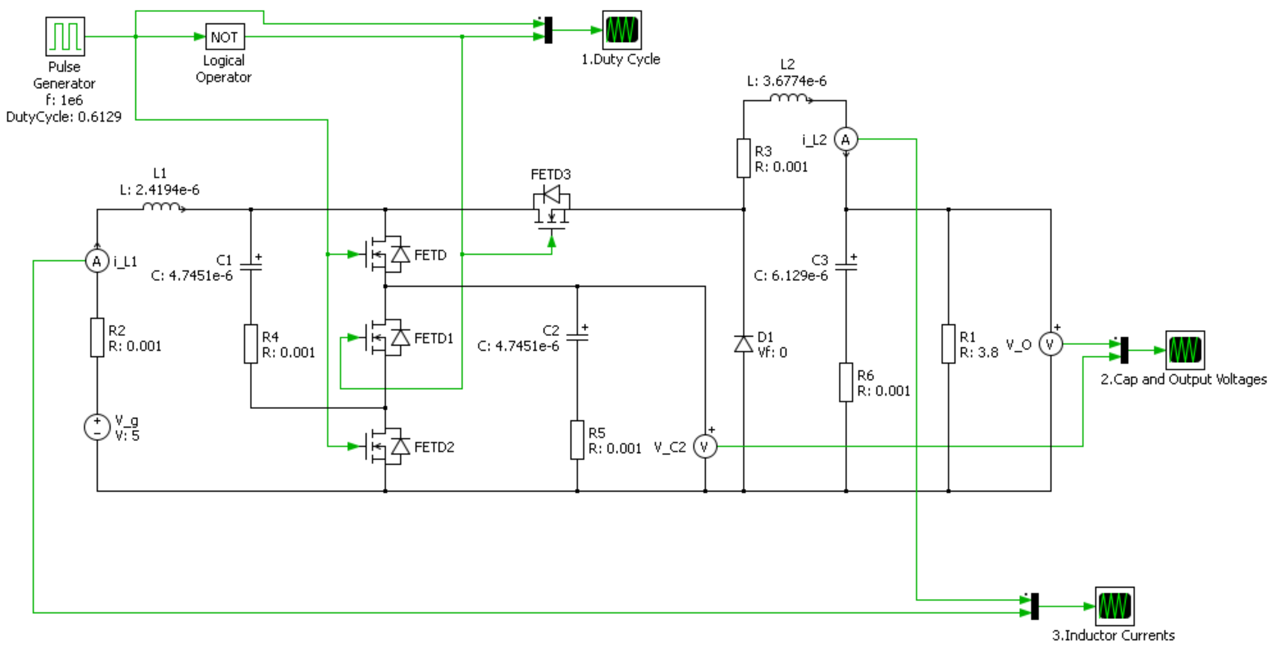
An Inductorless Step-down Converter Utilizing Inductance of Transmission Cables in Charging Applications

Circuit Simulation

D.K.M.A.M. Padmal - 140427D

1 Circuit

The circuit simulations in this report were done with the following circuit created using PLECS



2 Parameters

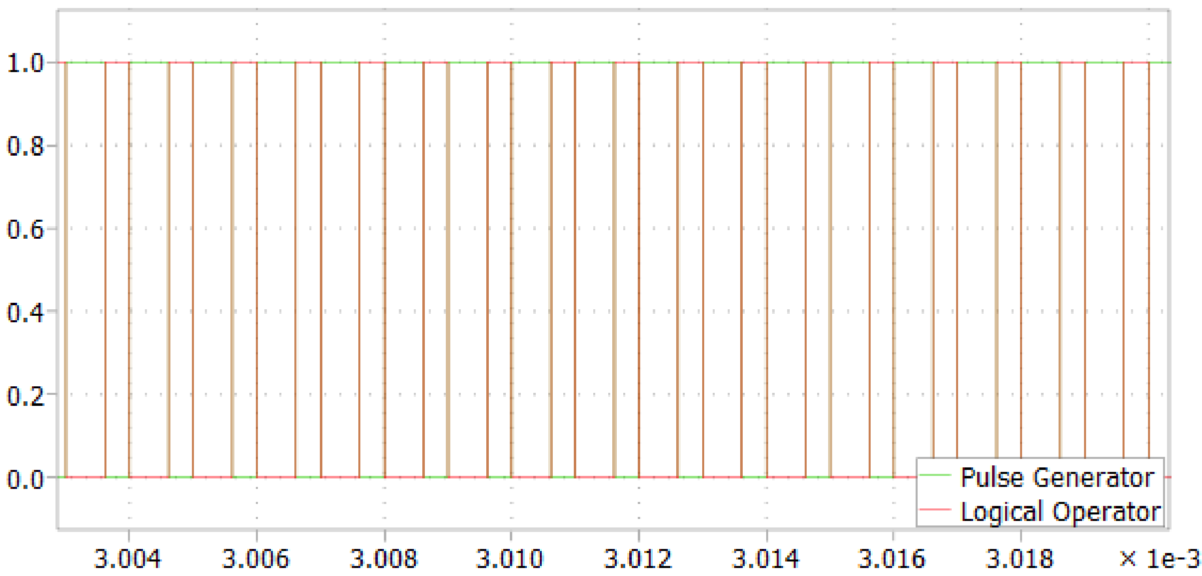
Following parameters were used in the circuit simulation

Component	Simulated Values
Source Voltage (V_g)	5 V
Duty Ratio (D)	0.6129
Load Resistance (R_o)	3.8 Ω
Output Voltage (V_o)	3.8 V
Switching Frequency (f_s)	1 MHz
Inductor (L_1)	2.4194 μH, ESR = 0.001Ω
Inductor (L_2)	3.6774 μH, ESR = 0.001Ω
Capacitor (C_1, C_2)	4.7451 μF, ESR = 0.001Ω
Capacitor (C_o)	6.1290 μF, ESR = 0.001Ω

3 Simulations

3.1 Duty Cycle

Pulse generator is used to generate the square wave to drive the MOSFETs and the following waveform is observed.



3.2 Output Voltage Waveforms

Output voltage waveform is observed across the R_o resistor and an intermediate waveform can be observed across the C_1 or C_2 capacitor.

Figure 1: Output Voltage Waveform

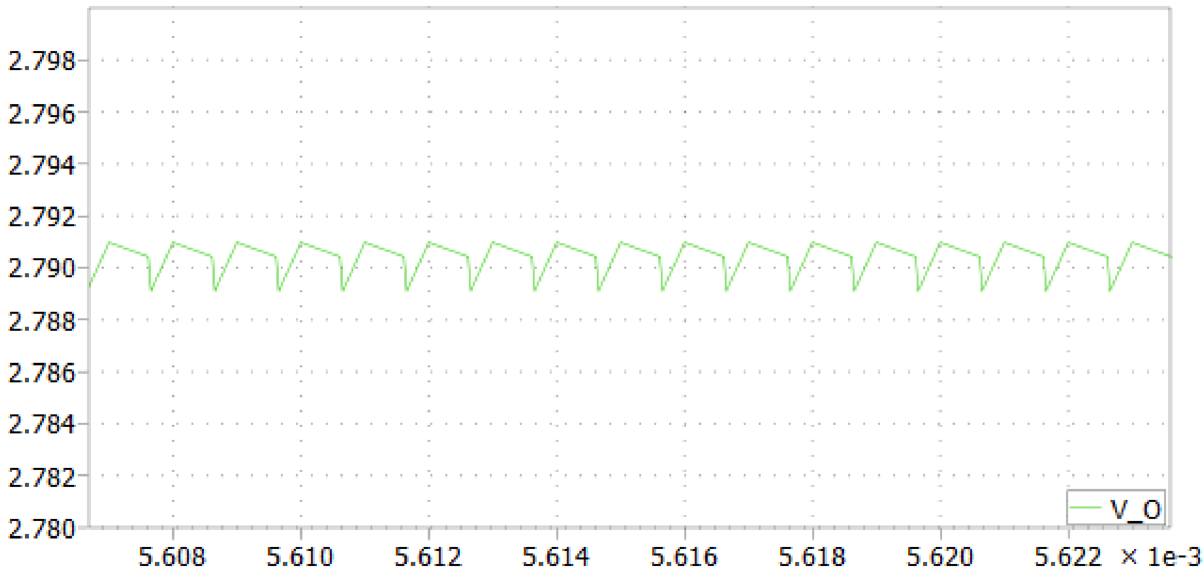
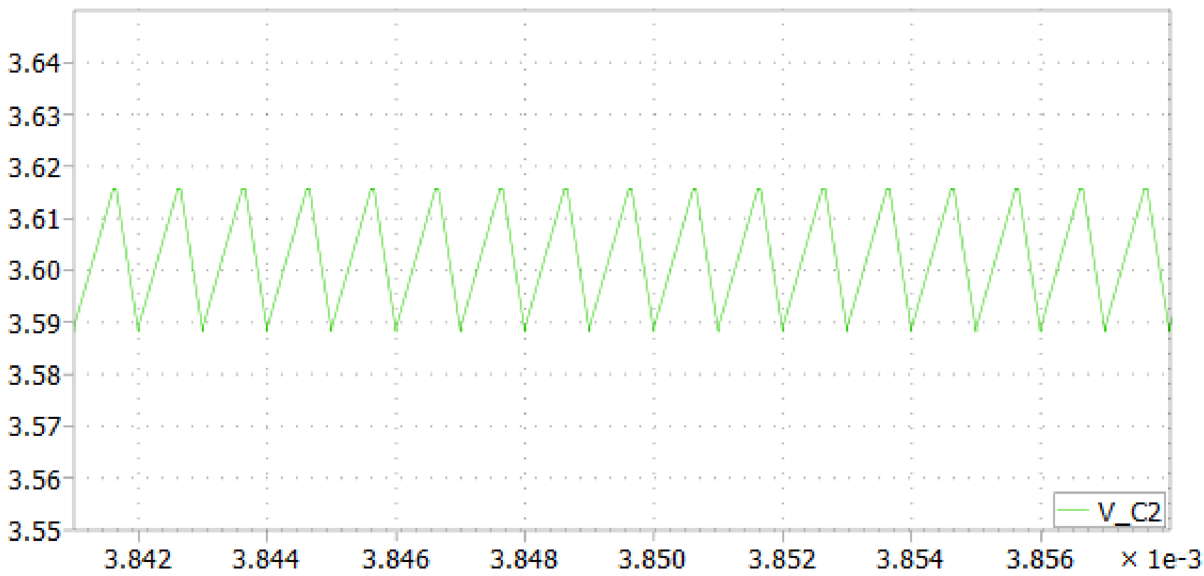


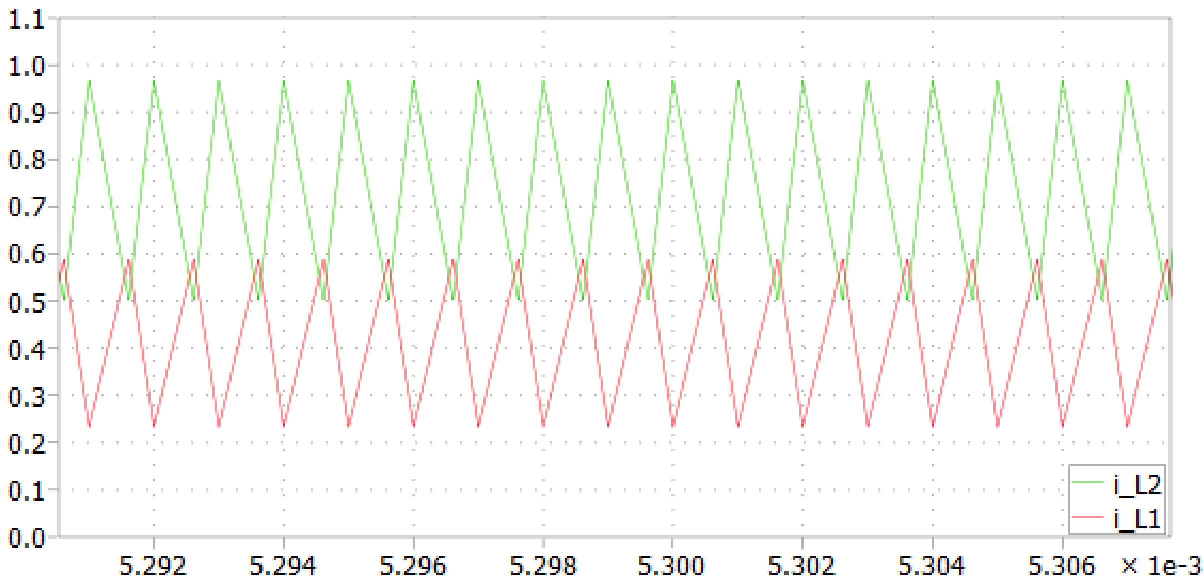
Figure 2: Capacitor Voltage Waveform



3.3 Inductor Current Waveforms

Current across the inductors L_1 and L_2 were observed as follows;

Figure 3: Inductor Current Waveforms



4 Voltage Gain

Output voltage expression was derived as follows;

$$V_o = \frac{2DV_g - (1+D)V_{D_1}D'}{(1+D) + \frac{R_Z}{R_o}}$$

By dividing both sides by V_g we can derive the voltage gain function for non ideal case.

$$\frac{V_o}{V_g} = \frac{2D - (1+D)\frac{V_{D_1}}{V_g}D'}{(1+D) + \frac{R_Z}{R_o}}$$

This will simplify into;

$$M = \frac{2D}{(1+D) + \frac{R_Z}{R_o}} - \frac{(1+D)\frac{V_{D_1}}{V_g}D'}{(1+D) + \frac{R_Z}{R_o}}$$

There is another step taken in the plots. That is when the diode forward voltage is zero and when it is 0.6 V.

For both ideal and non-ideal cases, gain function can be plotted as follows;

Figure 4: Gain Plots when $V_f = 0$ V

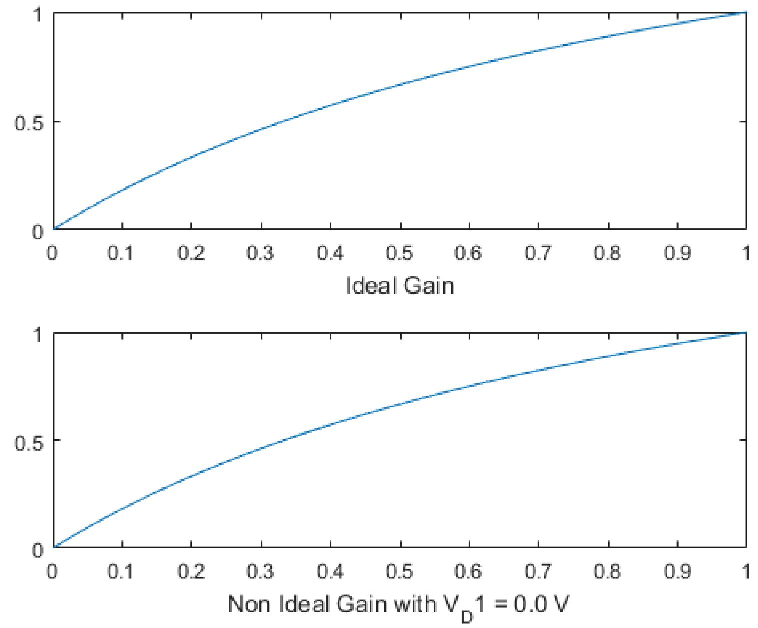
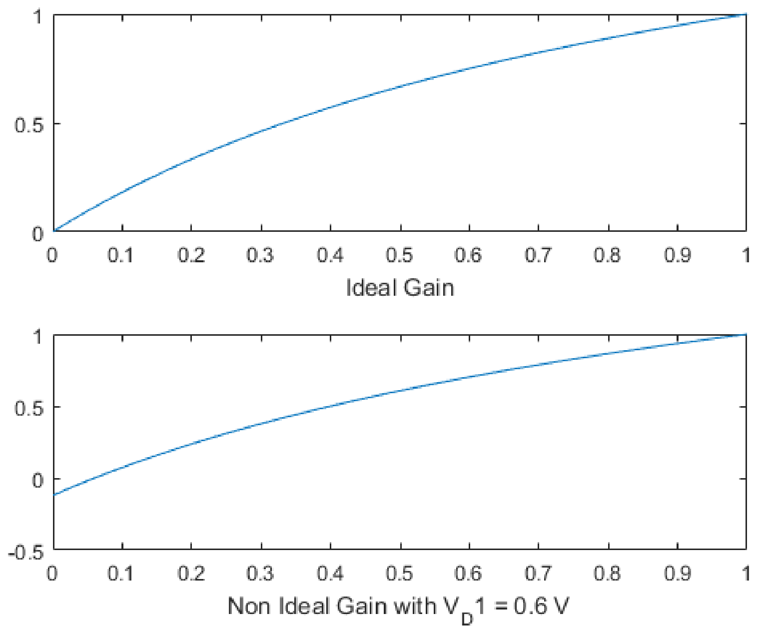


Figure 5: Gain Plots when $V_f = 0.6$ V



5 Transfer Functions

There are two transfer functions taken into consideration at four different input parameters.

5.1 Line to Output Transfer Function

Line to Output transfer function ($G_{vg}(s)$) is expressed as;

$$G_{vg}(s) = \frac{(1+D)}{2D}\frac{u(s)}{z(s)}$$

Where;

$$z(s) = \frac{R_o + (L_a + L_2)s + (L_aC_o + L_aC_a + L_2C_o)R_os^2 + L_aL_2C_as^3 + L_aC_aL_2C_oR_os^4}{1 + R(C_a + C_o) + L_2Cs^2 + L_2C_oCR_oS^3}$$

$$u(s) = \frac{R_o}{1 + R_oC_os}$$

$$L_a = \frac{4D^2}{(1+D)^2}L_1$$

$$C_a = \frac{C}{D^2}$$

5.2 Control to Output Transfer Function

Control to Output transfer function ($G_{vd}(s)$) is expressed as;

$$G_{vd}(s) = e(s)\frac{(1+D)}{2D}\frac{u(s)}{z(s)}$$

Where;

$$z(s) = \frac{R_o + (L_a + L_2)s + (L_aC_o + L_aC_a + L_2C_o)R_os^2 + L_aL_2C_as^3 + L_aC_aL_2C_oR_os^4}{1 + R(C_a + C_o) + L_2Cs^2 + L_2C_oCR_oS^3}$$

$$u(s) = \frac{R_o}{1 + R_oC_os}$$

$$L_a = \frac{4D^2}{(1+D)^2}L_1$$

$$C_a = \frac{C}{D^2}$$

5.3 Source Code

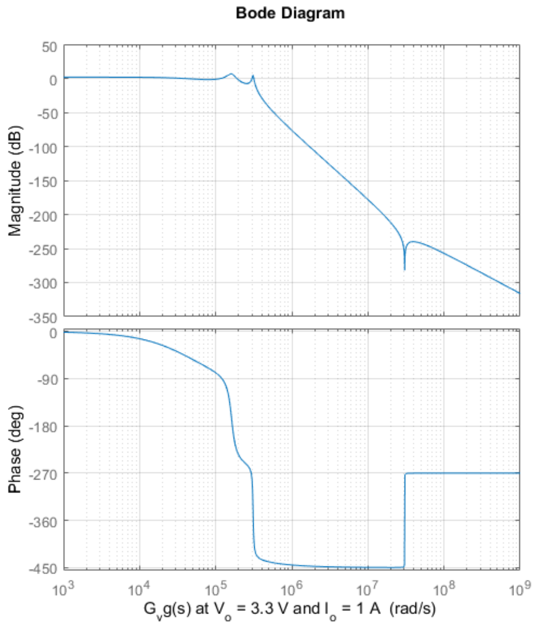
5.3.1 Gain Plots

```
% Duty Cycle
D = 0:0.001:1;
d = 1 - D;
% Ideal Condition
IdealGain = 2 * D ./ (1 + D);

% Non Ideal Condition
V_D1 = 0.6;
V_g = 5;
R_L1 = 0.001;
R_L2 = 0.001;
R_C1 = 0.001;
R_C2 = 0.001;
R_o = 3.8;

% On resistance of semiconductors are assumed to be zero, therefore
R_Z = (1 + D) .* R_L2 + (D / (1 + D)) .* (4 * D .* R_L1 + d .* (R_C1 +
    R_C2));

First_Term = 2 * D ./ (1 + D + (R_Z / R_o));
Second_Term = - ((1 + D) .* (V_D1 / V_g) .* d) ./ (1 + D + (R_Z / R_o))
    ;
NonIdealGain = (First_Term + Second_Term);

figure
subplot(2,1,1);
plot(D,IdealGain);
xlabel('Ideal Gain');

subplot(2,1,2);
plot(D,NonIdealGain);
xlabel('Non Ideal Gain with V_D1 = 0.6 V');
```

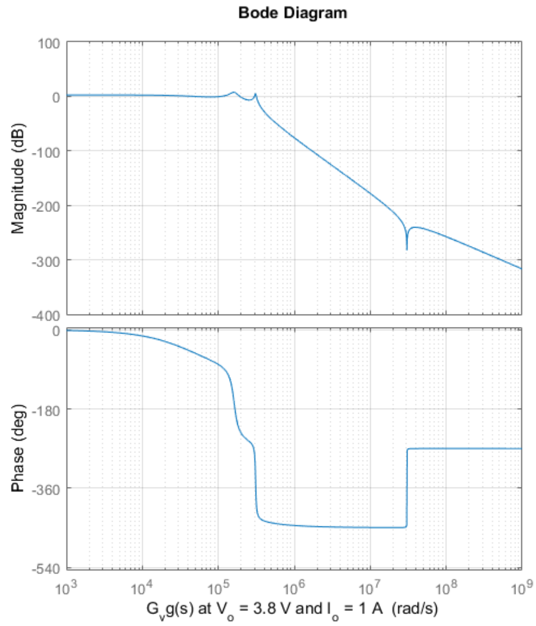
5.3.2 Transfer Functions

```
% Duty Cycle
D = 0.6129;

% Passive component values
R_o = 3.8;
C_o = 6.1290e-6;
C_c = 4.7451e-6;
L_1 = 2.4194e-6;
L_2 = 3.6774e-6;
```

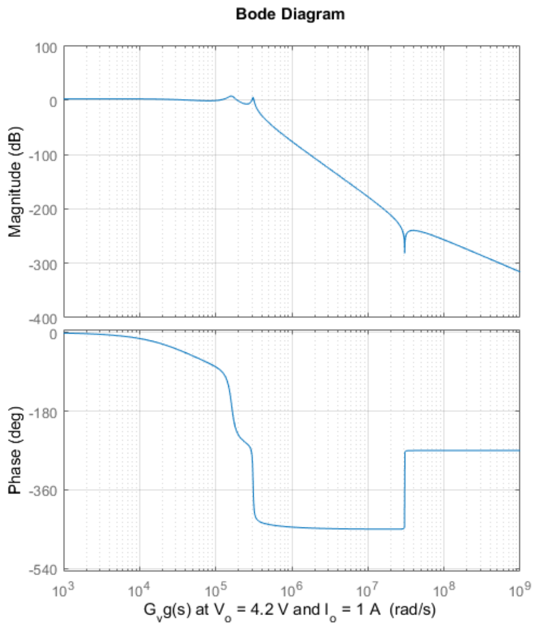
```
V_o = 3.3;

V_g = V_o * (1 + D) / (2 * D);
I_o = 1;

% Derived parameters
I_g = I_o * 2 * D / (1 + D); %
L_a = L_1 * ((4 * (D ^ 2))/((1 + D) ^ 2)); %
C_a = C_c / (D ^ 2); %
D_fac = 1 / (D + D ^ 2); %

% Intermediate transfer functions
U_S = tf(R_o, [(R_o * C_o), 1]); %
Z_S = tf([(L_a * C_a * L_2 * C_o * R_o), (L_a * L_2 * C_a), (R_o * (L_a * C_o + L_a * C_a + L_2 * C_o)), (L_a + L_2), R_o], [(L_2 * C_o * C_a * R_o), (L_2 * C_a), ((C_a + C_o) * R_o + 1)]); %
E_S = tf([(-4 * L_1 * V_g * C_c * D_fac / (1 + D)), (L_1 * I_g * D_fac), (-D * V_g * D_fac)], 1); %

% Transfer Functions
G_vg = ((1 + D) * U_S) / (2 * D * Z_S);
G_vd = ((1 + D) * U_S * 1) / (2 * D * Z_S);
bode(G_vd);
xlabel('G_vd(s) at V_o = 3.3 V and I_o = 1 A');
grid
```



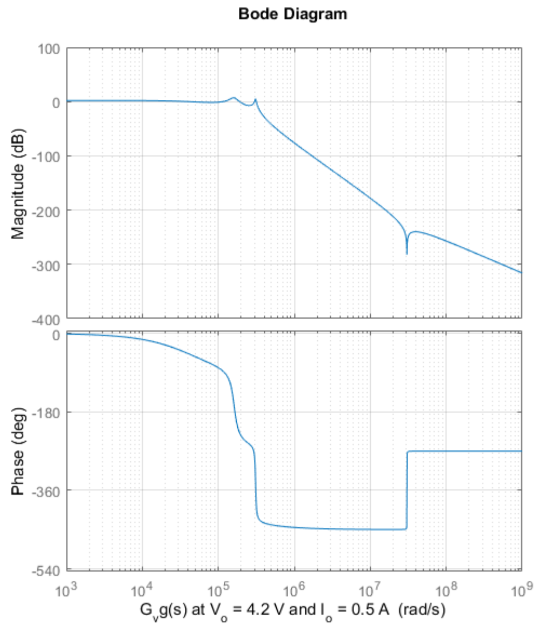
(a) $G_{vg}(s)$ when $V_o = 3.3V$ and $I_o = 1A$



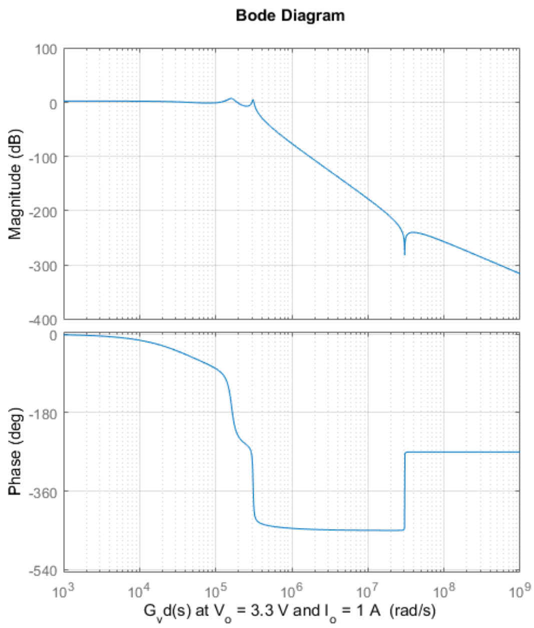
(b) $G_{vg}(s)$ when $V_o = 3.8V$ and $I_o = 1A$



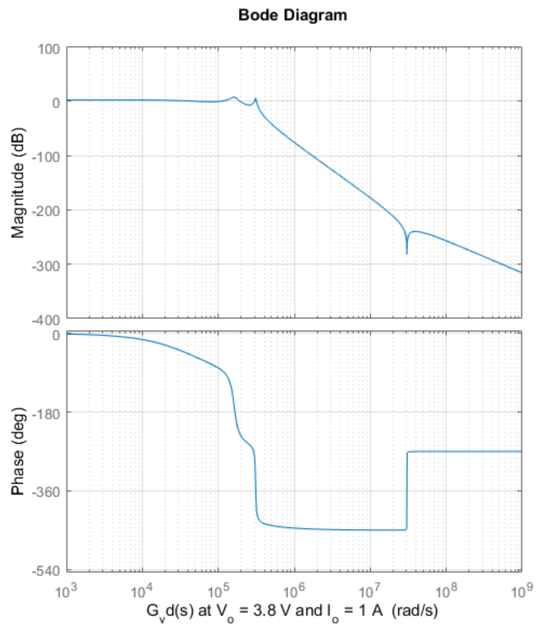
(c) $G_{vg}(s)$ when $V_o = 4.2V$ and $I_o = 1A$



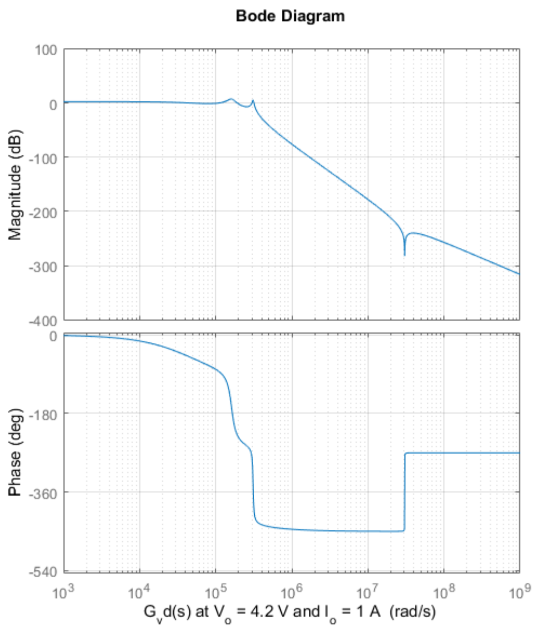
(d) $G_{vg}(s)$ when $V_o = 4.2V$ and $I_o = 0.5A$



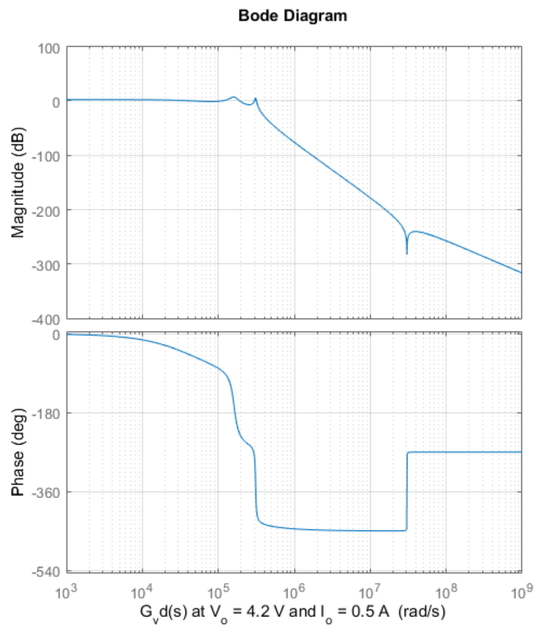
(a) $G_{vd}(s)$ when $V_o = 3.3V$ and $I_o = 1A$



(b) $G_{vd}(s)$ when $V_o = 3.8V$ and $I_o = 1A$



(c) $G_{vd}(s)$ when $V_o = 4.2V$ and $I_o = 1A$



(d) $G_{vd}(s)$ when $V_o = 4.2V$ and $I_o = 0.5A$