BJT Operation and Modeling

Dr. José Ernesto Rayas Sánchez

Some figures of this presentation were taken from the instructional resources of the following textbooks:

A. S. Sedra and K. C. Smith, *Microelectronic Circuits*. New York, NY: Oxford University Press, 2003.

A. R. Hambley, *Electronics: A Top-Down Approach to Computer-Aided Circuit Design*. Englewood Cliffs, NJ: Prentice Hall, 2000.

R. C. Jaeger, *Microelectronic Circuits Design*. New York, NY: McGraw Hill, 1997.

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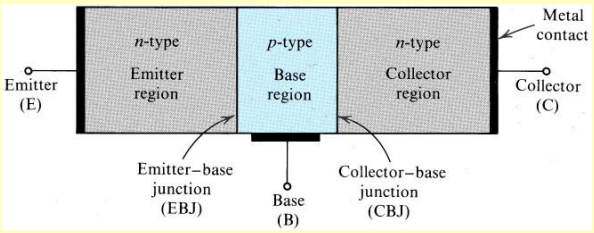
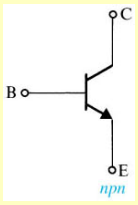
Outline

- Simplified physical structure and symbols
- Regions of operation
- Operation in the active region
- Models for the active region
- I-V characteristics: $i_C - v_{BE}$, $i_C - v_{CE}$, $i_C - v_{CB}$
- Early effect
- Models for the cutoff region
- Models for the saturation region
- Variation of β with I_C and temperature

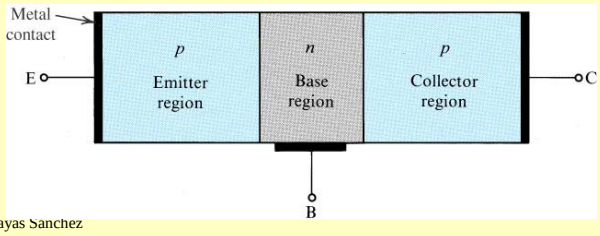
Simplified Structure of a BJT and Symbol

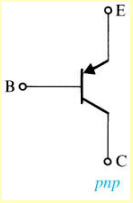
- NPN Transistor





- PNP Transistor





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Regions of Operation of the BJT

		Collector-Base Junction (CB)	
		Forward-biased	Reversed-biased
Base-Emitter Junction (BE)	Forward-biased	**Saturation Region** (switch on)	**Active Region** (good amplifier)
	Reversed-biased	**Inverted Active Region** (poor amplifier)	**Cutoff Region** (switch off)

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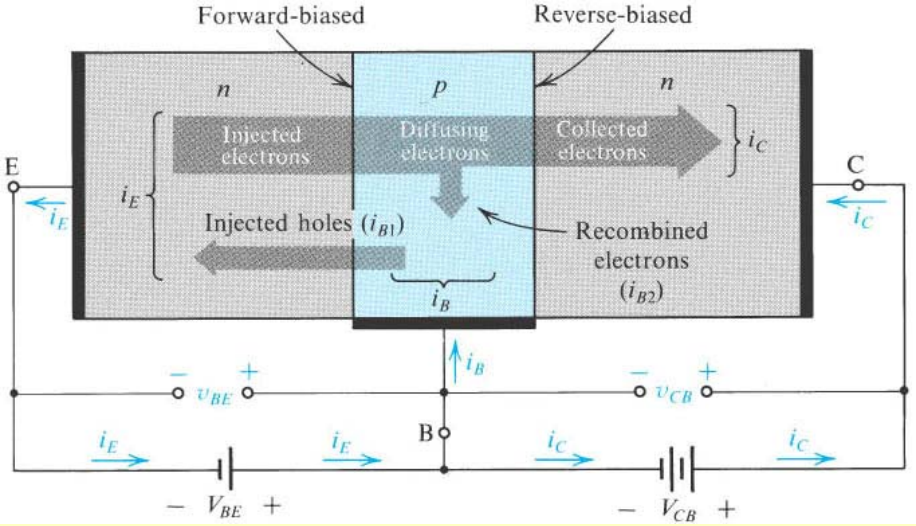
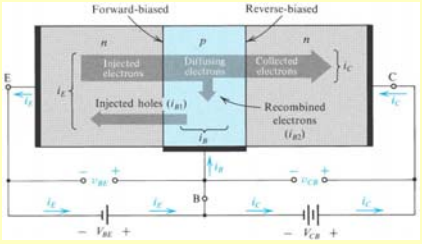
Operation in the Active Region



Operation in the Active Region (cont)



- Junction BE behaves as a forward biased diode

$$i_B \approx I_{SB} e^{\frac{V_{BE}}{\eta V_T}}$$

- Junction CB behaves as a current controlled current source

$$i_C = \alpha i_E$$

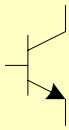
Since $i_E = i_C + i_B$ then $i_C = \dfrac{\alpha}{1-\alpha} i_B = \beta i_B$

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

Typically, $32.3 \le \beta \le 332.3$

Typically, $0.970 \le \alpha \le 0.997$

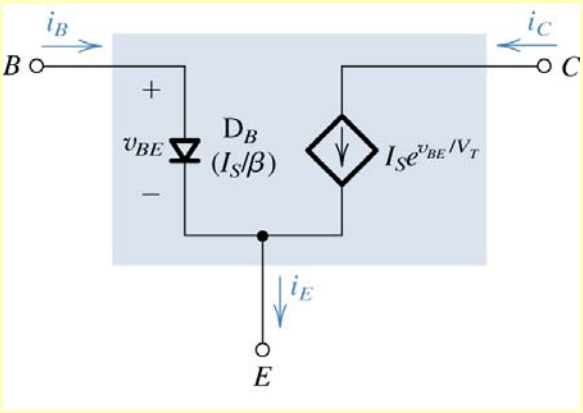
Models for the Active Region (NPN)



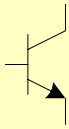
$$i_B = \frac{I_S}{\beta} e^{v_{BE}/V_T}$$

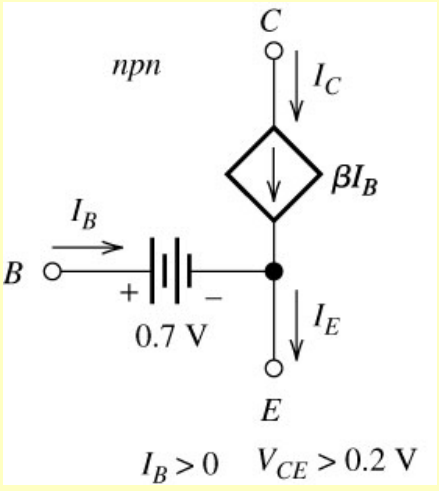
$$i_C = I_S e^{v_{BE}/V_T}$$

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

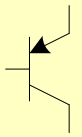


Models for the Active Region (NPN)





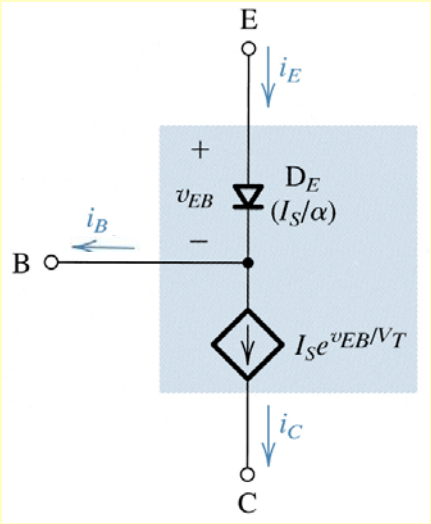
Models for the Active Region (PNP)



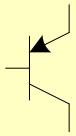
$$i_B = \frac{I_S}{\beta} e^{v_{EB}/V_T}$$

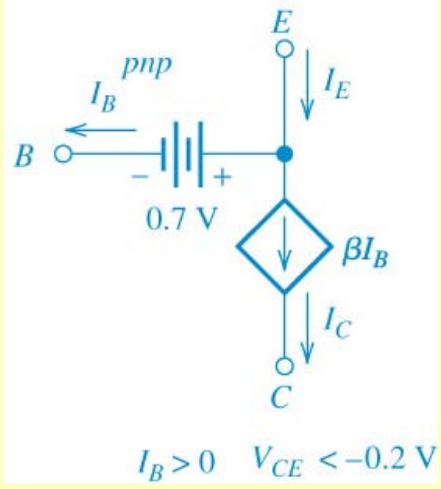
$$i_C = I_S e^{v_{EB}/V_T}$$

$$i_E = \frac{I_S}{\alpha} e^{v_{EB}/V_T}$$

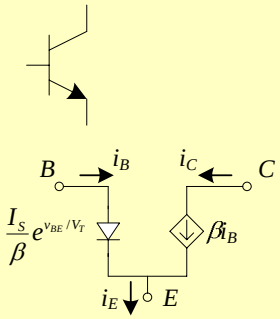


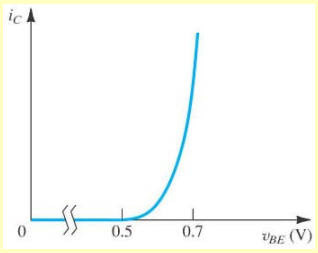
Models for the Active Region (NPN)



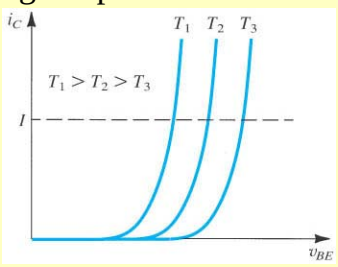


I-V Characteristics ($i_C - v_{BE}$)

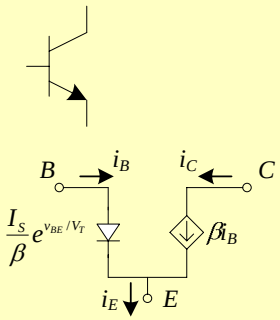


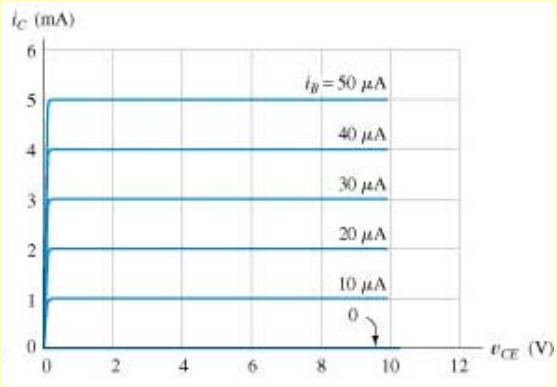


Considering temperature effects:

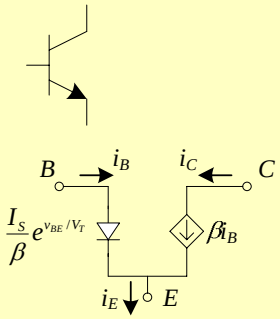


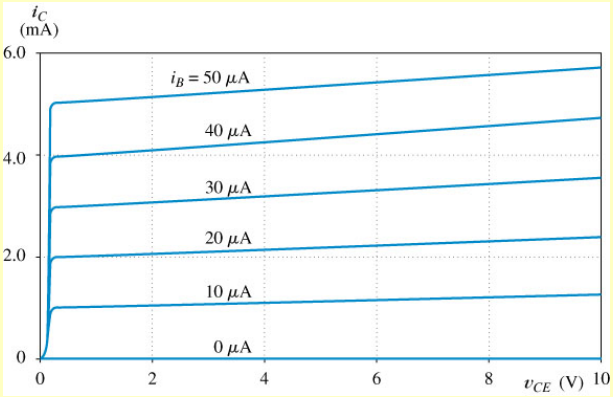
I-V Characteristics ($i_C - v_{CE}$ Ideal)





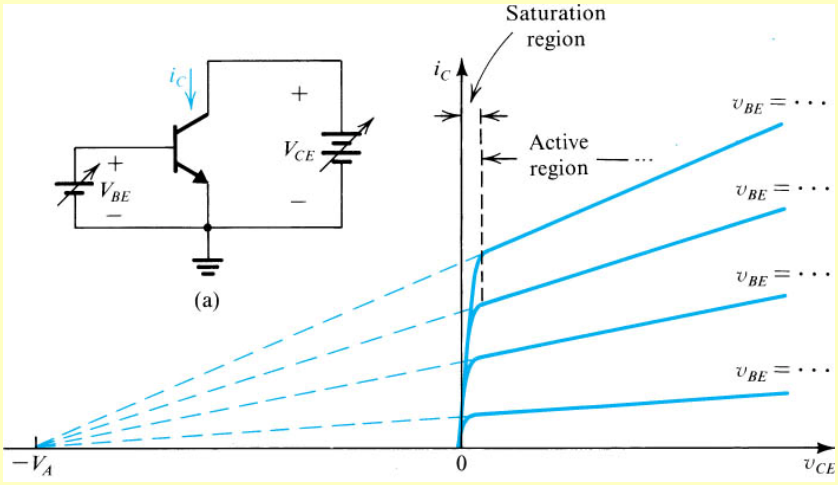
I-V Characteristics ($i_C - v_{CE}$ Real)



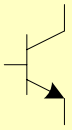


i_C increases with v_{CE} due to the Early effect

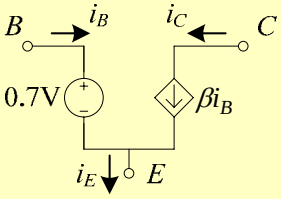
Early Effect and Early Voltage (V_A)

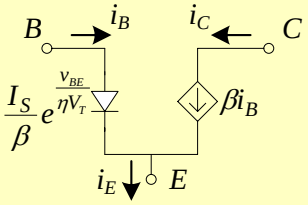


NPN BJT Models in the Active Region - Summary

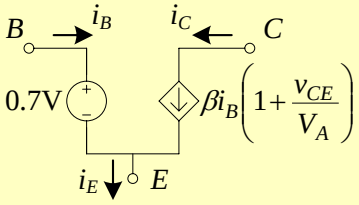


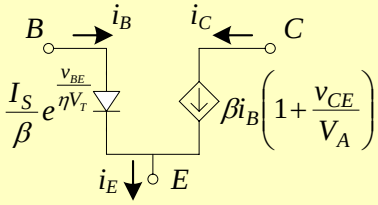
Neglecting the Early effect:





Considering the Early effect:





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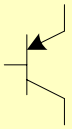
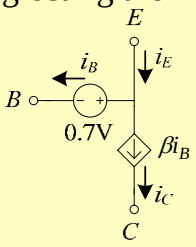
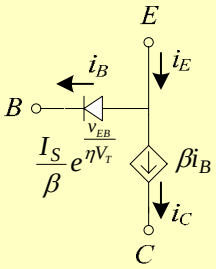
PNP BJT Models in the Active Region - Summary

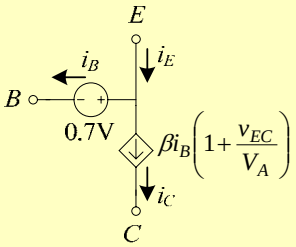


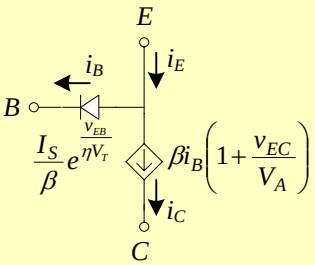
Neglecting the Early effect:





Considering the Early effect:





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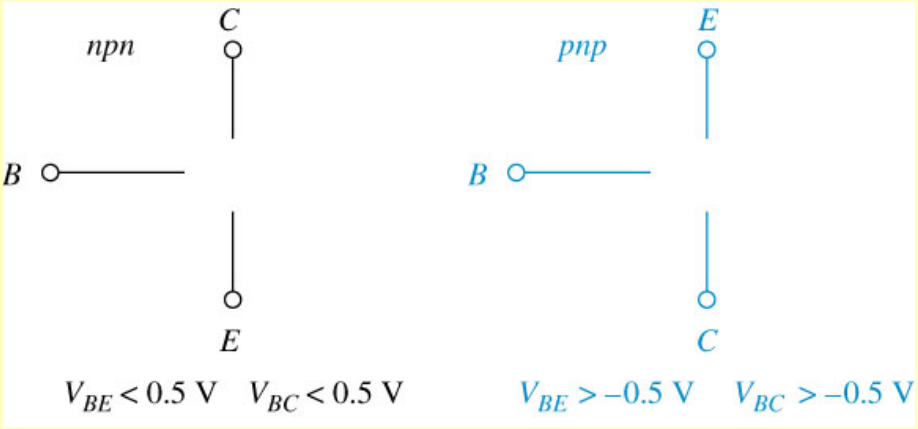
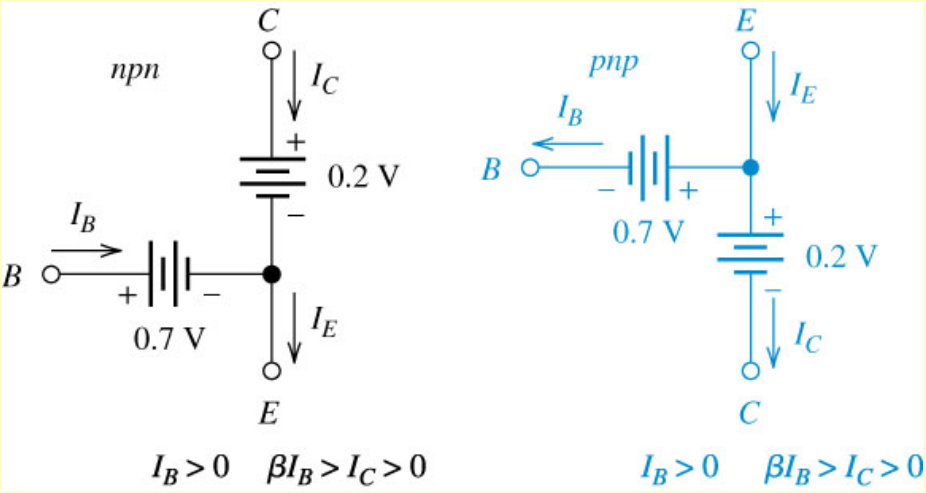
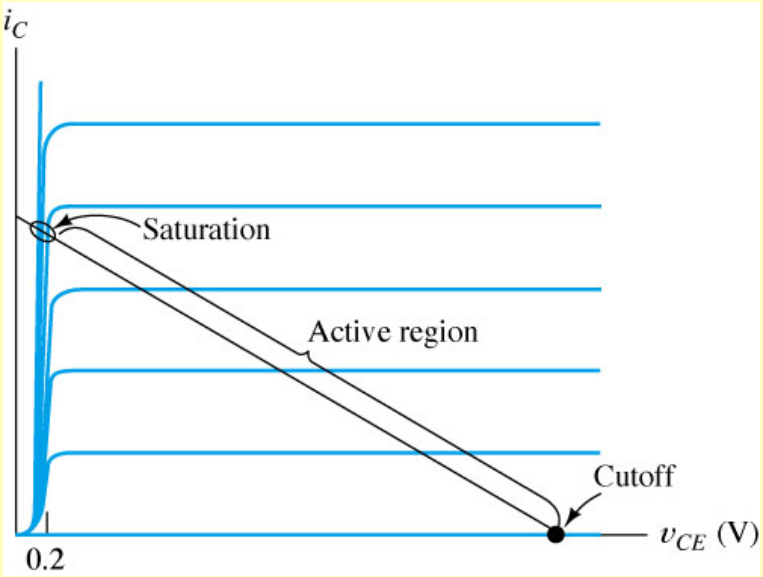
BJT Models for the Cutoff Region



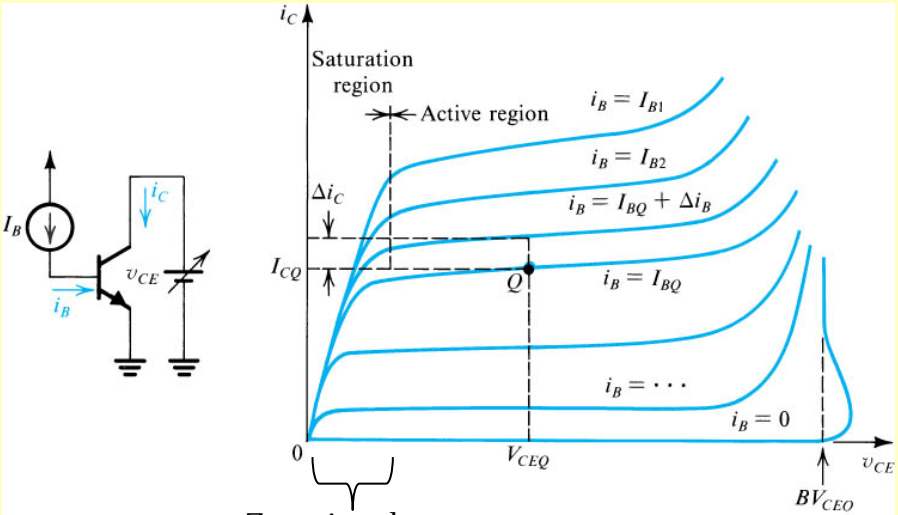
BJT Models for the Saturation Region



i_C-v_{CE} Characteristics

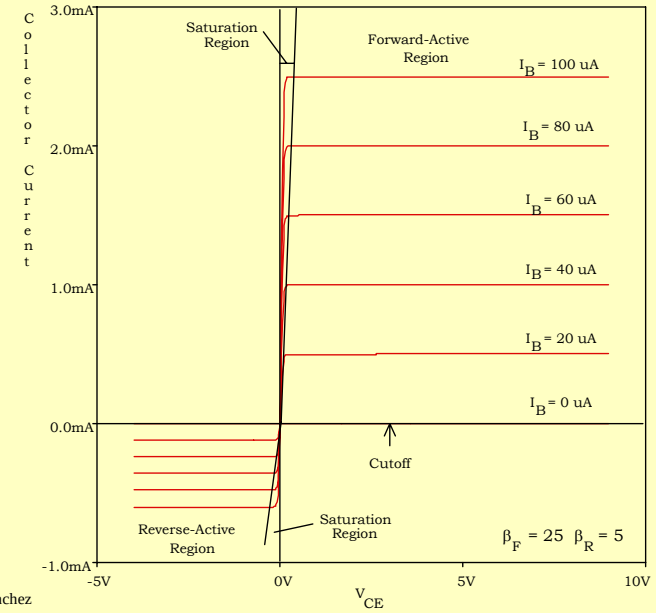


i_C-v_{CE} Characteristics Including Breakdown

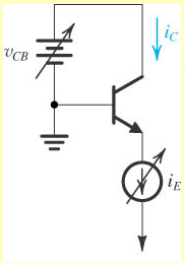


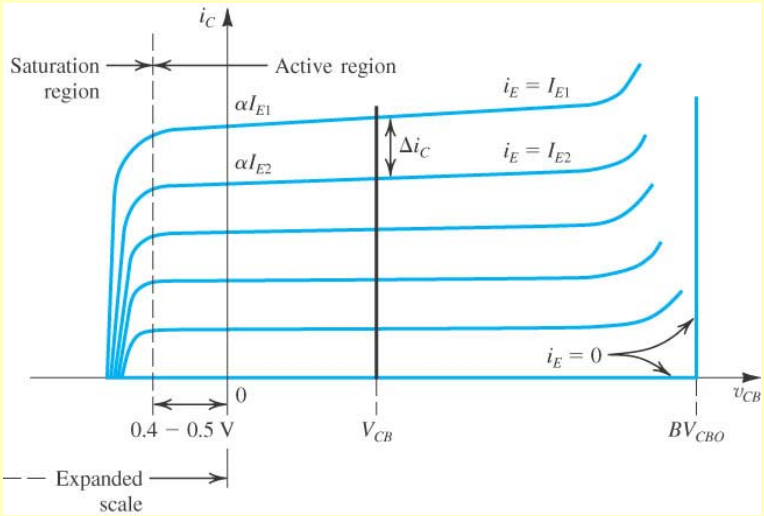
Zooming the saturation region

Active Region *vs* Inverted Active Region)

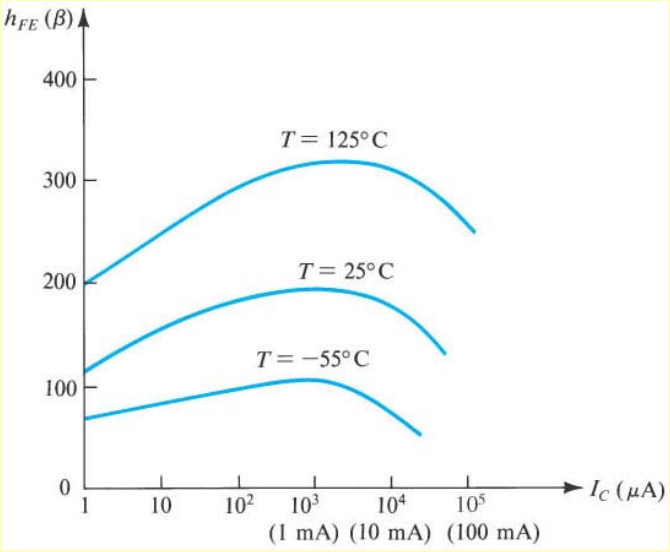


i_C-v_{CB} Characteristics





Typical Variation of β with I_C and Temperature



Variation of β with I_C – An Example