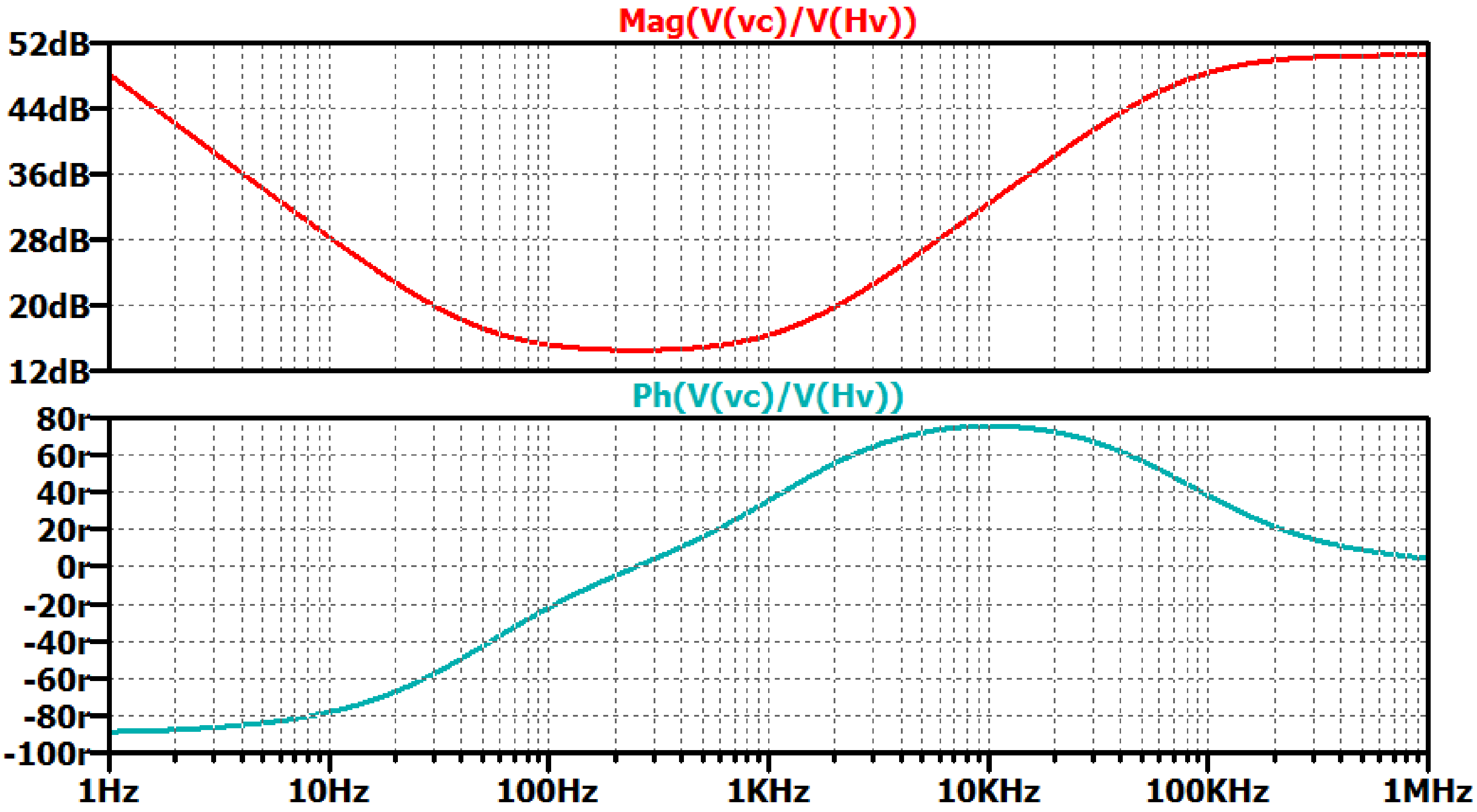
Complete Compensator

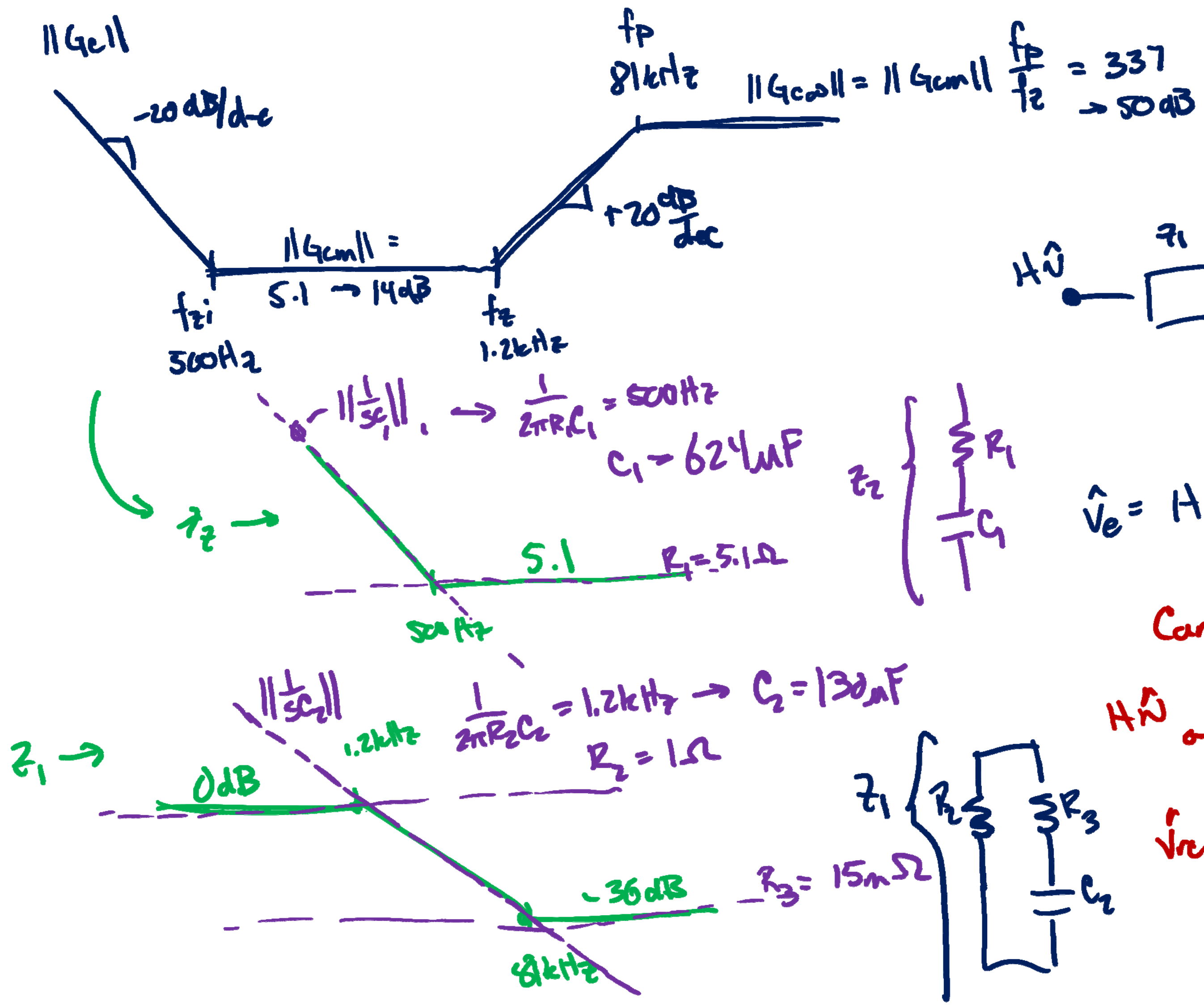


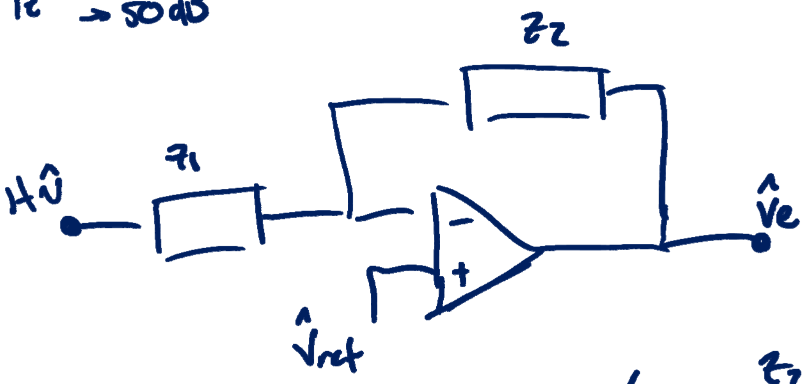
$$G_c = G_{cm}\left(1+\frac{2\pi(50\text{Hz})}{s}\right)\frac{\left(1+\frac{s}{2\pi(1.2\text{kHz})}\right)}{\left(1+\frac{s}{2\pi(81k\text{Hz})}\right)}$$

Compensator Realization

Designed Behavior

$$\hat{v}_e = G_c(s)\left(\hat{v}_{ref} - H\hat{v}\right)$$

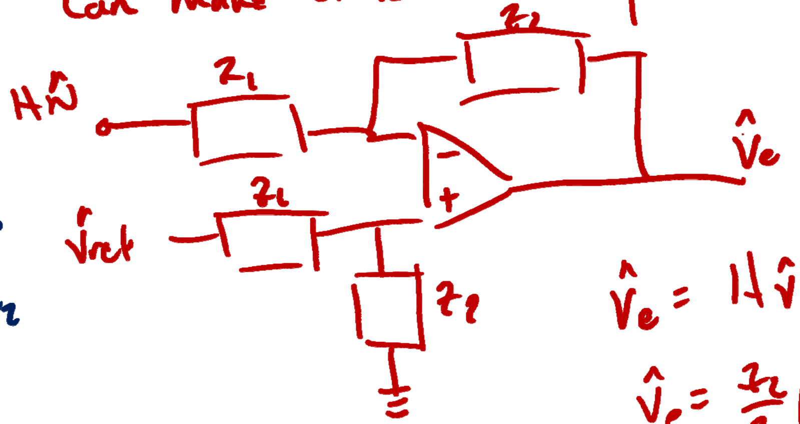




$$\hat{v}_e = H\hat{v}\left(\frac{-Z_2}{Z_1}\right) + \hat{v}_{ref}\left(1 + \frac{Z_2}{Z_1}\right)$$

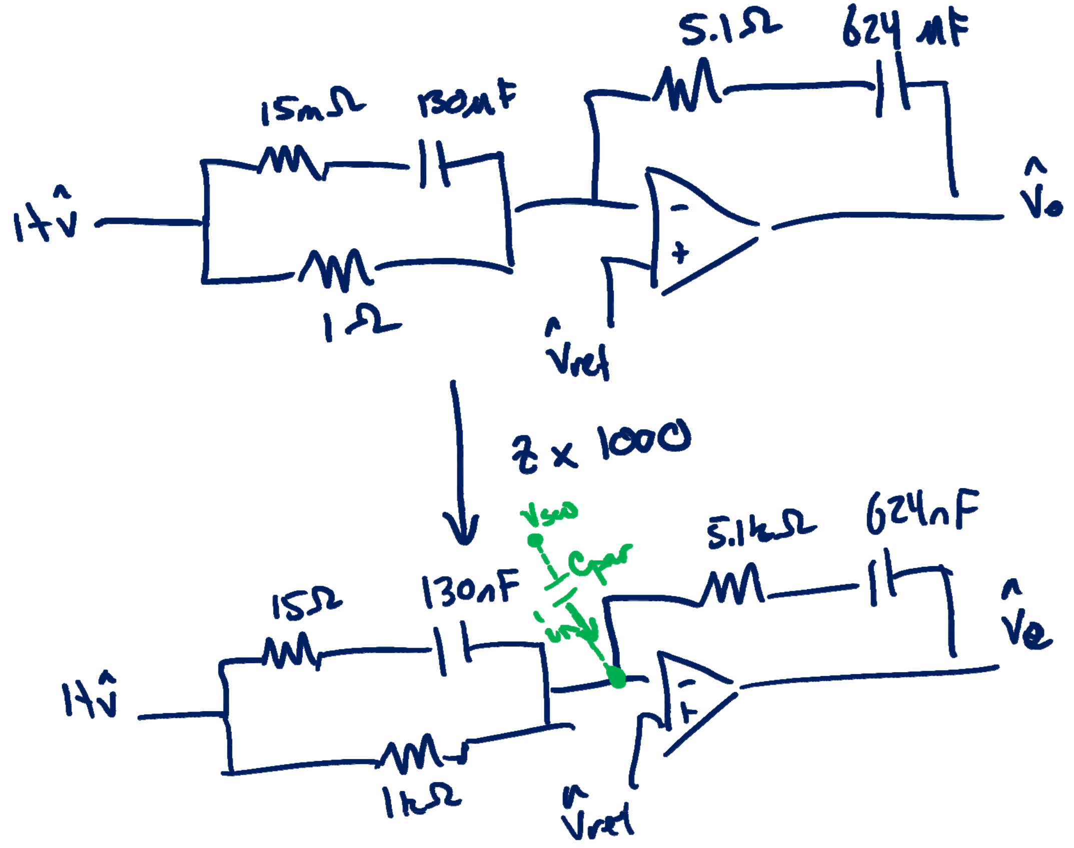
→ ok if we won't dynamically vary Vref (V = const)

Can make a balanced implementation



$$\hat{v}_e = H\hat{v}\left(\frac{-Z_2}{Z_1}\right) + \hat{v}_{ref}\left(\frac{Z_2}{Z_1+Z_2}\right)\left(\frac{Z_1+Z_2}{Z_1}\right)$$

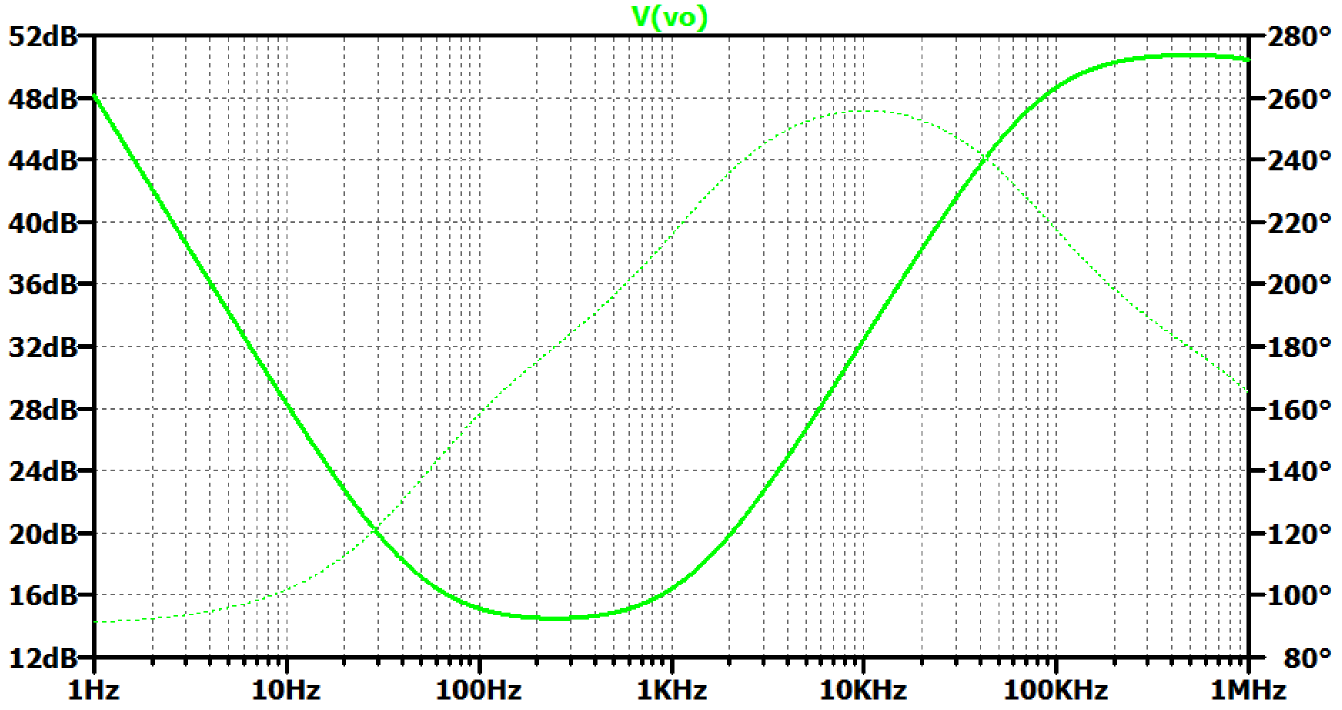
$$\hat{v}_e = \frac{Z_2}{Z_1}\left(\hat{v}_{ref} - H\hat{v}\right)$$

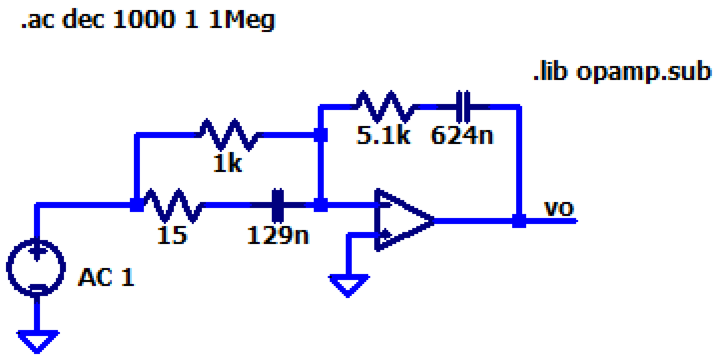


→ R's too small, C's too big } op-amp will be slew rate limited

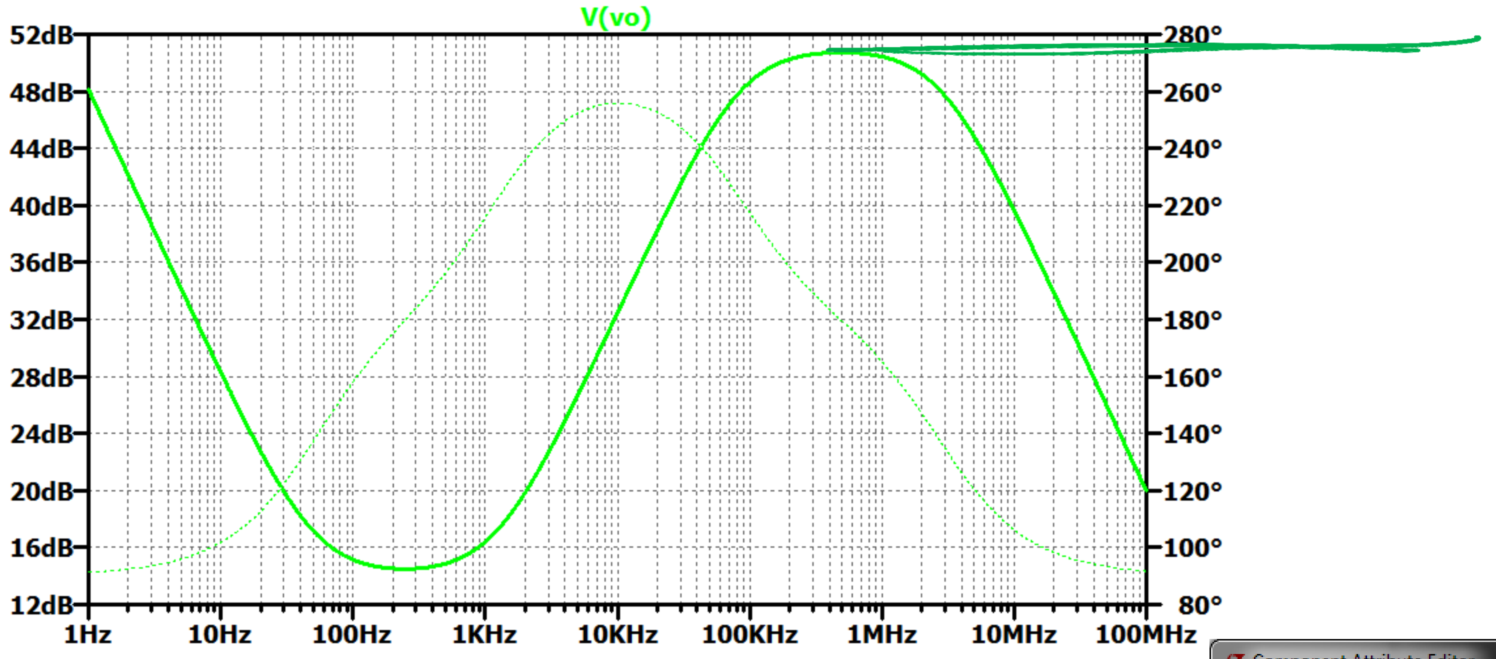
If Z's too large, increased noise susceptibility

Compensator TF

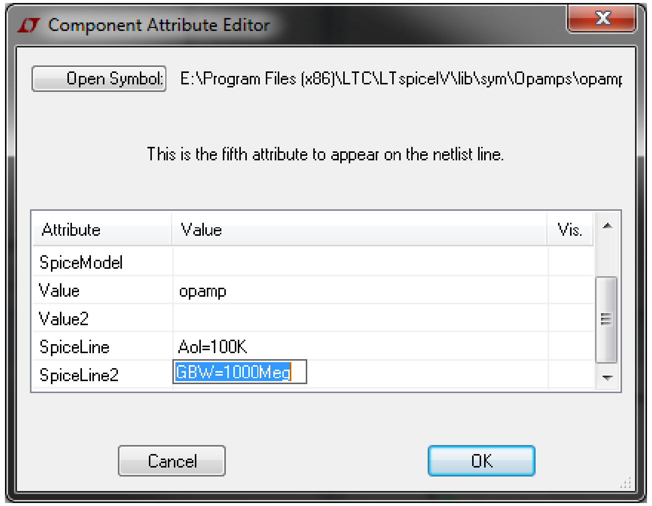




Op-amp GBW

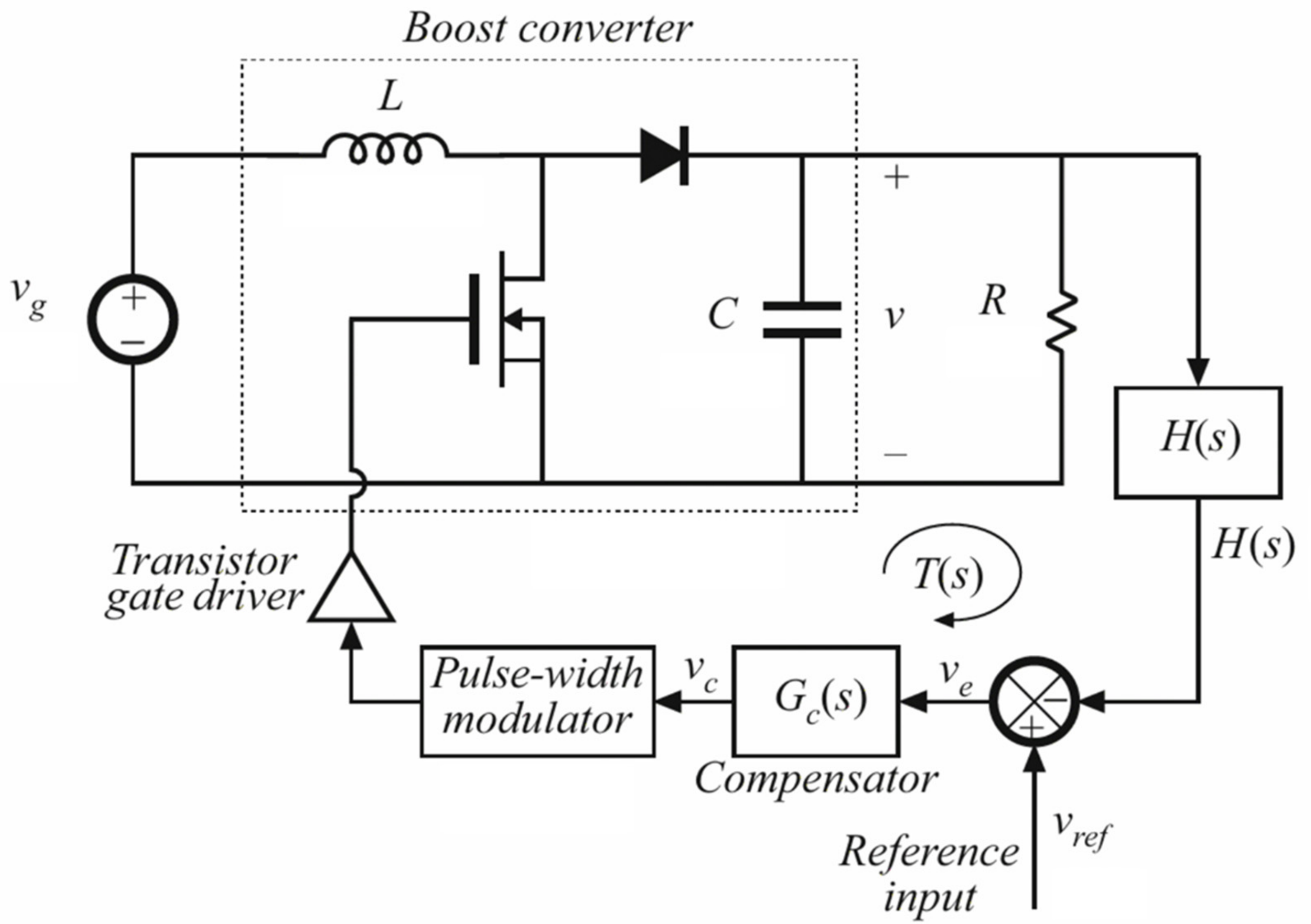


V(vo)
52dB
48dB
44dB
40dB
36dB
32dB
28dB
24dB
20dB
16dB
12dB
280°
260°
240°
220°
200°
180°
160°
140°
120°
100°
80°
1Hz
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz



Component Attribute Editor
Open Symbol:
E:\Program Files (x86)\LTC\LTspiceIV\lib\sym\Opamps\opamp
This is the fifth attribute to appear on the netlist line.
Attribute
Value
Vis.
SpiceModel
Value
opamp
Value2
SpiceLine
Aol=100K
SpiceLine2
GBW=1000Meg
Cancel
OK

Boost Converter Example



$V_g = 12\text{V}$

$R = 10\Omega$

$H = \frac{1}{20}$

$L = 5\mu\text{H}$

$C = 100\mu\text{F}$

$f_s = 500\text{kHz}$

$V_m = 4\text{V}$

$V_{ref} = 3\text{V}$

Boost TFs

$$G_{vd}(s) = G_{d0} \frac{\left(1 - \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{Q\omega_0} + \left(\frac{s}{\omega_0}\right)^2\right)}$$

Table 8.2 Salient features of the small-signal CCM transfer functions of some basic dc–dc converters

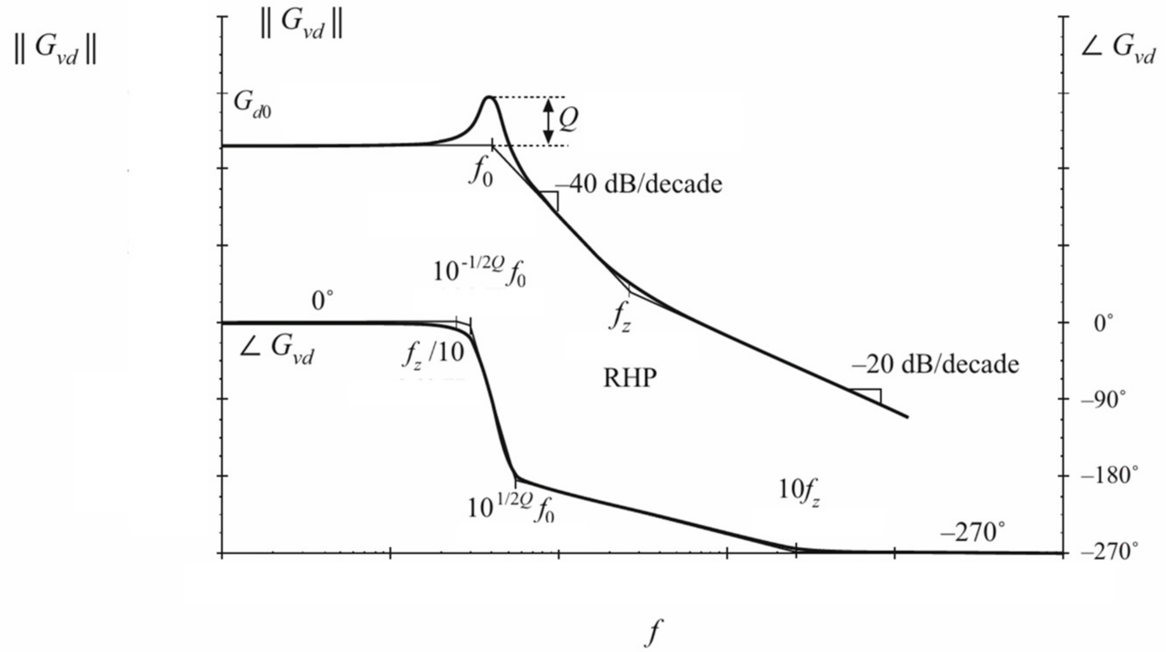
Converter	G_{g0}	G_{d0}	ω_0	Q	ω_z
Buck	D	$\frac{V}{D}$	$\frac{1}{\sqrt{LC}}$	$R\sqrt{\frac{C}{L}}$	∞
Boost	$\frac{1}{D'}$	$\frac{V}{D'}$	$\frac{D'}{\sqrt{LC}}$	$D'R\sqrt{\frac{C}{L}}$	$\frac{D'^2R}{L}$
Buck–boost	$-\frac{D}{D'}$	$\frac{V}{DD'}$	$\frac{D'}{\sqrt{LC}}$	$D'R\sqrt{\frac{C}{L}}$	$\frac{D'^2R}{DL}$

$G_{d0} = 300 \rightarrow 49.5\text{dB}$

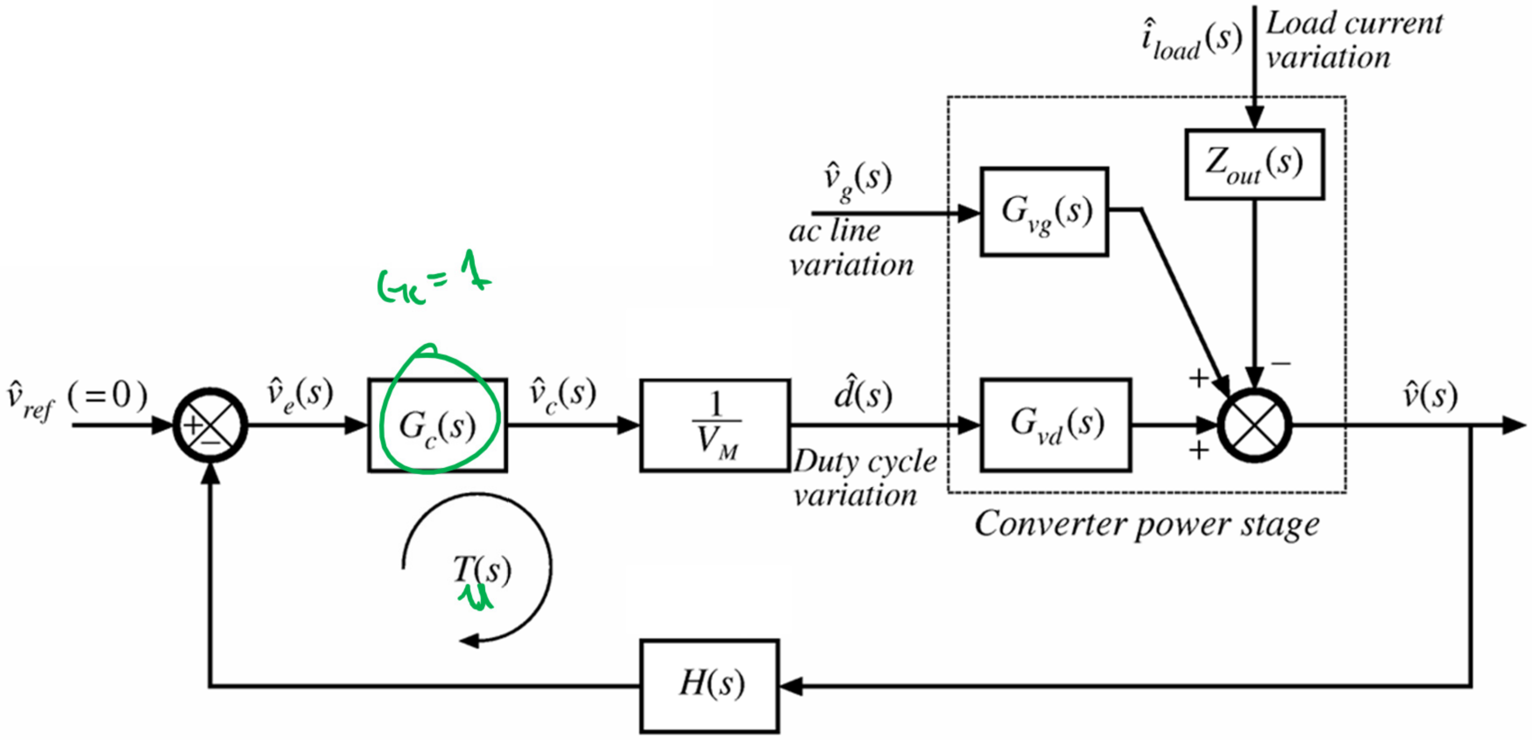
$\omega_0 = 8.96\text{krad/s} \rightarrow 1.4\text{kHz}$

$Q = 8.94 \rightarrow 19\text{dB}$

$\omega_z = 80\text{krad/s} \rightarrow 12.7\text{kHz}$

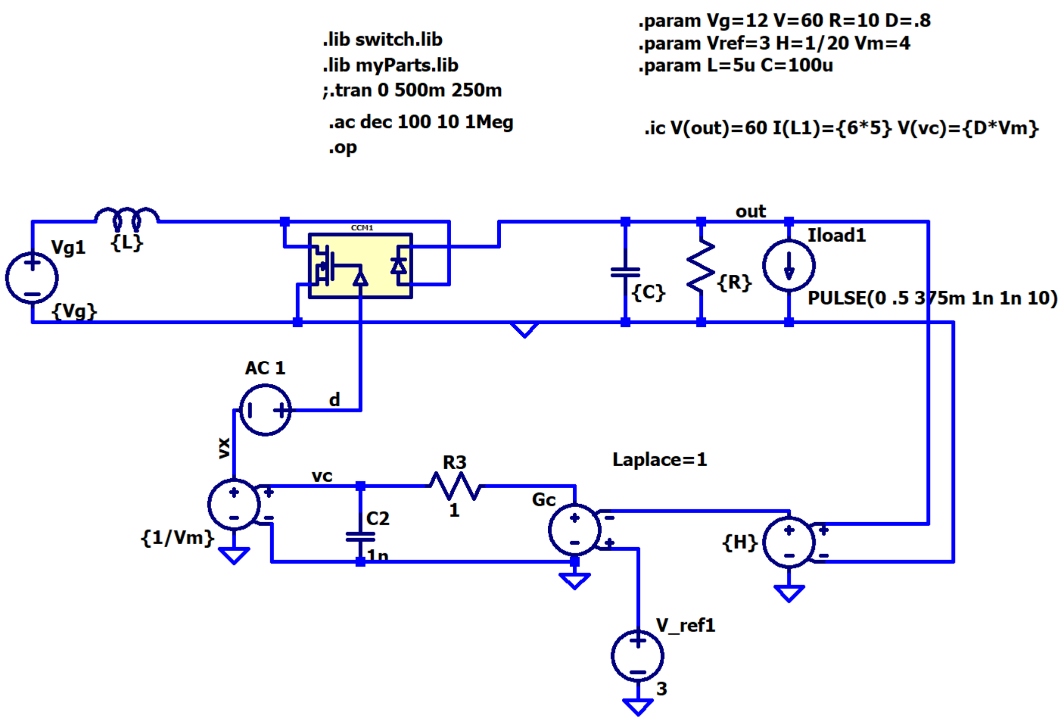


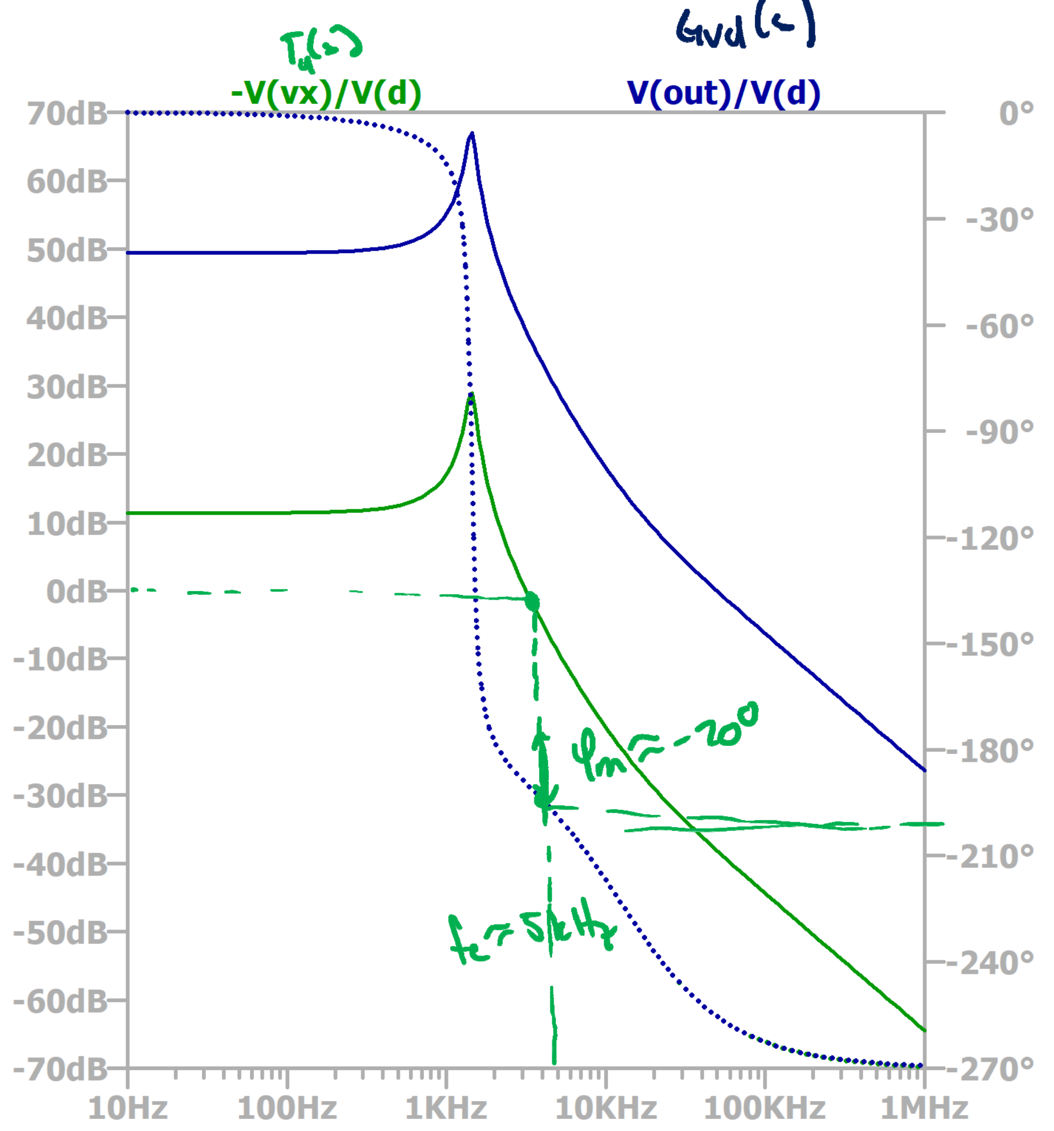
System Block Diagram



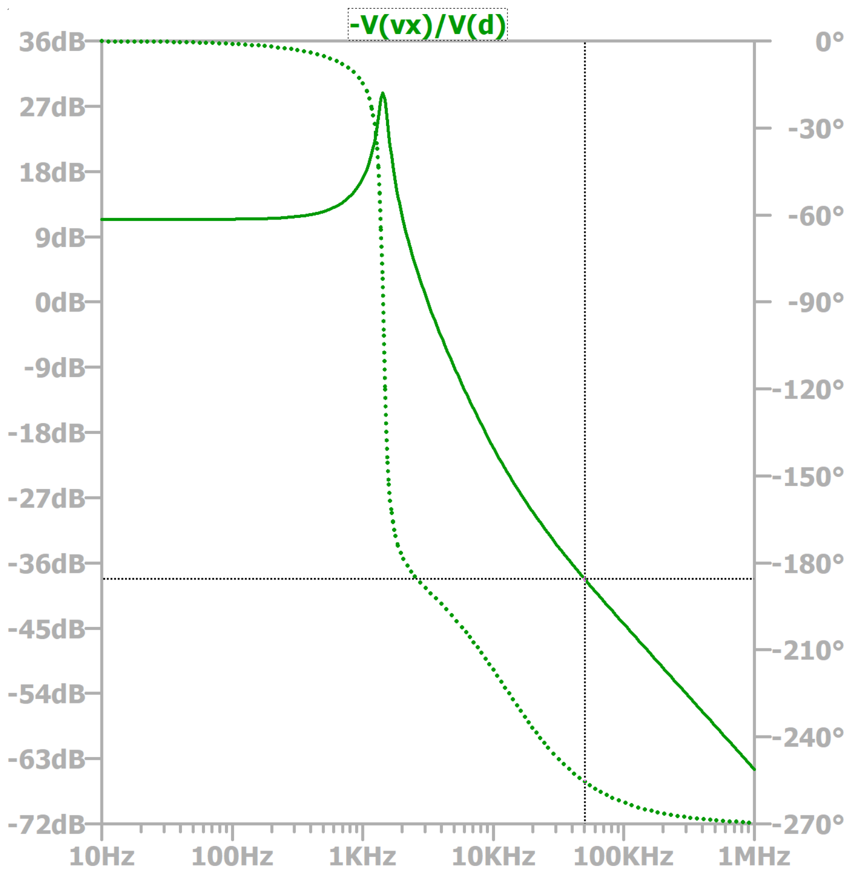
LTspice Simulation

$T_u(s) = G_{vd}\, H\, \frac{1}{V_m}$

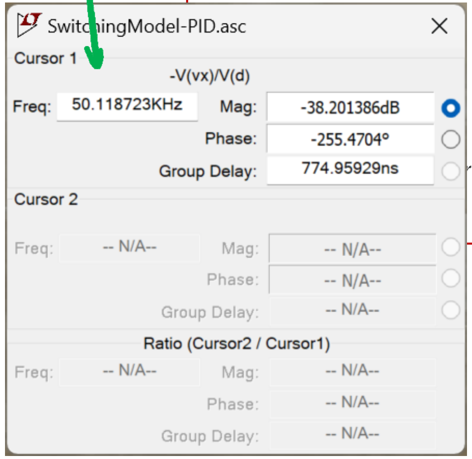


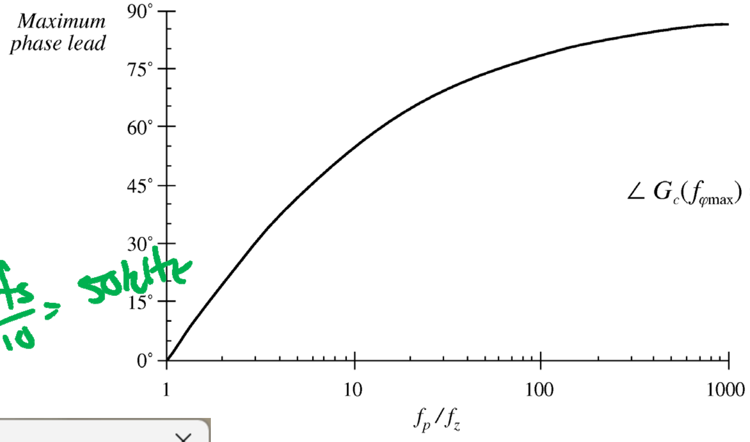


Impact of RHP Zero



If we try to set $f_c = \frac{f_s}{10} = 50kHz$





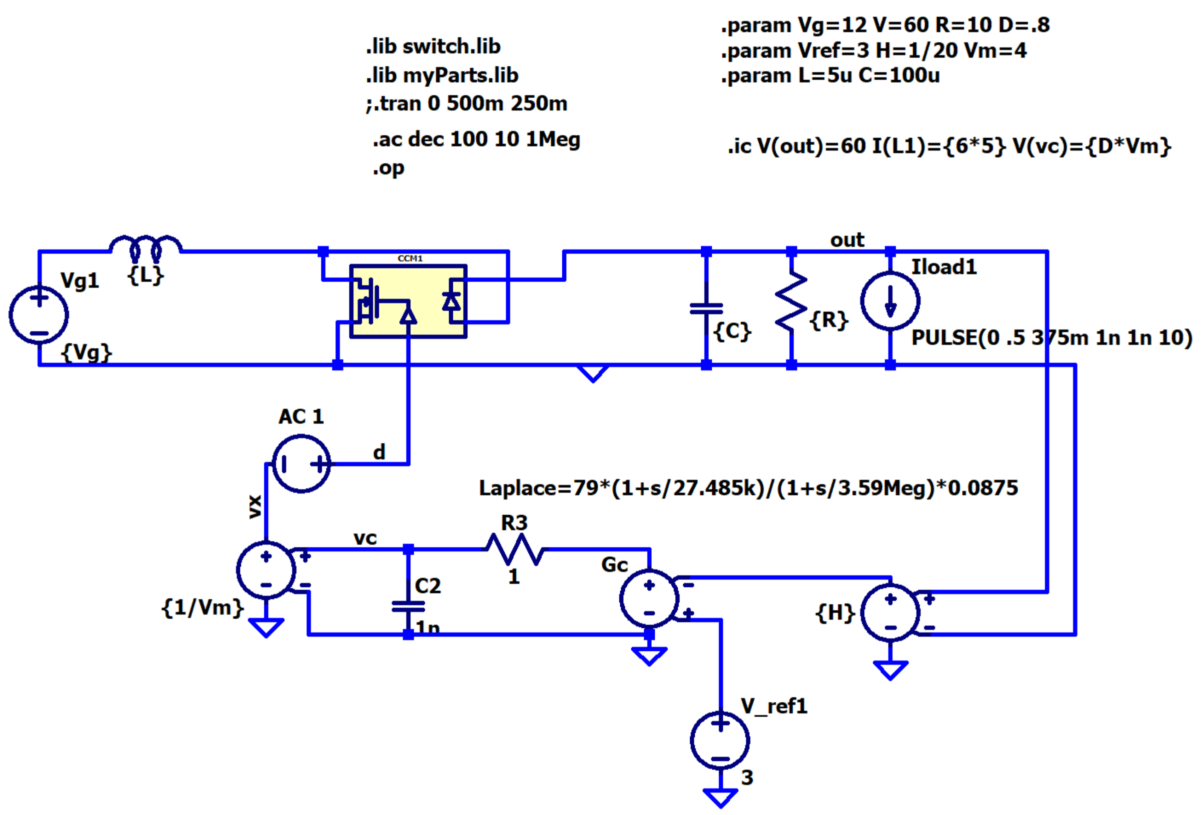
$$f_{\varphi max} = \sqrt{f_z f_p}$$

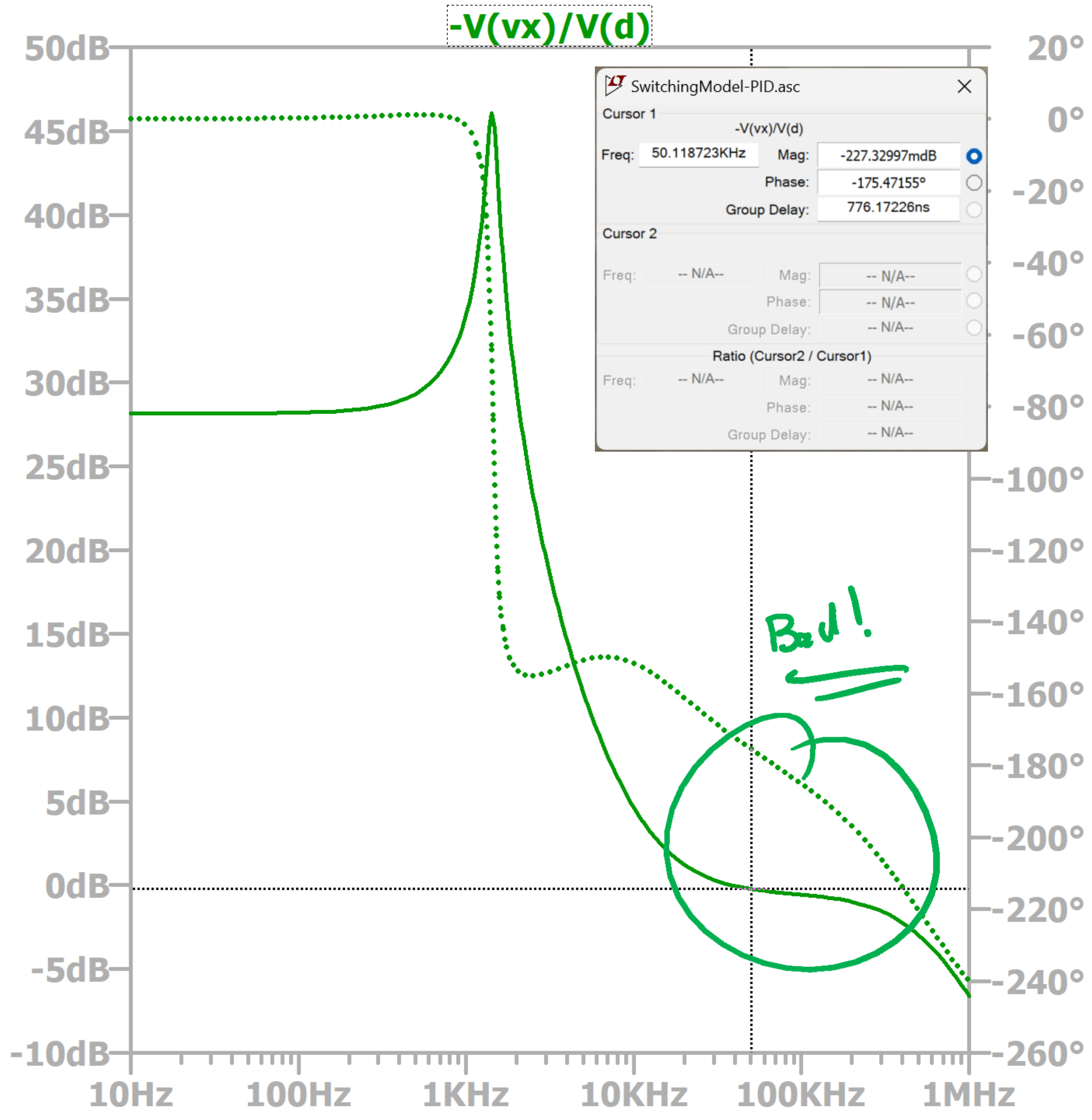
$$\angle G_c(f_{\varphi max}) = \tan^{-1}\left(\frac{\sqrt{\frac{f_p}{f_z}} - \sqrt{\frac{f_z}{f_p}}}{2}\right)$$

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

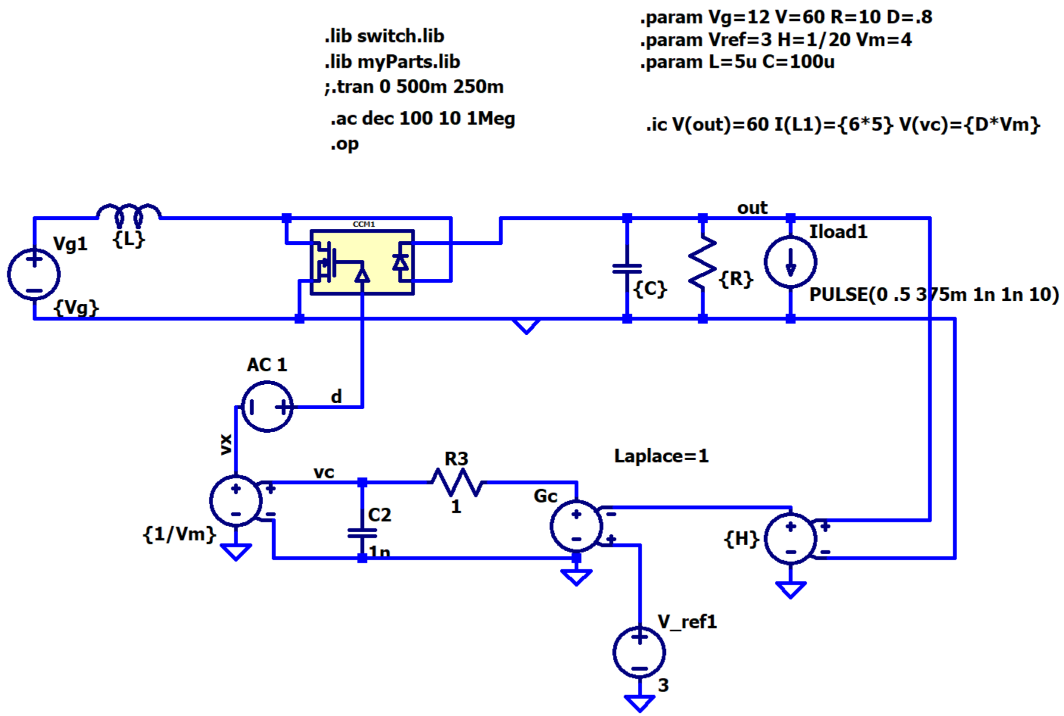
r Electronics 39 Chapter 9: Controller design

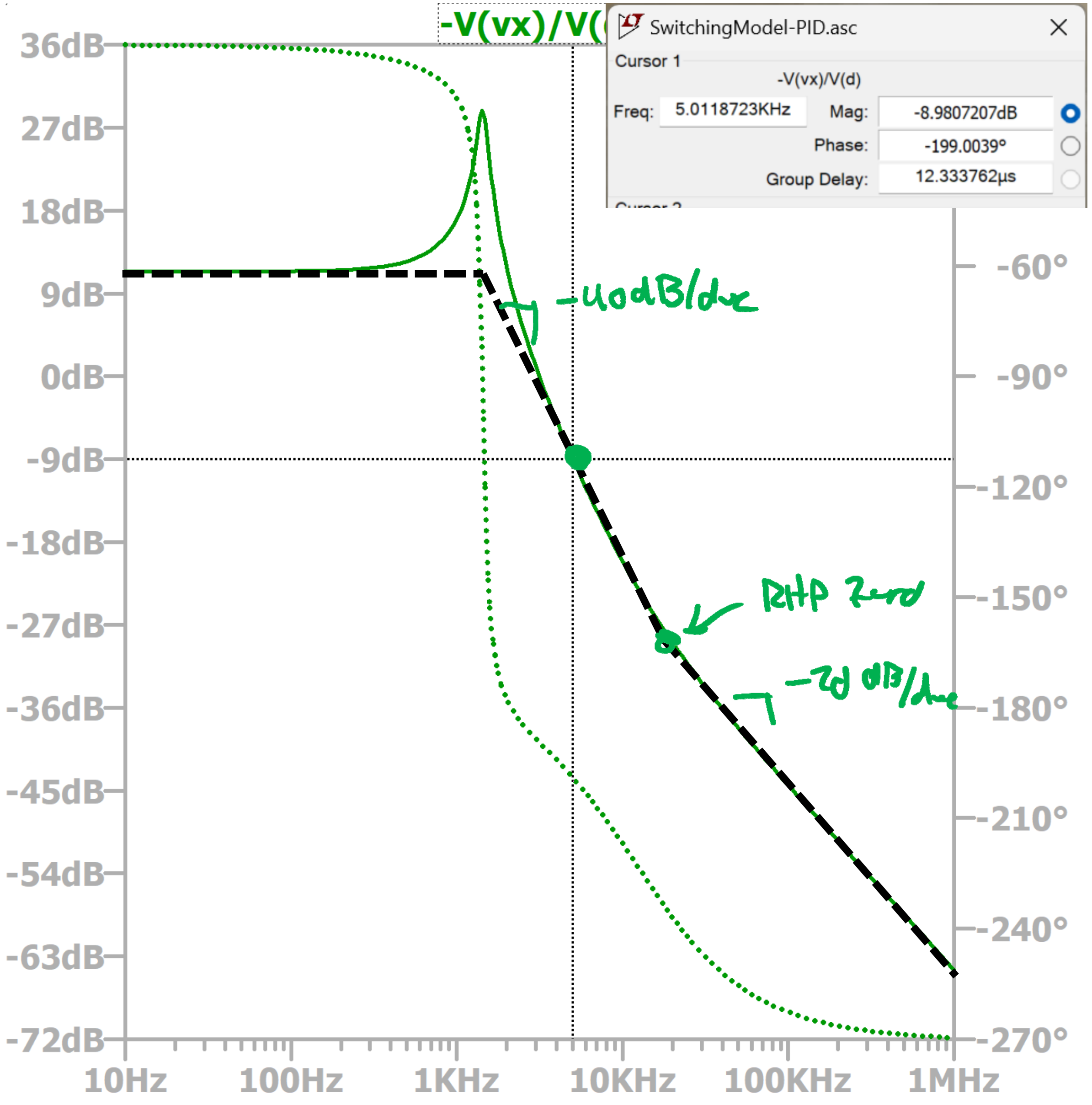
PD Design: f_c=50kHz, θ=80°





Design: f_c=5kHz

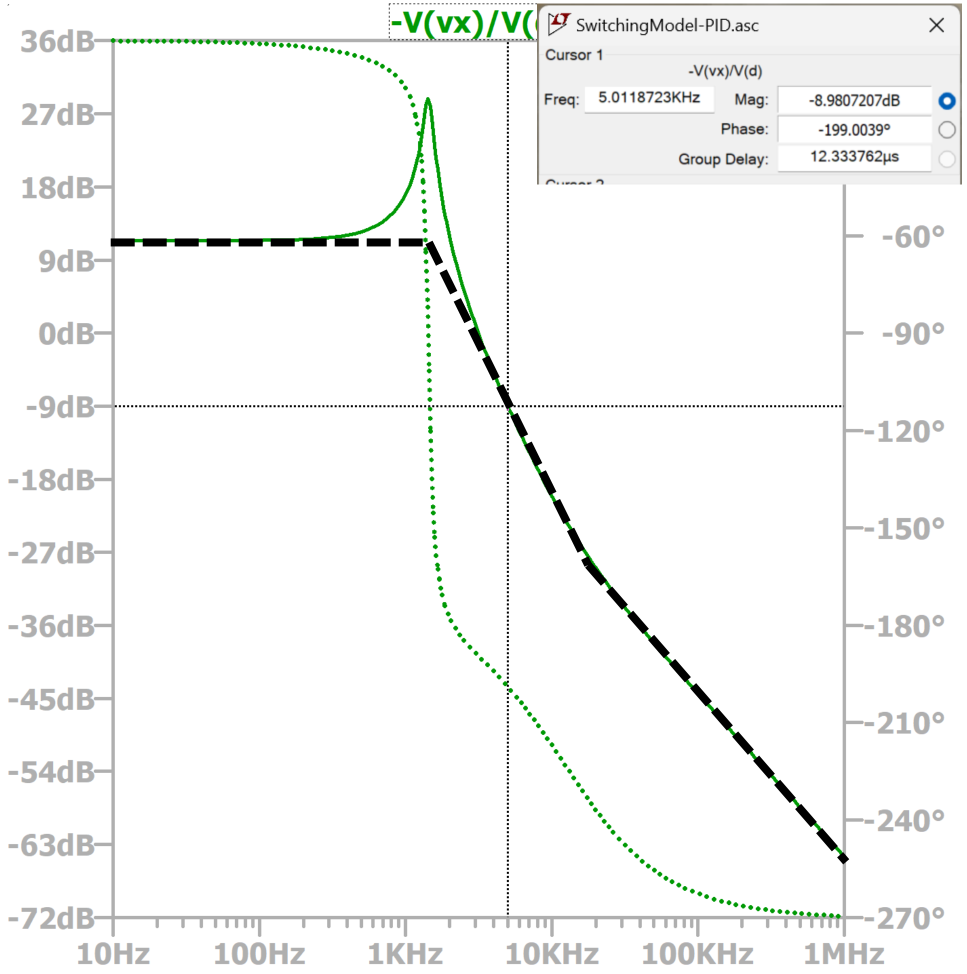




Targets:

- Set f_c=5kHz
- Set φ_m=52°
- Add PI zero at $f_c/10$

Compensator Design



PD

$\theta = \varphi_m + 19^\circ = 52^\circ + 19^\circ$
$= 71^\circ$

PI :

set $f_{zi} = \frac{f_c}{10} = 500$ Hz

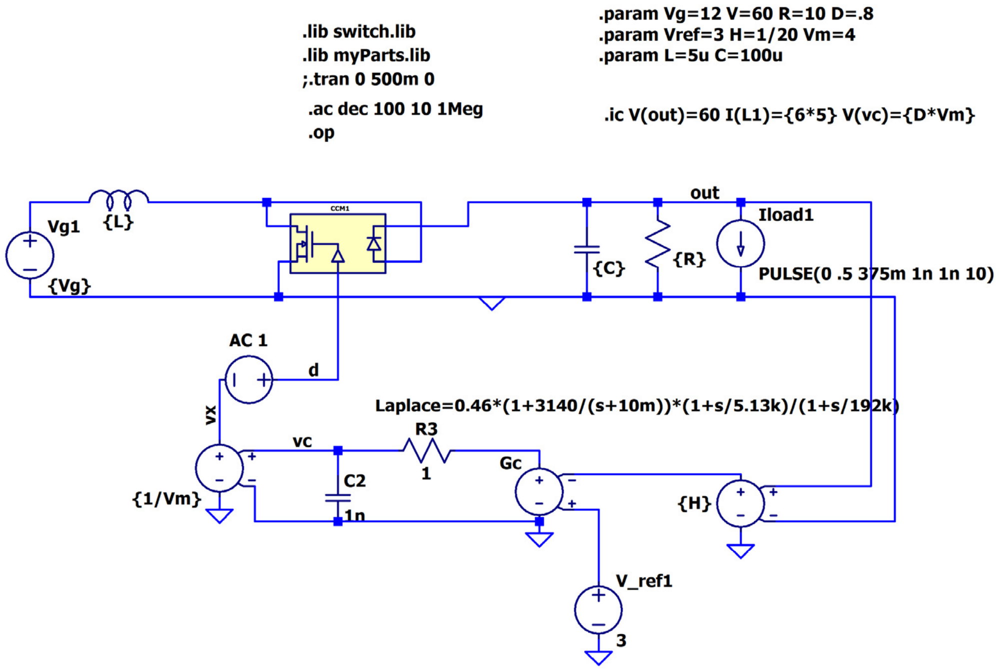
$$f_z = f_c \sqrt{\frac{1-\sin(\theta)}{1+\sin(\theta)}}$$

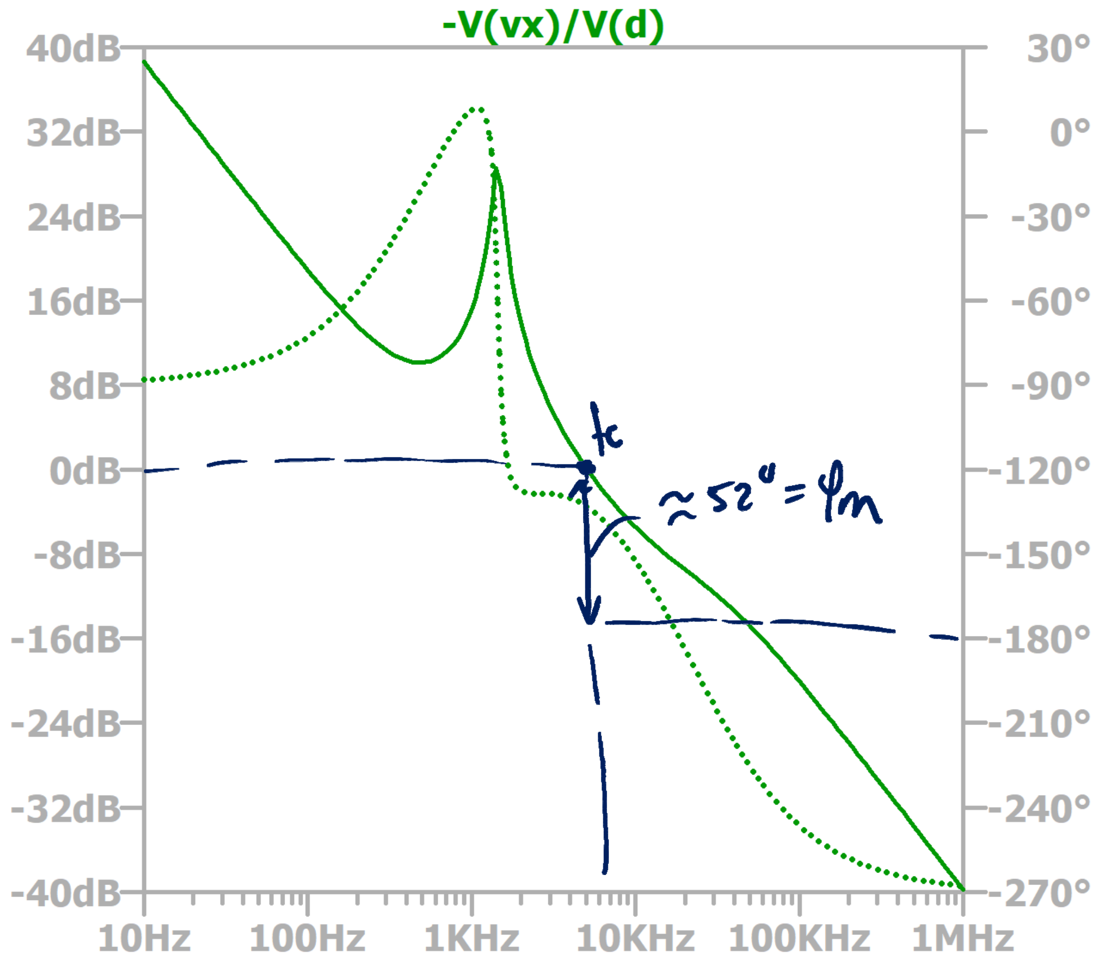
$$f_p = f_c \sqrt{\frac{1+\sin(\theta)}{1-\sin(\theta)}}$$

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

$$G_c = 0.46\left(1+\frac{2\pi(500\text{Hz})}{s}\right)\frac{\left(1+\frac{s}{2\pi(816\text{Hz})}\right)}{\left(1+\frac{s}{2\pi(30.6k\text{Hz})}\right)}$$

AC simulation





Transient Simulation