# PROBLEM 9.9

For the buck-boost converter, $D = \frac{15}{15+48} = 0.2381$

$$G_{d0} = \frac{V}{DD'} = 82.7 \Rightarrow 38\,dB$$

$$\omega_o = \frac{D'}{\sqrt{LC}} = 7264\ rad \Rightarrow f_o = 1156\ Hz$$

$$Q = D'R\sqrt{\frac{C}{L}} = 8 \Rightarrow 18\,dB$$

$$\omega_z = \frac{D'^2 R}{DL} = 244k\ rad \Rightarrow f_z \cong 39\,kHz$$

(a) $H = -\frac{1}{3}$ and $G_{pwm} = \frac{1}{V_M} = \frac{1}{3}$

∴ Uncompensated loop gain is

$$T_u(s) = \frac{G_{do}}{9} \frac{\left(1 - \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{Q\omega_0} + \frac{s^2}{\omega_0^2}\right)}$$

We can have a crossover frequency between 5 kHz and 20 kHz. We need a phase margin of 52° at least and high low frequency gain hence a PID compensator is required.

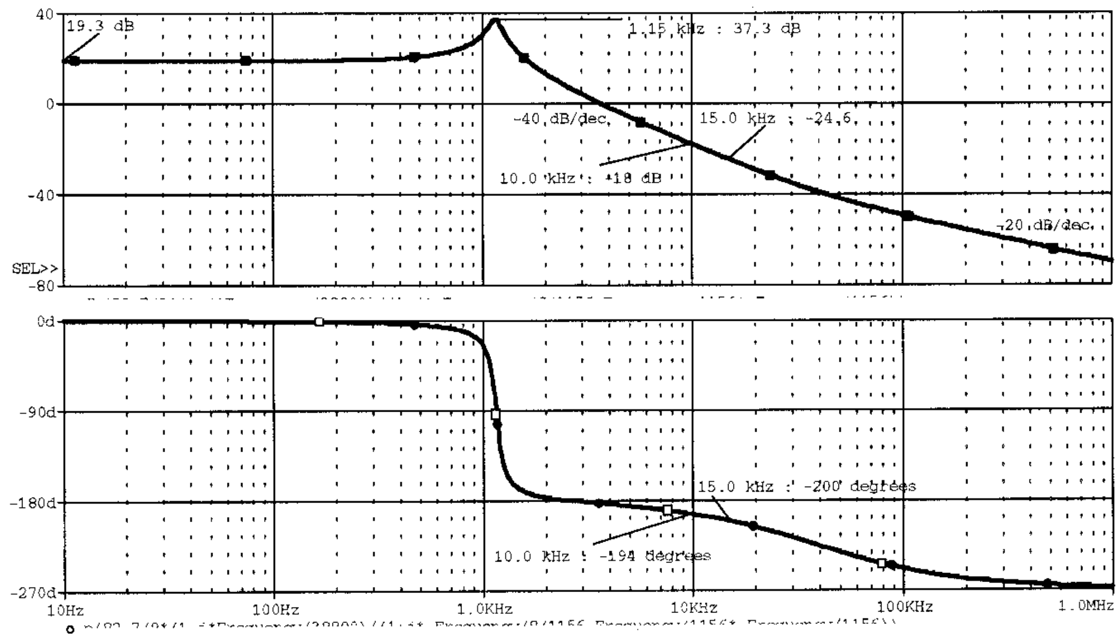
The transfer function of the compensator is

Eq. 9.43
Fig. 9.21

$$G_c(s) = G_{cm} \frac{\left(1 + \frac{\omega_L}{s}\right)\left(1 + \frac{s}{\omega_z}\right)}{\left(1 + \frac{s}{\omega_{p1}}\right)\left(1 + \frac{s}{\omega_{p2}}\right)}$$

We should select $f_L, f_z < f_c < f_{p1}, f_{p2}$

(a) Uncompensated loop gain magnitude and phase



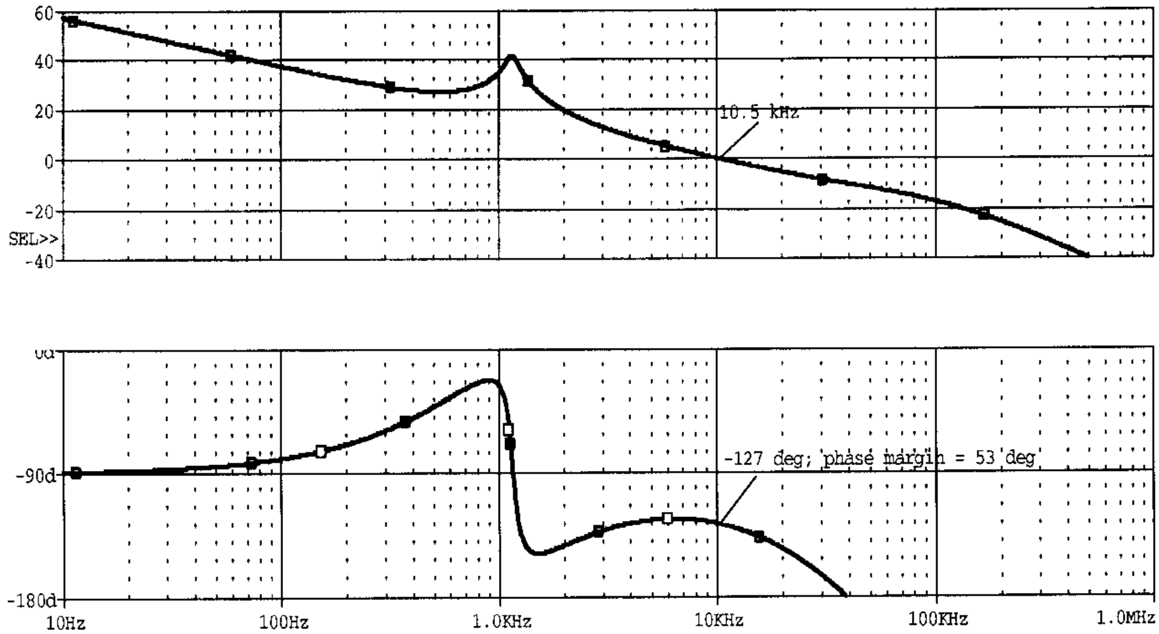

**Compensator design:** It is required that the crossover frequency be less than 20 kHz. If we have a crossover frequency tending to 20 kHz then the compensator poles will be placed near or beyond 200 kHz (switching frequency) and the attenuation of switching frequency ripple would not be sufficient. This is important here because the switching ripple is high for a buck-boost converter. If we have $f_c$ near 5 kHz then we can not place the PI controller to have a high gain at 120 Hz. The location of the inverted zero of the PI stage as well as the high frequency roll-off pole affects the maximum compensator phase at $f_c$. The phase at $f_c$ will be reduced by 5.7 ° if either a pole is placed at $10 \cdot f_c$ or an inverted zero is placed at $f_c$ /10. The total phase reduction will be about 12 ° with both.

We select a crossover frequency to be 10 kHz. We need the compensator to have a gain of 18 dB and phase of 66 ° at 10 kHz. We design for a maximum phase of 66 ° + 12 ° = 78 °. From Eq. 9.57, approximately, $f_z$ = 1 kHz and $f_p = f_{p1}$ =100 kHz. Then $G_{c0}$= 0.814 from Eq. 9.58. We also choose $f_{p2} = 10 \cdot f_c$ =100 kHz and $f_L = f_c$ /10=1 kHz. The plots for part (b) are attached.

**(c)** The loop gain at 120 Hz is 36 dB. More loop gain at 120 Hz can be obtained at the expense of switching frequency attenuation or phase margin. $f_L$ could be pushed higher but the compensator will have to be redesigned to increase the maximum phase.

Crossover frequency improvement is mainly limited by the required attenuation at switching frequency.

## (b) Bode plot of the compensated loop gain T(s)




## Magnitude of 1/(1+T) and T/(1+T)