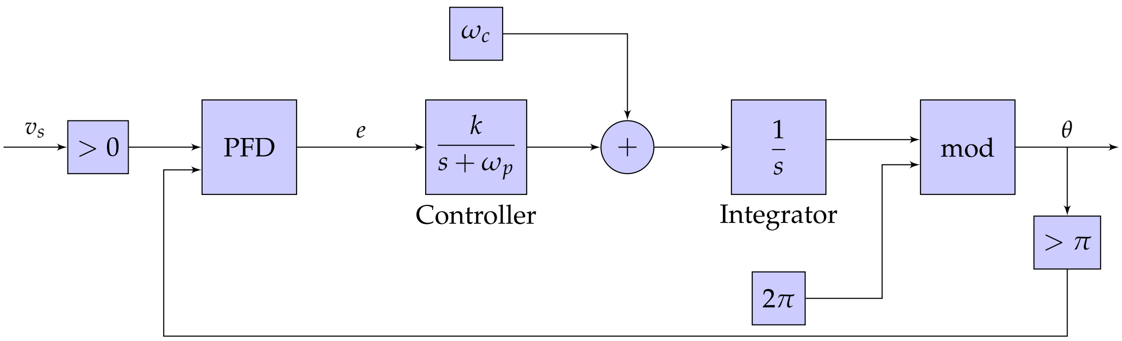
DIGITAL CONTROL OF POWER ELECTRONICS

Single Phase PLL



Phase Frequency detector. Multiple options

$$G_{PFD}(s) = \frac{U_{sat+} - U_{sat-}}{4\pi} = \frac{2}{4\pi} = \frac{1}{2\pi} \tag{1}$$

The controller is essentially a low pass filter shown below.

$$G_{LF}(s) = \frac{k}{s+\omega_p} \tag{2}$$

$$G_{VCO}(s) = \frac{K_{VCO}}{s} = \frac{1}{s} \tag{3}$$

$$G_{OL}(s) = \frac{1}{2\pi}\frac{k}{s+\omega_p}\frac{1}{s} \tag{4}$$

$$G_{CL}(s) = \frac{k}{2\pi(s^2+\omega_p s+\frac{k}{2\pi})} \tag{5}$$

Lets design the control loop by selecting a bandwidth ω_{BW} of the control loop and setting the damping ζ. In order to set the bandwidth, set the gain of the open loop transfer function to be one at the bandwidth frequency.

$$|G_{OL}(s)| = 1 = \frac{k}{2\pi\omega_{BW}}\frac{1}{\sqrt{1+(\frac{\omega_{BW}}{\omega_p})^2}} \tag{6}$$

The closed loop transfer function can be used to set the damping.

$$2\zeta\omega_n = \omega_p \qquad \omega_n^2 = \frac{k}{2\pi} \tag{7}$$

$$\omega_p = 2\zeta\sqrt{\frac{k}{2\pi}} \tag{8}$$

$$k = \frac{2^2\zeta^2 2\pi\omega_{BW}^2}{2} - \frac{\sqrt{(2^2\zeta^2 2\pi\omega_{BW}^2)^2 - 4(2\pi)^2\omega_{BW}^4}}{2} \tag{9}$$

Let select a damping ratio of 1 and a bandwidth 10Hz.

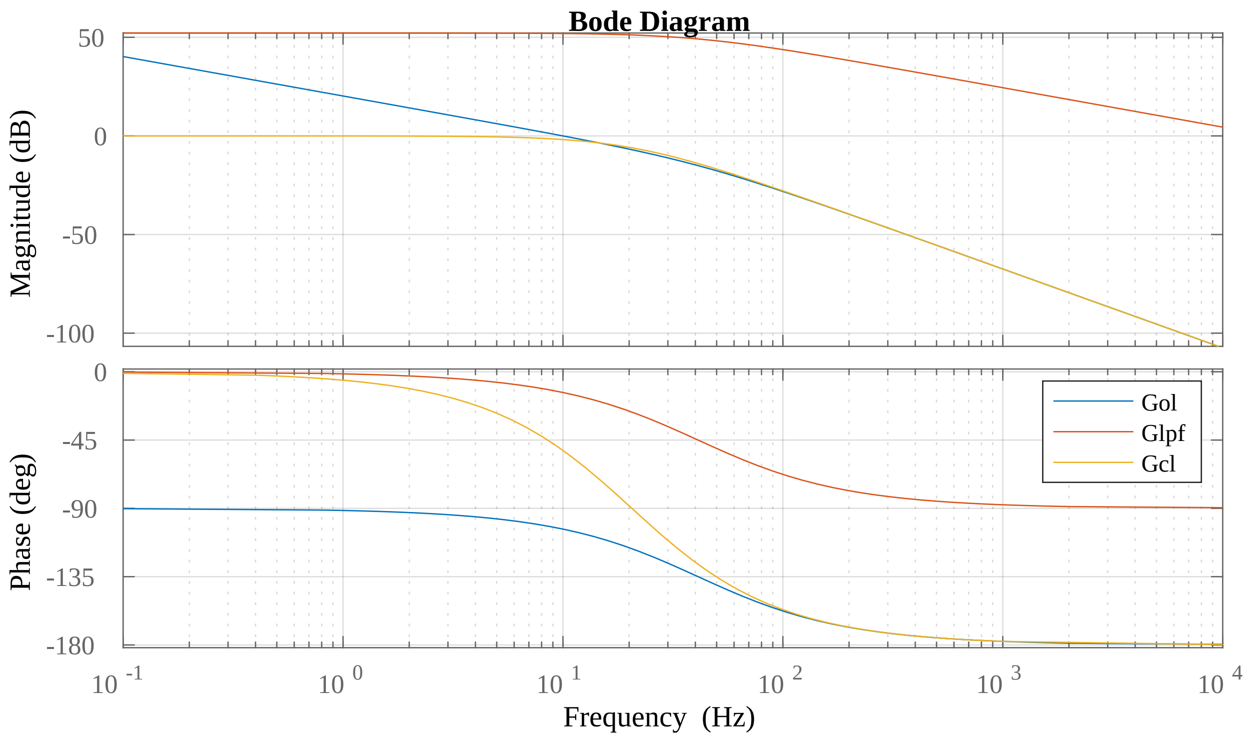
$$k = 105075 \quad \omega_p = 258.6 \tag{10}$$

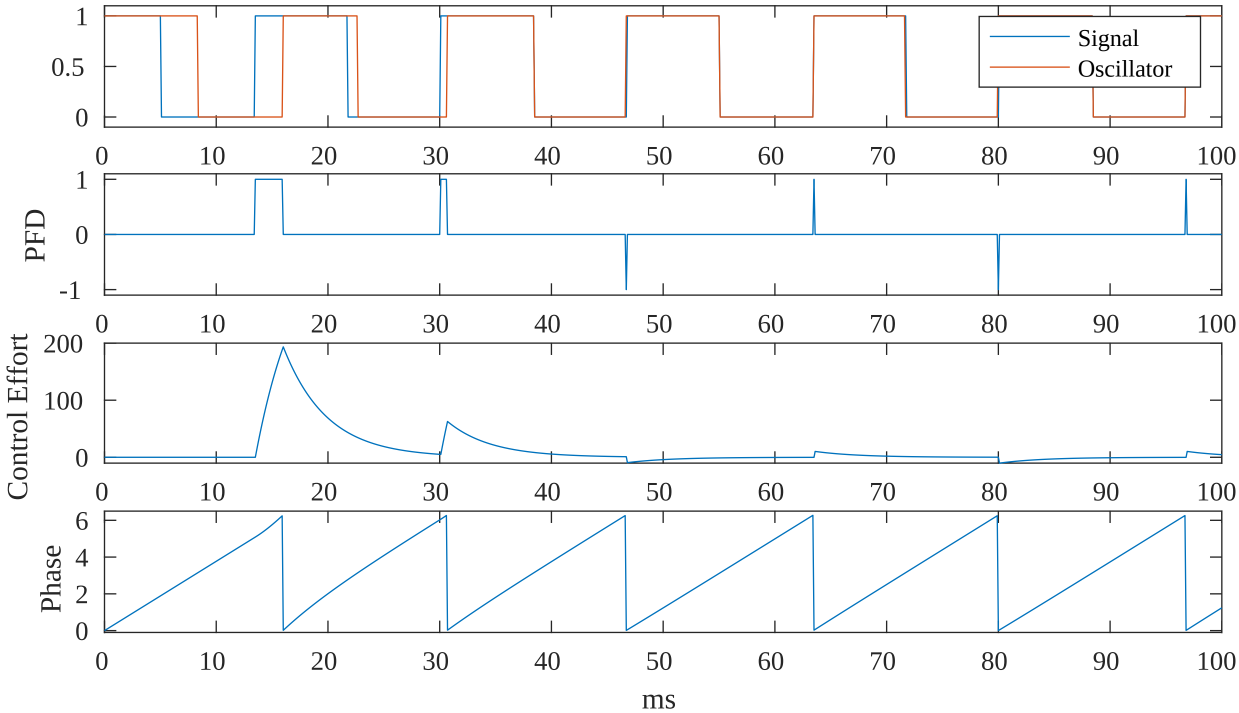
$$G_{LF}(s) = \frac{105075}{s+258.6} \tag{11}$$

$$G_{OL}(s) = \frac{16723}{s^2 + 258.6s} \tag{12}$$

$$G_{CL}(s) = \frac{16723}{s^2 + 258.6s + 16723} \tag{13}$$

$$p_1 = -129.3187 + 2.711329e - 06i, p_2 = -129.3187 - 2.711329e - 06i \tag{14}$$




1
0.5
0
Signal
Oscillator
PFD
1
0
-1
Control Effort
200
100
0
Phase
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
ms

Lets design the loop using a PI controller. Let the controller/loop filter be

$$G_{LF}(s) = \frac{k_p s + k_i}{s} \tag{15}$$

Now the open loop transfer function is as follows

$$G_{OL}(s) = \frac{1}{2\pi}\frac{k_p s + k_i}{s}\frac{1}{s} \tag{16}$$

and the closed loop transfer function is as follows

$$G_{CL}(s) = \frac{\frac{1}{2\pi}k_p s + k_i}{s^2 + \frac{k_p}{2\pi}s + \frac{k_i}{2\pi}} \tag{17}$$

Lets design the control loop based on a selected damping factor and natural frequency.

$$\omega_n^2 = \frac{k_i}{2\pi} \qquad 2\zeta\omega_n = \frac{k_p}{2\pi} \tag{18}$$

$$k_i = 2\pi\omega_n^2 \tag{19}$$

$$k_p = 2\zeta\sqrt{2\pi k_i} = 4\pi\zeta\omega_n \tag{20}$$

Let the damping ratio be 1 and natural frequency be $\omega_n = 2\pi 4$.

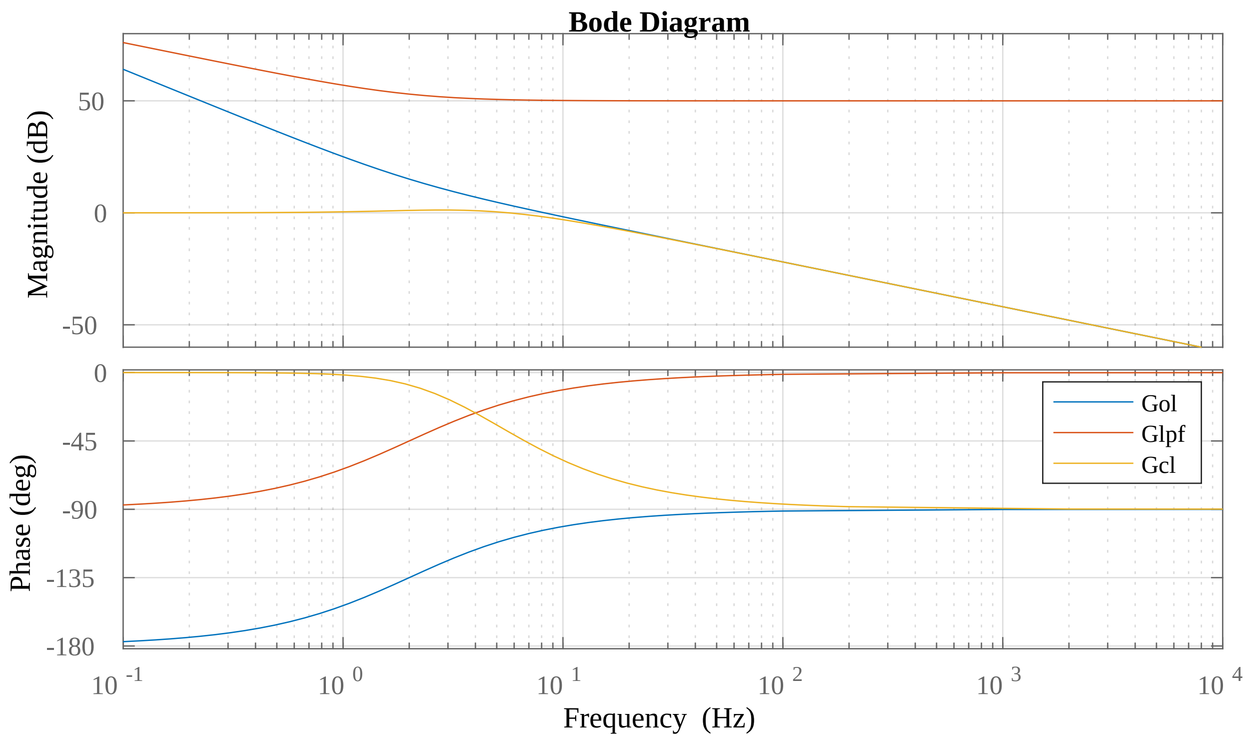
$$k_p = 315.8 \qquad k_i = 3968.8 \tag{21}$$

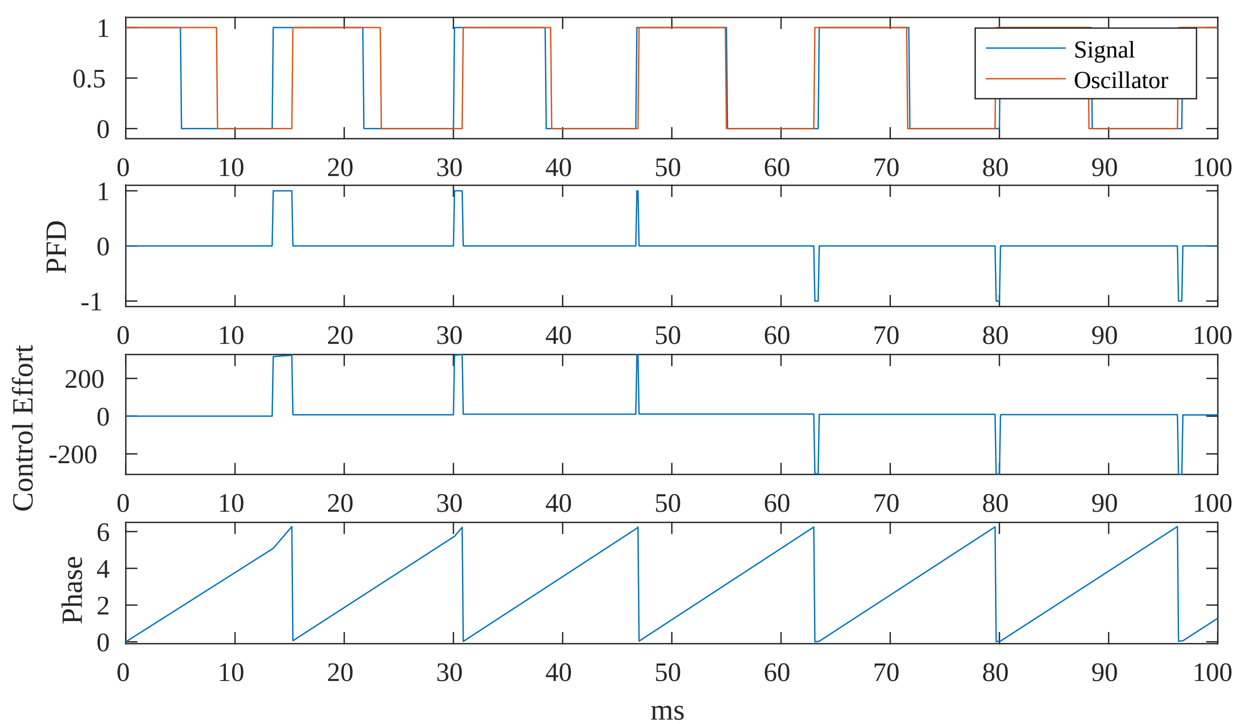
$$G_{LF}(s) = \frac{315.8s + 3969}{s} \tag{22}$$

$$G_{OL}(s) = \frac{50.27s + 631.7}{s^2} \tag{23}$$

$$G_{CL}(s) = \frac{50.27s + 631.7}{s^2 + 50.27s + 631.7} \tag{24}$$

$$p_1 = -129.3187 + 2.711329e - 06i, p_2 = -129.3187 - 2.711329e - 06i \tag{25}$$


Bode Diagram
Magnitude (dB)
50
0
-50
Phase (deg)
0
-45
-90
-135
-180
Gol
Glpf
Gcl
10 -1
10 0
10 1
10 2
10 3
10 4
Frequency (Hz)


Signal
Oscillator
PFD
Control Effort
Phase
ms
0
10
20
30
40
50
60
70
80
90
100