Politechnika Łódzka, Katedra Mikroelektroniki i Technik Informatycznych

R E P O R T

on Power Devices and Systems laboratory exercise

Exercise 7: Design and Prototyping of a Switched-Mode Power Converter
(Manual 7A ver. 1.8.4, 7C ver. 1.6.1)

Team No.:

Team Members (Given Name, Family Name, Student Book No.):

1.

2.

3.

Design Option Chosen (mark off): Basic — Full

Design Parameters:

f_s = D_{min} = D_{max} =

$I_{R3(av)max}$ = $t_{r(max)}$ = T_1:

Remarks:

1. *The form must be filled in by hand.*
2. *Strike-offs and corrections are allowed provided unambiguity is preserved.*
3. *Include all the formulae used and calculations carried out.*
4. *Final numerical results should be given with units, as numbers from the 0,1…1000 range using unit prefixes.*
5. *Pages that do not apply to the chosen option should be omitted.*
6. *All the attachments should be numbered in a sequence and referred to using this numbering.*
7. *If there is to little space in the form, a separate sheet may be enclosed as an appropriately numbered attachment.*

** Tasks applicable only to the full option. ** Tasks applicable only to the basic option.*

Teacher's Annotations

Board Design

Electronic Design

Testing and Measurements

TASK 1

COMPONENT PLACEMENT AND CONNECTION PLANNING ON THE PCB

Enclose a printout of the Płytka *sheet.* Attachment no. ▷

Enclose a printout of the Weryfikacja *sheet.* Attachment no. ▷

Remarks regarding board design; original solutions that you want to emphasize ▽
In the case of modification of the Węzły schematu *sheet, enclose its printout.*

TASK 2

CIRCUIT CHARACTERISTIC VALUES, UPPER ESTIMATE

Transformer secondary winding rms voltage ▷ $U_{sec(rms)}$ =

Transformer secondary winding voltage amplitude ▷ $U_{sec(m)}$ =

DC chopper input voltage amplitude [upper estimate] ▷ $U_{i(m)}$ ≤

Halogen lamp nominal power ▷ $P_{Lh(nom)}$ =

Halogen lamp nominal (rms) voltage ▷ $U_{Lh(nom)}$ =

Lamp power as function of its resistance (formula) ▷ P_{Lh} =

Halogen lamp resistance ▷ R_{Lh} =

Load current amplitude [upper estimate] ▷ $I_{o(m)}$ ≤

TASK 3*

SHORT-CIRCUIT PROTECTION

Maximum rms load current ▷ $I_{o(rms)max} = I_{o(rms)}\big|_{D=1}$ =

Rms load current at maximum
[required] duty cycle ▷ $I_{o(rms)}\big|_{Dmax}$ =

Optimal fuse link current-time characteristic ▷

Justification ▷

Fuse link designation ▷

Maximum [spread-related] voltage drop across the fuse ▷ $u_{F1(max)}$ =

TASK 4*

RECTIFIER FILTER

Parameters of the VSIN source modelling the secondary winding as entered

▷

Fuse link resistance ▷ R_{F1} =

On-state resistance
of the T_1 transistor ▷ $R_{DS(on)}$ = at a temperature of T_j =

Drain-source leakage current ▷ I_{DSS} = at a voltage of U_{DS} =

Off-state resistance of the T_1 transistor ▷ $R_{DS(off)}$ =

SBREAK switch parameters as entered ▷

Switching period of the switch ▷ $T_s = T_p =$

Switch driving pulse length ▷ $t_p =$

Parameters of the driving VPULSE source as entered ▷

Enclose printout of the schematic entered. Attachment no. ▷

Optimum capacitance of the C_1 capacitor ▷ $C_1 =$

Maximum [within one T_i period] average value of the rectified voltage u_d ▷ $u_{d(av)m} =$

Maximum [within one T_i period] peak-to-peak ripple of the u_d voltage ▷ $\Delta u_{d(pp)m} =$

Relative ripple value ▷ $\Delta u_{d(pp)m}/u_{d(av)m}$ [%] =

Enclose printout(s) of waveforms used to determine u_d parameters and validate C_1 selection.
Attachment no(s). ▷

TASK 5*

CONTROLLER SUPPLY VOLTAGE

Minimum [required] high level of the u_g voltage
based on T_1 transistor's threshold voltage ▷ $U_{GG(on)} > U_{GS(th)} =$

Minimum [required] high level of the u_g voltage
based on T_1 transistor's output characteristic ▷ $U_{GG(on)} \geq$

Maximum [considering current and temperature]
output voltage of the T_1 transistor ▷ $U_{DS}\big|(I_D=I_{o(m)};U_{GS}=U_{GG(on)}) =$

Definitively determined minimum [required]
high level of the gate drive voltage u_g ▷ $U_{GG(on)min}$ =

Minimum [required] supply voltage of the U_1 IC ▷ $U_{CC(min)}$ =

Supply voltage range [recommended] of the U_1 IC ▷ ≤ $U_{CC(rec),U1}$ ≤

Conclusion regarding supply conditions of the U_1 IC and possible design modifications ▽

TASK 6*

CONTROLLER POWER SUPPLY FILTER

Maximum [spread-related] supply current of the U_1 IC ▷ $I_{CC(max),U1}$ =

Maximum [required] (average) current
drawn the generator's auxiliary circuit ▷ $I_{R3(av)max}$ =

Total charge delivered to the T_1 transistor's gate ▷ $Q_{G(tot)}|(U_{GS}=U_{GG(on)min})$ =

Average current delivered to the T_1 transistor's gate ▷ $I_{G(on)av}$ =

Enclose printout of the schematic entered. Attachment no. ▷

Optimum capacitance of the C_3 capacitor ▷ C_3 =

Minimum [control-related] (average) value of the u_{CC} voltage ▷ $U_{CC(min)} = u_{CC(av)}|_{D=1}$ =

Peak-to-peak ripple of the u_{CC} voltage ▷ $\Delta u_{CC(pp)}$ =

Relative peak-to-peak ripple ▷ $\Delta u_{CC(pp)}/u_{CC(av)}$ [%] =

Comparison to the required value of $U_{CC(min)}$, possible design modification ▽

Minimum [control-related] high level
of the generator's output voltage u_g ▷ $U_{GG(on)min} = U_{GG(on)}\big|_{D=1}$ =

Maximum [control-related] (average) value of the u_{CC} voltage ▷ $U_{CC(max)} = u_{CC(av)}\big|_{D=0}$ =

Comparison and conclusion
regarding supply conditions of the U_1 IC ▷

Maximum [control-related] high level
of the generator's output voltage u_g ▷ $U_{GG(on)max} = U_{GG(on)}\big|_{D=0}$ =

Maximum [absolute rated] gate-source voltage of the T_1 transistor ▷ $U_{GS(max,rat)}$ =

Comparison and conclusion
regarding operating conditions of the T_1 transistor ▷

Possible design modifications and results obtained thereafter ▽

Enclose printout(s) of waveforms used to determine parameters of the u_{CC} waveform for all the cases. Attachment no(s). ▷

TASK 7

CONTROLLER SUPPLY VOLTAGE: MAXIMUM ESTIMATION

Maximum [control-related] amplitude of the rectified voltage u_d

▷ $U_{d(m)max} = U_{d(m)}\big|_{io=0}$ =

Maximum [control-related] controller supply voltage

▷ $U_{CC(max)} = U_{CC}\big|_{io=0}$ =

Maximum [control-related] high level
of the generator's output voltage u_g ▷ $U_{GG(on)max} = U_{GG(on)}\big|_{io=0}$ =

TASK 8

RECTIFIED VOLTAGE: MINIMUM AMPLITUDE ESTIMATION

Transformer secondary winding resistance ▷ R_{sec} =

Voltage drop across a single diode of the B_1 bridge ▷ $U_{F,B1}(I_{o(m)})$ =

Minimum [control-related] amplitude of the rectified voltage u_d

▷ $U_{d(m)min}$ =

TASK 9

CONTROLLER SUPPLY VOLTAGE: MINIMUM ESTIMATION

Maximum [required] average current
drawn by the auxiliary circuit of the U_1 IC ▷ $I_{R3(av)max}$ =

Maximum [spread-related] supply current of the U_1 IC ▷ $I_{CC(max),U1}$ =

Total gate charge delivered to the gate of the T_1 transistor ▷ $Q_{G(tot)}|(U_{GS}=U_{CC(max)})$ =

Switching frequency [required] of the T_1 transistor ▷ f_s =

Rectified voltage frequency u_d ▷ f_d =

Charge drawn from the C_3 capacitor within one T_d period

▷ ΔQ_{C3} =

Voltage change across the C_3 capacitor within one T_d period ▷ Δu_{CC} =

Duration of the D_1 diode current flow within one T_d period

▷ $\Delta t_{cond,D1}$ =

Maximum D_1 diode current ▷ $I_{D1(m)}$ =

Voltage drop across the D_1 diode at current maximum ▷ $U_{F,D1}(I_{D1(m)})$ =

Minimum [control-related] controller supply voltage

▷ $U_{CC(min)}$ =

Minimum [control-related] high level
of the generator's output voltage u_g ▷ $U_{GG(on)min}$ =

TASK 10

PULSE WAVE GENERATOR: CALCULATIONS

Maximum [control-related] average current drawn by the generator's auxiliary circuit as function of circuit component values (formula) ▷ $I_{R3(av)max}$ =

Maximum [required] average current drawn by the generator's auxiliary circuit ▷ $I_{R3(av)max}$ =

Minimum [required] resistance of the R_3 resistor ▷ $R_{3(min)}$ =

Equation system to calculate R_4 and R_5 ▽

Total R_4 potentiometer resistance (precise final result) ▷ R_4 =

Resistance of the R_5 resistor (precise final result) ▷ R_5 =

Values as aligned to preferred number series ▷ [R_4] =

▷ [R_3] = ▷ [R_5] =

Capacitance of the C_4 capacitor ▷ C_4 =

Value as aligned to the preferred number series ▷ [C_4] =

TASK 11

PULSE WAVE GENERATOR VERIFICATION

Enclose printout of the completed schematic. Attachment no. ▷

Circuit operating parameters (D – u_g waveform duty cycle; f_p – u_g waveform frequency; $I_{R3(av)}$ – average current drawn by the generator's auxiliary circuit) ∇

Enclose printouts of waveforms used to determine the values given below.

k	D	ΔD	f_p	$\Delta f_p / f_p$	$I_{R3(av)}$	Attachment No(s).
0						
0,5						
1						

Analysis in regard of meeting the design requirements, possible introduced modifications ∇

TASK 12

TRANSISTOR'S GATE CIRCUIT

Maximum [required] rise time for the T_1 transistor ▷ $t_{r(max)}$ =

Gate-drain charge ▷ Q_{GD} =

Plateau voltage of the gate charge characteristic ▷ $U_{GS(pl)}$ =

Maximum [required] gate resistor value

▷ $R_{6(max)}$ =

Value as adjusted to the preferred number series ▷ $[R_6]$ =

Gate current during
the rise time period ▷ $I_G(t_r)$ =

Gate current during
the fall time period ▷ $I_G(t_f)$ =

Current capability of the OUT pin of the U_1 IC

▷ sourced current $I_{OUT(source)max}$ = sunk current $I_{OUT(sink)max}$ =

Comparison and conclusion regarding the possibility of achieving the switching times ▽

Possible design modification and result re-calculation ▽

Definitive rise time ▷ t_r =

Definitive fall time ▷ t_f =

TASK 13

TRANSISTOR VOLTAGE RATING

Maximum [in time, within one T_i period]
off-state voltage across transistor ▷ $U_{DS(off)}$ =

Maximum [absolute rated] drain-source voltage of the T_1 transistor ▷ $U_{DSS(rat)}$ =

Safe operation condition ▷ $U_{DSS(rat)} \geq$

Conclusion on assertion of safe operation ▷

TASK 14

TRANSISTOR POWER LOSS

Maximum [expected] duty cycle ▷ D_{max} =

On-state drain-source resistance of the T_1 transistor

▷ $R_{DS(on)}(T_{j(max)})$ =

Maximum [control-related] amplitude [maximum in time within one T_i period]
of the average [over the T_s period] static power loss

▷ $P_{D(stat)m,max}$ =

Maximum [control-related] amplitude [maximum in time within one T_i period]
of the average [over the T_s period] dynamic power loss

▷ $P_{D(dyn)m,max}$ =

Maximum [control-related] amplitude [maximum in time within one T_i period]
of the total average [over the T_s period] power loss

▷ $P_{D(m,max)wrk}$ =

TASK 15

TRANSISTOR THERMAL SAFETY

Maximum [assumed] ambient temperature ▷ $T_{a(max)}$ =

Maximum [absolute rated] junction temperature for the T_1 transistor ▷ $T_{j(max)}$ =

Junction-ambient thermal resistance
of the T_1 transistor without an external heat sink ▷ $R_{\theta(j-a)}$ =

Maximum [absolute rated] average power loss in the T_1 transistor without an external heat sink

▷ $P_{D(av,max)adm}$ =

Safe operation condition (formula) ▷

Conclusion regarding asserting safe operation ▷

TASK 16

CONTROL CIRCUIT OPERATING CONDITIONS

Range [estimated] of controller supply voltage ▷ ≤ U_{CC} ≤

Range [recommended] of the supply voltage of the U_1 IC ▷ ≤ $U_{CC(rec),U1}$ ≤

Comparison and conclusion regarding supply conditions of the U_1 IC ▷

Range [estimated] of the high level
of the T_1 transistor gate drive voltage u_g ▷ ≤ $U_{GG(on)}$ ≤

Range [spread-related]
of the threshold voltage of the T_1 transistor ▷ ≤ $U_{GS(th)}$ ≤

Comparison and conclusion regarding proper turn-on ▷

Analysis of the operating point of the T_1 transistor for $U_{GS} = U_{GG(on)}$, $I_D = I_{o(m)}$
in respect of mode of operation and output voltage $U_{DS(on)}$ ▽

Maximum [absolute rated] gate-source voltage of the T_1 transistor ▷ $U_{GS(max)rat}$ =

Comparison and conclusion regarding gate safe operation ▷