Digital Switch
Transistors

- Transistors can act as amplifiers or switches
- Amplifiers are generally more complicated circuits
  - Small voltage at base results in large voltage at collector
- Switches are often quite simple
  - Sufficient voltage at base results in sufficient voltage at the output and the switch is “on”
Bipolar Junction Transistor (BJT)

- Several operating conditions based on relative terminals voltages
  1. **Constant Current Region**: Collector-Emitter current is proportional but greater than Base current (not used in switch)
  2. **Saturation Region**: High current conduction (model as closed circuit)
  3. **Cut-off Region**: Low (zero) current conduction, model as open circuit

<table>
<thead>
<tr>
<th>Applied voltages</th>
<th>Mode (NPN)</th>
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<tr>
<td>E &lt; B &lt; C</td>
<td>Constant Current</td>
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<tr>
<td>E &lt; B &gt; C</td>
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BJT Inverter Circuit

- **Vinput >0 puts BJT in Saturation Mode**
  - Vout is zero, since all the voltage from Vcc is lost across resistor
  - Switch is open or off
- **Vinput < 0 puts BJT in Cut off Mode**
  - Vout is Vcc, since there is no current and no voltage loss across the resistor
  - Switch is closed or on

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BJT Voltage Follower Circuit

- **Vin** > 0 puts BJT in Saturation Mode
  - Vout is Vcc, since transistor is like a short circuit, Vout “sees” Vcc
  - Switch is closed or on
- **Vin** < 0 puts BJT in Cut off Mode
  - Vout is 0, since transistor is like an open circuit, there is no current and Vout “sees” ground
  - Switch is open or off

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Junction Field-Effect Transistor (JFET)

- Physics are very different from BJT, but operating conditions are similar
  1. Constant Current Region: Collector-Emitter current is proportional to $V_{GS}$ (not used in switch)
  2. Triode Region: High current conduction (model as closed circuit/resistor)
  3. Cut-off Region: Low (zero) current conduction, model as open circuit
- Note that JFETs operate differently than MOSFETs
  - $V_{GS} = 0$ gate will be open (default on device)
  - $V_{GS} < 0$ voltage decreases current till pinch at $V_{GS} < V_p$

### Applied voltages

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<td>$0 &gt; V_{GS} &gt; V_p$, $V_{DS} &gt; V_{GS} - V_p$</td>
<td>Constant Current</td>
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<td>$0 &gt; V_{GS} &gt; V_p$, $V_{DS} &lt; V_{GS} - V_p$</td>
<td>Triode/Saturation</td>
</tr>
<tr>
<td>$V_{GS} &lt; V_p \approx 3V$</td>
<td>Cut-off</td>
</tr>
<tr>
<td>$V_{GS} &gt; 0$</td>
<td>Never used, acts like diode between G and S. allows current flow</td>
</tr>
</tbody>
</table>

Note there is no gate resistor
JFET Inverter Circuit

- $V_{GS} < V_p$ puts JFET in Cut Off Mode
  - Vout is Vcc, since there is no current and no voltage loss across the resistor
  - Switch is closed or on
- $V_{GS} = 0$ puts JFET in Saturation Mode
  - Vout is zero, since all the voltage from Vcc is lost across resistor
  - Switch is open or off

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JFET Voltage Follower Circuit

- $V_{GS} < V_p$ puts JFET in Cut off Mode
  - Vout is 0, since transistor is like an open circuit, there is no current and Vout “sees” ground
  - Switch is open or off
- $V_{GS} = 0$ puts JFET Saturation Mode
  - Vout is Vcc, since transistor is an open circuit, Vout “sees” Vcc
  - Switch is closed or on
- In our testing, $V_{input} = 0$ doesn’t deliver enough power to light LED
  - Why? Extra Credit Problem! Details later

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DC Analysis

- Similar equipment and VIs to last week
- `lv_curve.vi` uses 1 source meter connect to LED and series resistor
  - Sweep -5V to 5V, steps of 0.5V
- `BJT_iv_curve.vi` uses 2 source meters
  - One connected to +Base/-Emitter
  - One connected +Collector/-Emitter
  - Do not use a resistor Rc at the collector! (see diagram on VI)
- `FET_iv_curve.vi` uses 2 source meters
  - One connected to +Gate/-Source
  - One connected +Drain/-Source
- Select GPIBO from the pulldown menu
  - Top SM is #24, bottom SM is #25

Image from http://www.hardwaresecrets.com
DC Analysis

Parameters for JFET VI

For BJT VI, use default parameters
AC Analysis

• Set Freq to 1Hz to see LED flash, but scope has trouble with such a slow signal

• Set Freq. to 60Hz for screen capture, but LED can’t respond this fast, so it just stays on.

• For BJT Inverter and Voltage Follower use sine wave 0V to 5V

• For JFET Inverter use square wave -5v to 0V

• For JFET, Volt. Follower use square wave -5v to 0V
  • LED will flash, but it is very dim
  • Change max to +1V, it should be brighter (try +2V if still dim)
  • Stop Power Supply output (i.e.\(V_{DD}=0\)), LED should turn off
  • With \(V_{DD}=0\), increase DC offset on square wave, LED is on with \(V_{DD}=0\). JFET is acting like a diode, not a switch!
Extra Credit Problem

• Why do we need to use +1V and not 0V to light the LED in the JFET Voltage Follower but not the Inverter?

• Why don’t you need to change the $V_{\text{max}}$ or $V_{\text{min}}$ for the BJT voltage follower from the Inverter?

• HINT 1 – Look at the KVL for different JFET circuits

• HINT 2 – Look at the equations for $I_{\text{ssat}}$ in the JFET and $I_E$ in the BJT

\[ I_{\text{DSAT}} = I_{\text{DSS}} \left(1 + \frac{V_{\text{GS}}}{V_P}\right) \quad I_E = \alpha I_C + I_{\text{EO}} \left( e^{-\frac{V_{\text{BE}}}{kT}} - 1 \right) \]

constants

constants