Analog electronics

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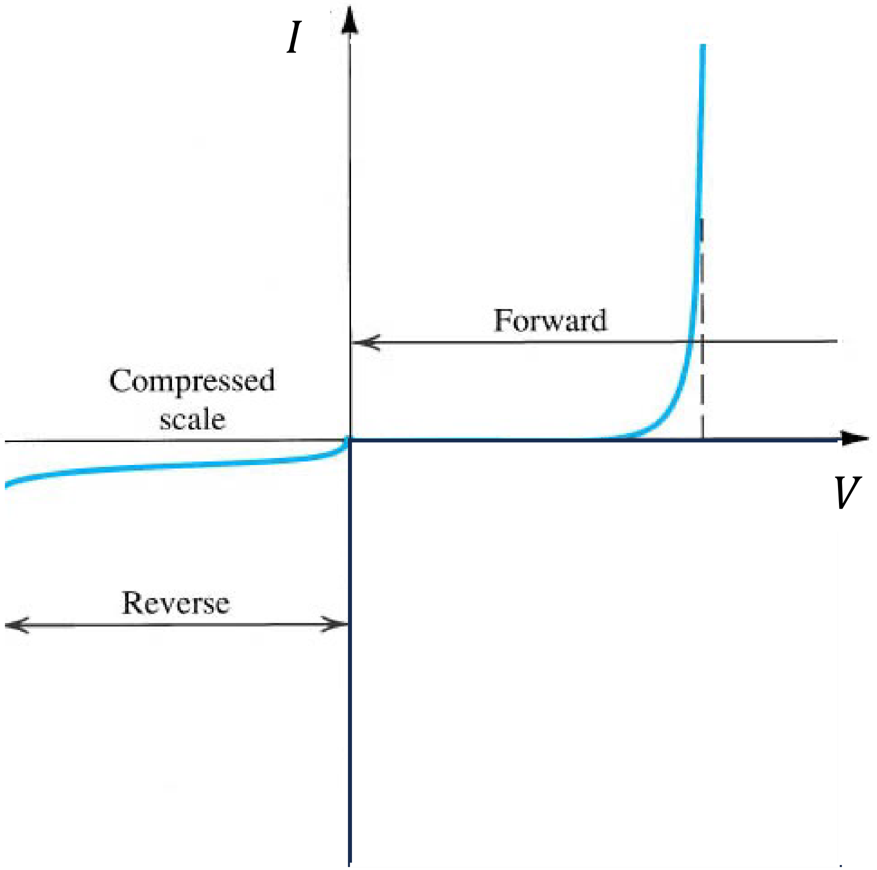
Agenda

- Diode
  - Recap I-V equation of PN junctions, diode models, solutions to assignments
  - Practical diode circuits
    - Logic gates
    - Half-wave rectifier & full-wave rectifier

Lec. 1 recap: PN junction- Shockley's equation



$$I = I_s\left(e^{\frac{V}{nV_T}} - 1\right)$$

For anything with PN junctions

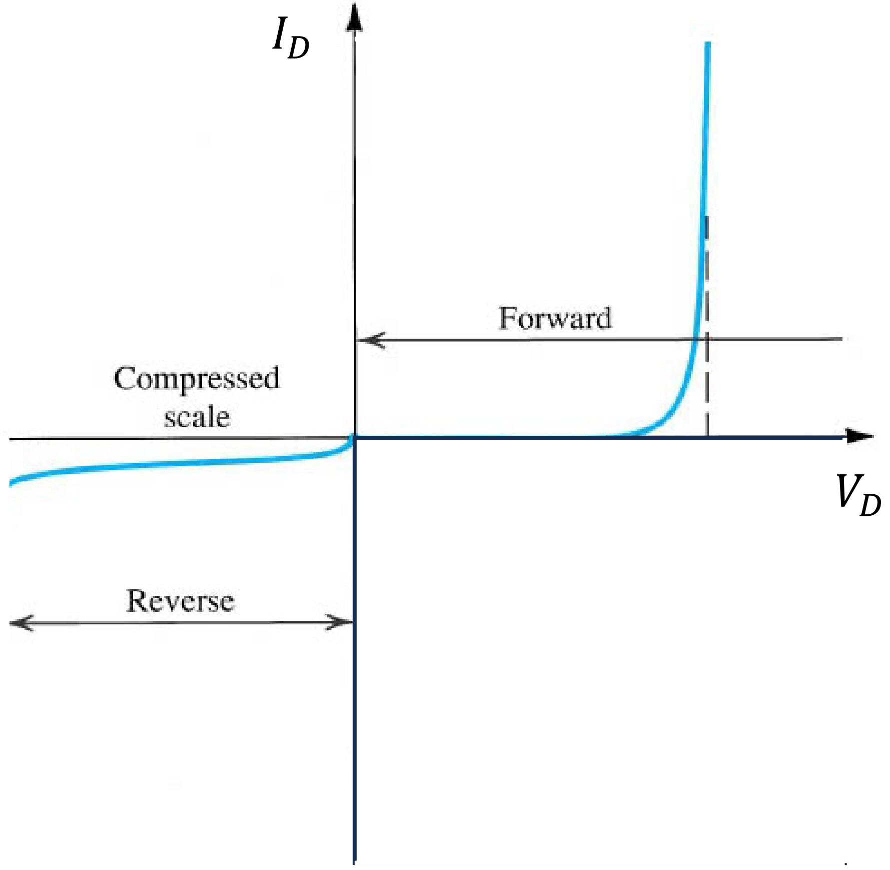
I_s : reverse saturation current, given in datasheet
V: voltage across the junction
n: ideal factor, depending on the construction of the PN junction, $1 < n < 2$, $n = 1$ for ideal PN junction
V_T: thermal voltage

$$V_T = \frac{KT_K}{q}$$

K: Boltzmann's constant = 1.38×10^{-23} J/K
T_K: the absolute temperature in kelvins = 273 + x °C
q: the magnitude of electronic charge = 1.6×10^{-19} C
$V_T \approx$ 26 mV @ 27 °C

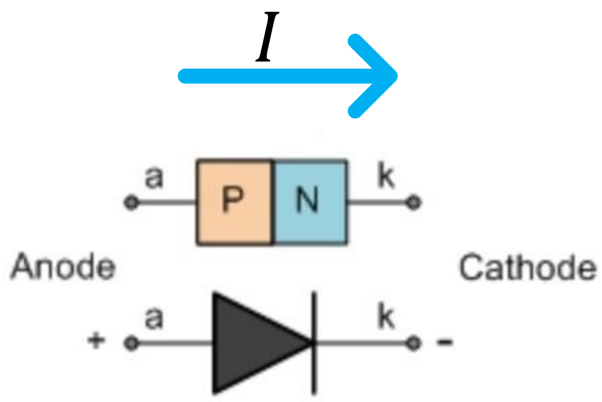
I_s and V_T are temperature dependent.
I_s doubles for every 5°C rise in temperature.

Lec. 1 recap: PN junction diode



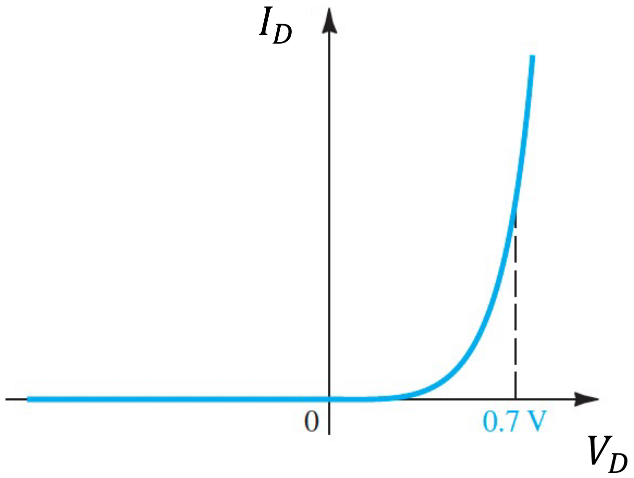
A two terminal component

- conducts current primarily in one direction
- 'passes' positive voltage & 'blocks' negative voltage



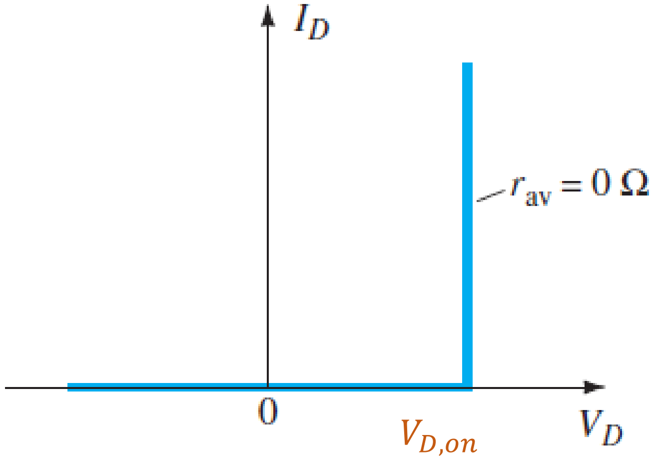
Lec. 1 recap: PN diode models

Exponential model
(usage rate =10-20%)

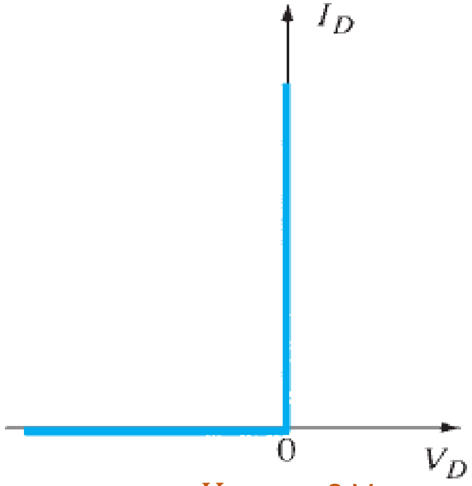


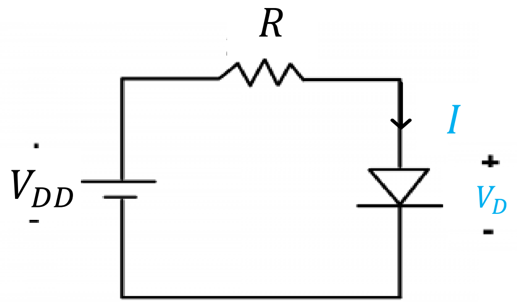
$$I_D = I_s\,(e^{\frac{V_D}{V_T}} - 1)$$

Constant voltage model
(usage rate = 70-80%)

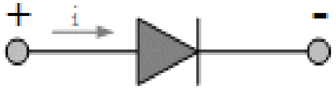


Ideal model
(usage rate =10-20%)

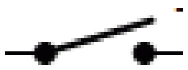




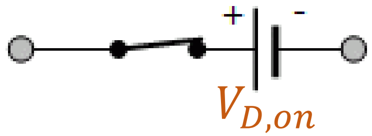
The diode has two states:



- $V_D \le V_{D,on} \rightarrow$ diode is off $\rightarrow$ open circuit

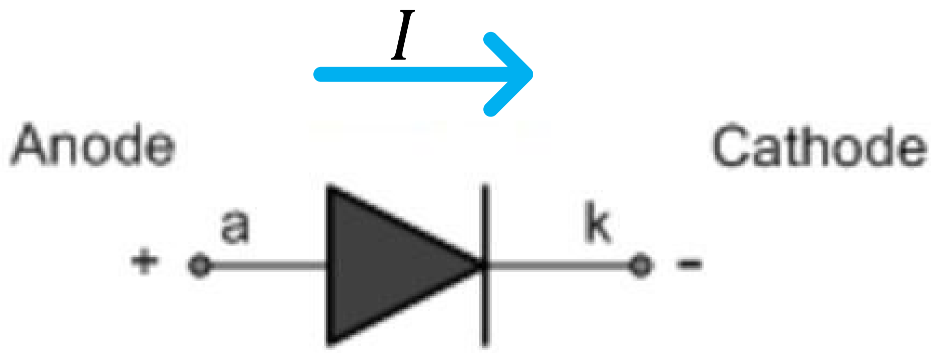


- $V_D > V_{D,on} \rightarrow$ diode is on $\rightarrow$ a voltage drop

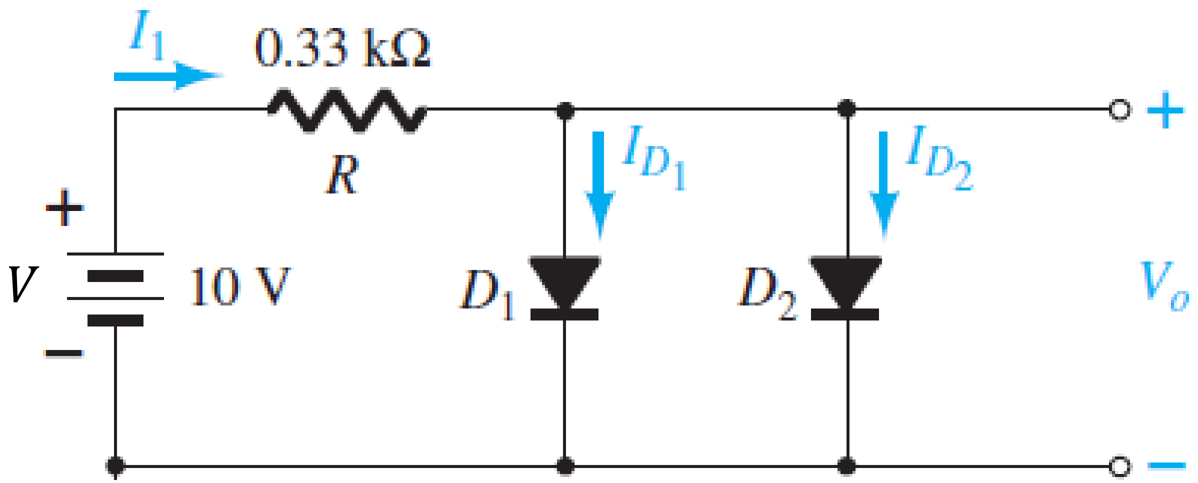


Principle of diode circuit analysis

- Begin by assuming a certain state of diodes, i.e., on or off, check the final results against these assumptions.
- If a diode is about to turn on or off, it must sustain a voltage of $V_{D,on}$, but the current flowing through it is small, i.e., approximating 0 A
- If a diode is on and carries a current, the current must flow from the anode to the cathode, i.e., along the direction of the arrow.



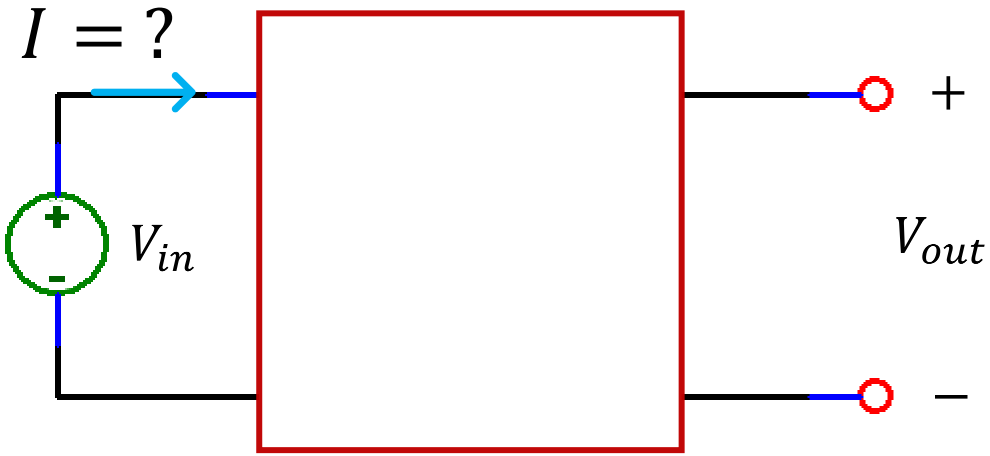
Example



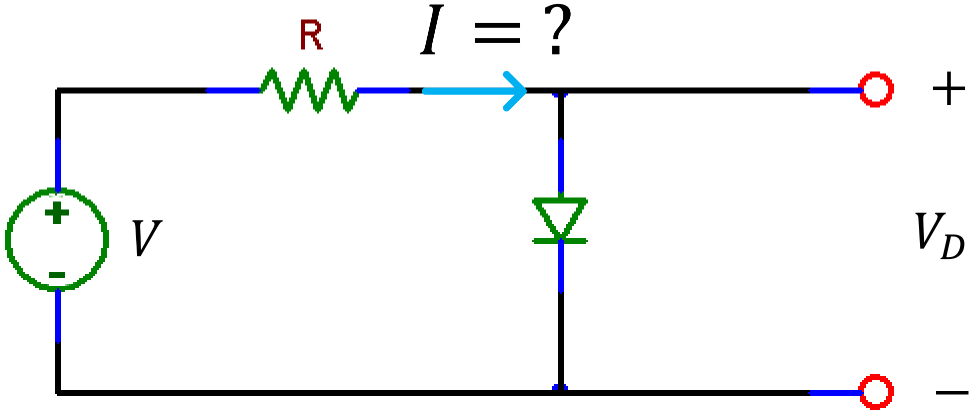
Assuming the constant voltage drop model and the diode in reverse and forward bias regions, I_1 , I_{D1}, I_{D2} and V_o = ?

Types of characteristics for circuits

- I-V characteristics
- Input-output characteristics
- Time response



PN diode circuit—I-V & input-output



Assuming the constant voltage drop model,
plot the I-V and V_D -V curves for the diode in reverse and forward bias regions.

Agenda

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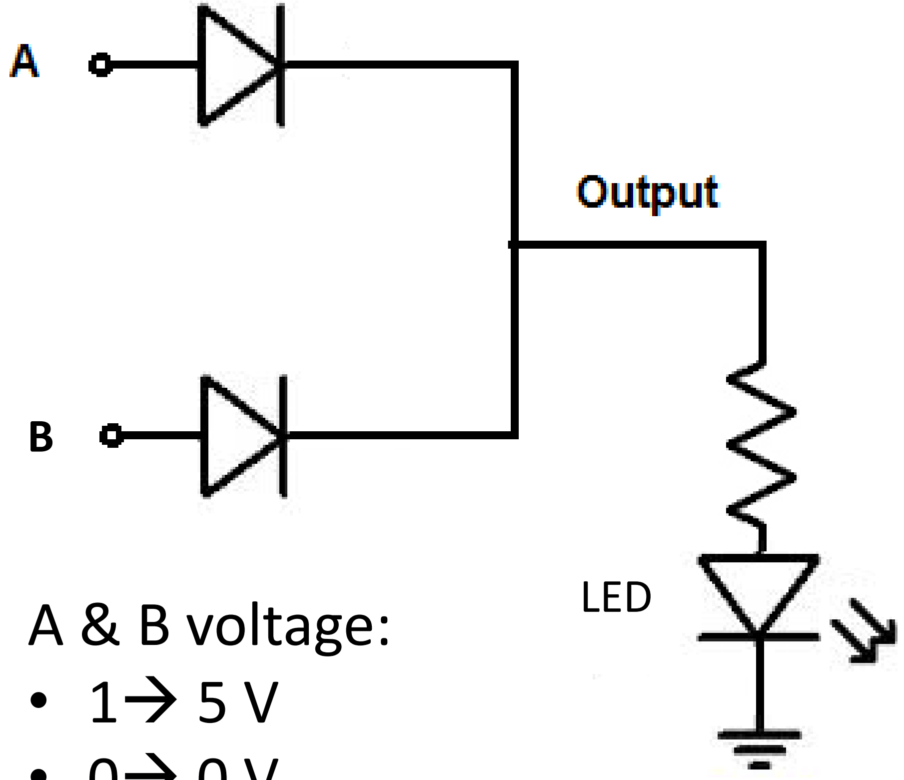
    - Half-wave rectifier & full-wave rectifier

Application example: OR logic gate

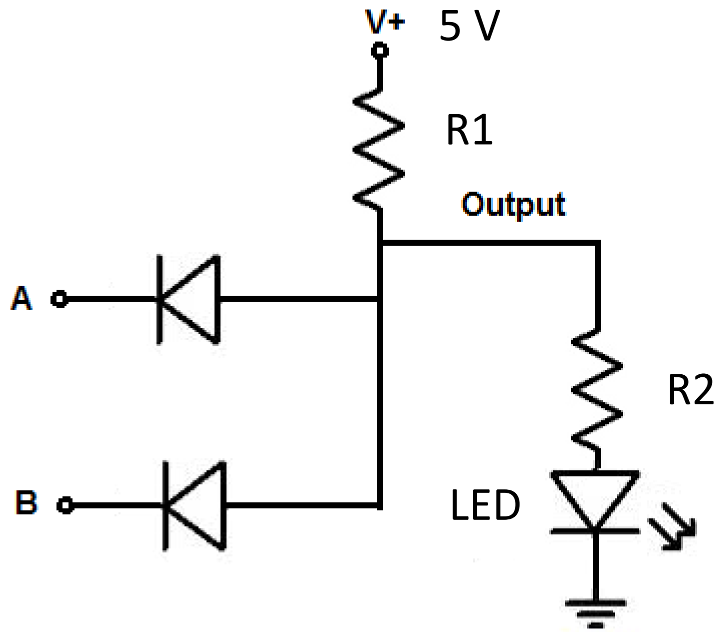


A	B	LED
0	0	0 (off)
0	1	1 (on)
1	0	1 (on)
1	1	1 (on)

A & B voltage:
- 1→ 5 V
- 0→ 0 V

The LED forward voltage drop is 2 V.

Quiz: ? logic gate



A	B	LED
0	0	
0	1	
1	0	
1	1	

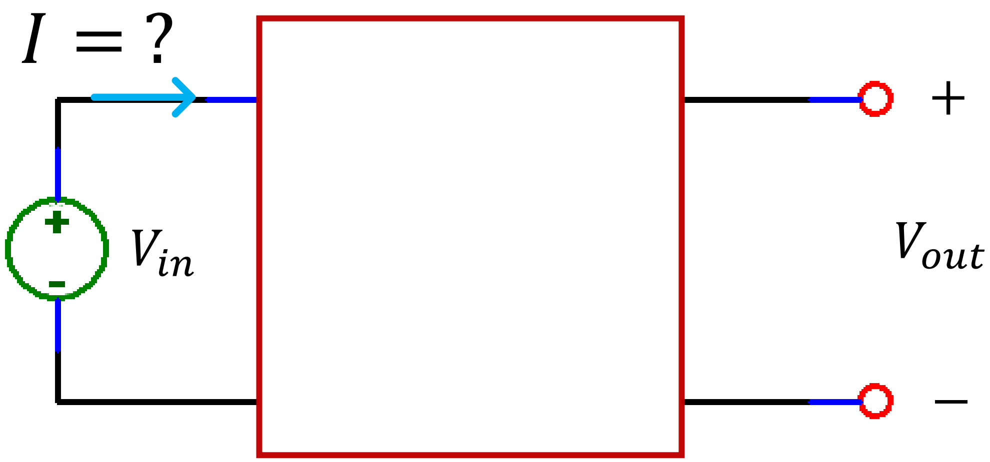
A & B voltage:

- 1→ 5 V
- 0→ 0 V

The LED forward voltage drop is 2 V.

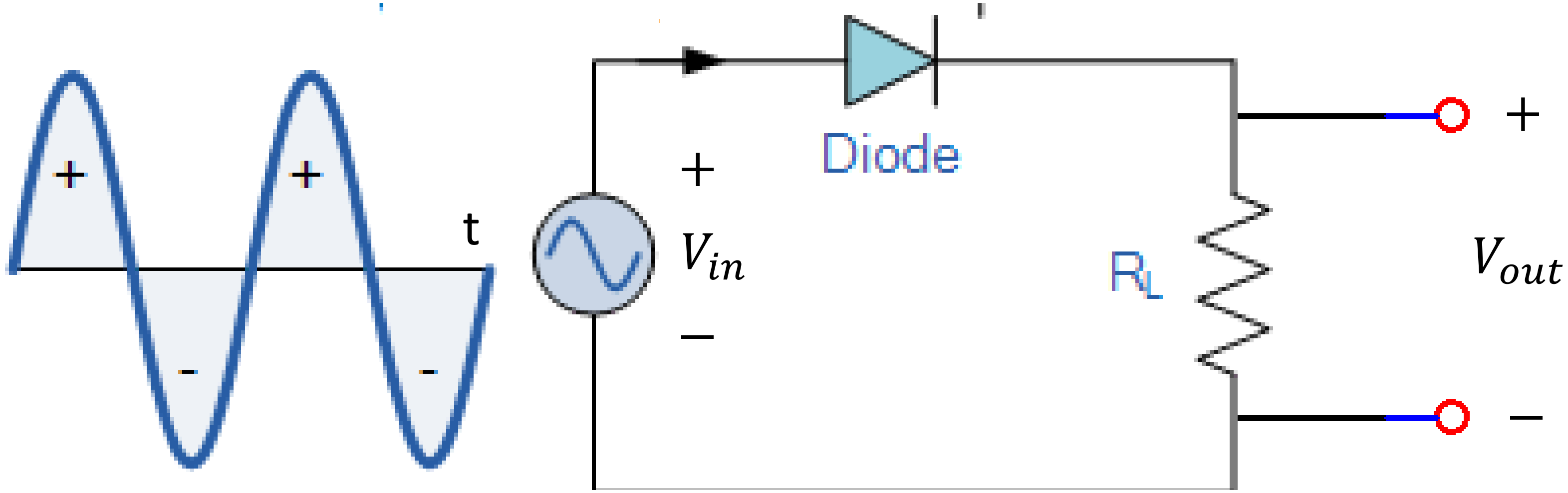
Types of characteristics for circuits

- I-V characteristics
- Input-output characteristics
- Time response



PN diode circuit— time reponse

Alternating Current (AC)
Direct Current (DC)
Rectifier: convert AC to DC

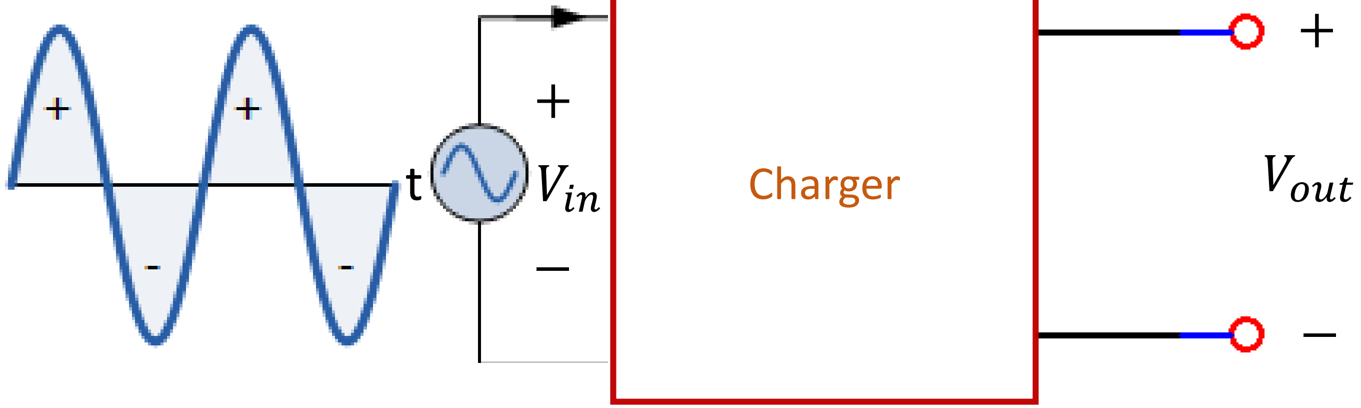


1. Ideal model
2. Constant-voltage drop model

PN junction diode application example: charger/adapter

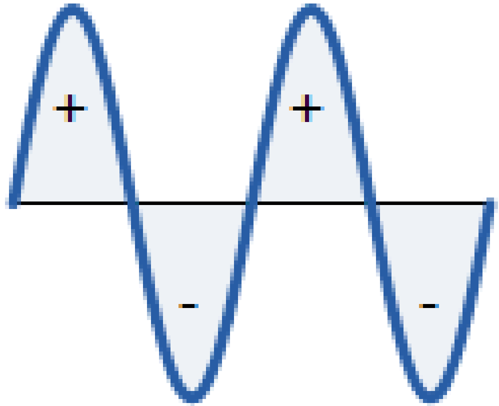
V_{out}:
- 5 V for cellphone
- 20 V for laptop

$V_{in}(t) = 230\sin(2\pi 50t)$

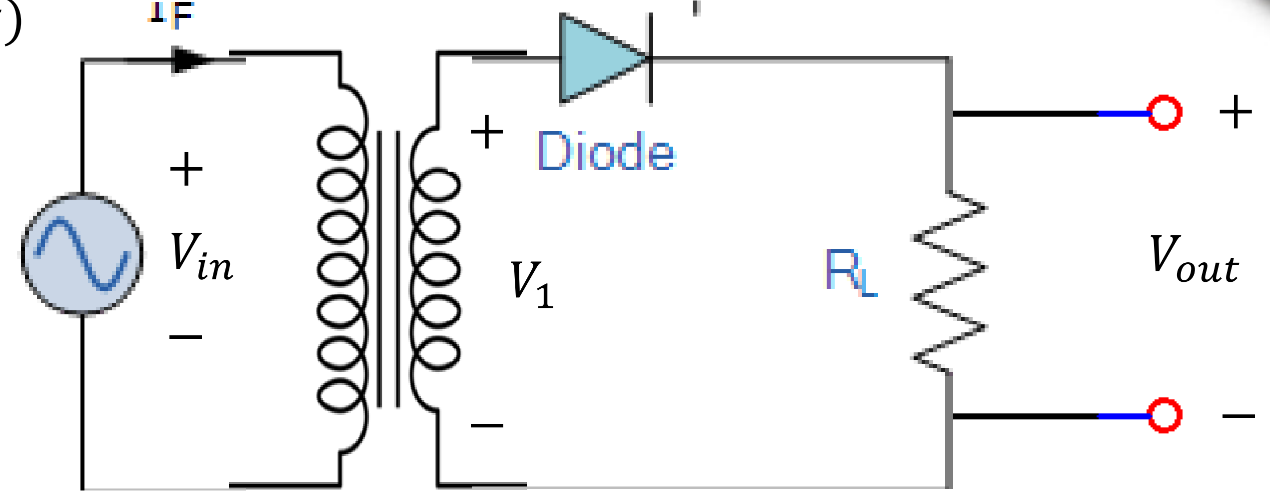


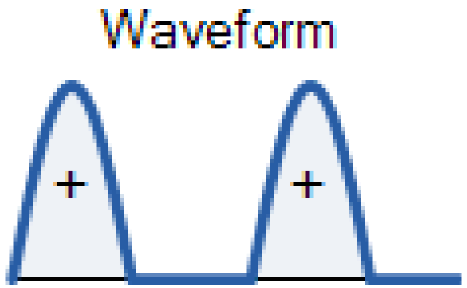
Half-wave rectifier

$V_{in}(t) = 230\sin(2\pi 50t)$



$V_1(t) = V_o\sin(2\pi 50t)$

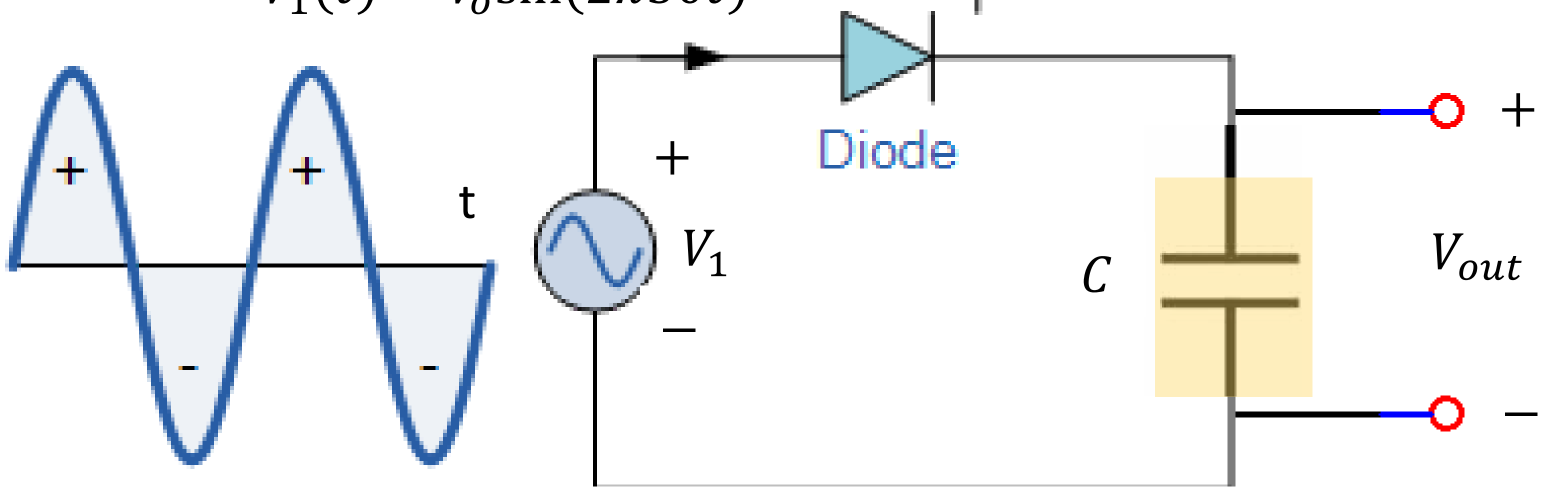




How to modify the circuit to get a desired DC output voltage?

Half-wave rectifier with capacitor

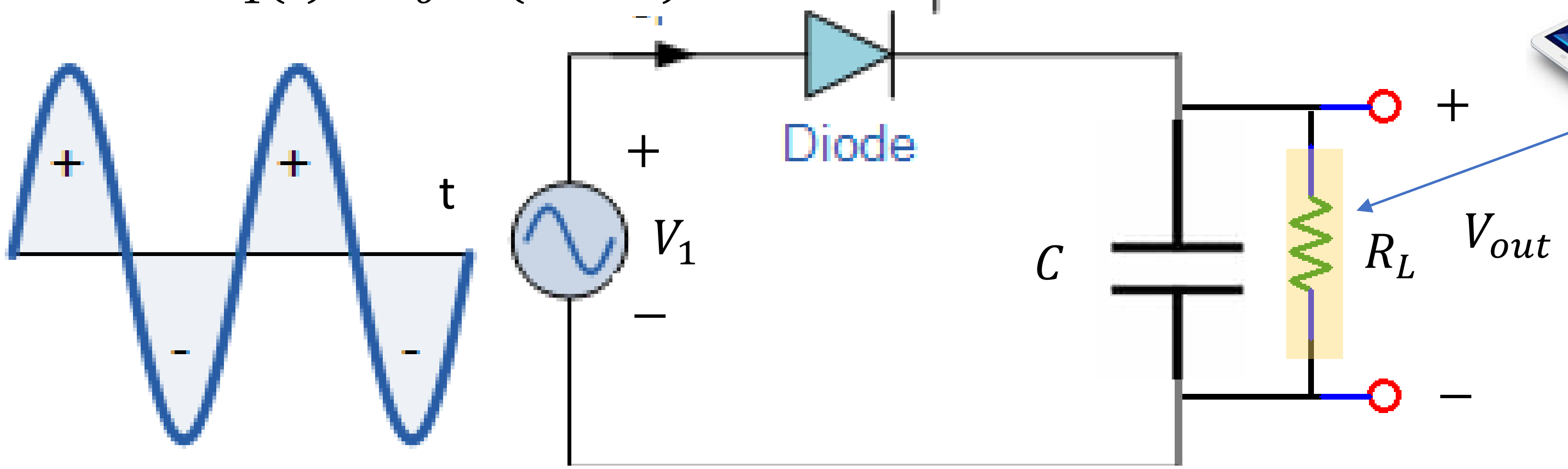
$$V_1(t) = V_o \sin(2\pi 50t)$$



How does the output voltage look like afterwards?

Half-wave rectifier with capacitor

$$V_1(t) = V_o \sin(2\pi 50 t)$$



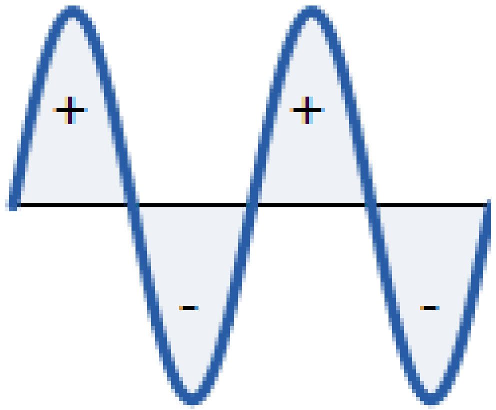
How does the output voltage look like afterwards?
How to calculate the ripple amplitude of the output voltage?

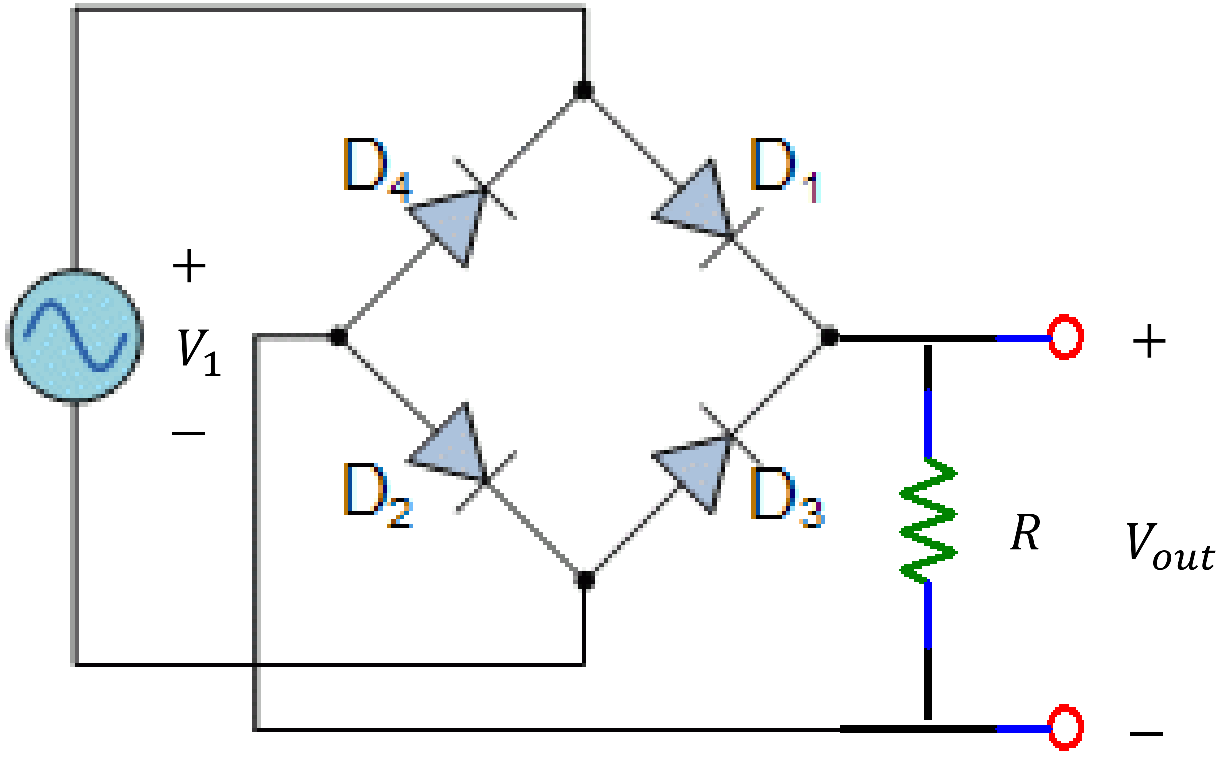
Full-wave rectifier Vs. half-wave rectifier

- The ripple amplitude becomes half ☺
- The maximum reverse voltage becomes half ☺
- More complex ☹

Full-wave rectifier

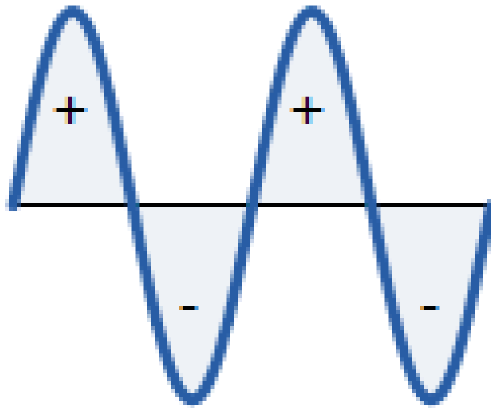
$$V_1(t) = V_o \sin(2\pi 50 t)$$

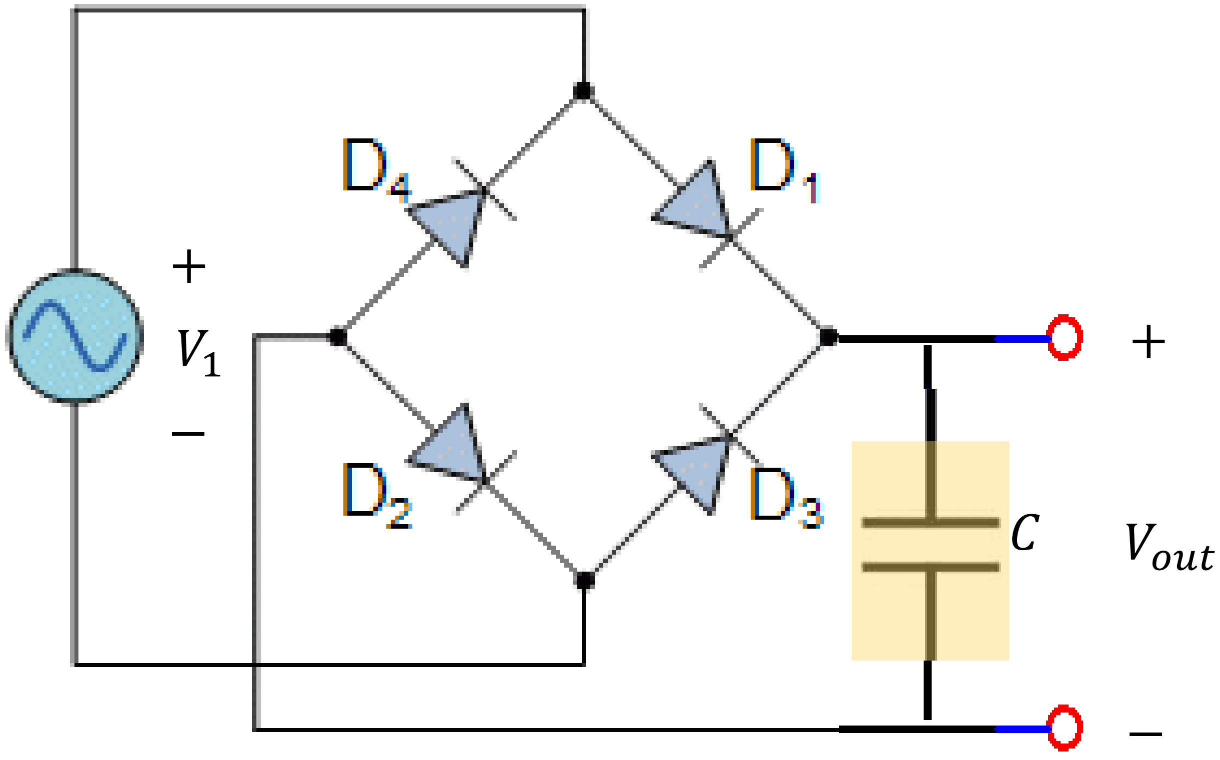




Quiz: Full-wave rectifier with capacitor

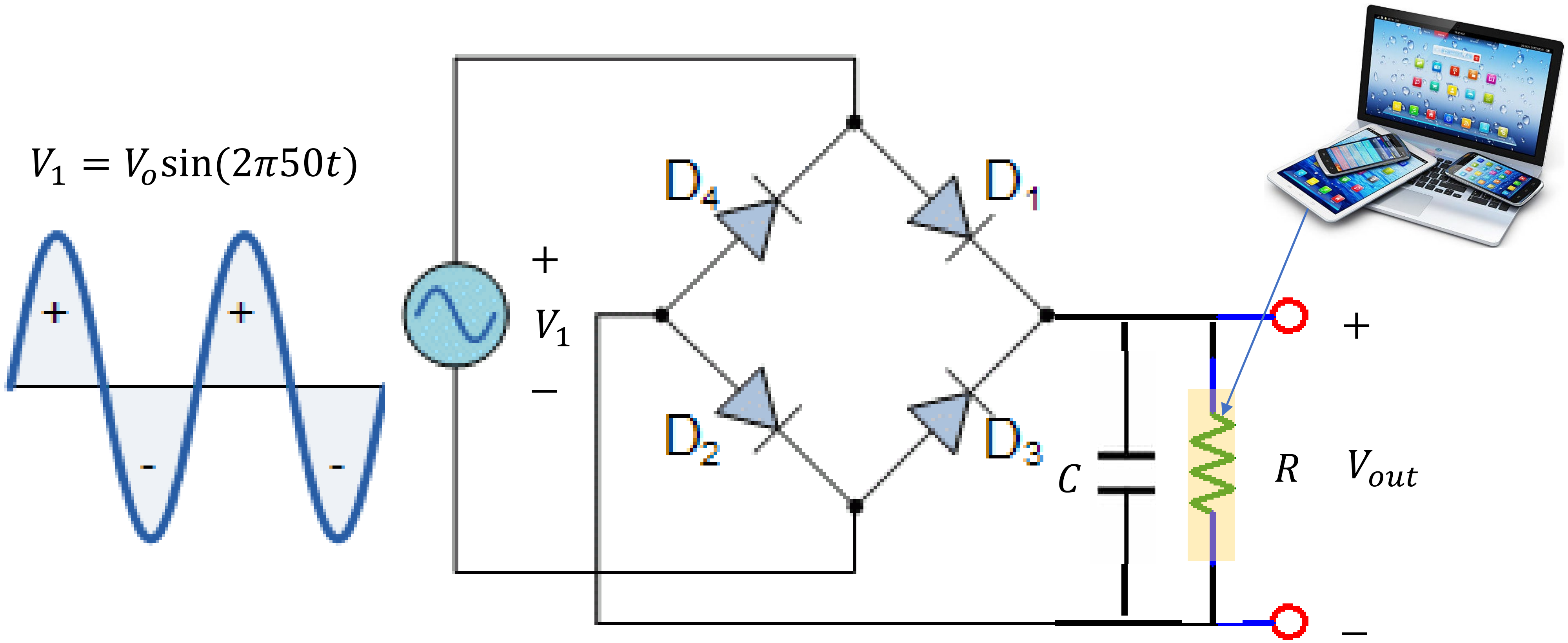
$V_1 = V_o \sin(2\pi 50 t)$



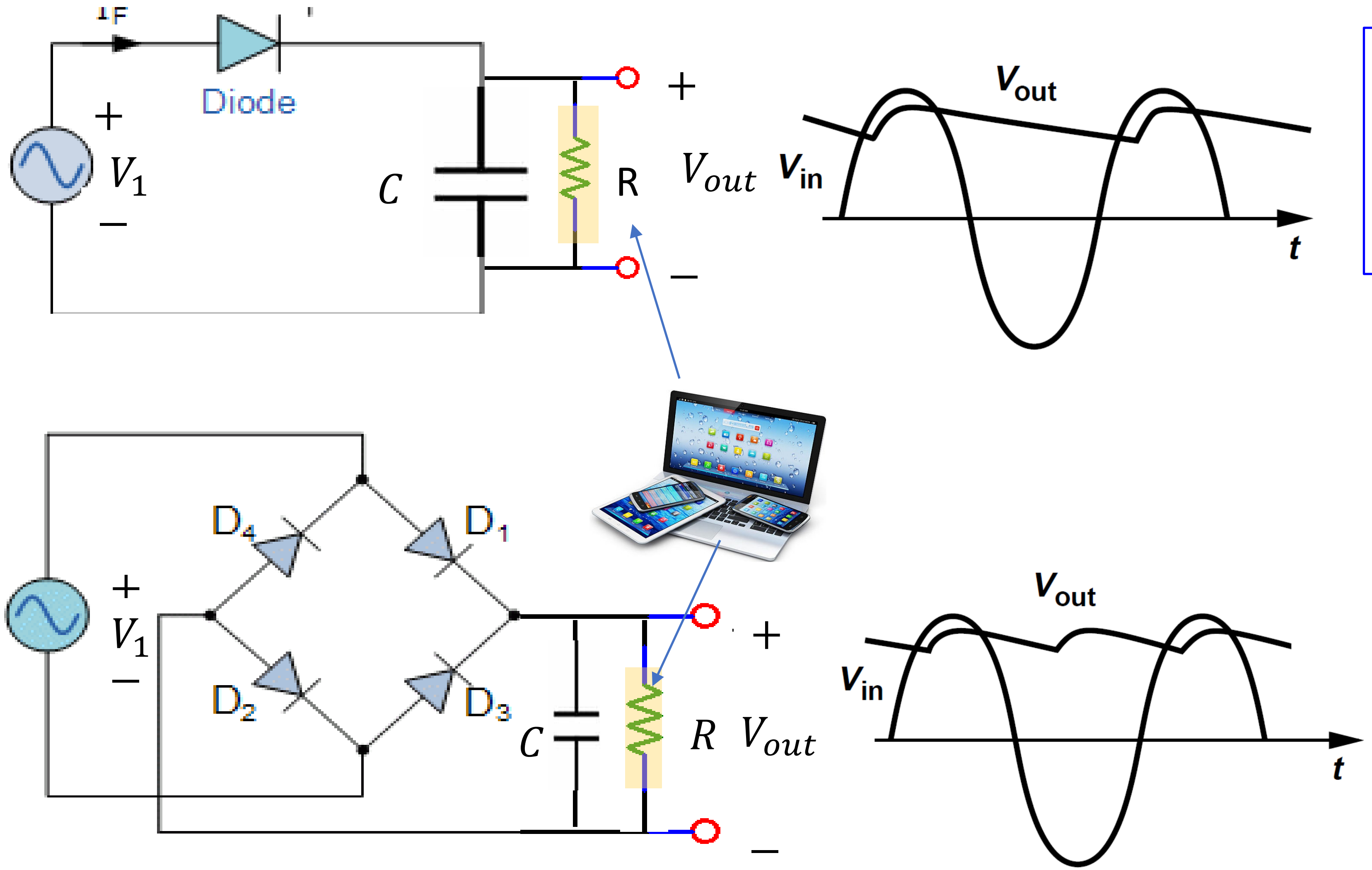


Full-wave rectifier with capacitor and load

$$V_1 = V_o \sin(2\pi 50t)$$



Recap: Half-wave rectifier Vs. Full-wave rectifier with capacitor and load



Ripple amplitude = $\frac{V_o - V_{D,on}}{fRC}$

Max reverse voltage = $2V_o - V_{D,on}$

Ripple amplitude = $\frac{V_o - 2V_{D,on}}{2fRC}$

Max reverse voltage = $V_o - V_{D,on}$