המחלקה להנדסת חשמל
אוניברסיטת בן-גוריון
קורס – "ממירי DC-DC"
361.1.4561

מבחן - מועד א'
6/2/2002

סמסטר א'
תשס"ב (2002)

- כל חומר עזר מותר
- אין להעביר חומר בין הנבחנים
- שימוש במחשבונים כולל מחשב מטלטל מותר

השאלות מתייחסות לדפי מפרט של LM2698.
יש לענות על 3 מתוך 4 השאלות הנתונות.

<u>שאלה מס' 1</u>

השאלה מתייחסת למעגל בעמוד ראשון.

מניחים Vin=4.5V , נגד עומס - 40Ω.

<u>1.1 (50%)</u>
חשב את A_p לסליל בהנחה B_{max}= 0.2 Tesla ;J=4.5 A/mm^2 ; K= .4

<u>1.2 (50%)</u>
בהנחה ש- A_p=245 mm^2 (זו איננה התוצאה הנכונה של סעיף 1.1) ; $l_e = \sqrt{6A_W}$, $\frac{A_W}{A_e} = 5$

והפסדי גרעין לפי: $P = f^2(\Delta B_{pp})^2 10^{-7}$ (mW/cm^3) חשב הפסדי הגרעין.

<u>שאלה מס' 2</u>

השאלה מתייחסת לשרטוט 6 בעמוד 13. מניחים עומס 50Ω ומתקיים: $\frac{i_L}{v_C} = 3\,A/V$ (אות קטן ממוצע)

<u>2.1 (65%)</u>
שרטט A_{OL} ו- 1/β של המערכת ומצא רוחב הסרט של βA_{OL} (f_0).

<u>2.2 (35%)</u>
הסבר איכותית מה התלות של f_0 בנגד העומס ב- CCM ו- DCM.

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<u>שאלה מס' 3</u>

השאלה מתייחסת לשרטוט מס' 7 בעמוד 14.
מניחים שמתח הכניסה – 5V והעומס 10Ω.

<u>3.1 (50%)</u>
שרטט צורת הזרם בכל אחד מהסלילים, בדיודה וצורת המתח ברגל 5 של הבקר.

<u>3.2 (25%)</u>
תן הערכה להפסדי ההולכה במתג ($Rds_{ON} = 0.3\Omega$) ובדיודה ($V_d = 0.4V$).

<u>3.3 (25%)</u>
חשב באיזה הספק מוצא יכנס הממיר למצב DCM (בהזנחת ההפסדים).

<u>שאלה מס' 4</u>

<u>4.1 (33%)</u>
שרטט מעגל ממוצע מקורב של שרטוט מס' 6 בעמוד 13. נגד העומס - 50Ω. מניחים שקבועי המערכת (למשל K_S, M_C) ידועים.

<u>4.2 (33%)</u>
הסבר כיצד תמדוד את הגבר החוג, אימפדנס מוצא (לאות קטן) ודחיית אות AC קטן מפריע בכניסה $\left(\frac{v_O}{v_{IN}}\right)$.

<u>4.3 (34%)</u>
הסבר עקרונית מה הצעדים הדרושים כדי לחלץ ביטוי אנאליטי לפונקצית התמסורת $\frac{i_L}{v_C}$ (אות קטן ממוצע).

Problem 1

$Vin := 4.5V$ $L := 10\mu H$ $mT := 10^{-3}T$

$R_o := 40\Omega$ $Vo := 12V$ $mW := 10^{-3}W$

1.1

Find Ap for the inductor. Assume $K := 0.4$, $J := 4.5\frac{A}{mm^2}$, $Bmax := 0.2T$

$$A_p = A_w \cdot A_e = \frac{L \cdot Ipk \cdot Irms}{J \cdot K \cdot Bmax}$$

For Boost topology:

$$\frac{Vo}{Vin} = \frac{1}{1-D}$$

$$D := \frac{Vo - Vin}{Vo} \qquad D = 0.63$$

$$Io := \frac{Vo}{R_o} \qquad Io = 0.3\text{ A}$$

Pin FSLCT is grounded, so switching frequency $f_{sw} := 600kHz$.

$$\Delta I := \frac{Vin \cdot D}{L \cdot f_{sw}} \qquad \Delta I = 0.469\text{ A}$$

Output current for CCM -> DCM condition is $\frac{\Delta I}{2} \cdot (1-D) = 0.088\text{ A} < Io$, so the converter is operating in CCM.

$$Ipk := \frac{Io}{1-D} + \frac{\Delta I}{2} \qquad Ipk = 1.034\text{ A}$$

$$I_{Lav} := \frac{Io}{1-D} \qquad I_{Lav} = 0.8\text{ A}$$

RMS current $Irms = \sqrt{I_{av}^2 + I_{ac}^2}$, for triangular waveshape Iac is approximately $\frac{\Delta I}{\sqrt{12}}$

$$Irms := \sqrt{I_{Lav}^2 + \frac{\Delta I^2}{12}} \qquad Irms = 0.811\text{ A}$$

$$A_p := \frac{L \cdot Ipk \cdot Irms}{J \cdot K \cdot Bmax} \qquad A_p = 23.313\,mm^4$$

1.2

Assuming $A_p := 245mm^4$, $l_e = \sqrt{6 \cdot A_w}$, $A_w = 5 \cdot A_e$, find core dissipation if

$$P_v = \left[f^2 \cdot \left(\Delta B_{pp}\right)^2 \cdot 10^{-7}\right] \frac{mW}{cm^3}$$

$$P_{core} = P_v \cdot V_e$$

$$V_e = A_e \cdot l_e = A_e \cdot \sqrt{30 \cdot A_e}$$

$$A_p = A_w \cdot A_e = 5 \cdot A_e^2$$

$$A_e := \sqrt{\frac{A_p}{5}} \qquad A_e = 7\,mm^2$$

$$V_e := A_e \cdot \sqrt{30 \cdot A_e} \qquad V_e = 0.101\,cm^3$$

$$\frac{\Delta B}{Bmax} = \frac{\Delta I}{Ipk}$$

$$\Delta B := Bmax \cdot \frac{\Delta I}{Ipk} \qquad \Delta B = 90.6\,mT$$

$$P_{core} := \left(600 \cdot 10^3\right)^2 \cdot (0.0906)^2 \cdot 10^{-7} \cdot 0.101 \qquad P_{core} = 29.8$$

Core dissipation - 29.8 mW

Problem 2

$R_o := 50\Omega$ $\quad \frac{i_L}{v_c} = 3\frac{A}{V}$ $\quad R_{FB1} := 1M\Omega$ $\quad R_{FB2} := 140k\Omega$

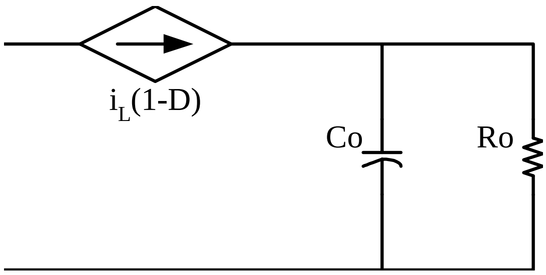
$Vin := 3V$ $\quad Vo := 10V$ $\quad R_c := 20k\Omega$ $\quad C_c := 4.7nF$

$C_o := 10\mu F$ $\quad \mu S := 10^{-6}S$

2.1

Draw A_{OL} and $1/\beta$. Find the bandwidth of βA_{OL} - f_0.

The output filter for small signal is:



Transfer function A_{OL} defined by:

$$A_{OL} = \frac{v_o}{v_c} = \frac{v_o}{i_L}\cdot\frac{i_L}{v_c}$$

$$v_o = i_L\cdot(1-D)\cdot Z_o \qquad Z_o = \frac{1}{\frac{1}{R_o} + j\omega\cdot C_o}$$

$$A_{OL} = \frac{(1-D)\cdot R_o}{1 + j\omega\cdot C_o\cdot R_o}\cdot 3\frac{A}{V}$$

$$D := \frac{Vo - Vin}{Vo}$$

$D = 0.7$

The pole in A_{OL}: $f_p := \frac{1}{2\pi\cdot C_o\cdot R_o}$

$f_p = 318.31\,\text{Hz}$

$$A_{OL}(f) := \frac{(1-D)\cdot R_o}{1 + j\cdot\frac{f}{f_p}}\cdot 3\frac{A}{V}$$

$A_{OL}(0Hz) = 45$

The transconductance of error amplifier $g_m := 135\mu S$

Transfer function of error amplifier with compensation network:

$$\beta_c = \frac{v_c}{v_{FB}} = \frac{i_c \cdot Z_c}{v_{FB}} \qquad \frac{i_c}{v_{FB}} = g_m \qquad Z_c = R_c + \frac{1}{j\omega \cdot C_c}$$

$$\beta_c = g_m \cdot Z_c = g_m \cdot \left(R_c + \frac{1}{j\omega \cdot C_c}\right) = g_m \cdot R_c \cdot \left(1 - j \cdot \frac{f_c}{f}\right)$$

Where $f_c := \frac{1}{2\pi \cdot C_c \cdot R_c}$ $\qquad f_c = 1.693\,kHz$

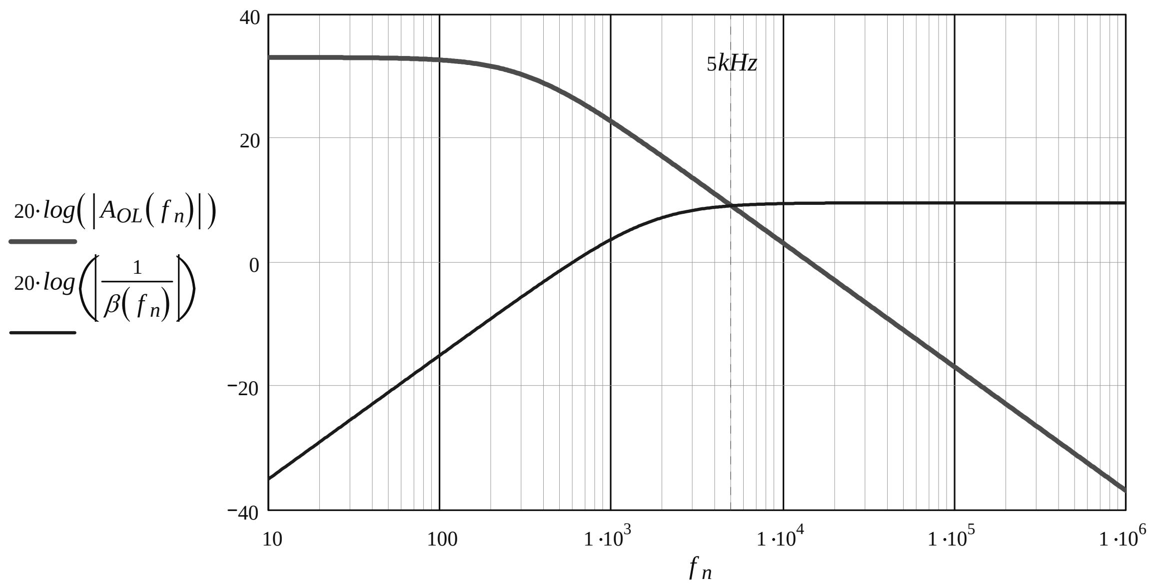
Transfer function β from v_o to v_c:

$$\beta = \beta_c \cdot \frac{v_{FB}}{v_o} = \beta_c \cdot \frac{R_{FB2}}{R_{FB1} + R_{FB2}}$$

$$\beta(f) := g_m \cdot R_c \cdot \frac{R_{FB2}}{R_{FB1} + R_{FB2}} \cdot \left(1 - \mathrm{j} \cdot \frac{f_c}{f}\right)$$

$start := 1 \qquad stop := 6 \qquad N := 100$

$n := start \cdot N \,..\, stop \cdot N \qquad f_n := 10^{\frac{n}{N}} Hz$



The bandwidth of close loop system - $f_o = 5kHz$

2.2

From the equation of A_{OL} it's clear that in CCM, for high frequencies (greater than fp) valid 1/Ro << 2πfCo, Therefore Ro is not effecting f_0.

$$A_{OL} = \frac{(1-D)\cdot R_o}{1 + j\omega\cdot C_o\cdot R_o}\cdot 3\frac{A}{V} = \frac{(1-D)}{\frac{1}{R_o} + j\omega\cdot C_o}\cdot 3\frac{A}{V}$$

In DCM the inductor behaves like current source, that's why Ro has no effect on bandwidth f_0.

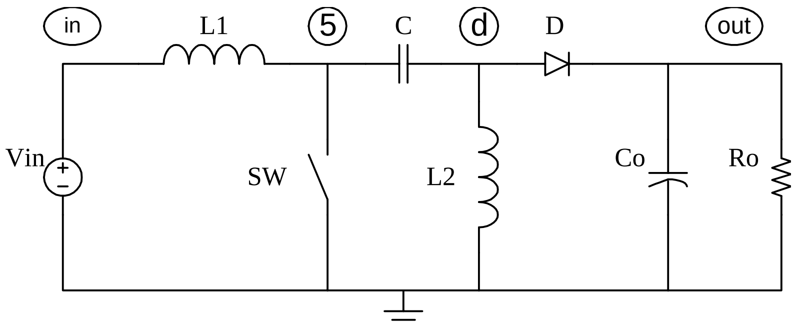
Problem 3

$Vin := 5V$ $\quad Vo := 3.3V$ $\quad L := 10\mu H$

$R_o := 10\Omega$ $\quad Vd := 0.4V$ $\quad f_{sw} := 1.25MHz$

3.1

Draw the waveforms of currents through inductors and diode and voltage on pin 5



Average voltage on both inductors must be zero. Therefore average voltage on the node "5" is Vin and average voltage on the node "d" is zero. Then the average voltage on the capacitor C is Vin.

When the switch is conducting, current through L1 and L2 grows linearly with the slope Vin/L1 and Vin/L2 (voltage on the node "5" is zero and voltage on the node "d" is -Vin).
When the switch is off voltage on the node "5" is Vout + Vd + Vin, therefore the current through L1 decreases linearly with the slope (Vout + Vd)/L1; voltage on the node "d" is Vout + Vd and the current through L2 decreases with the slope (Vout + Vd)/L2.
Average voltage on capacitor C is constant (Vin) therefore average current through it is zero. Then the average current through inductor L2 is equal to the average output current Io.

$$D := \frac{Vo + Vd}{Vin + Vo + Vd} \qquad D = 0.425$$

$$Io := \frac{Vo}{R_o} \qquad Io = 0.33\,A$$

$\Delta I = \Delta I_1 = \Delta I_2$

$\Delta I := \dfrac{Vin \cdot D}{L \cdot f_{sw}}$ $\qquad \Delta I = 0.17\ \text{A}$

$I_2 := Io$ $\qquad I_2 = 0.33\ \text{A}$

Niglecting losses we have:

$I_1 := \dfrac{Vo \cdot Io}{Vin}$ $\qquad I_1 = 0.218\ \text{A}$

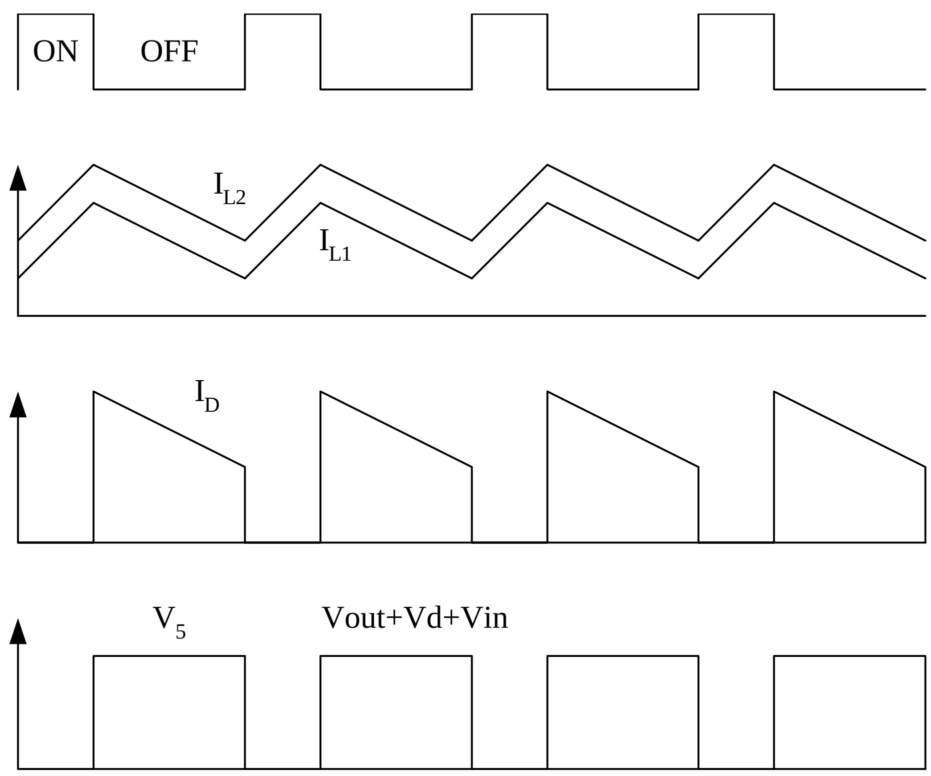
$I_{1pk} := I_1 + \dfrac{\Delta I}{2}$ $\qquad I_{1pk} = 0.303\ \text{A}$

$I_{2pk} := I_2 + \dfrac{\Delta I}{2}$ $\qquad I_{2pk} = 0.415\ \text{A}$

$Id_{pk} := I_{1pk} + I_{2pk}$ $\qquad Id_{pk} = 0.718\ \text{A}$

$\Delta Id := 2\Delta I$ $\qquad \Delta Id = 0.34\ \text{A}$

$V_{5max} := Vo + Vd + Vin$ $\qquad V_{5max} = 8.7\ \text{V}$



3.2

Give estimation for conduction loss in the switch and diode if $Rds_{on} := 0.3\Omega$

The RMS current through the switch:

$$Isw_{rms} := \sqrt{D \cdot \left(I_1^{\,2} + \frac{\Delta I^2}{12} \right)}$$

$$Isw_{rms} = 0.146\ \text{A}$$

$$Psw := Isw_{rms}^{\;2} \cdot Rds_{on}$$

$$Psw = 6.36\ mW$$

The average current through the diode (when the diode is conducting):

$$Id_{av} := \frac{Io}{1 - D}$$

$$Id_{av} = 0.574\ \text{A}$$

$$Pd := Id_{av} \cdot Vd \cdot (1 - D)$$

$$Pd = 132\ mW$$

3.3

What output power will drive the converter into DCM ?

Input average current is less than the output one, therefore L1 will be in DCM first. This happens when

$$I_1 = \frac{\Delta I}{2}$$

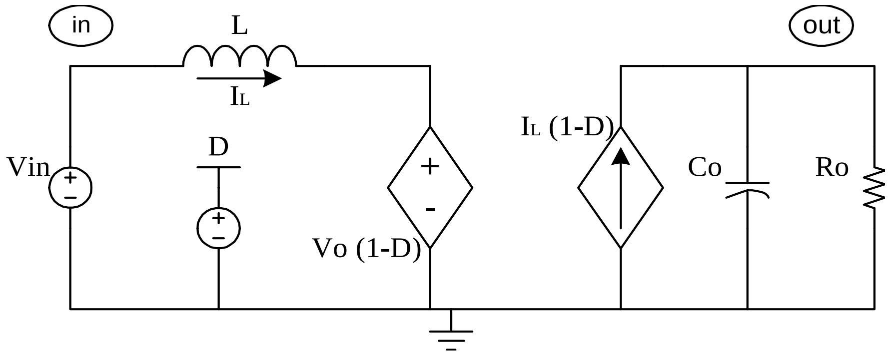
$$Po_{DCM} = Pin_{DCM} = Vin \cdot Iin = Vin \cdot \frac{\Delta I}{2}$$

$$Vin \cdot \frac{\Delta I}{2} = 425\ mW$$

Problem 4

4.1

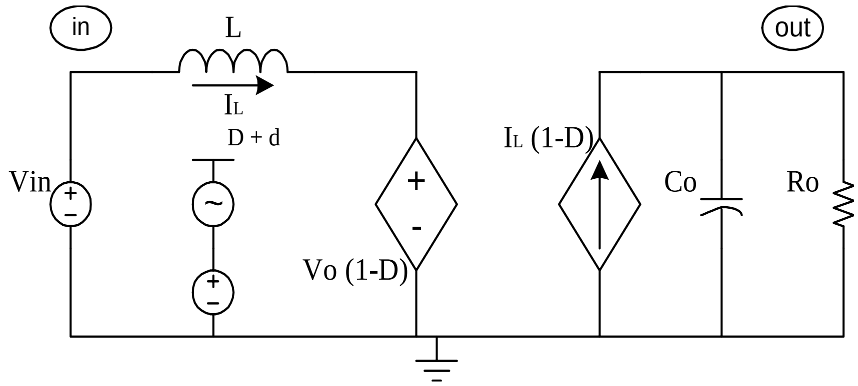
Draw average model for the Boost converter (Fig. 6). Ro = 50Ω, coefficients (like Ks, Mc) are known.



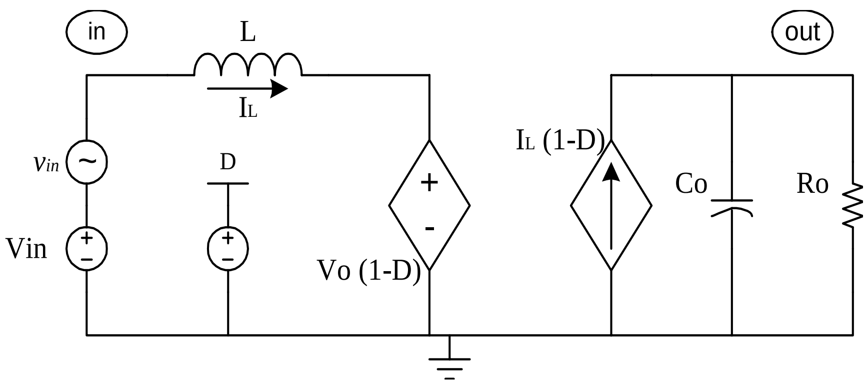
4.2

Explain how to measure transfer function, output impedance and rejection of input AC signal (v_o/v_i).

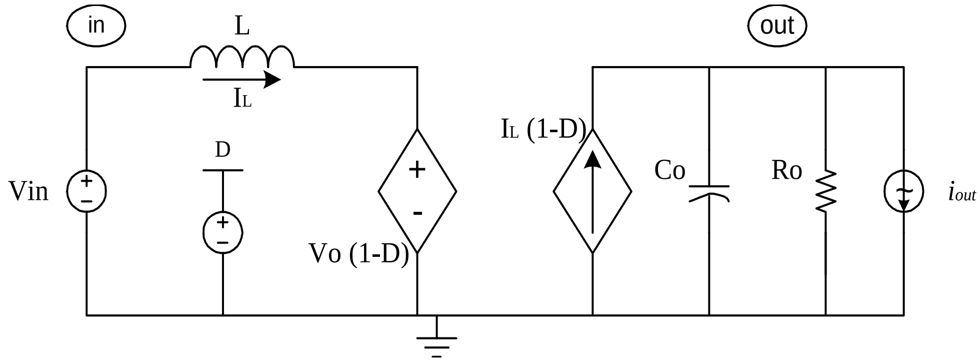
Insert AC sourse in series with operating point DC source of D and measure transfer function v_o/d



Insert AC sourse in series with operating point DC source of Vin and measure rejection of input AC signal v_o/v_i

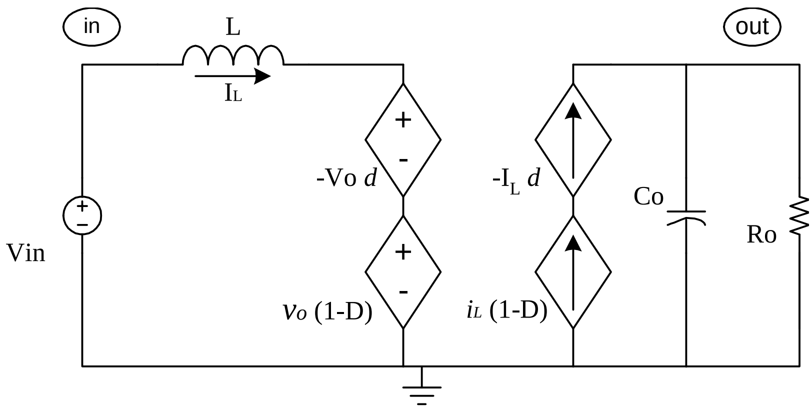


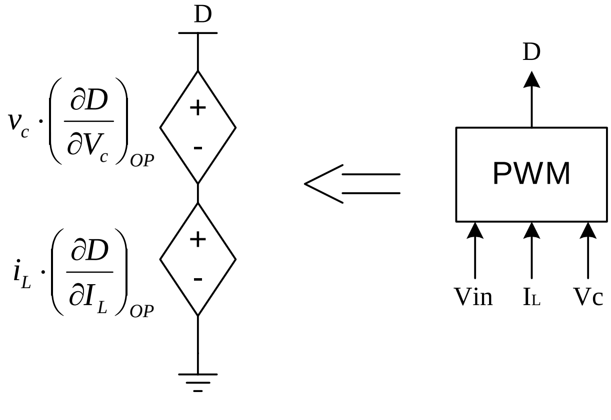
Insert AC sourse in parallel with the DC load and measure output impedance i_o/v_o



4.3

Explain what are the desired steps to derive the analytical expression for transfer function i_L/v_c





Using this circuit with partial derivatives of Vc, IL, VL, ID and Vin (equals tp zero!) in the operating point it's possible to derive the analytical expression for transfer function i_L/v_c .