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Title

R1: BOOST CONVERTER — BASIC DESIGN AND SIMULATIONS

Course Name

EE-365 Power Electronics

Keywords

Boost Converter, PLECS, Semiconductor

TABLE OF CONTENTS

BOOST CONVERTER SIZING

The first part of the project deals with sizing of the main elements of a Boost converter, according to given converter specifications and design requirements. Throughout the whole project continuous conduction mode (CCM) of the converter will be assumed. Fill out Table 1 with the parameters assigned to your group. Regarding the results, please provide them with two digits after the decimal point in the unit provided in the solution box and use the framed boxes below each question to insert your answers and explanations.

Table 1 Given parameters and design requirements for the Boost converter.

Property	Value	Unit
$P_{out,nom}$	50	W
$P_{out,min,CCM}$	10	W
$U_{in,nom}$	21	V
$U_{in,range,rel}$	$\pm$25	%
$U_{in,min}$	15.75	V
$U_{in,max}$	26.25	V
U_{out}	48	V
$\Delta U_{out,pp,rel}$	5	%
f_{sw}	125	kHz

Q1: VOLTAGE TRANSFER FUNCTION

Derive analytically the input-output voltage transfer function $\frac{U_{out}}{U_{in}} = f(D)$ of a Boost converter and solve it for the duty cycle $D = f(U_{in}, U_{out})$.

Since we are working in CCM, we have the following relations:
During t_{on}

$$\begin{aligned} v_L &= V_d \\ i_L &= i_d \\ i_C &= C\frac{dV_o}{dt} = -i_o = -\frac{V_o}{R} \end{aligned} \tag{1}$$

During t_{off}

$$\begin{aligned} v_L &= V_d - V_o \\ i_L &= i_d = i_C + i_o = C\frac{dV_o}{dt} + \frac{V_o}{R} \end{aligned} \tag{2}$$

Then by analyzing the steady state (average voltage across the inductance is zero and average current across the Capacitance is zero), we find

$$\frac{V_o}{V_d} = \frac{1}{1-D} \tag{3}$$

$\frac{U_{in}}{U_{out}}(D) = 1 - D$ | $D = 0,56$ | / 6 pt.

Q2: DUTY CYCLE

Calculate the duty cycle under the following operating conditions:

a) Nominal operation $D|_{U_{in,nom}}$;
b) Minimum input voltage $D|_{U_{in,min}}$;

c) Maximum input voltage $D|_{U_{in,max}}$.

$$D = \frac{V_o - V_{in}}{V_o} \tag{4}$$

and so we calculate the duty cycles with the different values of V_{in}

$D\|_{U_{in,nom}}$ =0,56	$D\|_{U_{in,min}}$ = 0,67	$D\|_{U_{in,max}}$ = 0,45	/ 3 pt.

Q3: INPUT INDUCTANCE

Derive analytically an expression to calculate the minimum input inductance L_{in} of the converter, considering that the Boost converter should operate down to $P_{out,min,CCM}$ in continuous conduction mode. After calculating L_{in}, choose an inductance value that you may want to use in your practical implementation.

Considering worst case operating conditions:

$$L = \frac{V_o}{\Delta I_{L,min}} D(1-D)T_s \tag{5}$$

$$I_{min} = \frac{P_{out,min,CCM}}{V_o(1-D)} \approx 347.2mA \text{ with } D = D_{max} \tag{6}$$

and for the converter to operate in CCM, $\Delta I_L < I_L \cdot 2 = 694.4mA$.

Moreover, $D(1-D)$ *is maximum for* $D = 0.5$

$\implies L = \frac{48}{4 \cdot 700 \cdot 125} \approx 141\mu H$

L_{in} = 141 µH	$L_{selected}$ = 200 µH	/ 7 pt.

Q4: OUTPUT CAPACITANCE

Derive analytically an expression to calculate the required output capacitance C_{out} to fulfill the output voltage ripple requirements under all operating conditions. After calculating C_{out}, choose a capacitance value that you may want to use in your practical implementation.

$$C = \frac{D \cdot T_s \cdot V_o}{R \cdot \Delta V_o} \tag{7}$$

$$= \frac{D \cdot T_s \cdot P_o}{V_o \cdot \Delta V_o} \tag{8}$$

$$= \frac{0.7 \cdot 50}{48 \cdot 2,4 \cdot 125 \cdot 10^3} \tag{9}$$

$$= 2,43\mu\text{F} \tag{10}$$

$$C = \frac{D \cdot T_s \cdot V_o}{R \cdot \Delta V_o} \tag{11}$$

however, $R = \frac{V_o{}^2}{P_o}$ and we want $R_m in$ so we take $P_o min$. Therefore,

$$C = \frac{D_m ax \cdot T_s \cdot P_o}{V_o \cdot \Delta Vo} = 2,43 \quad \mu\text{F} \tag{12}$$

C_{out} = 2,43 µF	$C_{selected}$ = 2,5 µF	/ 7 pt.

Q5: PLECS VALIDATION FOR MAXIMUM INPUT VOLTAGE

Now that you have determined both inductance and capacitance values, enter your parameters from Table 1 into the provided PLECS model of the Boost converter. Verify through simulations the results of Q3 for maximum input voltage (`OP = 2;`). For this purpose, include the following waveforms:

a) Output voltage;
b) Input current;
c) Voltage and current of the transistor;
d) Voltage and current of the diode.

For questions Q5, Q6 and Q7:
Show only three switching periods once the signals have reached their steady state. Additionally, from the scope, provide the measurement of output voltage ripple and minimum input current.

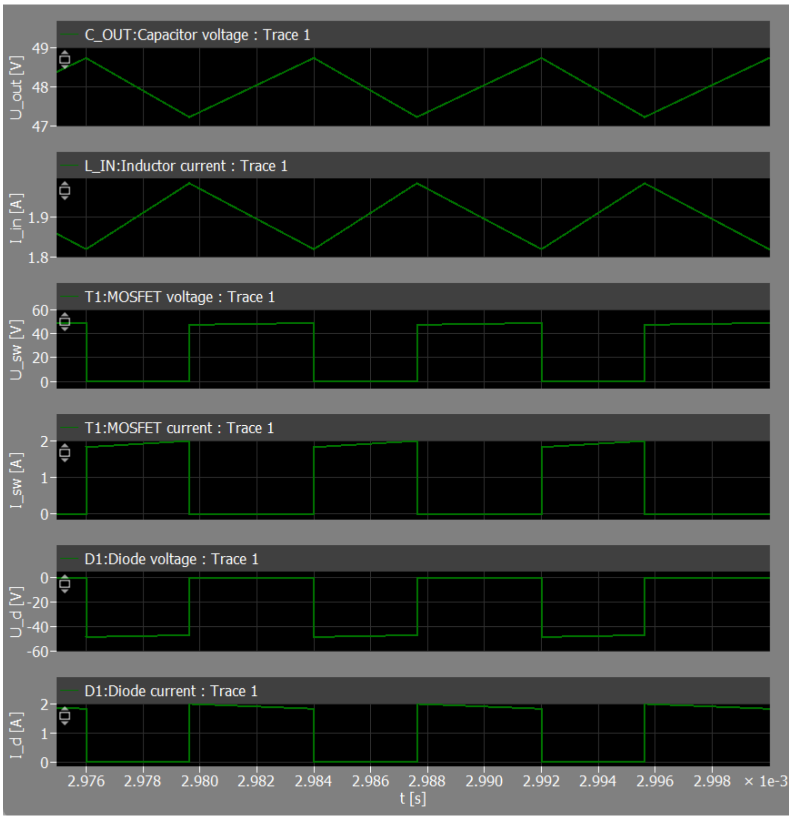


Figure 1 Voltage and current waveforms of interest. From top to bottom: output voltage $U_{out}(t)$, input current $I_{in}(t)$, transistor voltage $U_{sw}(t)$, transistor current $I_{sw}(t)$, diode voltage $U_D(t)$, diode current $I_D(t)$; all as a function of time.

$\Delta U_{out,pp}\big|_{U_{in,max}} = 1.5$ V

$I_{in,min}\big|_{U_{in,max}} = 1.82$ A

/ 4 pt.

Q6: PLECS VALIDATION FOR MINIMUM INPUT VOLTAGE

Using the provided PLECS model, verify through simulations the result of Q4 (`OP = 3;`) for minimum input voltage. For this purpose, include the following waveforms:

a) Output voltage;
b) Input current;
c) Voltage and current of the transistor;
d) Voltage and current of the diode.

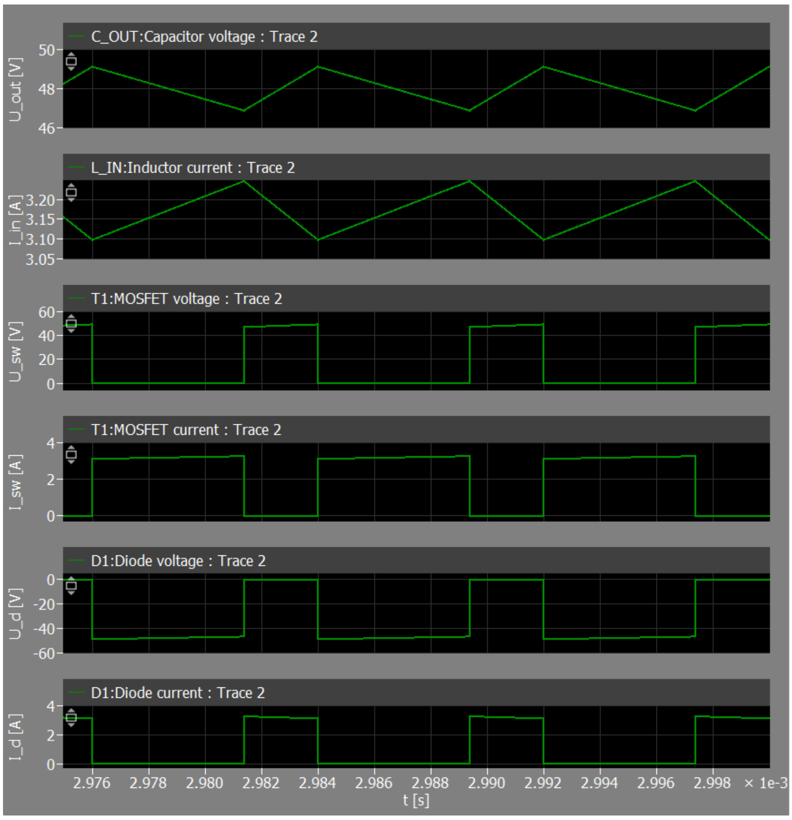


Figure 2 Voltage and current waveforms of interest. From top to bottom: output voltage $U_{out}(t)$, input current $I_{in}(t)$, transistor voltage $U_{sw}(t)$, transistor current $I_{sw}(t)$, diode voltage $U_D(t)$, diode current $I_D(t)$; all as a function of time.

$\Delta U_{out,pp}\big|_{U_{in,min}}$ =2.24 V

$I_{in,min}\big|_{U_{in,min}}$ = 3.1 A

/ 4 pt.

Q7: PLECS VALIDATION FOR CCM

Using the provided PLECS model, verify that your design stays in continuous conduction in steady state mode with the converter operating at the minimum allowed averaged output power (`OP = 4;`) by presenting the following waveforms over five switching periods:

a) Output voltage;
b) Inductor current;
c) Voltage and current of the transistor;
d) Voltage and current of the diode.

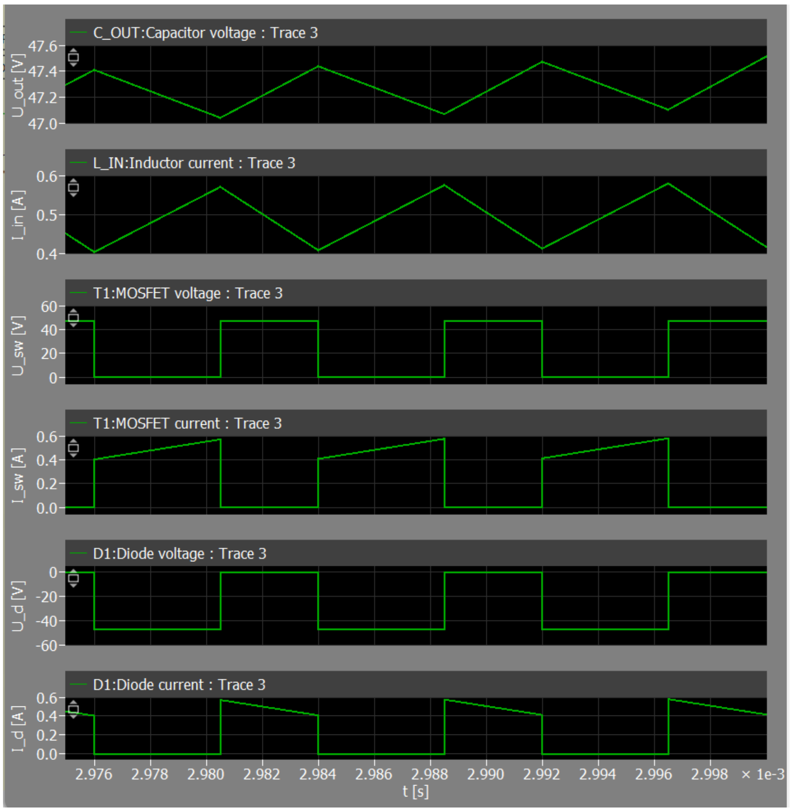


Figure 3 Voltage and current waveforms of interest. From top to bottom: output voltage $U_{out}(t)$, input current $I_{in}(t)$, transistor voltage $U_{sw}(t)$, transistor current $I_{sw}(t)$, diode voltage $U_D(t)$, diode current $I_D(t)$; all as a function of time.

$\Delta U_{out,pp}\big\vert_{P_{out,min,CCM}}$ = 370 mV	$I_{in,min}\big\vert_{P_{out,min,CCM}}$ = 410 mA	/ 4 pt.

SEMICONDUCTOR COMPONENTS

The second part of this report focuses on the semiconductors. You will have to derive equations for your design, eventually leading to the selection of proper semiconductors that you will use in your design. As in the first set of questions, provide numeric answers with a precision of two digits after the decimal point in the provided unit.

Q8: TRANSISTOR STRESSES

To select an appropriate transistor for your design, you need to determine maximum voltage and current stress that it has to handle in your circuit under the worse case condition of operation. For this purpose, provide with an explanation:

a) The maximum voltage over the transistor $u_{T,max}$;
b) The maximum current flowing through the transistor $i_{T,max}$.

Parasitic effects cause voltage overshoots. Therefore, a good practice is to scale the maximal voltage stress with factor of 1.5 for both components. Use theoretical waveforms or PLECS simulations from the last section.

$$\begin{aligned} u_{T,max} &= u_{o,max} + u_{diode,max} \\ &= 49.2V + 0.7V \approx 51V \end{aligned} \tag{13}$$

$$\begin{aligned} i_{T,max} &= I_{o,max} + \Delta i_{L,max}/2 \\ &= \frac{P_{out,max}}{V_{d,min}} + \Delta i_{L,max}/2 \\ &\frac{50W}{15.75V} + 200mA \\ &\approx 3.4A \end{aligned} \tag{14}$$

$u_{T,max} = 51V$	$i_{T,max} = 3.4A$	/ 5 pt.

Q9: DIODE STRESSES

Similarly to the previous question, in order to rate the diode, the maximum values of voltage and current must be identified. Thus, explaining your reasoning, provide:

a) The maximum voltage over the diode $u_{D,max}$;
b) The maximum current flowing through the diode $i_{D,max}$.

Again, use a scale factor of 1.5 for maximal voltage stress.

$$\begin{aligned} U_{D,max} &= v_{o,mox} \\ &= V_o + \Delta v_o \approx 50V \end{aligned} \tag{15}$$

$$\begin{aligned} i_{D,max} &== \frac{P_{out,max}}{V_{d,min}} + \Delta i_{L,max}/2 \\ &\approx 3.6A \end{aligned} \tag{16}$$

$u_{D,max} = 50V$	$i_{D,max} = 3.4A$	/ 5 pt.

Q10: SEMICONDUCTOR SELECTION

Based on the obtained values from Q8 and Q9, select from the offered lists in Tables 2 and 3 a specific MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) device and a specific diode for your design. Elaborate briefly why you chose exactly these two models and highlight them in the Tables, as it is exemplified for the first device.
Note that due to the low operating voltage, Schottky diodes are offered, and thus reverse recovery is not of concern for the design.
Note also that all devices are built in a TO-220 case, or variant, as shown in Fig. 4.

$$\begin{aligned} U_{D,sel} &= 1.5 \cdot U_{D,max} \approx 75V \\ i_{D,sel} &= 1.5 \cdot i_{D,max} \approx 5.1A \\ U_{T,sel} &= 1.5 \cdot U_{T,max} \approx 76.5V \\ i_{T,sel} &= 1.5 \cdot i_{T,max} \approx 5.1A \end{aligned} \tag{17}$$

MOSFET model No. : 2

Diode model No. : 4

/ 6 pt.

Table 2 The list of offered MOSFET devices. The parameter U_{ds} is the rated drain-source voltage, whereas the I_{cont} stands for continuous drain-source current.

No.	Manufacturer	Product	U_{ds} (V)	I_{cont} @ 100 °C (A)	$R_{ds,on}$ @ 25 °C (mΩ)
1	Nexperia	PSMN034-100PS	100	22	62 (@ 100 °C)
2	Onsemi	FDPF680N10T	100	7.6	68
3	Vishay	SIHF530-GE3	100	10	160
4	Vishay	IRF510PBF	100	4	540
5	Vishay	IRFI510GPBF	100	3.2	540
6	Vishay	IRFZ24PBF-BE3	60	12	100
7	Infineon	IRFZ24NPBF	55	12	70

Table 3 The list of offered Schottky diode devices. The parameter U_{dc} refers to the maximum dc blocking voltage, whereas I_{cont} is the continuous forward current.

No.	Manufacturer	Product	U_{dc} (V)	I_{cont} (A)	U_f @ 25 °C (mV)
1	Rohm	RB088T100NZC9	110	10	870
2	Rohm	RB205T-90NZC9	90	15	780
3	Rohm	RB085T-90NZC9	90	10	830
4	Rohm	RB095T-90NZC9	90	6	750
5	Onsemi	MBR1660	60	16	750
6	Rohm	RB205T-60NZC9	60	15	580
7	Rohm	RB095T-60NZC9	60	6	580
8	Vishay	VFT2045BP	45	20	570
9	Vishay	VS-12TQ045-M3	45	15	560

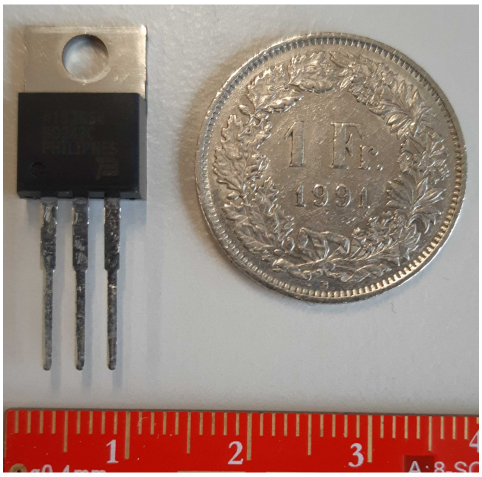


Figure 4 A semiconductor in a TO-220 case.

CALCULATION OF CURRENT AVERAGE AND RMS VALUES

To serve as a basis for the loss calculation using simplified models, expressions for average and RMS currents have to be derived and calculated. Through this section, base your calculations under **nominal operating conditions**.

The results have to be given with two digits after the decimal point using the given unit.

Q11: TRANSISTOR AVERAGE CURRENT

Consider the current passing through the transistor in the steady state operation of the Boost converter. Derive an analytical expression for the average current $I_{T,avg}$. To make the calculations easier, you can assume pulse-shaped waveforms (e.g. neglecting the output voltage ripple).

$$\begin{aligned} I_{D,avg} &= \frac{1}{T}\int_0^{DT} \frac{\Delta I_L}{D\cdot T}\cdot t + I_L - \frac{\Delta I_L}{2}\,dt \\ &= D\cdot I_L \\ &= 1.326\,A \end{aligned} \tag{18}$$

$I_{T,avg}$ = 1.326 A

/ 4 pt.

Q12: TRANSISTOR RMS CURRENT

Consider again the current passing through the transistor. Derive an analytical expression for the RMS current in steady state $I_{T,rms}$, again under the simplified constraints from the previous question.

$$\begin{aligned} I_{D,RMS} &= \sqrt{\frac{1}{T}\int_0^{DT}\left(\frac{\Delta I_L}{D\cdot T}\cdot t + I_L - \frac{\Delta I_L}{2}\right)^2 dt} \\ &= \sqrt{D\cdot\left(\frac{\Delta {I_L}^2}{12} + {I_L}^2\right)} \\ &= 1.77\,A \end{aligned} \tag{19}$$

when taking $\Delta I_L = 0.2 I_L$

$I_{T,rms}$ = 1,77 A

/ 6 pt.

Q13: DIODE AVERAGE CURRENT

Consider now the current passing through the diode in the steady state operation of the Boost converter. Derive an analytical expression for the average current $I_{D,avg}$. Also here, the simplifications can be used.

Taking all values to be at nominal operation. (We have made an implicit change of variable $t = t' - DT$)

$$\begin{aligned}
I_{D,avg} &= \frac{1}{T}\int_0^{(1-D)T} I_L \, dt \\
&= (1-D)I_L \\
&= (1-D)\frac{P_{out}}{U_d} \\
&= 0.4374 \cdot \frac{50W}{21V} \\
&= 1.04A
\end{aligned} \tag{20}$$

inside

$\boxed{I_{D,avg} = 1.04A}$

/ 4 pt.

Q14: DIODE RMS CURRENT

Consider again the current passing through the diode. Derive an analytical expression for the RMS current during steady state $I_{D,rms}$ with the simplified assumptions.

All values are taken at nominal value. (We have made an implicit change of variable $t = t' - DT$)
Using $\Delta i_L^2 << 1$:

$$\begin{aligned}
I_{D,rms} &= \sqrt{\frac{1}{T}\int_0^{(1-D)T} I_L^2\,dt} \\
&= \sqrt{\frac{1}{T}\int_0^{DT} (I_L + (\frac{t}{(1-D)T} - 0.5)\Delta i_L)^2\,dt} \\
&= \sqrt{\frac{1}{T}\int_0^{(1-D)T} I_L^2 + 2I_L(\frac{t}{(1-D)T} - 0.5)\Delta I_L + (\frac{t^2}{(1-D)^2T^2} - 2\frac{t}{DT} + 1)\Delta i_L^2\,dt} \\
&= \sqrt{(1-D)I_L^2 - (1-D)I_L\Delta i_L + (1-D)I_L\Delta i_L} \\
&= \sqrt{(1-D)I_L^2} \\
&= \sqrt{1-D}\frac{P_{out}}{U_d} \\
&= \sqrt{0.4374}\frac{50W}{21V} \\
&= 1.57A
\end{aligned} \tag{21}$$

$I_{D,rms}$ $= 1.57A$

/ 6 pt.

Q15: PLECS VERIFICATION FOR THE CURRENT CALCULATIONS

Using the provided PLECS model, verify your formulas by calculating the values under nominal operation conditions (`OP = 1;`) and comparing them with the model output:

a) The transistor RMS current $I_{T,rms}$;
b) The transistor average current $I_{T,avg}$;
c) The diode RMS current $I_{D,rms}$;
d) The diode average current $I_{D,avg}$.

	Calculated	Plecs simulation
$I_{t,rms}$	1.77 A	1.78 A
$I_{T,avg}$	1.326 A	1.34 A
$I_{D,rms}$	1.57 A	1.6 A
$I_{D,avg}$	1.04 A	1.04 A

We can see that the calculated and simulated values are approximatly equal to one another.

$I_{T,rms}|_{nom}$ =1,78 A

$I_{T,avg}|_{nom}$ = 1,34 A

$I_{D,rms}|_{nom}$ =1,6 A

$I_{D,avg}|_{nom}$ = 1,04 A

/ 4 pt.

THERMAL DESIGN BASED ON THE EXPECTED SEMICONDUCTOR LOSSES

Based on your previously calculated results, losses will be calculated and compared with the provided MATLAB Loss Tool. The results using the worst case (provided by the Loss Tool) will be used to select appropriate heatsinks for your design. As in the other questions, results should be given with two digits after the decimal point in the unit indicated. The Infineon Application Notes may serve you as a guideline for questions Q16, Q17 and Q18.

Q16: DIODE CONDUCTION LOSSES

Using the datasheet of your selected diode as well as the results from your calculations, calculate the diode conduction losses $P_{D,cond}$ at steady state under nominal operating conditions ($U_{in}|_{nom}$ and $P_o|_{nom}$). Note that the datasheet values may not be at the temperature your diode will operate, which is assumed to be 135 °C.

All values taken at nominal operation with diode temperature of 125°C.

$$\begin{aligned} P_{D,cond} &= U_{D,f} I_{D,avg} + R_{D,on} I_{rms}^2 \\ &= U_{D,f} I_{D,avg} + \frac{\Delta U}{\Delta I} I_{rms}^2 \\ &= 600mV \cdot 1.04A + \frac{0.1V}{1A}(1.86A)^2 \\ &= 0.97W \end{aligned} \tag{22}$$

$P_{D,cond}|_{nom}$ = 1 W

/ 7 pt.

Q17: TRANSISTOR CONDUCTION LOSSES

Using the datasheet of your selected transistor as well as the results from your calculations, calculate the transistor conduction losses at steady state under nominal operating conditions $P_{T,cond}|_{nom}$. Identical to the diode, the transistor operates at a temperature of 135 °C.

from the datasheet we can see that

$$R_{DSon}(135\,^\circ\mathrm{C}) = 1,85 \cdot R_{DSon}(25\,^\circ\mathrm{C}) \tag{23}$$
$$= 1,85 \cdot 68 \cdot 10^{-3} \tag{24}$$
$$= 126m\Omega \tag{25}$$
$$\tag{26}$$

and we know that

$$P_{T,cond} = R_{DSon} \cdot I_{T,rms}^2 \tag{27}$$
$$= 126 \cdot 10^{-3} \cdot 1,78^2 \tag{28}$$
$$= 0,4W \tag{29}$$
$$\tag{30}$$

$P_{T,cond}|_{nom}$ = 0, 4 W

/ 7 pt.

Q18: TRANSISTOR SWITCHING LOSSES

Using again the datasheet and your calculation results, calculate the transistor turn-on and turn-off losses $P_{T,on}$, $P_{T,off}$, at steady state under nominal operating conditions. Here it is not the temperature, but the proper scaling of the switching times and electrical values that are crucial.

$$
\begin{aligned}
W_{s,on} &= \frac{t_{ru} + t_{fi}}{2} \cdot U_{dd} \cdot I_{Don} + Q_{rr} \cdot Udd \\
&= \frac{48 \cdot 10^{-9} + 22 \cdot 10^{-9}}{2} \cdot 21 \cdot 2.13 + 35 \cdot 10^{-9} \cdot 21 \\
&= 2.3\,\mu\mathrm{J} \\
W_{s,off} &= \frac{t_{ru} + t_{fi}}{2} \cdot U_{dd} \cdot I_{D_{off}} \\
&\frac{48 \cdot 10^{-9} + 22 \cdot 10^{-9}}{2} \cdot 21 \cdot 2.6 \\
&\approx 1.91\,\mu\mathrm{J} \\
P_s &= \left(W_{s,on} + W_{s,off}\right) f_s \\
&\approx (1.91\,\mu\mathrm{J} + 2.3\,\mu\mathrm{J})\, 125\,\mathrm{kHz} \\
&= 0.525\,\mathrm{W}
\end{aligned} \tag{31}
$$

$P_{T,on}\big\vert_{nom}$ = 0.29 W	$P_{T,off}\big\vert_{nom}$ = 0.24 W	/ 12 pt.

Q19: EFFICIENCY

Now that the losses of the semiconductors are known, calculate the efficiency of your Boost converter under nominal operation $\eta|_{nom}$, when only semiconductor losses are considered. Please note that there will be other losses in your converter that will appear during the design. Nevertheless, semiconductor losses are a good indication of the overall converter performance.

$$
\begin{aligned}
\eta &= \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{T,sw} + P_{T,cond} + P_{D,cond}} \\
&= \frac{50\,\mathrm{W}}{50\,\mathrm{W} + 0.525\,\mathrm{W} + 0.4\,\mathrm{W} + 1\,\mathrm{W}} \\
&= 0.96
\end{aligned} \tag{32}
$$

$\eta\vert_{nom}$ = 0.96	/ 3 pt.

Q20: LOSS TOOL

Considering the output of the provided loss tool in MATLAB, acquire losses for multiple values of U_{in} and P_{out} indicated in Table 1. Add an additional operating point at half of the rated power; i.e., $P_{out} = 25\,\mathrm{W}$ (the loss tool has this operating point by default). From these results, identify the nominal operating point and compare it with your results; comment deviations in case they appear. Additionally, give a brief explanation for why there are more or less losses for different operating conditions.

As input for the loss tool, data from the previous calculations has to be provided. Read the comments in the code carefully to obtain valid results.

It can be observed that all increase as the output power increases. This is the case since the current $I \sim P_{out}$ and $P_{Loss} \sim I^2$. At nominal operating conditions the simulated losses are approximatviely equal to the calculated losses.

The strange value at 22 V for the graph with power $P_{out} = 10$ W is due to the powerloss tool misbehaving on both Linux and Mac. *(At each rerun of the script, a different set of columns would display incorrectly on Mac. On Linux all values are always incorrect.)*

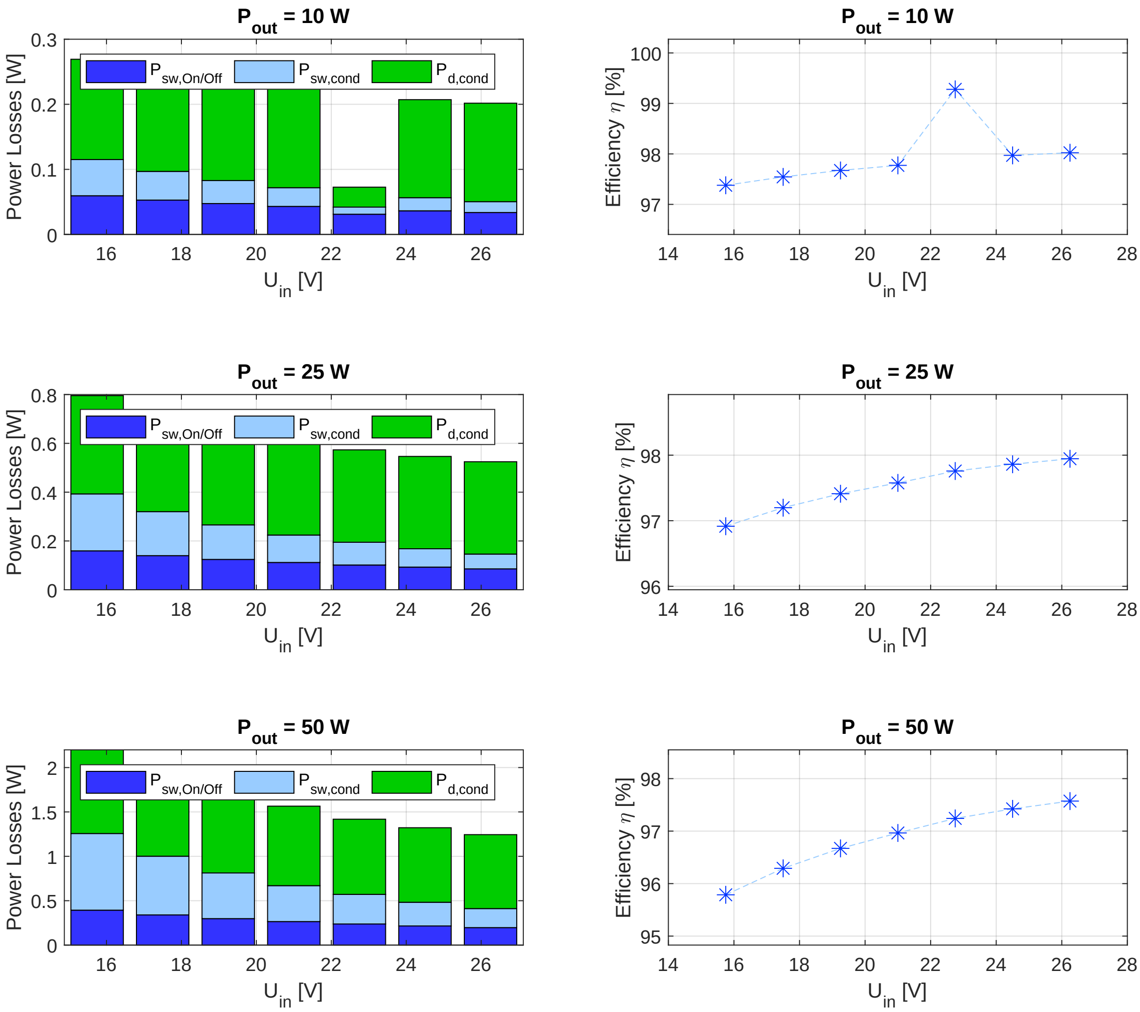


Figure 5 Semiconductor power losses and efficiencies achieved for different operating points.

/ 7 pt.

Q21: TRANSISTOR HEATSINK

To choose a proper heatsink, answer the following questions. For the calculations, assume a maximum ambient temperature of $\vartheta_a = 40\,^\circ\text{C}$, whereas the semiconductor junction temperature should not exceed $\vartheta_j = 135\,^\circ\text{C}$. Please note that there is already a thermal resistance from the junction to the case of the semiconductor.

a) Considering the output of the previous question, determine the worst case operation condition for the transistor in terms of power losses $P_T|_{wc}$.
b) Calculate the maximum allowed heatsink thermal resistance $R_{th,T,c-a}$ (where $_{c-a}$ indicates case to ambient).
c) Based on b), choose a heatsink from the selection provided in Table 4, their profile is also displayed in Fig. 6. Don't forget to highlight your selection in blue, as in Table 2.
d) Once the heatsink is selected, give the expected maximum junction temperature.

You may also consider not using a heatsink for the transistor and/or diode. Nevertheless, your decision should be based on your calculations and factors considered (i.e., temperature margin).

Using the following values:

$$\begin{aligned} R_{th(j-c)} &= 5.2\,^\circ\text{C/W} \\ R_{th(j-a)} &= 62.5\,^\circ\text{C/W} \\ R_{th(c-s)} &\approx 0.1\,^\circ\text{C/W} \\ T_{ambient} &\approx 35\,^\circ\text{C} \\ T_{j,max} &= 135\,^\circ\text{C} \\ P_{loss,max} &= 1.5\,\text{W} \end{aligned} \tag{33}$$

Variant without heat-sink:

$$T_j = T_{ambient} + P_{loss,max} R_{th(j-a)} \approx 130\,^\circ\text{C} \approx T_{j,max} - 5\,^\circ\text{C} \tag{34}$$

Variant with heat-sink:

$$\begin{aligned} T_j &= T_{ambient} + P_{loss,max}\left(R_{th(j-c)} + R_{th(c-s)} + R_{th(s-a)}\right) \le T_{j,max} \\ \Rightarrow R_{th(s-a)} &\le \frac{T_{j,max} - T_{ambient}}{P_{loss,max}} - R_{th(j-c)} - R_{th(c-s)} \\ &\le 60\,^\circ\text{C/W} \end{aligned} \tag{35}$$

Choosing heat-sink s.t. $R_{th(s-a)} = 3\,^\circ\text{C}\,\text{W}^{-1}$ (Aim for ultra low operating temperature)

$$\begin{aligned} \vartheta_{T,j,max} &= T_{ambient} + P_{loss,max}\left(R_{th(j-c)} + R_{th(c-s)} + R_{th(s-a)}\right) \\ &= 48\,^\circ\text{C} \end{aligned} \tag{36}$$

$P_T\|_{wc}$ = 1.5 W	$R_{th,T,c-a}$ = 3 K W^{-1}	MOSFET heatsink model No. : 1	$\vartheta_{T,j,max}$ = 50 °C	/ 7 pt.

Q22: DIODE HEATSINK

Similar to the transistor, a diode heatsink has to be selected. Assuming the same thermal constraints, answer the following questions:

a) Considering the output of the Loss Tool, determine the worst case operation condition for the diode in terms of losses $P_D|_{wc}$.
b) Calculate the maximum allowed heatsink thermal resistance $R_{th,D,c-a}$.
c) Select a suitable heatsink from the selection provided in Table 4 (this time highlight it green as in Table 3).
d) Give the expected maximum junction temperature.

Using the values

$$\begin{aligned} R_{th(j-c)} &= 1.75\,^\circ\mathrm{C/W} \\ R_{th(c-s)} &\approx 0.1\,^\circ\mathrm{C/W} \\ T_{ambient} &= 35\,^\circ\mathrm{C} \\ T_{j,max} &= 135\,^\circ\mathrm{C/W} \\ P_{loss,max} &= 1\,^\circ\mathrm{C/W} \end{aligned} \tag{37}$$

Reusing the equation derived in (35):

$$\begin{aligned} R_{th(s-a} &\leq \frac{T_{j,max} - T_{ambient}}{P_{loss,max}} - R_{th(j-c)} - R_{th(c-s)} \\ &\leq 98\,^\circ\mathrm{C/W} \end{aligned} \tag{38}$$

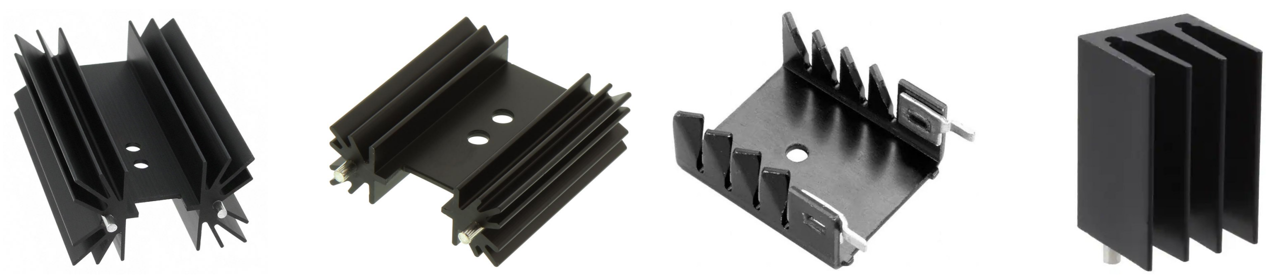
Choosing heat-sink s.t. $R_{th(s-a)} = 3\,^\circ\mathrm{C\,W^{-1}}$ (Aim for ultra low operating temperature)

$$\begin{aligned} \vartheta_{T,j,max} &= T_{ambient} + P_{loss,max}\left(R_{th(j-c)} + R_{th(c-s)} + R_{th(s-a)}\right) \\ &= 39.9\,^\circ\mathrm{C} \end{aligned} \tag{39}$$

$P_D\|_{wc}$ = 1 W	$R_{th,D,c-a}$ = $3\,\mathrm{K\,W^{-1}}$	Diode heatsink model No. : 1	$\vartheta_{D,j,max}$= $40\,^\circ\mathrm{C}$	/ 7 pt.

Table 4 List of the offered heatsinks.

No.	Manufacturer	Product	R^{th} ($\mathrm{K\,W^{-1}}$)	Figure
1	Ohmite	FA-T220-64E	3.00	6a
2	Ohmite	FA-T220-25E	4.70	6a
3	Ohmite	EA-T220-51E	7.50	6b
4	Ohmite	EA-T220-38E	10.40	6b
5	Wakefield-Vette	265-118ABHE-22	14.00	6c
6	Ohmite	E2A-T220-25E	16.40	6d



(a) Ohmite FA-T220-xxE **(b)** Ohmite EA-T220-xxE **(c)** Wakefield-Vette 265-118ABHE-xx **(d)** Ohmite E2A-T220-xxE

Figure 6 Available heatsinks. Images taken from the manufacturer websites.

REPORT 1 SUMMARY

Fill out the table below with your results as well as your chosen devices:

Table 5 Calculated parameter values, selected components and efficiency.

Property	Value	Unit
$D\|_{U_{in,nom}}$	0.56	–
L_{in}	200	µH
C_{out}	2.5	µF
MOSFET No.	2	–
Diode No.	4	–
$\eta\|_{nom}$	96	%
MOSFET heatsink No. (if present)	1	–
Diode heatsink No. (if present)	1	–

Total: / 125 pt.