

# DC to DC Converters

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# 1 DC to DC Converters

## Analysis hypothesis for the DC-DC converter

1. Periodic Steady state condition. The converter is in a periodic steady state regime, so all the waveforms are periodic. If the circuit is in PSS, the following is also true:
  - i. At the inductors, the average voltage is zero,  $v_L = 0$ .
  - ii. At the capacitors, the average current is zero,  $i_L = 0$
2. No power loss, unitary efficiency:  $\eta = \frac{P_i}{P_o} = 1$
3. The voltage in the capacitors is considered to be approximately constant,  $v_c \approx \text{constant}$
4. Ideal components: diodes, switches, capacitors...

Proof of 1.ii:

Small ripple approximation: In a well-designed converter, the output voltage ripple is small. Hence, the waveforms can be easily determined by ignoring the ripple:  $v_o(t) \approx V$

## Converter types:

Converter diagram

- **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.
- **Discontinuous Current Mode:** Current and thus the magnetic field in the inductive energy storage may reach or cross zero.

**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

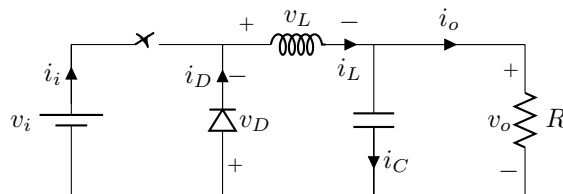
- $t_{OFF}$ , time of low value (zero)
- $D$ , duty cycle

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

Switching component

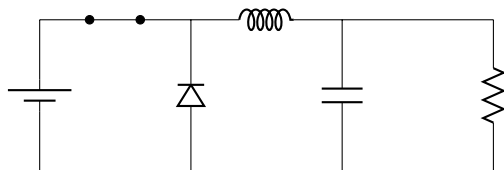
## 2 Non-isolated converters

### 2 Step-down Converter (Buck)

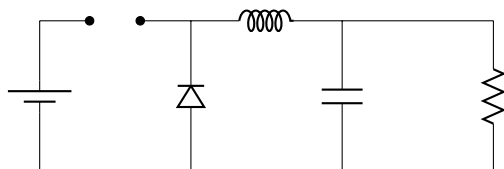


State of the diode

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

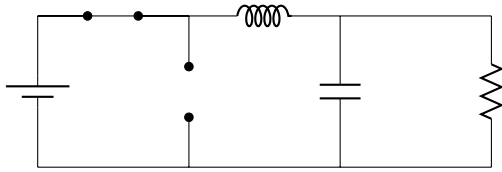


- **OFF circuit.** We can't know the state of the diode until the  $v_o$  and  $v_L$  voltages are known. Since in the ON circuit the diode is not conducting, the diode should be conducting in the OFF circuit or it won't have a purpose in the circuit. We suppose the diode to be forward polarized (ON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

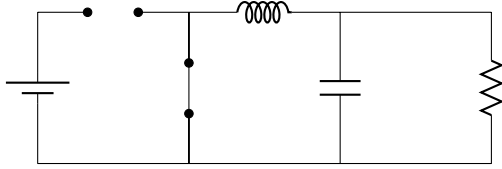


Diode table

ON equivalent circuit



### OFF equivalent circuit



### Inductor 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 demonstrate 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,  $\bar{v}_L = 0$

### Inductor current

### Switch tension

Switch current

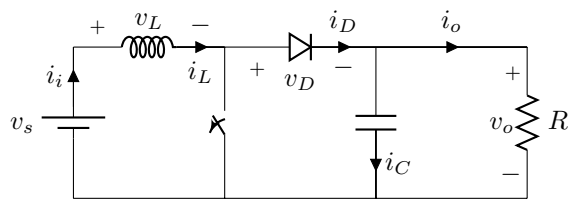
Diode tension

Diode current

Capacitor current

Output current

## 2 Step-up Converter (Boost)



State of the diode

- ON Circuit:

- OFF circuit

Diode table

ON equivalent circuit

**OFF equivalent circuit**

**Inductor voltage**

**Inductor current**

**Switch tension**

**Switch current**

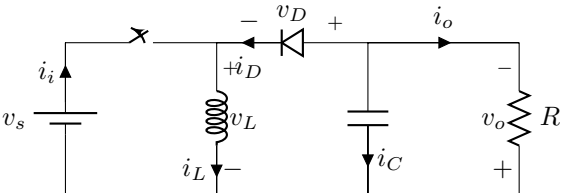
Diode tension

Diode current

Capacitor current

Output current

2 Buck-Boost Converter





## State of the diode

- ON Circuit:

- OFF circuit

## Diode table

## ON equivalent circuit

## OFF equivalent circuit

**Inductor voltage**

**Inductor current**

**Switch tension**

**Switch current**

**Diode tension**

Diode current

Capacitor current

Output current