Minimum Output Ripple and Fixed Operating Frequency Based on Modulation Injection for COT Ripple Control Converter

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Outline

1. Research Background
   - Applications of Switching Power Supply
   - Basic Switching Converter Architecture
2. Analysis of Step-down Switching Converter
   - Constant On-time Control of PWM Signals
   - Modulation Injection
3. Proposed Design of Buck Converter
   - Minimum Output Ripple with Modulation Injection
   - Experimental Results
4. Conclusions

1. Research Background

Research Objective & Approach

Objective

Development of switching power supply with

- ○ Fast response & high efficiency
- ○ Low EMI noise
- ○ Small output ripple

Approach

- ○ Analysis of Buck converter system based on constant on-time control of PWM signal
- ○ Ripple reduction with modulation injection

1. Research Background

Design Achievements of This Work

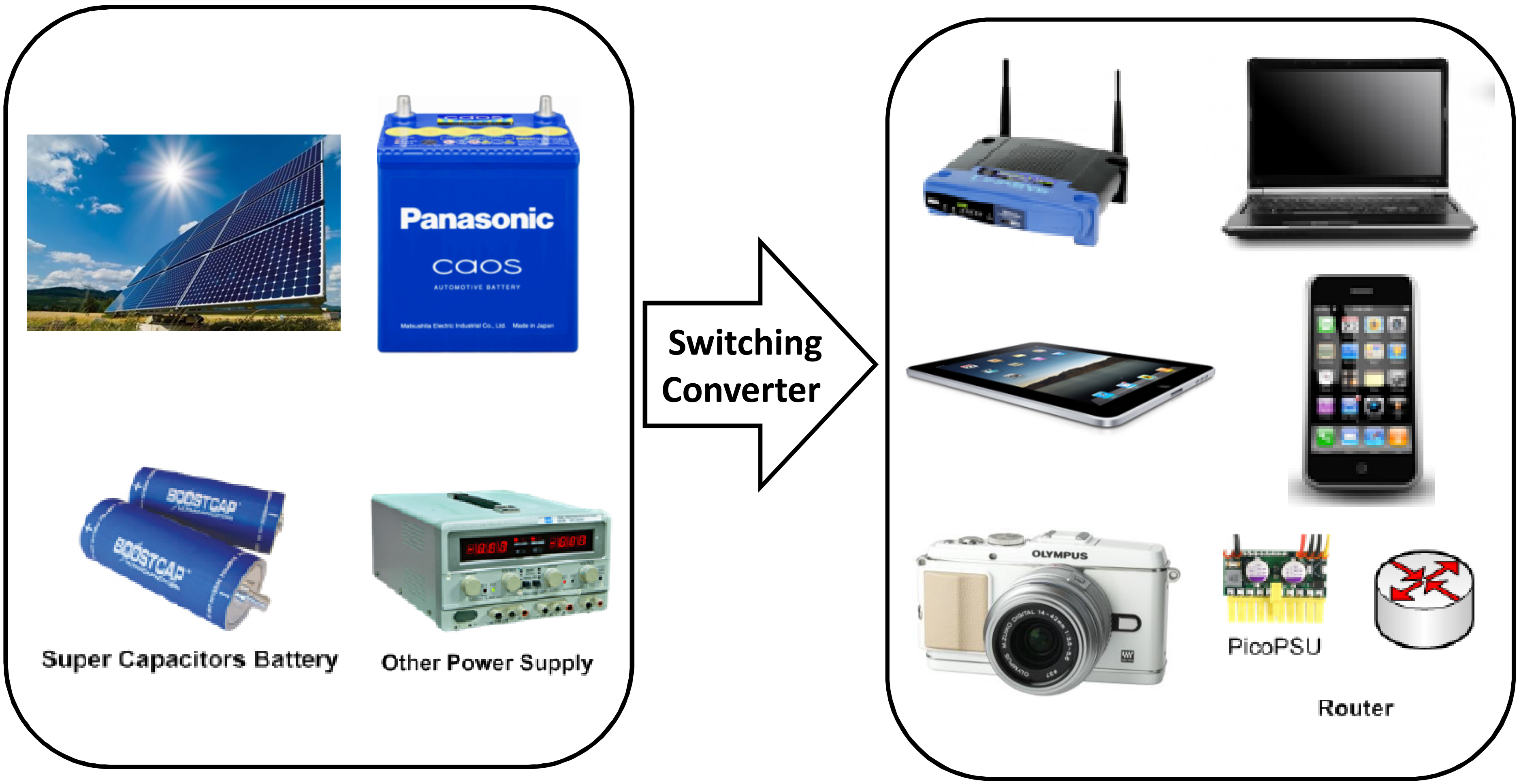
○ **Fixed operating frequency for PWM signals based on constant on-time control**

○ **Ripple reduction with modulation injection**
→Improvement of Ripple
from 16mVpp into 5mVpp

○ **EMI noise reduction with spread spectrum of PWM signals (0.05mVpp)**

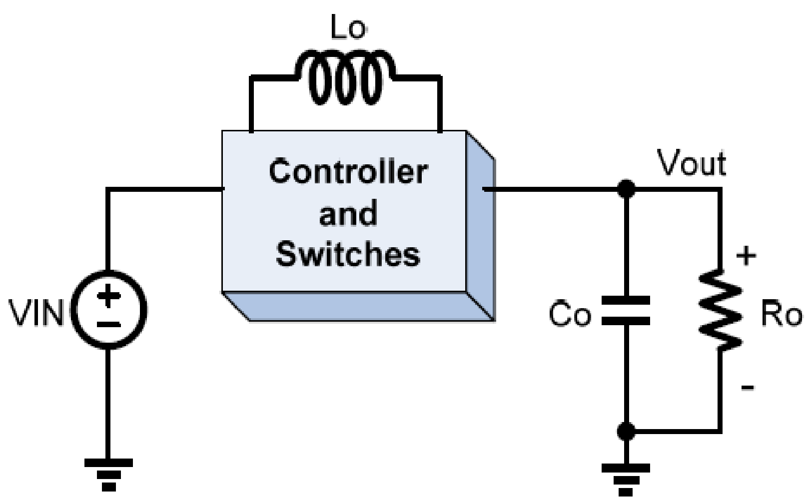
1. Research Background

Typical Applications of Switching Power Supply



1. Research Background

Basic Switching Converter Architecture



Basic Switching Converter

High Efficiency Switching

➔ **Reduce energy consumption**

➔ **Extend battery operating time**

➔ **Minimize costs of systems**

Merits

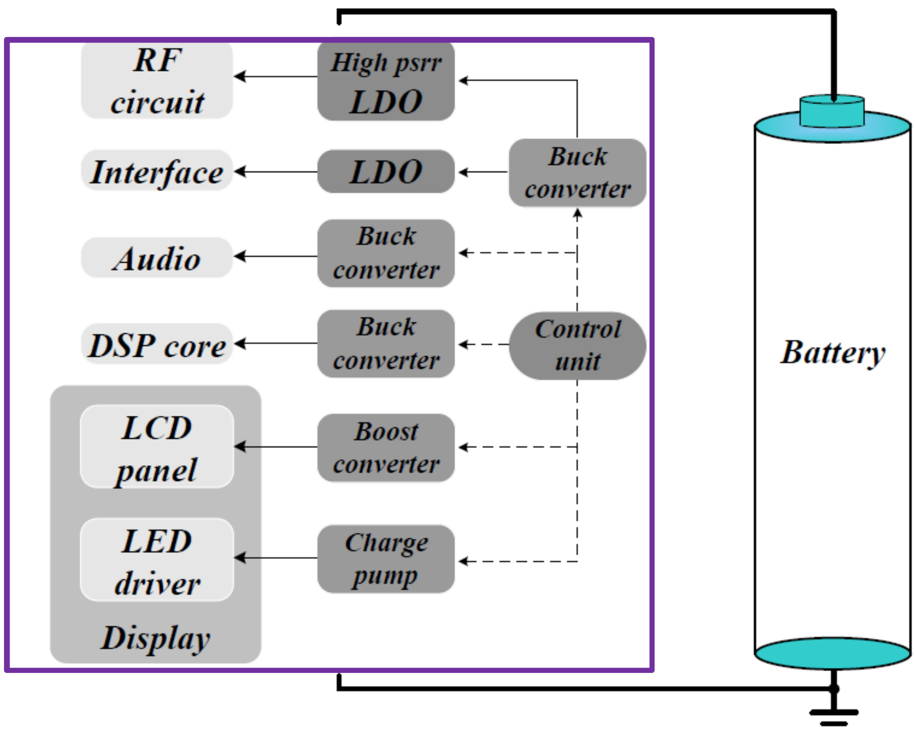
- Downsizing
- Light Weight
- High Efficiency

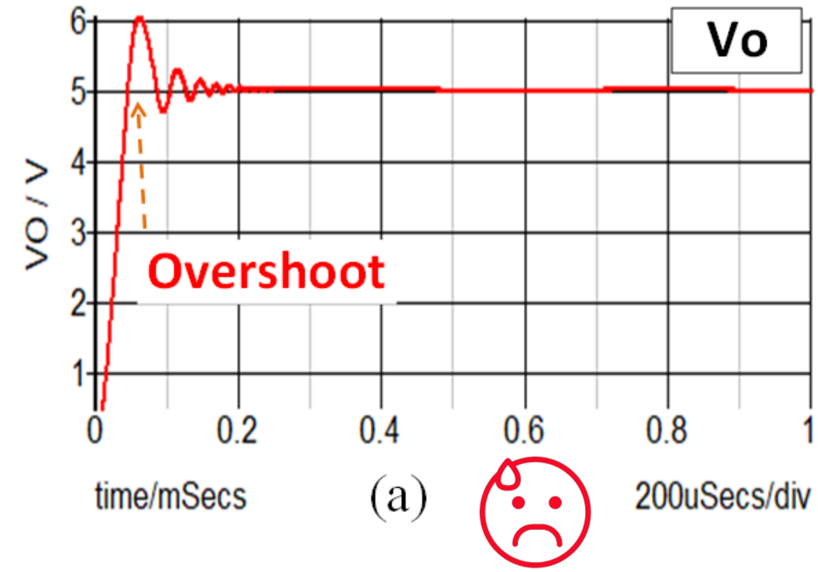
Demerits

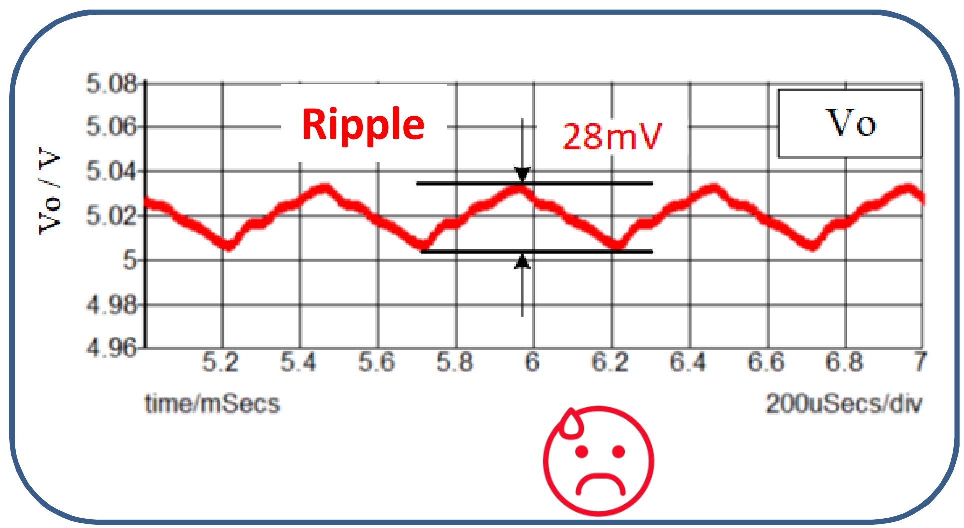
- Output Ripple
- Switching noise
- Harmonic noise

1. Research Background

Overshoot & Ripple Problems







1. Research Background

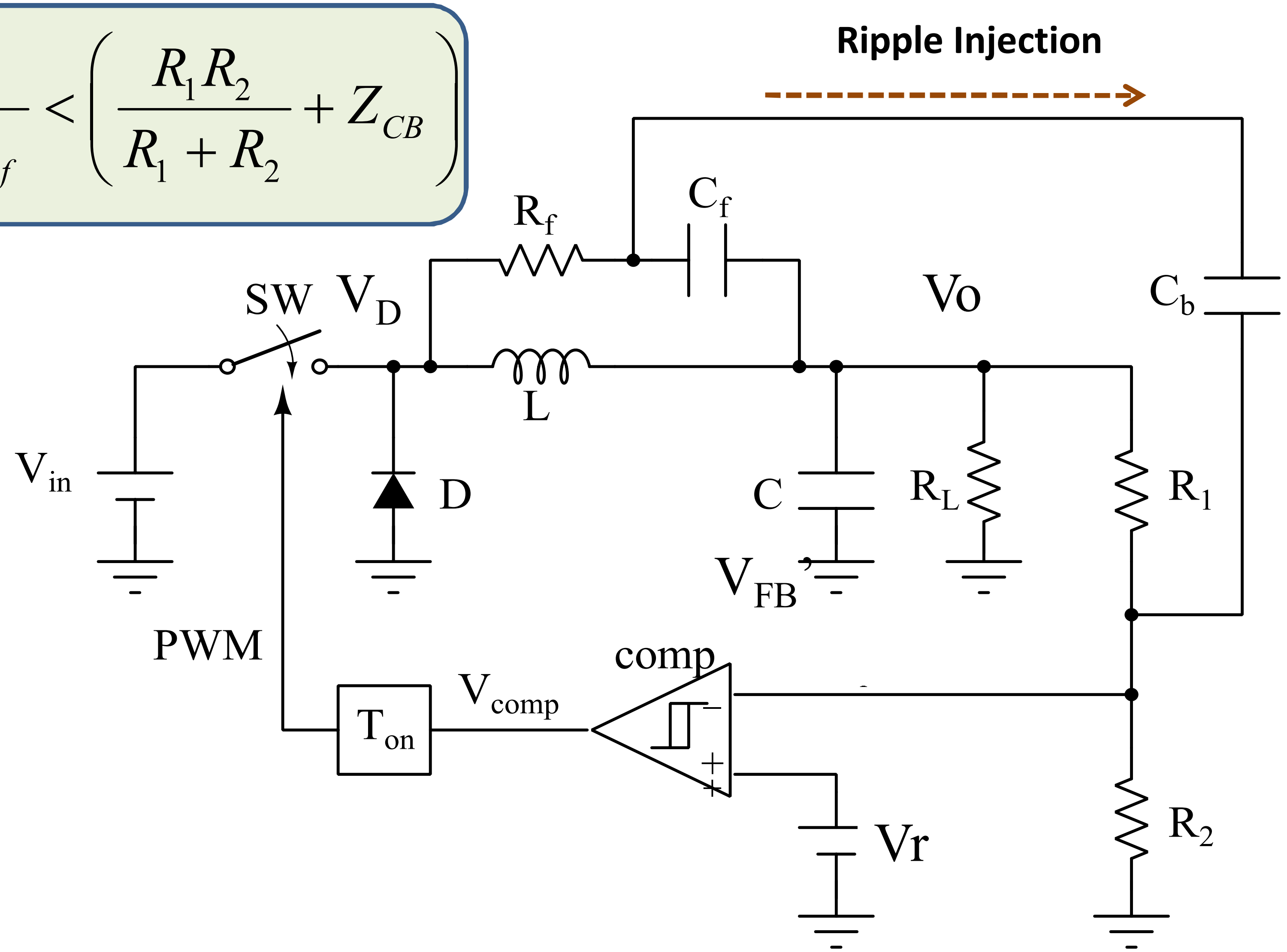
Constant ON-Time (COT) Hysteretic Regulator

- **Advantages**
  - Constant frequency vs. V_{IN}
  - High Efficiency at light load
  - Fast transient response
- **Disadvantages**
  - Requires ripple at feedback comparator
  - Sensitive to output noise, because it translates to feedback ripple

2. Analysis of Step-down Switching Converter

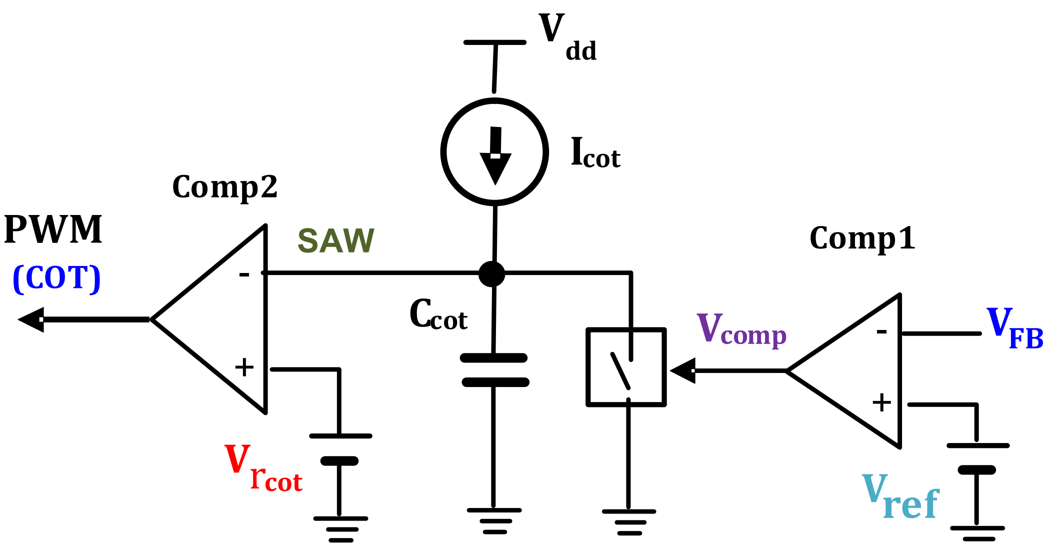
Ripple Controlled Converter with COT method

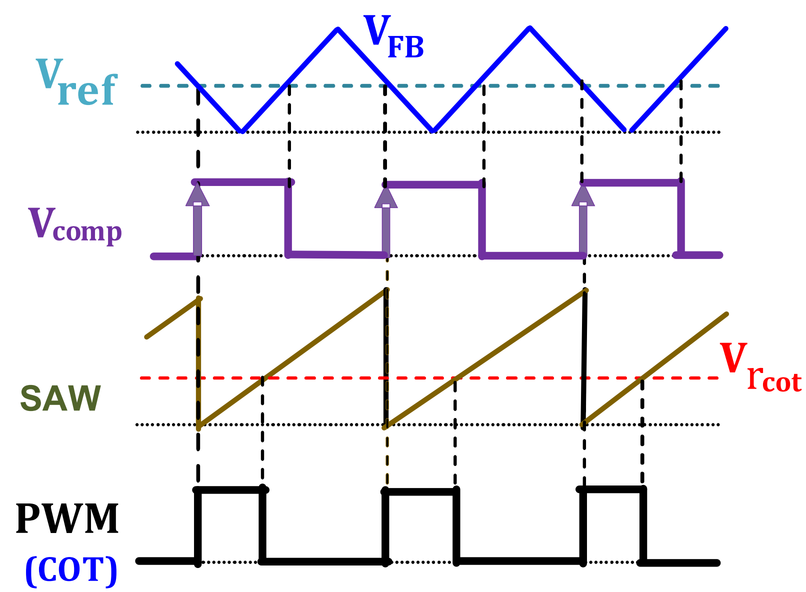
$$\frac{1}{2\pi f_{SW} C_f} < \left(\frac{R_1 R_2}{R_1 + R_2} + Z_{CB} \right)$$



2. Analysis of Step-down Switching Converter

Constant On-time Control for PWM Signals





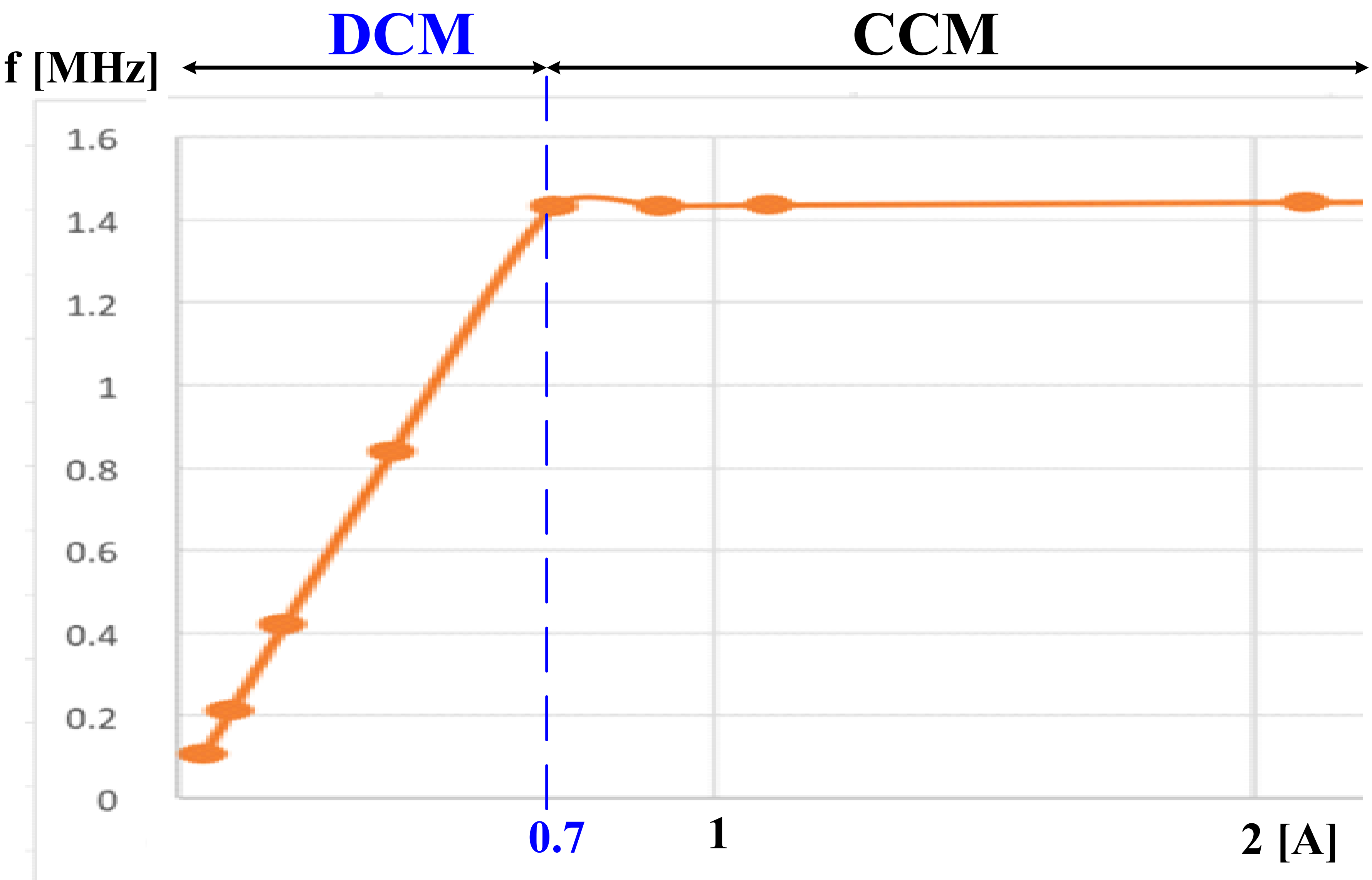
$$T_{COT} = \frac{V_{COT} * C_{COT}}{I_{COT}}$$

$$f_{op} = \frac{1}{T_{op}} = \frac{D}{T_{COT}}$$

D : Duty cycle of PWM

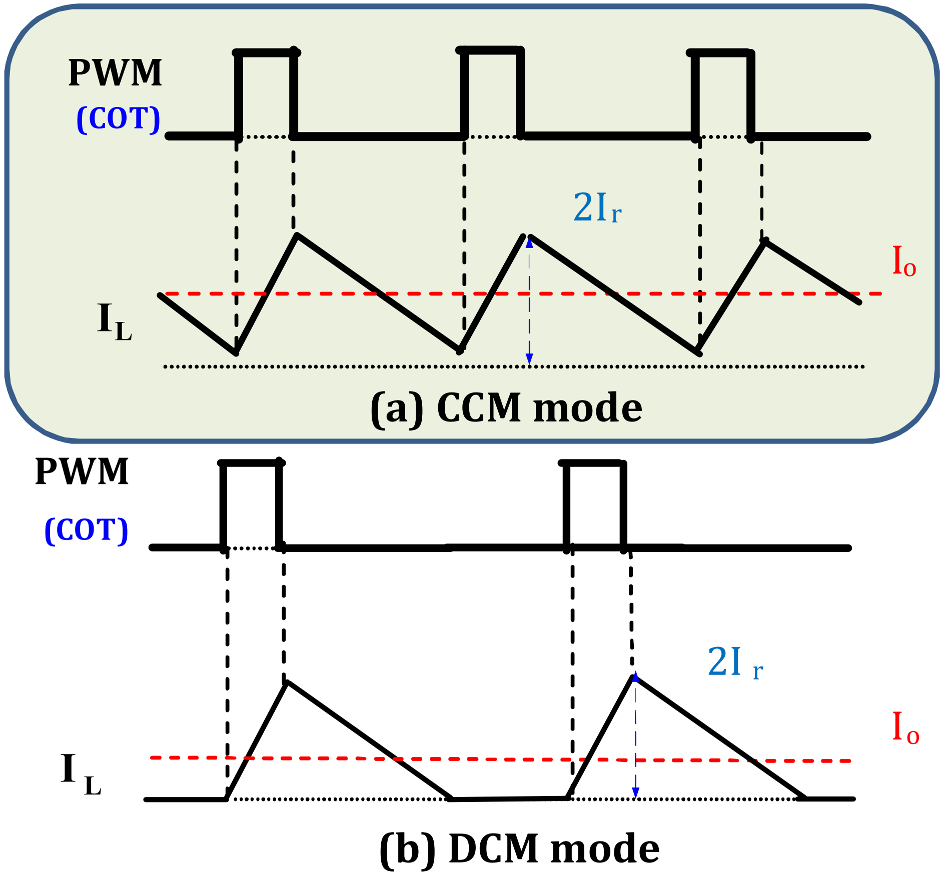
2. Analysis of Step-down Switching Converter

Operating Frequency Modes of COT Buck Converter



2. Analysis of Step-down Switching Converter

Continuous Conduction Modes of Operation (CCM)



$$D_{CCM} = \frac{T_{ON}}{T_{ON} + T_{OFF}}$$

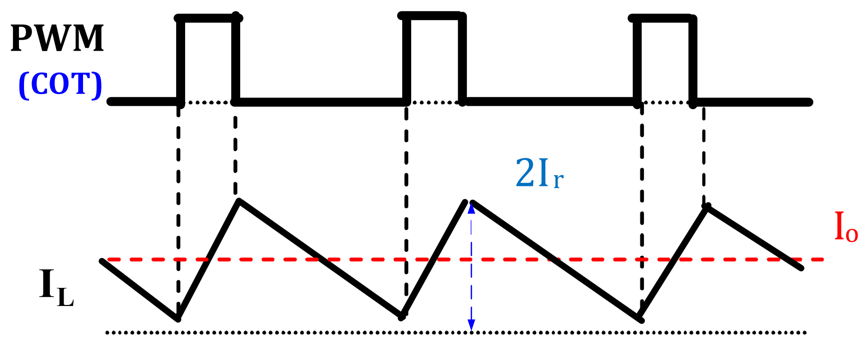
$$Q_{in} = I_L * T_{opCCM} = I_o * T_{opCCM}$$

$$f_{opCCM} = \frac{1}{T_{opCCM}} = \frac{D_{CCM}}{T_{COT}}$$

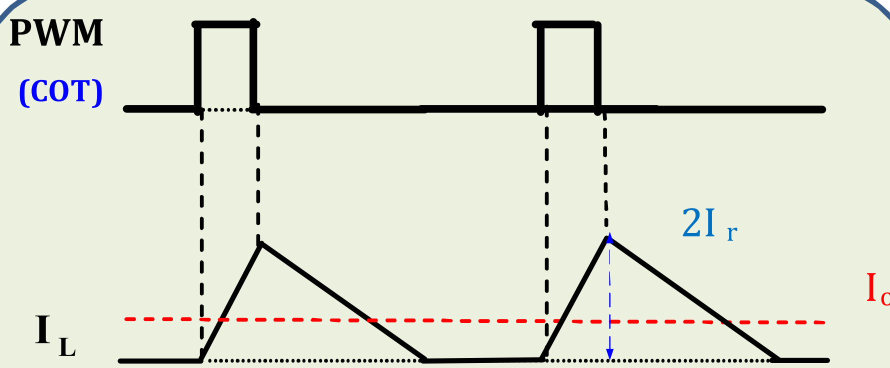
$$= \left(\frac{T_{ON}}{T_{ON} + T_{OFF}} \right) \frac{1}{T_{COT}}$$

2. Analysis of Step-down Switching Converter

Discrete Conduction Modes of Operation (DCM)



(a) CCM mode



(b) DCM mode

$$D_{DCM} = \frac{T_{COT}}{T_{COT} + T_{OFF}}$$

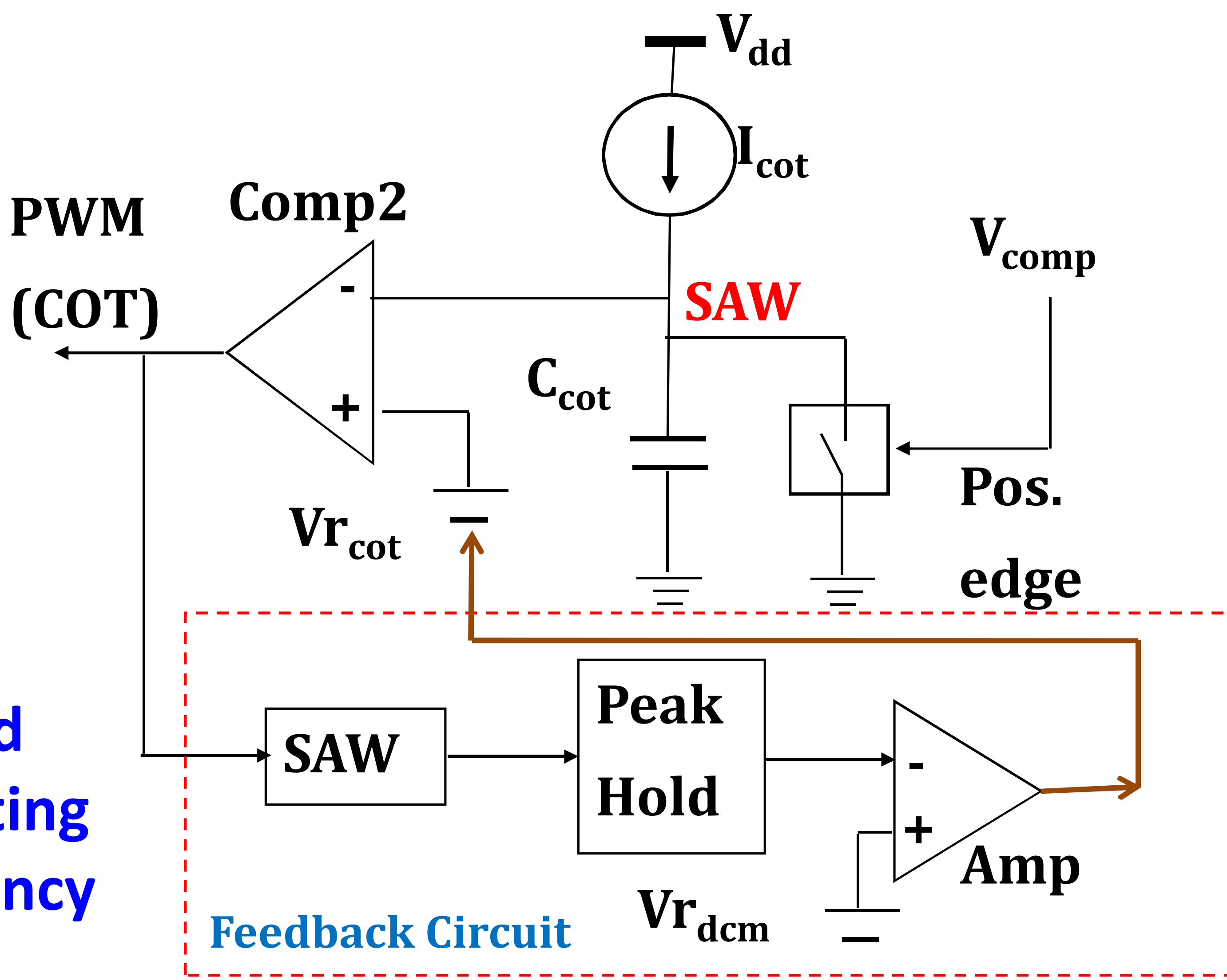
$$Q_{in} = I_r \cdot (T_{ON} + T_{OFF}) = I_o \cdot T_{opDCM}$$

$$I_r = \frac{T_{COT} \times (V_{in} - V_o)}{2L}$$

$$f_{opDCM} = \frac{1}{T_{opDCM}} = \left(\frac{1}{T_{ON} + T_{OFF}}\right)\frac{I_o}{I_r}$$

2. Analysis of Step-down Switching Converter

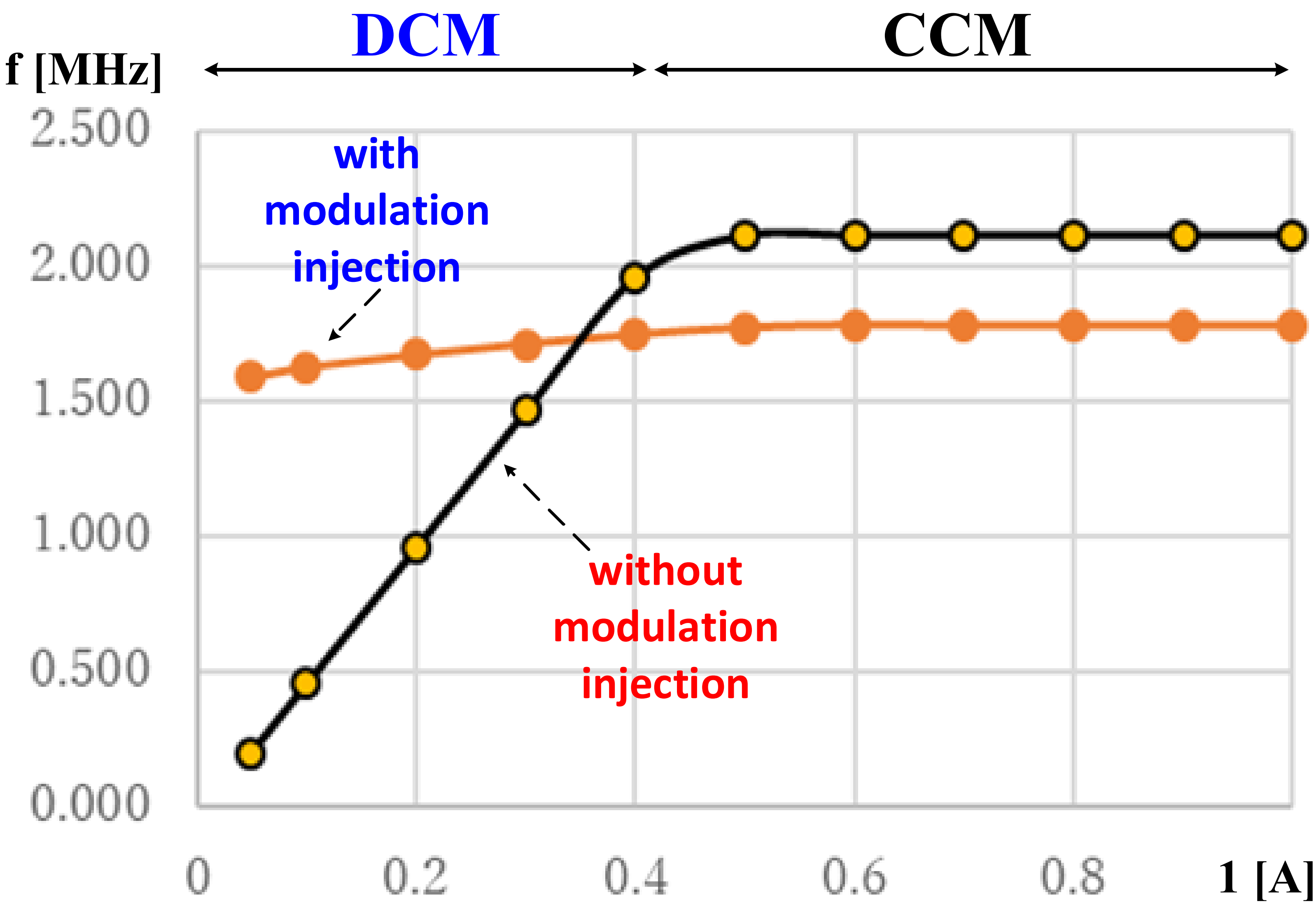
Fixed Operating Frequency for PWM Signals



Fixed Operating Frequency

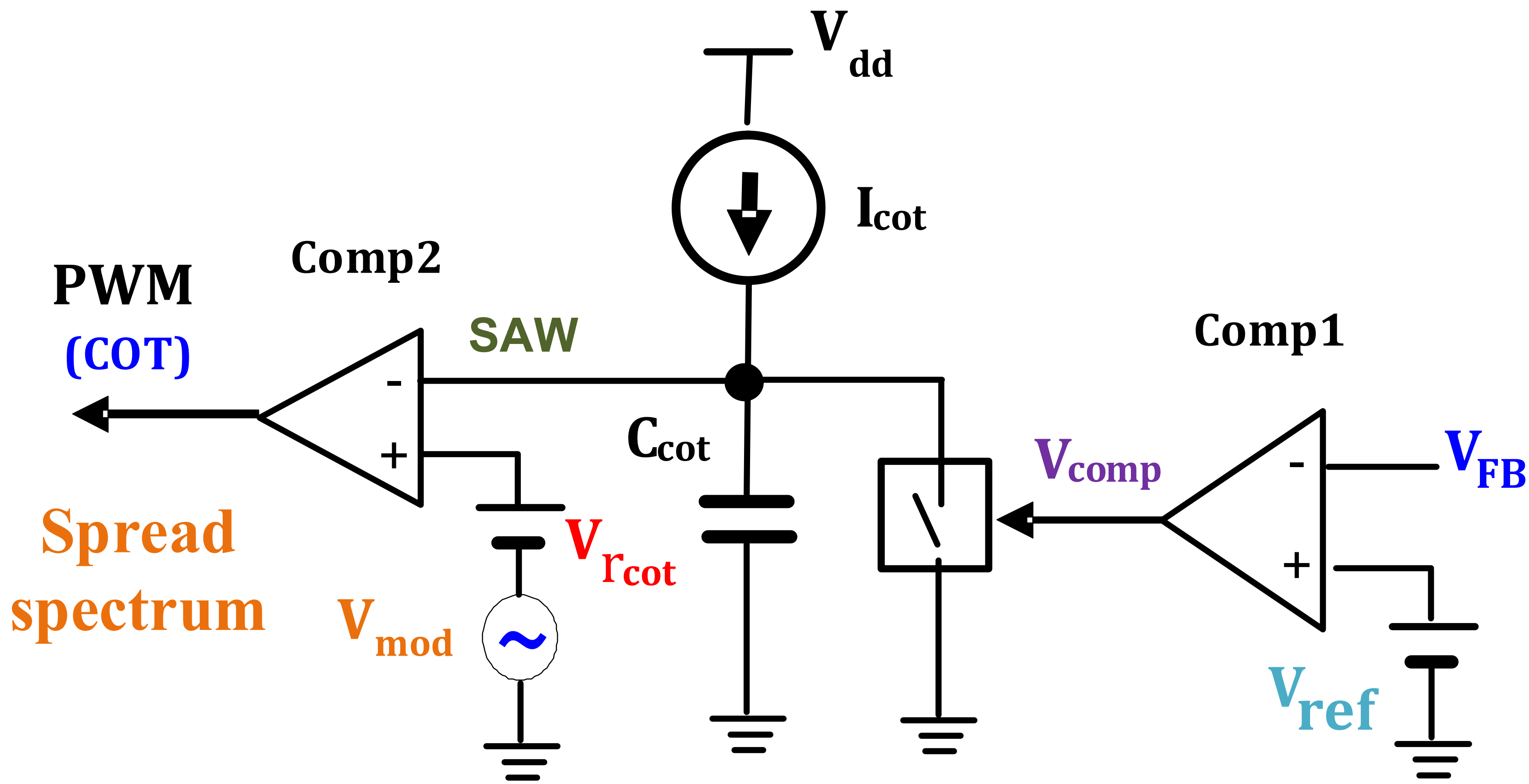
2. Analysis of Step-down Switching Converter

Fixed Operating Frequency on DCM Mode



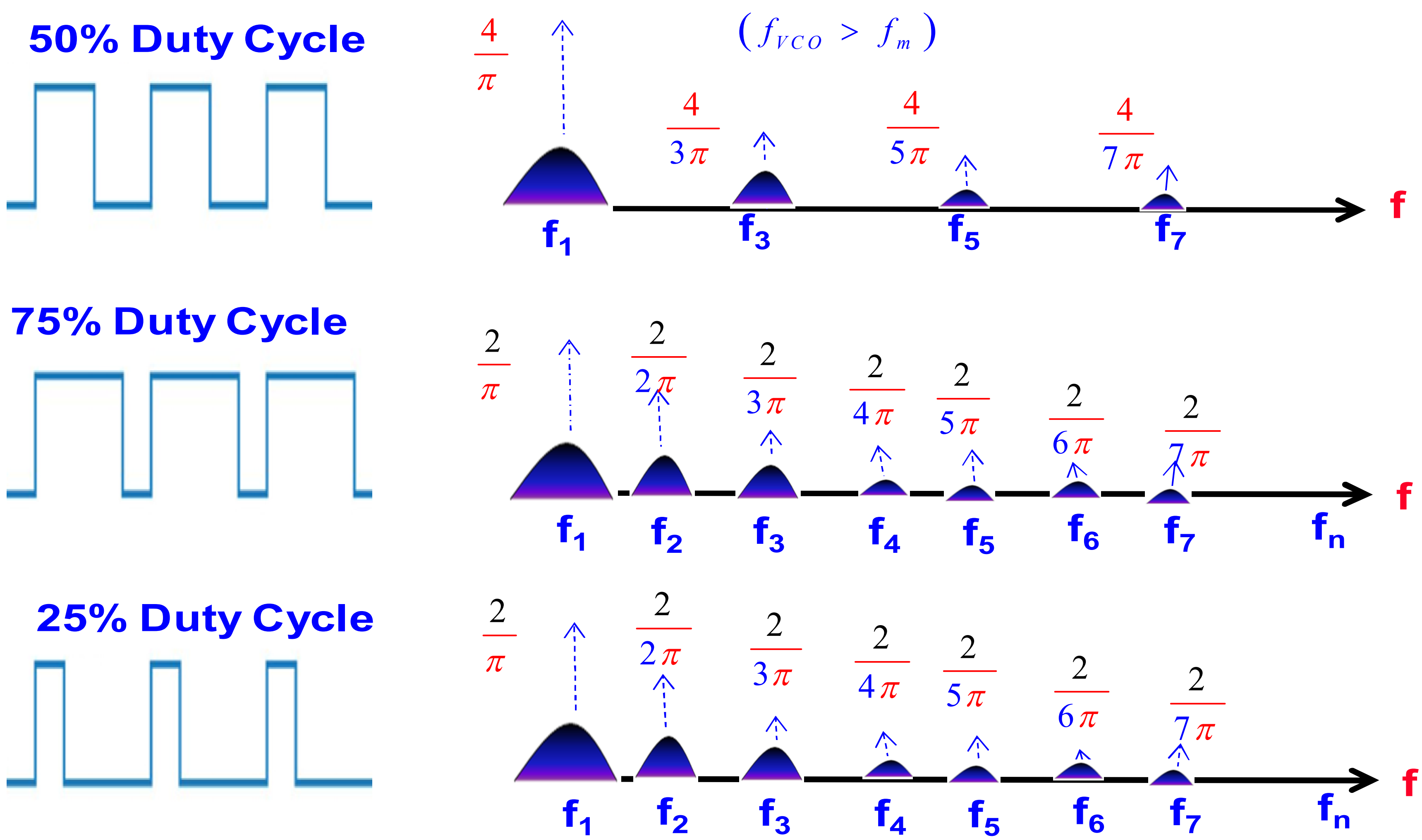
2. Analysis of Step-down Switching Converter

Frequency Modulation of PWM Signals



2. Analysis of Step-down Switching Converter

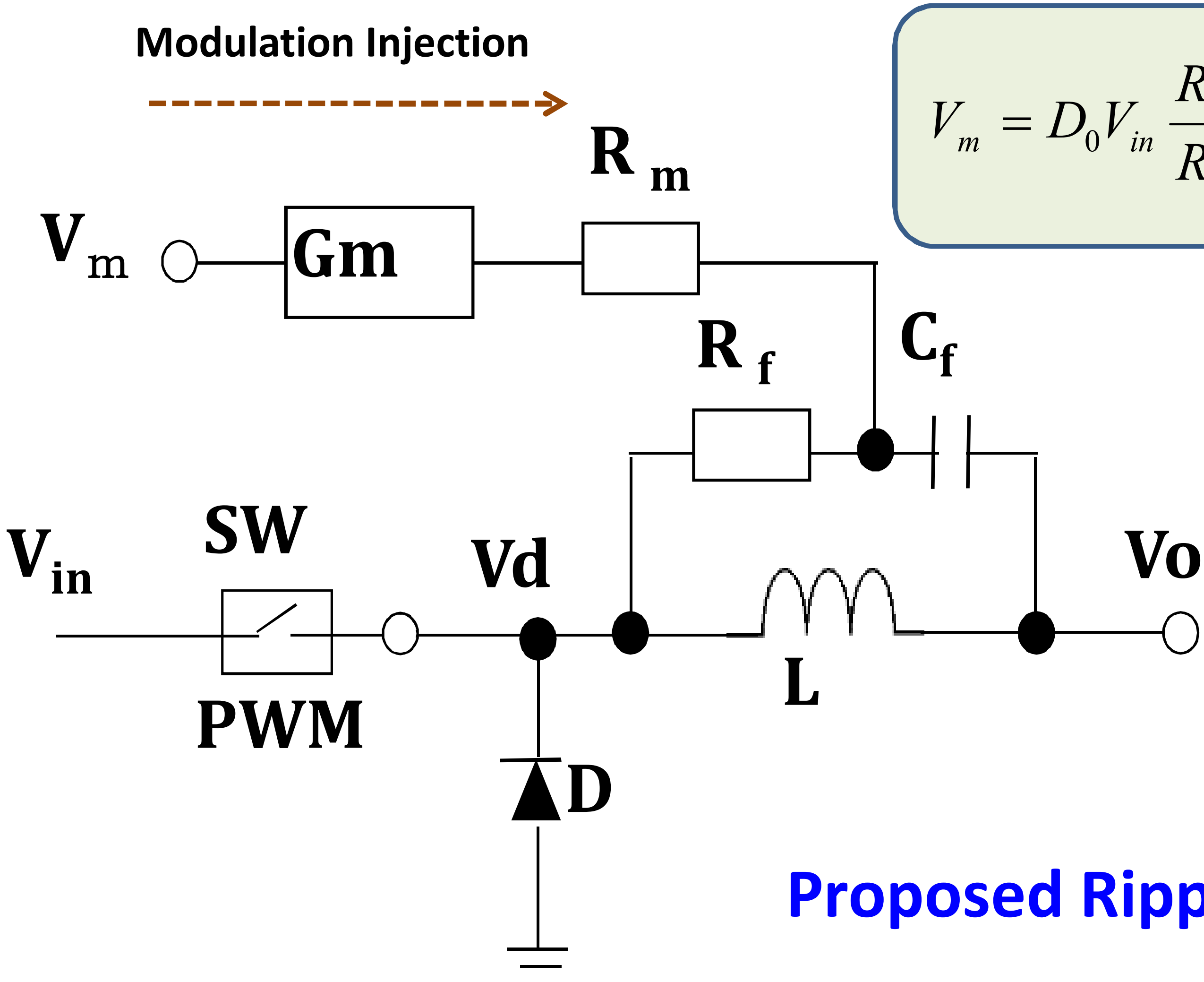
Spread Spectrum of PWM Signals



2. Analysis of Step-down Switching Converter

Ripple Reduction with Modulation Injection

$$V_m = D_0 V_{in} \frac{R_m}{R_f}\left(\frac{1}{1+sC_f R_m}\right) + V_o$$

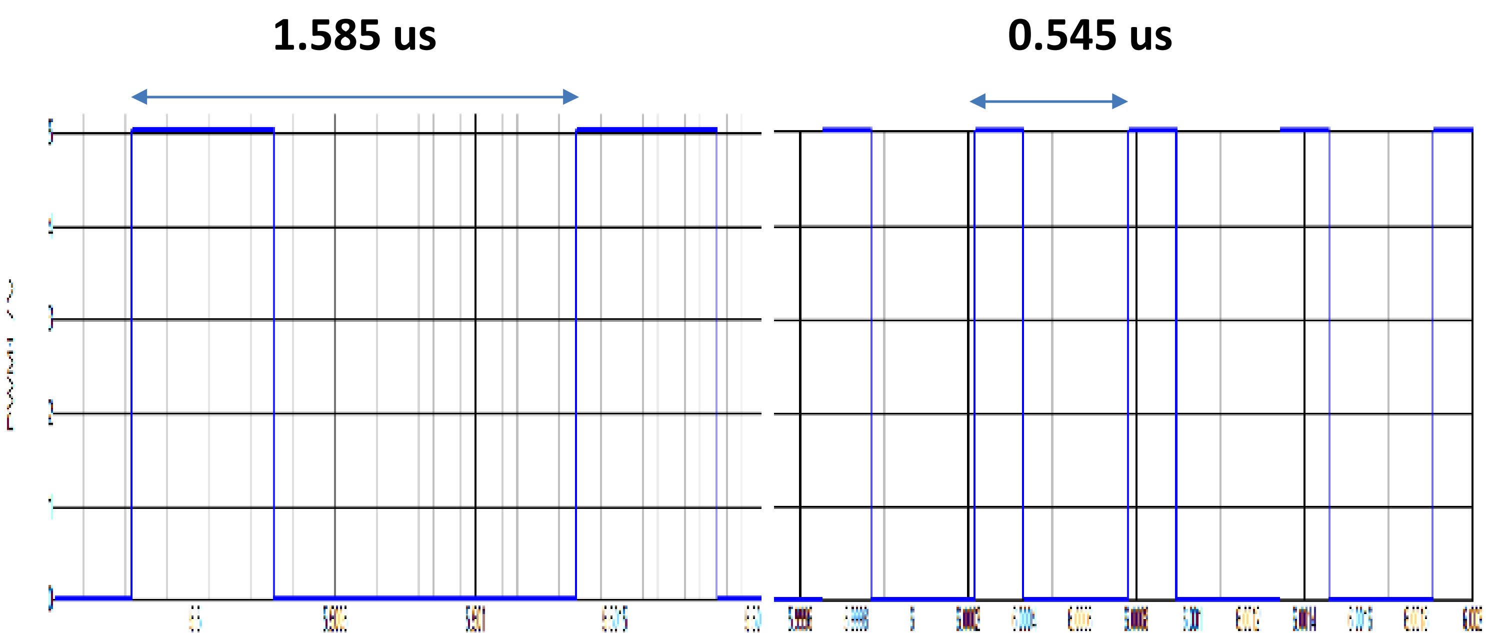


Proposed Ripple Reduction

2. Analysis of Step-down Switching Converter

Optimization of Modulation Injection Voltage

$$V_m = D_0 V_{in} \frac{R_m}{R_f}\left(\frac{1}{1+sC_f R_m}\right) + V_o$$

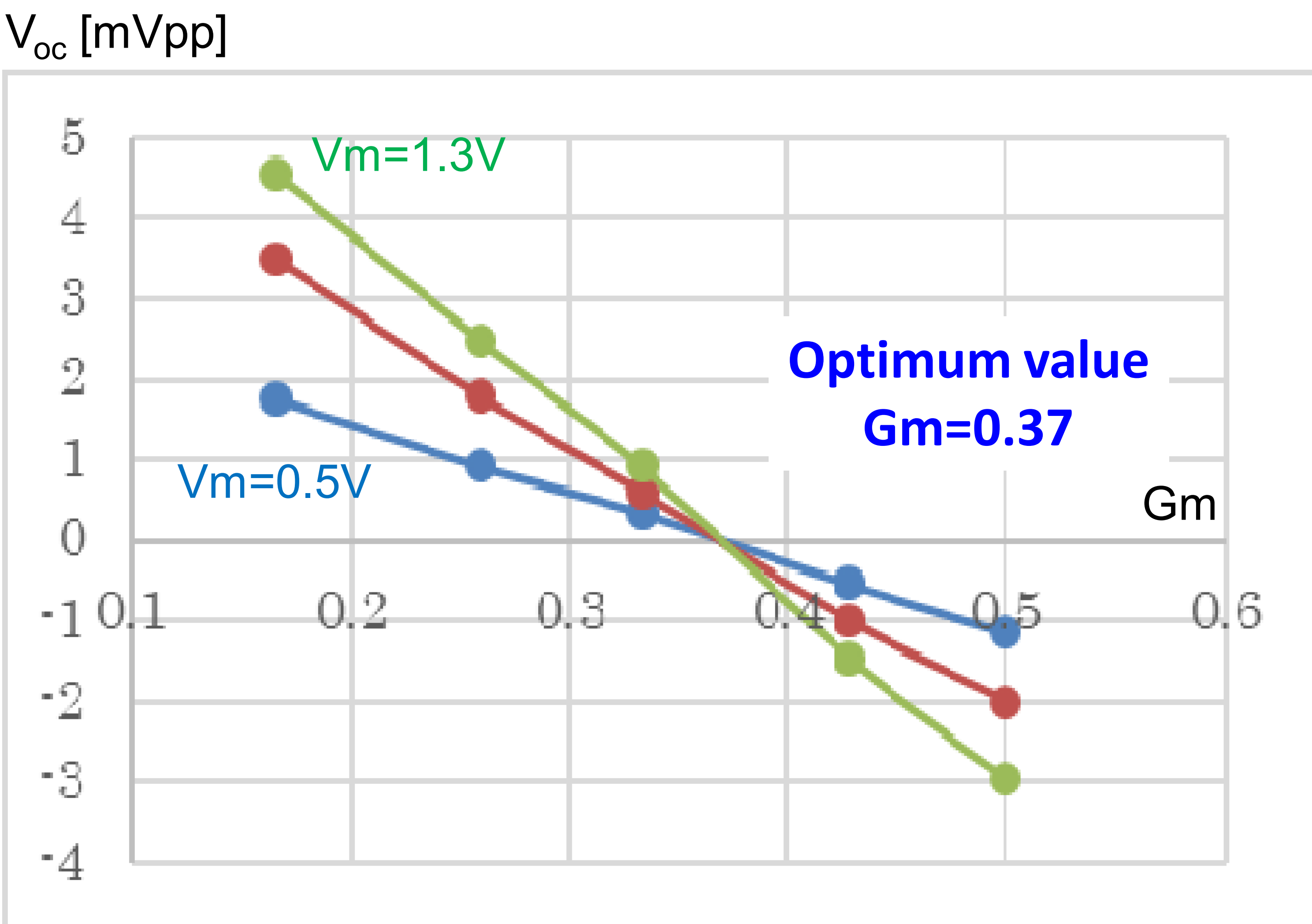


(A) V_m=1.5V

(B) V_m= 0.5V

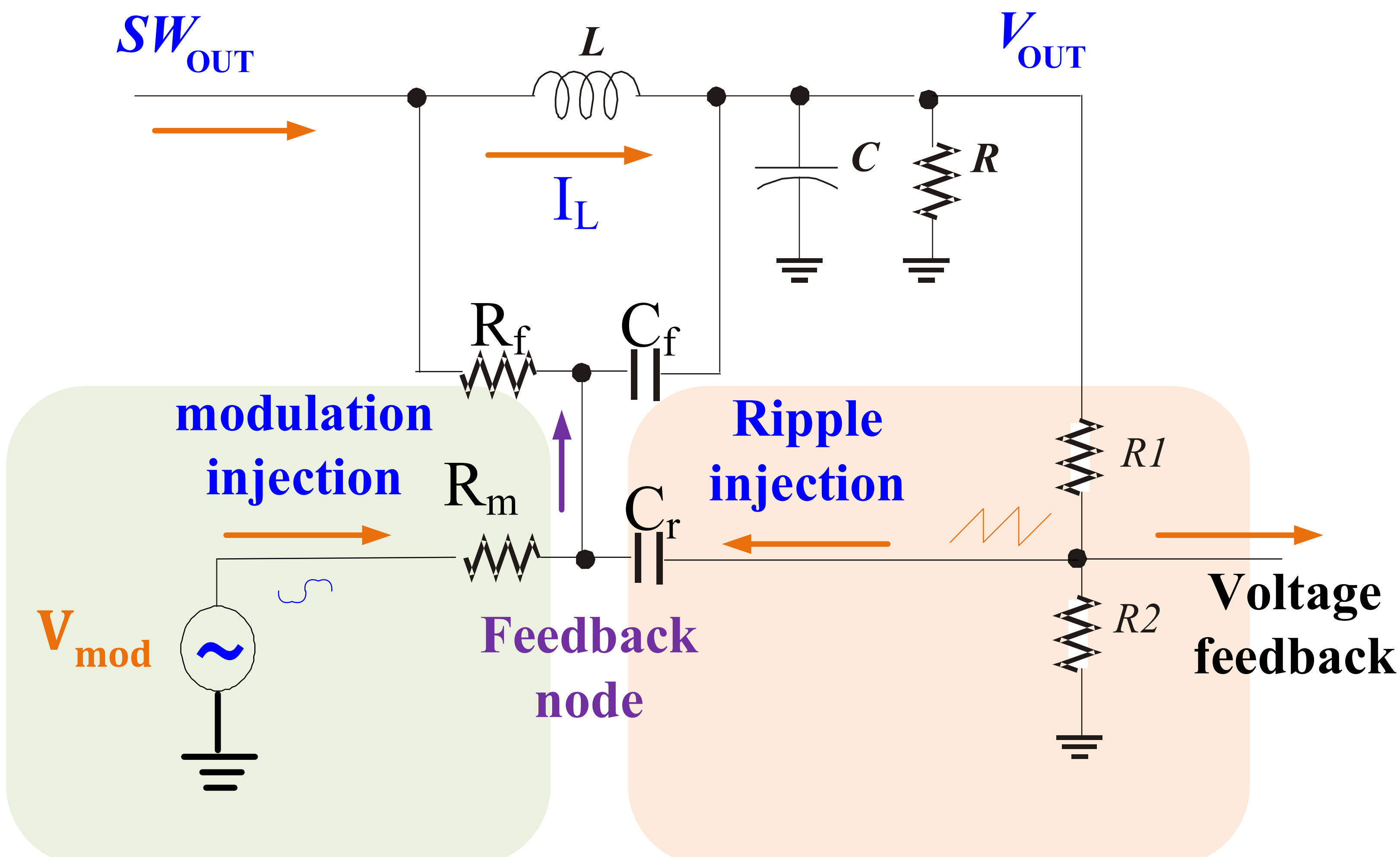
2. Analysis of Step-down Switching Converter

Optimum Trans-conductance Gain (Gm)



2. Analysis of Step-down Switching Converter

Proposed Design of Ripple Reduction Circuit



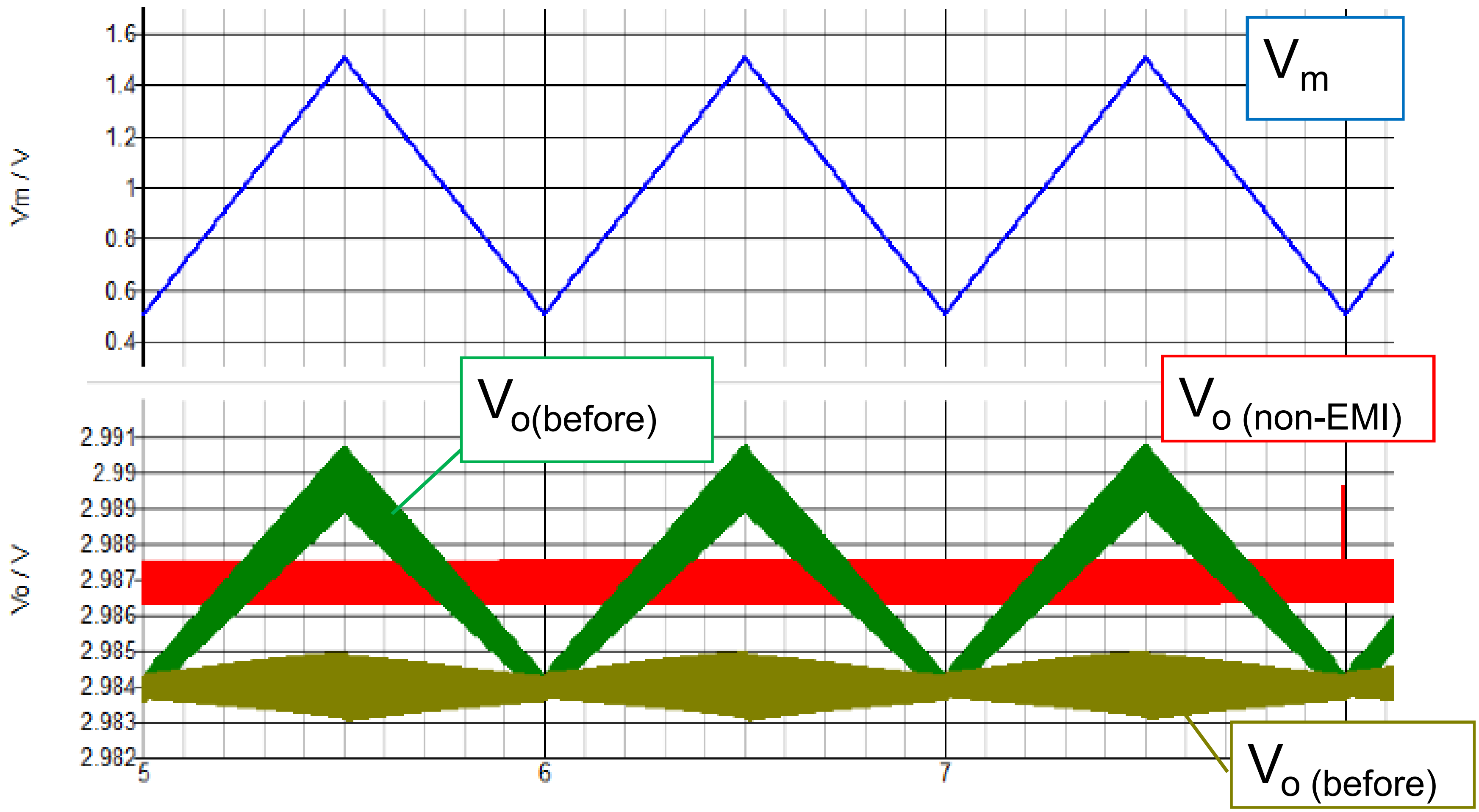
Proposed Ripple Reduction

Conventional one

2. Analysis of Step-down Switching Converter

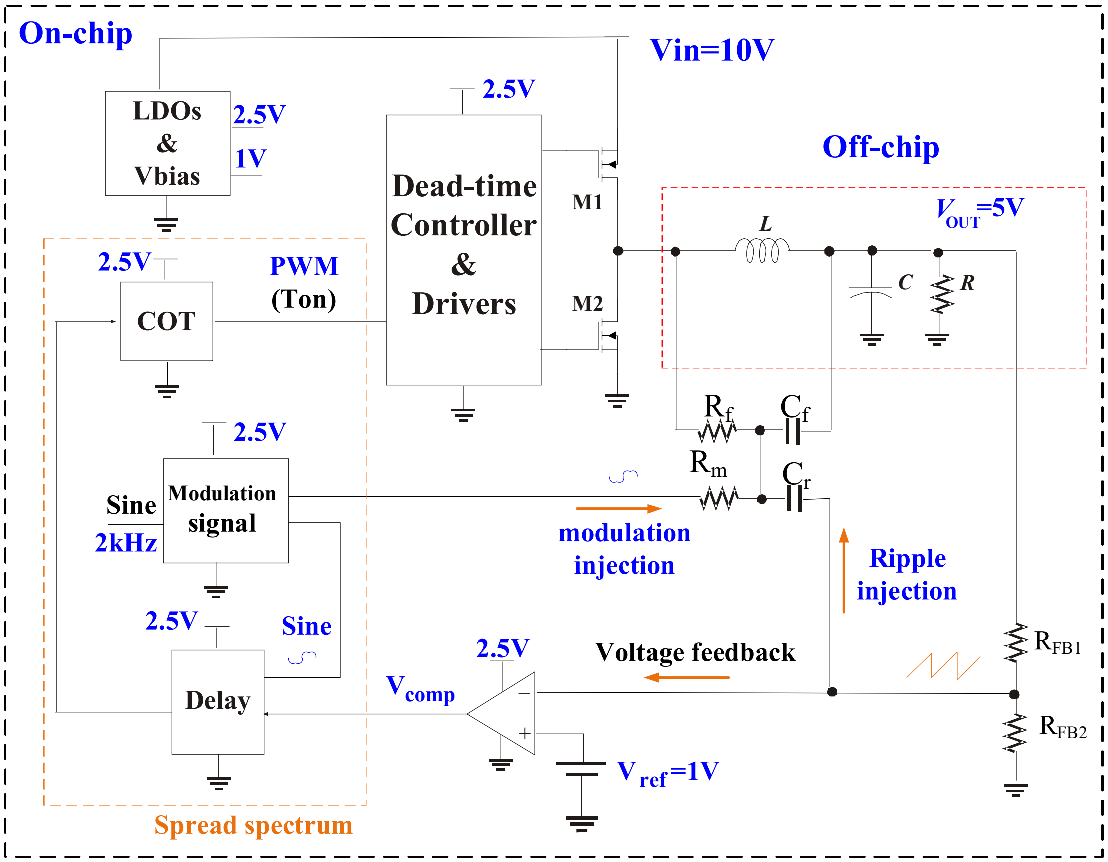
Improvement of Output Ripple

Ripple improvement: 2mVpp → 1mVpp



3. Proposed Design of Buck Converter

Minimum Output Ripple with Modulation Injection



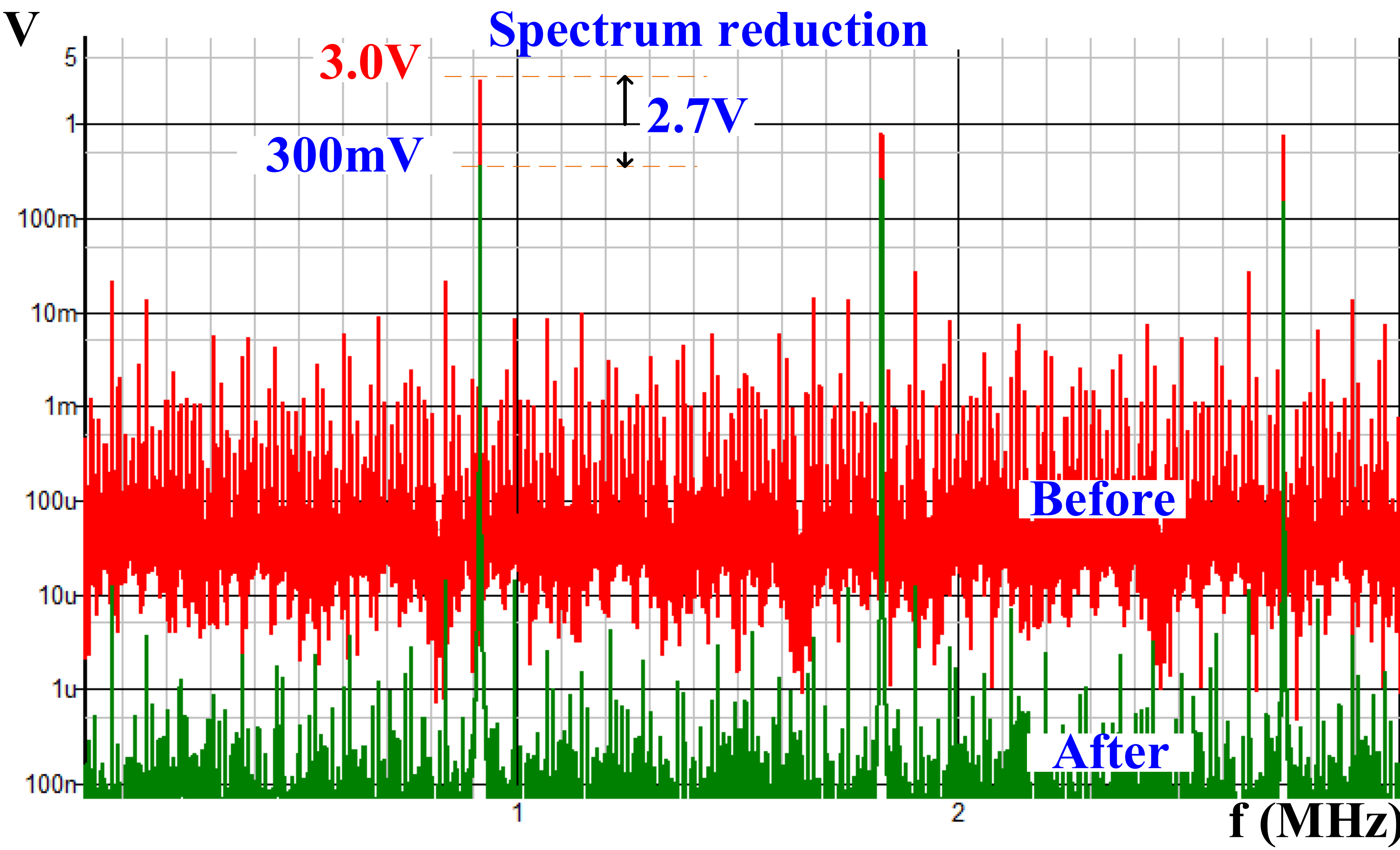
Input Voltage	Vin	10	[V]
Output Voltage	Vo	5	[V]
Output Current	Io	0.25	[A]
Inductance	Lo	200	[µH]
Capacitance	Co	470	[µF]
COT Time	T_{COT}	0.105	[µs]
Operating Frequency	F_{op}	1.6	[MHz]

EMI Reduction using Spread Spectrum of VCO

VCO : Voltage Controlled Oscillator

3. Proposed Design of Buck Converter

Spectrum of PWM Signals



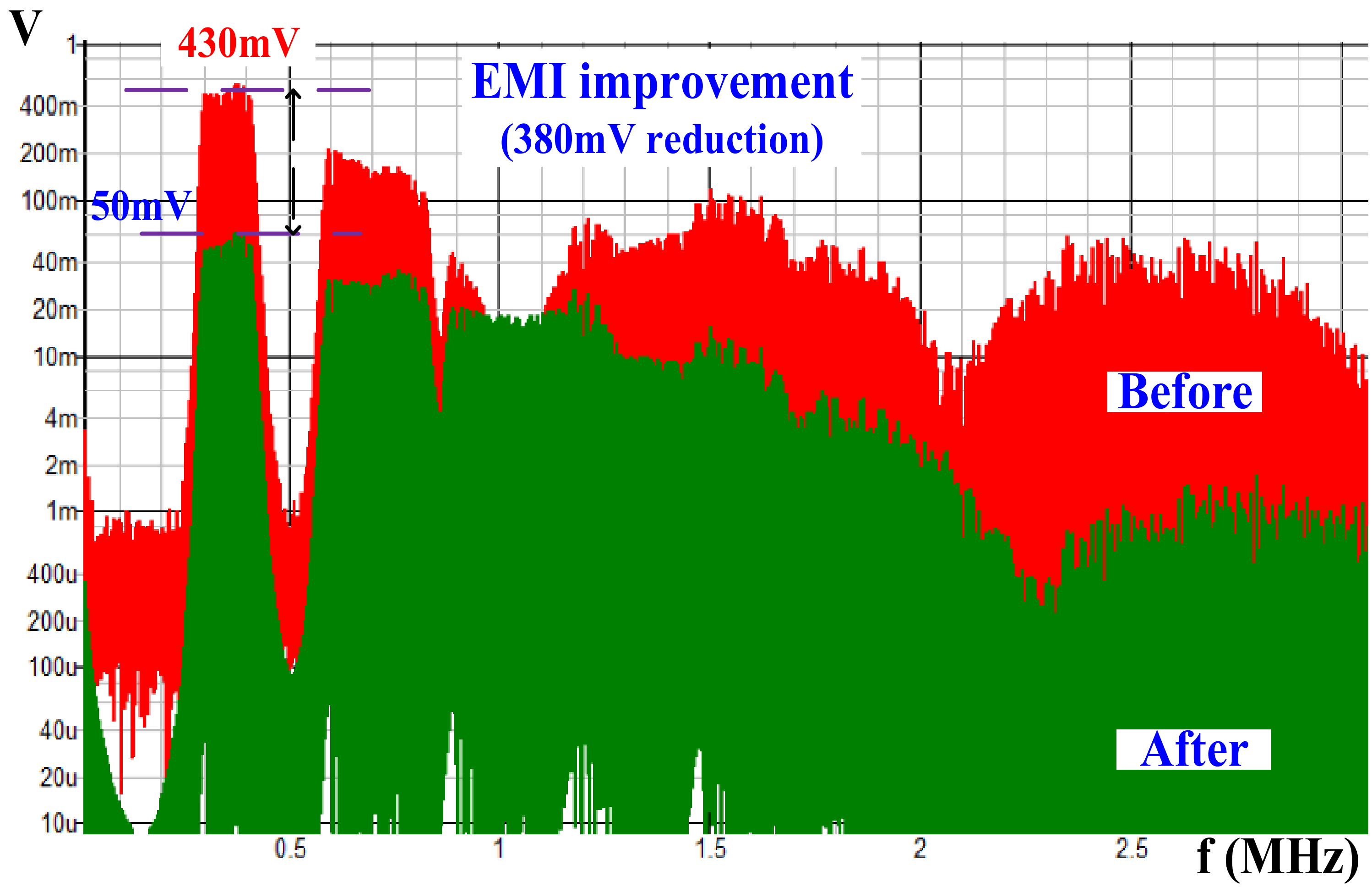
3. Proposed Design of Buck Converter

Spread Spectrum Improvement of EMI Noise

EMI noise reduction

430mV

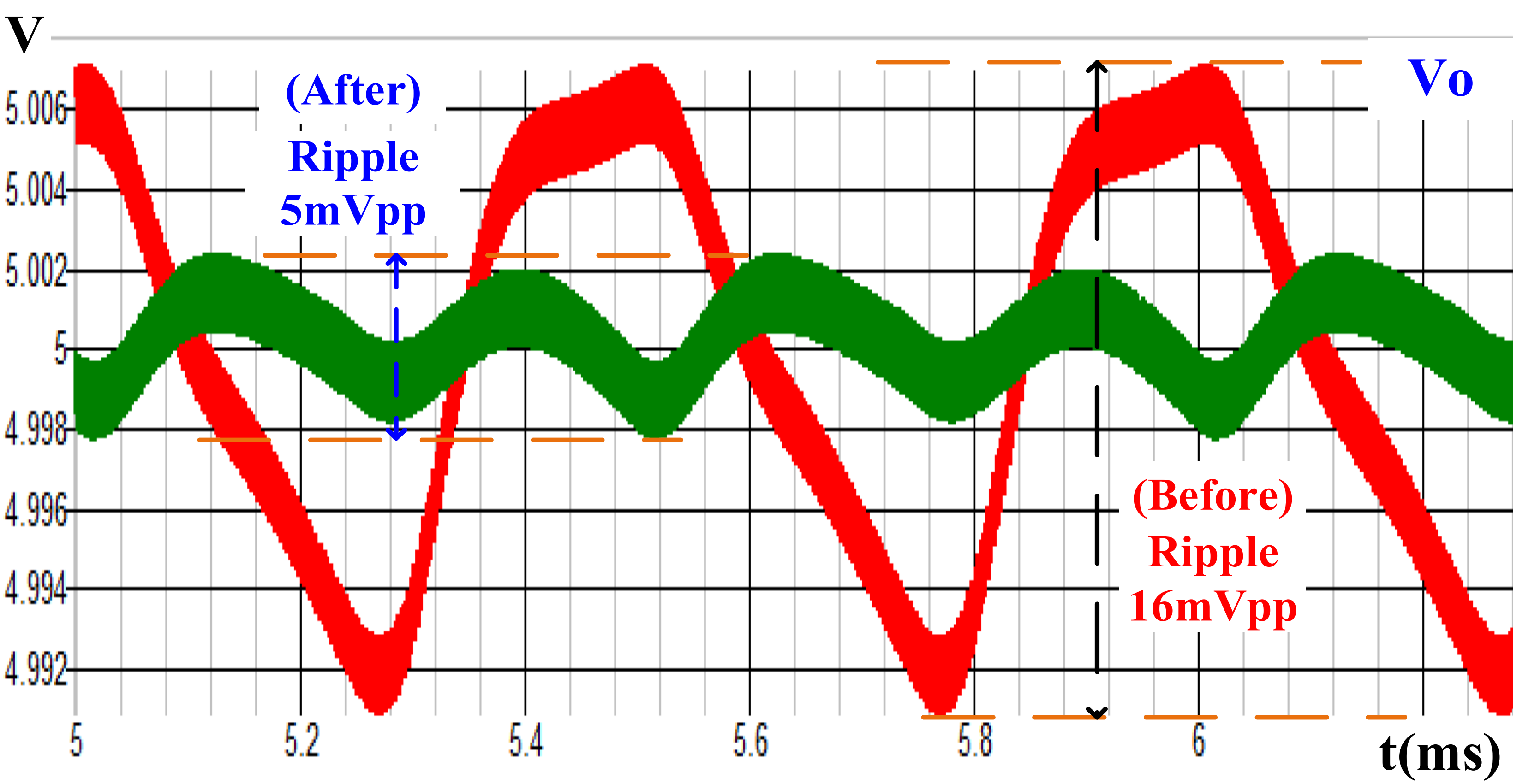
50mV



3. Proposed Design of Buck Converter

Output Voltage Ripple Reduction

Ripple improvement: 16mVpp → 5mVpp



4. Conclusions

This work:

- **Analysis model of Buck converter system based on constant on-time control of PWM signal**
- **Based on Modulation Injection**
  - **Fixed operating frequency**
  - **Minimum Output Ripple**

  → Ripple reduction

  from 16mVpp into 5mVpp

Future of Work:

- **Analysis of parasitic of RLC and other components**

Thanks for your kind attention!

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