Electromagnetic Energy Conversion
ELEC0431

Exercise session 10:
Electronic control systems

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In this class…

- The DC-DC converters
- Exercise 24: Regenerative braking
- Exercise 26: DC-DC buck converter
- Exercise 27: DC-DC boost converter

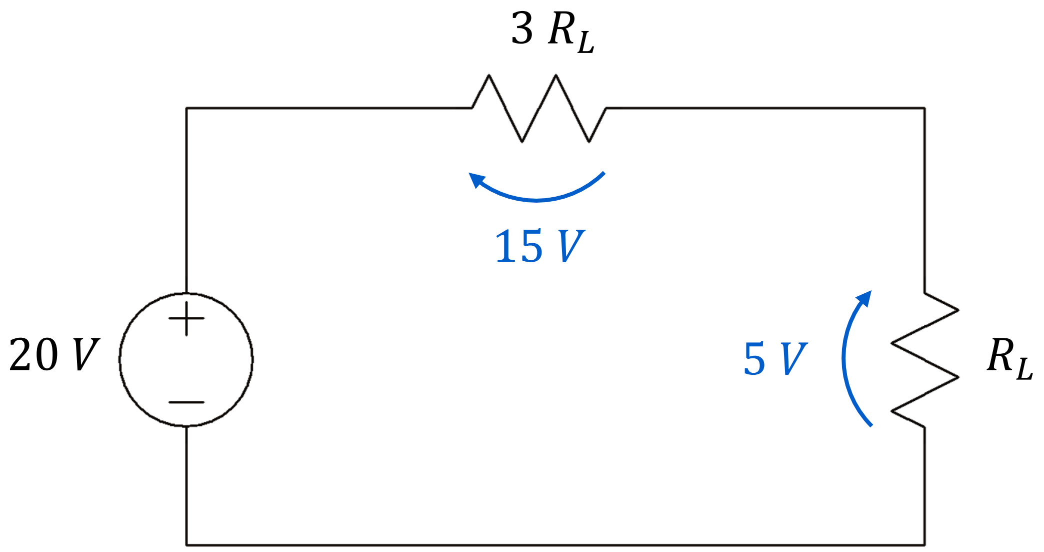
The DC-DC converters

You want to build a drone. For this, you use DC motors running at $20\ V$ and a $20\ V$ battery. However, the camera and the control part work at $5\ V$. When the drone is waiting to take off, the control part is in standby and takes only $3\ V$. **How to obtain 5 or $3\ V$ from the $20\ V$ battery** to supply the control part?

The DC-DC converters

How to obtain 5 or 3 V from the 20 V battery ?

➔ Use a resistive voltage divider



☺ We have the 5 V to power the control part.

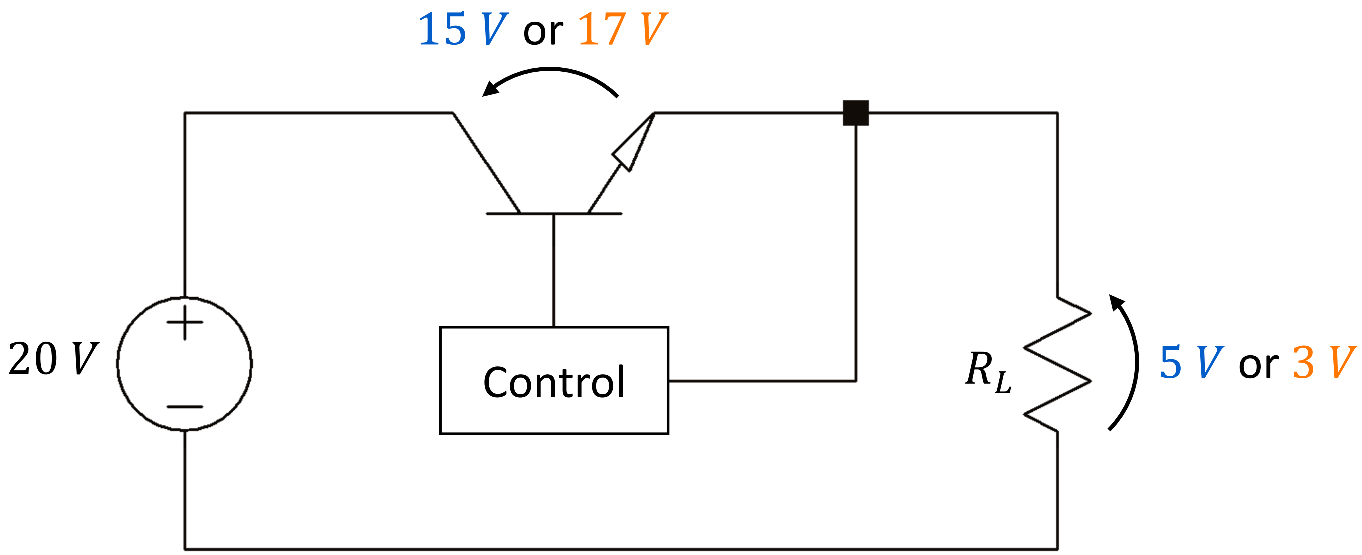
☹ Not possible to get the 3 V.

☹ Huge power losses.

The DC-DC converters

How to obtain 5 or 3 V from the 20 V battery ?

➔ Use a series pass regulator



☺ We have the 5 V to power the control part.

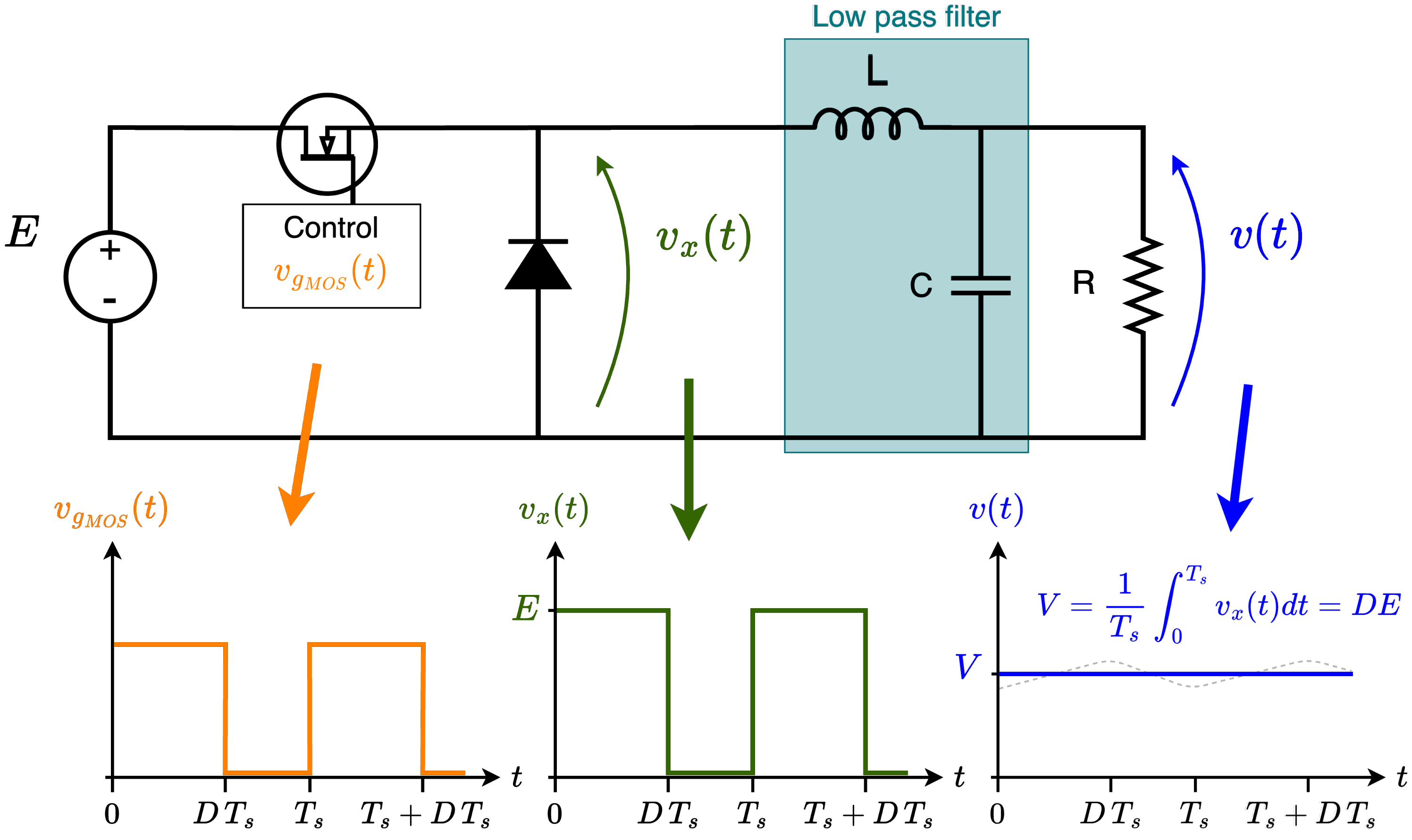
☺ Possible to get the 3 V.

☹ Huge power losses.

The DC-DC converters

How to obtain 5 or 3 V from the 20 V battery ?

➔ Use a DC-DC converter



D is the "duty cycle". It is the proportion of time during which the MOSFET conducts ($0 < D < 1$).

☺ We have the 5 V to power the control part.

☺ Possible to get the 3 V.

☺ High efficiency

NB: The analysis is made assuming that components are ideal (mosfet and diode), which is not the case in practice.

Exercises

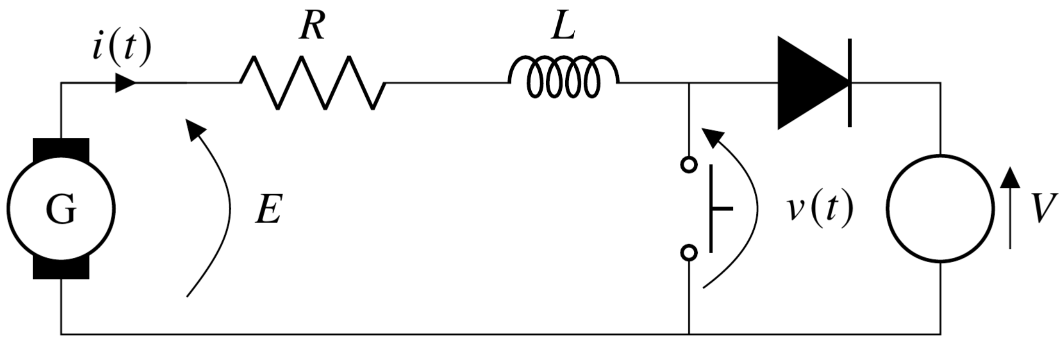
Exercise 24: Regenerative braking

Exercise 26: DC-DC buck converter

Exercise 27: DC-DC boost converter

Exercise 24: Regenerative braking

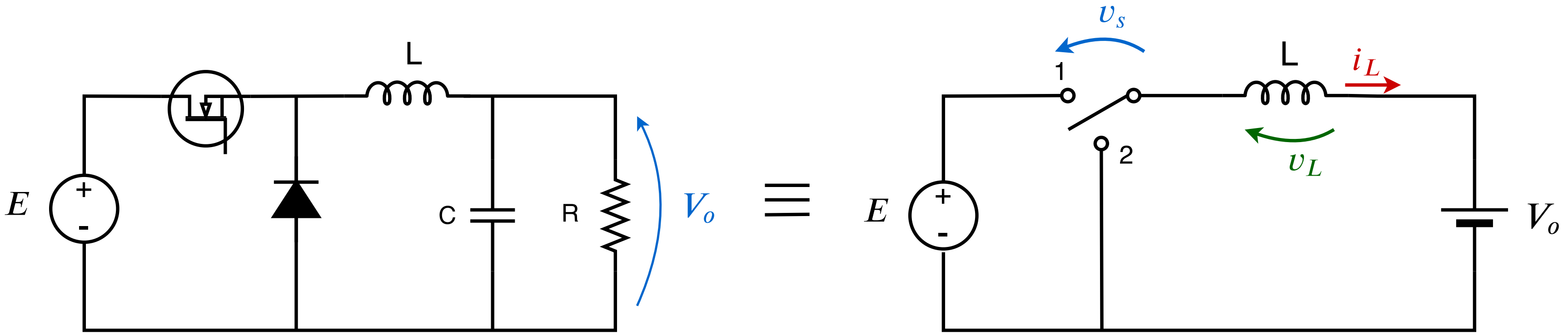
Hybrid electric vehicles are generally provided with regenerative braking, allowing to load onboard battery when the vehicle is braking or when the vehicle acts as a driving load. In this exercise, the DC motor, having an electromotive force E and internal resistance $R = 0.5\ \Omega$ is connected (when the regenerative breaking is active) to a battery delivering a current I under the voltage $V = 100\ V$ using a chopper DC-DC converter:



1. Find the mean value of $v(t)$: V_m.
2. Find the link between the mean input current I_m and the mean output current I.
3. Express the voltage V with respect to I_m, E, R and the duty cycle D.
4. Compute the duty cycle D allowing to obtain $V_m = 60$ V.
5. Compute the mean braking current I_m when the motor delivers an electromotive force $E = 70\ V$ for $V_m = 60\ V$.
6. Calculate the braking power $E\ I_m$ and the braking torque C_m if the motor speed of rotation is $\dot{\theta} = 955\ RPM$.

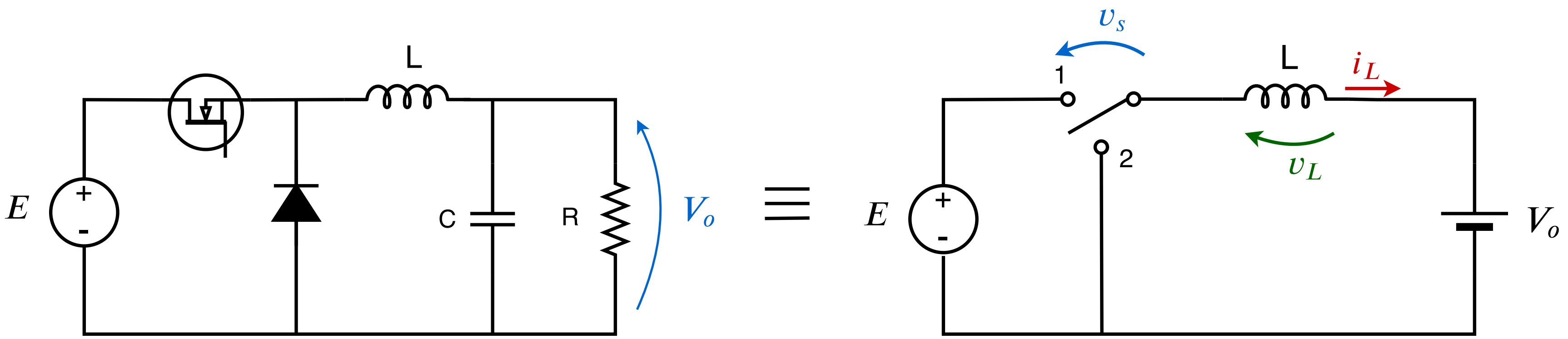
Exercise 26: DC-DC buck converter

DC-DC converters are used to adapt two different voltage levels. For instance, in particular model of an electric car, the battery voltage is set to $E = 302\ V$, whereas the auxiliaries (lights, cigar lighter, window and wiper motors, ...) are working with $V_o = 12\ V$. A DC-DC buck converter is used to reduce the battery high voltage to the lower value ($12\ V$) with high efficiency. The DC-DC buck converter can be modelled by the following circuit.



1. Find the waveforms of the voltage across the ideal switch (v_s) and the voltage across the inductance (v_L). Deduce the inductance current waveform from it.

Exercise 26: DC-DC buck converter



Assume steady-state conditions.

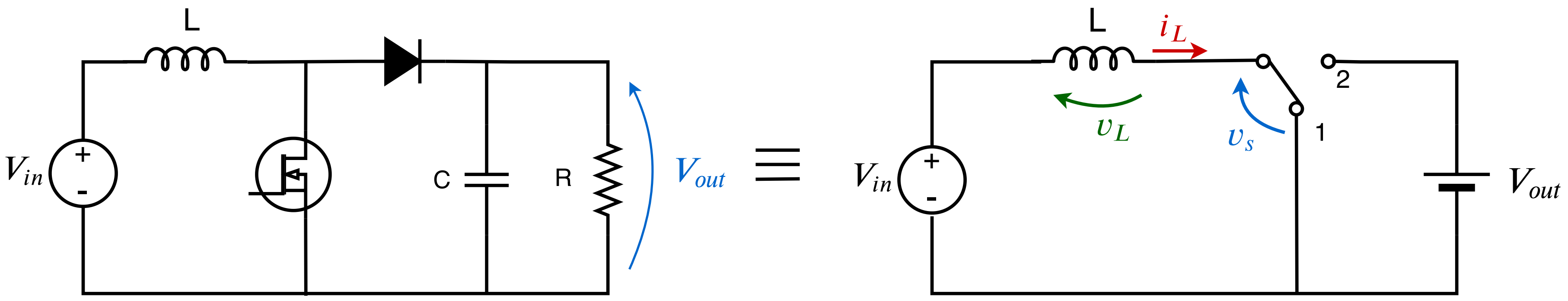
2. Express the ratio $\frac{V_o}{E}$ in terms of the duty cycle D.
3. Give the value of D in this situation.

The current ripple Δi is defined as the absolute difference between the maximum of current (during a switching period) and the average current I (over the same switching period).

4. Find the expression of the inductor current ripple Δi_L in terms of V_o, E, D, T_s and L.
5. Estimate the inductor current ripple Δi_L for a switching frequency $f_s = 1\ KHz$ and an inductance of $50\ mH$. Compare the value of the current ripple to the value of the output current if the auxiliaries draw $12\ W$.

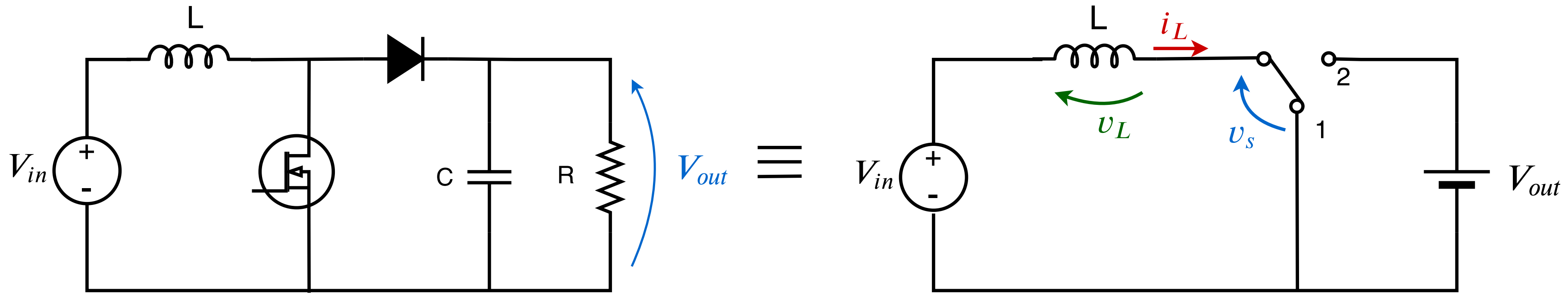
Exercise 27: DC-DC boost converter

DC-DC converters are used to adapt two different voltage levels. In some electronic calculator, the battery voltage is set as $V_{in} = 3\ V$, whereas the electronic parts work under $V_{out} = 9\ V$. A DC-DC boost converter is used to increase the battery low voltage to the higher value ($9\ V$) with high efficiency. The DC-DC boost converter can be modelled by the following circuit.



1. Find the waveforms of the voltage across the ideal switch (v_s) and the voltage across the inductance (v_L). Deduce the inductance current waveform from it.

Exercise 26: DC-DC buck converter



Assume steady-state conditions.

2. Express the ratio $\frac{V_{out}}{V_{in}}$ in terms of the duty cycle D.
3. Give the value of D in this situation.

The current ripple Δi is defined as the absolute difference between the maximum of current (during a switching period) and the average current I (over the same switching period).

4. Find the expression of the inductor current ripple Δi_L in terms of V_{out}, V_{in}, D, T_s and L.
5. Estimate the inductor current ripple Δi_L for a switching frequency $f_s = 30\ KHz$ and an inductance of $75\ mH$. Compare the value of the current ripple to the value of the output current if the system draws $15\ mW$.