Many bipolar junction transistors (BJTs) and field-effect transistors (FETs) are used as nonlinear devices where the collector current \( I_C \) is a strong function of the base-emitter voltage \( V_{BA} \). Weakly nonlinear devices are characterized as "small" in terms of the bias current \( I_B \).

Common examples include BJT, JFET, vacuum tube, MOSFET, etc.

- **BJT**: John Bardeen, Wiliam Shockley, and Walter Brattain worked on these devices in the 1940s.
- **JFET**: Reber, Shockley, and Bardeen at Bell Labs created the first JFET in 1950.
- **MOSFET**: Basic MOSFETs were invented in 1960.
- **Vacuum Tube**: Edwin H. Armstrong and others developed vacuum tubes in the early 20th century.

Electrical quantities and functions:

- **Input Voltage**: \( V_{in} \)
- **Input Current**: \( I_X \)
- **Output Voltage**: \( V_{out} \)
- **Bias Voltage**: \( V_{BA} \)
- **Collector Current**: \( I_C \)

**Diagram:**

- **Diode symbol**: Represents a single diode.
- **Transistor symbol**: Shows a transistor with its connections.
- **Current sources**: Indicate the direction and magnitude of current flow.

**Equations and Analysis:**

- \( V_{X} \) is some kind of turn-on voltage (almost linear, sharp), sometimes negative.
- \( V_{BA} \) is constant.

**Output Voltage Calculation:**

\[
V_{out} = V_{in} - V_{BA}
\]

**Source Follower, Emitter Follower, Cathode Follower:**

- **Source Follower**: 
  \[
  I_C = I_X = \frac{V_{in}}{R}
  \]
- **Emitter Follower**: 
  \[
  V_{out} = V_{in}
  \]
- **Cathode Follower**: 
  \[
  V_{out} = V_{in} - V_T
  \]

**Graph:**

- **Graph 1**: Shows the relationship between \( I_C \) and \( V_{BA} \).
- **Graph 2**: Illustrates the effect of \( V_{secret} \) on \( I_C \).

**Further Details:**

- **Linearization**: Large signal, operating point, small signal, device physics, frequency response.
Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

Do \( V_{b1} \) and \( V_{b2} \) matter much? Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

I\( _x \) passes through \( V_t \)

\[ V_{out} = \max (V_{m1}, V_{m2}) - V_t \]

\[ V_{tail} = \max (V_{m1}, V_{m2}) - V_t \]

Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

\[ I_x = g_m \delta V_n \]

\[ V_{in} = V_{out} \]

Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)

Why not just calculate it directly?

\[ V_o = V_{cc} - I_0 R \]

\[ I_c = I_s \left( e^{v_c/v_m} - 1 \right) \left( 1 + \frac{V_{CE}}{V_A} \right) \]

Simple BJT model

\[ V_o = V_{cc} - R I_s \left( e^{v_c/v_m} - 1 \right) \left( 1 + \frac{V_{CE}}{V_A} \right) \]

Painful to solve by hand

Easy for computers

\[ g_0 \delta V_{out} = -\delta I = -g_m \delta V_n \]

\[ \frac{\delta V_{out}}{\delta V_{in}} = -\frac{g_m}{g_0} = -9 \]

\[ \delta I = g_m \delta V_n \]

\[ V_{in} = V_{out} \]

Do \( V_{b1} \) and \( V_{b2} \) matter much? not as long as they are \( > V_{tail} + V_t \)
Closed form equations

unsolvable by hand
(easy for computer & DC sweep)

Linearization gives very accurate answer as long as you set the Region of Operation right.

\[ I_D = \begin{cases} 0 & \text{if } V_{GS}, V_{DS} \\
\frac{V_{GS} (V_{GS} - V_T)^2 (1+2V_{DS})}{L} & \text{otherwise} \end{cases} \]

\[ I_D(V_{GS}, V_{DS}) = I_D \]

At some point, \( V_{GS}, V_{DS} \)

\[ I_D(V_{GS} + \Delta V, V_{DS} + \Delta V) = I_D + \left. \frac{\partial I_D}{\partial V_{GS}} \right|_{V_{GS} + \Delta V, V_{DS}} \Delta V_{GS} + \left. \frac{\partial I_D}{\partial V_{DS}} \right|_{V_{GS} + \Delta V, V_{DS}} \Delta V_{DS} \]

\[ = I_D + g_m \Delta V + g_D \Delta V_{DS} \]

Linearization (Taylor)

\( f(x, y) \) continuous, \( f(x_0, y_0) = F_0 \)

best approx to \( f \) near \( x_0, y_0 \)

\[ f(x_0 + \Delta x, y_0 + \Delta y) = f(x_0, y_0) + \left. \frac{\partial f}{\partial x} \right|_{x_0, y_0} \Delta x + \left. \frac{\partial f}{\partial y} \right|_{x_0, y_0} \Delta y \]

\[ = F_0 + (x \text{ slope}) \Delta x + (y \text{ slope}) \Delta y \]