Lecture 12

Single Stage FET Amplifiers:
Common Gate Amplifier
Common Drain Amplifier

The Building Blocks of Analog Circuits - II

In this lecture you will learn:

• Common Gate (CG) and Common Drain (CD) Amplifiers
• Small signal models of amplifiers

An attribute of the common source amplifier:

The input resistance is very large:

\[ R_{in} = \infty \]

Not suitable for current amplifiers or transimpedance amplifiers
The Common Gate Amplifier

The gate terminal is “common” between the input and the output. The common gate amplifiers are useful when small input resistances and large output resistances are desired in amplifiers (they also have good high frequency performance – but that will come later in the course).

But the current gain is unity!

Note: The bulk is not tied to the source.
Choice of Substrate Potentials

In order to keep the source and drain PN-junctions with the substrate (or bulk) reverse biased at all times,

i) The P-substrate (for NFETs) is generally tied to the most negative voltage in the circuit
ii) The N-substrate or N-well (for PFETs) is tied to the most positive voltage in the circuit

The Common Gate Amplifier: Small Signal Model

Note:
\[ V_{bs} = V_{gs} \]
The Common Gate Amplifier: Short Circuit Current Gain

Short circuit current gain:

\[ i_{\text{test}} = -i_d = i_{\text{out}} \]

\[ A_i = \frac{i_{\text{out}}}{i_{\text{test}}} = 1 \]

Short circuit current gain is unity!

The Common Gate Amplifier: Input Resistance

Input resistance:

\[ i_{\text{test}} = -i_d = \left( \frac{(g_m + g_{mb})v_{gs} + 1}{r_o + (R || R_L)} \right) v_{gs} \]

\[ R_{in} = \frac{v_{gs}}{i_{\text{test}}} = \frac{r_o + (R || R_L)}{(g_m + g_{mb})v_{gs} + 1} \]

\[ R_{in} \text{ can be small if:} \]

\[ (g_m + g_{mb})v_{gs} > 1 \]

\[ R_{in} = r_o + (R || R_L) \left( g_m + g_{mb} \right) v_{gs} + 1 = \frac{1}{1 + \left( \frac{R || R_L}{r_o} \right) v_{gs}} \]
The Common Gate Amplifier: Open Circuit Voltage Gain

Open circuit voltage gain:
\[
V_{out} = -i_d R = -R \left( \frac{(g_m + g_{mb}) r_o + 1}{r_o + R} \right) V_{gs} = \left( g_m + g_{mb} + \frac{1}{r_o} \right) (R \parallel r_o) V_{gs}
\]

\[
\Rightarrow A_v = \frac{V_{out}}{V_{test}} = \frac{V_{out}}{V_{gs}} = \left( g_m + g_{mb} + \frac{1}{r_o} \right) (R \parallel r_o)
\]

\[
i_d = (g_m + g_{mb}) V_{gs} + \frac{V_{out}}{r_o} \Rightarrow i_d = \left( g_m + g_{mb} \right) V_{gs} + \frac{V_{out} + V_{gs}}{r_o}
\]

If:
\[
(g_m + g_{mb}) r_o >> 1
\]

\[
\Rightarrow A_v = \left( g_m + g_{mb} + \frac{1}{r_o} \right) (R \parallel r_o) \Rightarrow \text{Large if } R \text{ is large}
\]

The Common Gate Amplifier: Output Resistance

Output resistance:
\[
i_d = (g_m + g_{mb}) V_{gs} + \frac{V_{test} + V_{gs}}{r_o} = -\frac{V_{gs}}{r_o}
\]

\[
\Rightarrow V_{gs} = -V_{test} \left( \frac{1}{(g_m + g_{mb}) \parallel R_s} \right)
\]

\[
R_D = \frac{V_{test}}{i_d} = -\frac{r_o R_s}{(r_o \parallel (g_m + g_{mb}) \parallel R_s)} = r_o + R_s \left[ 1 + r_o (g_m + g_{mb}) \right]
\]
The Common Gate Amplifier: Output Resistance

Output resistance:
\[ R_D = r_o + R_s + r_o R_s (g_m + g_mb) \]
\[ R_{out} = (R \parallel R_D) \]
\[ = (R \parallel [r_o + R_s + r_o R_s (g_m + g_mb)]) \]
\[ \rightarrow R_{out} \text{ can be large if } R \text{ is large} \]

The Common Gate Amplifier: Transimpedance Gain

Transimpedance gain:
\[ i_{test} = -i_d \]
\[ R_m = \frac{v_{out}}{i_{test}} = -\frac{i_d R}{i_{test}} = R \]
\[ \rightarrow R_m \text{ can be large if } R \text{ is large} \]
The Common Gate Amplifier: A Current Buffer

\[ i_g \rightarrow g_m v_{gs} \rightarrow g_m v_{bs} \rightarrow i_d \rightarrow i_{out} \]

Source \( v_{gs} \)

Base \( v_{bs} \)

Drain \( v_{out} \)

\[ R_S \]

\[ R_o \]

\[ + \]

\[ - \]

\[ + \]

\[ - \]

\[ R_L \]

Compare with the standard current amplifier model:

\[ R_{out} \text{ can be large} \]
\[ R_m \text{ is small} \]
\[ A_i \text{ is unity} \]

It is a good current buffer!!

The Common Gate Amplifier: A Transimpedance Amplifier

\[ i_g \rightarrow g_m v_{gs} \rightarrow g_m v_{bs} \rightarrow i_d \rightarrow i_{out} \]

Source \( v_{gs} \)

Base \( v_{bs} \)

Drain \( v_{out} \)

\[ R_S \]

\[ R_o \]

\[ + \]

\[ - \]

\[ + \]

\[ - \]

\[ R_L \]

Compare with the standard transimpedance amplifier model:

\[ R_{out} \text{ can be large} \]
\[ R_m \text{ is small} \]
\[ R_m \text{ can be large} \]

It is a decent transimpedance amplifier!!
The Common Drain Amplifier (or the Source Follower)

The drain terminal is “common” between the input and the output.
The common drain amplifiers are useful when large input resistances and small output resistances are desired in voltage amplifiers.
The voltage gain is less than unity!

Note: The bulk is not tied to the source.

The Common Drain Amplifier: Small Signal Model

Note:
\[ v_{bs} = -v_{out} \]
The Common Drain Amplifier: Open Circuit Voltage Gain

Open circuit voltage gain:
\[ v_{test} = v_{gs} + v_{out} = v_{gs} + i_d r_o \]
\[ \Rightarrow v_{out} = i_d = \left( \frac{g_m v_{gs}}{r_o + R} \right) \]
\[ \Rightarrow v_{out} \left( \frac{1 + g_m r_o}{(r_o + R)} \right) = v_{gs} \left( \frac{g_m f_o}{(r_o + R)} \right) = (v_{test} - v_{out}) \left( \frac{g_m f_o}{(r_o + R)} \right) \]
\[ \Rightarrow v_{out} = \left( \frac{1 + g_m r_o}{(r_o + R)} \right) v_{test} \left( \frac{g_m f_o}{(r_o + R)} \right) \]
\[ \Rightarrow A_v = \frac{v_{out}}{v_{test}} = \frac{1}{1 + \frac{g_m r_o}{(r_o + R)}} < 1 \]

Less than unity – but can be very close to unity

The Common Drain Amplifier: Input Resistance

Input resistance:
\[ R_{in} = \frac{v_{test}}{i_{test}} = \infty \]
Large
The Common Drain Amplifier: Output Resistance

Output resistance:

\[ i_{\text{test}} = \frac{v_{\text{test}}}{R_o} - i_d \]
\[ = \frac{v_{\text{test}}}{R_o} \left( g_m r_o v_{gs} - \left( 1 + g_m r_o \right) v_{\text{test}} \right) \]
\[ = \frac{v_{\text{test}}}{R_o} + \frac{g_m r_o + 1 + g_m r_o}{R_o + R} v_{\text{test}} \]
\[ \Rightarrow \frac{1}{R_{out}} = \frac{i_{\text{test}}}{v_{\text{test}}} = \frac{1}{R_o} + \frac{\left( g_m + g_m r_o \right) r_o + 1}{R_o + R} \]

\[ R_{out} \text{ can be small if:} \]
\[ r_o \gg R \]
\[ (g_m + g_m r_o) r_o \gg 1 \]

and/or if \( R_o \) is small

The Common Drain Amplifier: A Voltage Buffer

Compare with the standard voltage amplifier model:

\[ R_{out} \text{ can be small} \]
\[ R_{in} \text{ is large} \]
\[ A_v \text{ can be almost unity} \]

It is a good voltage buffer!!
The CS, CG, and CD Topologies

The common source (CS) topology:
1) Large input resistance
2) Large output resistance
3) Decent voltage gain
4) A decent voltage amplifier
5) A decent transconductance amplifier

The common gate (CG) topology:
1) Can have small input resistance
2) Large output resistance
3) Decent voltage gain
4) Unity current gain
5) A good current buffer
6) A decent voltage amplifier
7) A decent transimpedance amplifier

The common drain (CD) topology:
1) Large input resistance
2) Small output resistance
3) Less than unity voltage gain
4) A good voltage buffer