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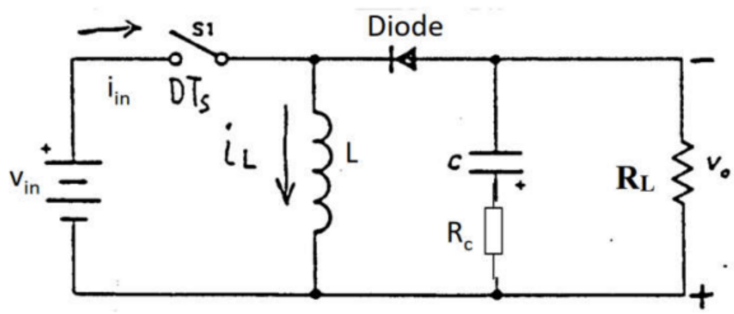
Submitted to: prof. Abdelmomen Mahgoub

Assignment 1

Average Model for Buck-Boost Converter

Buck-Boost converter to be analyzed (Consider Switch (S_1) & Diode are IDEAL):

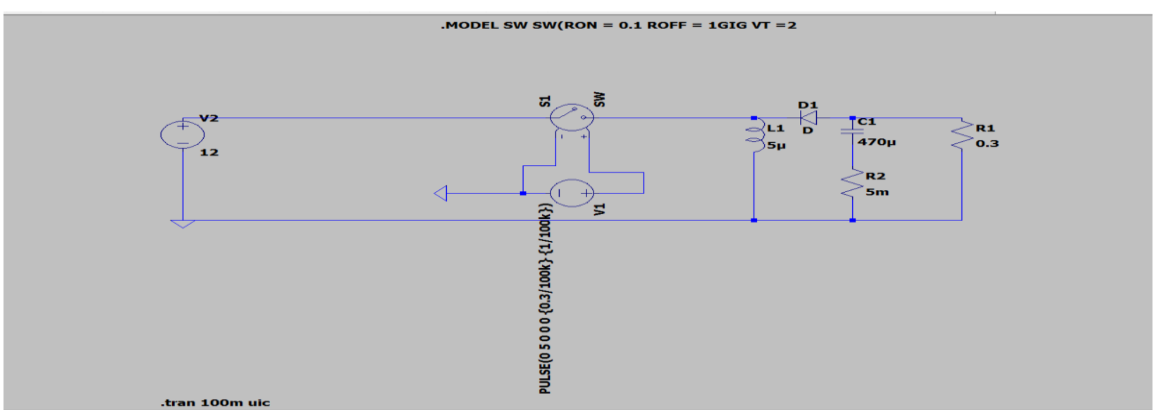


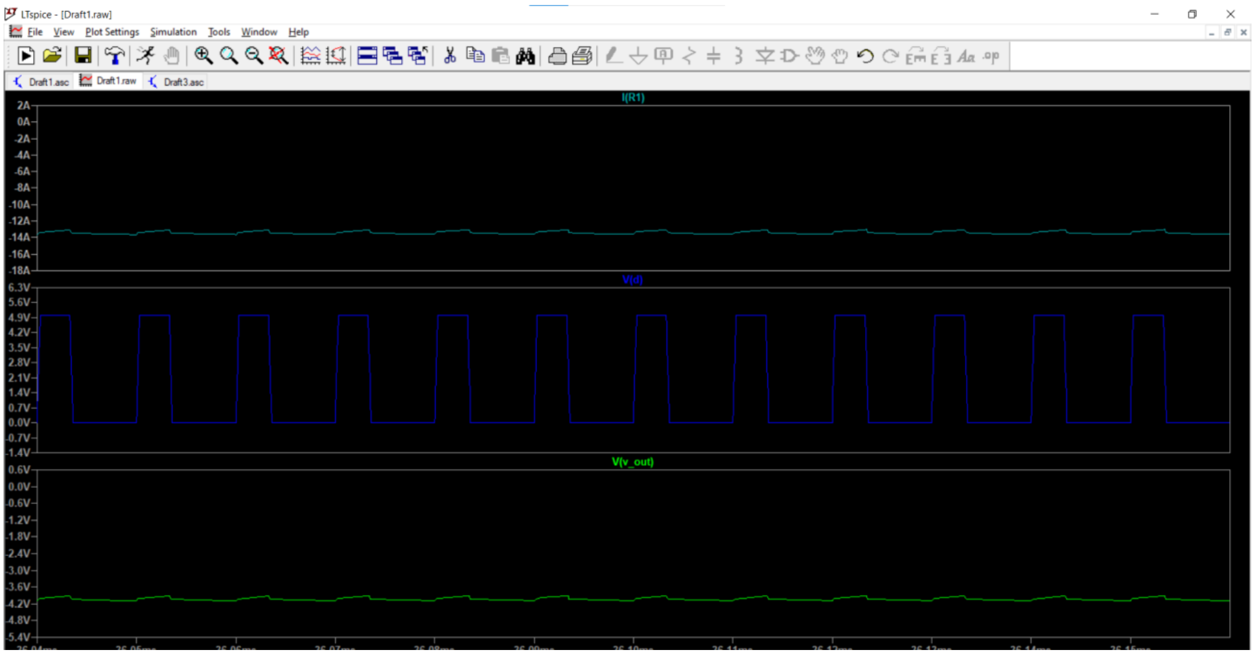
1) Derive the general expressions of (20%)$G_{vd}(s)=v_o(s)/d(s)$, and Output Impedance $Z_o(s)= v_o(s)/i_o(s)$ for the Buck-boost converter running at continuous current mode. Use the average model concept in chapter 01 class notes.

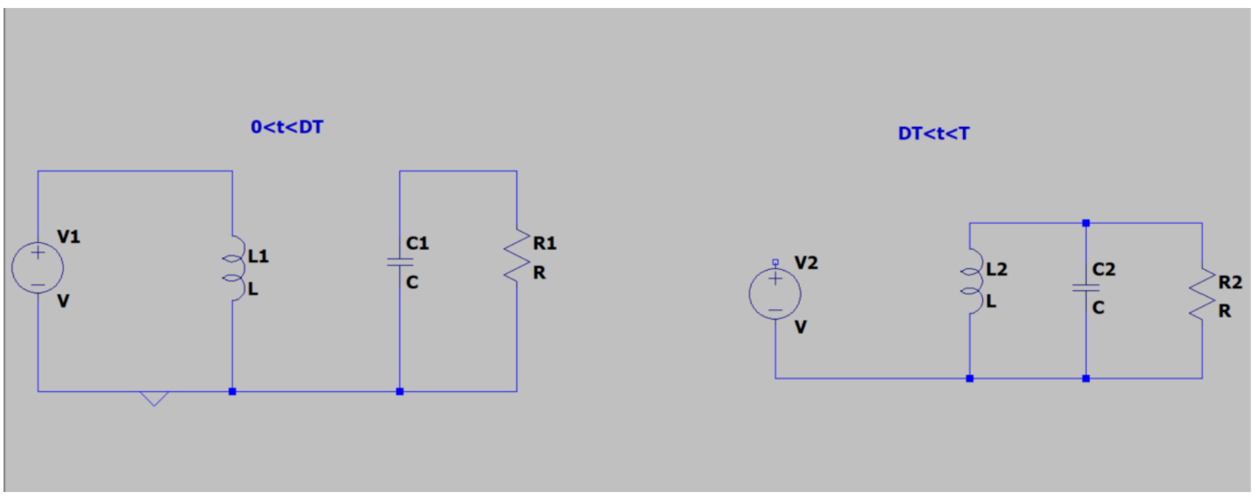
[Note:Get average equivalent circuit first, then small signal equivalent circuit, after that derive the transfer function equations from small signal equivalent circuit (Please show all necessary steps)
Do not use other methods from literature in this part]

Solution

1- Inverting Buck Boost converter DC model





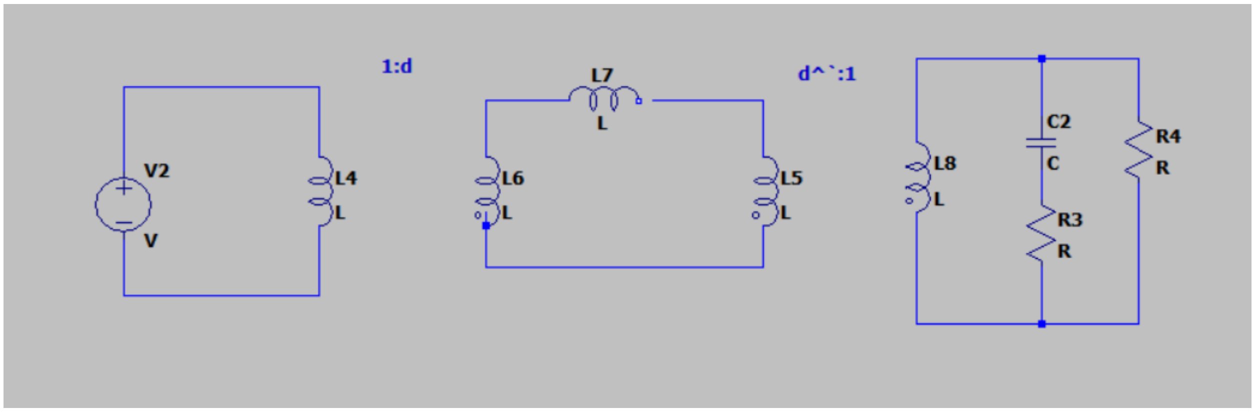


For steady state CCM:

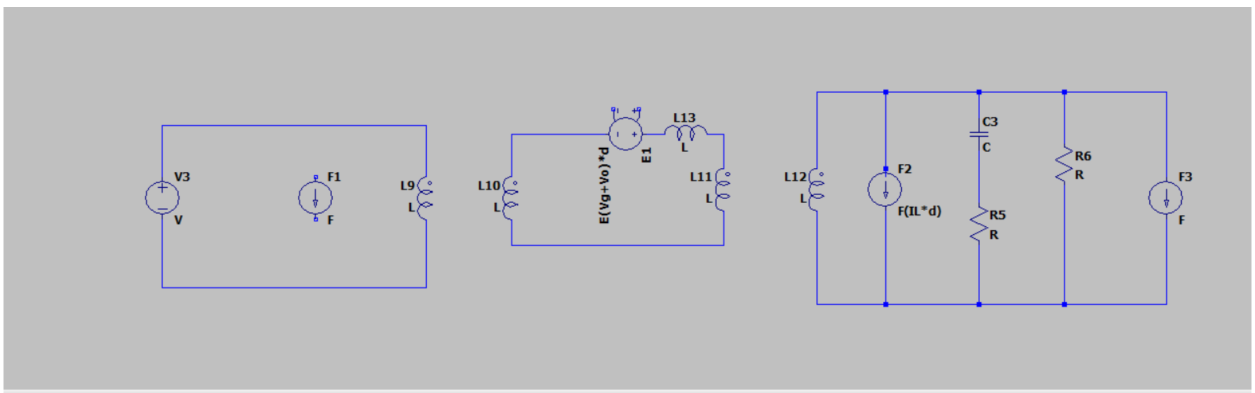
$$\Delta i \; = \; 0 = \frac{V_i}{L} DT + -\frac{V_o}{L}(1-D)T$$

$$V_i = < V_o > \frac{1-D}{D}$$

DC Model



Add AC model.



Perturb the signals

$$V_i = V_i + v_i^{`}$$

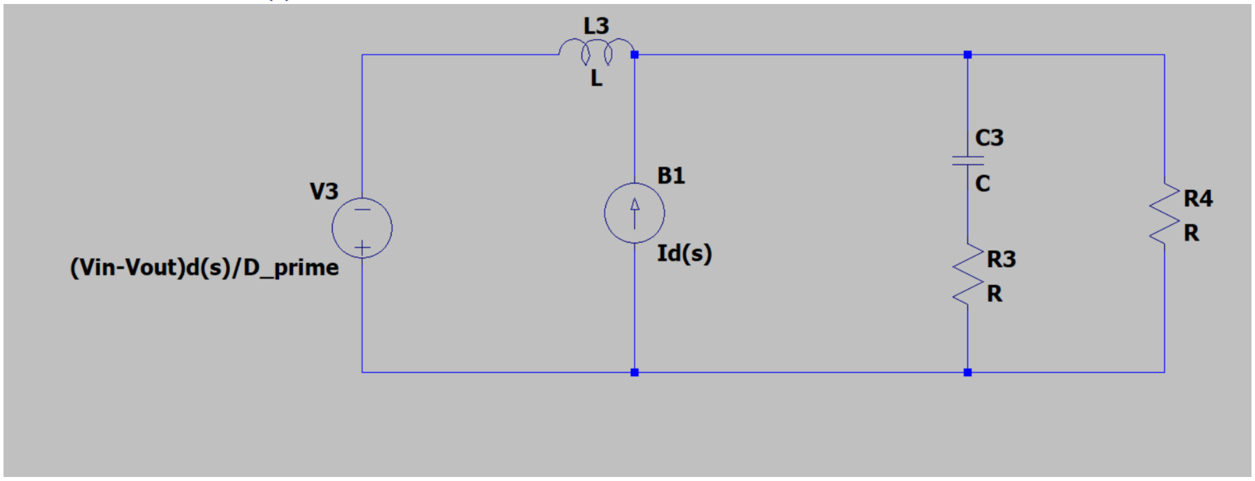
$$I_i = I_i + i_i^{`}$$

$$V_o = V_o + v_o^{`}$$

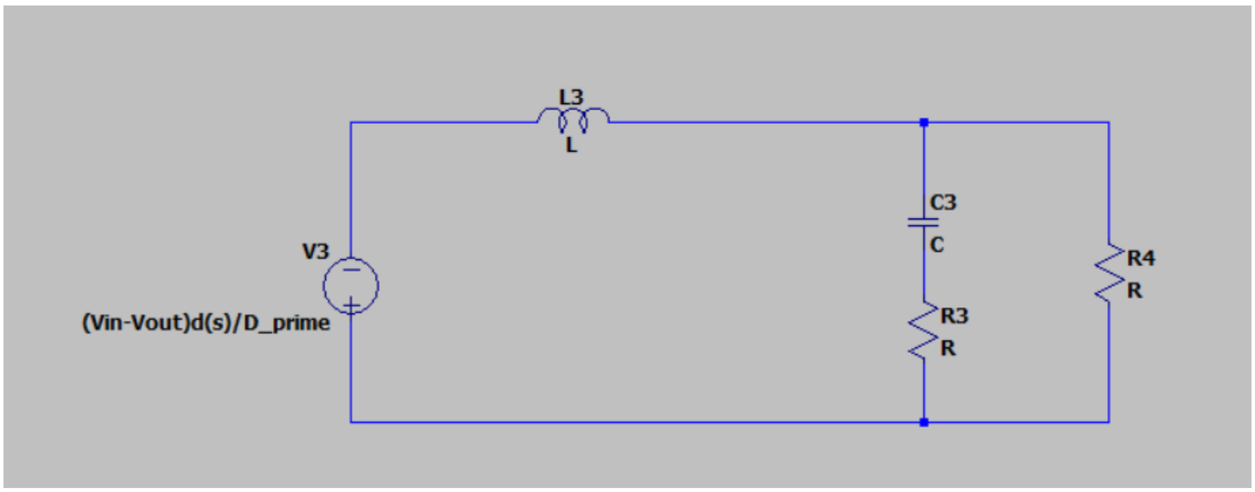
$$I_L = I_L + i_l^{`}$$

$$D = D + d^{`}$$

1- $G_{vd}(s) = \frac{V_o(s)}{d(s)} \mid V_g = 0, i_o{}^{\wedge} \ = 0$



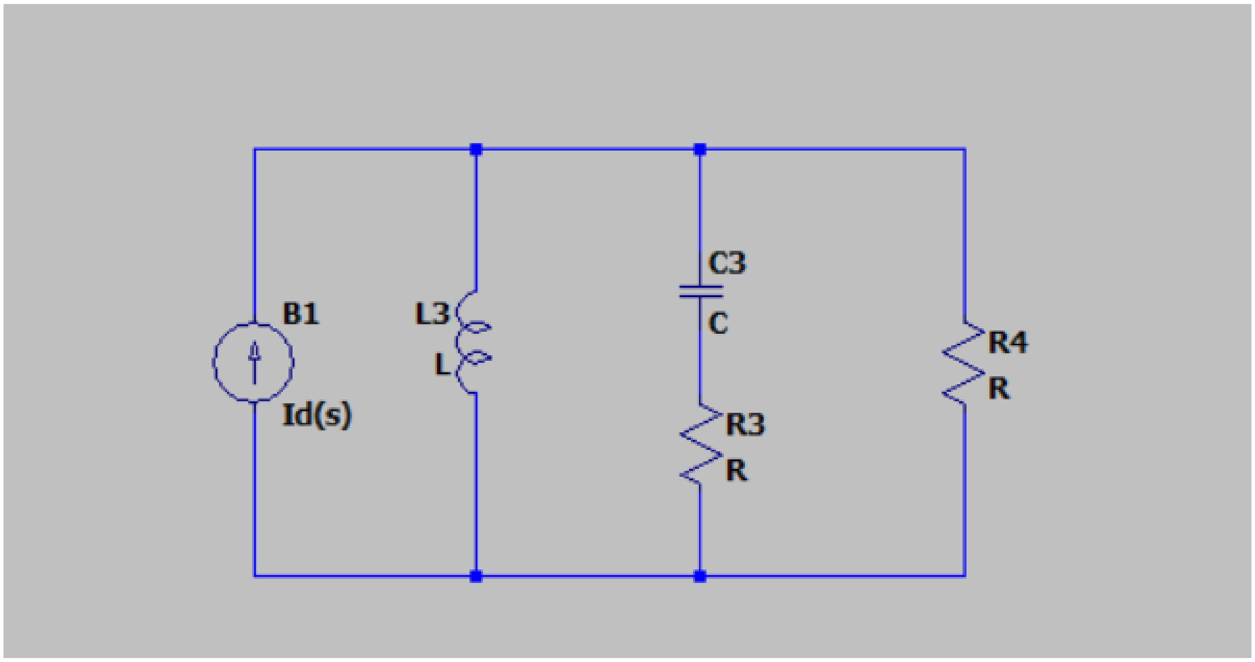
a- With voltage source superposition



$$\frac{V_o}{\hat{d}} = \frac{-V_g - V_o}{D^{`}} \frac{R \,||\left(r_c + \frac{1}{sC}\right)}{\frac{sL}{(D^{`})\text{^}2} + R \,||\left(r_c + \frac{1}{sC}\right)}$$

$$\frac{V_o}{\hat{d}} = \frac{-V_g - V_o}{D^{`}} \frac{\frac{R(1+sr_C C)}{1+sC(R+rc)}}{\frac{1+sC(R+rc)}{1+sC(R+rc)} + \frac{sL}{(D^{`})\text{^}2}} \qquad (1)$$

2- With the current source only



$$\frac{V_o}{\hat{d}} = I_L\ (\frac{sL}{(D`)^2}\ ||\ R\ ||\left(r_c + \frac{1}{sC}\right))$$

$$\frac{V_o}{\hat{d}} = I_L \frac{\frac{Ls}{(D`)^2}\frac{R(1+sr_cC)}{1+sC(R+r_c)}}{\frac{R(1+sr_cC)}{1+sC(R+r_c)} + \frac{Ls}{(D`)^2}} \qquad (2)$$

By summing the two equations (1) & (2)

$$G_{vd} = -\frac{(V_g + V_o)\left(\frac{I_L\, L\, s}{(V_g + V_o)(D-1)} + 1\right)(C\, r_c\, s + 1)}{(D-1)\left(\frac{s(C R r_c D^2 - 2 C R r_c D + L + C R r_c)}{R(D-1)^2} + \frac{C L s^2 (R + r_c)}{R(D-1)^2} + 1\right)}$$

The standard form

$$G(s) = G_o \frac{\left(1 + \frac{s}{\omega_{z1}}\right)\left(1 + \frac{s}{\omega_{z2}}\right)}{1 + \frac{s}{Q\omega_o} + \frac{s^2}{\omega_o^2}}$$

$G_{vdo} = -\frac{Vg+Vo}{D-1}$ where $V_g + V_o = \frac{V_o}{D}$

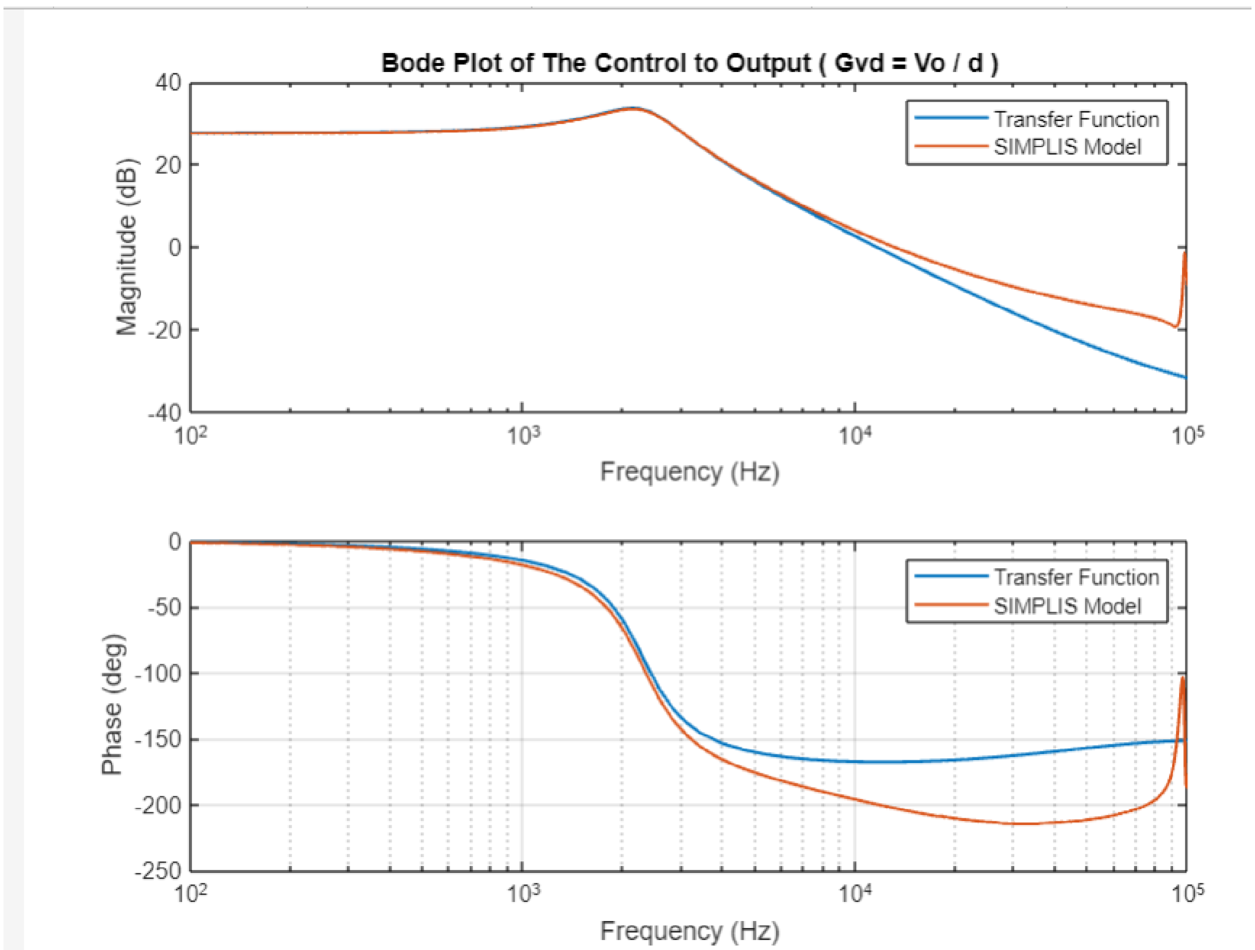
$$W_o = \sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}$$

$$W_z = \frac{(V_o + V_g)(D-1)}{I_l L}$$

$$W_{Esr} = \frac{1}{Cr_c} \quad \text{where } I_L = \frac{I_o}{R} = \frac{V_o}{RD}$$

$$Q = \frac{R(D-1)^2}{(CRr_cD^2 - 2CRr_cD + L + CRr_c)\sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}}$$

$$G_{vd} = -24.0833\frac{(2.3500e-06s+1)(8.5103e-07s-1)}{4.7949e-09s^2 + 3.5799e-05s + 1}$$



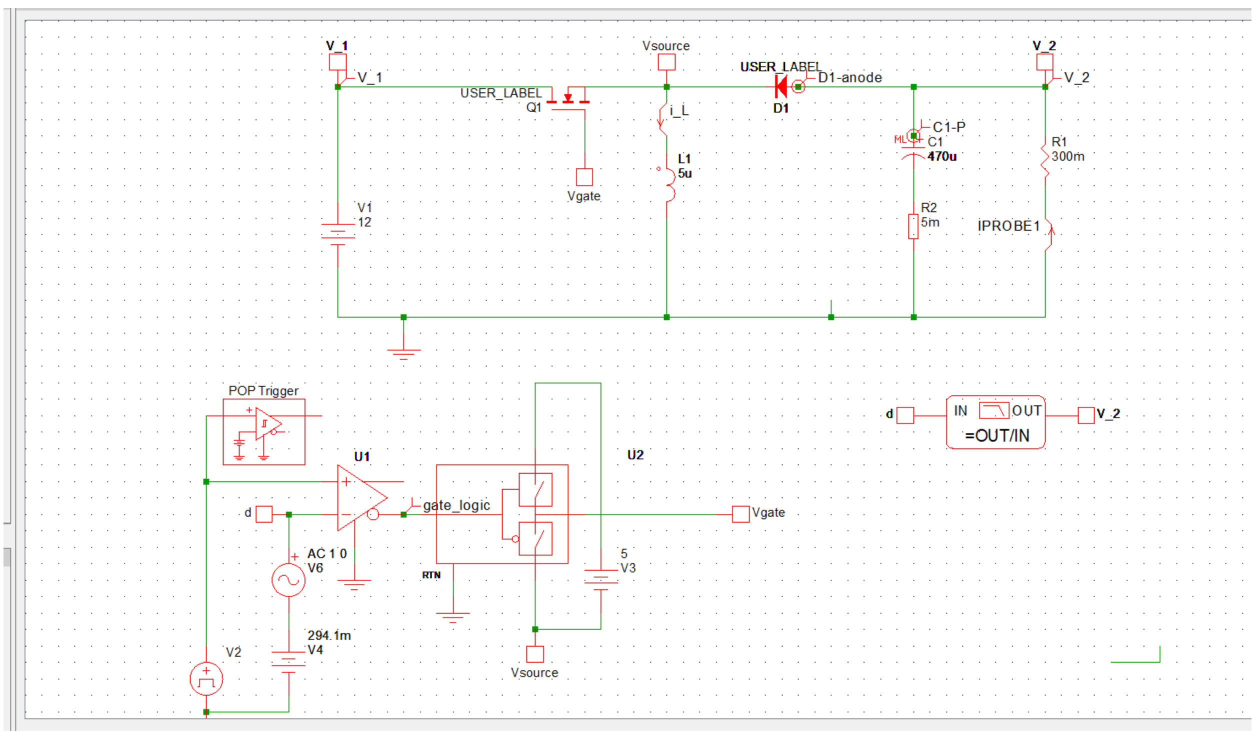
```
W0 =

   1.4441e+04


Wz =

  -1.1750e+06
```

```
Wesr =

   4.2553e+05


Q =

    1.9343
```

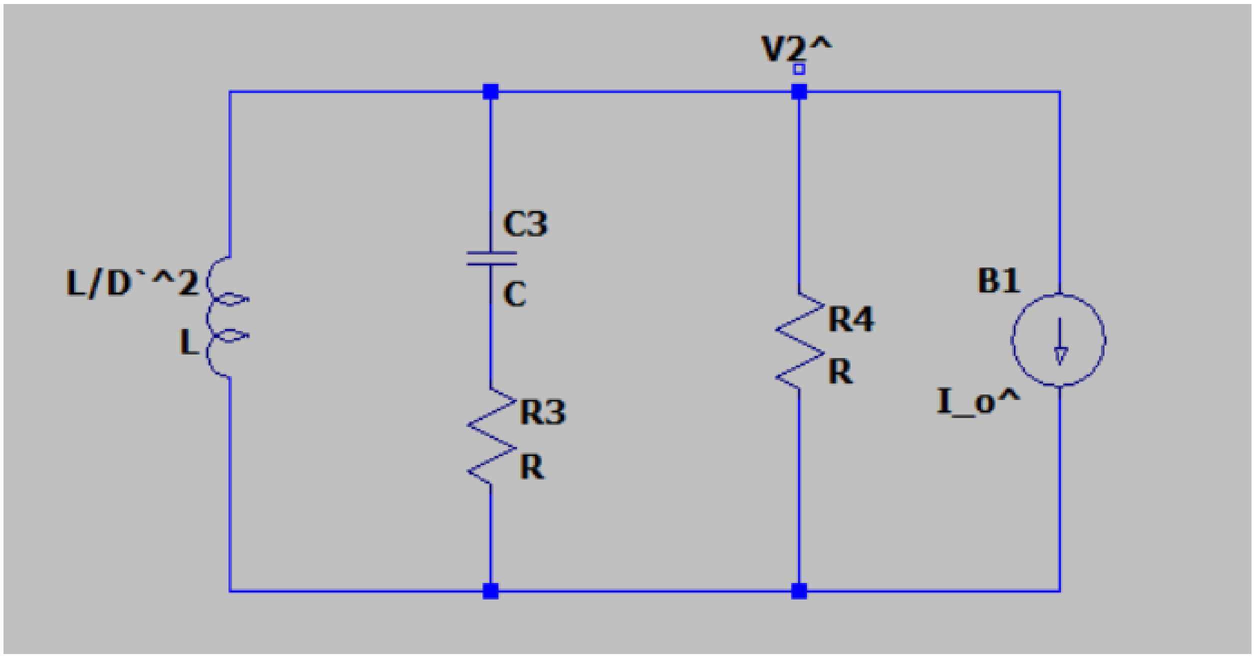
```
G_vdo = (V_g + V_o)/(D-1)
temp_1 = (IL *L*s)/((V_g+V_o)*(D-1));
G_vd_num = (temp_1 + 1) * (C*s*rc +1);
temp_2 = ((C*R*rc*D^2 - 2*C*R*rc*D*+L+C*R*rc)*s)/(R*(D-1)^2);
temp3 = (C*L*s^2*(R+rc))/(R*(D-1)^2);
G_vd_dnum = temp3 + temp_2 +1;
G_vd = -G_vdo*(G_vd_num/G_vd_dnum);
G_vd = G_vdo * ((1+s/Wesr) *(1+s/Wz)) / (1+s/(W0*Q) + (s/W0)^2)
w ={100*2*pi,10^5*2*pi};
[mag,phase,wout]= bode(G_vd,w);
mag_vd=squeeze (mag(1,1,:));
ph_vd=squeeze(phase(1,1,:));
f_vd=wout/(2*pi);
figure(1);
subplot(2,1,1)
semilogx(f_vd,20*log10(mag_vd),freq,Gain,'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( Gvd = Vo / d )');
legend('Transfer Function','SIMPLIS Model');
hold on
```

```

BB_data = xlsread('buckboostconverterG_vd.xlsx');

freq = BB_data(:,1);
Gain = BB_data(:,2);
Phase = BB_data(:,3);
s=tf('s');

V_g = 12;
V_o = 5;
f_sw = 100e3;
C = 470e-6;
L = 5e-6;
rc = 5e-3;
R = 0.3;%r(i);
D = 1/(V_g/V_o+1);
I_2 = V_o/R;
I_1 = D/(1-D)*I_2;
IL = D*I_1;
W0 = sqrt(R*(D - 1)^2 / (C*L*(R + rc)));
Wz = (V_o + V_g)*(D - 1)/(IL*L);
Wesr = 1/(rc*C);
Q = R*(D - 1)^2 / ((C*R*rc*D^2 - 2*C*R*rc*D + L + C*R*rc) * sqrt(R*(D - 1)^2 / (C*L*(R + rc))));

```

```
figure(1);
subplot(2,1,1)
semilogx(f_vd,20*log10(mag_vd),freq,Gain,'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( Gvd = Vo / d )');
legend('Transfer Function','SIMPLIS Model');
hold on
subplot(2,1,2)
semilogx(f_vd,ph_vd,freq,Phase,'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Phase (deg)');
legend('Transfer Function','SIMPLIS Model');
grid on;
hold on
```



3- For $Z_o = \frac{V_o}{i_o} \Big|_{V_g=0,d=0}$



$$using\ nodel\ analysis$$

$$\frac{\tilde{V_2}}{\frac{Ls}{D^{`2}}} + \frac{\tilde{V_2}}{\frac{1}{Cs}+r_c} + \tilde{i_o} = 0$$

$$Z_o = -\frac{Ls(Cr_cs+1)}{(D-1)^2\left(\frac{s(CRr_cD^2-2CRr_cD+L+CR_Lr_c)}{R(D-1)^2}+\frac{CLs^2(R+r_c)}{R(D-1)^2}+1\right)}$$

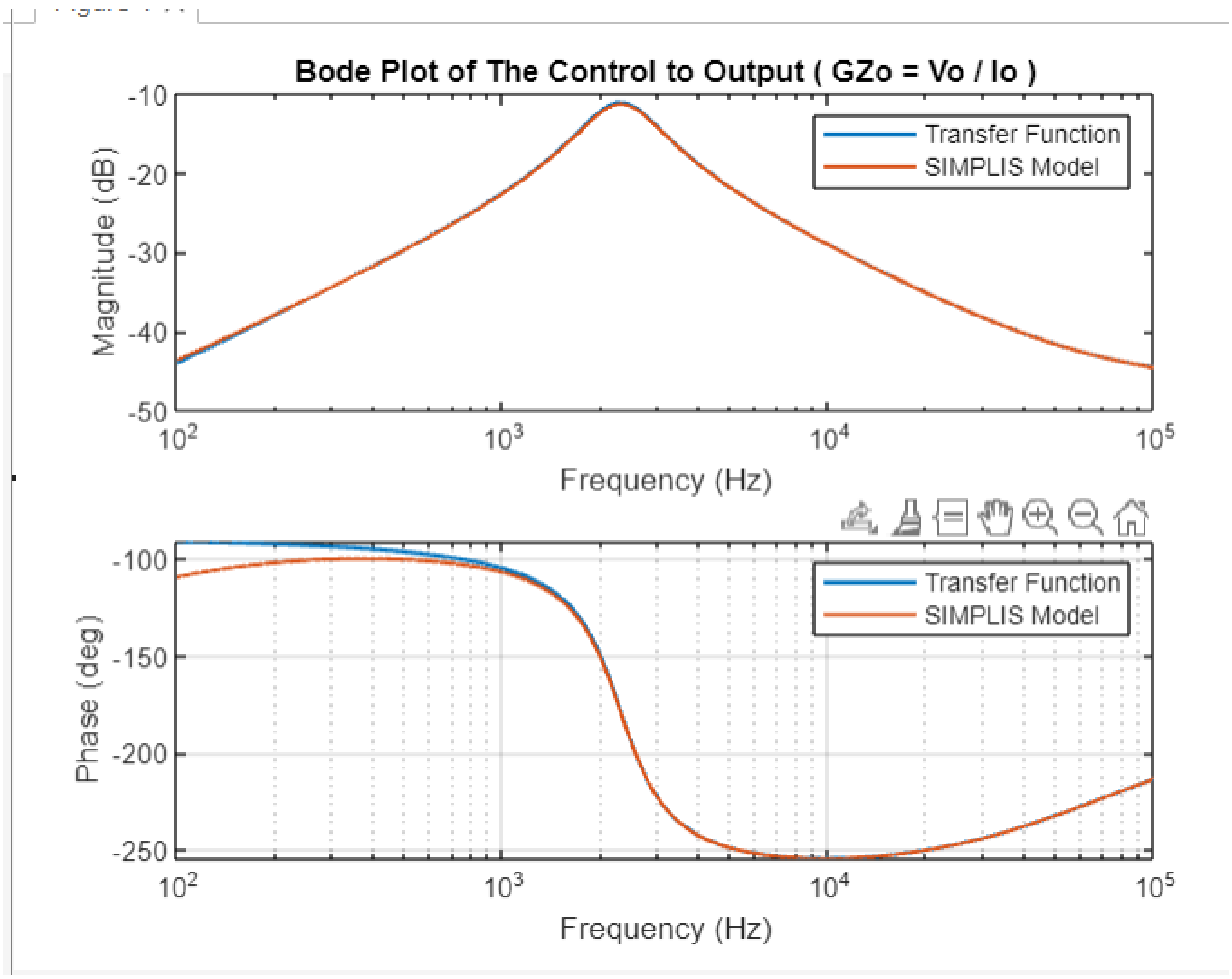
$$Q = \frac{R(D-1)^2}{(CRr_cD^2-2CRr_cD+L+CRr_c)\sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}}$$

$$W_o = \sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}$$

$$G_{zo} = -\frac{L}{(D-1)^2}$$

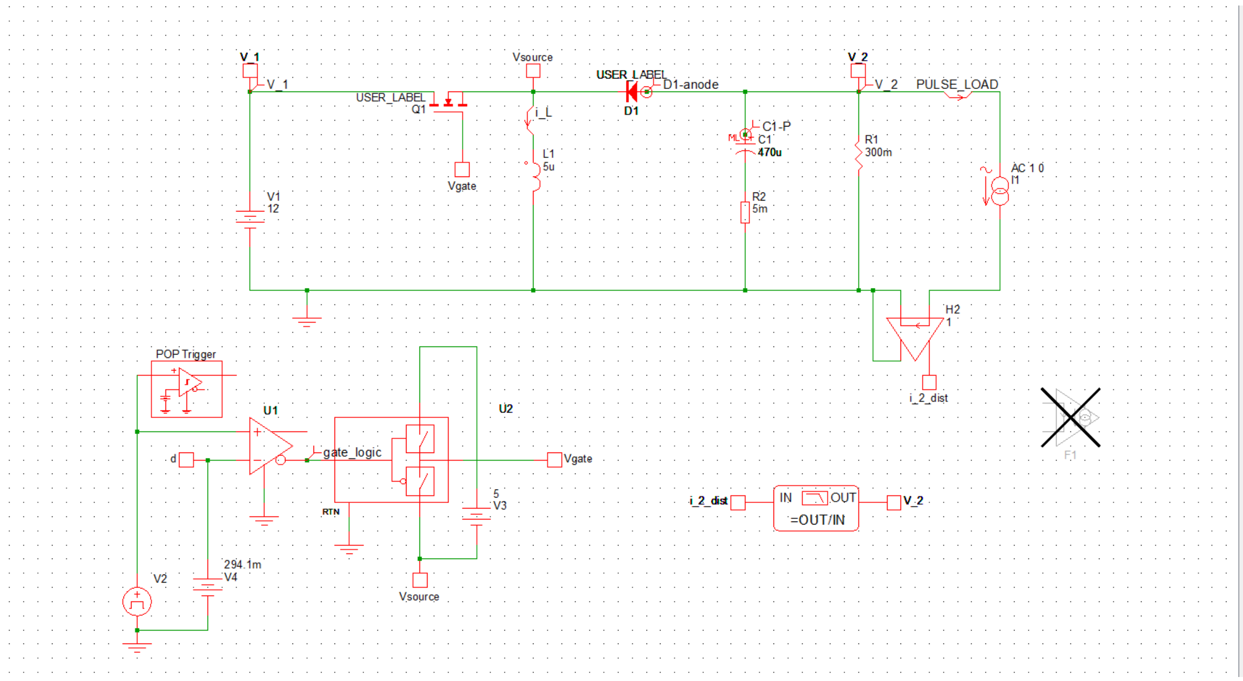
$$W_{ESR} = \frac{1}{Cr_c}$$

$$Z_O = \frac{-1.0035e-05s(2.3500e-06s+1)}{4.7949e-09\,s^2 + 3.5799e-05\,s + 1}$$

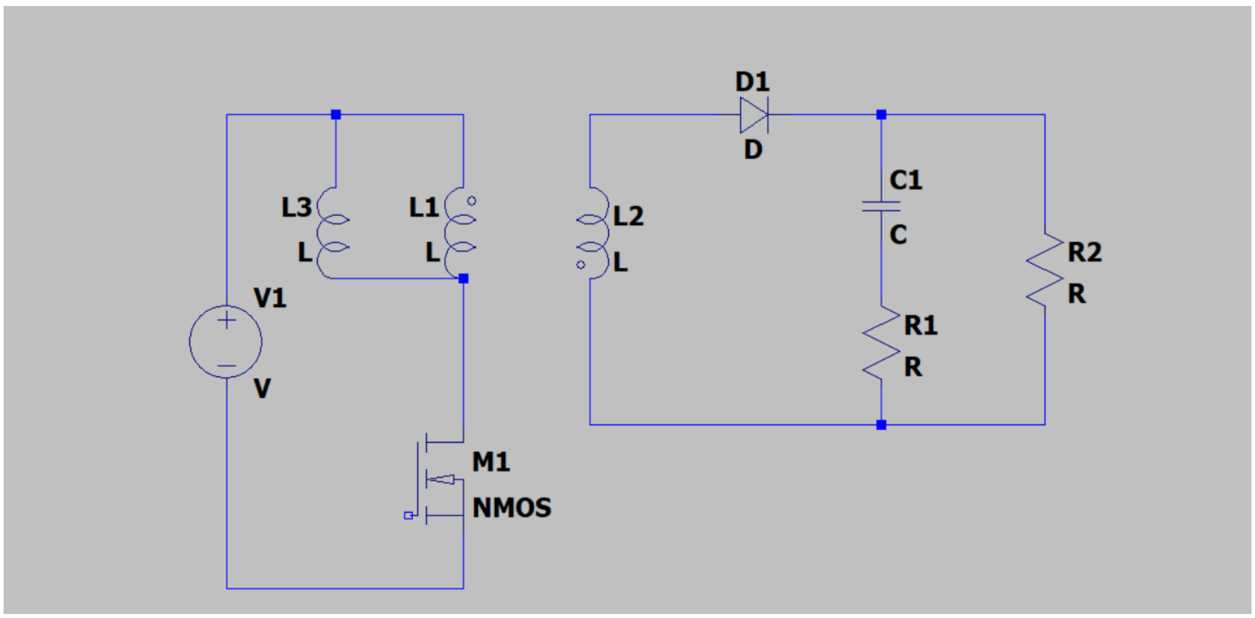



```
BB_data = xlsread('buckboostconverterZ_out.xlsx');

freq_zo = BB_data(:,1);
Gain_zo = BB_data(:,2);
Phase_zo = BB_data(:,3);
s=tf('s');
V_g = 12;
V_o = 5;
f_sw = 100e3;
C = 470e-6;
L = 5e-6;
rc = 5e-3;
R = 0.3;
D = 1/(V_g/V_o+1);
I_2 = V_o/R;
I_1 = D/(1-D)*I_2;
IL = D*I_1;
W0 = sqrt(R*(D - 1)^2 / (C*L*(R + rc)));
Wesr = 1/(rc*C);
Q = R*(D - 1)^2 / ((C*R*rc*D^2 - 2*C*R*rc*D + L + C*R*rc) * sqrt(R*(D - 1)^2 / (C*L*(R + rc))));
```

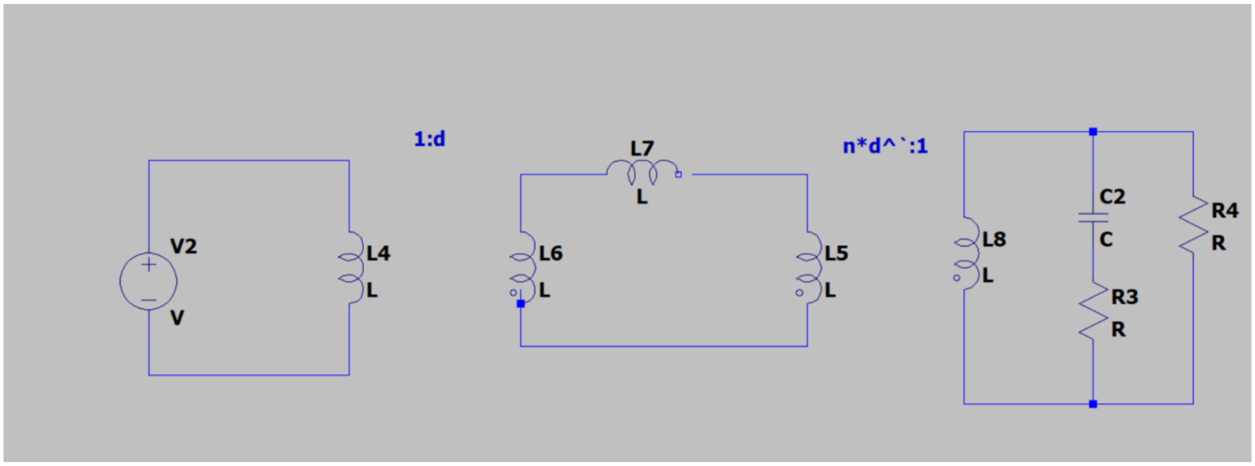
```
G_Z_Oo = -L/(D-1)^2;
% temp_1 = (IL *L*s)/((V_g+V_o)*(D-1));
G_Z_O_num = (C*rc*s+1);
temp_2 = ((C*R*rc*D^2 - 2*C*R*rc*D*+L+C*R*rc)*s)/(R*(D-1)^2);
temp3 = (C*L*s^2*(R+rc))/(R*(D-1)^2);
G_Z_O_dnum = temp3 + temp_2 +1;
% G_Z_O = s*G_Z_Oo*(G_Z_O_num/G_Z_O_dnum);
G_Z_O = s*G_Z_Oo*(1+(s/Wesr))/(1+(s/(W0*Q))+((s/W0)^2))
w ={100*2*pi,10^5*2*pi};
[mag,phase,wout]= bode(G_Z_O,w);
mag_zo=squeeze (mag(1,1,:));
ph_zo=squeeze(phase(1,1,:));
f_zo=wout/(2*pi);
figure(1);
subplot(2,1,1)
semilogx(f_zo,20*log10(mag_zo),freq_zo,Gain_zo,'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( GZo = Vo / Io )');
legend('Transfer Function','SIMPLIS Model');

subplot(2,1,2)
semilogx(f_zo,ph_zo-360,freq_zo,Phase_zo,'LineWidth',1.2);
xlabel('Frequency (Hz)');
```



Flyback converter



DC model



CCM

$$V_l = V_1$$

$$I_c = -\frac{v_2}{R}$$

Interval 2

$$\frac{V_L}{n} = -V_2$$

$$I_c = nI_L - i_2$$

For inductor voltage balance

$$v_2 = \frac{v_1 D}{D^{\sim}}$$

For capacitor balance

$$i_o = \frac{i_{in} D^{`}}{D}$$

Duty cycle perturbation

$$G_{vd} = -\frac{\left(\frac{I_L L s}{(D-1)(V_1+V_2)} + 1\right)(V_1+V_2)(Cr_c s + 1)}{n(D-1)\left(\frac{s(CRr_c D^2 - 2CRr_c D + CRr_c n^2 + L)}{Rn^2(D-1)^2} + \frac{CLs^2(R+r_c)}{Rn^2(D-1)^2} + 1\right)}$$

$$W_o = \sqrt{\frac{Rn^2(D-1)^2}{CL(R+r_c)}}$$

$$Q = \frac{Rn^2(D-1)^2}{(CR_L r_c D^2 n^2 - 2CR_L r_c D n^2 + L + CR_L r_c n^2)\sqrt{\frac{Rn^2(D-1)^2}{CL(R+r_c)}}}$$

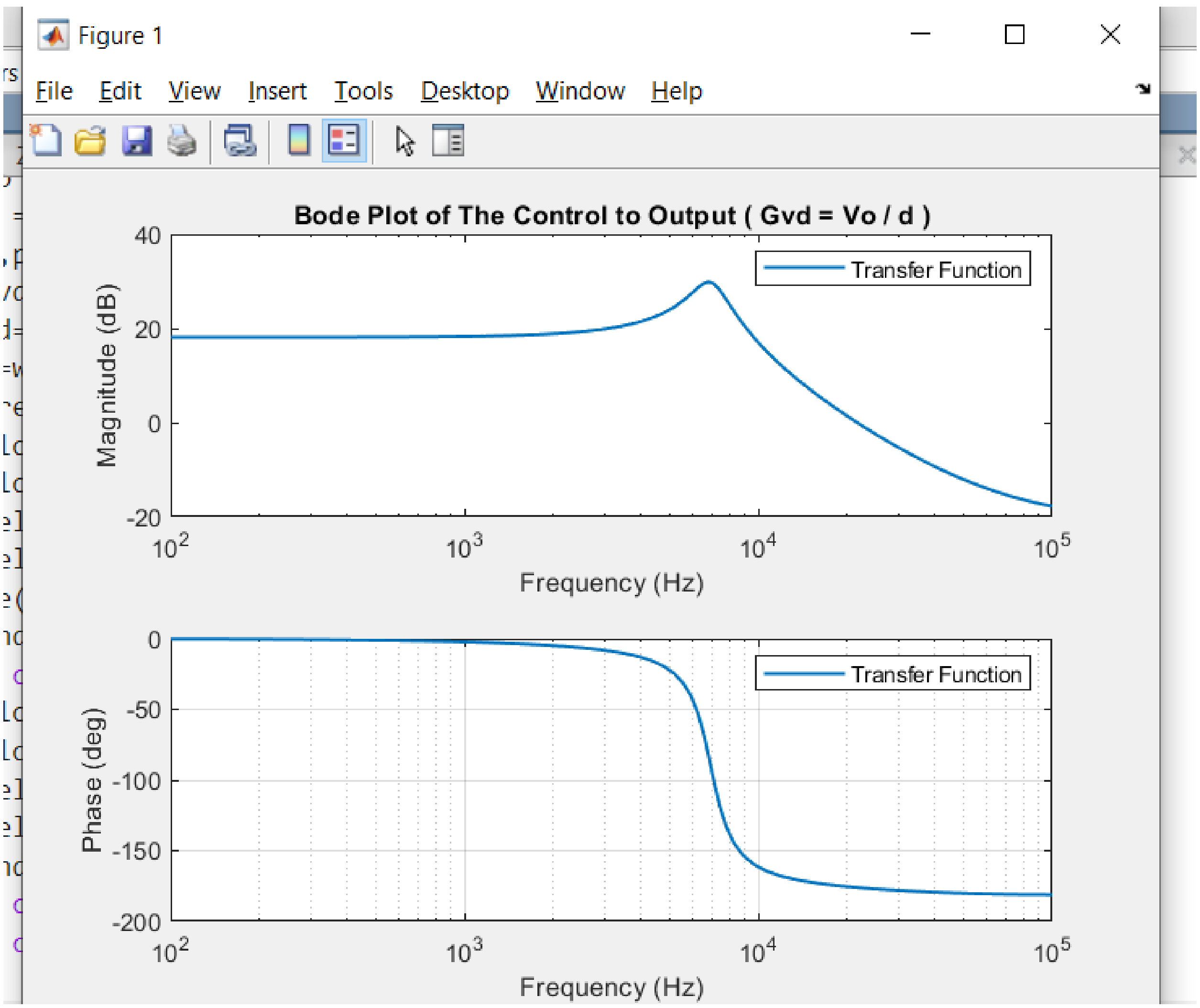
$$W_{ESR} = \frac{1}{Cr_c}$$

$$W_z = \frac{(V_1 + nV_2)(D-1)}{I_l L}$$

$$G_{vdo} = -\frac{(V_1 + nV_2)}{n(D-1)}$$

```
w ={100*2*pi,10^5*2*pi};
n = 3;
V_g = 12;
V_o = 5;
f_sw = 100e3;
C = 470e-6;
L = 5e-6;
rc = 5e-3;
R = 0.3;%r(i);
D = 1/(V_g/V_o+1);
I_2 = V_o/R;
I_1 = D/(1-D)*n*I_2;
IL = D*I_1;
W0 = sqrt(R*n^2*(D - 1)^2 / (C*L*(R + rc)));
Wz = (V_o + V_g)*(D - 1)/(IL*L);
Wesr = 1/(rc*C);
Q = R*n^2*(D - 1)^2 / ((C*R*n^2*rc*D^2 - 2*C*R*n^2*rc*D + L + C*n^2*R*rc) * sqrt(R*n^2*(D
G_vdo = (V_g + V_o)/(n*(D-1));
G_vd = G_vdo * ((1+s/Wesr) *(1+s/Wz)) / (1+s/(W0*Q) + (s/W0)^2);
[mag,phase,wout]= bode(G_vd,w);
mag_vd=squeeze (mag(1,1,:));
```

```
G_vd = G_vdo * ((1+s/Wesr) *(1+s/Wz)) / (1+s/(W0*Q) + (s/W0)^2);
[mag,phase,wout]= bode(G_vd,w);
mag_vd=squeeze (mag(1,1,:));
ph_vd=squeeze(phase(1,1,:));
f_vd=wout/(2*pi);
figure(1);
subplot(2,1,1)
semilogx(f_vd,20*log10(mag_vd),'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( Gvd = Vo / d )');
legend('Transfer Function');
hold on
subplot(2,1,2)
semilogx(f_vd,ph_vd-180,'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Phase (deg)');
legend('Transfer Function');
grid on;
hold on
```



Discussion

(1) What is the difference between $G_{vd}(s)=v_o(s)/d(s)$ of buck-boost and fly back converter? Explain why.

1-

The main difference between the flyback converter and buck boost converter is the turns ratio (n).

Why:

Because the presence of the transformer which will add an effect of its turns ratio, not only a single inductor.

(2) Does the right half plane zero exist in all transfer functions that you have derived in Question 1 for Buck-boost converter? What is the gain and phase characteristic of right half plane zero? and what is the physical origin of the right half plane zero? Explain why.

2-

The RHPZ only exist in $G_{vdo}\ tranfer\ function$.

RHPZ characteristic of the buck-boost converter's control-to-output transfer function, this occurs because an increase in the duty cycle during the positive half-cycle of the control signal results in a reduction in the diode's conduction period. Consequently, if the inductor current remains stable, the average diode current, which is equivalent to the output current, decreases as the duty cycle grows. This leads to a lower output voltage for the same load when the duty cycle is increased. Therefore, buck-boost converter designs must account for a specific operational range of duty cycles. It is within this range that adjustments to the duty cycle can be made to ensure uninterrupted operation.

Gain and phase characteristics (the system is non minimum phase system):

The gain will increase with increase of the frequency with (20 db/decade) and phase lags by -90 deg and non-minimum phase systems exhibit an initial response in the opposite direction of the final steady-state response due to the RHP zeros.
The effect of RHPZ will appear especially at high frequencies as we will have a negative sign.

The Physical origin:

As stated before, the energy stored in the conductor will increase as increasing of the duty cycle which will lead to decrease the diode conduction time. So, because of this the capacitor will start discharging and if we have a feedback loop as results of presence of RHPZ the will have a reversed direction feedback as an effect of non-minimum phase so the duty cycle will increase to achieve the request but this problem maybe solved with lower speed (low BW) controller so it will reject the high frequency change happened because of RHPZ.

(3) Why the double pole location is function of duty cycle in the buck-boost converter?

3-

As a result of capacitor and inductor presence, they are forming a second order system during off state.

(4) What is the effect of circuit parameters V_{in}, R_L, R_c and F_{sw} on transfer function $G_{vd}(s)$ for buck-boost in question 1?

4-

$$G_{vdo} = -\frac{Vg + Vo}{D-1}$$

$$W_o = \sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}$$

$$W_z = \frac{(V_o + V_g)(D-1)}{I_l L}$$

$W_{Esr} = \frac{1}{Cr_c}$ where $I_L = \frac{I_o}{R} = \frac{V_o}{RD}$`

$$Q = \frac{R(D-1)^2}{(CRr_cD^2 - 2CRr_cD + L + CRr_c)\sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}}$$

For R load:

1- For DC gain:

Changing load resistance has no effect on the dc gain as $G_{vdo} = -\frac{Vg+Vo}{D-1}$

2- Quality factor:

Increasing the load resistance will increase the quality factor.

3- Wz(RHPZ):

Decreasing load resistance will decrease W_z as $W_z = \frac{D`R}{DL}$ which lead to instability at low frequencies as $W_z\ decreased$

4- W_{esr}

It has no effect on W_{esr}

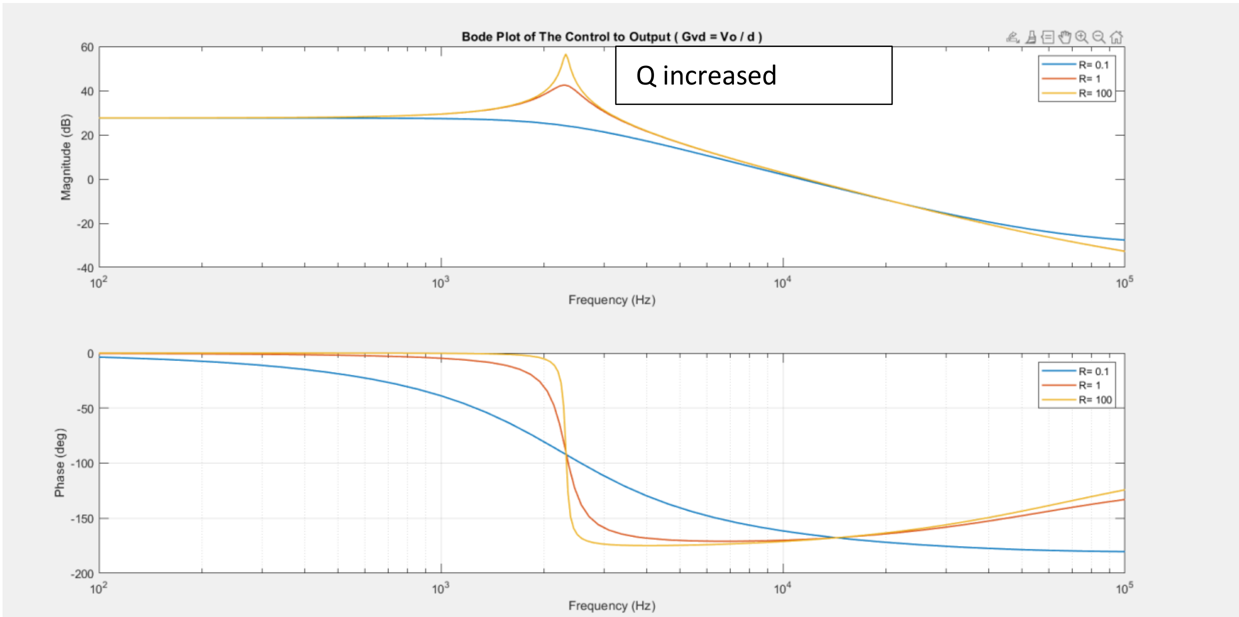
5- Increasing the load more than the critical resistance, leads to DCM mode.

$$I_{Lavg} = \geq \frac{\Delta I_l}{2}$$

$$\frac{V_o}{RD`} \geq \frac{V_{in}D}{2LF_{sw}}$$

$$R \leq \frac{2LF_{sw}}{D`^2}$$

$$R \leq \ 2.0069$$



For r_c :

1- For DC gain:

It has no effect on Dc gain. $G_{vdo} = -\frac{Vg+Vo}{D-1}$

2- W_{esr}:

Increasing r_C will cause a phase lead by 90 $degree$ at lower frequencies which enhance the stability.

3- Q:

Increasing r_c will decrease the Q and make the system more damped where,

$$Q = \frac{R(D-1)^2}{(CRr_cD^2 - 2CRr_cD + L + CRr_c)\sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}}$$

4- W_o

It has a small effect on W_o where,

$$W_o = \sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}$$

5- W_z

Increasing r_c will reduce the effect of RHPZ as it will introduce a phase lead by 90 degree which will enhance the stability.

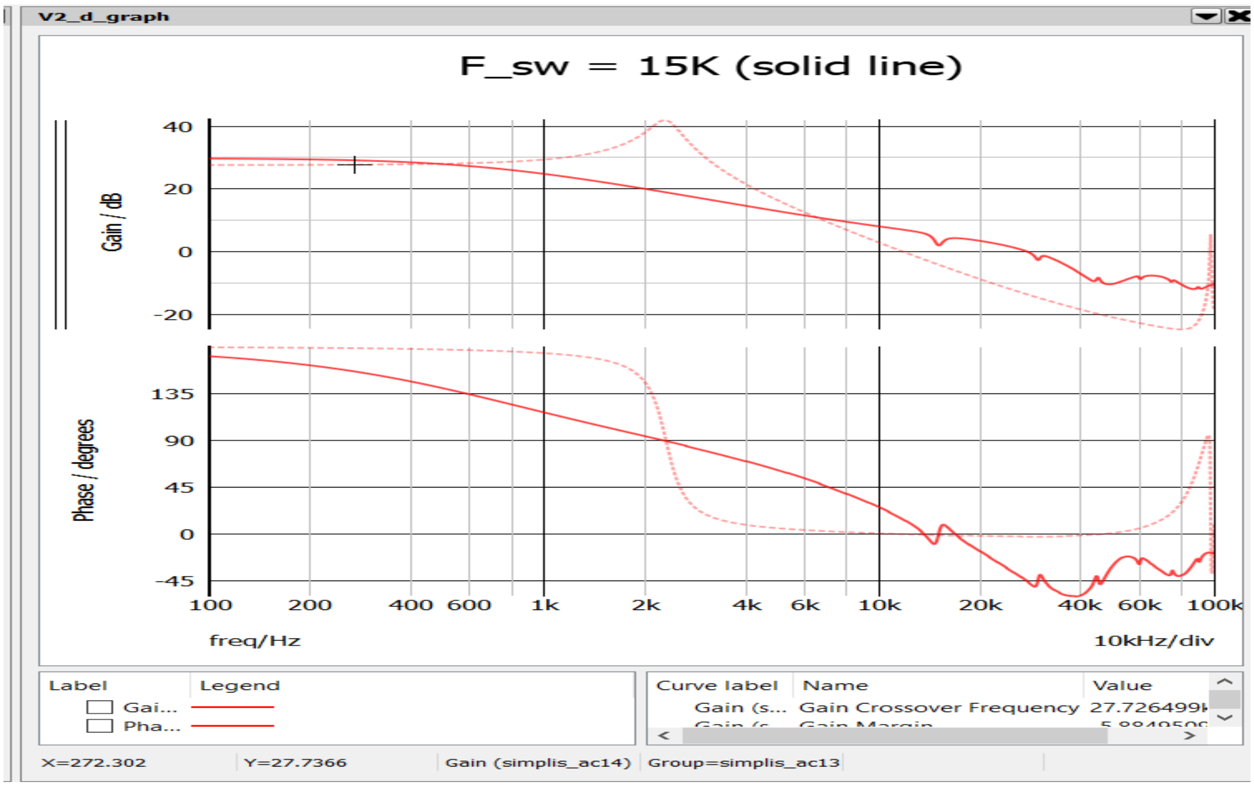
For F_{sw}:

1- Switching from CCM to DCM:

If we decreased the switching frequency below a certain limit, we will be in DCM mode.

$$F_{sw} \geq \frac{D'^2 R}{2L}$$

2- The dynamics frequency should be lower than $\frac{f_{sw}}{10}$ to avoid the switching harmonics.



For V_{in}:

1- DC gain:

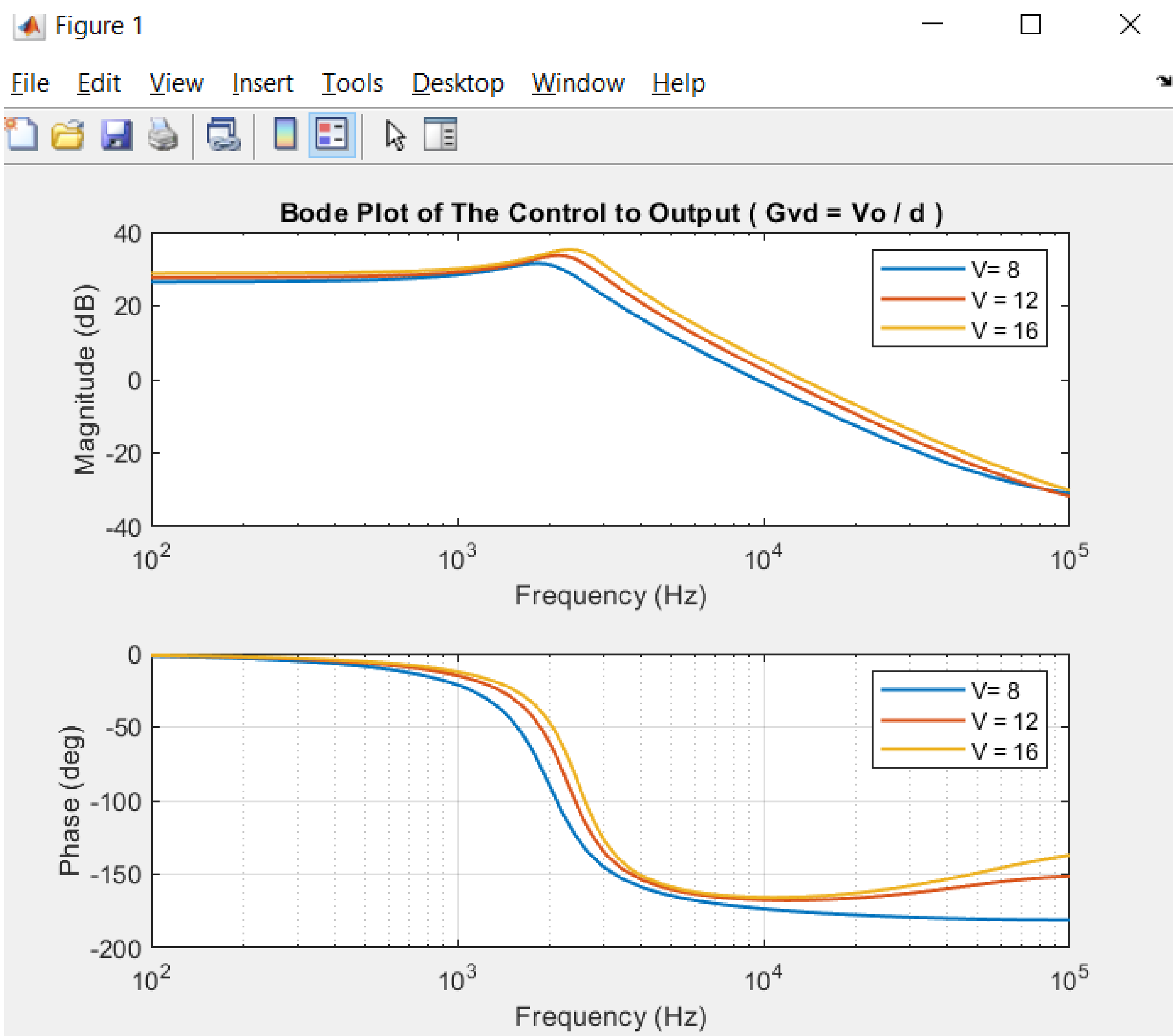
increasing V_{in} will increase the system Dc gain. $G_{vdo} = \frac{Vg+Vo}{D-1}$

2- W_o

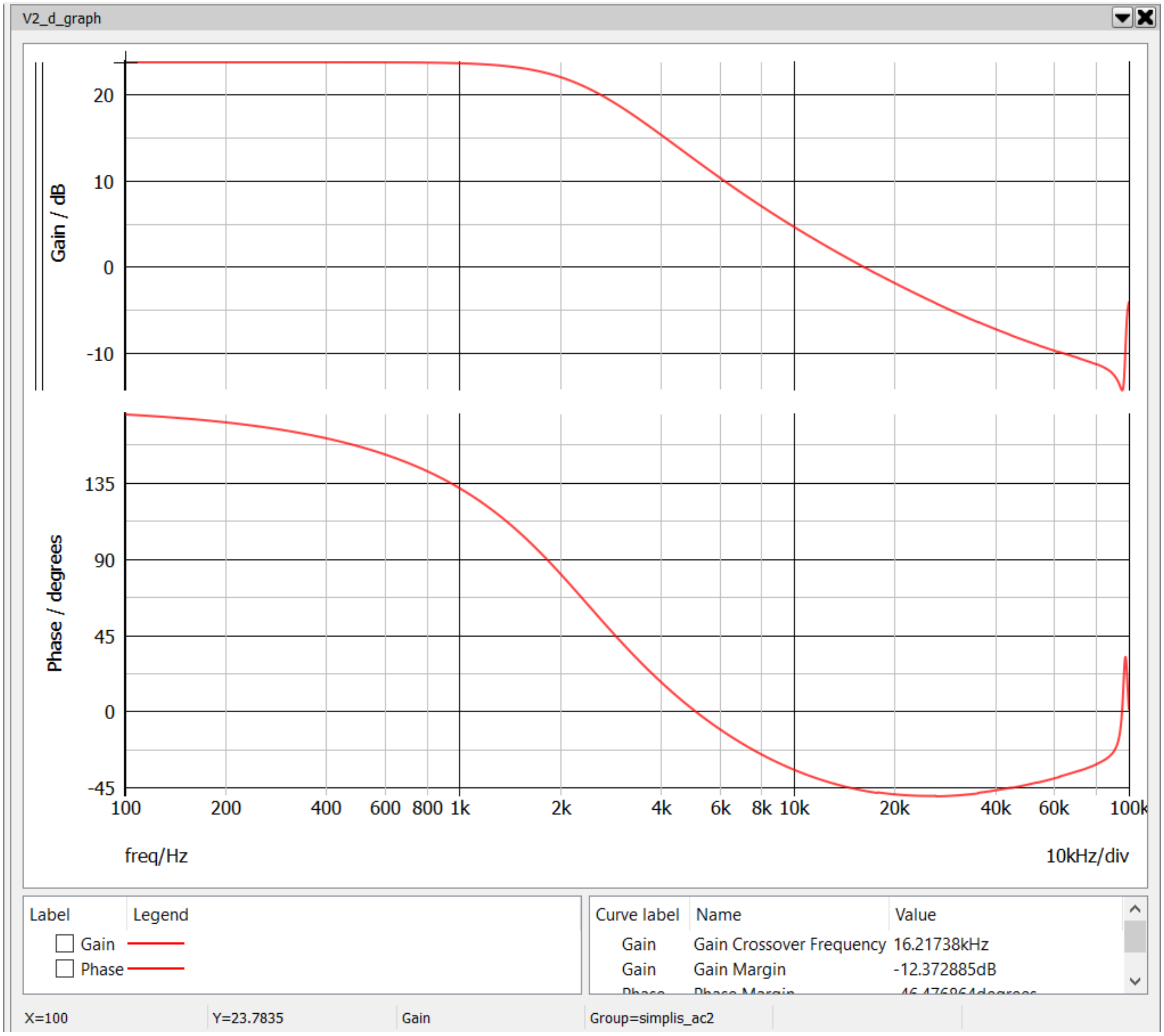
Increasing V_{in} will increase the phase delay at high frequencies.

3- Q

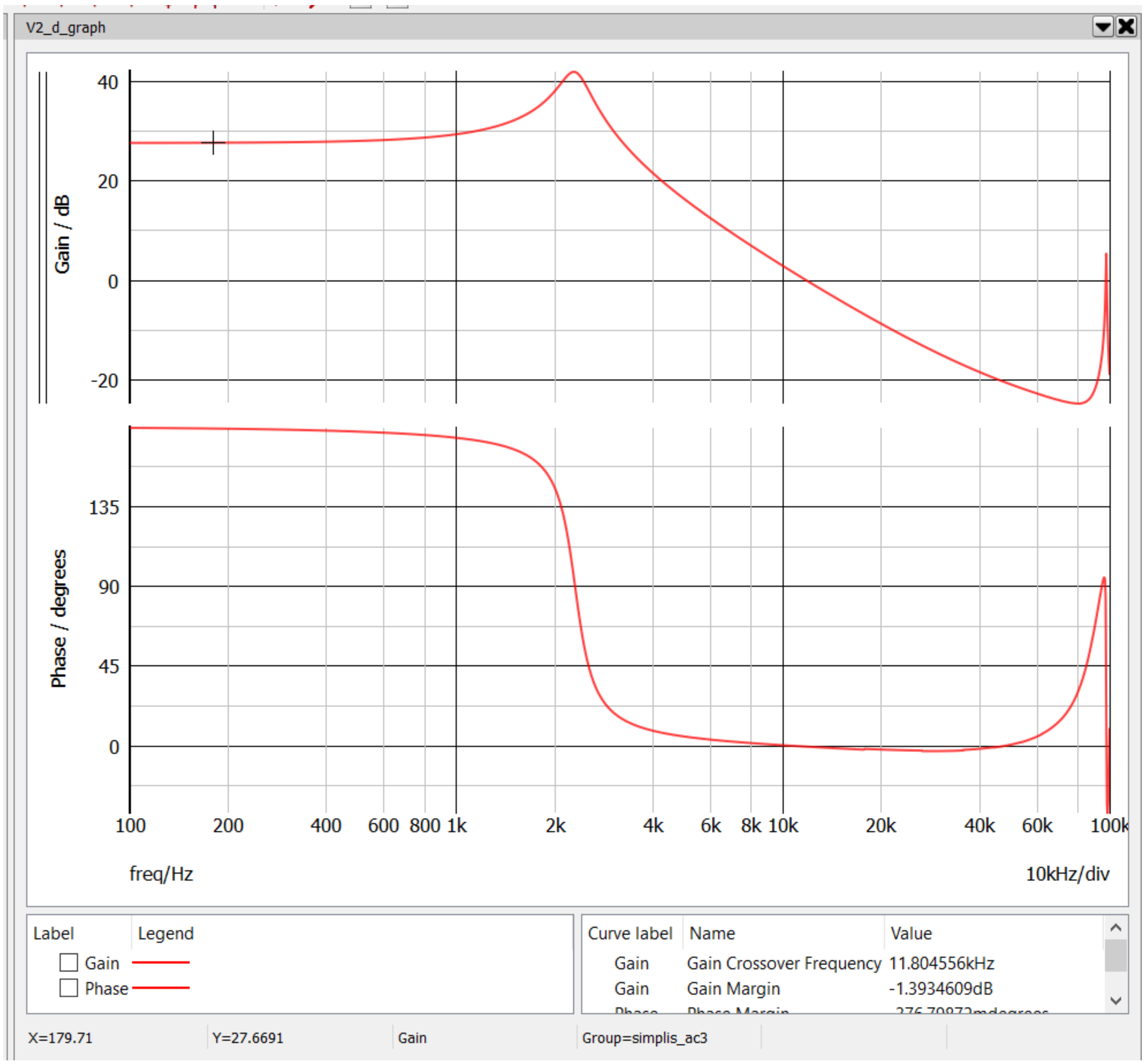
Increasing V_{in} will increase Q which will make the system less dapmped.



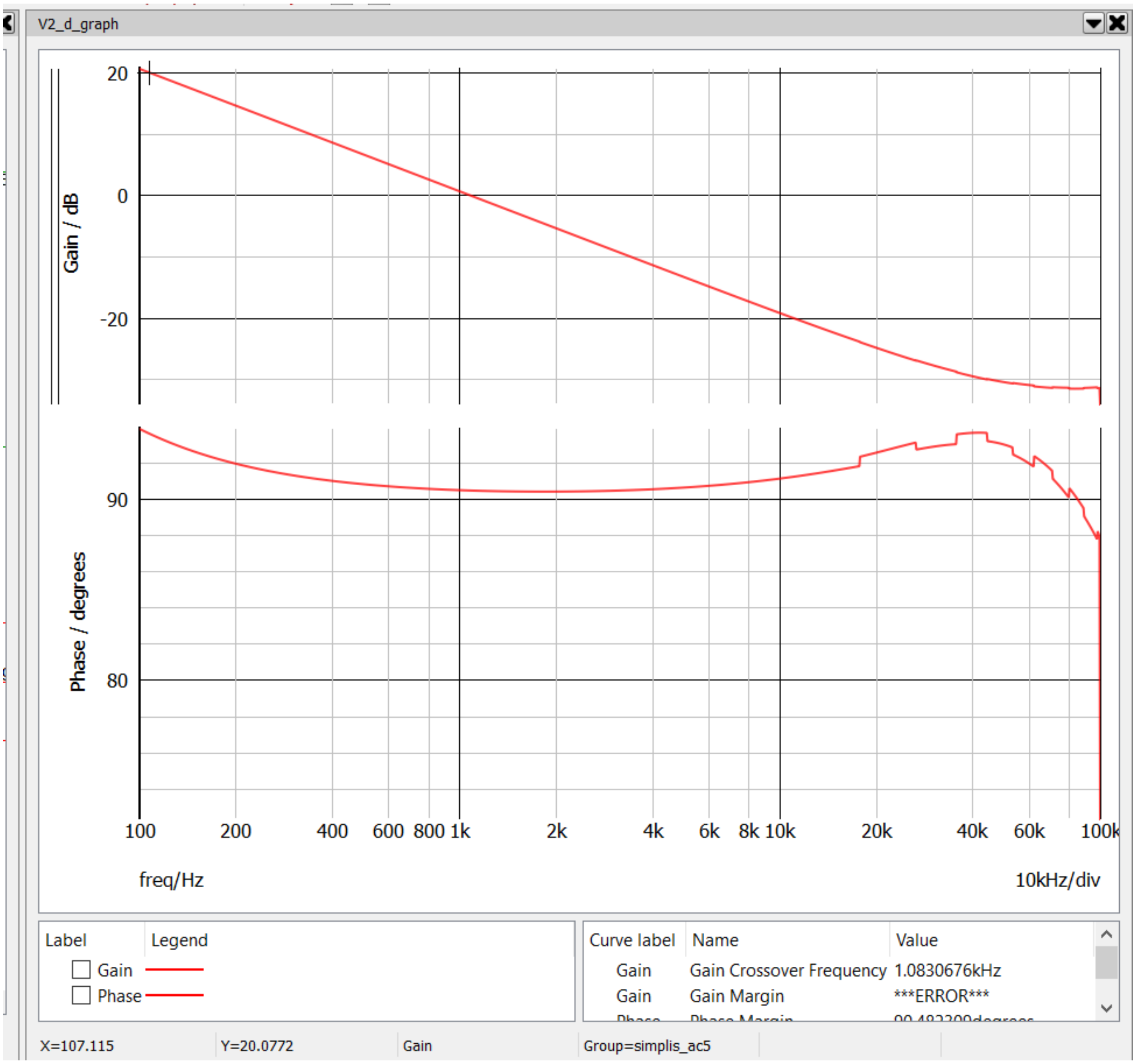
(5) What is the condition that you can use the expression $G_{vd}(s)$ derived in Question 1? Can you use it with V_{in}= 8V, 12V, 16V? Can you use it with R_L=100mΩ, 1Ω, 100Ω?



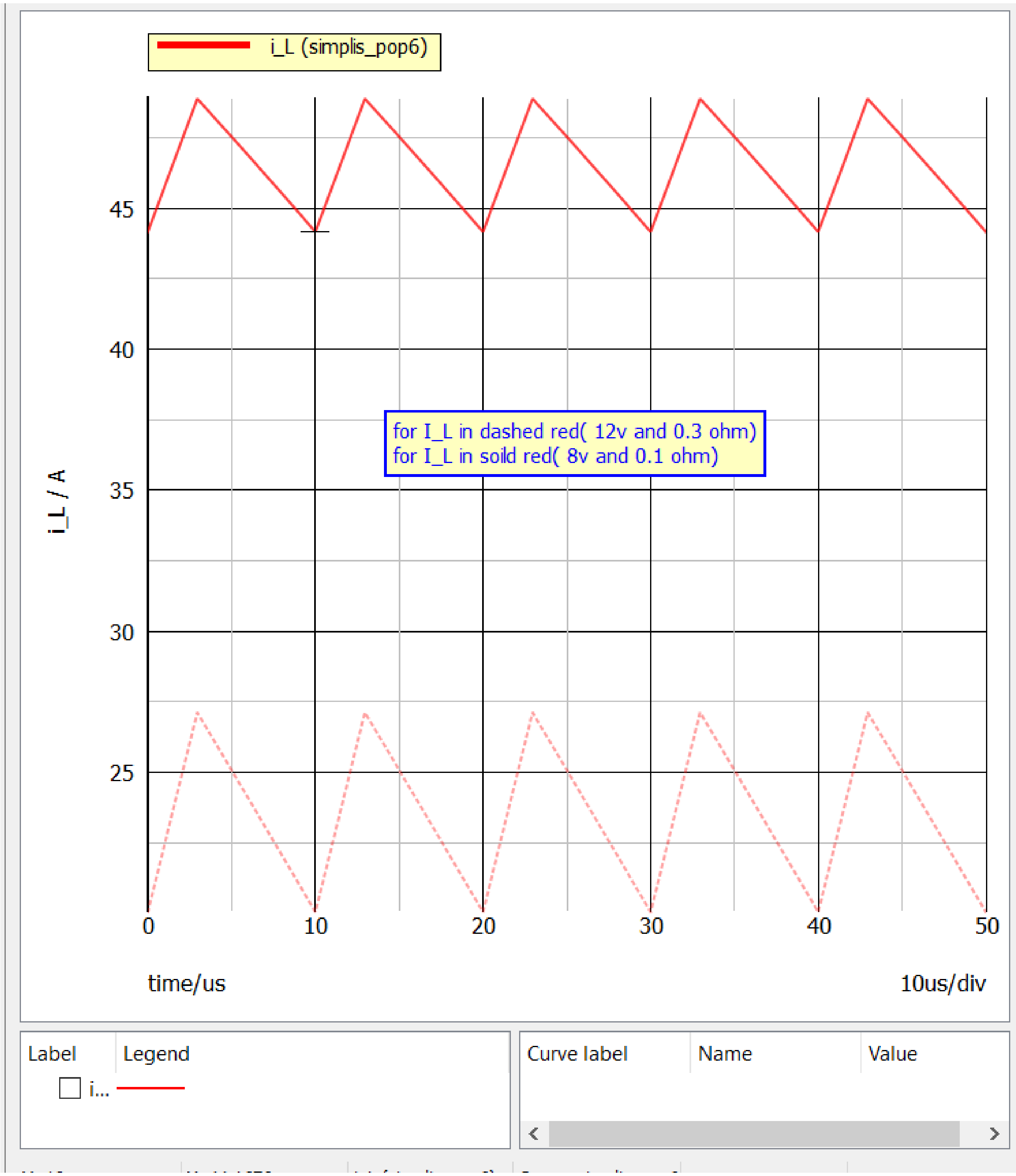
For 8 and 100 mohm



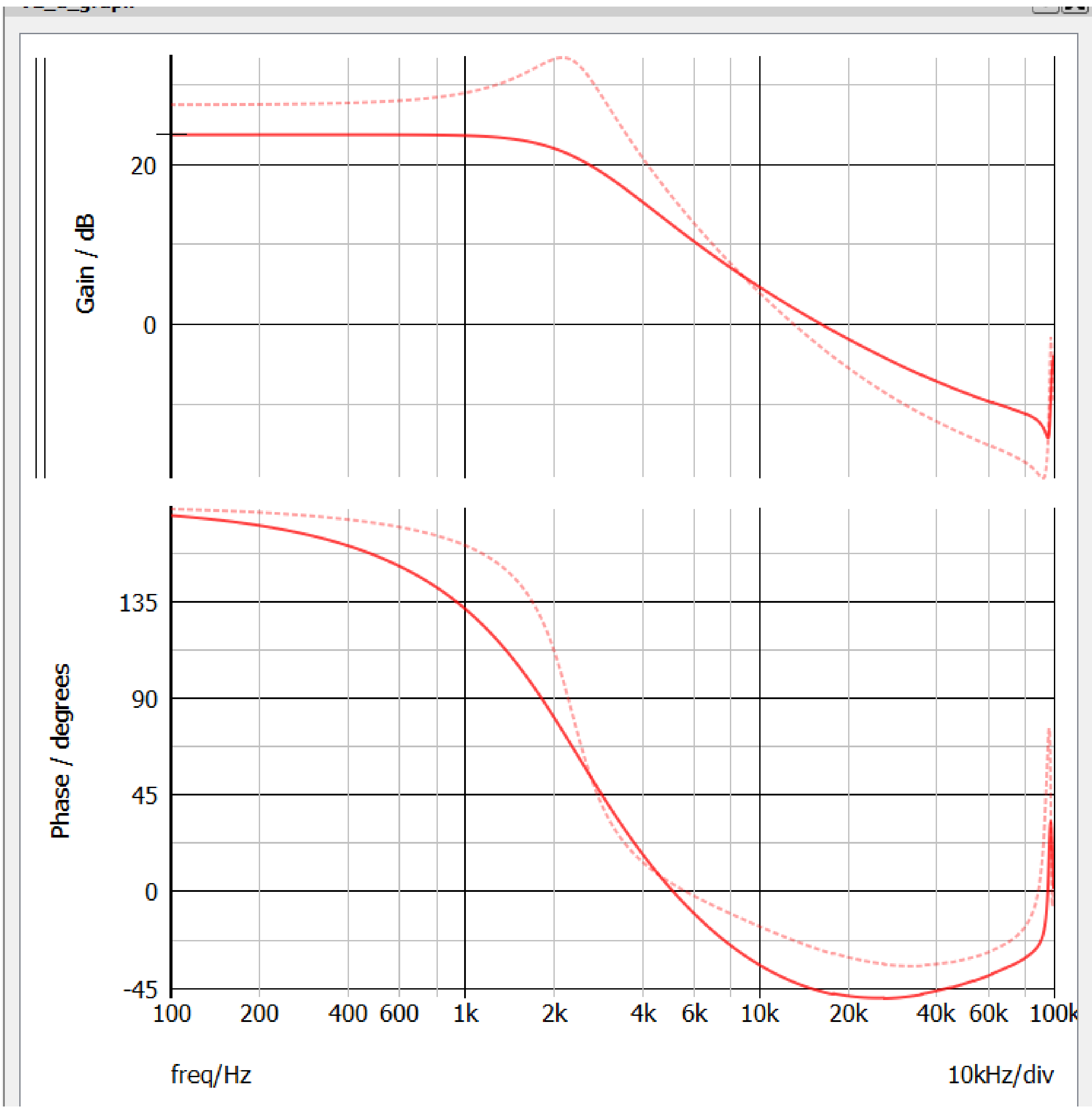
For 12v and 1 ohm

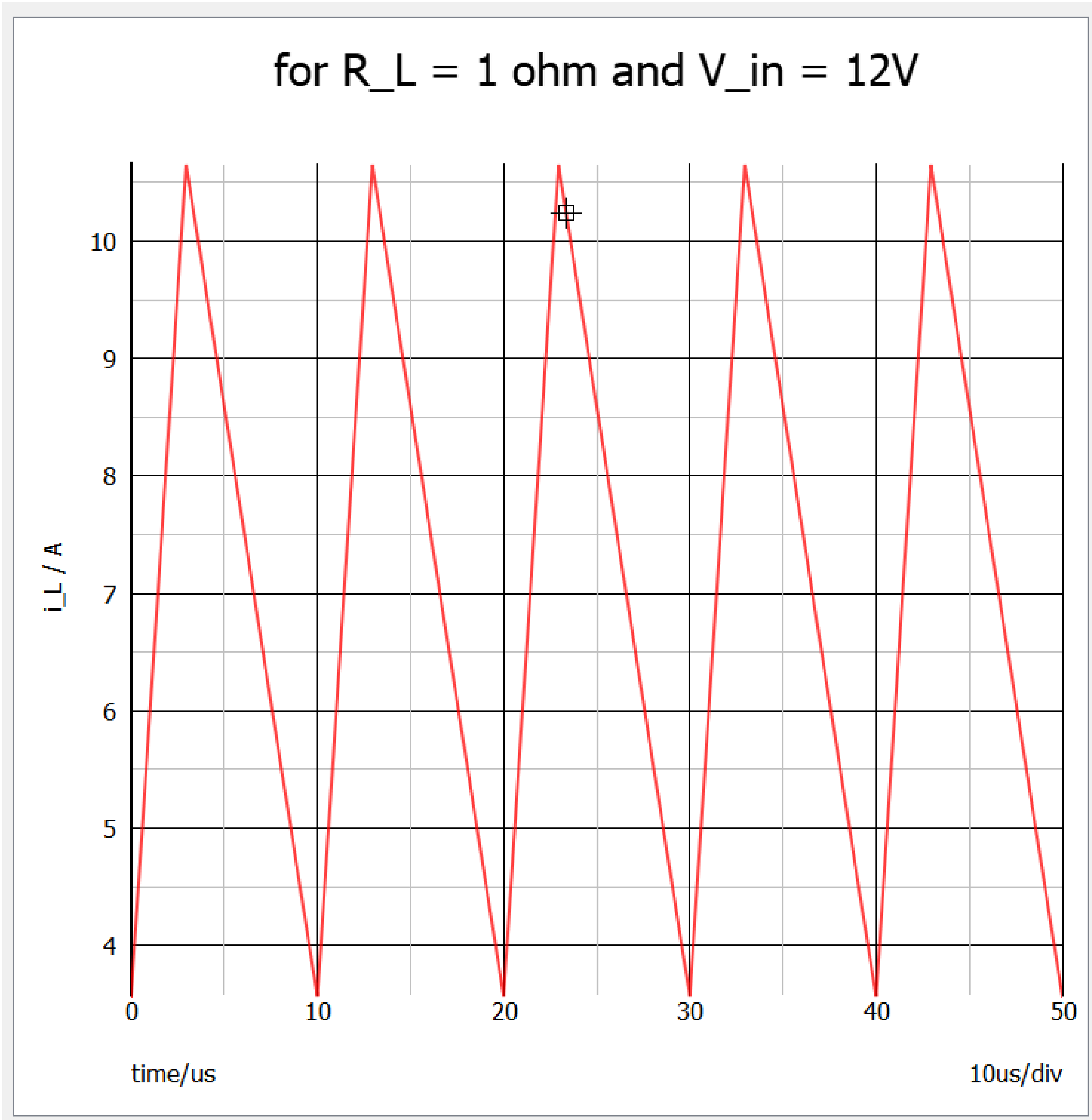


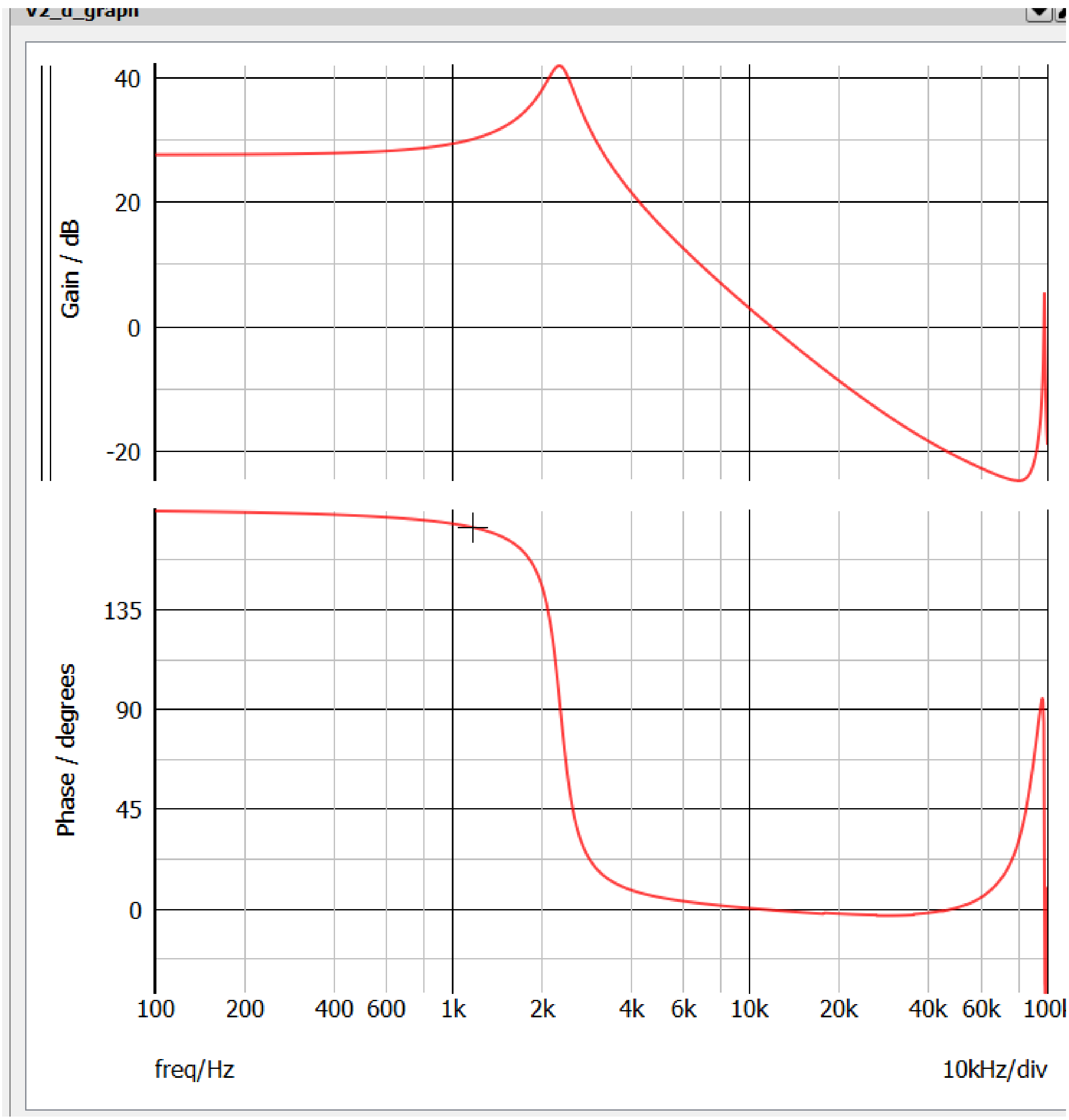
16V and 100 ohm

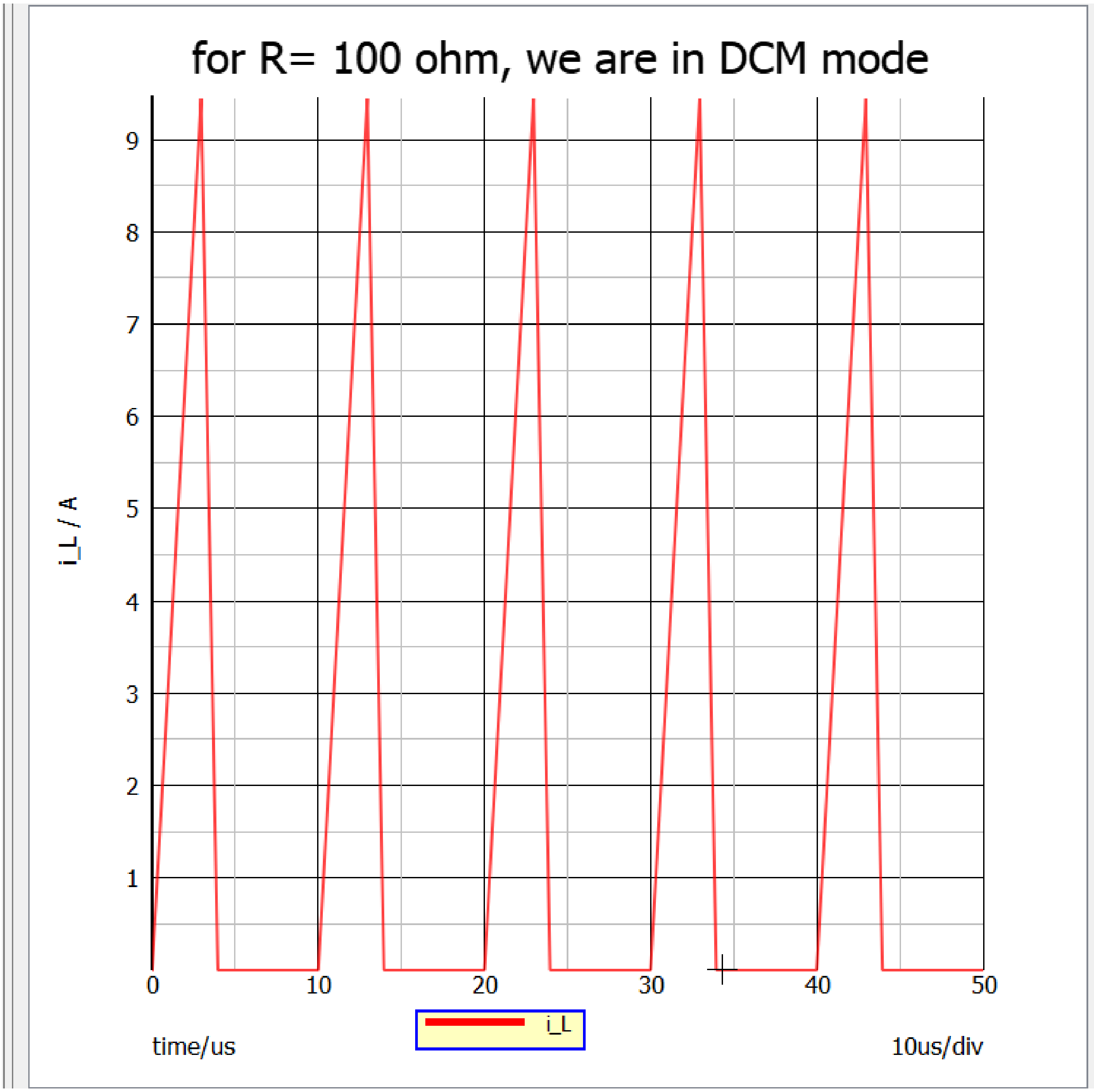


i_L (simplis_pop6)
for I_L in dashed red(12v and 0.3 ohm)
for I_L in soild red(8v and 0.1 ohm)
i_L / A
45
40
35
30
25
0
10
20
30
40
50
time/us
10us/div
Label
Legend
i...
Curve label
Name
Value


Gain / dB
20
0
Phase / degrees
135
90
45
0
-45
100
200
400
600
1k
2k
4k
6k
10k
20k
40k
60k
100k
freq/Hz
10kHz/div


for R_L = 1 ohm and V_in = 12V
i_L / A
10
9
8
7
6
5
4
0
10
20
30
40
50
time/us
10us/div


V2_d_graph
40
20
0
-20
Gain / dB
135
90
45
0
Phase / degrees
100
200
400
600
1k
2k
4k
6k
10k
20k
40k
60k
freq/Hz
10kHz/div



Conclusion:

1- Increasing R to a value higher than the $R_{critical}$, will lead to DCM mode.
2- Decreasing the load will lead to higher inductor current.
3- In case of (8V and 100 mohm) the system is overdamped.
4- In case of (12v and 1 ohm) the system is almost in CCM mode.
5- In case of (16v and 100 ohm) the system is operating in DCCM mode.

(6) What are the assumptions for the small signal model derived from average modeling concept introduced in chapter 1?

1- Converter is operating in CCM.
2- There is no transition from CCM to DCM.
3- The perturbation dynamics should be lower than $\frac{f_{sw}}{10}$ for practical approaches so the controller could compensate against the perturbation.

Matlab scripts for discussion questions:

Q4

Looping on R

```
r = [100e-3 1 100];

s=tf('s');

for i = 1:length(r)
V_g = 12;
V_o = 5;
f_sw = 100e3;
C = 470e-6;
L = 5e-6;
rc = 5e-3;
R = r(i);
D = 1/(V_g/V_o+1);
I_2 = V_o/R;
I_1 = D/(1-D)*I_2;
IL = D*I_1
%IL =  IL_arr(i);
W0 = sqrt(R*(D - 1)^2 / (C*L*(R + rc)));
Wz = (V_o + V_g)*(D - 1)/(IL*L);
Wesr = 1/(rc*C);
Q = R*(D - 1)^2 / ((C*R*rc*D^2 - 2*C*R*rc*D + L + C*R*rc) * sqrt(R*(D - 1)^2 / (C*L*(R + rc))));
```

```
G_vdo = (V_g + V_o)/(D-1)
temp_1 = (IL *L*s)/((V_g+V_o)*(D-1));
G_vd_num = (temp_1 + 1) * (C*s*rc +1);
temp_2 = ((C*R*rc*D^2 - 2*C*R*rc*D*+L+C*R*rc)*s)/(R*(D-1)^2);
temp3 = (C*L*s^2*(R+rc))/(R*(D-1)^2);
G_vd_dnum = temp3 + temp_2 +1;
G_vd = -G_vdo*(G_vd_num/G_vd_dnum);
G_vd = G_vdo * ((1+s/Wesr) *(1+s/Wz)) / (1+s/(W0*Q) + (s/W0)^2)
w ={100*2*pi,10^5*2*pi};
[mag,phase,wout]= bode(G_vd,w);
mag_vd=squeeze (mag(1,1,:));
ph_vd=squeeze(phase(1,1,:));
f_vd=wout/(2*pi);
figure(1);
subplot(2,1,1)
semilogx(f_vd,20*log10(mag_vd),'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( Gvd = Vo / d )');
legend('R= 0.1','R= 1','R= 100');
hold on
subplot(2,1,2)
```

Looping on Vin

```
V_in = [8 12 16];

s=tf('s');

for i = 1:length(V_in)
V_g = V_in(i);
V_o = 5;
f_sw = 100e3;
C = 470e-6;
L = 5e-6;
rc = 5e-3;
R = 0.3;
D = 1/(V_g/V_o+1);
I_2 = V_o/R;
I_1 = D/(1-D)*I_2;
IL = D*I_1;
%IL =  IL_arr(i);
W0 = sqrt(R*(D - 1)^2 / (C*L*(R + rc)));
Wz = (V_o + V_g)*(D - 1)/(IL*L);
Wesr = 1/(rc*C);
Q = R*(D - 1)^2 / ((C*R*rc*D^2 - 2*C*R*rc*D + L + C*R*rc) * sqrt(R*(D - 1)^2 / (C*L*(R + rc))));

G_vdo = (V_g + V_o)/(D-1)
temp_1 = (IL *L*s)/((V_g+V_o)*(D-1));
```

```
temp_2 = ((C*R*rc*D^2 - 2*C*R*rc*D +L+C*R*rc)*s)/(R*(D-1)^2);
temp3 = (C*L*s^2*(R+rc))/(R*(D-1)^2);
G_vd_dnum = temp3 + temp_2 +1;
G_vd = -G_vdo*(G_vd_num/G_vd_dnum);
G_vd = G_vdo * ((1+s/Wesr) *(1+s/Wz)) / (1+s/(W0*Q) + (s/W0)^2)
w ={100*2*pi,10^5*2*pi};
[mag,phase,wout]= bode(G_vd,w);
mag_vd=squeeze (mag(1,1,:));
ph_vd=squeeze(phase(1,1,:));
f_vd=wout/(2*pi);
figure(1);
subplot(2,1,1)
semilogx(f_vd,20*log10(mag_vd),'LineWidth',1.2);
xlabel('Frequency (Hz)');
ylabel('Magnitude (dB)');
title('Bode Plot of The Control to Output ( Gvd = Vo / d )');
legend('V= 8','V = 12','V = 16');hold on
subplot(2,1,2)
```

Buck boost converter transfer functions:

1- Input voltage perturbation

$$G_{vvo} = -\frac{D}{D-1}$$

$$Q = \frac{R(D-1)^2}{(CRr_cD^2 - 2CRr_cD + L + CRr_c)\sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}}$$

$$W_o = \sqrt{\frac{R(D-1)^2}{CL(R+r_c)}}$$

$$W_{Esr} = \frac{1}{Cr_c}$$