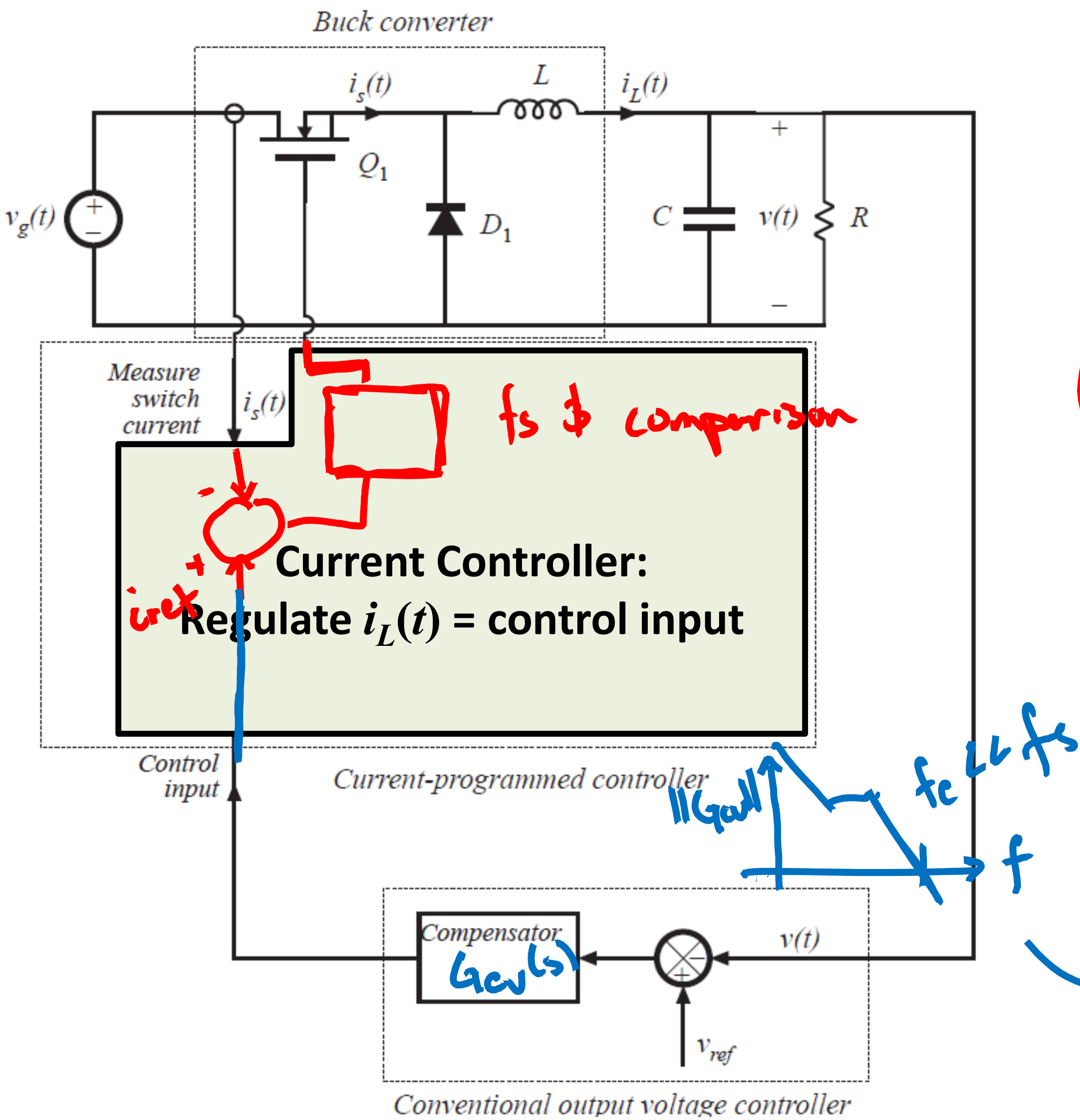
Current Control



Two control loops:

(1) Fast (inner) current loop control

– Not Averaged

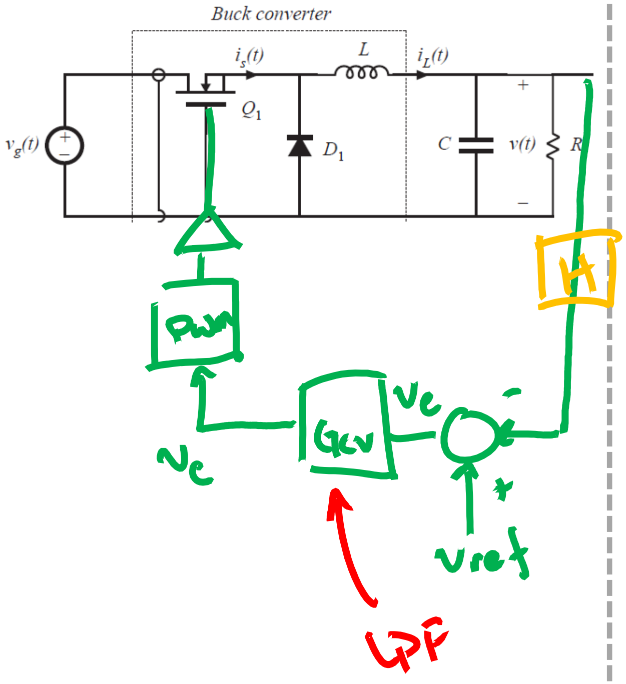
(2) Slow (outer) voltage loop control

– Averaged

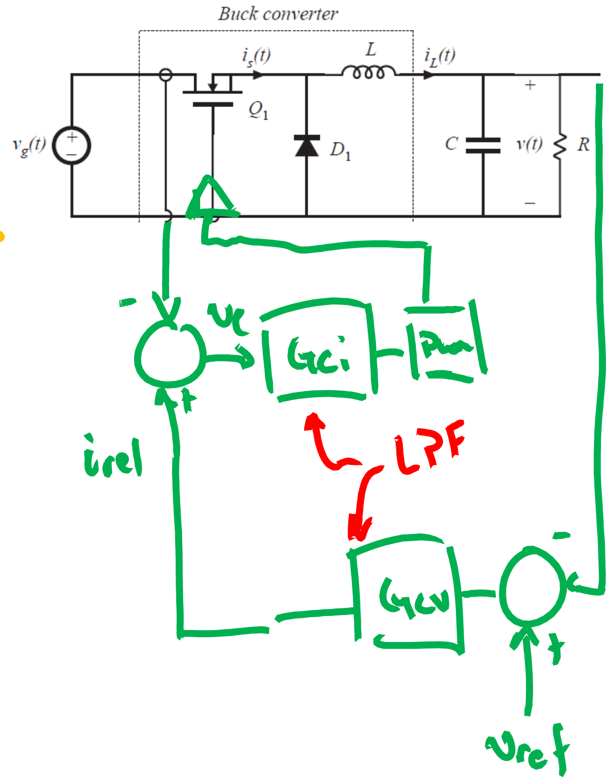
→ Effective low-pass filter averaged models can be used when $f_c << f_s$

Averaged vs CPM

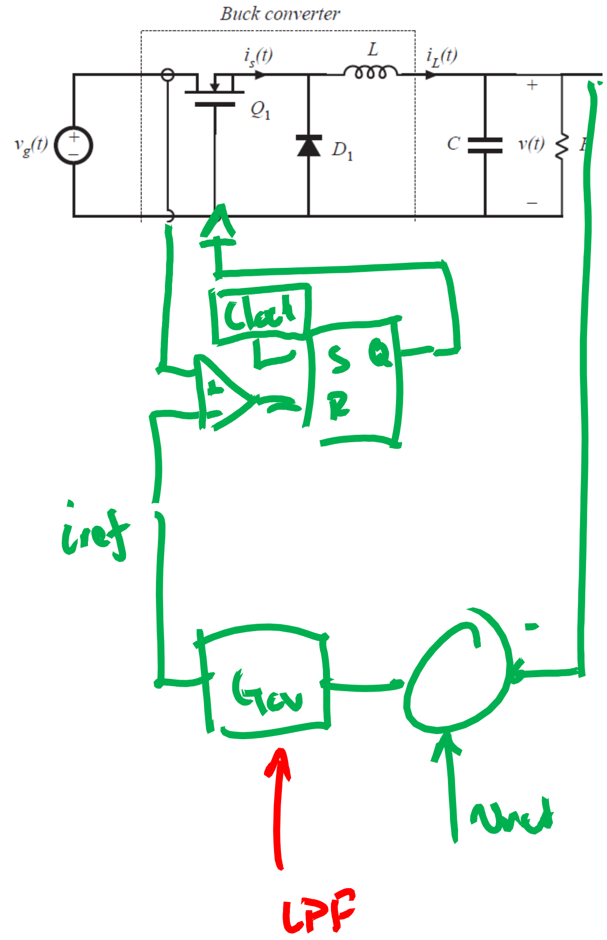
Voltage-Mode



Averaged Current-Mode

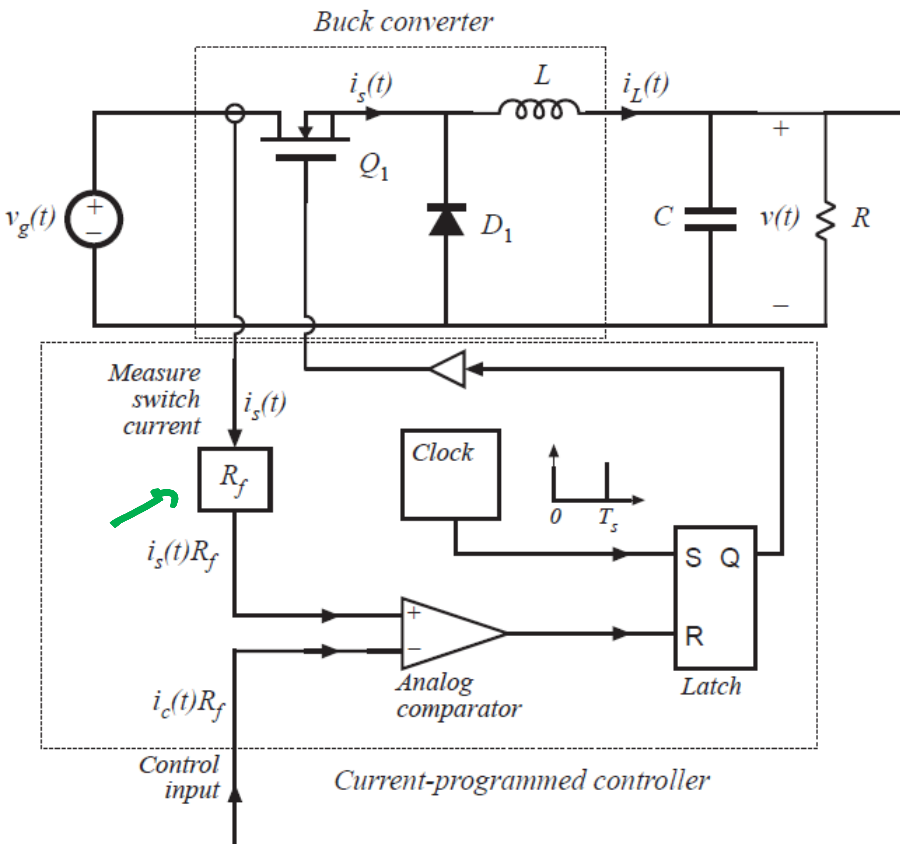


Current Programmed Mode



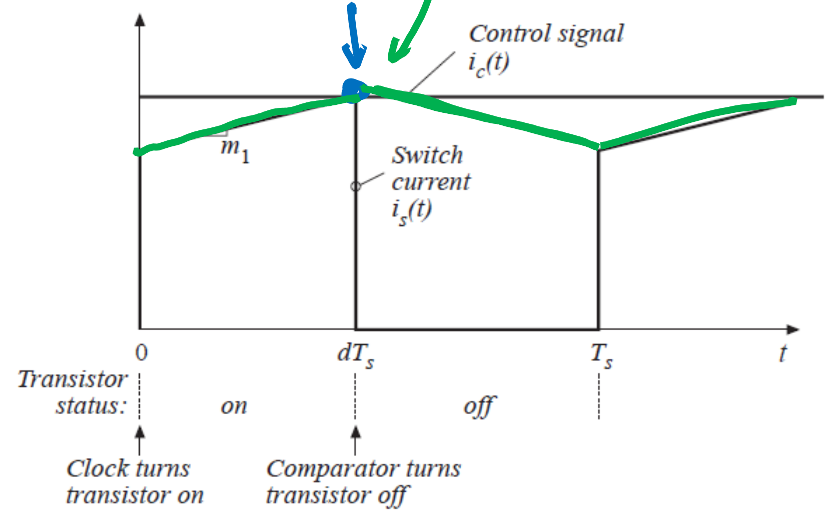
Current Programmed Control (CPM)

$R_f \rightarrow$ current-to-voltage gain of the sensing circuit

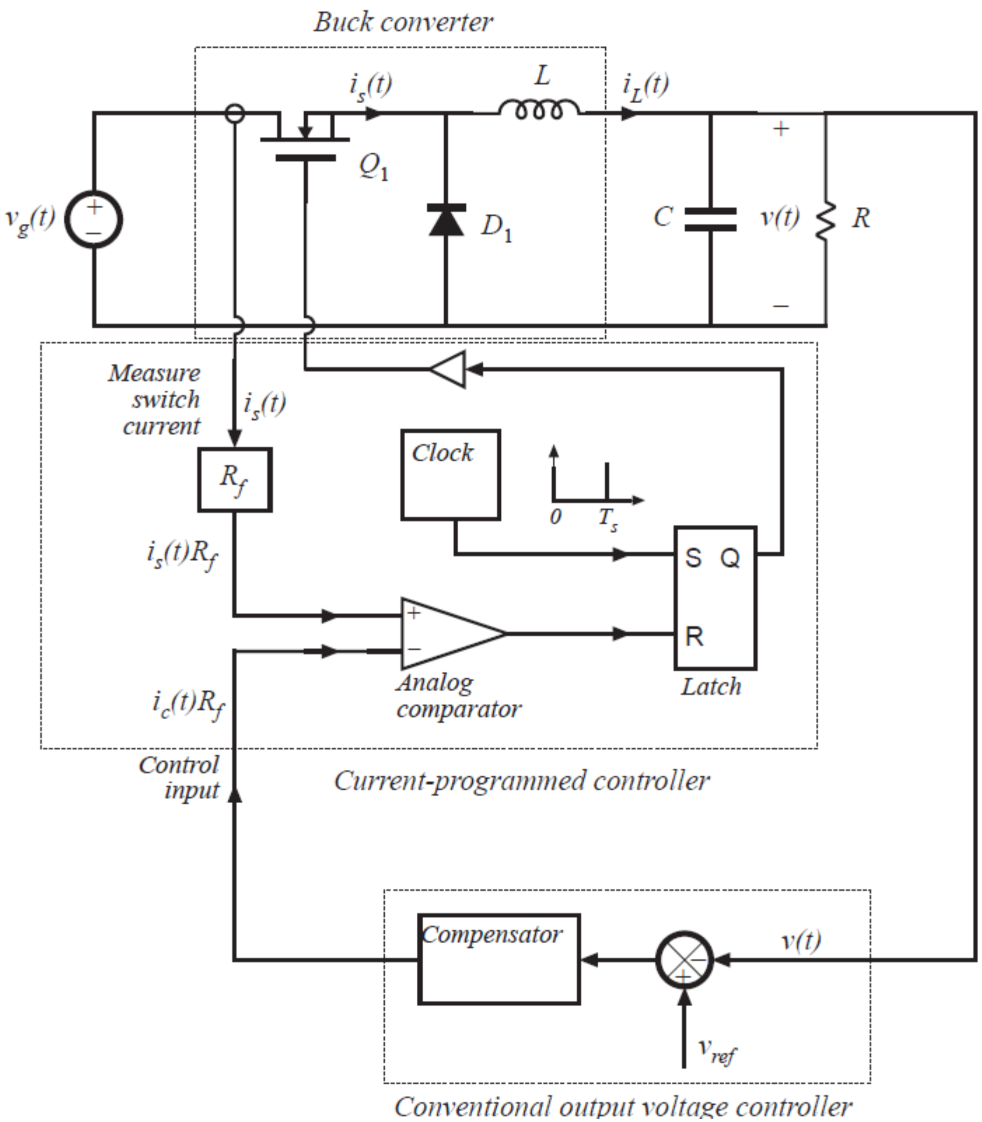


$i_{L,pk} = i_L(DT_s) = i_{ref}$ every period

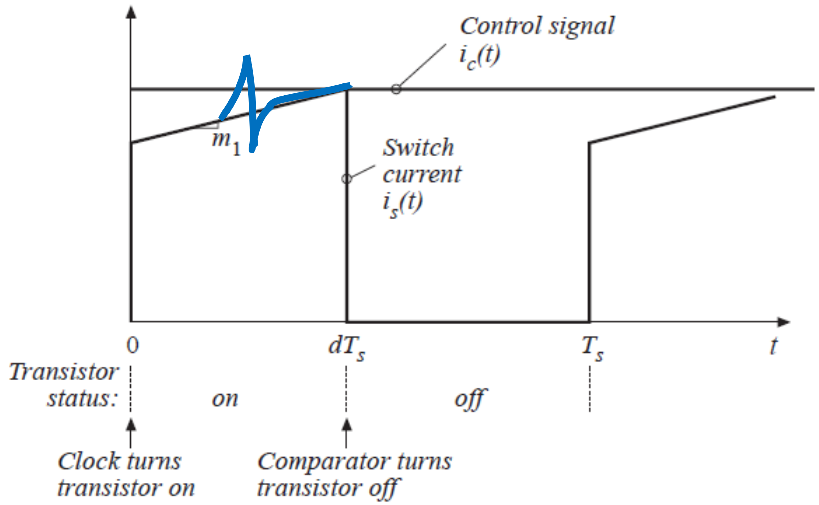
$i_{L,pk}$



CPM Voltage Loop



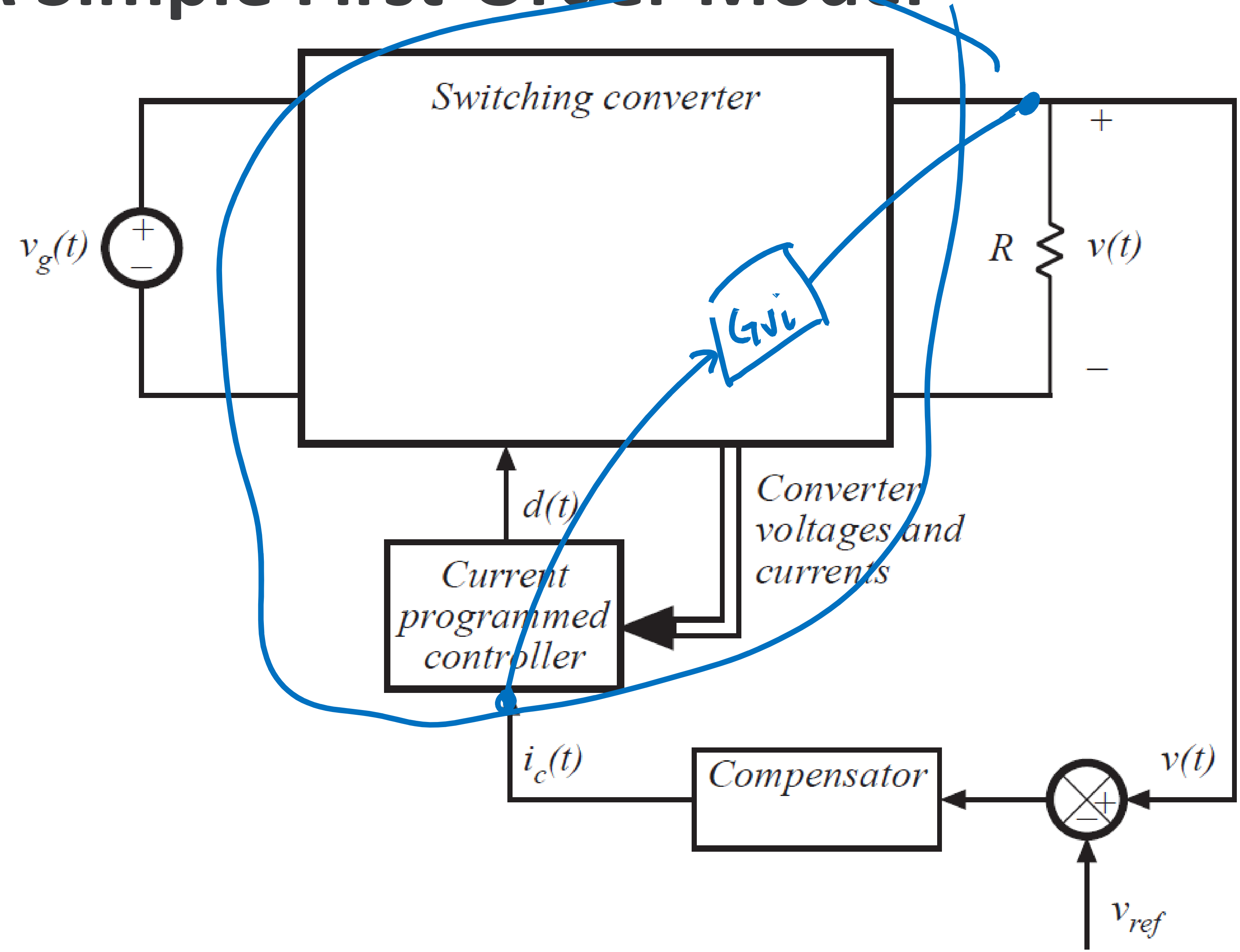
The peak transistor current replaces the duty cycle as the converter control input.



Current Programmed Control

- Covered in Ch. 12 of *Fundamentals of Power Electronics*
- Advantages of current programmed control:
  - Simpler dynamics —inductor pole is moved to high frequency
  - Simple robust output voltage control, with large phase margin, can be obtained without use of compensator lead networks
  - Transistor failures due to excessive current can be prevented simply by limiting $i_c(t)$
  - It is always necessary to sense the transistor current, to protect against overcurrent failures
  - Transformer saturation problems in bridge or push-pull converters can be mitigated
- A disadvantage: susceptibility to noise

A Simple First-Order Model



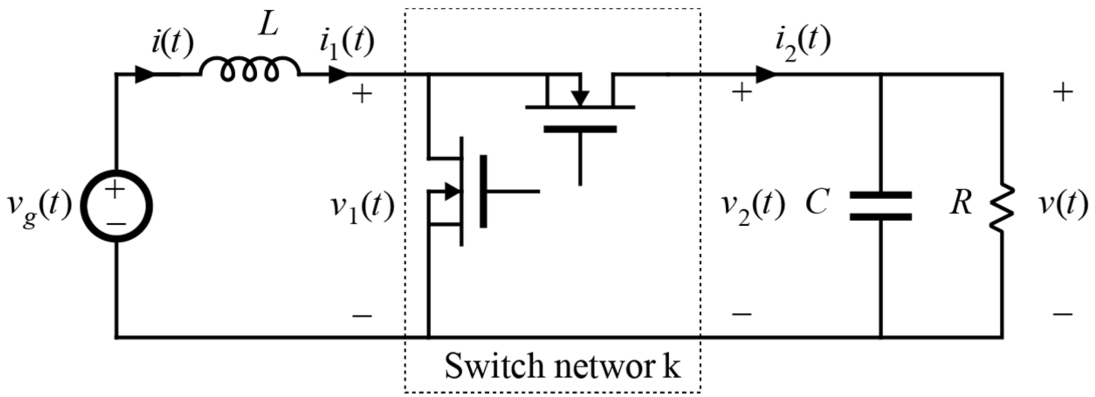
The First-Order Approximation

$$\left\langle i_L(t) \right\rangle_{T_s} = i_c(t)$$

- Neglects switching ripple
- Yields physical insight and simple first-order model
- Accurate when converter operates well into CCM (so that switching ripple is small
- Accurate when artificial ramp (discussed later) is small
- Resulting small-signal relation:

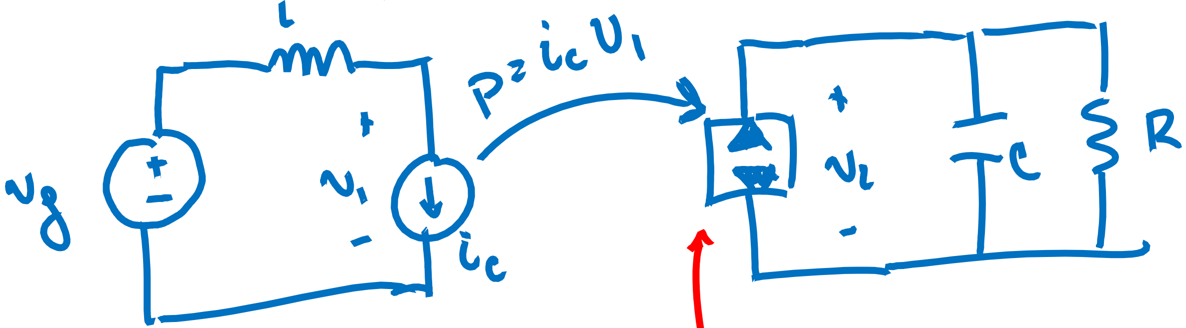
$$i_L(s) \approx i_c(s)$$

Averaged Modeling



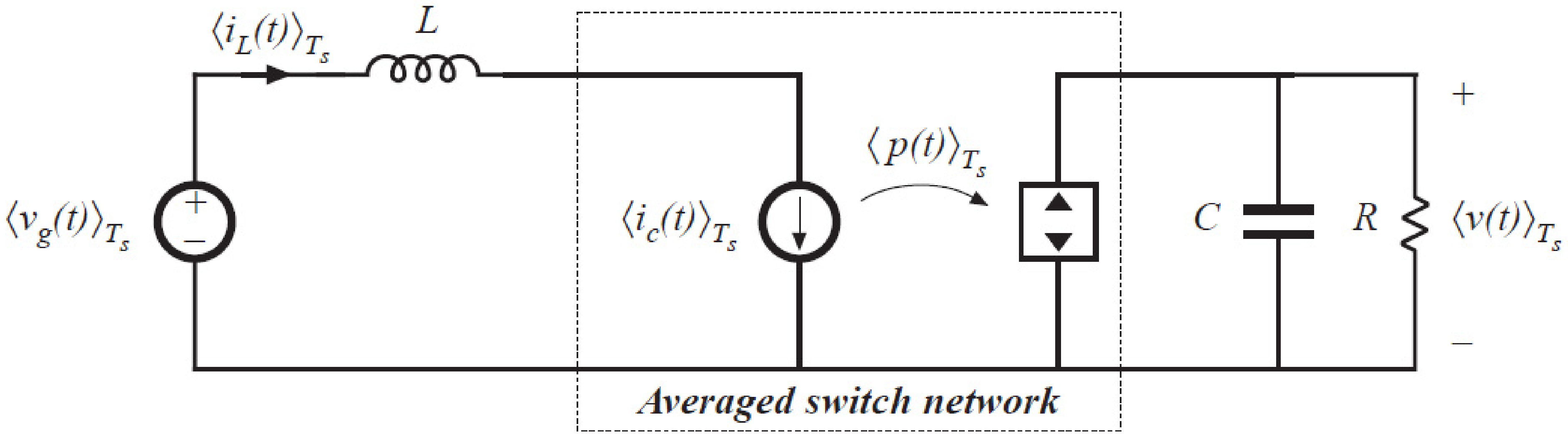
$i_c = i_{ref}$

if CPM is ideal $i_c = i_c$

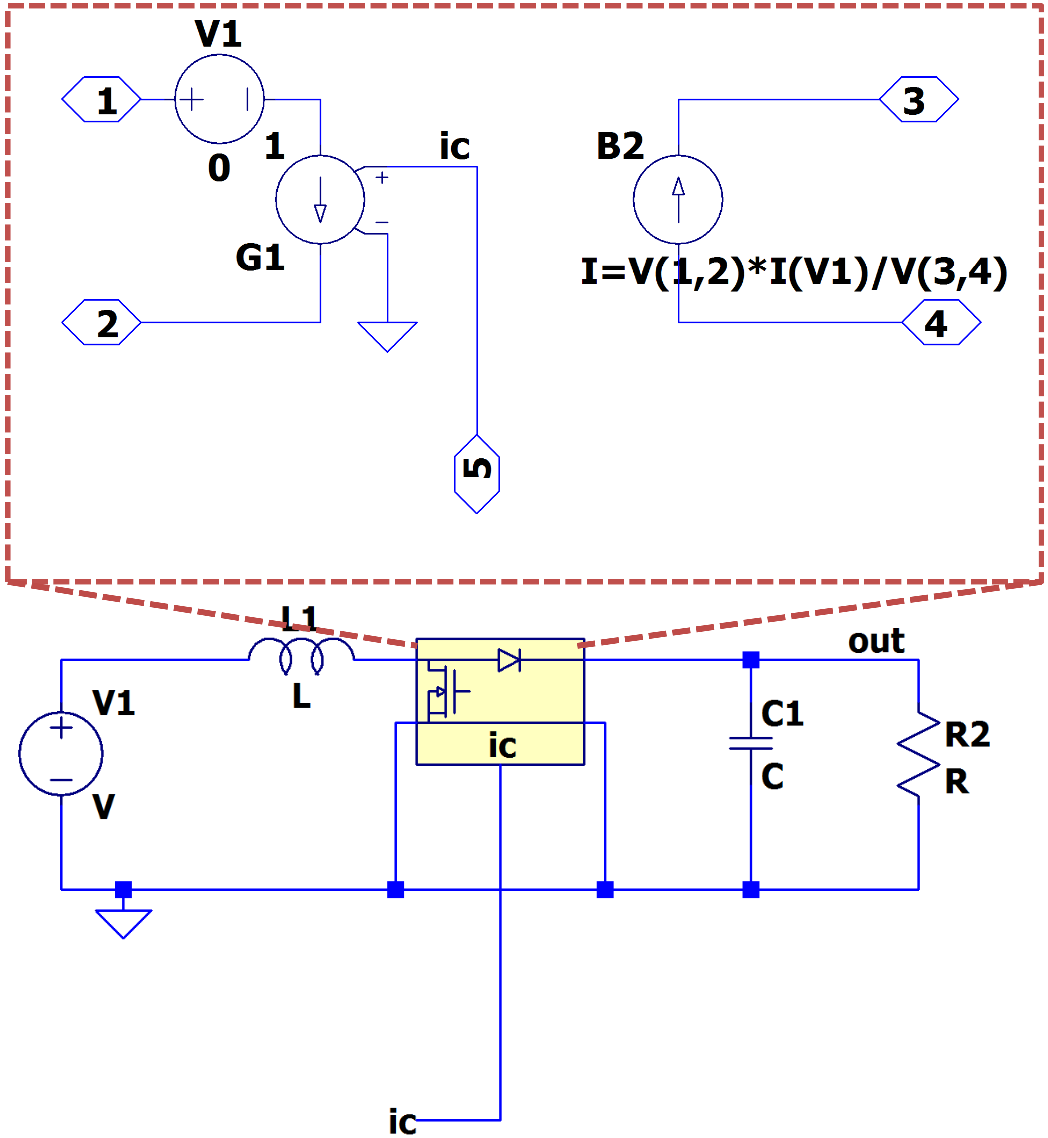


power source
(nonlinear)

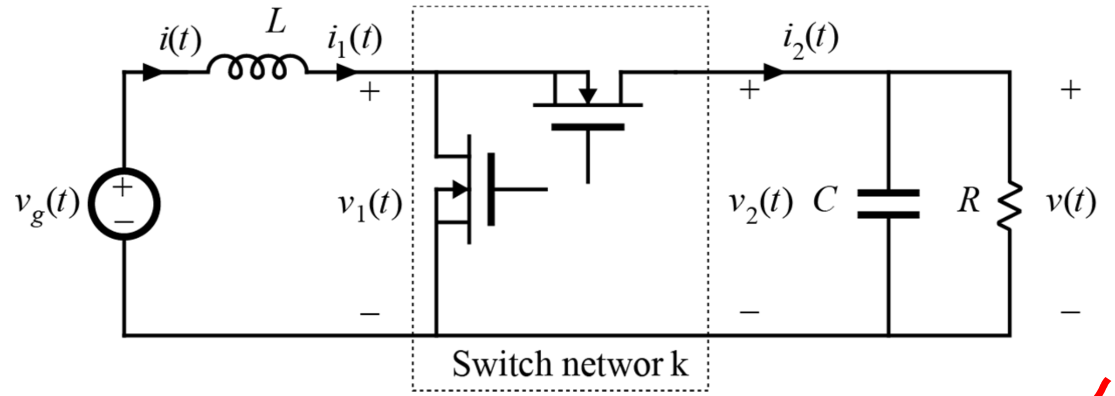
Large-Signal Nonlinear Model



Implementation in LTSpice



Averaged, Small-Signal Model



$$L\frac{d\langle i_L\rangle}{dt} = \langle v_g\rangle - d'(t)\langle v\rangle \qquad C\frac{d\langle v\rangle}{dt} = d'(t)\langle i_L\rangle - \frac{\langle v\rangle}{R}$$

- Replace $i_L = i_c$ (assuming ideal CPM)
- Linearize in laplace domain

$$sL\hat{i}_c = \hat{v}_g + V\hat{d} - D'\hat{v} \qquad sC\hat{v} = D'\hat{i}_c - I_L\hat{d} - \frac{\hat{v}}{R}$$

- $\hat{d}$ is no longer controlled $\rightarrow$ eliminate

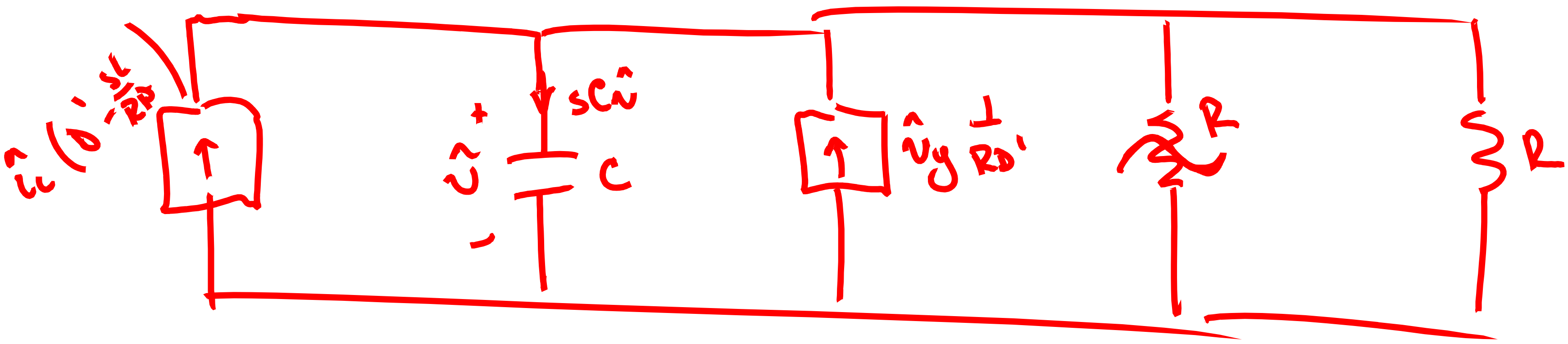
$$\hat{d} = \frac{1}{V}\left(sL\hat{i}_c - \hat{v}_g + D'\hat{v}\right)$$

$$sC\hat{v} = D'\hat{i}_L - \frac{\hat{v}}{R} - \frac{I_L}{V}\left(sL\hat{i}_L - \hat{v}_g - D'\hat{v}\right)$$

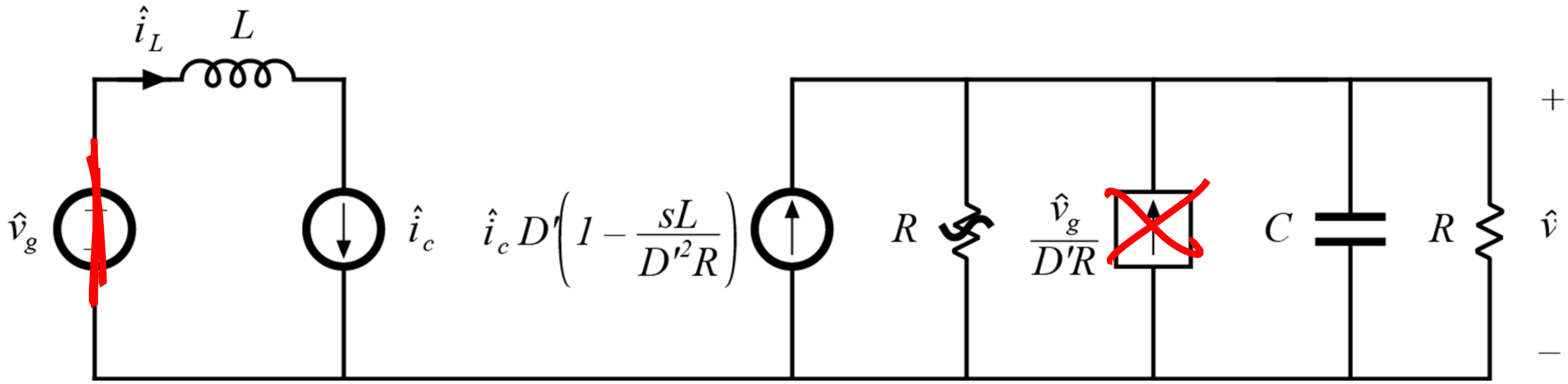
$$sC\hat{v} = \hat{i}_L\left(D' - \frac{I_L}{V}sL\right) + \hat{v}_g\frac{I_L}{V} - \frac{\hat{v}}{R} - \frac{I_L}{V}D'\hat{v}$$

$$I_{out} = D'I_L \rightarrow \frac{I_L}{V} = \frac{I_{out}}{D'V} = \frac{1}{RD'}$$

$$sC\hat{v} = \hat{i}_L\left(D' - \frac{sL}{RD'}\right) + \hat{v}_g\frac{1}{RD'} - \frac{\hat{v}}{R} - \frac{\hat{v}}{R}$$



Boost CCM CPM Small-Signal Model



$$G_{vi} = \left.\frac{\hat{v}}{\hat{i}_c}\right|_{\substack{\text{DC op point} \\ \hat{v}_g = 0}} = D'\left(1 - \frac{sL}{D'^2 R}\right) \cdot \underbrace{\left(R \,\|\, R \,\|\, \frac{1}{sC}\right)}_{\frac{1}{\frac{2}{R} + sC}}$$

$$\boxed{G_{vi} = \frac{D'R}{2} \frac{\left(1 - \frac{sL}{D'^2 R}\right)}{1 + s\frac{RC}{2}}}$$

Same RHP zero as in Gvd

single pole!!

for PWM control

$$G_{vd} = \frac{V}{D'} \frac{\left(1 - \frac{sL}{D'^2 R}\right)}{1 + s\frac{L}{RD'^2} + s^2\frac{LC}{D'^2}}$$

CPM Transfer Functions

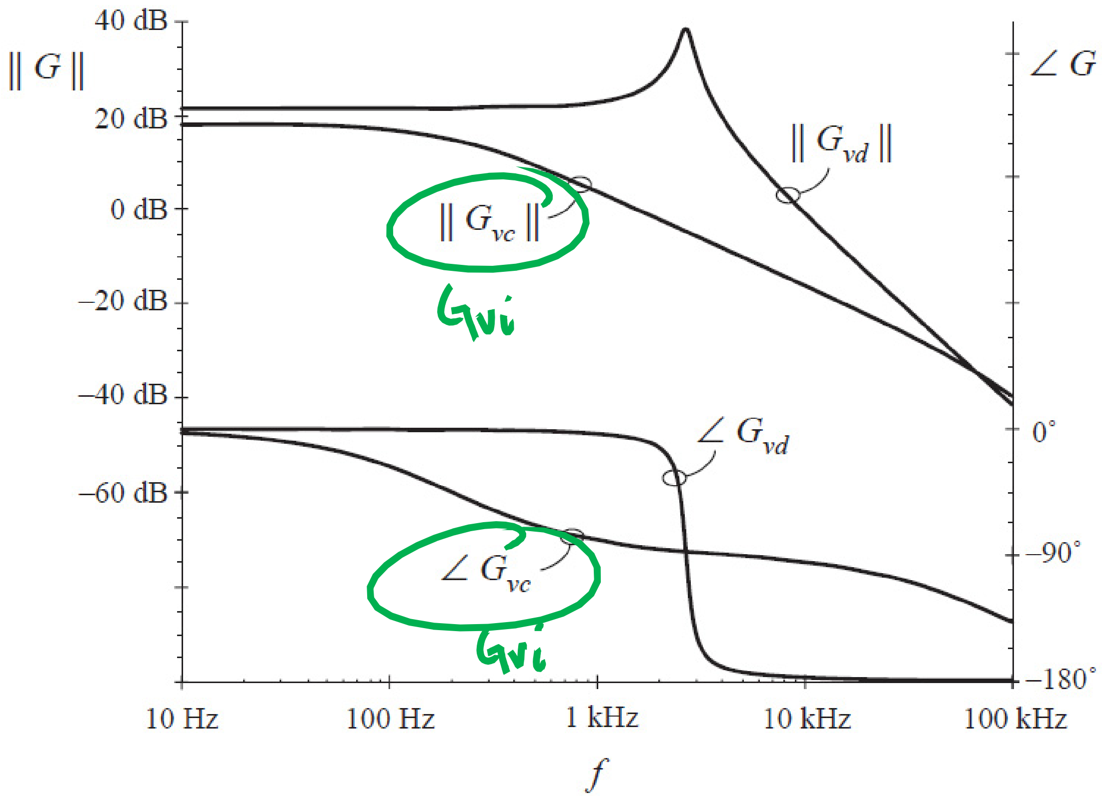
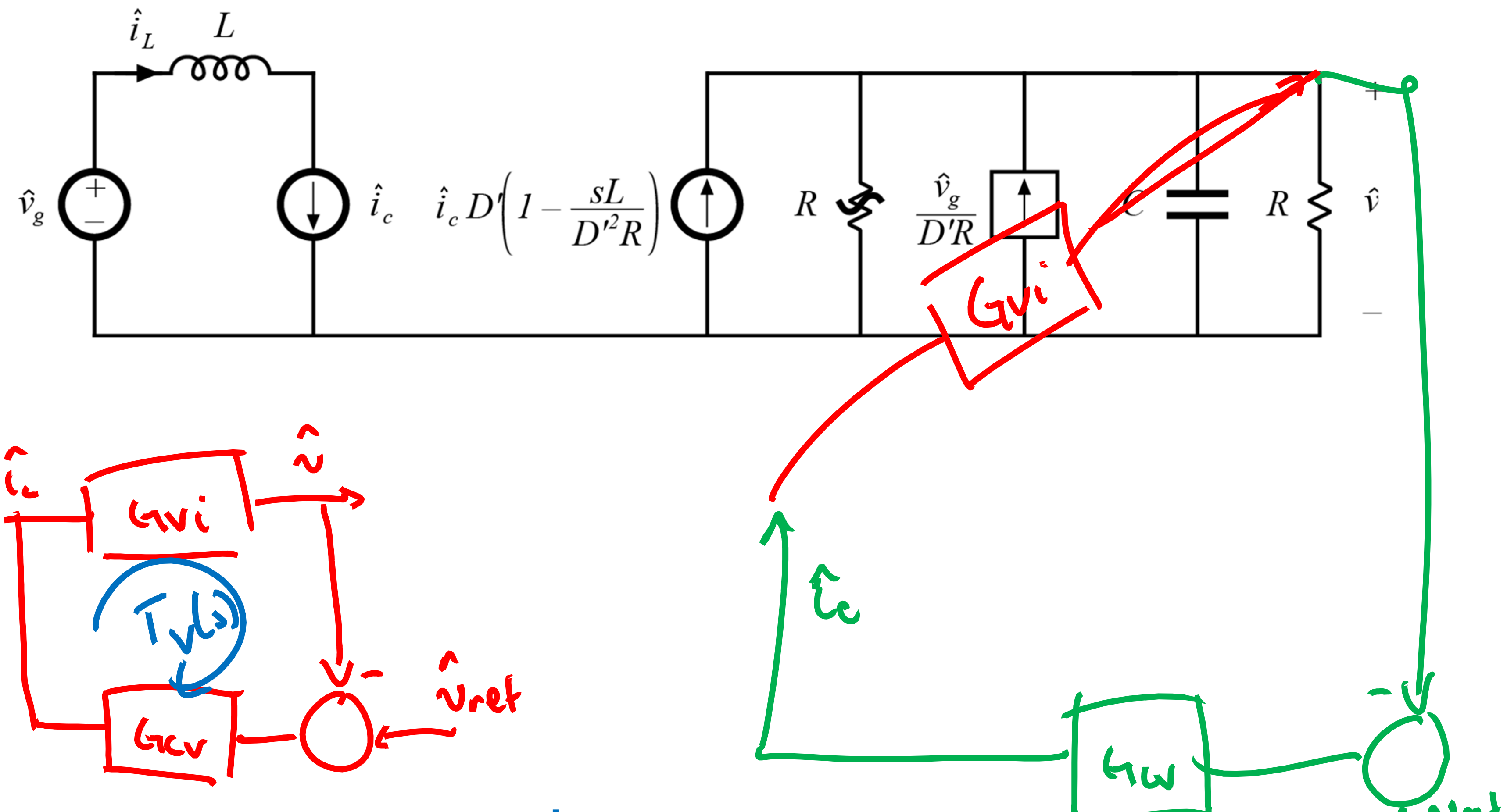


Fig. 12.28 Comparison of CPM control with duty-cycle control, for the control-to-output frequency response of the buck converter example.

Voltage Control



* Reminder: this neglects
R_f , H