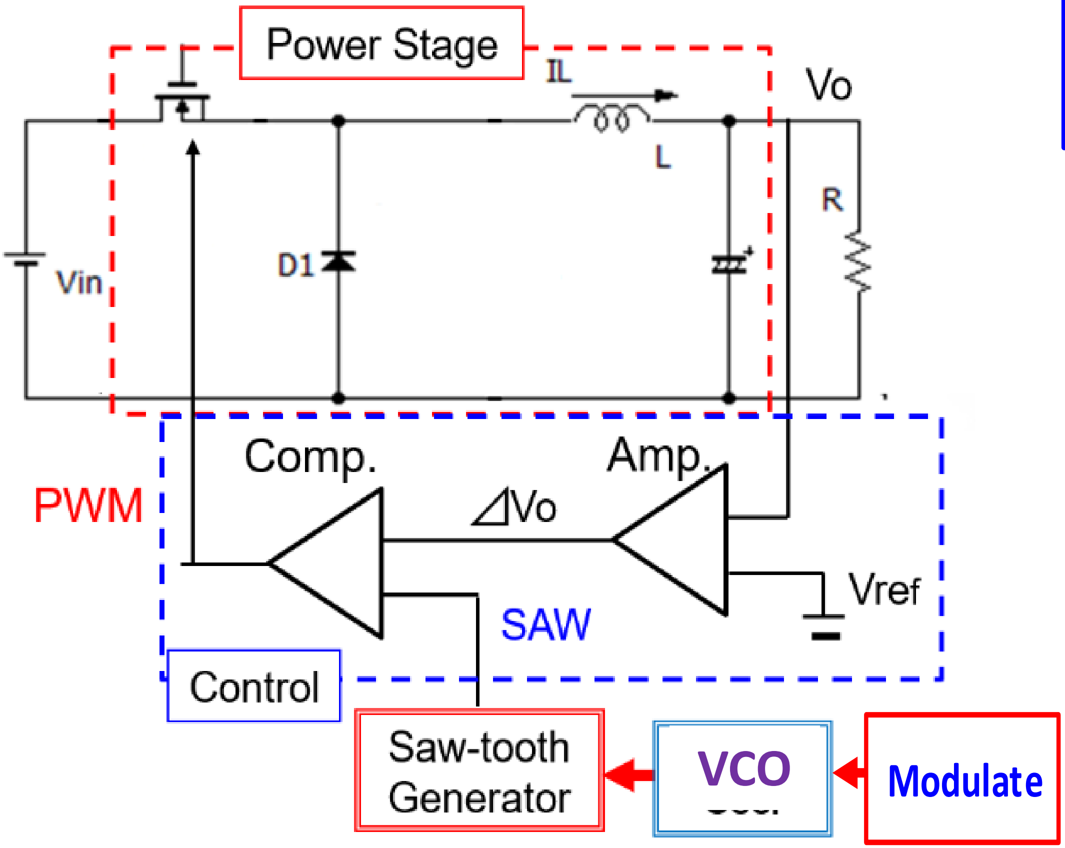
VCO Output = Clock Frequency (*Fck*)

$$F_{ck} = K \times \left(V_b + V_m\right)$$

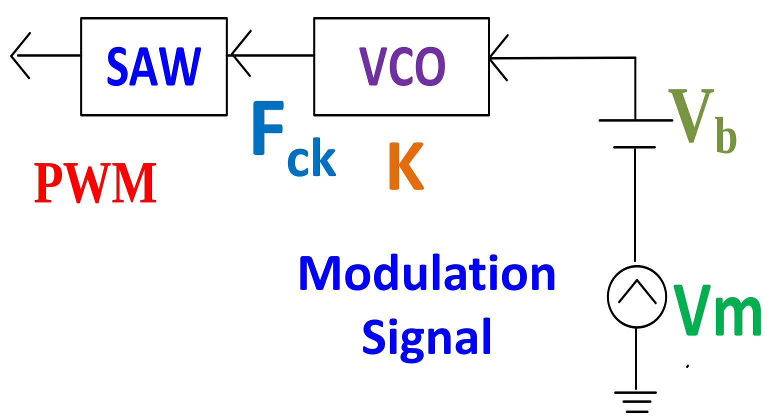
***K*: sensitivity of VCO**

V_b: bias voltage

V_m: modulation voltage



Circuit with Frequency Modulation



Frequency Modulation

2. Conventional EMI Reduction

Spread Spectrum of PWM Pulse

Spread Spectrum

w/o EMI Reduction

Noise level:

➔ Fck : V_{Fck} = 3.1V

➔ 3Fck : V_{3Fck} = 1.0V

Spread Spectrum

with EMI Reduction

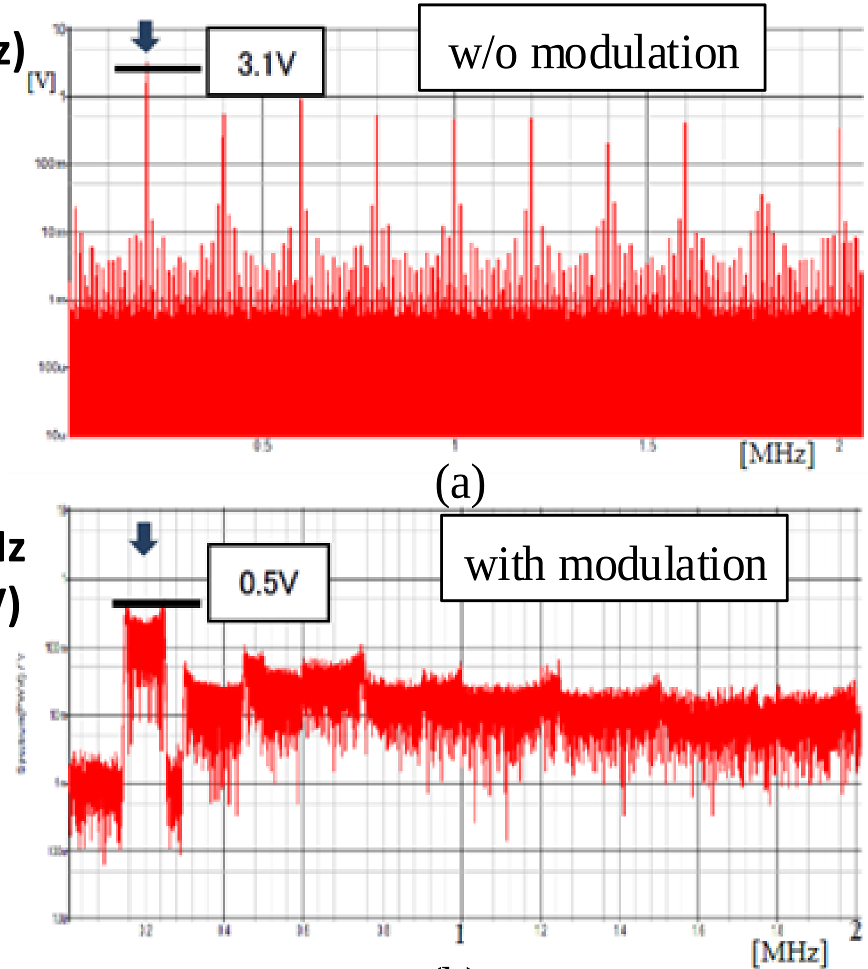
Noise level:

➔ Fck : V_{Fck} = 0.5 V (-16 dB)

➔ 3Fck : V_{3Fck} = 0.06V (-24dB)

(Fck=200kHz)

(Fm=2.0kHz , Vm=2.0V)



(a)

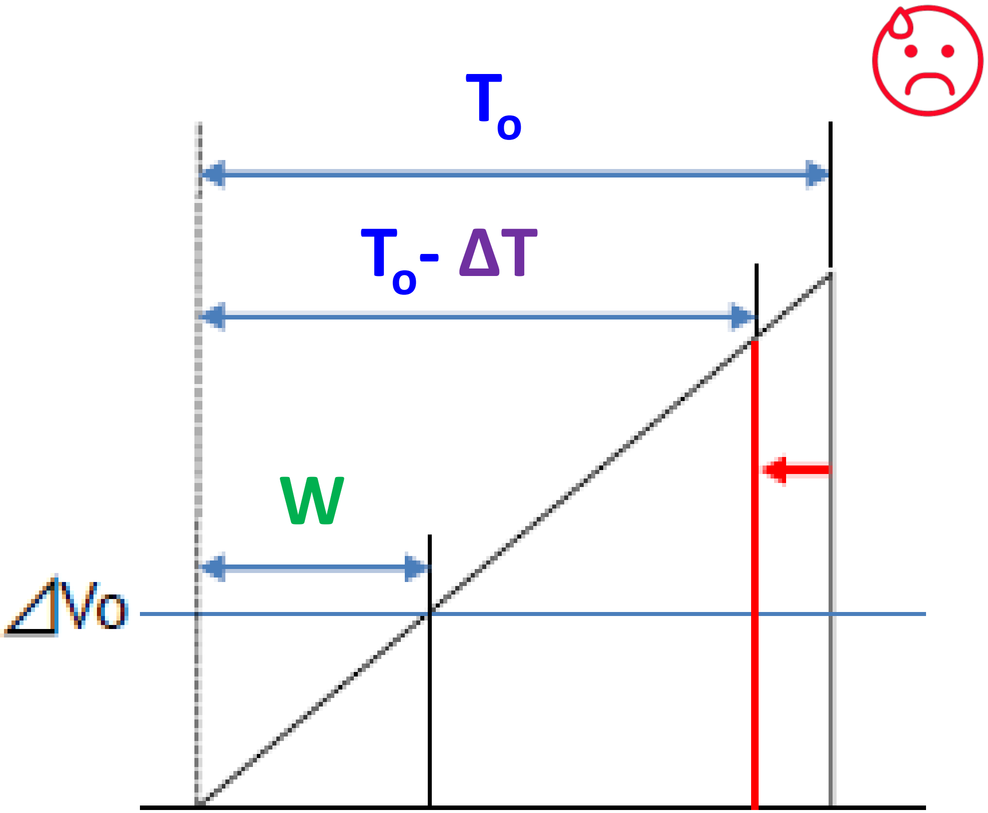
(b)

Spread Spectrum of PWM

2. Conventional EMI Reduction

PWM Duty variation (⊿D) with SAW Signal

Modified duty > Original duty



Duty Variation of SAW

Modified duty (D'):

$$D' = \frac{W}{T_o - \Delta T}$$

Original duty (Do):

$$D_o = \frac{W}{T_o}$$

Relation between D' & D_o

$$\frac{D'}{D_o} = \frac{\frac{W}{T_o - \Delta T}}{\frac{W}{T_o}} = 1 - \frac{\Delta T}{T_o}$$

2. Conventional EMI Reduction

Enlargement of Output Ripple

Duty variation (⊿D) ➔ Output Ripple Enlargement

(Fm=2.0kHz, Vm=2.0V, sine wave)

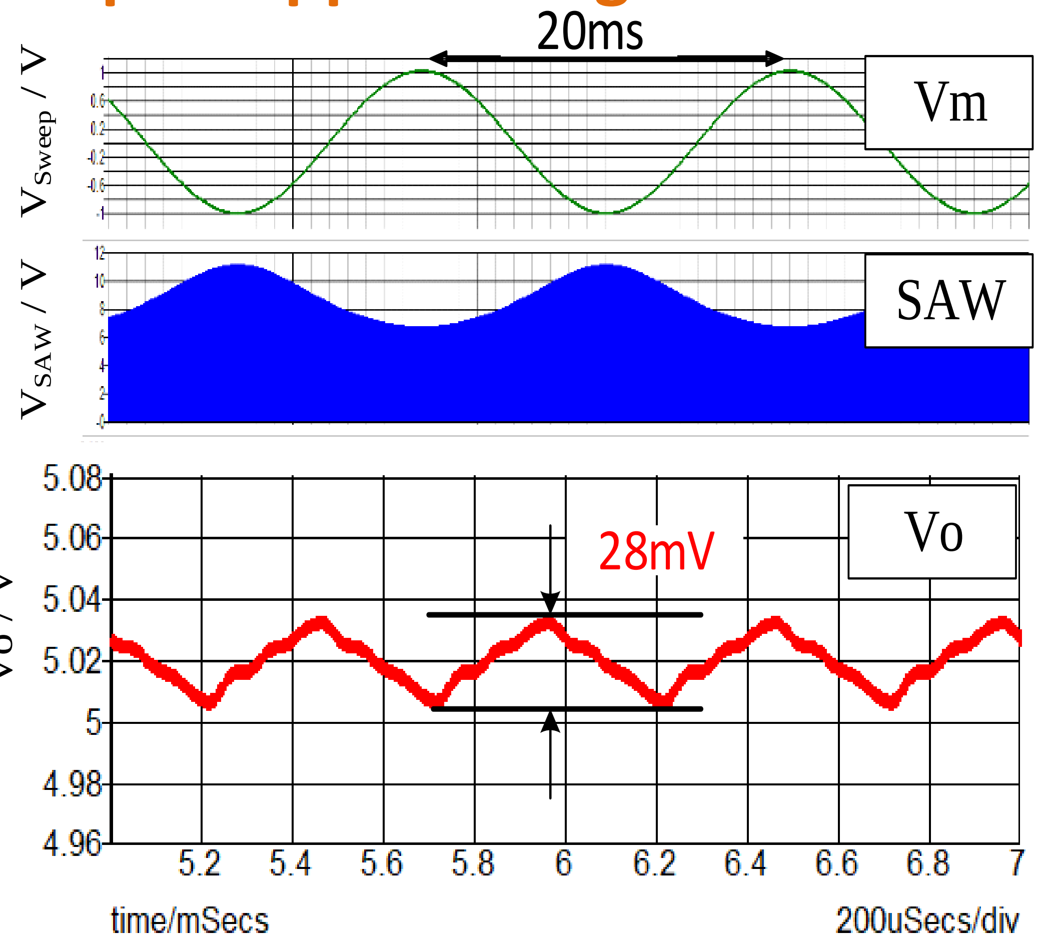
Output Ripple Enlargement

2.5 mV ⇒ 28.0 mV

(More than 10 times!)

Application Requirement

➔ Decrease Output Ripple with EMI Reduction



Waveforms with Modulation

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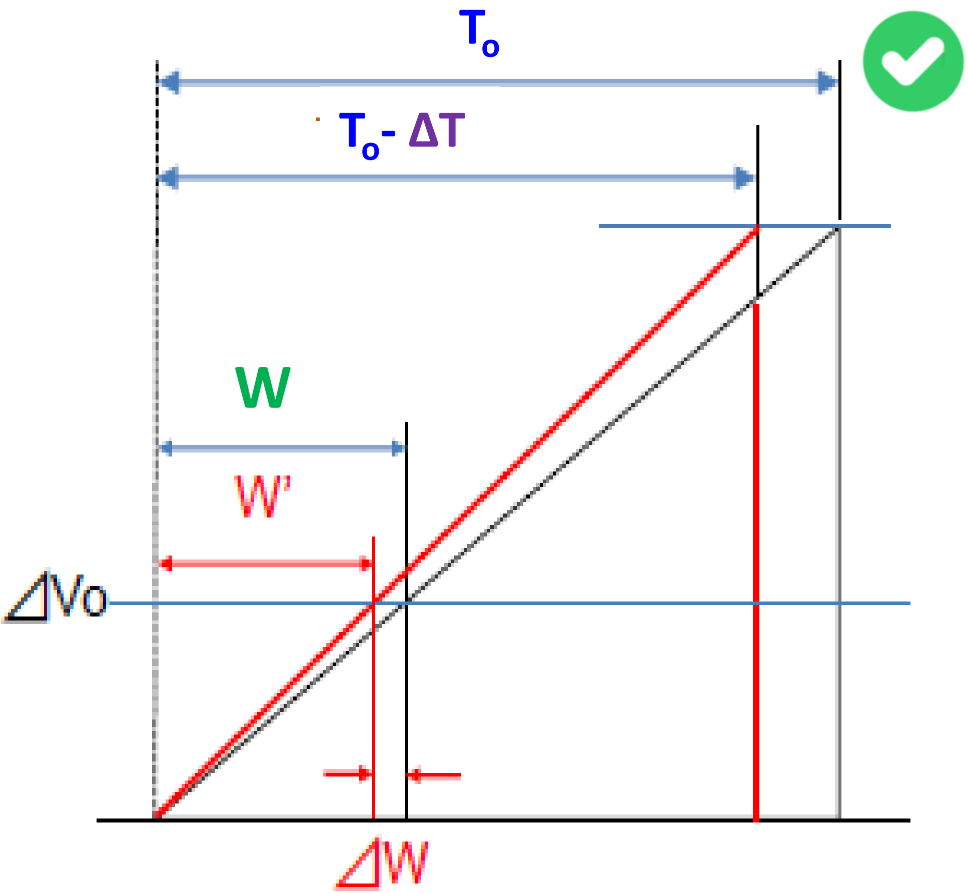
3. Proposed EMI Reduction with Ripple Improvement

Duty Compensation of SAW

Compensated duty = Original duty



Duty Compensation of SAW

Compensated duty (D_{comp}):

$$D_{comp} = \frac{W'}{T_o - \Delta T} = \frac{W - \Delta W}{T_o - \Delta T}$$

Original duty (Do):

$$D_o = \frac{W}{T_o}$$

Relationship between D_{comp} & D_o

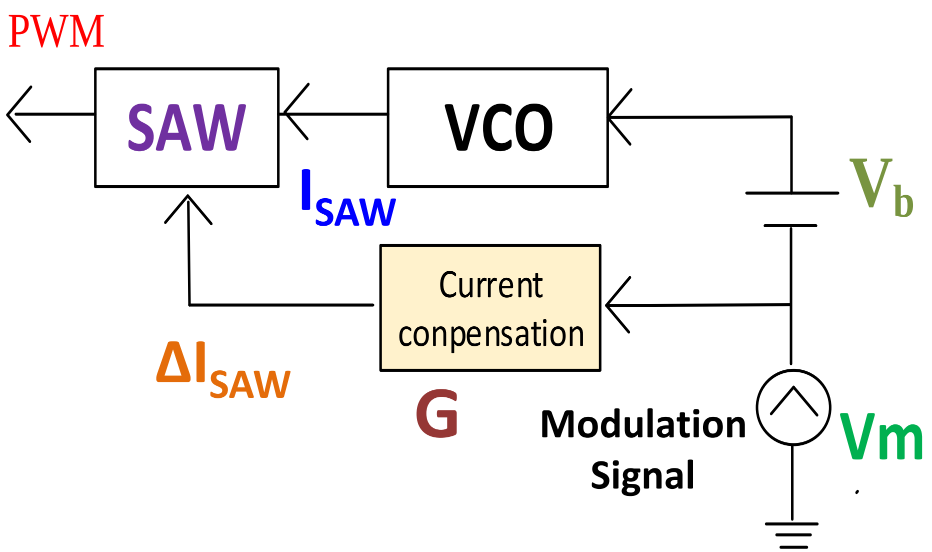
$$\frac{D_{comp}}{D_o} = \frac{\dfrac{W - \Delta W}{T_o - \Delta T}}{\dfrac{W}{T_o}} = \frac{\left(1 - \dfrac{\Delta W}{W}\right)}{\left(1 - \dfrac{\Delta T}{T_o}\right)} = 1$$

3. Proposed EMI Reduction with Ripple Improvement

Linear Swept Frequency Modulation

Conductance G:

$$G = \frac{I_{SAW}}{V_b}$$



SAW Current Compensation

Current compensation ΔI_{SAW} :

$$\Delta I_{SAW} = G \times V_m$$

Relationship between ΔI_{SAW}&I_{SAW}:

$$\frac{\Delta I_{SAW}}{I_{SAW}} = \frac{V_m}{V_b}$$

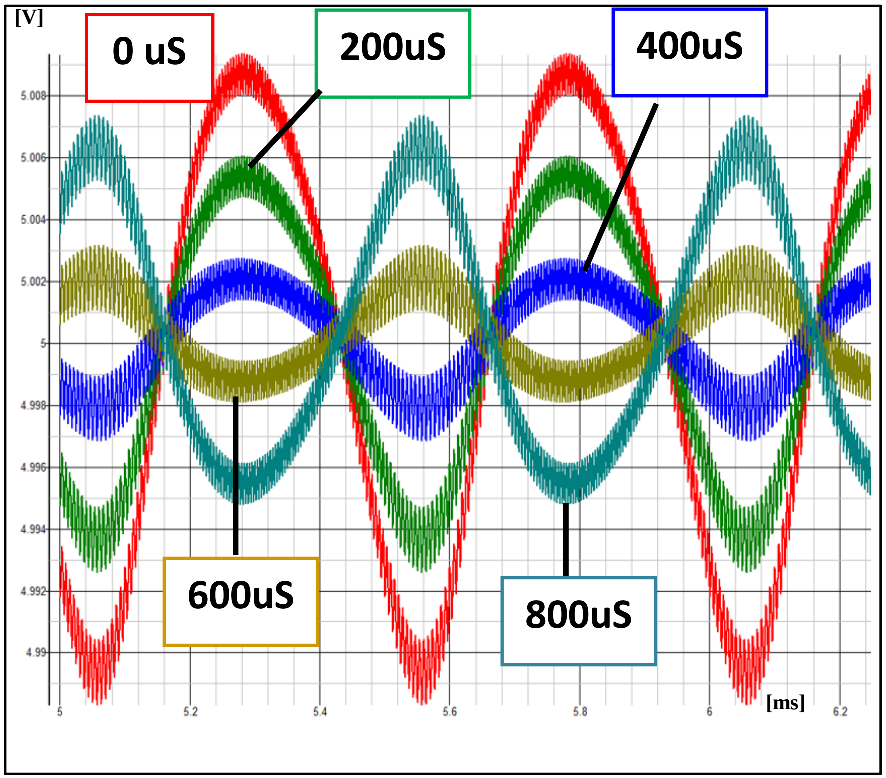
$$\Rightarrow \frac{\Delta I_{SAW}}{V_m} = \frac{I_{SAW}}{V_b}$$

3. Proposed EMI Reduction with Ripple Improvement

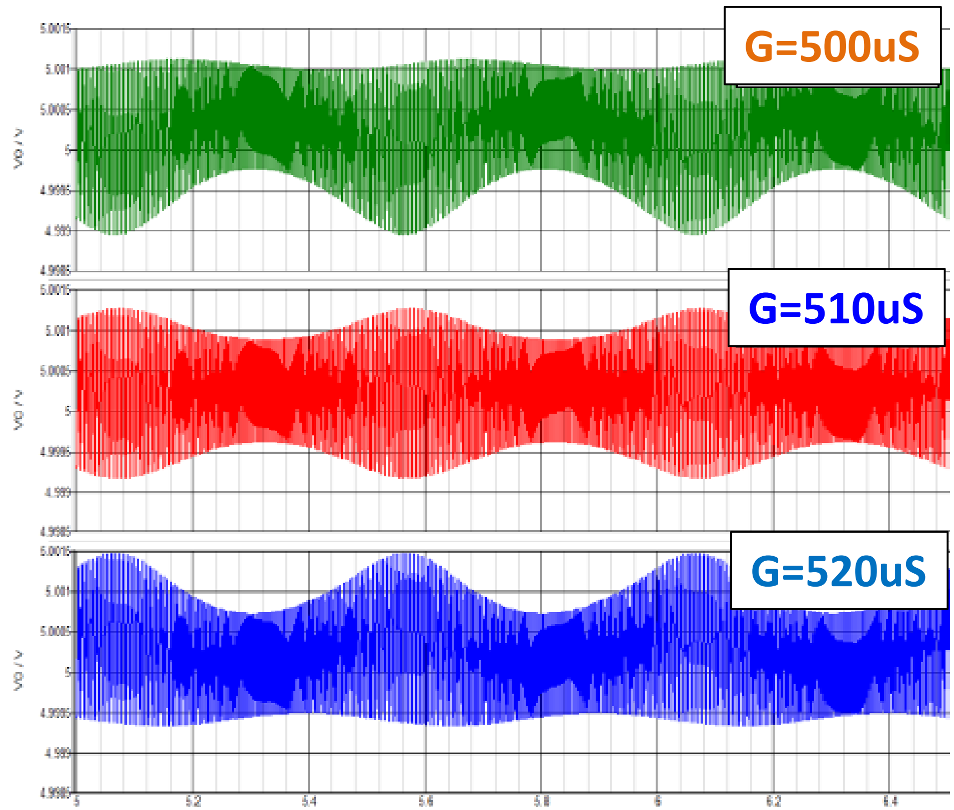
Optimization of Conduction G

Increase G ➔ Decrease ripple

Best conductance: G = 510uS



Ripple with various G (0～ 800uS)



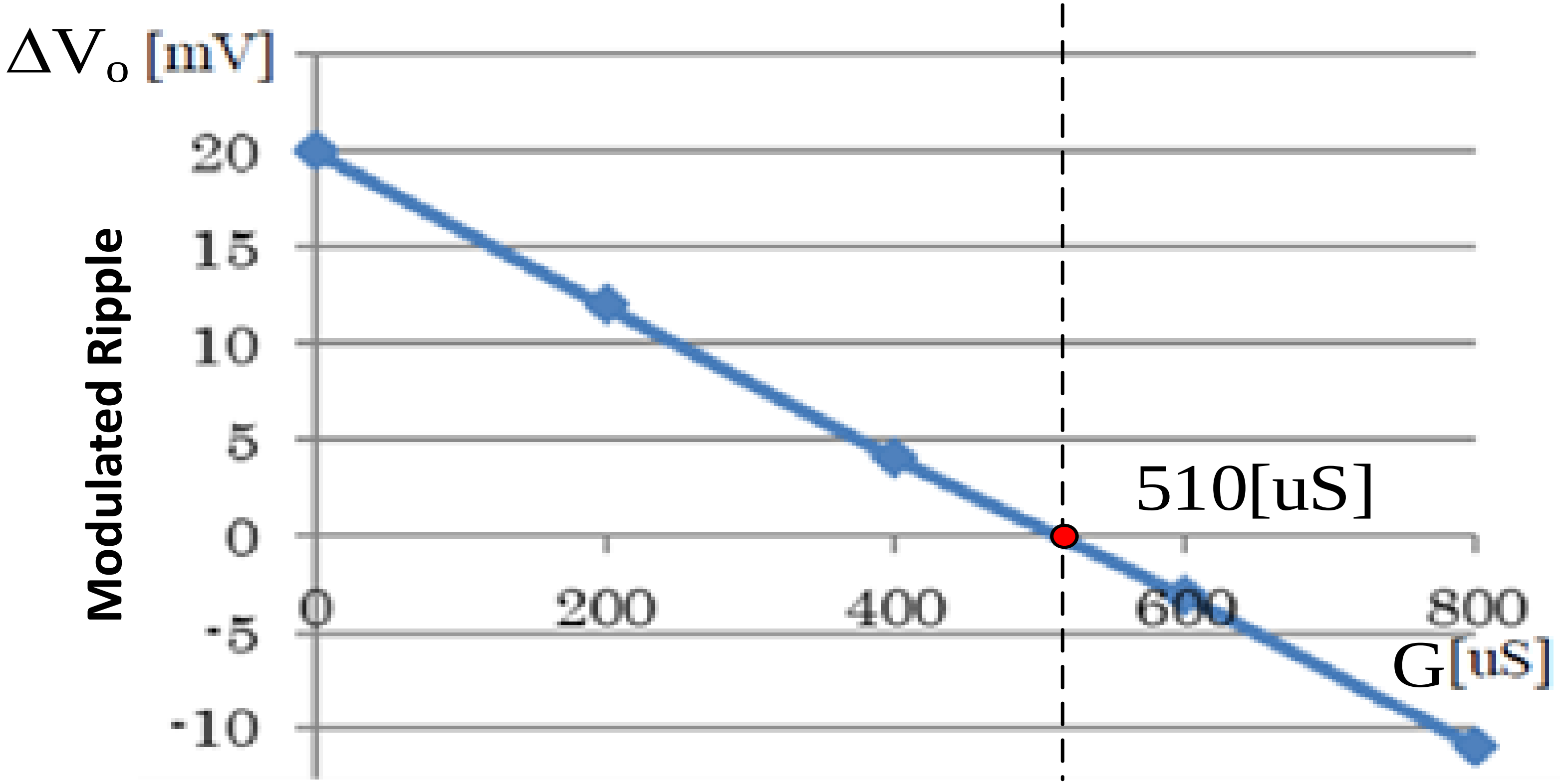
Ripple with various G (500～ 510uS)

3. Proposed EMI Reduction with Ripple Improvement

Conduction G vs Modulated Ripple (V_{MR})

$$V_{MR} = 20 - (31mV/800uS) \cdot G \ [mV]$$

Enlargement of G → Decrement of ΔVo



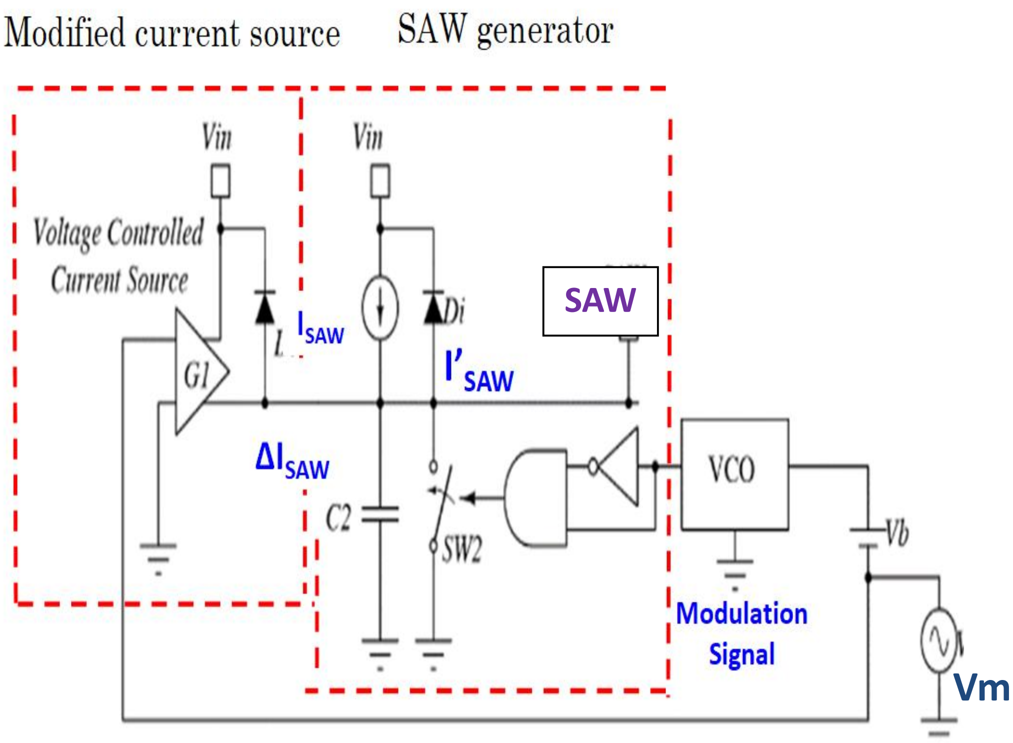
Conduction G vs Modulated Ripple

3. Proposed EMI Reduction with Ripple Improvement

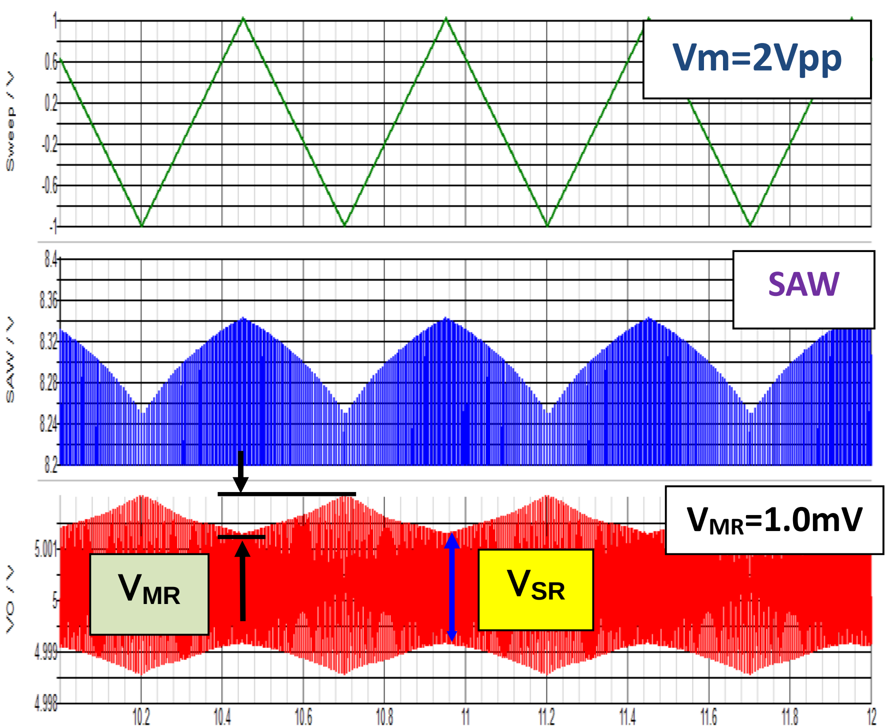
Conduction G vs Output Ripple

- Vm: 2.0Vpp, triangle wave
- G=510uS

Output Ripple
=Modulation Ripple +Switching Ripple
(V_{MR} = 1.0 mV) (V_{SR} = 2.2 mVpp)



Linear Swept Frequency Modulation



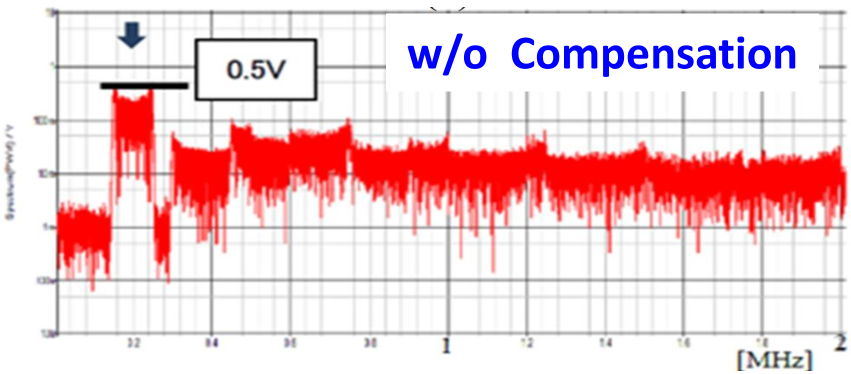
Ripple with G=510 uS

3. Proposed EMI Reduction with Ripple Improvement

Spectrum with Compensation

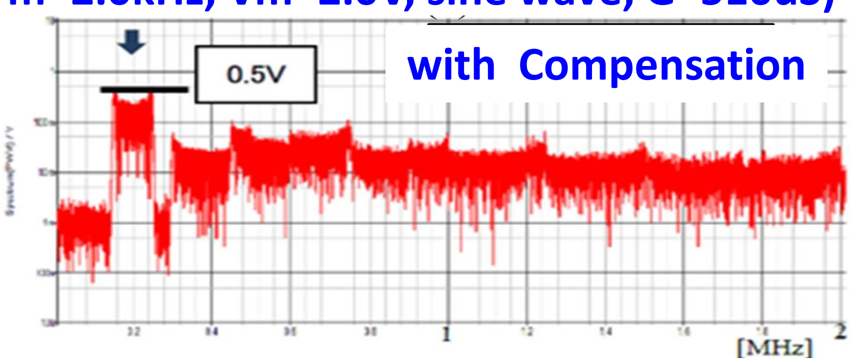
With Current Compensation ➔Fck Spectrum：0.5V (-16 dB Reduction)

(Same as w/o compensation)



(a) Only EMI reduction w/o Compensation

(Fm=2.0kHz, Vm=2.0V, sine wave, G=510uS)

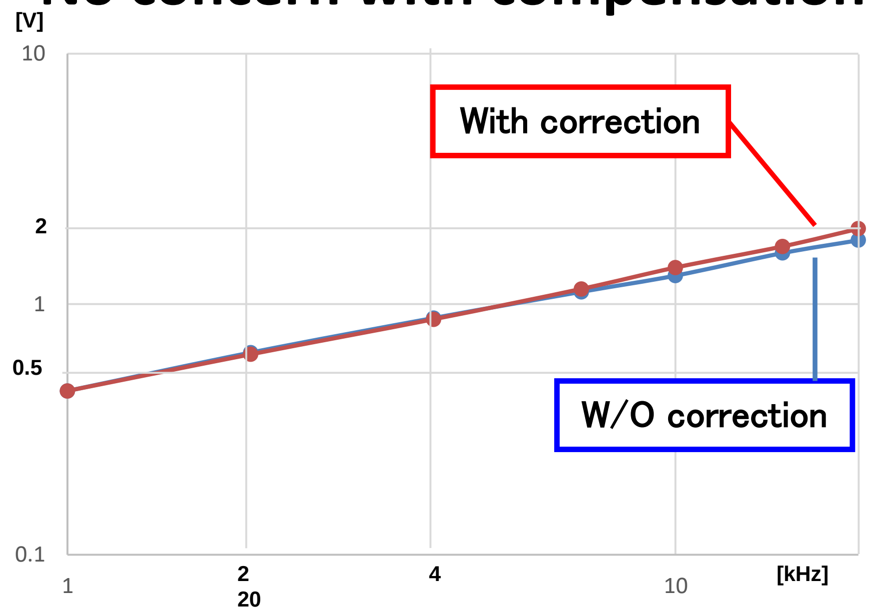


(b) With Compensation

Spectrums w/o & with compensation

Spectrum level vs. Fm

- ∗ Peak level: proportional to Fm
- ∗ No concern with compensation



Spectrum level vs. Fm

3. Proposed EMI Reduction with Ripple Improvement

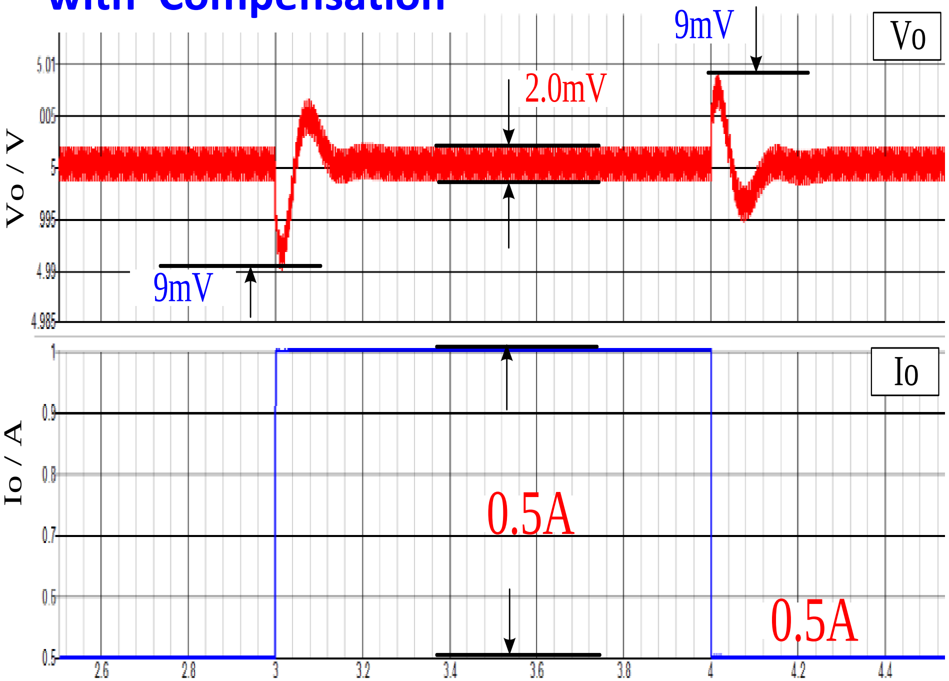
Ripple Improvement with Compensation

With Compensation : 28mV➔ 2mV

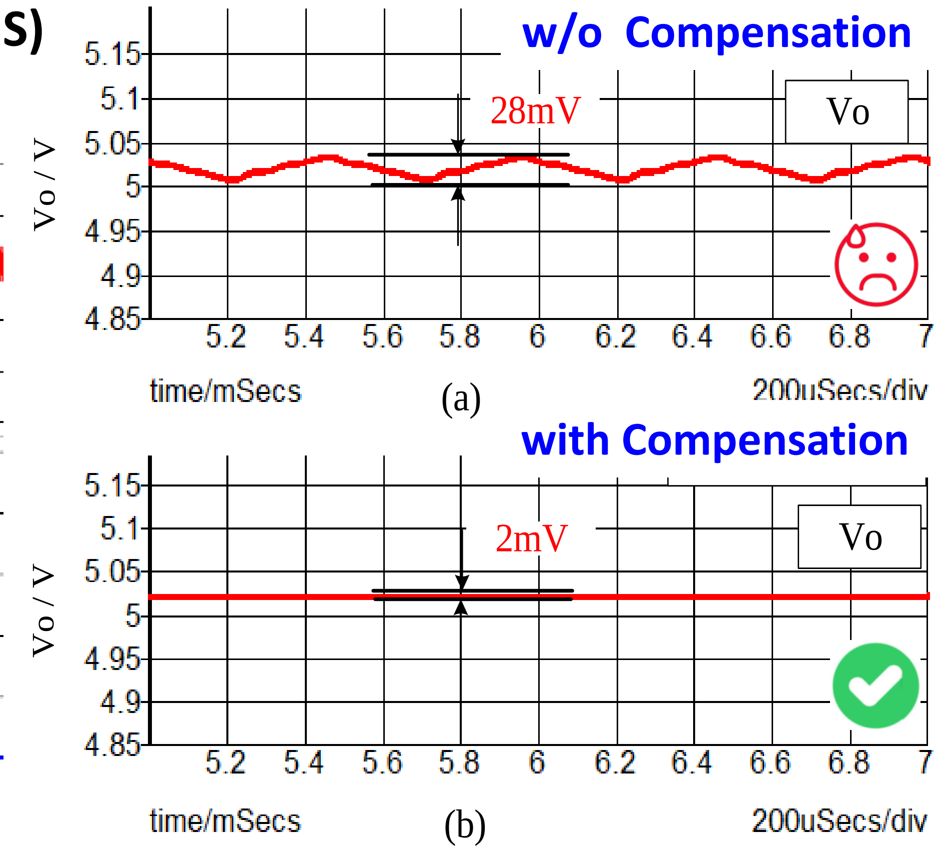
Over/under-shoot: +/- 9mV, ⊿Io= +/- 0.5A

(Fm=2.0kHz, Vm=2.0V, sine wave, G=510uS)

with Compensation



Over/under-shoot & step response



Ripple improvement

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4. Conclusions

DC-DC Switching Converter:

- **Developed output ripple compensation method with Fck modulation & EMI reduction**
- **Analyzed relationship between Fck modulation level and compensated current of SAW generator.**

$$G = I_{saw} / V_b$$

- **Keep output ripple < 2mV and EMI reduction –16 dB**

Future of Work

- **Implement this method**
- **Apply to other types of converters**

Thanks for your kind attention!

Appendix

＊ ⊿T in a single cycle

To

$$\Delta T = \frac{T_{MAX} - T_{MIN}}{F_o / \left(\frac{1}{2} F_m \right)} \approx \frac{2\left(V_m / V_b\right)}{T_m / T_o}$$

$$\frac{\Delta T}{T_o} = \frac{\Delta W}{W} = \frac{2\left(V_m / V_b\right)}{T_m}$$

Current I_{SAW} of SAW

$$I_{SAW} = \frac{V_{SAW} * C}{T_o}$$