ELEC-E8421 Components of Power Electronics **Exam 10.12.2020**

You should not copy paste material directly from the course material or any other source available electronically when answering the questions. Only data sheets are accepted if they are necessary to explain your numerical answer.

1. Explain shortly (2...4 sentences + possible drawing), what the following terms mean
   - Miller effect
   - Reverse recovery charge
   - SOA
   - Prospective short-circuit current
   - ESR.

2. Describe the construction, functioning principle and properties of IGBT.

3. Discuss filters used for the filtering of EMC, their operating principles and components used.

4. A three-phase full-wave diode rectifier package consists of six diode dies within a single module. DC load current of the rectifier is 100 A and it is assumed to be constant because of the high DC side inductance. The diode on-state voltage is 1 V when it is conducting. The junction-to-case thermal resistance of each die is 0,24 K/W. The module is mounted on a heatsink with a module-to-heatsink contact thermal resistance of 0,2 K/W and a heatsink-to-ambient thermal resistance of 0,1 K/W. The maximum ambient temperature is 30°C.
   a) Calculate the diode junction temperature.
   b) The rectifier lifetime will double when the junction temperature decreases by 10 °C. What is the allowed load current in this case?
   c) If the load current remains at 100 A, what is the needed heatsink when double lifetime is required., i.e. 10 °C lower junction temperature as in a).

5. A step-down dc-dc converter has an inductor made from ferrite toroid TN26/15/10-3C90. When the converter switch is on, there is a 19 V voltage over the inductor for the period of 10 μs and inductor current should increase from zero to 0,5 A peak value during this time.
   a) How many turns you need to build the required inductance?
   b) What is the maximum flux density in the core?
   c) Is this ferrite toroid suitable for the purpose? Give reasoning for your answer, yes or no is not enough.

Ferrite toroids TN26/15/10

RING CORES (TOROIDS)

Effective core parameters

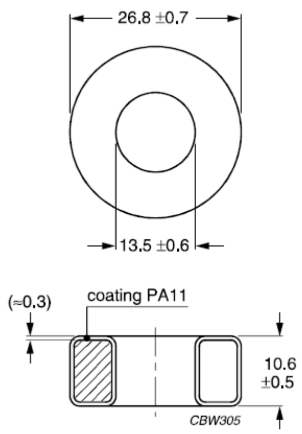
SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	1.08	mm^{-1}
V_e	effective volume	3360	mm^3
l_e	effective length	60.1	mm
A_e	effective area	55.9	mm^2
m	mass of core	≈ 17	g

Coating

The cores are coated with polyamide 11 (PA11), flame retardant in accordance with *"UL 94V-2"*; UL file number E 45228 (M).
The colour is white.
Maximum operating temperature is 160 °C.

Isolation voltage

DC isolation voltage: 2000 V.
Contacts are applied on the edge of the ring core, which is also the critical point for the winding operation.



Dimensions in mm.

Fig.1 TN26/15/10 ring core.

Ring core data

GRADE	A_L (nH)	μ_i	TYPE NUMBER
4A11	817 ± 25%	≈ 700[1]	TN26/15/10-4A11
3C90	2645 ± 25%	≈ 2300	TN26/15/10-3C90
3C11	5000 ± 25%	≈ 4300	TN26/15/10-3C11
3E25	6420 ± 25%	≈ 5500	TN26/15/10-3E25

1. Old permeability specification maintained.

Properties of cores under power conditions

GRADE	B (mT) at	CORE LOSS (W) at	
	H = 250 A/m; f = 25 kHz; T = 100 °C	f = 25 kHz; $\hat{B}$ = 200 mT; T = 100 °C	f = 100 kHz; $\hat{B}$ = 100 mT; T = 100 °C
3C90	≥320	≤ 0.38	≤ 0.38

ELEC-E8421 Components of Power Electronics **Exam 10.12.2020**

Proposed answers

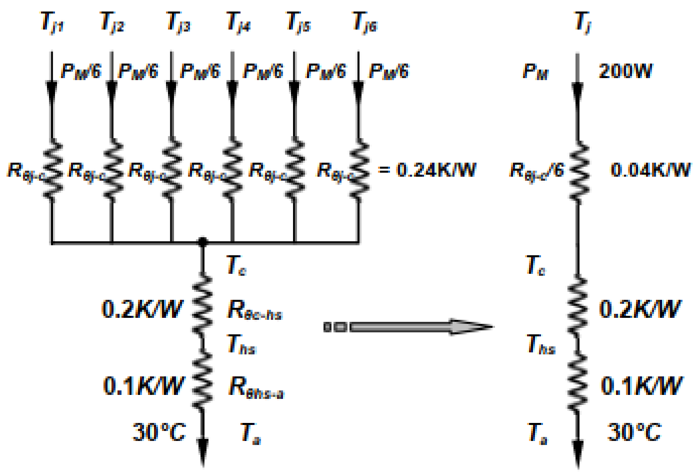
Q1 and Q2, see textbook and slides

Q3 see slides and the extra material

Question 4

The solution is adapted from page 122 of the textbook. During rectification two diodes always conduct therefore total module conduction
losses are
$PM = 2 \cdot I_o \cdot V_{Don} = 2 \cdot 100\text{A} \cdot 1\text{V} = 200$ W

The figure shows how the six thermal paths can be reduced to the simplified equivalent thermal model on the right.



a) Diode junction temperature is

$$T_j - T_a = P_M \times \left(\tfrac{1}{6} R_{\theta j-c} + R_{\theta c-hs} + R_{\theta hs-a}\right)$$

$$T_j - 30°\text{C} = 200\text{W} \times \left(\tfrac{1}{6} \times 0.24\text{K/W} + 0.2\text{K/W} + 0.1\text{K/W}\right) \Rightarrow T_j = 98°\text{C}$$

b) In this case the allowed junction temperature is 88 °C and thus the allowed loss is

$$T_j - T_a = P_M \times \left(\tfrac{1}{6} R_{\theta j-c} + R_{\theta c-hs} + R_{\theta hs-a}\right)$$

$$88°\text{C} - 30°\text{C} = P_M \times \left(\tfrac{1}{6} \times 0.24\text{K/W} + 0.2\text{K/W} + 0.1\text{K/W}\right) \Rightarrow P_M = 170.6\text{W}$$

and the current should be reduced from 100 A to

$$P_M = 2 \times I_o \times V_{Don}$$

$$170.6\text{W} = 2 \times I_o \times 1\text{V} \Rightarrow I_o = 85.3\text{A}$$

c) If current is not reduced to 85,3 A, lifetime can be increased by improving the cooling

$$T_j - T_a = P_M \times \left(\frac{1}{6} R_{\theta j-c} + R_{\theta c-hs} + R_{\theta hs-a} \right)$$

$$88°C - 30°C = 200W \times \left(0.04K/W + 0.2K/W + R_{\theta hs-a} \right)$$

$\Rightarrow R_{\theta hs\text{-}a} = 0{,}05$ K/W

Question 5

The needed inductance value is $L = 19\ \text{V} \cdot 10\ \mu\text{s}/0{,}5\ \text{A} \approx 380\ \mu\text{H}$

a) From the datasheet we can see that the inductance factor $A_L = 2645$ nH and thus the number of turns is obtained from

$$L \approx \frac{\mu_0 N^2}{\frac{l_g}{A_g} + \frac{C_1}{\mu}} = \frac{\mu_0 \mu_e N^2 A_e}{l_e} = A_L N^2$$

and it give N = 12.

b) From the data sheet, A_e =55,9 mm2 and thus

$B = U \cdot t / A_e / N = 19\ \text{V} \cdot 10\ \mu\text{s}/55{,}9\ \text{mm}^2/12 = 280\ \text{mT}$

The same value is of course also obtained from $LI/ A_e /N$

c) The saturation flux density of the core is 320 mT and 280 mT is already quite close to it. Also, the datasheet gives the losses of the core only at 200 mT and 100 mT. The losses might be to high at high switching losses and selection of a larger core could be considered.