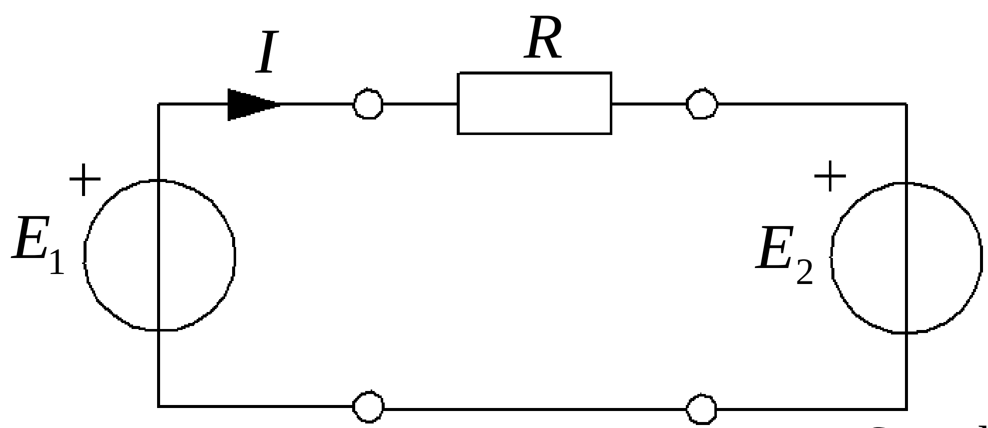
# Energy transfer with a resistor

An emf $E_1$ with a higher voltage can charge an other emf $E_2$ with a lower voltage if you connect them to together with a current limiting resistor. $E_1 > E_2$.




$$I = \frac{E_1 - E_2}{R}$$

The delivered energy

$$W_1 = E_1 I t$$

$$W_R = R I^2 t$$

Stored energy

$$W_2 = E_2 I t$$

During charging, there becomes heat losses in *R*.

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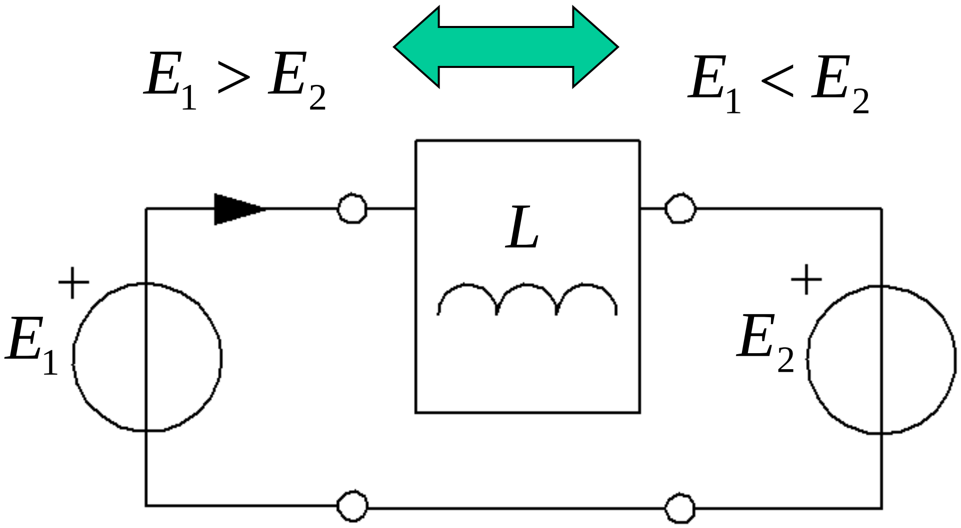
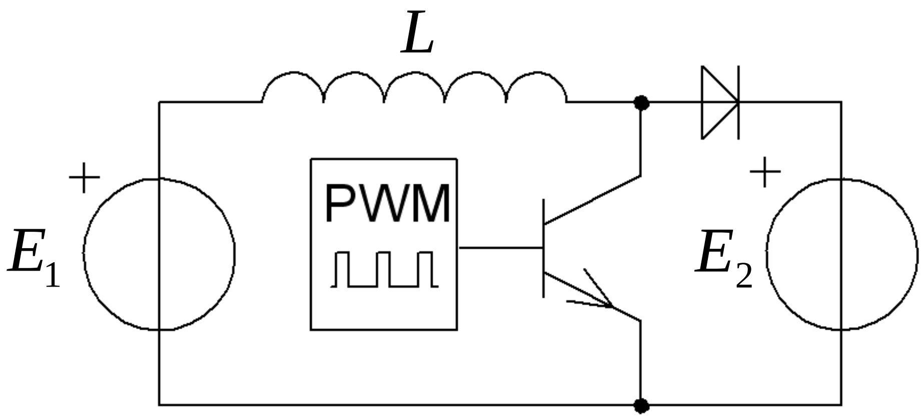
# Energy transfer with an inductor

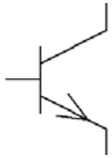



With an inductor one can transfer energy from a larger emf to a smaller, $E_1>E_2$, **Step Down**, but also from a smaller emf to a larger, $E_1<E_2$, **Step Up**. This in theory is completely without losses.

# Step Up



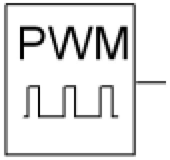

$E_1 < E_2$



- Transistor

- Diode

Pulse width modulation




- PWM-unit

Transistor and diode acts together as a switch controlled by the PWM unit.

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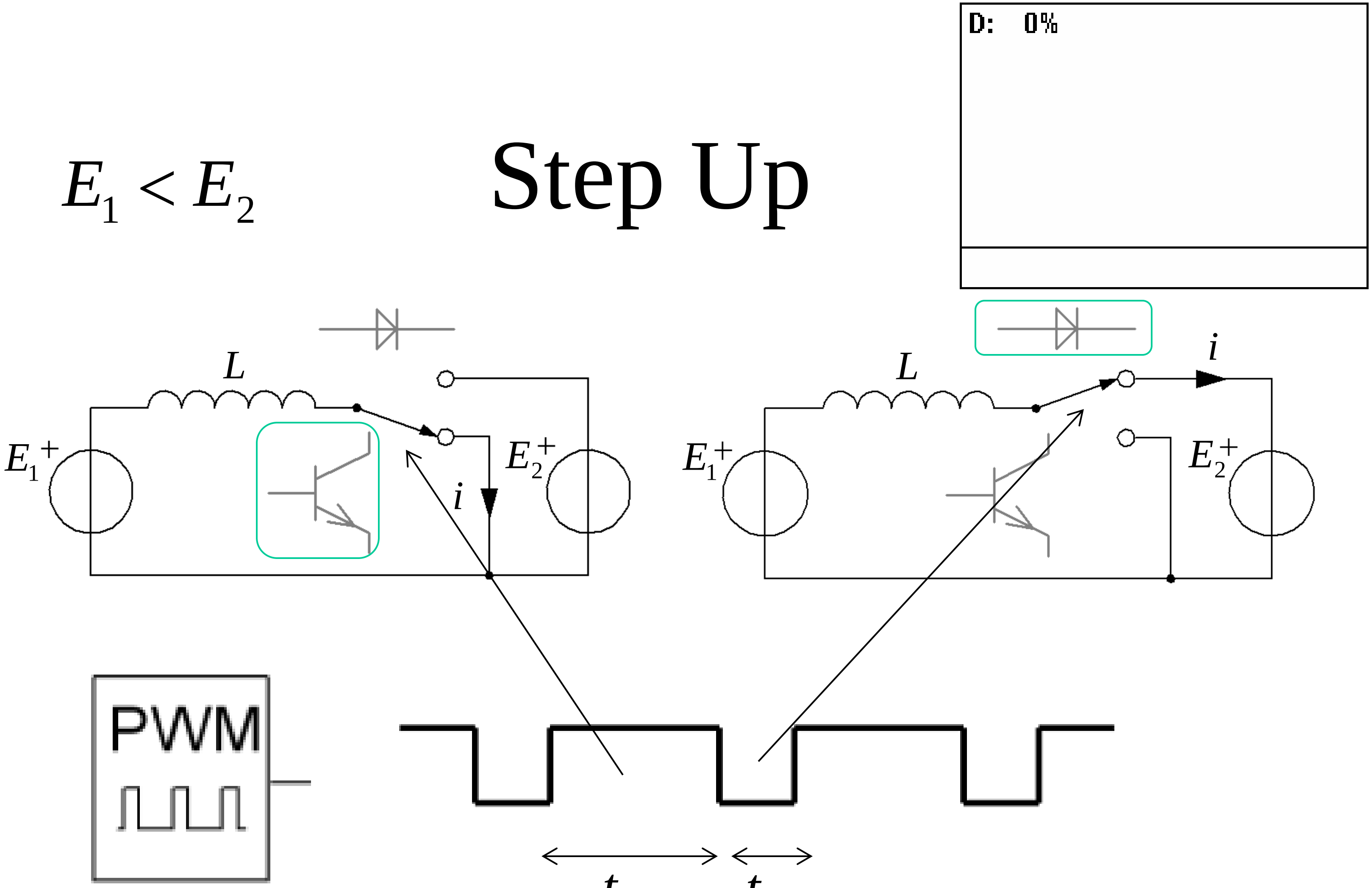
$E_1 < E_2$

# Step Up

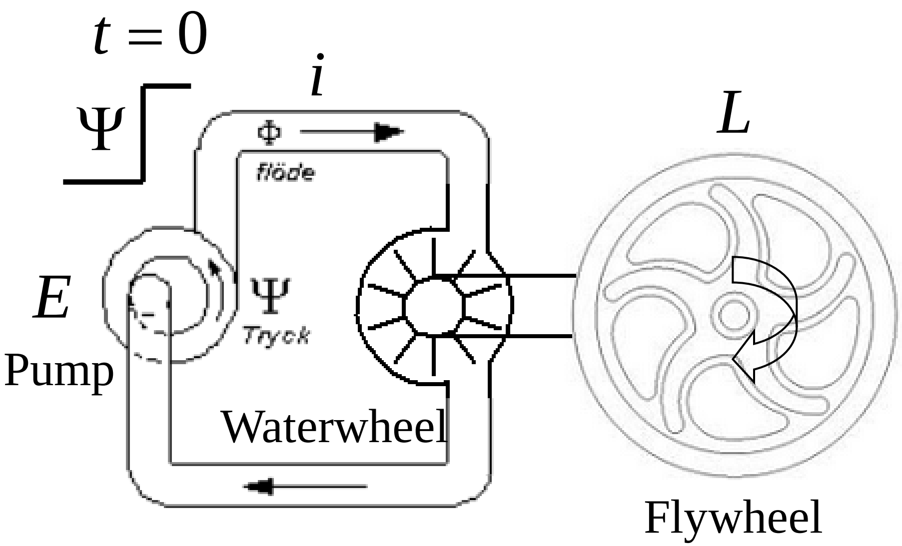



$t_{on}$ $t_{off}$

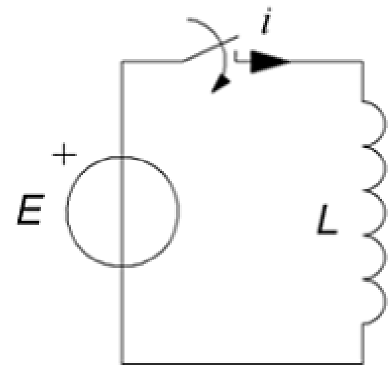
- DutyCycle $D$ :

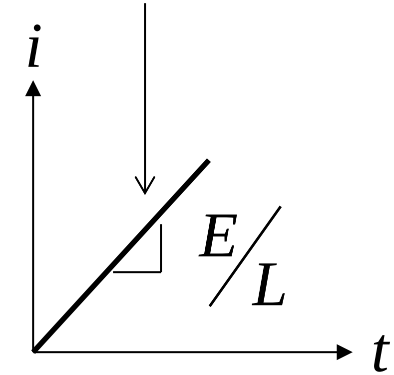
$$D = \frac{t_{on}}{t_{on} + t_{off}}$$

# The coil current inertia



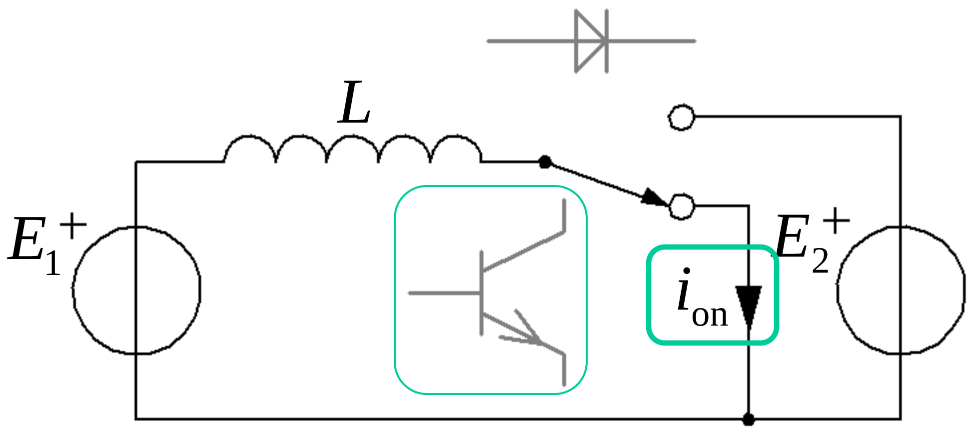

$$E = L\frac{di}{dt} \Leftrightarrow \frac{di}{dt} = \frac{E}{L}$$



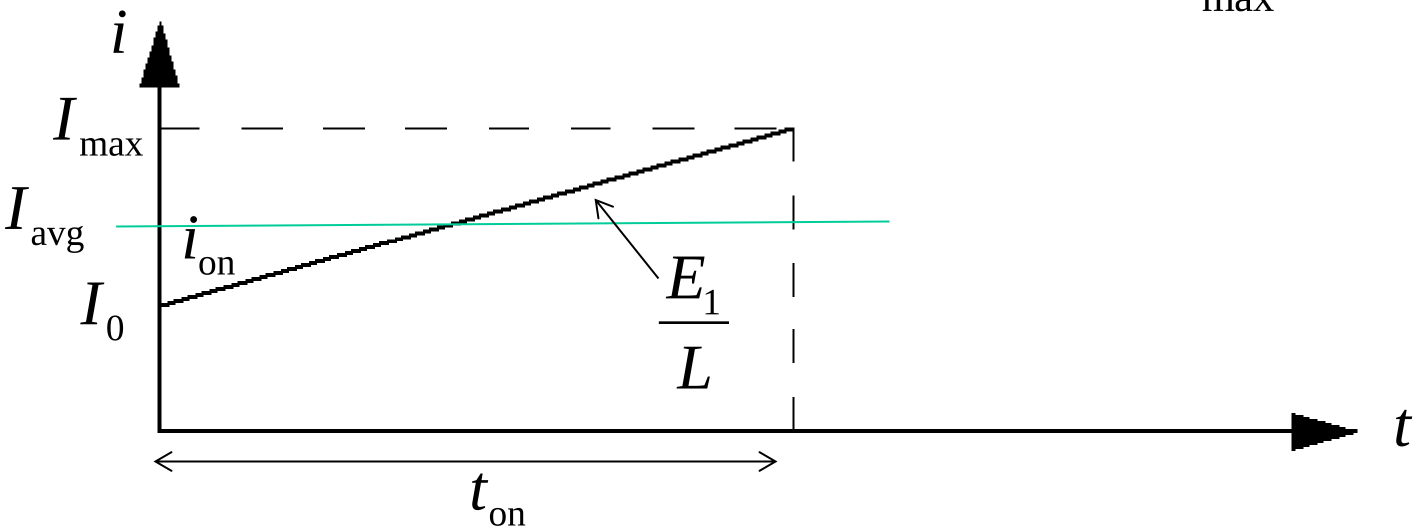




The inductor has **current-inertia**. The current can not change immediately. A fluid analogy: The inductor is a water mill with a flywheel.

# Energy transfer with an inductor




Let $E_1$ drive an increasing current through $L$ during $t_{on}$. The current then reaches $I_{max}$.

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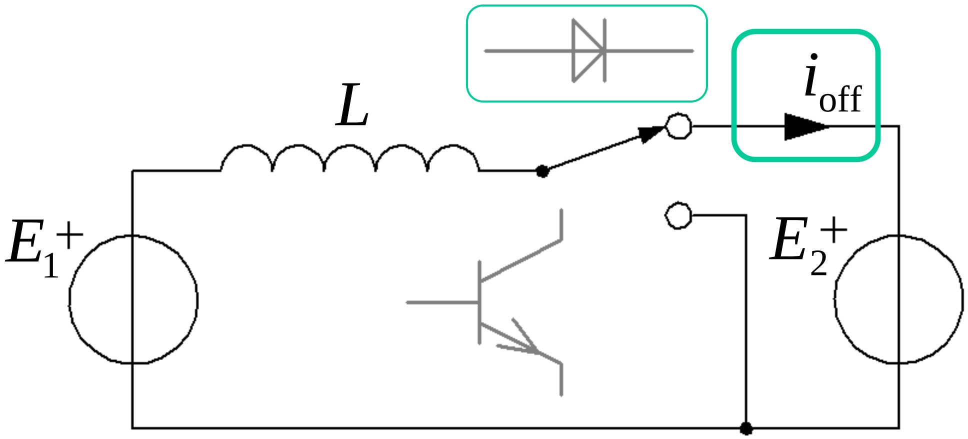
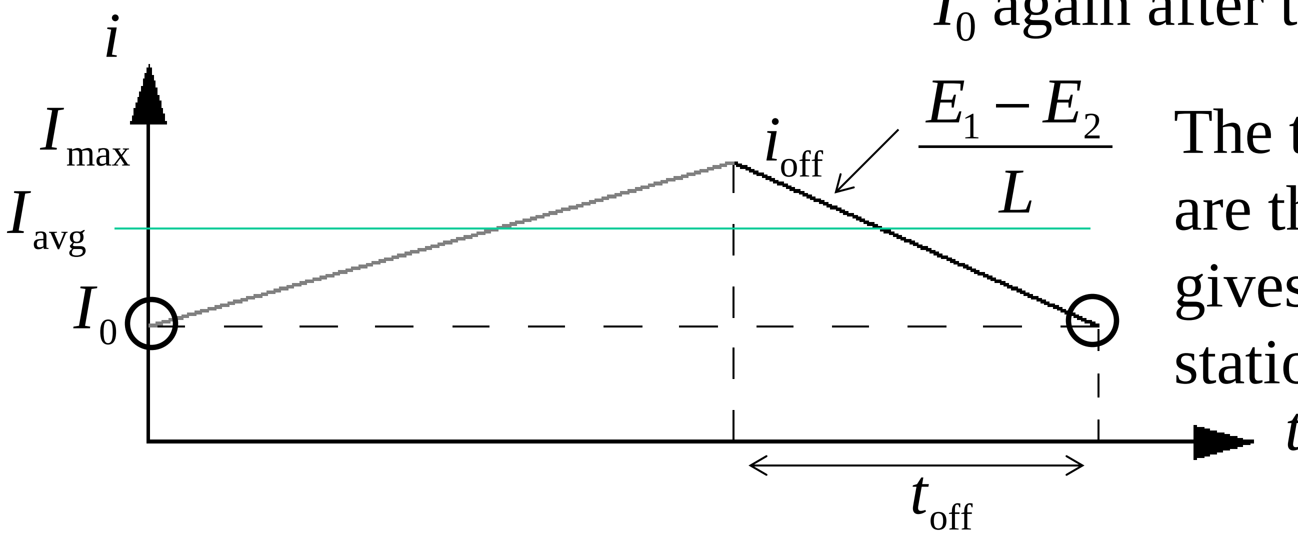
# Energy transfer with an inductor




switch the inductor so that $L$ now continnues the current through $E_2$. $E_2 > E_1$ means that the current will be decreasing. It will reach $I_0$ again after time $t_{off}$ .




The times $t_{on}$, $t_{off}$ are those that gives us a stationary plot.

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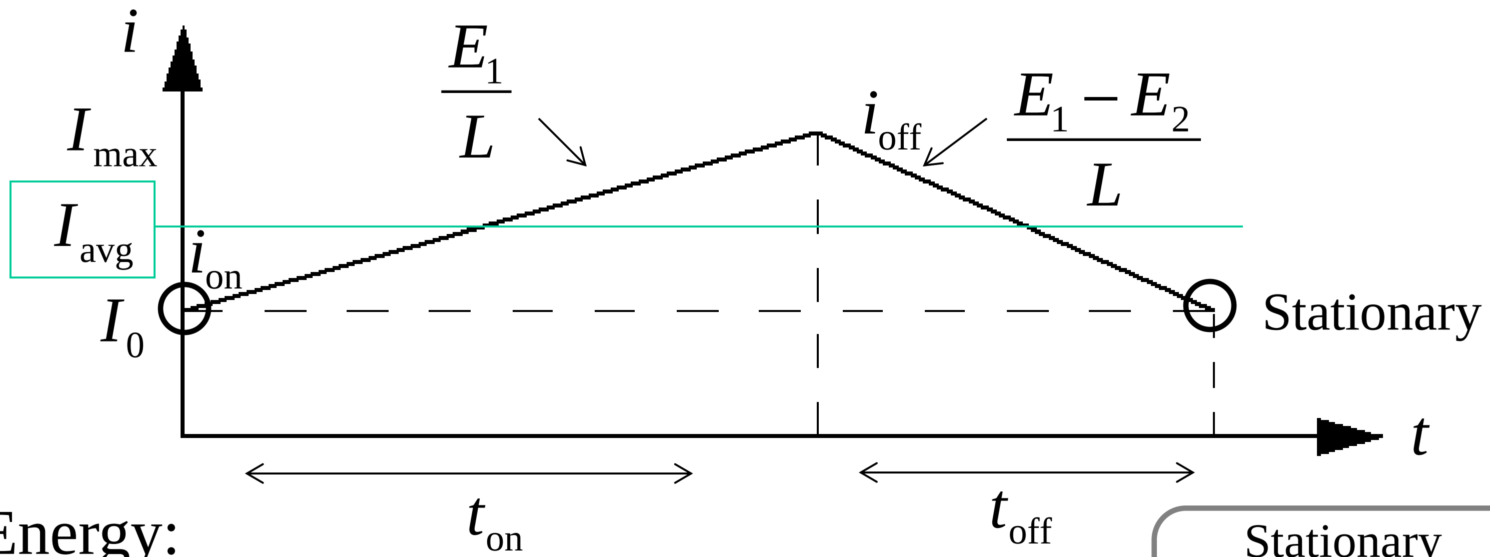
# Energy transfer with an inductor




Energy:

$$W_{on} = E_1 \cdot I_{avg} \cdot t_{on} \qquad W_{off} = (E_1 - E_2) \cdot I_{avg} \cdot t_{off}$$

Stationary

$$W_{on} + W_{off} = 0$$

$$\frac{E_2}{E_1} = \frac{t_{on} + t_{off}}{t_{off}} = \cdots = \frac{1}{1-D} \qquad E_2 = E_1 \cdot \frac{1}{1-D}$$

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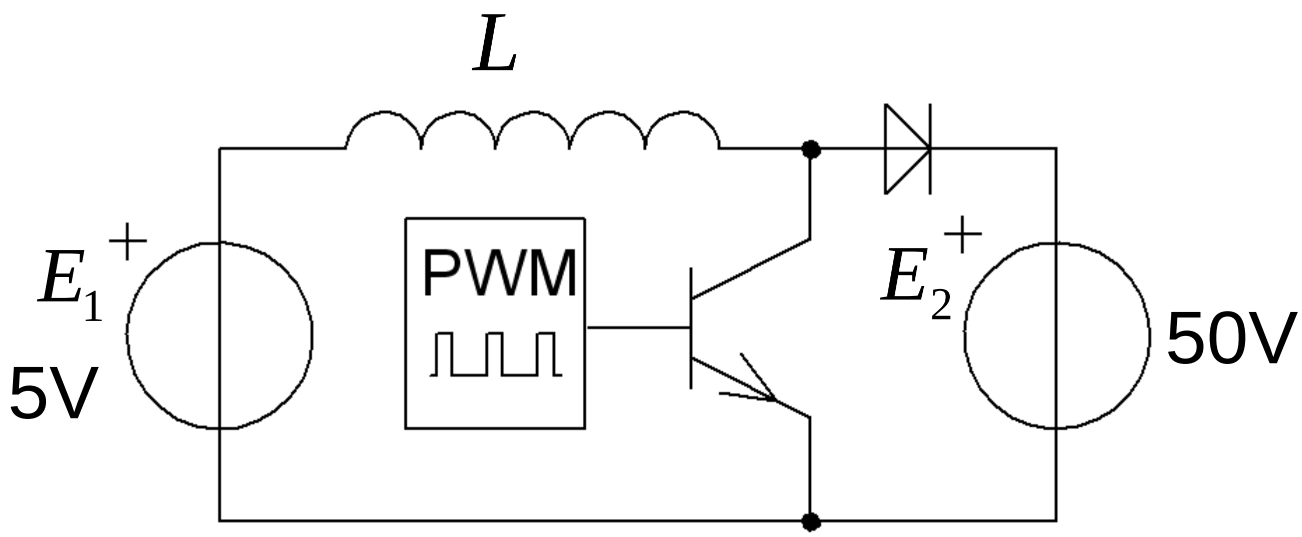
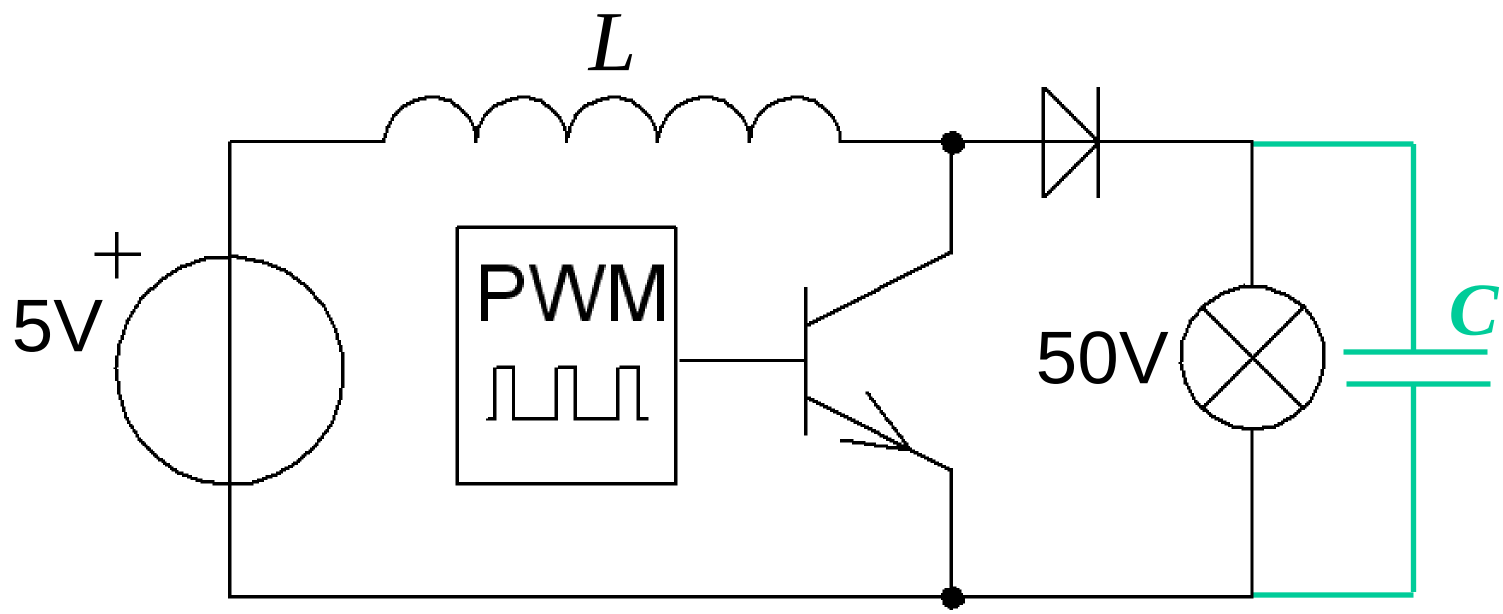
# $5V \rightarrow 50V$ ?




- Dutycycle equation:

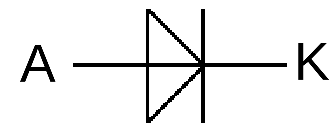
$$E_2 = E_1 \cdot \frac{1}{1-D} \Rightarrow D = 1 - \frac{E_1}{E_2} = 1 - \frac{5}{50} = 90\%$$

# Resistiv load?



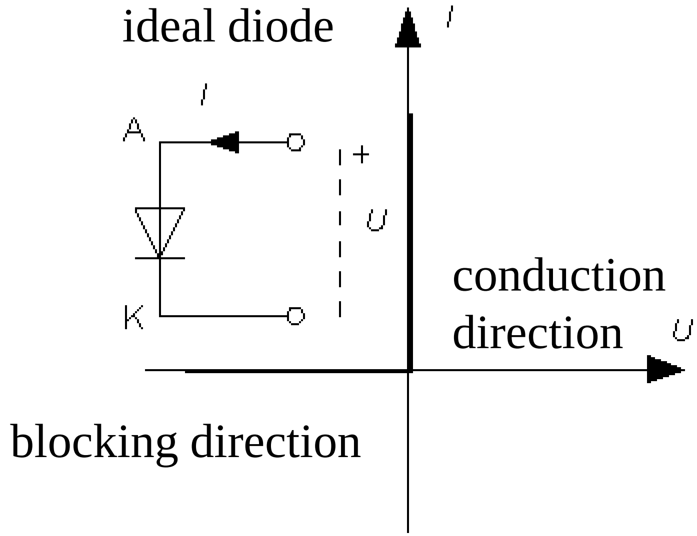

The current to the load will flow intermittently only during $t_{off}$, so the voltage needs to be smoothed with a capacitor $C$.

# ( What is a diode? )



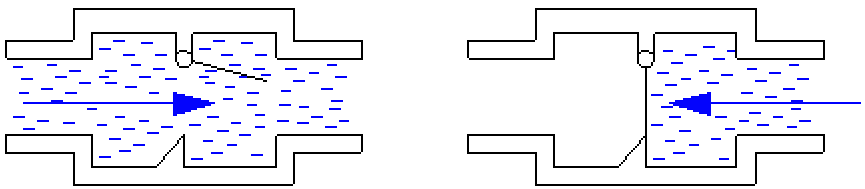

Semiconductor diode

Symbol and characteristic




Fluid Analogy

check valve



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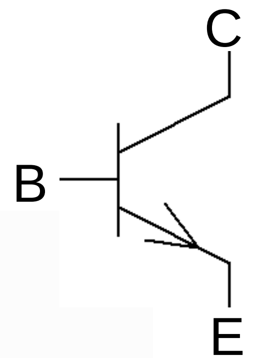
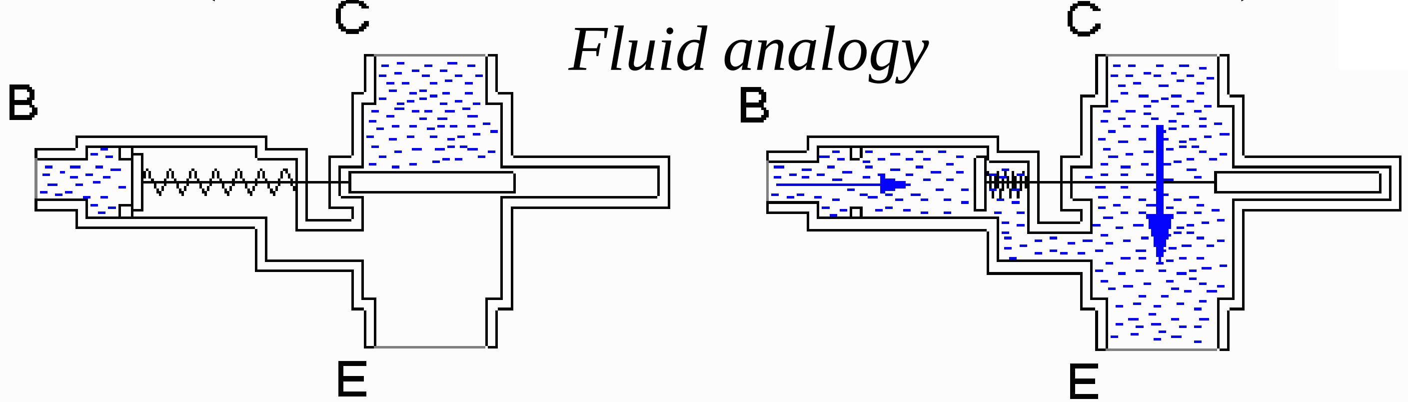
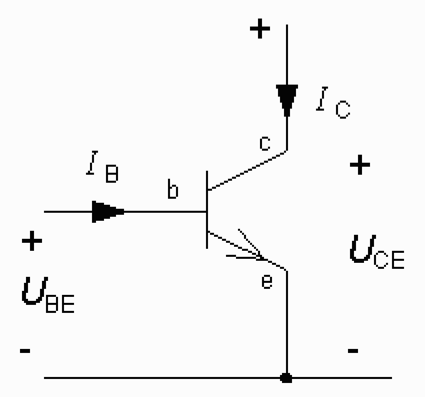
# ( What is a transistor? )




*Fluid analogy*

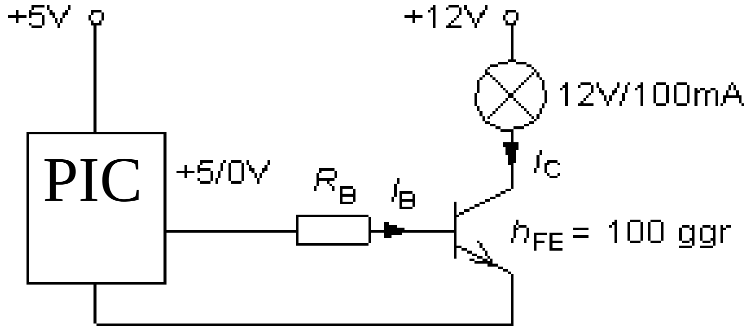



The classic bipolar transistor, is earlier development than the MOS transistor. A small "base current" $I_B$ can control up to 100 times ($h_{FE}$) bigger ”collector current” $I_C$.




$$h_{FE} = \frac{I_C}{I_B}$$

$$h_{FE} \approx 100$$




$$I_B > 1\,\text{mA} \quad \Rightarrow \quad I_C = 100\,\text{mA}$$

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# Practical dimensioning?

It is simple to set up the Step-up converter's output voltage with the DutyCycle *D*! This we do at the lab.

In practice it is much more *difficult*. An electronics engineer is faced with many questions:
At what current "saturate" the coil iron core? How big internal resistance has the inductor? How big are the load variations? What values to $L$ and $C$ and $f$ should be choosen? It is common to simulate the circuit with more realistic component models than what we use here.

LT:s App note has the title ”**Switching Regulators for Poets**”

LINEAR TECHNOLOGY Application Note 25

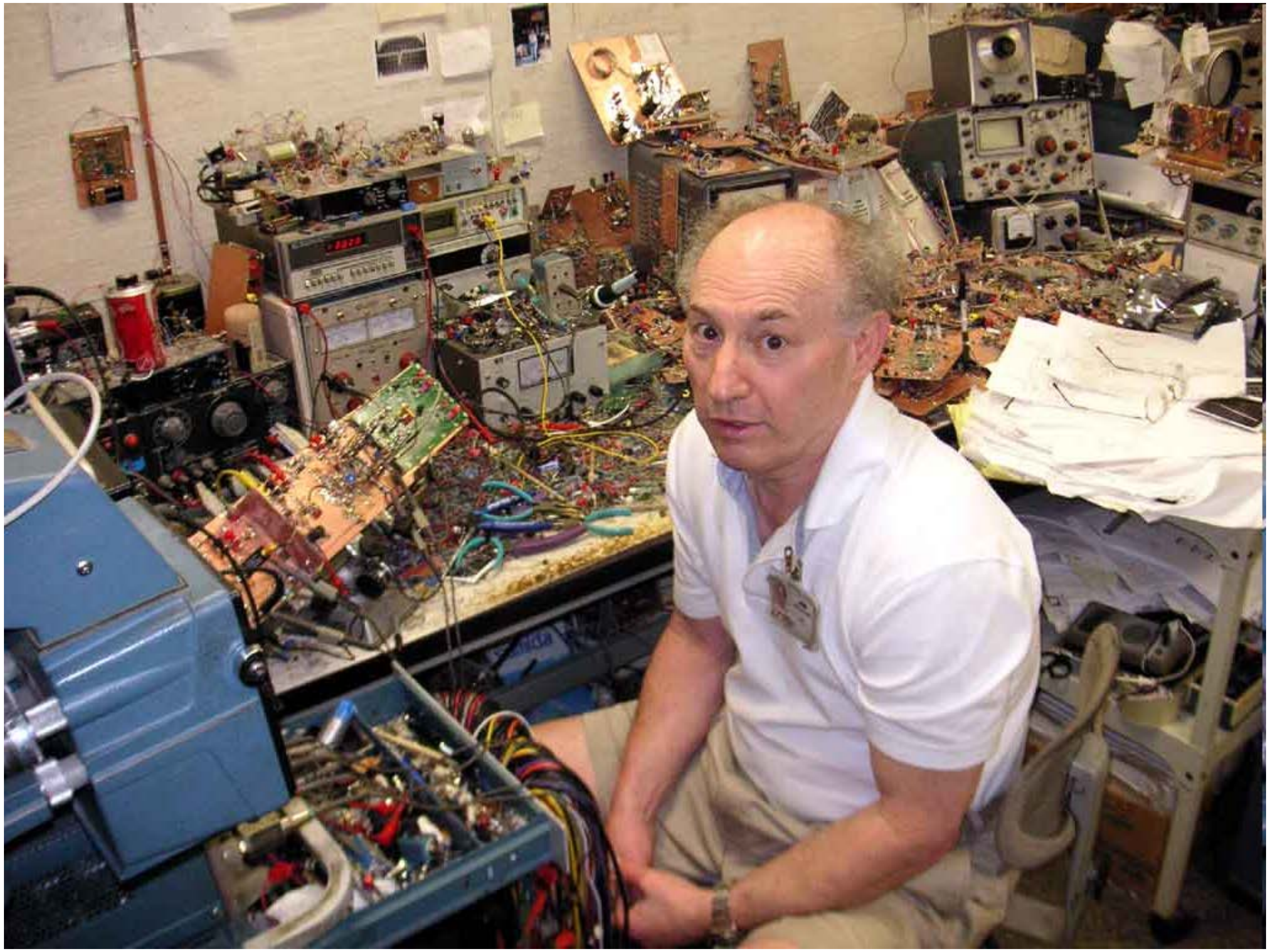
Switching Regulators for Poets A Gentle Guide for the Trepidatious

**A problem is that while everyone agrees that working switching regulators are a good thing, everyone also agrees that they are difficult to get working.**

Unfortunately, switching regulators are one of the most difficult linear circuits to design. Mysterious modes, sudden, seemingly inexplicable failures, peculiar regulation characteristics and just plain explosions are common occurrences. Diodes conduct the wrong way. Things get hot that shouldn't. Capacitors act like resistors, fuses don't blow and transistors do. The output is at ground, and the ground terminal shows volts of noise. …

***Jim Williams***

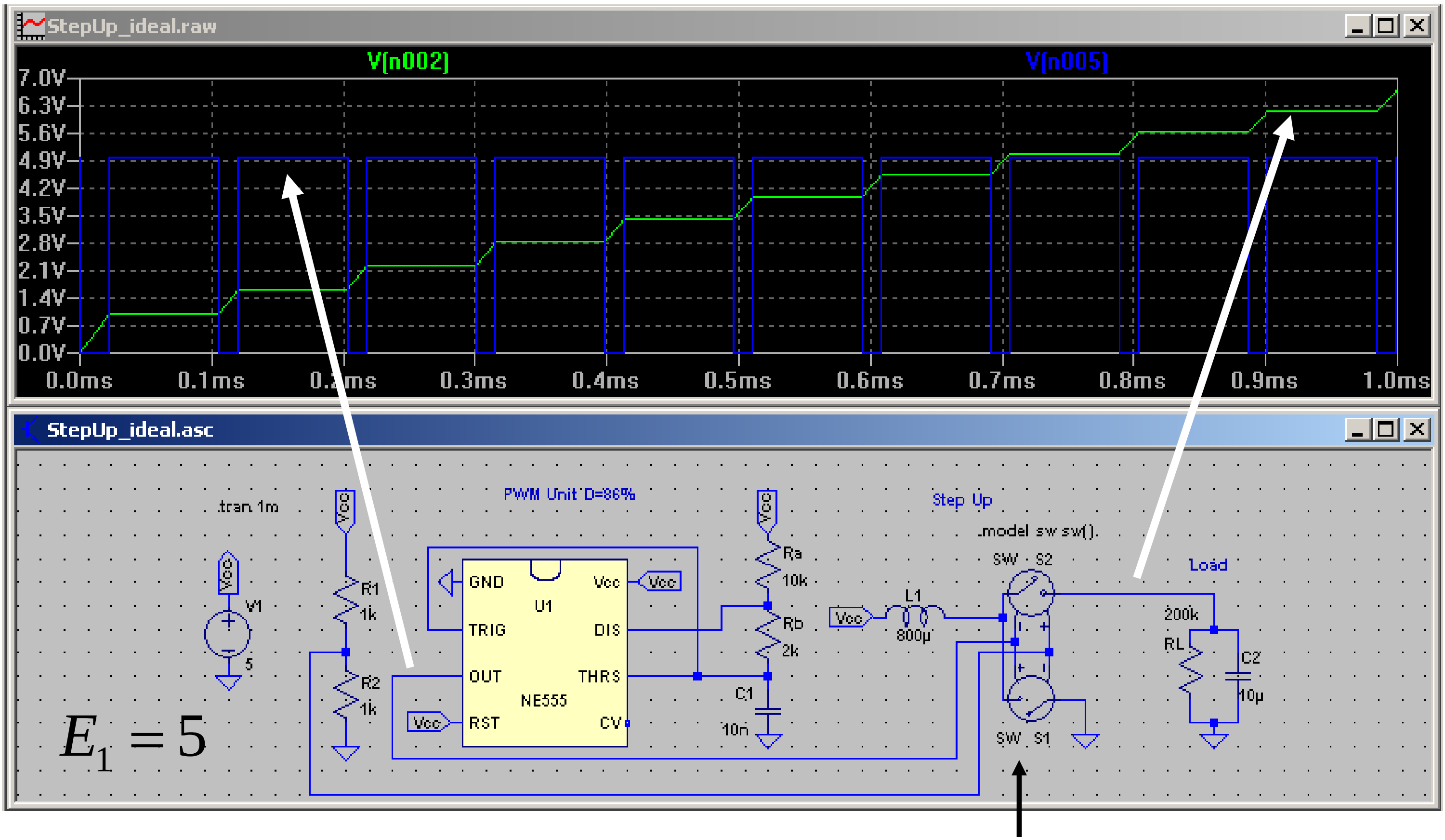
# ***Jim Williams*** *at lab*



# Simulation

$D = 86$ %

Startup Sequence 0…1ms




The voltage is stepping upwards…

*Simulation with an ideal switch*

# Simulation

$E_2 \approx 30$

Stationary at 100 ms

$E_1 = 5\text{V}$
$E_2 \approx 30\text{V}$

$D = 86\%$