# *Bipolar Junction Transistor Characteristics*

# Bipolar Junction Transistors

- **Bipolar Junction Transistor (BJT) key transistor device**
  - **Formed by closely spaced pn junctions separated by narrow base**
  - **Carriers commonly injected from emitter through narrow base to collector**
  - **Small amount of carriers recombine in base to generate small base current**
  - **Emitter injection efficiency $\gamma$ also significant source of base current**
  - **Generates large DC current gain $\beta$ (or $h_{FE}$) given by $I_C/I_B$**
  - **Bipolar transistors may be formed by using a *pnp* or *npn* device**

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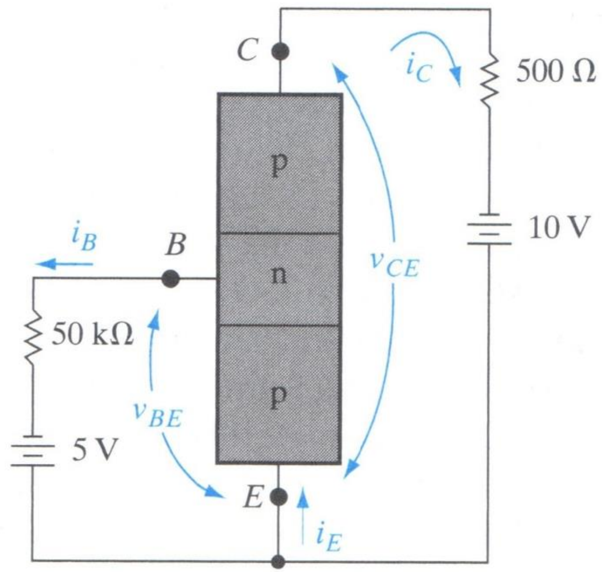
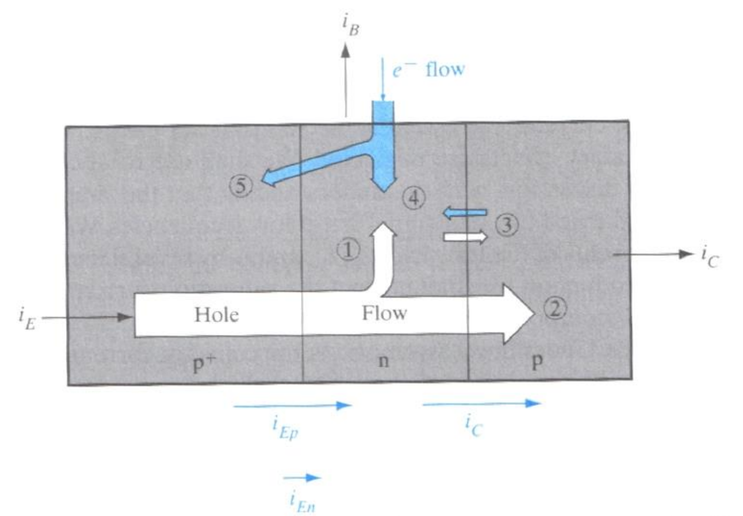
- **Common emitter most widely used BJT configuration**
  - **Common emitter configuration commonly used as amplifier or switch**
  - **Emitter-base junction commonly forward biased and base-collector junction reversed biased in active mode to achieve high current gain**
  - **Can create amplifier in this mode using large gain**
  - **Also can cutoff device by reverse biasing both junctions**
  - **Can also drive into saturation by forward biasing junctions**
  - **Can create switch by driving device from cutoff (OFF) to saturation (ON)**
  - **Inverted mode with junctions reversed from active mode is not commonly optimized to achieve high level of performance and is seldom used**

# Bipolar Junction Transistors




***Amplification in bipolar common emitter circuit configuration (left) caused by (1) hole recombination in base, (2) holes injected from emitter into the collector, (3) reverse saturation current at collector junction, (4) base current, and (5) electrons injected into emitter (right).***

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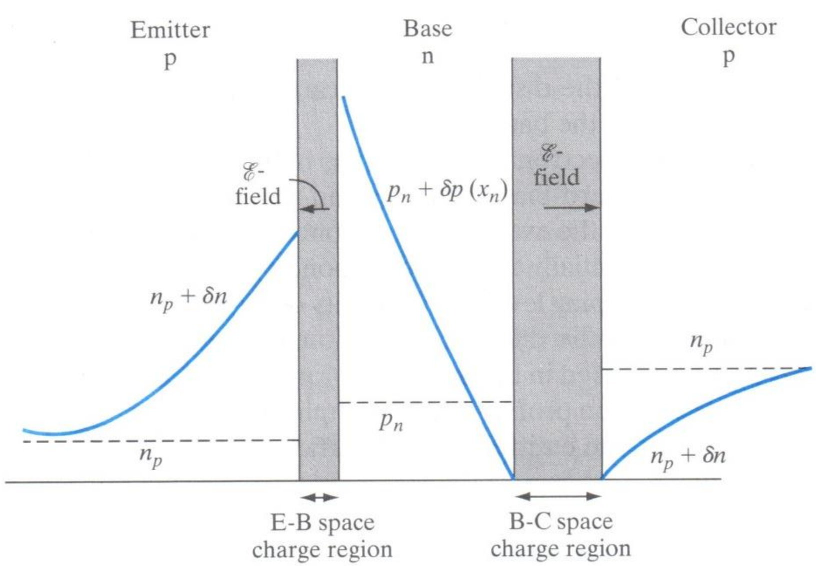


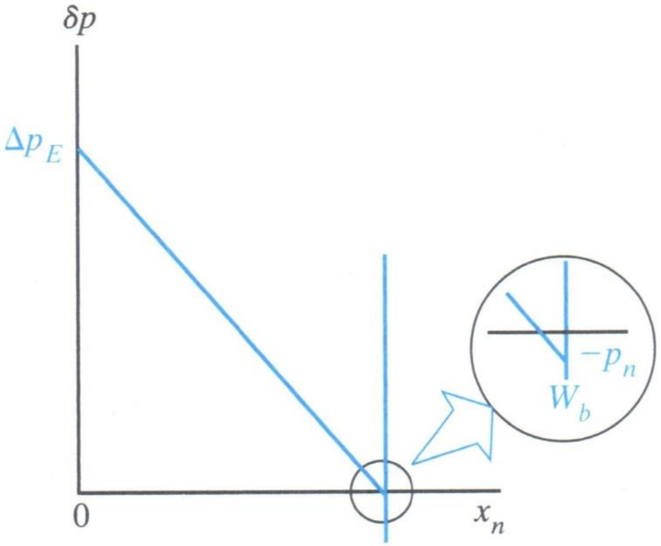


***Electron and hole distribution generated across a bipolar transistor (left) and more realistic representation of hole distribution in the base (right).***

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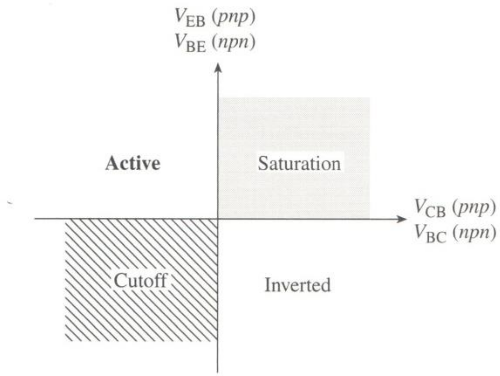
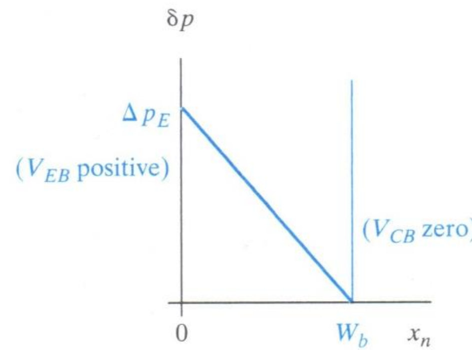
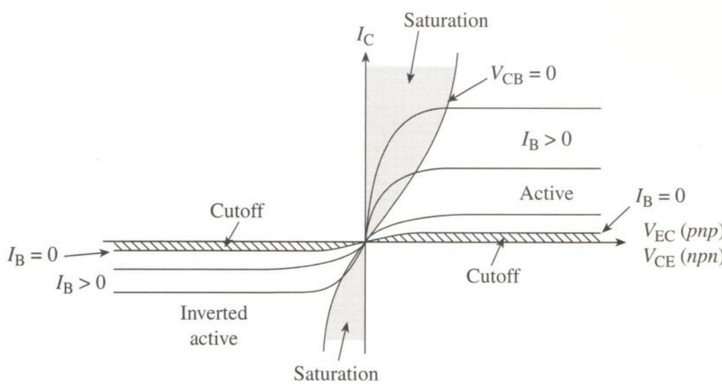
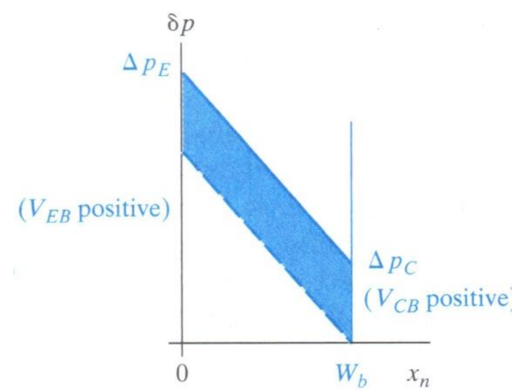
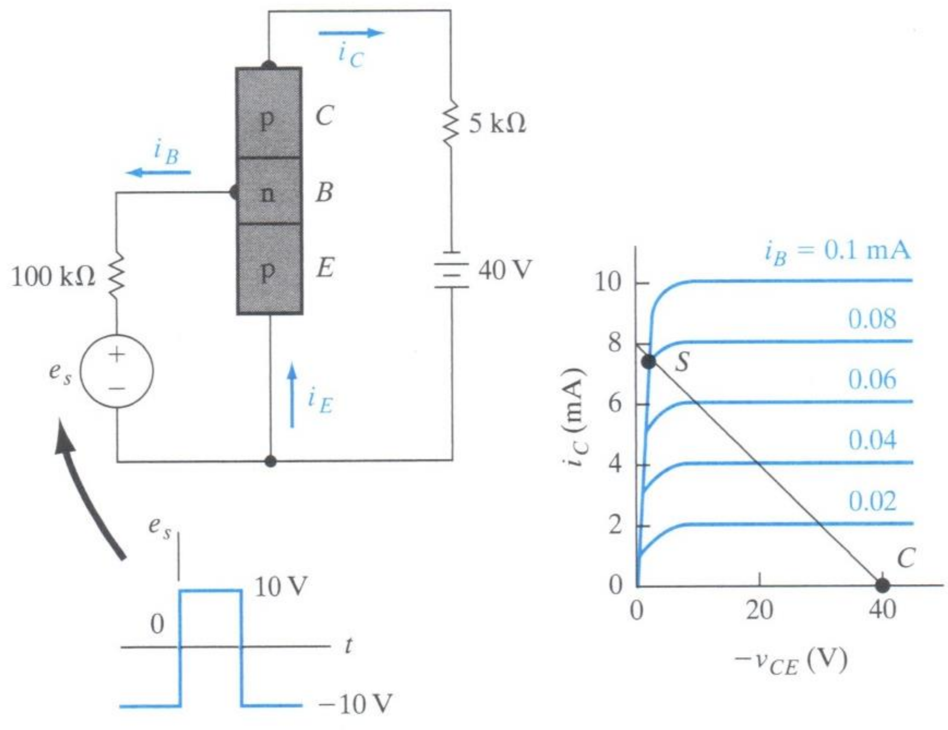


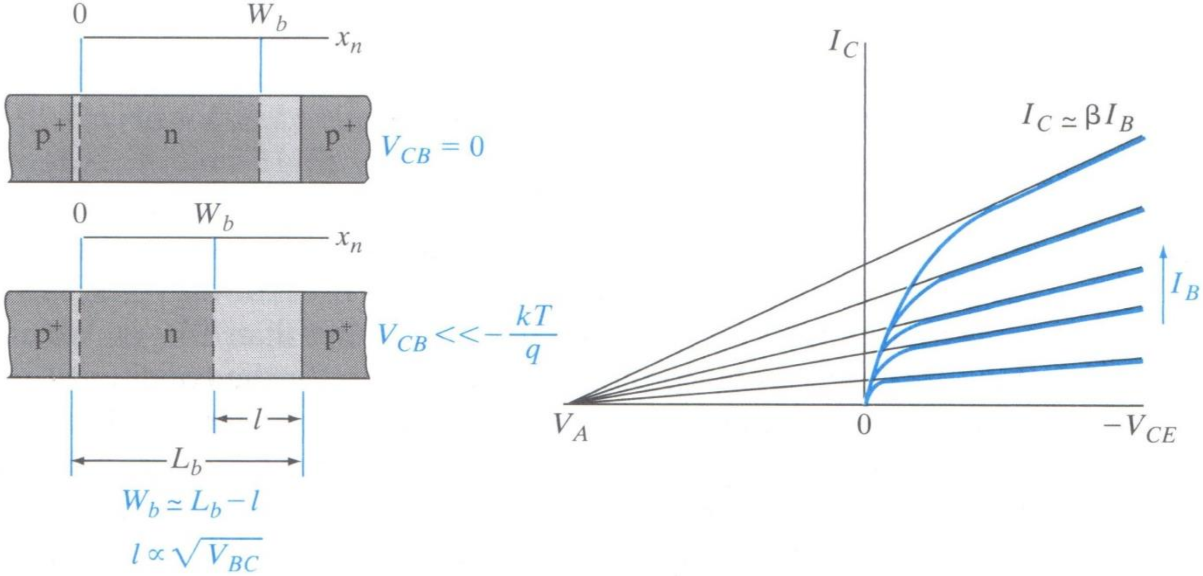




***Four biasing modes of a bipolar device (upper left), regions of bipolar output characteristics associated with biasing modes (lower left), hole distribution at saturation when $V_{CB}$ = 0 (upper right), and hole distribution caused by oversaturation when $V_{CB}$ becomes positive (lower right).***



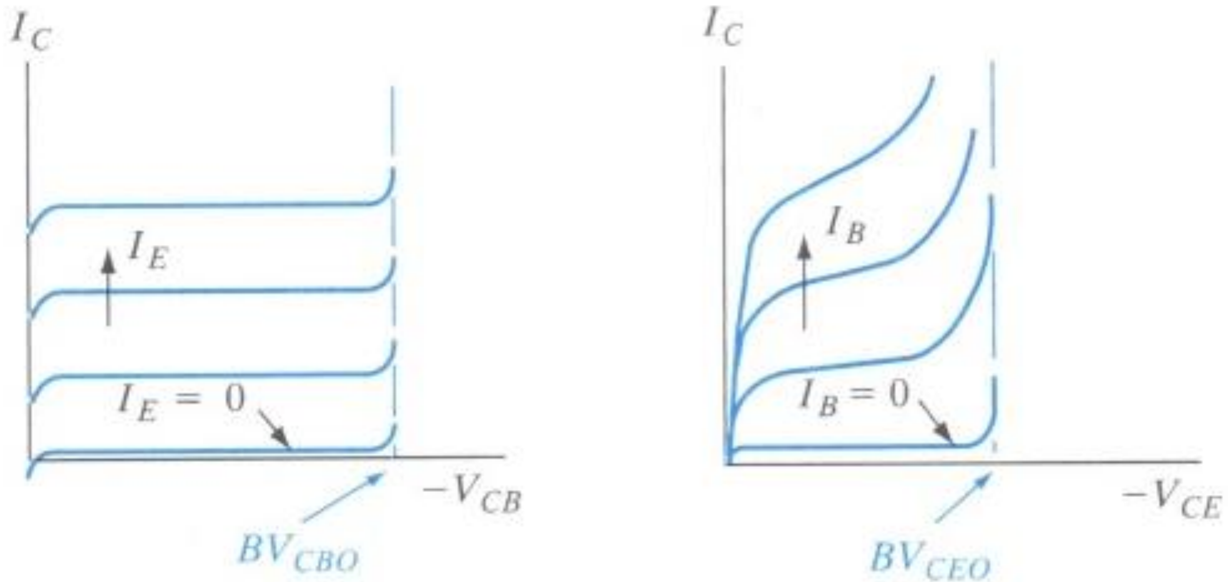

*Biasing circuit used to switch bipolar device in common emitter configuration (left) and resultant output characteristics showing response of this device as it varies from cutoff (C) through saturation (S) (right).*

- Early effect caused by base narrowing at increasing reverse bias
  - Increases $I_C$ at increasing $V_{CE}$ as base narrows
  - Causes upward slope of $I_C$-$V_{CE}$ characteristic in active region
  - Slope increases at increasing $I_B$ because of higher $I_C$ caused by current gain
  - Causes slope to intersect voltage axis at Early voltage $V_A$




*Base narrowing of p-n-p transistor (left) causing increase in collector current in the common emitter configuration (right). Output characteristics can be roughly extrapolated to an intersection at the voltage axis at the Early voltage $V_A$.*

- **BJT will also suffer avalanche breakdown at high voltage**
  - **Common base configuration with $I_E = 0$ will undergo avalanche breakdown at $BV_{CBO}$ near breakdown voltage of collector-base junction**
  - **Common emitter with $I_B = 0$ will undergo breakdown at even lower voltage**
  - **Caused by carriers with the same carrier type as the base being swept back into the base after impact ionization in the collector junction**
  - **Causes increase in emitter current to compensate increased charge in base**
  - **Higher emitter current causes even more avalanche multiplication at collector junction lowering $BV_{CEO}$ for common emitter compared to $BV_{CBO}$**




***Avalanche breakdown occurring at $BV_{CBO}$ in common base configuration at $I_E = 0$ (left) and at $BV_{CEO}$ in common emitter configuration at $I_B = 0$ (right).***

- **Will evaluate five different BJT characteristics**
  - **DC current gain $h_{FE}$ given by $I_C/I_B$**
  - **Small-signal current gain $h_{fe}$ given by $\Delta I_C/\Delta I_B$**
  - **Output conductance $h_{oe}$ given by $\Delta I_C/\Delta V_{CE}$**
  - **Early effect as represented by the Early voltage $V_A$**
  - **Breakdown voltage given by $BV_{CEO}$**

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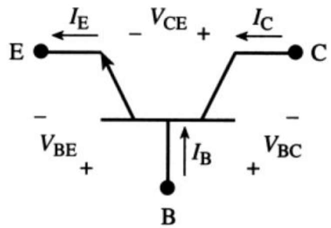
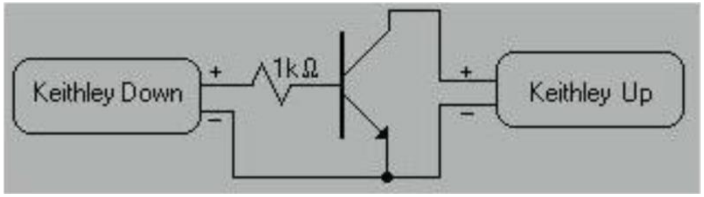


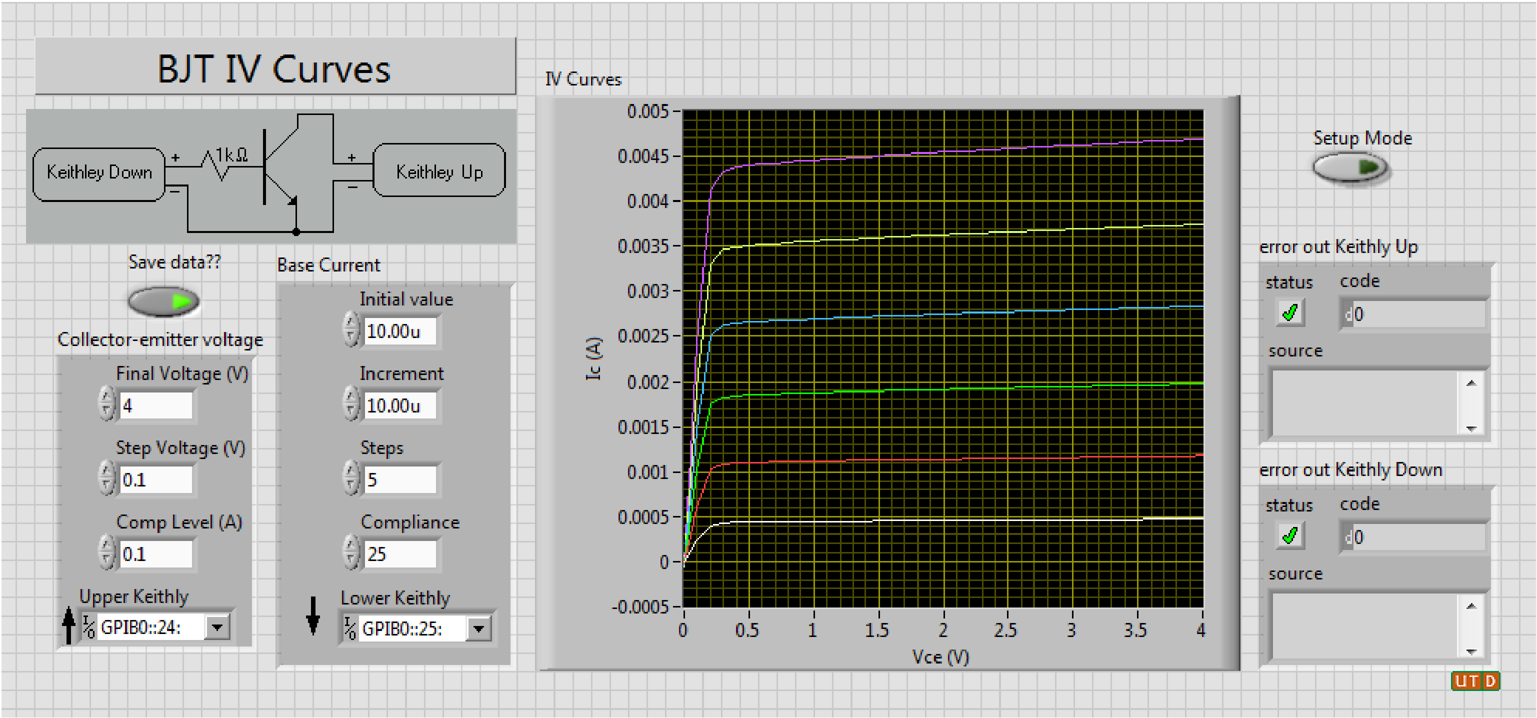

*Pin configuration for 2N4400 NPN transistor (upper left), NPN transistor symbol (upper right), and common emitter test circuit (bottom)*

## *Relevant Measurements:*

1) $h_{FE} = I_C/I_B$ *(DC Current Gain at $V_{CE}$)*
2) $h_{fe} = \Delta I_C / \Delta I_B$ *(AC Current Gain at $V_{CE}$)*
3) $h_{oe} = \Delta I_C / \Delta V_{CE}$ *(Conductance at $I_B$)*
4) *Create Tables for Various Parameters*

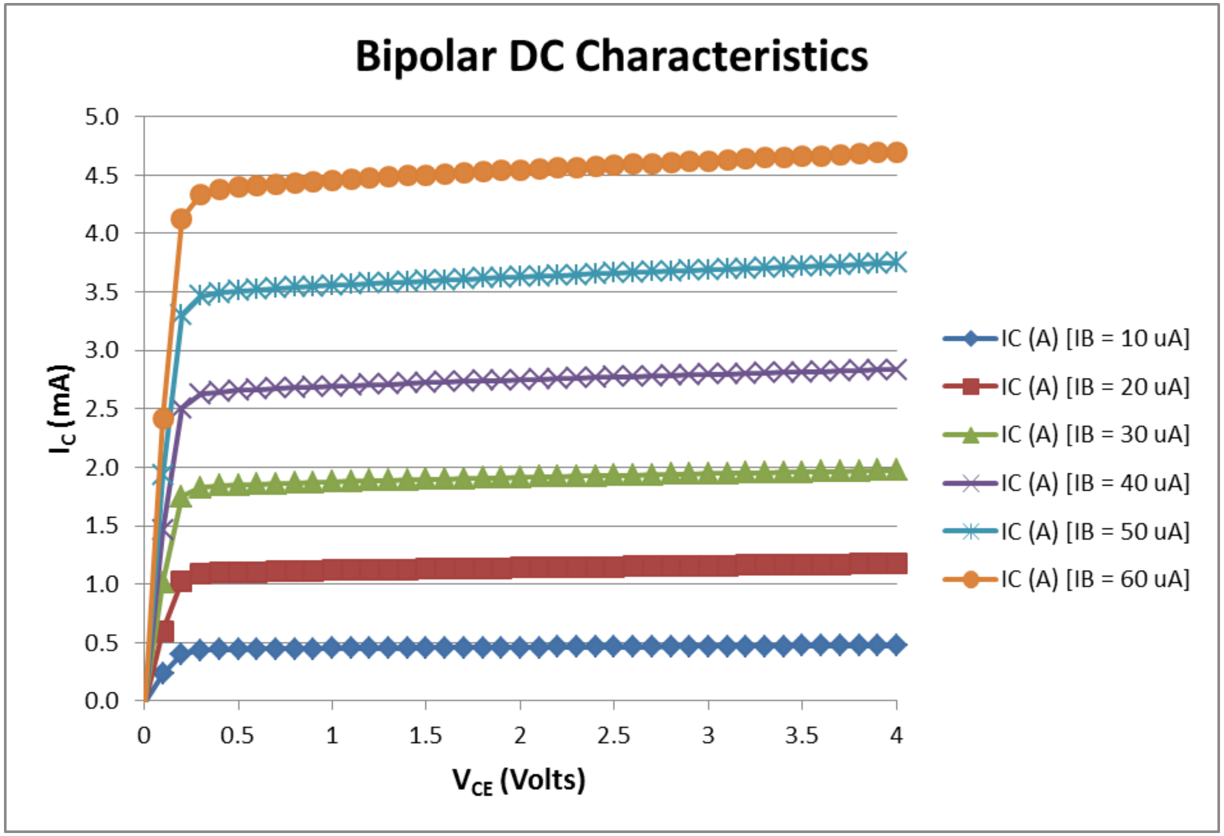
*DC Current $I_C$ and current gain $h_{FE}$ measured at different $I_B$ versus $V_{CE}$*

| $I_B$ [μA] | 10 | | 20 | | 30 | | 40 | | 50 | | 60 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $V_{CE}$ | $I_C$ | $h_{FE}$ | $I_C$ | $h_{FE}$ | $I_C$ | $h_{FE}$ | $I_C$ | $h_{FE}$ | $I_C$ | $h_{FE}$ | $I_C$ | $h_{FE}$ |
| 1 V | | | | | | | | | | | | |
| 2 V | | | | | | | | | | | | |
| 3 V | | | | | | | | | | | | |
| 4 V | | | | | | | | | | | | |



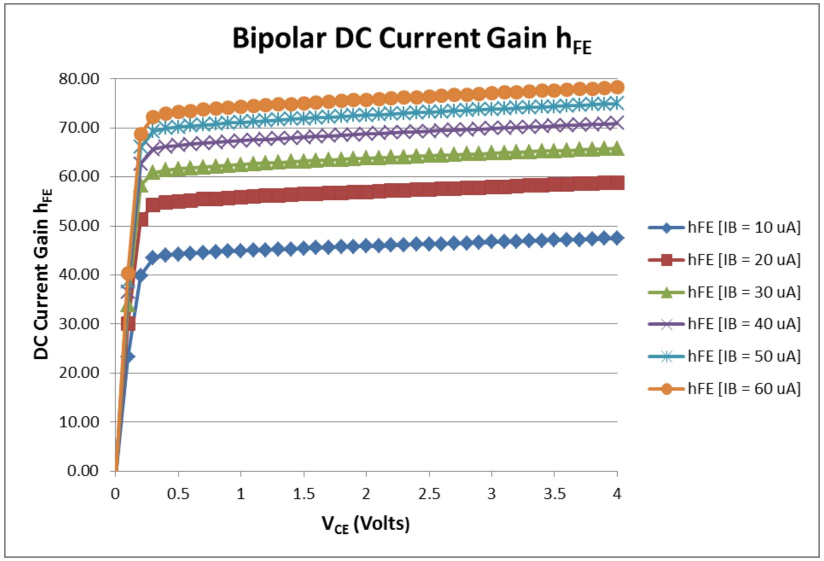

*Bipolar $I_C - V_{CE}$ Test Curves*

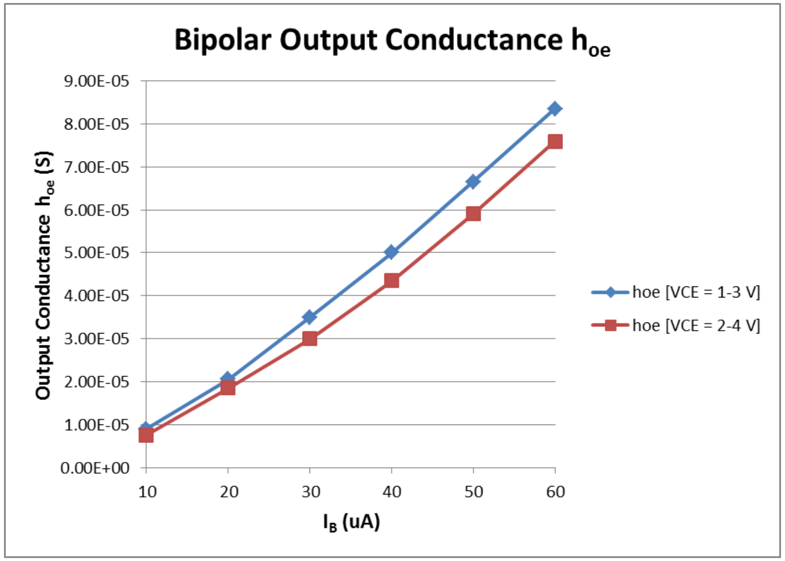
# Bipolar Junction Transistors



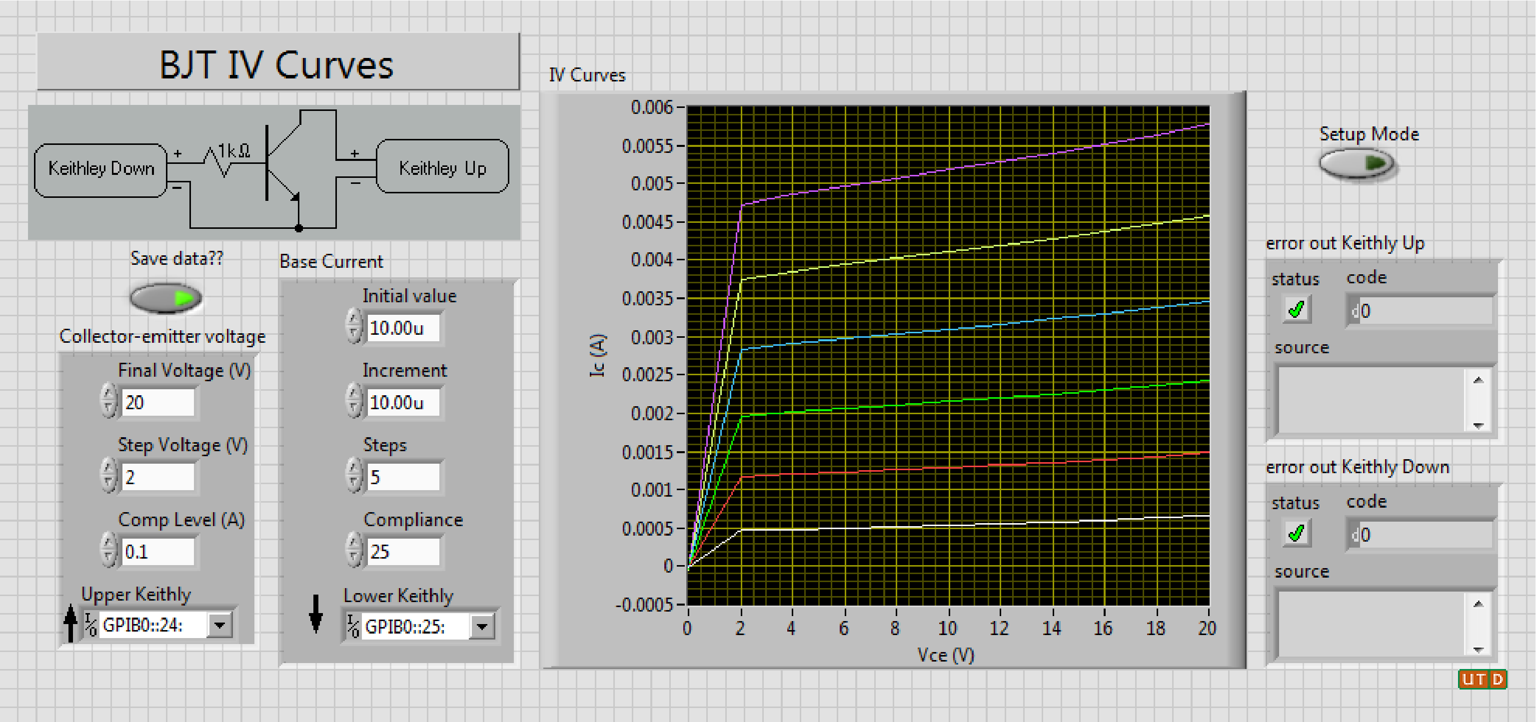

*Bipolar $I_C - V_{CE}$ DC Characteristics*

# Bipolar Junction Transistors

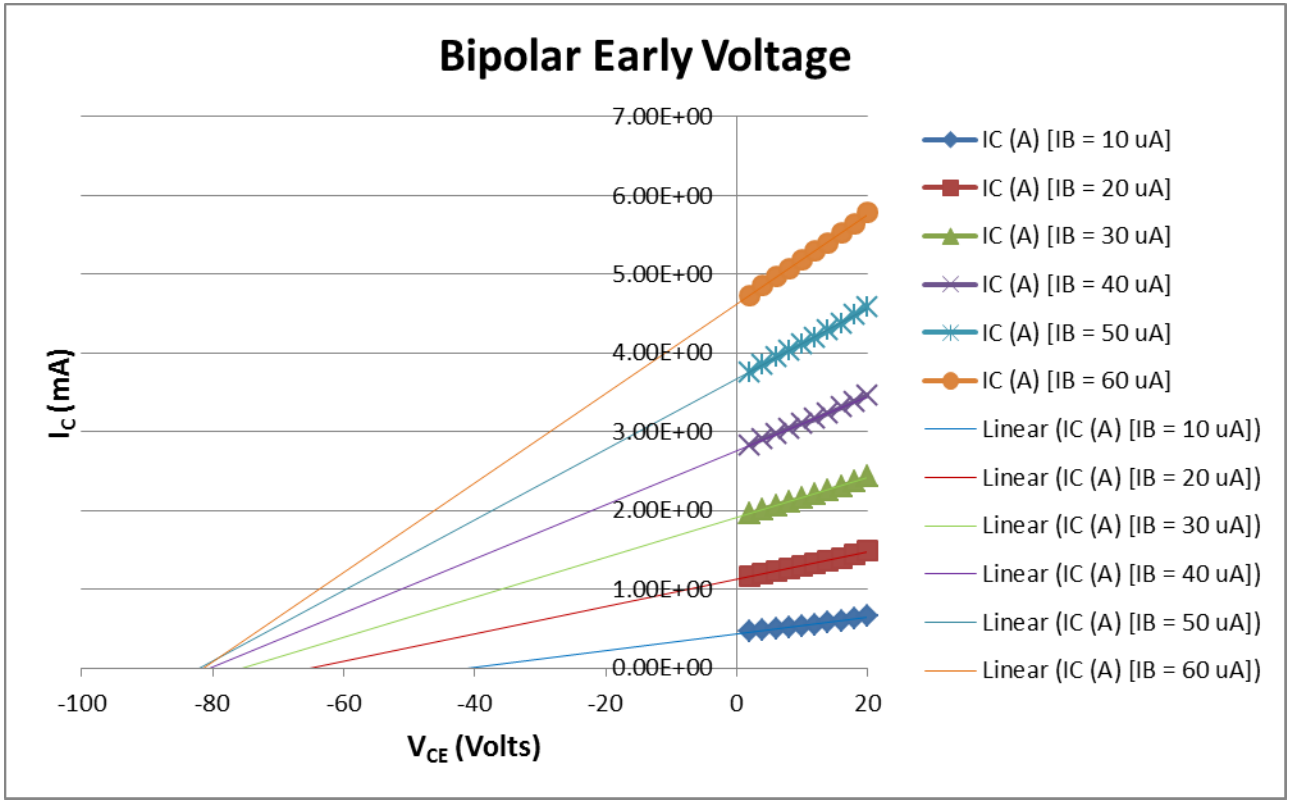


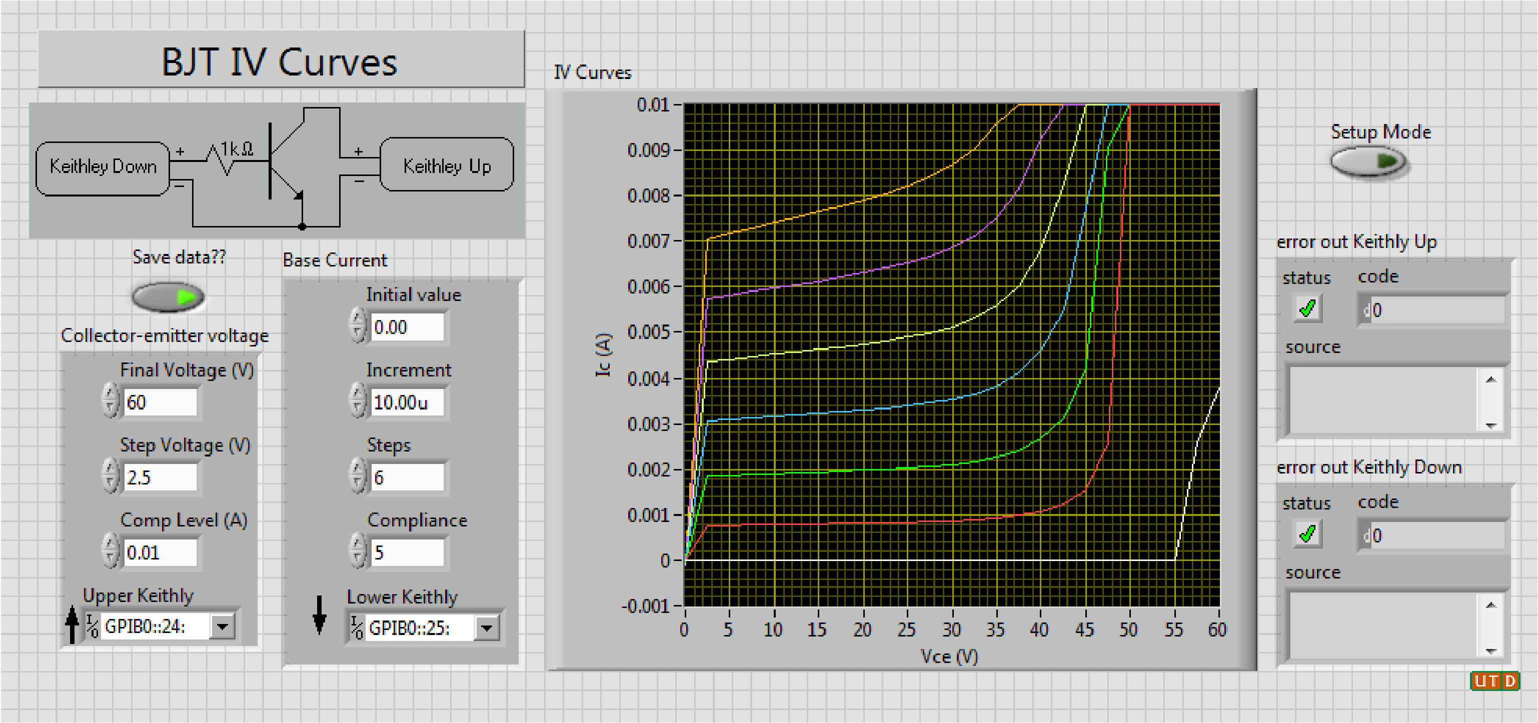

***DC current gain $h_{FE}$ calculated at increasing $I_B$ versus $V_{CE}$ (left) and output conductance $h_{oe}$ measured between two voltages calculated at increasing $V_{CE}$ versus $I_B$ (right).***



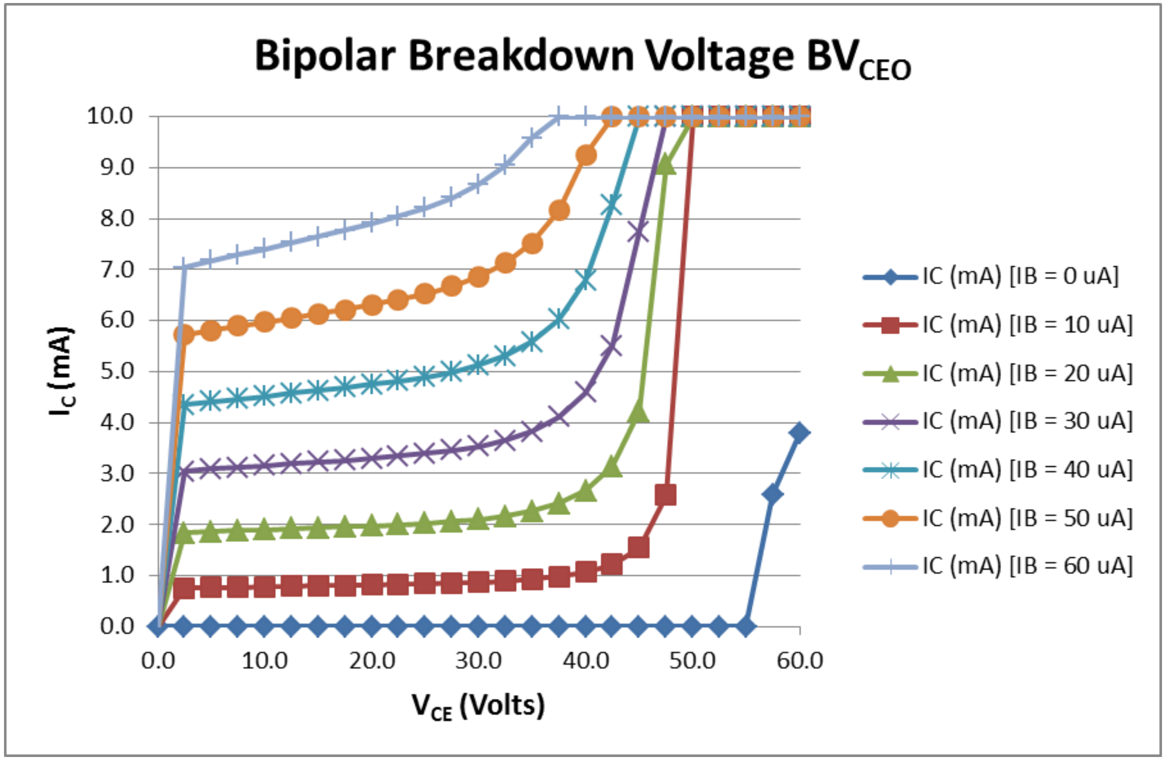

*Bipolar Early Voltage Test Curves*




***Bipolar $I_C$ – $V_{CE}$ DC Characteristics Used to Extract Early Voltage***




*Bipolar Common Emitter Breakdown Characteristics*




***Bipolar Breakdown Characteristics Used to Determine Breakdown Voltage $BV_{CEO}$***