Basic Single-Stage BJT Amplifier Equations: Hybrid-pi Model ($r_\pi$)

- $R_b = \text{Thevenin Equivalent Resistance seen looking out from base to ground}$
- $R_c = \text{Thevenin Equivalent Resistance seen looking out from collector to ground}$
- $R_e = \text{Thevenin Equivalent Resistance seen looking out from emitter to ground}$
- $R_s = \text{Signal Source Internal Resistance}$ & $R_L = \text{Load Resistance}$
- $I_E$ & $I_C$ & $I_B = \text{dc emitter}$ & $\text{collector}$ & $\text{base current}$
- $\alpha = \frac{I_C}{I_E}$ & $\beta = \frac{I_C}{I_B}$ & $\alpha = \frac{\beta}{(\beta + 1)}$ & $\beta = g_m r_\pi$
- $r_e = \frac{V_T}{I_E}$ & $g_m = \frac{I_C}{V_T}$ & $r_\pi = (\beta + 1) r_e$ & $r_o = \frac{V_A}{I_C}$
- $V_T = 25 \text{ mV at 290 K}$ & $V_A = \text{Early Voltage}$

<table>
<thead>
<tr>
<th>Input</th>
<th>$R_b$</th>
<th>$R_c$</th>
<th>$R_e$</th>
<th>$R_s$</th>
<th>$R_L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_e &gt; 0$</td>
<td>$R_c &gt; 0$</td>
<td>$R_b = 0$</td>
<td>$R_c = R_C$</td>
<td>$R_e = R_L$</td>
<td></td>
</tr>
<tr>
<td>$R_b = R_s$</td>
<td>$R_b = R_s$</td>
<td>$R_c = R_C$</td>
<td>$R_e = R_s$</td>
<td>$R_b = R_s$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$R_o$</th>
<th>$r_o \left(1 + \frac{\beta R_c}{R_e + r_\pi + R_b}\right)$</th>
<th>$r_o \left(1 + \frac{\beta R_c}{R_e + r_\pi}\right)$</th>
<th>$r_o \left(1 + \frac{\beta R_c}{R_e + r_\pi + R_b}\right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_i$</td>
<td>$r_\pi + r_x$</td>
<td>$r_x + r_\pi + (\beta + 1)R_c$</td>
<td>$r_x + r_\pi + (\beta + 1)R_c$</td>
</tr>
<tr>
<td>$\frac{v_o}{v_i}$</td>
<td>$\frac{-\beta (R_c/r_o)}{r_x + r_\pi}$</td>
<td>$\frac{-\beta R_c}{r_x + r_\pi + (\beta + 1)R_c}$</td>
<td>$\frac{\beta R_c}{r_x + r_\pi}$</td>
</tr>
<tr>
<td>$\frac{v_i}{v_s}$</td>
<td>$\frac{R_i}{R_i + R_s}$</td>
<td>$\frac{R_i}{R_i + R_s}$</td>
<td>$\frac{R_i}{R_i + R_s}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\frac{v_o}{v_i}$</th>
<th>$\frac{v_o}{v_i}$</th>
<th>$\frac{v_o}{v_i}$</th>
<th>$\frac{v_o}{v_i}$</th>
<th>$\frac{v_o}{v_i}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\frac{v_i}{v_s}$</td>
<td>$\frac{v_i}{v_s}$</td>
<td>$\frac{v_i}{v_s}$</td>
<td>$\frac{v_i}{v_s}$</td>
<td>$\frac{v_i}{v_s}$</td>
</tr>
</tbody>
</table>
Basic Single-Stage BJT Amplifier Equations: Tee Model ($r_e$)

- $R_b =$ Thevenin Equivalent Resistance seen looking out from base to ground
- $R_c =$ Thevenin Equivalent Resistance seen looking out from collector to ground
- $R_e =$ Thevenin Equivalent Resistance seen looking out from emitter to ground
- $R_s = $ Signal Source Internal Resistance & $R_L = $ Load Resistance
- $I_E \& I_C \& I_B = $ dc emitter & collector & base current
- $\alpha = I_C / I_E \quad \beta = I_C / I_B \quad \alpha = \beta / (\beta + 1)$
- $r_e = V_T / I_E \quad g_m = I_C / V_T \quad \beta = g_m r_\pi \quad r_\pi = (\beta + 1) r_e \quad r_o = V_A / I_C$
- $V_T = 25 \text{ mV at 290 K} \quad V_A = \text{Early Voltage}$

<table>
<thead>
<tr>
<th>Input</th>
<th>CE</th>
<th>Output</th>
<th>CB</th>
<th>CC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>base</td>
<td>base</td>
<td>emitter</td>
<td>base</td>
</tr>
<tr>
<td>CE R_e &gt; 0</td>
<td>$r_e = V_T / I_E$</td>
<td>$R_e &gt; 0$</td>
<td>$R_b = 0$</td>
<td>$R_c = 0$</td>
</tr>
<tr>
<td></td>
<td>$R_c = R_C$</td>
<td>$R_c = R_C$</td>
<td>$R_c = R_L$</td>
<td>$R_e = R_s$</td>
</tr>
<tr>
<td></td>
<td>$R_b = R_s$</td>
<td>$R_b = R_s$</td>
<td>$R_b = R_s$</td>
<td>$R_b = R_s$</td>
</tr>
</tbody>
</table>

| $R_o$ | $r_o = 1 + \frac{\beta R_e}{R_e + (\beta + 1) r_e + R_b}$ | $r_o = 1 + \frac{\beta R_e}{R_c + (\beta + 1) r_e}$ | $r_o /\left[ \frac{R_b + r_x + R_e}{\beta + 1} + r_e \right]$ |
| $r_x + (\beta + 1) r_e$ | $r_x + (\beta + 1) (r_e + R_b)$ | $r_x /\left[ \frac{r_x}{\beta + 1} + r_e \right]$ | $r_x + (\beta + 1) (r_e + R_b) / r_o$ |

| $\frac{v_o}{v_s}$ | $\frac{v_i}{R_i + R_s}$ | $\frac{R_i}{R_i + R_s}$ | $\frac{R_i}{R_i + R_s}$ | $\frac{R_i}{R_i + R_s}$ |
| $\frac{v_o}{v_i}$ | $\frac{x}{v_i}$ | $\frac{x}{v_i}$ | $\frac{x}{v_i}$ | $\frac{x}{v_i}$ |

| $\frac{v_o}{v_s}$ | $\frac{v_i}{v_s}$ | $\frac{v_o}{v_i}$ | $\frac{v_i}{v_s}$ | $\frac{v_o}{v_i}$ | $\frac{v_i}{v_s}$ |
Sedra-Smith 4.11 Basic Single-Stage BJT Amplifier Configurations

Transistor Parameters

\[ I_E \& I_C \& I_B = \text{dc emitter \& collector \& base current} \]

\[ \alpha = \frac{I_C}{I_E} \quad \beta = \frac{I_C}{I_B} \quad \alpha = \frac{\beta}{(\beta + 1)} \]

\[ r_e = \frac{V_T}{I_E} \quad g_m = \frac{I_C}{V_T} \quad \beta = g_m r_\pi \quad r_\pi = (\beta + 1) r_e \quad r_o = \frac{V_A}{I_C} \]

\[ V_T = 25 \text{ mV at } 290 \text{ K} \quad V_A = \text{Early Voltage} \]

\[ R_b = \text{Thevenin Equivalent Resistance seen looking out from base to ground} \]

May include bias resistors and output resistance of previous stage or
signal source internal resistance (usually denoted as \( R_s \))

\[ R_c = \text{Thevenin Equivalent Resistance seen looking out from collector to ground} \]

May include bias resistors and input resistance of next stage or
load resistor (usually denoted as \( R_L \))

\[ R_e = \text{Thevenin Equivalent Resistance seen looking out from emitter to ground} \]

May include bias resistors and either output resistance of previous stage or
signal source internal resistance (usually denoted as \( R_s \)) or input resistance
of next stage or load resistor (usually denoted as \( R_L \))

\[ R_{inQ} = \text{Thevenin Equivalent Resistance seen looking into BJT signal input terminal} \]

e. g. base for Common-Emitter or Common-Collector or
emitter for Common-Base

\[ R_{outQ} = \text{Thevenin Equiv. Resistance seen looking into BJT signal output terminal} \]

e. g. collector for Common-Emitter or Common-Base or
emitter for Common-Collector
The Common Emitter (CE) Stage  

See Fig. 4.43 on p. 283.

\[ R_e = 0 \quad R_b = R_s \quad R_c = R_C \]

Signal Input Terminal is Base and Signal Output Terminal is Collector

In Section 4.11 it is assumed that \( r_x = 0 \)

Note that the equations in Sedra-Smith for the CE amplifier are in terms of \( r_\pi \) and not \( r_e \).

Input Resistance \( R_i = R_\text{inQ} = r_\pi \) \hfill (4.59)

Output Resistance \( R_o = R_C // R_\text{outQ} = R_C // r_0 \) where \( R_\text{outQ} = r_0 \) \hfill (4.67)

\[ \frac{v_o}{v_s} = \frac{v_c}{v_b} \times \frac{v_b}{v_s} \]

\[ \frac{v_c}{v_b} = \frac{v_c}{v_\pi} = - g_m \left( R_C // r_0 \right) \hfill (4.61) \]

\[ \frac{v_b}{v_s} = \frac{R_i}{(R_s + R_i)} = \frac{r_\pi}{(R_s + r_\pi)} \hfill (4.60) \]

\[ v_o/v_s = \left[- g_m (R_C // r_0) \right] \times \left[r_\pi / (R_s + r_\pi) \right] = -[\beta (R_C // r_0)] / (R_s + r_\pi) \hfill (4.62) \]

For \( r_x > 0 \)  

See Fig. 4.70 on p. 323

Input Resistance \( R_i = R_\text{inQ} = r_\pi + r_x \)

\[ \frac{v_c}{v_b} = \frac{v_c}{v_\pi} \times \frac{v_\pi}{v_b} = \left[- g_m (R_C // r_0) \right] \times \left[r_\pi / (R_s + r_\pi + r_x) \right] = -\beta (R_C // r_0) / (R_s + r_x + r_\pi) \]

\[ \frac{v_b}{v_s} = \frac{R_i}{(R_s + R_i)} = \frac{(r_\pi + r_x) / (R_s + r_x + r_\pi)} \]

\[ \frac{v_c}{v_s} = -\beta (R_C // r_0) / (R_s + r_x + r_\pi) \]
The Common Emitter (CE) Stage with a Resistance in the Emitter: Fig. 4.44

\[ R_e > 0 \quad R_b = R_s \quad R_c = R_C \quad \text{Assume } r_x = 0 \]

Signal Input Terminal is Base and Signal Output Terminal is Collector

Output Resistance \( R_o = R_c//R_{outQ} \) where \( R_{outQ} = r_o [1 + (\beta R_e)/(R_c + r_\pi + R_s)] \)

Derivation of \( R_{outQ} \) to be posted. The equation for \( R_{outQ} \) also includes a term \( R_e/(r_\pi + R_s) \) that was neglected because it is small.

Note that \( R_{outQ} \) can be much greater than \( r_o \). For that reason \( r_o \) is ignored by Sedra-Smith in Fig. 4.44 (c) to simply the following calculations:

Note that the equations in Sedra-Smith for the CE stage with a resistance in the emitter are in terms of \( r_e \) and not \( r_\pi \).

Equations will be presented in terms of both \( r_e \) and \( r_\pi \) in alternating order. The equation number in Sedra-Smith is given when available.

For \( r_x = 0 \) & \( r_o = \infty \)

Input Resistance \( R_i = R_{inQ} = (\beta + 1)(r_e + R_c) \) \hspace{1cm} (4.70)

\[ R_i = R_{inQ} = r_\pi + (\beta + 1)R_e \]

\( \frac{v_o}{v_s} = \frac{v_c}{v_b} x \frac{v_b}{v_s} \)

For \( r_x = 0 \) & \( r_o = \infty \)

\[ \frac{v_c}{v_b} = -\frac{(\alpha R_C)}{(r_e + R_c)} \]

\[ \frac{v_c}{v_b} = \frac{[\beta/(\beta + 1) x R_C]}{[r_e + R_c]} = -\frac{\beta R_C}{r_\pi + (\beta + 1)R_e} \]
\[ \frac{v_b}{v_s} = \frac{R_i}{(R_s + R_i)} \]

For \( r_x = 0 \) \& \( r_o = \infty \)

\[ \frac{v_b}{v_s} = \frac{[(\beta + 1)(r_c + R_c)]}{(R_s + (\beta + 1)(r_c + R_c))} \]

\[ \frac{v_b}{v_s} = [r_\pi + (\beta + 1)R_c] \div [R_s + r_\pi + (\beta + 1)R_c] \]

\[ \frac{v_o}{v_s} = -\beta R_C \div [R_s + (\beta + 1)(r_c + R_c)] \quad (4.75) \]

\[ \frac{v_o}{v_s} = -\beta R_C \div [R_s + r_\pi + (\beta + 1)R_c] \]

If \( r_x > 0 \) \& \( r_o = \infty \)

\[ R_i = R_{in,Q} = r_x + (\beta + 1)(r_c + R_c) \]

\[ R_i = R_{in,Q} = r_x + r_\pi + (\beta + 1)R_c \]

\[ \frac{v_o}{v_b} = -\beta R_C \div [r_x + (\beta + 1)(r_c + R_c)] \]

\[ \frac{v_o}{v_b} = -\beta R_C \div [r_x + r_\pi + (\beta + 1)R_c] \]

\[ \frac{v_b}{v_s} = [r_x + (\beta + 1)(r_c + R_c)] \div [R_s + (\beta + 1)(r_c + R_c)] \]

\[ \frac{v_b}{v_s} = [r_x + r_\pi + (\beta + 1)R_c] \div [R_s + r_\pi + (\beta + 1)R_c] \]

\[ \frac{v_o}{v_s} = -\beta R_C \div [R_s + r_x + (\beta + 1)(r_c + R_c)] \]

\[ \frac{v_o}{v_s} = -\beta R_C \div [R_s + r_x + r_\pi + (\beta + 1)R_c] \]
The Common-Base (CB) Stage

See Sedra-Smith Fig. 4.45 on p. 289

\[ R_b = 0 \quad R_e = R_s \quad R_c = R_C \quad \text{Assume for } r_x = 0 \]

Signal Input Terminal is Emitter and Signal Output Terminal is Collector

Output Resistance \( R_o = R_C / R_{outQ} \) where \( R_{outQ} = r_o[1 + (\beta R_c)/(R_s + r_{\pi})] \)

Note: a term \( R_s // r_{\pi} \) in the equation for \( R_{outQ} \) was neglected

Note also that \( R_{outQ} \) can be much greater than \( r_o \). For that reason \( r_o \) is ignored by Sedra-Smith in Fig. 4.45 (b) to simply the following calculations.

Note that the equations in Sedra-Smith for the CB are in terms of \( r_e \) and not \( r_{\pi} \).

Equations will be presented in terms of both \( r_e \) and \( r_{\pi} \) in alternating order. The equation number in Sedra-Smith is given when available.

For \( r_x = 0 \) & \( r_o = \infty \)

\[ \text{Input Resistance } R_i = R_{inQ} = r_e \quad (4.77) \]

\[ v_o/v_s = v_c/v_e \times v_e/v_s \]

\[ v_c/v_e = (-\alpha i_e R_C)/(-i_e r_e) = \alpha R_C/r_e \]

\[ v_c/v_e = \beta R_C/((\beta + 1)r_e) = \beta R_C/r_{\pi} \]

\[ v_b/v_s = R_i / (R_s + R_i) \]

\[ v_b/v_s = r_i / (R_s + r_e) \]

\[ v_b/v_s = [r_{\pi}/(\beta + 1)] \div [R_s + r_{\pi}/(\beta + 1)] = r_{\pi} \div [(\beta + 1)R_s + r_{\pi}] \]

\[
\begin{align*}
\text{Output Resistance } R_o &= R_C / R_{\text{outQ}} \\
&= r_o \left[ 1 + \left( \frac{\beta R_c}{R_s + r_{\pi}} \right) \right]
\end{align*}
\]

Note: a term \( R_s // r_{\pi} \) in the equation for \( R_{\text{outQ}} \) was neglected.

Note also that \( R_{\text{outQ}} \) can be much greater than \( r_o \). For that reason \( r_o \) is ignored by Sedra-Smith in Fig. 4.45 (b) to simply the following calculations.

Note that the equations in Sedra-Smith for the CB are in terms of \( r_e \) and not \( r_{\pi} \).

Equations will be presented in terms of both \( r_e \) and \( r_{\pi} \) in alternating order. The equation number in Sedra-Smith is given when available.

For \( r_x = 0 \) & \( r_o = \infty \)

\[ \text{Input Resistance } R_i = R_{\text{inQ}} = \frac{r_e}{(\beta + 1)} \]  

\[ v_o/v_s = v_c/v_e \times v_e/v_s \]

\[ v_c/v_e = \frac{-\alpha i_e R_C}{-i_e r_e} = \frac{\alpha R_C}{r_e} \]

\[ v_c/v_e = \frac{\beta R_C}{(\beta + 1)r_e} = \frac{\beta R_C}{r_{\pi}} \]

\[ v_b/v_s = \frac{R_i}{R_s + R_i} \]

\[ v_b/v_s = \frac{r_e}{R_s + r_e} \]

\[ v_b/v_s = \frac{r_{\pi}}{(\beta + 1)} \div \frac{R_s + r_{\pi}}{(\beta + 1)} = \frac{r_{\pi}}{[(\beta + 1)R_s + r_{\pi}]} \]
\[
\frac{v_o}{v_s} = [\alpha R_C/\tau_c] \div [R_s + r_e]
\]

\[
\frac{v_o}{v_s} = [\beta \ R_C] \div [(\beta + 1)R_s + r_\pi]
\]

For \( r_x > 0 \)

\[
R_{outQ} = r_o[1 + \beta R_s/(R_s + r_\pi + r_x)]
\]

For \( r_x > 0 \) & \( r_o = \infty \)

Input Resistance \( R_i = R_{inQ} = (r_x + r_\pi) / (\beta + 1) \)

\[
\frac{v_o}{v_s} = v_c/v_e \times v_e/v_s
\]

\[
\frac{v_o}{v_e} = (-\alpha i_e R_C)/(-i_e \tau_e) = \alpha R_C/[r_e + r_x/(\beta + 1)]
\]

\[
\frac{v_c}{v_e} = [\beta/(\beta + 1)] \times R_C \div [r_e + r_x/(\beta + 1)] = \beta \ R_C/(r_\pi + r_x)
\]

\[
\frac{v_c}{v_s} = R_i / (R_s + R_i)
\]

\[
\frac{v_o}{v_s} = [r_x/(\beta + 1) + r_e] \div [R_s + r_x/(\beta + 1) + r_e]
\]

\[
\frac{v_b}{v_s} = [(r_x + r_\pi)/(\beta + 1)] \div [R_s + (r_x + r_\pi)/(\beta + 1)] = (r_x + r_\pi) \div [(\beta + 1)R_s + r_x + r_\pi]
\]

\[
\frac{v_o}{v_s} = [\alpha R_C] \div [R_s + r_x/(\beta + 1) + r_e]
\]

\[
\frac{v_o}{v_s} = [\beta R_C] \div [(\beta + 1)R_s + r_x + r_\pi]
\]
The Common-Collector (CC) Stage  

See Sedra-Smith Fig. 4.46 on p. 291

\[ R_c = 0 \quad R_b = R_s \quad R_e = R_L \]

Signal Input Terminal is Base and Signal Output Terminal is Emitter

In Section 4.11 it is assumed that \( r_x = 0 \)

Note that the equations in Sedra-Smith for the CC are in terms of \( r_e \) and not \( r_\pi \).

Equations will be presented in terms of both \( r_e \) and \( r_\pi \) in alternating order. The equation number in Sedra-Smith is given when available.

For \( r_x = 0 \) & \( r_o < \infty \)

Input Resistance \( R_i = R_{inQ} = (\beta + 1)(r_e + R_L// r_o) \)  

Input Resistance \( R_i = R_{inQ} = r_\pi + (\beta + 1)x(R_L// r_o) \)  

For \( r_o >> R_L \),  \( R_i = R_{inQ} = r_\pi + (\beta + 1)R_L \)

Output Resistance \( R_o = R_{outQ} = r_o//[ r_e + R_s/(\beta + 1)] \)

\( R_o = R_{outQ} = r_o//[(r_\pi + \frac{R_s}{(\beta + 1)})] \) (4.87)

For \( r_o >> \frac{(r_\pi + R_s)}{(\beta + 1)} \)

\( R_o = R_{outQ} = r_e + \frac{R_s}{(\beta + 1)} \)

\( R_o = R_{outQ} = \frac{r_\pi + R_s}{(\beta + 1)} \)  

\( \frac{v_o}{v_s} = \frac{v_e}{v_b} \times \frac{v_b}{v_s} \)

\( \frac{v_o}{v_b} = \frac{[R_L// r_o]}{[r_e + \frac{R_L}{r_o}]} \)  

or \( \frac{v_e}{v_b} = \frac{[(\beta + 1)x(R_L// r_o)]}{[r_\pi + (\beta + 1)x(R_L// r_o)]} \) (4.84)
\[
v_b/v_s = R_i / (R_s + R_i)
\]

or
\[
v_b/v_s = [r_\pi + (\beta + 1)x(R_L/\ r_o)] / [R_s + r_\pi + (\beta + 1)x(R_L/\ r_o)]
\]

\[
v_o/v_s = v_c/v_s = [(\beta + 1)x(R_L/\ r_o)] / [R_s + (\beta + 1)(r_e + R_L/\ r_o)]
\]

also
\[
v_o/v_s = v_c/v_s = (R_i/\ r_o) / [R_s/\ (\beta + 1) + r_e + (R_L/\ r_o)]
\]

or
\[
v_o/v_s = v_c/v_s = [(\beta + 1)x(R_L/\ r_o)] / [R_s + r_\pi + (\beta + 1)x(R_L/\ r_o)]
\]

If \( r_x > 0 \)

Input Resistance \( R_i = R_{inQ} = r_x + (\beta + 1)(r_e + R_L/\ r_o) \)

or Input Resistance \( R_i = R_{inQ} = r_x + r_\pi + (\beta + 1)x(R_L/\ r_o) \)

\[
v_c/v_b = [R_L/\ r_o] / [r_x/(\beta + 1) + r_e + R_L/\ r_o]
\]

or
\[
v_e/v_b = [(\beta + 1)x(R_L/\ r_o)] / [r_x + r_\pi + (\beta + 1)x(R_L/\ r_o)]
\]

\[
v_b/v_s = R_i / (R_s + R_i) = [r_x + (\beta + 1)(r_e + R_L/\ r_o)] / [R_s + r_x + (\beta + 1)(r_e + R_L/\ r_o)]
\]

or
\[
v_b/v_s = [r_x + r_\pi + (\beta + 1)x(R_L/\ r_o)] / [R_s + r_x + r_\pi + (\beta + 1)x(R_L/\ r_o)]
\]

Also
\[
v_o/v_s = v_c/v_s = (R_i/\ r_o) / [(R_s + r_x) / (\beta + 1) + r_e + (R_L/\ r_o)]
\]

or
\[
v_o/v_s = v_c/v_s = [(\beta + 1)x(R_L/\ r_o)] / [R_s + r_x + r_\pi + (\beta + 1)x(R_L/\ r_o)]
\]

For \( r_o >> R_L \) replace \( (R_L/\ r_o) \) by \( R_L \)
Basic Single-Stage FET Amplifier Equations:

- $R_g$ = Thevenin Equivalent Resistance seen looking out from gate to ground
- $R_d$ = Thevenin Equivalent Resistance seen looking out from drain to ground
- $R_s$ = Thevenin Equivalent Resistance seen looking out from source to ground
- $R_L$ = Load Resistance
- $R_{gen}$ = Thevenin Equivalent Resistance of Signal Source

Note that $R_s$ is often used to denote the Thevenin Equivalent Resistance of Signal Source, but that $R_s$ denotes the Thevenin Equivalent Resistance seen looking out from source to ground.

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>$R_s$</th>
<th>$R_d$</th>
<th>$R_s$</th>
<th>$R_d$</th>
<th>$R_s$</th>
<th>$R_d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>gate</td>
<td>drain</td>
<td>0</td>
<td>$R_L$</td>
<td>0</td>
<td>$R_L$</td>
<td>0</td>
<td>$R_L$</td>
</tr>
<tr>
<td>gate</td>
<td>drain</td>
<td>$R_s$ &gt; 0</td>
<td>$R_s$ &gt; 0</td>
<td>$R_g$ = 0</td>
<td>$R_d$ = $R_L$</td>
<td>$R_s$ = $R_{gen}$</td>
<td>$R_g$ = $R_{gen}$</td>
</tr>
<tr>
<td>$R_o$</td>
<td>$r_o$</td>
<td>$r_o [1 + g_m R_s]$</td>
<td>$r_o [1 + g_m R_s]$</td>
<td>$r_o$</td>
<td>$1 \over g_m$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_i$</td>
<td>$\infty$</td>
<td>$\infty$</td>
<td>$\left[ \frac{1}{g_m} \right]$</td>
<td>$\infty$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_o$</td>
<td>$v_i$</td>
<td>$-g_m R_d$</td>
<td>$-g_m R_d$</td>
<td>$g_m R_d$</td>
<td>$g_m (R_s // R_o)$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$v_{gen}$</td>
<td>$v_{gen}$</td>
<td>$1 + g_m R_s$</td>
<td>$1 + g_m R_s$</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>$v_o$</td>
<td>$v_i$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
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</tr>
<tr>
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<td>$v_{gen}$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
<td>$v_o \times v_i$</td>
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