1) $V_o = 3V \Rightarrow I_e = 200\mu A \Rightarrow V_s - V_{SB} = 200mV

V_T = V_{TH} + V_T (\frac{-2\overline{V}_{BE} + V_{BE}}{1})
= 0.7 + 0.5 \frac{1.1}{1.0 - 1}
= 747.7mV

\frac{1}{2} \mu m C_{ox} \frac{V}{2} (V_{SB} - V_T)^2 = 200 \mu A
\frac{V_{SB} - V_T}{2} = 0.4
V_{SB} = 1.38V
V_B = V_{GS} + V_S = 1.58V

1.58V

\text{Diagram}

2) $V_S = (g_m V_{GS} + g_m V_{BS}) R_E$

$V_S = V_G - V_T$

$V_{BS} = V_S - V_T$

$V_S = (g_m V_G + g_m V_{BS}) R_E$

$V_S = g_m V_G R_E - g_m V_S R_E - g_m V_B R_E$

$R_E = \frac{g_m R_E}{1 + (g_m + g_m) R_E}$

$V_S = (g_m V_G + g_m V_{BS}) R_E = V_S \frac{R_E}{R_E}$

$V_S = \frac{g_m R_E}{1 + (g_m + g_m) R_E}$

3) $f_m = \frac{12 \mu m C_{ox} V^2}{\pi} = 632 \mu s$

$f_m = \frac{V_m}{2 \pi V_{BE} V_{BO}}$

$V_{BE} = 3.55$

4) $f_t = \frac{g_m}{(C_{ox} + C_1)} = 5.26 \text{ GHz}$

5) $f_{MB} = \frac{2 \pi c g_m (1 + \alpha c) c^2 \cdot C_1}{R_{BE} + (g_m + g_m) R_E}$

$R_{MB} = \frac{1}{5 \times 100} = 5 \times 4.65 \times 10^6 \times 10^3 \text{ GHz}$

$f_{MB} = 205 \text{ MHz}$

5) Replace $R_E$ by $R_E \| R_{EC}$

$V_o = \frac{g_m R_E}{1 + (g_m + g_m) R_E} = \frac{g_m R_E (1 + 2 g_m R_C c)}{1 + 2 g_m R_C (1 + 2 g_m R_C c) R_E}$

$\text{zero at } \omega = \frac{1}{R_E c} = 50 \text{ MHz}$

$\text{pole at } \omega = \frac{1}{2 \pi R_E c} = 88.8 \text{ MHz}$
The action of this capacitor can be thought of as shorting out resistor $R_E$. At frequencies above $\omega = 1/(g_m + g_{gb})R_E$, the impedance $R_E/\omega$ gets lower and lower, so the gain rises and rises. This is why it creates a zero in the transfer function.

Once the gain reaches what it would be if $R_E = 0$, it levels off. This creates the pole in the transfer function.

The pole is at $\frac{\omega_p^2}{\omega_c^2} = 1 + (g_m + g_{gb})R_E$, times the frequency of the zero, so the gain is increased by $1 + (g_m + g_{gb})R_E$ at frequencies past the zero. The new zero gain is

$$\frac{V_o}{V_i} = \frac{g_m R_E}{1 + (g_m + g_{gb})R_E} \approx g_m R_E \approx 6.32$$

Because of the Miller effect, $V_{gb}$ is not a function of $V_o$.

The zero 3dB frequency is

$$\omega_{z3dB} = \frac{1}{R_E C_E + R_E (1 + h_{fe}) C_E + R_E C_E} \approx 15 kHz$$

$F_{z3dB} = 170$ MHz
2) bipolar transistor

\[ I_c = 2V/1k = 2mA \]
\[ g_m = \|/V_T = 80\mu m/s \]
\[ r_o = R/g_m = 1.25 \Omega \]

**Calculating \( r_o \)**

When calculating \( r_o \), ignore any \( R \); include any \( g_m \).

\[ r_o = \frac{V_T}{I_c} = \frac{80}{2} = 40 \Omega \]

\[ v_o = I_o (\frac{g_m}{p} - 1) \]
\[ v_i - v_b = I_o (\frac{g_m}{p} - 1) \]

\[ v_{be} = \frac{v_i}{1 + g_m \cdot \frac{p}{r_o}} \]

\[ A_v = \frac{v_o}{v_i} = \frac{g_m}{1 + g_m \cdot \frac{p}{r_o}} \]

\[ A_i = \frac{v_i}{v_o} = \frac{1}{1 + g_m \cdot \frac{p}{r_o}} \]

\[ r_o = r_o (p+1) \cdot 1k = 102.25 \Omega \]

**Calculating \( r_o \)**

When calculating \( r_o \), ignore \( r_s \); include any \( g_m \).

\[ L_o = \frac{V_T}{I_o} = \frac{80}{2} = 40 \Omega \]
\[ L_s = \left( g_m \cdot \frac{p}{r_s} \right) \]

\[ L_o = \left( g_m \cdot \frac{p}{r_s} \right) \]

\[ L_s = \frac{L_o}{1 + \frac{g_m}{p} \cdot \frac{r_s}{r_s}} \]

\[ v_o = \frac{v_i}{L_o} = 21.79 \mu \varepsilon \]

\[ v_i = \frac{3}{\mu \varepsilon} \cdot 666 \cdot 10^3 \mu \varepsilon \]

**Calculating \( V_{BE} \)**

\[ V_{BE} = \frac{V_o}{V_T} = \frac{80}{2} \]

\[ V_{BE} = \frac{V_o}{V_T} \]

\[ V_{BE} = \frac{V_o}{V_T} \]

**Using Miller approximation**

\[ C_w = C_m + (1 - \frac{V_o}{V_T}) C_m \]
\[ C_w = C_m + \frac{C_m}{\log_{10} \frac{V_o}{V_T}} = 21.3 \mu \varepsilon \]

\[ R_w = R_s \parallel \left( \frac{1}{r_o (p+1) R_s} \right) = 0.97 \Omega \]

\[ V_{BE} = \frac{1}{R_w C_w} = 97 \times 10^{-7} \mu \varepsilon \]
MOS, $V_{bs} = 0$

$I_D = \frac{2V}{1k} = 2mA$

$J_n = \sqrt{2eV_k} I_D = 2mS$

$\gamma = \frac{Q}{V_k}$

$\frac{Q}{V_k} = 333 \Omega$

$\frac{Q}{V_k} = \frac{1}{1k + 3m}$

$\Omega = \frac{3m}{1k + 3m} = 0.666$

$\Omega_{0} = \frac{V_{gs}}{1k + 3m} = 53.35\Omega$

$C_{sw} = C_{gs} + C_{gd} = 53.35\Omega$

$R_{sw} = R_{k} = 1k$

$\Omega_{3dB} = \frac{1}{R_{sw} C_{sw}} = 18.75 \times 10^6 \Omega$

$\Omega_{3dB} = \frac{1}{R_{sw} C_{sw}} = 18.75 \times 10^6 \Omega$

$\frac{Q}{V_k} = \frac{3m}{1k + 3m} = 16.66 \times 10^6 \Omega$
The BJT is clearly the best choice for many applications, as it has the best gain, bandwidth, and output resistance.

If something needs to bebuffered that has very high input impedance, or that can't have any DC current drawn from it, the MOS is very useful.

Using $V_{BE}$, $R_{E}$ generally produces a better amplifier, as its gain is close to 1, and the gain can get much closer to 1 as $R_{E}$ is increased.

Unfortunately, much of the time there is not the choice to use a BJT or to use constant feedback to the source. MOS processes are much cheaper, and in standard practice you don't have the option to connect the bulk to the source of the NMOS or you'd be stuck using a MOS with the bulk grounded, even if there are better choices.

### Table 1

<table>
<thead>
<tr>
<th>Device</th>
<th>$h_{IE}$</th>
<th>$h_{OE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJT</td>
<td>166 V/10$^6$</td>
<td>16 V/10$^6$</td>
</tr>
<tr>
<td>MOS</td>
<td>0.666</td>
<td>0.608</td>
</tr>
</tbody>
</table>

Likewise, the gain is much closer to unity for the BJT amplifier, because of its much higher $g_m$.

### Table 2

<table>
<thead>
<tr>
<th>Device</th>
<th>$h_{IE}$</th>
<th>$h_{OE}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BJT</td>
<td>13.75 V/10$^6$</td>
<td>16.90 V/10$^6$</td>
</tr>
<tr>
<td>MOS</td>
<td>0.917</td>
<td></td>
</tr>
</tbody>
</table>

The $f_T$ frequency is considerably better for the BJT than for the MOS, but not as much better as the difference in their $g_m$'s. This is because the bandwidth is limited by $f_T$ instead of by $g_m$.

Also, notice that $f_T$ for the MOS is actually higher than $f_T$ for the BJT. At high frequencies, the capacitive effect looks like a short circuit from input to output, so the signal will undergo dc across. Obviously, this looks like a nice and not a buffer, as the high input resistance and low output resistance are lost, and it's not actually useful.