1. In order to obtain the for $\beta_{DC}$, $\beta_{ac}$, $r_\pi$, $g_m$, and $r_o$, 4 plots must be generated. The input characteristics $I_c$ vs $V_{BE}$ and $I_B$ vs $V_{BE}$, the output characteristic $I_C$ vs $V_{CE}$, and the $I_C$ vs $I_B$ plot.

![IC vs VBE with VCE=1.5V](image1)

The value for $g_m$ can be extracted from this plot. Taking data near $I_C=0.5mA$

$$g_m = \frac{\partial I_C}{\partial V_{BE}} \bigg|_{I_C=0.5mA} = \frac{192 \mu A}{10.0mV} = 19.2 \frac{mA}{V}$$

![IB vs VBE with VCE=1.5V](image2)

The value for $g_\pi$ can be extracted from this plot. Taking data near $I_C=0.5mA$

$$g_\pi = \frac{\partial I_B}{\partial V_{BE}} \bigg|_{I_C=0.5mA} = \frac{1.35 \mu A}{10.0mV} = 135 \frac{\mu A}{V}$$

Thus, $r_\pi = 1/g_\pi = 741k\Omega$. 
The value for $g_o$ can be extracted from this plot. Taking data near $I_C=0.5mA$

$$g_o = \frac{\partial i_C}{\partial v_{CE}} \bigg|_{I_C=0.5mA} = 6.70 \mu A \frac{1000mV}{V} = 6.70 \mu A$$

Thus, $r_o=1/g_o=149k\Omega$.

The value for $\beta_{DC}$ and $\beta_{AC}$ can be extracted from this plot. Taking data near $I_C=0.5mA$

$$\beta_{DC} = \left. \frac{I_C}{I_B} \right|_{I_C=0.5mA} = \frac{501\mu A}{4.09\mu A} = 122$$

$$\beta_{AC} = \left. \frac{\partial i_C}{\partial i_B} \right|_{I_C=0.5mA} = \frac{200\mu A}{1.29\mu A} = 142$$
2. 

\[ V = 5V \]

\[ R_b \]

\[ R_c \]

\[ \beta \]

\[ I_c = 0.5mA \]

\[ I_c \cdot R_c = \frac{I_c \cdot R_c}{V} = 10 \]

\[ I_c \cdot R_c = 10 \frac{V}{25.9mV} = 259mV \]

\[ \text{Using } I_c = 0.5mA \]

\[ R_c = \frac{259mV}{0.5mA} = 520 \Omega \]

\[ I_b = \frac{I_c}{\beta} = \frac{0.5mA}{122} = 4.10 \mu A \]

From Problem #1 \[ I_b = 4.10 \mu A \text{ at } V_{BE} = 0.647V \]

\[ R_b = \frac{5V - 0.647V}{4.10 \mu A} = 1.06 \Omega \]

*Note, you could also use \( V_{BE} = 0.7V \) approximation instead of \( 0.647V \) but the Mathisim wouldn't match as well.*
2. **Multisim DC Operating Points**

**hw5_p2**

**DC Operating Point Analysis**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Operating point value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 V(posc)</td>
<td>6.47.46663 m</td>
</tr>
<tr>
<td>2 V(out)</td>
<td>4.72742</td>
</tr>
<tr>
<td>3 I(Q1[IB])</td>
<td>4.10616 u</td>
</tr>
<tr>
<td>4 I(Q1[IC])</td>
<td>524.1991 u</td>
</tr>
<tr>
<td>5 I(Q1[IE])</td>
<td>-528.30527 u</td>
</tr>
</tbody>
</table>

**Multisim Bode Plots**

From the top magnitude plot, the mid-band gain is 20.3dB – which is near 10V/V. The bottom phase plot shows the inverting nature of the amplifier with a mid-band phase shift of -180°. The magnitude and phase plots show a DC zero and a low frequency pole both due to the input capacitor. The input pole is at roughly

\[
f_{p,i} = \frac{1}{2\pi (R_B||r_T)C_{in}} = \frac{1}{2\pi (1.06\, M\Omega || 7.41k\Omega) 10\mu F} = 2.16\, Hz
\]
Thevenin Equivalent Bias Circuit

\[ I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_S}{\beta+1}} = \frac{3.33V - 0.7V}{2.1K + \frac{66.7K}{151}} = 1.03 \text{mA} \]

\[ I_B = \frac{I_E}{\beta+1} = \frac{1.03 \text{mA}}{151} = 6.85 \mu\text{A} \]

\[ I_C = \beta I_B = 150(6.85 \mu\text{A}) = 1.027 \text{mA} \]

\[ V_E = I_E R_E = 1.03 \text{mA} \times (2.1K\Omega) = 2.16 \text{V} \]

\[ V_B = V_E + 0.7V = 2.16 \text{V} + 0.7V = 2.86 \text{V} \]

\[ V_C = V_C - I_C R_C = 10V - 1.027 \text{mA} \times 3K = 6.92 \text{V} \]

\[ g_m = \frac{I_{CEQ}}{V_{TH}} = \frac{1.027 \text{mA}}{25.9 \text{mV}} = 39.7 \text{ mS/V} \]

\[ V_{TH} = \frac{V_{TH}}{I_{EQ}} = 3.78 \text{kV} \quad I_C = \frac{V_{TH}}{I_{EQ}} = 25.0 \Omega \]
3. DC Operating Points

![Diagrams showing an electronic circuit with components labeled Vcc, RB1 200kΩ, RC 3kΩ, RB2 100kΩ, RE1 100Ω, RE2 2kΩ, Q1 2N3904, base, collector, and emitter.]

![Image of a grapher view showing DC Operating Point Analysis with variables such as V(bias), V(collector), V(2), V(emitter), and collector and emitter currents.]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Operating point value</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(bias)</td>
<td>2.842V</td>
</tr>
<tr>
<td>V(collector)</td>
<td>6.912V</td>
</tr>
<tr>
<td>V(2)</td>
<td>2.075V</td>
</tr>
<tr>
<td>V(emitter)</td>
<td>2.176V</td>
</tr>
<tr>
<td>I(Q(III))</td>
<td>7.269mA</td>
</tr>
<tr>
<td>I(Q(II))</td>
<td>1.029mA</td>
</tr>
<tr>
<td>I(Q(I))</td>
<td>1.006mA</td>
</tr>
</tbody>
</table>
2. Common Emitter Amplifier

\[ A_V = - \frac{g_m (R_C \ll R_L)}{1 + \frac{g_m R_E}{k}} = - \frac{(39.7 \text{mS})(3 \text{k} \ll 20 \text{k})}{1 + \frac{(89.7 \text{mS})(100 \text{R})}{0.993}} \]

\[ A_V = -20.7 \text{ V/V} = 26.3 \text{ dB} \]

\[ R_{in} = R_B \| (r_{\pi} + (B\|r)R_E) \]

\[ = 66.7 \Omega \| [3.78 \Omega + 151(100)] \]

\[ R_{in} = 14.7 \Omega = 83.3 \text{ dB} \]

\[ R_{out} = R_L = 3 \Omega = 69.5 \text{ dB} \]

\[ G_V = \frac{R_{in}}{R_{in} + R_s} A_V = \frac{14.7 \Omega}{14.7 \Omega + 50} (-20.7) \]

\[ G_V = -20.6 \text{ V/V} = 26.3 \text{ dB} \]
2. Common Emitter Amplifier

The simulated value of 26.2dB closely matches the hand calculation of 26.3dB for both $A_v$ and $G_v$.

The simulated $R_{in}$ value of 83.6dBΩ closely matches the hand calculation of 83.3dBΩ.

The simulated $R_{out}$ value of 69.5dBΩ closely matches the hand calculation of 69.5dBΩ.
3. Common Collector Amplifier

\[ A_v = \frac{R_E \parallel R_L}{R_E + R_E \parallel R_L} = \frac{2.1 \text{k} \Omega / 70 \text{k} \Omega}{25 \text{k} \Omega + 2.1 \text{k} \Omega / 20 \text{k} \Omega} \]

\[ A_v = 0.987 \frac{V}{V} = -0.114 \text{ dB} \]

\[ R_{in} = R_E \parallel \left[ r_T + (B+1)(R_E \parallel R_L) \right] \]

\[ = \frac{66.7 \text{k} \Omega}{\left[ 3.78 \text{k} \Omega + (151)(2.1 \text{k} \Omega / 20 \text{k} \Omega) \right]} \]

\[ R_{in} = 54.3 \text{k} \Omega = 9.47 \text{ dB} \]

\[ R_{out} = R_E \parallel \left[ r_C + \frac{R_S \parallel R_E}{B+1} \right] \]

\[ = \frac{2.1 \text{k} \Omega}{\left[ 25 \text{k} \Omega + \frac{50 / 66.7 \text{k} \Omega}{151} \right]} \]

\[ R_{out} = 25.6 \text{k} \Omega = 28.0 \text{ dB} \]

\[ G_v = \frac{A_v}{R_{in} + R_S} = \frac{54.3 \text{k} \Omega}{54.3 \text{k} \Omega + 50} \]

\[ G_v = 0.986 \frac{V}{V} = -0.121 \text{ dB} \]
3. Common Collector Amplifier

The simulated $A_v$ value of -0.117dB matches closely the hand calculation of -0.114dB. The simulated $G_v$ value of -0.125dB matches closely the hand calculation of -0.121dB.

The simulated $R_{in}$ value of 94.8dBΩ closely matches the hand calculation of 94.7dBΩ.

The simulated $R_{out}$ value of 28.0dBΩ closely matches the hand calculation of 28.0dBΩ.
4. Common Base Amplifier

\[ A_V = \ImaginaryPart \left( R_c \parallel R_L \right) = 39.7 \text{ mV} \left( \frac{3 \text{k} \Omega}{12 \text{k} \Omega} \right) \]

\[ A_V = 104 \text{ \%V} = 40.3 \text{ dB} \]

\[ R_{in} = R_E \parallel r_e = \frac{2.1 \text{k} \Omega}{25.0 \Omega} \]

\[ R_{in} = 24.7 \Omega = 27.9 \text{ dB} \]

\[ R_{out} = r_C = 3 \text{k} \Omega = 69.5 \text{ dB} \]

\[ G_V = \frac{R_{in}}{R_{in} + R_S} = \frac{24.7}{24.7 + 50} \left( 104 \right) = 34.4 \text{ \%V} \]

\[ G_V = 34.4 \text{ \%V} = 30.7 \text{ dB} \]
4. Common Base Amplifier

**AV and GV**

The simulated AV value of 39.9dB matches closely the hand calculation of 40.3dB. The simulated GV value of 30.6dB matches closely the hand calculation of 30.7dB.

**Rin**

The simulated Rin value of 28.3dB Ohm closely matches the hand calculation of 27.9dB Ohm.

**Rout**

The simulated Rout value of 69.4dB Ohm closely matches the hand calculation of 69.5dB Ohm.