Laboratory exercise

DC-DC SWITCH-MODE CONVERTERS
FLYBACK CONVERTER

OBSERVE!
The home assignment must be completed in order to be allowed to start the laboratory exercise

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Name

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Exercise approved

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Date

Lab Board

The laboratory board is a multi-purpose board that gives the possibility to test various circuits using different magnetic boards and connections between the transistors and diodes. The board includes a switched load, but this load will not be used during this laboratory exercise. Instead, external load resistors are used that have to be connected via lab-cables.

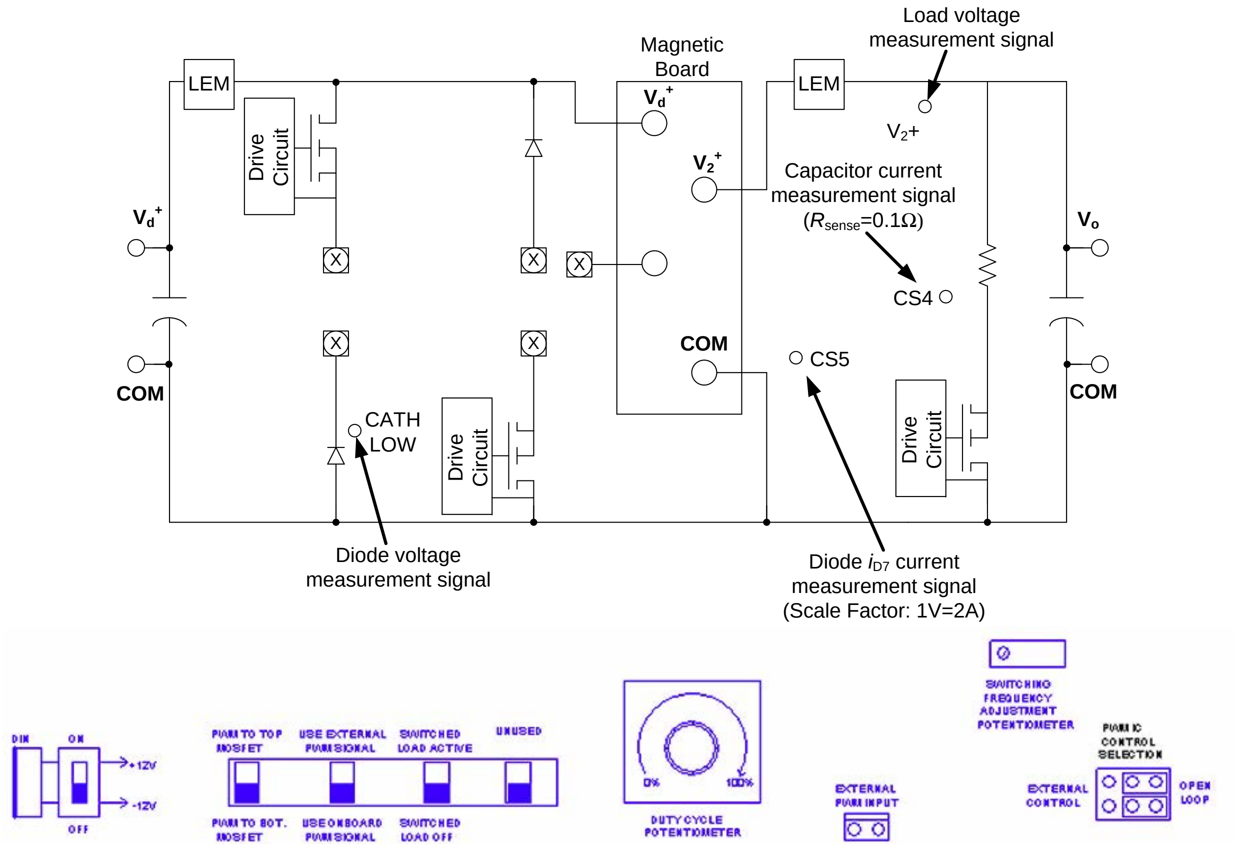


Figure 1. *Sketch over the laboratory board with no magnetic board attached.*

System parameters

Source voltage (V_d)	15V (Adjustable via external power supply)
Magnetizing Inductance (L_m)	Not Known (mounted on external magnetic board)
Transformer Turns Ratio	N_1=N_2=N_3 (27 turns on each winding)
Output Capacitance (C)	680µF
Load Resistance (R_L)	10Ω to 50Ω
Switching frequency (f_{sw})	10kHz to 100kHz
Duty ratio (D)	0 to 0.5 (limited by winding N_2)

Transformer Core Parameters

Relative Permeability (μ_r)	1660
Effective Area (A_e)	76mm^2
Effective magnetic length (l_e)	72mm
Air Gap Length (l_g)	0.7mm

Main circuit of the Flyback converter

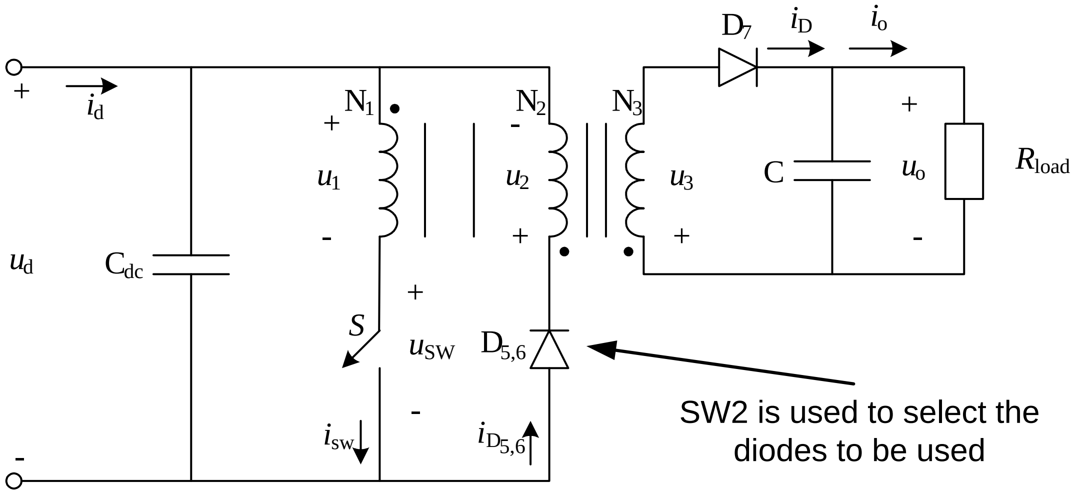


Figure 2. *The ideal main circuit of the buck converter.*

Home Assignment

(1) Determine the primary magnetizing inductance of the transformer. Use the data given for the core and the windings.

(2) How can the magnetizing inductance value be determined if the current waveform i_{D7} and the output voltage is known?

(3) What is winding N_2 in Figure 1 used for and how (Refer to lecture, tutorial 5 or PSpice 3 for detail)? What is the maximum possible voltage on the switch S in the absence of the second winding?

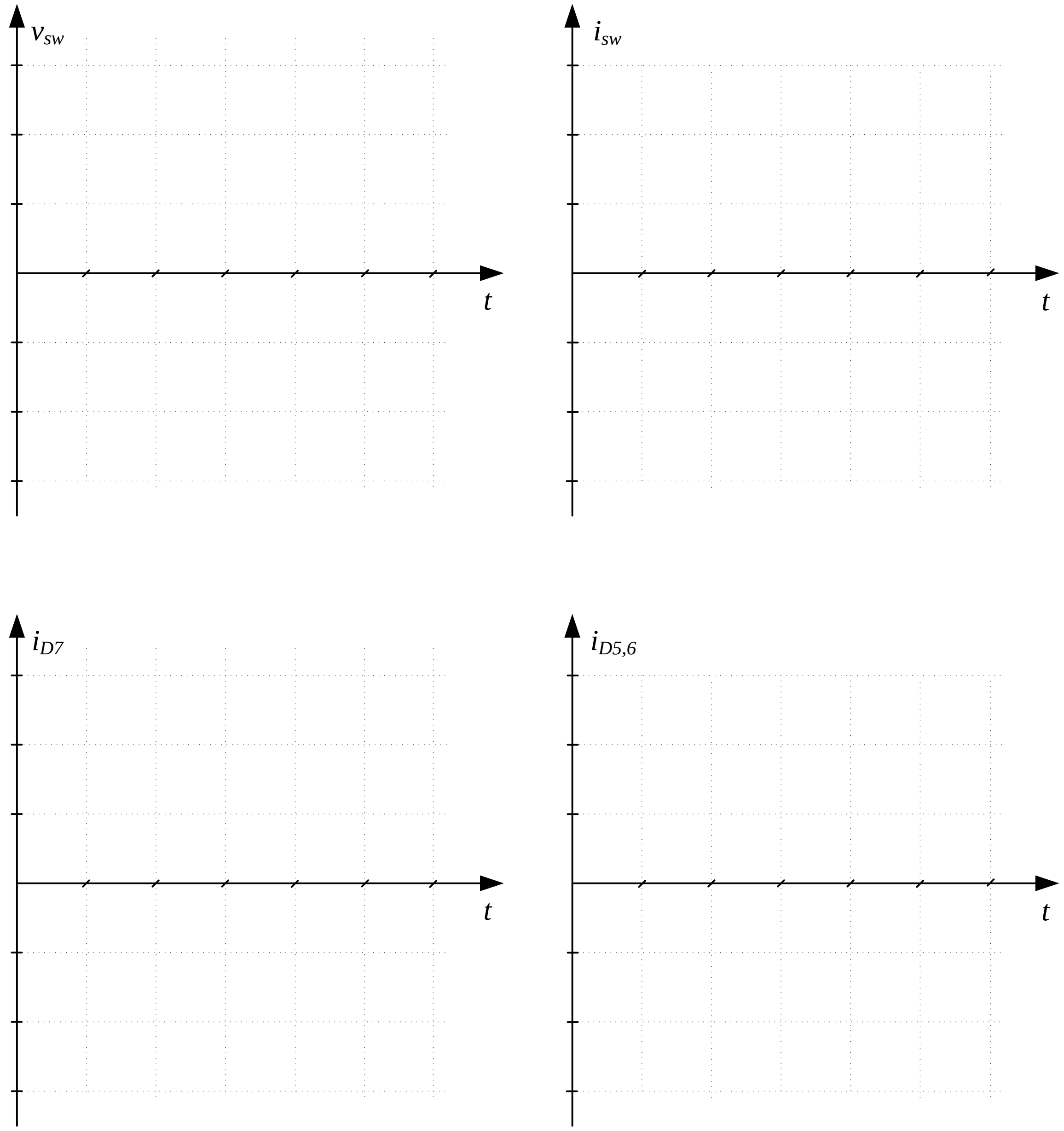
(4) Complete the Flyback converter in Figure 1. Draw the necessary connections between the diode, transistor and the magnetic board. The magnetic board for the flyback lab consists of a three-winding transformer and a diode. Observe that not all diodes and MOSFET's on the lab board need to be used.

(5) The Flyback converter can operate in either DCM or CCM. Draw the ideal waveforms of v_{sw}, i_{sw}, i_{D7} and $i_{D5,6}$ for $D = 0.3$, $R_{load} = 20\Omega$ for two switching frequencies on pages 4 and 5 ($f_{sw} = 20kHz$, $f_{sw} = 100kHz$). Hint: One switching frequency will result in DCM operation and the other one to CCM operation.

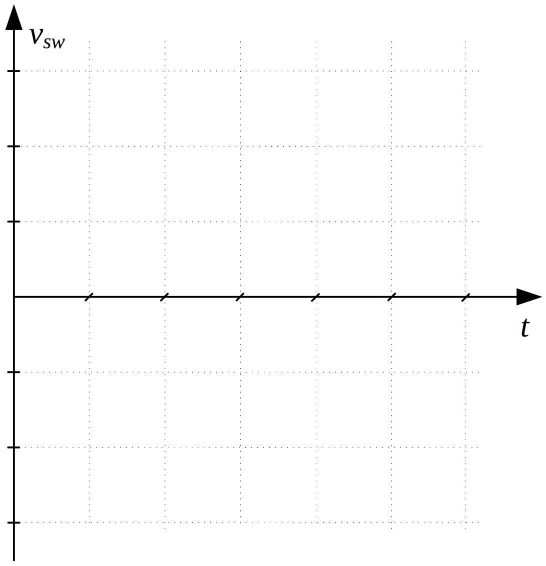
(6) Assume that $R_L = \infty$, $D = 0.3$ and $f_{sw} = 20kHz$. Draw the ideal waveforms for v_{sw}, i_{sw}, i_{D7} and $i_{D5,6}$ on page 6.

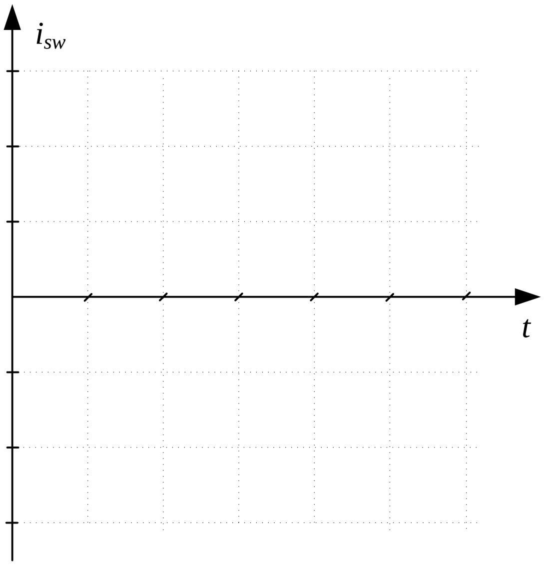
(7) Derive the expression for the input/output voltage ratio for both CCM and DCM. Use these expressions to complete the tables on page 9 and 11 for the specified values of the duty-cycles. Use $R_L = 20\Omega$, $f_{sw} = 20kHz$ and $f_{sw} = 100kHz$.

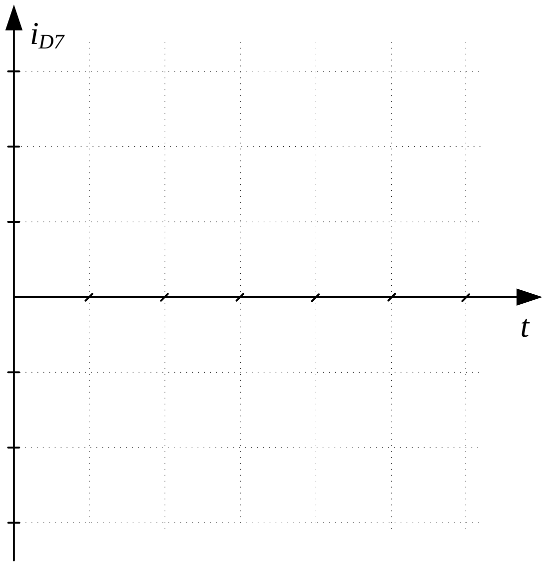
Theoretical waveforms, CCM:

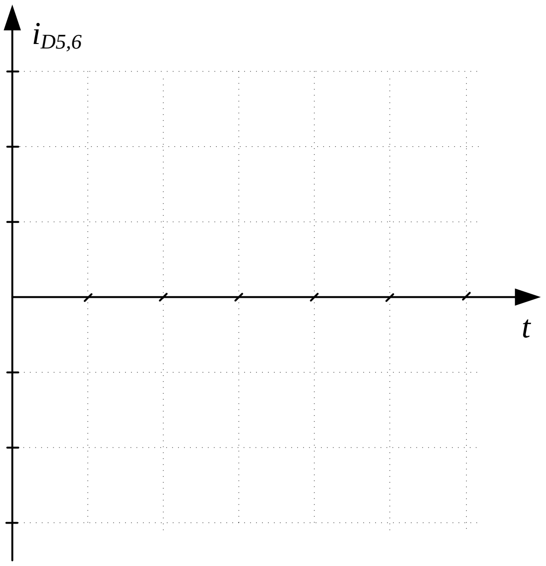


Theoretical waveforms, DCM:

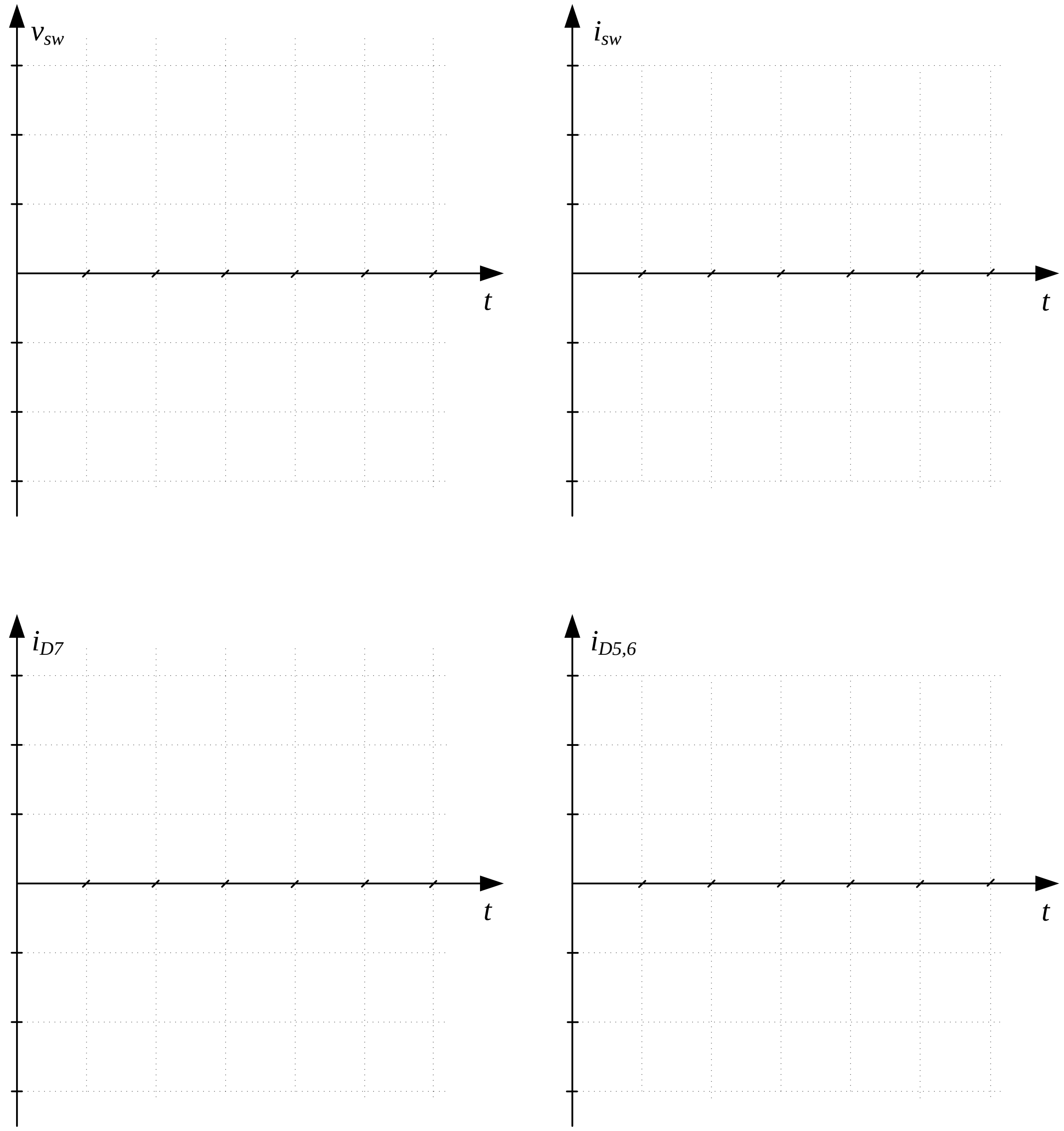








Theoretical waveforms, unloaded converter:



How to prepare the board before the laboratory exercise:

There are a few steps that you have to follow before you can start your lab:

1. Study the circuit and locate the main components of the flyback converter. Apply the magnetic board consisting of the transformer. Locate the correct test points for current and voltage measurements (see appendix A and B).

2. Check that the switches (S30) are set in the following positions:

   S30:1 – BOT FET.
   S30:2 – PWM INT.
   S30:3 – LOAD OFF.
   S30:4 – Not used.

3. Check that the signal-supply switch (S90) is in OFF position. Connect the ±12V control supply voltage (two black transformers) to the board.

4. Switch on the signal supply, check that the green LED is turned on.

5. Turn the duty cycle down to a minimum by turning the duty-cycle knob (RV63).

6. Set the load resistance to 20Ω.

7. Check that the slow diode for winding N_2 (D_5) is disconnected by setting the switch in position "OFF" and check that the red LED on the magnetics board is turned off.

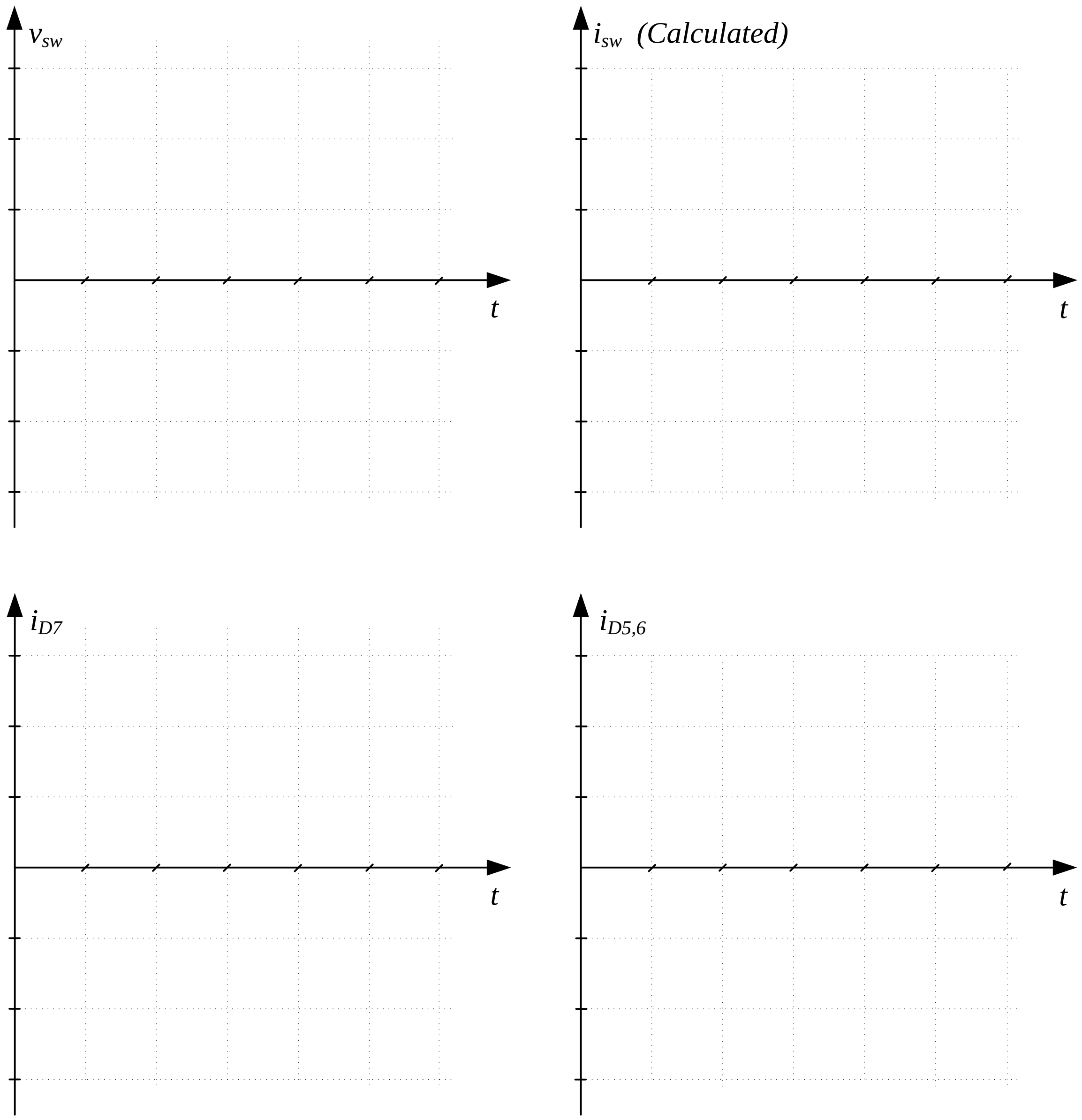
8. Apply the main input voltage source of 15V to the terminals V_1+ and COM.

It is not allowed to turn on the power supply until a lab-assistant has checked all connections!

Check Appendix for measurement pins!

<u>Task 1a:</u>

After the set-up has been checked by the laboratory assistant, turn the power supply on and set the switching frequency to 100kHz. Draw the measured curves for v_{sw}, i_{sw}, i_{D7} and $i_{D5,6}$ in CCM and compare with the calculated results for $D = 0.3$ and $R_{load} = 20\Omega$.



Any differences between the theoretical results and the measurements?

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Task 1b:

Calculate the average output voltage as a function of the duty cycle for CCM operation. Compare the obtained results with the measured ones and determine the efficiency of the system. Measure the input- and output voltage of the converter by using a multimeter. Be sure to measure directly on the laboratory board in order to get a good accuracy of the measurement.

Output voltages and efficiency, CCM

	Calculated output voltage	Measure d output voltage	Measured input voltage	Input power	Output power	Efficiency
D=0.2						
D=0.4						
D=0.49						

Any differences between the theoretical results and the measurements? How does the efficiency compared to the Buck converter and why?

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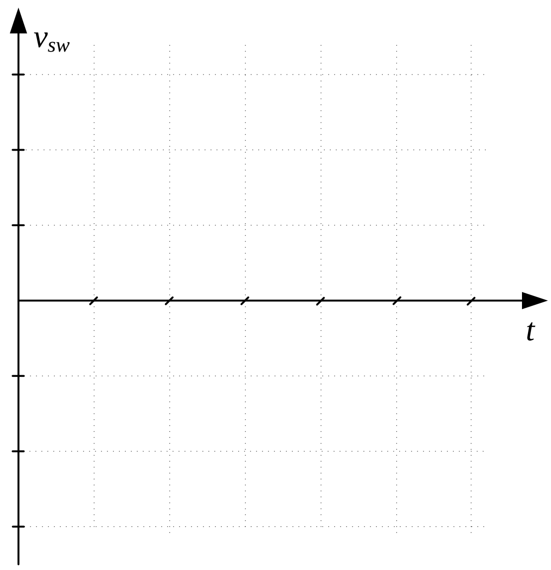
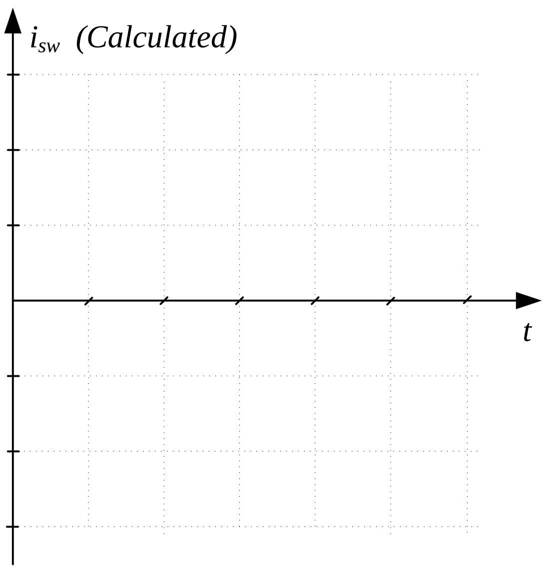
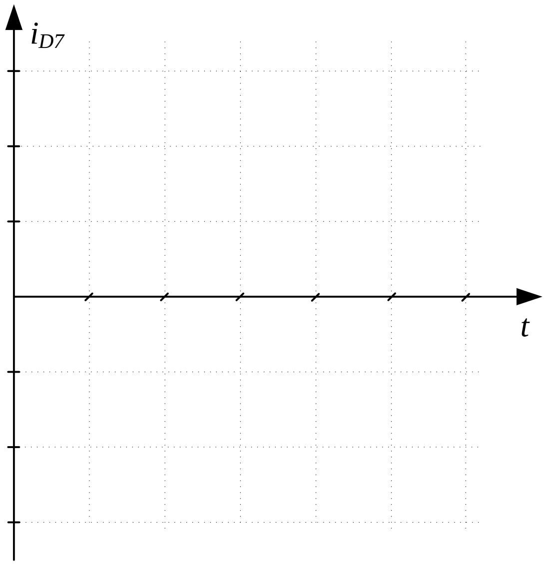
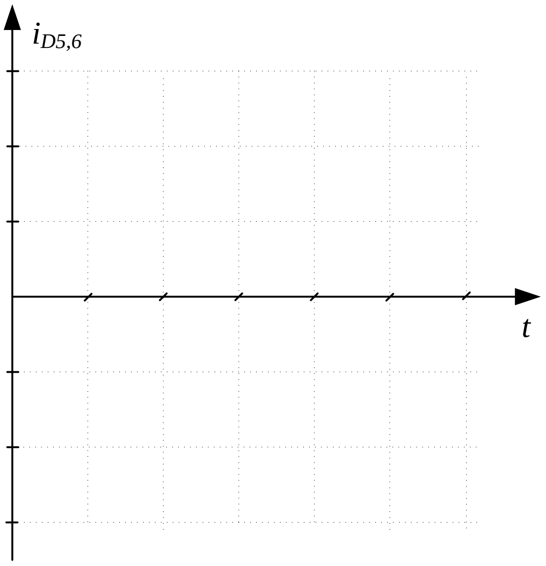
Task 2a:

Now, set the switching frequency to 20kHz and do not change it for the rest of the experiment. Draw the measured curves for v_{sw}, i_{sw}, i_{D7} and $i_{D5,6}$ in DCM and compare with the calculated results for $D = 0.3$ and $R_{load} = 20\Omega$. Using the measurements for V_0 and i_{D7}, can you estimate the value of the magnetizing inductance ?









Any differences between the theoretical results the measurements?

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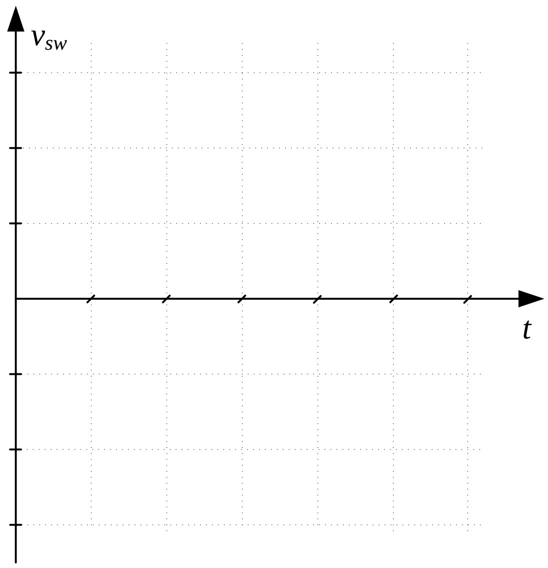
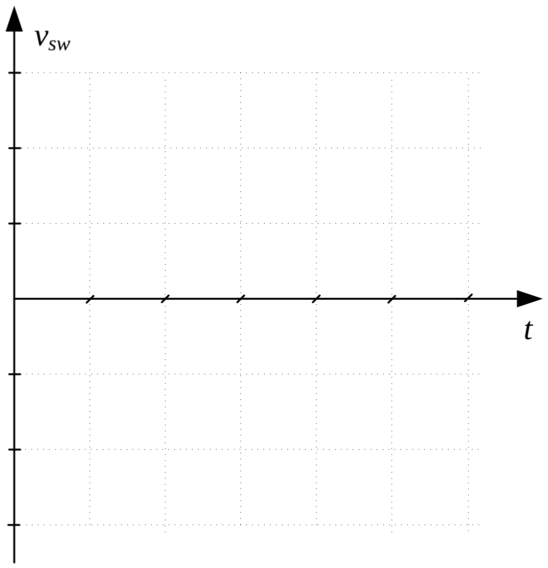
<u>Task 2b:</u>

Use SW1 to connect and disconnect the snubber circuit. What effect does the snubber have on the switch voltage wave form?

With snubber



Without snubber



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Task 2c:

Calculate the average output voltage as a function of the duty cycle for DCM operation. Compare the obtained results with the measured ones and determine the efficiency of the system. Measure the input- and output voltage of the converter by using a multimeter. Be sure to measure directly on the laboratory board in order to get a good accuracy of the measurement.

Output voltages and efficiency, DCM

	Calculated output voltage	**Measured output voltage**	**Measured input voltage**	**Input power**	**Output power**	**Efficiency**
D=0.2						
D=0.4						
D=0.49						

Any differences between the theoretical results and the measurements? How does the efficiency compared to the Buck converter and why?

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Task 3:

Measure v_{sw}, i_{sw}, i_{D7} and $i_{D5,6}$ in no-load operation ($R_L = \infty$ and $D = 0.3$) and compare with your theoretical curves. Do the results match?

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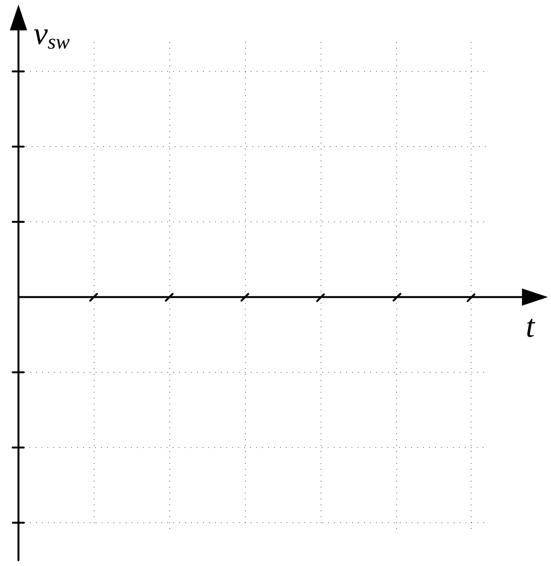
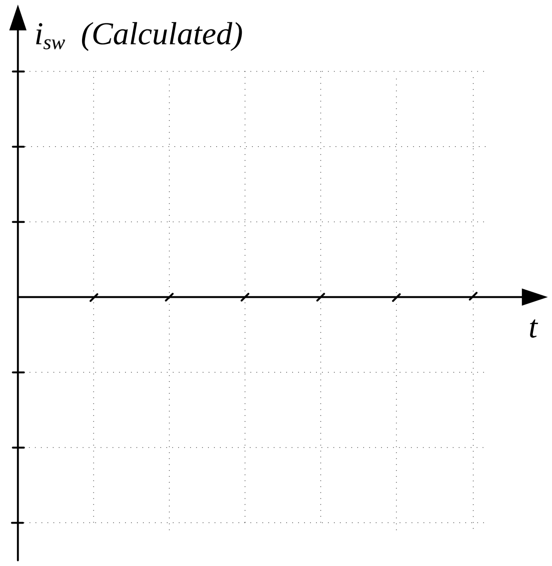
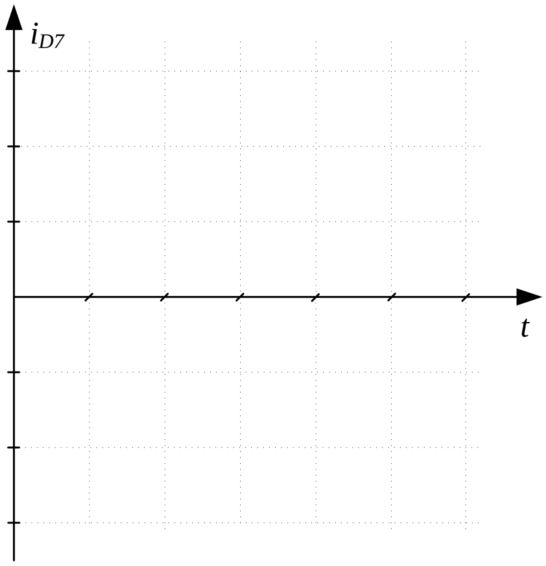
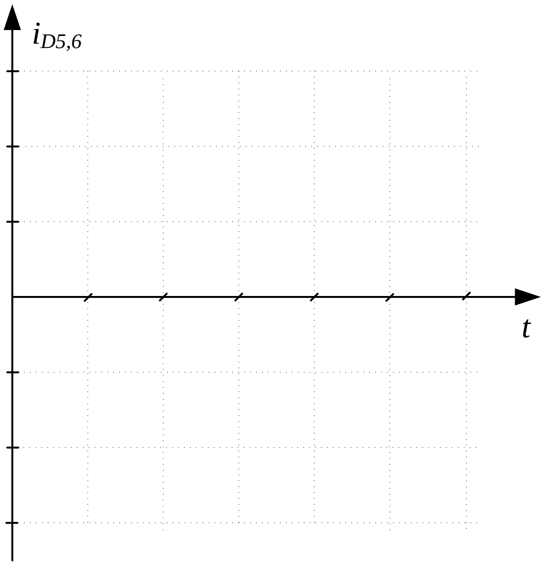




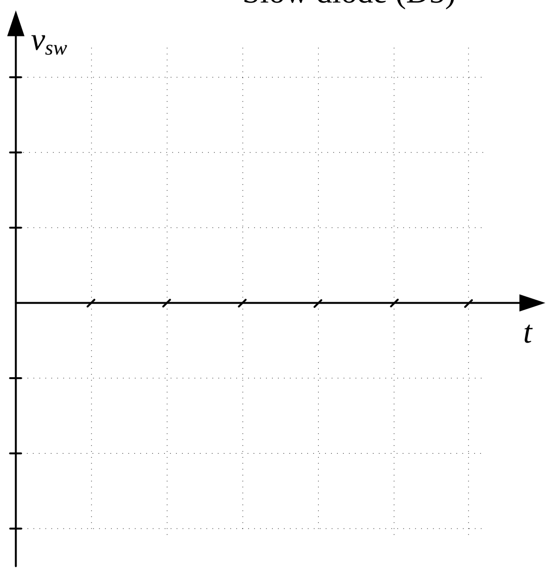




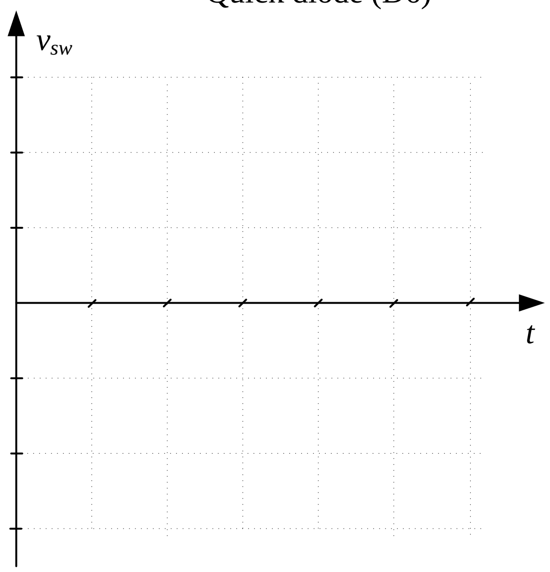
Task 4:

There is a diode with a low on-state voltage drop, D_5 that can be used in parallel with the diode, D_6 that has higher on-state losses. Operate the circuit using 20 kHz switching frequency in no-load operation mode with a duty-cycle close to 0.45. Use SW2 and keep the finger on D_5. Draw the waveforms of the current through winding 2 for the two switch positions. Also sketch the switch voltage during the process.

Slow diode (D5)



Quick diode (D6)



What happens with D_5 after a while and why? What is the reason for the difference in the curves for the two cases?

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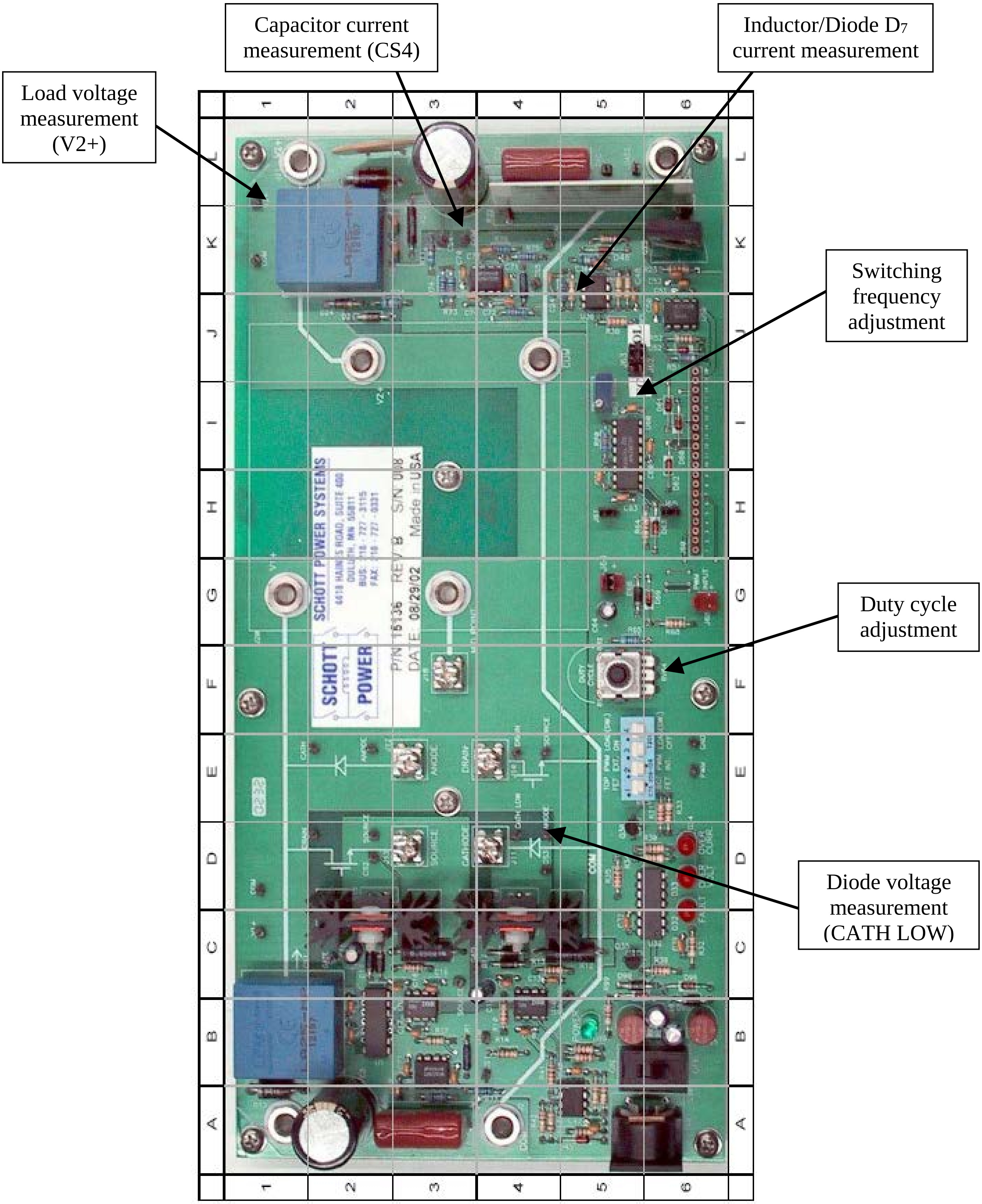
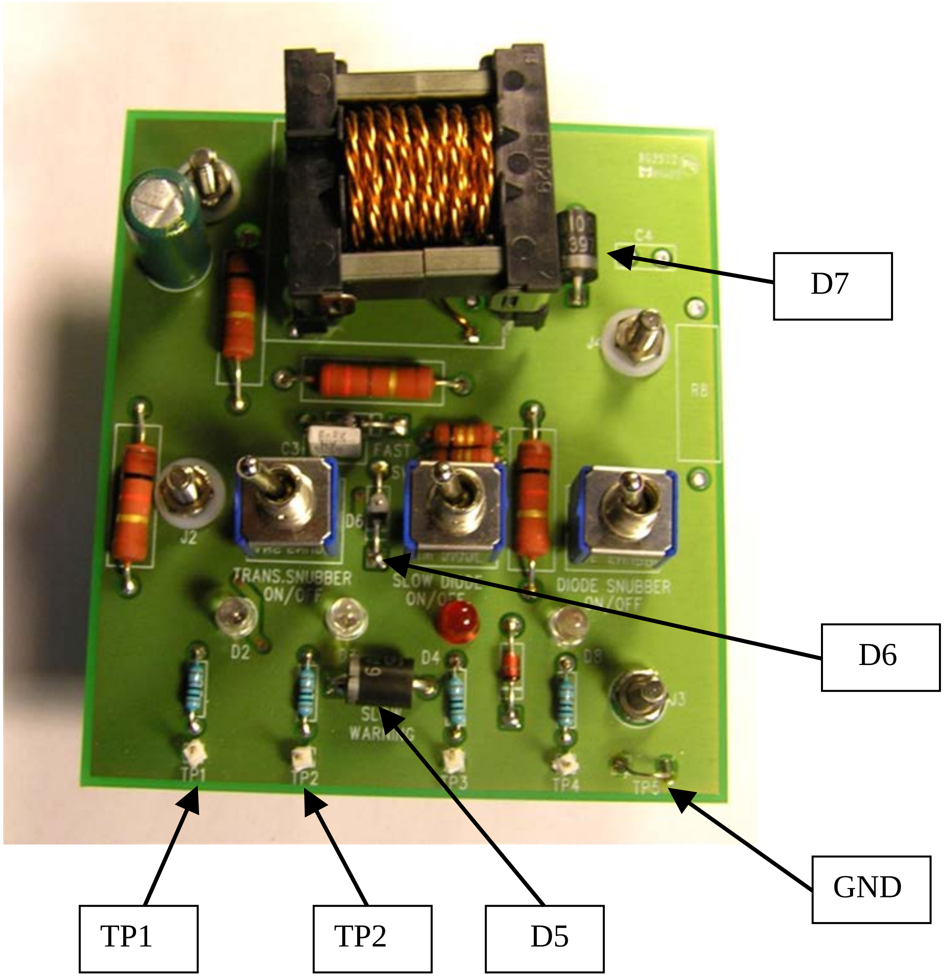
Appendix A. Lab board



Appendix B. Magnetics board



TP1: Measurement of the voltage over the switch (v_{sw})

TP2: Measurement of the current through diode 5 and 6 $(i_{D5,6})$ with a scaling factor of 1V=2A.