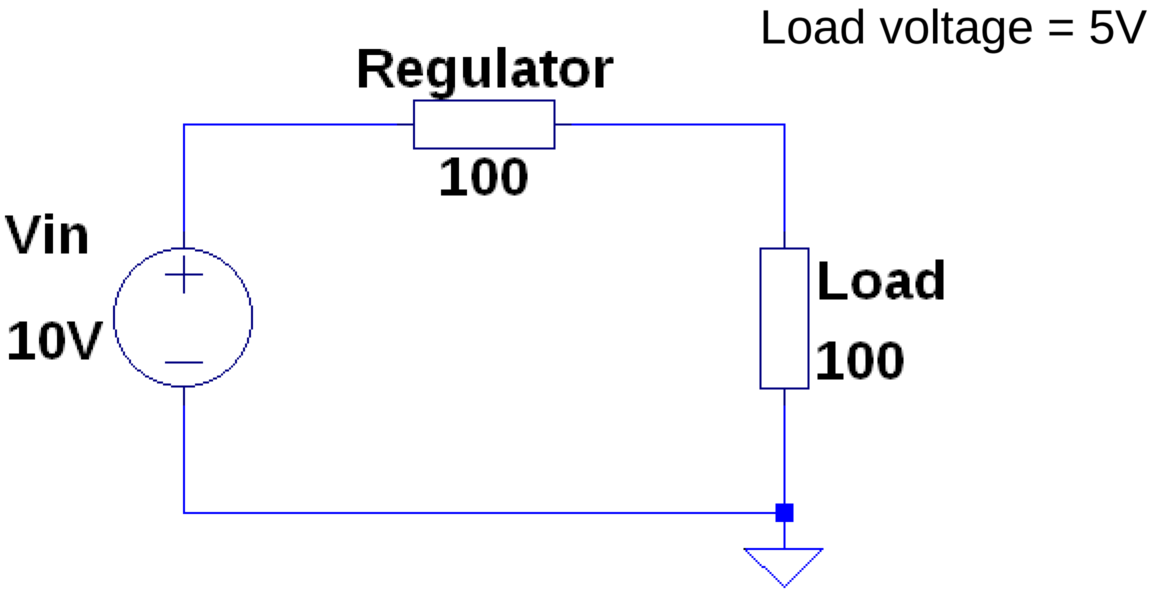
DC Voltage regulation

DC Voltage regulation

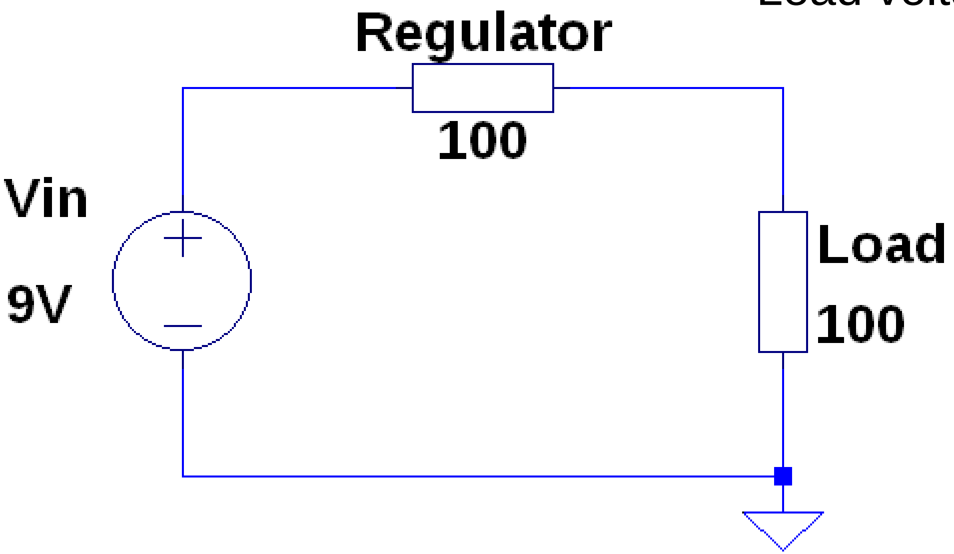
Keep the output voltage constant despite:
Input voltage variation
Output current variation

DC Voltage regulation



DC Voltage regulation

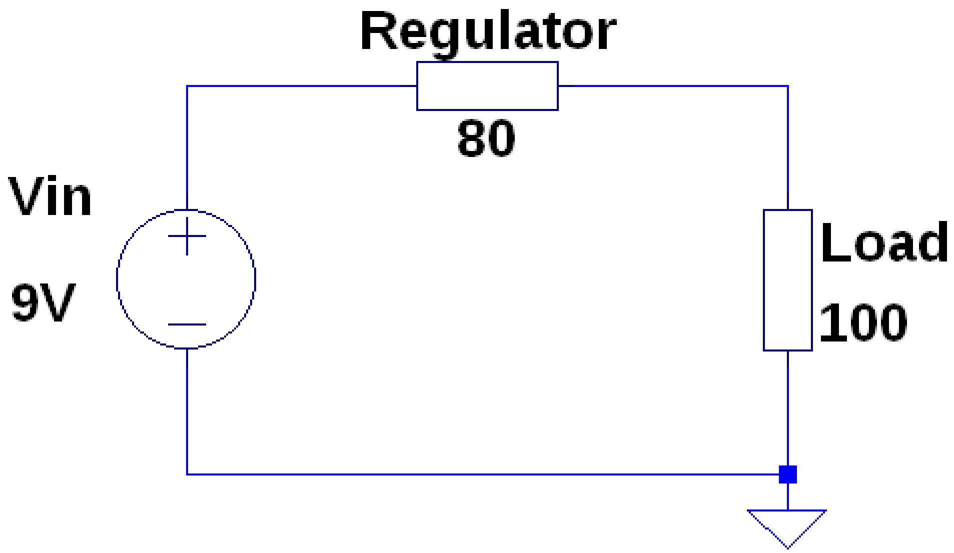
Load voltage = 4.5V



What should the regulator do to restore the load voltage to 5V?

DC Voltage regulation

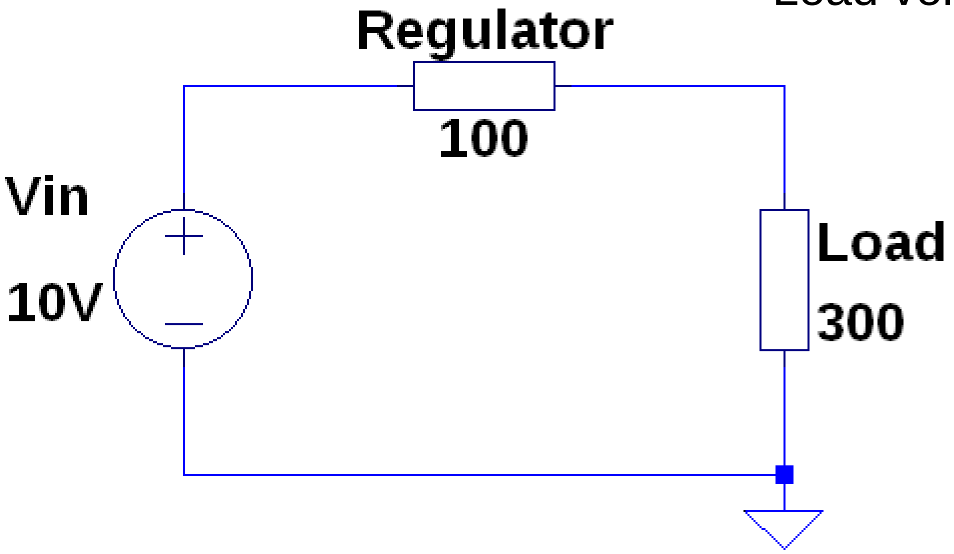
Load voltage = 5V



It must lower its resistance

DC Voltage regulation

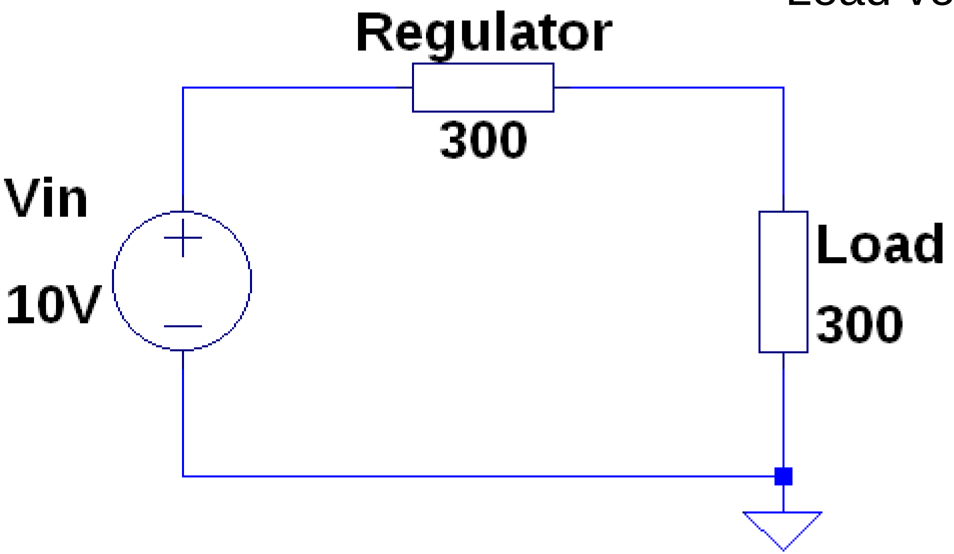
Load voltage = 7.5V



How should the regulator respond?

DC Voltage regulation

Load voltage = 5V



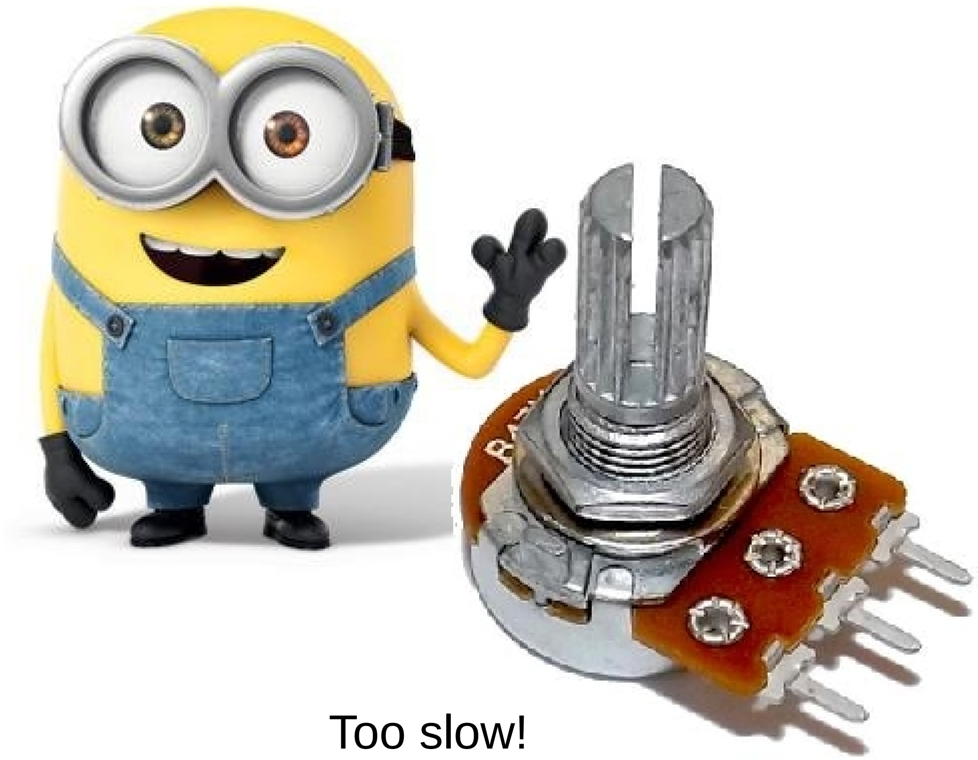
It should raise its resistance

DC Voltage regulation

This sort of regulator is known as a **Linear Voltage Regulator**

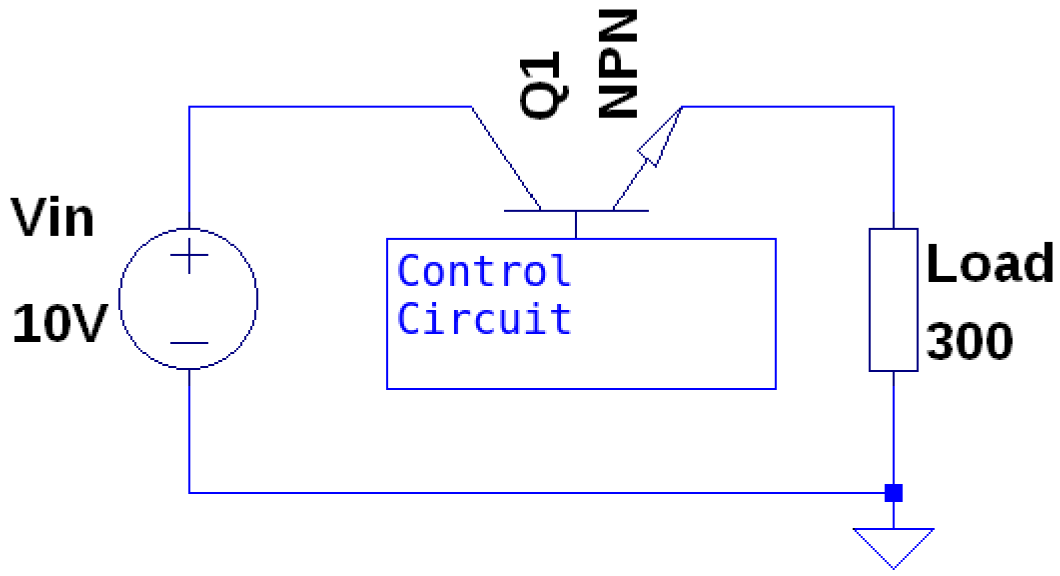
Automatic variation of conductivity of the regulator keeps the output voltage stable

DC Voltage regulation

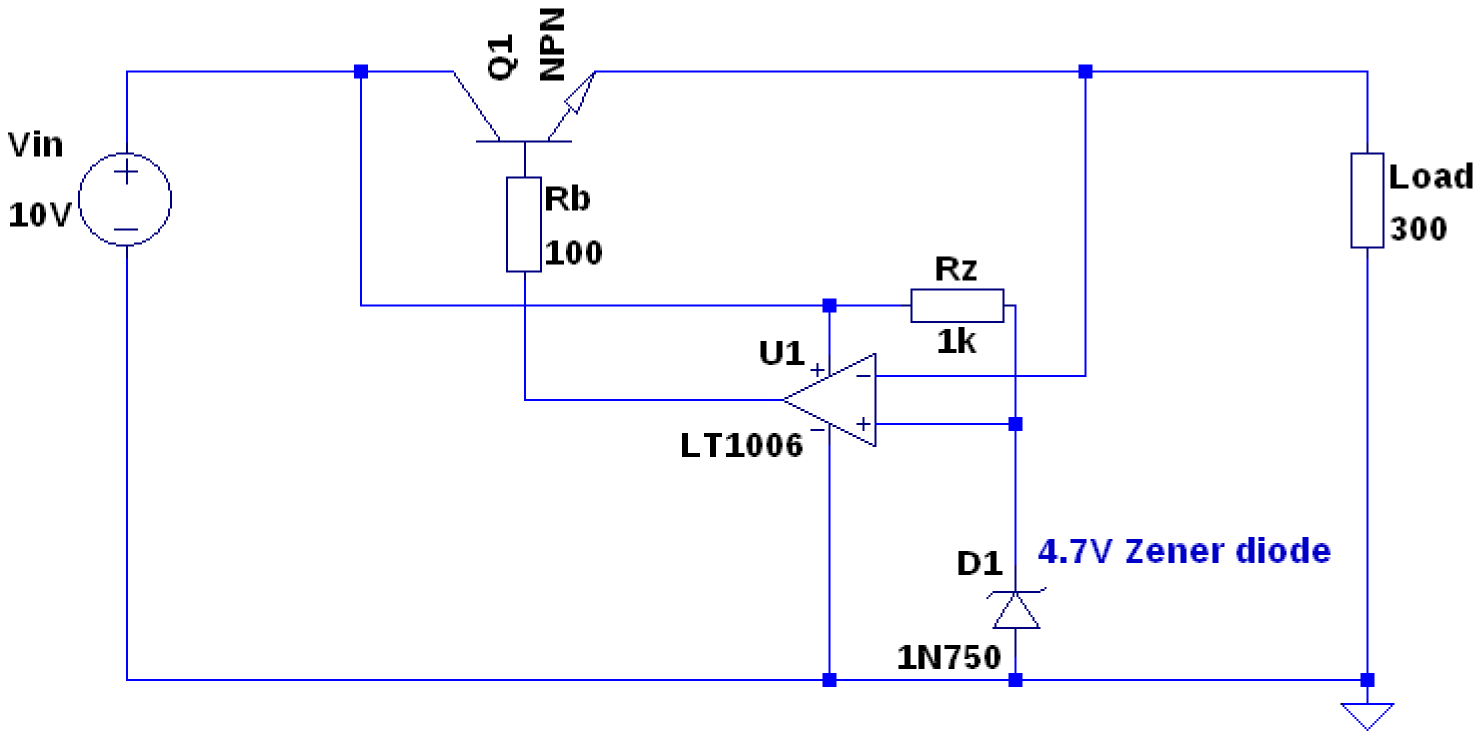


Too slow!

DC Voltage regulation



DC Voltage regulation



DC Voltage regulation

The zener diode provides a stable voltage reference in spite of variations in Vin

As a result of the negative feedback, the op-amp will attempt to make the voltages on its two input pins equal

Simulation

DC Voltage regulation

How “good” is this regulator?

- Efficiency?
- Ability to keep the output voltage stable (regulation)?
- Operating limits?

DC Voltage regulation

Efficiency:

The efficiency is poor.
Example:
Vin = 12V, Output voltage = 5V, Load resistance = 100 Ohms

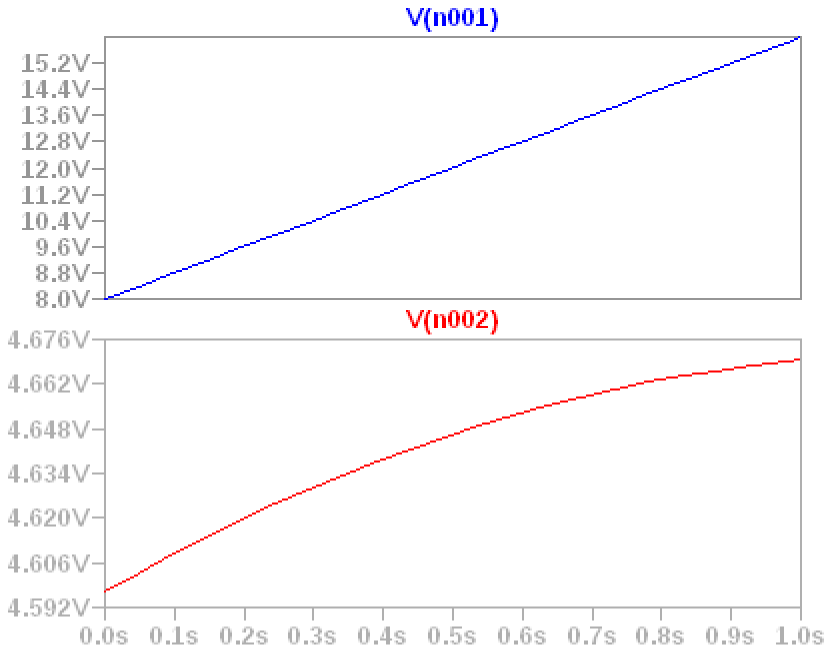
How much energy is lost in the regulator?

What is the efficiency?

What is “quiescent” current”

DC Voltage regulation

Regulation:
How good is our circuit at keeping the output voltage constant?



Vo increases 62mV when Vin changes from 8V to 16V

$$\frac{\Delta V_o}{\Delta V_i} = \frac{0.062}{8} = 0.00775$$

DC Voltage regulation

Operating limits:

The input voltage must be greater than the zener breakdown voltage. Typically the input voltage for a fixed voltage regulator should be about 1 to 2V above the rated output voltage

Low Drop Out (LDO) regulators allow the input voltage to be closer to the output voltage

The input voltage must be less than the maximum op-amp and transistor breakdown voltages

The load current must not be so high that the regulator overheats.

DC Voltage regulation

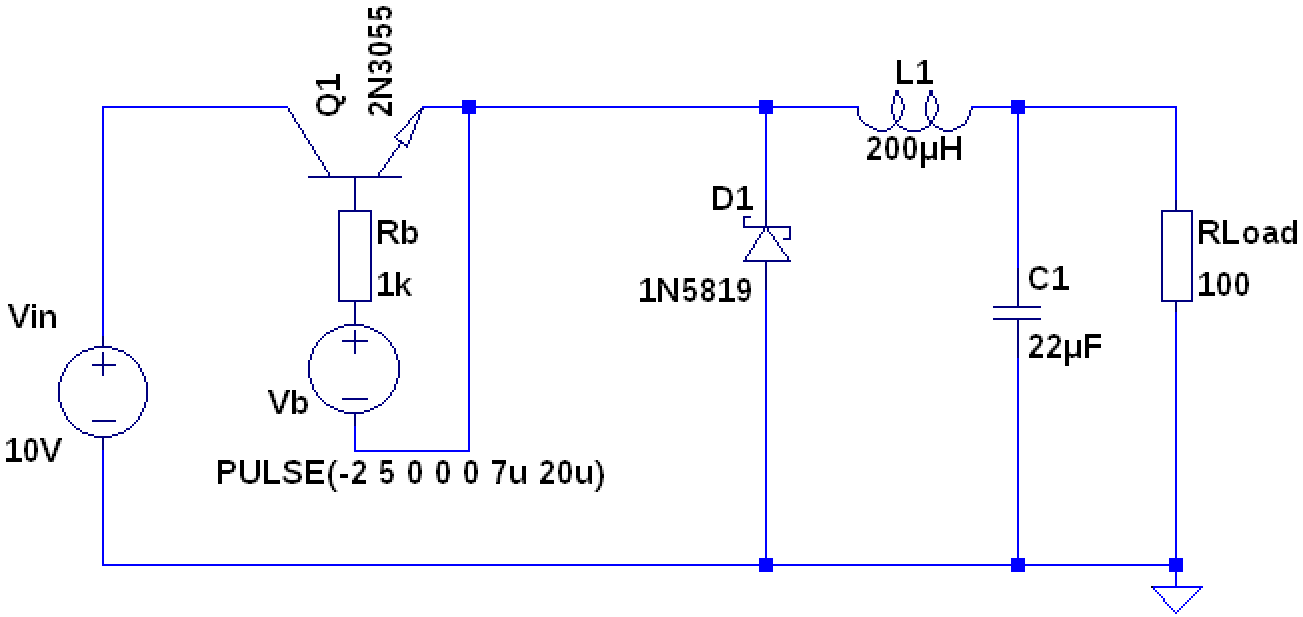
Linear voltage regulators are good for low power applications.

They are simple to use, require little or no external components and are low noise.

Higher power DC voltage regulation requires a different approach

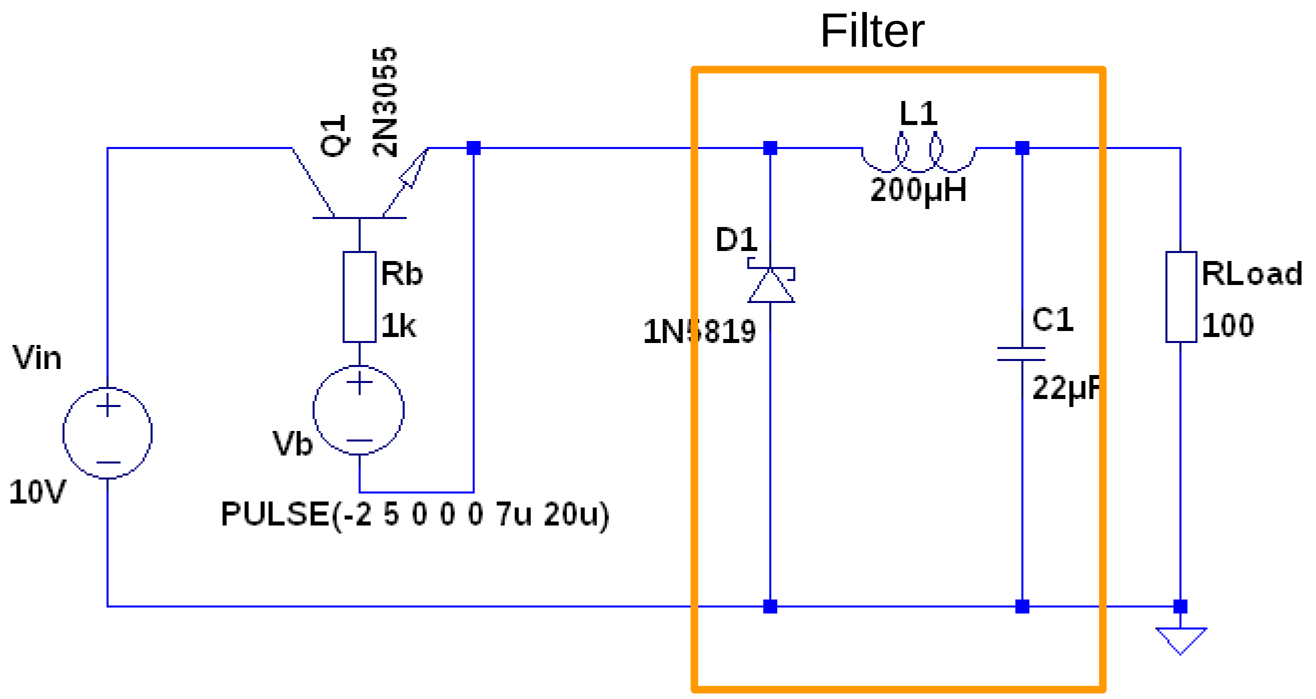
DC Voltage regulation

The switching (step down) voltage regulator

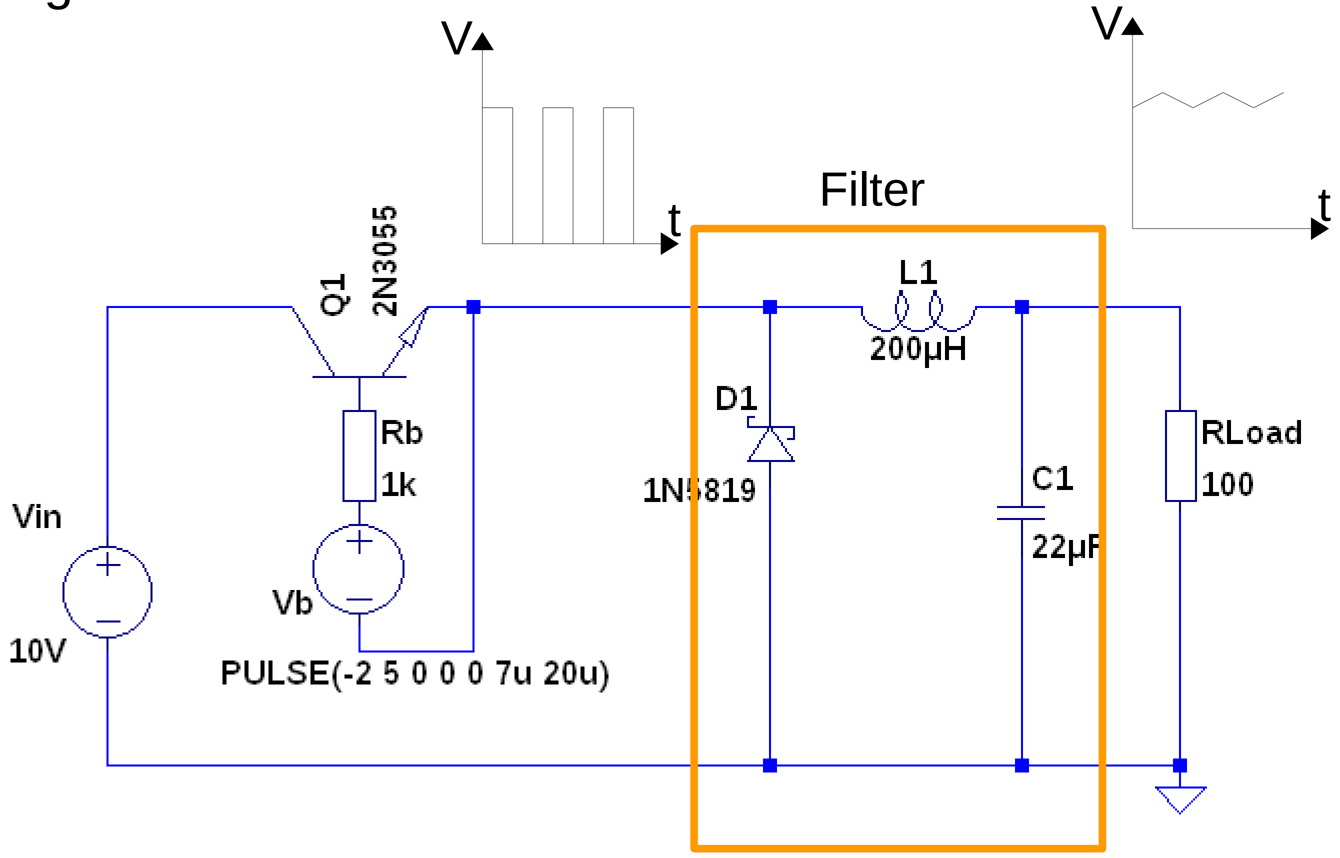


DC Voltage regulation

The switching (step down) voltage regulator



DC Voltage regulation



DC Voltage regulation

The switching (step down) voltage regulator

Different switching elements may be used e.g. MOSFET, IGBT

A control circuit varies the Duty (ratio of ON to OFF time) of the switch in response to load variations.

The (ideal) output voltage is given by:

$$Vo = DVin$$

Where D is the Duty cycle.
e.g. The switch is on for 30% of the time, Vin = 15V
Vo = DVin = 0.3*15 = 4.5V

DC Voltage regulation

The switching (step down) voltage regulator

Choice of switching frequency:

A slow switching speed (< 1kHz) would lead to higher values for the filter elements.

Large Capacitors and Inductors reduce the reaction speed of the regulator

Generally, it is desirable to keep switching speed high but not so high that switching losses are excessive

DC Voltage regulation

The switching (step down) voltage regulator

Analysis:

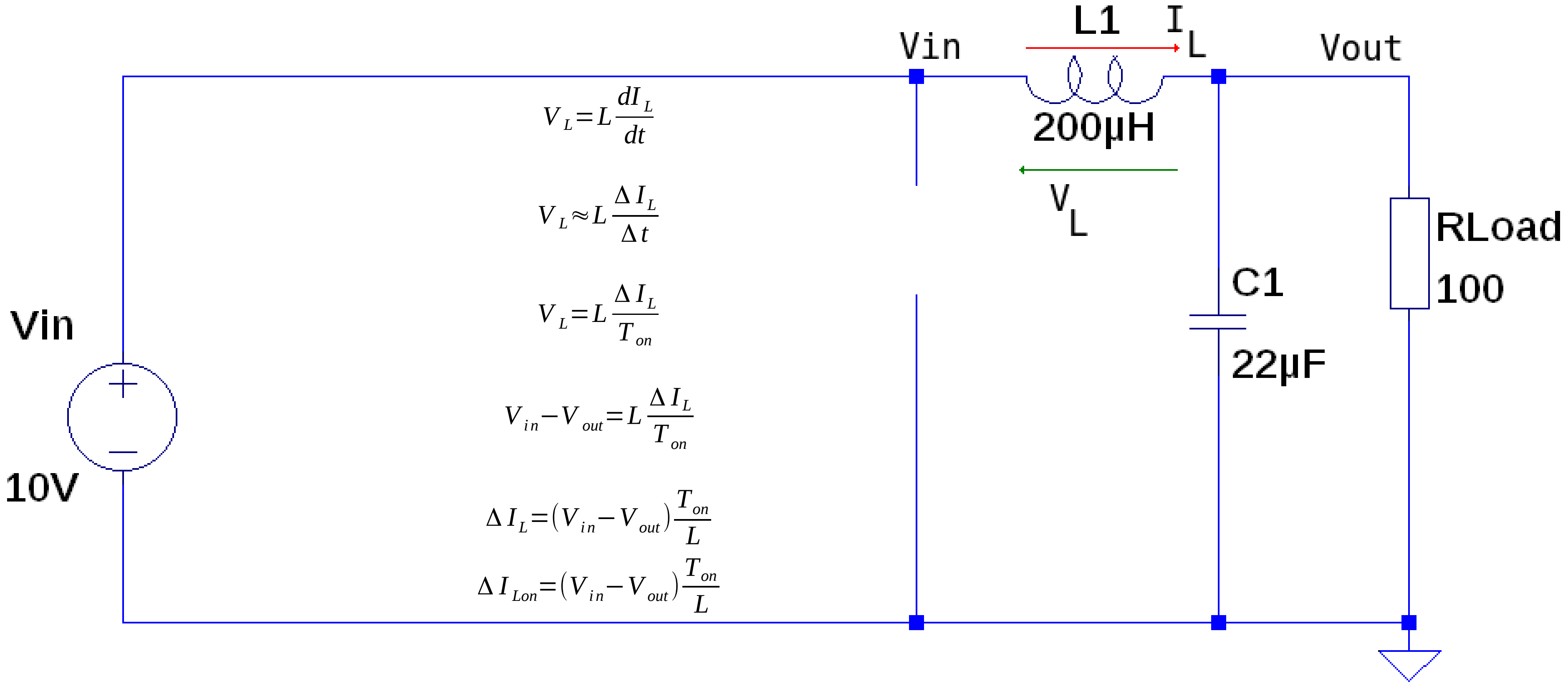
Assumptions:

Inductor currents rise and fall linearly during a switching cycle

Capacitor voltages remain roughly constant during a switching cycle

DC Voltage regulation

The switching (step down) voltage regulator



$$V_L = L\frac{dI_L}{dt}$$

$$V_L \approx L\frac{\Delta I_L}{\Delta t}$$

$$V_L = L\frac{\Delta I_L}{T_{on}}$$

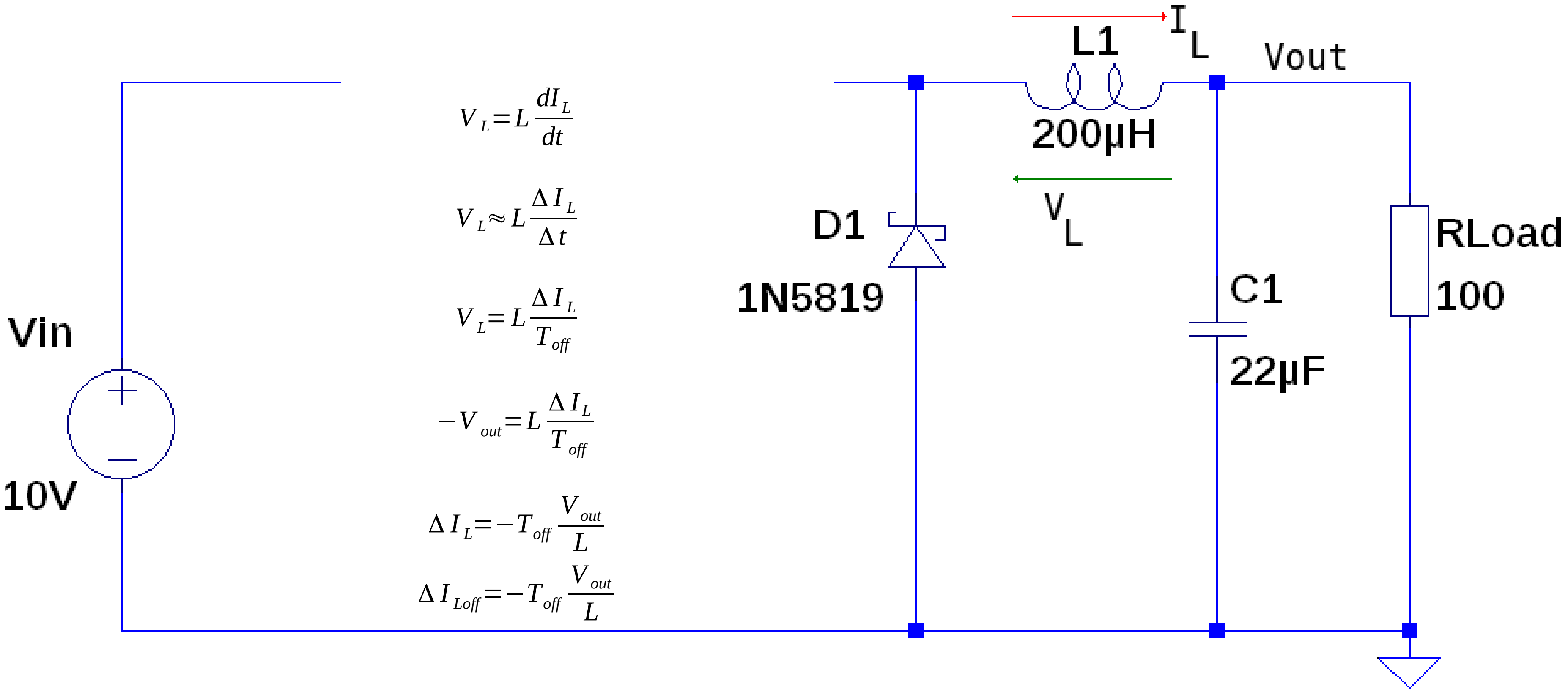
$$V_{in} - V_{out} = L\frac{\Delta I_L}{T_{on}}$$

$$\Delta I_L = (V_{in} - V_{out})\frac{T_{on}}{L}$$

$$\Delta I_{Lon} = (V_{in} - V_{out})\frac{T_{on}}{L}$$

DC Voltage regulation

The switching (step down) voltage regulator



$$V_L = L\frac{dI_L}{dt}$$

$$V_L \approx L\frac{\Delta I_L}{\Delta t}$$

$$V_L = L\frac{\Delta I_L}{T_{off}}$$

$$-V_{out} = L\frac{\Delta I_L}{T_{off}}$$

$$\Delta I_L = -T_{off}\frac{V_{out}}{L}$$

$$\Delta I_{Loff} = -T_{off}\frac{V_{out}}{L}$$

DC Voltage regulation

The switching (step down) voltage regulator

When the regulator has settled down:

$$\Delta I_{Loff} = -\Delta I_{Lon}$$

$$-T_{off}\frac{V_{out}}{L} = -(V_{in} - V_{out})\frac{T_{on}}{L}$$

$$T_{off}\frac{V_{out}}{L} = (V_{in} - V_{out})\frac{T_{on}}{L}$$

$$T_{off}V_{out} = (V_{in} - V_{out})T_{on}$$

$$(T_{on} + T_{off})V_{out} = V_{in}T_{on}$$

$$V_{out} = V_{in}\frac{T_{on}}{(T_{on} + T_{off})}$$

$$Period = T = T_{on} + T_{off}$$

$$Duty\,Cycle = D = \frac{T_{on}}{T}$$

$$V_{out} = V_{in}\frac{DT}{T}$$

$$\boxed{V_{out} = DV_{in}}$$