Midterm Project

- Select a (dc-dc) converter steady-state hardware design problem
- Detail
  - Application specification
  - Performance specification
    - should advance on SotA; near-optimal design
  - Design parameters
- Apply techniques from class
  - Design using MATLAB
  - Validate through simulation (PLECs/Spice)
- Should result in prototype-ready paper design
- Finalize scope by October 4th
  - 5 pts, text entry or pdf
  - Briefly describe application, performance spec, and design parameters
- Report Due October 18th
  - Narrative of analysis and results
  - Clear but minimally "wordy"
  - IEEE format (though incomplete content w.r.t. review and explanation)
- Class presentations thereafter

Large-signal steady-state

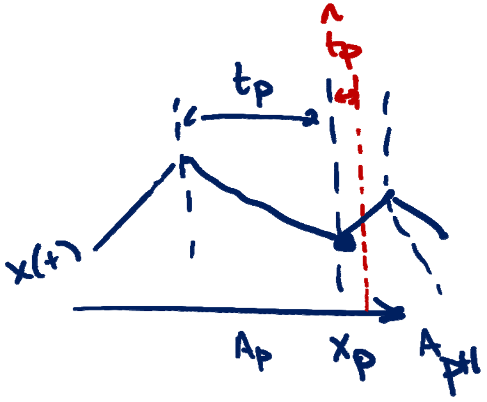
$$X(T_s) = \overbrace{\left[\prod_{i=k}^{1} e^{A_i t_i}\right]}^{\Phi} X_0 + \left[\overbrace{\sum_{i=1}^{k} \left(\prod_{j=k}^{i+1} e^{A_j t_j}\right)}^{\Psi} \overbrace{\int_{0}^{t_i} e^{A_i(t_i-\tau)} B_i \, d\tau}^{A_i^{-1}(e^{A_i t_i} - I)B_i}\right] u_i$$

Discrete-time transient model

$$x[k+1] = \overbrace{\left[\prod_{i=k}^{1} e^{A_i t_i}\right]}^{\Phi(t_i)} x[k] + \left[\overbrace{\sum_{i=1}^{k} \left(\prod_{j=k}^{i+1} e^{A_j t_j}\right)}^{\Psi(t_i)} \int_{0}^{t_i} e^{A_i(t_i-\tau)} B_i \, d\tau\right] u[k]$$

Small-signal linearization for constant fs modulation

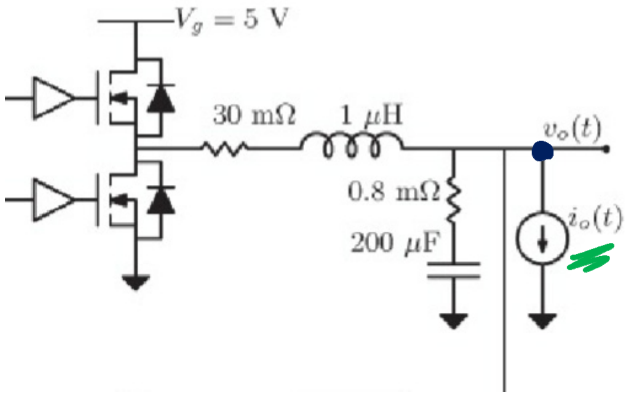
$$\hat{x}[k+1] = \overbrace{\left[\prod_{i=k}^{1} e^{A_i t_i}\right]}^{\Phi} \hat{x}[k] + \overbrace{\left[\sum_{i=1}^{k} \left(\prod_{j=k}^{i+1} e^{A_j t_j}\right) \int_{0}^{t_i} e^{A_i(t_i-\tau)} B_i \, d\tau\right]}^{\Psi} \hat{u}[k] + \cdots$$



p^{th} interval perturbed $p \le k$

$$\underbrace{\left[\prod_{i=k}^{p+1} e^{A_i t_i}\right]\left[\overbrace{(A_p - A_{p+1})X_{p^+} + (B_p - B_{p+1})U}^{\hat{x}_a}\right]}_{\Gamma} \hat{t}_p[k]$$

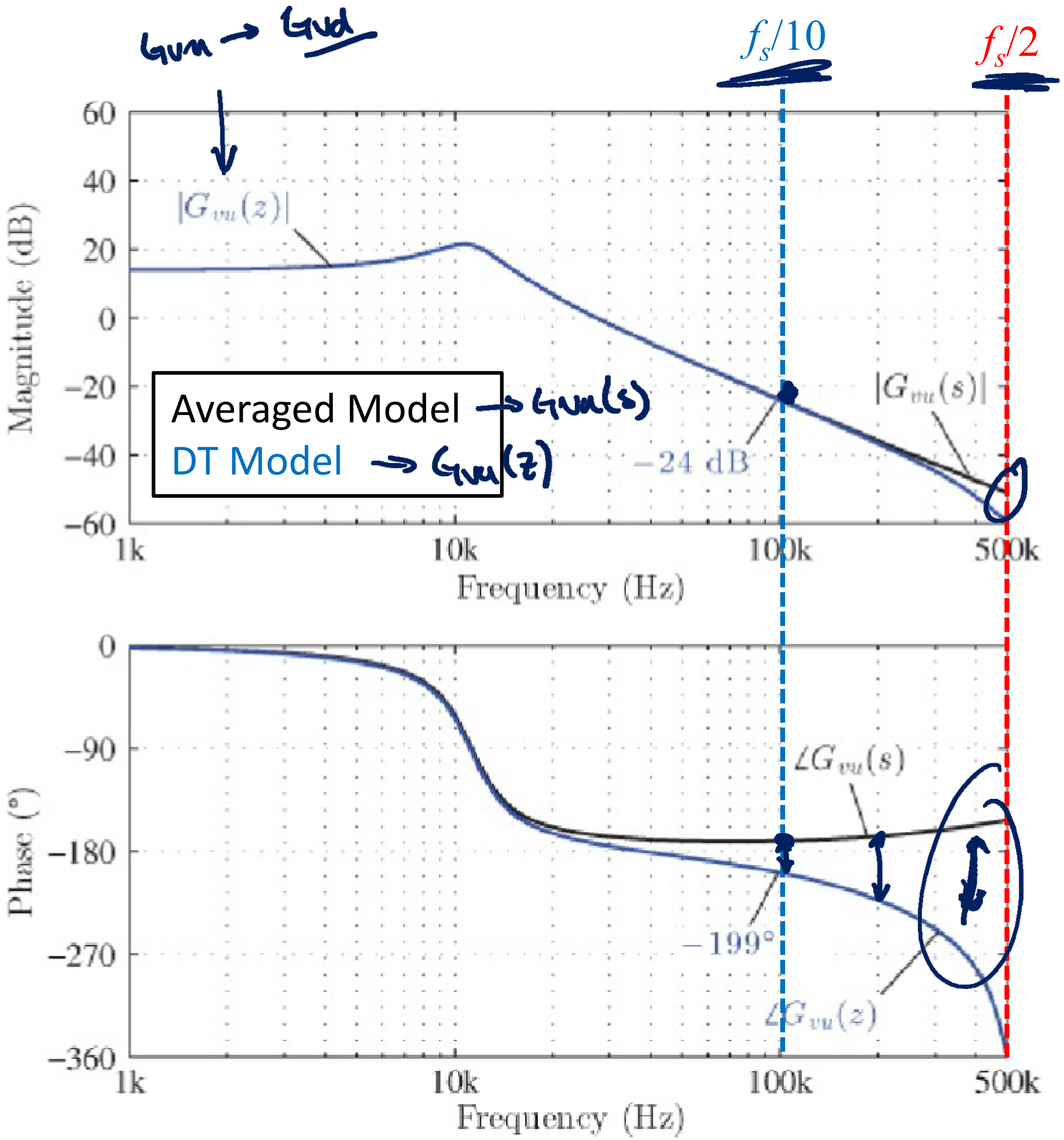
Example Results



* Includes t_d=760ns of delay in feedback loop

400 ns of ADC conversion & control calculation

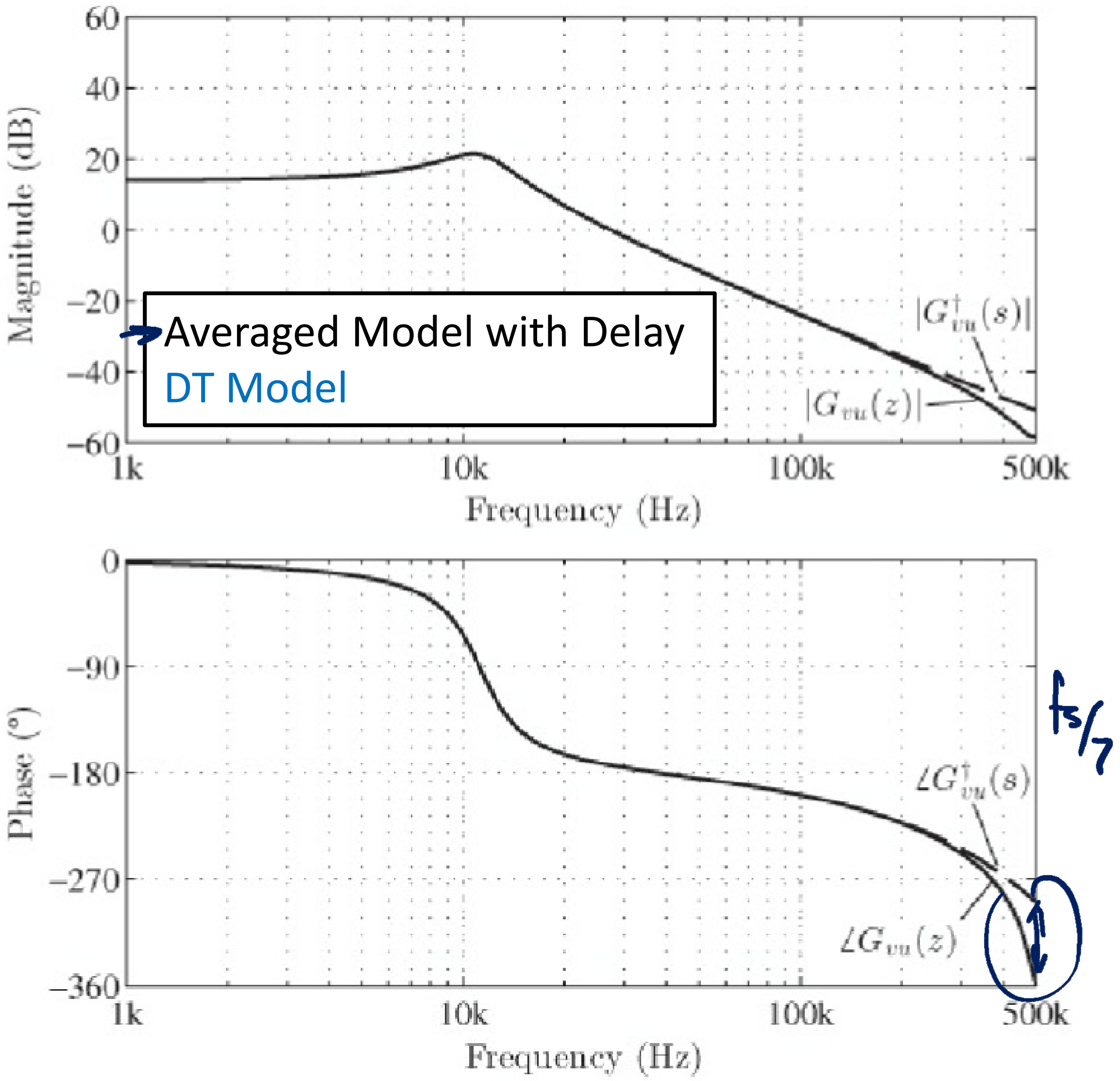
360ns = DT_s = t_{pwm}



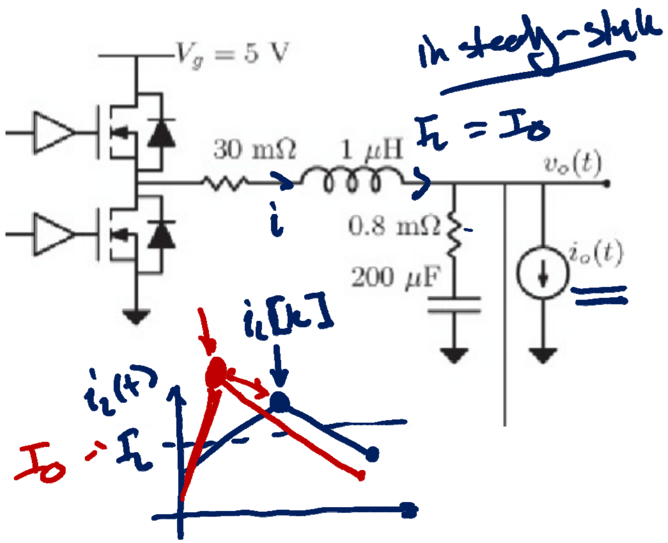
Inclusion of Delay

sampled Data model

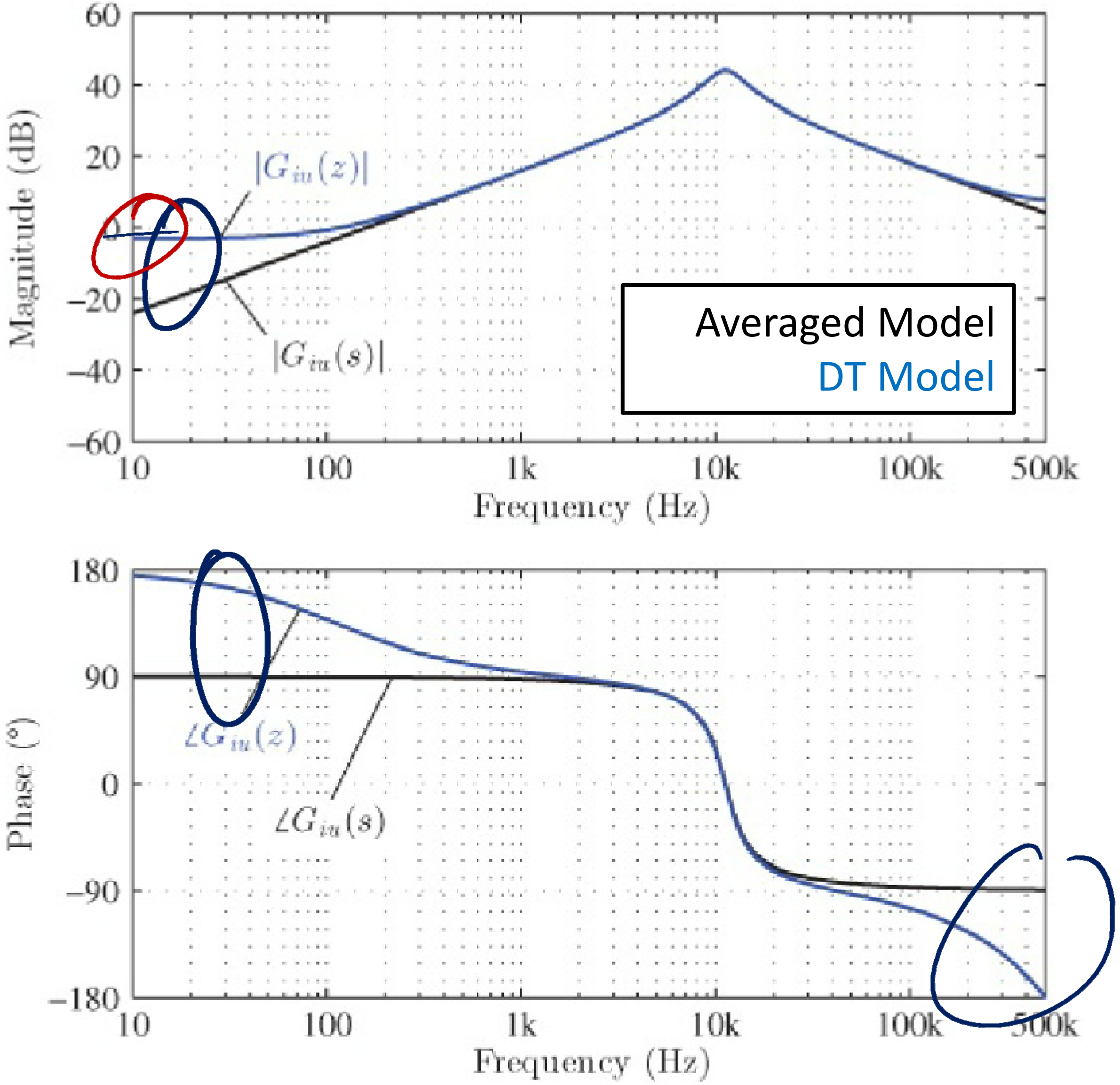
$$G_{vu}^{\dagger}(s) = \underbrace{G_{vu}(s)}\underbrace{e^{-st_d}}$$



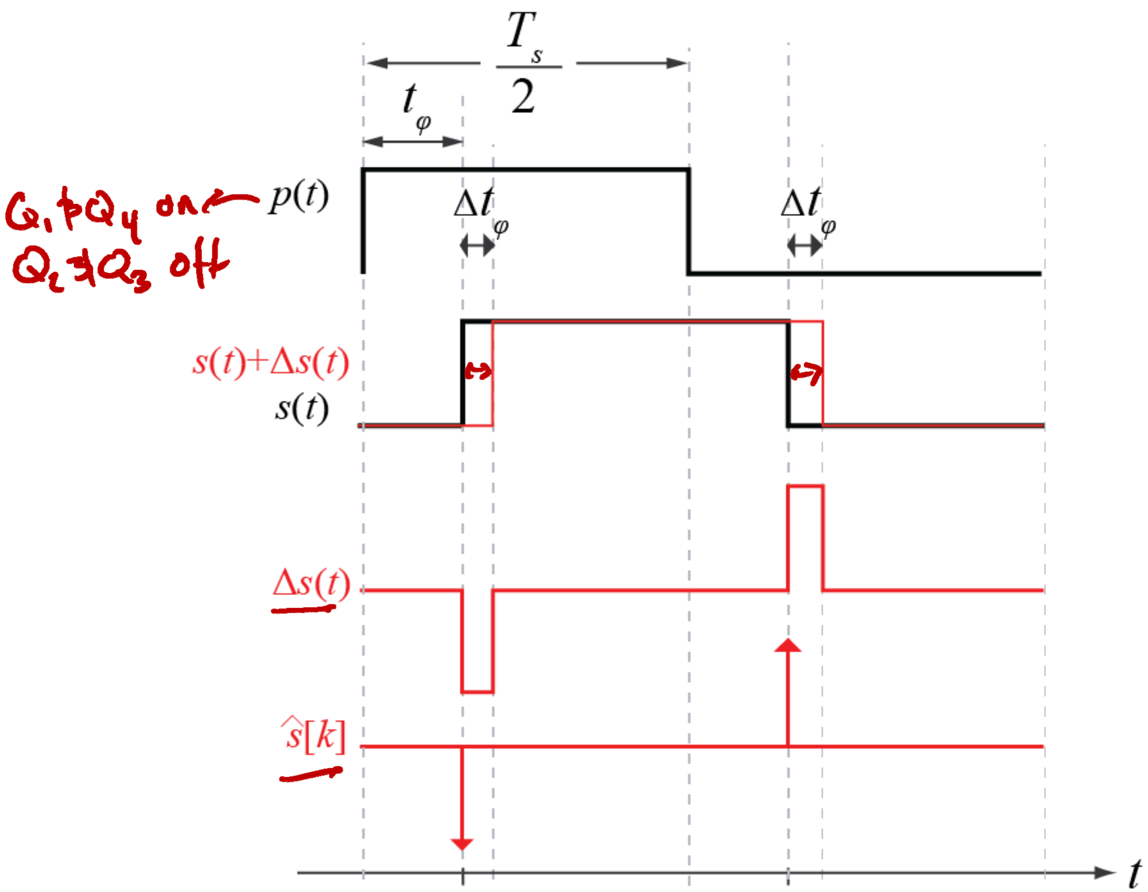
Current Control



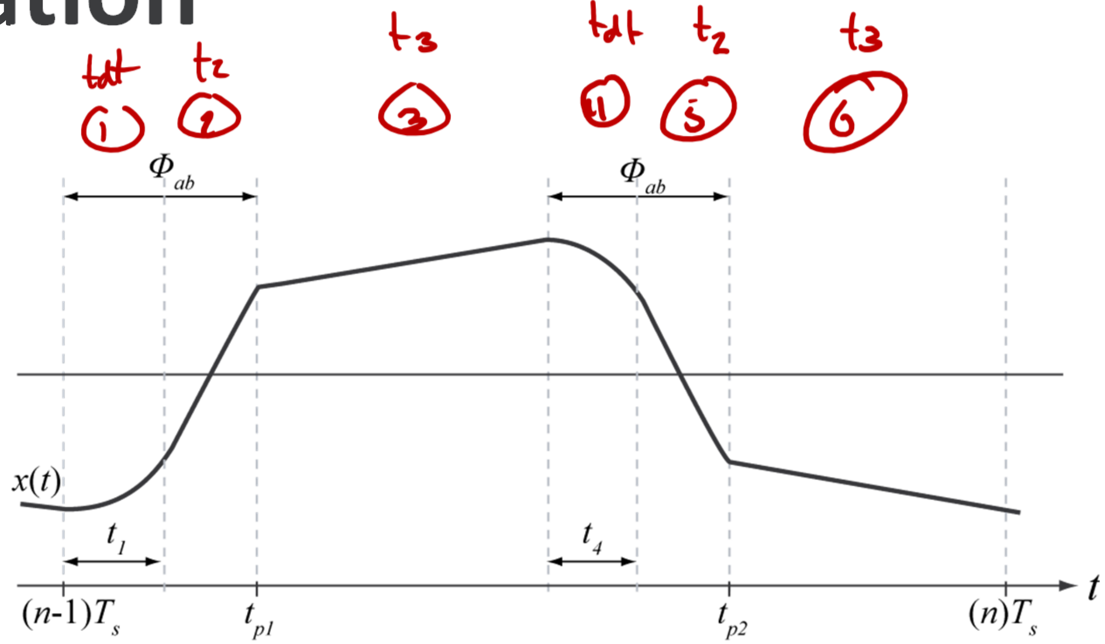
Giu → Gid



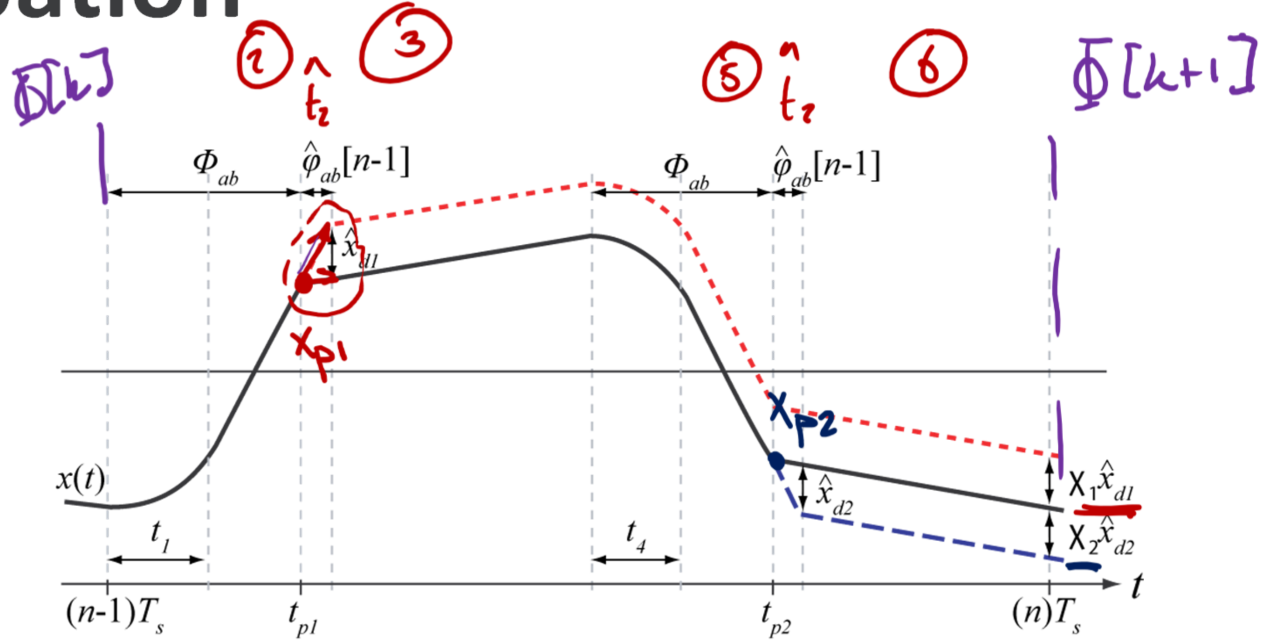
Example: Phase Shift Modulation



Dual Perturbation



Dual Perturbation



$$\hat{x}_{d1} = \left[(A_2 - A_3) X_{p1} + (B_2 - B_3) u \right] \hat{t}_2$$

$$X_1 = e^{A_6 t_6} e^{A_5 t_5} e^{A_4 t_4} e^{A_3 t_3}$$

$$\hat{x}_{d2} = \left[(A_5 - A_6) X_{p2} + (B_5 - B_6) u \right] \hat{t}_5 \quad , \quad \underline{\underline{\hat{t}_5 = \hat{t}_2}}$$

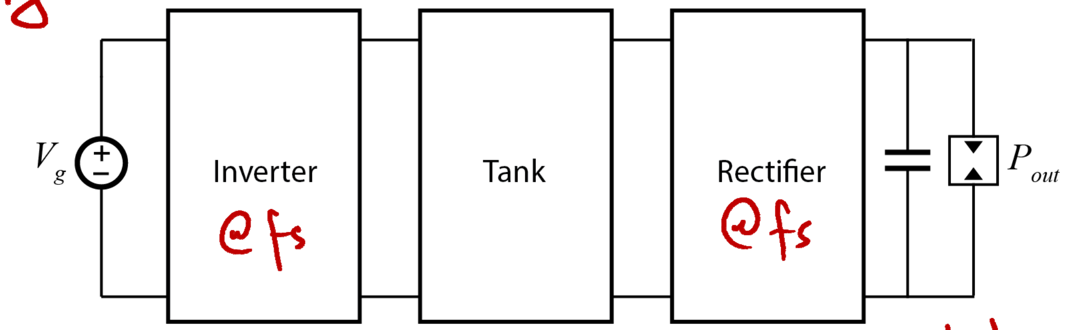
$$X_2 = e^{A_6 t_6}$$

$$\frac{\hat{x}}{\hat{t}_2} = \Gamma = \left[e^{A_6 t_6} e^{A_5 t_5} e^{A_4 t_4} e^{A_3 t_3} \left[(A_2 - A_3) X_p + (B_2 - B_3) u \right] + e^{A_6 t_6} \left[(A_5 - A_6) X_{p2} + (B_5 - B_6) u \right] \right]$$

Symmetric Converters

HW #3 solution
Applies symmetry

AC-link Topologies



DC + ripple

waveforms ac-only @ fs

DC + ripple

Converter waveforms exhibit defined symmetry

- All waveforms are periodic about fs
- ac waveforms have half-period antisymmetry
- dc waveforms have half-period symmetry

without symmetry, using Augmented SS

$$\tilde{x}(T_s) = \left(\prod_{i=n_i}^{1} e^{\tilde{A}_i t_i} \right) \tilde{x}(0)$$

n_i = number of switching intervals in one period

$$\tilde{X}_{ss} \rightarrow \text{null}\left(I - \prod_{i=n_i}^{1} e^{\hat{A}_i t_i} \right)$$

using symmetry arguments:

$$\tilde{x}(T_s/2) = \left(I_{HC} \prod_{i=\frac{n_i}{2}}^{1} e^{\hat{A}_i t_i} \right) \tilde{x}(0)$$

$$x(t) = \begin{bmatrix} x_{DC} \\ x_{AC} \end{bmatrix} \rightarrow \quad I_{HC} = \begin{bmatrix} I & \emptyset \\ \emptyset & -I \end{bmatrix}$$

$$\tilde{X}_{ss} \rightarrow \text{null}\left(I - I_{HC} \prod_{i=\frac{n_i}{2}}^{1} e^{\hat{A}_i t_i} \right)$$

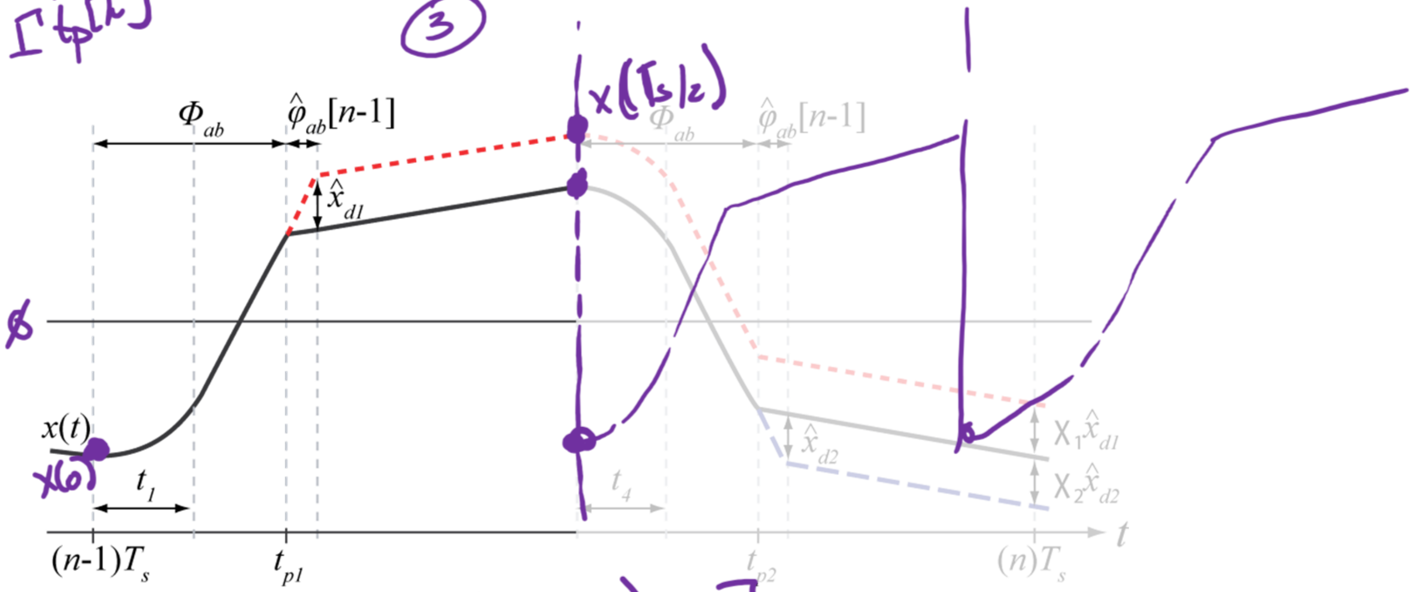
Half-Cycle Model

$\hat{x}[k+1] = \Phi \hat{x}[k] + \Psi \hat{u}[k] + \Gamma \hat{t}_p[k]$

sampled @ $\frac{T_s}{2}$

& φ_{ab} updated every half-period.

3

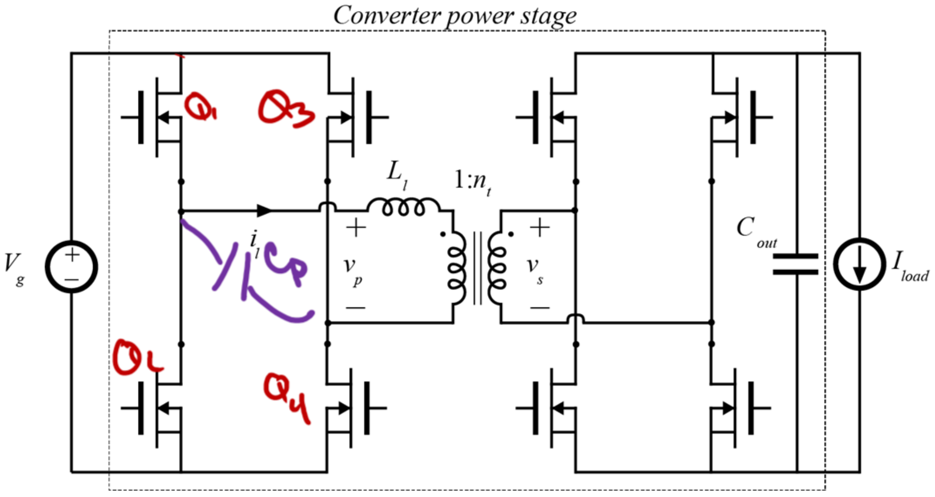


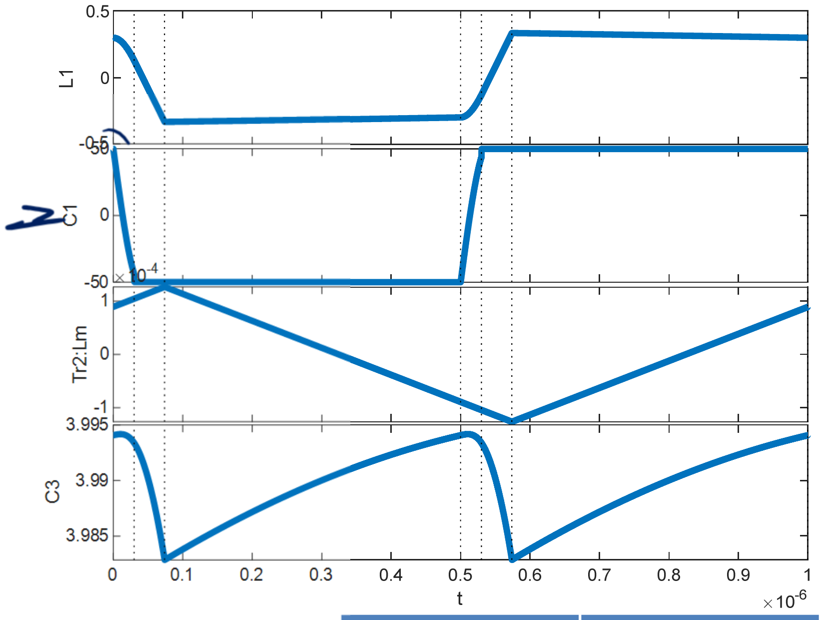
$$\Gamma = e^{A_3 t_3}\left[(A_2 - A_3)x_{p1} + (B_2 - B_2)u\right]$$

$$\Phi = e^{A_3 t_3} e^{A_2 t_2} e^{A_1 t_1}(I + C)$$

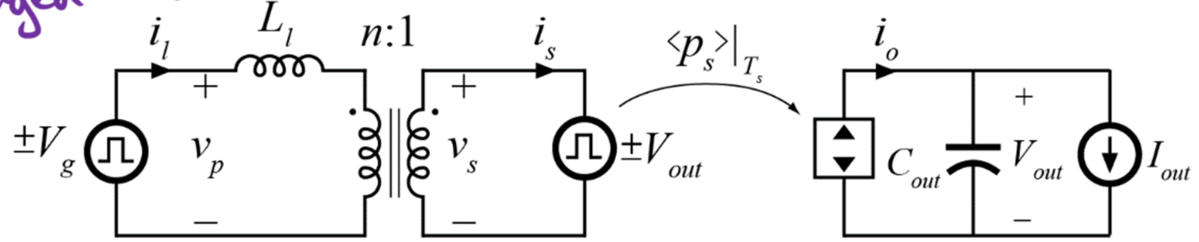
$$\Psi = \sum_{i=1}^{3}\left(\prod_{j=3}^{i+1} e^{A_j t_j}\right) A_i^{-1}\left(e^{A_i t_i} - I\right) B_i$$

Example: Introductory DAB





Averaged model:



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

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%

DAB Transfer Function Comparison

```
Gvphi = ss(PHI, GAMMA, C, 0, Ts);
bode(Gvhpi);
```

or

```
z = tf('z',Ts);
Gvphi = C*(z*eye(ns)-PHI)^-1*GAMMA;
bode(Gvphi);
```