ELEC-E8417 Switched-Mode Power Supplies **Exam 3.6.2021**

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 Flyback converter output voltage U_o = 5 V, supply voltage 12 V ≤ U_d ≤ 24 V, output power 10 W ≤ P_o ≤ 60 W, switching frequency f_s = 200 kHz, and N_1:N_2 = 1. Calculate the maximum value of the magnetizing inductance of the Flyback transformer so that the converter is always in the complete demagnetization area.

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 °C 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.

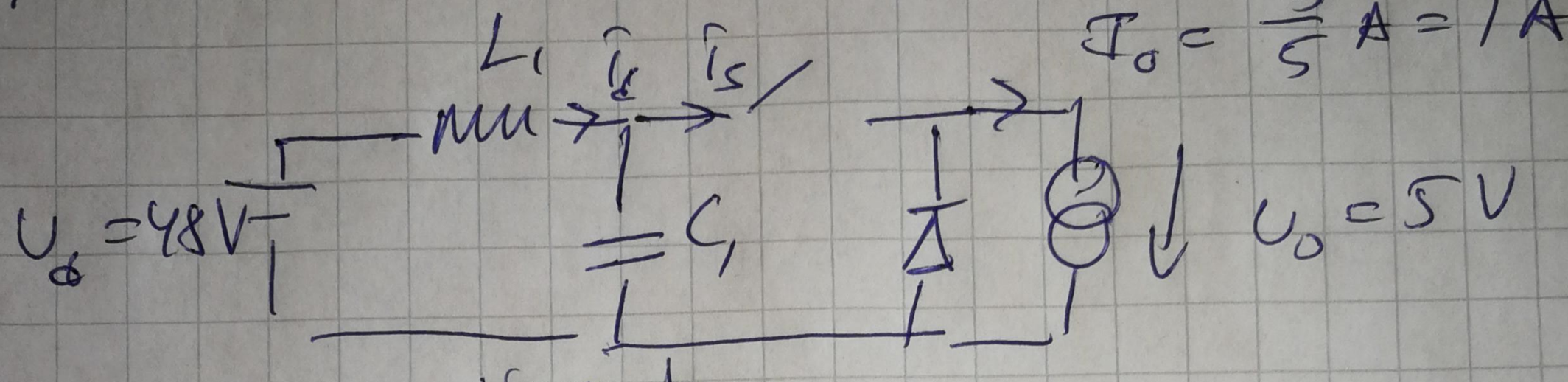
Question 4

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)?

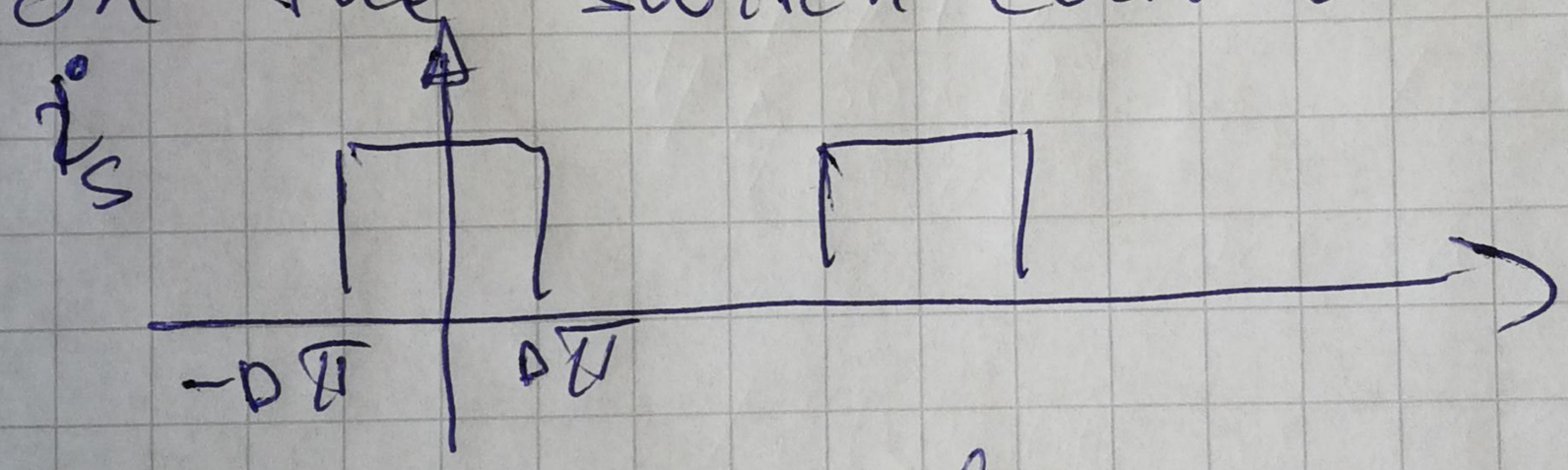
Question 1



$$I_0 = \frac{5}{5} A = 1A$$

$$U_0 = D U_d \Rightarrow D = \frac{4}{48} \approx 0,104$$

Current from the supply depends on the switch current i_s

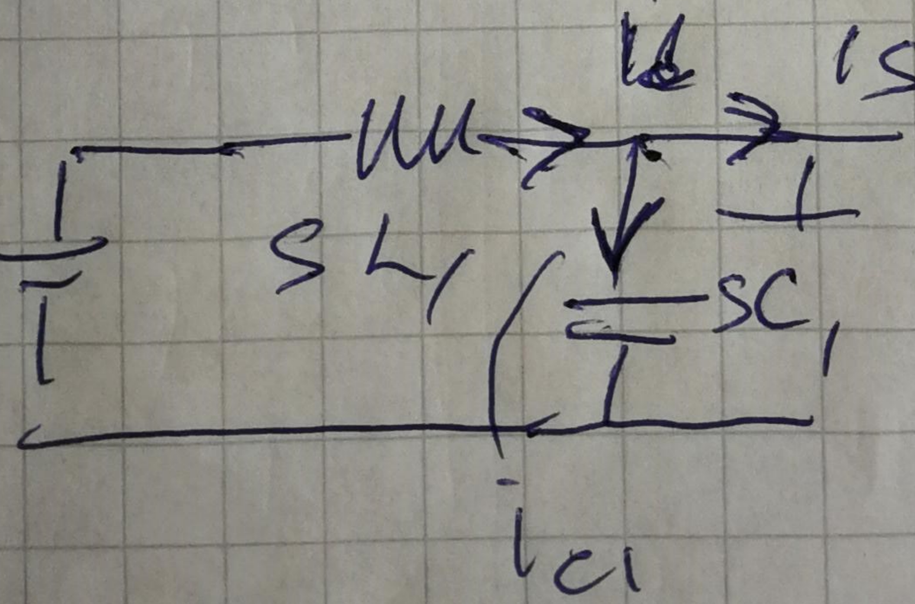


Fourier-series of i_s is

$$i_s(x) = D I_0 + \frac{2 I_0}{\pi} \sum_{n=1}^{\infty} \frac{1}{n} \sin(n D \pi) \sin(n x)$$

Largest value is $n=1$

$$i_{d1} = \frac{2 I_0}{\pi} \sin(D\pi) \approx 0,2046 A$$



In ac-analysis

$$\frac{i_{C_1}(s)}{sC_1} = -i_d(s)sL_1,$$

$$\Rightarrow \quad i_{C_1}(s) = -i_d(s)s^2L_1C_1$$

For currents

$$i_L(s) = i_S(s) + i_{C_1}(s) = i_S(s) - i_d(s)s^2L_1C_1$$

$$\Rightarrow \quad \frac{i_d(s)}{i_S(s)} = \frac{1}{1+s^2L_1C_1} = \frac{1}{1-\left(\frac{\omega}{\omega_{01}}\right)^2}$$

$$\omega_{01} = \frac{1}{\sqrt{L_1C_1}}$$

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

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

$$\omega_{01} = \omega_S\sqrt{\frac{1}{1+\frac{i_{S1}}{i_{d1}}}} \approx 12021\ \frac{\text{rad}}{\text{s}}$$

Question 2

In exercise 7, question 2 it has been shown that in the demagnetising area of Flyback

$$\frac{U_o}{U_d} = D\sqrt{\frac{R}{2L_m f_s}} \quad \text{where } R = \frac{U_o}{I_o}$$

In CCM of Flyback

$$\frac{U_o}{U_d} = \frac{N_2}{N_1}\cdot\frac{D}{1-D} \Rightarrow D = \frac{\frac{N_2}{N_1}\frac{U_d}{U_o}}{1+\frac{N_2}{N_1}\frac{U_d}{U_o}}$$

and in the borderline both comply

$$D\sqrt{\frac{R}{2L_m f_s}} = \frac{N_2}{N_1}\frac{D}{1-D}$$

$$\Rightarrow L_m = \frac{R(1-D)^2}{2 f_s} \quad \text{when } N_2 = N_1$$

Converter should operate always in the complete demagnetization area. Therefore, we need to use the maximum load

$$R_m = \frac{5}{12}$$

If we calculate with minimum duty cycle ($U_{d\,max}$) then L_m would be too large and it would not be in DCM with $U_{d\,min}$

$$D_{max} = \frac{1}{\frac{12}{5}+1} \approx 0{,}29$$ and then

$$L_m = \cancel{24}\ \mu H$$
$$0{,}519\ \mu H$$

Question 2

If not using equation given in Exercise 7, solution can be as follows

Peak current of the output diode is

$$\hat{I}_D = \frac{N_1}{N_2} \frac{V_d}{2m} \Phi T_S$$

Output current at boundary

$$I_{OB} = \frac{1}{2} \hat{I}_D \cdot (1-D) = \frac{1}{2} \frac{N_1}{N_2} \frac{V_d}{2m} D(1-D) T_S$$

$$\frac{V_0}{V_d} = \frac{N_2}{N_1} \frac{D}{1-D} \Rightarrow$$

$$I_{OB} = \frac{1}{2} \left(\frac{N_1}{N_2}\right)^2 \frac{V_d}{2m} (1-D)^2 T_S$$

$$= 0,52 \mu H$$

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

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

$$U = N \frac{d\Phi}{dt} \Rightarrow N = \frac{U dt}{\Phi} = \frac{U_1 \, PT_S}{2 A_{emin} B_{ac}}$$

$$\approx \frac{\cancel{100,866}}{115,47} \Rightarrow N_1 = \cancel{106} \quad U_1 = U_{d\,min}$$

In Forward converter $\frac{U_0}{U_d} = \frac{N_2}{N_1} \cdot D$

$$\Rightarrow N_2 = \frac{U_0}{U_d} \frac{N_1}{D} = \frac{12}{200} \cdot \frac{\cancel{106}\,116}{0,15} = \frac{\cancel{12,36}}{13,92} = \cancel{13}\,14$$

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

and with airgap

$$\mathcal{R}_{ges} = \mathcal{R}_m + \mathcal{R}_g = \frac{l_c}{\mu A_c} + \frac{l_g}{\mu_0 A_j} = \frac{N^2}{L}$$

$$\Rightarrow l_g = \frac{N^2 \mu_0 A_c}{L} - \frac{l_c}{\mu_r} \qquad A_j \approx A_c$$

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

$$\mu = \mu_r \mu_0 = 5{,}88 \cdot 10^{-3} \frac{Vs}{Am} \Rightarrow \mu_r = 4440$$

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