# Derivation of Loop Gain from Output Impedances in DC-DC Buck Converter

Nobukazu Tsukiji*

Y. Kobori and H. Kobayashi

Faculty of Science and Technology

Gunma University

(S06-7)


群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

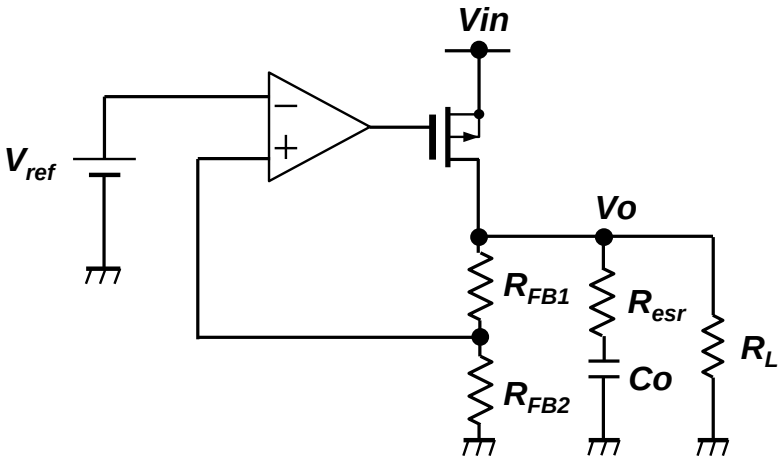
# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

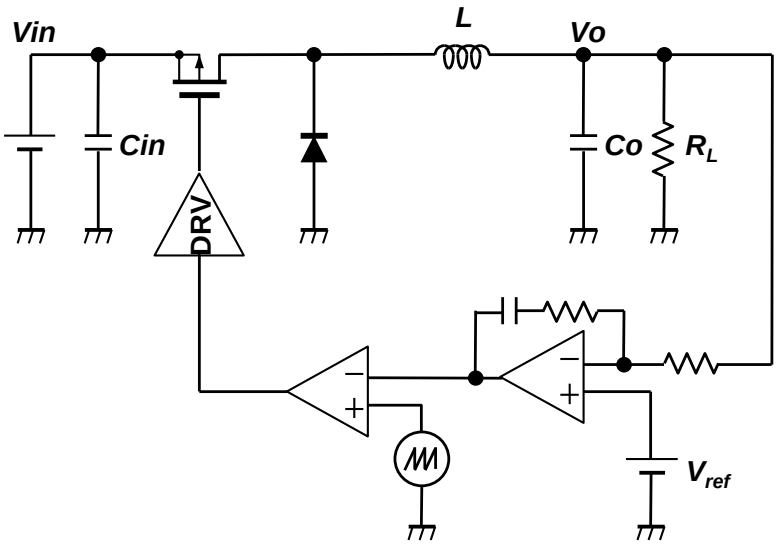
# Research Background(1)

- There are a lot of applications using negative feedback systems.

## Low Drop Out Regulator

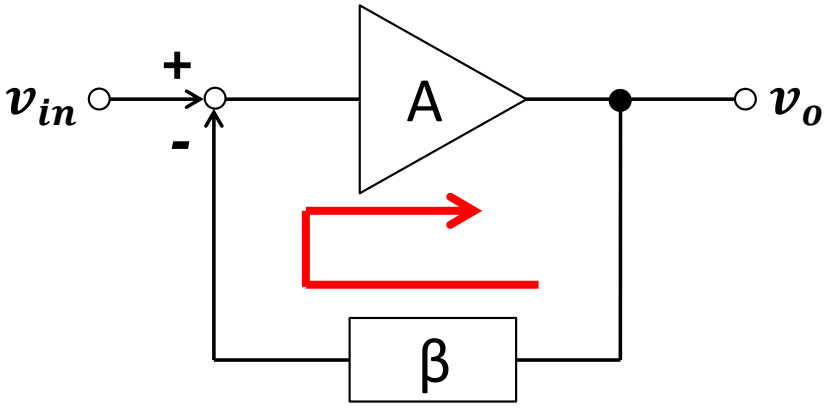


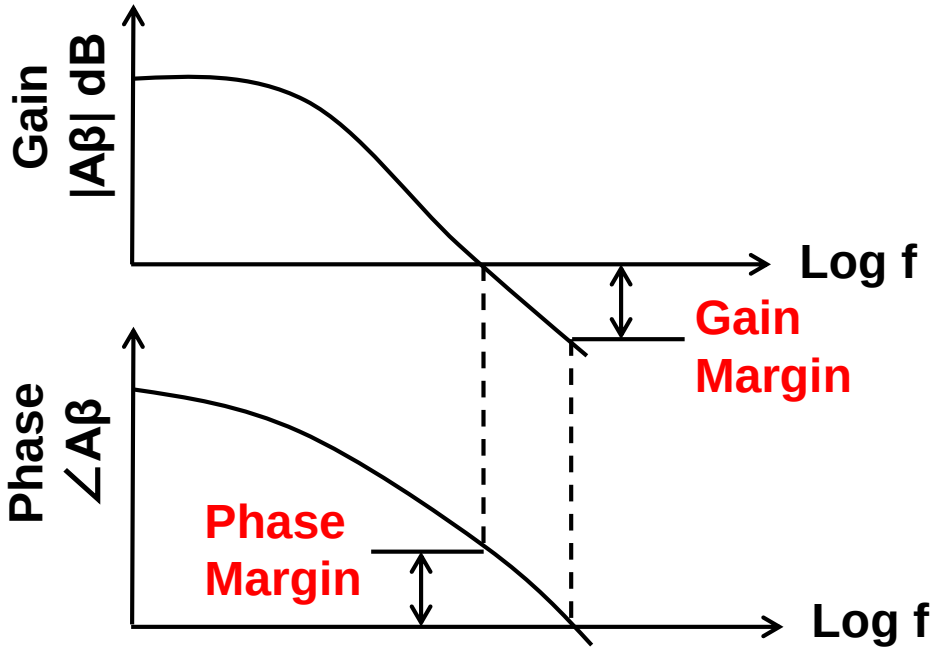

## Switching Regulator



# Research Background(2)

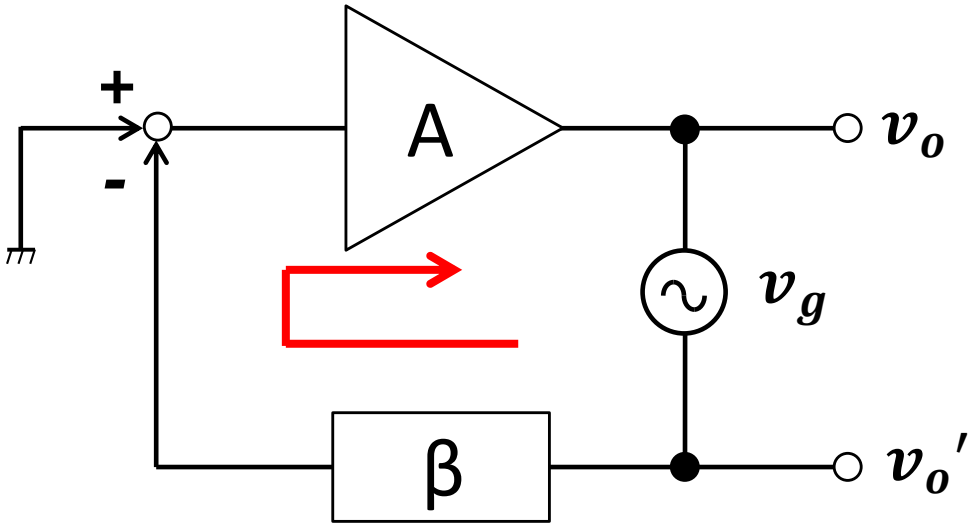
- Measurement of the loop gain is important to evaluate the stability of the negative feedback system.



# Research Background(3)

- Conventional loop gain measurement method




***Loop Gain T***

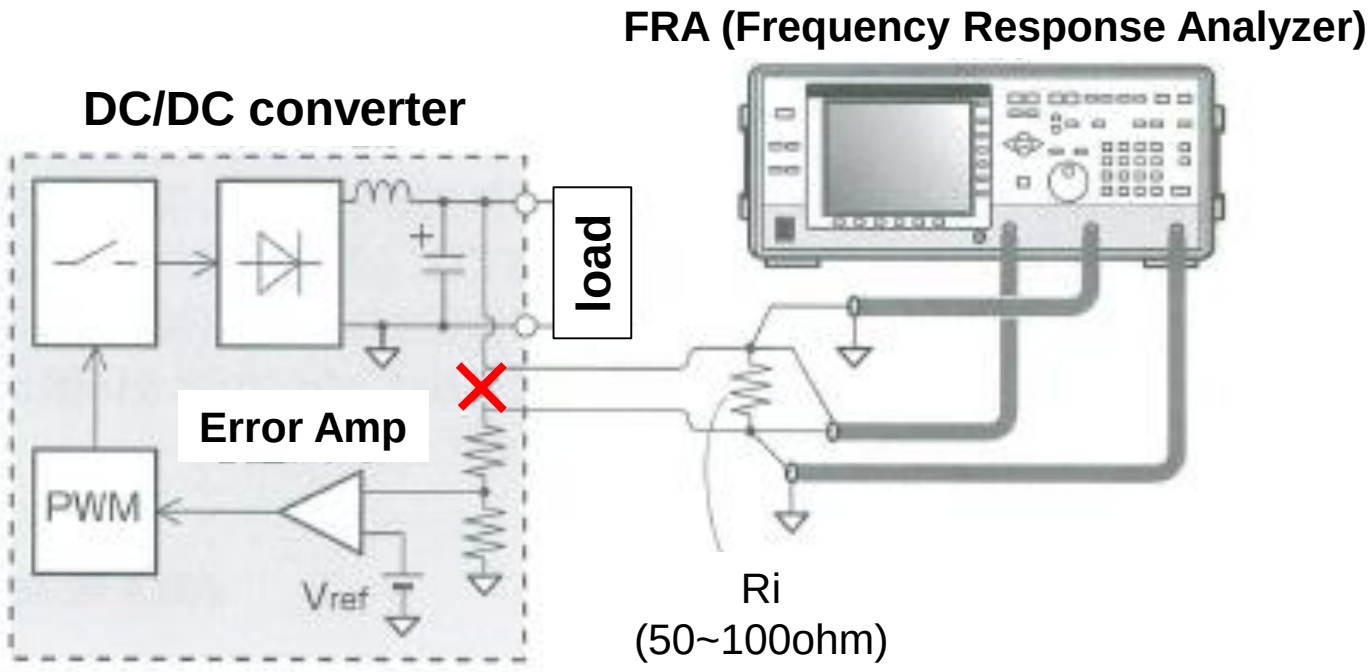
$$|T| = \frac{v_o}{v_o'} = A\beta$$

# Disadvantage of Conventional Method

- It is necessary to inject a voltage signal

  into the feedback loop by breaking the loop.
- If the control circuits are implemented on an IC,

  this method is NOT applicable.



# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

# Purpose of This Work

- To measure the loop gain

  without breaking the feedback loop.
- To develop a new method

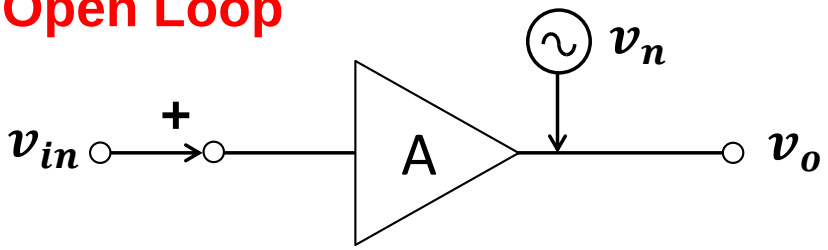
  to derive the loop gain from output impedances

  in dc-dc buck converter.
- To demonstrate the proposed method

  by simulation and experimental evaluations.

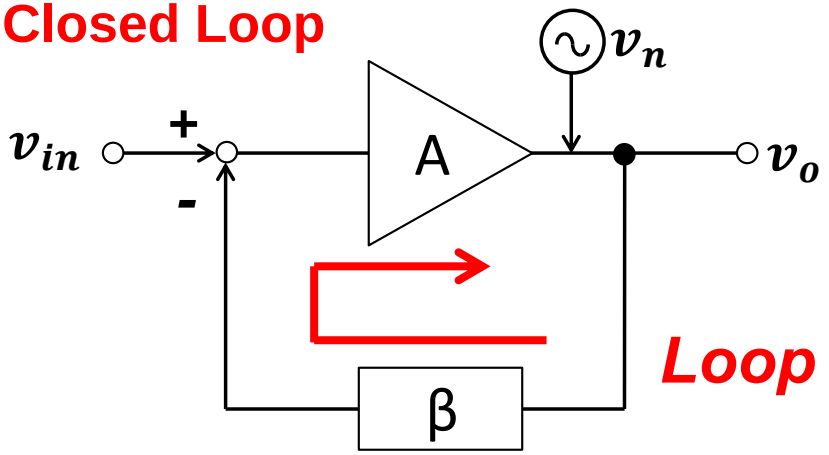
# Keypoint of Proposed Method

**Open Loop**




$$v_o = Av_{in} + v_n$$

**Closed Loop**




$$v_o = \frac{1}{\beta} \cdot \frac{T}{1+T} v_{in} + \frac{v_n}{1+T}$$

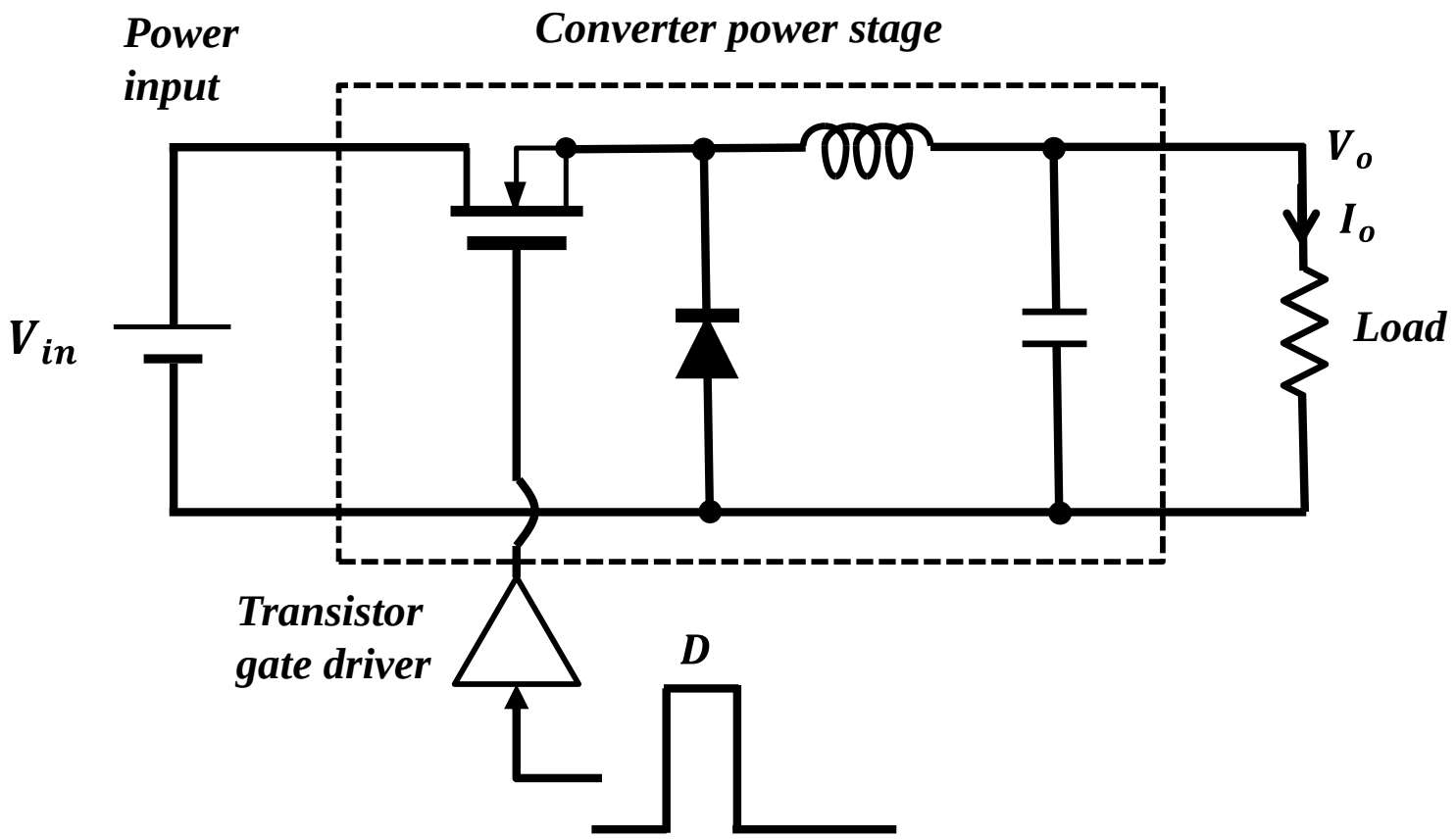
***Loop Gain T = Aβ***

Negative feedback reduces the noise by a factor of 1/(1+T) .
This theory can be applied to loop gain measurement .

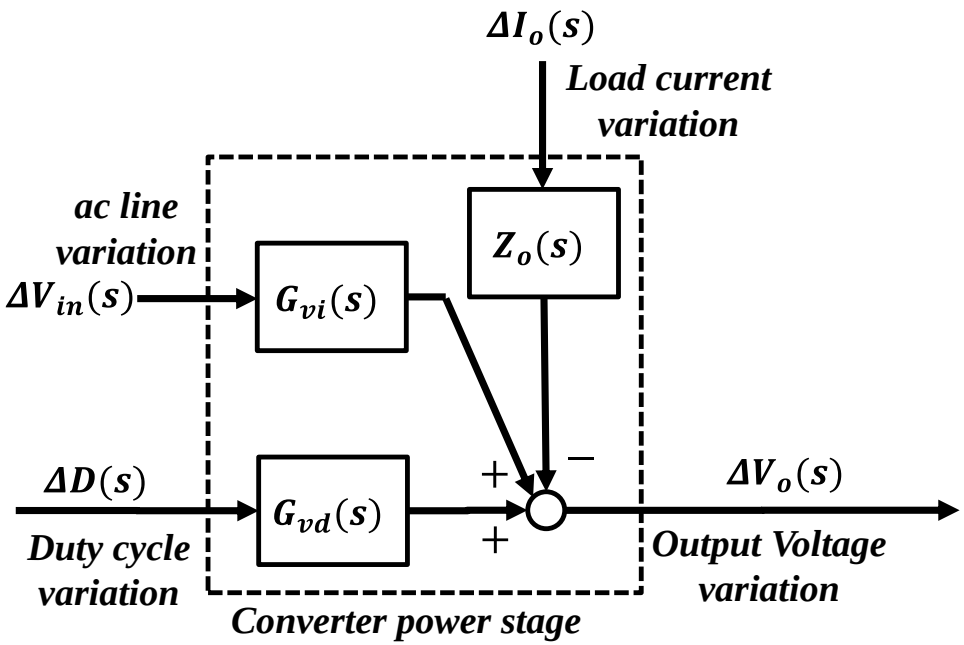
# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

# DC-DC Buck Converter Circuit in Open Loop



# Functional Block Diagram in Open Loop

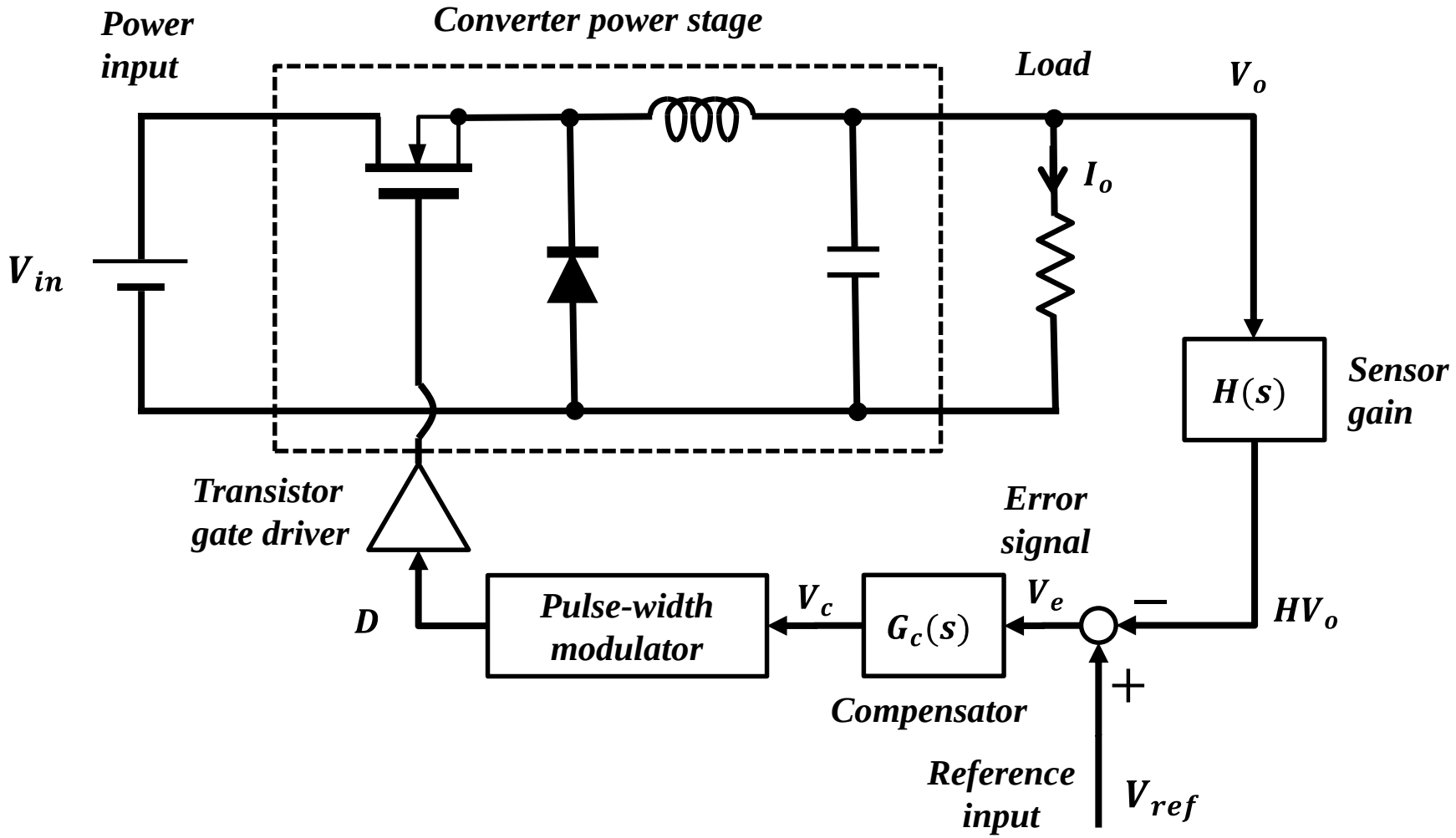



$$\Delta V_o = G_{vd}\Delta D + G_{vi}\Delta V_{in} - Z_o\Delta I_o$$

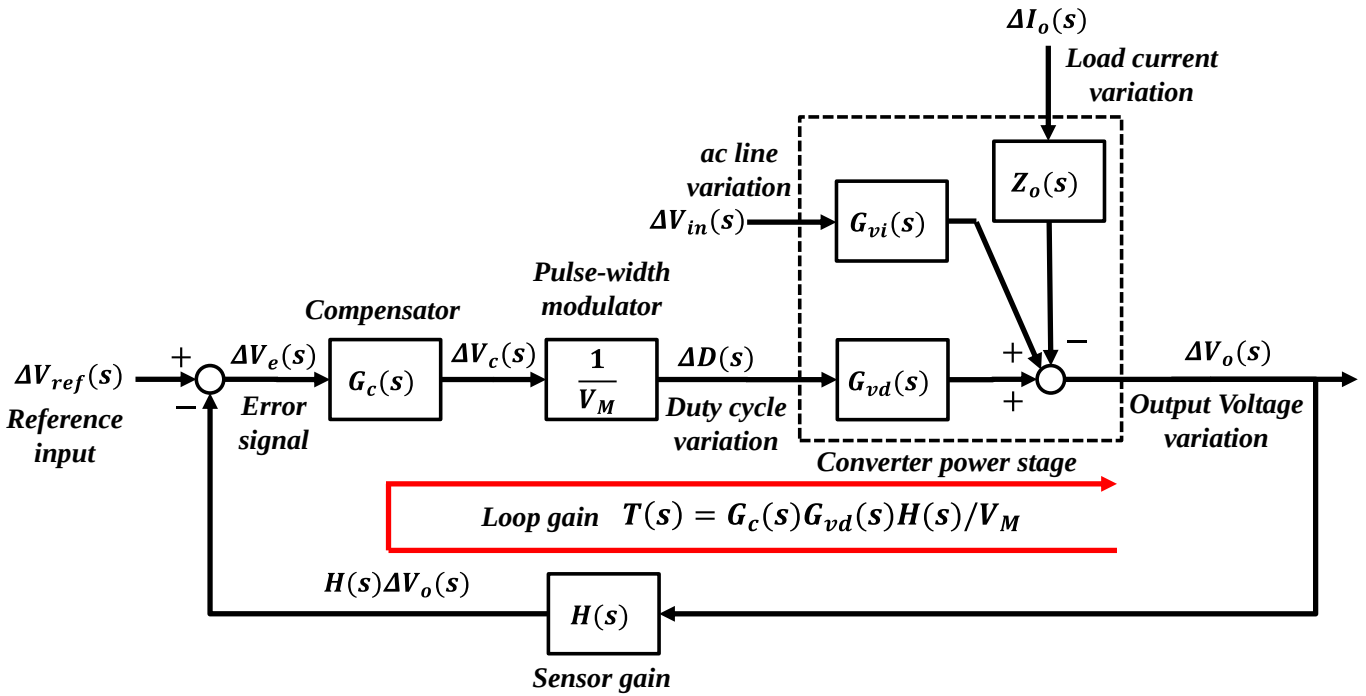
$$Z_o \equiv -\left.\frac{\Delta V_o}{\Delta I_o}\right|_{\Delta D=0,\Delta V_{in}=0}$$

**converter output impedance in open loop**

# DC-DC Buck Converter Circuit in Closed Loop



# Functional Block Diagram in Closed Loop




$$\Delta V_o = \frac{1}{H}\frac{T}{1+T}\Delta V_{ref} + \frac{G_{vi}}{1+T}\Delta V_{in} - \frac{Z_o}{1+T}\Delta I_o$$

$$Z_{oc} \equiv -\left.\frac{\Delta V_o}{\Delta I_o}\right|_{\Delta V_{ref}=0,\Delta V_{in}=0} = \frac{Z_o}{1+T}$$

**converter output impedance in closed loop**

# Derivation of Proposed Method

$$Z_{oc}(s) = \frac{Z_o(s)}{1 + T(s)} \quad \Rightarrow \quad T(s) = \frac{Z_o(s) - Z_{oc}(s)}{Z_{oc}(s)}$$

## Magnitude of Loop Gain

$$20 \log_{10} |T| = 20 \log_{10} \left[ \frac{|Z_o - Z_{oc}|}{|Z_{oc}|} \right]$$

## Phase of Loop Gain

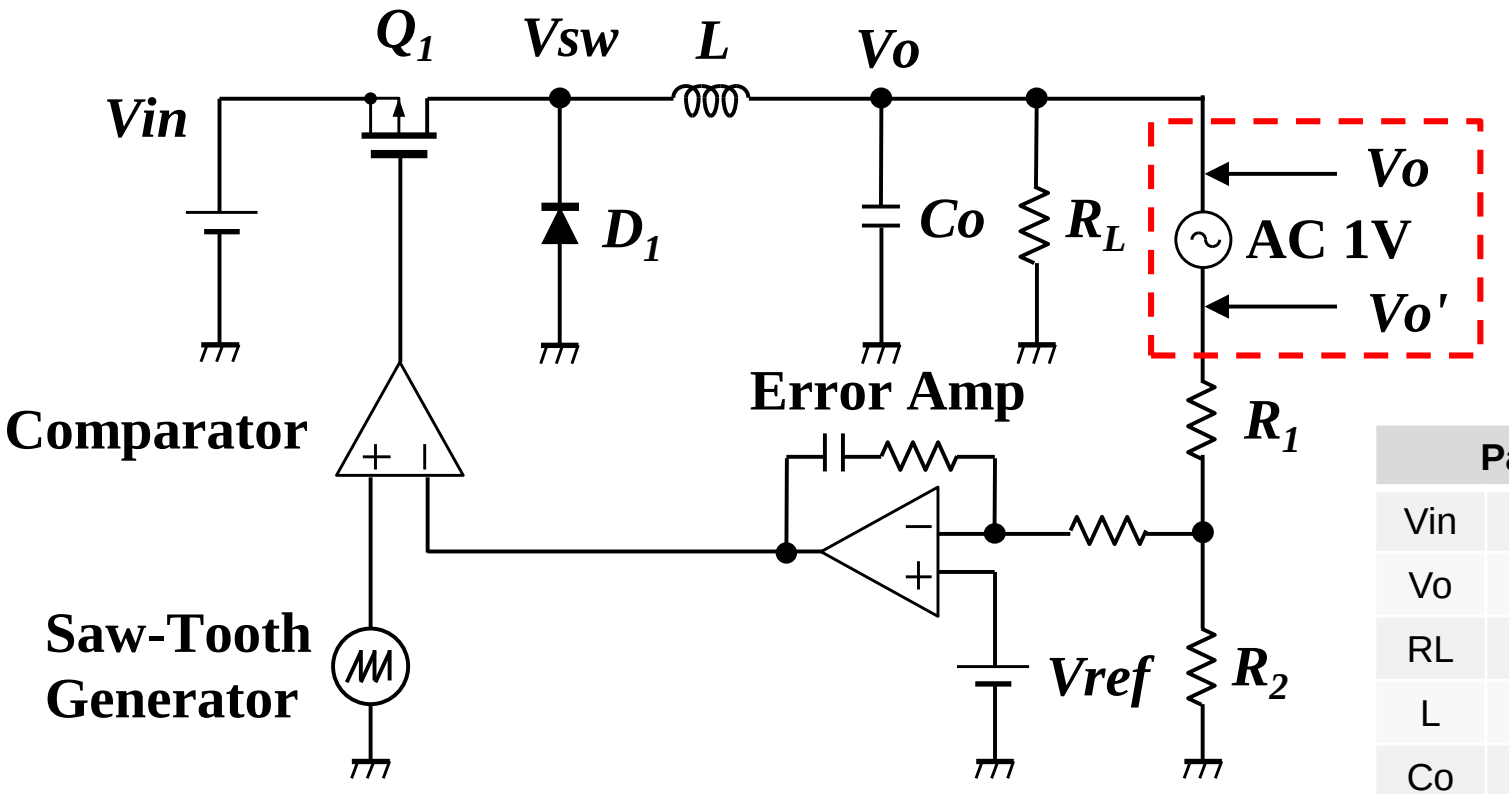
$$\arg(T) = \arg(Z_o - Z_{oc}) - \arg(Z_{oc})$$

# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

# Simulation Circuits

**Conventional**

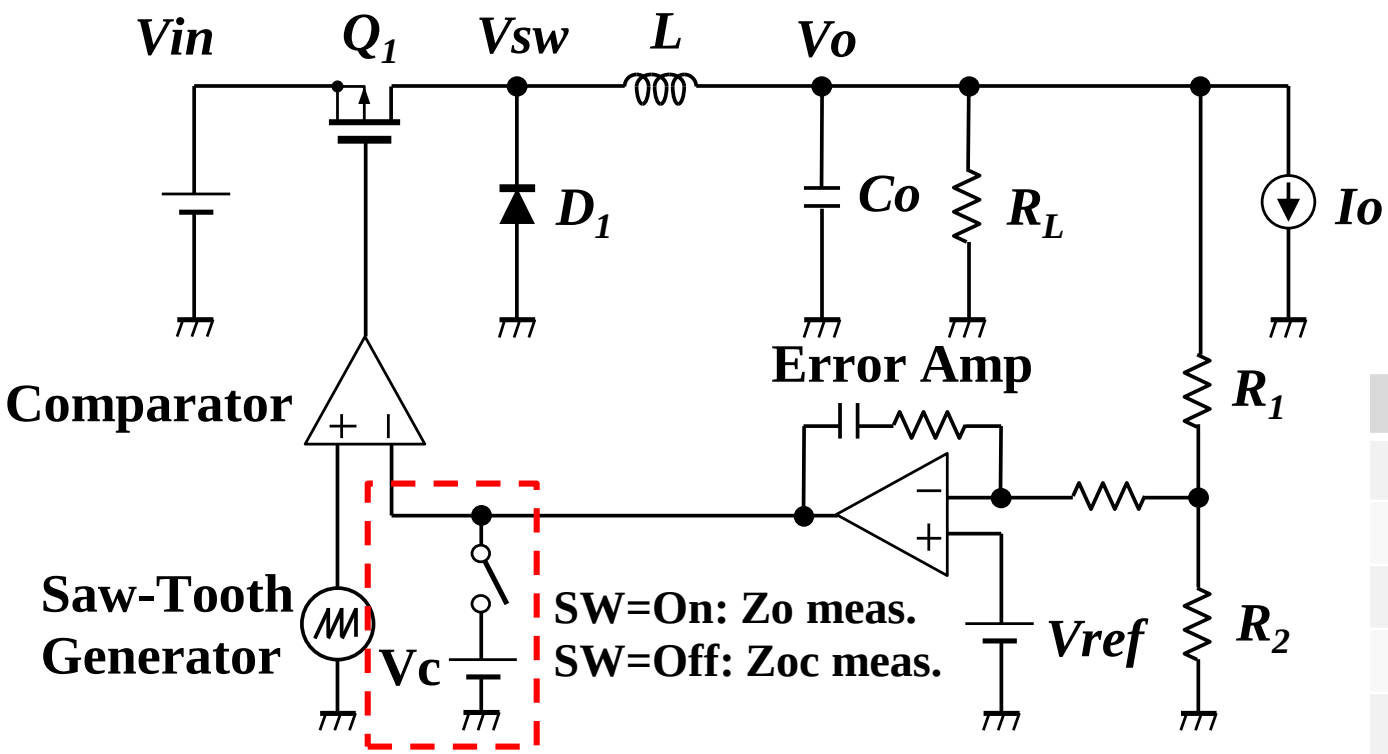



| Parameter | |
|---|---|
| Vin | 12V |
| Vo | 5V |
| RL | 5Ω |
| L | 120uH |
| Co | 1.2mF x 2 (ESR=40mΩ) |

**Loop Gain T = Vo/Vo'**

# Simulation Circuits

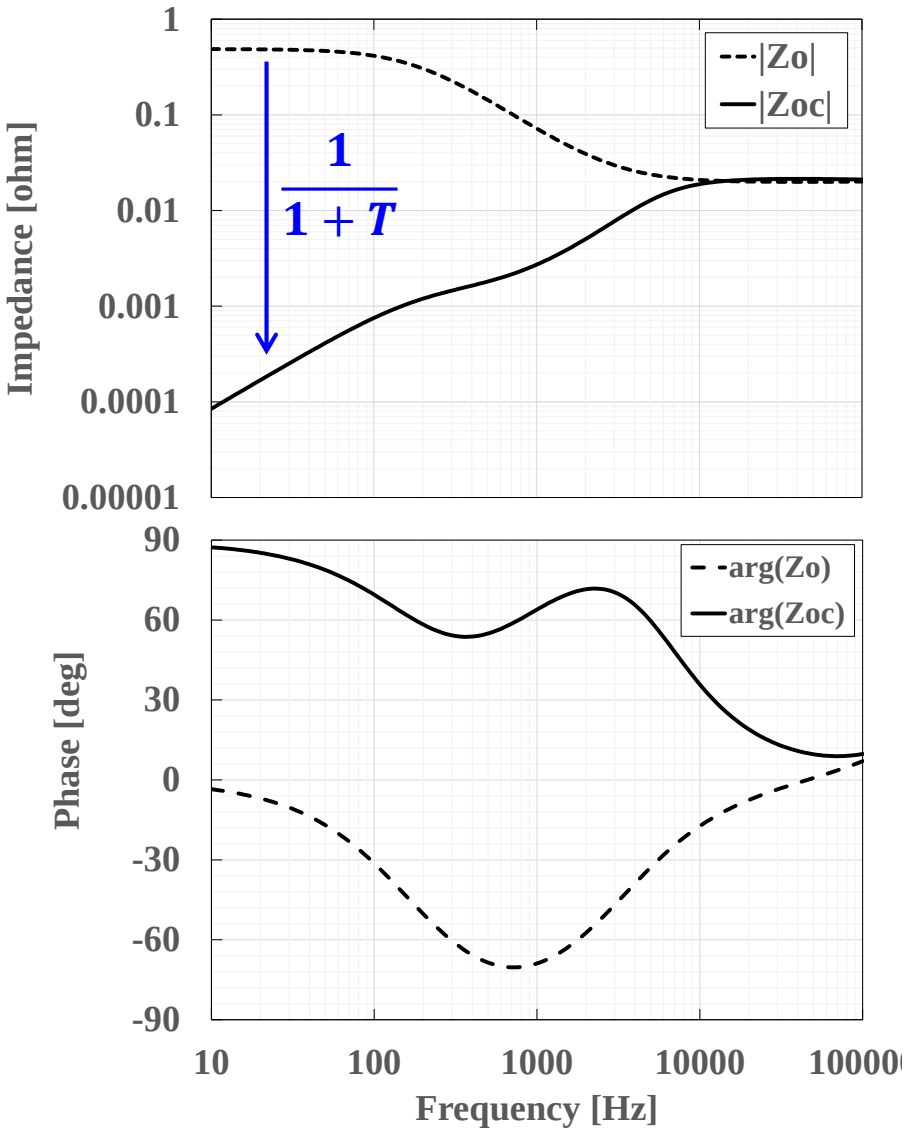
**Proposed**

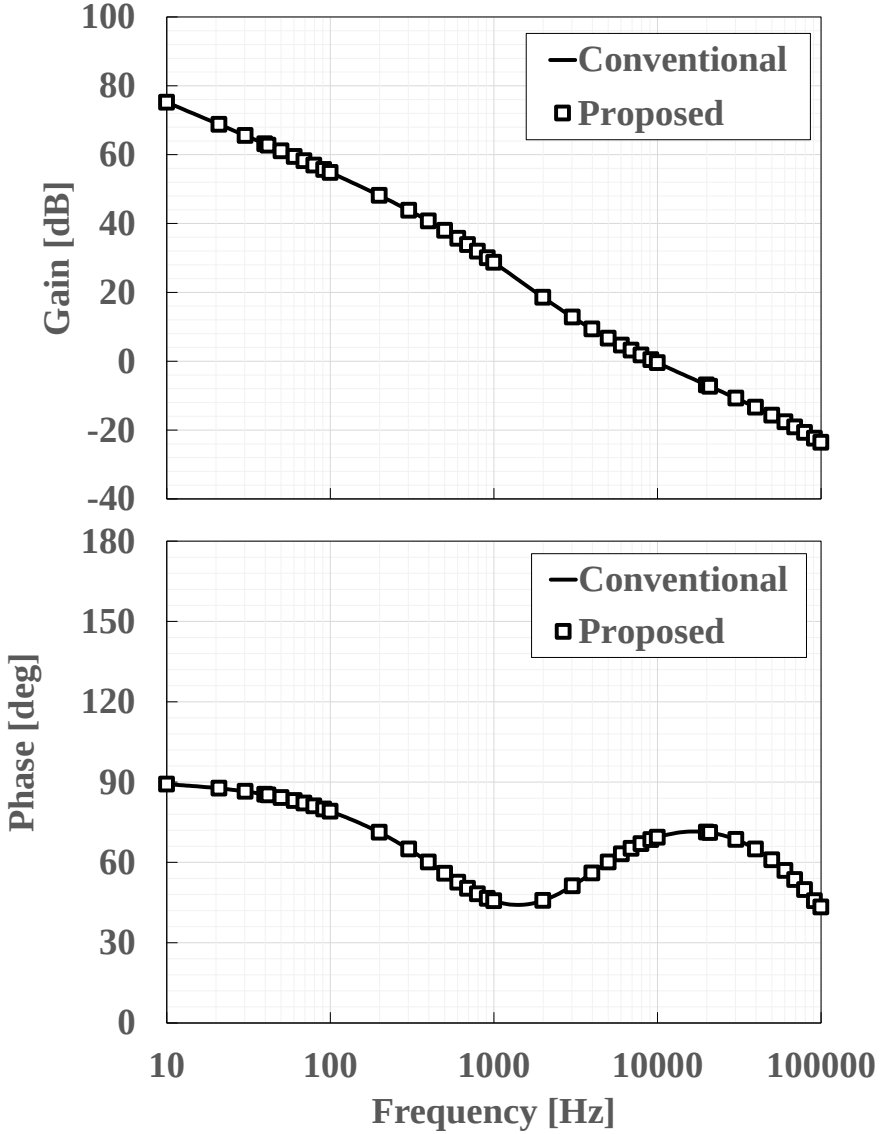



| Parameter | |
|---|---|
| Vin | 12V |
| Vo | 5V |
| RL | 5Ω |
| L | 120uH |
| Co | 1.2mF x 2 (ESR=40mΩ) |

**Loop Gain T = (Zo-Zoc)/Zoc**

# Simulation Results

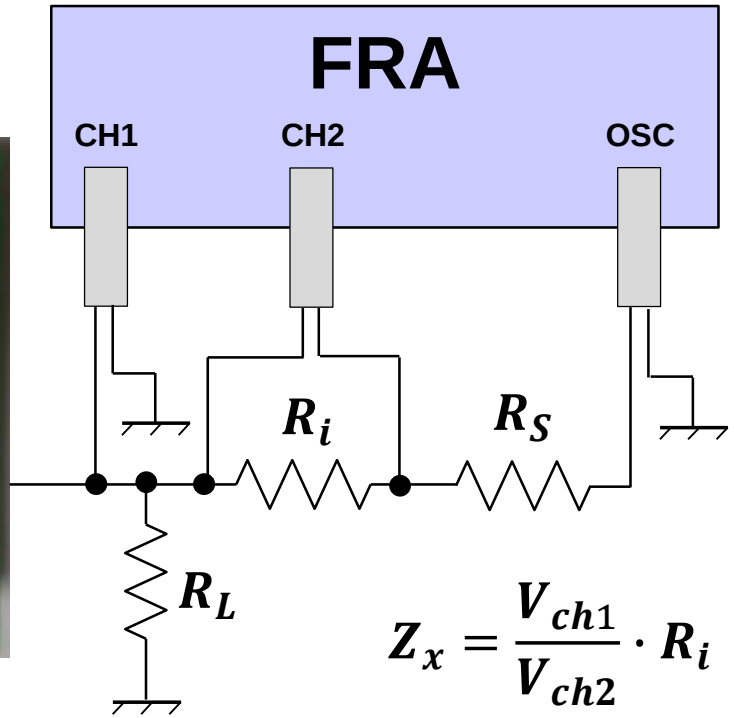


# Experimental Setup

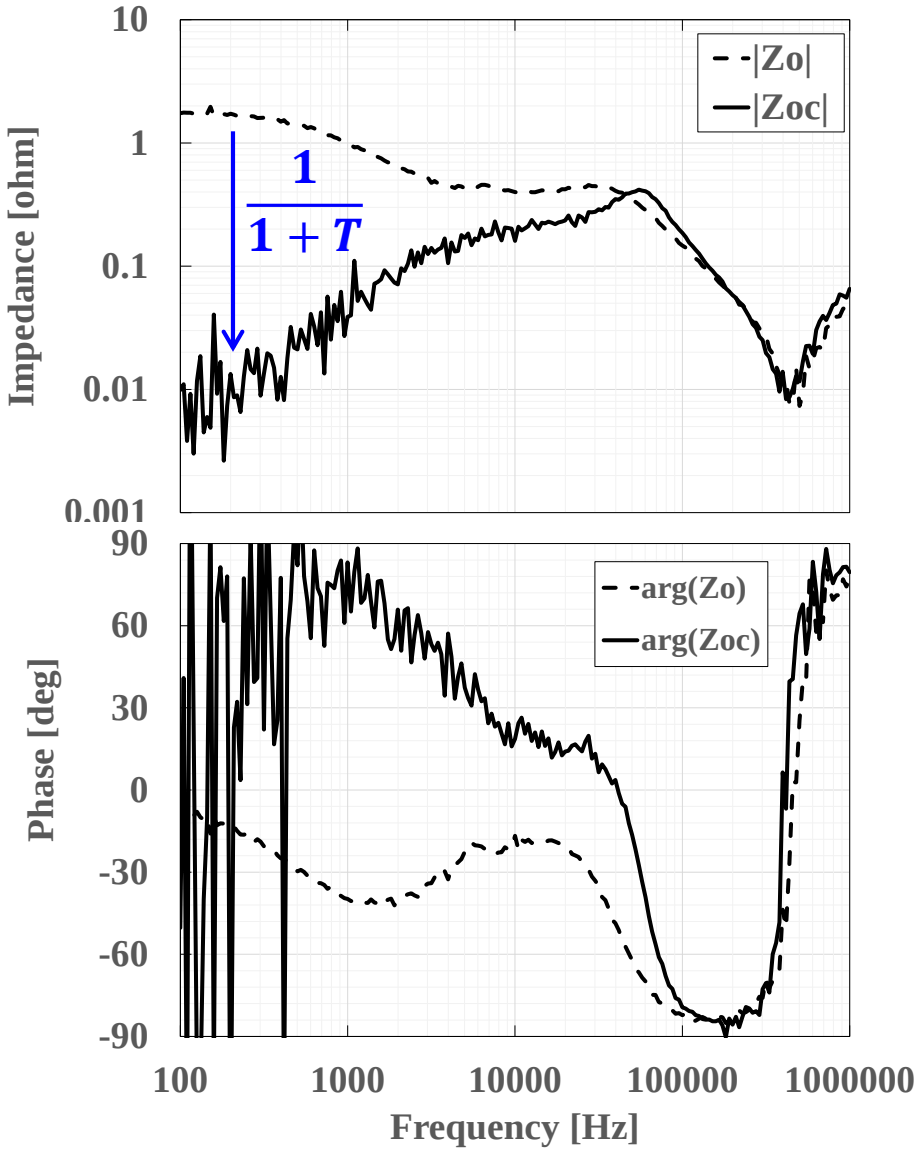
- IC:BD9329A (Rohm Semiconductor)
  - Synchronous buck converter with integrated FET
  - Switching frequency: 380kHz

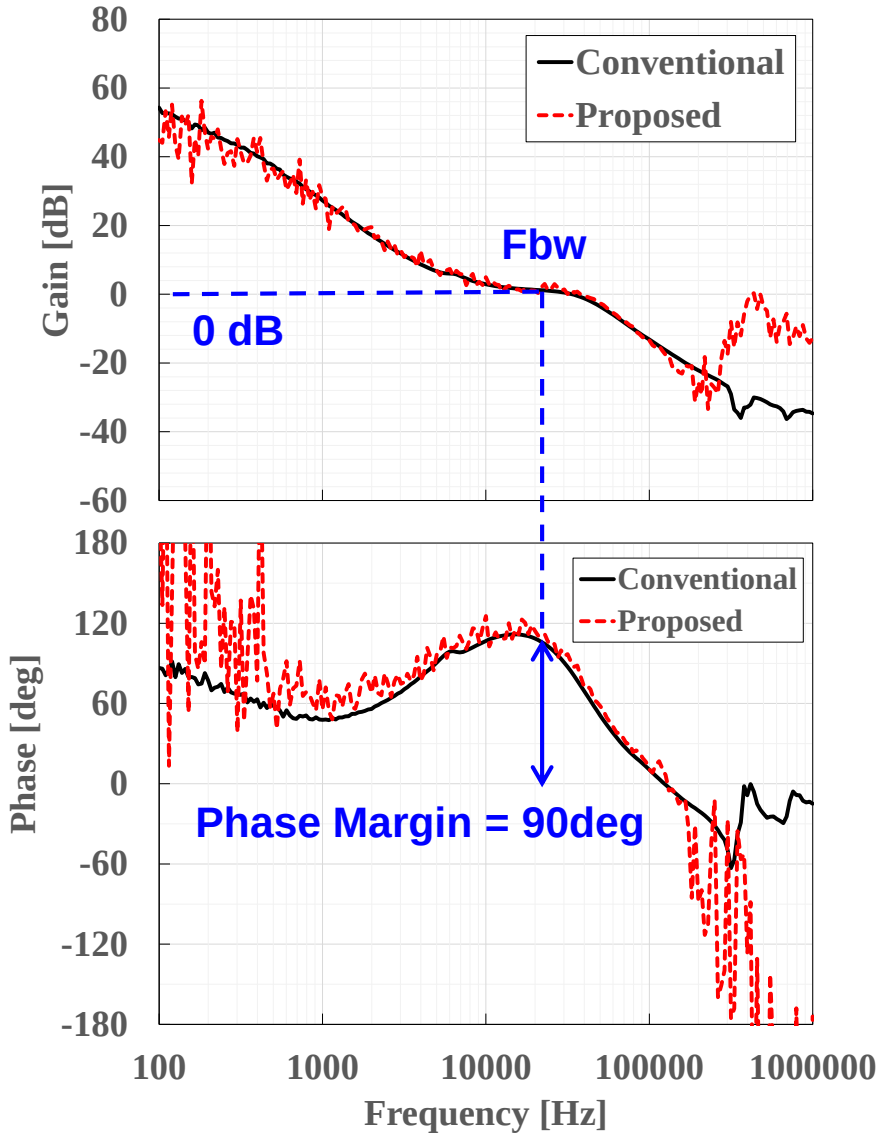

**Evaluation board**




| Parameter | |
|---|---|
| Vin | 12V |
| Vo | 3.3V |
| RL | 3Ω |
| L | 10uH |
| Co | 10uF x 2 |
| Ri | 1Ω |
| Rs | 1kΩ |

# Experimental Results



# Outline

- Research Background
- Purpose of This Work
- Derivation of Proposed Method
- Simulation and Measurement Result
- Summary

# Summary

- We have proposed a method
  to derive the loop gain from the output impedances
  in dc-dc buck converter.
- We showed effectiveness of the proposed method
  with simulations and experiments
  of dc-dc buck converter.
- We found out that sufficient evaluation of
  phase margin and gain margin is possible.

# Thank you for listening !!

# Q & A

- Q1:主な用途は何か？
- A1:例えば、DC-DC電源、LDO、増幅回路に使用できる。この方法は負帰還回路を使用していれば、どんな回路でも応用可能です。
- Q2:どんなときにこの方法を使用するの？
- A2:テスト時を想定しています。フィードバックループが集積化されている場合は従来方法が使用できません。