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

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Research Background

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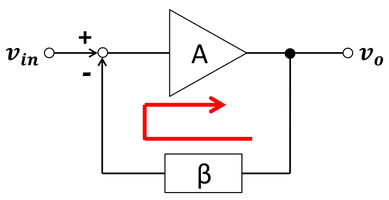
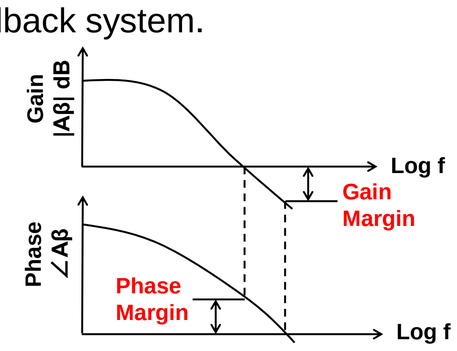
- Measurement of the loop gain is important to evaluate the stability of the negative feedback system.

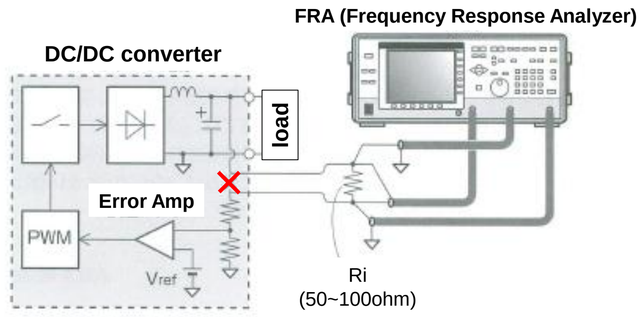
Loop Gain T = Aβ





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.

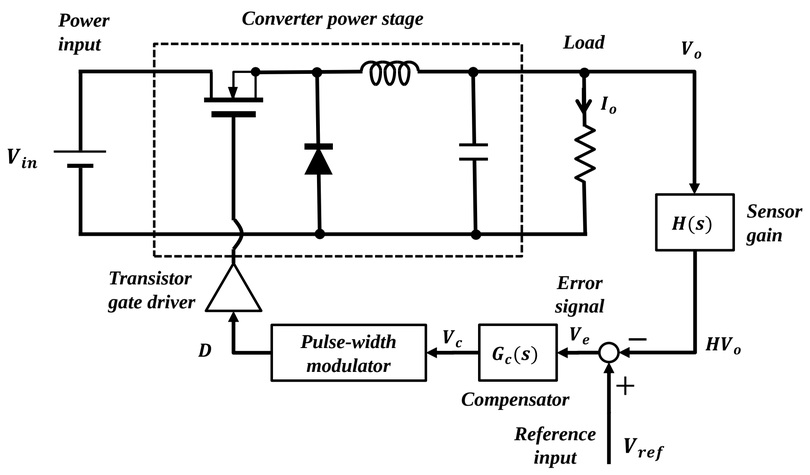


Purpose of This Work

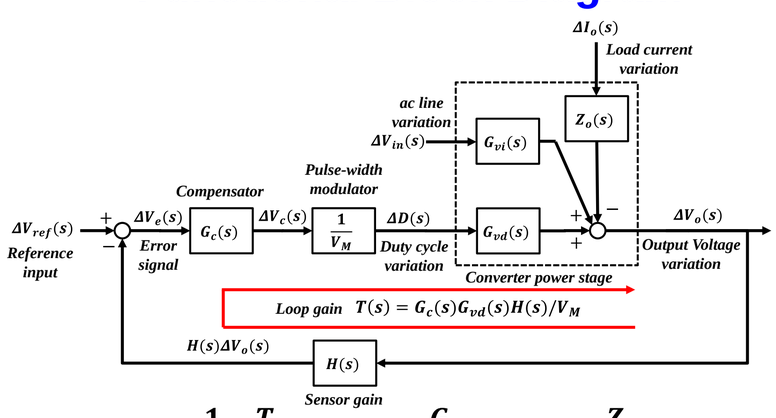
- To measure the loop gain without breaking the feedback loop.
- To develop a new method to derive the loop gain from output impedances in dc-dc buck converter.
- To demonstrate the proposed method by simulation and experimental evaluations.

Derivation of Proposed Method

DC-DC Buck Converter Circuit



Functional Block Diagram



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

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

converter output impedance in closed loop

Derivation of Proposed Method

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

Zo is output impedance in open loop
Zoc is output impedance in closed loop

Magnitude of Loop Gain

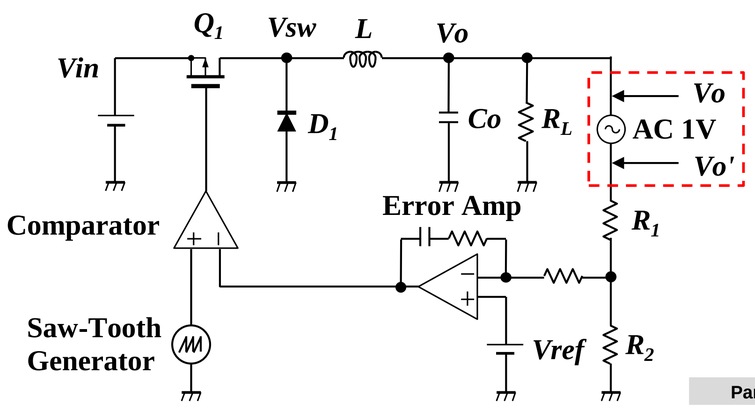
$$20\log_{10}|T| = 20\log_{10}\left[\frac{|Z_o - Z_{oc}|}{|Z_{oc}|}\right]$$

Phase of Loop Gain

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

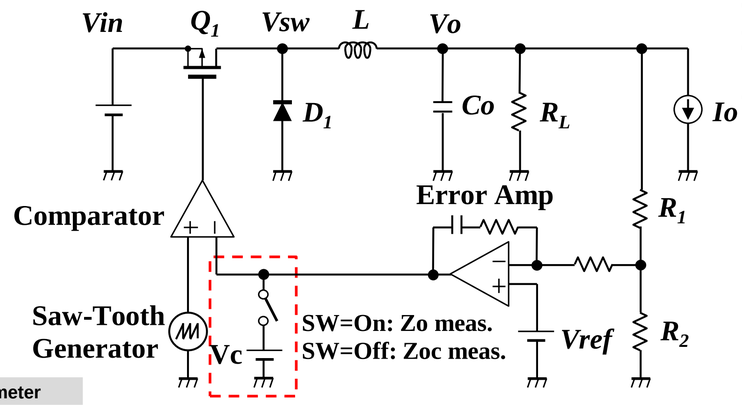
Simulation Results

Conventional method



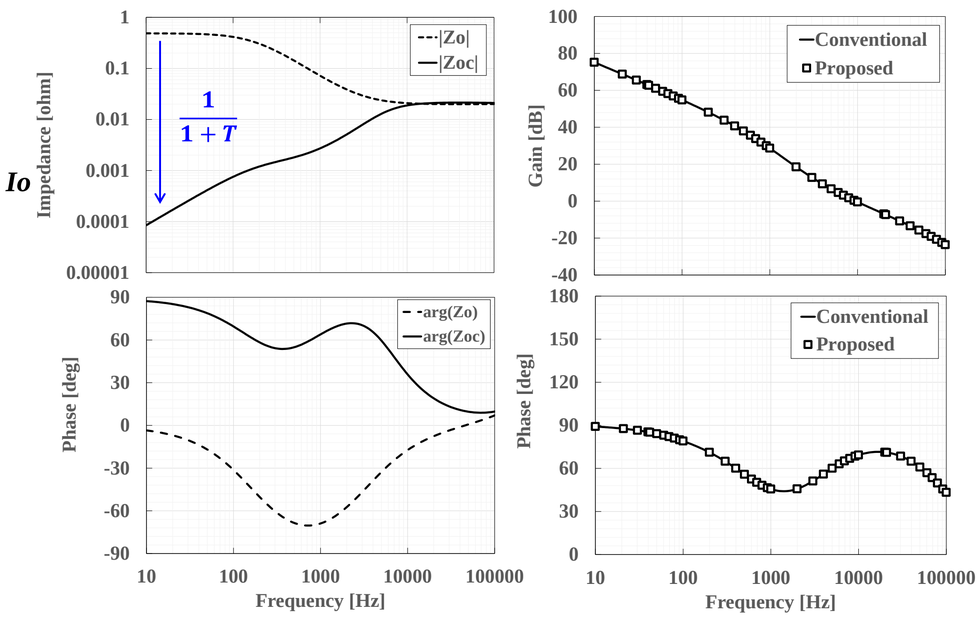
Loop Gain T = Vo/Vo'

Proposed method



Loop Gain T = (Zo-Zoc)/Zoc

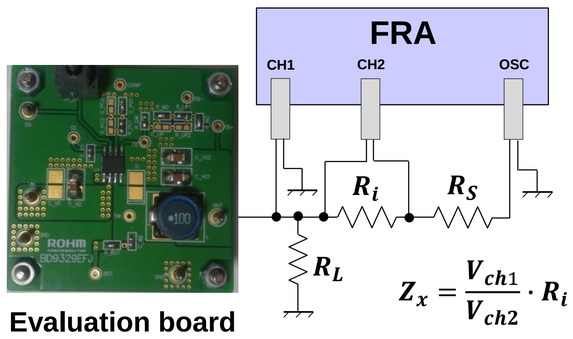
Parameter	
Vin	12V
Vo	5V
RL	5Ω
L	120uH
Co	1.2mF x 2 (ESR=40mΩ)



Experimental Results

Experimental Setup

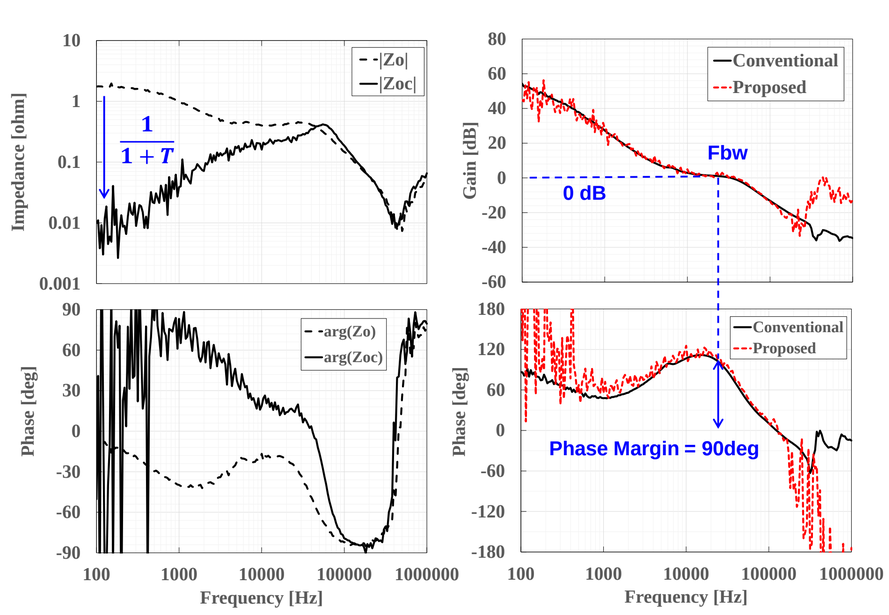
- IC:BD9329A (Rohm Semiconductor)
  - Synchronous buck converter with integrated FET
  - Switching frequency: 380kHz



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



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.

[Ref1] N. Tsukiji, Y. Kobori, H. Kobayashi "Derivation of the loop gain from output impedances in DC-DC buck converter" 2016 IEEE 13th International Conference on Solid-State and Integrated Circuit Technology (ICSICT-2016), Hangzhou, China (Oct. 25-28, 2016).

[Ref2] N. Tsukiji, Y. Kobori, H. Kobayashi "Derivation of the loop gain from open loop and closed loop output impedances in DC-DC buck converter" The 2nd Taiwan and Japan Conference on Circuits and Systems (TJCAS2016), National Cheng kung University, Tainan, Taiwan (Aug. 2, 2016), Paper S3B.5.