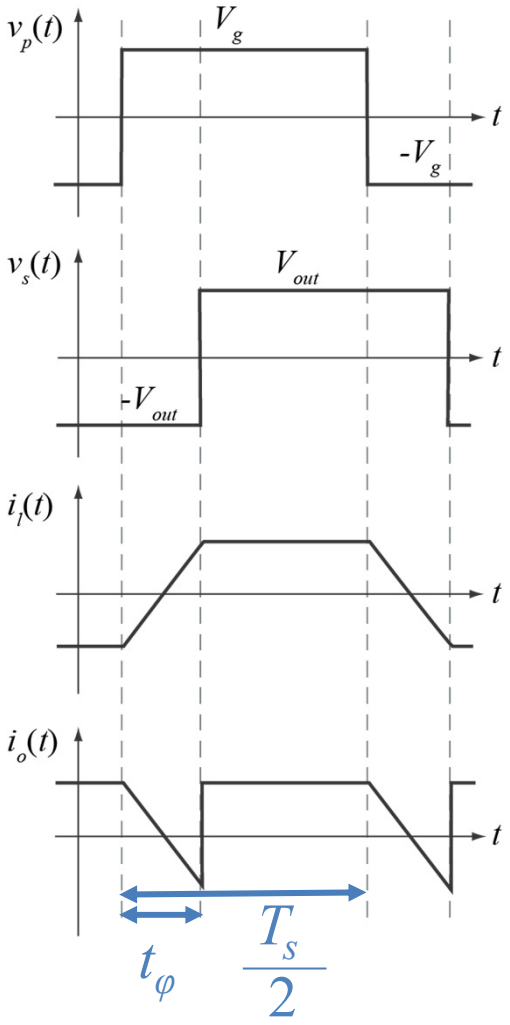
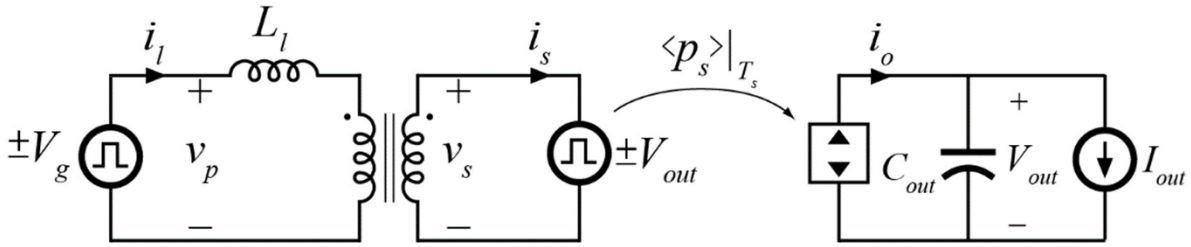
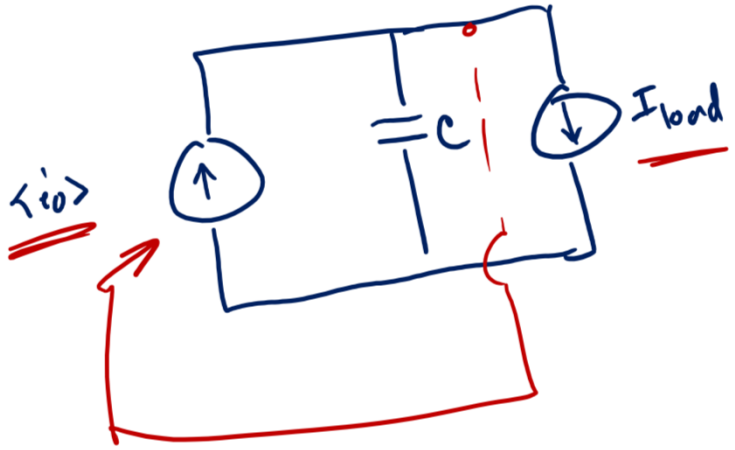
Linear Averaged Modeling of DAB





$$\langle i_o \rangle \Big|_{T_s} = \frac{V_g}{n_t L_l T_s}\left(T_s t_\varphi - 2{t_\varphi}^2\right)$$



Average Model Transfer Functions

$$\langle i_o \rangle \Big|_{T_s} = \frac{V_g}{n_t L_l T_s}\left(T_s t_\varphi - 2t_\varphi{}^2\right)$$

$$\langle i_o \rangle|_{T_s} - I_{load} = C\frac{dV}{dt}$$

$$I_o(s) - I_{load}(s) = sCV(s)$$

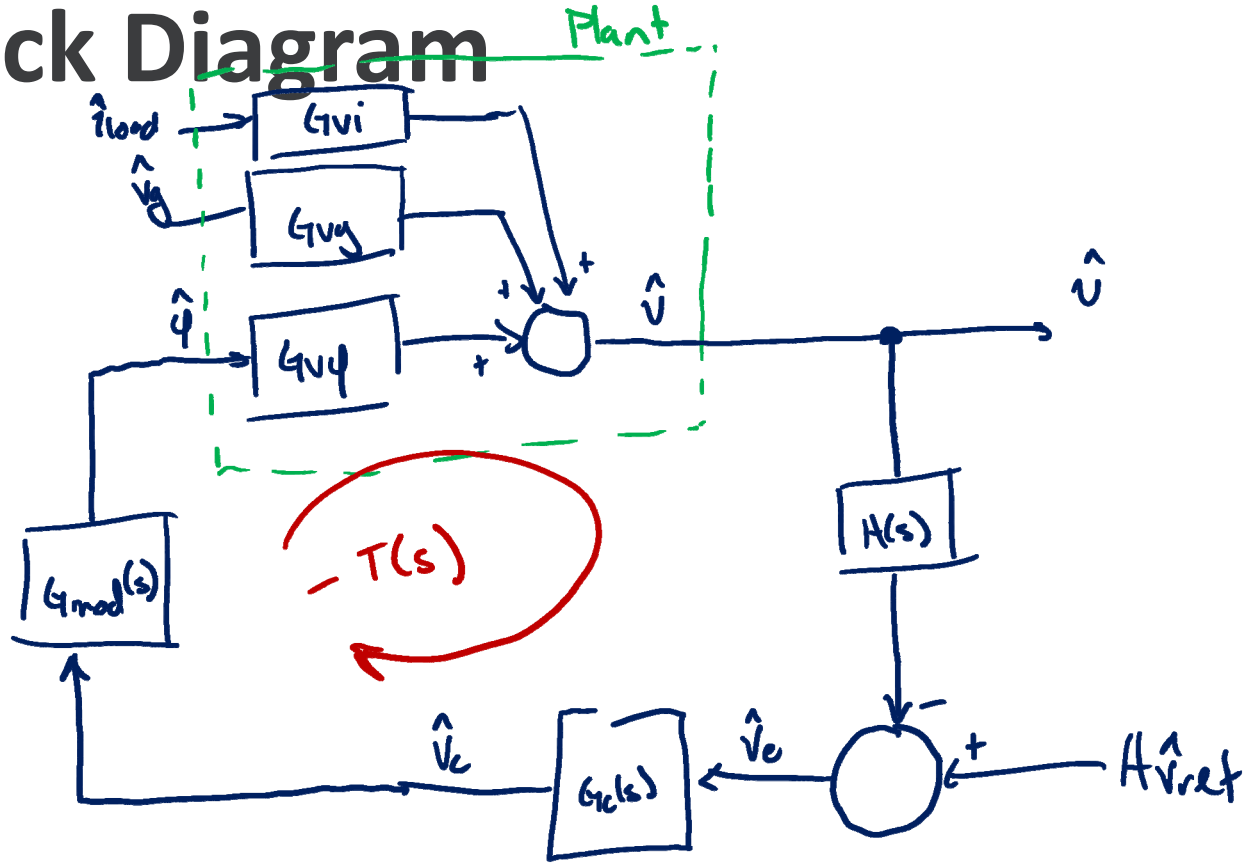
$$V(s) = \frac{1}{sC}\left[K_1 I_{load}(s) + k_2 T_p(s) + k_3 V_g(s)\right]$$

$$G_{vg}(s) = \frac{\hat{v}}{\hat{v}_g} = \frac{1}{sC}\frac{\partial i_o}{\partial v_g}\Big|_{DC} = \frac{1}{sC}\left(\frac{1}{n_t L_l T_s}\left(T_s t_\varphi - 2t_\varphi{}^2\right)\right)\Big|_{DC}$$

$$G_{v\varphi}(s) = \frac{\hat{v}}{\hat{t}_\varphi} = \frac{1}{sC}\frac{\partial i_o}{\partial t_\varphi} = \frac{1}{sC}\left[\frac{V_g}{n_t L_l T_s}\left(t_s - 4t_\varphi\right)\Big|_{DC}\right]$$

$$G_{vi}(s) = \frac{\hat{v}}{\hat{i}_{load}} = -\frac{1}{sC}$$

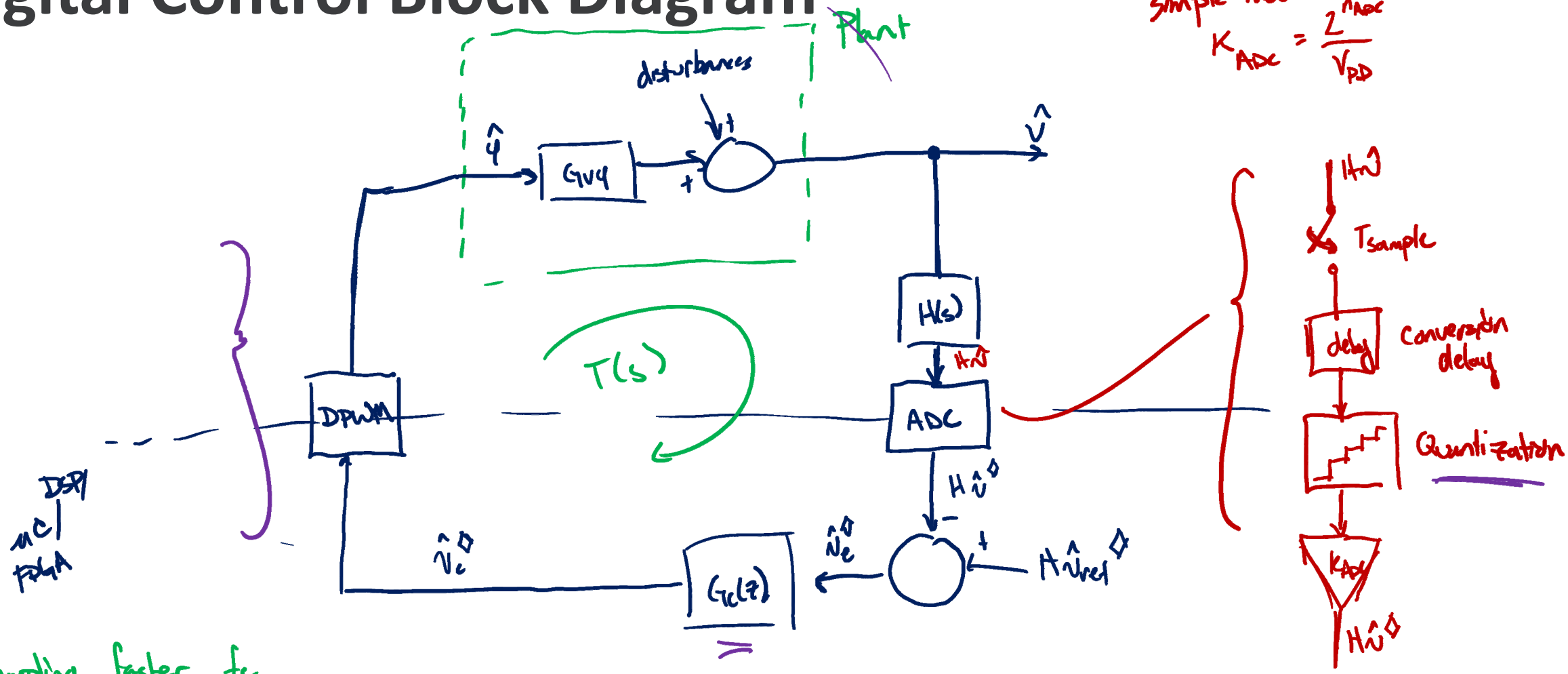
Converter Block Diagram



$$\hat{v} = \hat{v}_{ref}\frac{T}{1+T} + \hat{i}_{load}\frac{1}{1+T} + \hat{v}_g\frac{1}{1+T}$$

Compensation Goal: Large $T(s)$ over a wide frequency range $f_L \sim f_s/10$ & $\phi_m \geq 30^\circ$

Digital Control Block Diagram



If sampling faster fc

If n_{ADC} is sufficiently large (compared to DPWM resolution)

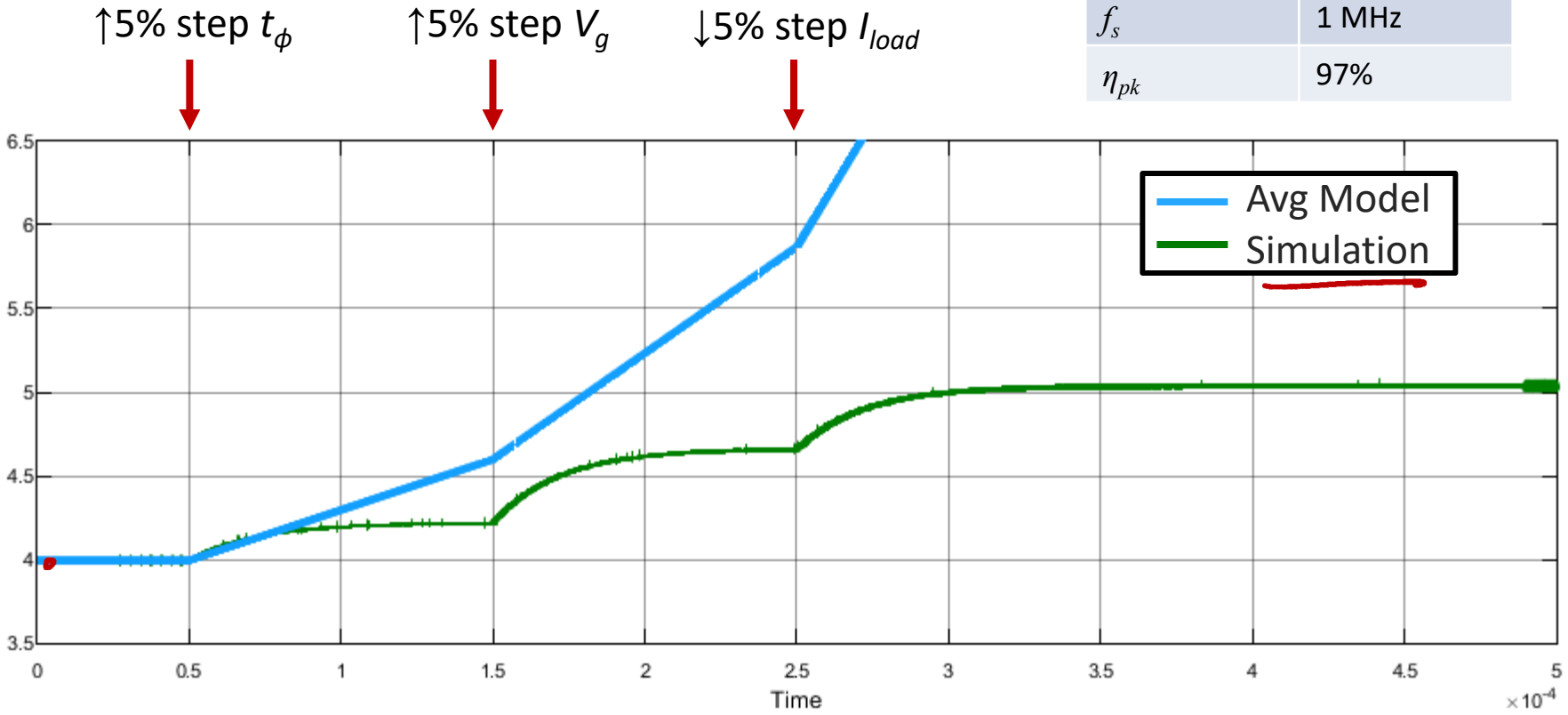
If all delays are nearly zero relative to T_s

then digital loop ≈ averaged s-domain loop

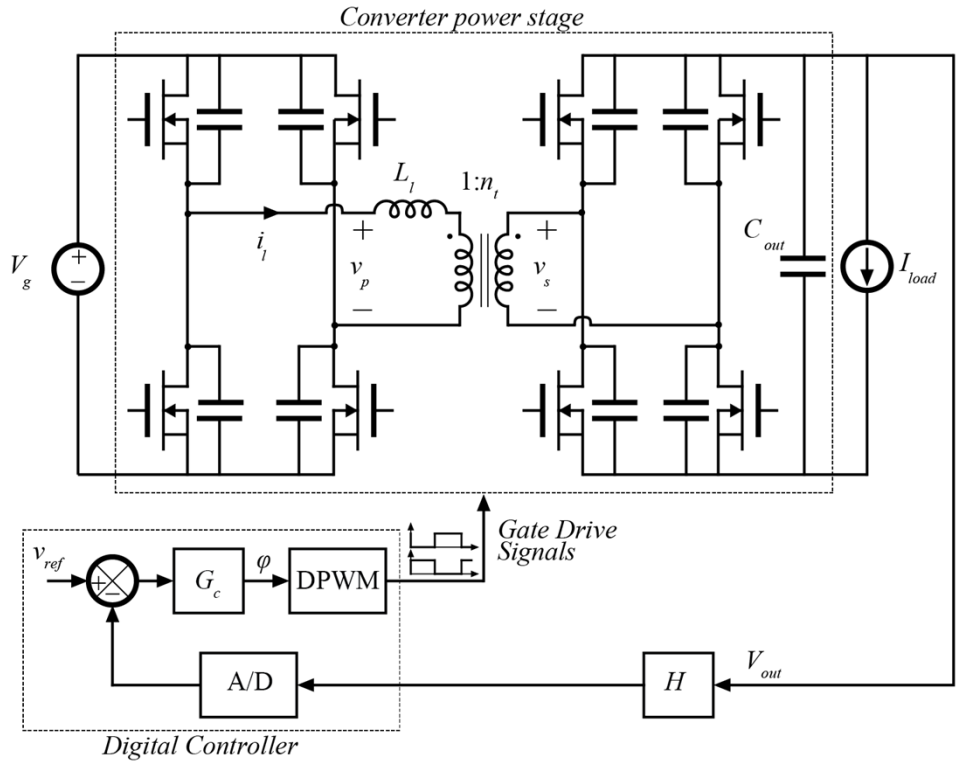
Model Validation

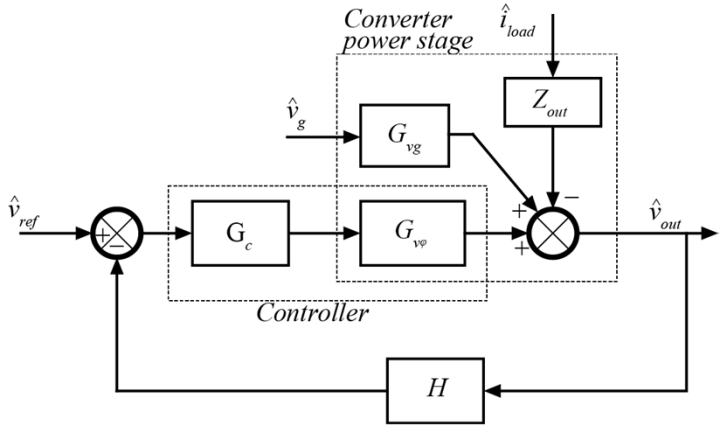
$R_L = 330m\Omega$
$C_{DS} = 75pF$

Parameter	Value
V_g	50 V
V_{out}	4 V
I_{load}	3.5 A
C_{out}	20 µF
L_l	9.5 µH
n_t	25:2
f_s	1 MHz
η_{pk}	97%



Control Design





$G_{v\varphi}(s) = k\frac{1}{s}$

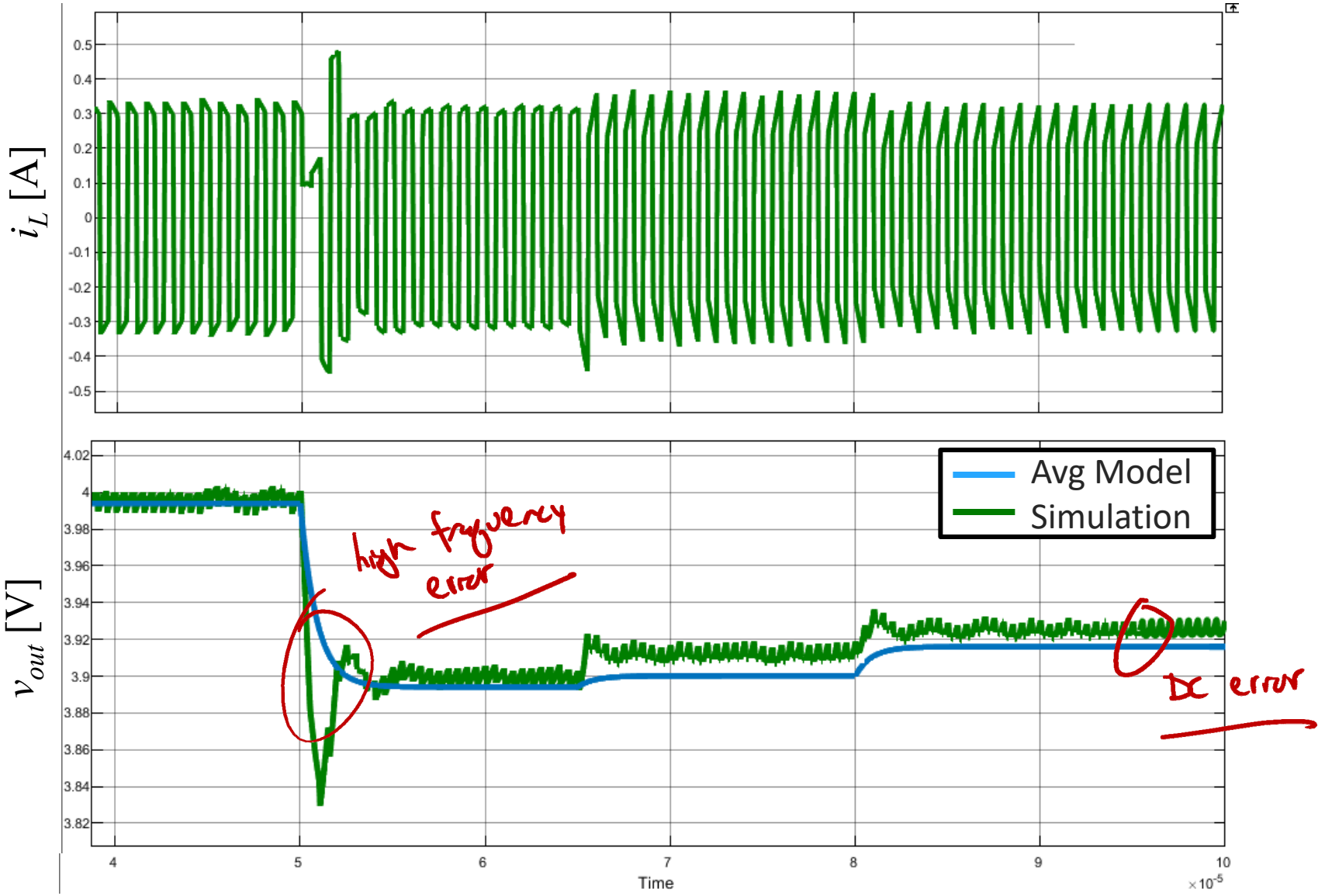
can be stabilized w/ $G_c(s) = k_p$

$k_p = 5 \times 10^{-7}$

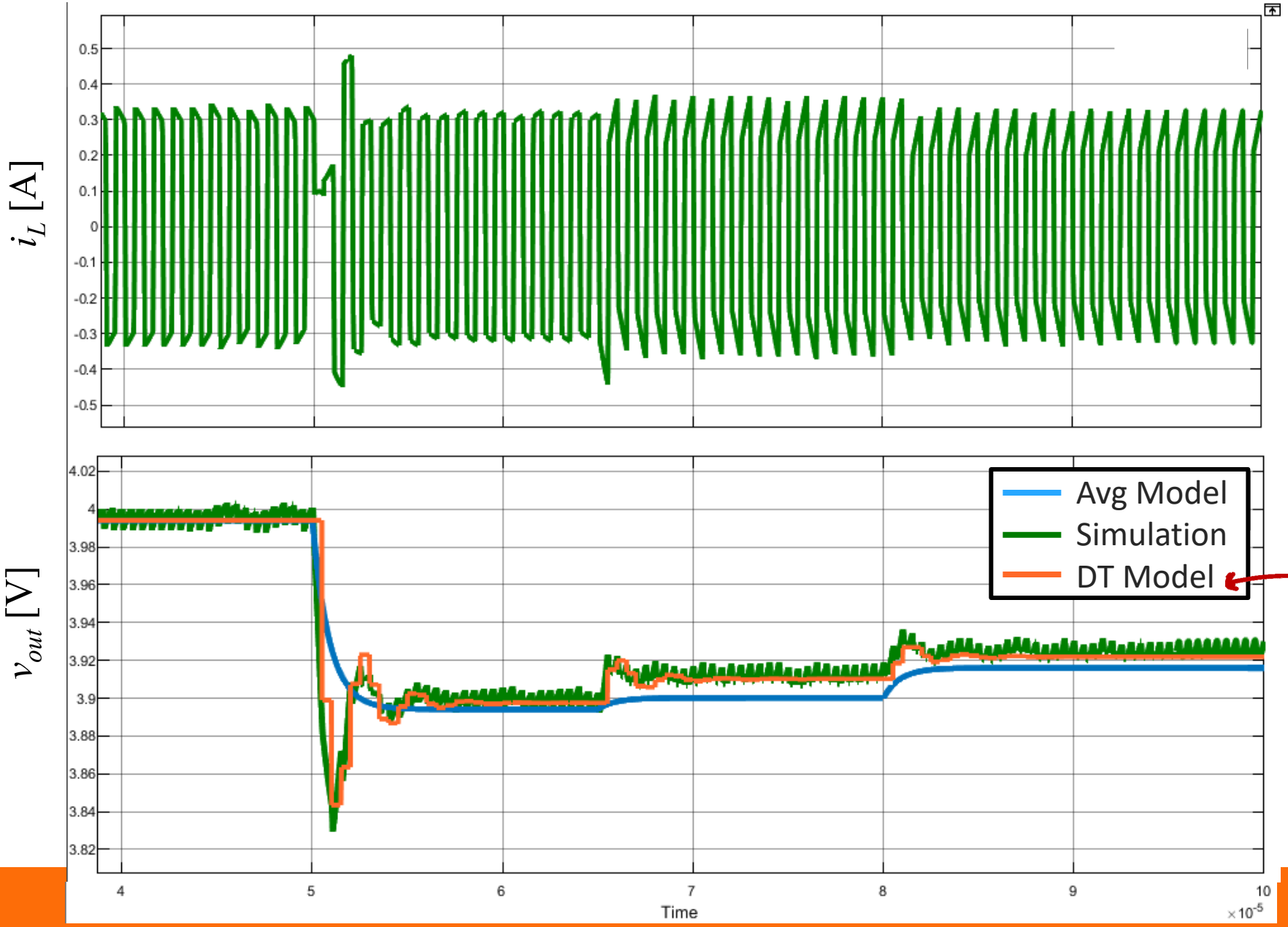
$f_c = 200\text{kHz}$

$\gamma_m = 90°$

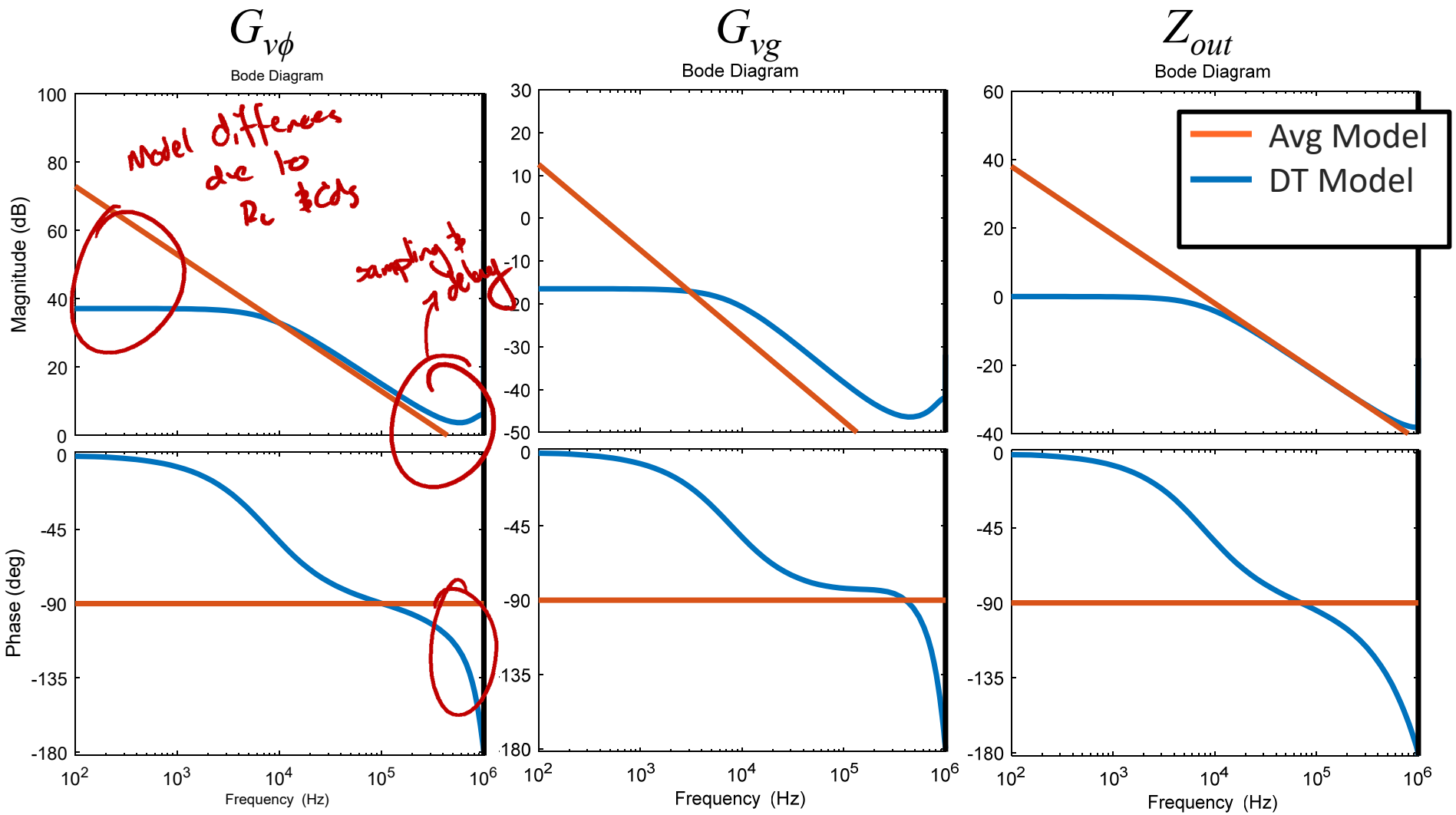
Averaged Model Comparison



Discrete Time Model Comparison



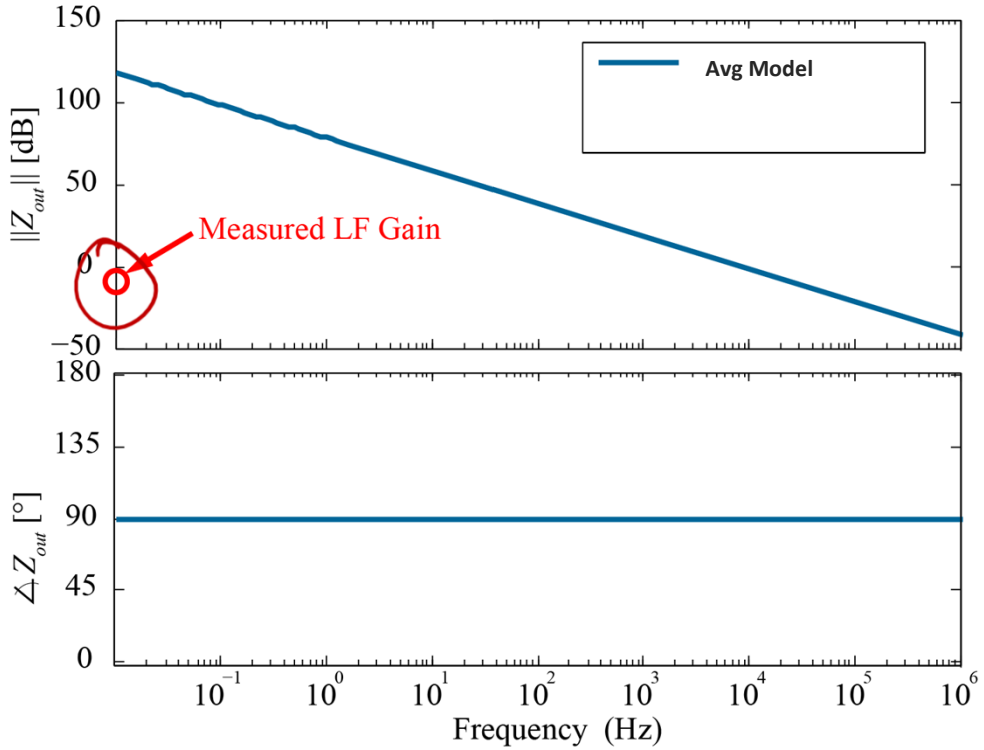
Transfer Function Comparison

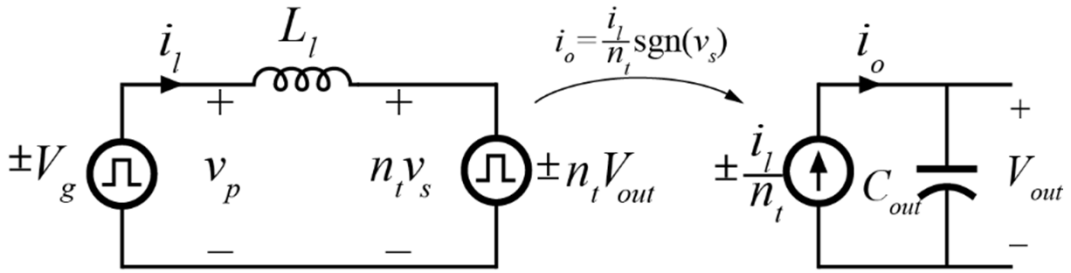


Experimental Measurement of Z_{out}

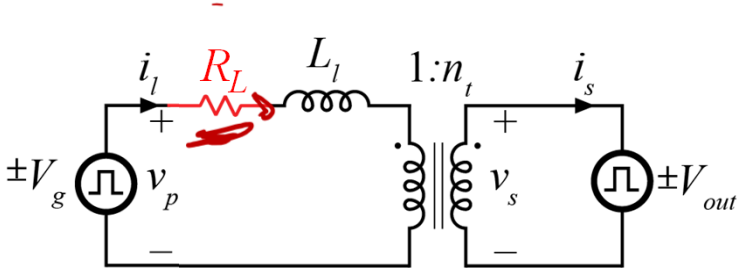
- Prototype DAB constructed

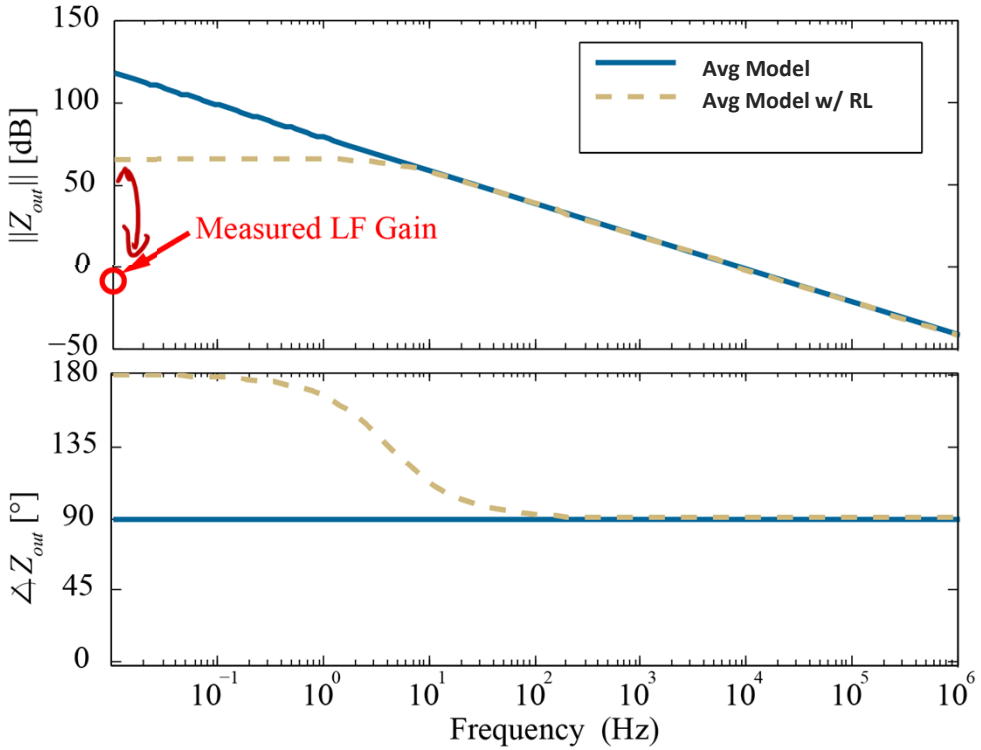
Parameter	Value
V_g	50 V
V_{out}	4 V
I_{load}	2.5-3.5 A
C_{out}	20 µF
L_l	9.5 µH
n_t	25:2
η_{pk}	97%





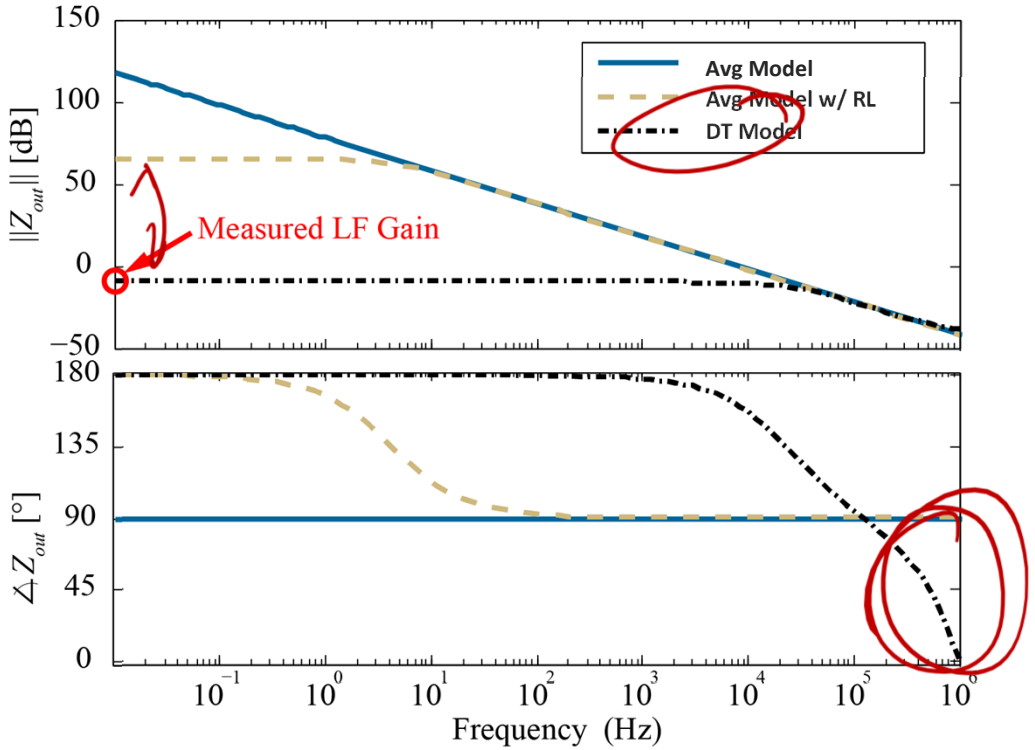
Including Conduction Losses



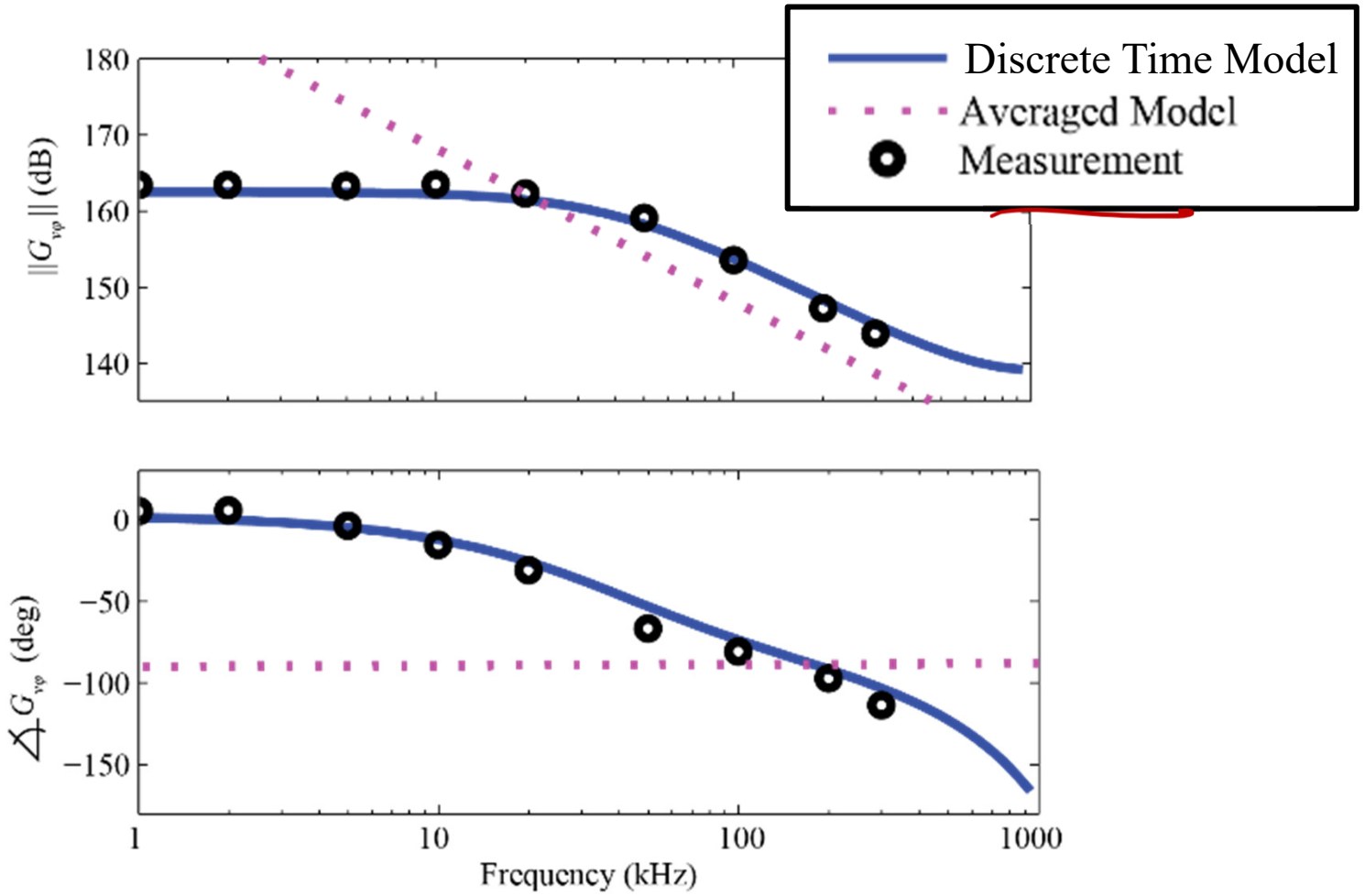


D. Segaran, D. Holmes, and B. McGrath, "Enhanced load step response for a bidirectional DC-DC converter," IEEE Trans. Power Electron., vol. 28, no. 1, pp. 371–379, 2013.

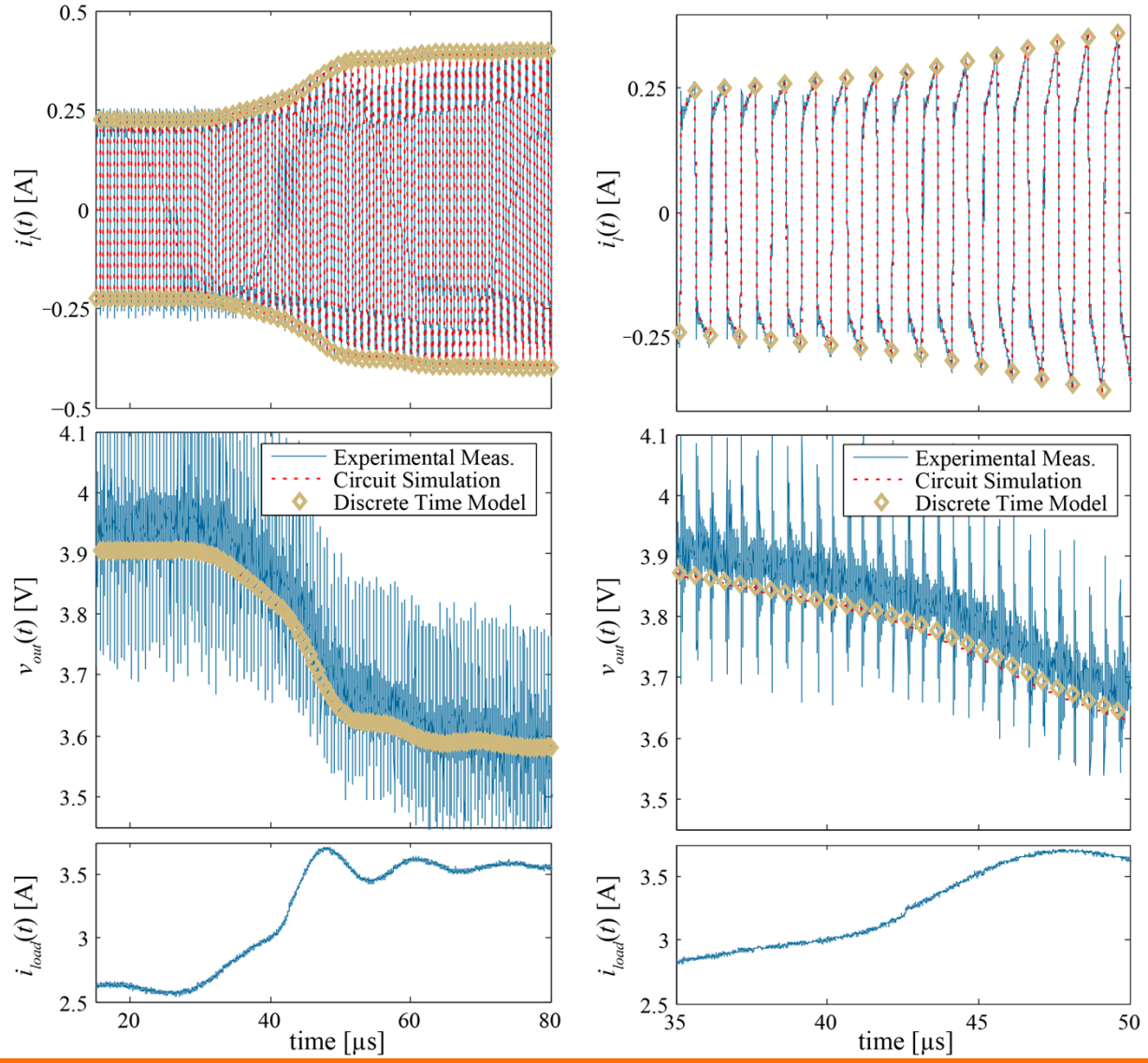
Discrete Time Model: Results



Control-to-Output Transfer Function



Transient Comparison



Topics Covered

- Steady-state modeling of switched systems
  - State space representation ✓
  - Discrete time model
  - Steady-state solution
  - Averaging and singularities
- Dynamic models of switched systems
  - Small-signal discrete time modeling
  - Model reduction
  - DPWM and ADC
  - Delays and Quantization
- Digital Control
  - Hardware implementation
  - Compensator Design
  - Advanced techniques
- Additional Topics in design and control of power electronics