Analog electronics

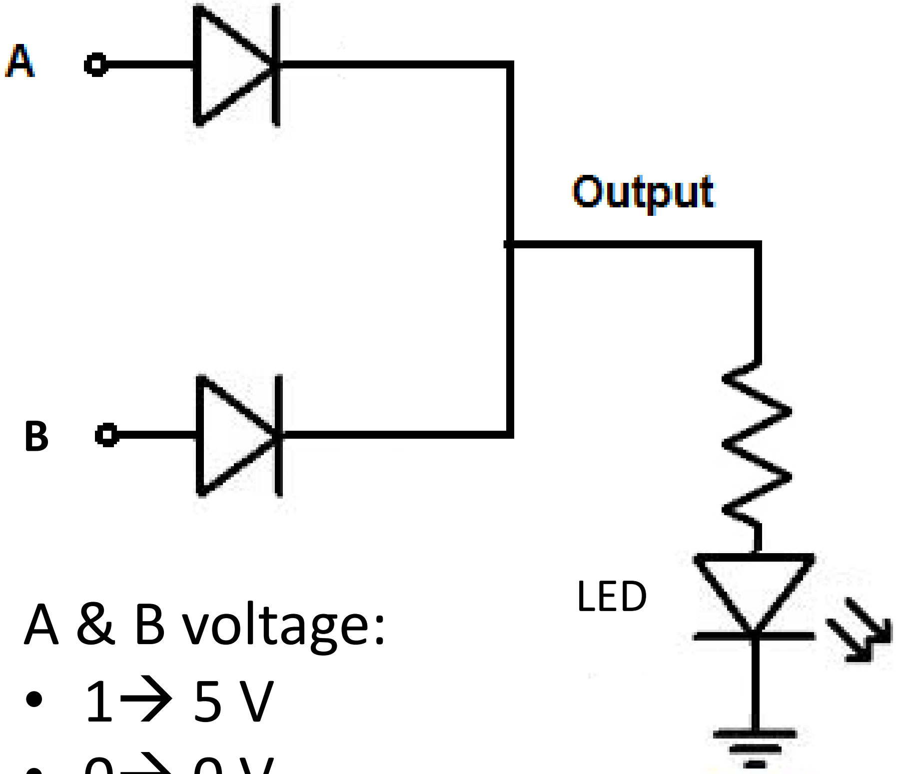
Fengchun Zhang

fz@es.aau.dk

Agenda

- Diode
  - Recap diode circuit analysis principle, practical diode circuits, solutions to assignments
  - Practical diode circuits:
    - Clipper or limiter
    - Voltage doubler/multiplier
  - Small signal model

Recap: application example: OR logic gate



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

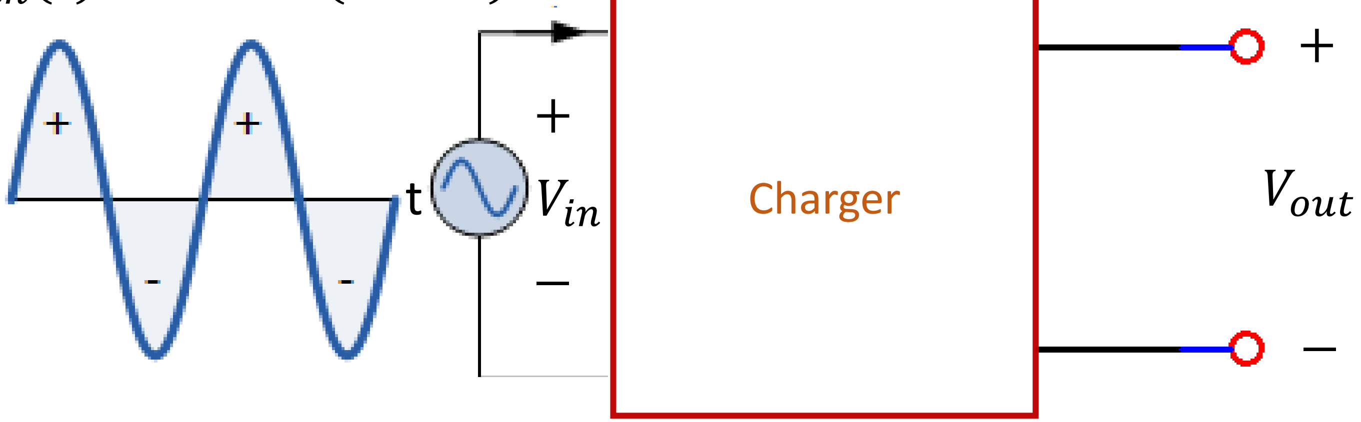
A & B voltage:
- 1→ 5 V
- 0→ 0 V

The LED forward voltage drop is 2 V.

PN junction diode application example: charger/adapter

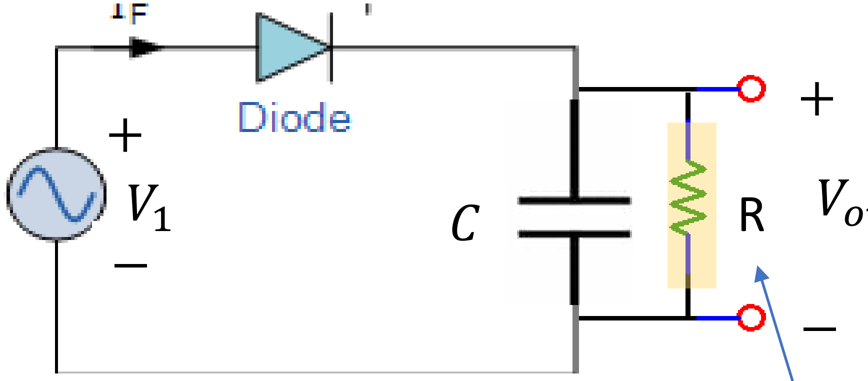
V_{out}:
- 5 V for cellphone
- 20 V for laptop

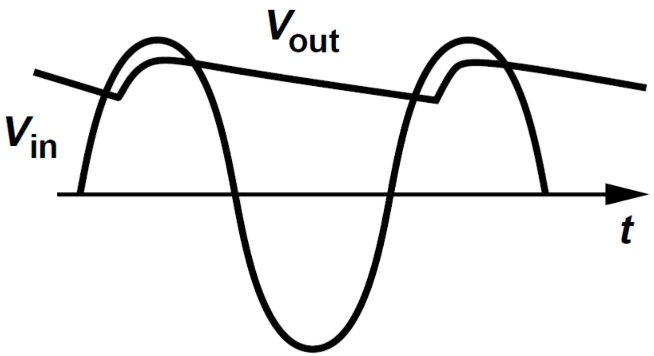
$V_{in}(t) = 230\sin(2\pi 50t)$



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

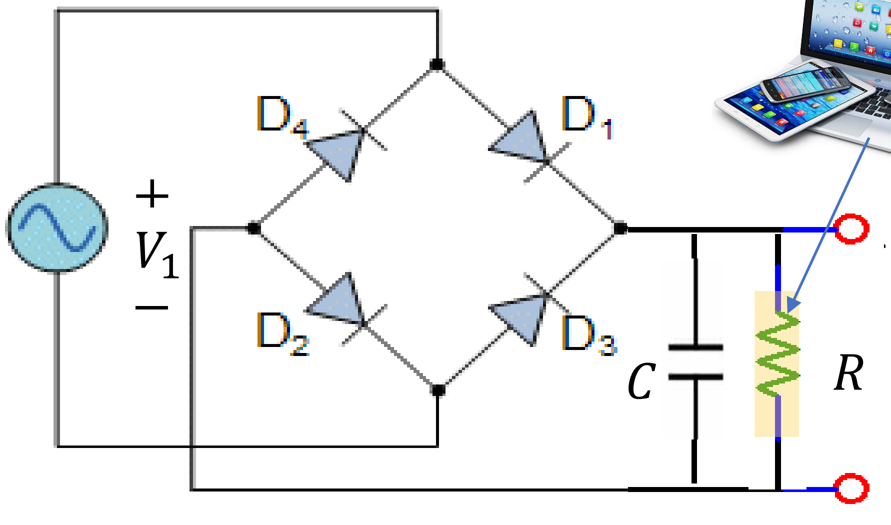
Recap: Half-wave rectifier Vs. Full-wave rectifier with capacitor and load

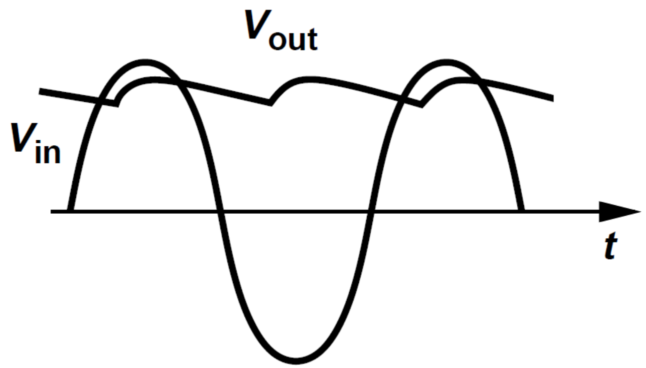




Ripple amplitude = $\frac{V_o - V_{D,on}}{fRC}$

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





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

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

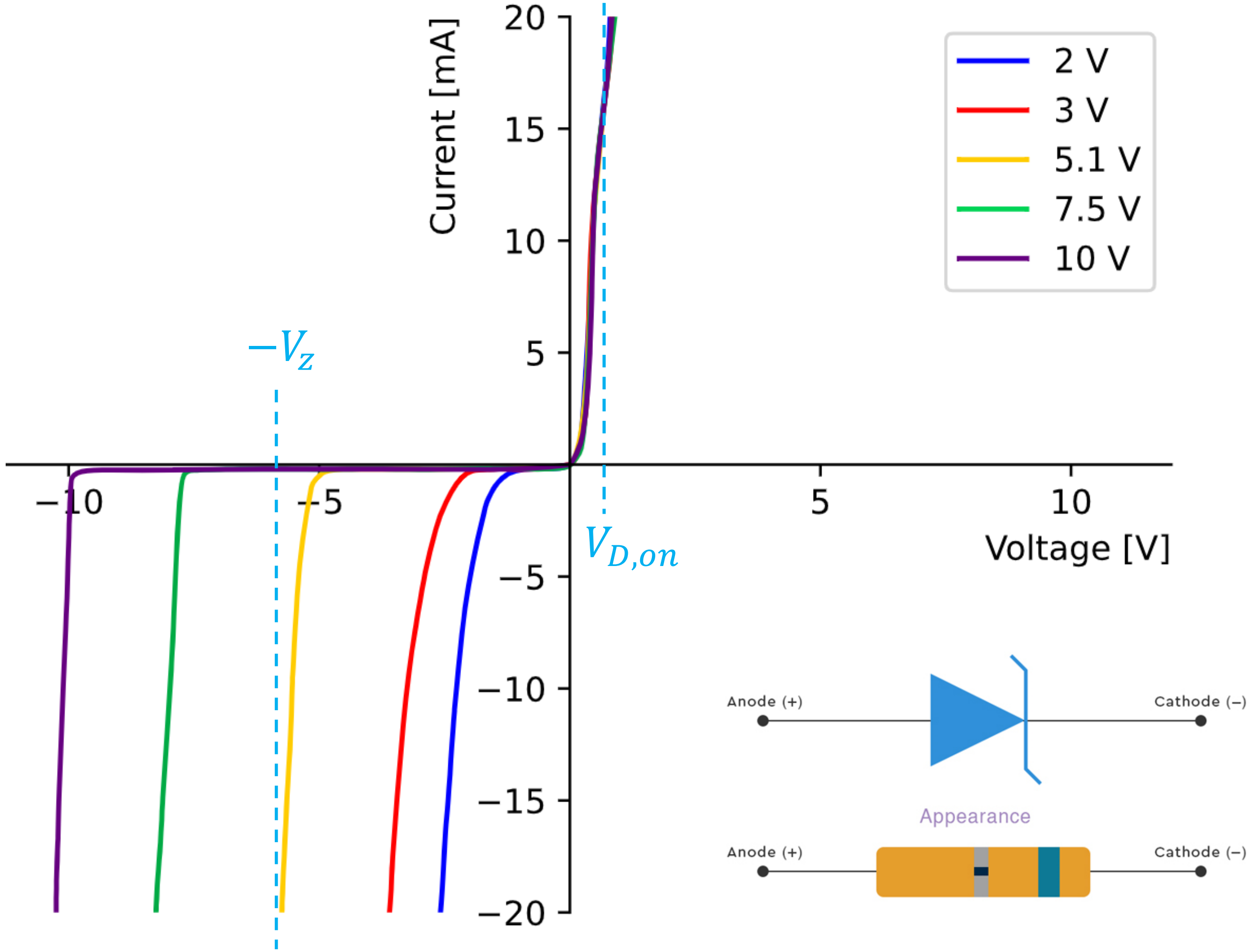
Agenda

- Diode
  - Recap diode circuit analysis principle, practical diode circuits, solutions to assignments
  - Practical diode circuits:
    - Clipper or limiter
    - Voltage doubler/multiplier
  - Small signal model

Clipper/limiting circuits

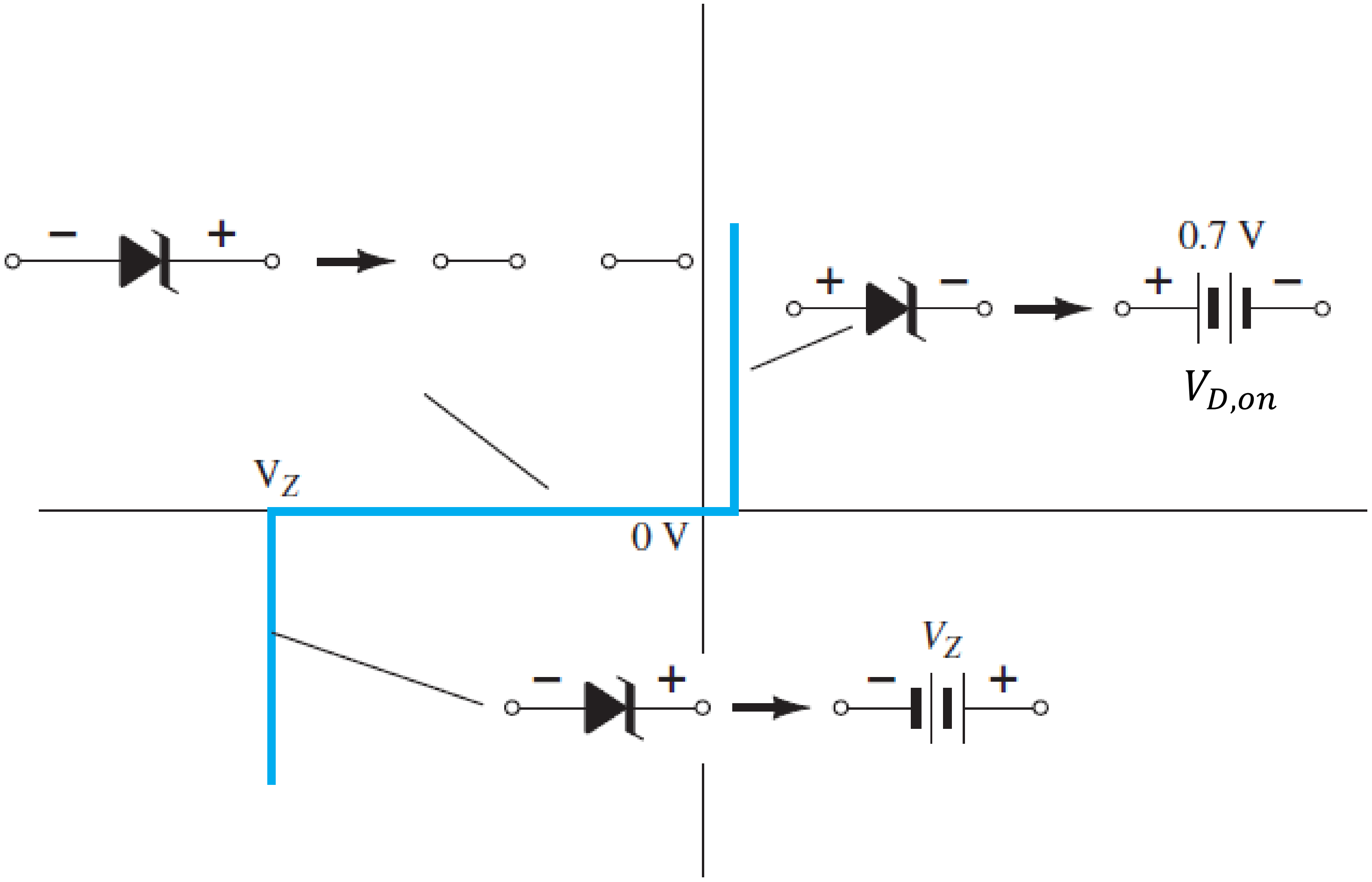
Zener diode

- Designed to work in the reverse breakdown region.
- Stable and predicable voltage drop.
- Often used for clipper and limiter circuits.

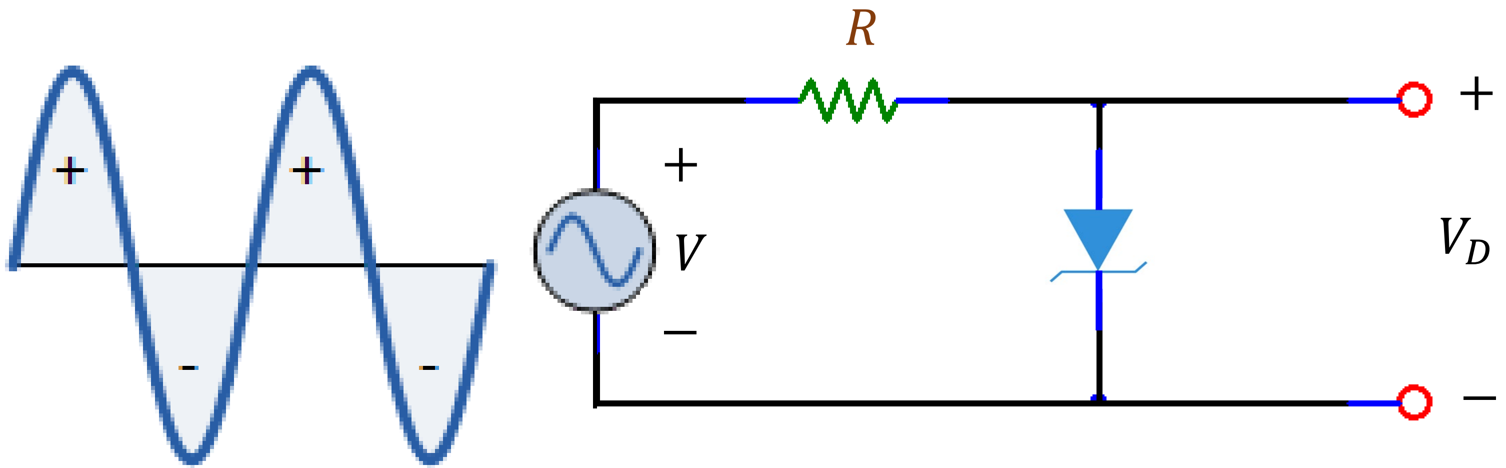


Device	Zener Voltage	
	Min.	Max.
BZX79C2V4	2.2	2.6
BZX79C2V7	2.5	2.9
BZX79C3V0	2.8	3.2
BZX79C3V3	3.1	3.5
BZX79C3V6	3.4	3.8
BZX79C3V9	3.7	4.1
BZX79C4V3	4	4.6
BZX79C4V7	4.4	5
BZX79C5V1	4.8	5.4
BZX79C5V6	5.2	6
BZX79C6V2	5.8	6.6
BZX79C6V8	6.4	7.2
BZX79C7V5	7	7.9
BZX79C8V2	7.7	8.7
BZX79C9V1	8.5	9.6
BZX79C10	9.4	10.6
BZX79C11	10.4	11.6
BZX79C12	11.4	12.7
BZX79C13	12.4	14.1
BZX79C15	13.8	15.6
BZX79C16	15.3	17.1
BZX79C18	16.8	19.1
BZX79C20	18.8	21.2
BZX79C22	20.8	23.3
BZX79C24	22.8	25.6

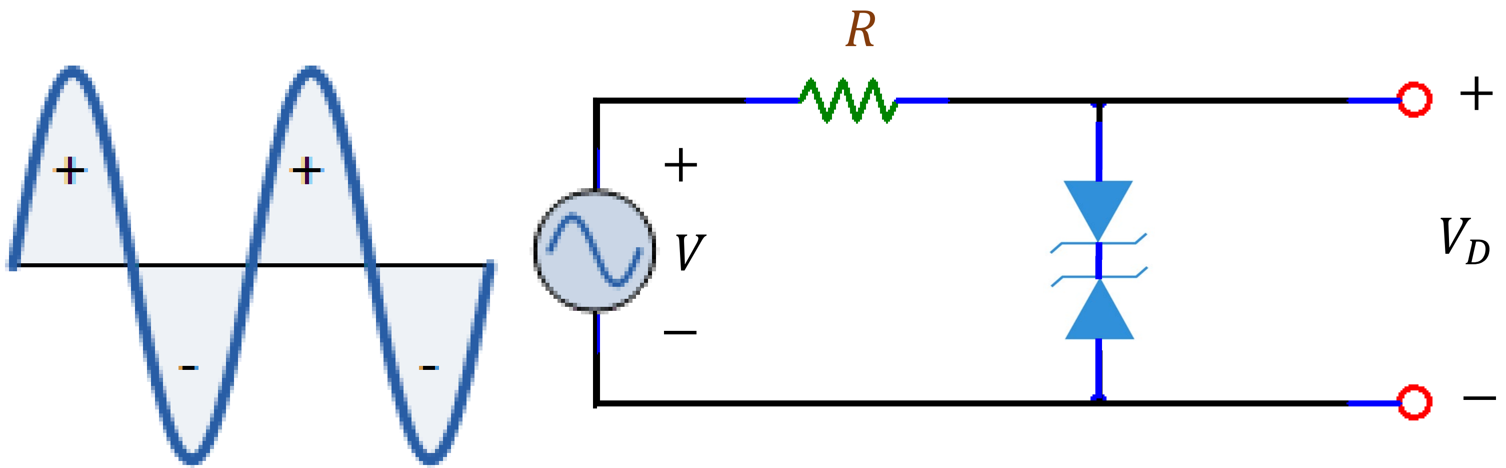
Zener diode—constant voltage drop model



Quiz: Clipper/limiting circuits



Clipper/limiting circuits



Agenda

- Diode
  - Recap diode circuit analysis principle, practical diode circuits, solutions to assignments
  - Practical diode circuits:
    - Clipper or limiter
    - Voltage doubler/multiplier
  - Small signal model

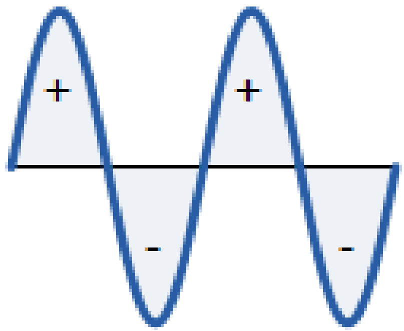
Voltage doubler circuits

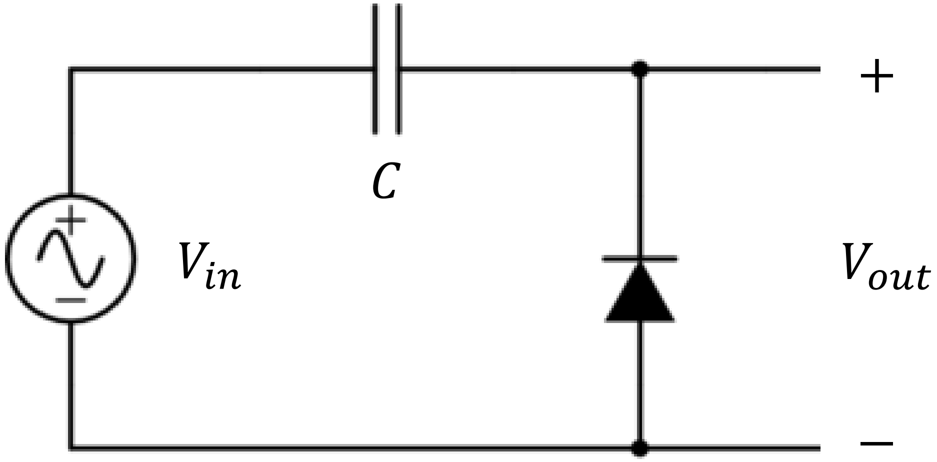
Passports with RFID (Radio-Frequency Identification) chips do not have batteries.

The reader emits radio waves that power the passive RFID chip in the passport.

Voltage doubler circuits

$V_{in}(t) = V_o \sin(2\pi f t)$

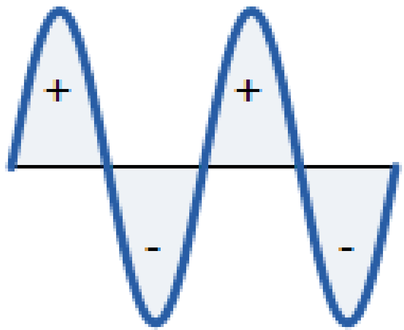


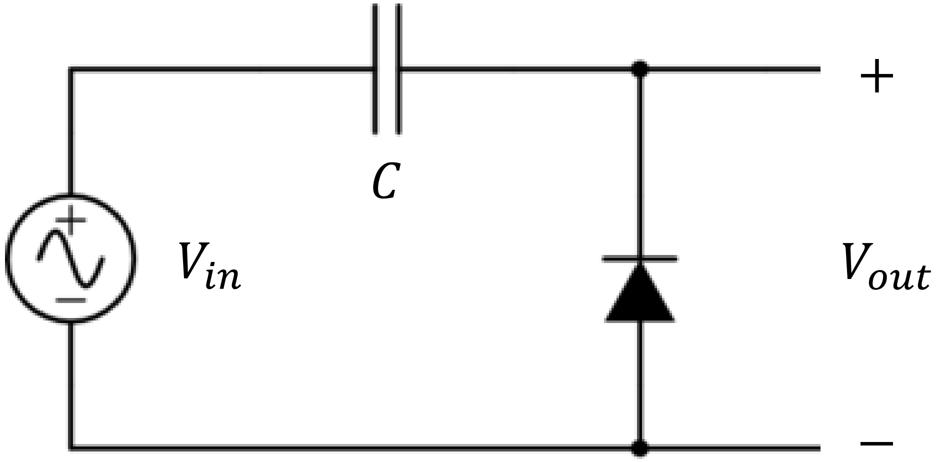


Assume ideal diode model

Quiz

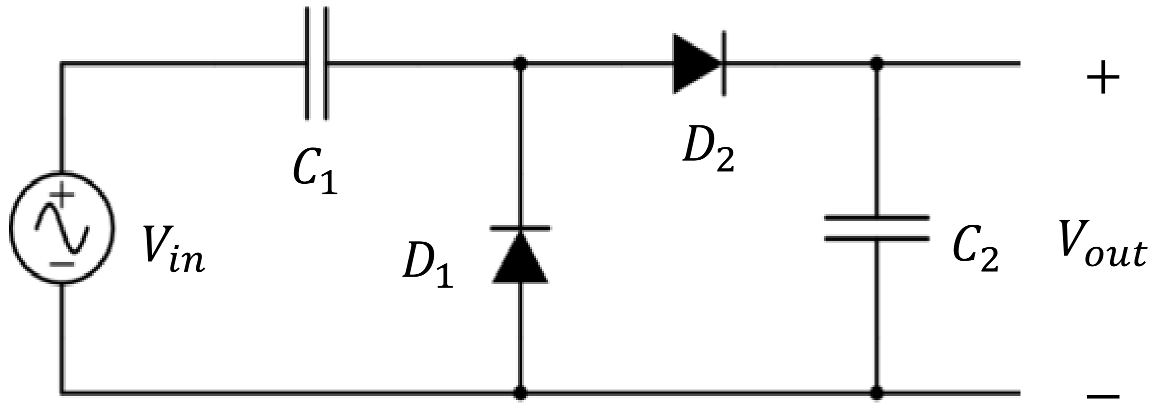
$V_{in}(t) = V_o \sin(2\pi f t)$





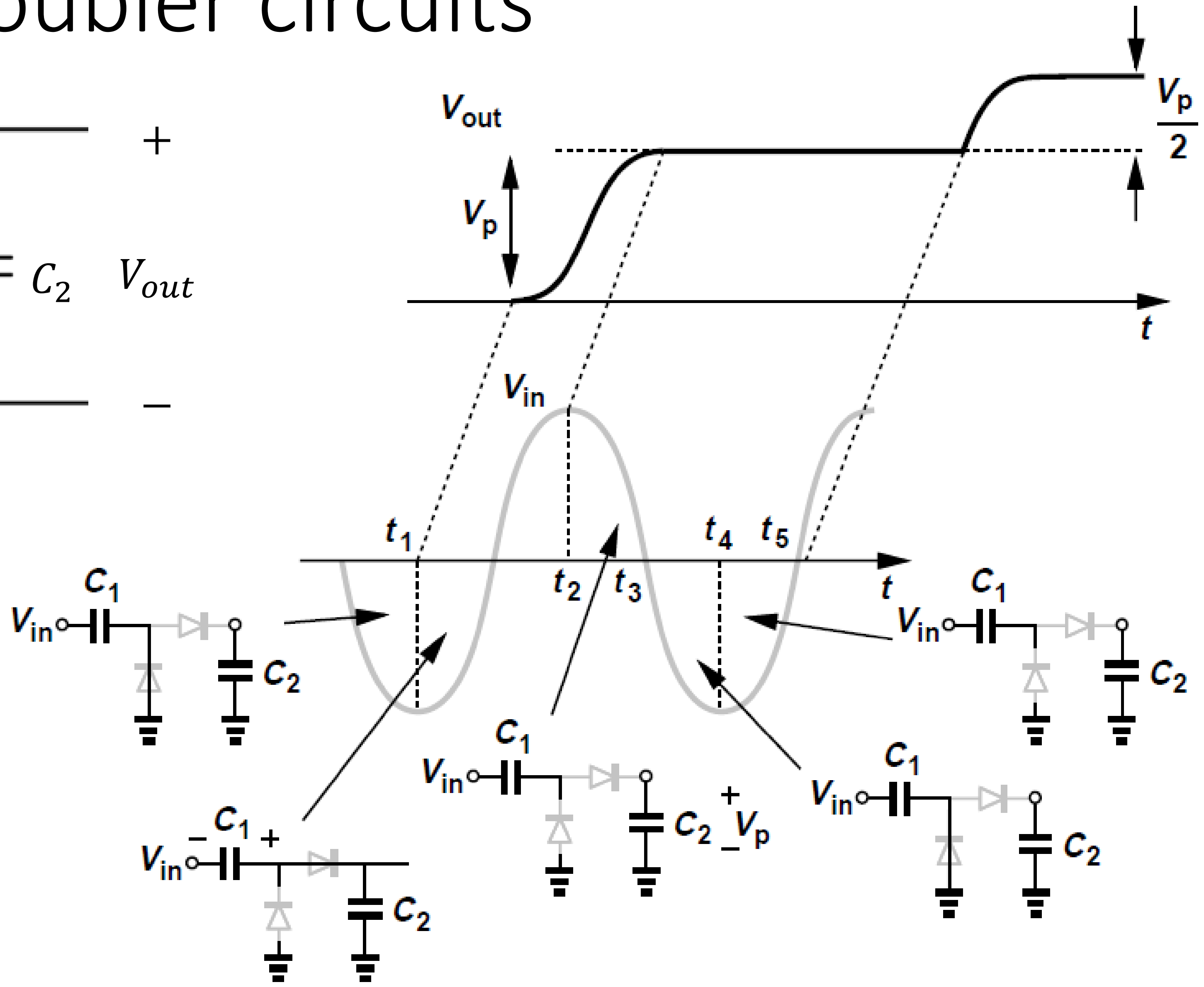
Assume constant voltage drop model

Actual voltage doubler circuits



$$V_{in}(t) = V_p \sin(2\pi f t)$$

Assume ideal diode model



LTspice simulation: voltage doubler

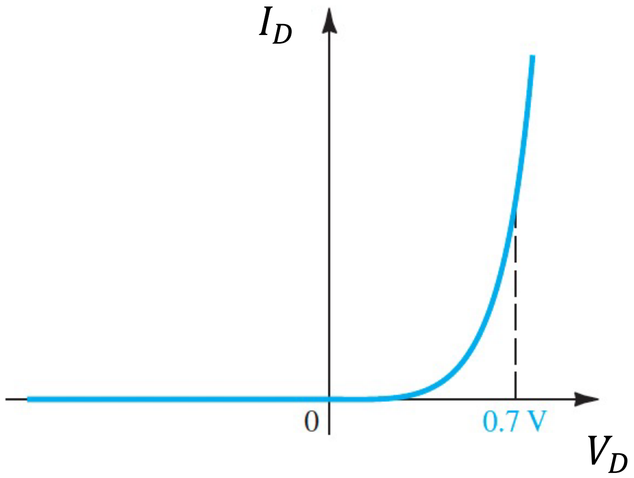
- V = 3 $\sin(2\pi 50t + \pi)$
- C1 = C2 = 0.0001 F
- Diodes: 1N4007

Agenda

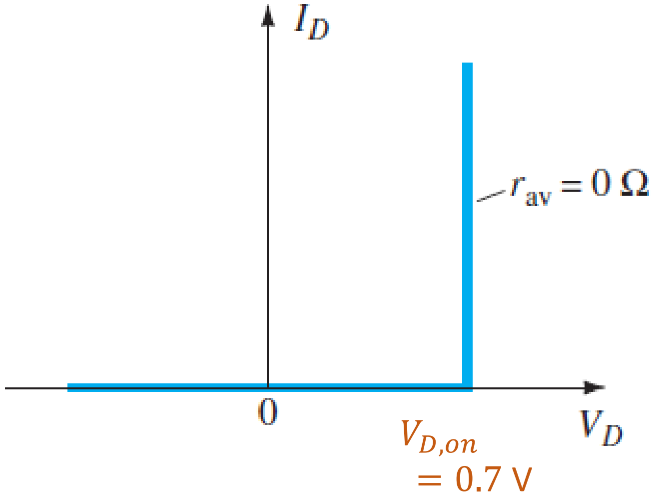
- Diode
  - Recap diode circuit analysis principle, practical diode circuits, solutions to assignments
  - Practical diode circuits:
    - Clipper or limitter
    - Voltage doubler/multiplier
  - Small signal model

PN diode models

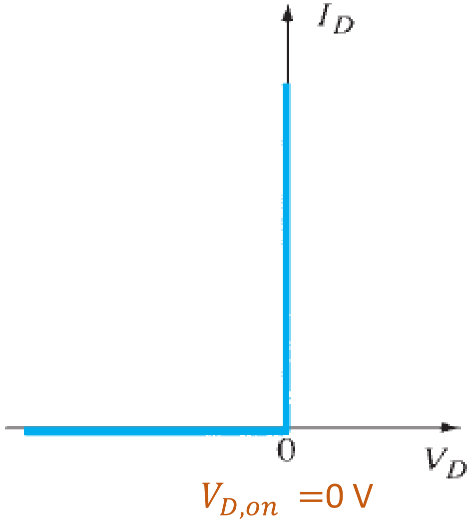
Exponential model
(usage rate =10-20%)



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



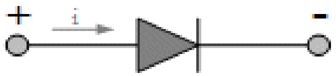
Ideal model
(usage rate =10-20%)



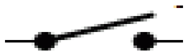
$$I_D \approx I_s\, e^{\frac{V_D}{V_T}}$$

Simplify calculation
Approximate results

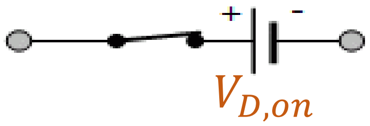
The diode has two states:



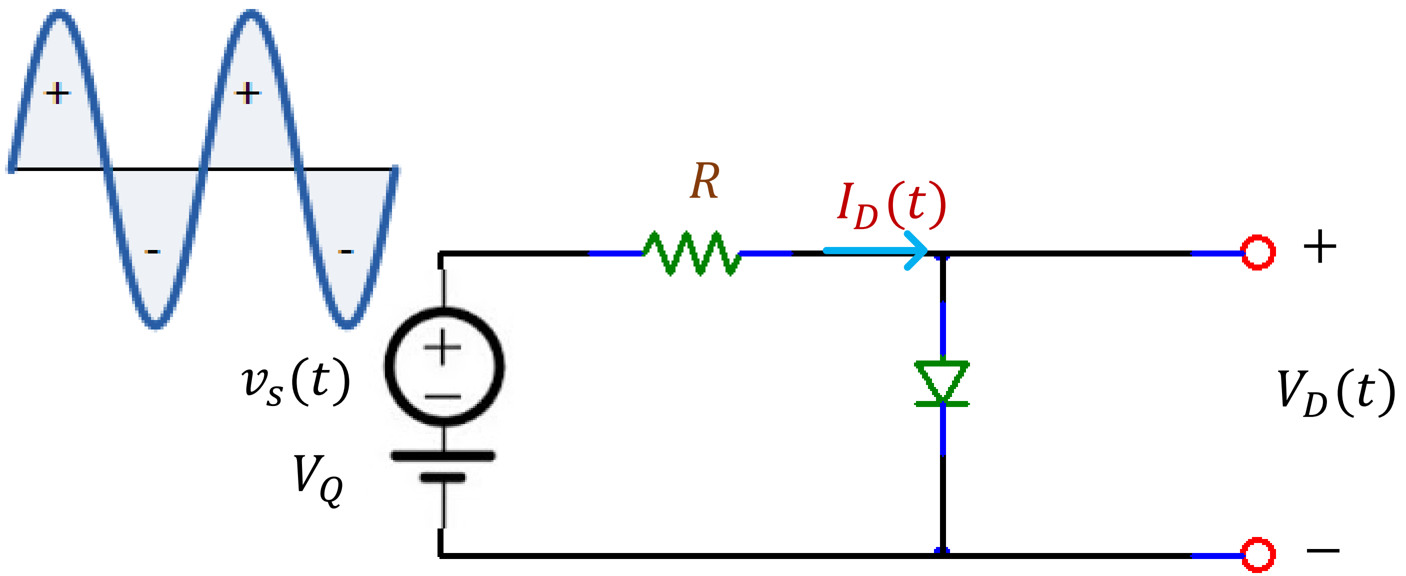
- $V_D < V_{D,on}$ → diode is off → open circuit

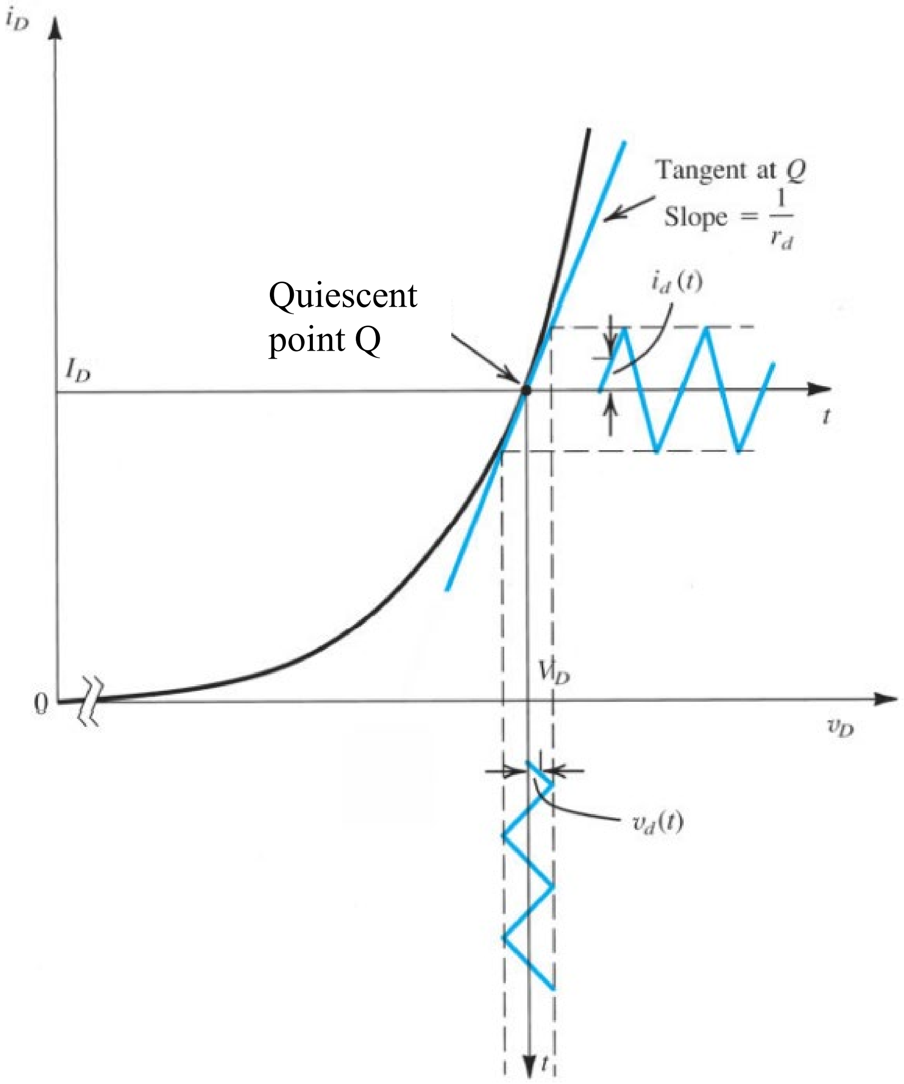


- $V_D \geq V_{D,on}$ → diode is on → a voltage drop



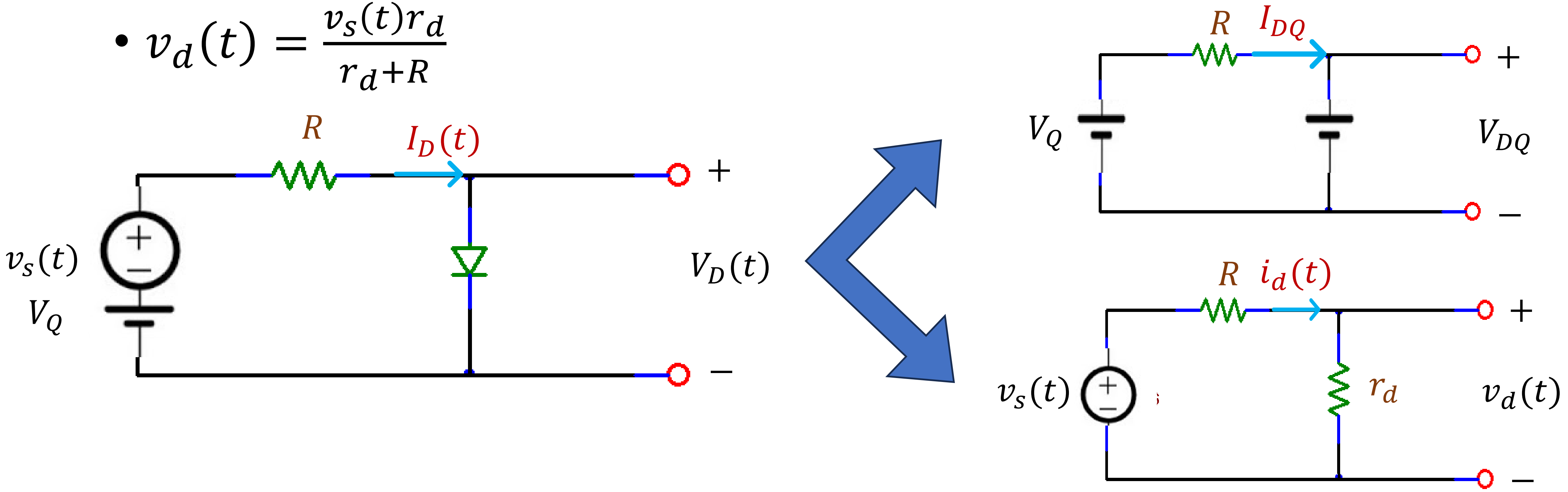
Small-signal model





Procedure

- DC analysis to get I_{DQ}.
- Calculate the diode small-signal resistance $r_d = \frac{V_T}{I_{DQ}}|_{V_{DQ}}$.
- $v_d(t) = \frac{v_s(t) r_d}{r_d + R}$



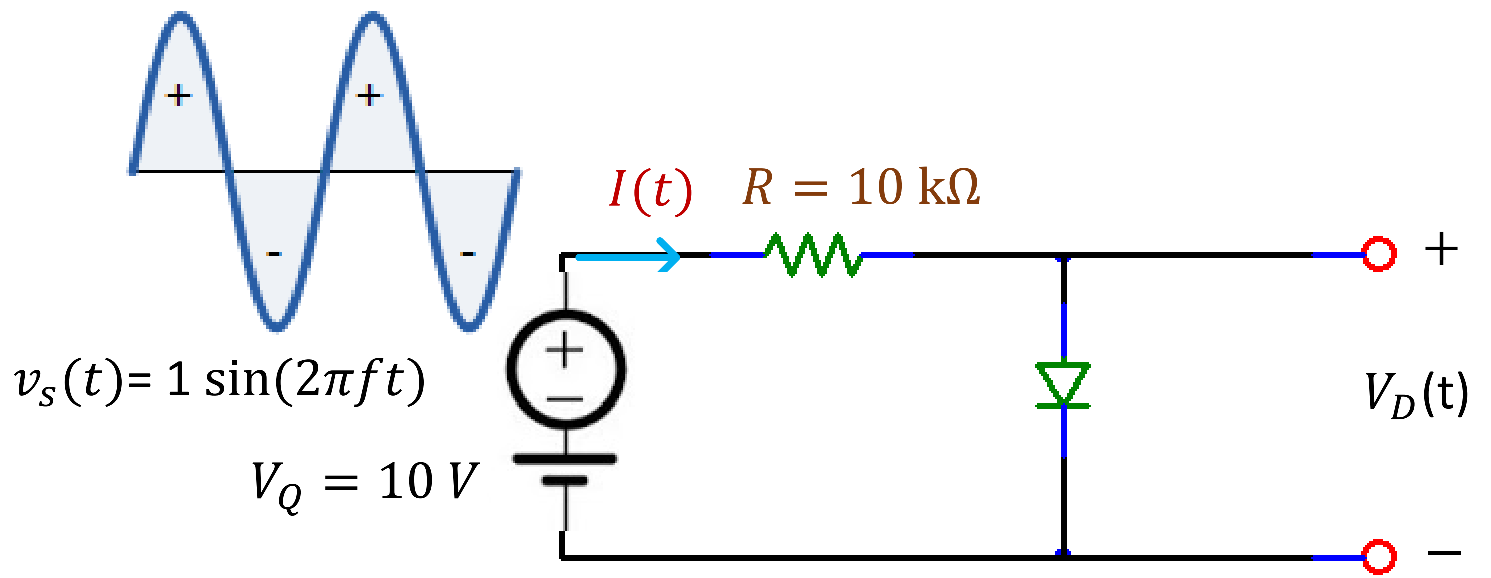
Quiz: Small-signal model

The DC current of a diode is 1 mA.

(a) Determine the current change if V_D changes by 1 mV.

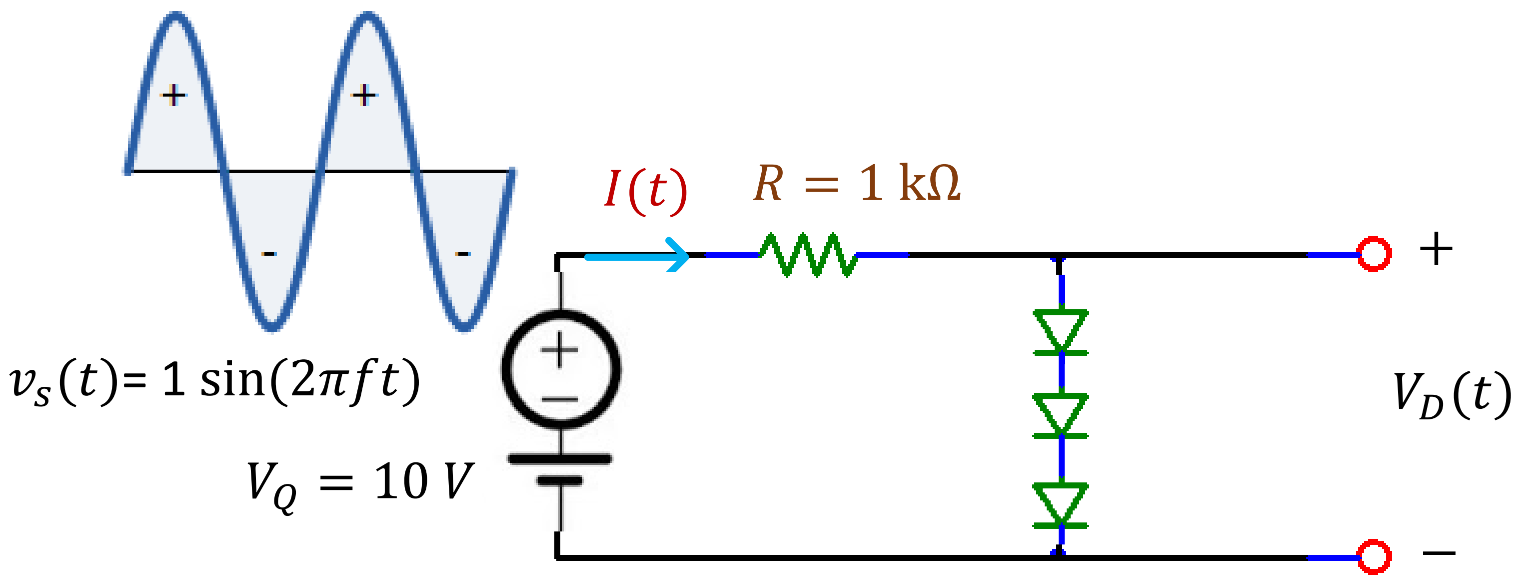
(b) Determine the voltage change if I_D changes by 10%.

example: small signal model



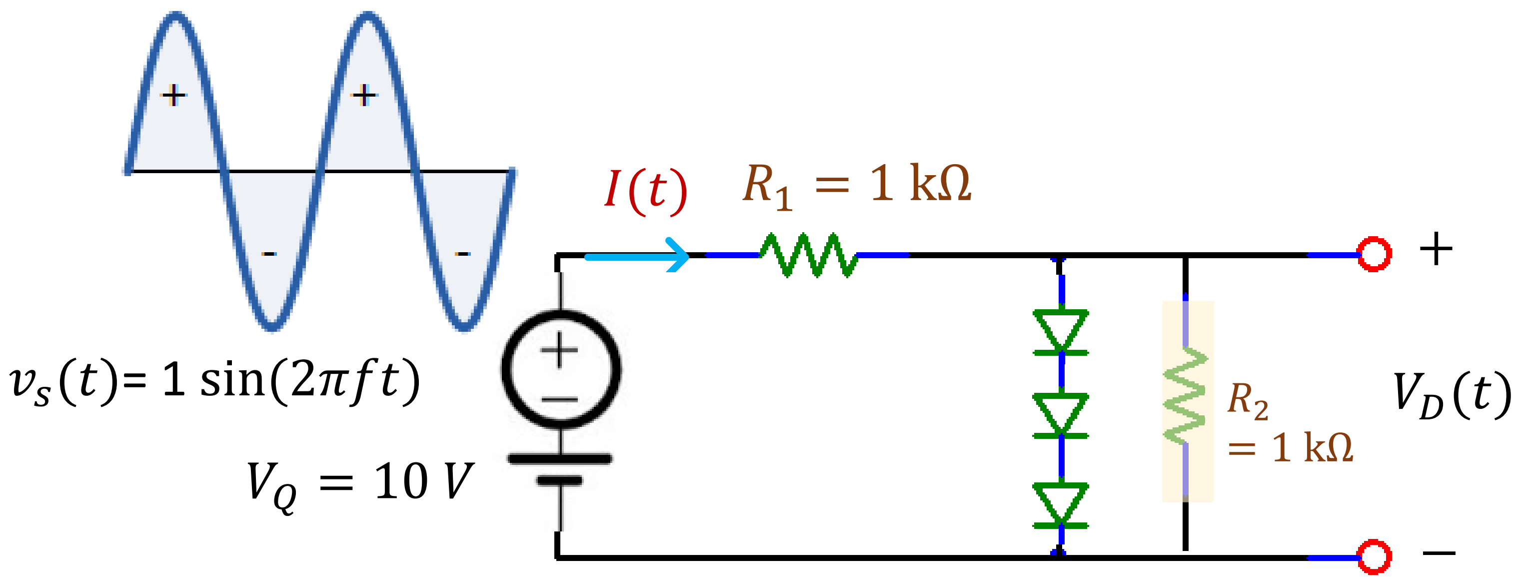
The voltage drop across the diode V_{DQ}= 0.7 V when only the DC voltage is applied.

excercise: small signal model



The voltage drop across each diode is V_{DQ}= 0.7 V when only the DC voltage is applied.

excercise: small signal model



The voltage drop across each diode is V_{DQ}= 0.7 V when only the DC voltage is applied.

Small-signal model approximation error

$$I_D(t) = I_s e^{[V_{DQ}+v_d(t)]/nV_T} = I_s e^{V_{DQ}/nV_T}\, e^{v_d(t)/nV_T} = I_{DQ}\, e^{v_d(t)/nV_T}$$

$$I_D(t) = \mathrm{I_{DQ}} + i_\mathrm{d}(\mathrm{t})$$

$\rightarrow i_\mathrm{d}(\mathrm{t}) = I_D(t) - \mathrm{I_{DQ}} = I_{DQ}(e^{v_d(t)/nV_T}$-1) actual $i_\mathrm{d}(\mathrm{t})$

Small-signal approximated $i_\mathrm{d}(\mathrm{t})$: $\widehat{i_\mathrm{d}}(\mathrm{t})$ = $I_{DQ}\, v_d(t)/nV_T$

$$\rightarrow \frac{i_\mathrm{d}(\mathrm{t})}{\widehat{i_\mathrm{d}}(\mathrm{t})} = \frac{e^{v_d(t)/nV_T}-1}{v_d(t)/nV_T}$$

$v_d(t)/_{nV_T}$	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**
$\frac{i_\mathrm{d}(\mathrm{t})}{\widehat{i_\mathrm{d}}(\mathrm{t})}$	1.05	1.11	1.17	1.23	1.30	1.37	1.45