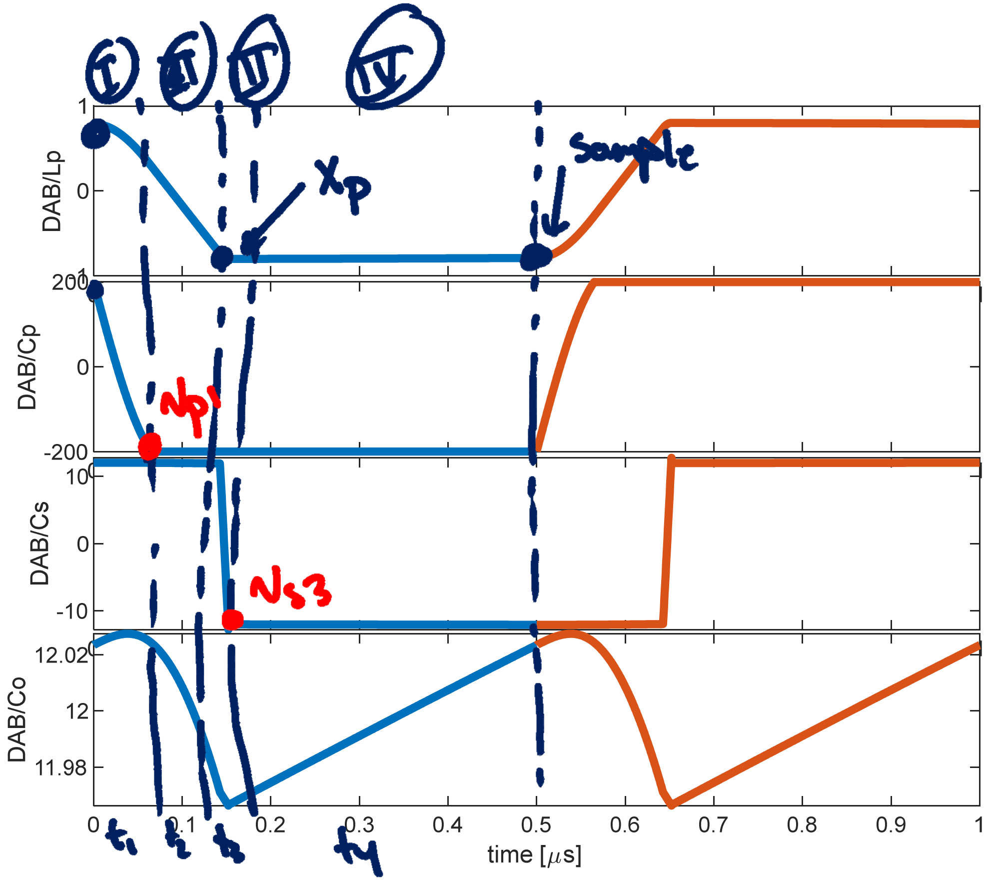
Example Design



DAB (HWb)

200-to-12V, 10A I_{out}

$C_o = 20\mu F$

$f_s = 1MHz$

$L_l = 35\mu H$

$r_{on,p} = 50m\Omega$

$r_{on,s} = 1m\Omega$

$n_p : n_s = 1 : \frac{V_g}{V}$

ADC and PWM Model

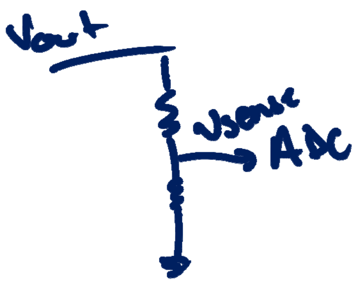
ADC : 10-bit $V_{FS} = 3.3V$ $t_{conv} \le t_1$

$$k_{ADC} = \frac{2^{10}}{3.3}$$

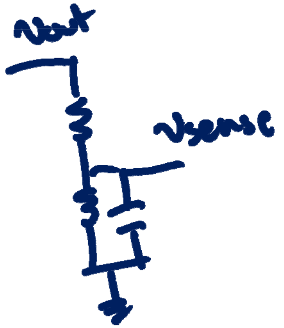
PWM : $f_{clk} = 200MHz$ $N_r = \frac{f_{clk}}{f_s} = 200$

$$K_{PWM} = \frac{T_s}{N_r}$$

Sensing Gain $H = \frac{1}{10}$ →

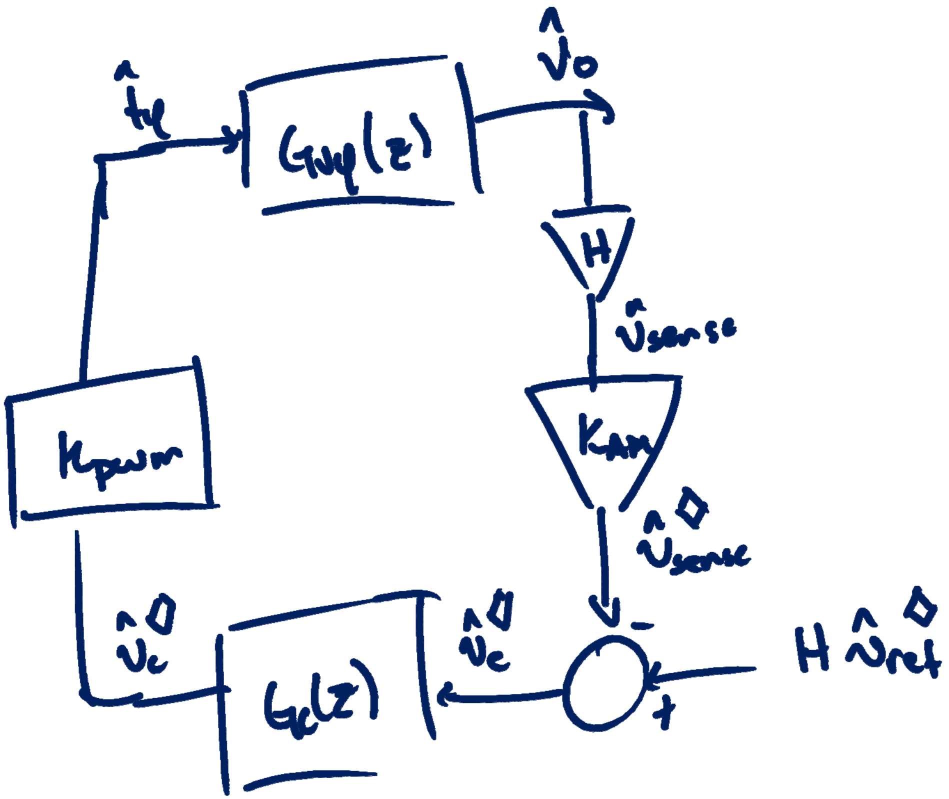


Note:



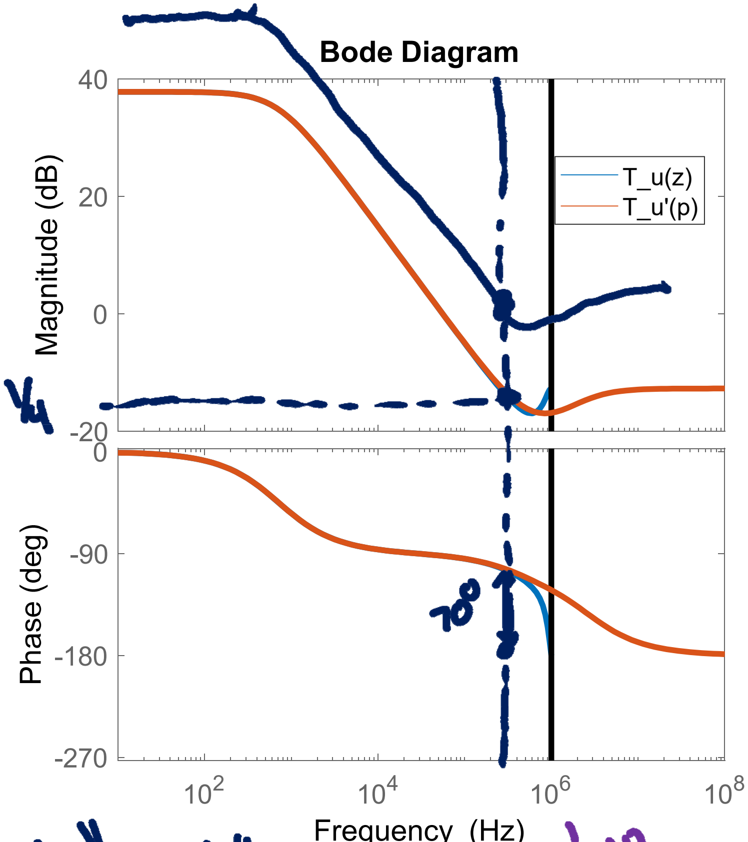
In this case, include filter in plant model

Loop Gain



$$T_u(z) = G_{v\varphi}(z)\, H\, K_{ADC}\, K_{pwm}$$

Compensator Design



$T_u(z) \rightarrow T_u\left(z \rightarrow \frac{1+p\frac{T_s}{4}}{1-p\frac{T_s}{4}}\right) = T_u'(p)$

[Also, in MATLAB $T_u'(p) = d2c(T_u(z), \text{'Tustin'})$]

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target $f_c = 250\text{ kHz}$

$f_c' = \frac{4}{T_s}\tan\left(2\pi f_c \frac{T_s}{4}\right) = 263.7\text{ kHz}$

Proportional

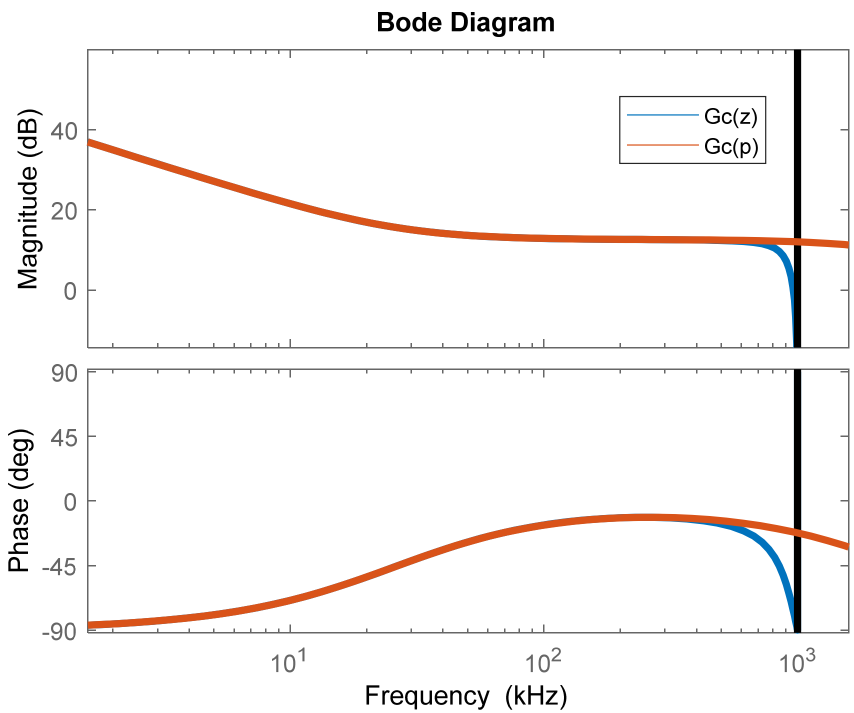
$k_p = \frac{1}{\|T_u'(\omega_c')\|} = \frac{1}{\|G_{vg}(\omega_c')\|}\,\frac{1}{H}\,\frac{V_{ps}}{2^{N_{hpr}}}\,\frac{N_r}{T_s}$

Integral term:

$\frac{k_i}{p} \rightarrow k_i = \frac{\omega_c' k_p}{10}$

$G_c(p) = \frac{k_p}{1+\frac{p}{\omega_{HF}}} + \frac{k_i}{p}$ ← Not actually necessary in digital control

Compensator Digital Implementation



$$G_c(p) = \frac{k_p}{1+\frac{p}{\omega_{HF}}} + \frac{k_i}{p}$$

$$G_c\left(p \to \frac{4}{T_s}\,\frac{1-z^{-1}}{1+z^{-1}}\right) =$$

$$= k_p \frac{1}{1+\frac{1}{\omega_{HF}}\frac{4}{T_s}\frac{1-z^{-1}}{1+z^{-1}}} + k_i \frac{T_s}{4}\,\frac{1+z^{-1}}{1-z^{-1}}$$

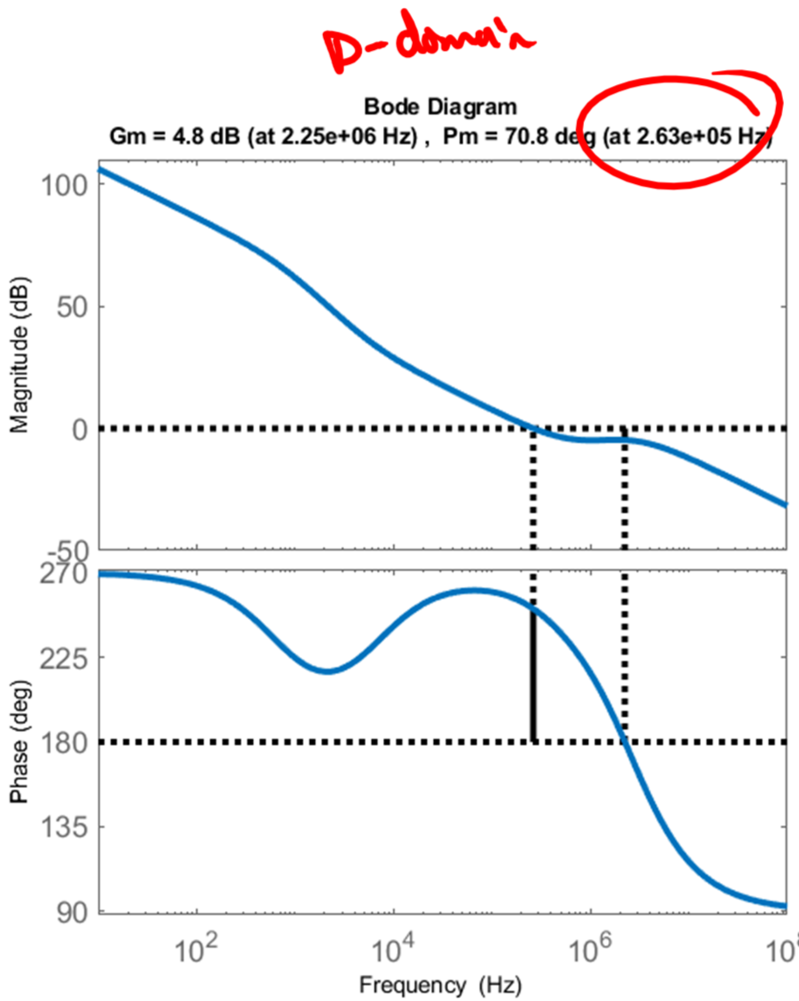
$$= k_p \frac{1+z^{-1}}{\left(1+\frac{4}{T_s\omega_{HF}}\right) + z^{-1}\left(1-\frac{4}{T_s\omega_{HF}}\right)} + \frac{k_i T_s}{4}\,\frac{1+z^{-1}}{1-z^{-1}}$$

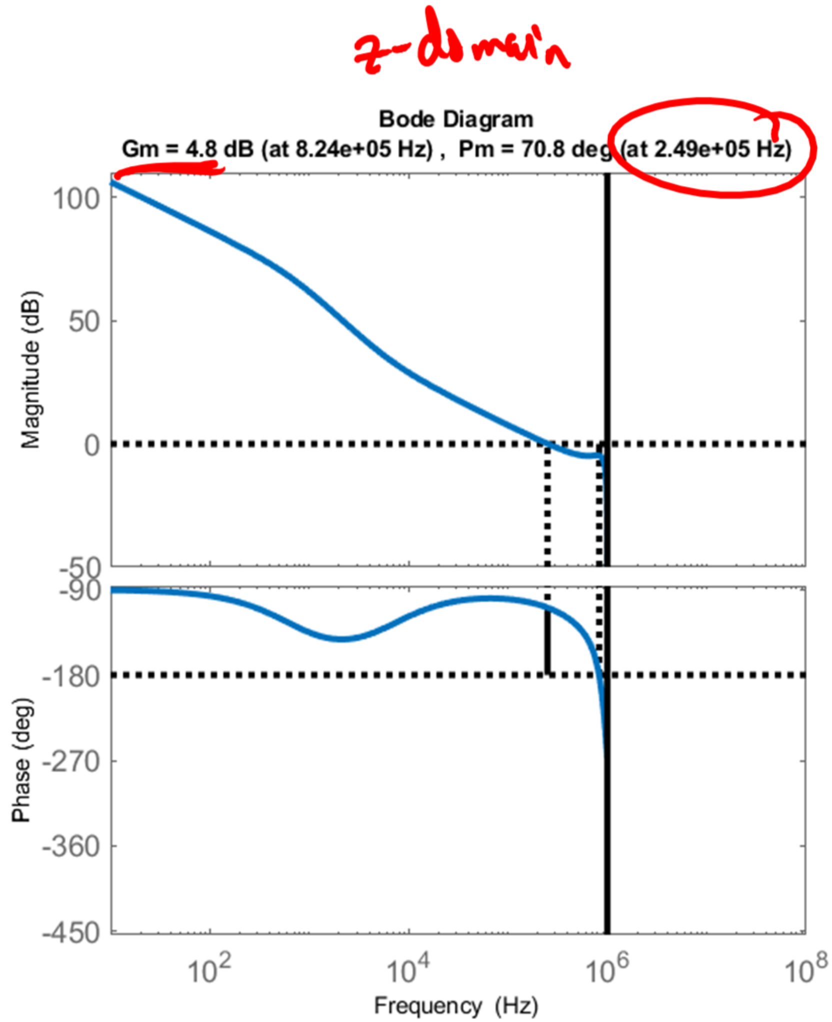
$$= \underbrace{\frac{k_p}{1+\frac{4}{T_s\omega_{HF}}}}_{k_{pz}}\;\frac{1+z^{-1}}{1+z^{-1}\frac{1-\frac{4}{T_s\omega_{HF}}}{1+\frac{4}{T_s\omega_{HF}}}} + \underbrace{\frac{k_i T_s}{4}}_{k_{iz}}\,\frac{1+z^{-1}}{1-z^{-1}}$$

Also:

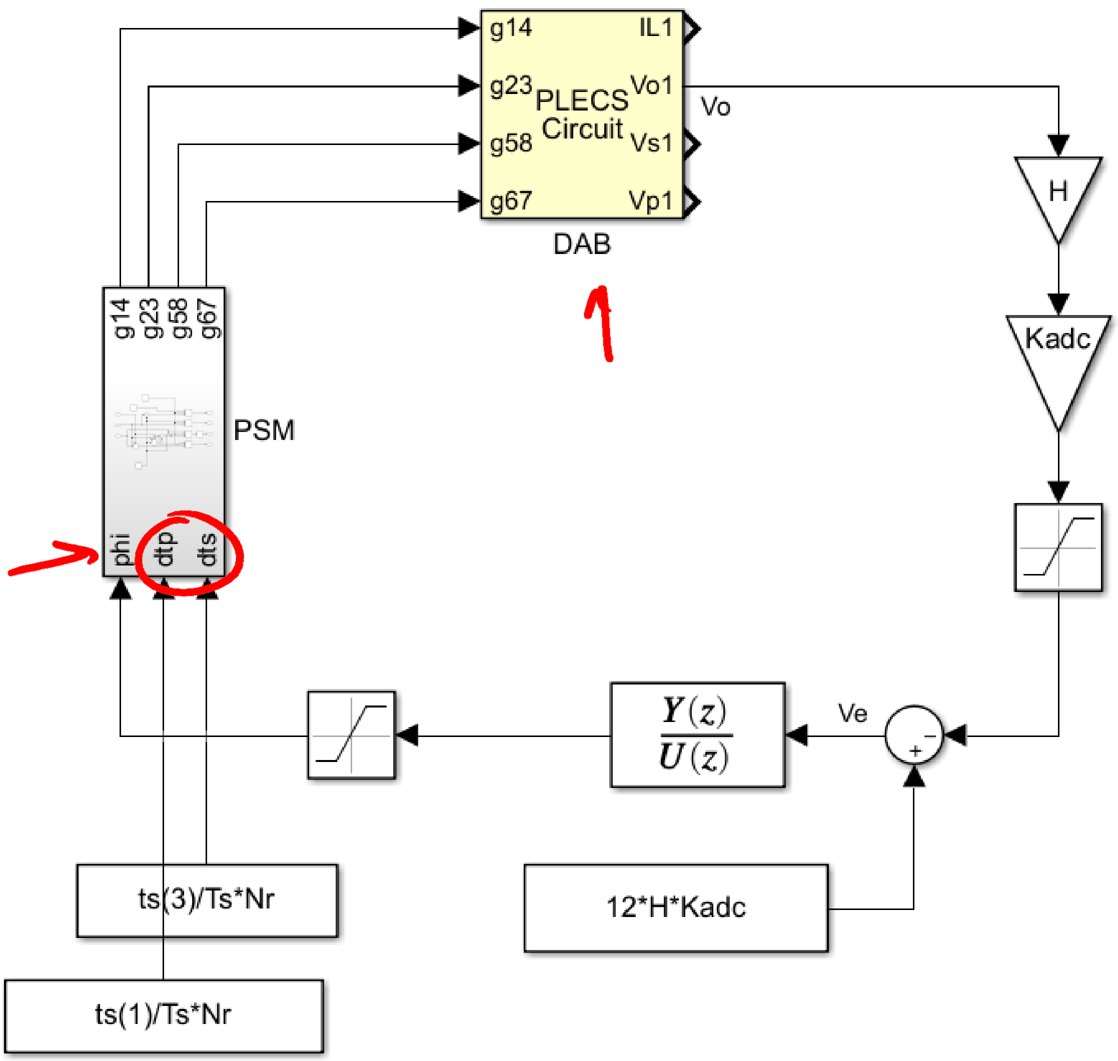
c2d(Gc(p), $\frac{Ts}{2}$, 'Tustin')

Compensated Loop Gain



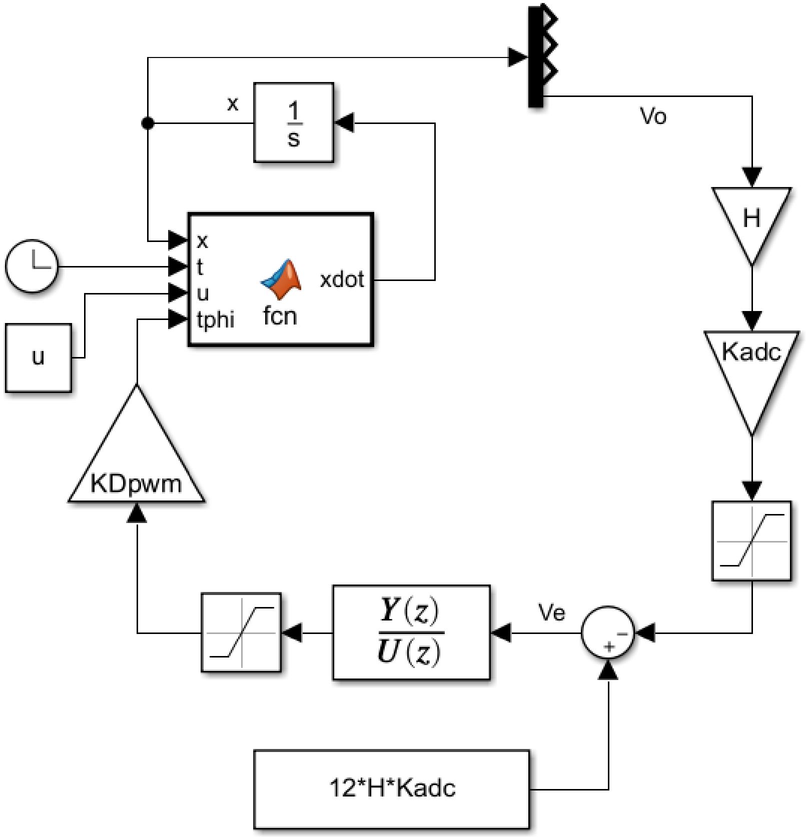


Simulation (Large Signal)



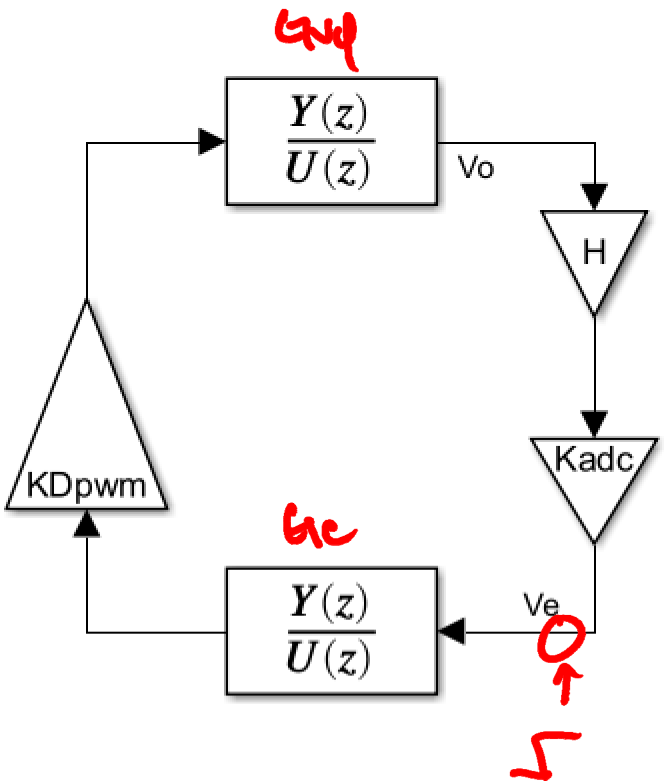
Alternative Simulation (Large Signal)

(L13– L15)

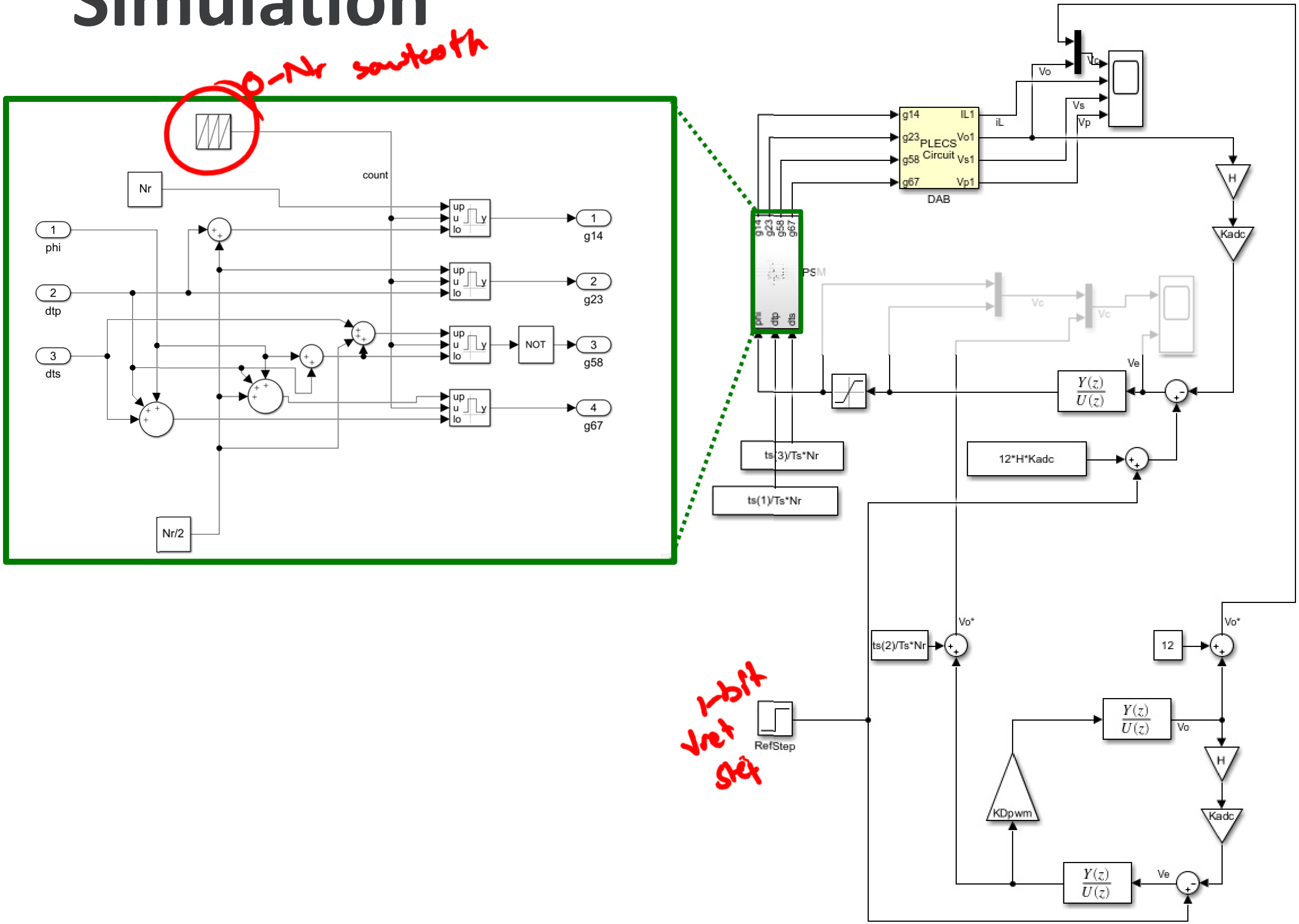



```
function xdot = fcn(x, t,
    u,tphi, A1, A2, B1, B2, Ts)

tp = mod(t,Ts);

if(tp<tphi)
    xdot = A1*x + B1*u;
else
    xdot = A2*x+B2*u;
end
```

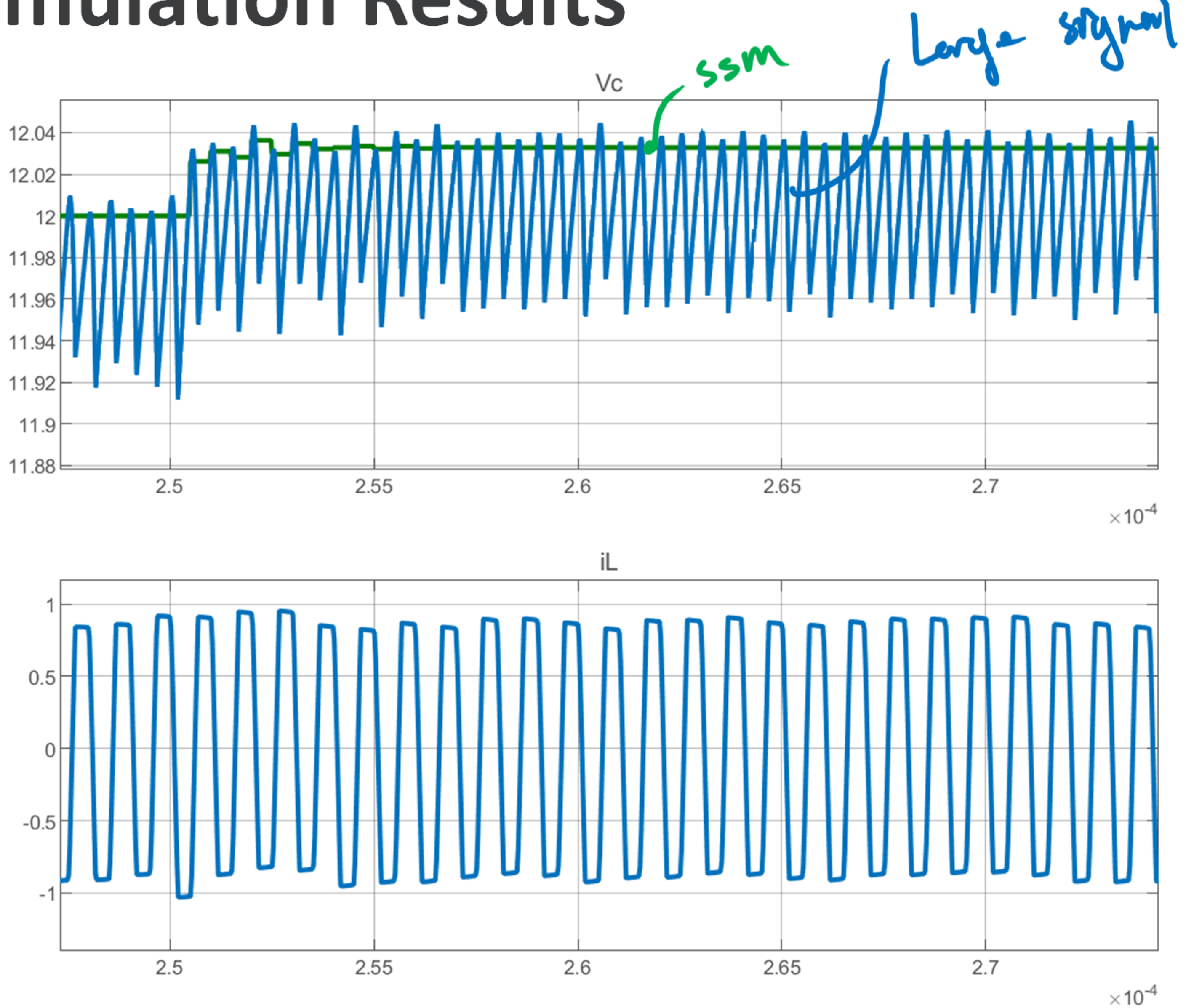
Simulation (Small Signal)



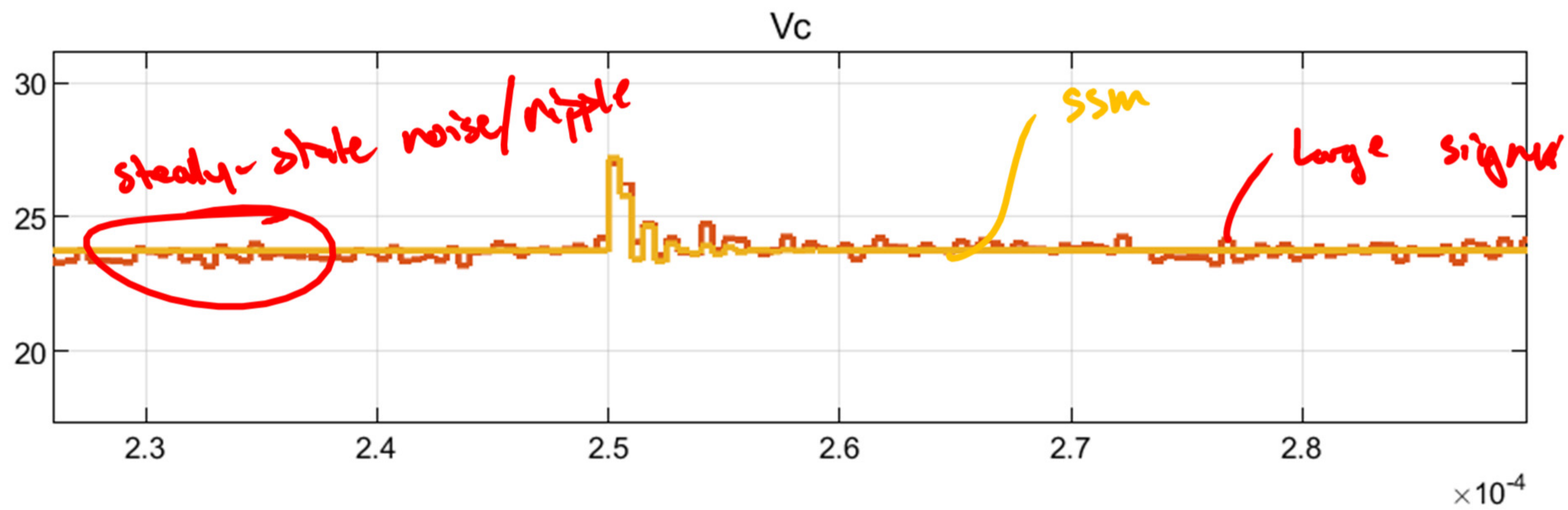
Simulation

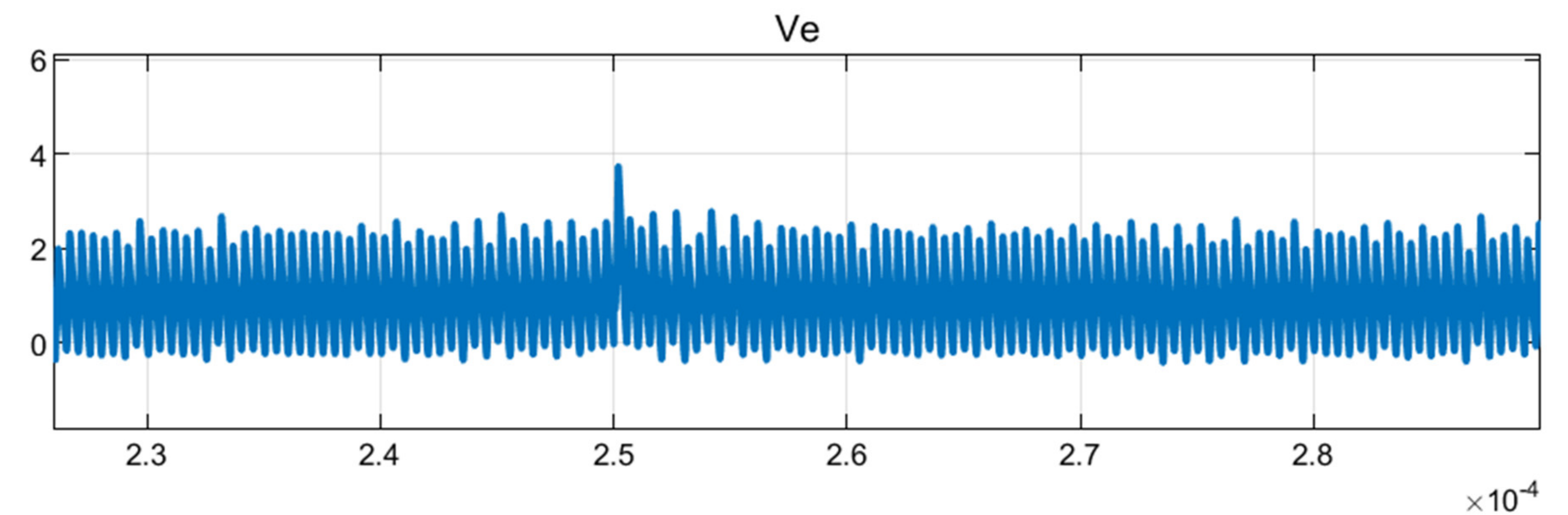

0-Nr sawtooth
count
Nr
phi
dtp
dts
up
u
lo
y
NOT
g14
g23
g58
g67
Nr/2
g14
g23
g58
g67
PLECS
Circuit
IL1
Vo1
Vs1
Vp1
DAB
iL
Vo
Vs
Vp
Vc
PSM
H
Kadc
Ve
Y(z)
U(z)
ts(3)/Ts*Nr
ts(1)/Ts*Nr
12*H*Kadc
Vo*
ts(2)/Ts*Nr
12
1-bit
Vref
step
RefStep
KDpwm

Simulation Results

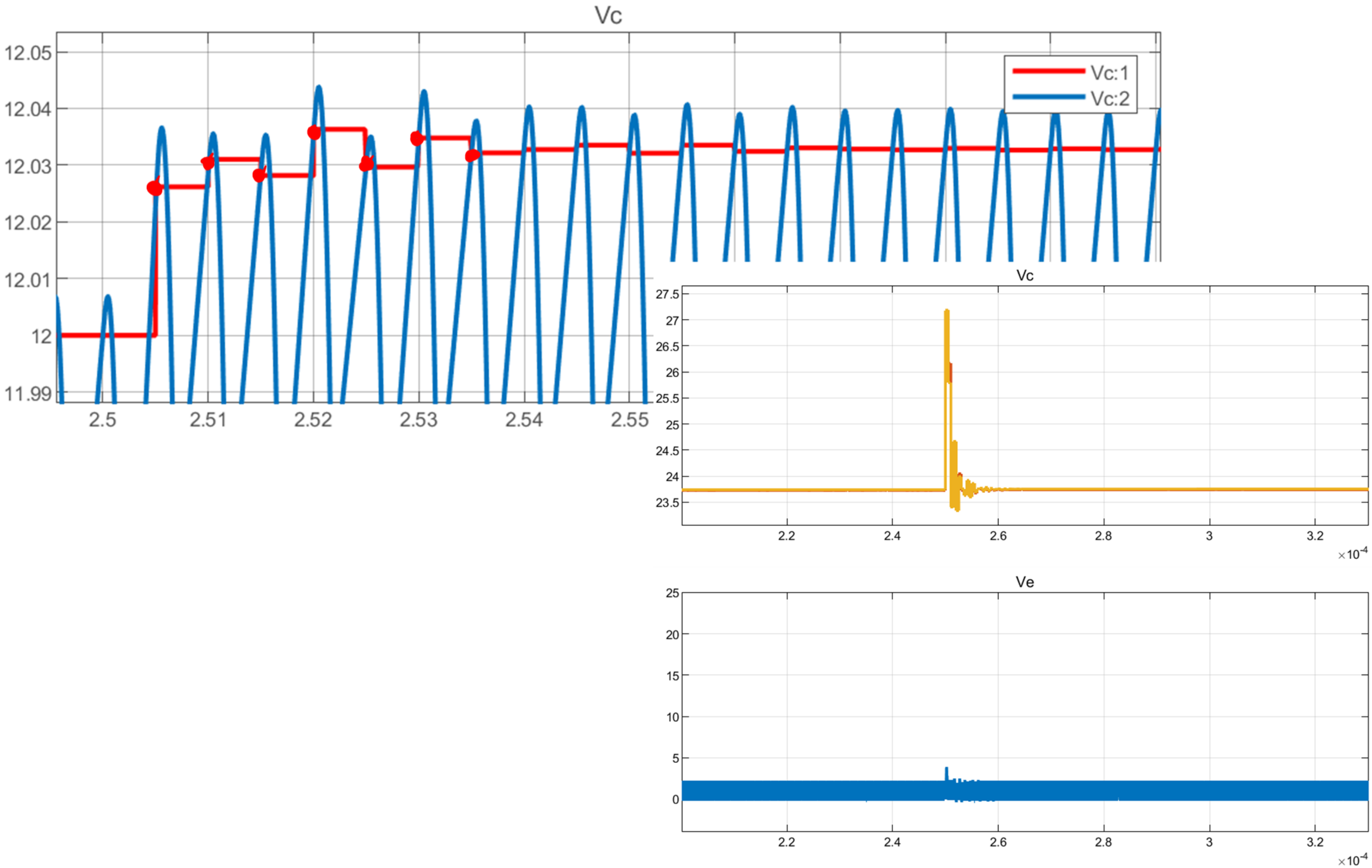


Simulation Results (cont)

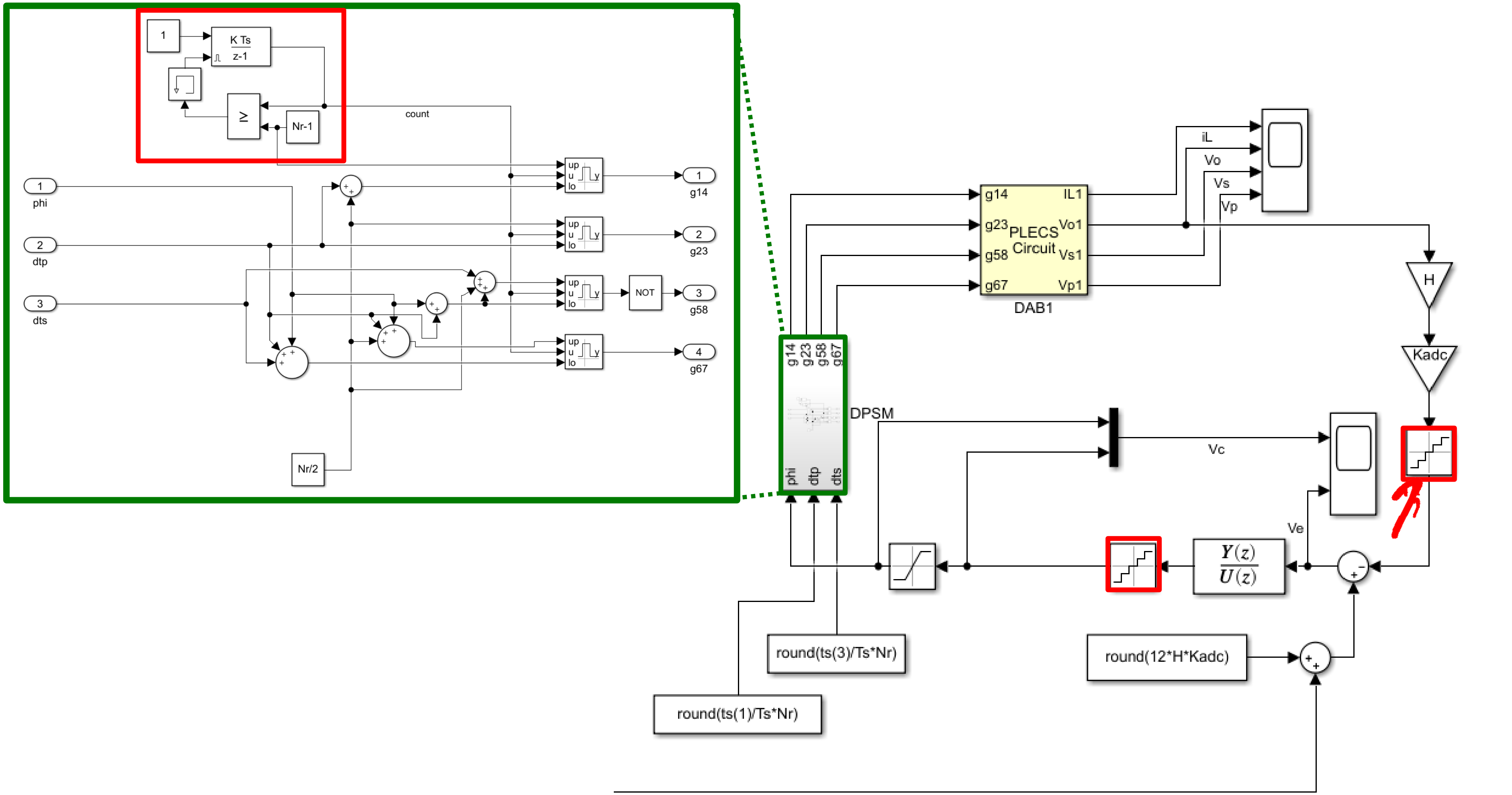




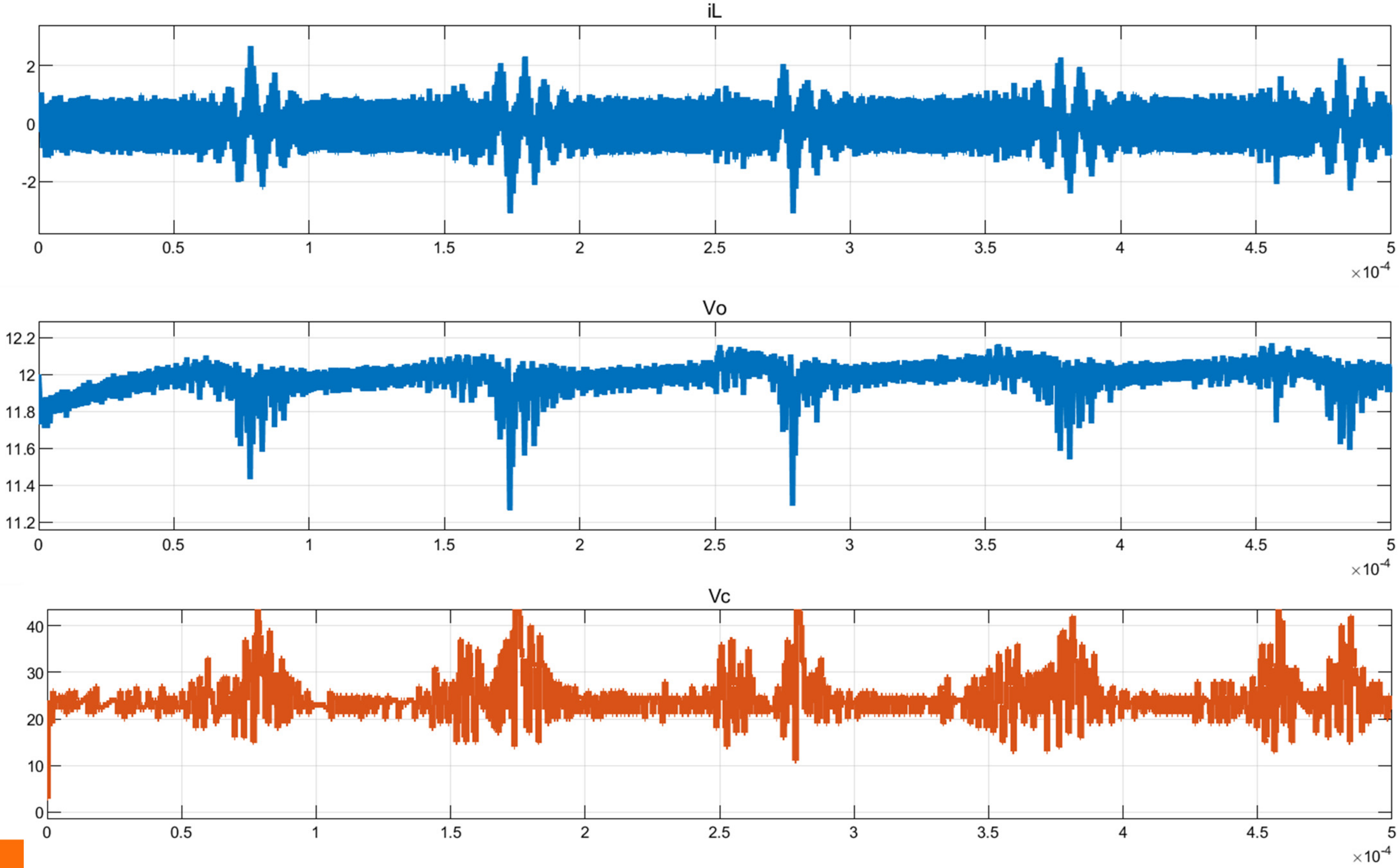
Simulation Results (max step 10ps)



Quantization



Simulation with Quantization



Quantization Impact

Limit cycling