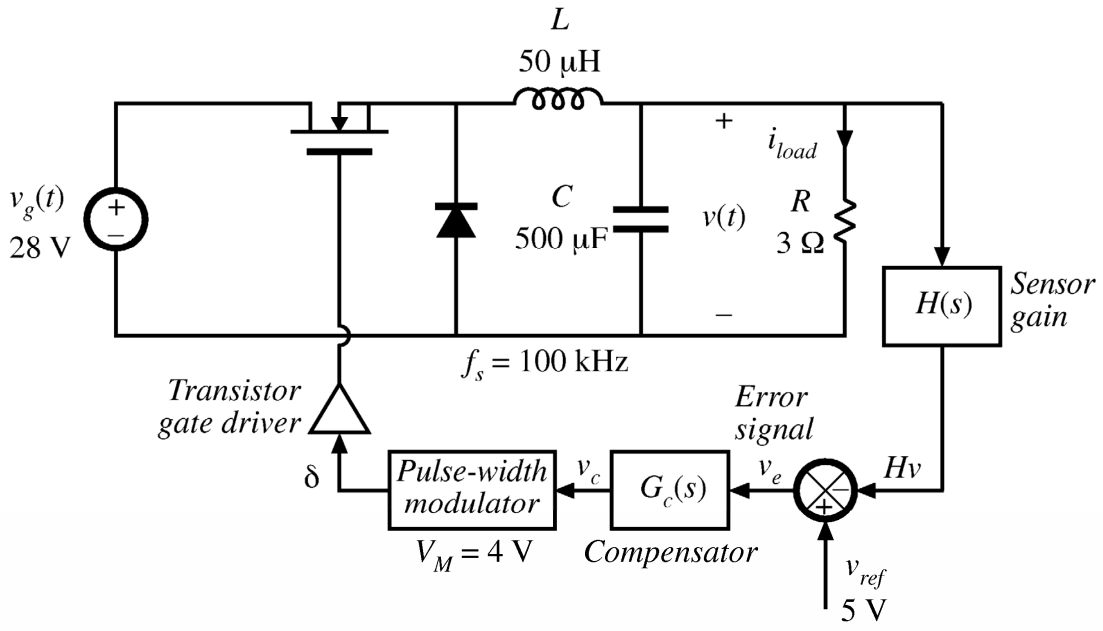
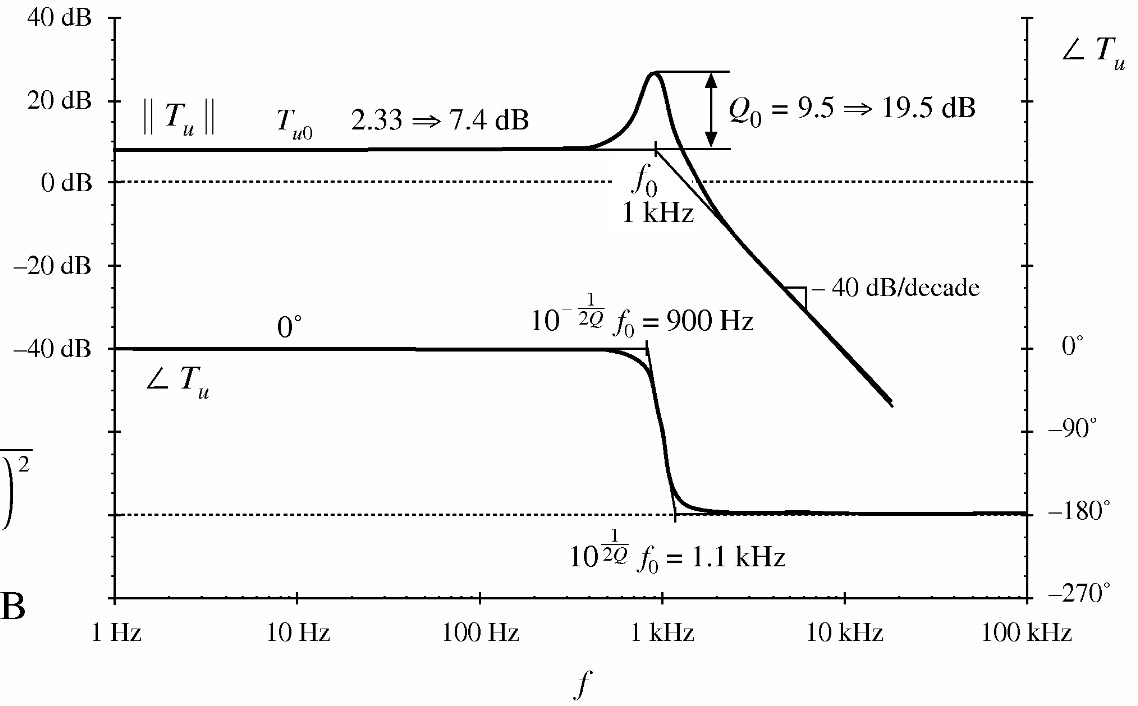
Example Design of Buck Compensator



Input voltage	$V_g = 28\text{V}$
Output	$V = 15\text{V},\ I_{load} = 5\text{A},\ R = 3\Omega$
Quiescent duty cycle	$D = 15/28 = 0.536$
Reference voltage	$V_{ref} = 5\text{V}$
Quiescent value of control voltage	$V_c = DV_M = 2.14\text{V}$
Gain $H(s)$	$H = V_{ref}/V = 5/15 = 1/3$

Plotting Uncompensated Loop Gain



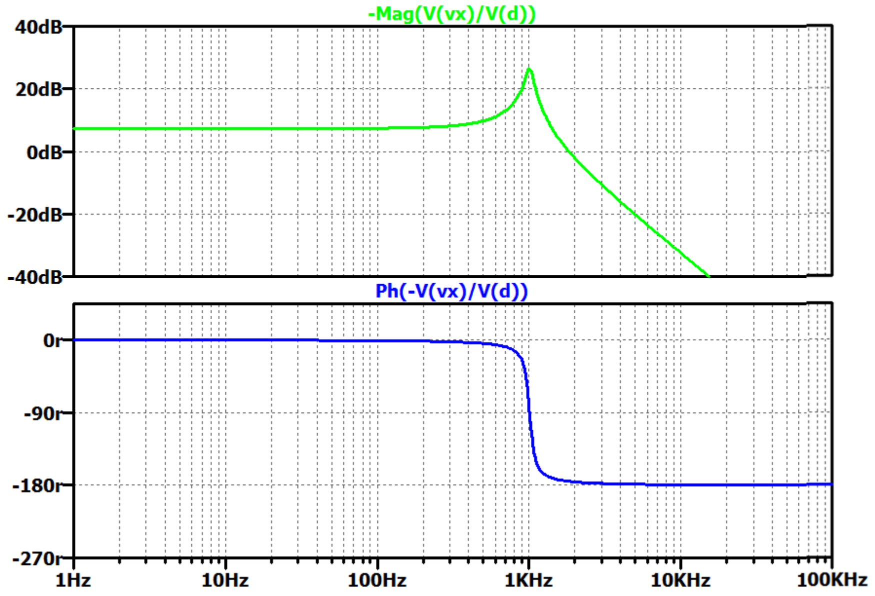
With $G_c = 1$, the loop gain is

$$T_u(s) = T_{u0} \frac{1}{1 + \frac{s}{Q_0\omega_0} + \left(\frac{s}{\omega_0}\right)^2}$$

$$T_{u0} = \frac{H\ V}{D\ V_M} = 2.33 \Rightarrow 7.4\text{dB}$$

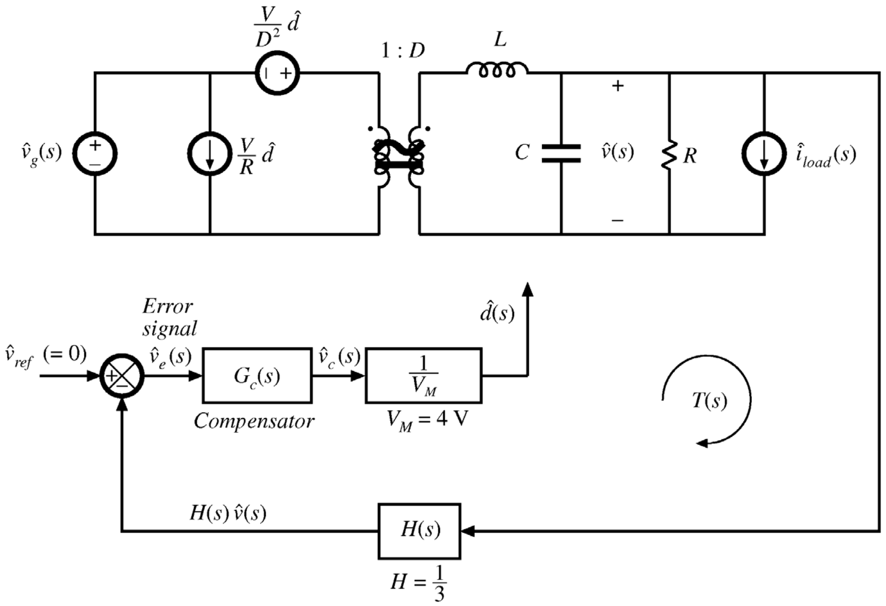
$f_c = 1.8$ kHz, $\varphi_m = 5^\circ$

LTSpice Simulation – AC, Uncompensated

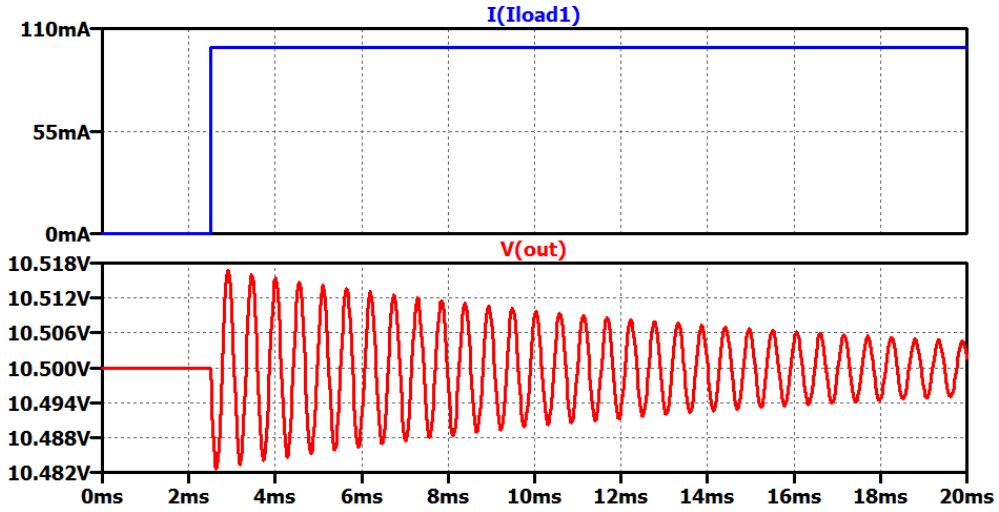


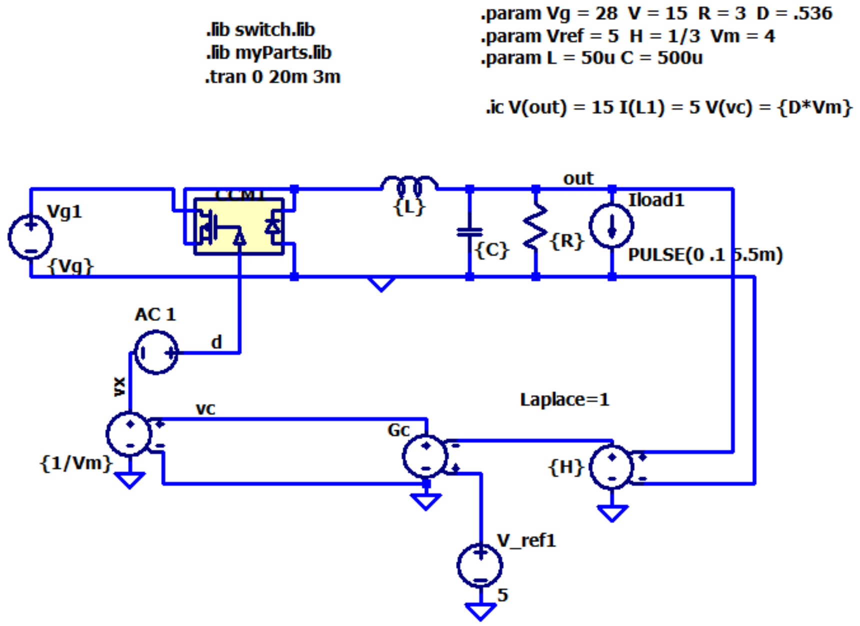
.lib myParts.lib
.ac dec 1000 1 1Meg

.param Vg = 28 V = 15 R = 3 D = .536
.param Vref = 5 H = 1/3 Vm = 4
.param L = 50u C = 500u

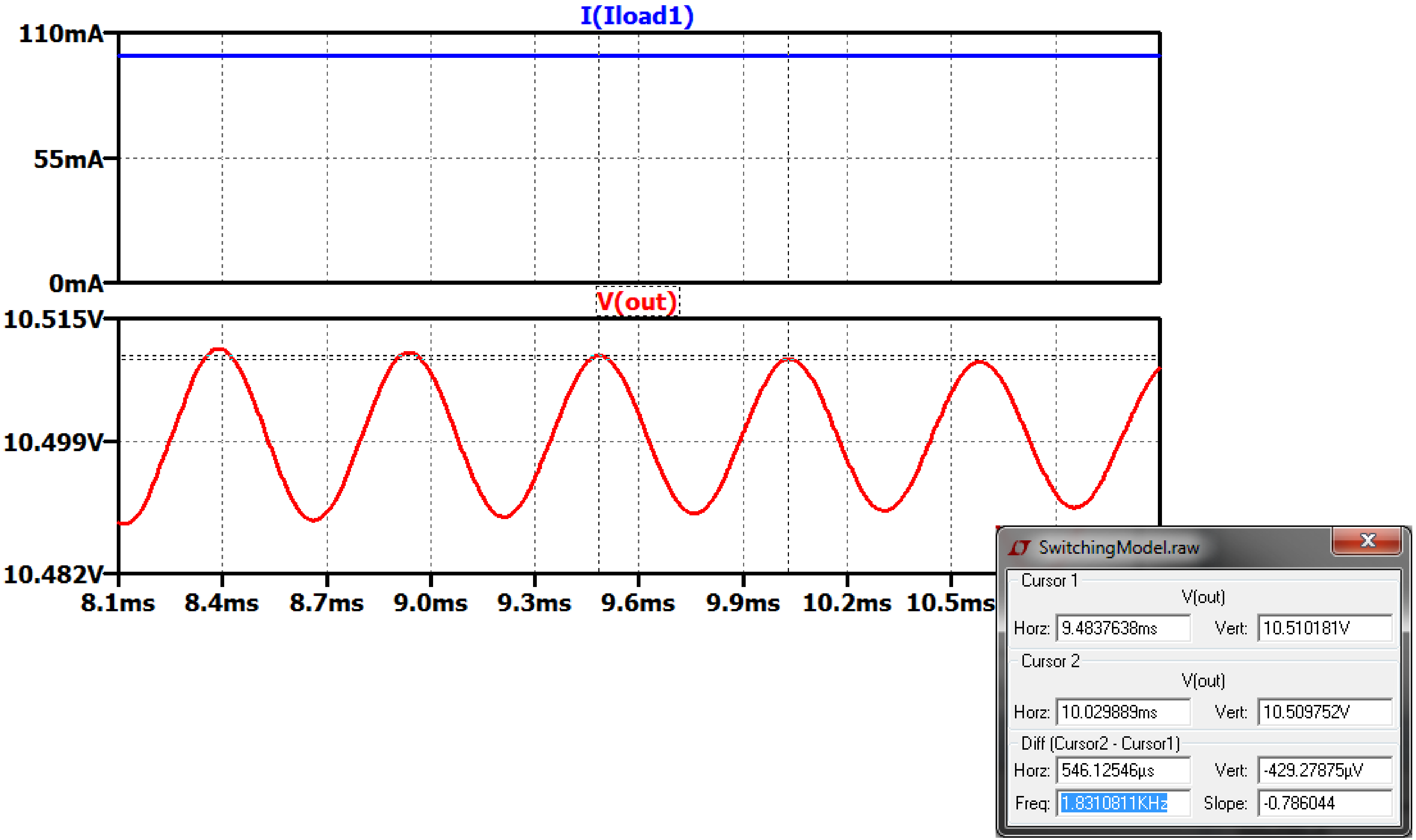


Transient Simulation, Uncompensated

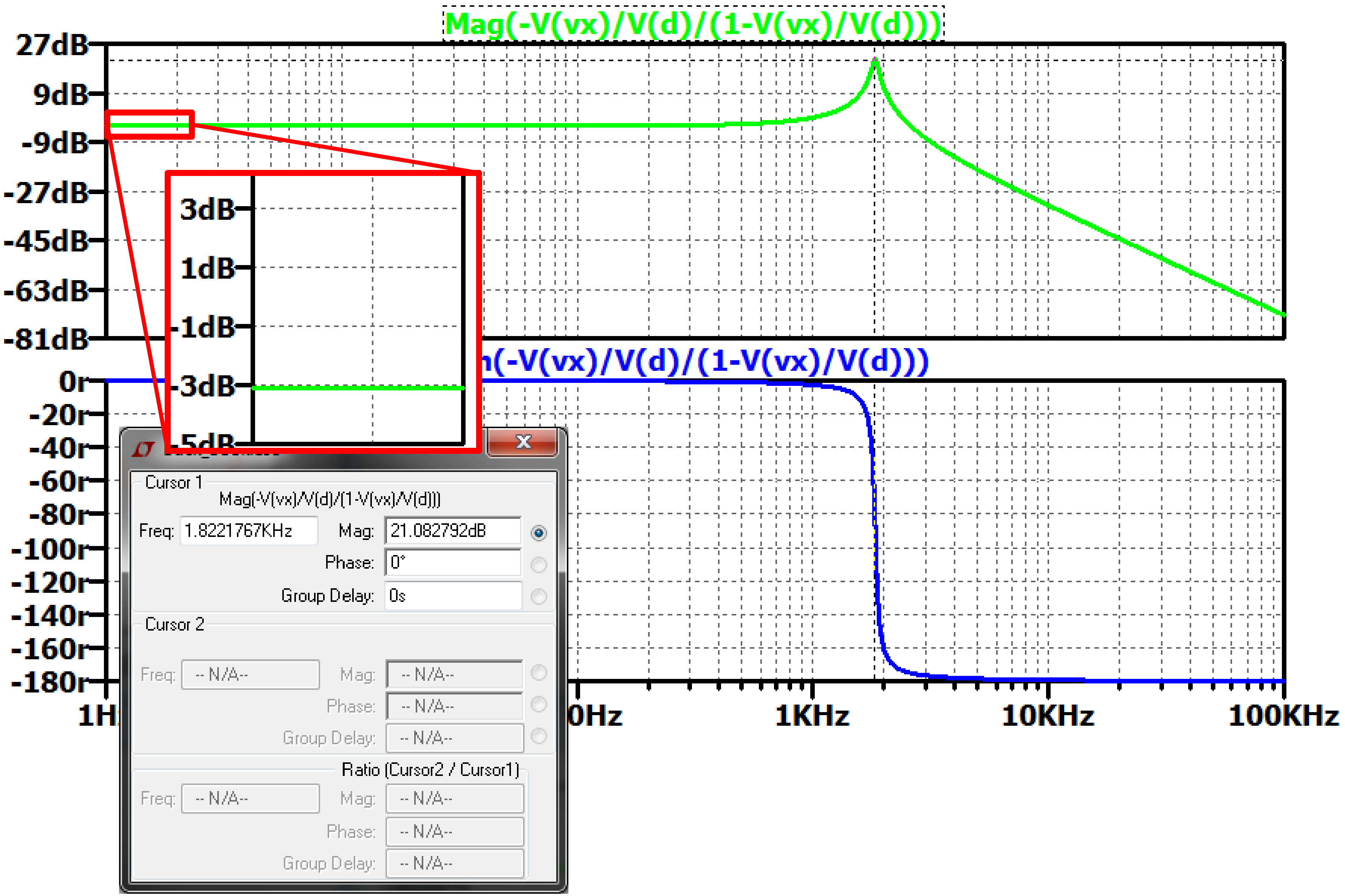




Ringing Frequency



$T/(1+T)$



Mag(-V(vx)/V(d)/(1-V(vx)/V(d)))
27dB
9dB
-9dB
-27dB
-45dB
-63dB
-81dB
3dB
1dB
-1dB
-3dB
-5dB
n(-V(vx)/V(d)/(1-V(vx)/V(d)))
0r
-20r
-40r
-60r
-80r
-100r
-120r
-140r
-160r
-180r
1H
0Hz
1KHz
10KHz
100KHz
Cursor 1
Mag(-V(vx)/V(d)/(1-V(vx)/V(d)))
Freq: 1.8221767KHz
Mag: 21.082792dB
Phase: 0°
Group Delay: 0s
Cursor 2
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--
Ratio (Cursor2 / Cursor1)
Freq: -- N/A--
Mag: -- N/A--
Phase: -- N/A--
Group Delay: -- N/A--

Summary: Uncompensated Behavior

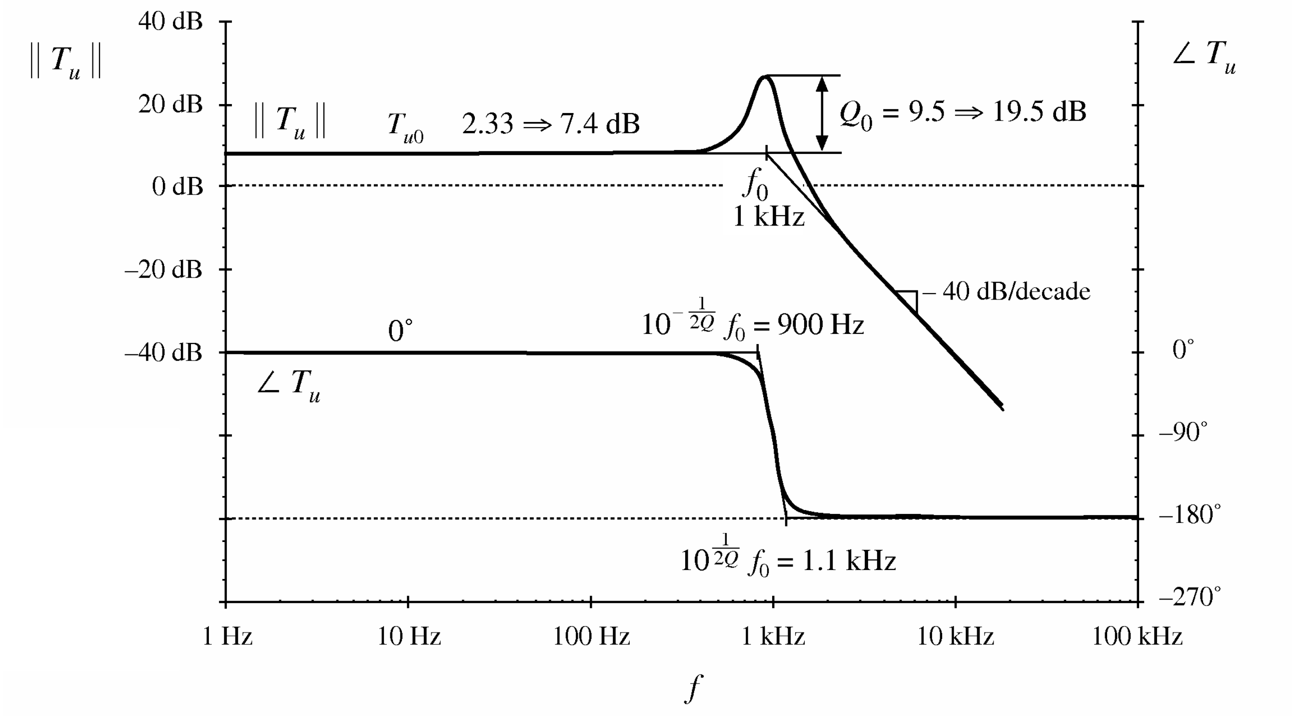
- Significant steady-state error
  - Need to increase low-frequency gain
- Barely stable; significant ringing
  - Need to increase ϕ_m
- Speed: ~ok
  - f_c = 1.8 kHz
  - $(BW)_{CL}$ = 2.6 kHz
  - OK for $f_s \approx$ 10 kHz or above

Compensator Design

- As an example, try to
  - Increase f_c to 10 kHz
  - Increase ϕ_m to 76° (Q_{CL}=0.5)
  - Increase $\|T_0\|$ to ∞

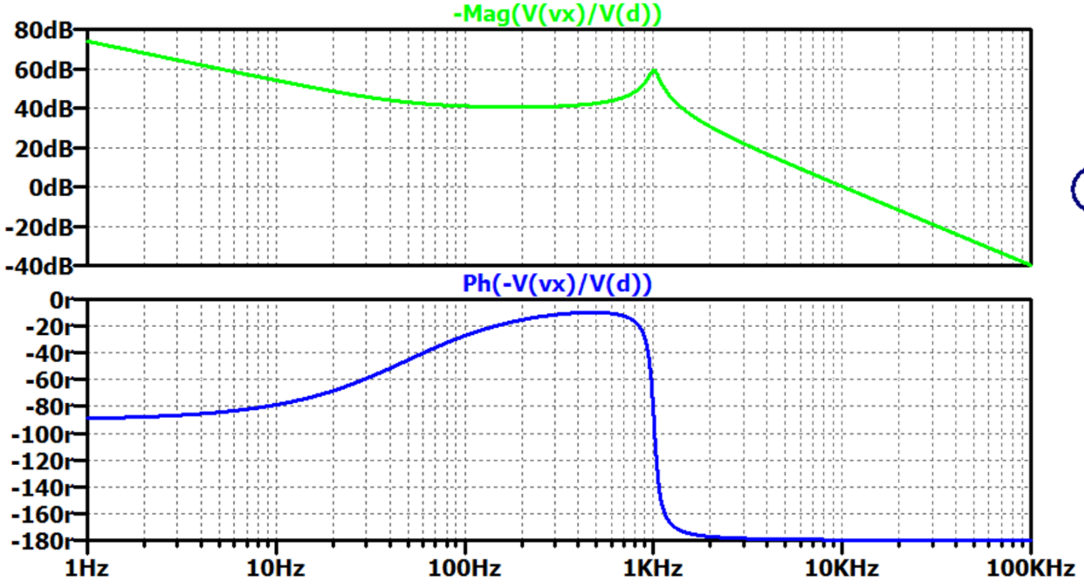
- Note: Book Chooses f_c = 5 kHz and ϕ_m =52° (Q=0.5)

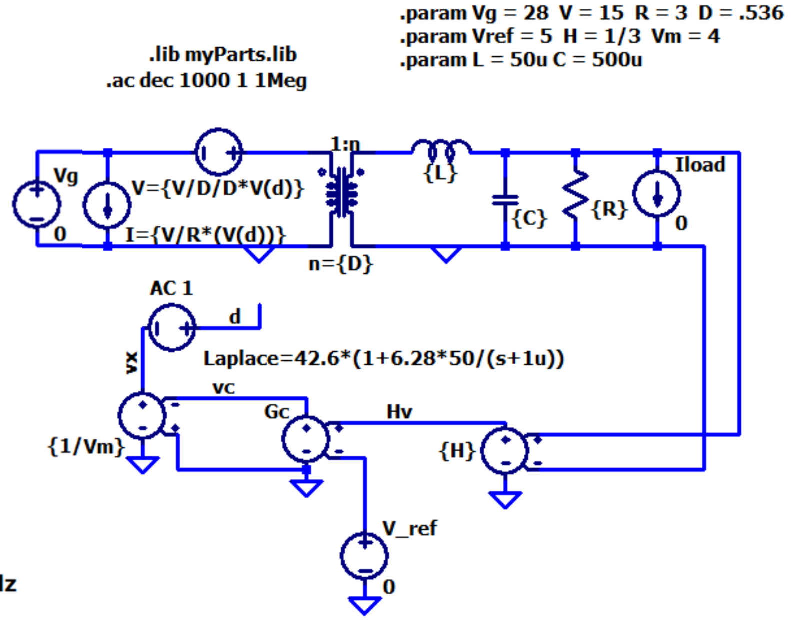
PI Design



40 dB
20 dB
0 dB
–20 dB
–40 dB
‖ T_u ‖
‖ T_u ‖
T_u0 2.33 ⇒ 7.4 dB
Q_0 = 9.5 ⇒ 19.5 dB
f_0
1 kHz
– 40 dB/decade
0°
10^(−1/2Q) f_0 = 900 Hz
∠ T_u
∠ T_u
0°
–90°
–180°
–270°
10^(1/2Q) f_0 = 1.1 kHz
1 Hz
10 Hz
100 Hz
1 kHz
10 kHz
100 kHz
f

PI Simulation





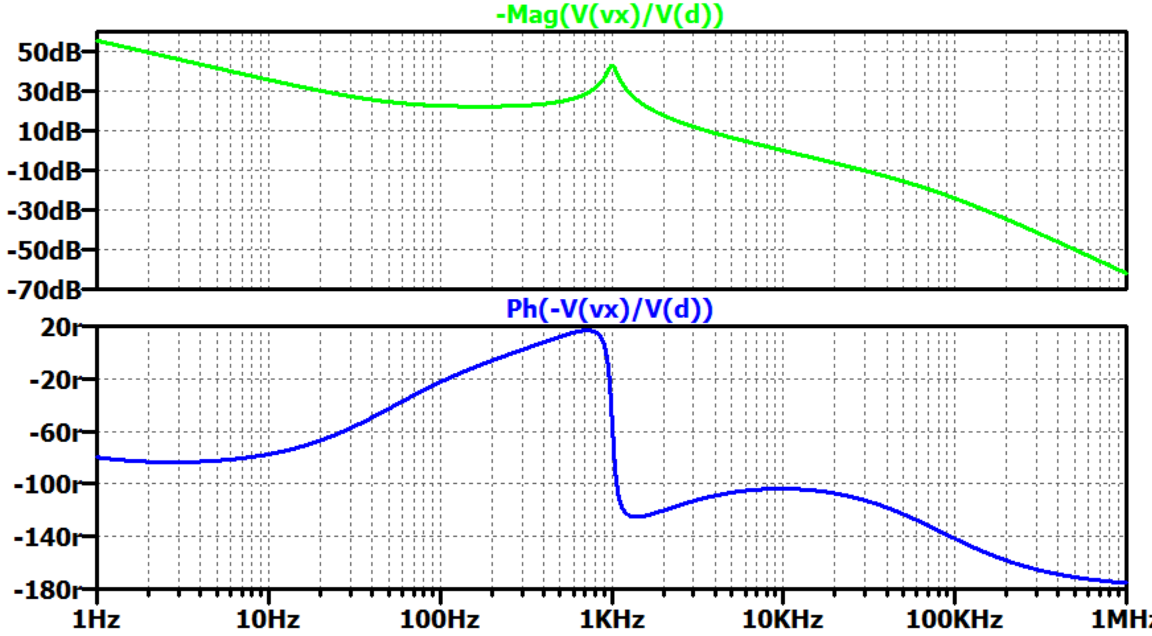
PD Design

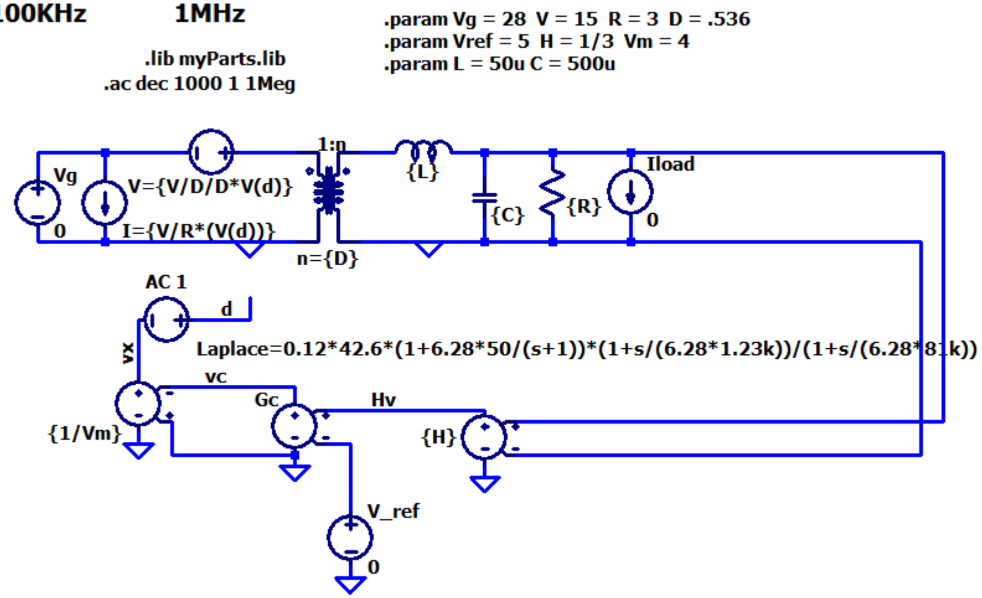
$$f_z = f_c \sqrt{\frac{1 - \sin(\theta)}{1 + \sin(\theta)}}$$

$$f_p = f_c \sqrt{\frac{1 + \sin(\theta)}{1 - \sin(\theta)}}$$

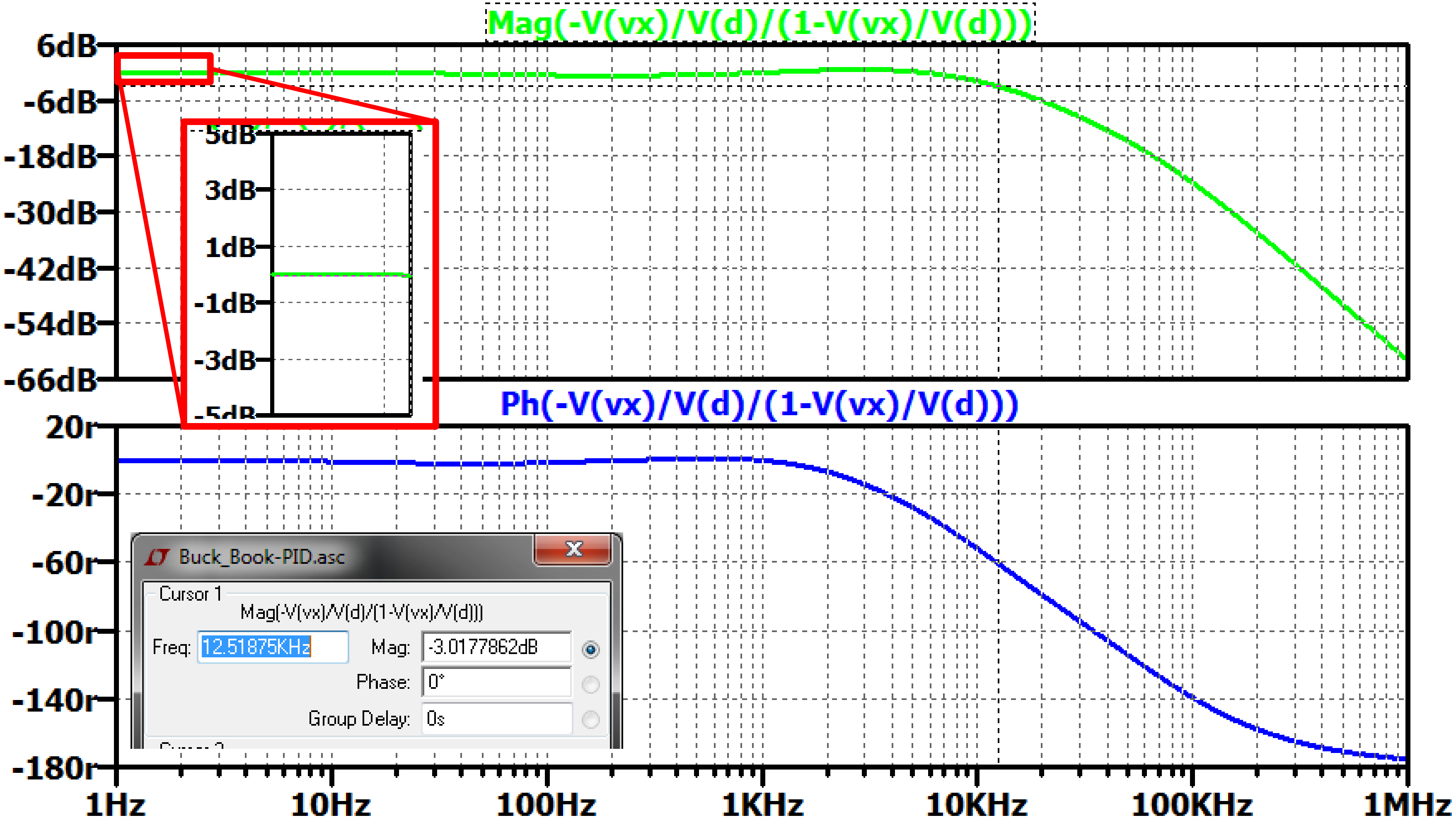
$$G_{c0} = \sqrt{\frac{f_z}{f_p}}$$

PID Simulation



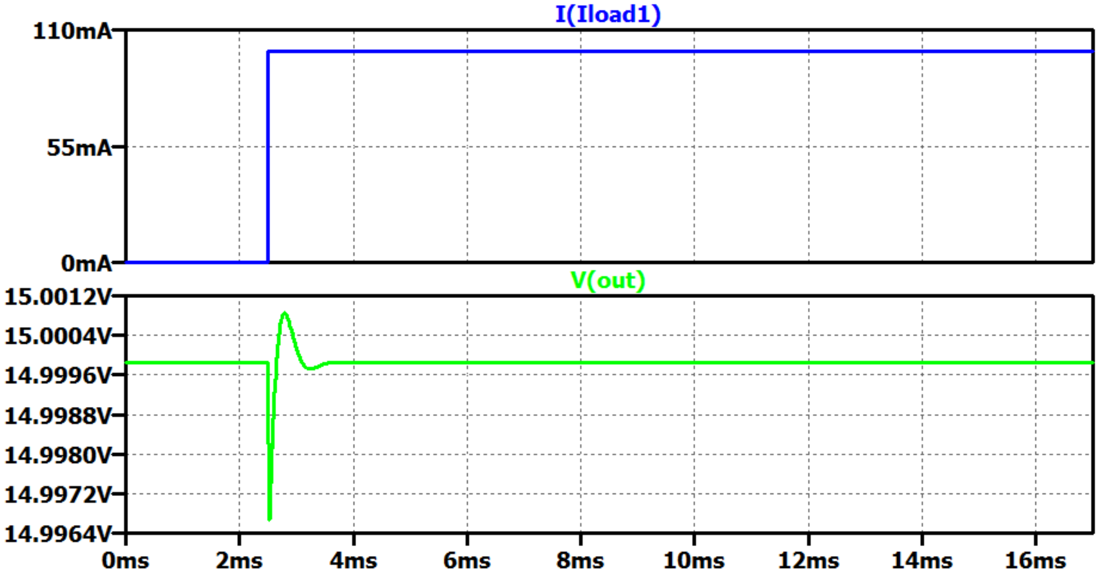


$T/(1+T)$



Mag(-V(vx)/V(d)/(1-V(vx)/V(d)))
6dB
-6dB
-18dB
-30dB
-42dB
-54dB
-66dB
5dB
3dB
1dB
-1dB
-3dB
Ph(-V(vx)/V(d)/(1-V(vx)/V(d)))
20r
-20r
-60r
-100r
-140r
-180r
Buck_Book-PID.asc
Cursor 1
Mag(-V(vx)/V(d)/(1-V(vx)/V(d)))
Freq: 12.51875KHz
Mag: -3.0177862dB
Phase: 0°
Group Delay: 0s
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz

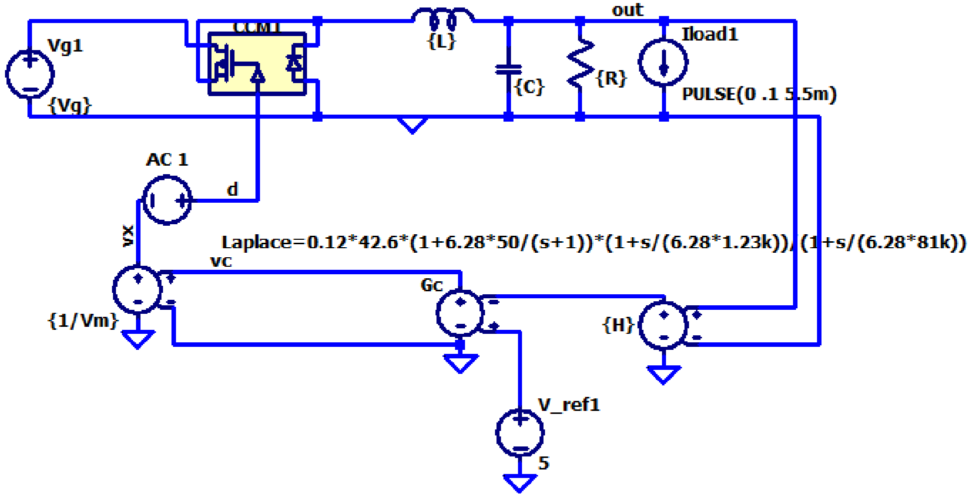
Transient Simulation



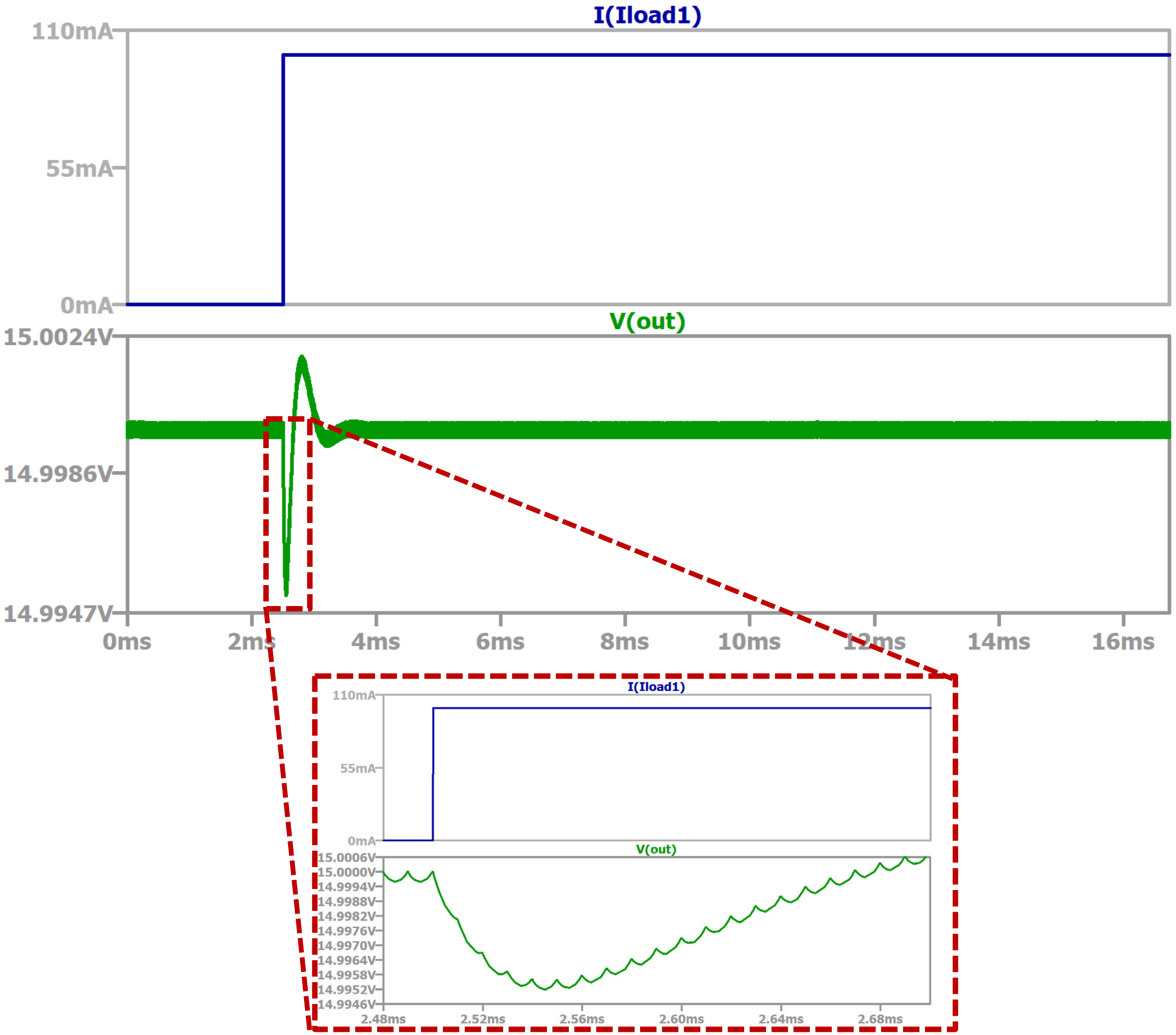

```
.lib switch.lib
.lib myParts.lib
.tran 0 20m 3m
```

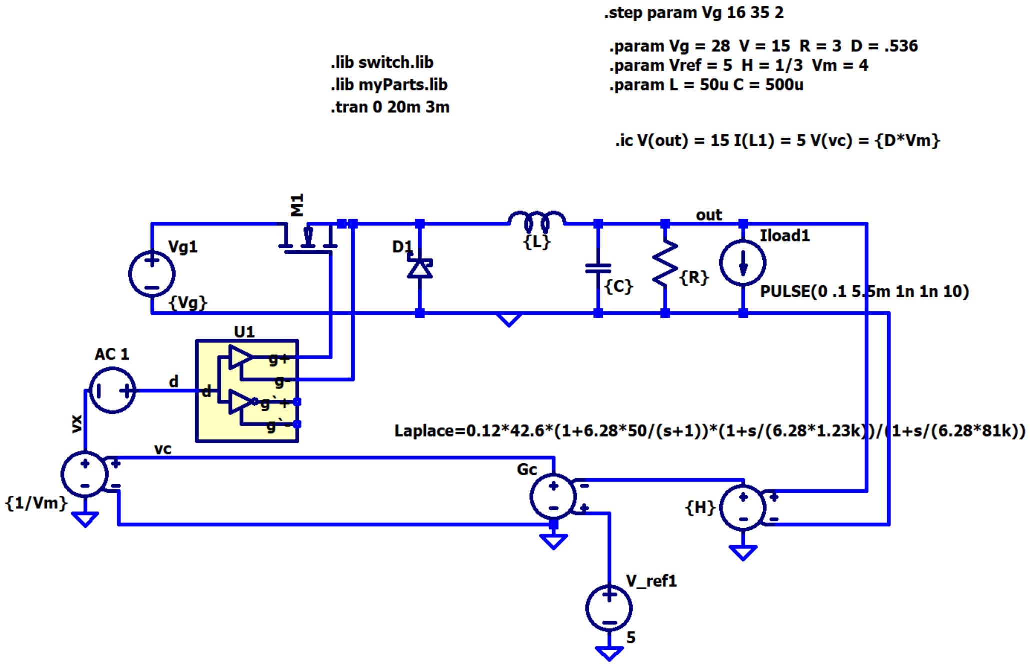
```
.param Vg = 28  V = 15  R = 3  D = .536
.param Vref = 5  H = 1/3  Vm = 4
.param L = 50u C = 500u

.ic V(out) = 15 I(L1) = 5 V(vc) = {D*Vm}
```

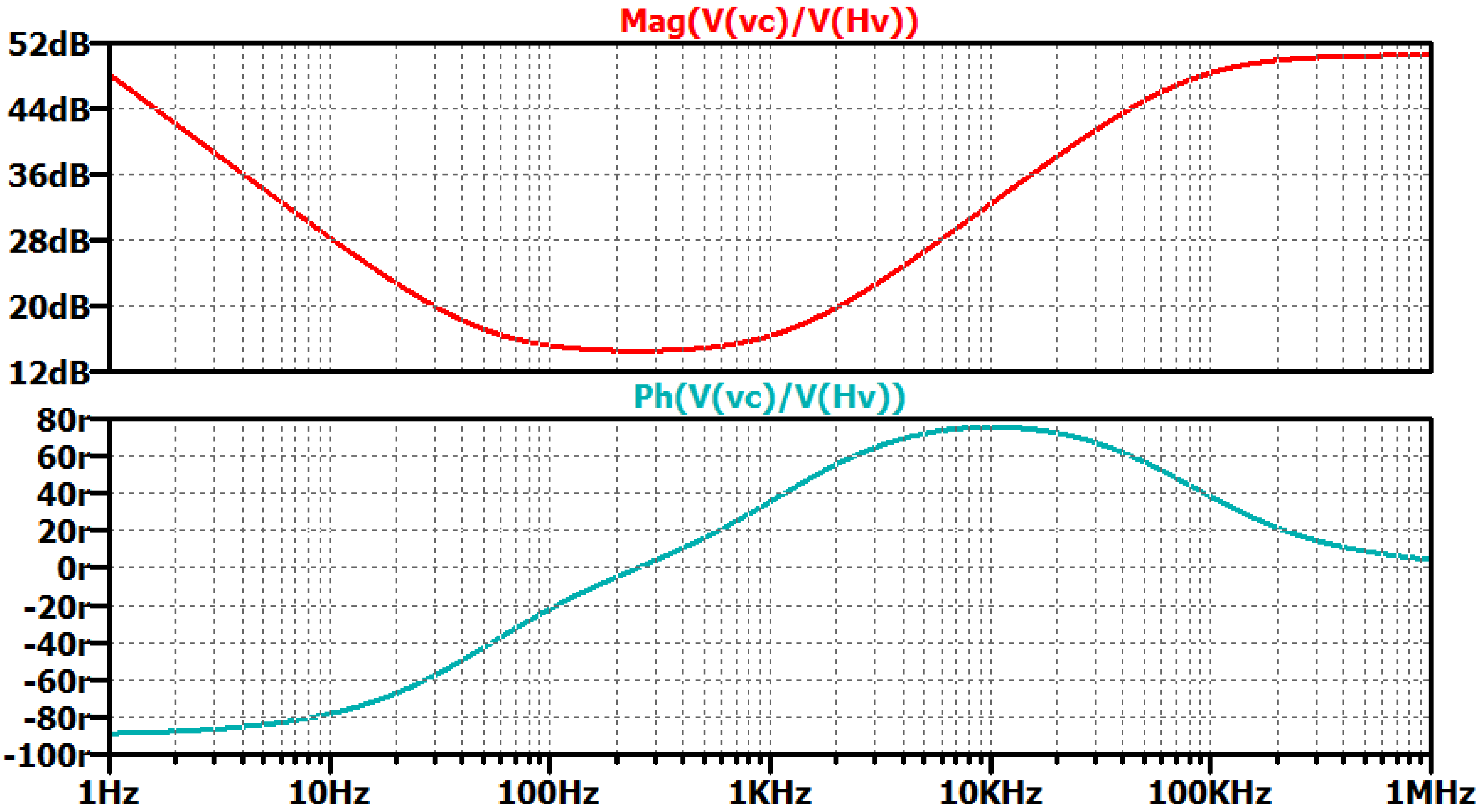


Switching Simulation





Complete Compensator



$$G_c = G_{cm}\left(1 + \frac{2\pi(50\text{Hz})}{s}\right)\frac{\left(1 + \frac{s}{2\pi(1.2\text{kHz})}\right)}{\left(1 + \frac{s}{2\pi(81k\text{Hz})}\right)}$$

Compensator Realization