Bipolar Junction Transistors (BJT)

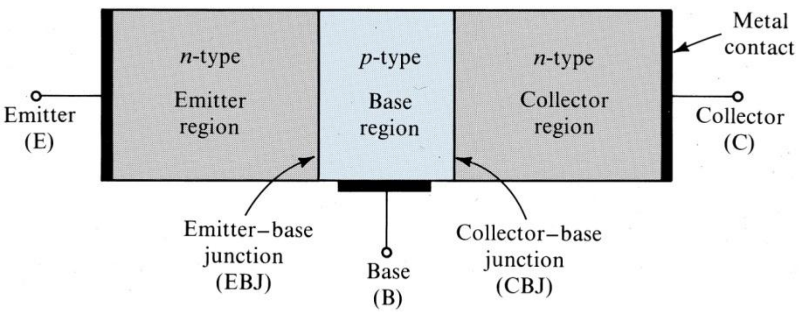
Signal amplification is important in many applications, such as telecommunications. Before the advent of transistors, signal amplification was accomplished using vacuum tubes. Transistors are much smaller and do not need a long warm-up time needed with vacuum tubes. The invention of the bipolar junction transistor started a revolution which placed electronics on a path of miniaturization; a fact that would have been impossible with vacuum tubes.

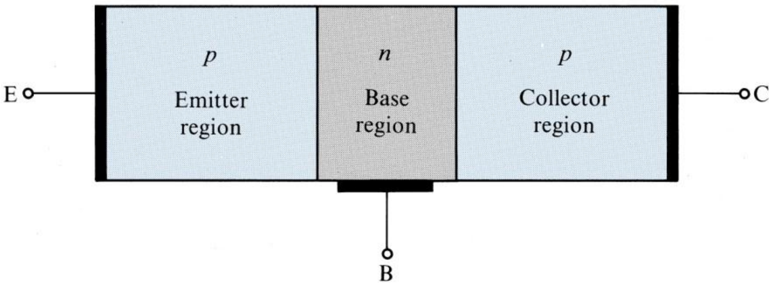
In summary, the transistor and subsequently the integrated circuit must certainly qualify as two of the greatest inventions of the twentieth century.

BJT Structure

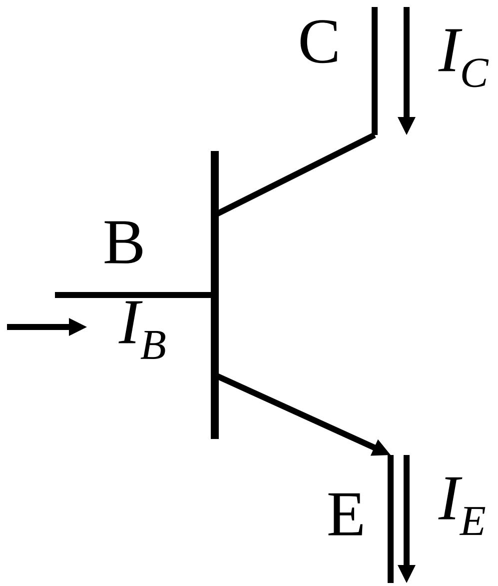
By placing two PN junctions together we can create a bipolar transistor.A BJT transistor has three terminals. The base (B), the collector (C), and the emitter (E).

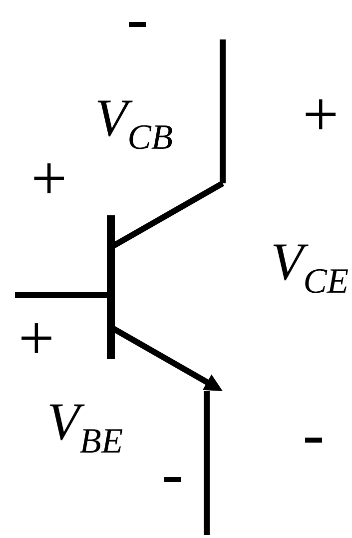
- Transistors are three-terminal devices. The terminals are labelled the base, the emitter and the collector. Each BJTs consist of two *pn* junctions (where a '*p* type' material joins to a 'n type material'). Therefore, a transistor may be made up from a piece of *p* type material sandwiched between two n type regions (*npn*), or it may be made up from a piece of 'n type' material sandwiched between two 'p type' regions (*pnp*)





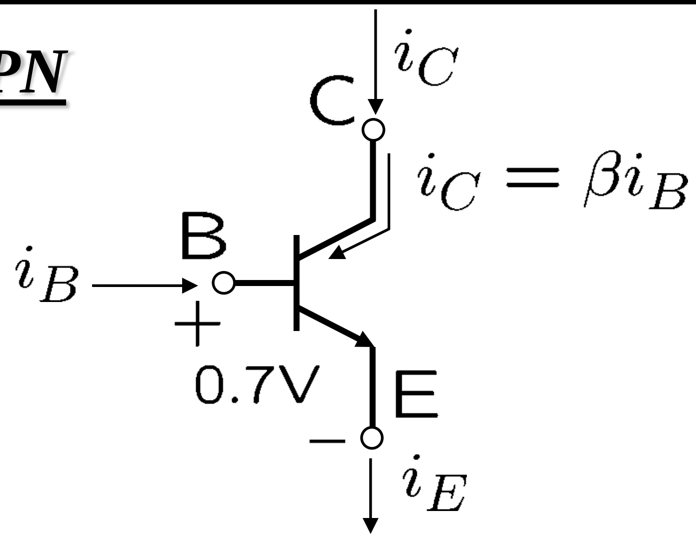
3 Currents and 3 Voltages in the BJT *npn* Transistor



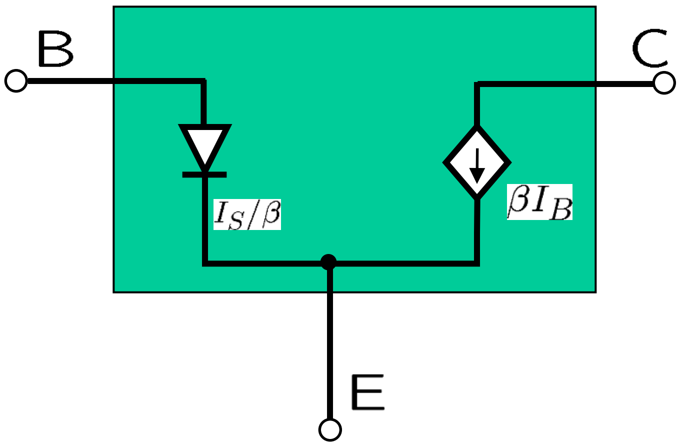


Equivalent circuit of the transistors in the active mode

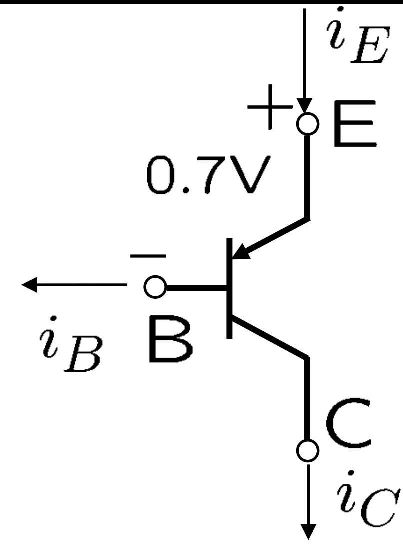
NPN



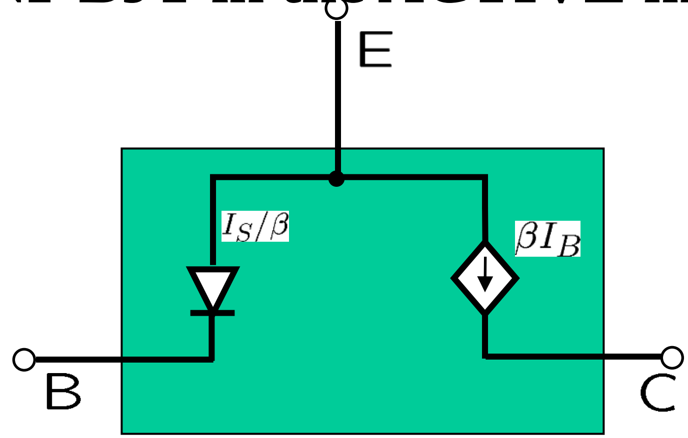
Equivalent Circuit of the NPN BJT in the ACTIVE mode



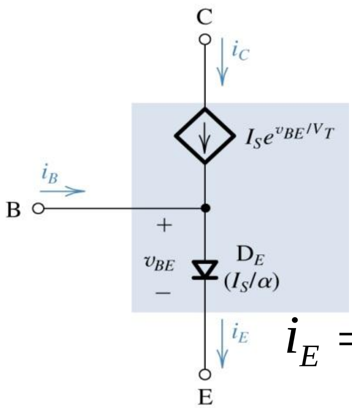
PNP



Equivalent Circuit of the PNP BJT in the ACTIVE mode

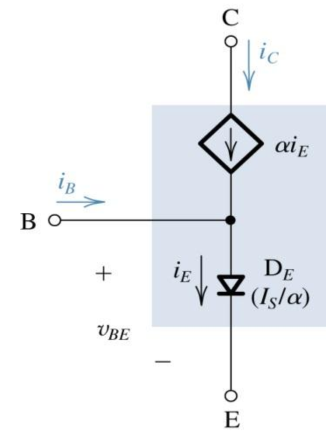


Large-Signal Equivalent-Circuit Models of the *npn* BJT operating in the active mode

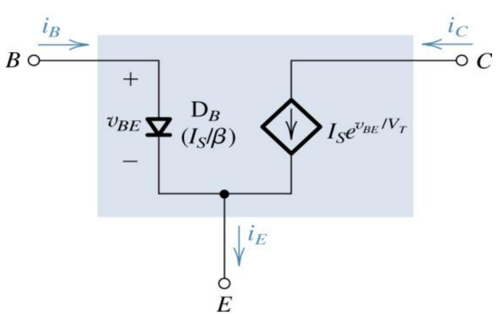


$$i_E = (I_S / \alpha) e^{v_{BE} / V_T}$$

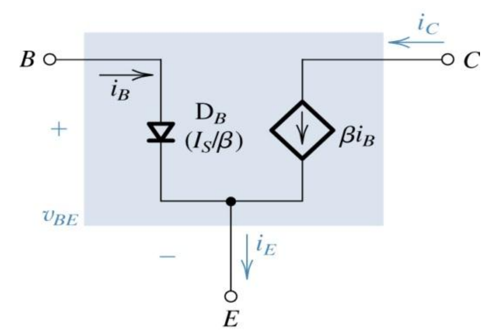
Voltage - controlled Current Source (a)



(b) Current - controlled Current Source



(c)



(d)

$$i_C = I_s e^{v_{BE}/V_T}$$

$$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$$

$$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$$

$$i_C = \alpha i_E ; i_B = (1-\alpha) i_E = \frac{i_E}{\beta + 1}$$

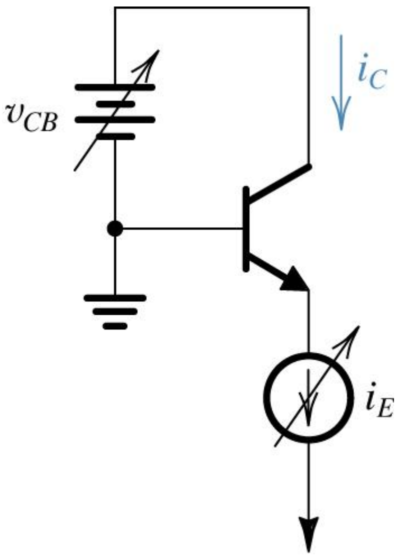
$$i_C = \beta i_B ; i_E = (\beta + 1) i_B$$

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

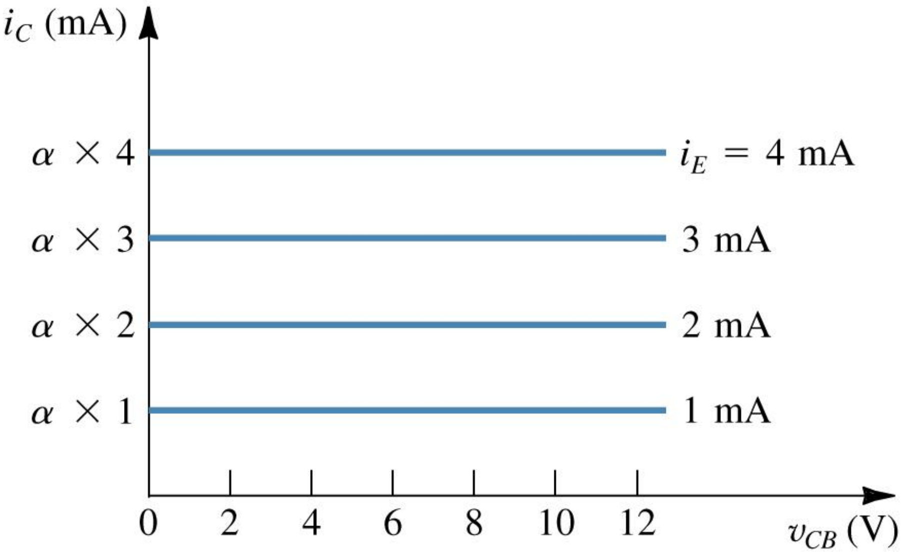
- The basic principle involves the use of the voltage between two terminals to control the current flowing in the third terminal.
- Current is conducted by both electrons and holes, therefore the name bipolar.
- α is called the common-base current gain.
- β is called the common-emitter current gain.

The i_C-v_{CB} Characteristics of an *npn* Transistor

$$i_C = I_s e^{v_{BE}/V_T}$$



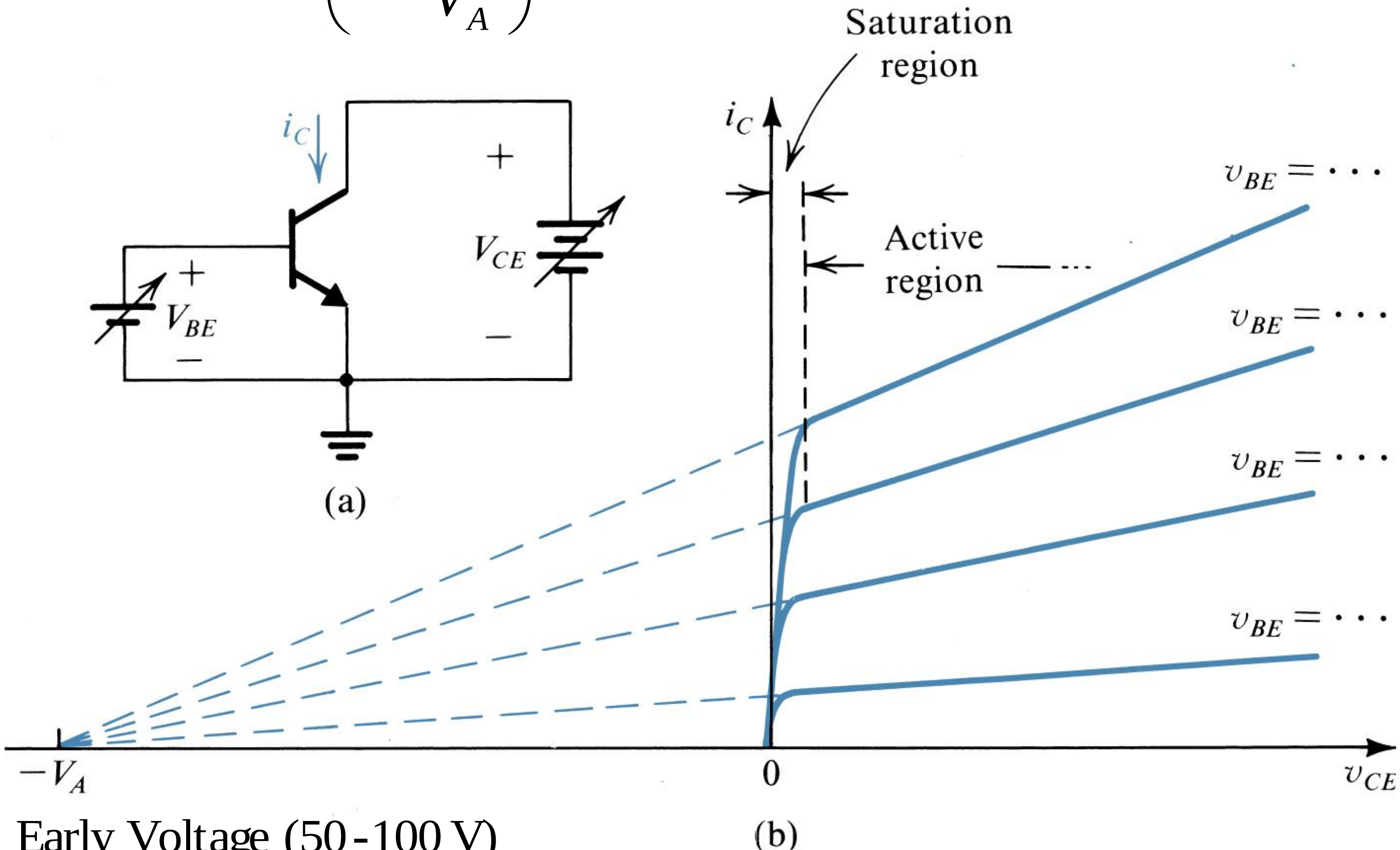
(a)



(b)

Measuring the i_C-v_{CE} Characteristics of the BJT

$$i_C = I_S e^{v_{BE}/V_T}\left(1+\frac{v_{CE}}{V_A}\right)$$



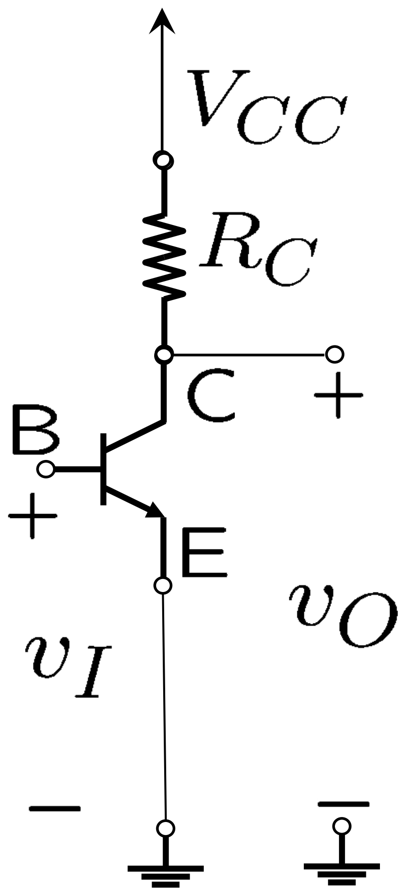
Early Voltage (50-100 V)

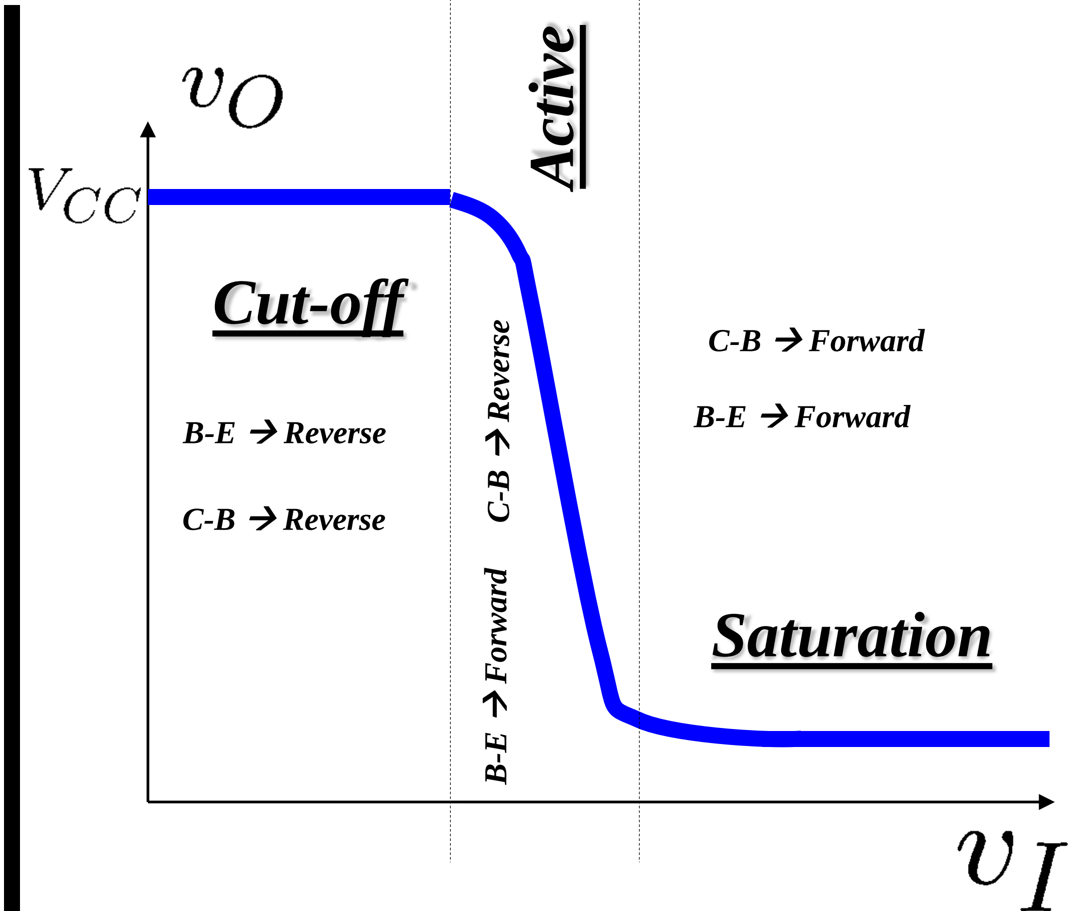
Amplification in BJT:

1. We first derive the Input/Output transfer characteristics of a "*skeleton*" BJT circuit.
2. Then we see, on a qualitative basis, how those characteristics can be used in the amplification.
3. After that we ***"calculate"*** the actual voltage amplification factor.
4. Finally, we develop a systematic approach that will be used to analyze/design more complicated and general amplifier circuits.

1.Deriving the Input/Output transfer characteristics of a "*skeleton*" BJT circuit.

This characteristics have been explained in class





Simple Skeleton circuit

2. **Then we see, on a qualitative basis, how those characteristics can be used in the amplification.**

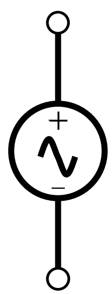
Now assume that v_I

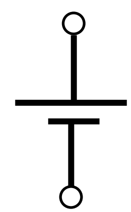
$$\Downarrow$$

$$v_i + V_{BE}$$

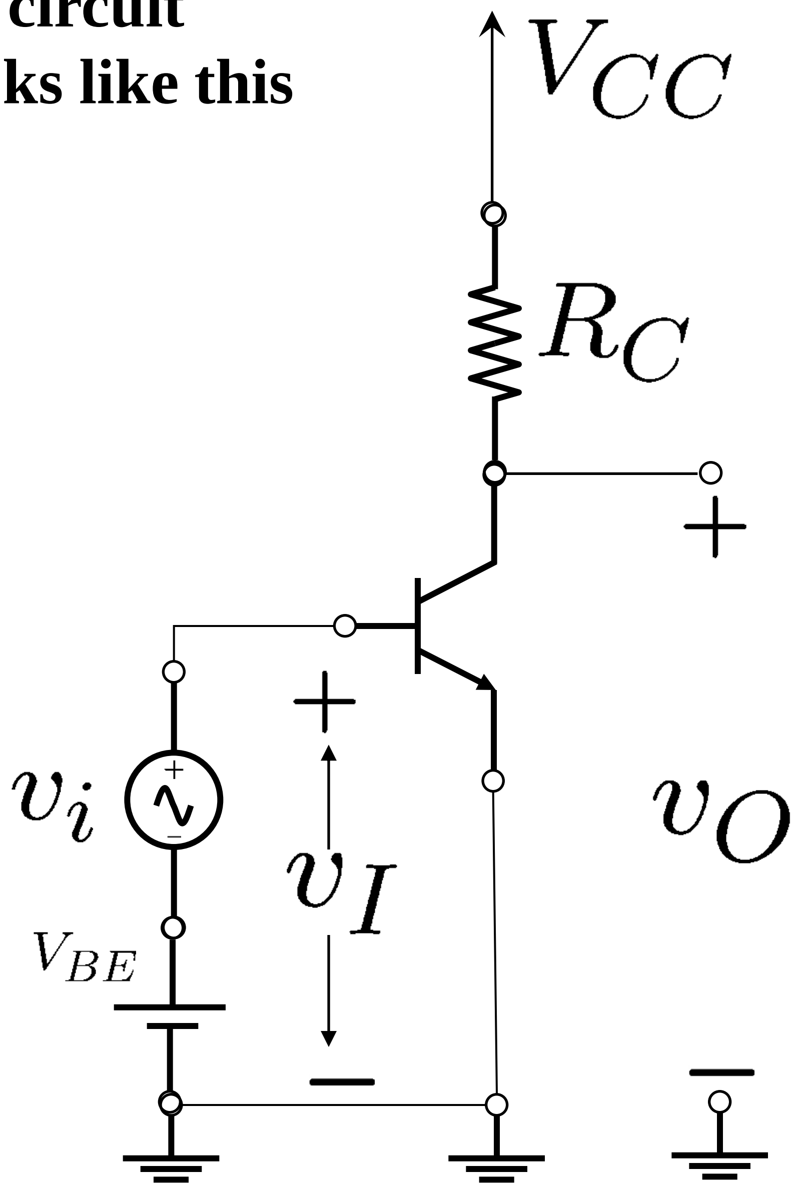
Small pure sinusoidal | *Large pure Constant (dc)*

Symbolized by





The circuit now looks like this



We want now to see how the output will change in response to the changes in the input

AC Small-Signal Analysis

First Separate

Each ***current*** and ***voltage***

into

Constant Component

Which we denote by

$\boxed{\text{Capital Letter}_{\text{Capital Letter}}}$

Time-varying component

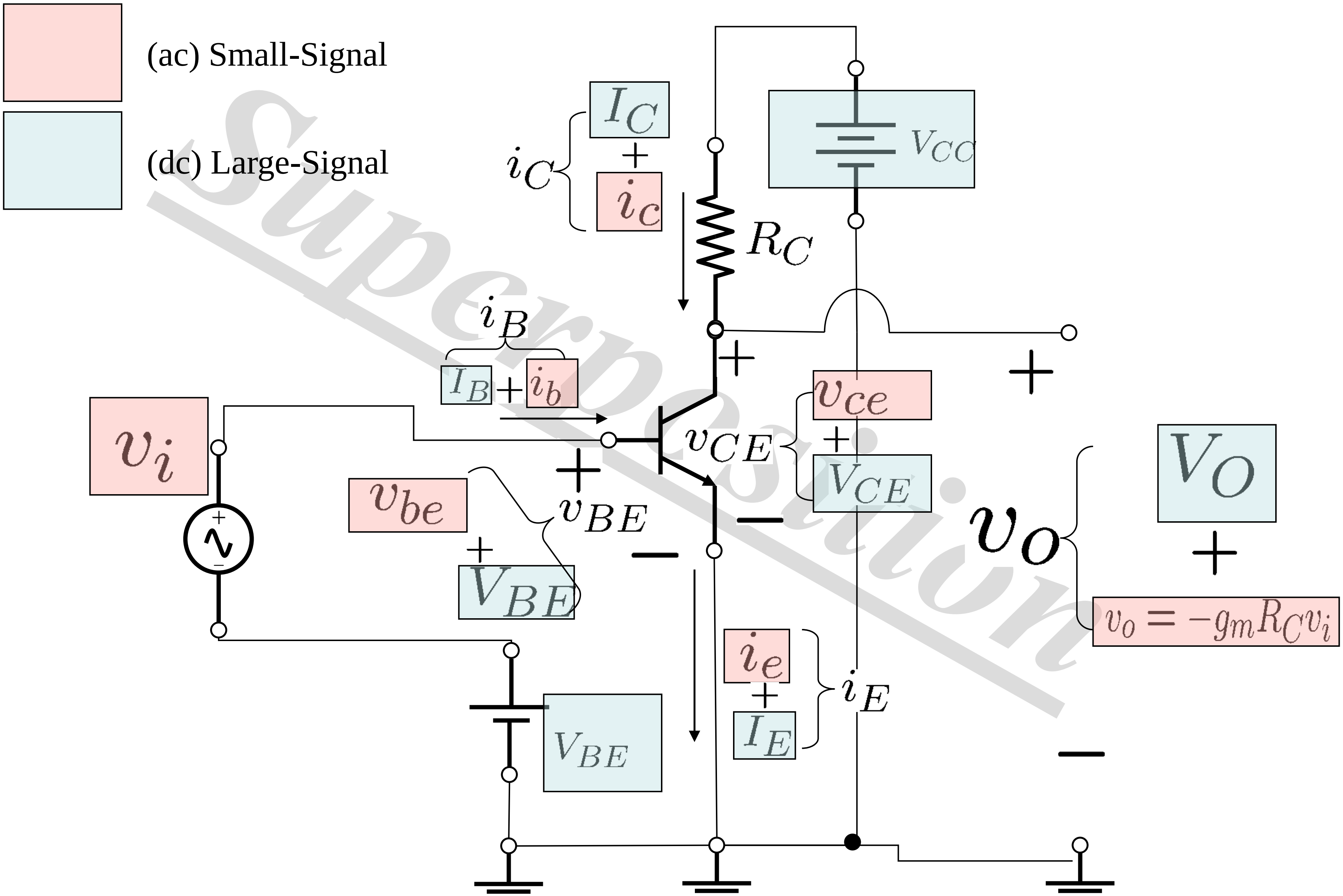
Which we denote by

$\boxed{\text{Small Letter}_{\text{Small Letter}}}$

$+$

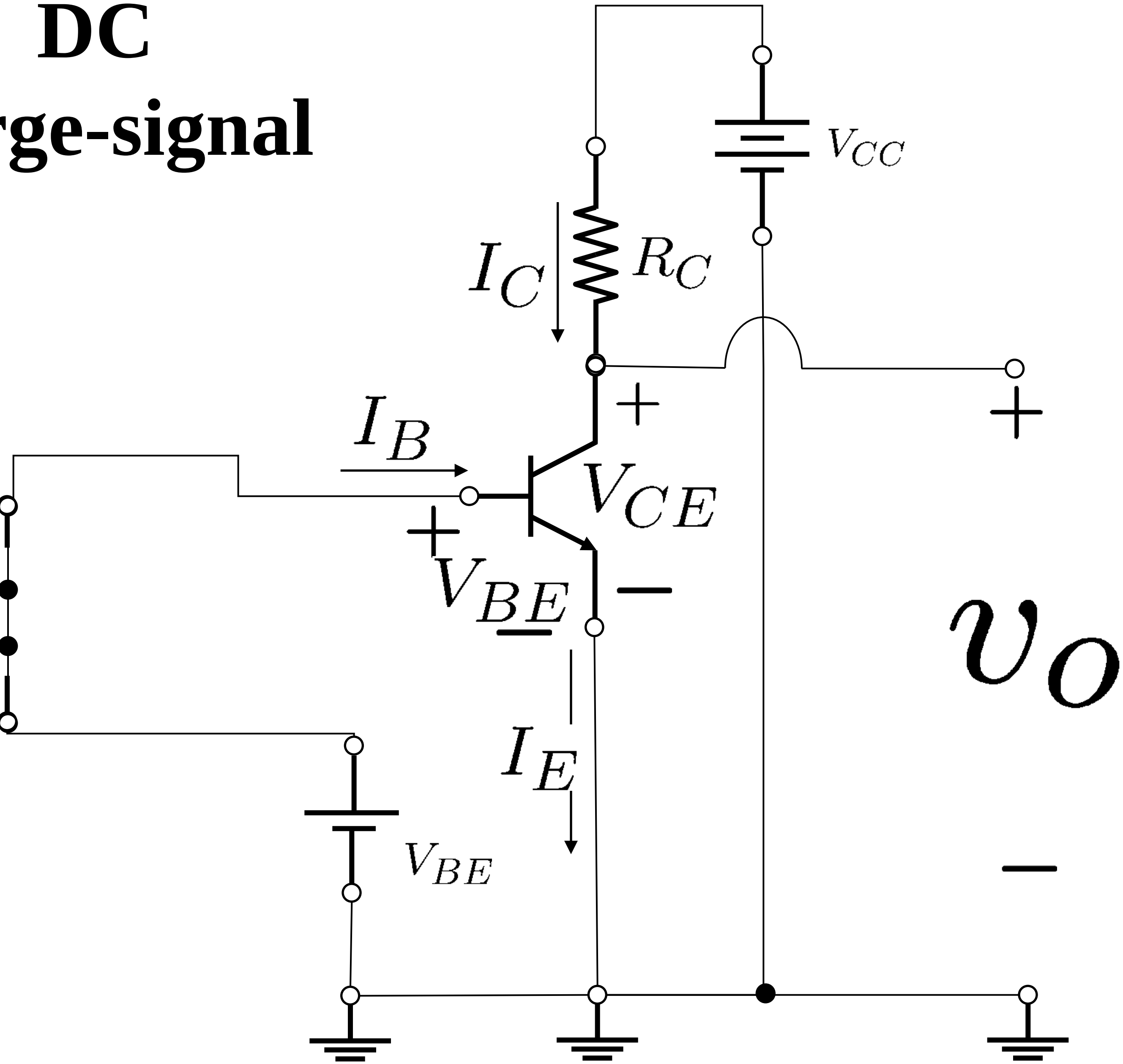
The total we denote by

$\boxed{\text{Small Letter}_{\text{Capital Letter}}}$



(ac) Small-Signal
(dc) Large-Signal
Superposition
i_C
I_C
+
i_c
R_C
V_{CC}
i_B
$I_B + i_b$
v_i
+
v_{be}
+
V_{BE}
v_{BE}
−
v_{CE}
+
−
v_{ce}
+
V_{CE}
v_o
+
V_O
+
$v_o = -g_m R_C v_i$
−
i_e
+
I_E
i_E
V_{BE}

DC
Large-signal



AC
Small Signal