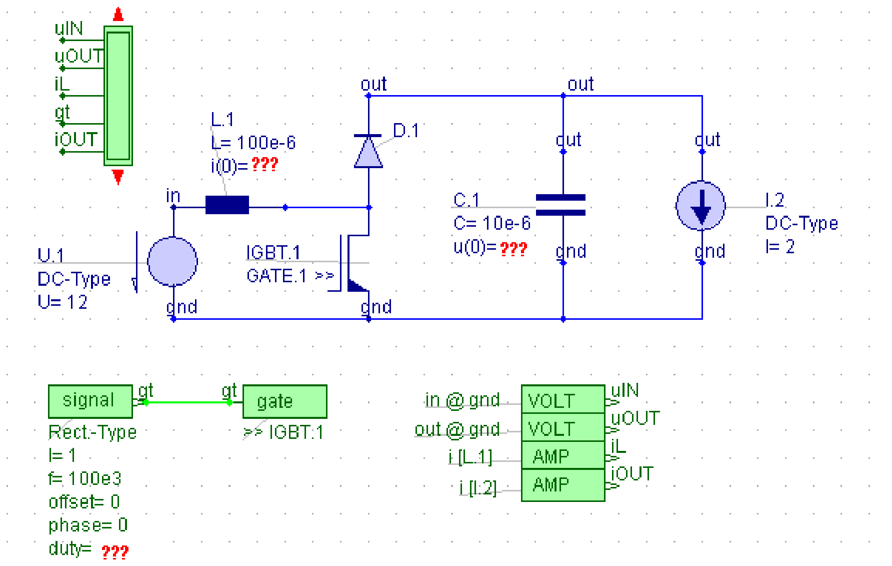
Exercise A: Buck-Converter

Here, we examine the behavior of the Buck-Converter from the figure below, whose input is modeled via an ideal 12V voltage source. The converter output is a load resistor R_{Load} and an output capacitor C_{out} with an equivalent series resistance R_C . The Buck-Converter choke is an ideal inductor L with a series resistance R_L . The switching frequency is fixed at f_S = 100 kHz.



Build a simulation model of the Buck-Converter in GeckoCIRCUITS. Please use the component values as given in the circuit sheet. Plot the following converter variables within the GeckoCIRCUITS scope: Output voltage, u_{OUT}, input voltage u_{IN}, inductor current i_L and the gate signal *gt* of the switch. Please familiarize yourself with the various plotting settings of the GeckoCIRCUITS scope: You can plot several curves within a single graph, vary the curve colors, or set the plotting mode to "digital" for the gate signal. The labels in the graphs will be set according to the labels that you apply in your circuit sheet.

For the exercise parts 1 to 5, you shall assume that the converter operates in continuous conduction mode.

1. Calculate the value of the duty ratio *D*, so that the average output voltage is U_{out} = 5 V in the stationary state. Insert your calculated value of *D* into the model and verify the output voltage in your simulation. You can try to set the initial values of the output capacitor and the choke to the correct values, so that the circuit is already in steady-state.
   Try to find out the reason for the deviation of the output voltage from 5V by varying the corresponding simulation parameters, e.g. the diode and switch conduction resistances or the diode forward voltage drop. Please also ensure that the simulation step-width (which is set to 1sec as default value) does not have an influence on your simulation. Probably, you have to decrease the simulation step-width value.

2. Now, set the duty ratio to *D* = 0.5 . How does the output voltage U_{out} change? Verify your answer in a simulation.

3. In a next step, we want to limit the choke current ripple to i_L = 1 A (peak-to-peak). Calculate the required inductance value *L* and simulate the model. Please consider that the current ripple is dependent on *D*. Therefore, you can assume the "worst case" value for D.

4. In the following, we consider the non-ideality of the choke. We assume $R_L = 1\ \Omega$. How does the output voltage u_{out} change? Also have a look at the shape of the choke current i_L. Would such a choke with a $1\ \Omega$ series resistance be useful/reasonable for this application?

Set the resistance value back to $R_L = 0\ \Omega$. Calculate the output capacitance value C_{out} so that the maximum voltage ripple of the output voltage u_{out} is limited to $u_{aus} = 50$ mV (peak-to-peak).

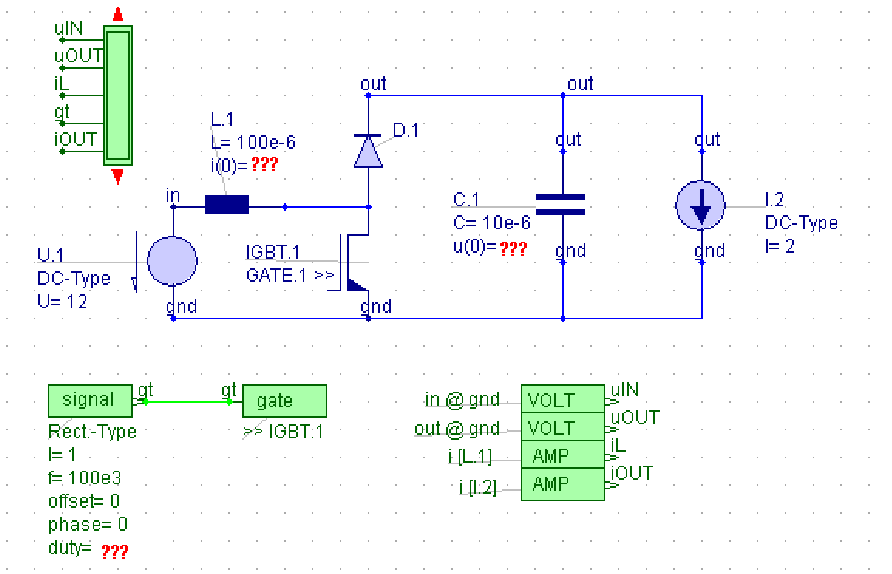
1. *Hint*: To calculate the capacitor value, you can assume that the output voltage u_{aus} (and therefore also the resistor current) is constant as a good approximation. Using the current of the capacitor C_{out}, you can calculate the charge that is responsible for the output voltage ripple u_{out}. Hence, you can calculate the ripple current in a good approximation.

In the next tasks, the Buck-Converter shall operate in the discontinuous conduction mode. Assume a value of $R_{Load} = 20\ \Omega$ and a capacitance of $C_{out} = 20$ F.

2. Calculate the duty ratio D_{limit} for the Buck-Converter, so that the circuit operates at the limit between continuous and discontinuous conduction mode. Insert your result into GeckoCIRCUITS and check your result.
3. Try to increase and decrease the duty ratio by 20% in each case. How does the model behave – consider especially the time needed for the model to reach steady state. Can you explain this behavior?
4. Now, set $D = 0.4$. Compare the output voltage u_{out} for the cases $R_C = 0\ \Omega$ and $R_C = 0.2\ \Omega$. You can visualize the difference between the selected duty-ratios within one simulation in the scope by using the "Simulation->Parameter->t_{break}" function.

Exercise B: Boost-Converter

Using the available 12 V DC voltage source, we want to produce a constant 50 V output voltage. Therefore, we use the ideal boost-converter model as shown in the figure below.



Save the Buck-Converter model from task A, *„buck.ipes“*, into a file with the name *"boost.ipes"* and modify the circuit corresponding to the boost converter figure above. Use the component values as given in the figure. For the exercise parts 1 to 3, you can assume that the boost converter operates in the continuous conduction mode.

1. Calculate the duty ratio D, so that the output voltage becomes U_{aus} = 50 V at steady-state. Insert your result into the simulation, and set the initial conditions of the energy storage components to the correct steady state values.
2. How long does the simulation need to reach steady state? Which loss components does the circuit contain? Play with the parameter values of the diode and the switch. Try to determine the long-term ringing frequency at the simulation start. Do you have an idea on how to calculate this frequency? (*Hint*: Consider a resonant circuit together with the step-up ratio of the converter)
3. Calculate the output capacitor value C_{out} , so that the output voltage ripple is limited to a maximum of u_{aus} = 500 mV (peak-to-peak).
4. Now, please reduce the inductance value to L = 3 H. What happens to the output voltage? Please interpret your results. How long does the converter need to reach steady state?
5. Which value do you have to select now for the duty ratio D to reach the required voltage of u_{out}=50V?