Basic BJT and MOS Amplifier Topologies

CE/CS, CC/CD, CB/CG
Since the MOS case is just a special case of the BJT case that can be obtained by setting $r_\pi$ to infinity, we will analyze the BJT case for generality.
In a CB/CB topology, the input signal is applied to the emitter/source of the transistor, while the output is taken at the collector/drain.

Consider the BJT case, let’s obtain the amplifier equivalent circuit.
CB/CG Amplifier Topology

- We can obtain the 2-port equivalent circuit of this topology by solving the circuit and put in the equation in the standard form.

\[ V_1 = i_1 \cdot r_{in} + A_{VR} \cdot V_2 \]
\[ V_2 = i_2 \cdot r_{out} + A_{V0} \cdot V_1 \]
CB/CG Amplifier Topology

- We can obtain the 2-port equivalent circuit of this topology by solving the circuit and put in the equation in the standard form.

![Diagram of CB/CG amplifier topology]

Applying KCL at the input and output node, obtain

\[
\begin{align*}
  i_1 &= \frac{v_1}{r_\pi} + \frac{v_1 - v_2}{r_o} + g_m \cdot v_1 \\
  i_2 &= \frac{v_2 - v_1}{r_o} - g_m \cdot v_1
\end{align*}
\]

\[
\begin{align*}
  v_1 &= i_1 \cdot r_{in} + A_{VR} \cdot v_2 \\
  v_2 &= i_2 \cdot r_{out} + A_{V0} \cdot v_1
\end{align*}
\]
CB/CG Amplifier Topology

\[ r_{in} = \left( \frac{1}{g_m + g_\pi + g_o} \right) \approx \frac{1}{g_m} \]

\[ r_{out} = r_o \]

\[ A_{V0} = (1 + g_m \cdot r_o) \approx g_m \cdot r_o \]

\[ A_{VR} = \left( \frac{g_o}{g_m + g_\pi + g_o} \right) \approx \frac{1}{g_m \cdot r_o} \]

CB topology is bilateral
Gain is large and non-inverting
Low input impedance but high output impedance
CB/CG Amplifier Topology

◆ The CB/CG topology can incorporate a load resistance
CB/CG Amplifier Topology

Manipulate the circuit to put it in the desired form

\[ r_{in} = \left( \frac{1}{g_m + g_{\pi} + g_o} \right) \approx \frac{1}{g_m} \]

\[ r_{out} = \left( r_o \parallel R_C \right) = \frac{R_C \cdot r_o}{R_C + r_o} \approx R_C \]

\[ A_{V0} = \left( \frac{g_o + g_m}{g_o + g_C} \right) \approx g_m \cdot R_C \]

\[ A_{VR} = \left( \frac{g_o}{g_m + g_{\pi} + g_o} \right) \approx \frac{1}{g_m \cdot r_o} \]
Manipulate the circuit to put it in the desired form \( \rightarrow \) it can also be done directly.

\[
\begin{align*}
\text{Manipulate the circuit to put it in the desired form} & \quad \text{or it can also be done directly} \\
V_{\text{in}} & \rightarrow V_{\text{out}} \\
\text{CB topology with load resistance is bilateral} & \\
\text{Gain is large and non-inverting} & \\
\text{Low input impedance but mid-range output impedance} & \\
\end{align*}
\]
The MOS-based CD topology is just a special case of the BJT-based topology.
CB/CG Amplifier Topology

- The MOS-based CD topology is just a special case of the BJT-based topology.

\[ r_{in} = \left( \frac{1}{g_m + g_{\pi} + g_o} \right) \]
\[ r_{out} = r_o \]
\[ A_{V0} = (1 + g_m \cdot r_o) \]
\[ A_{VR} = \left( \frac{g_o}{g_m + g_{\pi} + g_o} \right) \]

CB topology is bilateral

CG topology is also bilateral
CB/CG Amplifier Topology

◆ The MOS-based CD topology is just a special case of the BJT-based topology → can incorporate a load resistance

CG topology with load resistance is bilateral

\[ r_{in} = \left( \frac{1}{g_m + g_o} \right) \]

\[ r_{out} = (r_o \parallel R_D) = \frac{R_D \cdot r_o}{R_D + r_o} \]

\[ A_{V0} = \left( \frac{g_o + g_m}{g_o + g_D} \right) \]

\[ A_{VR} = \left( \frac{g_o}{g_m + g_o} \right) \]
CB/CG Amplifier Topology

- CB and CG are both bilateral (but very weak)
- Very low Input impedance (for BJT and MOS)
- Voltage Gain is large and non inverting, mid-range output impedance
- Widely used as a amplifier when low input impedance is desired

\[
\begin{align*}
    r_{in} &= \left( \frac{1}{g_m + g_{\pi} + g_o} \right) 
    \approx \frac{1}{g_m} \\
    r_{out} &= \left( r_o \parallel R_C \right) 
    = \frac{R_C \cdot r_o}{R_C + r_o} 
    \approx R_C \\
    A_{V0} &= \left( \frac{g_o + g_m}{g_o + g_C} \right) 
    \approx g_m \cdot R_C \\
    A_{VR} &= \left( \frac{g_o}{g_m + g_{\pi} + g_o} \right) 
    \approx \frac{1}{g_m \cdot r_o}
\end{align*}
\]
CB/CG Amplifier Topology

- **Application** ➔ What is the input impedance \( (R_{in}) \) of the CB/CG topology ➔ note that \( R_{in} \) is the input impedance of the amplifier as if it is a 1-port circuit ➔ we compute it while the output is open

- **In general**, \( R_{in} \) is not \( r_{in} \) except in unilateral amplifiers

\[ R_{in} = \frac{V_{in}}{I_{in}} \]

(Common Base)

\[ R_{in} = \frac{V_{in}}{I_{in}} \]

(Common Gate)
CB/CG Amplifier Topology

◆ Application ➞ What is the input impedance \( R_{in} \) of the CB/CG topology ➞ note that \( R_{in} \) is the input impedance of the amplifier as if it is a 1-port circuit ➞ we compute it while the output is open

◆ In general, \( R_{in} \) is not \( r_{in} \) except in unilateral amplifiers

\[
R_{in} = \frac{v_{in}}{i_{in}}
\]

\[
i_{in} = \left( v_{in} - \left( \frac{g_o}{g_m + g_o + g_o} \right) v_{out} \right) \cdot (g_m + g_o + g_o) = \left( g_m + g_o + g_o \right) \cdot v_{in} - g_o \cdot \left( \frac{g_o + g_m}{g_o + g_C} \right) \cdot v_{in}
\]

\[
\approx \left( g_m - \frac{g_o \cdot g_m}{g_C} \right) \cdot v_{in} \approx g_m \cdot v_{in}
\]
CB/CG Amplifier Topology

- **Application** → What is the input impedance ($R_{in}$) of the CB/CG topology → note that $R_{in}$ is the input impedance of the amplifier as if it is a 1-port circuit → we compute it while the output is open

- In general, $R_{in}$ is not $r_{in}$ except in unilateral amplifiers

\[ R_{in} = \frac{V_{in}}{I_{in}} \]

\[ i_{in} = \left( v_{in} - \frac{g_o}{g_m + g_o} v_{out} \right) \cdot (g_m + g_o) = \left( g_m + g_o \right) v_{in} - g_o \cdot \left( \frac{g_o}{g_o + g_m} \right) v_{in} \]

\[ \approx g_m - \frac{g_o \cdot g_m}{g_D} \cdot v_{in} \approx g_m \cdot v_{in} \]

\[ R_{in} \approx \frac{1}{g_m} \]
**CB/CG Amplifier Topology**

- **Application** → What is the output impedance ($R_{out}$) of the CB/CG topology → note that $R_{out}$ is the output impedance of the amplifier computed while the input is zero (shorted)

- $R_{out}$ is ALWAYS $r_{out}$ whether the amplifier is unilateral or not

\[
R_{out} = \frac{V_{out}}{i_{out}}
\]
**Application** → What is the output impedance \( (R_{out}) \) of the CB/CG topology → note that \( R_{out} \) is the output impedance of the amplifier computed while the input is zero (shorted)

\( R_{out} \) is ALWAYS \( r_{out} \) whether the amplifier is unilateral or not

\[ R_{out} = \left( r_o \parallel R_C \right) = \frac{R_C \cdot r_o}{R_C + r_o} \approx R_C \]

\[ i_{out} = v_{out} \cdot (g_o + g_C) \]

\[ R_{out} = v_{out} / i_{out} \]
CB/CG Amplifier Topology

◆ Application → What is the output impedance ($R_{out}$) of the CB/CG topology → note that $R_{out}$ is the output impedance of the amplifier computed while the input is zero (shorted)

◆ $R_{out}$ is ALWAYS $r_{out}$ whether the amplifier is unilateral or not

$$R_{out} = \left( r_o \parallel R_D \right) = \frac{R_D \cdot r_o}{R_D + r_o} \approx R_D$$

$$i_{out} = v_{out} \cdot (g_o + g_D)$$
Since the MOS case is just a special case of the BJT case that can be obtained by setting $r_{\pi}$ to infinity, we will analyze the BJT case for generality.
In a CEwRE/CSwRS topology, the input signal is applied to the base/gate of the transistor, while the output is taken at the collector/drain. The emitter/source is connected to ground through a resistance.

Consider the BJT case, let’s obtain the amplifier equivalent circuit.
We can obtain the 2-port equivalent circuit of this topology by using the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[ v_1 = i_1 \cdot r_{in} + A_{VR} \cdot v_2 \]

\[ v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1 \]
We can obtain the 2-port equivalent circuit of this topology by using the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[ \begin{align*}
    i_{\text{TEST}} &= \left( \frac{v_{\text{TEST}} - v_E}{r_\pi} \right) \\
    v_E &= \left( \frac{v_{\text{TEST}} - v_E}{r_\pi} \right) + g_m \left( v_{\text{TEST}} - v_E \right) \cdot \left( R_E \parallel r_o \right)
\end{align*} \]

\[ \begin{align*}
    \frac{v_{\text{TEST}}}{i_{\text{TEST}}} &= \frac{v_{\text{TEST}}}{\left( \frac{v_{\text{TEST}} - v_E}{r_\pi} \right) + g_m \left( v_{\text{TEST}} - v_E \right) \cdot \left( R_E \parallel r_o \right)} \\
    r_{in} &= r_\pi + \left( 1 + g_m \cdot r_\pi \right) \cdot \left( R_E \parallel r_o \right)
\end{align*} \]
We can obtain the 2-port equivalent circuit of this topology by using the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[ v_1 = i_1 \cdot r_{in} + A_{VR} \cdot v_2 \]
\[ v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1 \]

\[
\begin{align*}
    i_{\text{TEST}} &= \frac{v_{\text{TEST}} - v_E}{r_o} - g_m \cdot v_E \\
    v_E &= i_{\text{TEST}} \cdot (R_E \parallel r_\pi)
\end{align*}
\]

\[
\begin{align*}
    r_{out} &= \frac{v_{\text{TEST}}}{i_{\text{TEST}}} = r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_\pi)
\end{align*}
\]
We can obtain the 2-port equivalent circuit of this topology by using the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[ v_1 = i_1 \cdot r_{\text{in}} + A_{\text{VR}} \cdot v_2 \]

\[ v_2 = i_2 \cdot r_{\text{out}} + A_{\text{V0}} \cdot v_1 \]

\[ v_E = \frac{v_{\text{TEST}} - v_E}{r_{\pi}} \cdot R_E \]

\[ v_{\text{OUT-TEST}} = v_E - g_m \cdot (v_{\text{TEST}} - v_E) \cdot r_o \]

\[ A_{\text{V0}} = \frac{v_{\text{OUT-TEST}}}{v_{\text{TEST}}} = -\left(\frac{g_m \cdot r_{\pi} \cdot r_o - R_E}{R_E + r_{\pi}}\right) \]
CE/CS with E/S Resistance Amplifier Topology

We can obtain the 2-port equivalent circuit of this topology by using the $V_{\text{TEST}} : i_{\text{TEST}}$ method.

\[ v_1 = i_1 \cdot r_{in} + A_{VR} \cdot v_2 \]
\[ v_2 = i_2 \cdot r_{out} + A_{V0} \cdot v_1 \]

\[
\begin{align*}
\begin{cases}
v_E = \left( v_{\text{TEST}} - v_E \right) \cdot R_E \\
v_{\text{OUT-TEST}} = v_E
\end{cases}
\end{align*}
\]

\[
\begin{align*}
A_{VR} = \frac{v_{\text{OUT-TEST}}}{v_{\text{TEST}}} = \frac{R_E}{R_E + r_o}
\end{align*}
\]
CE/CS with E/S Resistance Amplifier Topology

\[ r_{in} = r_\pi + (1 + g_m \cdot r_\pi) \cdot (R_E \parallel r_o) \]
\[ \approx (1 + g_m \cdot R_E) \cdot r_\pi = r_\pi + \beta \cdot R_E \]

\[ r_{out} = r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_\pi) \]
\[ \approx (1 + g_m \cdot R_E) \cdot r_o \]

\[ A_{V0} = -\left( \frac{g_m \cdot r_\pi \cdot r_o - R_E}{R_E + r_\pi} \right) \]
\[ \approx -\left( \frac{g_m}{1 + g_m \cdot R_E} \right) [(1 + g_m \cdot R_E) \cdot r_o] = -g_m \cdot r_o \]

\[ A_{VR} = \frac{R_E}{R_E + r_o} \approx 0, \text{ but not zero} \]

CEwRE topology is bilateral
Gain is high and inverting
High input and output impedance
The CEwRE/CSwRS topology can incorporate a load resistance.
Manipulate the circuit to put it in the desired form

\[ r_{in} = r_{\pi} + (1 + g_m \cdot r_{\pi}) \cdot \left(\frac{R_E}{R_E + r_o}\right) \]
\[ \approx (1 + g_m \cdot R_E) \cdot r_{\pi} = r_{\pi} + \beta \cdot R_E \]
\[ r_{out} = \left[r_o + (1 + g_m \cdot r_o) \cdot \left(\frac{R_E}{r_{\pi}}\right)\right] \parallel R_C \]
\[ \approx \left[(1 + g_m \cdot R_E) \cdot r_o\right] \parallel R_C \approx R_C \]
\[ A_{V0} = -\left(\frac{g_m \cdot r_{\pi} \cdot R_E}{R_E + r_{\pi}}\right) \frac{R_C}{R_C + r_o + (1 + g_m \cdot r_o) \cdot \left(\frac{R_E}{r_{\pi}}\right)} \]
\[ = -\left(\frac{g_m}{1 + g_m \cdot R_E}\right) \cdot \left(\frac{R_C}{(1 + g_m \cdot R_E) \cdot r_o}\right) \]
\[ = -\left(\frac{g_m \cdot R_C}{1 + g_m \cdot R_E}\right) = -\left(\frac{R_C}{R_E}\right) \]

\[ A_{VR} = \frac{R_E}{R_E + r_o} \approx 0 \text{, but not zero} \]
CE/CS with E/S Resistance Amplifier Topology

Manipulate the circuit to put it in the desired form → it can also be done directly.

$$r_{in} = r_{\pi} + (1 + g_m \cdot r_{\pi}) \cdot (R_E \parallel r_o)$$
$$\simeq (1 + g_m \cdot R_E) \cdot r_{\pi} = r_{\pi} + \beta \cdot R_E$$

$$r_{out} = \left[ r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_{\pi}) \right] \parallel R_C$$
$$\simeq \left[ (1 + g_m \cdot R_E) \cdot r_o \right] \parallel R_C \simeq R_C$$

$$A_{V0} = -\left( \frac{g_m \cdot r_{\pi} \cdot r_o - R_E}{R_E + r_{\pi}} \right) \left( \frac{R_C}{R_C + r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_{\pi})} \right)$$
$$= -\left( \frac{g_m}{1 + g_m \cdot R_E} \right) \cdot (R_C \parallel (1 + g_m \cdot R_E) \cdot r_o)$$
$$= -\left( \frac{g_m \cdot R_C}{1 + g_m \cdot R_E} \right) = -\left( \frac{R_C}{R_E} \right)$$

$$A_{VR} = \frac{R_E}{R_E + r_o} \neq 0$$, but not zero

CEwRE topology with load resistance is bilateral.
Gain is inverting and ratio between resistors.
High input and output impedance.
The MOS-based CD topology is just a special case of the BJT-based topology.
The MOS-based CD topology is just a special case of the BJT-based topology.

\[ r_{in} = r_\pi + (1 + g_m \cdot r_\pi) \cdot (R_E \parallel r_o) \]
\[ r_{out} = r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_\pi) \]
\[ A_{V0} = -\left( \frac{g_m \cdot r_\pi \cdot r_o - R_E}{R_E + r_\pi} \right) \]
\[ A_{VR} = \frac{R_E}{R_E + r_o} \]

CE\text{w}RE topology is bilateral.

\[ r_{in} = \infty \]
\[ r_{out} = r_o + (1 + g_m \cdot r_o) \cdot R_S \]
\[ A_{V0} = -g_m \cdot r_o \]
\[ A_{VR} = \frac{R_S}{R_S + r_o} \]

CSwRS topology is bilateral.
The MOS-based CD topology is just a special case of the BJT-based topology → can incorporate a load resistance

\[ r_{in} = \infty \]

\[ r_{out} = \left[ r_o + (1 + g_m \cdot r_o) \cdot R_E \right] \parallel R_D \]

\[ A_{V0} = -\left( g_m \cdot r_o \right) \cdot \frac{R_D}{R_D + r_o + (1 + g_m \cdot r_o) \cdot R_S} \]

\[ = -\left( g_m \cdot R_S \right) \cdot \frac{R_D (1 + R_D)}{(1 + g_m \cdot R_S) \cdot r_o} \]

\[ = -\left( \frac{g_m \cdot R_D}{1 + g_m \cdot R_S} \right) = -\left( \frac{R_D}{R_S} \right) \]

\[ A_{VR} = \frac{R_S}{R_S + r_o} \approx 0 \text{, but not zero} \]

CSwRS topology with load resistance is bilateral
Gain is inverting and ratio between resistors
High input and output impedance
CE/CS with E/S Resistance Amplifier Topology

\[ r_{in} = r_\pi + (1 + g_m \cdot r_\pi) \cdot (R_E \parallel r_o) \]
\[ = (1 + g_m \cdot R_E) \cdot r_\pi + \beta \cdot R_E \]
\[ r_{out} = \left[ r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_\pi) \right] \parallel R_C \]
\[ = \left[ (1 + g_m \cdot R_E) \cdot r_o \right] \parallel R_C \simeq R_C \]

\[ A_{V0} = -\left( \frac{g_m \cdot r_\pi \cdot r_o - R_E}{R_E + r_\pi} \right) \cdot \frac{R_C}{R_C + r_o + (1 + g_m \cdot r_o) \cdot (R_E \parallel r_\pi)} \]
\[ = -\left( \frac{g_m}{1 + g_m \cdot R_E} \right) \cdot \frac{R_C}{R_C \parallel (1 + g_m \cdot R_E) \cdot r_o} \]
\[ = -\left( \frac{g_m \cdot R_C}{1 + g_m \cdot R_E} \right) = -\left( \frac{R_C}{R_E} \right) \]

\[ A_{VR} = \frac{R_E}{R_E + r_o} \approx 0 \text{, but not zero} \]

- CEwRE and CSwRS are both bilateral
- Input impedance is high (infinite for MOS)
- Voltage Gain is negative and accurate
- Mid-range output impedance

\[ r_{in} = \infty \]
\[ r_{out} = \left[ r_o + (1 + g_m \cdot r_o) \cdot R_E \right] \parallel R_D \]
\[ = \left[ (1 + g_m \cdot R_E) \cdot r_o \right] \parallel R_D = R_D \]
\[ A_{V0} = -\left( g_m \cdot r_o \right) \cdot \frac{R_D}{R_D + r_o + (1 + g_m \cdot r_o) \cdot R_S} \]
\[ = -\left( \frac{g_m}{1 + g_m \cdot R_S} \right) \cdot \frac{R_D}{R_D \parallel (1 + g_m \cdot R_S) \cdot r_o} \]
\[ = -\left( \frac{g_m \cdot R_D}{1 + g_m \cdot R_S} \right) = -\left( \frac{R_D}{R_S} \right) \]

\[ A_{VR} = \frac{R_S}{R_S + r_o} \approx 0 \text{, but not zero} \]