Examination	**ENM060 Power Electronic Converters**
Date and time	Tuesday August 25th, 2015, 14:00 – 18:00
Responsible Teacher:	Andreas Karvonen, tel. 0709-524924
Authorised Aids:	Chalmers-approved calculator (Casio FX82..., Texas Instruments Ti-30... and Sharp EL-W531...)
Grades:	U, 3, 4 or 5. (The limit for a 3 on the exam is 20p, a 4 is 30p and 5 is 40p. The maximum number of points is 50.)
Solutions:	Course webpage (Ping-Pong), August 26th 2015
Review of Exam	September 17th and September 21st, 12:00-13:00. Fredrik Lamms Room. Division of Electric Power Engineering (1st floor). From September 22nd 2015, the exams can be picked-up at the exam office, Department of Energy and Environment. Location: EDIT building, Maskingränd 2, 3Ö (east) floor, room 3434A. Opening hours during semesters: Monday-Friday 12:30-14:30

Observe that the questions are not arranged in any kind of order.

On the last pages there are some formulas that can be used in the examination. Always assume steady-state conditions in all tasks unless otherwise stated.

Please, read through the exam before you start.

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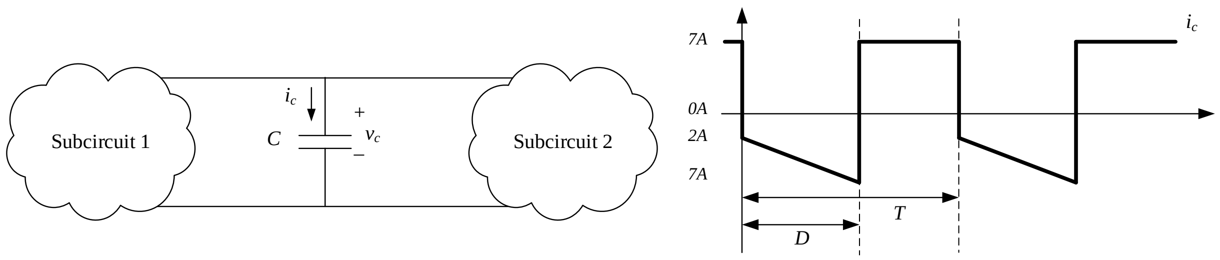
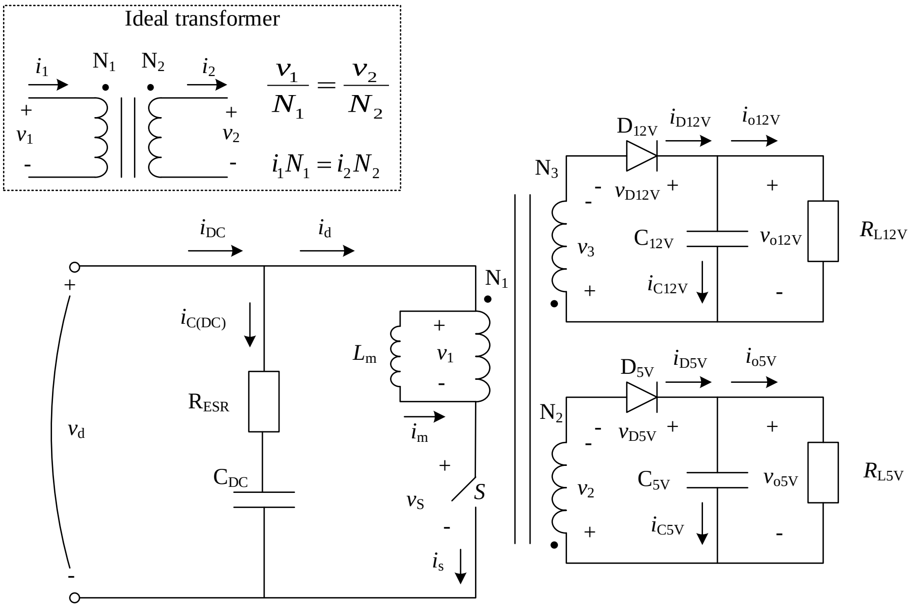
1) For the circuit below with $T = 20\mu s$ and $D = 0.6$, draw the resulting voltage ripple and calculate the capacitance needed if the peak-to-peak voltage ripple is to be lower than 8mV. (3p)



2) A flyback converter in a computer power supply has two secondary windings, see schematic below. Can both outputs be regulated with the duty ratio? If not, motivate which output that should be selected as the controlled one. (2p)

$$f_{sw} = 120kHz$$
$$C_{5V} = 470\mu F \qquad I_{o(5V)} = 0 - 10A$$
$$C_{12V} = 470\mu F \qquad I_{o(12V)} = 0 - 100mA$$

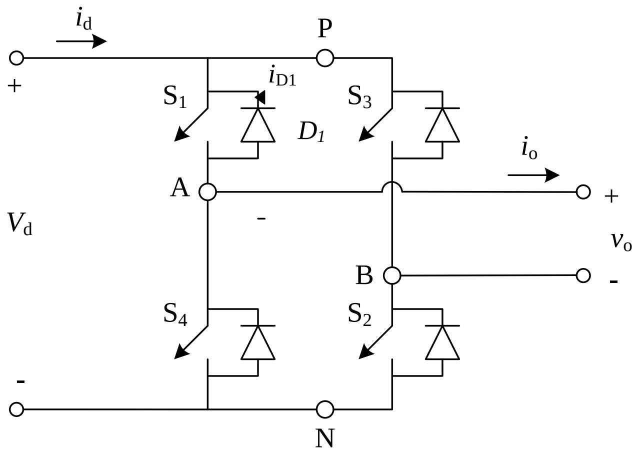


3) **The flyback converter in (2) is designed with a transformer with 1:1:1 turns ratio ($L_m = 70\mu H$). If only the 5V-output is considered at a certain operating point ($I_{o(5V)} = 8A$, $V_d = 30V$, $T_a = 30°C$), the converter will be operating in CCM. Draw the voltage over the diode on the secondary side (v_{D5V}), calculate the power loss in the diode <u>using Simpsons formula</u> and select a suitable diode from the attached datasheets. (6p)**

4) **The Flyback converter in (3) is now used with a varying input voltage $20V \leq V_d \leq 34V$ Calculate the maximum power dissipation in the input capacitor if $R_{ESR} = 175m\Omega$. Assume that the capacitor is so large so that the input voltage is constant and that the input current is a pure DC-current. (5p)**

5) **The transformer in the flyback converter needs to be redesigned. You have two different RM6R-cores made of material 3D3 to choose between; a core with 0.7mm airgap and a core without airgap (see attached datasheet). Calculate the primary magnetizing inductance for both cores if $N_1 = 33$ with <u>both</u> the A_L-value and the reluctance of the core. Which core is most suitable in a flyback transformer? Why? (4p)**

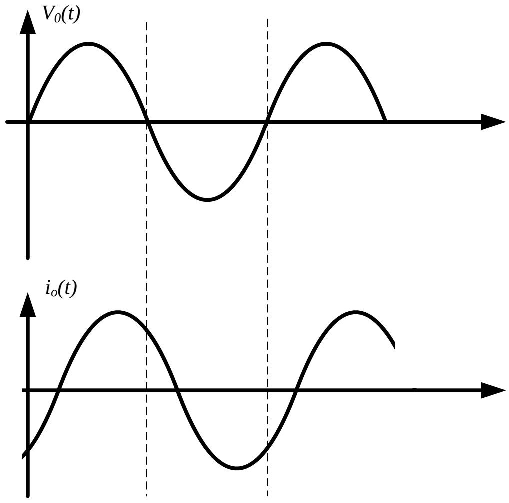
6) **The single phase inverter below is operating in square-wave mode. Draw the output voltage, v_o, the output current, i_o, and the diode current, i_{D1}, waveforms. Calculate also the average diode current, I_{D1}. (4p)**



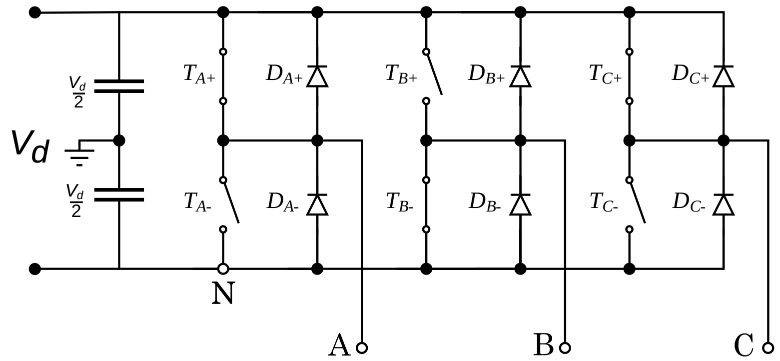
Nominal values for square wave inverter

Source voltage	$V_d = 200V$
Load inductance	$L = 20mH$
Fundamental frequency	$f_{s,1} = 50Hz$

7) Consider a single phase inverter operating in PWM mode without blanking time where the output current is sinusoidal and lagging the voltage, see below. If blanking time is added, how will the output current and voltage be affected? Sketch the resulting waveforms and comment on the harmonic content. (4p)



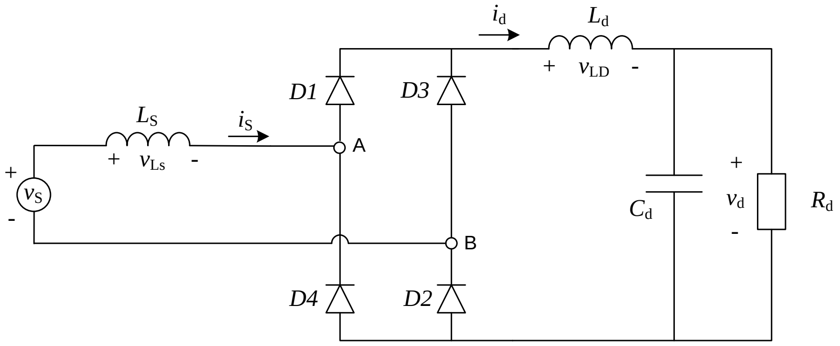
8) The three phase inverter below is operating in square wave mode with $V_d = 250V$ and a fundamental frequency component of 50Hz. Draw the resulting line-to-line voltage and calculate the amplitude of the first 9 harmonic components. (4p)



9) The three phase inverter in (8) is operating in square wave mode ($V_d = 250V$ and $f_0 = 50Hz$) with a purely inductive load ($L = 1mH$). Draw both the input and the output current and calculate the peak ripple in both currents. (5p)

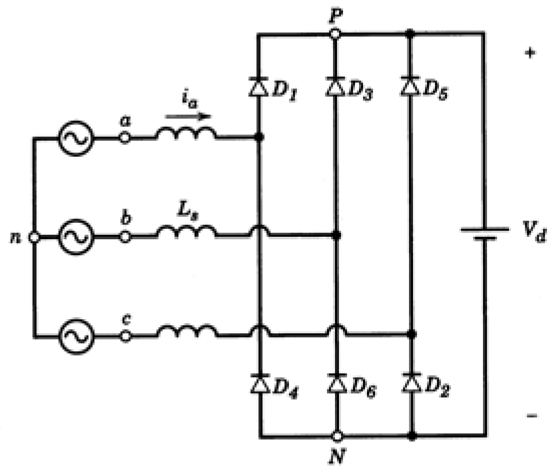
10) If the three phase inverter in (8) is operated with an RL-load, sketch the resulting input and output currents. No absolute values needs to be calculated, just approximate graphs. Compare the active and reactive power transfer to the load with task 10. (3p)

11) **In the single phase diode rectifier below, the DC-side inductance is assumed to be so large that a constant current flows on the DC-side. The AC-voltage is a 50Hz square waveform with an amplitude of 250V, $I_d = 18A$ and $L_S = 820\mu H$. Calculate the commutation angle u and the power dissipation in the load resistor R_d. (3p)**



12) **The diodes in the single phase diode rectifier in (11) are replaced by thyristors. Calculate the required delay angle in order to get an output power of 2kW. Calculation of the commutation angle is needed for full points. (3p)**

13) **The diode rectifier below is supplied with a sinusoidal voltage. The DC-side current is a constant current (I_d), the source voltages are $230V$ ($\pm 5\%$) at $50Hz$ and the source inductance (L_s) is $800\mu H$ in each phase. Calculate the maximum commutation angle and resulting average output voltage (V_d) that is obtained for $P_{DC} = 5kW$. (4p)**



Diode 1:

FAIRCHILD

May 2015

FSV1045V
10 A, 45 V Ultra-Low VF Schottky Rectifier

Features

- Ultra-Low Forward Voltage Drop:
  - 0.41 V Typical at 10 A, T_A = 25°C
  - 0.44 V Maximum at 10 A, T_A = 25°C
- Low Thermal Resistance
- Very Low Profile: Typical Height of 1.1 mm
- RoHS Compliant
- Halogen Free
- Meets MSL 1 per JESD22-A111 Full-Body Solder Immersion

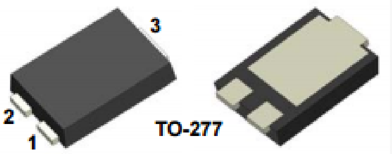
Description

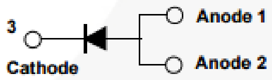
The FSV1045V schottky rectifier offers break-through size and performance. The device is optimized for mobile charger applications. It sinks only 18 mA reverse current at high temperature and provides forward voltage drop of 0.18 V at 1 A operating current in a charger design.

All this capability is packed into a small, flat-lead, TO-277 package, optimized for space-constrained applications. The FSV1045V supports a typical Z height of 1.1 mm. It is RoHS compliant and halogen free. It is also qualified for a wave soldering process.

Applications

- Mobile Charger
- Solar Panel
- Reverse Polarity Protection





Electrical Characteristics

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Conditions		Min.	Typ.	Max.	Unit
V_{BR}	Breakdown Voltage	I_T = 500 µA		45			V
V_F	Forward Voltage Drop	I_F = 1 A	T_A = 25°C		0.28		V
		I_F = 10 A			0.41	0.44	
		I_F = 1 A	T_A = 125°C		0.18		
		I_F = 10 A			0.36	0.39	
I_R	Maximum Leakage	$V = V_{RWM}$	T_A = 25°C		0.065	0.220	mA
			T_A = 125°C		19	32	

Thermal Characteristics(4)

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Minimum Land Pattern	Maximum Land Pattern	Unit
$R_{\theta JA}$	Junction-to-Ambient Thermal Resistance	100	40	°C/W
Ψ_{JL}	Junction-to-Lead Thermal Characteristics, Thermocouple Soldered to Anode	15	12	°C/W
	Junction-to-Lead Thermal Characteristics, Thermocouple Soldered to Cathode	6	5	

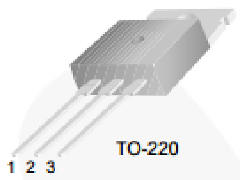
Diode 2:

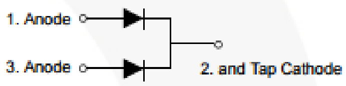
July 2014

MBR20200CT
Dual High Voltage Schottky Rectifier

Features

- Low Forward Voltage Drop
- Low Power Loss and High Efficiency
- High Surge Capability
- RoHS Compliant
- Matte Tin (Sn) Lead Finish
- Terminal Leads Surface is Corrosion Resistant and and able to Withstand to 260°C
- Wave Soldering or per MIL-STD-750 Method 2026.





Thermal Characteristics[1]

Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Value	Unit
$R_{\theta JC}$	Thermal Resistance, Junction-to-Case per Leg	1.5	°C/W
$R_{\theta JA}$	Thermal Resistance, Junction-to-Ambient per Leg	62.5	°C/W

Note:
1. MIL standard 883-1012 and JESD51-10.

$$\boxed{R_{thCA} = 5.9°C/W}$$

Electrical Characteristics[2]

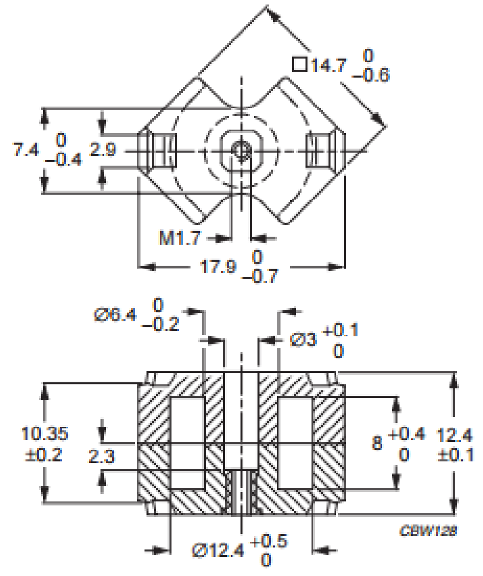
Values are at T_A = 25°C unless otherwise noted.

Symbol	Parameter	Conditions	Min.	Max.	Unit
I_R	Reverse Current	V_R = 200 V, T_C = 25°C		0.2	mA
		V_R = 200 V, T_C = 125°C		2.0	
V_F	Forward Voltage	I_F = 10 A, T_C = 25°C		0.9	V
		I_F = 10 A, T_C = 125°C		0.8	
		I_F = 20 A, T_C = 25°C		1.0	
		I_F = 20 A, T_C = 125°C		0.9	

CORE SETS

Effective core parameters

SYMBOL	PARAMETER	VALUE	UNIT
$\Sigma(l/A)$	core factor (C1)	0.810	mm^{-1}
V_e	effective volume	810	mm^3
l_e	effective length	25.6	mm
A_e	effective area	32.0	mm^2
A_{min}	minimum area	23.8	mm^2
m	mass of set	= 4.5	g



Dimensions in mm.

Fig.1 RM6R core set.

Core sets for filter applications

Clamping force for A_L measurements, 40 ±20 N.

GRADE	A_L (nH)	μ_e	TOTAL AIR GAP (μm)	TYPE NUMBER (WITH NUT)	TYPE NUMBER (WITHOUT NUT)
3D3 sup	40 ±3%	= 26	= 1200	RM6R-3D3-E40/N	RM6R-3D3-E40
	63 ±3%	= 41	= 700	RM6R-3D3-E63/N	RM6R-3D3-E63
	100 ±3%	= 65	= 400	RM6R-3D3-E100/N	RM6R-3D3-E100
	160 ±3%	= 103	= 200	RM6R-3D3-A160/N	RM6R-3D3-A160
	1000 ±25%	= 650	= 0	–	RM6R-3D3
3H3 sup	160 ±3%	= 103	= 230	RM6R-3H3-A160/N	RM6R-3H3-A160
	250 ±3%	= 161	= 110	RM6R-3H3-A250/N	RM6R-3H3-A250
	315 ±3%	= 203	= 90	RM6R-3H3-A315/N	RM6R-3H3-A315
	400 ±3%	= 258	= 70	RM6R-3H3-A400/N	RM6R-3H3-A400
	2200 ±25%	= 1420	= 0	–	RM6R-3H3

Formulas for Examination in Power Electronic Converters (ENM060)

Table 3-1 Use of Symmetry in Fourier Analysis

Symmetry	*Condition Required*	a_h and b_h
Even	$f(-t)=f(t)$	$b_h=0 \quad a_h=\frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\,d(\omega t)$
Odd	$f(-t)=-f(t)$	$a_h=0 \quad b_h=\frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\,d(\omega t)$
Half-wave	$f(t)=-f(t+\frac{1}{2}T)$	$a_h=b_h=0$ for even h $a_h=\frac{2}{\pi}\int_0^{\pi} f(t)\cos(h\omega t)\,d(\omega t)$ for odd h $b_h=\frac{2}{\pi}\int_0^{\pi} f(t)\sin(h\omega t)\,d(\omega t)$ for odd h
Even quarter-wave	Even and half-wave	$b_h=0$ for all h $a_h=\begin{cases}\frac{4}{\pi}\int_0^{\pi/2} f(t)\cos(h\omega t)\,d(\omega t) & \text{for odd } h\\ 0 & \text{for even } h\end{cases}$
Odd quarter-wave	Odd and half-wave	$a_h=0$ for all h $b_h=\begin{cases}\frac{4}{\pi}\int_0^{\pi/2} f(t)\sin(h\omega t)\,d(\omega t) & \text{for odd } h\\ 0 & \text{for even } h\end{cases}$

Definition of RMS-value:

$$F_{RMS}=\sqrt{\frac{1}{T}\int_{t_o}^{t_o+T} f(t)^2dt}$$

Definition of RMS-value with Fourier-series:

$$F_{RMS}=\sqrt{F_0^2+\sum_{n=1}^{\infty}F_n^2}=\sqrt{\left(\frac{a_0}{2}\right)^2+\sum_{n=1}^{\infty}\left(\frac{\sqrt{a_n^2+b_n^2}}{\sqrt{2}}\right)^2}$$

$$\sin^2(\alpha)+\cos^2(\alpha)=1$$

$$\sin(\alpha+\beta)=\sin(\alpha)\cos(\beta)+\cos(\alpha)\sin(\beta) \qquad \sin(\alpha-\beta)=\sin(\alpha)\cos(\beta)-\cos(\alpha)\sin(\beta)$$

$$\cos(\alpha+\beta)=\cos(\alpha)\cos(\beta)-\sin(\alpha)\sin(\beta) \qquad \cos(\alpha-\beta)=\cos(\alpha)\cos(\beta)+\sin(\alpha)\sin(\beta)$$

$$\sin(\alpha)\sin(\beta)=\frac{1}{2}\left(\cos(\alpha-\beta)-\cos(\alpha+\beta)\right) \qquad \sin(\alpha)\cos(\beta)=\frac{1}{2}\left(\sin(\alpha-\beta)+\sin(\alpha+\beta)\right)$$

$$\cos(\alpha)\cos(\beta)=\frac{1}{2}\left(\cos(\alpha-\beta)+\cos(\alpha+\beta)\right)$$

$$\int\sin(ax)dx=-\frac{1}{a}\cos(ax),\ \int x\sin(ax)dx=\frac{1}{a^2}\left(\sin(ax)-ax\cos(ax)\right),\ \int\cos(ax)dx=\frac{1}{a}\sin(ax)$$

$$\int x\cos(ax)dx=\frac{1}{a^2}\left(\cos(ax)+ax\sin(ax)\right)$$

$$PF=\frac{P}{S}=\frac{V_sI_{s1}\cos\phi_1}{V_sI_s},\ DPF=\cos\phi_1,\ \%THD_i=100\frac{I_{dis}}{I_{s1}}=100\frac{\sqrt{I_s^2-I_{s1}^2}}{I_{s1}}=100\sqrt{\sum_{h\neq1}\left(\frac{I_{sh}}{I_{s1}}\right)^2}$$

Electromagnetics

$$e=\frac{d}{dt}\psi \qquad \psi=N\phi \qquad \phi=BA \qquad R=\frac{l}{A\mu_r\mu_0} \qquad L=\frac{\Psi}{i}$$

$$NI=R\phi=mmf \qquad N\phi=LI \qquad L=A_LN^2 \qquad W=\frac{1}{2}LI^2$$

Simpson's rule

Let $f(x)$ be a polynomial of maximum third degree, this means

$$f(x)=a_1+a_2x+a_3x^2+a_4x^3$$

For this function the integral can be calculated as

$$\frac{1}{T}\int_{t_0}^{t_0+T} f(x)dx=\frac{1}{6}\left(f(t_0)+4f(t_0+\frac{T}{2})+f(t_0+T)\right)$$