Lecture4: Diode circuits

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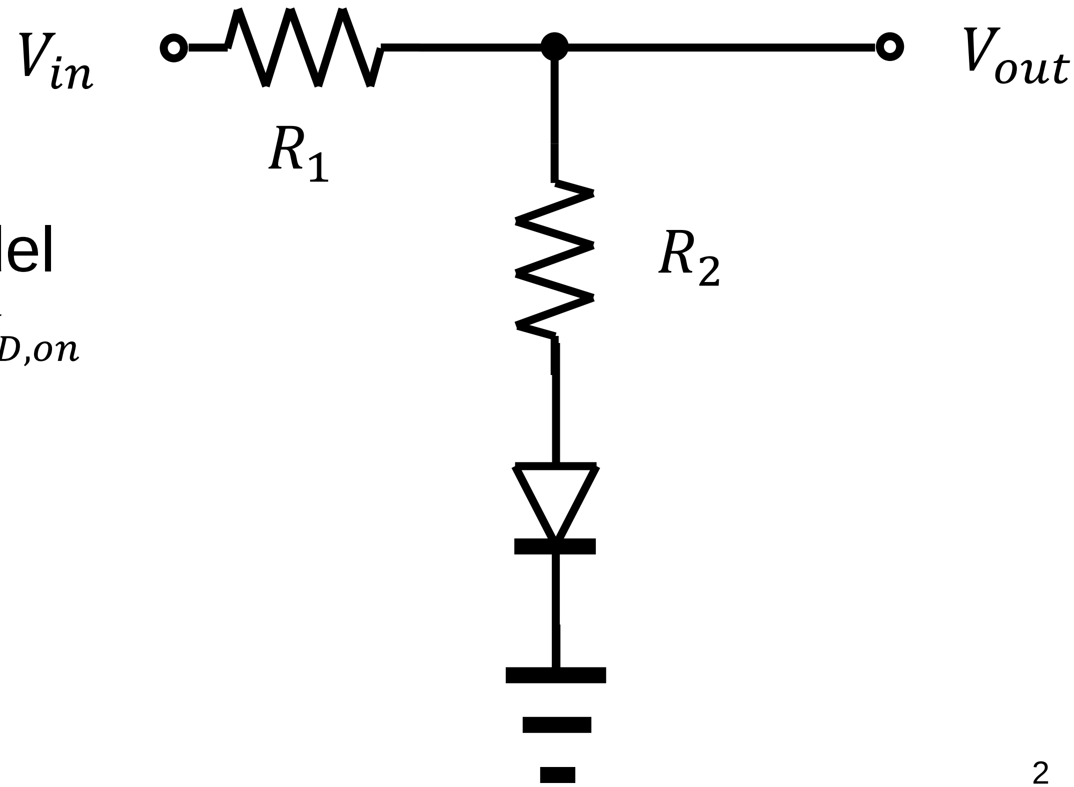
PN junction as a diode

- Exponential model

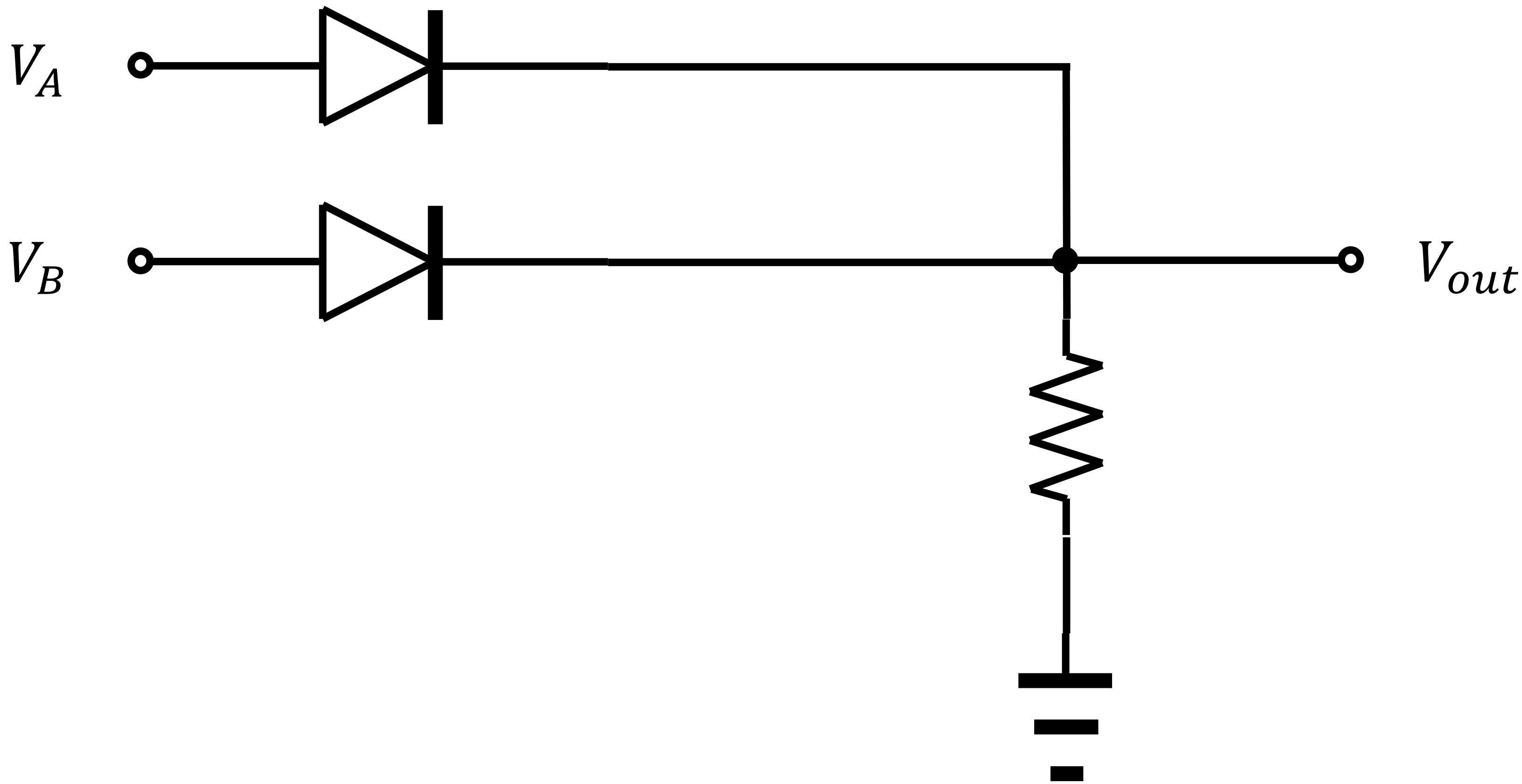
$$I_D = I_s\left(\exp\frac{V_D}{V_T} - 1\right)$$



- Constant-voltage model
  - An “offset” voltage of $V_{D,on}$

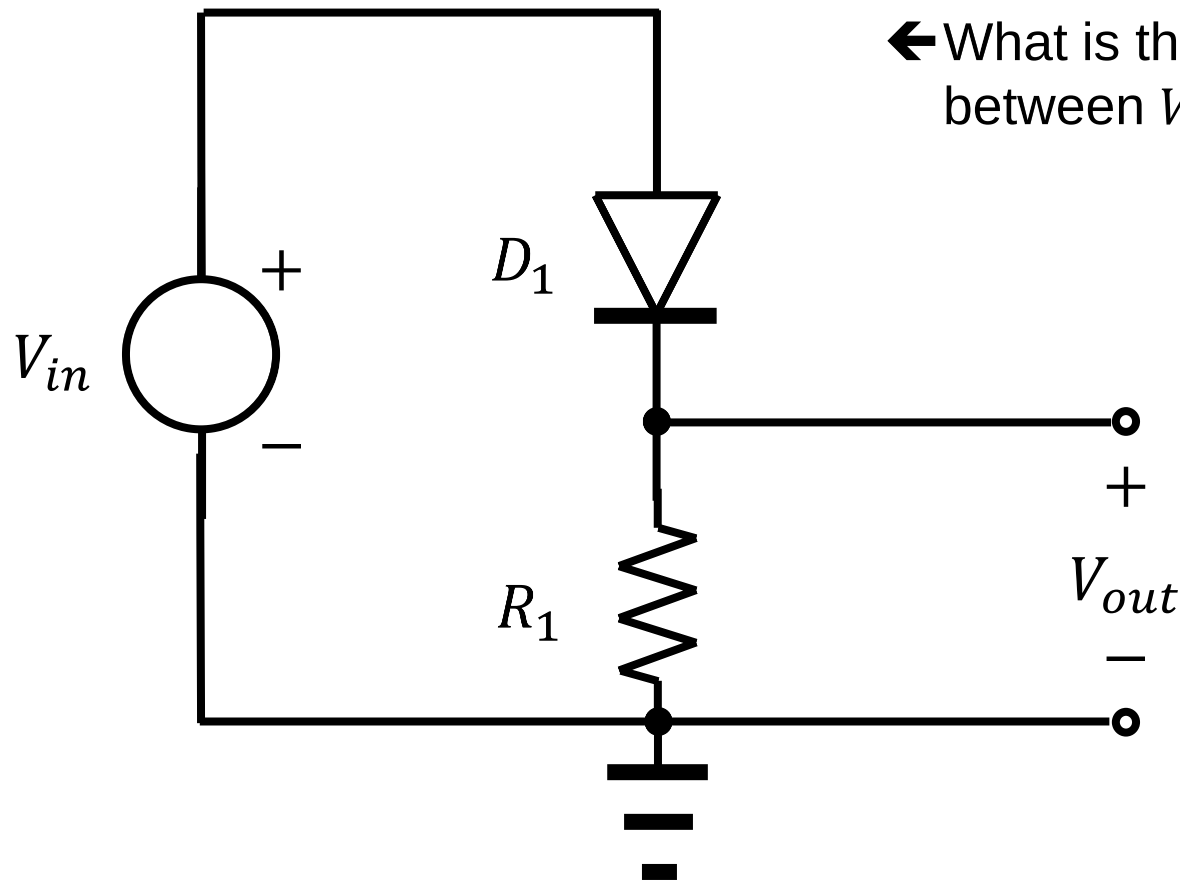
Example 3.6 (Razavi)

- An OR gate



Rectifier

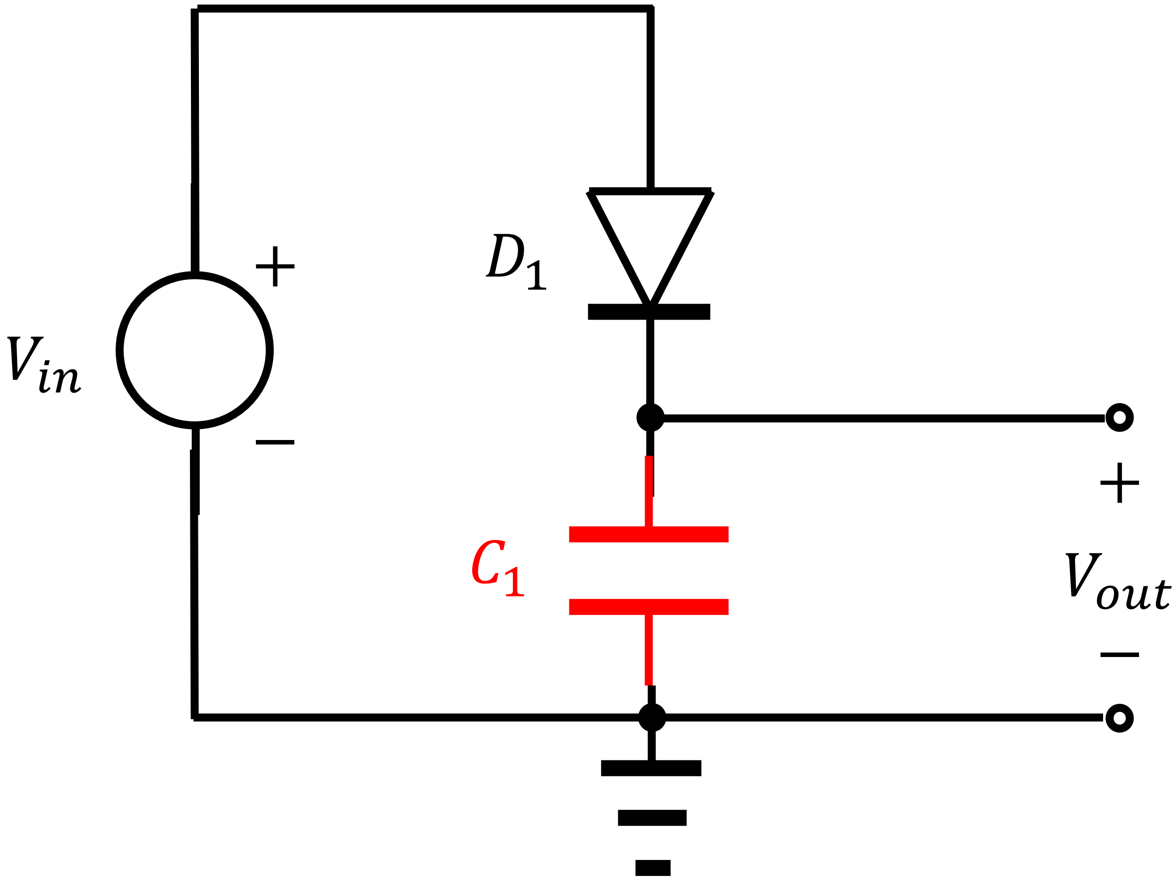
- Revisiting our first example



← What is the relation between V_{in} and V_{out}?

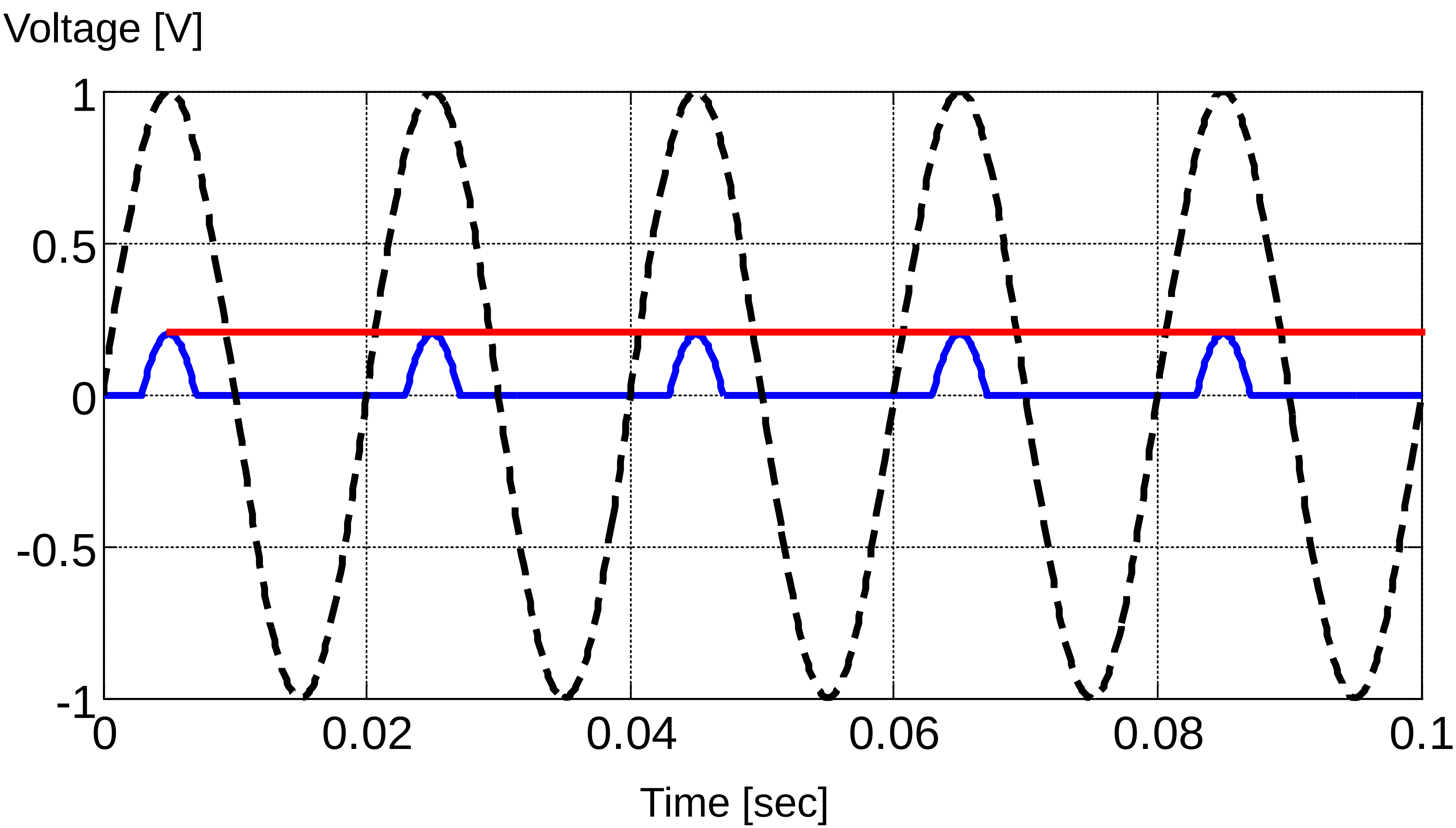
Introducing a capacitor

- Difference from the previous one?



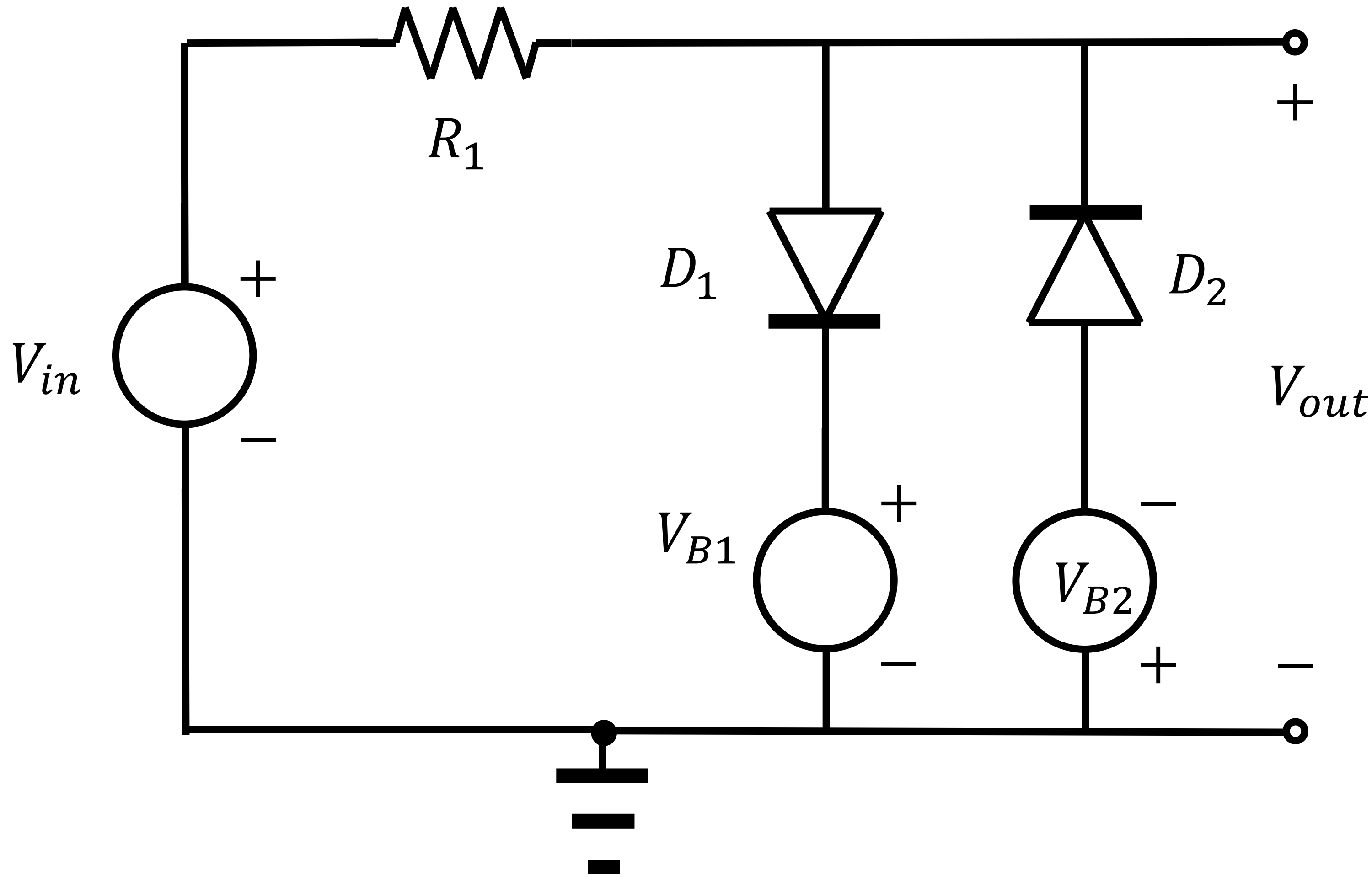
Introducing a capacitor

- Difference from the previous one?



Limiter

- Level-shift for both half cycles



A simple math, again

- Taylor series expansion
  - Consider a function, $f(x)$.
  - Then, at $x_0 + \Delta x$ (Δx is small.), the function value would be similar to that at x_0:

$$f(x_0 + \Delta x) \approx f(x_0)$$

  - A better approximation?

$$f(x_0 + \Delta x) \approx f(x_0) + \left.\frac{df(x)}{dx}\right|_{x=x_0} \Delta x$$

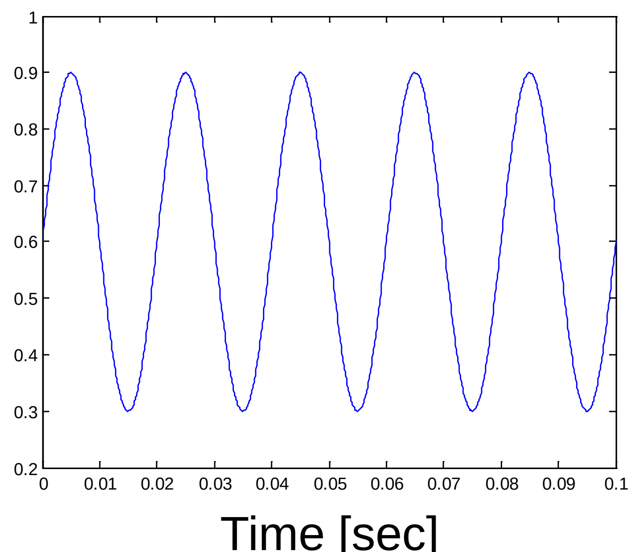
  - Nonlinear function ➔ linearly approximated!

A system

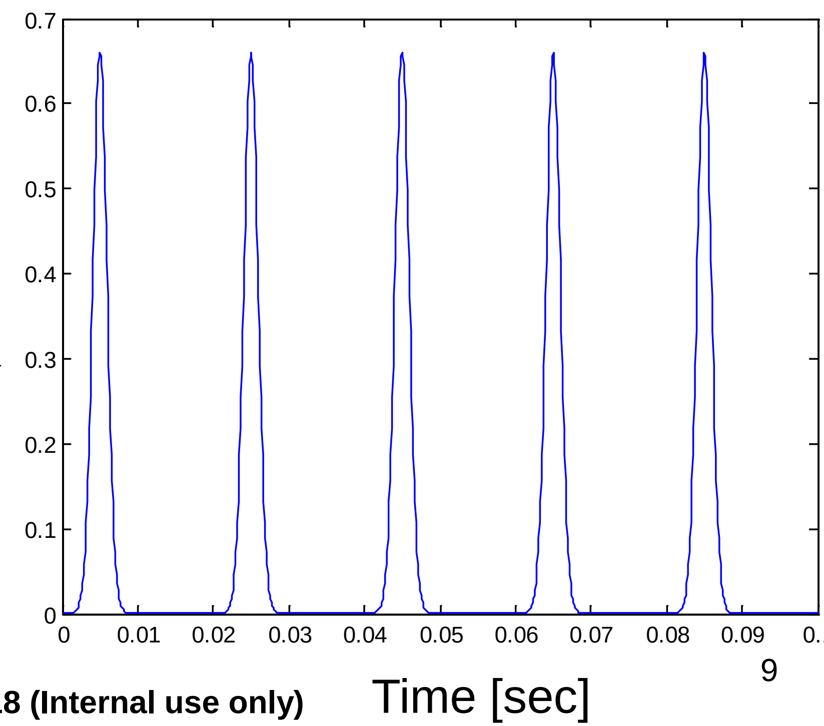
- A system (You know what it actually represents.)

$$V_{in} \longrightarrow \boxed{I_{out} = I_s \exp\frac{V_{in}}{V_T}} \longrightarrow I_{out}$$

- When $V_{in} = 0.6 + 0.3\sin 2\pi f t$,
  - Certainly, nonlinear!

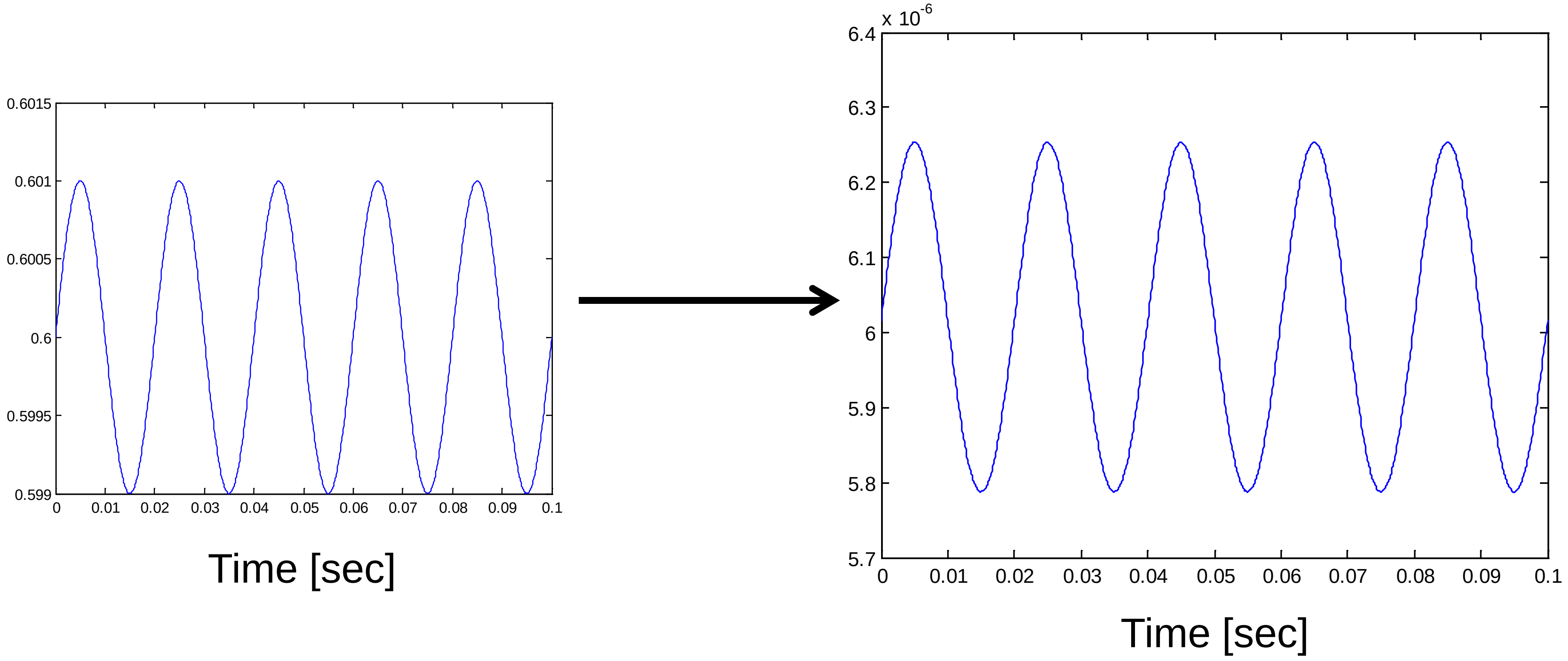


$\longrightarrow$



Smaller amplitude?

- When $V_{in} = 0.6 + 0.001 \sin 2\pi f t$,
  - Nonlinear?



Verbatim (p. 66)

- These thought lead us to the extremely important concept of "*small-signal operation*," whereby the circuit experiences only small changes in voltages and currents.

- Therefore it can be simplified through the use of "*small-signal models*" for nonlinear devices.

- The simplicity arises because such models are linear, allowing standard circuit analysis and obviating the need for iteration.

Exponential

- Simple, but important example
  - A diode is biased to a voltage V_{D1}.
  - The current is given by I_{D1}.

$$I_{D2} = I_s \exp\frac{V_{D1} + \Delta V}{V_T} = I_s \exp\frac{V_{D1}}{V_T} \exp\frac{\Delta V}{V_T}$$

$$I_{D2} \approx I_{D1}\left(1 + \frac{\Delta V}{V_T}\right)$$

Example3.18

- A diode is biased at a current of 1 mA.
  - Determine the current change if V_D changes by 1 mV.

$$\Delta I_D = \frac{I_D}{V_T} \Delta V_D \approx 40\mu\text{A}$$

- Small-signal resistance
  - As far as small changes in the diode current and voltage are concerned, the device behaves as a linear resistor.

$$r_d = \frac{V_T}{I_D}$$

Example3.19

- When the small change in the diode voltage is time-varying,
  - What happens?

$$I_{D2} = I_s \exp\frac{V_{D1} + \Delta V}{V_T} = I_s \exp\frac{V_{D1}}{V_T} \exp\frac{\Delta V}{V_T}$$

$$I_{D2} \approx I_{D1}\left(1 + \frac{\Delta V}{V_T}\right)$$

$$I_{D2} = I_s \exp\frac{V_{D1} + \Delta V \cos\omega t}{V_T} = I_s \exp\frac{V_{D1}}{V_T} \exp\frac{\Delta V \cos\omega t}{V_T}$$

$$I_{D2} \approx I_{D1}\left(1 + \frac{\Delta V \cos\omega t}{V_T}\right)$$