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# Mathematical Analysis and Design of Parallel RLC Network in Step-down Switching Power Conversion System

Minh Tri Tran[a], Yifei Sun[b], Noriyuki Oiwa[c]
Yasunori Kobori[d], Anna Kuwana[e], Haruo Kobayashi[f]

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

# Outline

1. Research Background
   - Applications of Switching Power Supply
   - Basic Switching Converter Architecture
2. Analysis of Step-down Switching Converter
   - Conventional Classical Technique
   - Superposition Principle
3. Proposed Design of Buck Converter
   - Overshoot Improvement with Parallel RLC Network
   - Simulation Results
4. Conclusions

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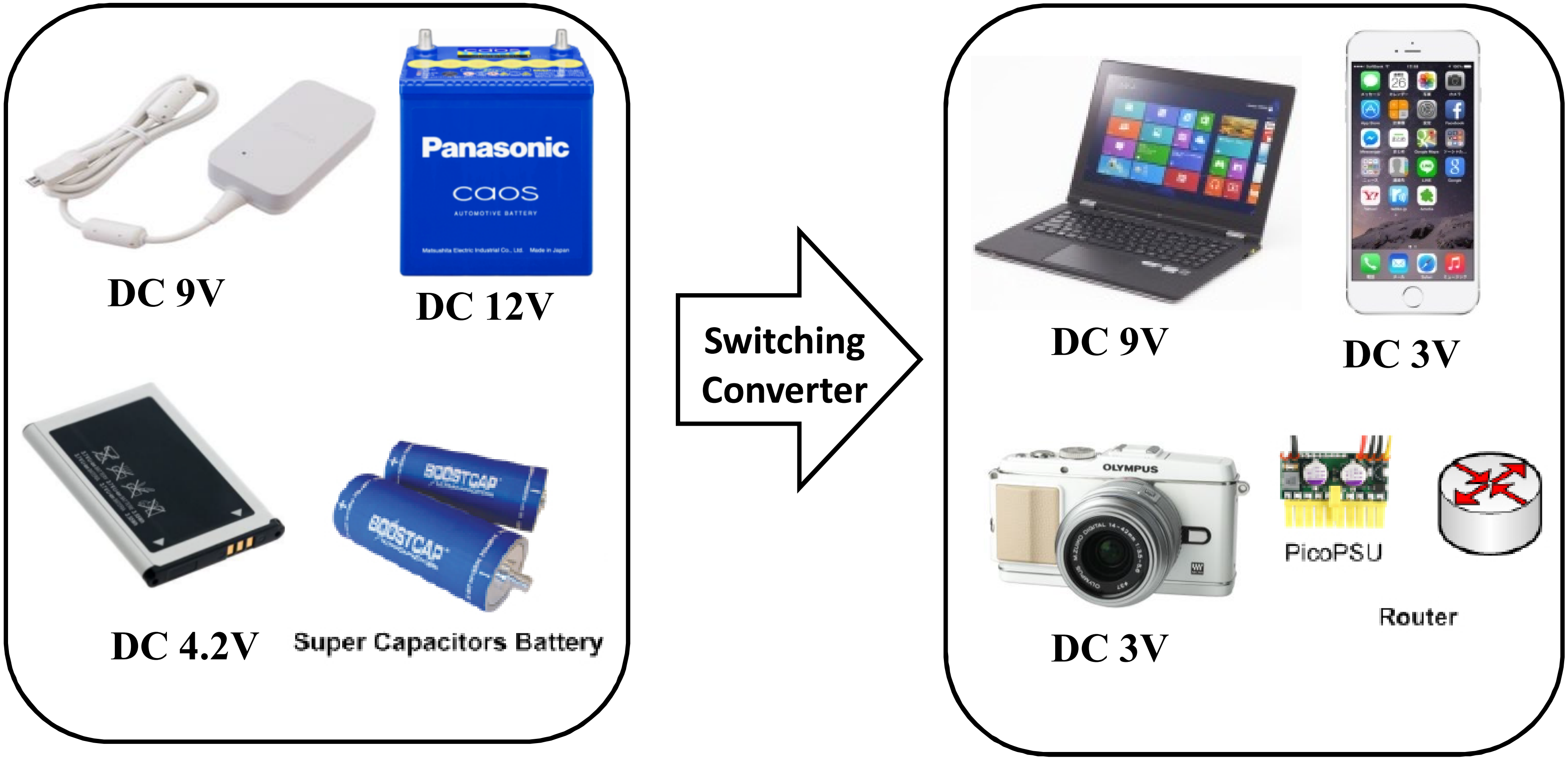
# 1. Research Background

## Typical Applications of Switching Power Supply



# 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 classical technique and superposition principle
- ○ Overshoot reduction using parallel RLC network

# 1. Research Background

## Design Achievements

**Achievements**

○ **Derivation of transfer function of buck converter based on superposition principle**

○ **Overshoot cancelation based on balanced charge-discharge time condition:**

$$|Z_L| = |Z_C| = 2R \Rightarrow \omega L = \frac{1}{\omega C} = 2R \qquad \omega = \frac{1}{\sqrt{LC}} = \frac{1}{2RC}$$

○ **Overshoot improvement with parallel RLC**

**→ Overshoot improvement from 1Vpp into 0.1Vpp**

○ **Ripple reduction using spread spectrum of PWM signals (0.05mVpp)**

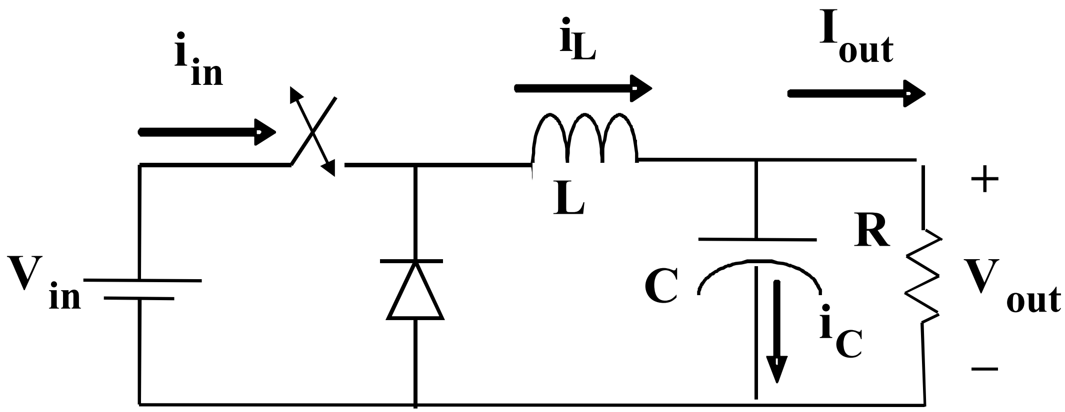
# 1. Research Background

## Trade-offs of Switching Power Supply

| | Linear Regulator | Switching Regulator | |
|---|---|---|---|
| | | Inductive | Charge Pump |
| Efficiency | 20-60% | 90-95% | 75-90% |
| Ripple | Very low | Low | Moderate |
| EMI Noise | Very low | Moderate | Low |
| PCB Area | Very small | Largest | Medium |
| Cost | Lowest | Highest | Medium |

# 1. Research Background

## Basic Switching Converter Architecture




Basic Switching Converter

**Merits**
- Downsizing
- Light Weight
- High Efficiency

**High Efficiency Switching**

➔ Reduce energy consumption

➔ Extend battery operating time

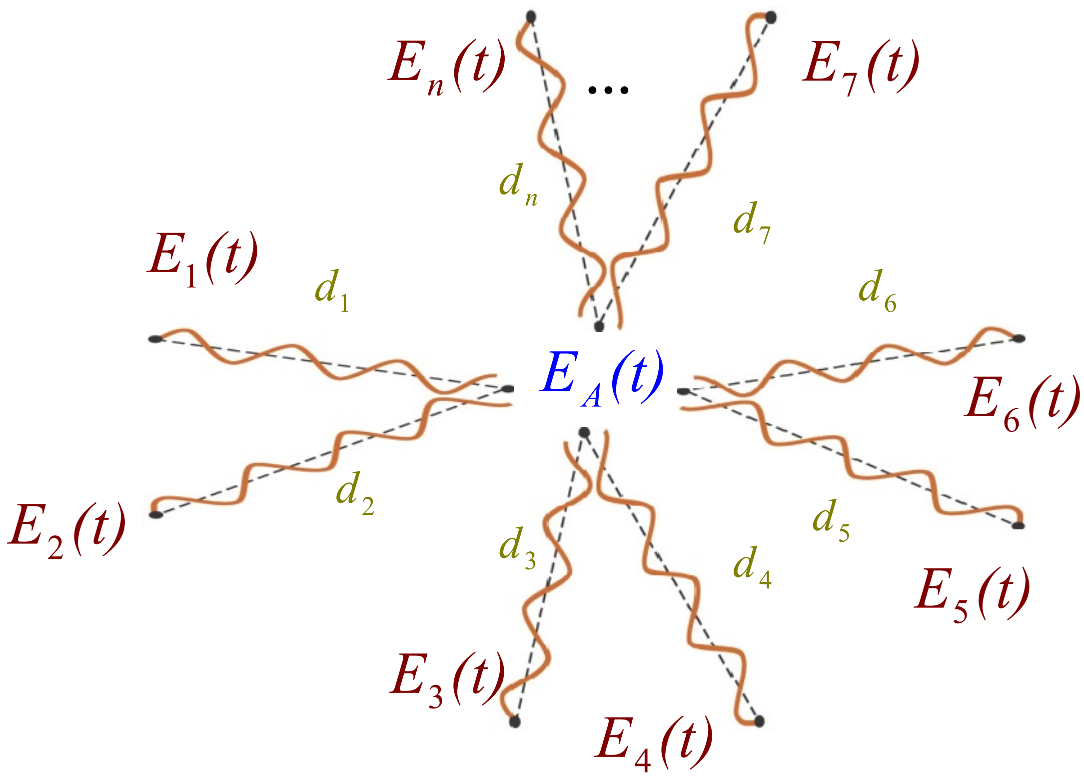
➔ Minimize costs of systems

**Demerits**
- Output Ripple
- Switching noise
- Harmonic noise

# 1. Research Background

## Superposition Principle

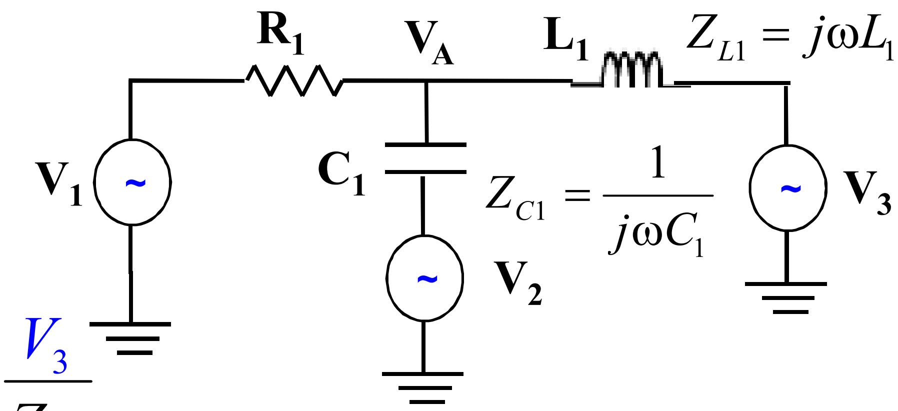
$$E_A(t)\sum_{i=1}^{n}\frac{1}{d_i}=\sum_{i=1}^{n}\frac{E_i(t)}{d_i}$$



# 1. Research Background

## Example1 of Superposition Principle

$$V_A\left(\frac{1}{R_1}+\frac{1}{Z_{C1}}+\frac{1}{Z_{L1}}\right)=\frac{V_1}{R_1}+\frac{V_2}{Z_{C1}}+\frac{V_3}{Z_{L1}}$$



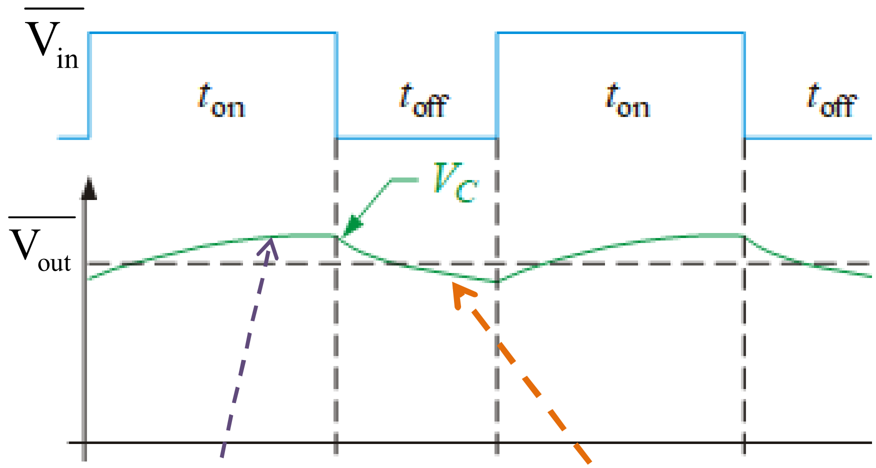

$$V_A\left(\frac{(R_1+Z_{C1})Z_{L1}+R_1Z_{C1}}{R_1Z_{C1}Z_{L1}}\right)=\frac{V_1}{R_1}+\frac{V_2}{Z_{C1}}+\frac{V_3}{Z_{L1}}$$

$$V_A=\frac{V_1Z_{C1}Z_{L1}+V_2R_1Z_{L1}+V_3R_1Z_{C1}}{(R_1+Z_{C1})Z_{L1}+R_1Z_{C1}}$$

$$V_A=\frac{V_1j\omega L_1-V_2\omega^2R_1L_1C_1+V_3R_1}{j\omega L_1-\omega^2R_1L_1C_1+R_1}$$

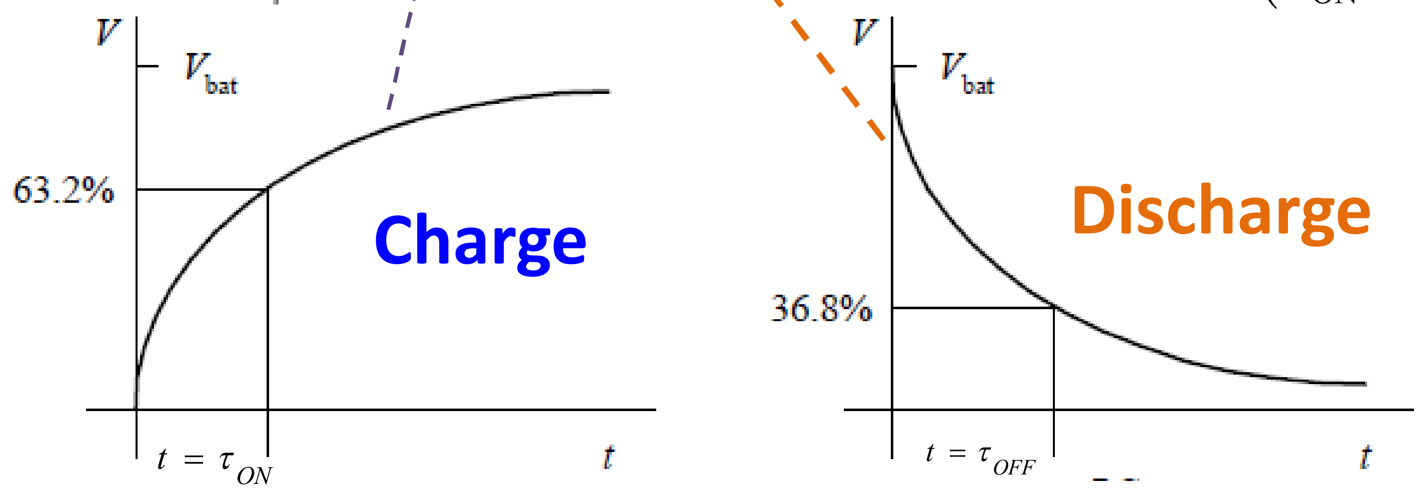
# 1. Research Background

## Switching Regulator




**Independence of PWM Frequency**

$$\overline{V_{out}} = \frac{T_{ON}}{(T_{ON} + T_{OFF})}\overline{V_{in}}$$

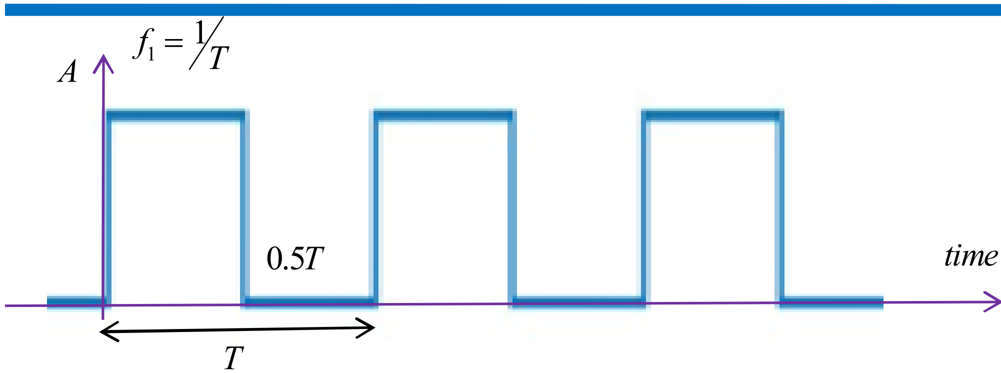



$$V_{Charge}(t_i) = \overline{V_{discharge}(t_{i-1})}\left(1 - e^{\frac{-t}{\tau_{ON}}}\right)$$

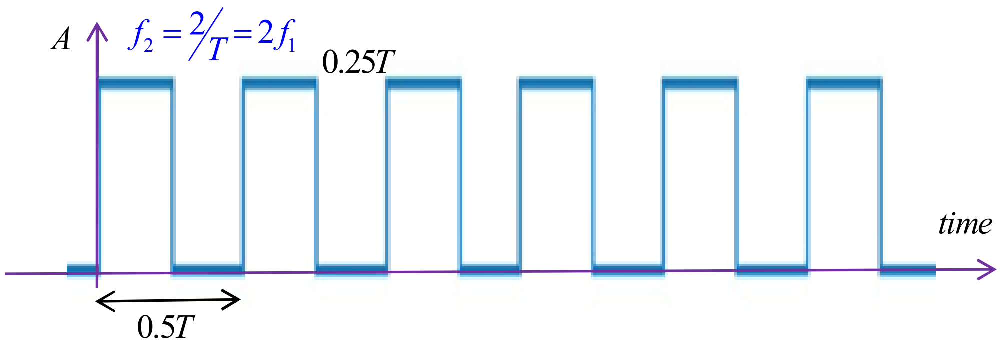
$$V_{discharge}(t_i) = \overline{V_{charge}(t_i)}e^{\frac{-t}{\tau_{OFF}}}$$

# 1. Research Background

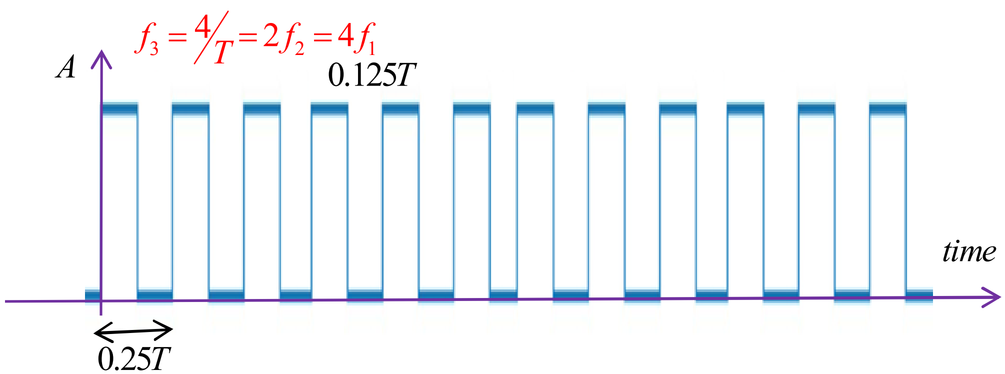
## Square Wave Functions




$$S_1(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi\left(2k-1\right)\left(f_1\right)t\right)}{2k-1}$$




$$S_2(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi\left(2k-1\right)\left(2f_1\right)t\right)}{2k-1}$$

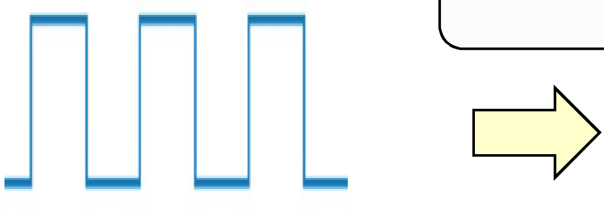



$$S_3(t) = \frac{4}{\pi}\sum_{k=1}^{\infty}\frac{\sin\left(2\pi\left(2k-1\right)\left(4f_1\right)t\right)}{2k-1}$$

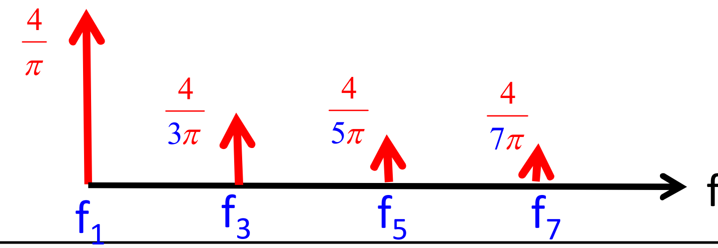
# 1. Research Background

## Harmonics of PWM Signals

50% Duty Cycle

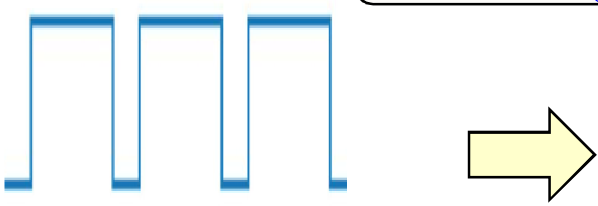


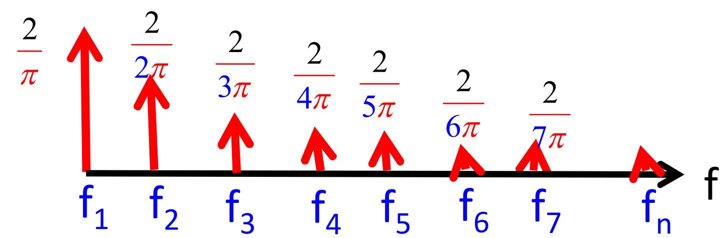
$$S_{PWM}(t)=\frac{4}{\pi}\left(\sin(2\pi ft)+\frac{1}{3}\sin(3*2\pi ft)+\frac{1}{5}\sin(5*2\pi ft)+\ldots\right)$$




75% Duty Cycle

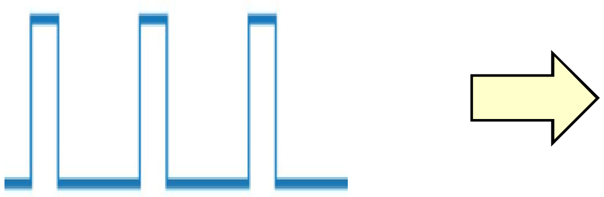
$$S_{PWM}(t)=\frac{4}{\pi}\left(\sin(2\pi ft)+\frac{1}{2}\sin(2*2\pi ft)+\frac{1}{3}\sin(3*2\pi ft)+\frac{1}{4}\sin(4*2\pi ft)+\frac{1}{5}\sin(5*2\pi ft)+\ldots\right)$$

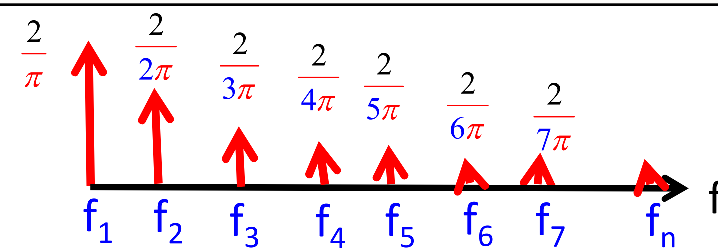





$$S_{PWM}(t)=\frac{4}{\pi}\left(\sin(2\pi ft)-\frac{1}{2}\sin(2*2\pi ft)+\frac{1}{3}\sin(3*2\pi ft)-\frac{1}{4}\sin(4*2\pi ft)+\frac{1}{5}\sin(5*2\pi ft)+\ldots\right)$$

25% Duty Cycle





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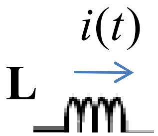
# 2. Analysis of Step-down Switching Converter

## Conventional Classical Technique

### Inductor

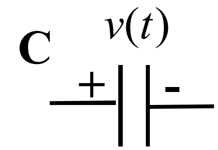



**Magnetic energy**

$$i(t) = \frac{1}{L}\int_{-\infty}^{t_0} v(\tau)d\tau + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau$$

$$= i(t_0^-) + \frac{1}{L}\int_{t_0}^{t} v(\tau)d\tau$$

### Capacitor




**Electric energy**

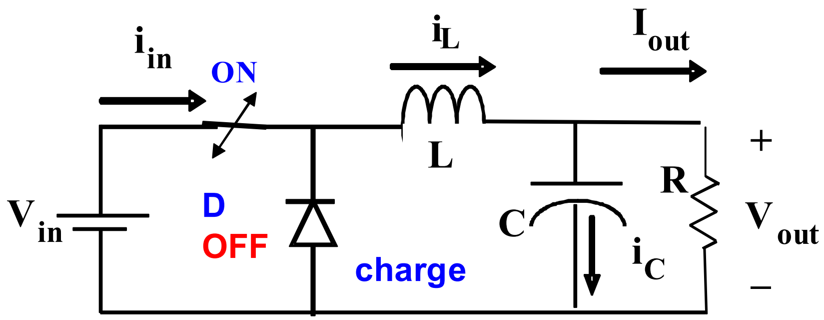
$$v(t) = \frac{1}{c}\int_{-\infty}^{t_0} i(\tau)d\tau + \frac{1}{c}\int_{t_0}^{t} i(\tau)d\tau$$

$$= v(t_0^-) + \frac{1}{c}\int_{t_0}^{t} i(\tau)d\tau$$

- **Advantages**
  - **Converts differential equation into algebraic equation.**
  - **Rapidly provides stability & transient response.**
- **Disadvantages**
  - **Applicable only to Linear, Time-Invariant (LTI) systems**

# 2. Analysis of Step-down Switching Converter

## Analysis of Buck Converter (Switch ON)




$$i_L(t) = I_{out}(t) + i_C(t)$$

$$V_{out}(t) = \frac{Q(t)}{C}; I_{out}(t) = \frac{V_{out}(t)}{R}; i_C(t) = C\frac{d\left(V_{out}(t)\right)}{dt}; i_L(t) = \frac{1}{L}\int_0^{T_{ON}} \left(V_{in} - V_{out}(t)\right)dt$$

$$\frac{V_{out}(t)}{R} + C\frac{dV_{out}(t)}{dt} = \frac{1}{L}\int_0^{T_{ON}} \left(V_{in} - V_{out}(t)\right)dt$$

$$\frac{V_{out}(t)}{R} + \frac{1}{L}\int_0^{T_{ON}} V_{out}(t)dt + C\frac{dV_{out}(t)}{dt} = \frac{1}{L}\int_0^{T_{ON}} V_{in}dt$$

$$\frac{1}{R}\frac{dV_{out}(t)}{dt} + \frac{V_{out}(t)}{L} + C\frac{d^2V_{out}(t)}{dt^2} = 0$$

$$\frac{d^2V_{out}(t)}{dt^2} + \frac{1}{RC}\frac{dV_{out}(t)}{dt} + \frac{V_{out}(t)}{LC} = 0$$

# 2. Analysis of Step-down Switching Converter

## Analysis of Buck Converter (Switch ON)

$$\frac{d^2V_{out}(t)}{dt^2}+\frac{1}{RC}\frac{dV_{out}(t)}{dt}+\frac{V_{out}(t)}{LC}=0$$

$$V_{out}(t)=Ae^{st}=A_1e^{s_1t}+A_2e^{s_2t}$$

$$\frac{d^2\left(Ae^{st}\right)}{dt^2}+\frac{1}{RC}\frac{d\left(Ae^{st}\right)}{dt}+\frac{\left(Ae^{st}\right)}{LC}=0$$

$$s^2+\frac{1}{RC}s+\frac{1}{LC}=0$$

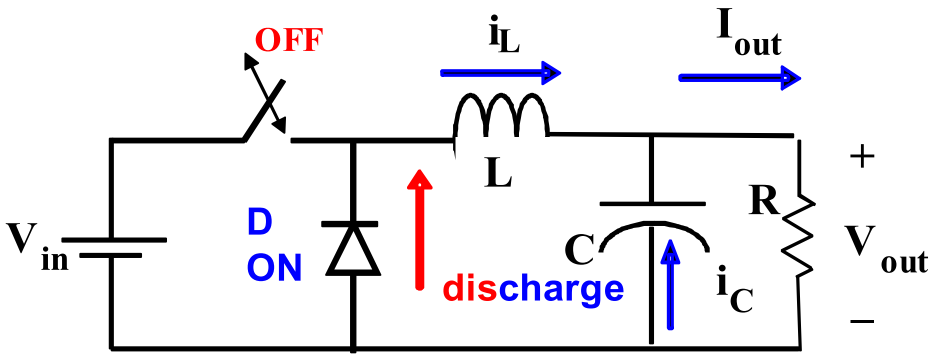
$$s_1=-\frac{1}{2RC}+\sqrt{\left(\frac{1}{2RC}\right)^2-\frac{1}{LC}} \quad \vee \quad s_2=-\frac{1}{2RC}-\sqrt{\left(\frac{1}{2RC}\right)^2-\frac{1}{LC}}$$

$$\omega_{2RC}=\frac{1}{2RC};\omega_{LC}=\frac{1}{\sqrt{LC}};$$

$$V_{charge}(t)=A_{ch1}e^{\left(-\omega_{2RC}+\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}+A_{ch2}e^{\left(-\omega_{2RC}-\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}$$

# 2. Analysis of Step-down Switching Converter

## Analysis of Buck Converter (Switch OFF)




$$I_{out}(t) = i_L(t) + i_C(t)$$

$$V_{dis}(t) = \frac{Q(t)}{C}; I_{out}(t) = \frac{V_{dis}(t)}{R}; i_C(t) = C\frac{d\left(V_{dis}(t)\right)}{dt}; i_L(t) = \frac{1}{L}\int_{T_{ON}}^{T_{OFF}}\left(V_{dis}(t) - V_{diode}\right)dt$$

$$\frac{V_{dis}(t)}{R} = C\frac{dV_{dis}(t)}{dt} + \frac{1}{L}\int_{T_{ON}}^{T_{OFF}}\left(V_{dis}(t) - V_{diode}\right)dt$$

$$C\frac{dV_{dis}(t)}{dt} - \frac{V_{dis}(t)}{R} + \frac{1}{L}\int_{T_{ON}}^{T_{OFF}} V_{dis}(t)dt = \frac{1}{L}\int_{T_{ON}}^{T_{OFF}} V_{diode}dt$$

$$C\frac{dV_{dis}(t)}{dt} - \frac{V_{dis}(t)}{R} + \frac{1}{L}\int_{T_{ON}}^{T_{OFF}} V_{dis}(t)dt = 0$$

$$\frac{d^2V_{dis}(t)}{dt^2} - \frac{1}{RC}\frac{dV_{dis}(t)}{dt} + \frac{V_{dis}(t)}{LC} = 0$$

# 2. Analysis of Step-down Switching Converter

## Analysis of Buck Converter (Switch OFF)

$$\frac{d^2 V_{dis}(t)}{dt^2} - \frac{1}{RC}\frac{dV_{dis}(t)}{dt} + \frac{V_{dis}(t)}{LC} = 0$$

$$V_{dis}(t) = A_{dis} e^{st} = A_3 e^{s_{dis1} t} + A_3 e^{s_{dis2} t}$$

$$\frac{d^2\left(A_{dis} e^{st}\right)}{dt^2} - \frac{1}{RC}\frac{d\left(A_{dis} e^{st}\right)}{dt} + \frac{\left(A_{dis} e^{st}\right)}{LC} = 0$$

$$s^2 - \frac{1}{RC}s + \frac{1}{LC} = 0$$

$$s_{dis1} = \frac{1}{2RC} + \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}} \quad \vee \quad s_{dis2} = \frac{1}{2RC} - \sqrt{\left(\frac{1}{2RC}\right)^2 - \frac{1}{LC}}$$

$$\omega_{2RC} = \frac{1}{2RC}; \omega_{LC} = \frac{1}{\sqrt{LC}};$$

$$V_{discharge}(t) = A_{dis1} e^{\left(\omega_{2RC} + \sqrt{\left(\omega_{2RC}\right)^2 - \omega_{LC}^2}\right)t} + A_{dis2} e^{\left(\omega_{2RC} + \sqrt{\left(\omega_{2RC}\right)^2 - \omega_{LC}^2}\right)t}$$

# 2. Analysis of Step-down Switching Converter

## Balanced Charge-Discharge Time Condition

$$\overline{V_{out}} = \frac{1}{(T_{ON}+T_{OFF})}\left(\int_0^{T_{ON}}\left(A_{ch1}e^{\left(-\omega_{2RC}+\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}+A_{ch2}e^{\left(-\omega_{2RC}-\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}\right)dt + \int_{T_{ON}}^{T_{OFF}}\left\{A_{dis1}e^{\left(\omega_{2RC}+\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}+A_{dis2}e^{\left(\omega_{2RC}-\sqrt{(\omega_{2RC})^2-\omega_{LC}^2}\right)t}\right\}dt\right)$$

$$\omega_{2RC}=\omega_{LC} \Leftrightarrow \omega = \frac{1}{\sqrt{LC}} = \frac{1}{2RC}$$

$$\omega L = \frac{1}{\omega C} = 2R$$

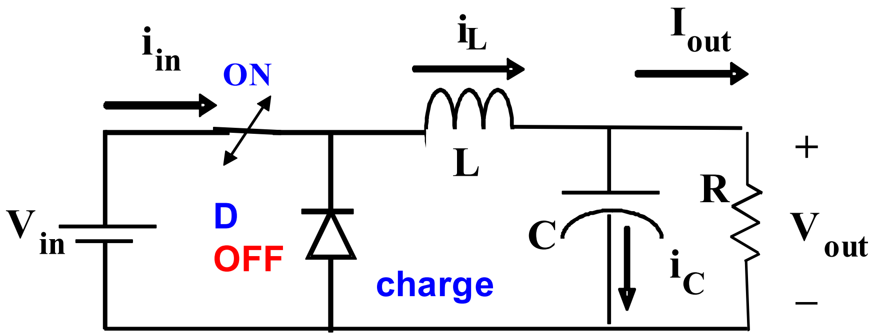
$$|Z_L| = |Z_C| = 2R$$

**Balanced Charge-Discharge Time Condition**

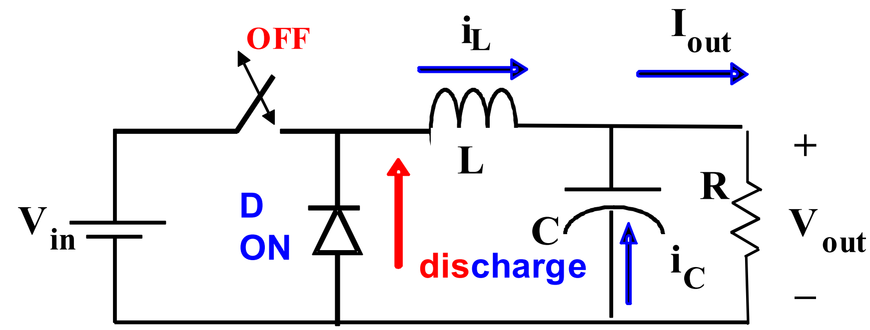
$$\overline{V_{out}} = \frac{1}{(T_{ON}+T_{OFF})}\left(\int_0^{T_{ON}} A_{ch}e^{-\omega t}dt + \int_{T_{ON}}^{T_{OFF}} A_{dis}e^{\omega t}dt\right)$$

# 2. Analysis of Step-down Switching Converter

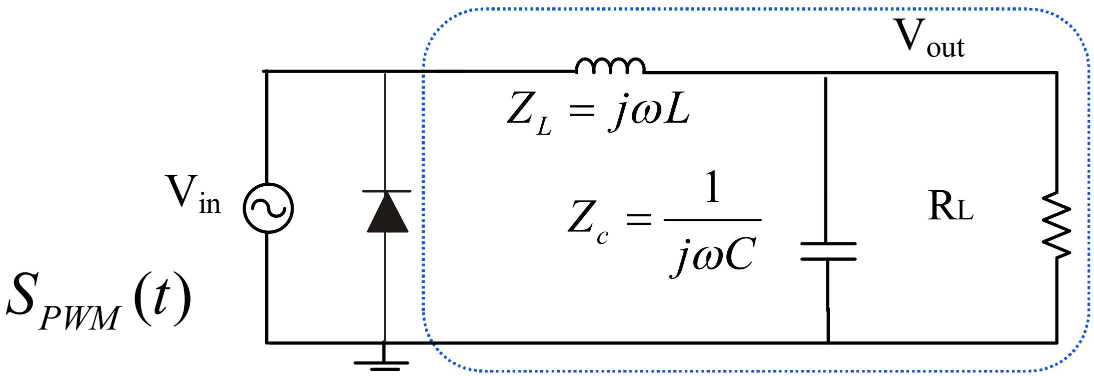
## Proposed Analysis Model of Buck Converter




**Switch ON**




**Switch OFF**

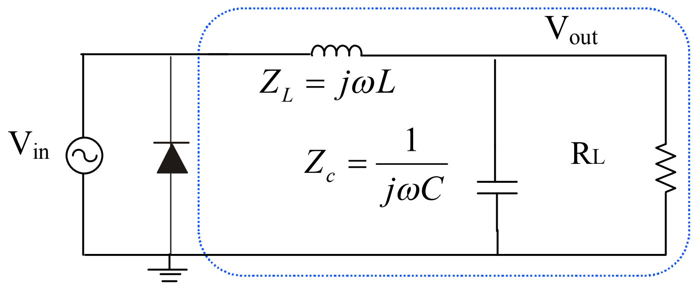



**Model of Buck Converter**

# 2. Analysis of Step-down Switching Converter

## Transfer Function of Proposed Analysis Model

**Proposed analysis model**




**Superposition principle**

$$V_o\left(\frac{1}{Z_L}+\frac{1}{Z_C}+\frac{1}{R}\right)=\frac{V_{in}}{Z_L}$$

**Output Voltage**

$$V_o=V_{in}\frac{RZ_C}{R\left(Z_L+Z_C\right)+Z_LZ_C}$$

**Transfer Function**

$$H=\frac{V_o}{V_{in}}=\frac{RZ_C}{R\left(Z_L+Z_C\right)+Z_LZ_C}$$

$$H\left(j\omega\right)=\frac{\frac{1}{LC}}{\left(j\omega\right)^2+j\omega\frac{1}{RC}+\frac{1}{LC}}$$

# 2. Analysis of Step-down Switching Converter

## Max Power Propagation Condition

**Transfer Function**

$$H(j\omega) = \frac{\frac{1}{LC}}{(j\omega)^2 + j\omega\frac{1}{RC} + \frac{1}{LC}}$$

$$H(j2\pi f) = \frac{\frac{1}{(2\pi)^2 LC}}{(j*f)^2 + j*f\frac{1}{2\pi RC} + \frac{1}{(2\pi)^2 LC}}$$

$$|H(f)| = \frac{\frac{1}{(2\pi)^2 LC}}{\sqrt{\left(\frac{1}{(2\pi)^2 LC} - f^2\right)^2 + \left(\frac{f}{2\pi RC}\right)^2}}$$

$$|Z_L| = |Z_C| = 2R$$

**Balanced Charge-Discharge Time Condition**

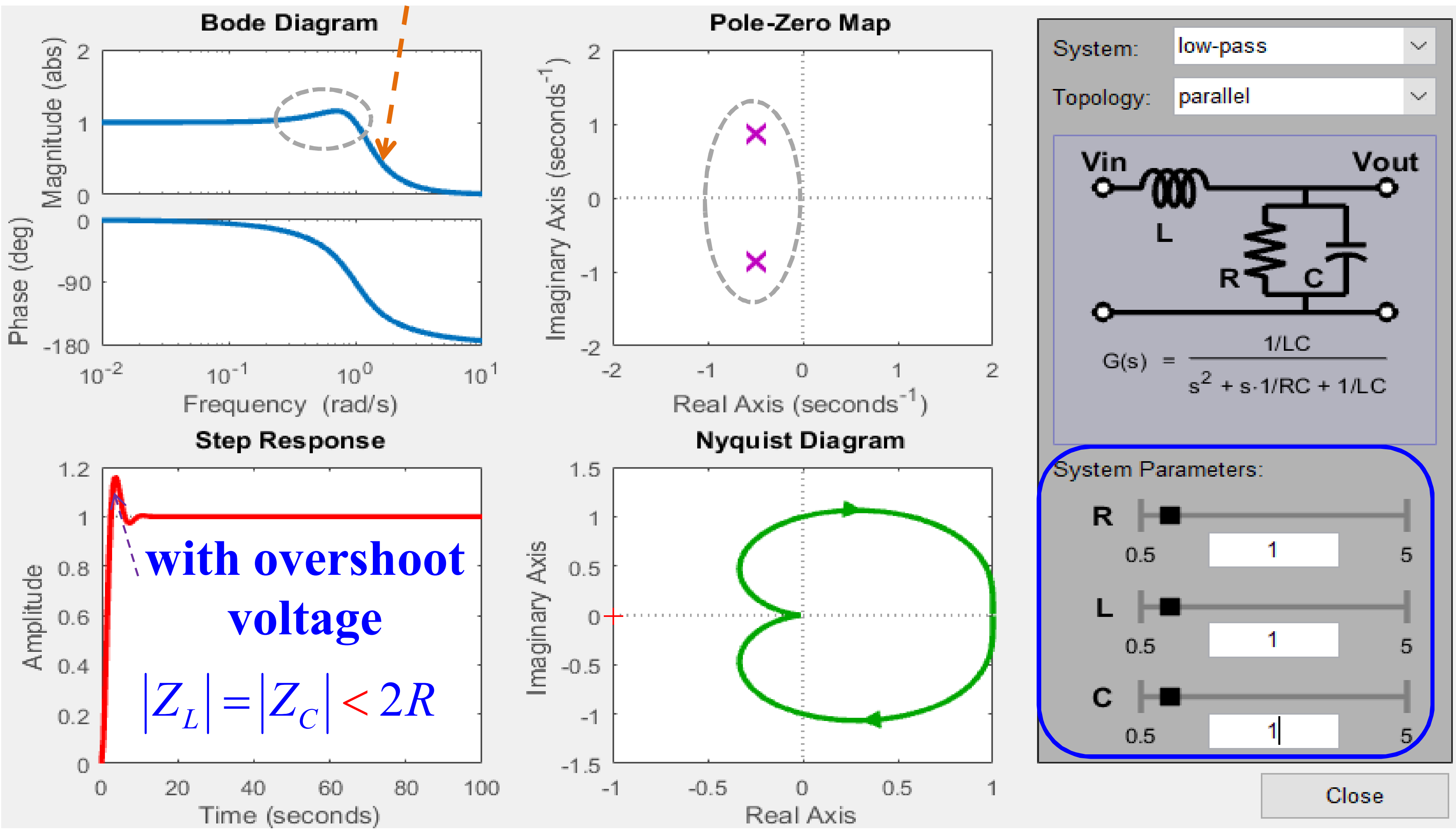
$$|H(f)| = \frac{\frac{1}{(2\pi)^2 LC}}{\left(\frac{1}{4\pi RC}\right)^2 + f^2} \Rightarrow |H(f)| = \frac{1}{2}$$

*when* $f = \frac{1}{4\pi RC} = \frac{1}{2\pi\sqrt{LC}}$

# 2. Analysis of Step-down Switching Converter

## Simulation of Un-balanced Charge-discharge Time

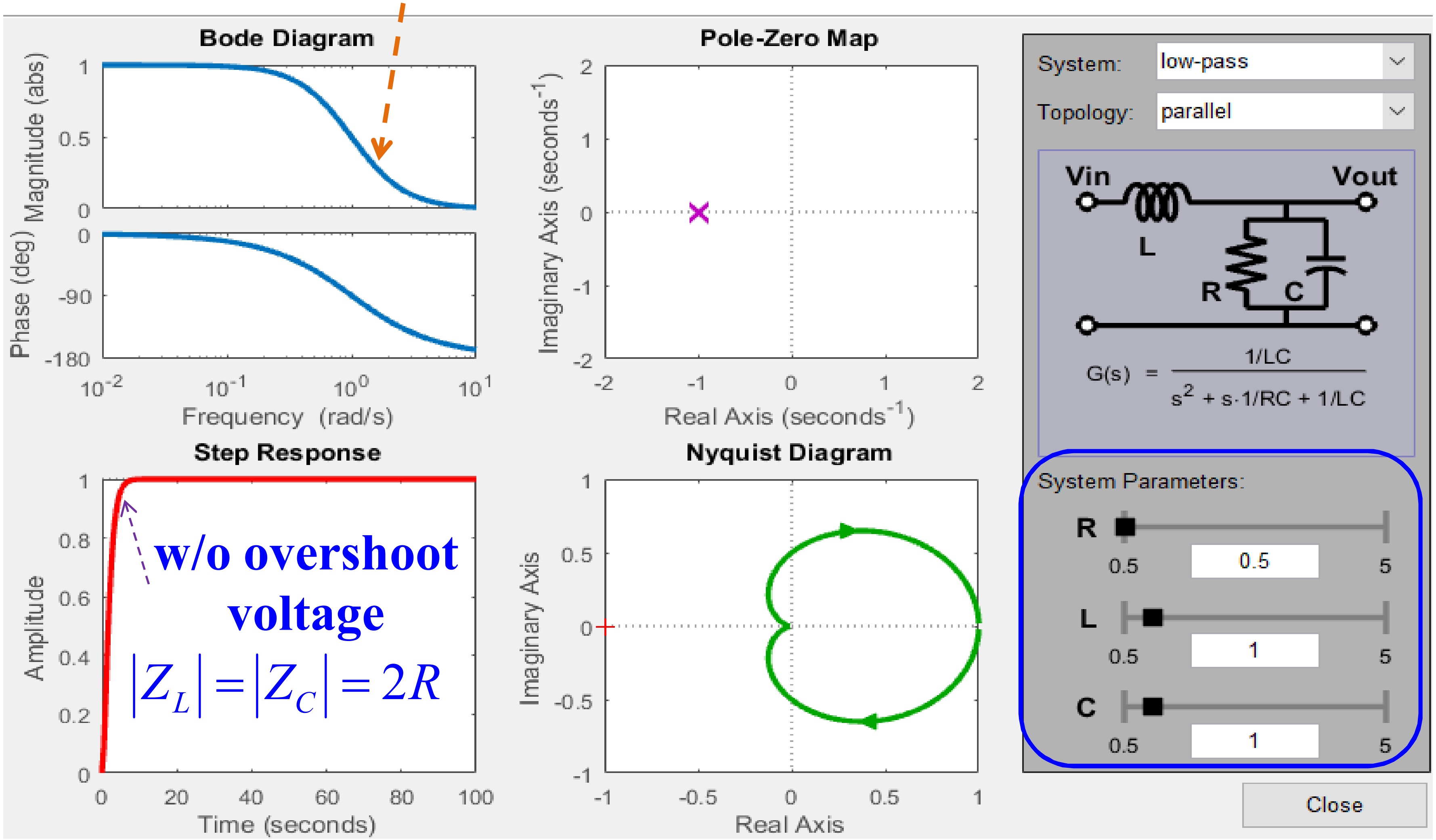
$$\omega_{cut\_off} = \frac{1}{\sqrt{LC}} = 1(rad/s) \qquad |Z_L| = |Z_C| = 1\Omega;\ 2R = 2\Omega$$



# 2. Analysis of Step-down Switching Converter

## Simulation of Balanced Charge-discharge Time

$$\omega_{cut\_off} = \frac{1}{\sqrt{LC}} = 1(rad/s) \qquad |Z_L| = |Z_C| = 1\Omega;\ 2R = 1\Omega$$



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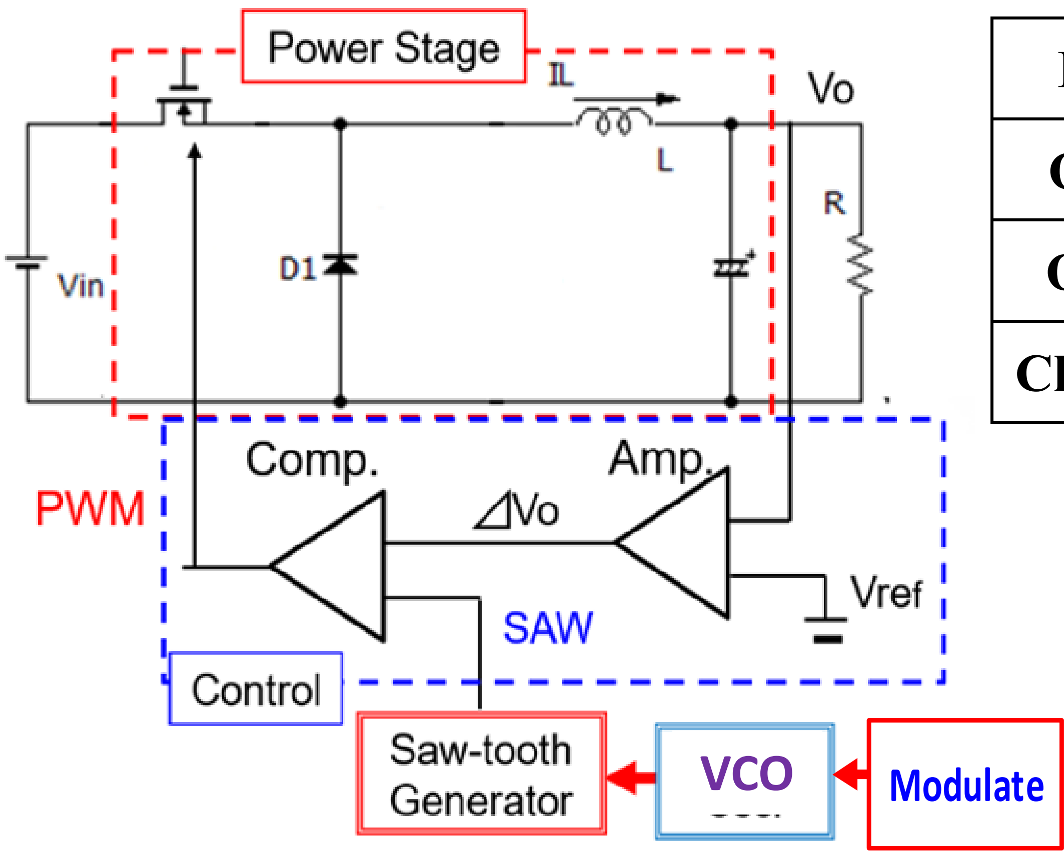
# 3. Proposed Design of Buck Converter

## Conventional Step-down Switching Converter

**VCO : Voltage Controlled Oscillator**




| | |
|---|---|
| Input Voltage (Vin) | 12V |
| Output Voltage (Vo) | 5.0V |
| Output Current (Io) | 1.0A |
| Clock Frequency (Fck) | 200kHz |

**EMI Reduction using Spread Spectrum of VCO**

**Circuit with Frequency Modulation**

# 3. Proposed Design of Buck Converter

## Frequency Modulation of VCO

**Frequency Modulation function:**

$$\theta_{VCO}(t) = \omega_{VCO}t + \phi_m(t)$$

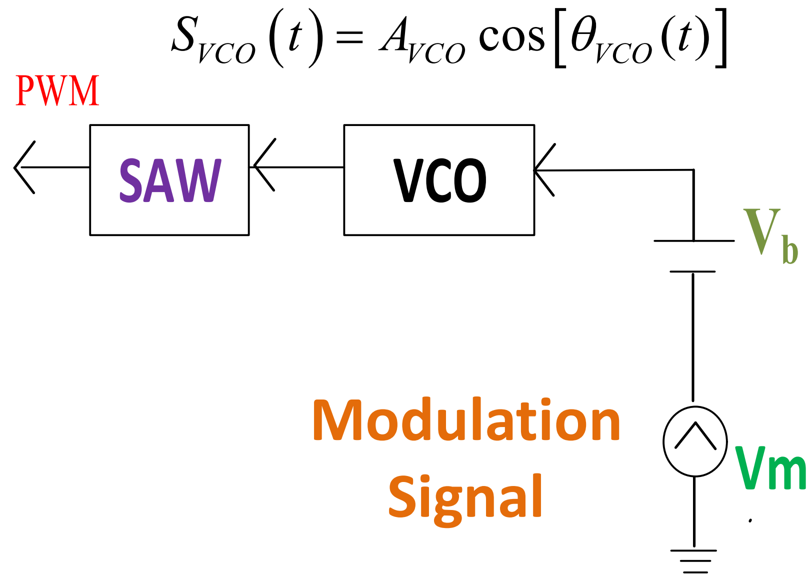
$$S_{VCO}(t) = A_{VCO}\cos\left[\omega_{VCO}t + \phi_m(t)\right]$$

$$\omega_{VCO} = KV_b$$

$$V_m(t) = A_m\cos(2\pi f_m t)$$

$$\phi_m(t) = KV_m(t) = KA_m\cos(2\pi f_m t)$$

$$\theta_{VCO}(t) = KV_b t + KA_m\cos(2\pi f_m t)$$



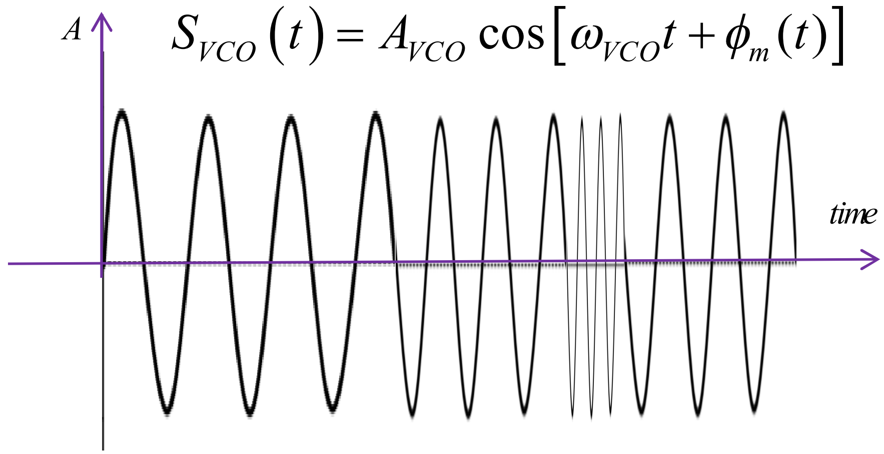

$K$: sensitivity of VCO

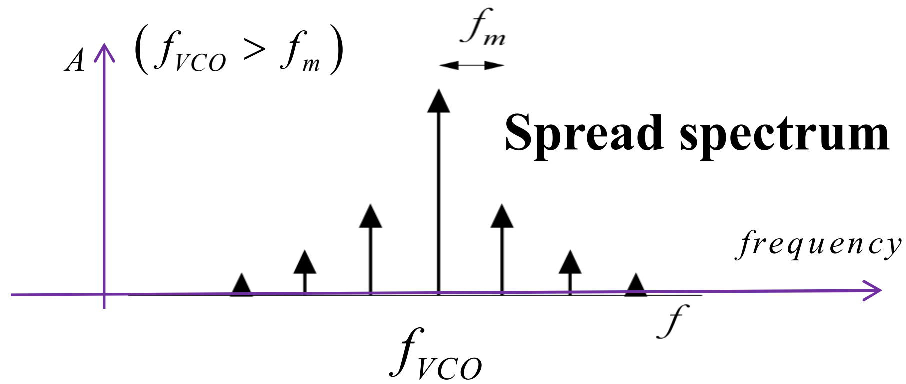
$V_b$: bias voltage

$V_m$: modulation signal

# 3. Proposed Design of Buck Converter

## Spectrum of VCO Signals




$$\cos(x) = \sum_{k=0}^{\infty}\frac{(-1)^k x^{2k}}{(2k)!} = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + $$

Frequency Modulation function:

$$\theta_{VCO}(t) = KV_bt + KA_m\cos(2\pi f_m t)$$
$$= KV_bt + KA_m\sum_{k=0}^{\infty}\frac{(-1)^k(2\pi f_m t)^{2k}}{(2k)!}$$
$$= KV_bt + KA_m\left(1 - \frac{(2\pi f_m t)^2}{2!} + \frac{(2\pi f_m t)^4}{4!} - \frac{(2\pi f_m t)^6}{6!} + \right)$$

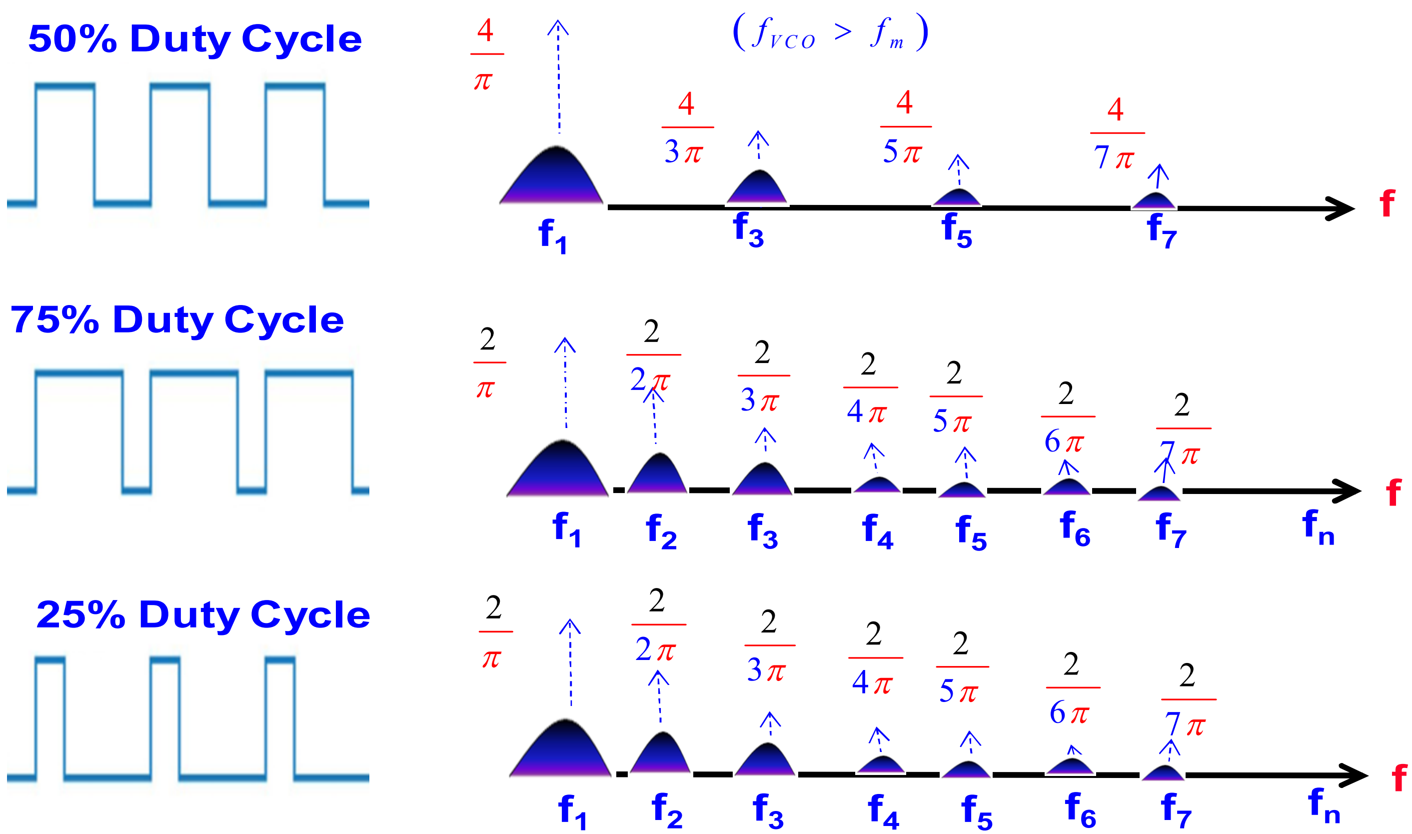
$$V_m(t) = A_m\cos(2\pi f_m t)$$
$$= \sum_{k=0}^{\infty}\frac{(-1)^k(2\pi f_m t)^{2k}}{(2k)!}$$
$$= 1 - \frac{(2\pi f_m t)^2}{2!} + \frac{(2\pi f_m t)^4}{4!} - \frac{(2\pi f_m t)^6}{6!} + $$

# 3. Proposed Design of Buck Converter

## Spread Spectrum of PWM Signals

$$S_{VCO}(t) = A_{VCO}\cos\left[\omega_{VCO}t + \phi_m(t)\right]$$

$$= A_{VCO}\cos\left[KV_b t + KA_m\left(1 - \frac{(2\pi f_m t)^2}{2!} + \frac{(2\pi f_m t)^4}{4!} - \frac{(2\pi f_m t)^6}{6!} + \right)\right]$$

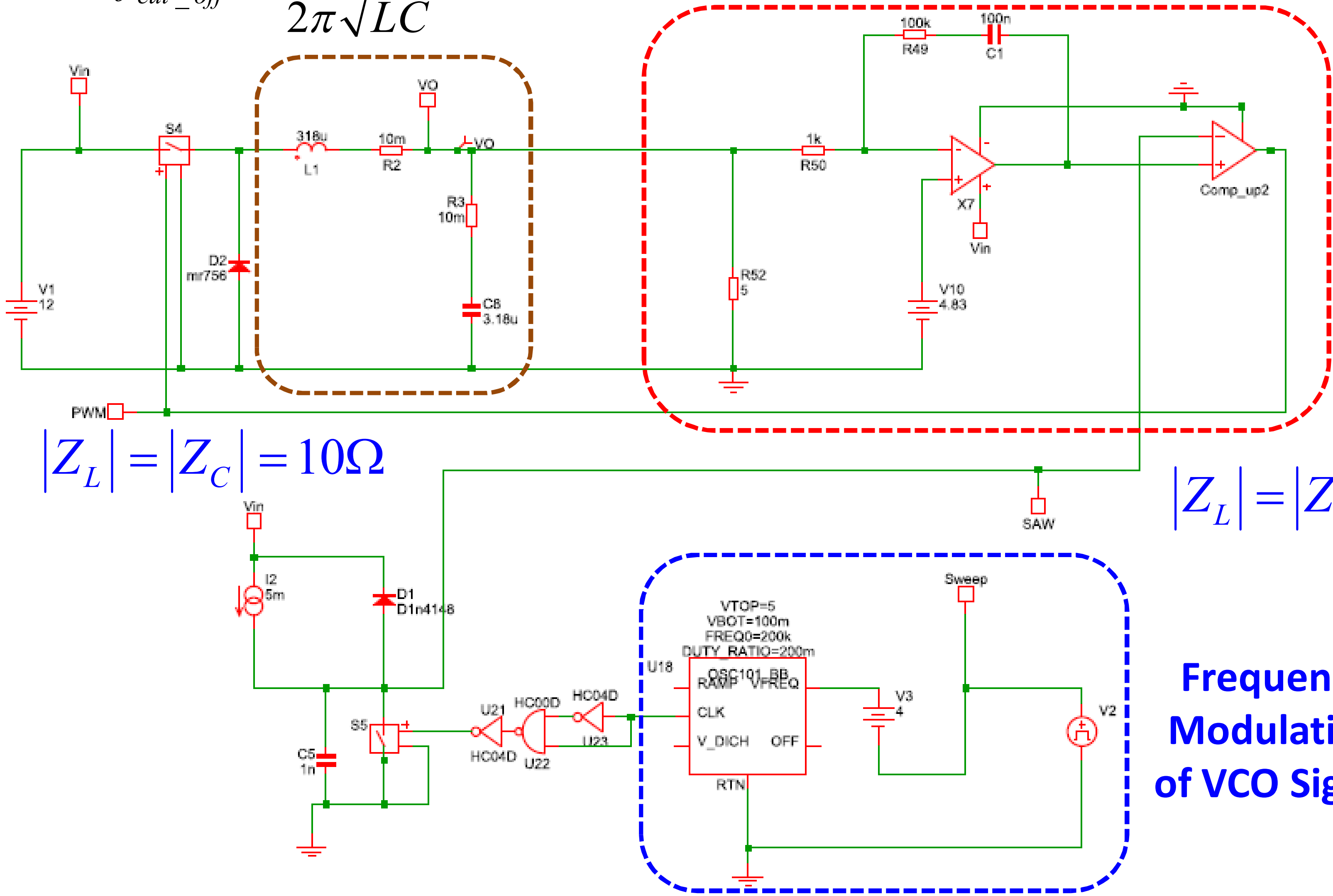


# 3. Proposed Design of Buck Converter

## Simulation of Conventional Buck Converter

$$f_{cut\_off} = \frac{1}{2\pi\sqrt{LC}} = 5kHz$$

$$R_{total} > 5\Omega$$



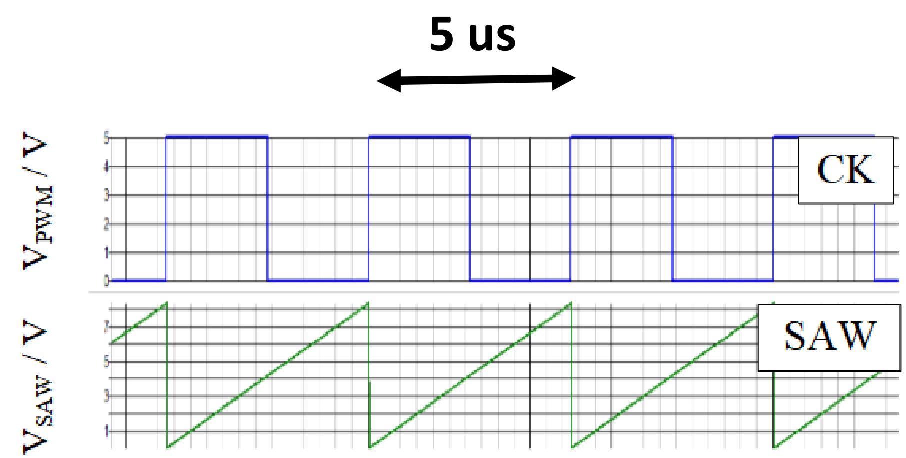

$$|Z_L| = |Z_C| = 10\Omega$$

$$|Z_L| = |Z_C| < 2R$$

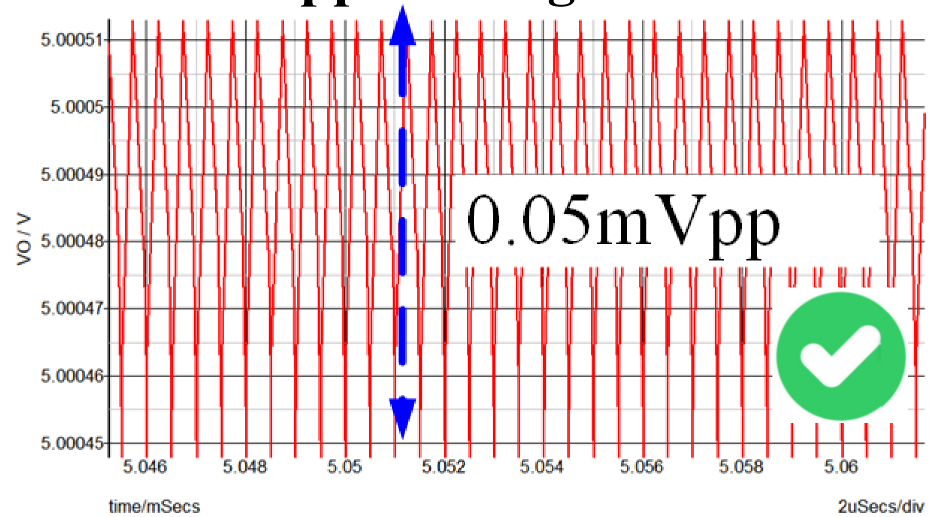
**Frequency Modulation of VCO Signal**

# 3. Proposed Design of Buck Converter

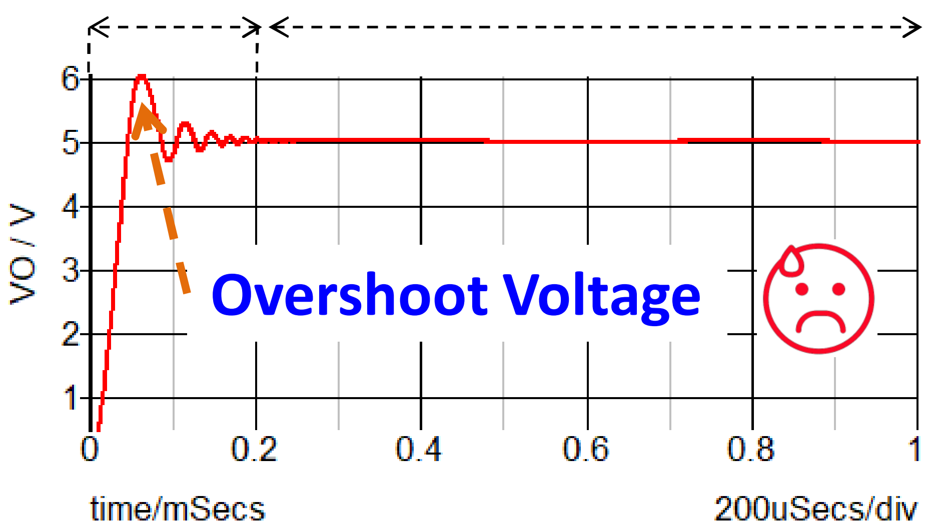
## Waveforms of Conventional Buck Converter



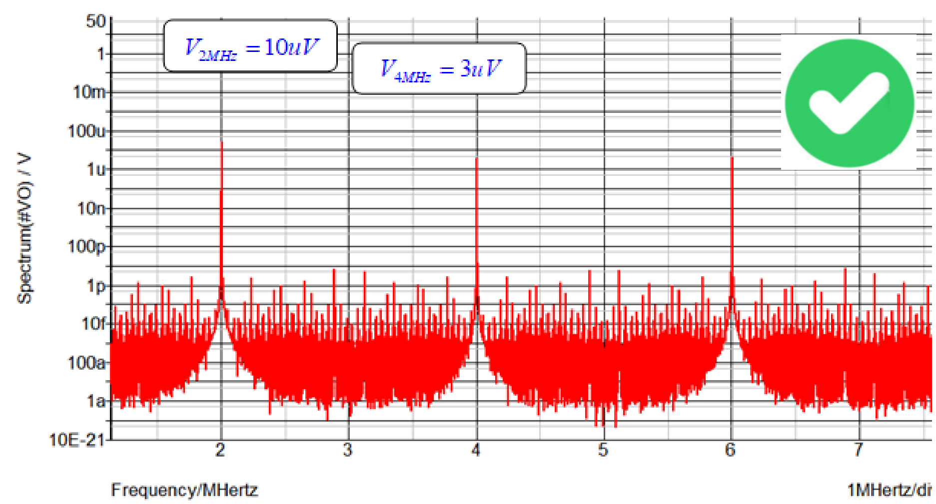

**Ripple voltages**




**Transient state** **Stable state**

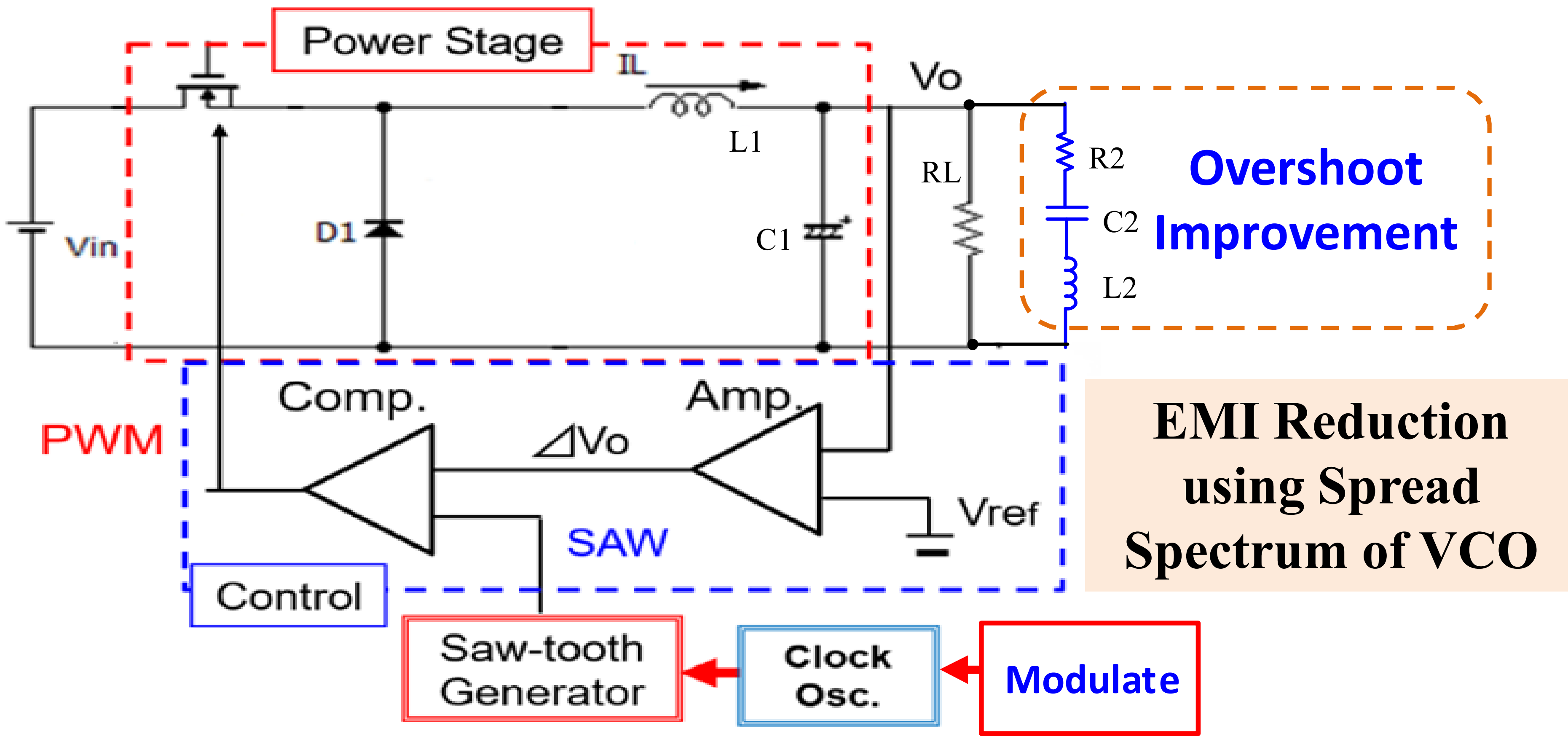



**Spectrum of ripple voltages**



# 3. Proposed Design of Buck Converter

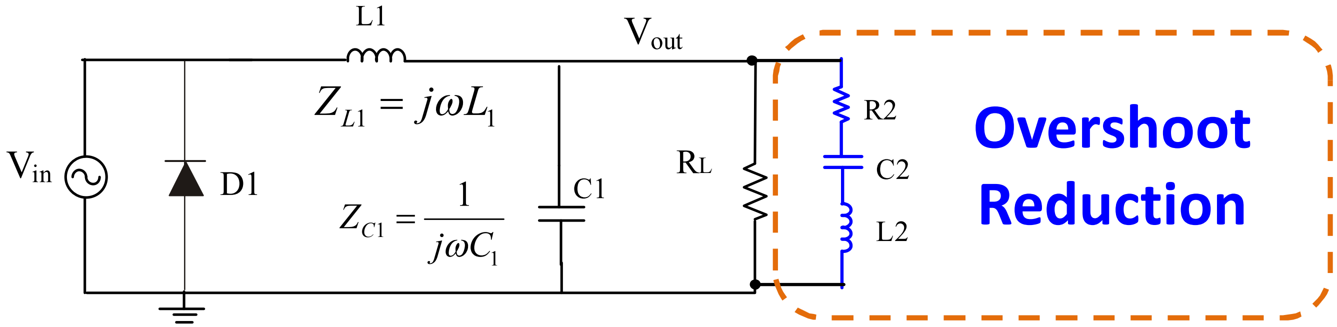
## Proposed Design of Step-down Switching Converter



# 3. Proposed Design of Buck Converter

## Overshoot Improvement with Parallel RLC Network

**Proposed model**




**Superposition principle**

$$V_o\left(\frac{1}{Z_{L1}}+\frac{1}{Z_{C1}}+\frac{1}{R_L}+\frac{1}{R_2+Z_{L2}+Z_{C2}}\right)=\frac{V_{in}}{Z_{L1}}$$

**Output Voltage**

$$V_o = V_{in}\frac{\left(Z_{L2}+Z_{C2}+R_2\right)Z_{L1}R_L}{\left(Z_{L2}+Z_{C2}+R_2\right)\left[R_L\left(Z_{L1}+Z_{C1}\right)+Z_{L1}Z_{C1}\right]+Z_{L1}Z_{C1}R_L}$$

**Transfer Function**

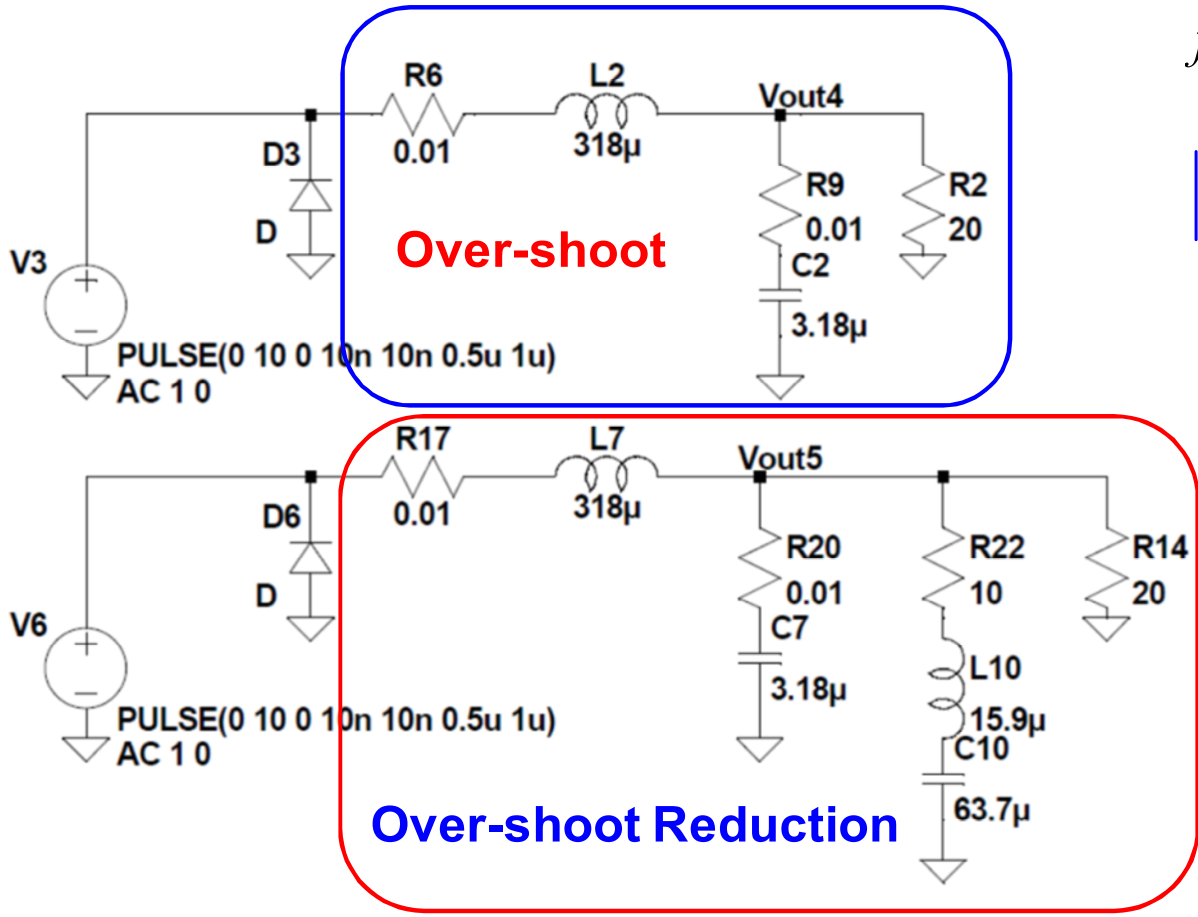
$$H=\frac{V_o}{V_{in}}=\frac{\left(Z_{L2}+Z_{C2}++R_2\right)Z_{L1}R_L}{\left(Z_{L2}+Z_{C2}+R_2\right)\left[R_L\left(Z_{L1}+Z_{C1}\right)+Z_{L1}Z_{C1}\right]+Z_{L1}Z_{C1}R_L}$$

$$H(j\omega)=\frac{\frac{1}{L_1C_1}\left((j\omega)^2+j\omega\frac{R_2}{L_2}+\frac{1}{L_2C_2}\right)}{\left((j\omega)^2+j\omega\frac{R_2}{L_2}+\frac{1}{L_2C_2}\right)\left((j\omega)^2+j\omega\frac{1}{R_LC_1}+\frac{1}{L_1C_1}\right)+\frac{(j\omega)^2}{L_2C_1}}$$

# 3. Proposed Design of Buck Converter

## Simulation of Parallel RLC Network

$$|Z_L| = |Z_C| = 10\Omega < 2R = 40\Omega$$




**Cutoff frequency**

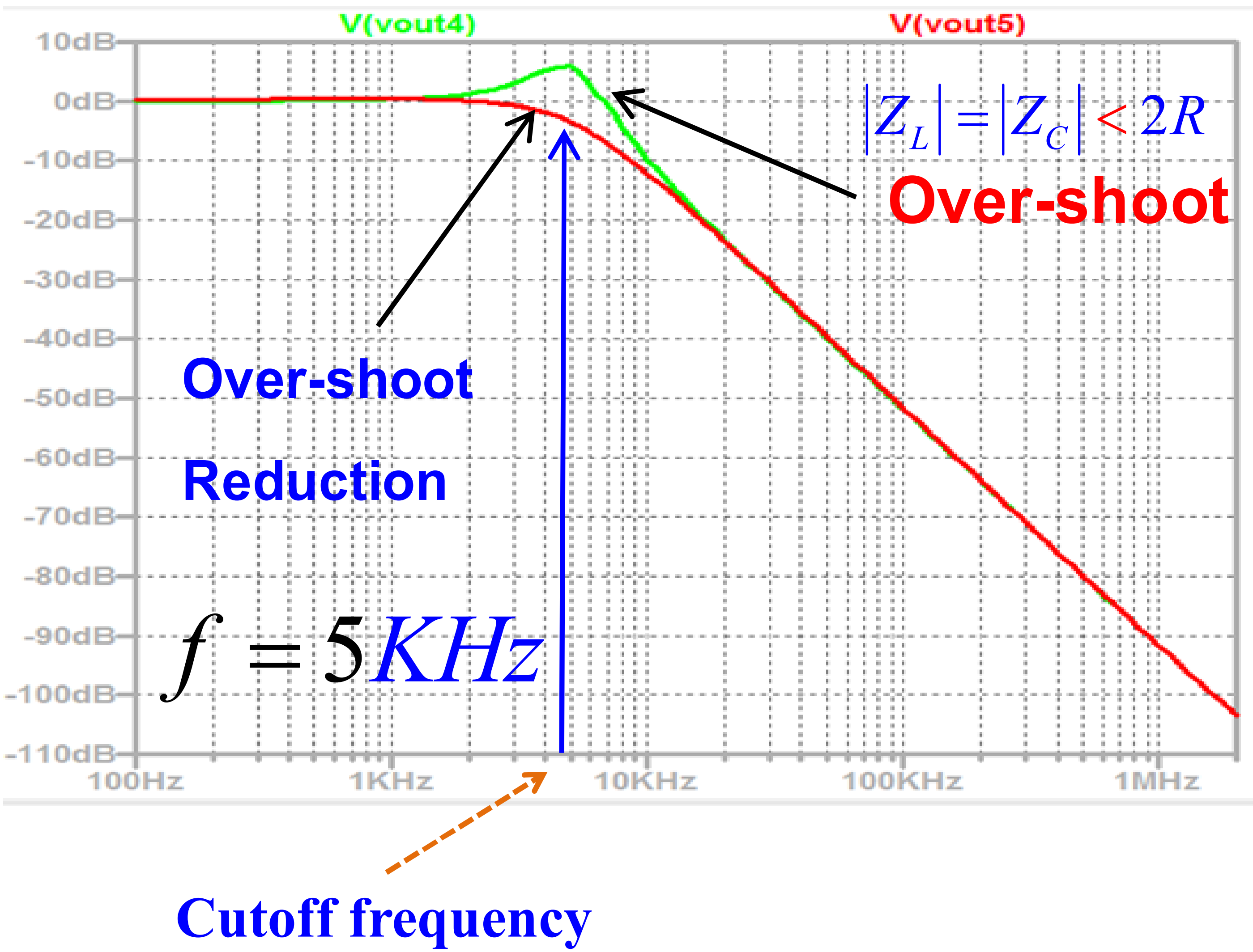
$$f_{cut\_off} = \frac{1}{2\pi\sqrt{LC}} = 5kHz$$

$$|Z_L| = |Z_C| = 10\Omega;$$

$$2R = 40\Omega$$

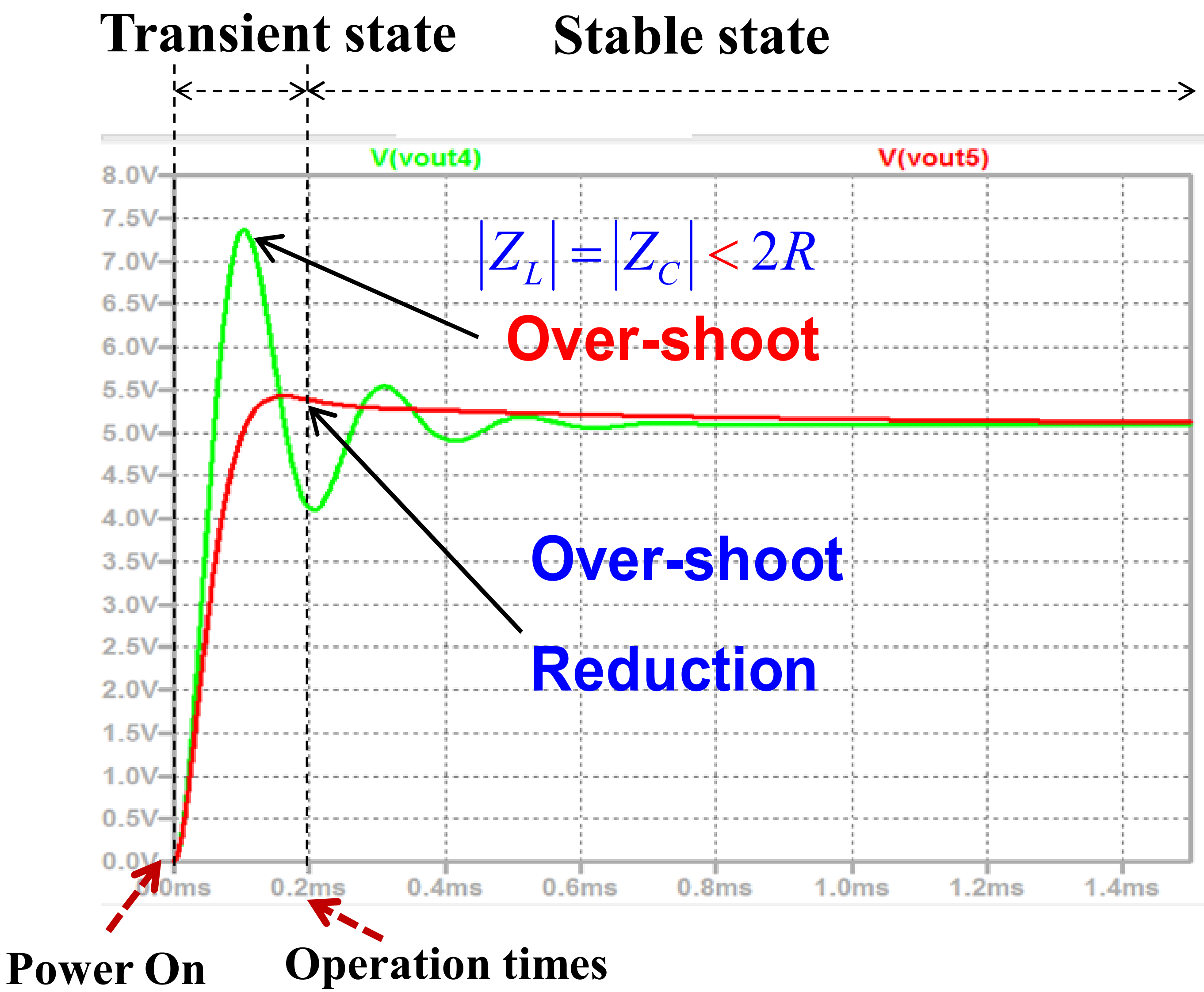
# 3. Proposed Design of Buck Converter

## Frequency Response of Parallel RLC Network



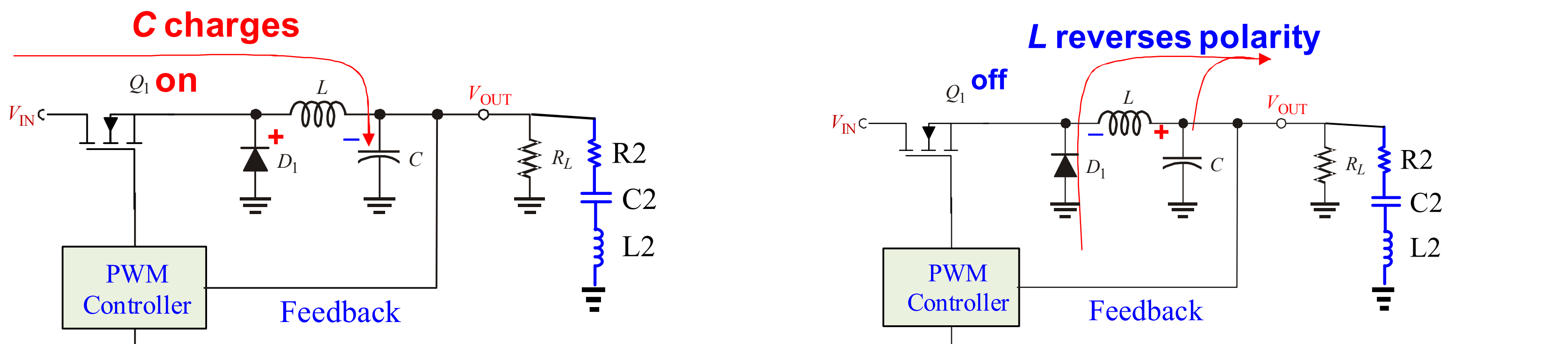
# 3. Proposed Design of Buck Converter

## Transient Response of Parallel RLC Network



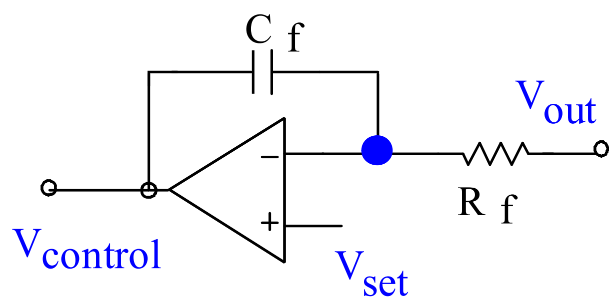
# 3. Proposed Design of Buck Converter

## Analysis of Feedback Voltage Control




(a) (b)

**Feedback Voltage Control**




(c)

$$V_{set}\left(\frac{1}{Z_f}+\frac{1}{R_f}\right)=\frac{V_{control}}{Z_f}+\frac{V_{out}}{R_f}$$

**Keep small difference**

$$V_{control}=V_{set}+\frac{Z_{Cf}}{R_f}\left(V_{set}-V_{out}\right)=V_{set}+\boxed{\frac{1}{j\omega C_f R_f}\left(V_{set}-V_{out}\right)}$$

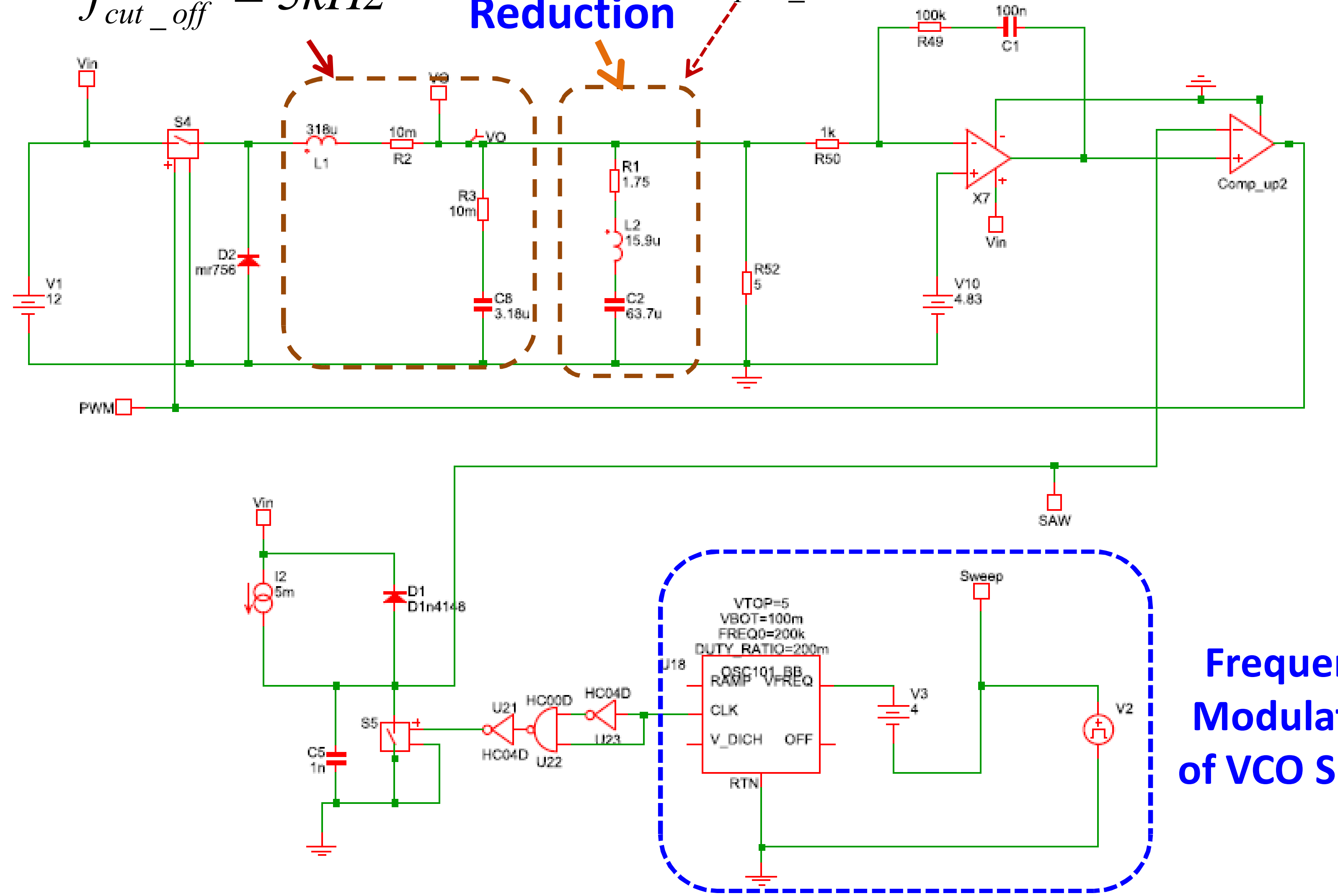
# 3. Proposed Design of Buck Converter

## Proposed Design of Step-down Switching Converter

$$f_{cut\_off} = 5kHz$$

**Overshoot Reduction**

$$f_{par\_RLC} = 5kHz$$




**Frequency Modulation of VCO Signal**

# 3. Proposed Design of Buck Converter

## Overshoot Reduction Waveforms

**without parallel RLC network**

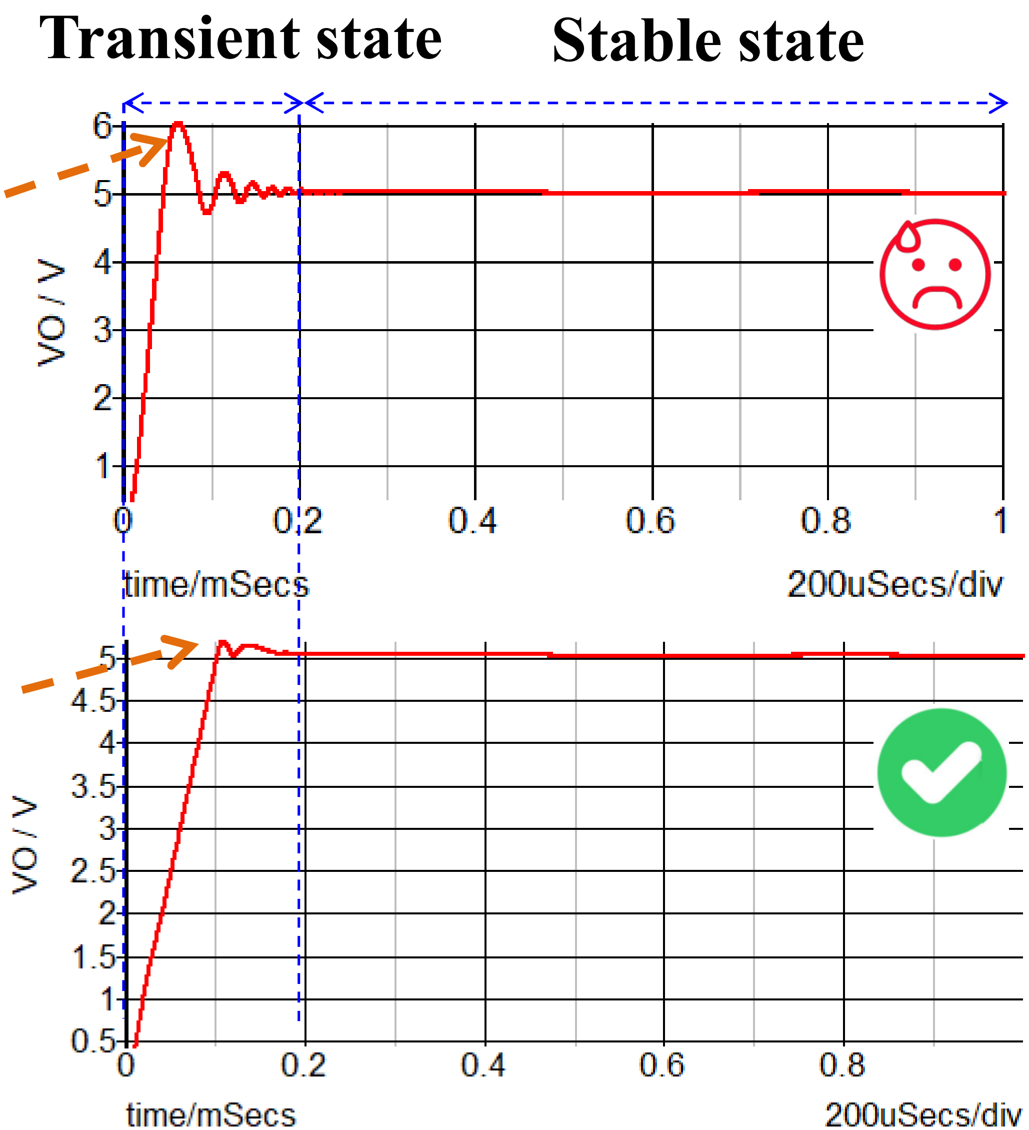
**Overshoot Voltage**

**>1 Vpp**

**with parallel RLC network**

**Overshoot Voltage Reduction**

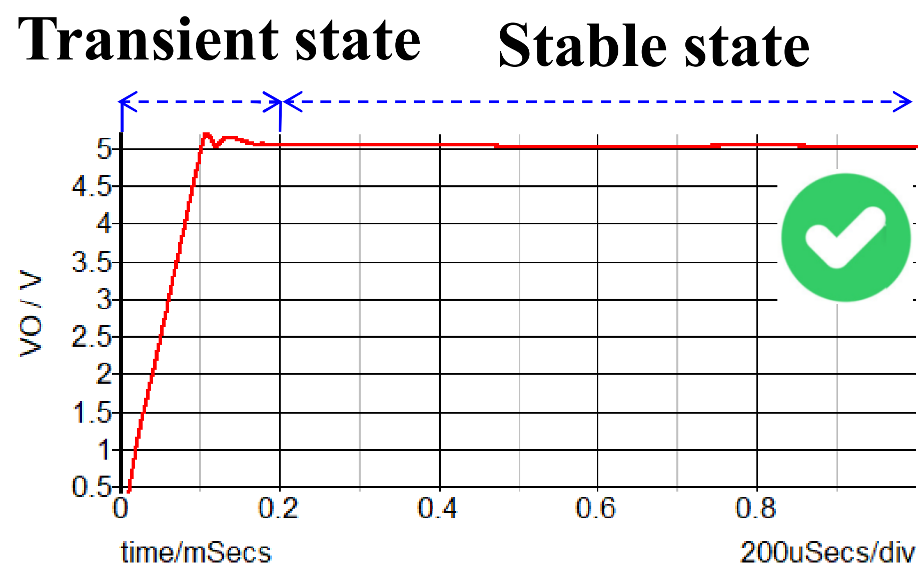
**< 0.1 Vpp**



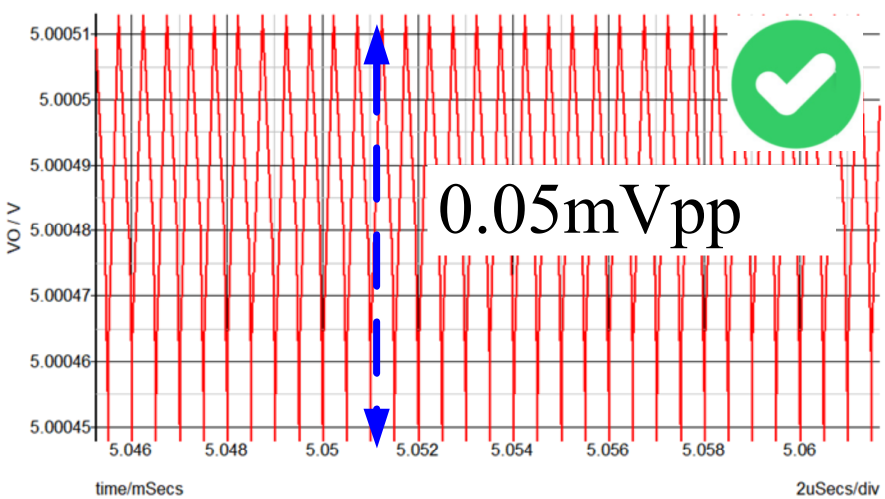
# 3. Proposed Design of Buck Converter

## Waveforms of Proposed Buck Converter

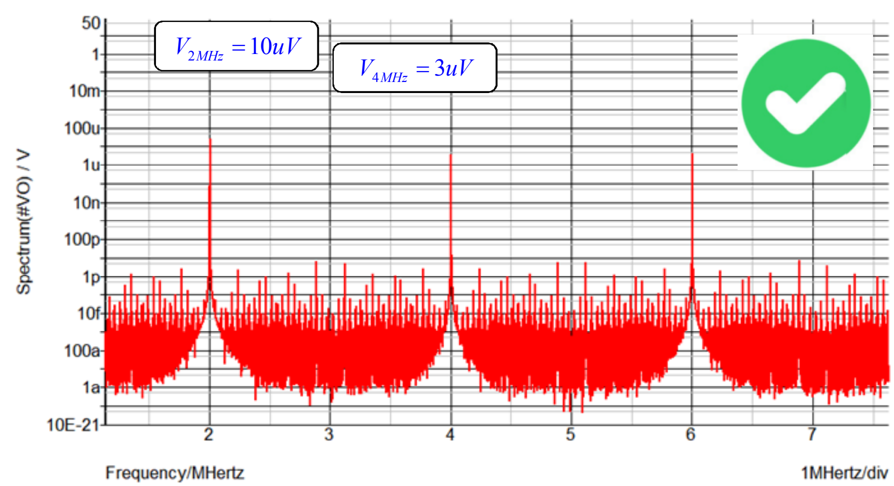
- Input Voltage (Vin): 12V
- Output Voltage (Vo): 5.0V
- Output Current (Io): 1A
- Clock Frequency (Fck): 200kHz
- Overshoot: 0.1V
- Ripple Voltage: 0.05mVpp




**Ripple voltages**




**Spectrum of ripple voltages**



# Outline

1. Research Background
    - Applications of Switching Power Supply
    - Basic Switching Converter Architecture
2. Analysis of Step-down Switching Converter
    - Conventional Classical Technique
    - Superposition Principle
3. Proposed Design of Buck Converter
    - Overshoot Improvement with Parallel RLC Network
    - Simulation Results
4. **Conclusions**

# 4. Conclusions

**This work:**

- **Balanced charge-discharge time condition**

$$|Z_L| = |Z_C| = 2R \Rightarrow \omega L = \frac{1}{\omega C} = 2R \qquad \omega = \frac{1}{\sqrt{LC}} = \frac{1}{2RC}$$

- **Analysis model of Buck converter system based on classical technique and superposition principle**
- **Overshoot improvement with parallel RLC network**

  **→ Overshoot reduction from 1Vpp into 0.1Vpp**

**Future of Work**

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

# Thanks for your kind attention!

# Questions & Answers

1) **Why was the balanced charge-discharge time condition introduced in this research?**

   → **Because the overshoot phenomena will be detected if this balanced condition is not satisfied.**

   **(Based on the selection of R, L and C components, the overshoot voltage can be perfectly controlled.)**

2) **Was the source code program written to simulate the parallel low-pass filter of Buck converter on Mat-labs?**

   → **No, it wasn't.**

   **(There is a stool on Mat-labs to simulate this filter.)**