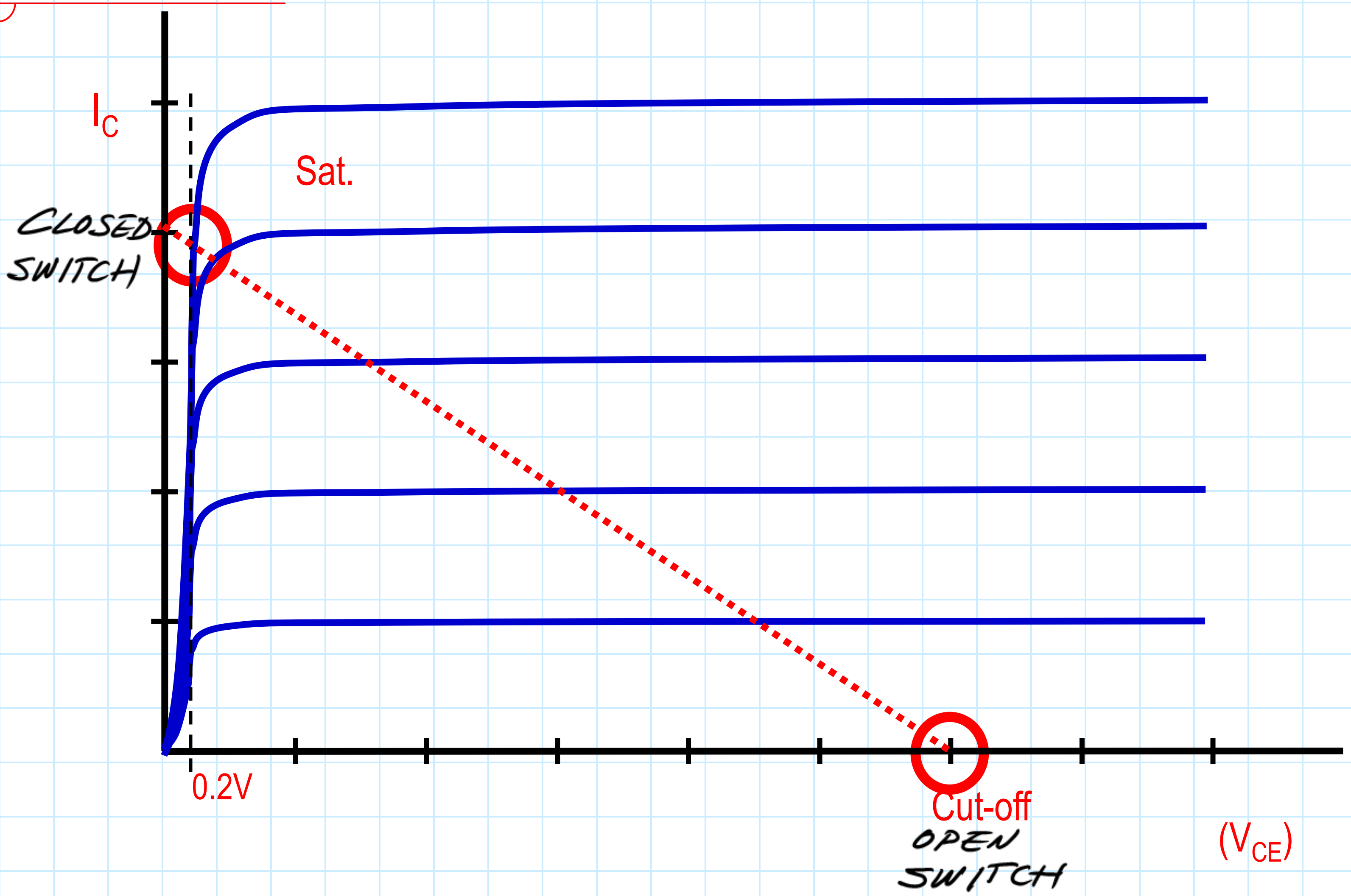
1.8 The BJT in switching mode (1)

- Transistors operate either cut-off (OFF) or saturated (fully ON) :
  - Two very different states
  - Minimum power consumption
  - Very suitable for digital circuits

- The collector and emitter form the switch terminals and the base is the switch handle (control).

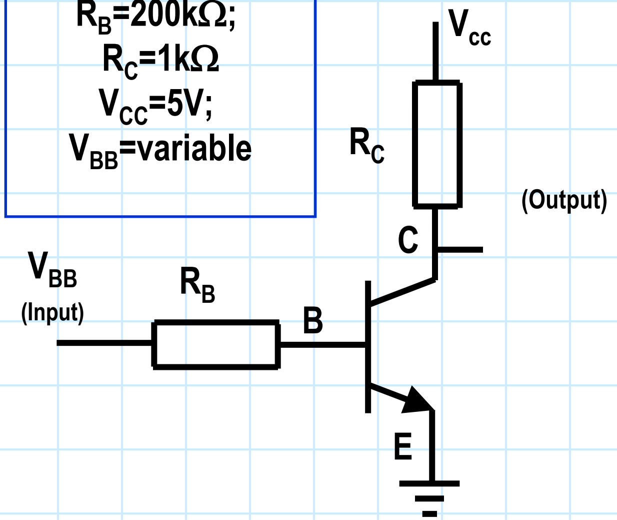
- In other words, the small base current can be used to control a much larger current between the collector and emitter.

1.8 The BJT in switching mode (&2)



1.9 Transistor-based logic gates : The inverter

Data: β=500
R_B=200kΩ;
R_C=1kΩ
V_{CC}=5V;
V_{BB}=variable



Let V_{BB} be a voltage source switching between 0 and 5V, the output will be:

- In the OFF state:

  if $V_{BB} = 0$; $I_C = 0$; V_C= 5V (BJT is OFF)

  - $P = I_C * V_{CE} = 0$

- In the full ON state:

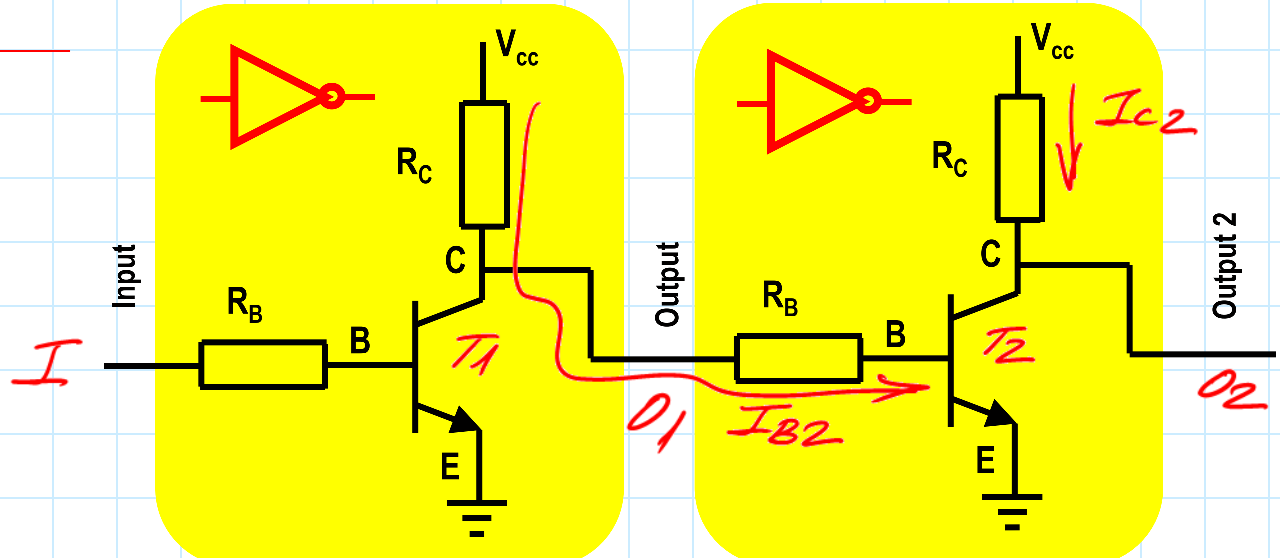
  if $V_{BB} = 5V$; $V_o \sim 0$ $(V_o = V_{CE(SAT)} = 0.2V)$

  (provided that BJT is SAT)

  - $P = I_C * V_{CE} \sim 0$

    as V_{CE} is almost 0 so the power is very small

1.9 Transistor-based logic gates

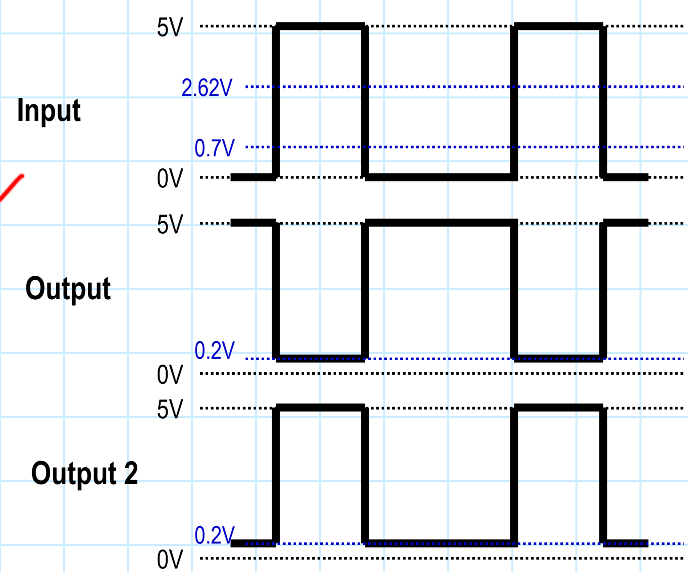


$I = 0$

T_1 OFF, $V_{CE_1} = V_{cc} \Rightarrow$

T_2 ON; $V_{O2} = V_{CE_2} \simeq 0V$

$\Rightarrow O_2 = 0$



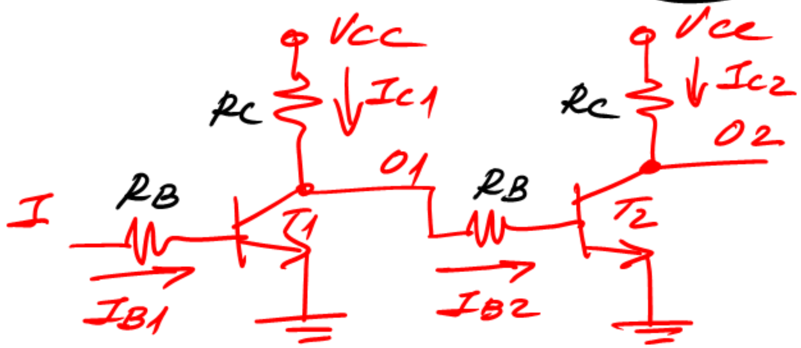
$I = 1$

T_1 ON $\Rightarrow V_{O1} \simeq 0V \Rightarrow$

T_2 OFF $\Rightarrow V_{O2} = V_{cc}$

$\Rightarrow O_2 = 1$

In more depth : $I=0$



T_1 $\quad V_I < V_{BE(ON)} \Rightarrow \underline{T_1\ OFF}$

$I_{C1}=0 \Rightarrow V_{O1}=V_{CE1}=V_{CC}$

$I_{B1}=0$

$\boxed{I=0 \Rightarrow O_1=1}$

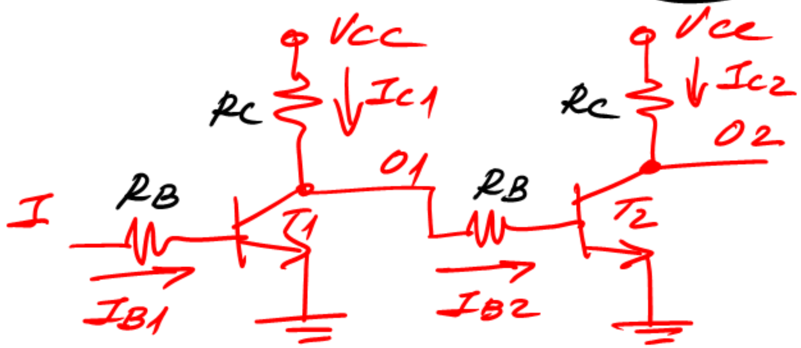
T_2 $\quad V_{O1}=V_{CC}>V_{BE(ON)} \Rightarrow \underline{T_2\ ON}$

$I_{B2}>0$; $I_{C2}>0$, $I_{C2}<\beta I_{B2}$ (R_C and R_B, β) specially chosen to put T_2 in saturation)

$\Rightarrow V_{O2}=V_{CE2}=V_{CE(SAT)}=0.2V \Rightarrow$

$\boxed{O_1=1 \Rightarrow O_2=0}$

In more depth : $I=1$



T1 $V_I > V_{BE(ON)} \Rightarrow \underline{T_1\ ON}$

$I_{B1} > 0$; $I_{C1} < \beta I_{B1}$ (R_{C}, R_{B1}, β) chosen for saturating

$T_1 \Rightarrow V_{O1} = V_{C1} = V_{CE(SAT)} = 0.2V$

$\boxed{I = 1 \Rightarrow O_1 = 0}$

T2 $V_{O1} = 0.2V < V_{BE(ON)} \Rightarrow \underline{T_2\ OFF}$

$I_{B2} = I_{C2} = 0mA$; $V_{O2} = V_{CE_2} = V_{CC} \Rightarrow$

$\boxed{O_1 = 0 \Rightarrow O_2 = 1}$

Chapter 1. Summary (1)

In this chapter we first reviewed the operation of the PN junction, which we approximated by different models. These approaches have allowed us to simplify the analysis of diode circuits.

Secondly, we introduced some of the most important diode circuits, used in digital systems. As a examples, we described a circuit for input protection of MOSFET, and various circuits implementing digital logic gates.

Subsequently, we described the Schottky diode, which achieves higher speed and lower V□ than the conventional diode, thereby making it particularly important for switching applications.

Similarly, we described the main characteristics of the LEDs, showing some of their application circuits. As an example, we described circuits that allow us to identify the output logic level of digital circuits. We also described another special-purpose diode, such as the photodiode, which achieves the opposite effect that the LED, as soon as it turns a light radiation into an electrical current.

Chapter 1. Summary (and 2)

After studying the diode, we have focused on the BJT transistor, explaining the basis of its operation and its output curves.

Subsequently, we introduced the operating regions of BJT: cut-off when it does not conduct, and linear and saturation regions when it is conducting current. We also introduced the load line, that is dependent on the external components to the transistor, and determines its quiescent point.

Once known the operating regions of BJT, emphasis has been placed in the two regions used in digital applications (cut-off and saturation). Placing the BJT in these regions makes it to operate in switching (digital) mode.

Finally, we have described several transistor-based circuits for digital applications, with examples related to logic gates, as the logic inverter gate.

Appendix: Pspice parameters

Diode and BJT

PSpice parameters for diodes

Parameter Name	Symbol	SPICE Name	Units	Default Value
Saturation current	I_S	IS	A	1.0 E-14
Emission coefficient	n	N	-	1
Series resistance	R_S	RS	Ω	0
Transit time	τ_T	TT	sec	0
Zero-bias junction capacitance	C_{j0}	CJ0	F	0
Grading coefficient	m	M	-	0.5
Junction potential	ϕ_0	VJ	V	1

First Order SPICE diode model parameters.

$$I_D = I_S\left(e^{V_D / \eta V_T} - 1\right)$$

- $\mathbf{I_S}$ = reverse saturation current (negligible)
- $\mathbf{V_J}$ = contact potential, $V_J \approx V_\gamma$ (elbow voltage)
- Device's name for *Schematics*: **Dbreak**
- You can also use a known diode model and modify its parameters

PSpice parameters for BJTs

Parameter Name	Symbol	SPICE Name	Units	Default Value
Transport Saturation Current	I_S	IS	A	1.0E–16
Maximum Forward Current Gain	β_F	BF	–	100
Forward Current-Emission Coefficient	n_F	NF	–	1
Forward Early Voltage	V_{AF}	VAF	V	∞
Maximum Reverse Current Gain	β_R	BR	–	1
Reverse Current-Emission Coefficient	n_R	NR	–	1
Reverse Early Voltage	V_{AR}	VAR	V	∞
Corner for Forward Beta High-Current Roll-off[a]	I_{KF}	IKF	A	∞
be Junction Leakage Saturation Current[a]		ISE	A	1.0E–13
be Junction Leakage Emission Coeff. (low-current condition)[a]		NE	–	1.5
Corner for Reverse Beta High Current Roll-off[a]	I_{KR}	IKR	A	∞
bc junction leakage saturation current[a]		ISC	A	1.0E–13
bc junction leakage emission coeff. (low-current condition)[a]		NC	–	2
Ideal Forward Transit Time	τ_F	TF	sec	0
Ideal Reverse Transit Time	τ_R	TR	sec	0

a. Gummel-Poon Model Parameter

Parameter Name§	Symbol§	SPICE Name§	Units§	Default Value§
Emitter Resistance§	r_E§	RE§	Ω§	0§
Collector Resistance§	r_C§	RC§	Ω§	0§
Zero-Bias Base Resistance§	r_B§	RB§	Ω§	0§
Minimum Base Resistance§	§	RBM§	Ω§	RB§
Current where RB falls halfway to RBM§	§	IRB§	A§	∞§
Zero-Bias be-Junction Capacitance§	C_{be0}§	CJE§	F§	0§
be-Junction Grading Coeff.§	m_{be}§	MJE§	–§	0.33§
be-Junction Built-in Voltage§	ϕ_{be}§	VJE§	V§	0.75§
Zero-Bias bc-Junction Capacitance§	C_{bc0}§	CJC§	F§	0§
bc-Junction Grading Coeff.§	m_{bc}§	MJC§	–§	0.33§
bc-Junction Built-in Voltage§	ϕ_{bc}§	VJC§	V§	0.75§
Zero-Bias Collector-Substrate Cap.§	C_{cs0}§	CJS§	F§	0§
cs-Junction Grading Coeff.§	m_{cs}§	MJS§	–§	0§
cs-Junction Built-in Voltage§	ϕ_{cs}§	VJS§	V§	0.75§

- $\beta_F \approx \beta$ (beta of transistor) (BF)
- $V_{JE} \approx V_{BE(on)}$ (VJE)
- Device's name for *Schematics*: **QbreakN** (NPN), **QbreakP** (PNP)
- You can also use a known BJT model and modify its parameters

Editing parameters in PSpice

- You can modify the Pspice model parameters as follows :
  - **Edit->Model-> Edit Instance Model (Text)**
  - In the text file, change the parameter after the first line and before the "* $" of the end: example of changing β = 500 for a bipolar transistor (default value is 100):

```
.model QbreakN-X5 NPN
BF=500
*$
```