Lecture7: Diode circuit & small-signal analysis

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

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

GIST Lecture on March 25, 2019 (Internal use only)

PN junction

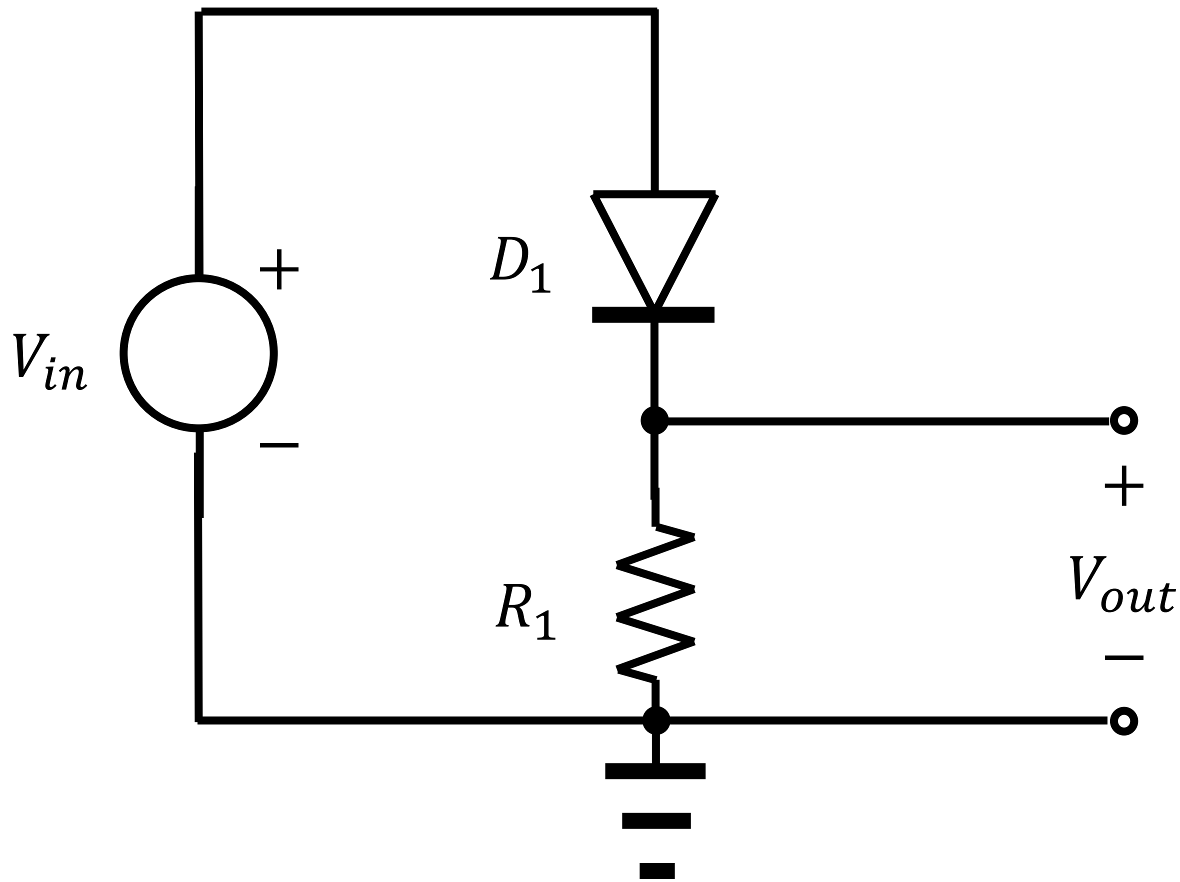
- Exponential model

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

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

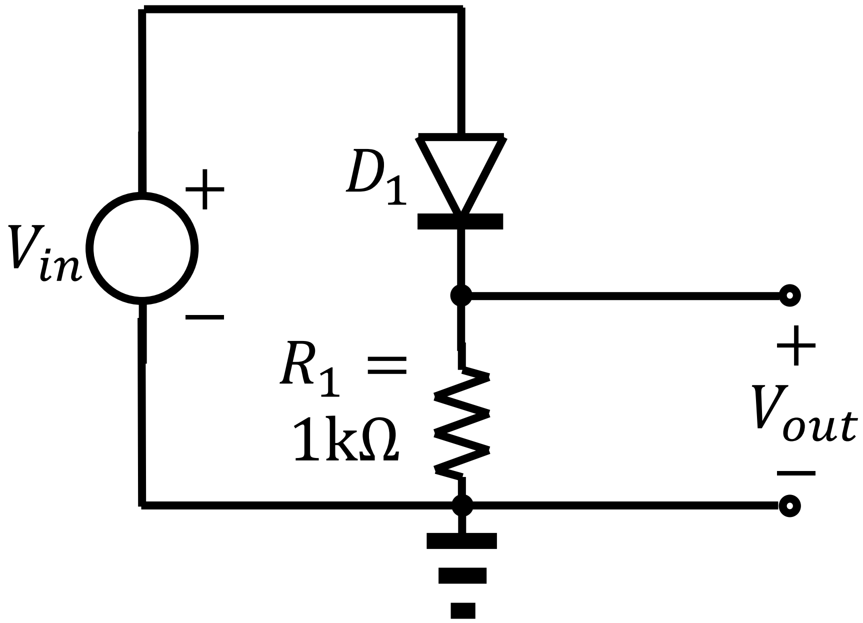
Rectifier

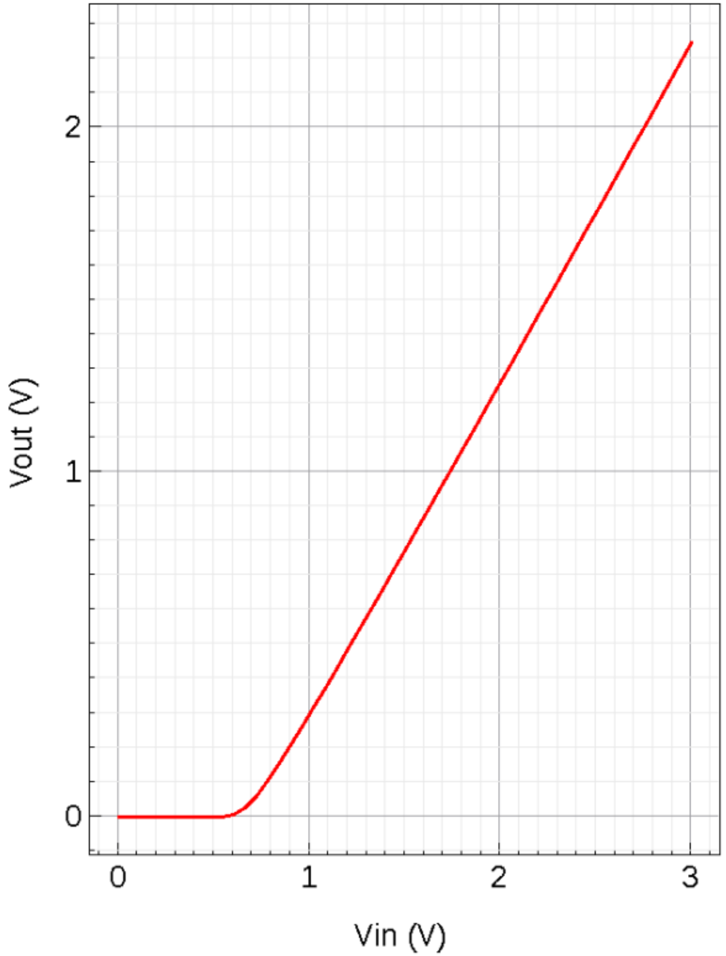
- Analyze it!
  - When $V_{in} < V_{D,on}$?
  - When $V_{in} > V_{D,on}$?



Simulation result

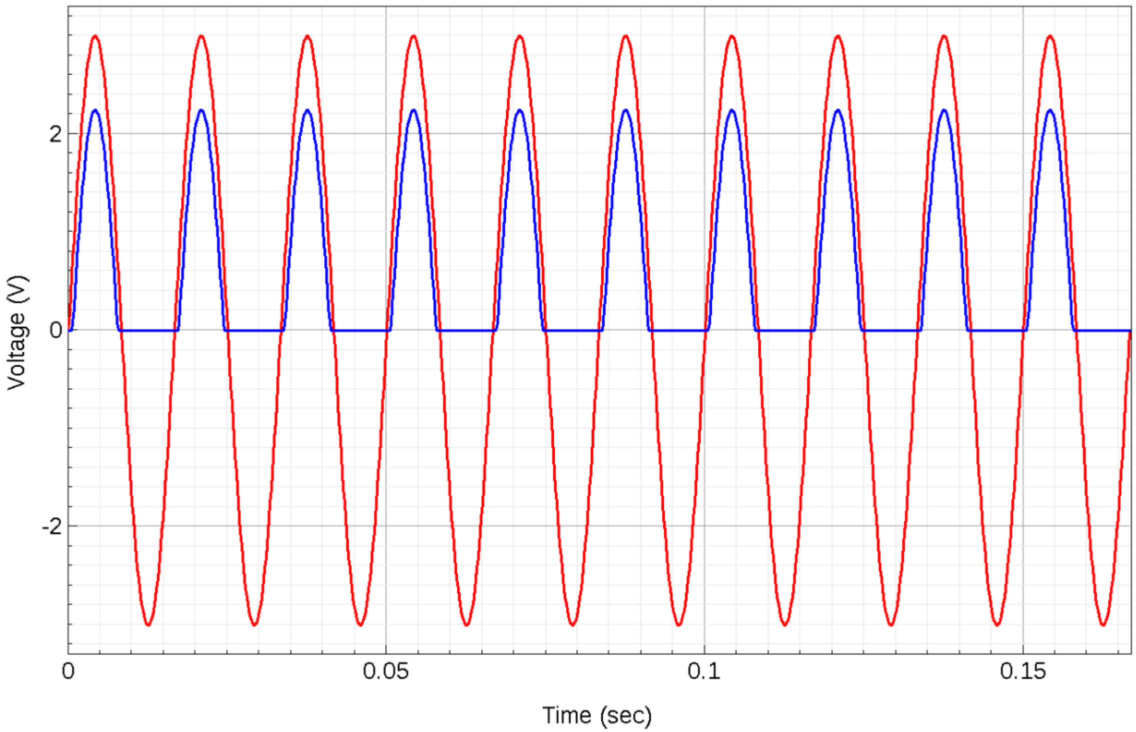
- Example) $I_s = 0.5\ \text{fA}$ and $R_1 = 1\ \text{k}\Omega$





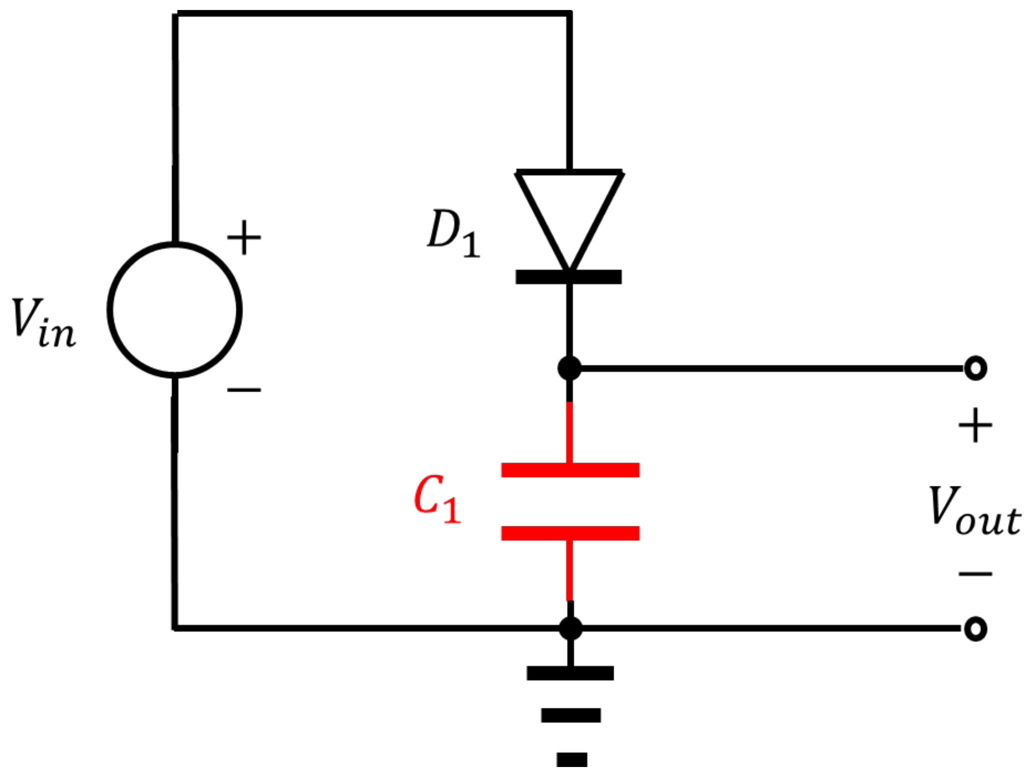
Time-varying voltage source

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



Introducing a capacitor

- Difference from the previous one?
  - First, consider the DC case.
  - Remember that $I_C = C_1 \frac{d}{dt} V_{out}$.



Qualitative understanding (1)

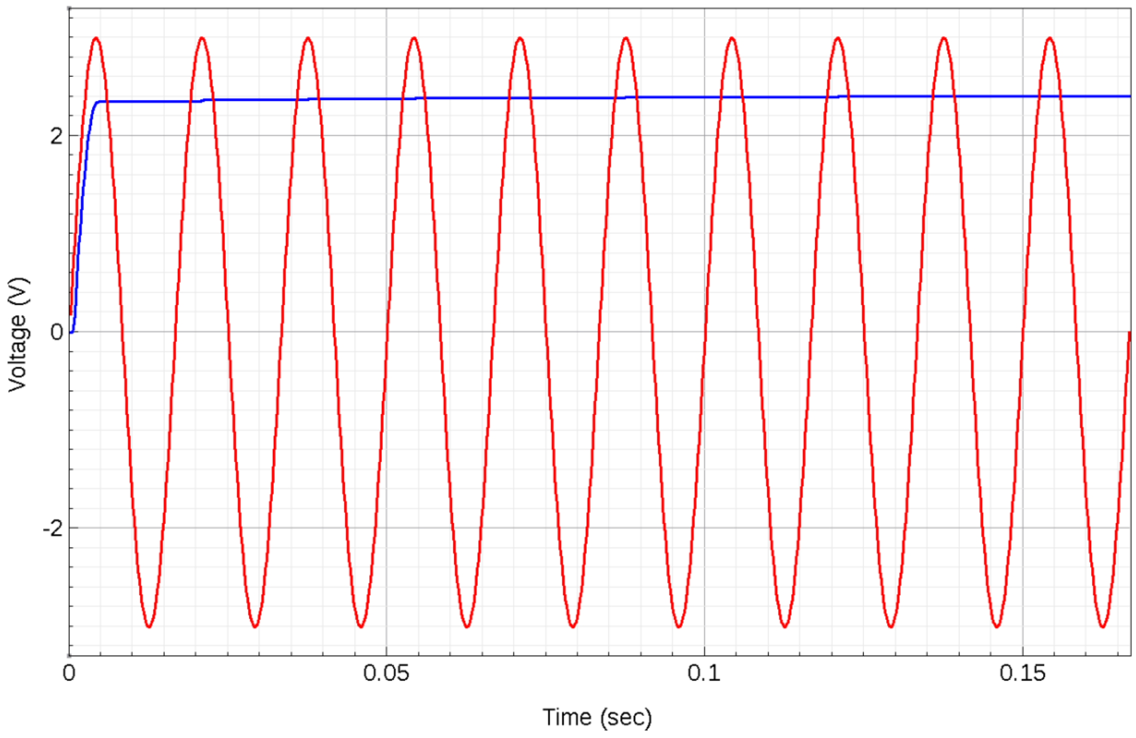
- Consider the first period.
  - When the input voltage exceeds $V_{D,on}$, the diode is turned on.
  - The charge is stored in the capacitor. Hence, the output voltage increases.
  - When the input voltage is lower than $V_{D,on}$, the output voltage does not change. (*Why?*)

Qualitative understanding (2)

- 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, $C_1 = 1\ \mu\mathrm{F}$.



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?

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

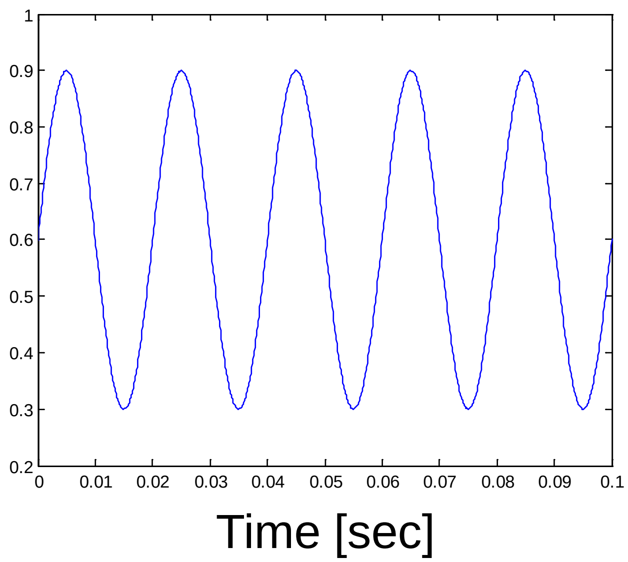
  - Nonlinear function ➔ linearly approximated!

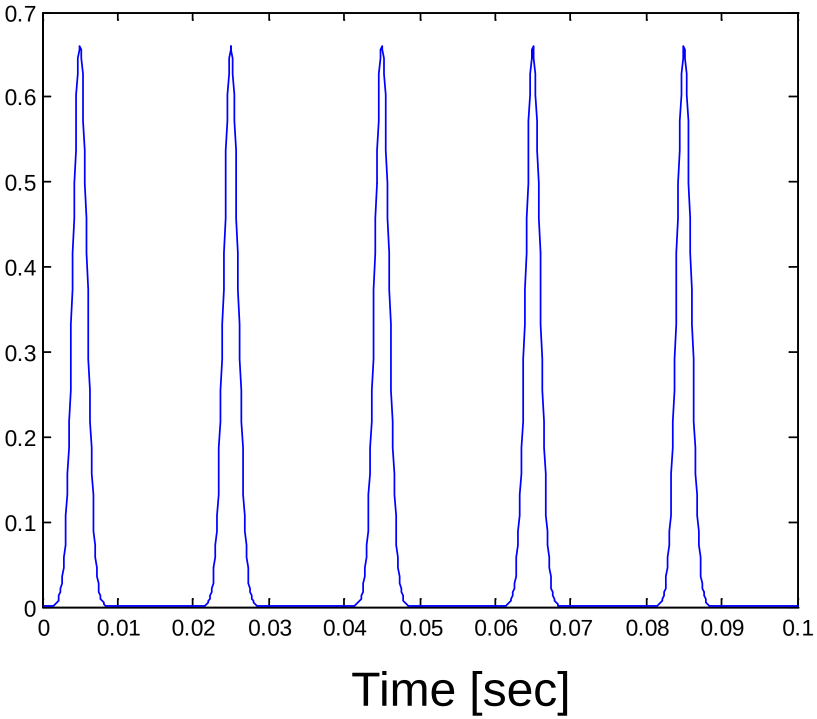
Nonlinear system

- A diode: Input V_D, output I_D

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

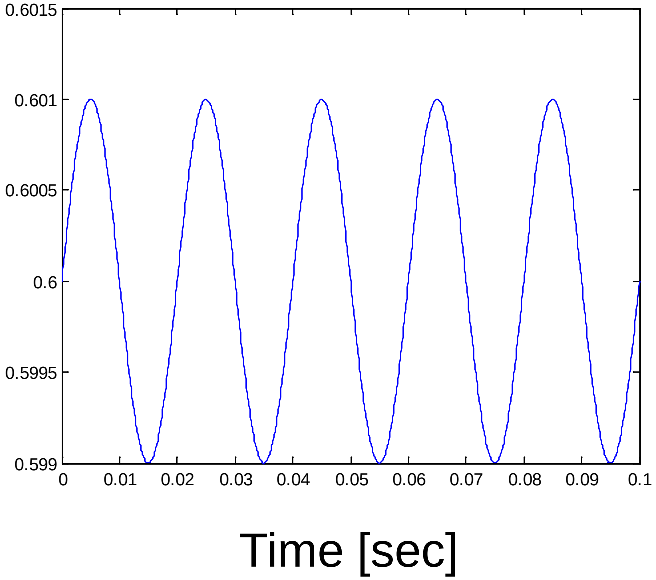
- When $V_{in} = 0.6 + \mathbf{0.3}\sin 2\pi f t$,

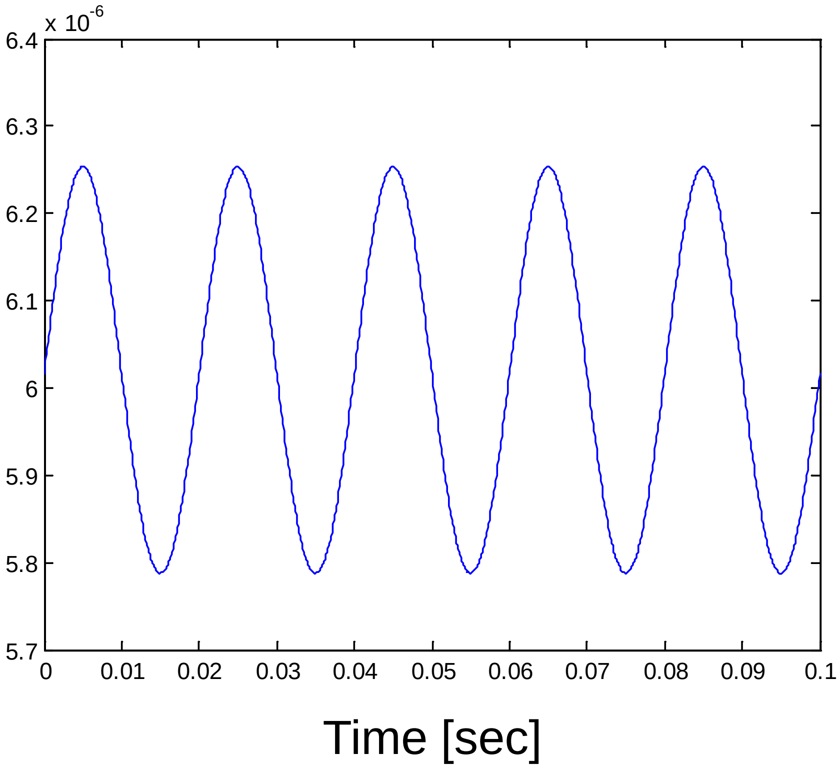




Small input amplitude

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





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 output current has the same frequency!