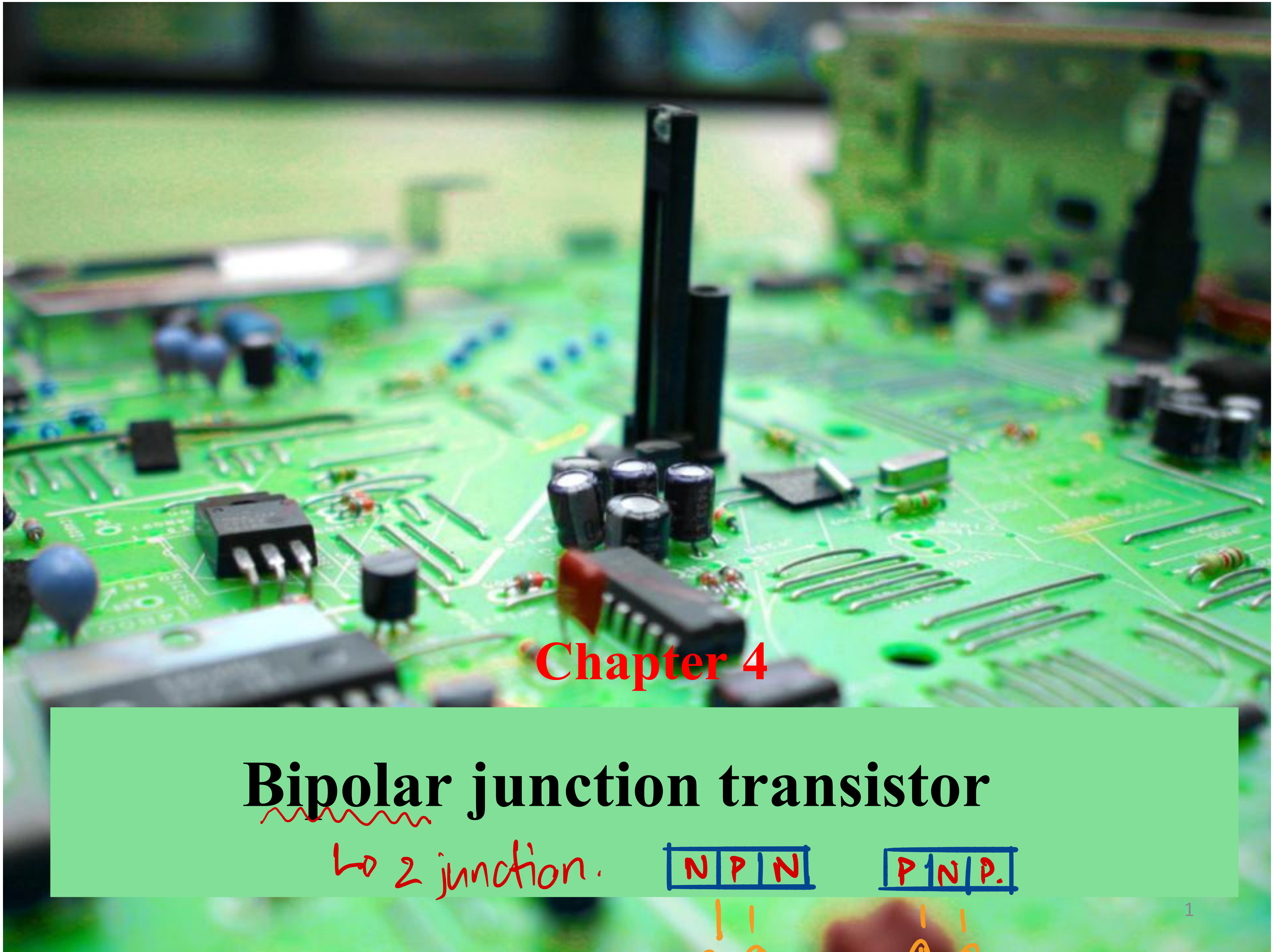


Chapter 4

Bipolar junction transistor

↳ 2 junction.

N P N

1 2

P N P.

1 2.

Objectives

- Describe the basic structure of the bipolar junction transistor (BJT)
- Explain and analyze basic transistor bias and operation

การจ่ายไฟ.

- Discuss the parameters and characteristics of a transistor and how they apply to transistor circuits

มี 2 ลักษณะ

1. amplifier. input → Amp → output. วงจรขยาย.
2. switch. ON, OFF.

ขึ้นอยู่กับการจ่าย bias.

transistor. — ขยาย

(e⁻ ข้ามไปอีกฝาก)

* 0.7V for Si / 0.3V for Ge

- **BJT.** — Bipolar junction transistor (กระแสควบคุม)
- **FET.** (Field effect transistor) (แรงดัน, สนามไฟฟ้า)
  - **JFET.**
    - **Depletion.**
      - N-ch.
      - P-ch.
  - **MOSFET.** — Metal Oxide
    - **Depletion.**
      - N-ch
      - P-ch
    - **Enhancement.**
      - N-ch
      - P-ch.

CMOS.

ทำแรม / RAM

Transistor

- What is transistor?
  - three-terminal device whose output current, voltage and/or power are controlled by its input.
  - 2 basic transistor types: BJT and FET

Transistor Construction

There are two types of transistors:

- ***pnp***
- ***npn***

The terminals are labeled:

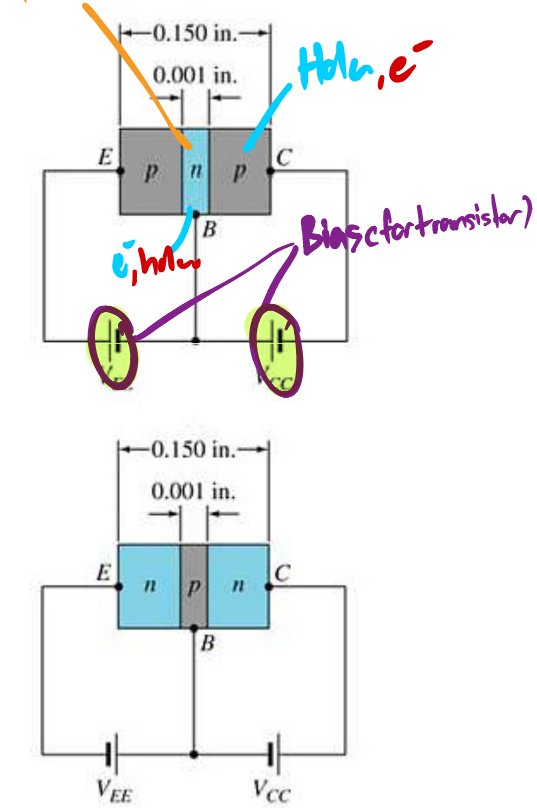
- **E – Emitter**
- **B - Base**
- **C - Collector**

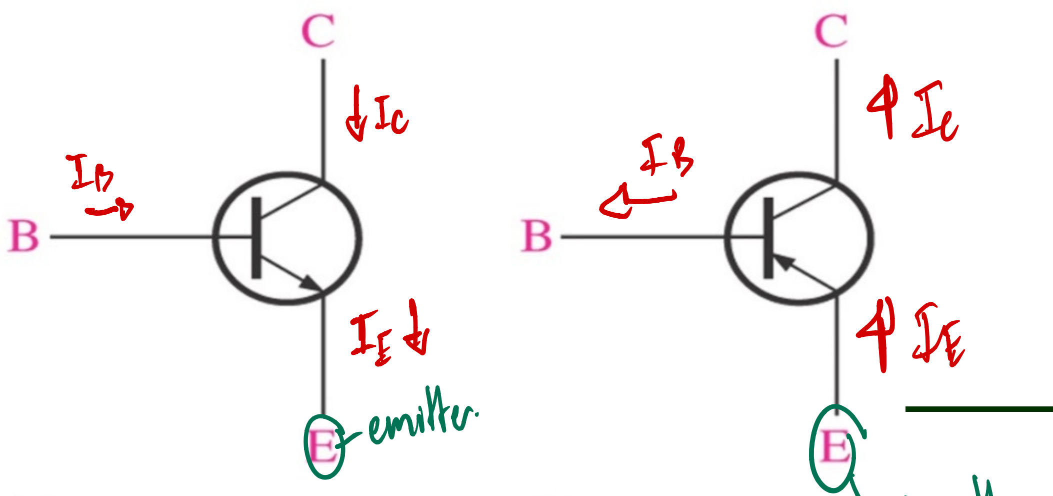
$I_E = I_B + I_C$ (not KCL)

non-linear

pnp

npn





(a) *npn*

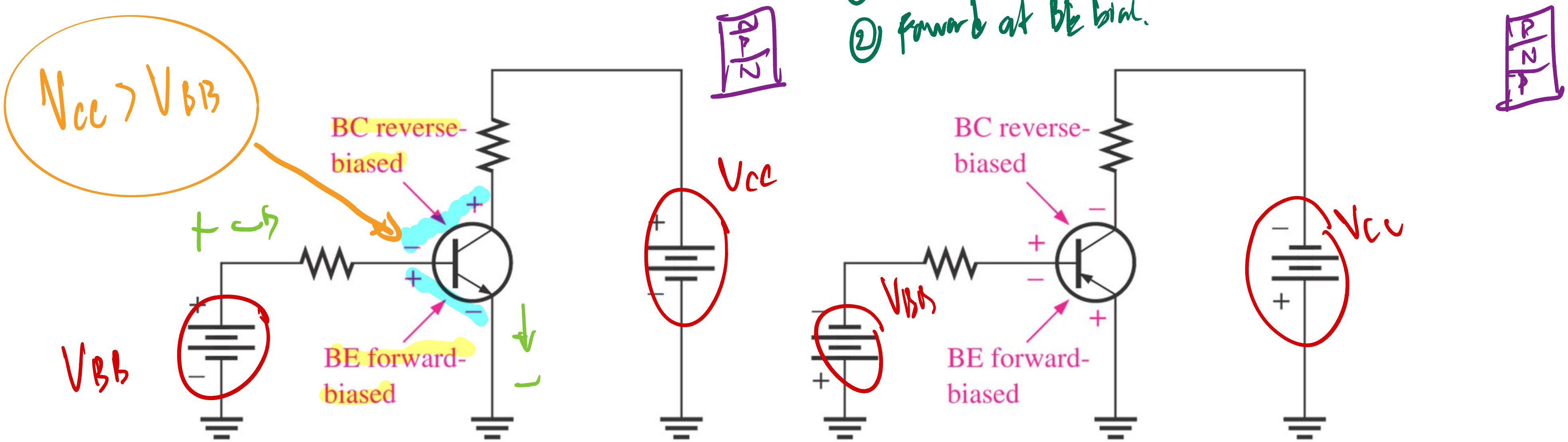
(b) *pnp*

Transistor Operation

Biasing:

- two pn junction must be correctly biased with external dc voltages to operate the transistor properly.
- The figure shown the proper bias arrangement for both *npn* and *pnp* transistor for active operation as an amplifier.

① Reverse at BC bias.
② forward at BE bias.



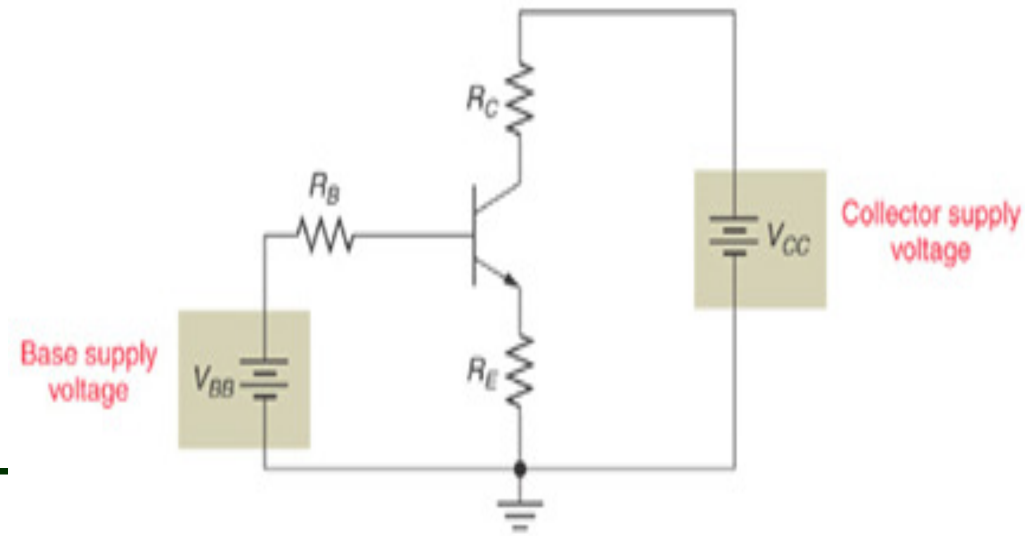
(a) *npn* (b) *pnp*

Transistor Operation

Transistor Voltages:

- V_{CC} – collector supply voltage. This is a power supply voltage applied directly to collector of transistor.
- V_{BB} – base supply voltage. this is dc voltage used to bias base of transistor.
- V_{EE} – emitter supply voltage. dc biasing voltage and in many cases, VEE is simply a ground connection.

② แหล่งจ่าย.



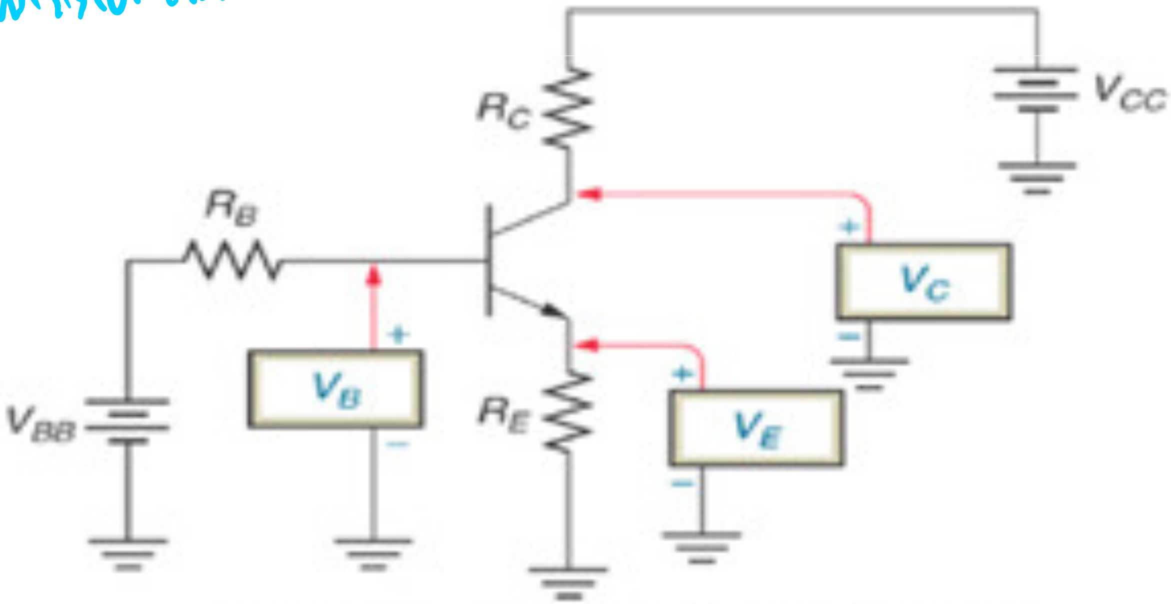
(a) Transistor supply voltages

Transistor Operation

Transistor Voltages:

- V_C – dc voltage measured from collector terminal of component to ground
- V_B – dc voltage measured from base terminal to ground.
- V_E – dc voltage measured from emitter terminal to ground.

[illegible] transistor diagram.

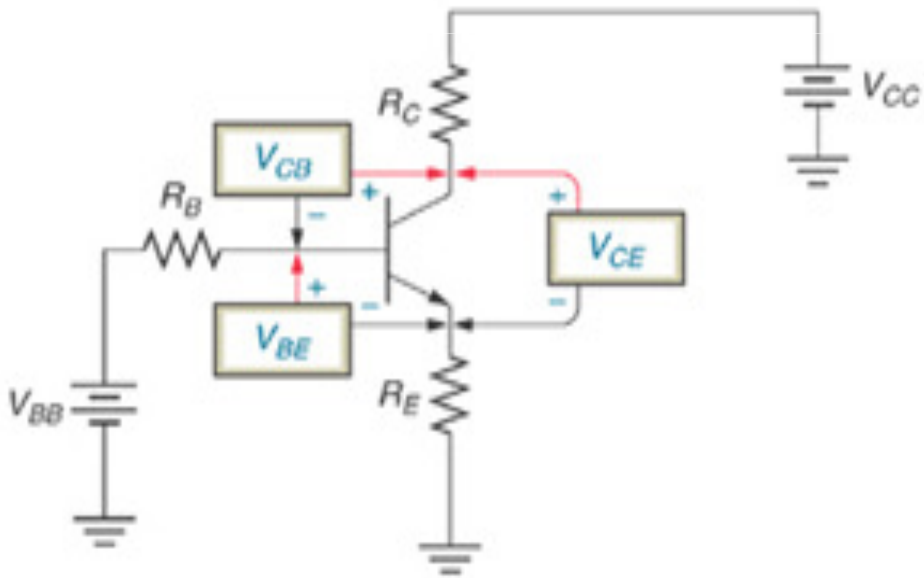


(b) Transistor terminal voltages to ground

Transistor Operation

Transistor Voltages:

- V_{CE} – dc voltage measured from collector to emitter terminal of transistor.
- V_{BE} – dc voltage measured from base to emitter terminal of transistor.
- V_{CB} – dc voltage measured from collector to base terminal of transistor.



(c) The voltages measured across the transistor junctions

Currents in a Transistor

Emitter current is the sum of the collector and base currents:

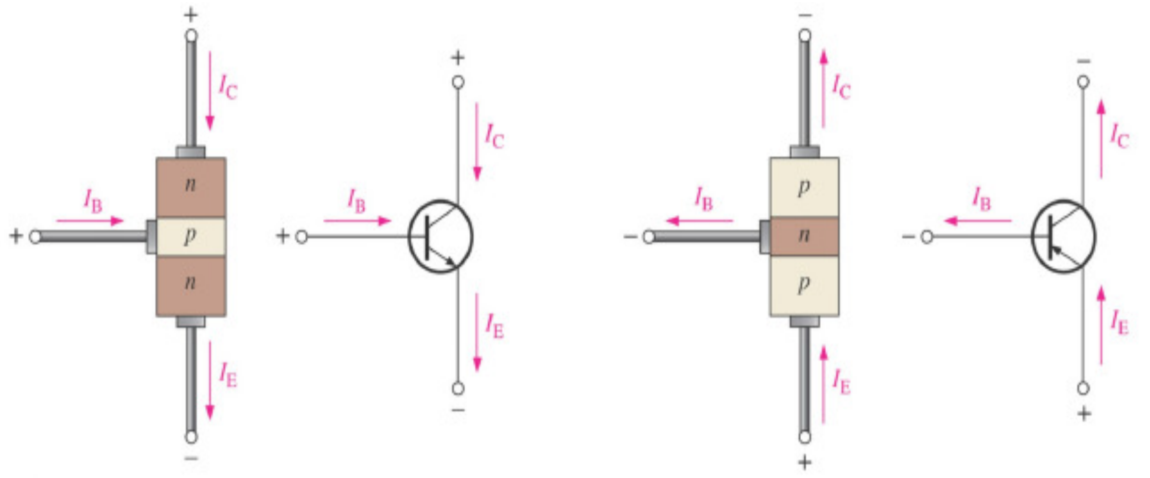
$$\boxed{I_E = I_B + I_C}$$

$I_E = I_B + \beta I_B$

Current gain (β) → factor by which current increases from base of transistor to its collector.

อัตราการขยาย.

$$\boxed{I_C = \beta_{DC} I_B}$$



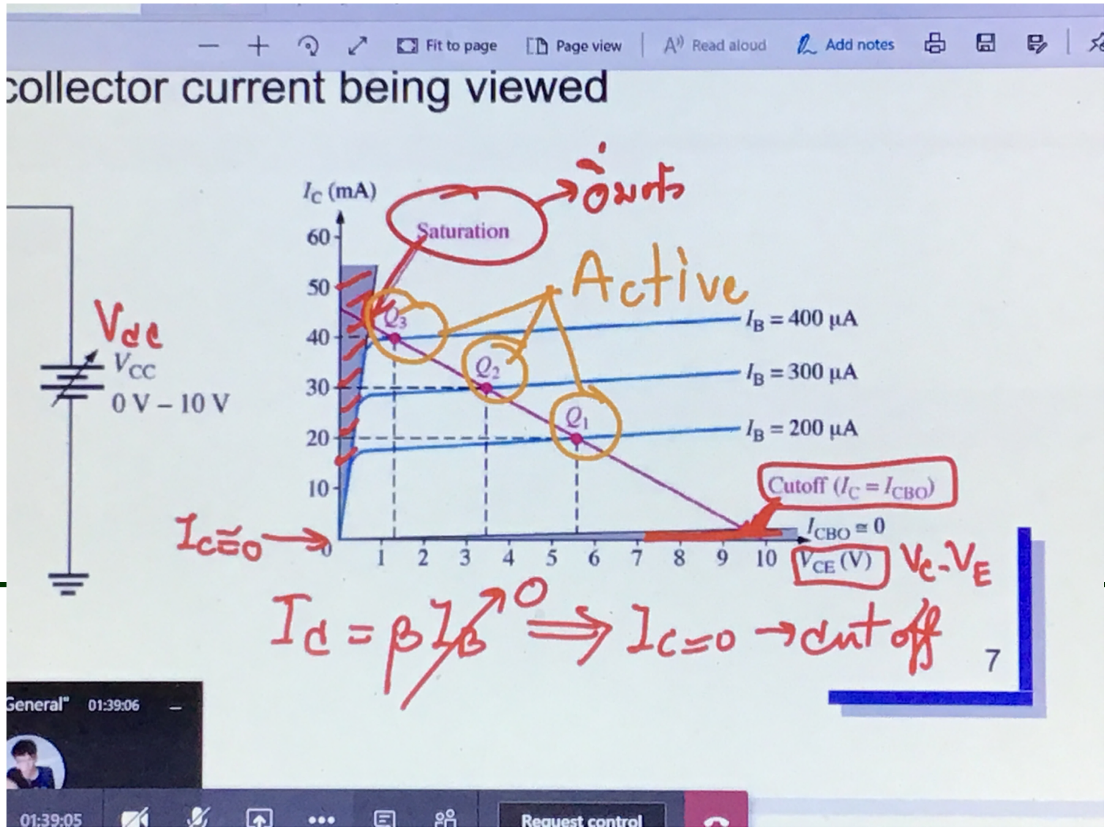
(a) *npn* (b) *pnp*

Operating Regions

- **Active – Operating range of the amplifier.** → transistor ไม่ทำงาน.
- **Cutoff – The amplifier is basically off. There is voltage, but little current.**
- **Saturation – The amplifier is full on. There is current, but little voltage.**

$I_c = 0$

ดับไฟ.



$V_{sat} \approx 0.2V.$

Operating Regions

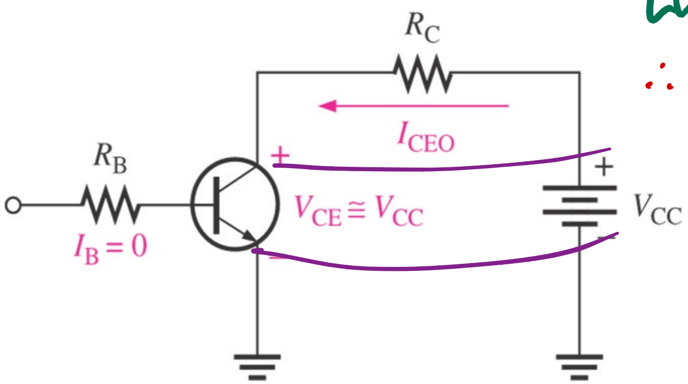
$I_C = 0$ (cutoff)

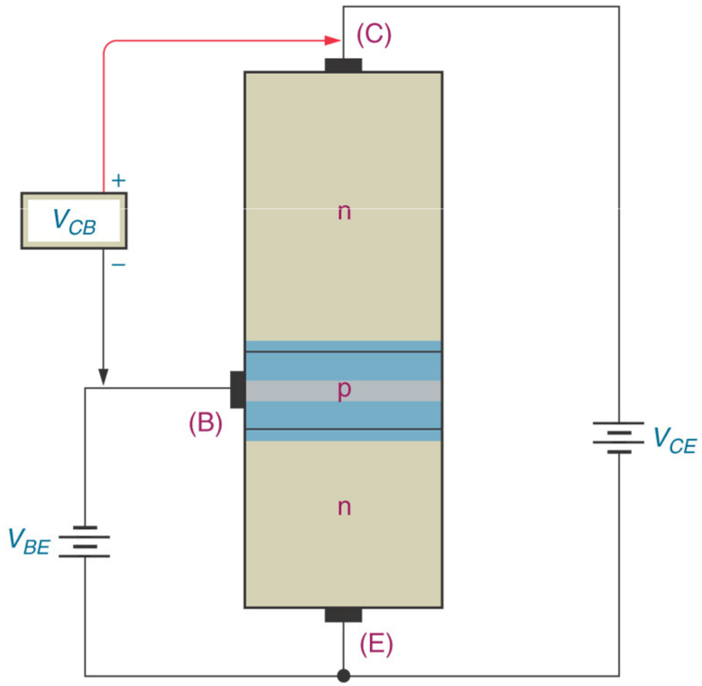
Cutoff region

- **Both transistor junctions** are **reverse biased**.
- With large depletion region between C-B and E-B, reverse current, I_{CEO} passes from emitter to collector and can be neglected.
- So, $\mathbf{V_{CE} = V_{CC}}$

$I_C = \beta I_B = 0$ → cutoff.

$\therefore V_{CE} = V_{CC}$



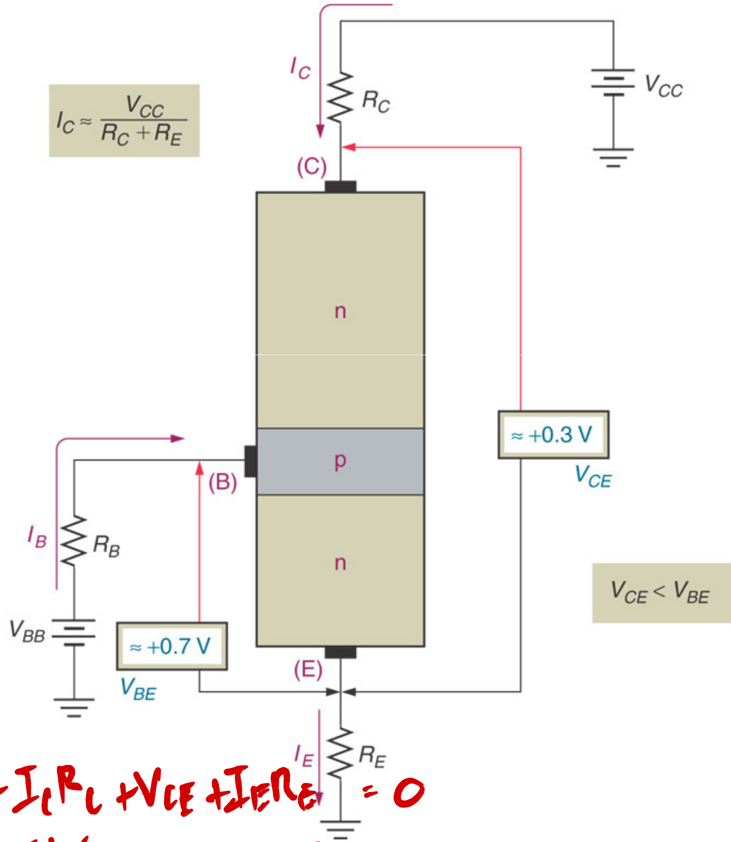


Operating Regions

Saturation region

- **Both transistor junctions** are **forward-biased**.
- I_C reaches its maximum value as determined by V_{CC} and total resistance in C-E circuit.
- I_C is **independently** from relationship of β and I_B.
- V_{BE} is approximately **0.7V** and $V_{CE} < V_{BE}$.

$$I_C = \frac{V_{CC}}{R_C + R_E}$$



Eq. $-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0$

(ให้ I_B มีค่าน้อย, $I_C \approx I_E$)

$\therefore V_{CC} = I_C(R_C + R_E) + V_{CE}$

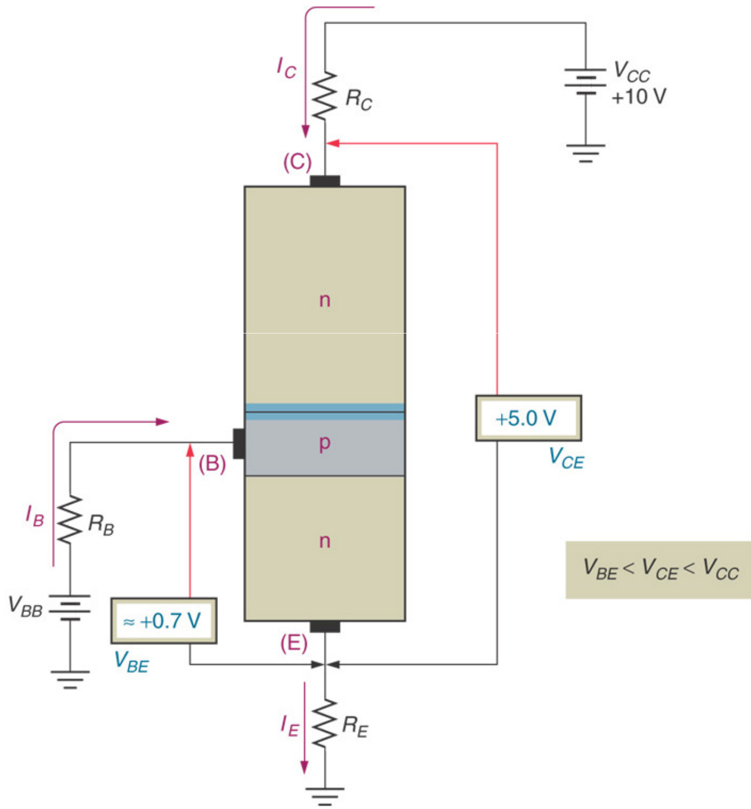
$\therefore I_C = \frac{V_{CC} - \cancel{V_{CE}}^{\,0}}{R_C + R_E}$

$\therefore I_{C\,max} = \frac{V_{CC} - V_{CE}}{R_C + R_E}$

Operating Regions

<u>Active region</u>

- ***BE*** **junction** is **forward biased** and the ***BC*** **junction** is **reverse biased**.
- All terminal currents have some measurable value.
- The magnitude of I_C depends on the values of and I_B.
- V_{CE} is approximately near to **0.7V** and V_{CE} falls in ranges $V_{BE}<V_{CE}<V_{CC}$.

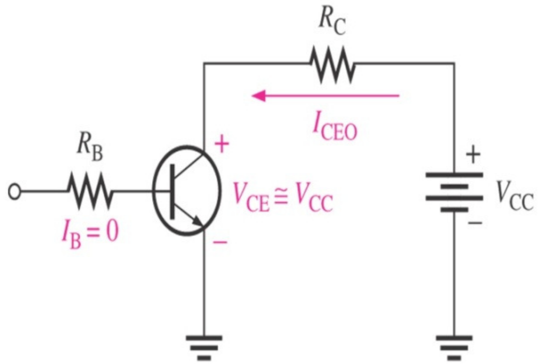


Operating Regions

Transistor Operating Regions:

1.Cutoff region:

- Both transistor junctions are reverse biased
- All terminal current are approximately equal to zero. Since I_{CEO} neglected, $\mathbf{V_{CE} = V_{CC}}$

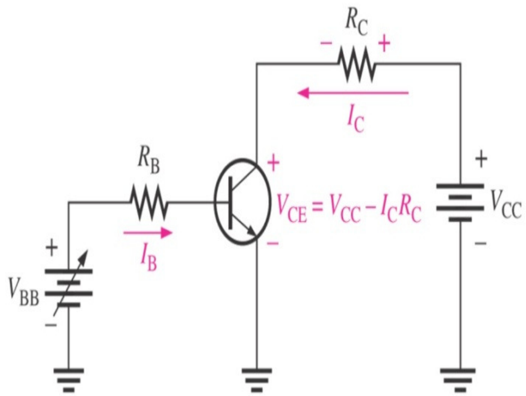


2.Active region:

- The *BE* junction is forward biased and the *BC* junction is reverse biased
- All terminal currents have some measurable value
- The magnitude of *IC* depends on the values of β and *IB*
- VCE is approximately near to 0.7V and VCE falls in ranges VBE<VCE<VCC

3.Saturation:

- Both transistor junctions are forward biased
- *IC* reaches its maximum values- determine by the component in the CE circuit, and independent of the values of β and *IB*
- VBE is approximately 0.7V and VCE < VBE



Approximations

Emitter and collector currents:

$$I_C \cong I_E$$

Base-emitter voltage:

$$V_{BE} = 0.7\ V \quad (\text{for Silicon})$$

Alpha (α)

Alpha (α) is the ratio of I_C to I_E :

$$\alpha_{dc} = \frac{I_C}{I_E}$$

Ideally: $\alpha = 1$
In reality: α is between 0.9 and 0.998

Beta (β)

β represents the amplification factor of a transistor. (β is sometimes referred to as h_{fe}, a term used in transistor modeling calculations)

In DC mode:

$$\beta_{dc} = \frac{I_C}{I_B}$$

Relationship between amplification factors β and α

$$\alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{\alpha - 1}$$

Relationship Between Currents

$$I_C = \beta I_B \qquad I_E = (\beta + 1) I_B$$

BJT CHARACTERISTICS & PARAMETERS

Current and Voltage Analysis:

- When the *BE* junction is forward-biased, like a forward biased diode and the voltage drop is $V_{BE} \cong 0.7V$
- Since the emitter is at ground (0V), by Kirchhoff's voltage law, the voltage across R_B is: $V_{R_B} = V_{BB} - V_{BE}$ …….(1)
- Also, by Ohm's law: $V_{R_B} = I_B R_B$ ……..(2)
- From (1) ->(2) :

$$V_{BB} - V_{BE} = I_B R_B$$

- Therefore, the dc base current is:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

BJT CHARACTERISTICS & PARAMETERS

Current and Voltage Analysis:

- The voltage at the collector with respect to the grounded emitter is:

$$V_{CE} = V_{CC} - V_{R_C}$$

- Since the drop across R_C is: $$V_{RC} = I_C R_C$$
- The dc voltage at the collector with respect to the emitter is:

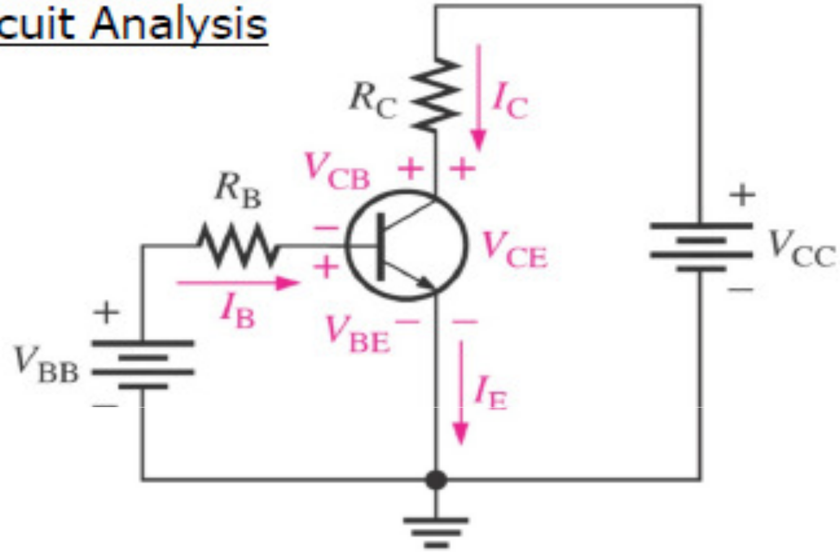
$$V_{CE} = V_{CC} - I_C R_C$$

- where $$I_C = \beta_{DC} I_B$$
- The dc voltage at the collector with respect to the base is:

$$V_{CB} = V_{CE} - V_{BE}$$

BJT CHARACTERISTICS & PARAMETERS

BJT Circuit Analysis



- KVL at B-E loop

$$-V_{BB} + V_{R_B} + V_{BE} = 0$$

$$I_B R_B = V_{BB} - V_{BE}$$

$$\boxed{I_B = \frac{V_{BB} - V_{BE}}{R_B}}$$

Note : V_{BE}=0.7V

- KVL at C-E loop

$$-V_{CC} + V_{R_C} + V_{CE} = 0$$

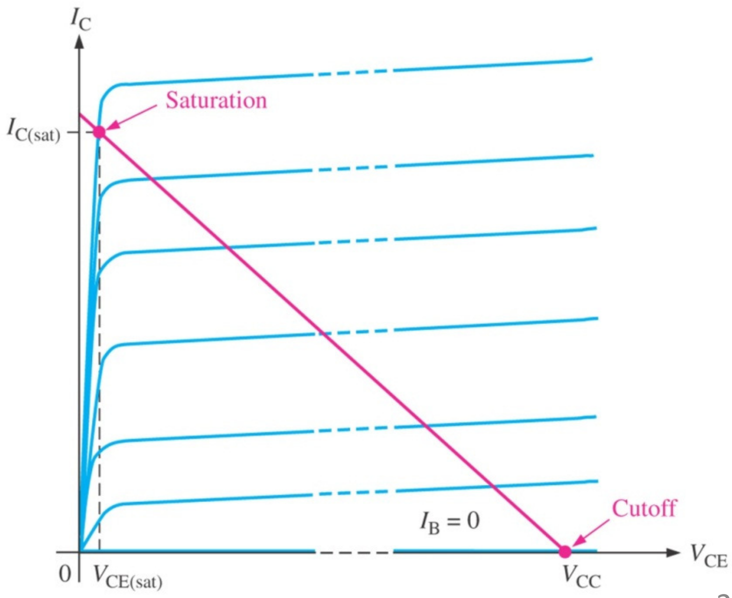
$$V_{CE} = V_{CC} - V_{R_C}$$

$$V_{CE} = V_{CC} - I_C R_C$$

BJT CHARACTERISTICS & PARAMETERS

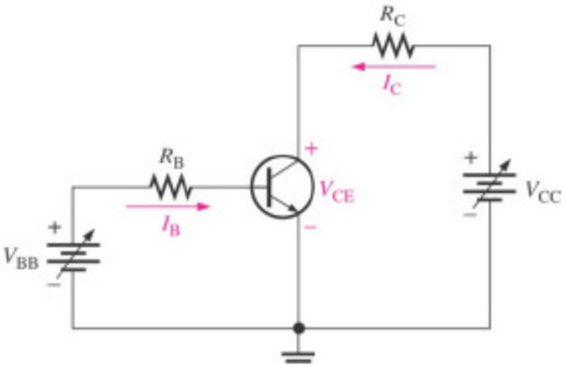
DC Load Line:

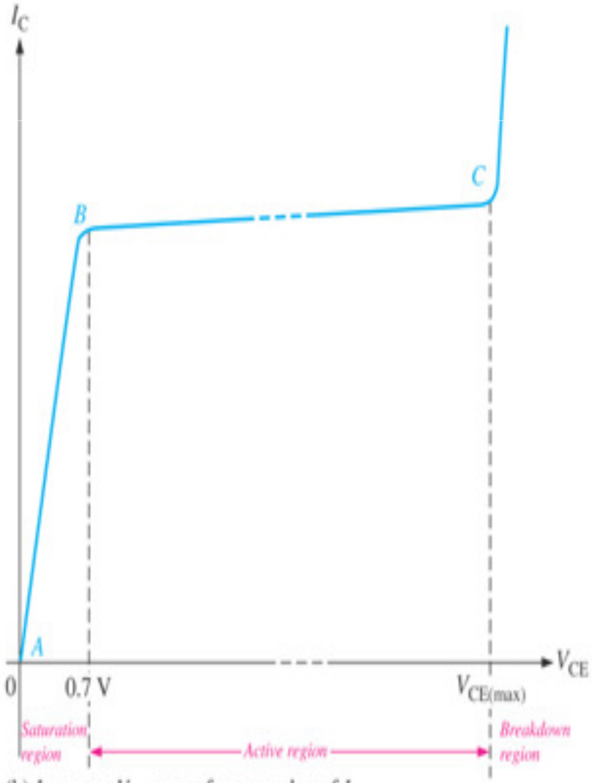
- Cutoff and saturation can be illustrated in relation to the collector characteristic curves by the use of a load line.
- DC load line drawn on the connecting cutoff and saturation point.
- The bottom of load line is ideal cutoff where $I_C=0$ & $V_{CE}=V_{CC}$.
- The top of load line is saturation where $I_C=I_{C(sat)}$ & $V_{CE}=V_{CE(sat)}$
- In between cutoff and saturation is the active region of transistor's operation.



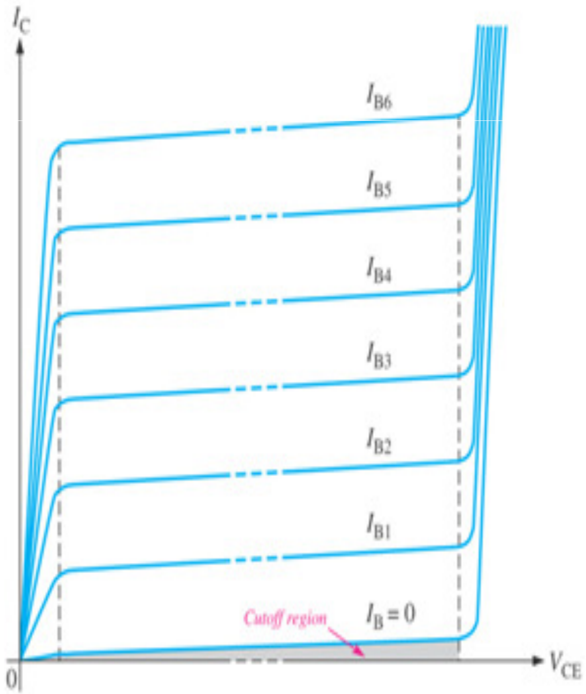
BJT CHARACTERISTICS & PARAMETERS

Collector Characteristic Curve:





(b) I_C versus V_{CE} curve for one value of I_B

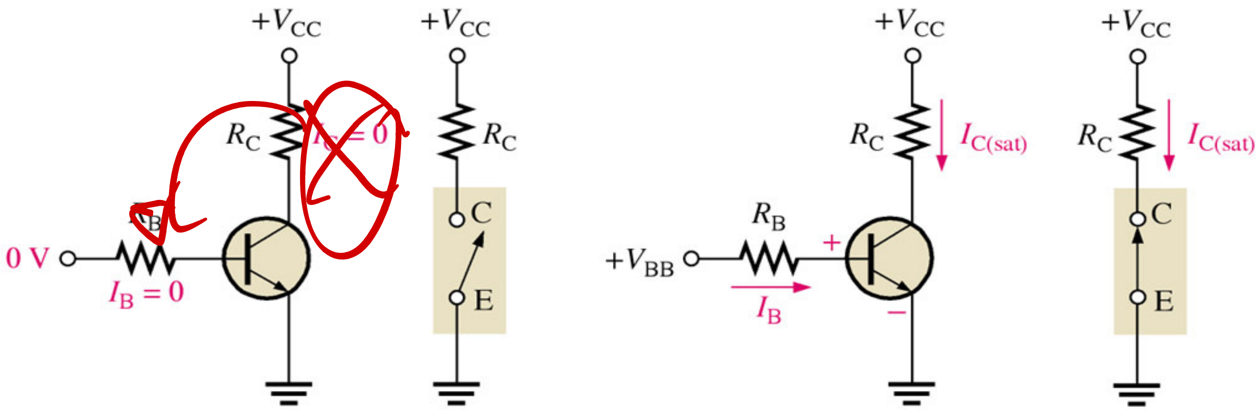


(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

BJT AS A SWITCH

A transistor when used as a switch is simply being biased so that it is in:

1. cutoff (switched off)
2. saturation (switched on)



(a) Cutoff — open switch (b) Saturation — closed switch

BJT AS A SWITCH

Conditions in Cutoff

$$V_{CE(cutoff)} = V_{CC}$$

Neglect leakage current and all currents are zero. BE junction is reverse biased.

Conditions in Saturation

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

Since $V_{CE(sat)}$ is very small compared to V_{CC}, it can be neglected.

$$I_{B(\min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Transistor Specification Sheet

MAXIMUM RATINGS

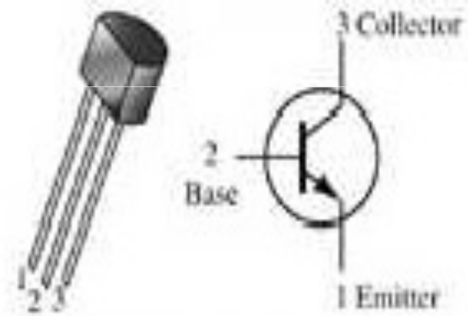
Rating	Symbol	2N4123	Unit
Collector-Emitter Voltage	V_{CEO}	30	Vdc
Collector-Base Voltage	V_{CBO}	40	Vdc
Emitter-Base Voltage	V_{EBO}	5.0	Vdc
Collector Current – Continuous	I_C	200	mAdc
Total Device Dissipation @ $T_A = 25°C$ Derate above 25°C	P_D	625 5.0	mW mW/°C
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	83.3	°C/W
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

2N4123

CASE 29-04, STYLE 1
TO-92 (TO-226AA)



GENERAL PURPOSE
TRANSISTOR
NPN SILICON

Transistor Specification Sheet

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Max	Unit
OFF CHARACTERISTICS				
Collector-Emitter Breakdown Voltage (1) (I_C = 1.0 mAdc, I_B = 0)	$V_{(BR)CEO}$	30		Vdc
Collector-Base Breakdown Voltage (I_C = 10 μAdc, I_E = 0)	$V_{(BR)CBO}$	40		Vdc
Emitter-Base Breakdown Voltage (I_E = 10 μAdc, I_C = 0)	$V_{(BR)EBO}$	5.0	–	Vdc
Collector Cutoff Current (V_{CB} = 20 Vdc, I_E = 0)	I_{CBO}	–	50	nAdc
Emitter Cutoff Current (V_{BE} = 3.0 Vdc, I_C = 0)	I_{EBO}	–	50	nAdc
ON CHARACTERISTICS				
DC Current Gain(1) (I_C = 2.0 mAdc, V_{CE} = 1.0 Vdc) (I_C = 50 mAdc, V_{CE} = 1.0 Vdc)	h_{FE}	50 25	150 –	–
Collector-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{CE(sat)}$	–	0.3	Vdc
Base-Emitter Saturation Voltage(1) (I_C = 50 mAdc, I_B = 5.0 mAdc)	$V_{BE(sat)}$	–	0.95	Vdc
SMALL-SIGNAL CHARACTERISTICS				
Current-Gain – Bandwidth Product (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz)	f_T	250		MHz
Output Capacitance (V_{CB} = 5.0 Vdc, I_E = 0, f = 100 MHz)	C_{obo}	–	4.0	pF
Input Capacitance (V_{BE} = 0.5 Vdc, I_C = 0, f = 100 kHz)	C_{ibo}	–	8.0	pF
Collector-Base Capacitance (I_E = 0, V_{CB} = 5.0 V, f = 100 kHz)	C_{cb}	–	4.0	pF
Small-Signal Current Gain (I_C = 2.0 mAdc, V_{CE} = 10 Vdc, f = 1.0 kHz)	h_{fe}	50	200	–
Current Gain – High Frequency (I_C = 10 mAdc, V_{CE} = 20 Vdc, f = 100 MHz) (I_C = 2.0 mAdc, V_{CE} = 10 V, f = 1.0 kHz)	h_{fe}	2.5 50	– 200	–
Noise Figure (I_C = 100 μAdc, V_{CE} = 5.0 Vdc, R_S = 1.0 k ohm, f = 1.0 kHz)	NF	–	6.0	dB

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

Transistor Testing

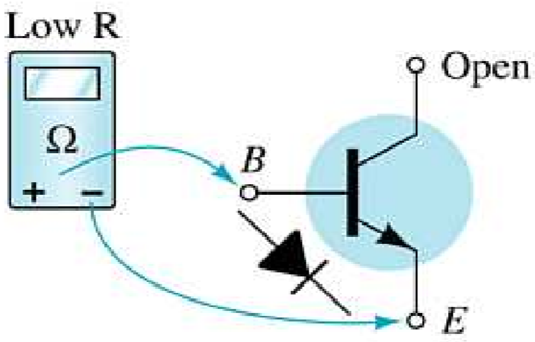
- **Curve Tracer**

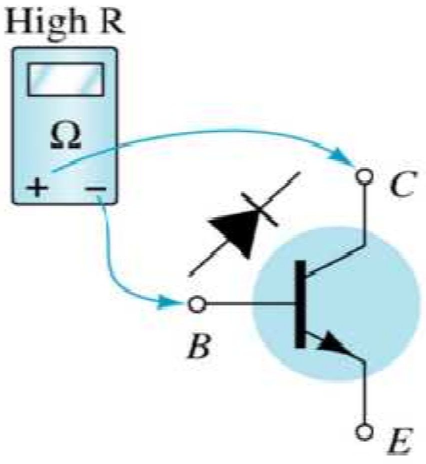
  Provides a graph of the characteristic curves.

- **DMM**

  Some DMMs measure β_{DC} or h_{FE}.

- **Ohmmeter**





Transistor Terminal Identification