Derivation of Loop Gain and Phase from Output Impedances in Analog Circuit with Negative Feedback

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Outline

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

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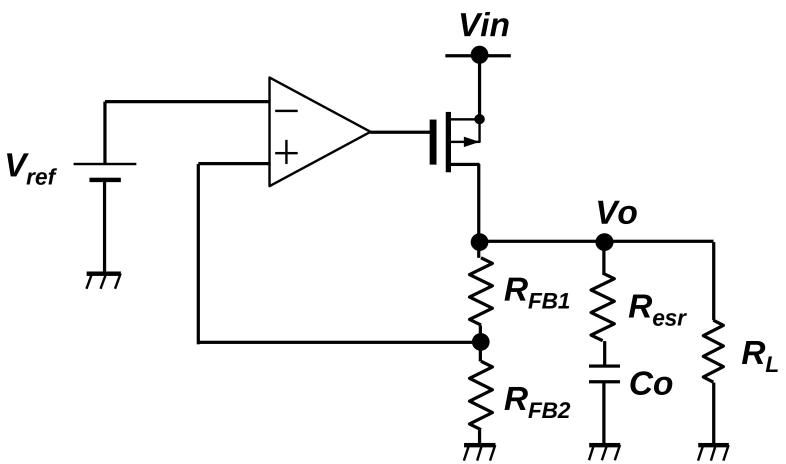
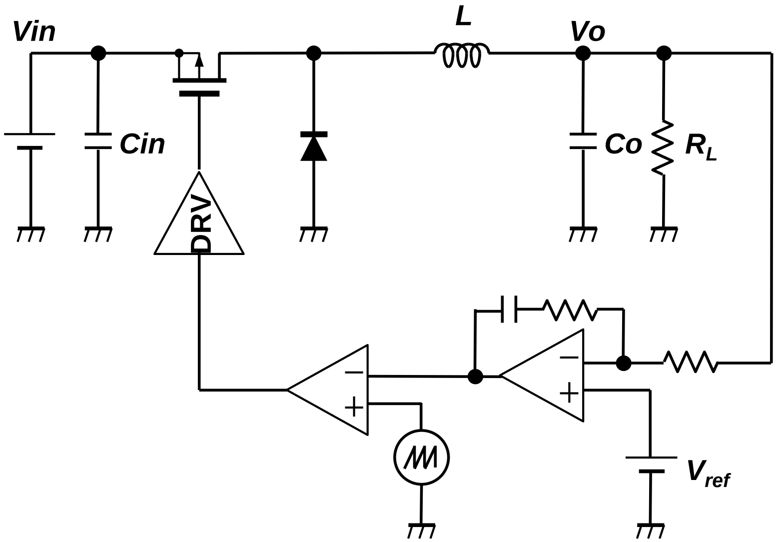
Research Background(1)

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

Low Drop Out Regulator

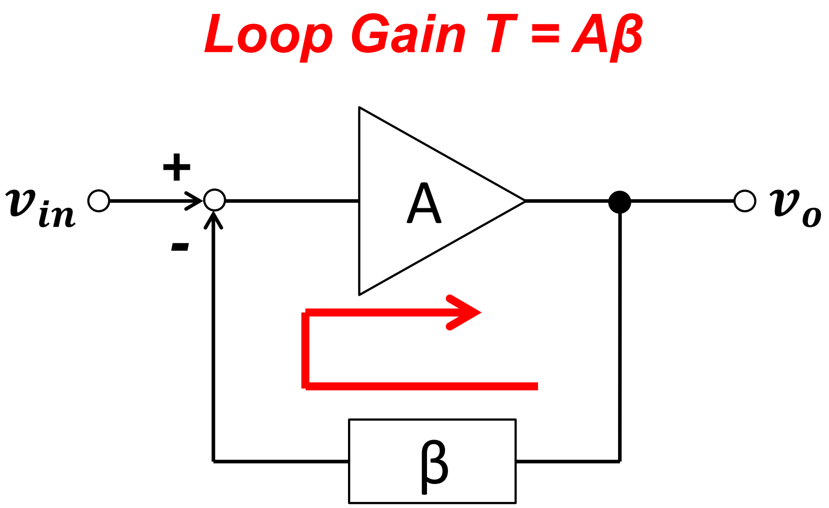


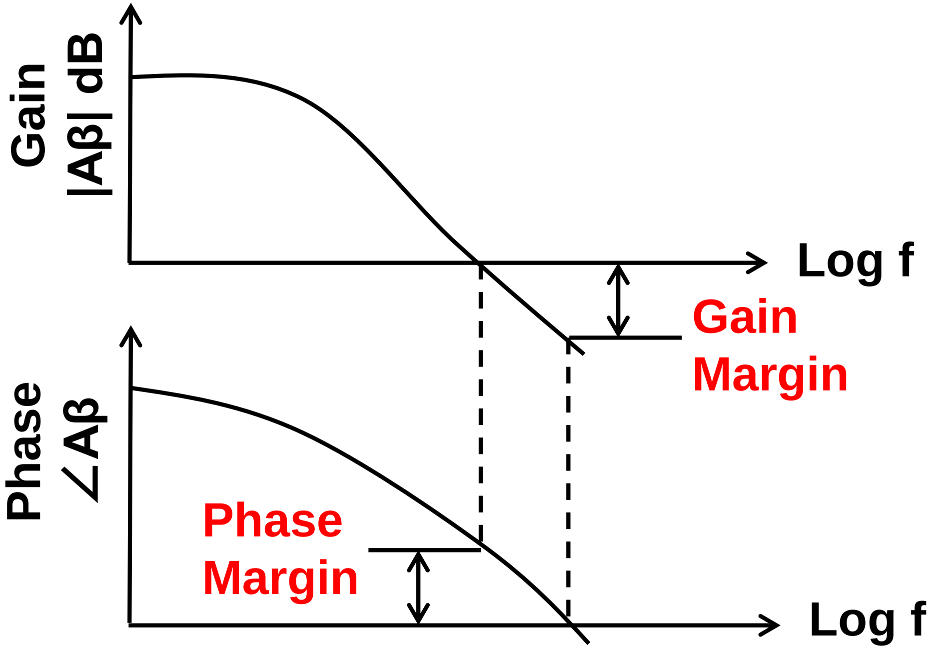
Switching Regulator



Research Background(2)

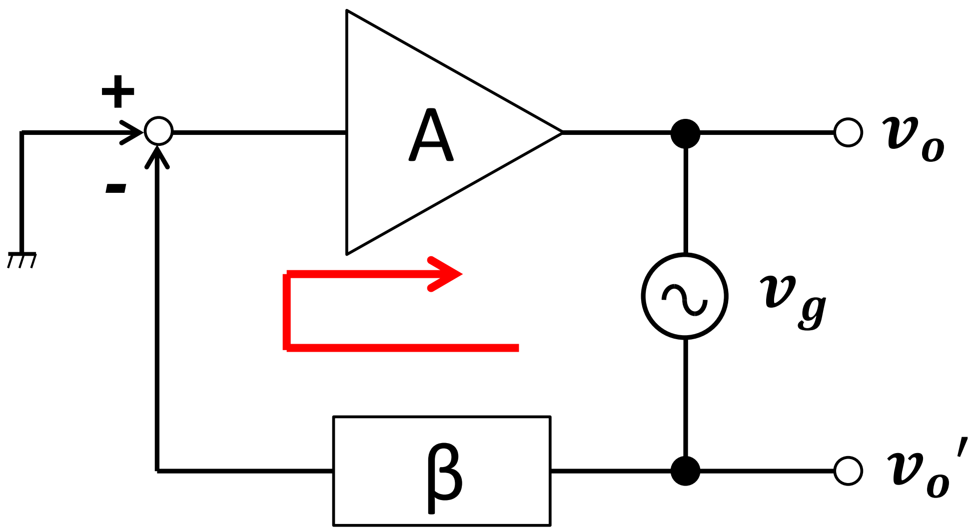
- Measurement of the loop gain is important to evaluate the stability of the negative feedback system.





Research Background(3)

- Conventional loop gain measurement method

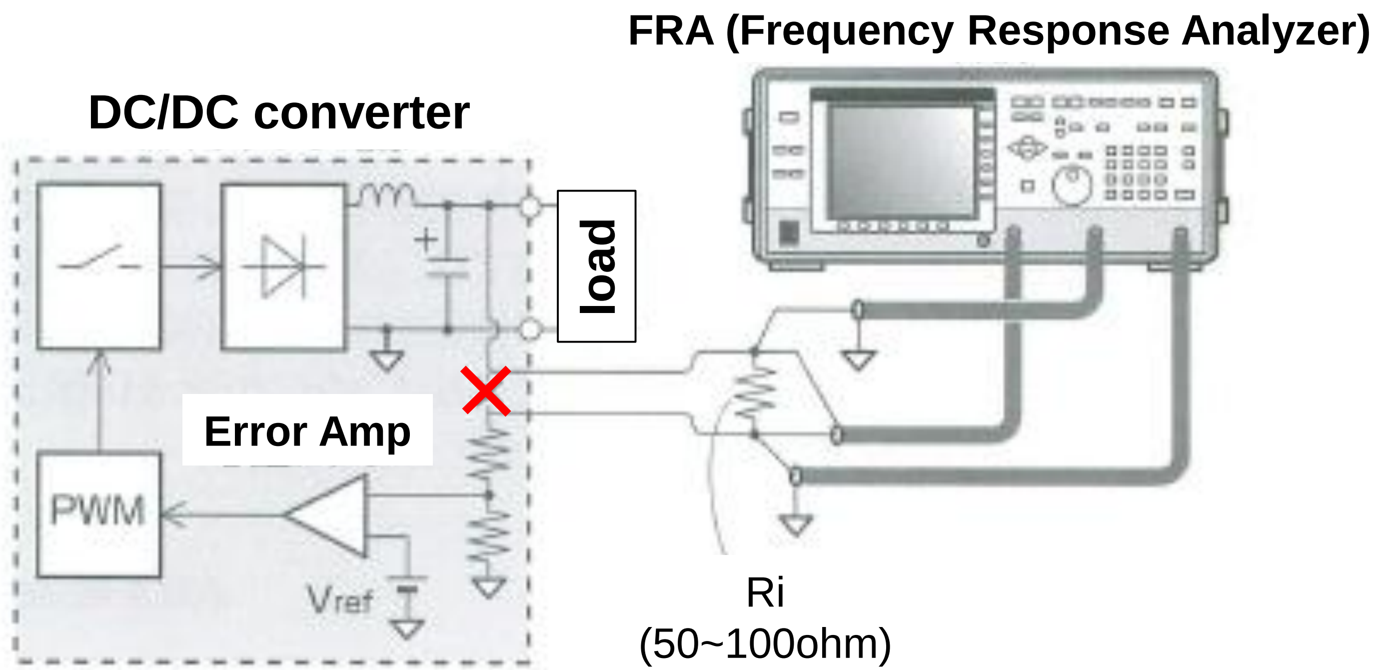


Loop Gain T

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

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.



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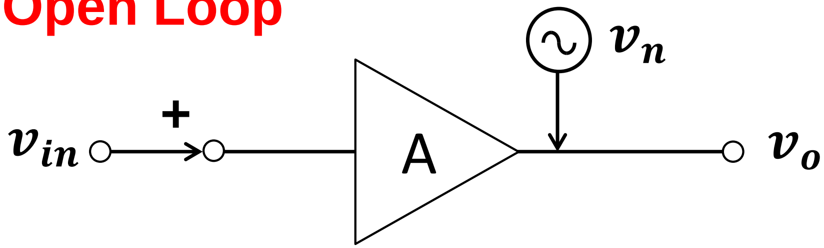
Purpose of This Work

- 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.

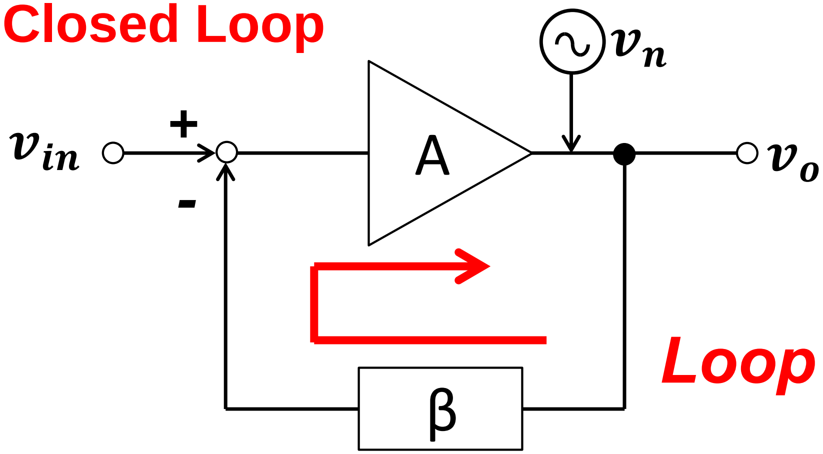
Keypoint of Proposed Method

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 .

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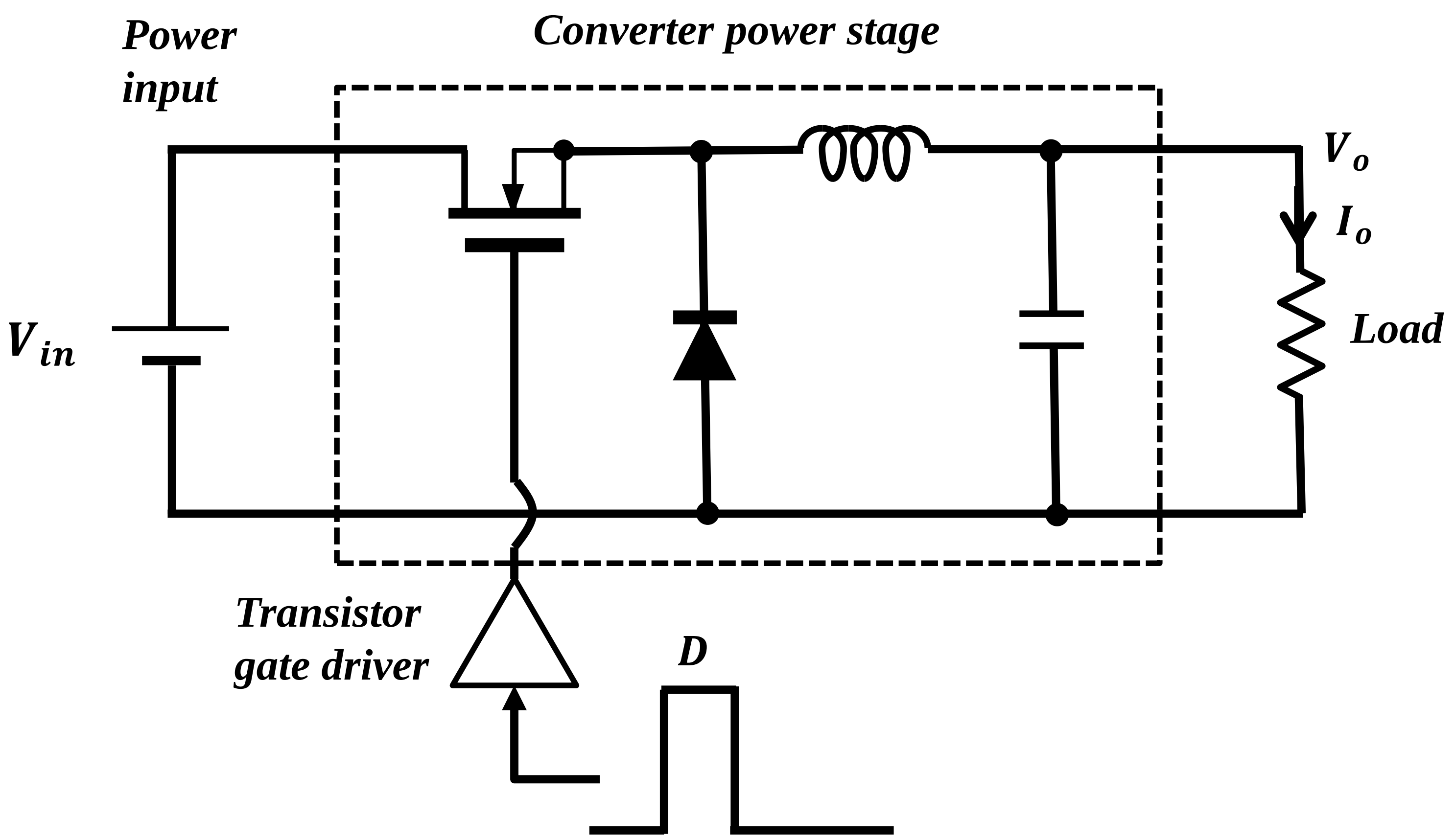
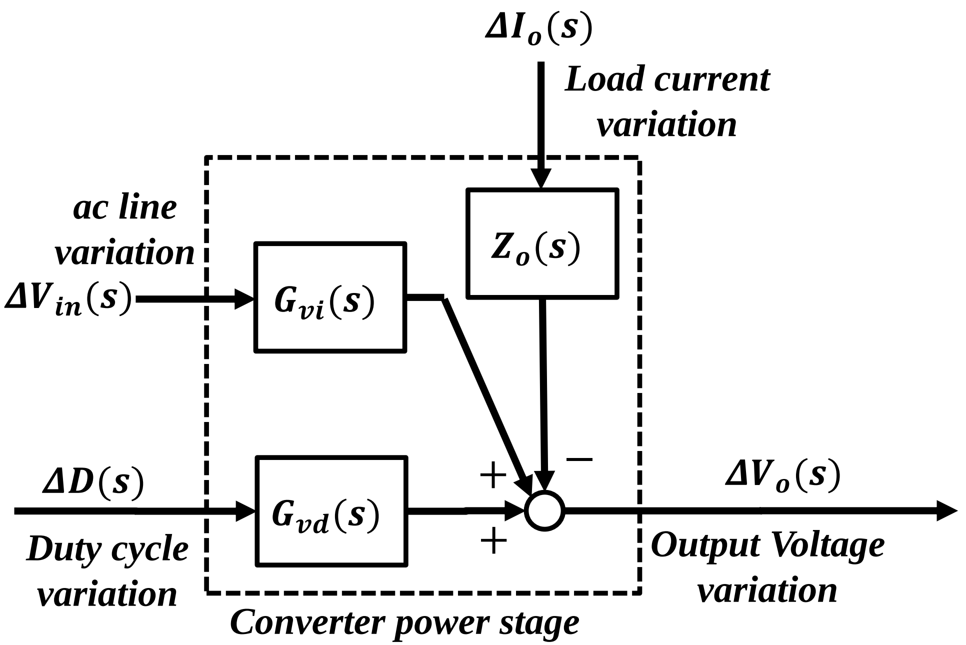
DC-DC Buck Converter Circuit in Open Loop



Functional Block Diagram in Open Loop

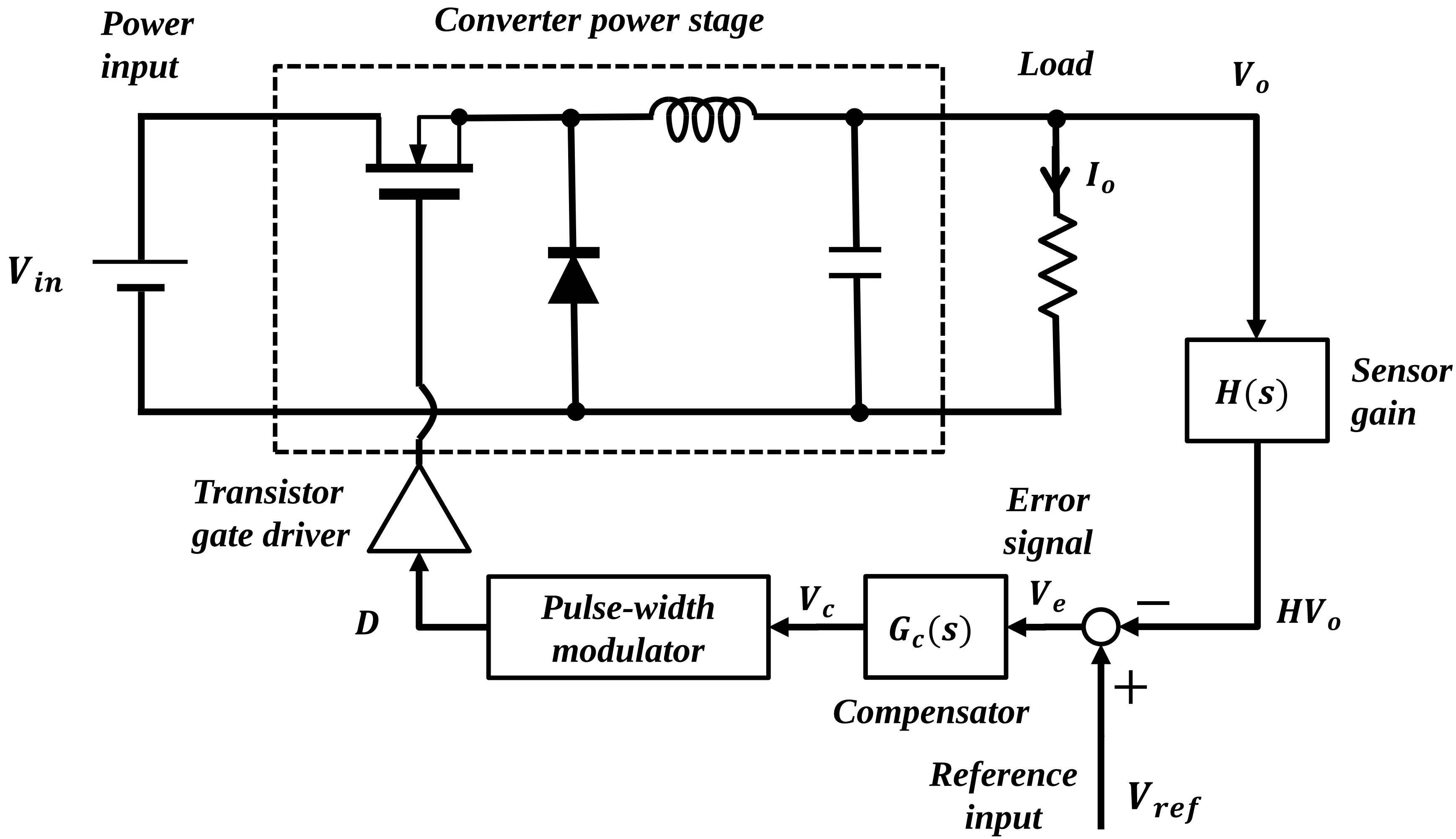


$$\Delta V_o = G_{vd}\Delta D + G_{vi}\Delta V_{in} - Z_o \Delta I_o$$

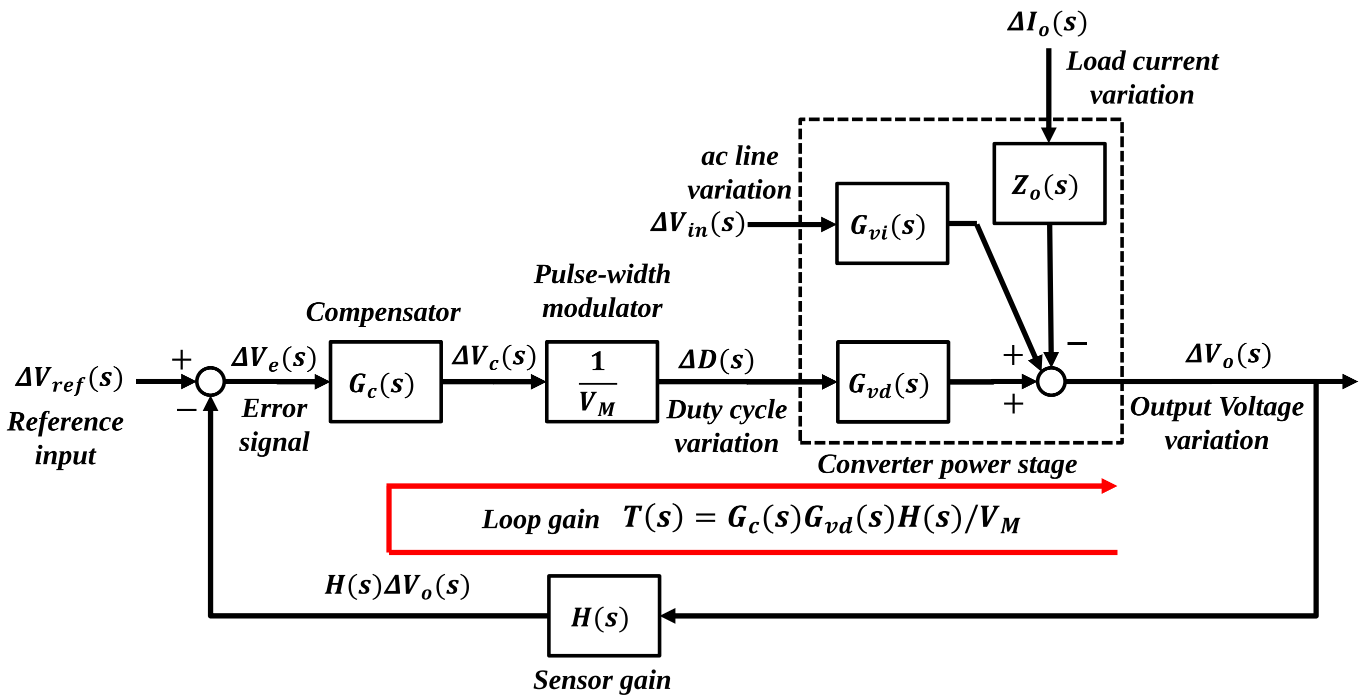
$$Z_o \equiv -\left.\frac{\Delta V_o}{\Delta I_o}\right|_{\Delta D=0,\Delta V_{in}=0}$$

converter output impedance in open loop

DC-DC Buck Converter Circuit in Closed Loop



Functional Block Diagram in Closed Loop



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

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

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

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

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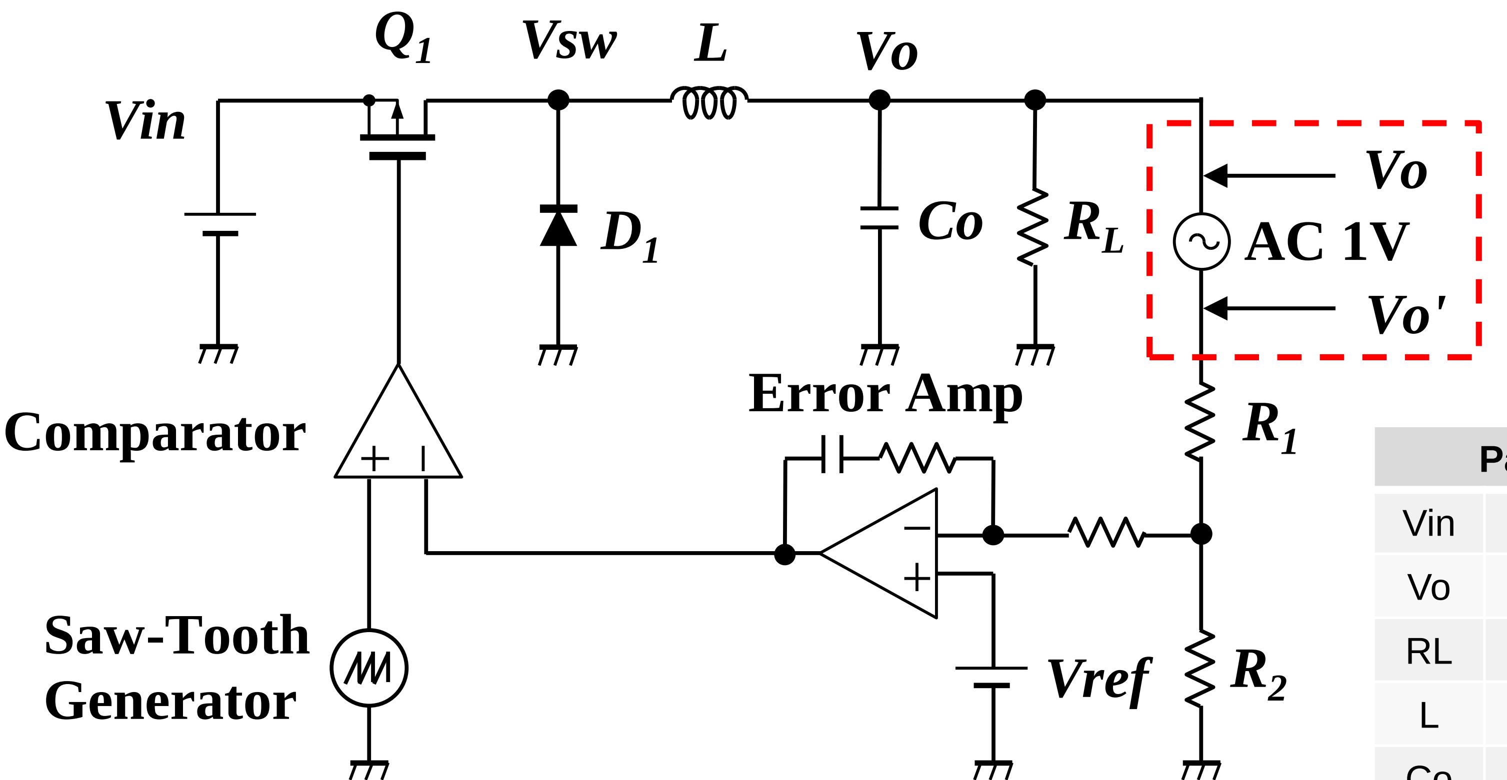
Simulation Circuits

Conventional

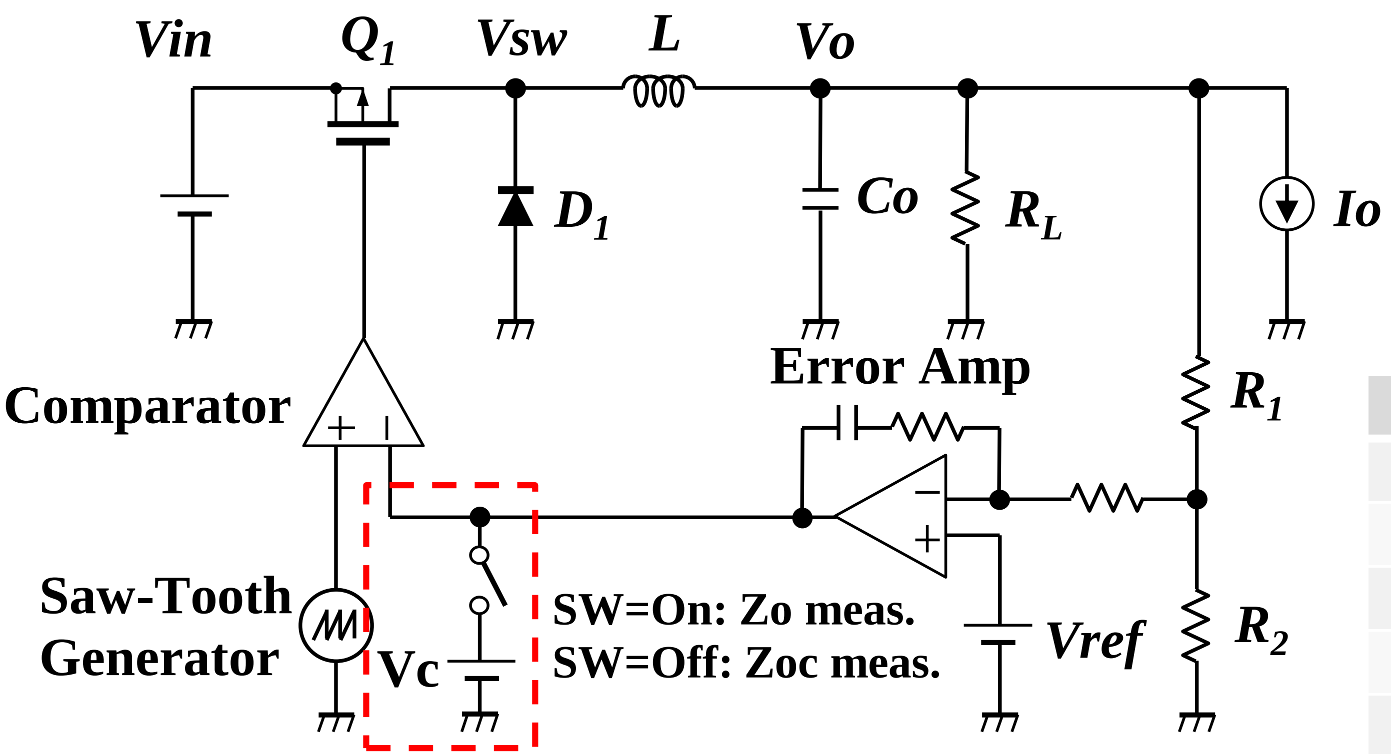


Parameter	
Vin	12V
Vo	5V
RL	5Ω
L	120uH
Co	1.2mF x 2 (ESR=40mΩ)

Loop Gain T = Vo/Vo’

Simulation Circuits

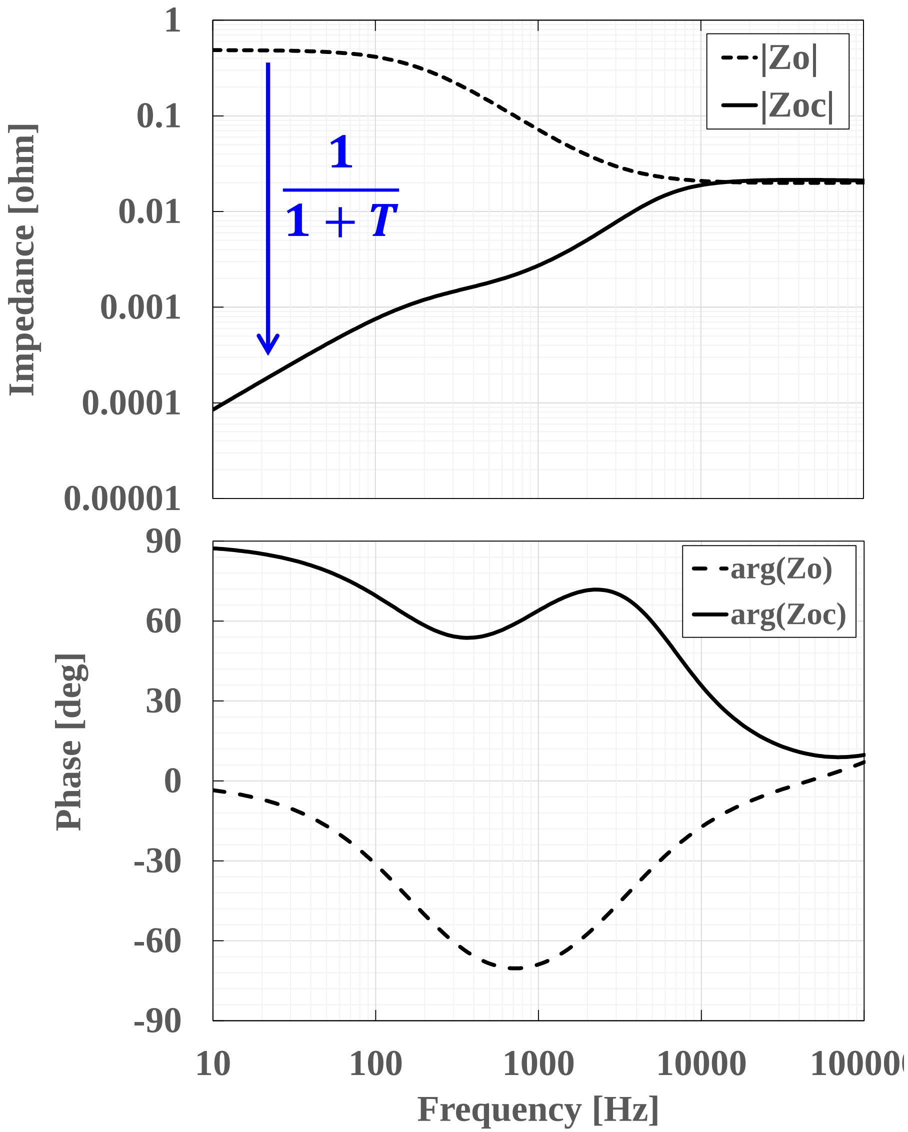
Proposed

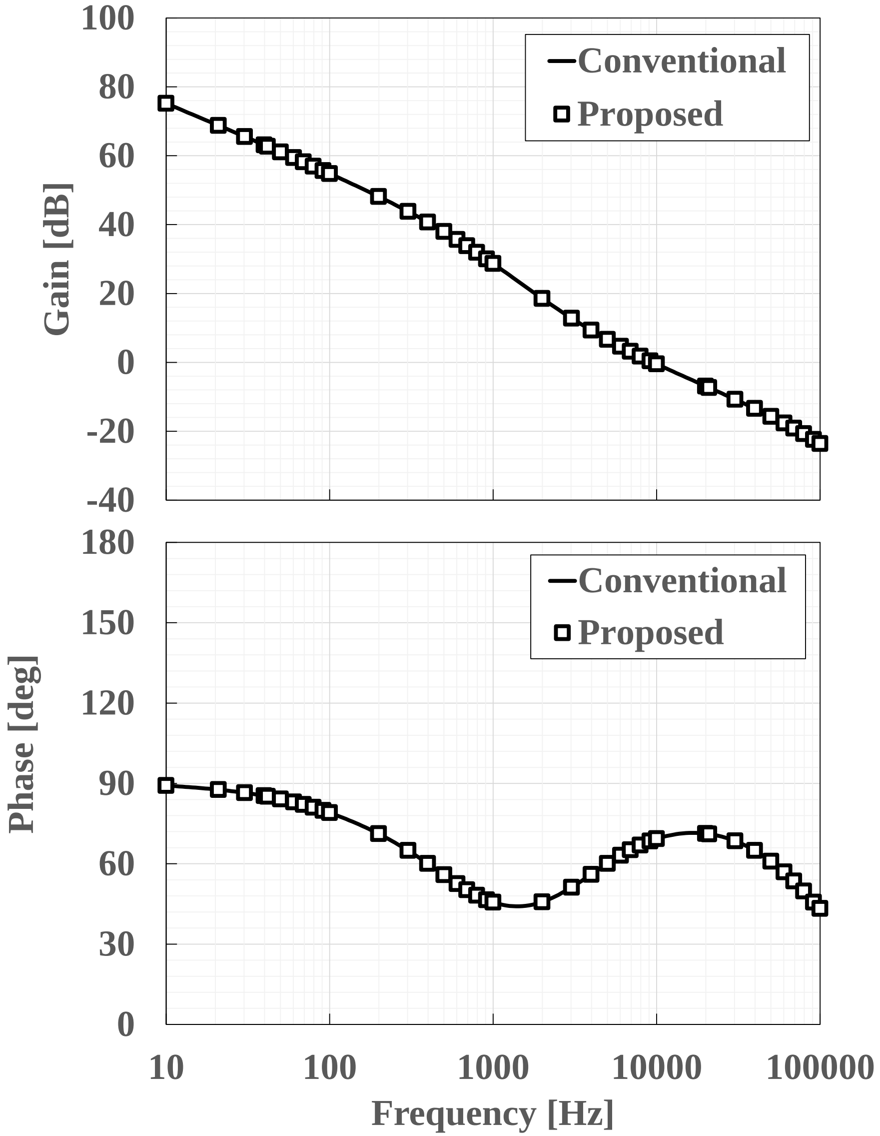


Parameter	
Vin	12V
Vo	5V
RL	5Ω
L	120uH
Co	1.2mF x 2 (ESR=40mΩ)

Loop Gain T = (Zo-Zoc)/Zoc

Simulation Results

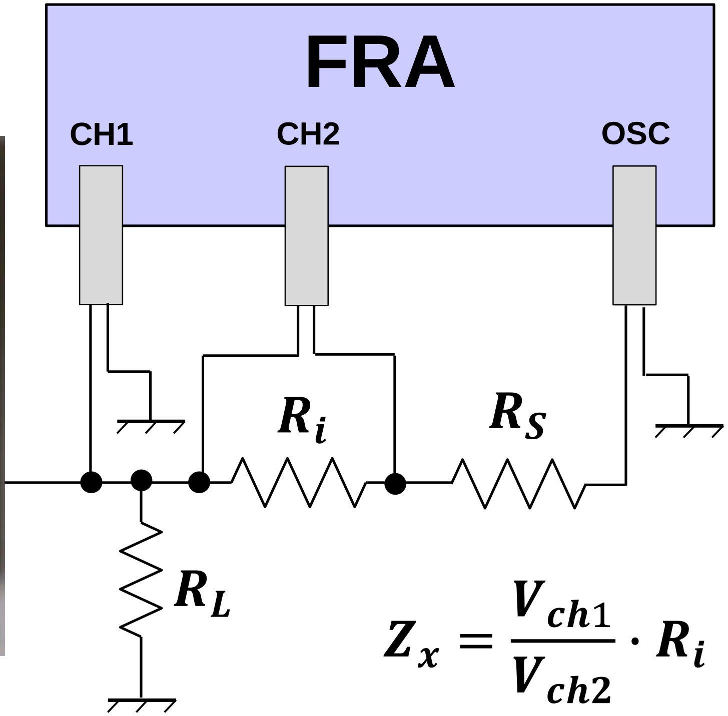




Experimental Setup

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

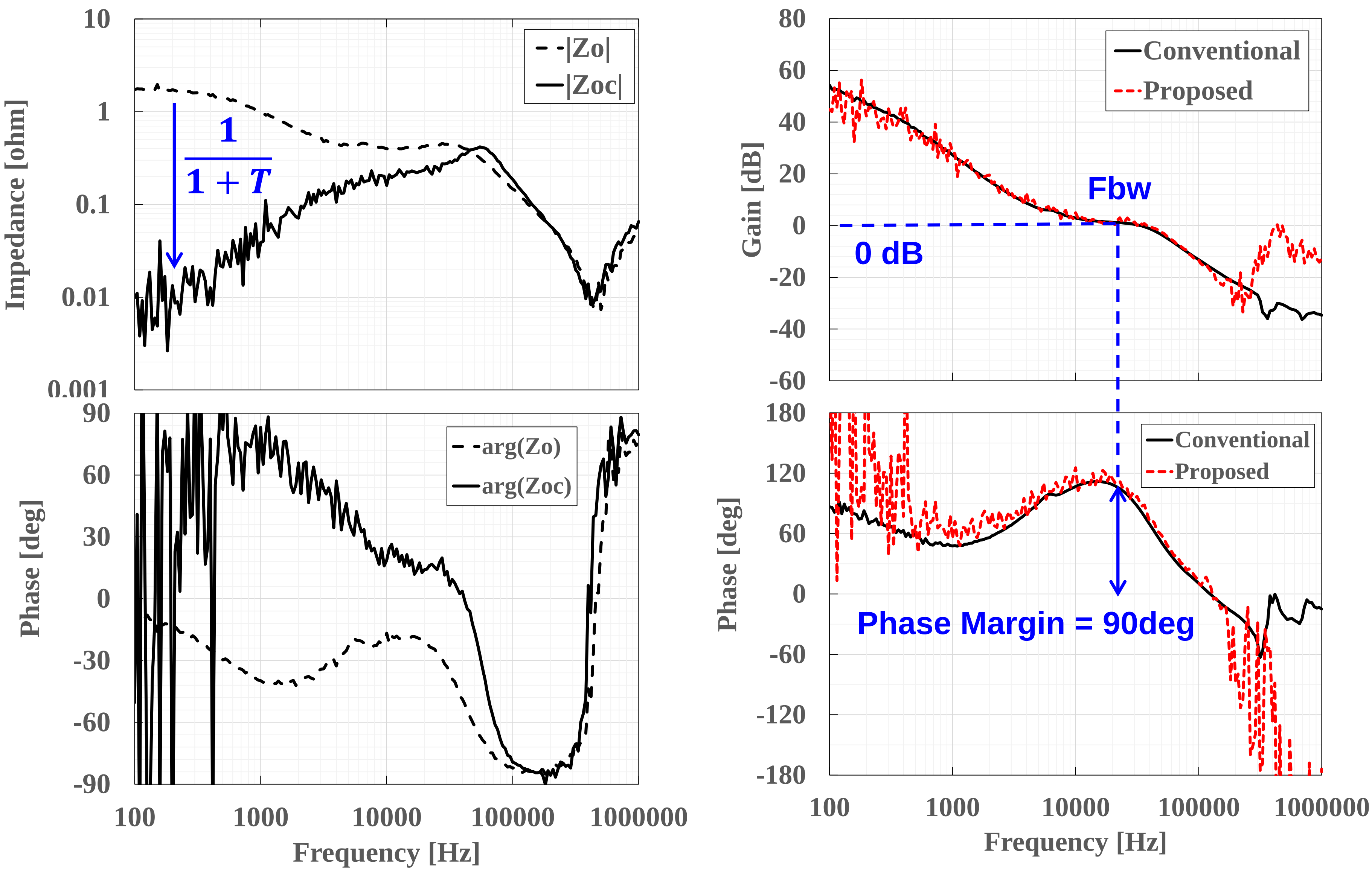
Evaluation board



$$Z_x = \frac{V_{ch1}}{V_{ch2}} \cdot R_i$$

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

Experimental Results



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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 !!