

**MIDDLE EAST TECHNICAL UNIVERSITY**

**DEPARTMENT OF ELECTRICAL AND ELECTRONICAL ENGINEERING**

**EE 464 HOMEWORK 3**

**Compensator Design for Buck Converter**

**Student 1:** Erdem Canaz 2374676

**GitHub Page:** https://github.com/erdemcanaz/EE464-HW3

**Submission Date:** 24.05.2024

**Introduction**

You are required to design a 200 W full bridge isolating converter with 24 Vin and 200 Vout with 1% output voltage ripple. Switching frequency of the converter is 250kHz

**Question 1:**

*Explain the meaning of input-to-output transfer function and control-to-output transfer function in words.*

In this context, the input-to-output transfer function refers to the relationship between the input voltage (i.e Vin) and the output voltage (i.e. Vout). On the other hand, the control-to-output transfer function describes the relationship between the control signal (such as the duty cycle) and the output voltage Vout.

**Question 2:**

*Obtain the bode plot for control-to-output transfer function of buck converter with and without ESR (rC ) on single graph on MATLAB. How do nonidealities affect the characteristic? Comment on phase margin & gain margin.*

* *L = 8 uH,*
* *C = 8 uF,*
* *rC = 15 mohm*
* *VIN = 5 V*
* *Vo= 3.3 V*
* *Io = 4 A*
* *fsw = 250 kHz*
* *Vref = 1.2 V*
* *Vosc= 1.8 V*

****

The bode plot of the given control-to-output transfer function Gp(s) of the buck converter with and without the ESR can be found in Fig. 1. The MATLAB script used can be found in Appendix I.

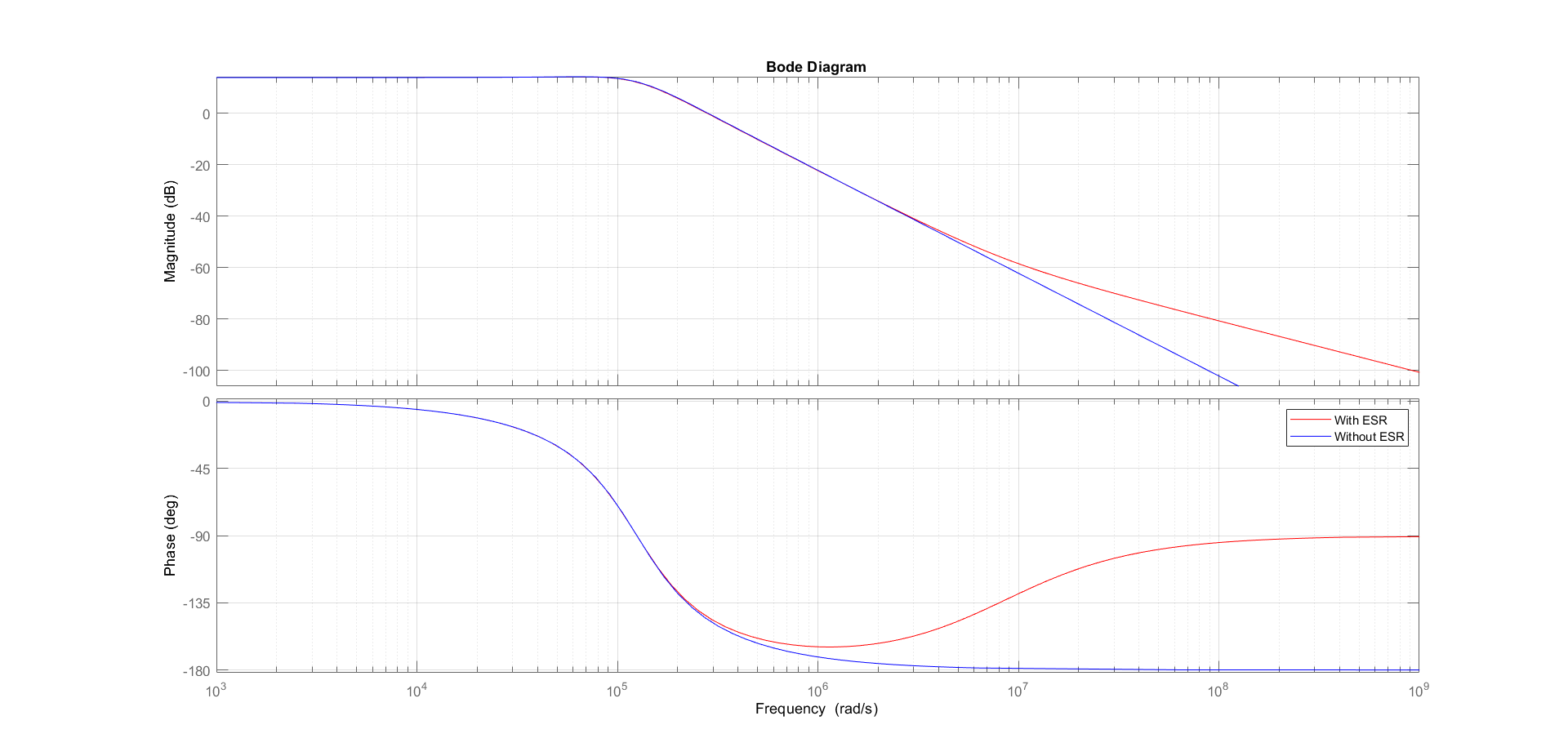


Figure 1 The bode plot of the control-to-output transfer function of the buck converter with and without the ESR

**The main differences between circuits with/without the ESR is, a zero is introduced at around 107 rad/s**. It causes a change in the slope of the magnitude and phase angle behaviors. Lets say magnitude G is;. Gp(s) is of the form

We may replace s with (jw)

Then can be found as;

We can assume the modulus of a complex number can be approximated solely as either real or complex part provided one is much greater magnitude wise (i.e. 10 times). Then the contribution of zero introduced due to ESR can be written as.

It can be further simplified as;

It is obvious that the contribution is zero until . Then it contributes 20dB per decade. Resulting in -40dB/dec slope to become -20dB/dec. For the phase discussion, one can simply consider any complex number as a complex exponential. Knowing real numbers are of the form Ae0 and complex ones are Aei, we can simplify ESR contribution to phase as follows;

Both of gain and phase discussions are well seen in the Fig. 1.

Using MATLAB’s built-in function, gain margins are calculated as infinity for both and phase margins are calculated as and for with and without ESR cases respectively.

The Difference in the phase margins is due to introduced zero has a positive contribution to phase even when .

**Question 3:**

*Identify the pole and zero frequencies for non-ideal buck converter. List them from lower to higher including switching frequency.*

The compact form of the *Gp,ESR(s)* is

The root that make numerator zero is

Whereas roots that make denominator zero are

The frequencies of zeros and poles than found to be

The switching frequency is

Then;

One can use below formulas for the frequency of the poles and zeros directly. [REFERENCE]

*You need to design two different compensators for this application and then you will compare. You can choose different crossover frequencies for two compensators or you can design two compensators with different phase-gain margins having same crossover frequency. It is advised you to apply different options and observe the bode plots and performances. At the end you need to report two of the options and compare performances. Final designs should be stable. An example of a compensator is given in Fig. X.*

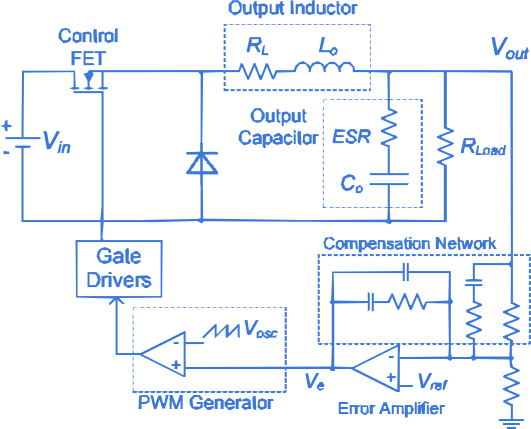
**

Figure x - Simplified circuit diagram of a buck converter with a voltage mode error-amplifier

**Question 4:**

*What does a crossover frequency mean? What is the typical limit for a crossover frequency? Select a crossover frequency for your application, give your reasoning.*

In the application note[REFERENCE], the term “crossover frequency,” also known as the “bandwidth of the loop,” is defined as the point where the open-loop gain of the system equals 0 dB (unity gain). The selection of the crossover frequency is influenced by two factors: the desired response speed to transient changes and the need for effective filtering of switching noise. A higher crossover frequency leads to a faster response, while a lower crossover frequency results in better noise filtering. These two parameters inherently involve a tradeoff; improving one typically compromises the other. It is recommended that the crossover frequency be set between 1/10 to 1/5 of the switching frequency for practical applications. Since the switching frequency is 250kHz, one can choose crossover frequency as

**Conclusion**

**Appendix I:** The matlab script to plot bode plot for control-to-output transfer function of buck converter

|  |
| --- |
| clear  clearvars  clc  % Parameters  L\_out = 8e-6; % H  C\_out = 8e-6; % F  R\_c = 15e-3; % Ohm  V\_in = 5; % V  V\_out = 3.3; % V  I\_out = 4; % A  f\_sw = 250e3; % Hz  V\_ref = 1.2; % V  V\_osc = 1.8; % V  %determined variables  R\_load = V\_out/I\_out; % Load resistance  % Transfer function with esr: G\_p\_with\_ESR(s)  numerator\_with\_ESR = V\_in\*R\_load \* [C\_out \* R\_c, 1];  denominator\_with\_ESR = [L\_out \* C\_out \* (R\_load + R\_c), (L\_out + R\_load \* C\_out \* R\_c), R\_load];  G\_p\_with\_ESR = tf(numerator\_with\_ESR, denominator\_with\_ESR);  % Transfer function without esr: G\_p\_without\_ESR(s)  numerator\_without\_ESR = V\_in\*R\_load \* [0, 1];  denominator\_without\_ESR = [L\_out \* C\_out \* R\_load, L\_out, R\_load];  G\_p\_without\_ESR = tf(numerator\_without\_ESR, denominator\_without\_ESR);  % Plot Bode plots  figure;  bode(G\_p\_with\_ESR, 'r', G\_p\_without\_ESR, 'b');  legend('With ESR', 'Without ESR');  grid on;  % Display transfer functions as fractions  disp('Transfer function with ESR:');  G\_p\_with\_ESR  disp('Transfer function without ESR:');  G\_p\_without\_ESR  % Gain margin and phase margin  [Gm\_with\_ESR, Pm\_with\_ESR, Wcg\_with\_ESR, Wcp\_with\_ESR] = margin(G\_p\_with\_ESR);  [Gm\_without\_ESR, Pm\_without\_ESR, Wcg\_without\_ESR, Wcp\_without\_ESR] = margin(G\_p\_without\_ESR);  % Display margins  disp('With ESR:');  fprintf('Gain Margin: %.2f dB\n', 20\*log10(Gm\_with\_ESR));  fprintf('Phase Margin: %.2f degrees\n', Pm\_with\_ESR);  disp('Without ESR:');  fprintf('Gain Margin: %.2f dB\n', 20\*log10(Gm\_without\_ESR));  fprintf('Phase Margin: %.2f degrees\n', Pm\_without\_ESR); |