ME133 Lecture ~~6~~ 7

1/31/23

Last time:

> BJT – overview

> BJT as a switch

Polling:

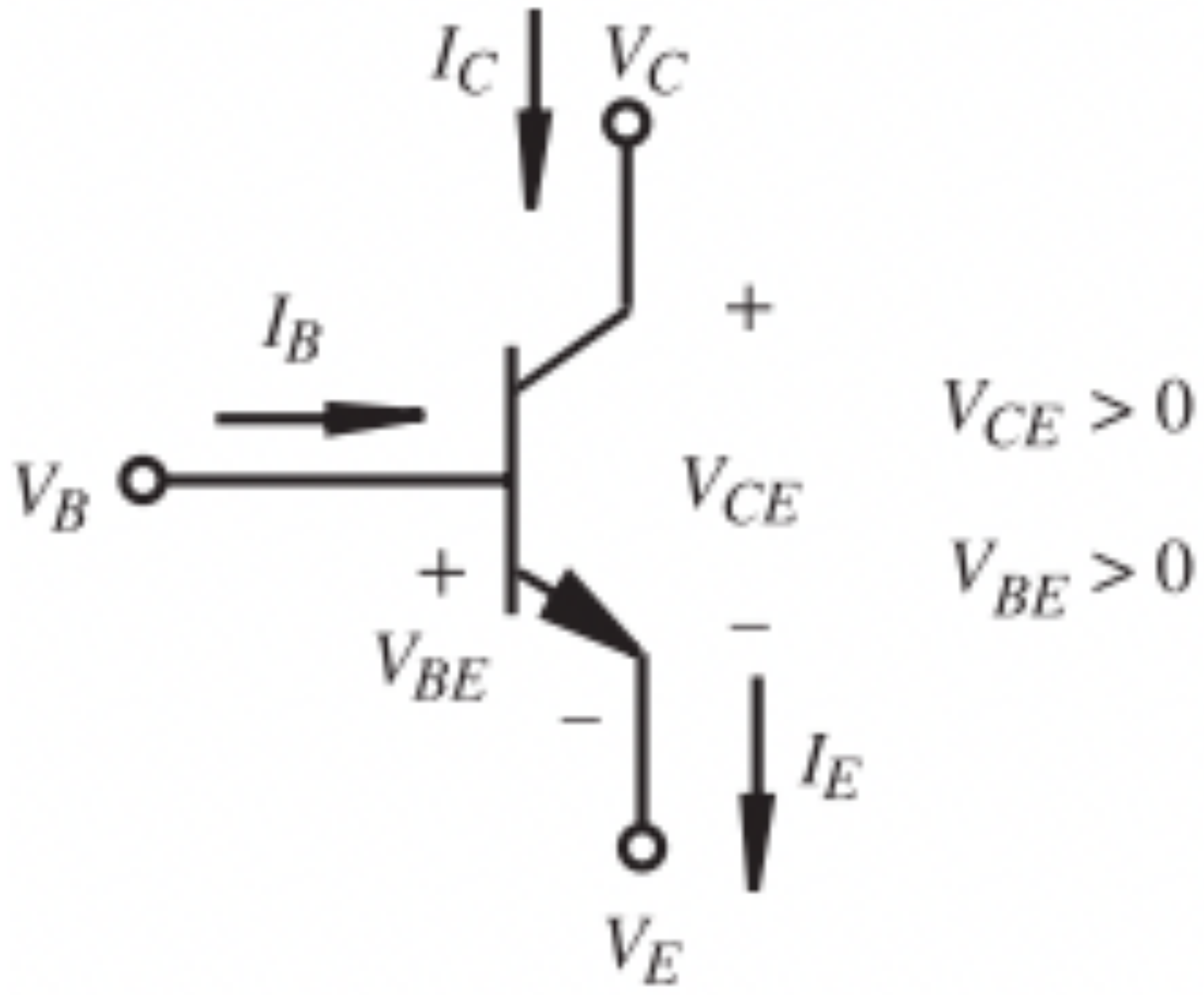
```
while(1) {
 digitalread(pin)
   if pin == High
   break;
}
```

Today:

- Emitter Degeneration

- FET , Field effect transistors

Recall npn BJT fundmentals

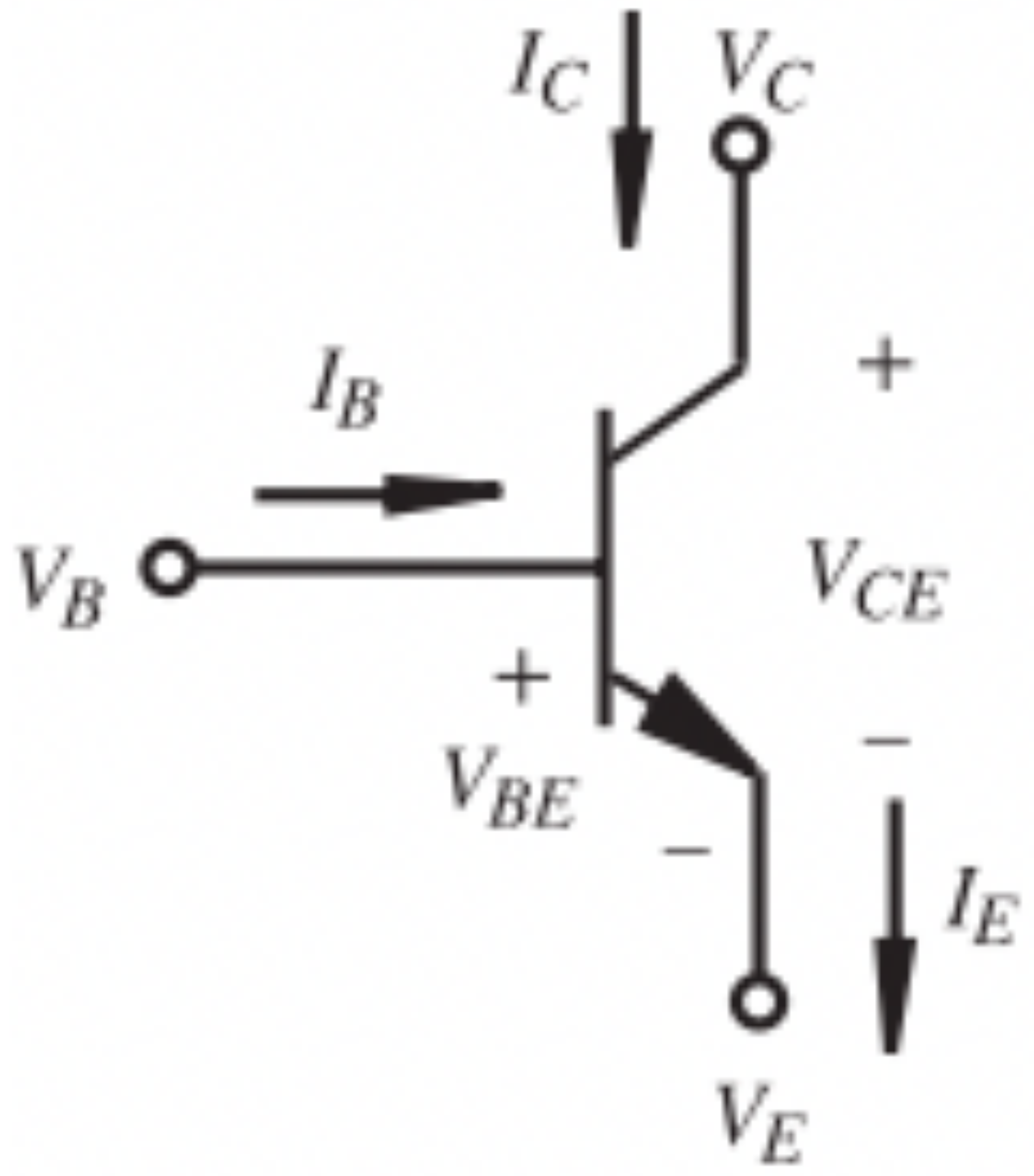


$$I_E = I_C + I_B$$

$$V_{BE} = V_B - V_E$$

$$V_{CE} = V_C - V_E$$

Recall npn BJT fundmentals



$V_{CE} > 0$

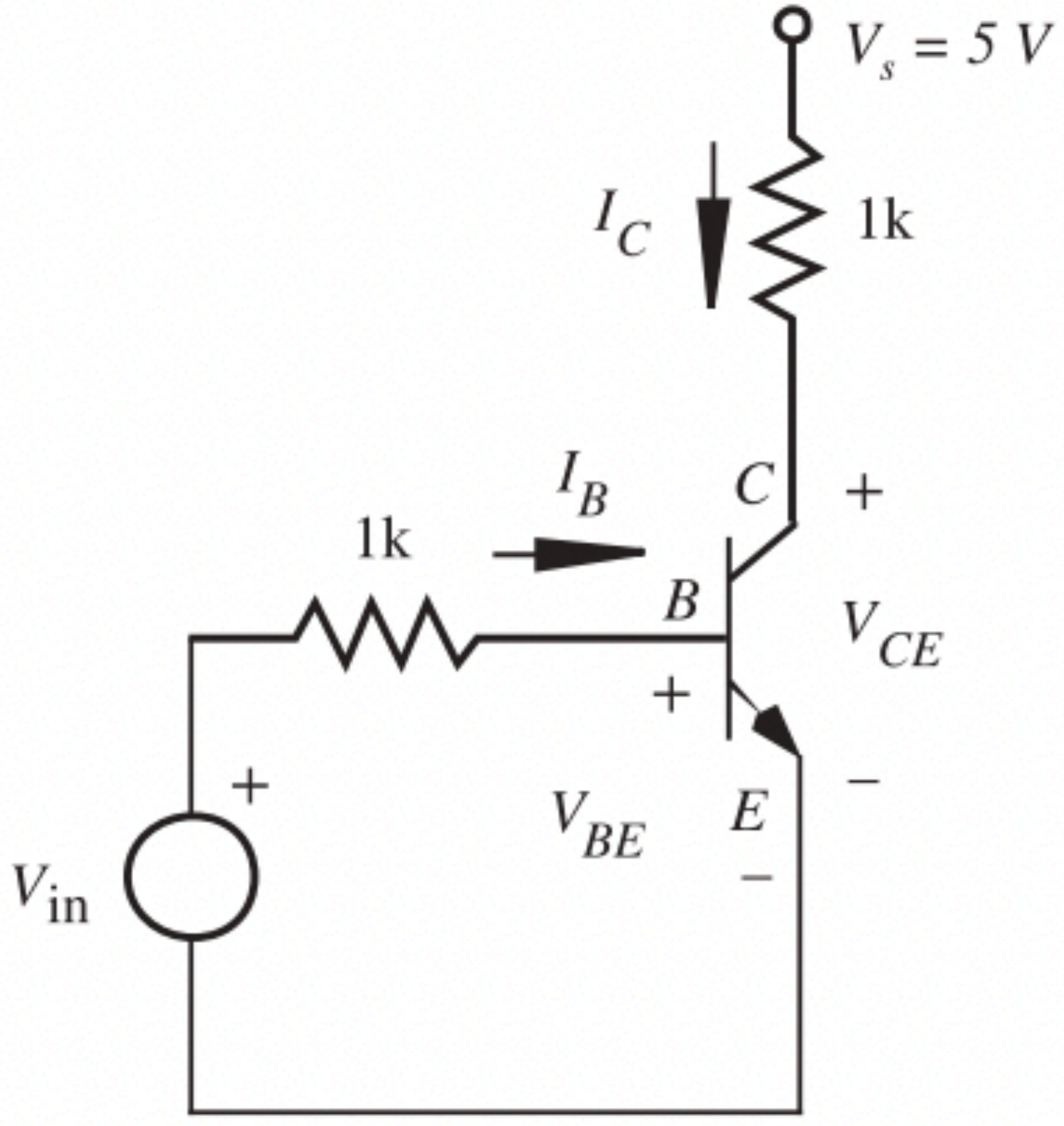
$V_{BE} > 0$

$$I_E = I_C + I_B$$

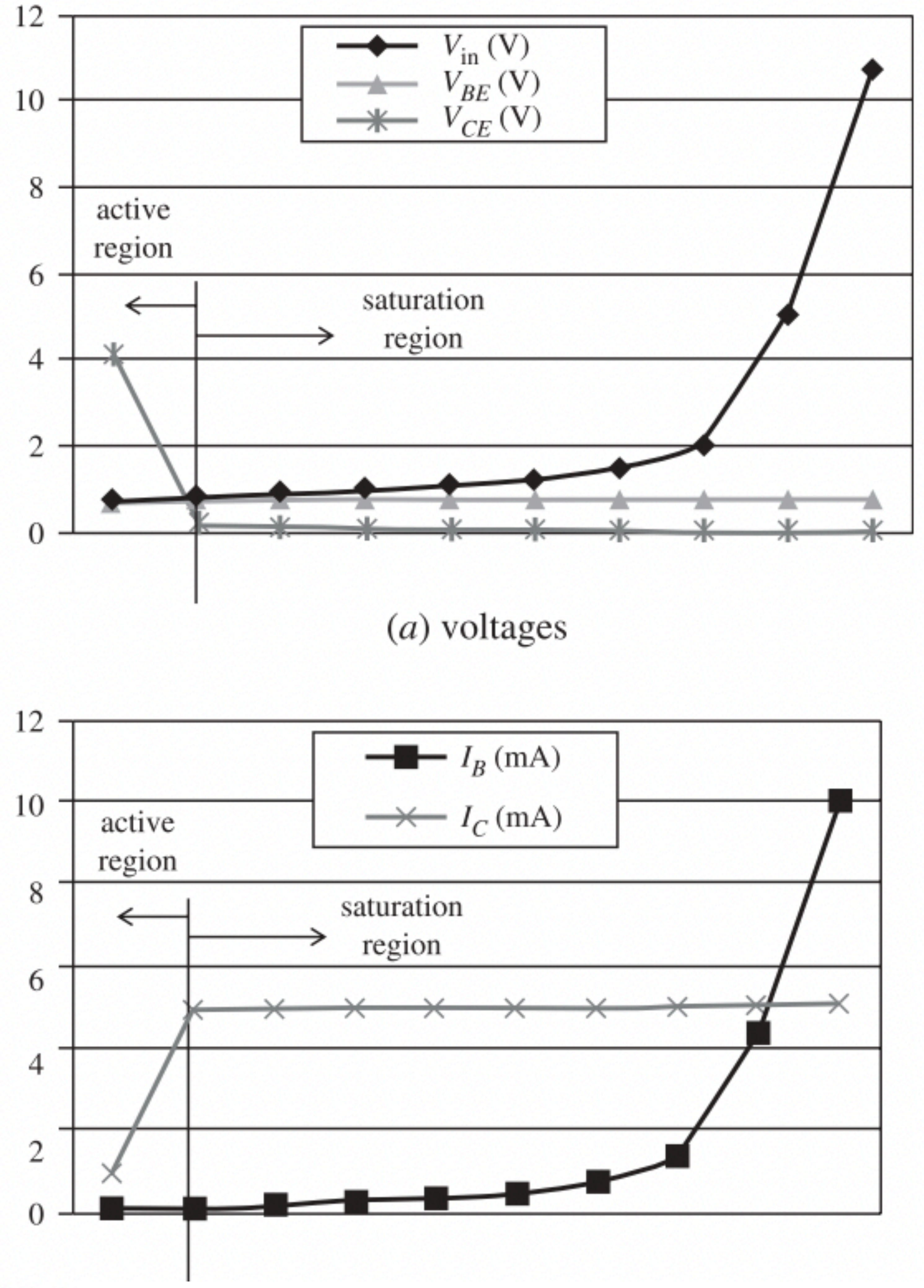
$$V_{BE} = V_B - V_E$$

$$V_{CE} = V_C - V_E$$

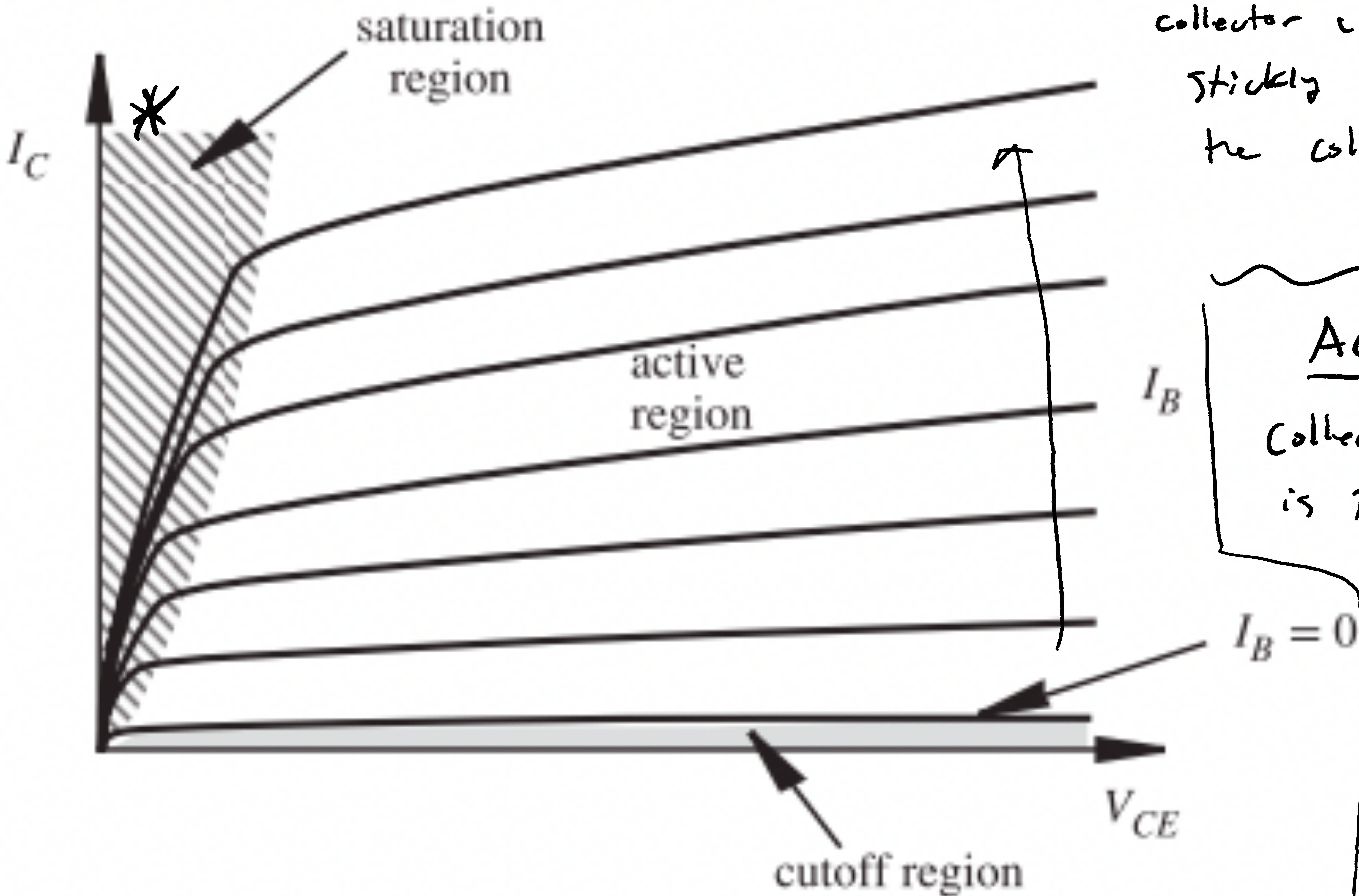
Real Data



(*a*) common emitter



common emitter characteristics



* Saturation Region

collector current is strictly controlled by the collector circuit (Load)

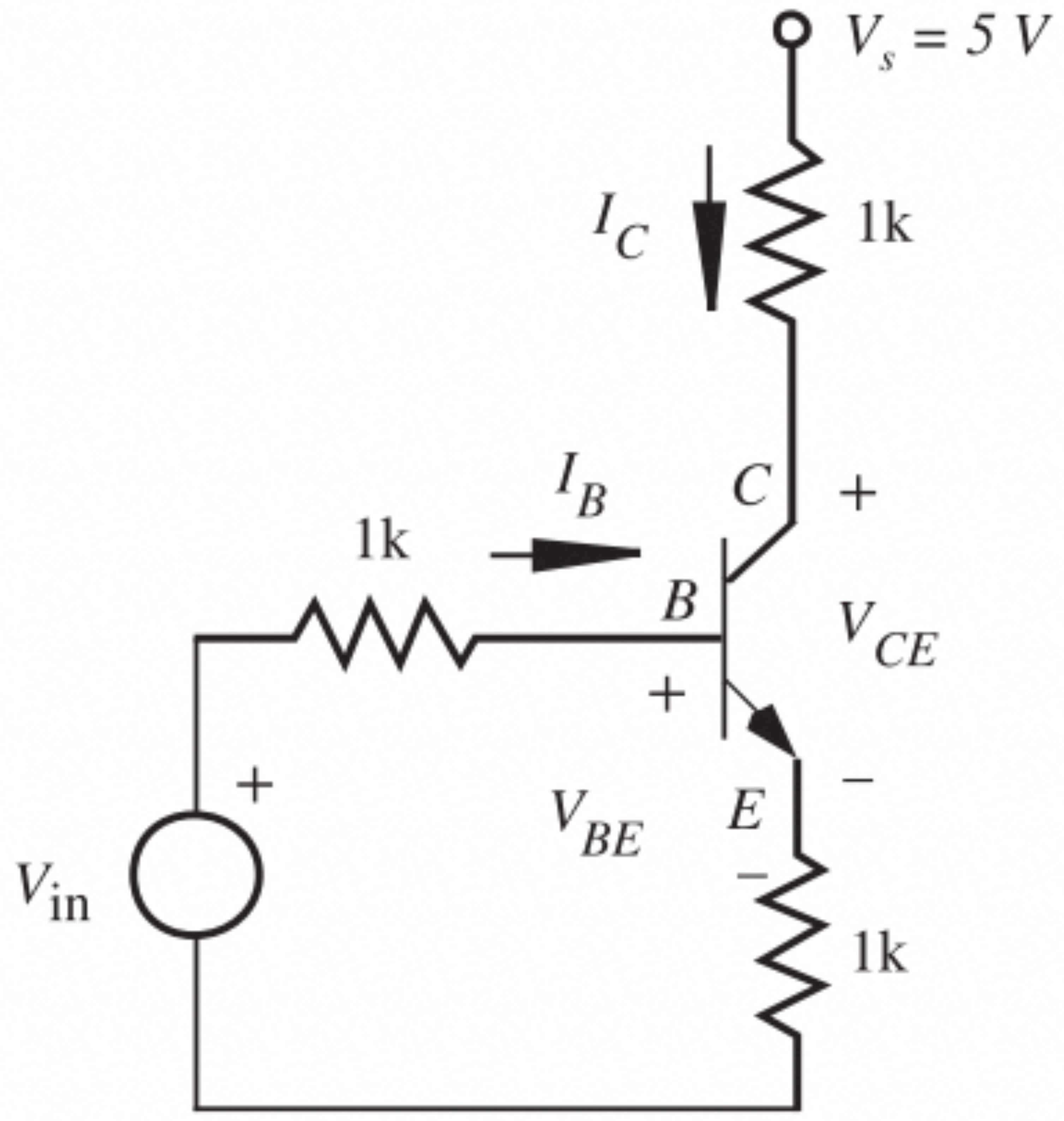
Active Region

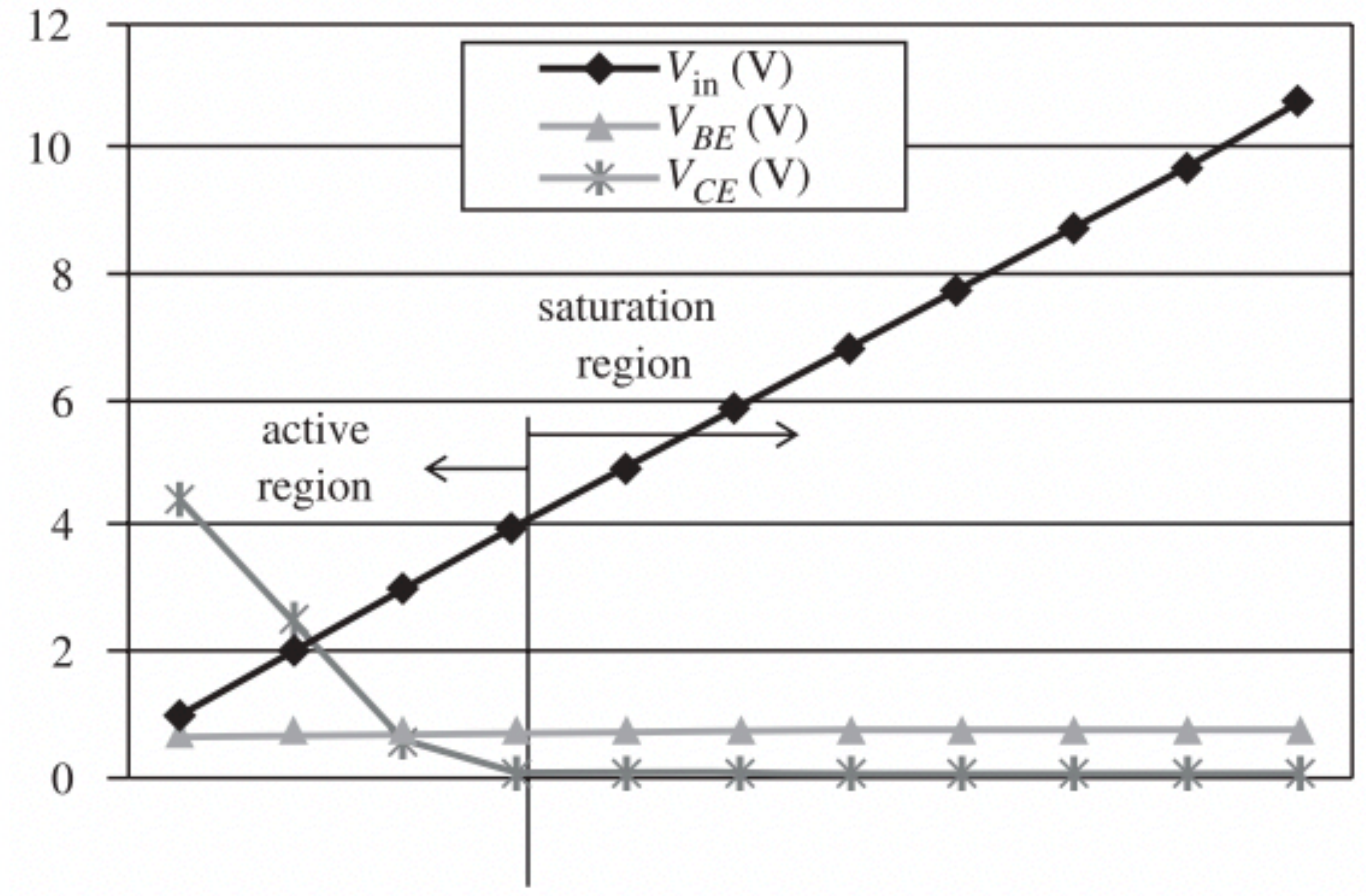
Collector current is proportional to base current

Cutoff

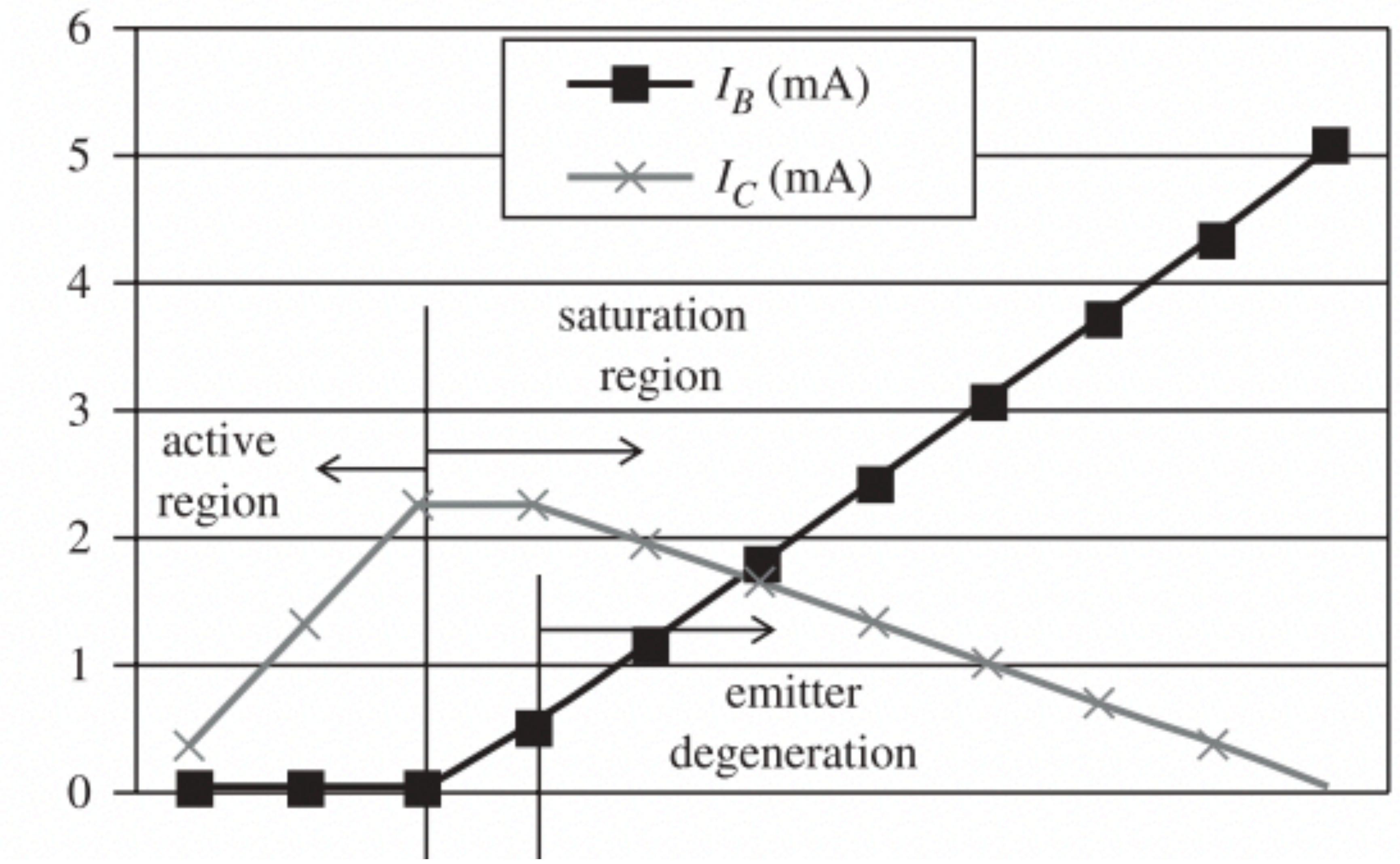
no collector current.

Emitter Degeneration





(a) voltages



as base current is increased, the collector current drops, why?

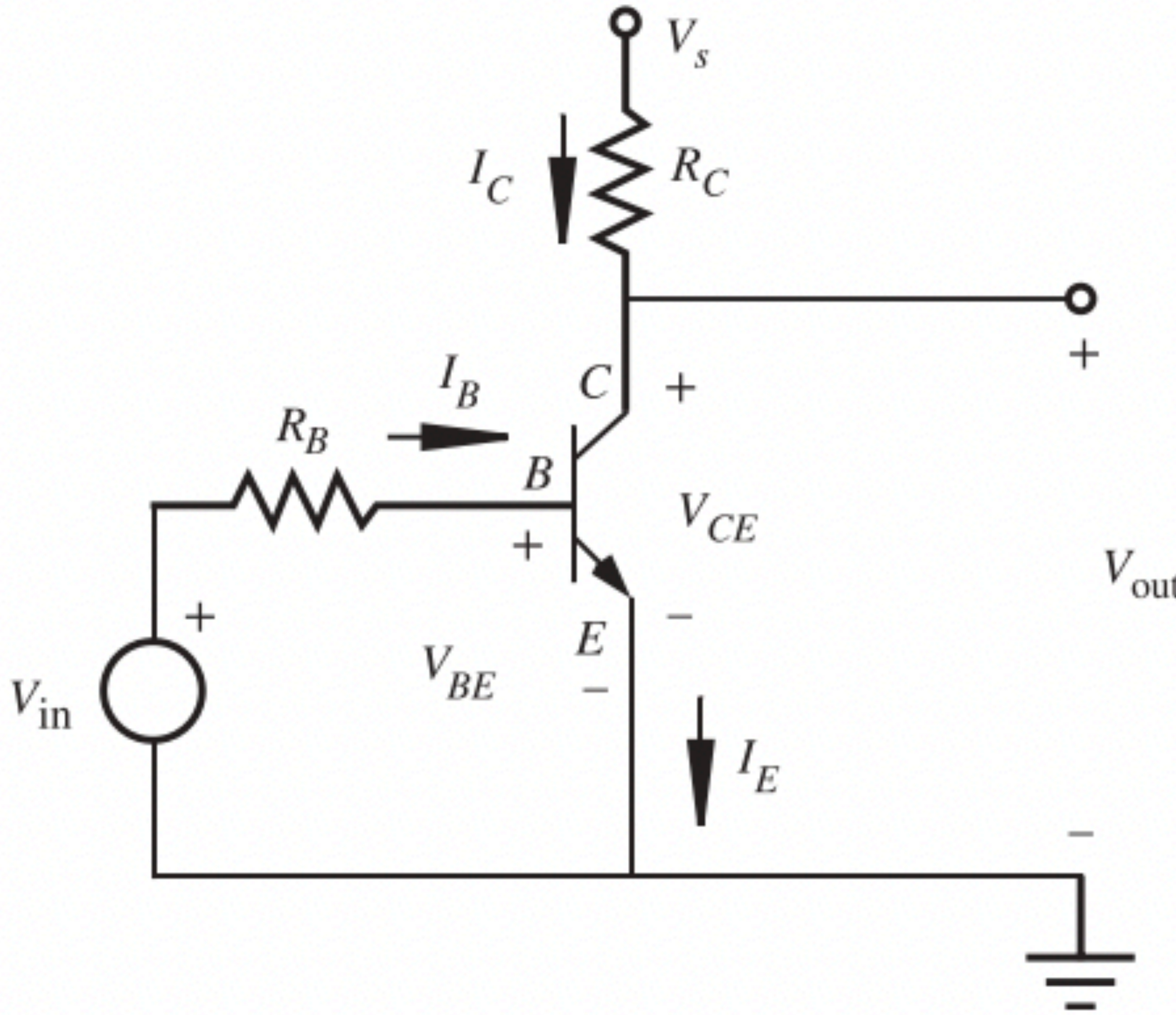
$$I_E = I_C + I_B$$

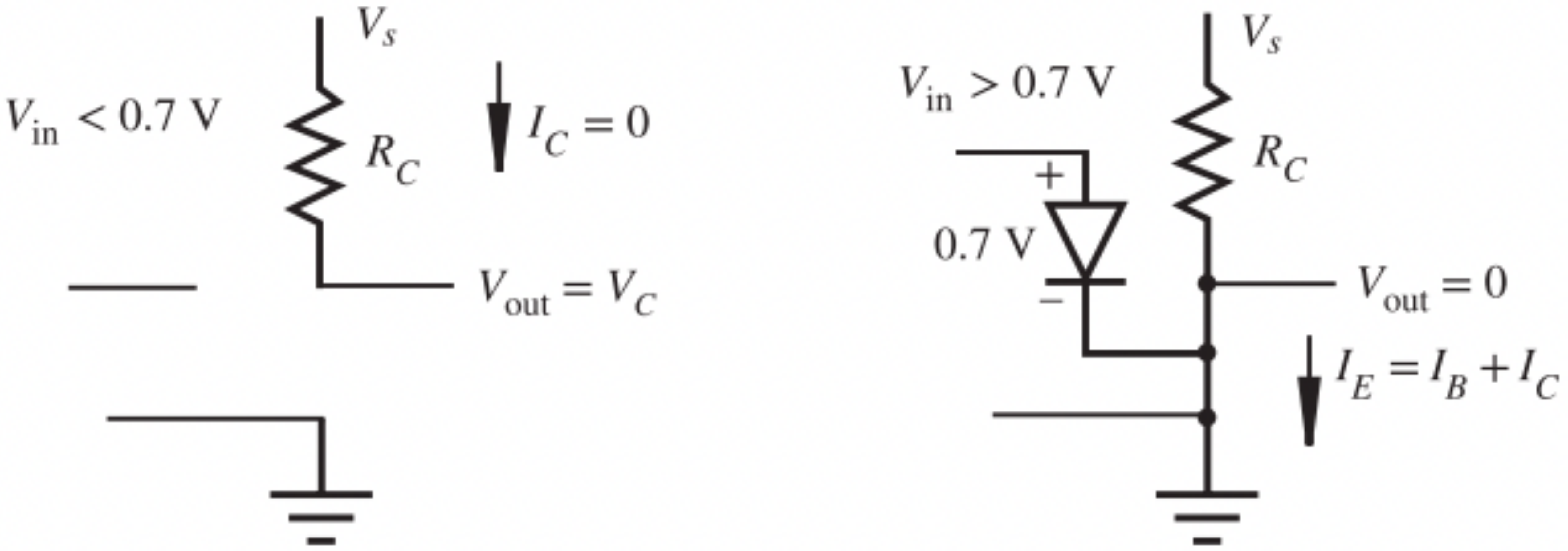
creates a larger voltage across the emitter resistor

$$V_E = I_E R_E$$

this reduces the difference across the collector resistor → no voltage difference, → no current flow

Summary of BJT Switch





(a) OFF (b) ON

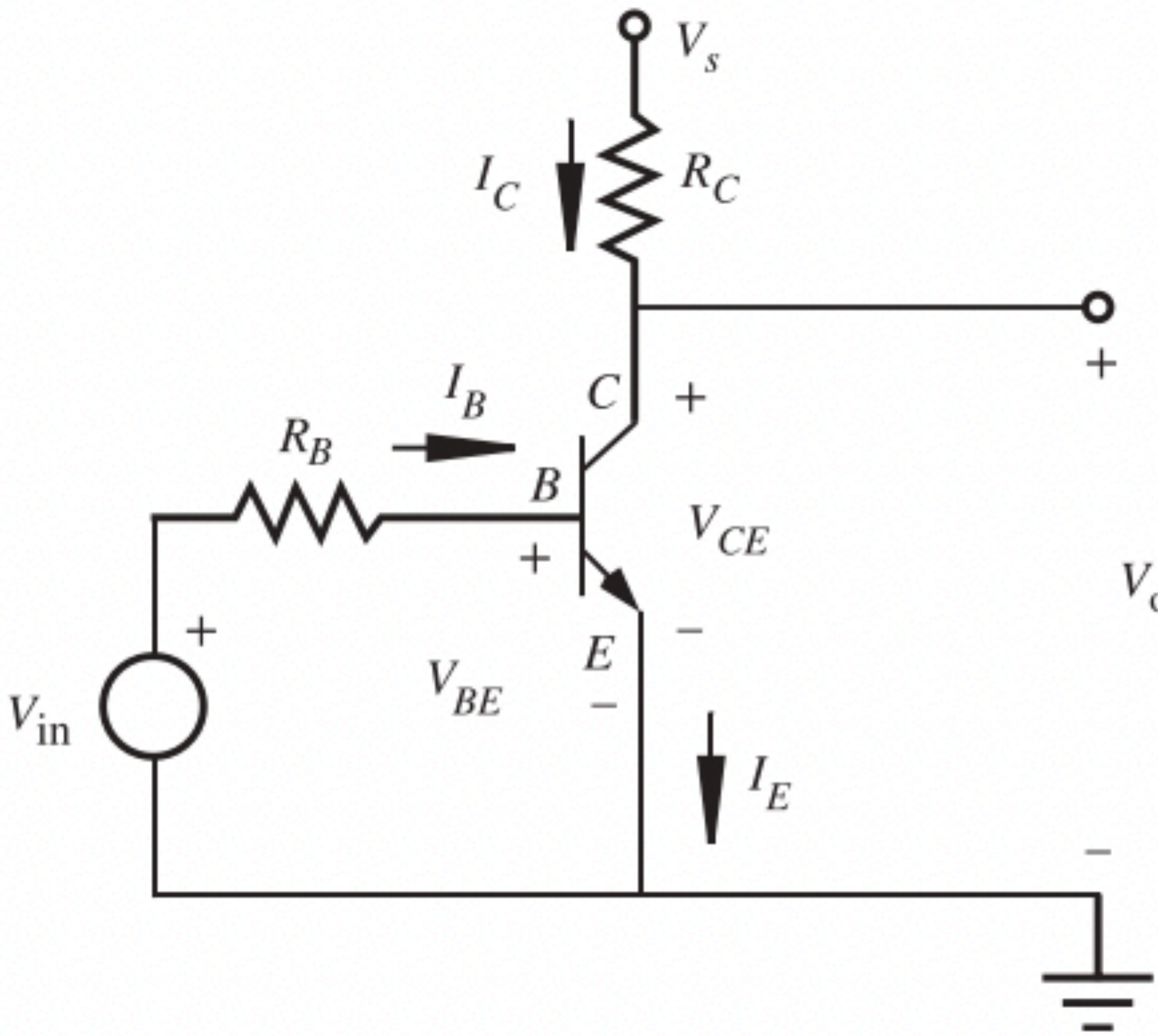
For typical mechatronic applications the common emitter configuration is more appropriate because it is easier to ensure saturation → max current flow

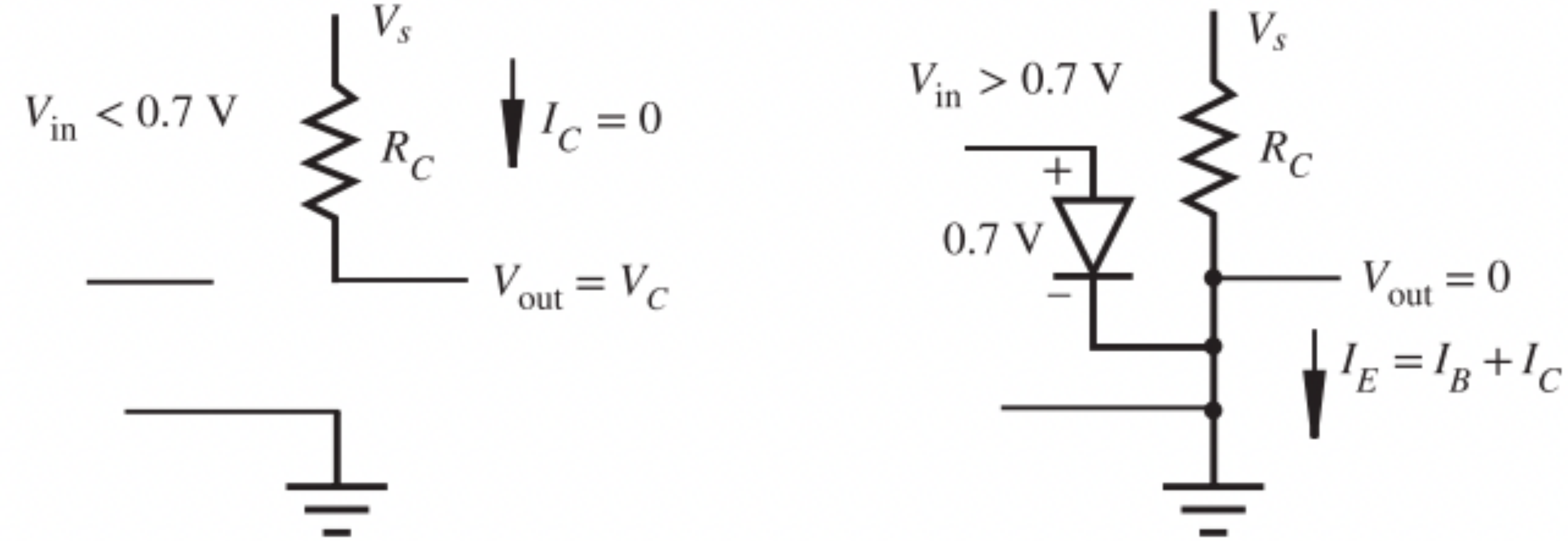
Rb is required

$$I_B = (V_{in} - V_B)/R_B \qquad I_C = (V_s - V_C)/R_C$$

$$V_B = V_{BE} = 0.7\text{ V} \qquad V_C = V_{out} = 0.2\text{V}$$

Summary of BJT Switch





(a) OFF (b) ON

① $V_C > V_B > V_E$

collector must be more positive than base & emitter

② To turn on $V_{BE} > 0.7$ V

③ I_C is independent of I_B, iff saturation!

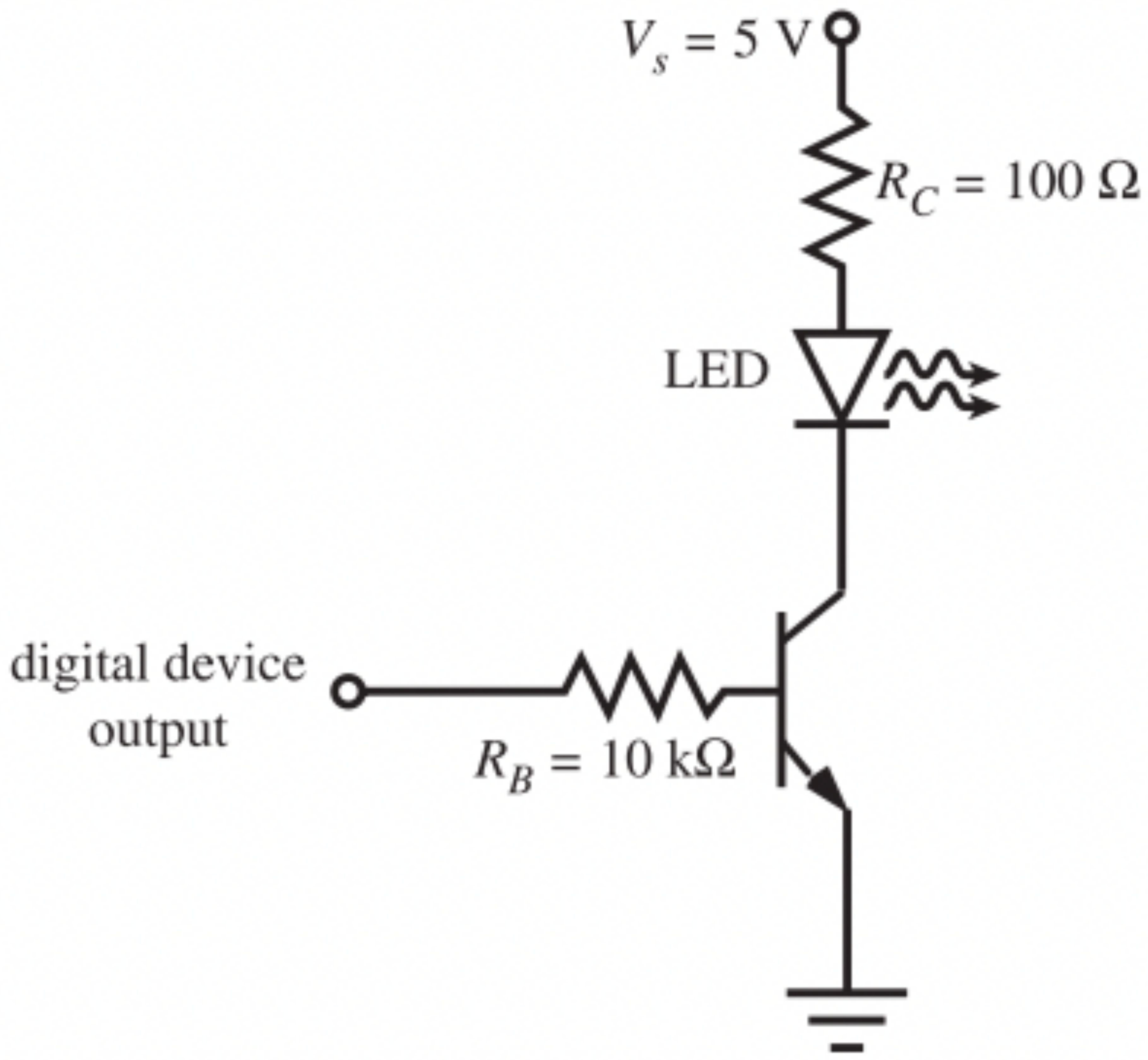
Rb is required

$$I_B = (V_{in} - V_B)/R_B \qquad I_C = (V_s - V_C)/R_C$$

$$V_B = V_{BE} = 0.7 \text{ V} \qquad V_C = V_{out} = 0.2\text{V}$$

④ Minimum base current I_B for saturation can be estimated $I_{B_{min}} \approx I_C/\beta$ $I_B = 10 \cdot I_{B_{min}}$

BJT Switch Applications



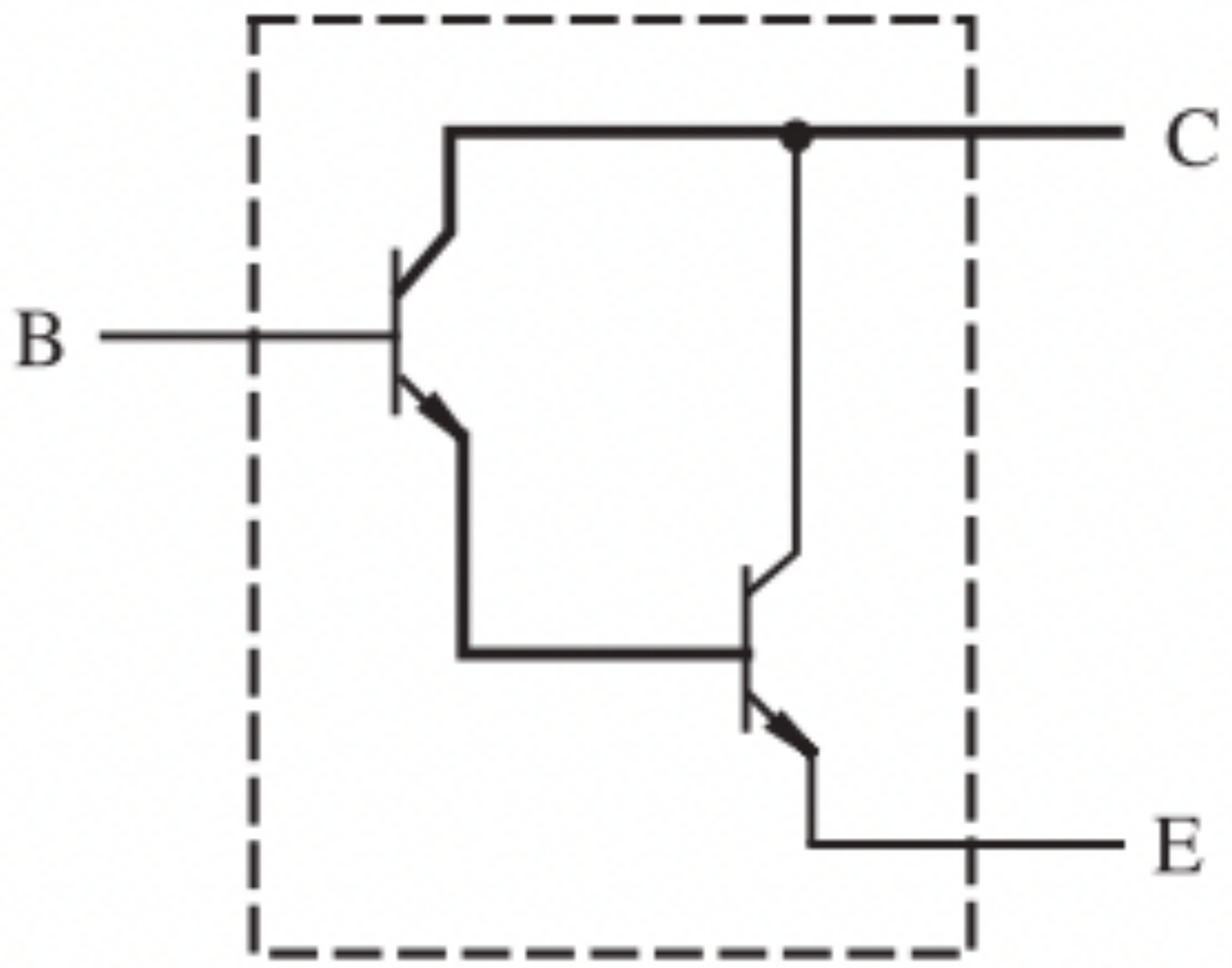
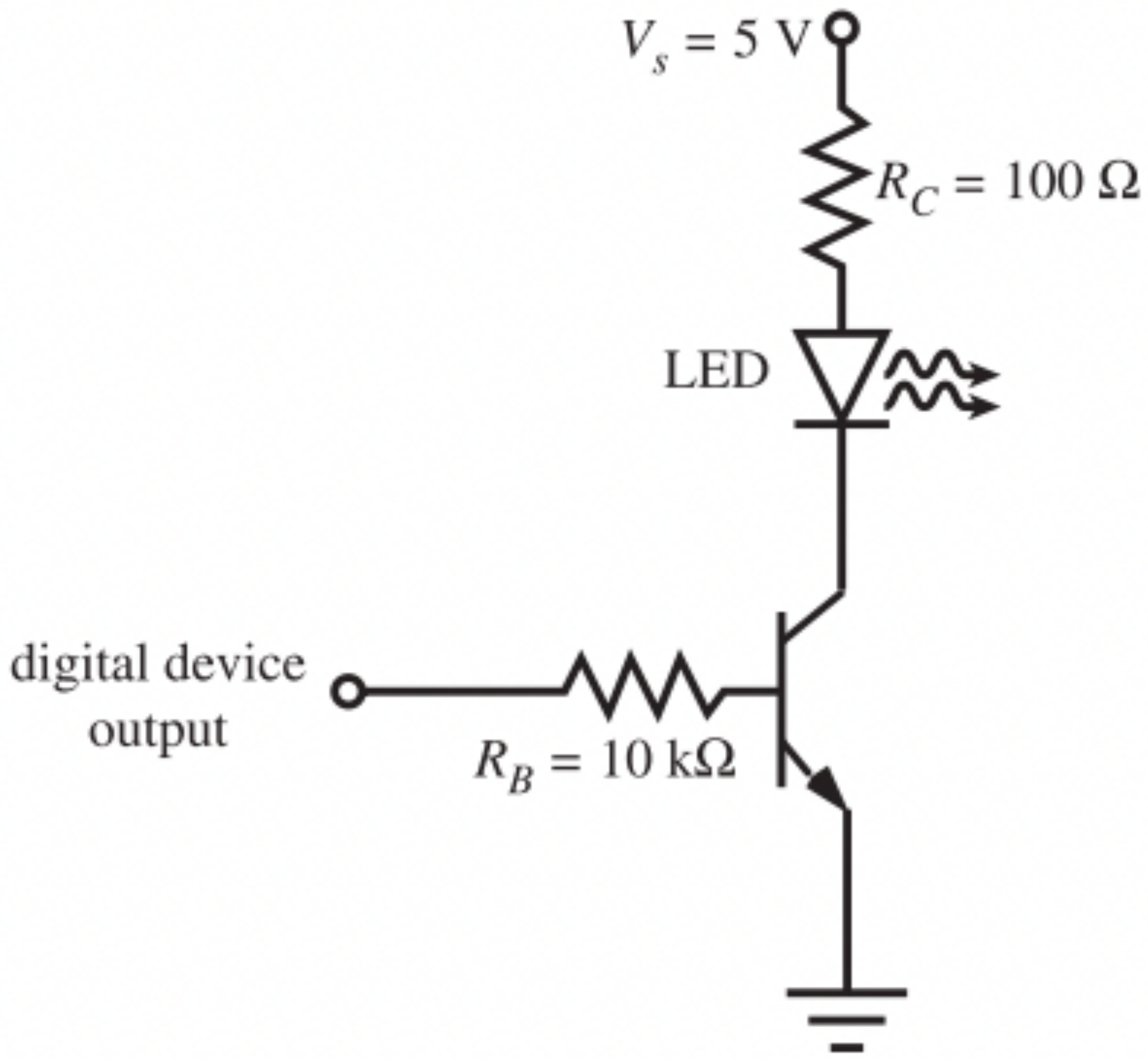


Figure 3.30 Darlington pair.

Current gain ~ 10000

BJT Switch Applications



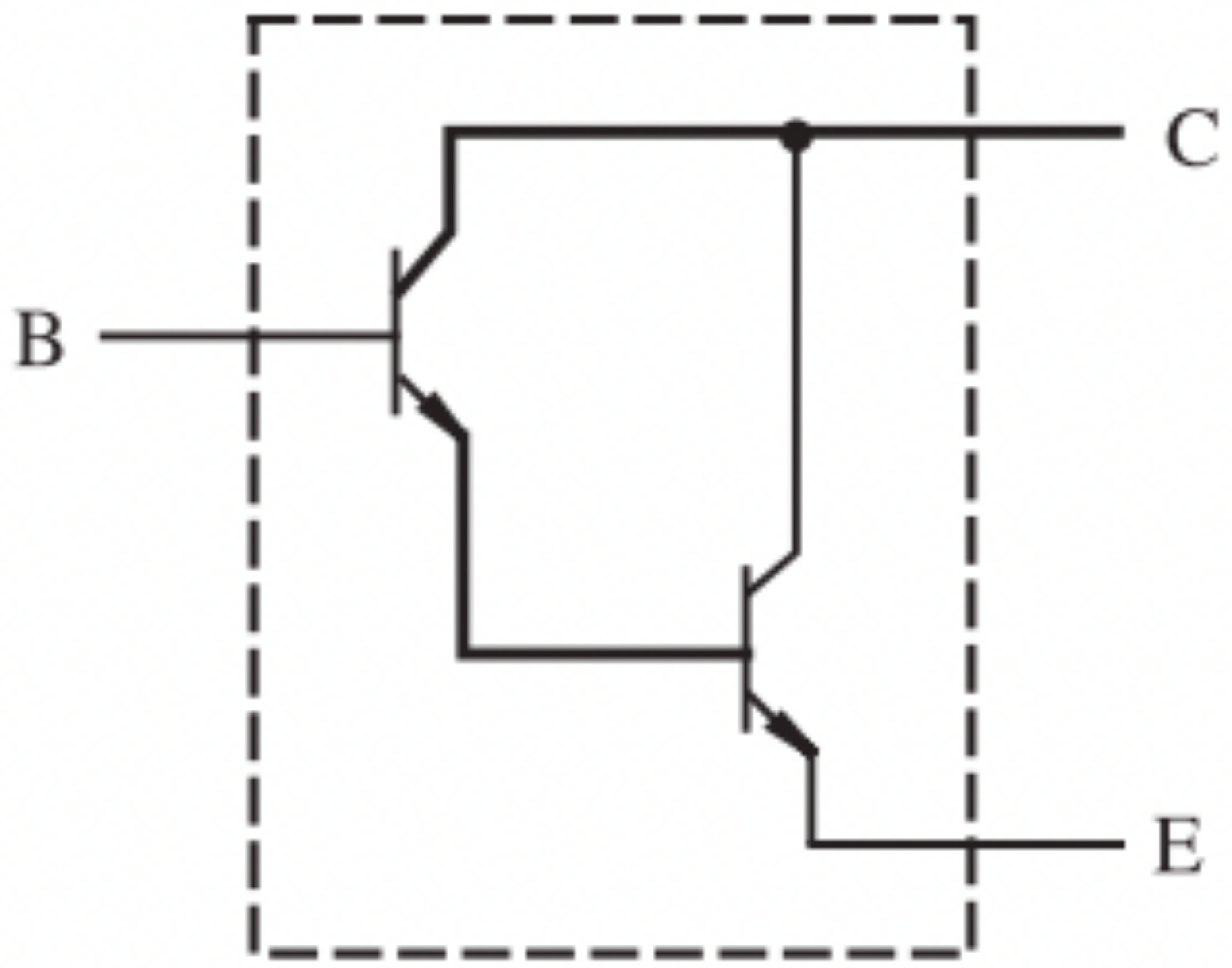


Figure 3.30 Darlington pair.

Current gain ~ 10000

BJT Switch Applications

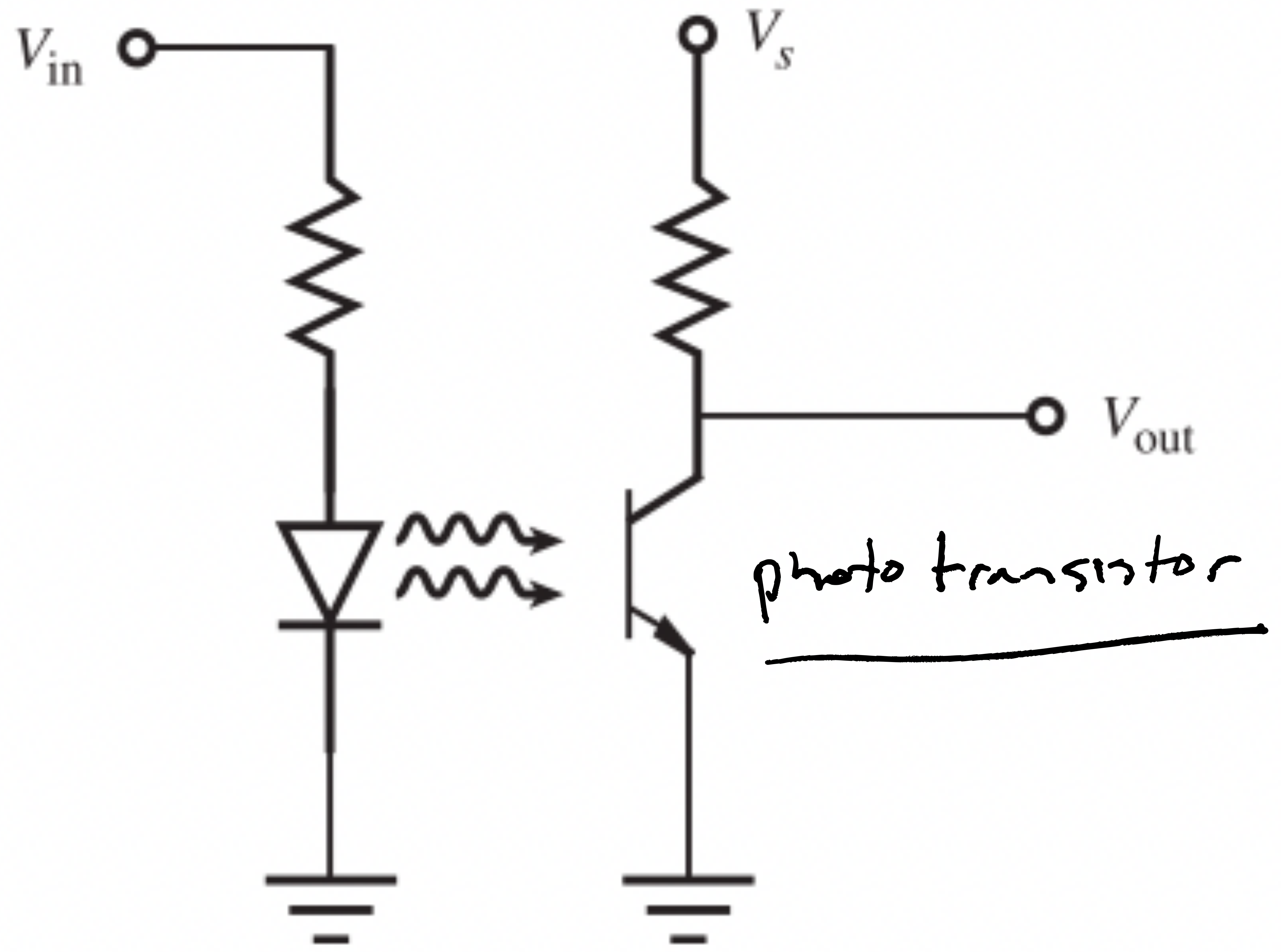
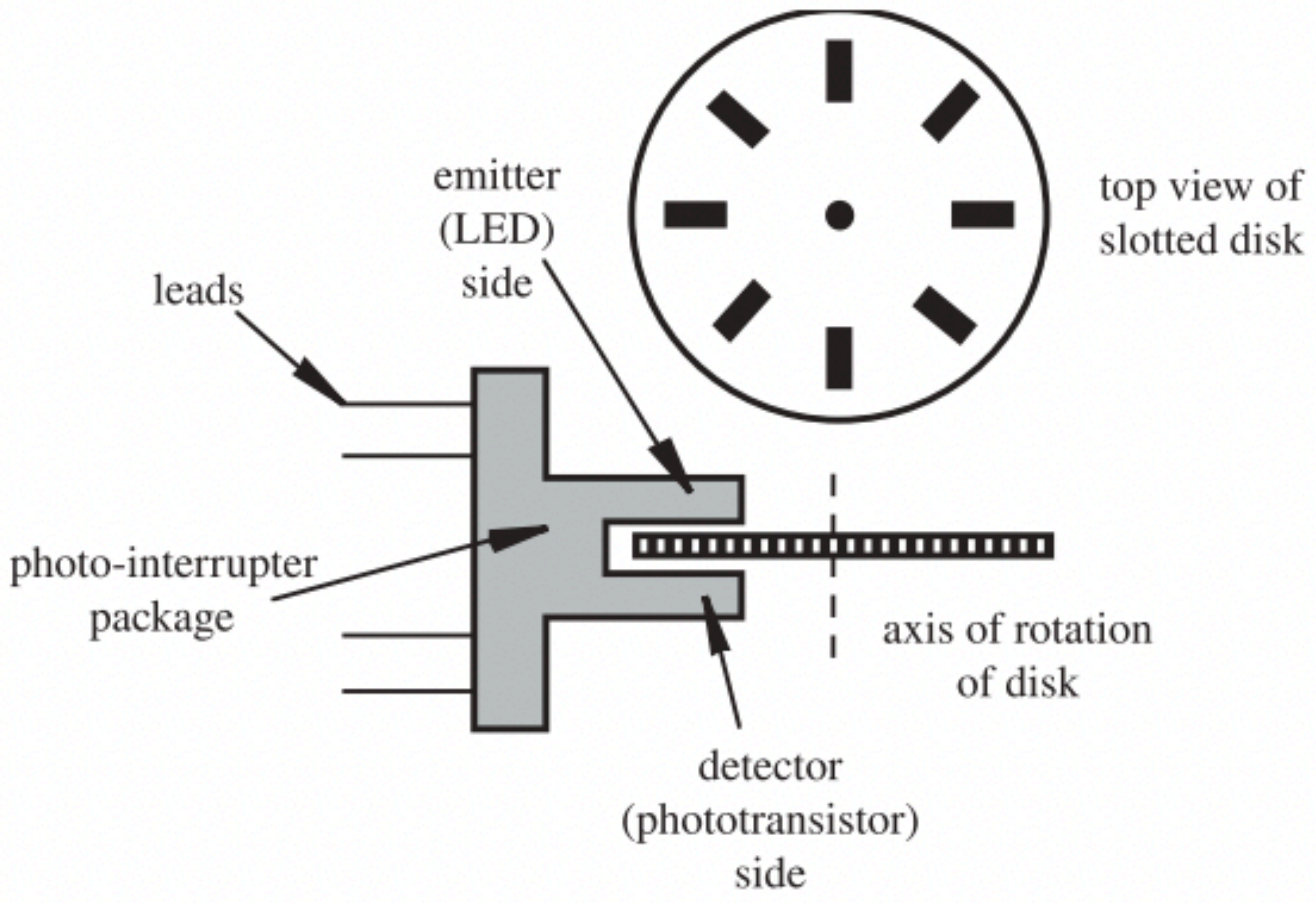


Figure 3.31 Optoisolator.



Types of optoisolators

Device type[note 5]	Source of light[7]	Sensor type[7]	Speed	Current transfer ratio
Resistive opto-isolator (Vactrol)	Incandescent light bulb	CdS or CdSe photoresistor (LDR)	Very low	<100%[note 6]
	Neon lamp		Low	
	GaAs infrared LED		Low	
Diode opto-isolator	GaAs infrared LED	Silicon photodiode	Highest	0.1–0.2%[22]
Transistor opto-isolator	GaAs infrared LED	Bipolar silicon phototransistor	Medium	2–120%[22]
		Darlington phototransistor	Medium	100–600%[22]
Opto-isolated SCR	GaAs infrared LED	Silicon-controlled rectifier	Low to medium	>100%[23]
Opto-isolated triac	GaAs infrared LED	TRIAC	Low to medium	Very high
Solid-state relay	Stack of GaAs infrared LEDs	Stack of photodiodes driving a pair of MOSFETs or an IGBT	Low to high[note 7]	Practically unlimited

BJT Packages

Field Effect Transistor (FET)

- Basic idea:

  voltage on one electrode controls charge carriers in a "channel"

- channel: narrow region where current flows

- transconductance amplifier

  → output current is controlled by input voltage

(BJT is current-to-current amplifier
FET is voltage controlled current amplifier)

Flavors

enhancement / depletion mode metal oxide semiconductor (MOSFET)

Junction FET

Enhancement mode

→ off $V_g = 0$

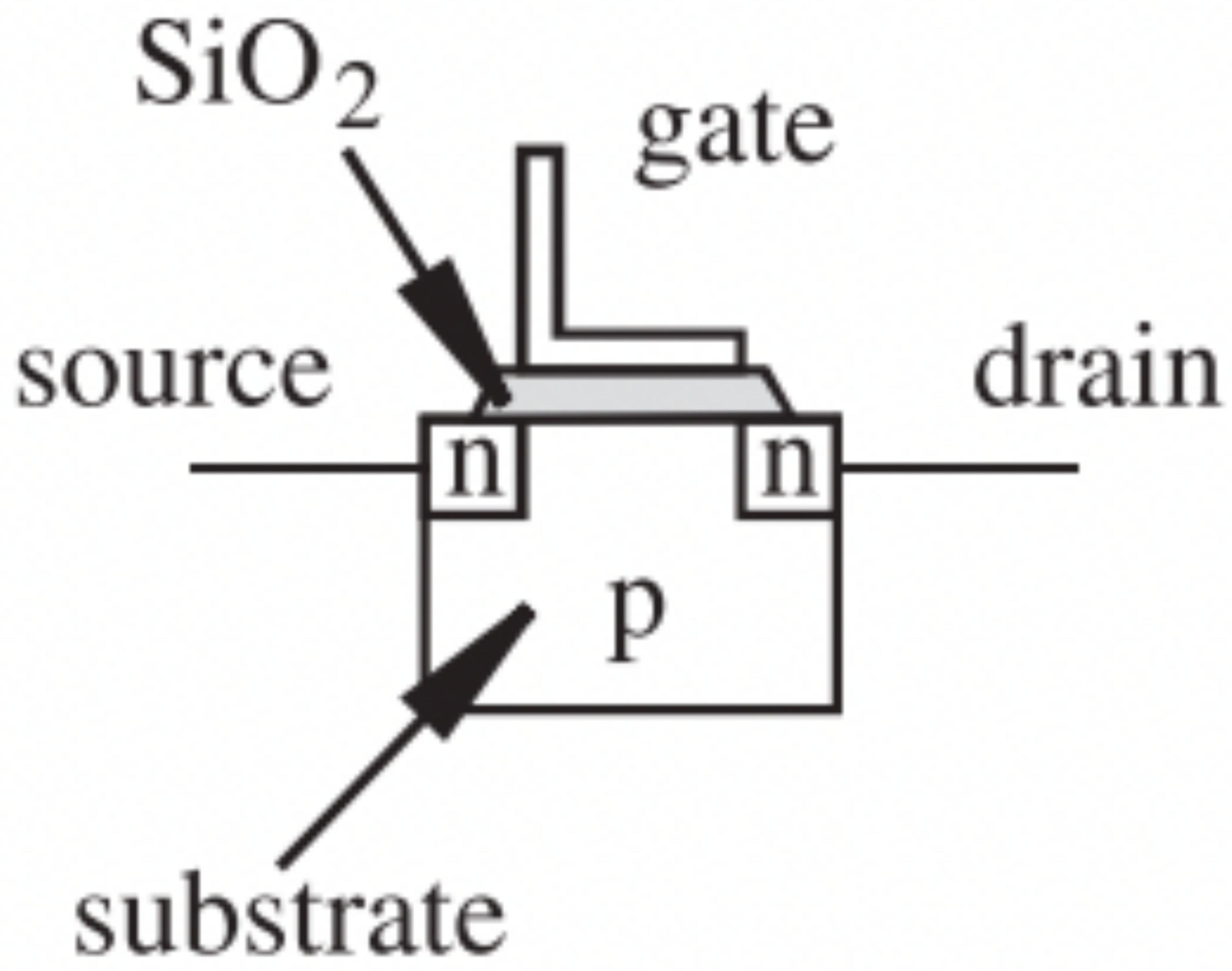
Depletion mode

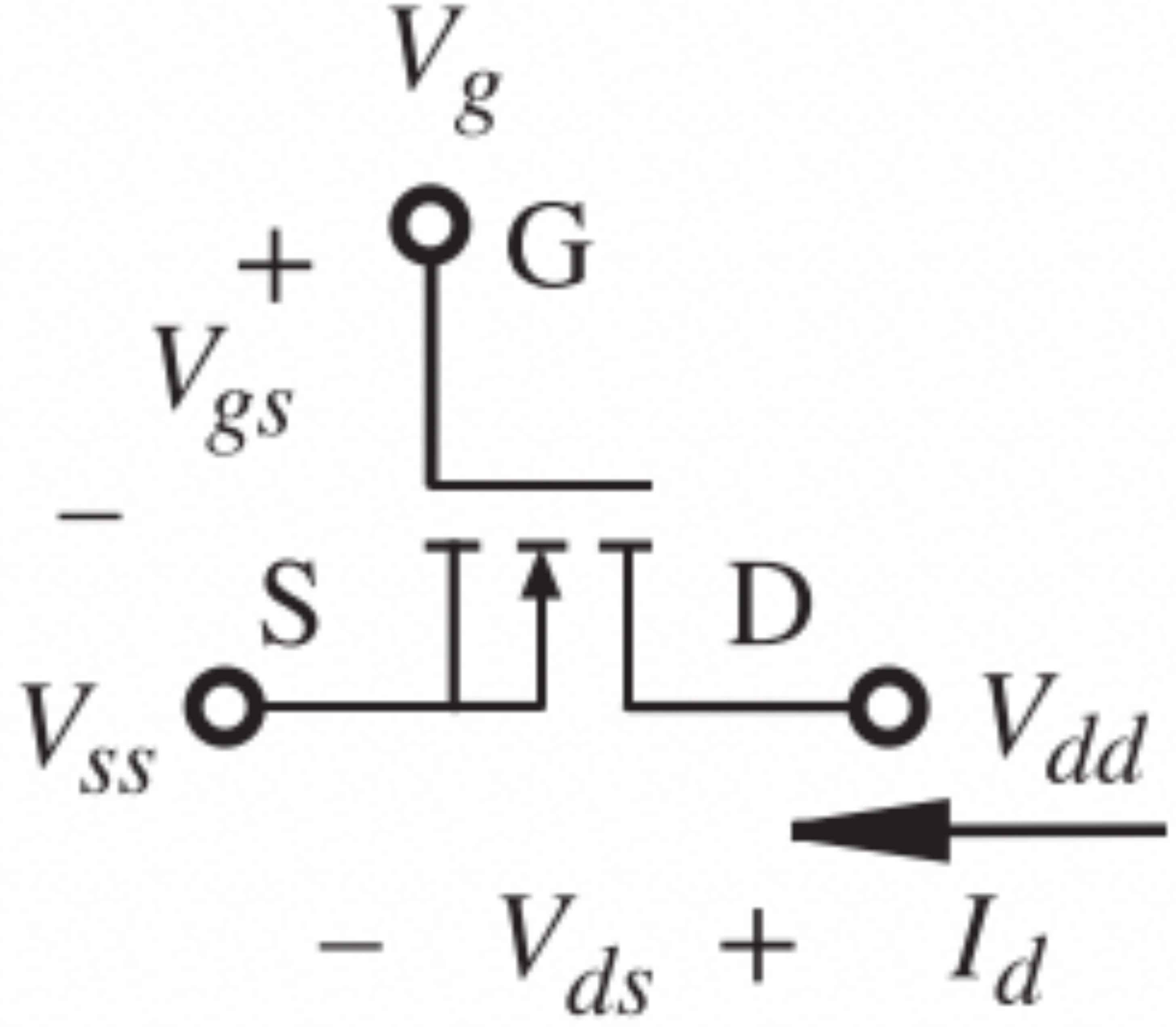
→ on $V_g = 0$

JFET are Depl. mode

Application dependent

Field Effect Transistor (FET)

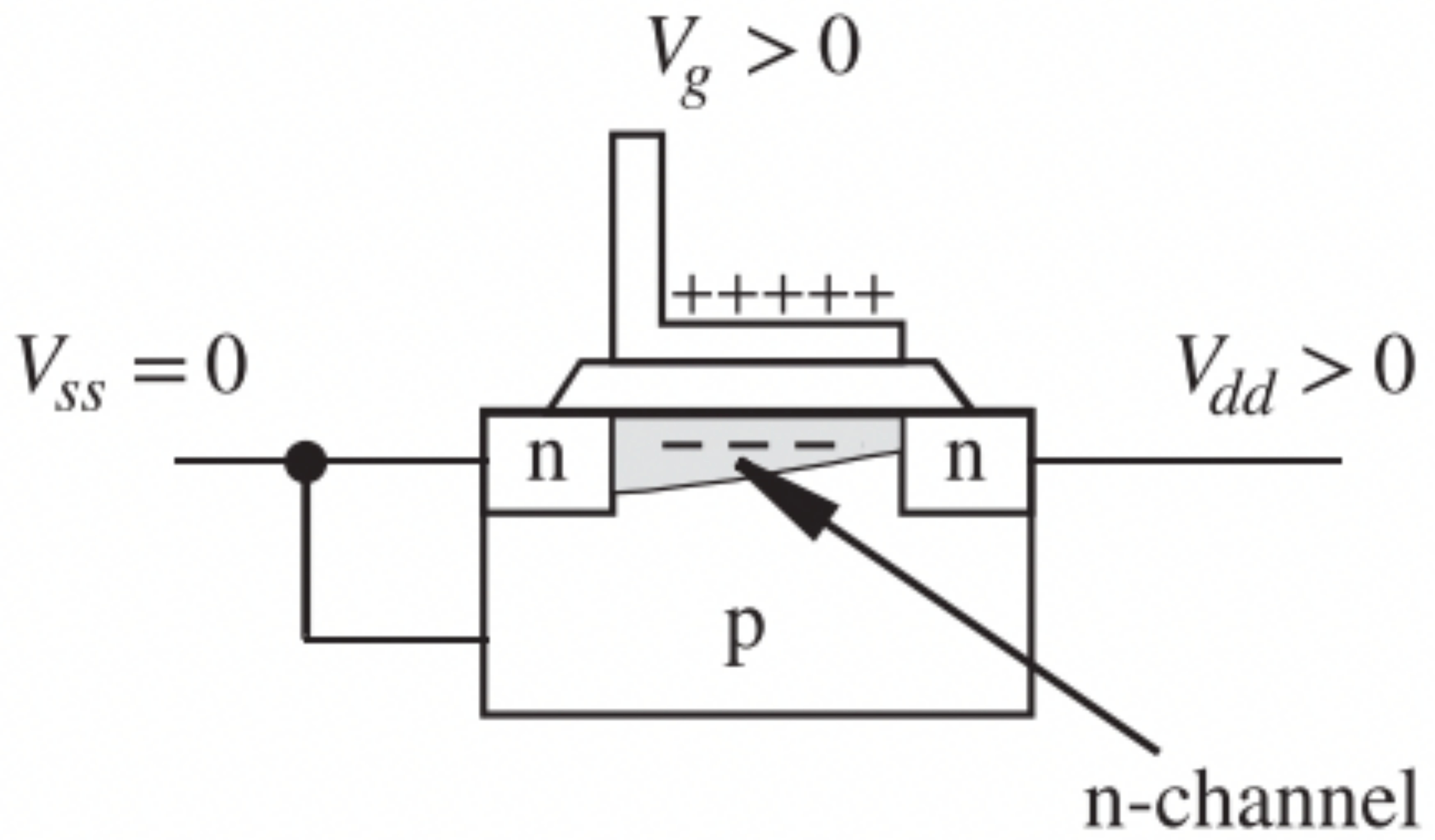




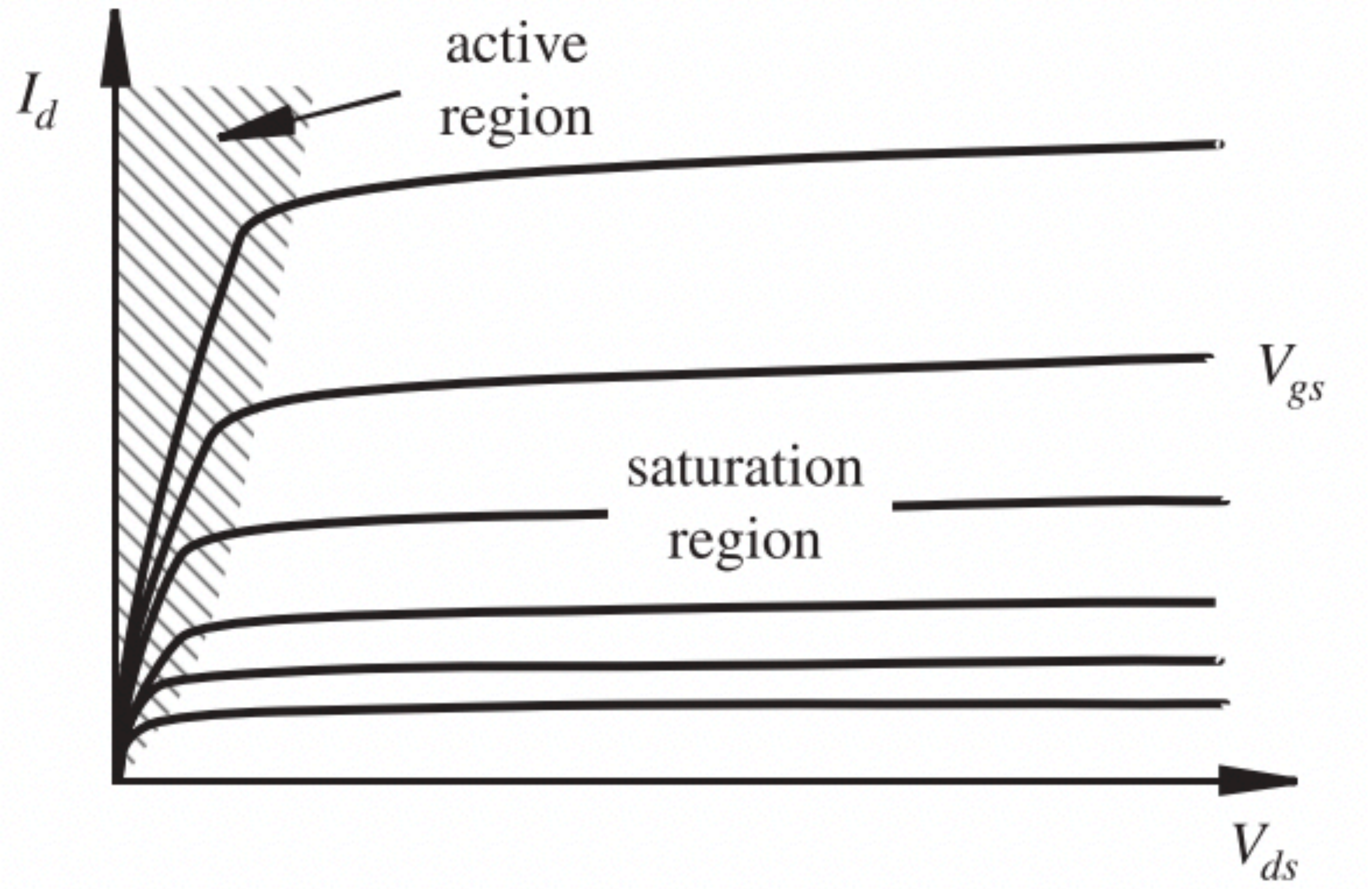
n - channel

G - gate (base BJT)
D - drain (collector)
S - source (emitter)

Field Effect Transistor (FET)



n-Channel enhancement-mode MOSFET characteristic curves



Active Region
(Ohmic Region)
Variable Resistor

Saturation
current nearly constant

amp, high-freq

What's good with MOSFETs?

> High-current voltage controlled switch

> analog switches (gates)

> motor drives

> operate @ much lower input current than BJT

→ less power, less heat

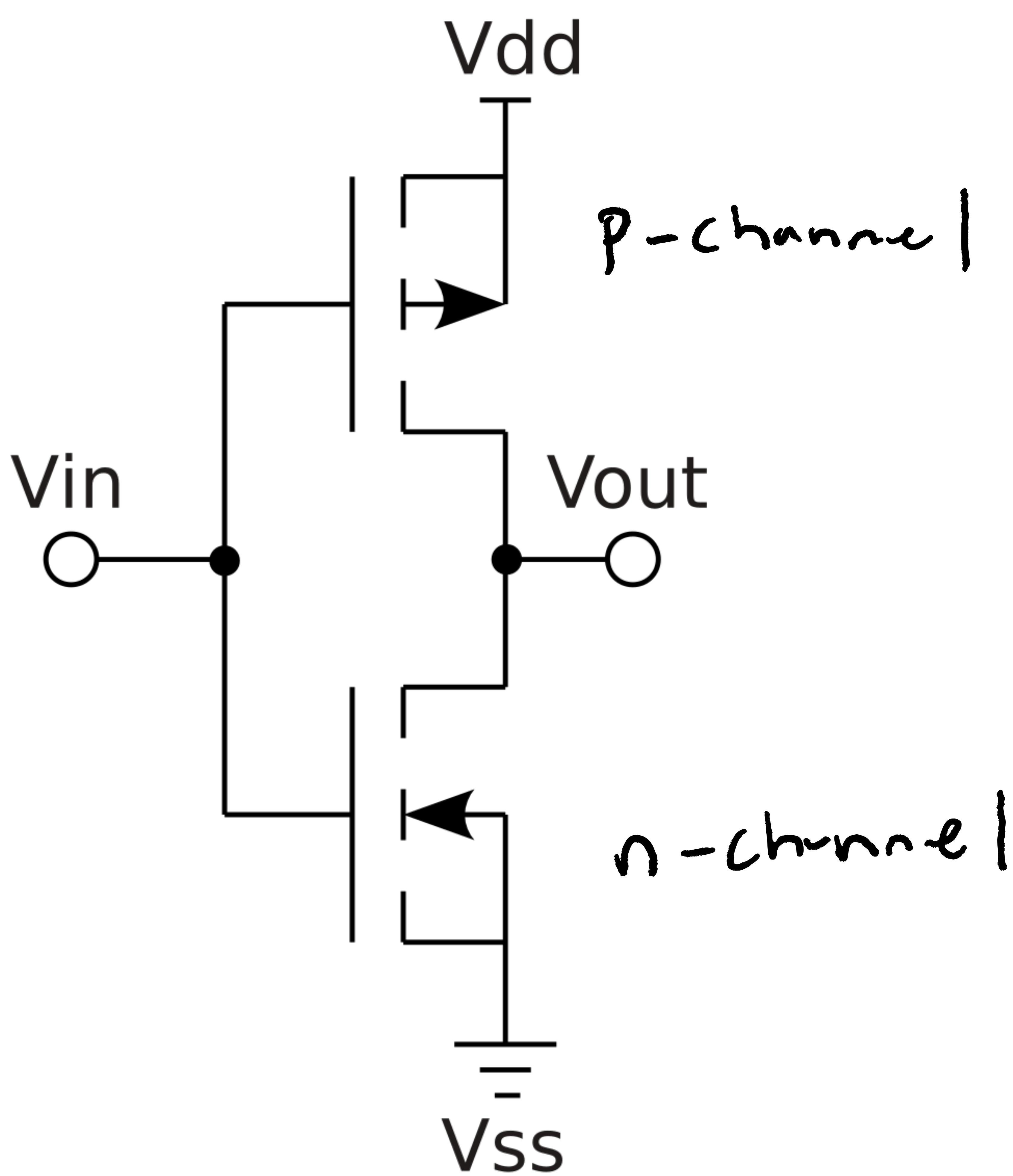
> most common transistor in Integrated circuits (CPU, etc)

> Can be fabricated extremely small, and in complementary pair (n-channel & p-channel)

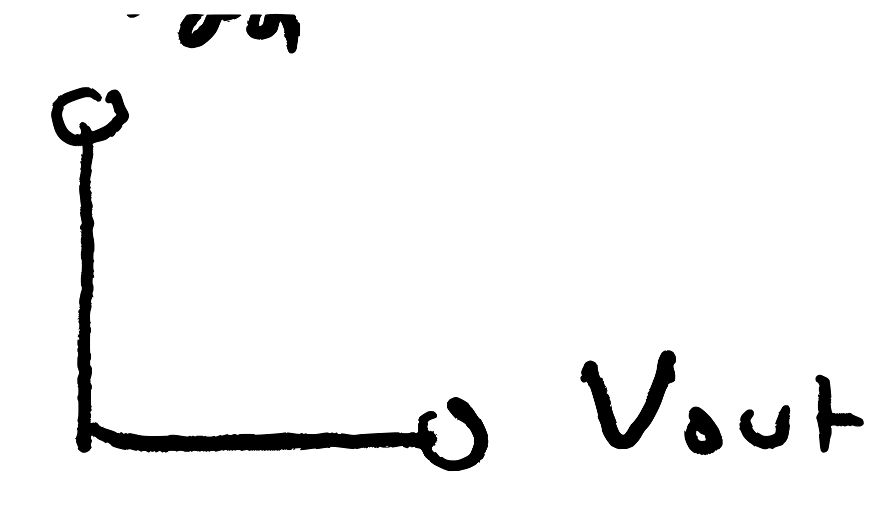
→ CMOS

→ symmetry allow for extreme compact fab

CMOS Teaser - Inverter



$V_{in} \approx 0V$

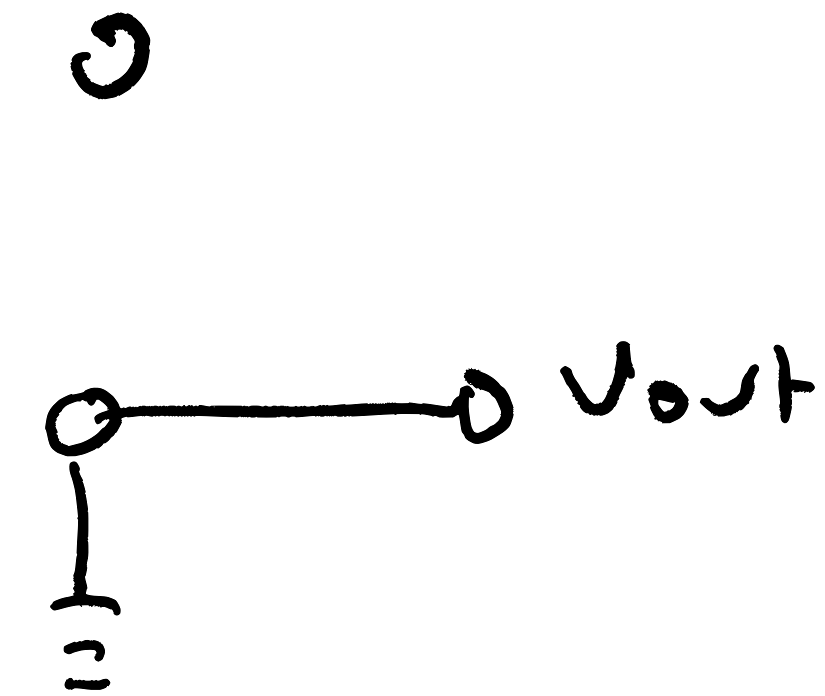


$V_{out} = Vdd$

(High logic)

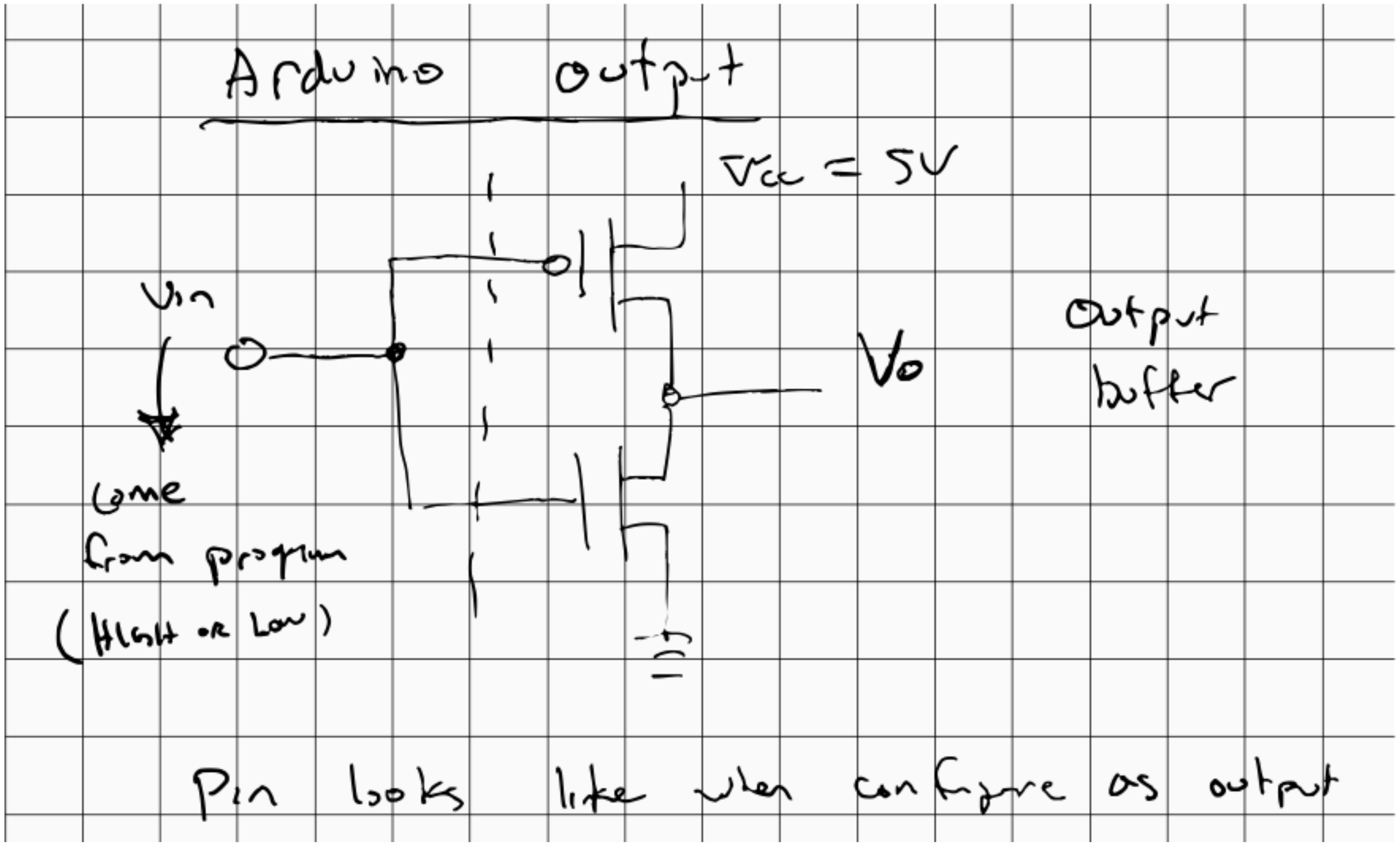
$V_{in} \approx Vdd$

$V_{out} = 0$



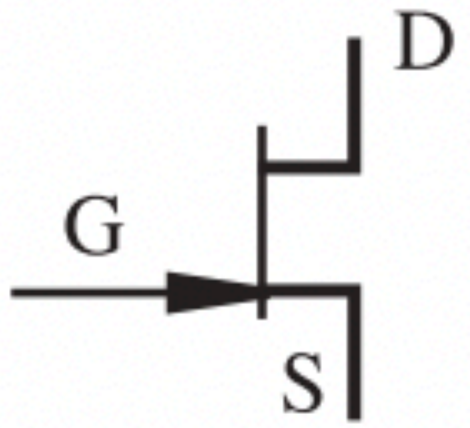
(Low logic)

Arduino output pins use CMOS architecture

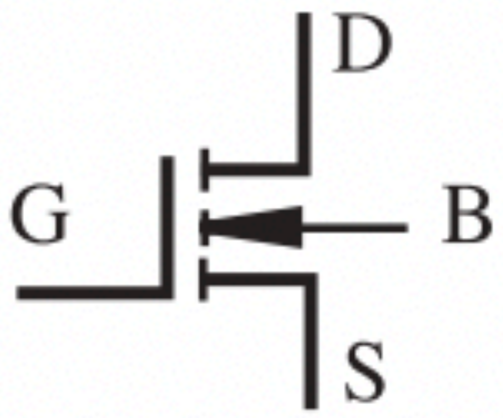


- power efficient
- actively driven in both direction
- very little power to hold state
- most important: easy to fabricate

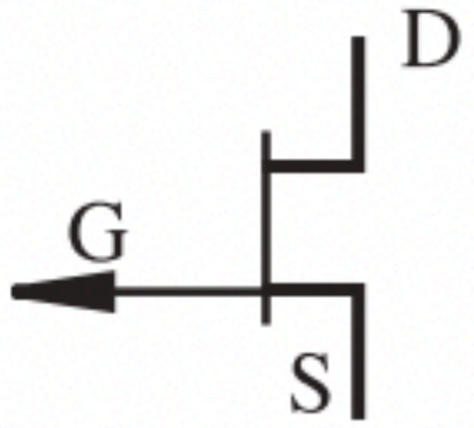
FET Symbols



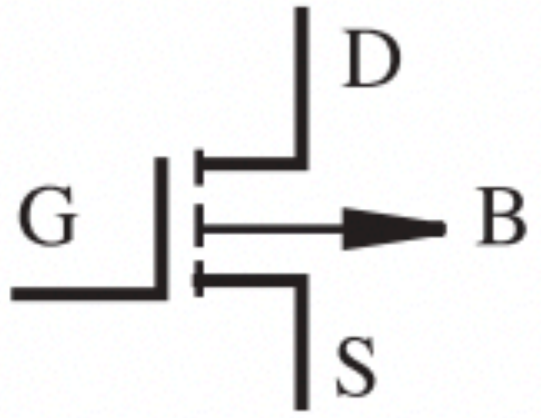
n-channel depletion-mode JFET



n-channel enhancement-mode MOSFET



p-channel depletion-mode JFET



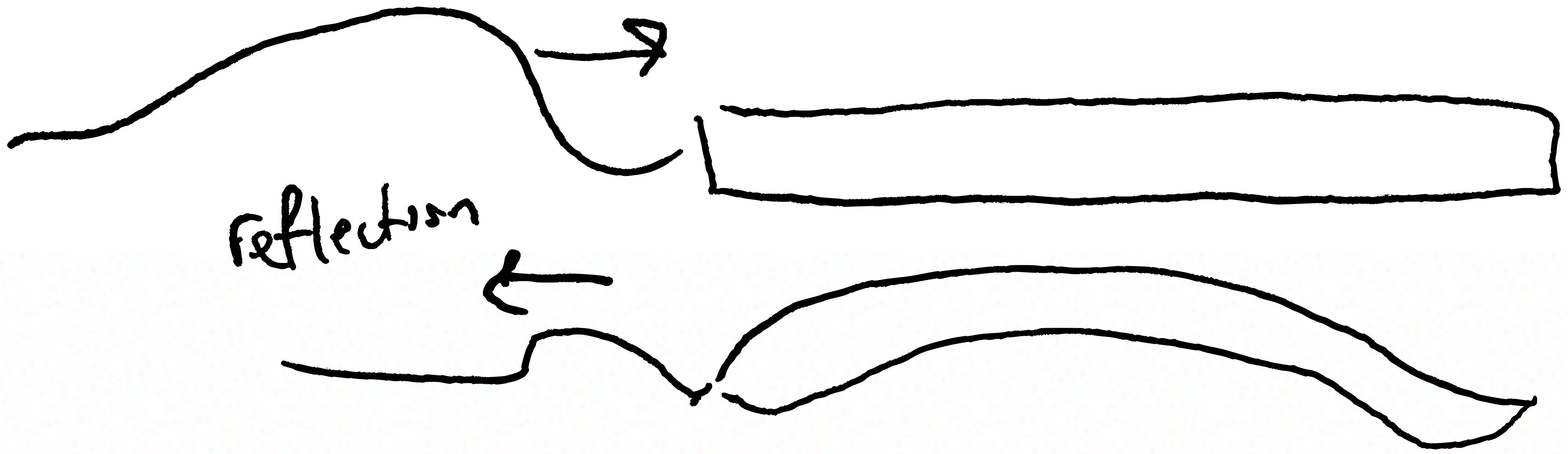
p-channel enhancement-mode MOSFET

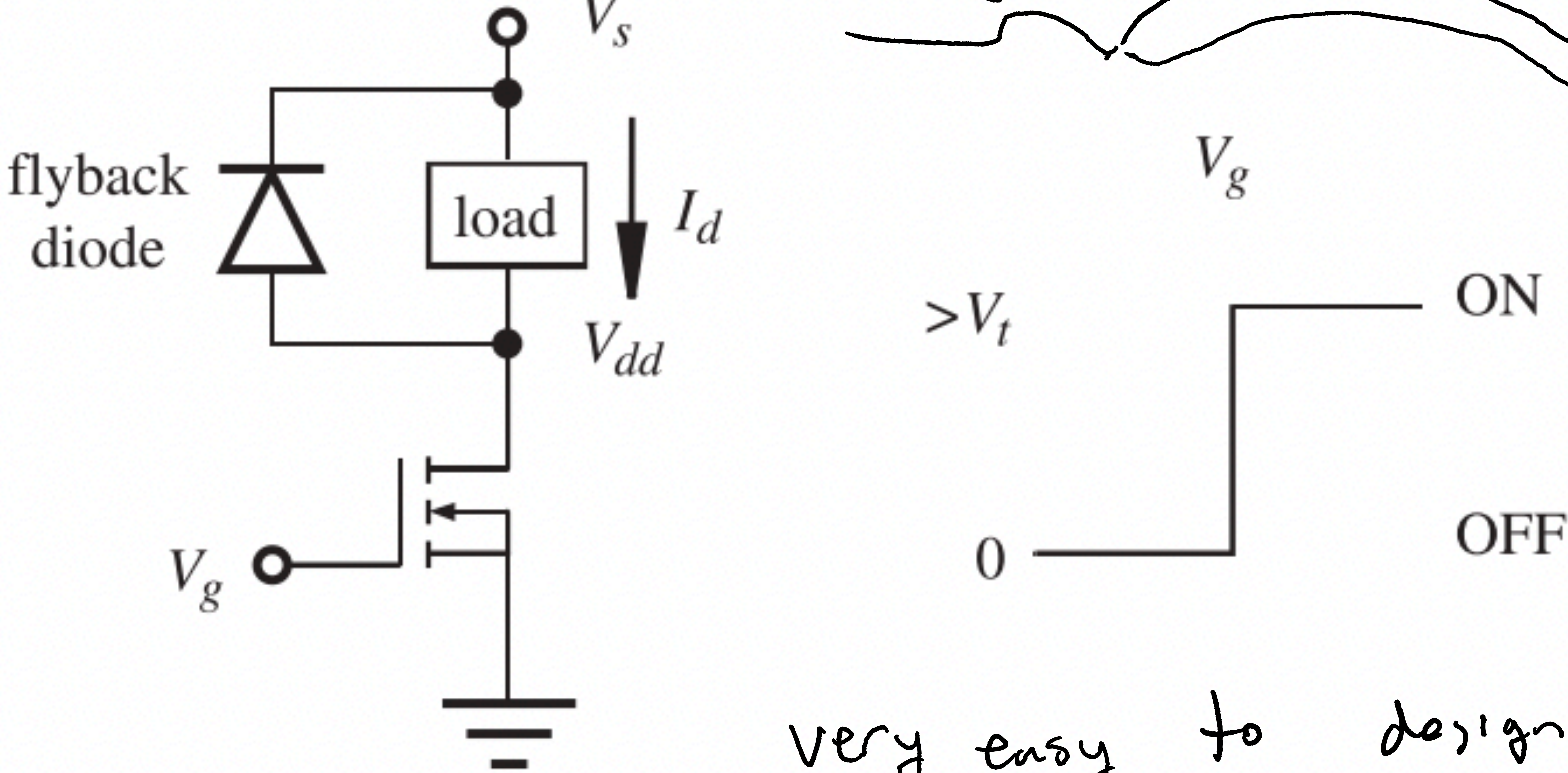
1. The direction of the arrow distinguishes between n- or p-channel

2. A seperation between gate & source is for MosFET

3. A broken line indicates enhancement-mode

FET Power Switch



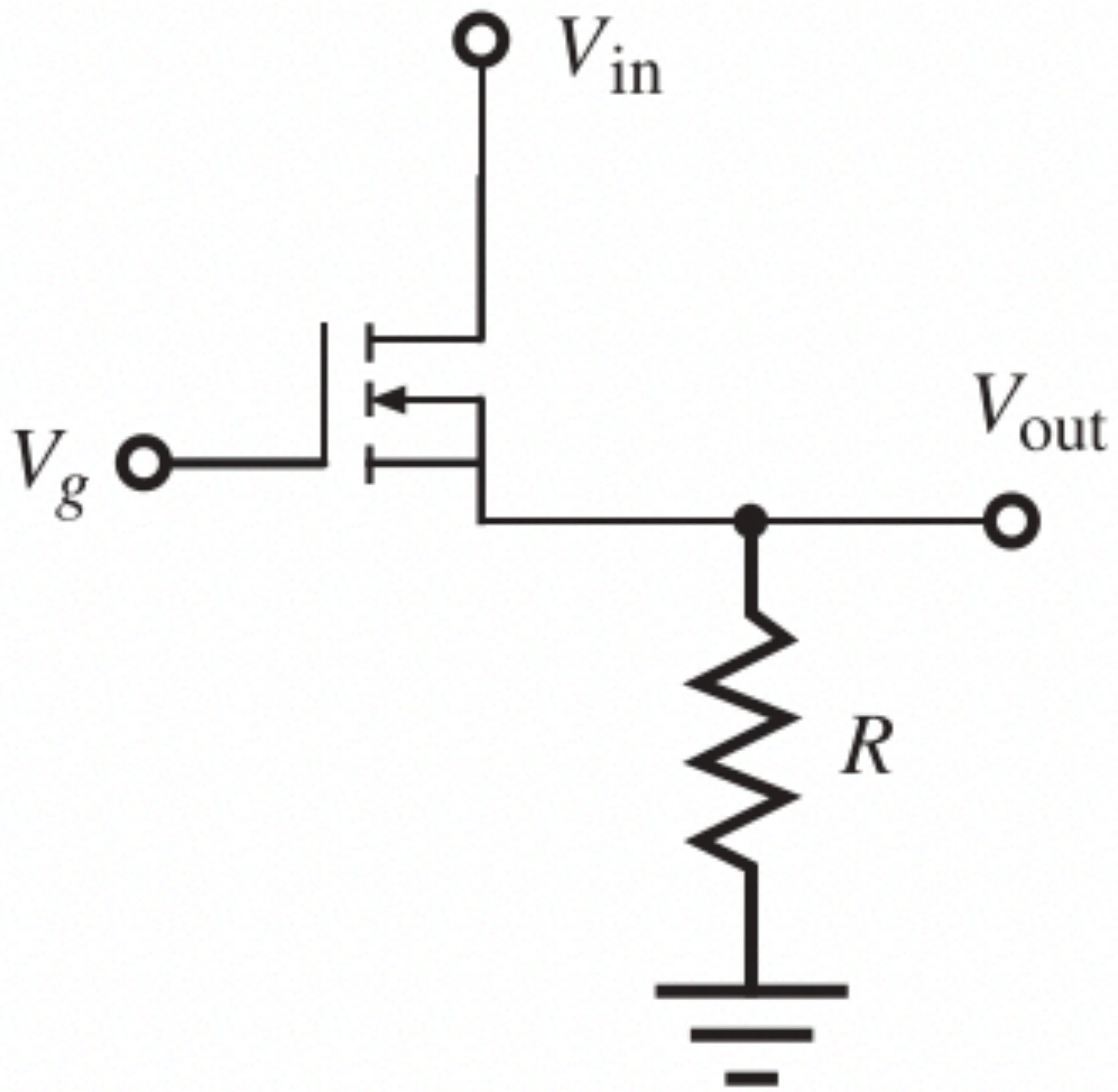


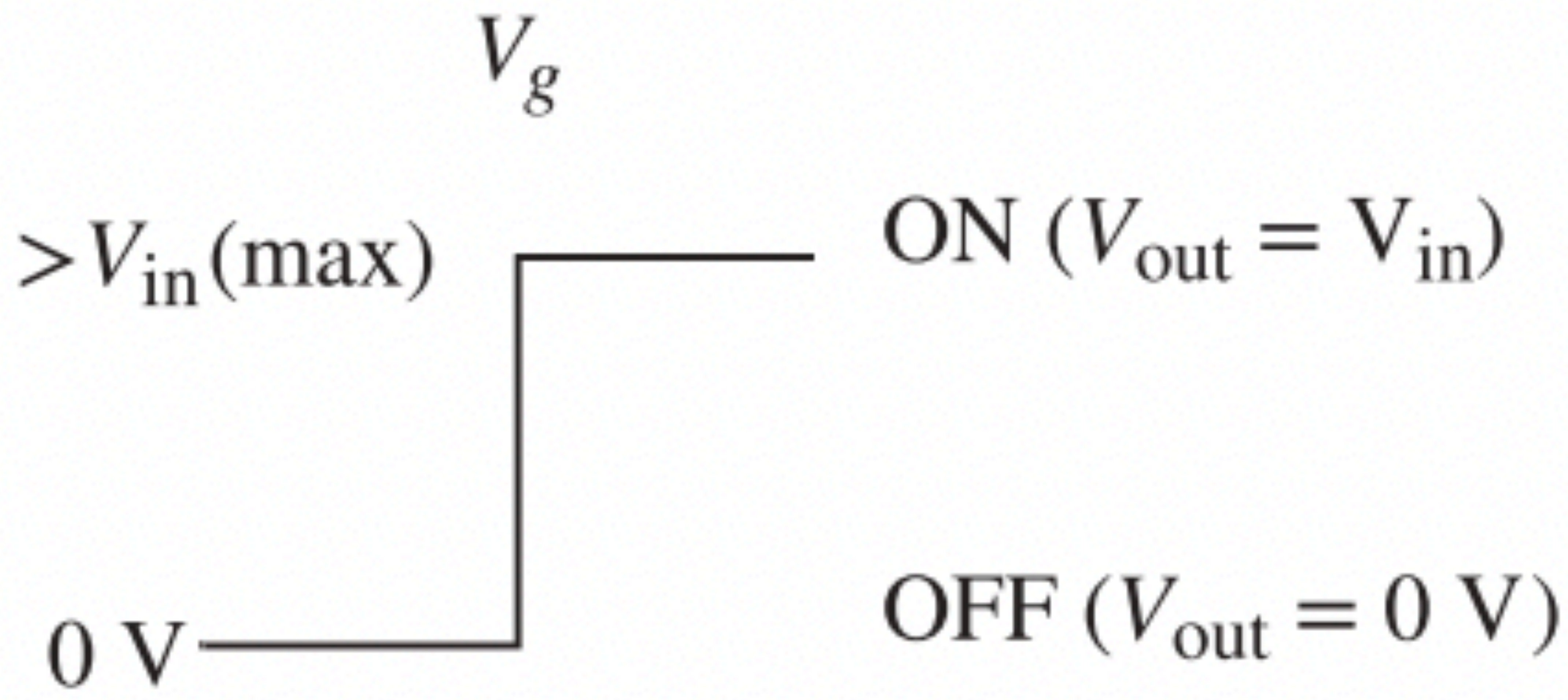
very easy to design!

practically no gate current (high input impedance)

Major design concern: Id – load current → how to size MOSFET

FET Analog Switch





Pull-down resistor → ensure $V_{out} \to 0$, when transistor is off.

Summary BJT vs FET

Control

BJT: current controlled

FET: voltage controlled

Gain

BJT: larger current gain

FET: gain small

Size

BJT: large compared FET

FET: very tiny (Moore's Law)