Lecture7: Diode

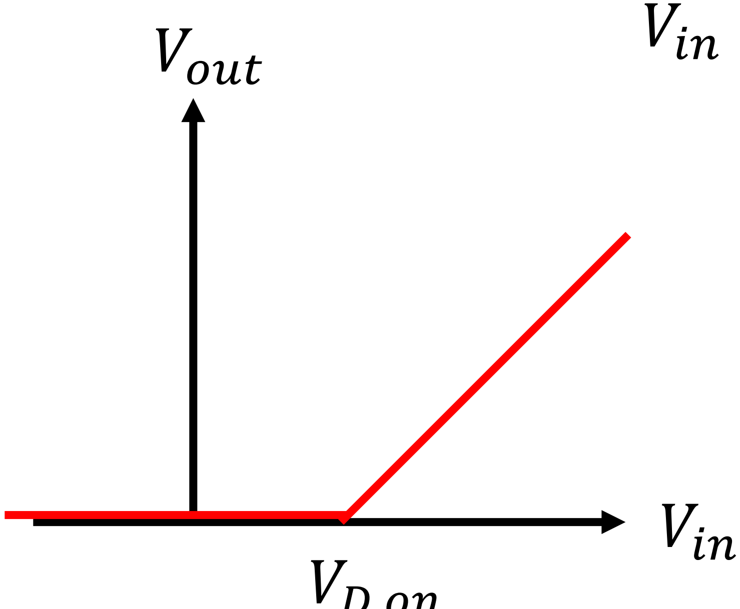
Sung-Min Hong (smhong@gist.ac.kr)

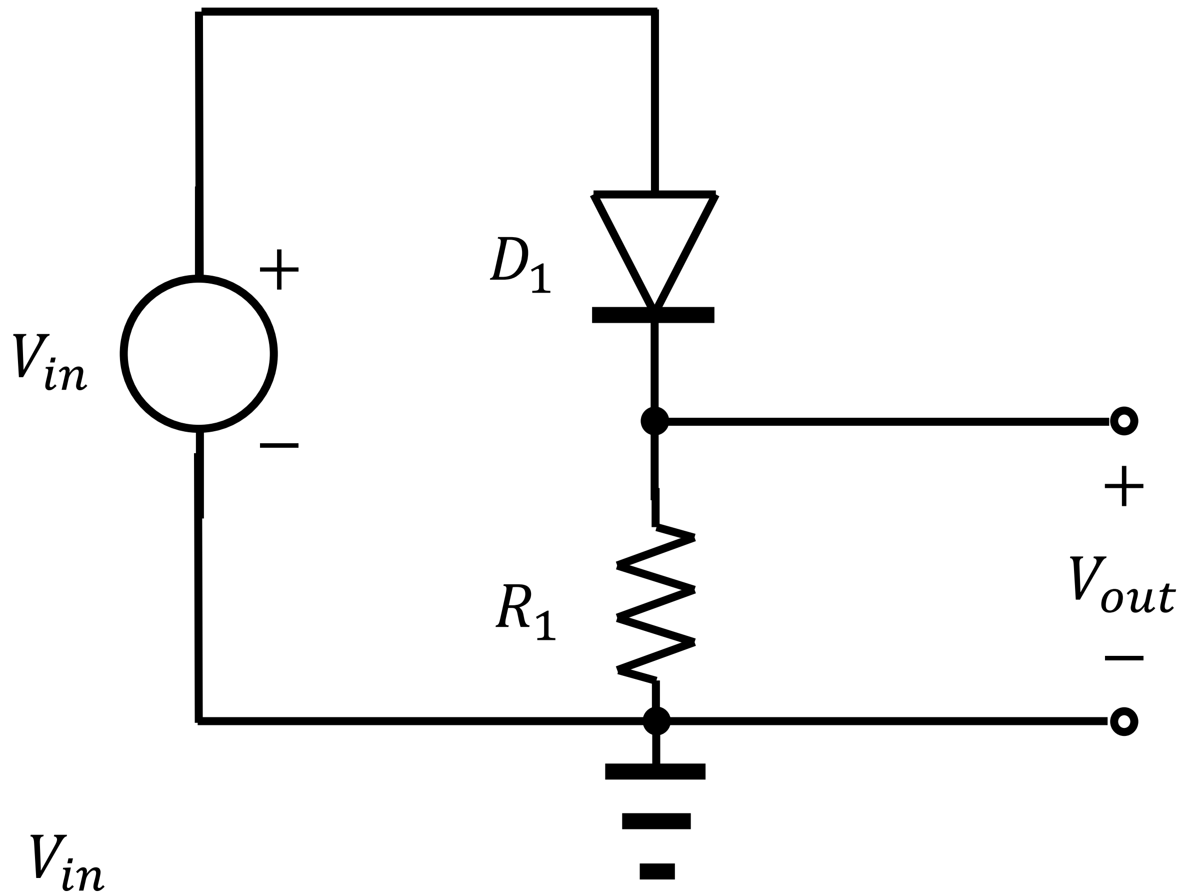
Semiconductor Device Simulation Lab.
School of Electrical Engineering and Computer Science
Gwangju Institute of Science and Technology

GIST On-Line Lecture on April 6, 2020 (Internal use only)

Rectifier

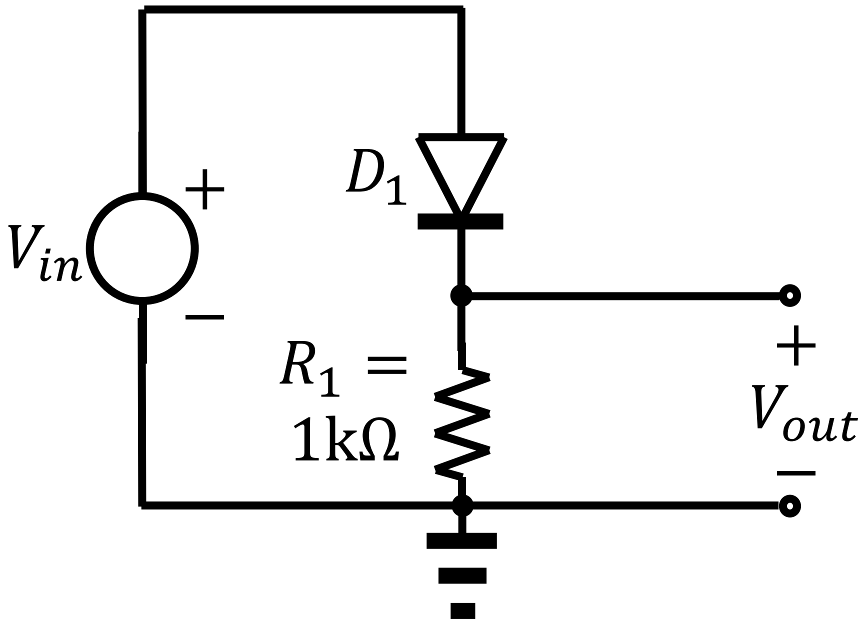
- Analyze it!
  - When $V_{in} < V_{D,on}$?
  - When $V_{in} > V_{D,on}$?

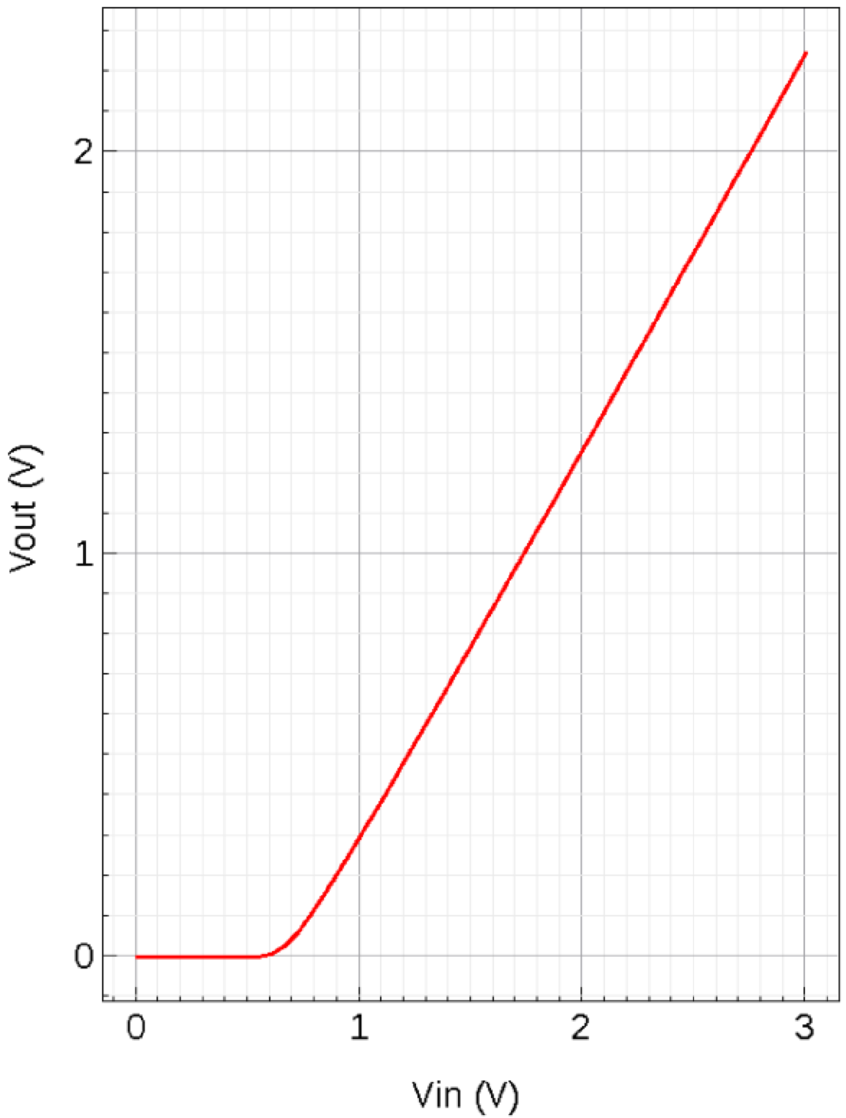




Simulation result

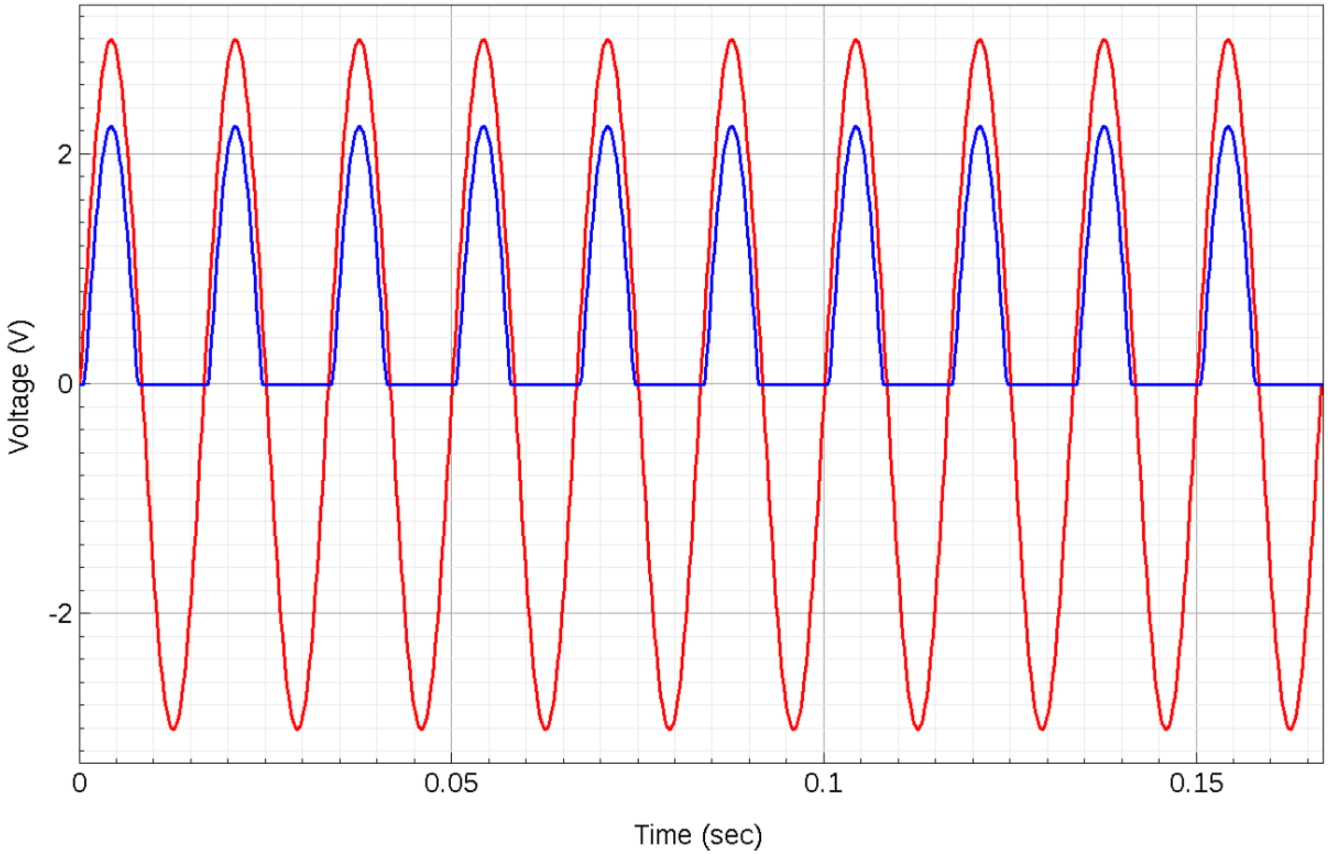
- $I_s = 0.5$ fA and $R_1 = 1\ \mathrm{k\Omega}$





Time-varying input voltage

- For example, $V_{in}(t) = 3\sin(2\pi f t)$ V. 60 Hz. 10 periods



Frequency domain

- $V_{in}(t) = A\sin(2\pi f t)$ V and $V_{out}(t) = A\sin(2\pi f t)\,u(\sin(2\pi f t))$ V

<<Frequency analysis of V_{in}>>

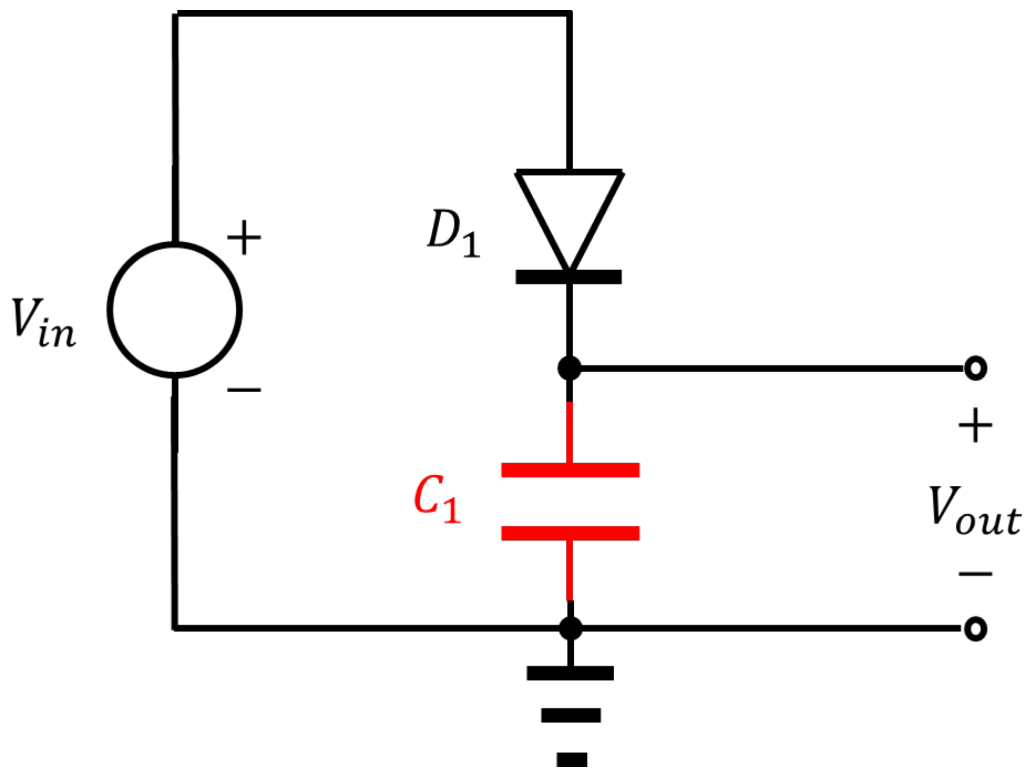
  - Component at f: A V

<<Frequency analysis of V_{out}>>

  - DC component: $\frac{A}{\pi}$ V
  - Component at f: $\frac{A}{2}$ V
  - Component at $2f$: $-\frac{2A}{3\pi}$ V (For a cosine function)

Introducing a capacitor

- Difference from the previous one?
  - Assume a sinusoidal input voltage. (AC input)
  - Guess the output waveform.

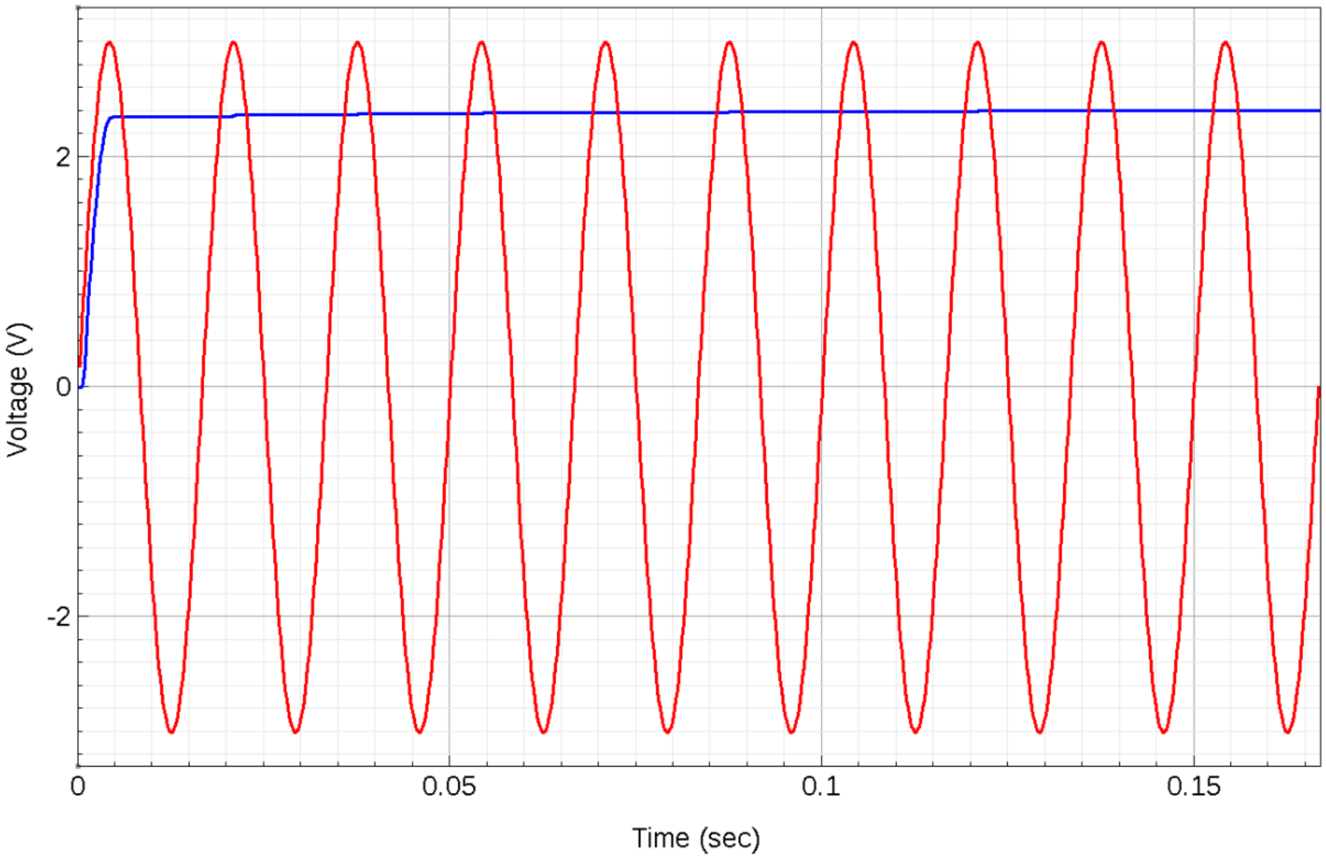


Qualitative understanding

- Consider the first period.
  - When the input voltage exceeds $V_{D,on}$, the diode is turned on.
  - The diode conducts a current.
  - The charge is stored in the capacitor. Hence, the output voltage increases.
  - When the input voltage is lower than $V_{D,on}$, the output voltage does not change. (*Why?*)
- After the first period…
  - In the second period, the diode current is smaller than the one in the first period. (*Why?*)
  - After some periods, the diode current vanishes.
  - A DC output voltage is established.

Simulation result

- The capacitance, $C_1 = 1\ \mu\mathrm{F}$.
  - Generating a DC output



Simple math

- 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?

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

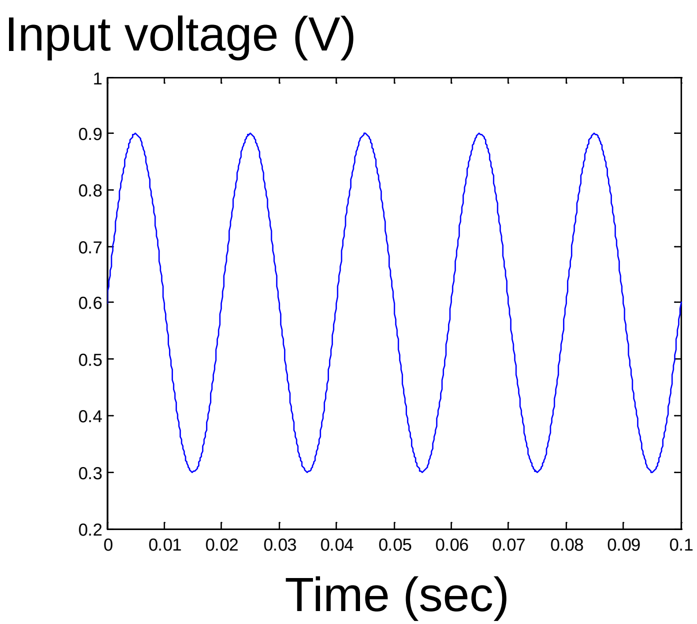
  - Nonlinear function ➔ linearly approximated!

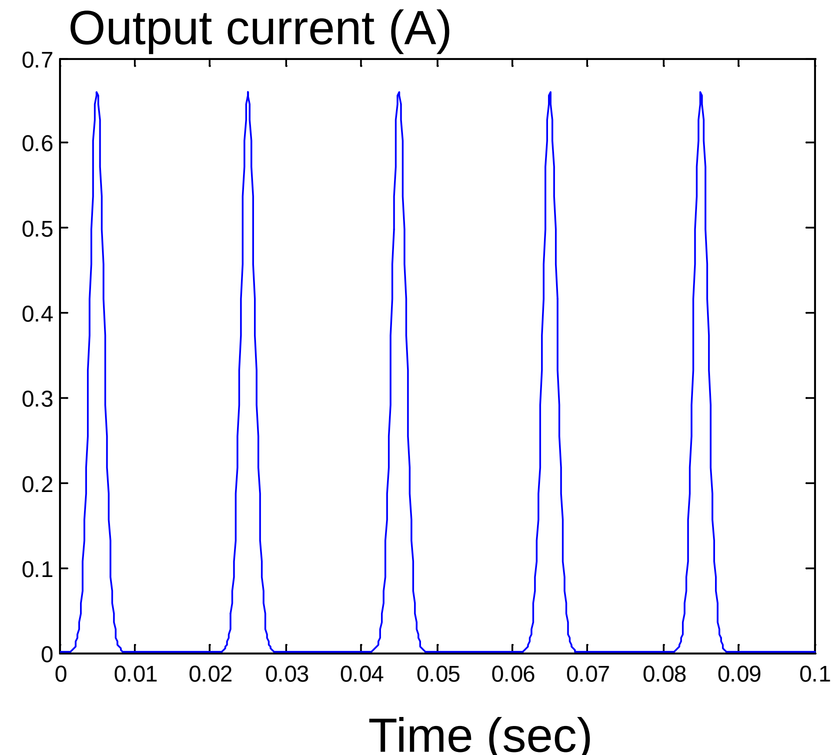
Nonlinear system

- A diode: Input $V_D (= V_{anode} - V_{cathode})$, output $I_D (= I_{anode})$

$$V_D \longrightarrow \boxed{I_D = I_S \exp \frac{V_D}{V_T}} \longrightarrow I_D$$

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

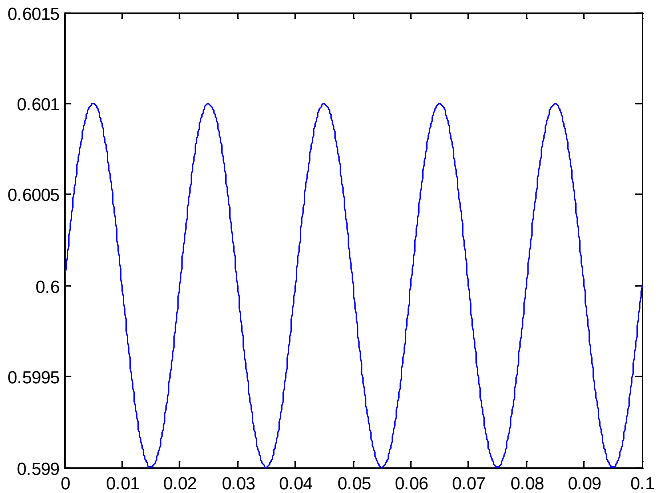




Small input amplitude

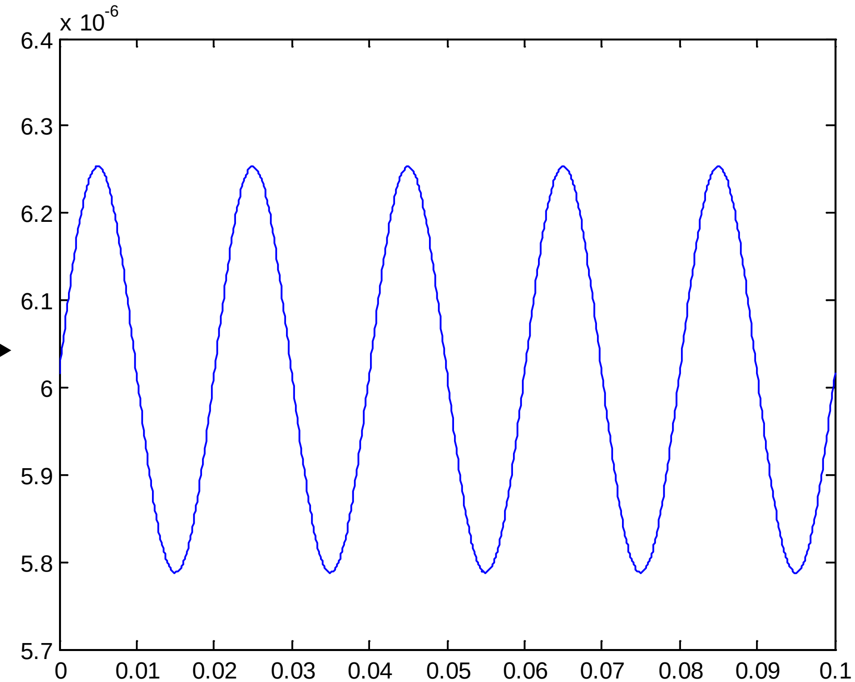
- When $V_{in} = 0.6 + \mathbf{0.001} \sin 2\pi f t$,
  - I_D is almost sinusoidal.

Input voltage (V)



Time (sec)

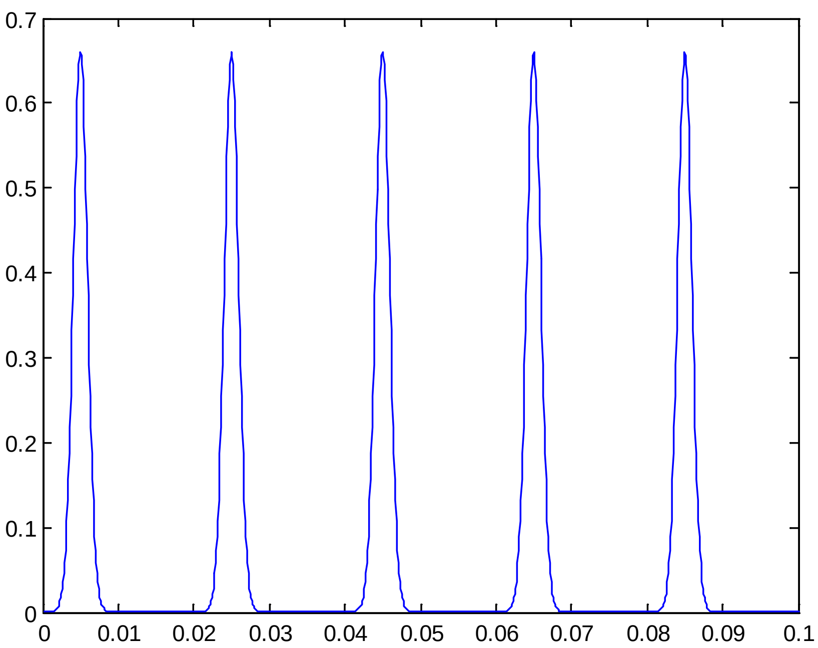
Output current (A)

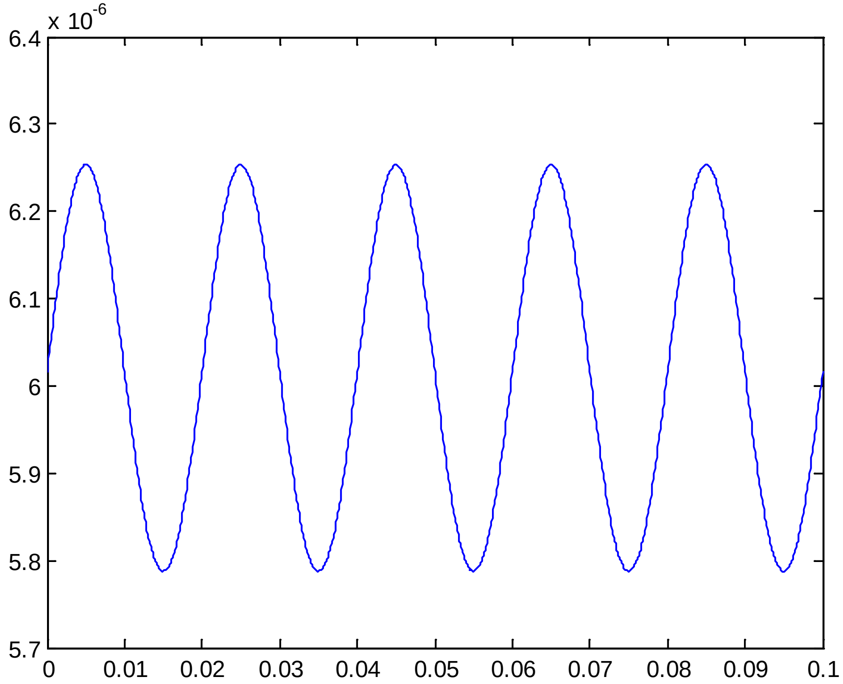


Time (sec)

Questions!

- You know the solution for $V_{in} = 0.6 + \mathbf{0.3} \sin 2\pi f t$.
  - Draw $I_D(t)$ when $V_{in} = 0.6 + \mathbf{0.6} \sin 2\pi f t$.
- You know the solution for $V_{in} = 0.6 + \mathbf{0.001} \sin 2\pi f t$.
  - Draw $I_D(t)$ when $V_{in} = 0.6 + \mathbf{0.002} \sin 2\pi f t$.





Small-signal analysis

- General case

$$V_{D,DC} + v_{D,AC}(t) \rightarrow \boxed{I_D = I_S \exp \frac{V_D}{V_T}} \rightarrow I_{D,DC} + i_{D,AC}(t)$$

- "Small-signal" case
  - When $v_{D,AC}(t)$ is small, then, the AC current is given by

$$i_{D,AC}(t) \approx I_{D,DC} \frac{v_{D,AC}(t)}{V_T}$$

$$v_{D,AC}(t) \longrightarrow \boxed{I_{D,AC}(t) = I_{D,DC} \frac{v_{D,AC}(t)}{V_T}} \longrightarrow i_{D,AC}(t)$$

Application to a diode

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

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

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

$$I_D(t) = I_s \exp \frac{V_{D,DC} + \Delta V \cos \omega t}{V_T} = I_s \exp \frac{V_{D,DC}}{V_T} \exp \frac{\Delta V \cos \omega t}{V_T}$$

$$I_D(t) \approx I_{D,DC} \left(1 + \frac{\Delta V \cos \omega t}{V_T} \right)$$

  - The AC output current has the same frequency!

Razavi, Example 3.18

- A diode is biased at a current of 1 mA.
  - Small-signal resistance is given by

$$r_d = \frac{V_T}{I_D} = 25.85\ \Omega$$

  - When an AC voltage with 1 mV amplitude is applied, the amplitude of the AC current is

$$\frac{1\ \mathrm{mV}}{r_d} = 38.7\ \mu\mathrm{A}$$

- A diode is biased at a current of 1 µA.
  - Small-signal resistance is given by

$$r_d = \frac{V_T}{I_D} = 25.85\ \mathrm{k}\Omega$$