DC to DC Converters

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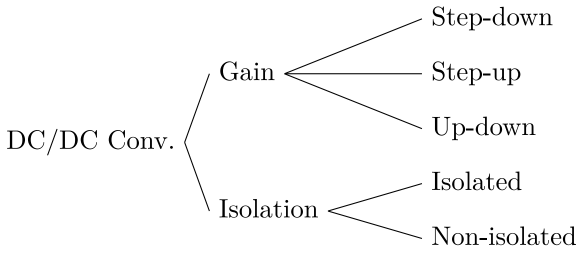
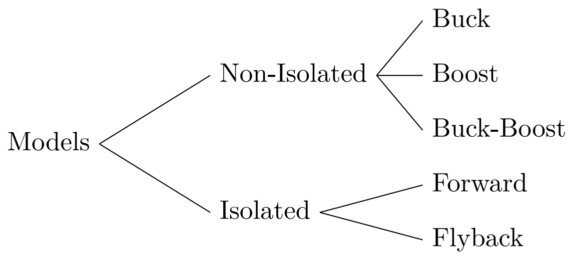
1 DC to DC Converters

Converter types:



- **Step-down**: A converter where output voltage is lower than the input voltage (like a Buck converter).
- **Step-up**: A converter that outputs a voltage higher than the input voltage (like a Boost converter).



Converter operation regimes, conduction modes:

- **Continuous Current Mode**: Current and thus the magnetic field in the inductive energy storage never reach zero. In CCM
$$\frac{1}{2}\Delta i_l < \bar{i}_L$$
- **Discontinuous Current Mode**: Current and thus the magnetic field in the inductive energy storage may reach or cross zero. In DCM
$$\frac{1}{2}\Delta i_l > \bar{i}_L$$

Control signal The control signal of a DC converter is a square signal, which applied to the MOSFET or IGBT gate is responsible of switching of the current.

The control signal is a square function

$$f(t) =$$

Some of the parameters of the control signal are:

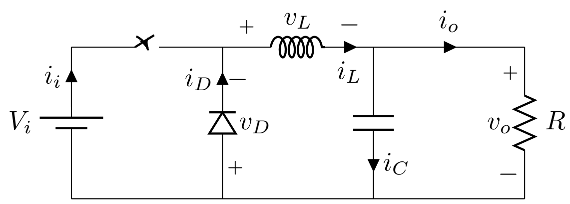
- T, period of the signal
- t_{ON}, time of high value
- t_{OFF}, time of low value (zero)
- D, duty cycle

$$D = \frac{t_{ON}}{T}$$

Switching component

2 Non-isolated converters

2.1 Step-down Converter (Buck)

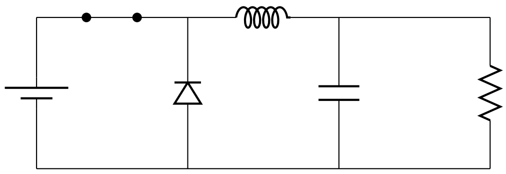


Known variables: V_i, D, L, C, R.

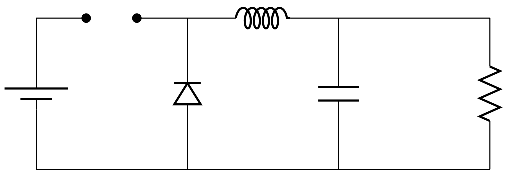
State of the diode

- **ON Circuit**: During the ON state of the circuit, the diode is backwards polarized by the DC source (OFF, not conducting).

$$v_D = -V_i$$



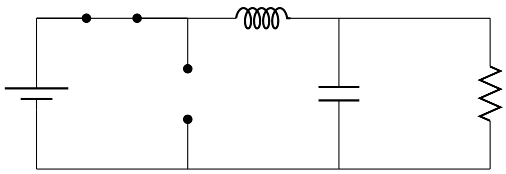
- **OFF circuit**. We can't know the state of the diode until the v_o and v_L voltages are known. Since in the ON circuit the diode is not conducting, the diode should be conducting in the OFF circuit or it won't have a purpouse in the circuit. We suposse the diode to be forward polarized (ON or conducting state), although at the end of the circuit analysis it will be necessary to check if the hypothesis was correct.



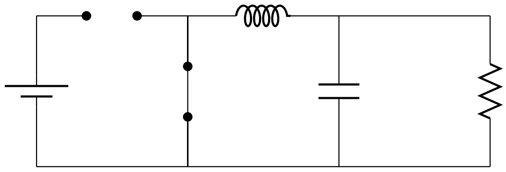
Diode table

Switch	D
ON	OFF
OFF	ON

ON equivalent circuit

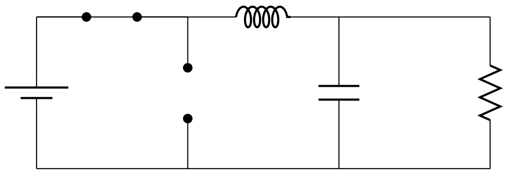


OFF equivalent circuit

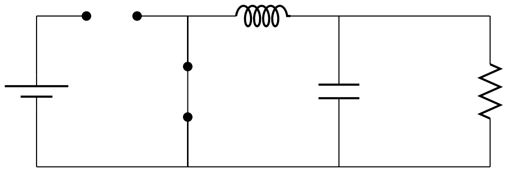


Inductor voltage, output voltage

1. ON Circuit, KVL: $v_i = v_L + v_o \rightarrow v_L = v_i - v_o$



2. OFF circuit, KVL: $0 = v_L + v_o \rightarrow v_L = -v_o$



To know the sign of the voltage in the inductor, we need to obtain the sign of v_i and v_o first. Knowing that this is a step-down and non-inverting converter, we can suppose both v_i and v_o positive and $v_i > v_o$. To demostrate this is the case, we have to apply the periodic steady state of the inductor condition.

1. In periodic steady state, the average voltage of an inductor is zero, $\bar{v_L} = 0$

2. Small-ripple approximation: $v_o(t)$ can be considered constant: $v_o(t) \approx V_o$.

$$(V_i - V_o)D\cancel{T} + (-V_o)(1-D)\cancel{T} = 0$$
$$(V_i D - \cancel{V_o D} - V_o + \cancel{V_o D} = 0$$
$$V_o = V_i D$$

Duty Cycle

$$D = \frac{V_o}{V_i}$$

Inductor current

Switch tension

Switch current

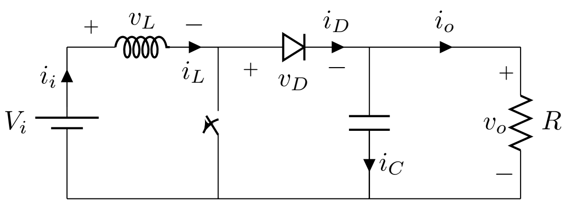
Diode tension

Diode current

Capacitor current

Output current

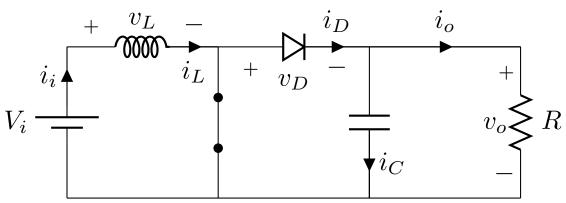
2.2 Step-up Converter (Boost)



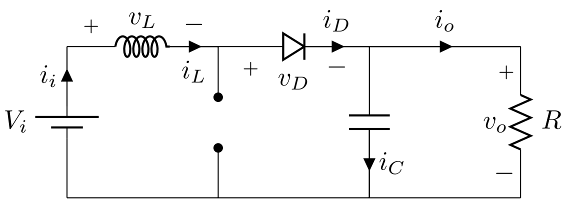
Known variables: V_i, D, L, C, R.

State of the diode

- **ON Circuit**: Since $v_D = 0 - v_o = -v_o$, the diode is reverse polarized (OFF), if $v_o > 0$. We can make that asumprion and check later.



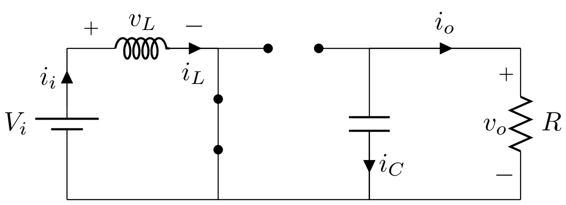
- **OFF circuit**: $v_D = V_i - v_L - V_o$. We assume the diode is ON for the current in the inductor to be continuous.



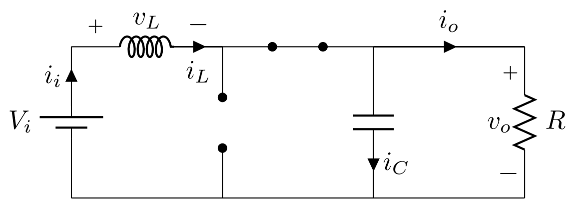
Diode table

Switch	D
ON	OFF
OFF	ON

ON equivalent circuit

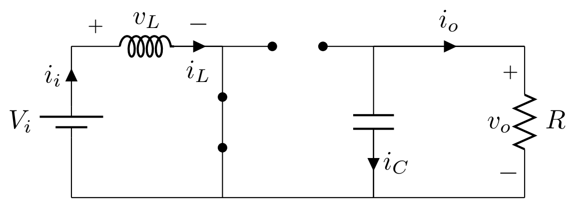


OFF equivalent circuit

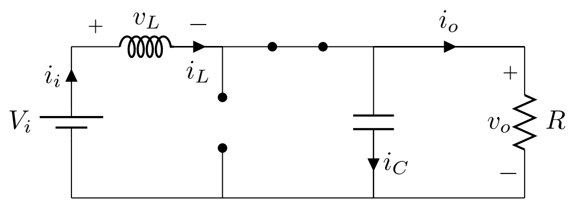


Inductor voltage, output voltage

1. ON Circuit: $v_L = v_i$



2. OFF circuit: $v_L = v_i - v_o$



1. In periodic steady state, the average voltage of an inductor is zero, $\bar{v_L} = 0$

2. Small-ripple approximation: $v_o(t)$ can be considered constant: $v_o(t) \approx V_o$.

$$V_i D \cancel{T} + (V_i - V_o)(1 - D)\cancel{T} = 0$$

$$\cancel{V_i D} + V_i - \cancel{V_i D} - V_o + V_o D = 0$$
$$V_i = V_o(1 - D)$$

$$V_o = V_i \frac{1}{1 - D}$$

Duty Cycle

$$D = 1 - \frac{V_i}{V_o}$$

Output power

$$P_o = \frac{V_o^2}{R}$$

Inductor current

Switch tension

Switch current

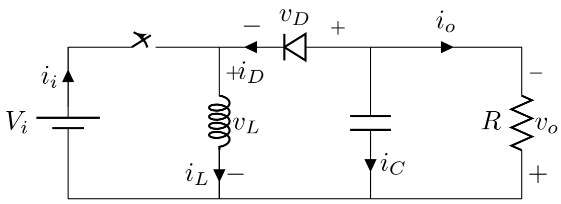
Diode tension

Diode current

Capacitor current

Output current

2.3 Buck-Boost Converter



Known variables: V_i, D, L, C, R.

State of the diode

- **ON Circuit**:

- **OFF circuit**

Diode table

Switch	D
ON	OFF
OFF	ON

ON equivalent circuit

OFF equivalent circuit

Inductor voltage

Inductor current

Switch tension

Switch current

Diode tension

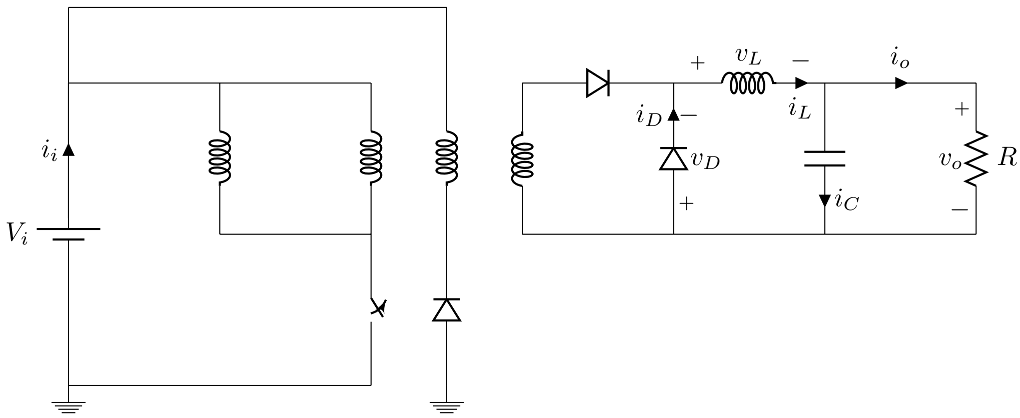
Diode current

Capacitor current

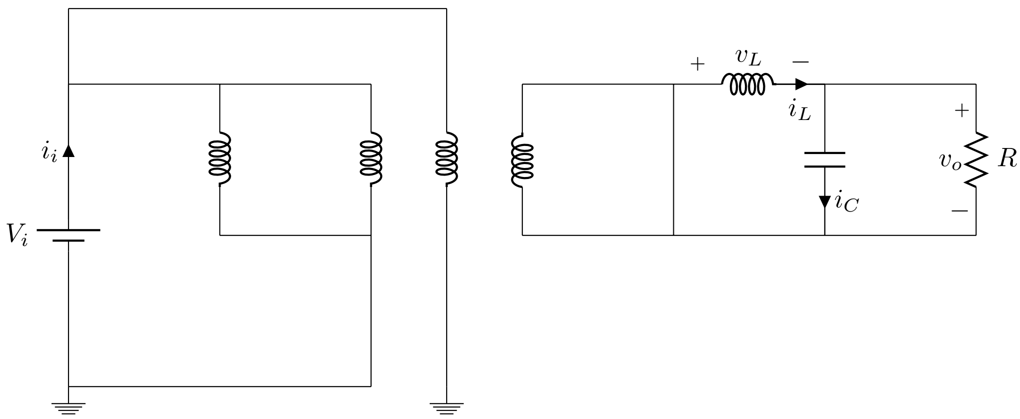
Output current

3 Isolated Converters

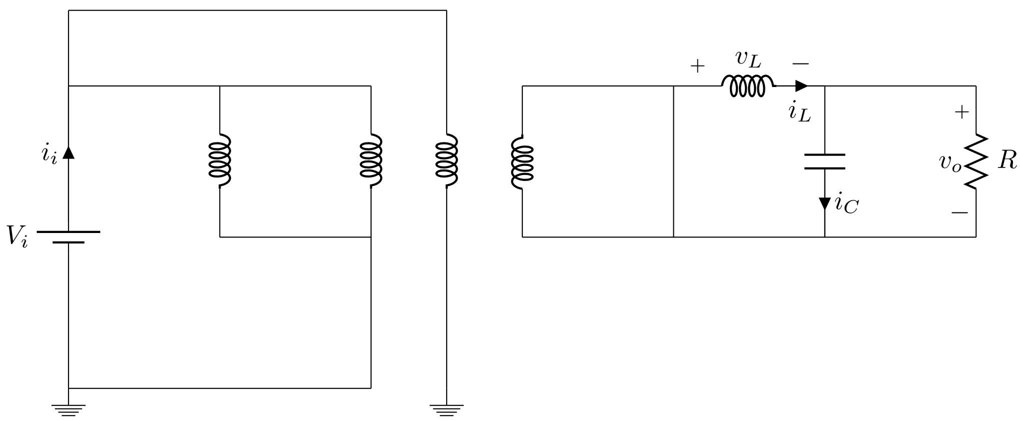
3.1 Forward Converter



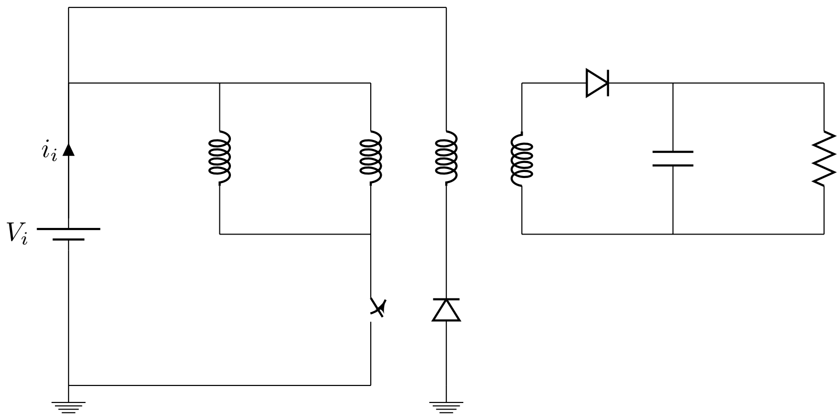
ON circuit



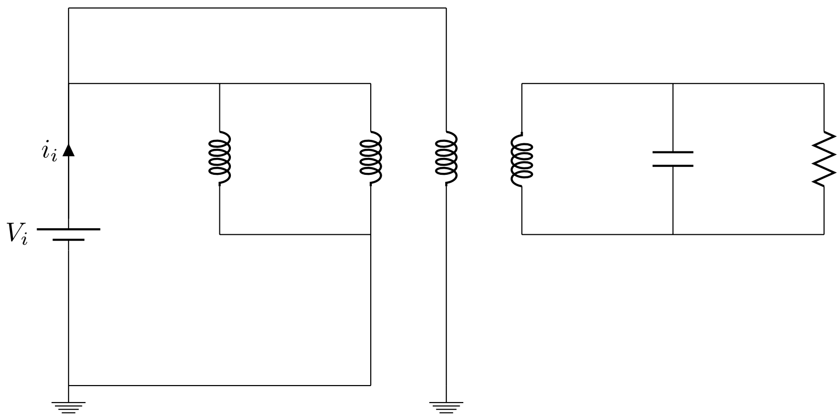
OFF circuit



3.2 Flyback Converter



ON circuit



OFF circuit