First-Time User Guide
BJT Lab V2.0

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Introduction: What is a BJT?

-Bipolar Junction Transistor (BJT): Three-terminal device used for amplifying or switching

BJT can be $npn$ or $pnp$ depending on doping.

$n/N/n+$: donor impurities

$p/P/p+$: acceptor impurities
Introduction: Working of a BJT

- Functioning of BJT: current controlled current regulators
- Base current: controlling current
- Emitter-collector current: controlled current

Refer to [1] https://nanohub.org/resources/5084/ for detailed information about the operation of BJT.
What Can Be Simulated in BJT Lab?

Different structure and operation modes of BJT

- Simulate *npn* or *pnp* BJT structure
- Simulate BJT in common emitter or common base operation mode
- Design the device structure
What Can Be Simulated in a BJT Lab?

Material parameters for BJT simulation

Specify material and minority carrier lifetimes

Specify doping level for Emitter, Collector, and Base regions
**What Can Be Simulated in BJT Lab?**

### Output Plots from BJT Lab

- **Gummel plot input deck**
  - Gummel plot is useful in extracting beta, $\beta$ parameter for a BJT device

### Gummel Plot

<table>
<thead>
<tr>
<th>Structure</th>
<th>Materials</th>
<th>Gummel Plot</th>
<th>Output Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applied Collector Voltage, $V_c$ (for Gummel Plot)</td>
<td>3.5V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Emitter Voltage start value, $V_{em}$</td>
<td>0V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Emitter Voltage and value, $V_{em}$</td>
<td>0V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Base Voltage start value, $V_{bb}$</td>
<td>0V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Applied Base Voltage and value, $V_{bb}$</td>
<td>0V</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Number of data points: 12

- **Output Characteristics**
  - Useful in determining output resistance, early voltage, etc.

Set position for 1D plot less than X1 to view Emitter profile!
What If You Just Hit “Simulate”?

BJT Lab simulates the default input deck

Default device:
NPN type BJT in common emitter mode

<table>
<thead>
<tr>
<th>Result</th>
<th>Emitter</th>
<th>Base</th>
<th>Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Band Diagram (at final bias)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electron density and Hole density (at equilibrium)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Charge Density (at equilibrium)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrostatic Potential (at equilibrium)</td>
<td></td>
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<td>Energy Band Diagram (at final bias)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric Field (at equilibrium)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recombination Rate (at equilibrium)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Density vs. Position (at final bias)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guassian Plot</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Output Characteristics</td>
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</tbody>
</table>

Input Parameters

- Output Log

Download

<table>
<thead>
<tr>
<th>Length (µm)</th>
<th>Emitter</th>
<th>Base</th>
<th>Collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Doping (/cm³)

- Emitter: \(1 \times 10^{19}\)
- Base: \(1 \times 10^{18}\)
- Collector: \(1 \times 10^{17}\)
What If You Just Hit “Simulate”? 

**Gummel Plot**
- $I_{\text{collector}}$ and $I_{\text{base}}$ vs. $V_{\text{eb}}$.
- Users can extract the beta or $h_{\text{fe}}$ parameter $\beta = \frac{I_{\text{collector}}}{I_{\text{base}}}$.

**Output Characteristics ($I_{\text{collector}}$ Vs $V_{\text{collector-emitter}}$)**
- The relatively flat region is the active region.
- The slope of $I_c$ vs. $V_{\text{ce}}$ is output (or collector) resistance, $R_s$. 

$\beta \sim 56.8$

$R_s \sim 11.8 \, \text{k}\Omega$
What If You Just Hit “Simulate”? 

Current density vs. position 1D plot

- Emitter: x=0-0.05μm
- Base: x=0.05-0.15μm
- Collector: x=0.15-1.15μm
- Reduction in current density due to flaring out of collector current into larger region

Some of the base hole current recombines with electron current & rest drifts towards Emitter contact.

Electron current

Hole Current

Emitter Base Collector

Small controlling current large controlled current
Examples: What if the Collector Doping is Changed?

Changing collector doping to $1 \times 10^{19} /\text{cm}^3$

<table>
<thead>
<tr>
<th>Length ($\mu$m)</th>
<th>Emitter</th>
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<th>Collector</th>
</tr>
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<tr>
<td>0.05</td>
<td>$1 \times 10^{19}$</td>
<td>$1 \times 10^{18}$</td>
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</tbody>
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Base width modulation or early effect

Refer to [1] [https://nanohub.org/resources/5084/](https://nanohub.org/resources/5084/) for detailed information about the operation of BJT.
Examples: What if the Base Width is Changed?

Changing base width to 0.2 µm

<table>
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<tr>
<td>Length (µm)</td>
<td>0.05</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>Doping (/cm³)</td>
<td>1×10¹⁹</td>
<td>1×10¹⁸</td>
<td>1×10¹⁷</td>
</tr>
</tbody>
</table>

Increasing base width leads to smaller current gain factor.

Refer to [1] https://nanohub.org/resources/5084/ for detailed information about the operation of BJT.

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Tool Limitations and Comments

- Large physical dimensions (>10 \( \mu \text{m} \)) might lead to non-convergence or large compute time.
- Take note that while plotting the 1D plot, the distance needs to be smaller than \( X_1 \) (defined in Structure tab) to view the emitter region profile.
- Take note of the applied voltage values signs, while working with npn and pnp type.
References

BJT Theory

• [1] BJT OPERATION: https://nanohub.org/resources/5084/
• PADRE

If you reference this work in a publication, please cite as follows:

Saumitra Raj Mehrotra; Abhijeet Paul; Gerhard Klimeck; Dragica Vasileska (2008), "BJT Lab," DOI: 10254/nanohub-r3984.7.

We welcome comments about this tool, including those about problems using the tool. Please submit via the following link: https://nanohub.org/resources/3984/reviews?action=addreview#reviewform