ELEC-E8417 Switched-Mode Power Supplies **Exam 2.6.2022**

ONLINE EXAM

Question 1

In a Buck converter output voltage U_o = 5 V, supply voltage U_d = 48 V, output power P_o = 5 W, and switching frequency f_s = 50 kHz. Output filter components (L and C) are so large that output current of the converter is ideal dc. Harmonic currents of the supply voltage source are limited, and the switching frequency component can in maximum be 0,3 mA. What is the maximum allowed resonance frequency of the input filter?

Question 2

In a Forward converter output voltage U_o = 5 V, supply voltage U_d = 48 V ± 15 % V, output power 20 W ≤ P_o ≤ 55 W, switching frequency f_s = 100 kHz, and N_1:N_3 = 1. Calculate the minimum value of ratio N_2:N_1 that can be used. Calculate the minimum value of the output filter inductance so that output filter remains in continuous conduction mode.

Question 3

In a Forward converter output voltage U_o = 12 V, supply voltage 200 V ≤ U_d ≤ 320 V, output power 15 W ≤ P_o ≤ 50 W and switching frequency f_s = 50 kHz. The transformer is built from ferrite 3C8 with ETD 34 core. Its volume is 7640 mm^3, effective area 97,1 mm^2 and the smallest surface area of the core is $A_{c,min}$ = 86,6 mm^2. Copper filling factor is assumed to be 0,6 and saturation flux density at 100 ºC is 0,32 T. Calculate the number of turns in the transformer when demagnetization winding N_3 = N_1. Remanence flux density can be assumed to be zero. Primary inductance of the transformer is 10 mH, calculate the needed airgap length.

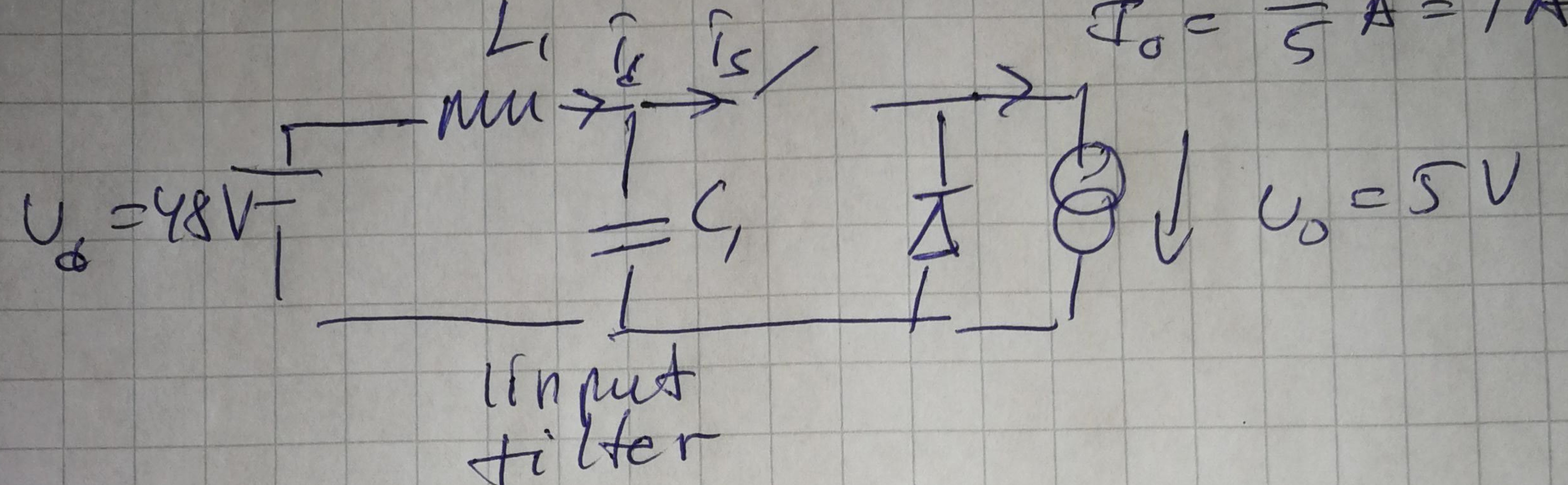
Question 4

Efficiency is important in switched mode power supplies. One part of the losses are the switching losses of the power semiconductor devices. What kind of methods can be used to reduce the losses created by these switches in SMPS. Describe also shortly other sources of losses in SMPS.

Question 5

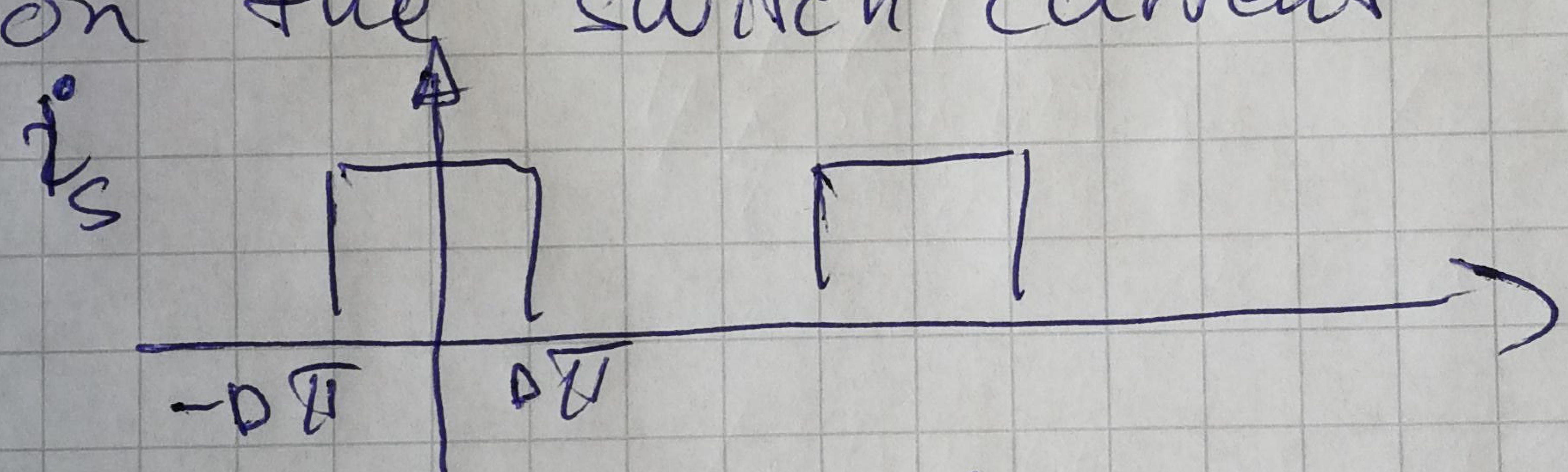
What kind of methods can be used to implement current-mode control in SMPS? What are the advantages of current-mode control when compared to the voltage-mode control (PWM duty ratio control)?

Question 1



$U_o = D U_d \Rightarrow D = \frac{5}{48} \approx 0{,}104$

Current from the supply depends on the switch current i_s

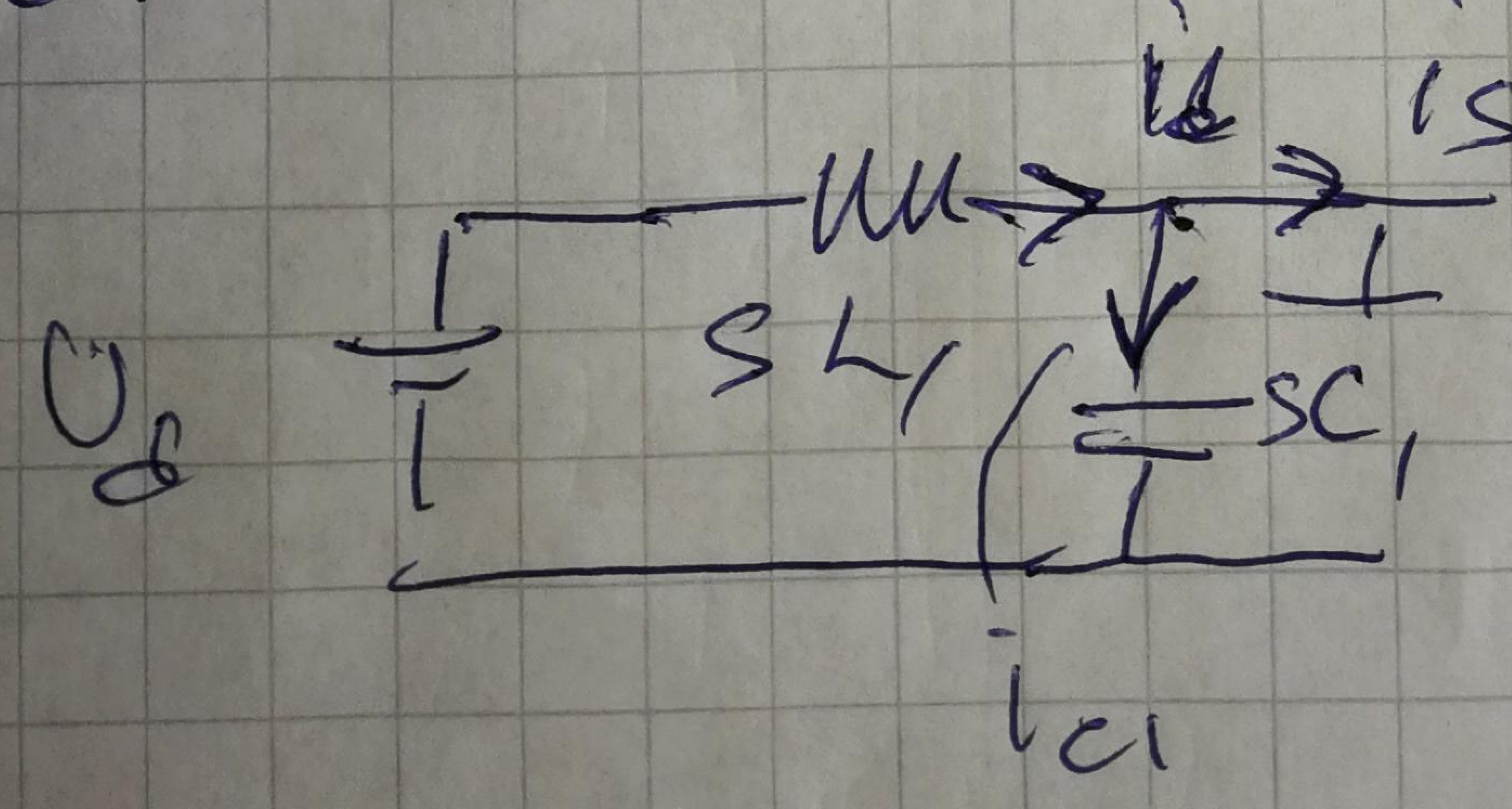


Fourier-series of i_s

$$i_s(x) = D I_o + \frac{2 I_o}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \sin(n D\pi) \sin(nx)$$

Largest value is $n=1$

$$\hat{i}_{d1} = \frac{2 I_o}{\pi} \sin(D\pi) \approx 0{,}2046 A$$



In ac-analysis

$$\frac{i_{C1}(s)}{sC_1} = -i_d(s)\,sL_1$$

$$\Rightarrow \quad i_{C1}(s) = -i_d(s)\,s^2 L_1 C_1$$

For currents

$$i_d(s) = i_S(s) + i_{C1}(s) = i_S(s) - i_d(s)\,s^2 L_1 C_1$$

$$\Rightarrow \quad \frac{i_d(s)}{i_S(s)} = \frac{1}{1+s^2 L_1 C_1} = \frac{1}{1-\left(\frac{\omega}{\omega_{01}}\right)^2}$$

$$\omega_{01} = \frac{1}{\sqrt{L_1 C_1}}$$

Switching frequency component of i_d should be less than 0,3 mA $\Rightarrow$ with absolute values

$$\frac{i_{d1}}{i_{S1}} = \frac{1}{\left|1-\left(\frac{\omega}{\omega_{01}}\right)^2\right|} = \frac{1}{\left(\frac{\omega}{\omega_{01}}\right)^2 - 1}$$

$$\omega_{01} = \omega_S \sqrt{\frac{1}{1+\frac{i_{S1}}{i_{d1}}}} \approx 12\,021 \ \frac{\text{rad}}{\text{s}}$$

Question 2

It has been shown in lecture that in Forward

$$V_o = \frac{N_2}{N_1} D V_d$$

We should be able to get the desired output $V_o = 5V$ with the varying input $V_d = 48 \pm 15\%$
$= 40{,}80V < V_d < 55{,}20V$

Demagnetizing the core requires also $D_{max} = 0{,}5$
Therefore we need to calculate with V_{dmin}

$$\left(\frac{N_2}{N_1}\right)_{min} = \frac{V_o}{D_{max} V_{dmin}} = \frac{5}{0{,}5 \cdot 40{,}80} = \frac{1}{4{,}08} \approx \frac{1}{4}$$

During switch off, i.e $(1-D)T_s$, the output inductor current i_L decreases from the peak value $\hat{I}_L$ to zero.

$$i_L = \hat{I}_L - \frac{V_o}{L}(1-D)T_s = 0$$ as we are in the

borderline of CCM and DCM. Average value of i_L is equal to I_o and thus

$$I_o = \frac{1}{2}\hat{I}_L = \frac{V_o}{2L}(1-D)T_s$$ and then

$$L_{min} = \frac{1-D_{min}}{2 I_{LB,min}} V_o T_s \hat{=} 4 \mu H$$

Question 3

In Forward - converter duty ratio is limited due to the demagnetisation time needed

$$D_{max} = \frac{1}{1+\frac{N_3}{N_1}} = \frac{1}{2}, \quad N_3 = N_1$$

In Forward magnetisation is only in one quadrant and therefore

$$\Delta B_{max} = \frac{B_{sat}}{2}$$

Here input voltage can change and saturation should not occur even with the highest voltage

$$B_{ac} = \frac{B_{sat}}{2} \cdot \frac{V_{d\,min}}{V_{d\,max}} = \frac{0{,}32}{2} \cdot \frac{200}{320} \approx 0{,}1\,T$$

$$v = N \frac{d\phi}{dt} \Rightarrow N = \frac{v\,dt}{\phi} = \frac{U_1\, D\, T_s}{2\, A_{e\,min}\, B_{ac}}$$

$$\approx \sout{102{,}866}\ 115{,}47 \Rightarrow N_1 = 116 \quad U_1 = U_{d\,min}$$

In Forward converter $\frac{U_o}{U_d} = \frac{N_2}{N_1} \cdot D$

$$\Rightarrow N_2 = \frac{U_o}{U_d} \cdot \frac{N_1}{D} = \frac{12}{200} \cdot \frac{\sout{103}\,116}{0{,}5} = \sout{12{,}36}\ 13{,}92 = \sout{13}\ 14$$

$$L_m = \frac{N^2}{R} \quad \text{where } R = \frac{l}{\mu A}$$

and with airgap

$$R = R_m + R_g = \frac{l_e}{\mu A_e} + \frac{l_g}{\mu_0 A_g} = \frac{N^2}{L}$$

$$\Rightarrow l_g = \frac{N^2 \mu_0 A_e}{L} - \frac{l_e}{\mu_r} \qquad A_g \approx A_e$$

μ_r was not given in the question paper, but e.g. from Exercise 4

$$\mu = \mu_r \mu_0 = 5{,}58 \cdot 10^{-3} \frac{Vs}{Am} \Rightarrow \mu_r = 4440$$

$$l_g = 1{,}6 \text{ mm}$$