Example Design of Buck Compensator

DC (Quiescent) Operating Point

- Input voltage: \( V_s = 28 \text{V} \)
- Output: \( V = 15 \text{V}, I_{\text{load}} = 5 \text{A}, R = 3 \Omega \)
- Quiescent duty cycle: \( D = 15/28 = 0.536 \)
- Reference voltage: \( V_{\text{ref}} = 5 \text{V} \)
- Quiescent value of control voltage: \( V_c = DV_{\text{ref}} = 2.14 \text{V} \)
- Gain \( H(s) \): \( H = V_{\text{ref}}/V = 5/15 = 1/3 \)
AC Power Stage Model

\[ V_{in} \frac{d}{dt} \]

\[ V_{out} \]

\[ L \]

\[ C \]

\[ R \]

\[ i_{out}(t) \]

\[ \frac{1}{V_{in}} \]

\[ G_{c}(s) \]

\[ H(s) \]

\[ V_{in} = 4V \]

\[ T(s) = G_{c}(s) \left( \frac{1}{V_{in}} \right) G_{e}(s) H(s) \]

\[ T(s) = \frac{G_{c}(s) H(s)}{V_{in} \left( 1 + \frac{s}{\omega_n^2} + \frac{1}{\omega_n} \right)} \]

\[ \hat{V} = \hat{V}_{ref} \frac{1}{\tau} \frac{T}{1 + \frac{T}{\tau}} + \hat{V}_{in} \frac{1}{\tau} \frac{1}{1 + \frac{T}{\tau}} + \hat{V}_{out} \frac{1}{\tau} \frac{1}{1 + \frac{T}{\tau}} \]

\[ \frac{1}{V_{out}} \]

\[ \hat{x}(s) \]

\[ \frac{1}{V_{in}} \]

\[ G_{e}(s) \]

\[ H(s) \]

\[ i_{out}(t) \]

\[ T_0 \]

\[ \text{Converter power stage} \]

\[ \text{Fundamentals of Power Electronics} \]

48

Chapter 9: Controller design

System Block Diagram

\[ \hat{x}(s) \]

\[ H(s) \]

\[ \frac{1}{V_{out}} \]

\[ G_{e}(s) \]

\[ \hat{V}_{ref}(t) \]

\[ \frac{1}{V_{in}} \]

\[ G_{c}(s) \]

\[ \frac{1}{V_{in}} \]

\[ H(s) \]

\[ \text{Fundamentals of Power Electronics} \]

51

Chapter 9: Controller design
Plotting Uncompensated Loop Gain

(1) $T_m$ too small → Risk instability, Bad transient ringing
(2) Low gain too low → Steady-state error
(3) $f_c$ too low

With $G_i = 1$, the loop gain is

$$T(s) = \frac{T_m}{1 + \frac{s}{Q_f\omega_n} + \left(\frac{s}{\omega_c}\right)^2}$$

$$T_m = \frac{H V}{D V_i} = 2.33 \rightarrow 7.4 \text{dB}$$

$$f_c = 1.8 \text{ kHz}, \eta_m = 5^\circ$$

LTSpice Simulation – AC, Uncompensated
Transient Simulation, Uncompensated

\[ V = \frac{V_{\text{res}} \cdot R_0}{R_1 + R_0} = 15 \text{, } \frac{2.33}{1+2.33} > 10.5 \]

Ringing Frequency

\[ V = \frac{V_{\text{res}} \cdot R_0}{R_1 + R_0} = 15 \text{, } \frac{2.33}{1+2.33} > 10.5 \]
Summary: Uncompensated Behavior

- Significant steady-state error
  - Need to increase low-frequency gain
- Barely stable; significant ringing
  - Need to increase $\phi_m$
- Speed: ok
  - $f_c = 1.8$ kHz
  - $(BW)_{CL} = 2.6$ kHz
  - OK for $f_s \approx 10$ kHz or above
Compensator Design

• As an example, try to
  ✓ Increase $f_c$ to 10 kHz
  ✓ Increase $\phi_m$ to 76° (Q=0.5)
  ✓ Increase $\|T_0\|$ to $\infty$

• Note: Book Chooses $f_c = 5$ kHz and $\phi_m = 52°$ (Q=0.5)
**PI Simulation**

**PD Design**

\[ f_c = f_e \sqrt{\frac{1 - \sin \theta}{1 + \sin \theta}} \]
\[ f_p = f_e \sqrt{\frac{1 + \sin \theta}{1 - \sin \theta}} \]

\[ G_c = \sqrt{\frac{f_p}{f_c}} \]

\[ \theta = 76^\circ \]
\[ f_c = 100kHz \]

\[ f_p = 1.23kHz \]
\[ f_e = 8kHz \]
\[ G_{co} = 0.12 \]

\[ \frac{G_{co}}{1 + \frac{f_p^2}{f_c^2}} \]
$T/(1+T)$

**PID Simulation**

$\omega_n = 10k\text{Hz}$

$\phi_m = 76^\circ$
Transient Simulation

~ zero steady-state error