Lecture 12

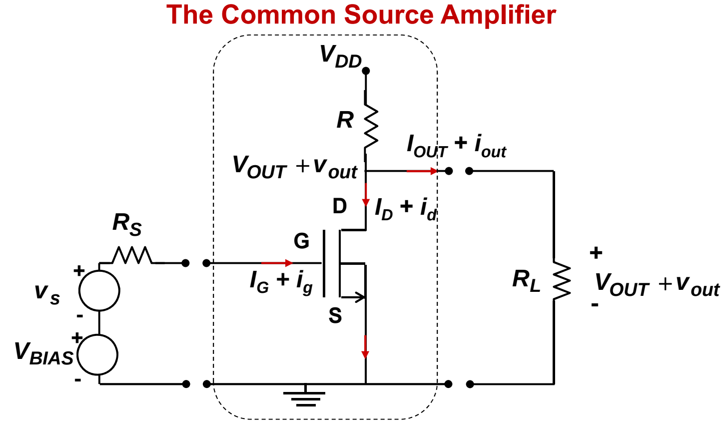
Single Stage FET Amplifiers: Common Gate Amplifier Common Drain Amplifier

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**

The Common Source Amplifier



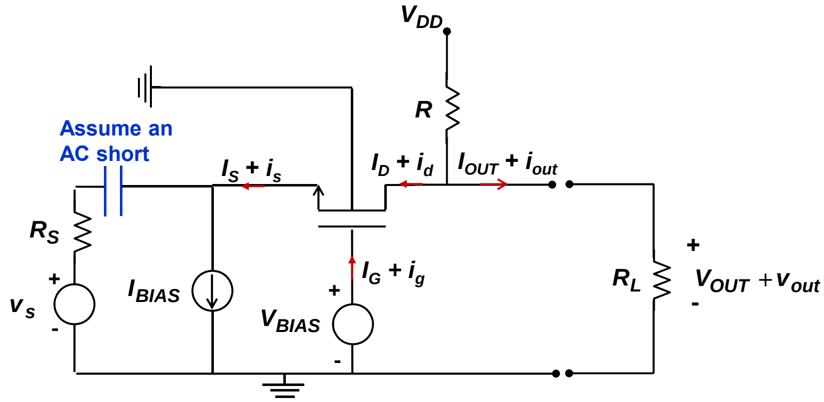
An attribute of the common source amplifier:

The input resistance is very large:

$$R_{in} = \infty$$

Not suitable for current amplifiers or transimpedance amplifiers

The Common Gate Amplifier



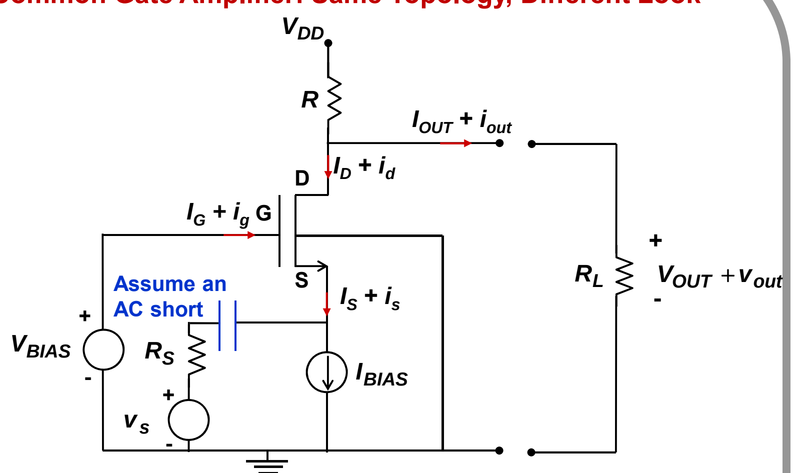
The gate terminal is "common" between the input and the output

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

The Common Gate Amplifier: Same Topology, Different Look



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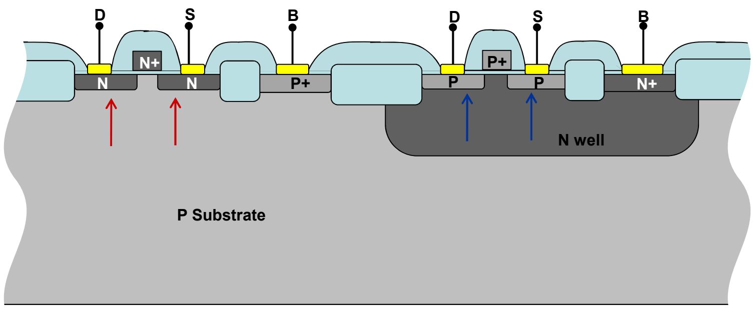
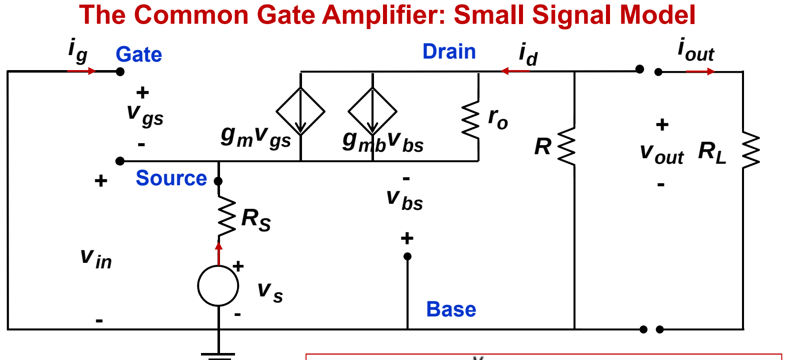
Choice of Substrate Potentials



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

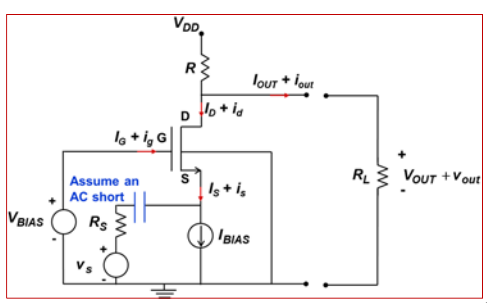
i) The P-substrate (for NFETs) is generally tied to the most negative voltage in the circuit
ii) The N-substrate or N-well (for PFETs) is tied to the most positive voltage in the circuit

The Common Gate Amplifier: Small Signal Model

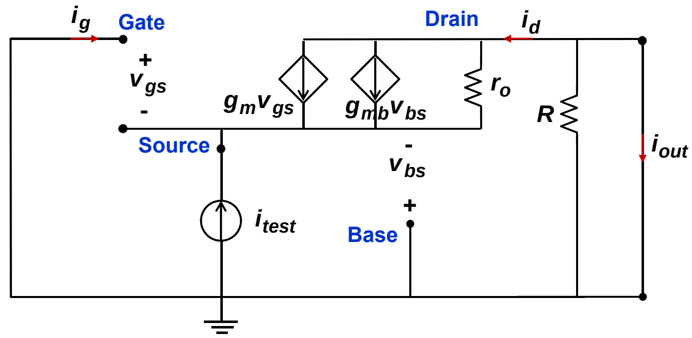


Note:

$v_{bs} = v_{gs}$



The Common Gate Amplifier: Short Circuit Current Gain

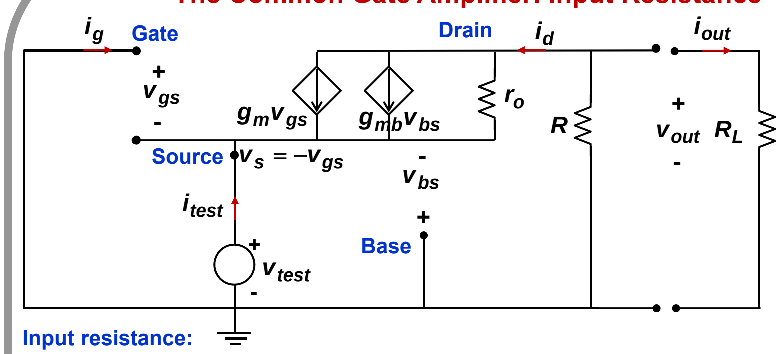


Short circuit current gain:

$$i_{test} = -i_d = i_{out}$$

$$A_i = \frac{i_{out}}{i_{test}} = 1 \longrightarrow \text{Short circuit current gain is unity!}$$

The Common Gate Amplifier: Input Resistance



Input resistance:

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

$$R_{in} = \frac{v_{test}}{i_{test}} = -\frac{v_{gs}}{i_{test}} = \frac{r_o + (R \,||\, R_L)}{(g_m + g_{mb})r_o + 1}$$

R_{in} can be small if:

$$(g_m + g_{mb})r_o >> 1$$

$$\Rightarrow R_{in} = \frac{r_o + (R \,||\, R_L)}{(g_m + g_{mb})r_o + 1} \approx \frac{1}{(g_m + g_{mb})}\left[1 + \frac{(R \,||\, R_L)}{r_o}\right] \rightarrow \text{Small}$$

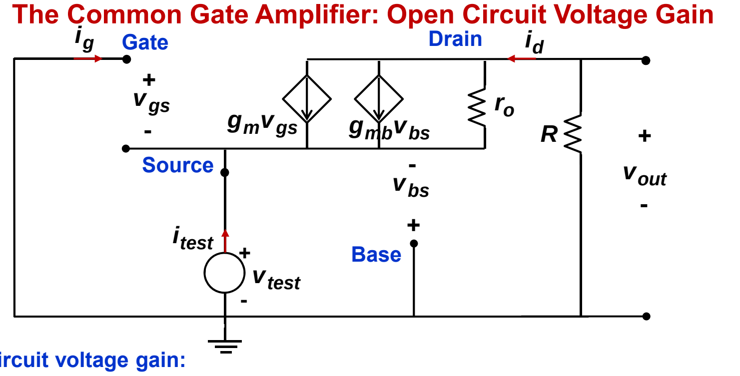
$$i_d = (g_m + g_{mb})v_{gs} + \frac{v_{out} + v_{gs}}{r_o}$$

$$= (g_m + g_{mb})v_{gs} + \frac{v_{gs}}{r_o} - i_d \frac{(R \,||\, R_L)}{r_o}$$

$$i_d = \frac{(g_m + g_{mb})v_{gs} + \frac{v_{gs}}{r_o}}{1 + \frac{(R \,||\, R_L)}{r_o}}$$

$$= \frac{(g_m + g_{mb})r_o + 1}{r_o + (R \,||\, R_L)} v_{gs}$$

The Common Gate Amplifier: Open Circuit Voltage Gain



Open circuit voltage gain:

$$v_{out} = -i_d R = -R\left(\frac{(g_m + g_{mb})\, r_o + 1}{r_o + R}\right) v_{gs} = -\left(g_m + g_{mb} + \frac{1}{r_o}\right)(R \,||\, r_o)\, v_{gs}$$

$$\Rightarrow A_v = \frac{v_{out}}{v_{test}} = -\frac{v_{out}}{v_{gs}} = \left(g_m + g_{mb} + \frac{1}{r_o}\right)(R \,||\, r_o)$$

$$i_d = (g_m + g_{mb}) v_{gs} + \frac{v_{out} + v_{gs}}{r_o}$$

$$= (g_m + g_{mb}) v_{gs} + \frac{v_{gs}}{r_o} - i_d \frac{R}{r_o}$$

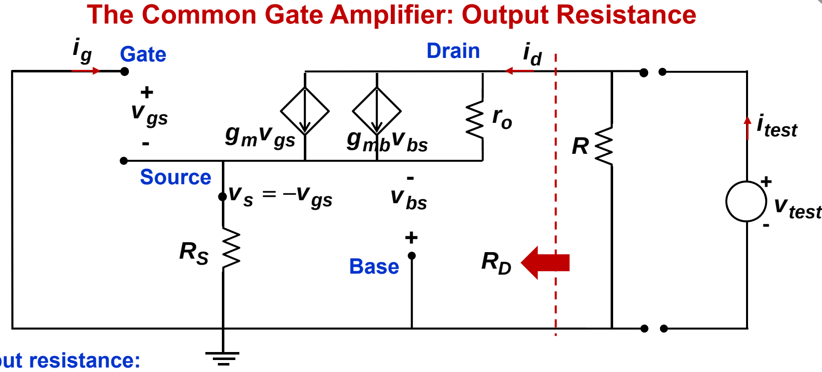
$$i_d = \frac{(g_m + g_{mb})\, r_o + 1}{r_o + R}\, v_{gs}$$

If:

$$(g_m + g_{mb}) r_o >> 1$$

$$\Rightarrow A_v = \left(g_m + g_{mb} + \frac{1}{r_o}\right)(R \,||\, r_o) \sim (g_m + g_{mb})(R \,||\, r_o) \longrightarrow$$ **Large if R is large**

The Common Gate Amplifier: Output Resistance



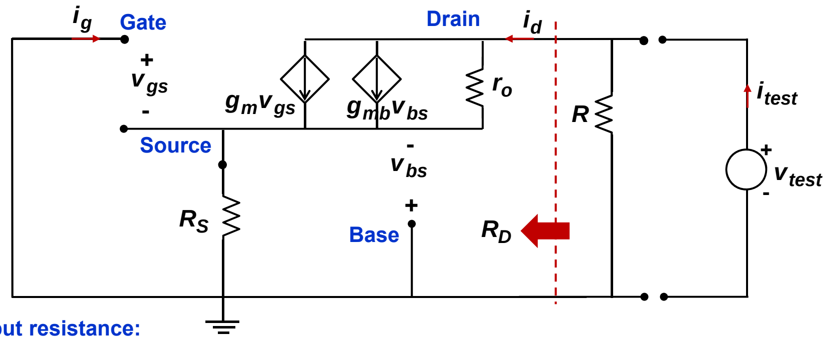
Output resistance:

$$i_d = (g_m + g_{mb}) v_{gs} + \frac{v_{test} + v_{gs}}{r_o} = -\frac{v_{gs}}{R_s}$$

$$\Rightarrow v_{gs} = -v_{test} \frac{\left(r_o \,||\, \frac{1}{(g_m + g_{mb})} \,||\, R_s\right)}{r_o}$$

$$R_D = \frac{v_{test}}{i_d} = \frac{r_o R_s}{\left(r_o \,||\, \frac{1}{(g_m + g_{mb})} \,||\, R_s\right)} = r_o + R_s\left[1 + r_o (g_m + g_{mb})\right]$$

The Common Gate Amplifier: Output Resistance



Output resistance:

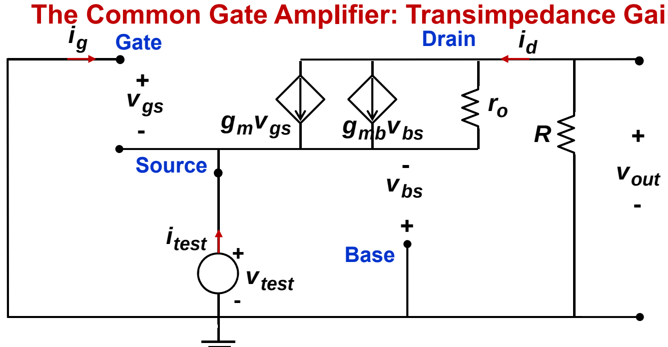
$$R_D = r_o + R_s + r_o R_s (g_m + g_{mb})$$

$$R_{out} = (R \,||\, R_D)$$
$$= (R \,||\, [r_o + R_s + r_o R_s (g_m + g_{mb})])$$

$\longrightarrow$ R_{out} can be large if R is large

R_{out} depends on R_s

The Common Gate Amplifier: Transimpedance Gain



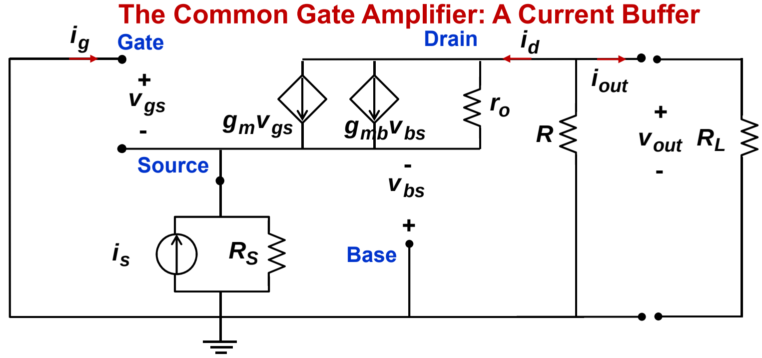
Transimpedance gain:

$$i_{test} = -i_d$$

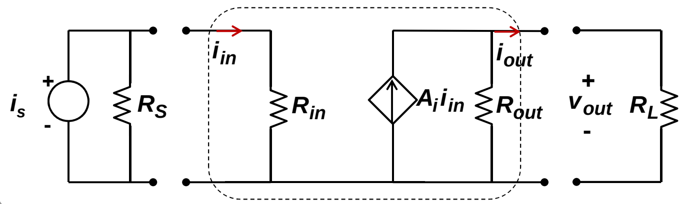
$$R_m = \frac{v_{out}}{i_{test}} = -\frac{i_d R}{i_{test}} = R$$

$\longrightarrow$ R_m can be large if R is large

The Common Gate Amplifier: A Current Buffer



Compare with the standard current amplifier model:



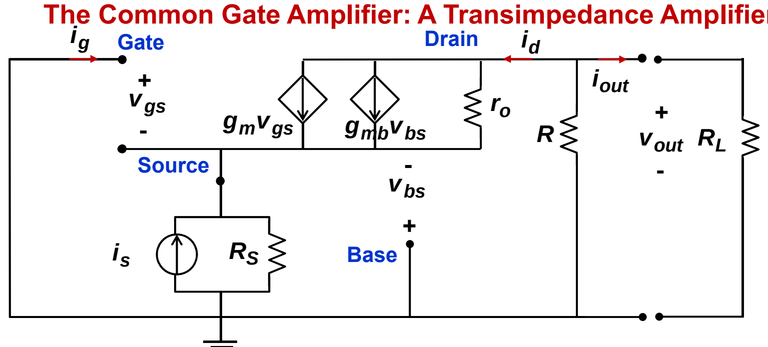
R_{out} can be large

R_{in} is small

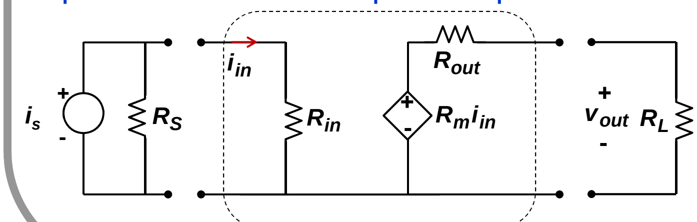
A_i is unity

It is a good current buffer!!

The Common Gate Amplifier: A Transimpedance Amplifier



Compare with the standard transimpedance amplifier model:



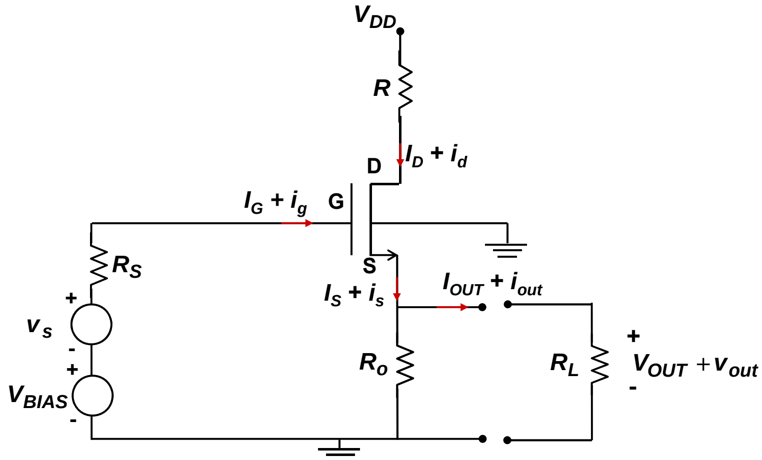
R_{out} can be large

R_{in} is small

R_m can be large

It is a decent transimpedance amplifier!!

The Common Drain Amplifier (or the Source Follower)



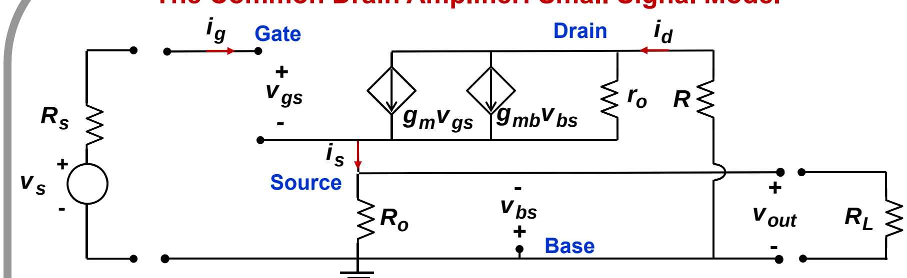
The drain terminal is "common" between the input and the output

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!

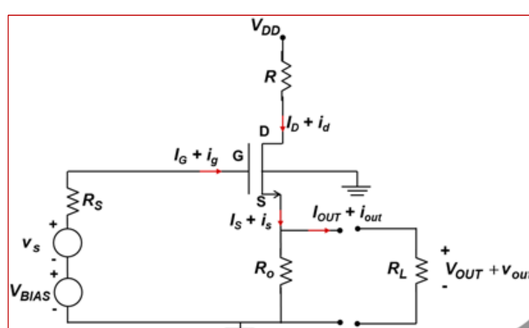
Note: The bulk is not tied to the source

The Common Drain Amplifier: Small Signal Model

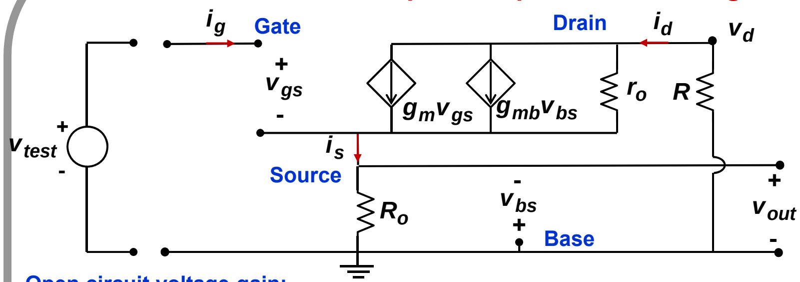


Note:

$v_{bs} = -v_{out}$



The Common Drain Amplifier: Open Circuit Voltage Gain



Open circuit voltage gain:

$$v_{test} = v_{gs} + v_{out} = v_{gs} + i_d R_o$$

$$\Rightarrow \frac{v_{out}}{R_o} = i_d = \frac{\left(g_m r_o v_{gs} - (1+g_{mb} r_o) v_{out}\right)}{(r_o + R)}$$

$$\Rightarrow v_{out}\left(\frac{1}{R_o} + \frac{(1+g_{mb} r_o)}{(r_o+R)}\right) = v_{gs}\frac{g_m r_o}{(r_o+R)} = (v_{test} - v_{out})\frac{g_m r_o}{(r_o+R)}$$

$$\Rightarrow v_{out}\left(\frac{1}{R_o} + \frac{(1+g_{mb} r_o)}{(r_o+R)} + \frac{g_m r_o}{(r_o+R)}\right) = v_{test}\frac{g_m r_o}{(r_o+R)}$$

$$\Rightarrow A_v = \frac{v_{out}}{v_{test}} = \frac{\dfrac{g_m r_o R_o}{(r_o+R)}}{1 + \dfrac{(g_m + g_{mb}) r_o R_o}{(r_o+R)}} < 1$$

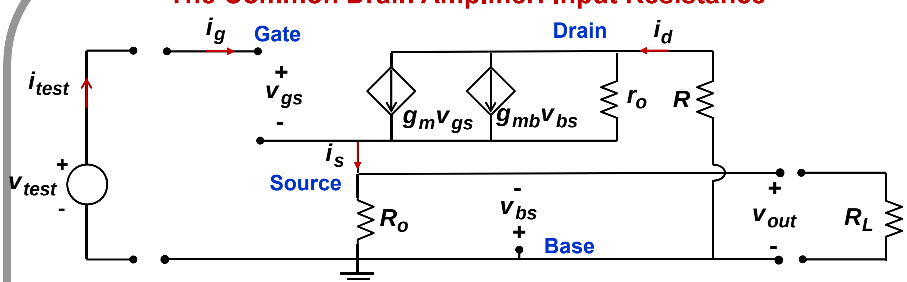
→ Less than unity – but can be very close to unity

$$i_d = g_m v_{gs} - g_{mb} v_{out} + \frac{v_d - v_{out}}{r_o}$$

$$= g_m v_{gs} - g_{mb} v_{out} + \frac{-i_d R - v_{out}}{r_o}$$

$$\Rightarrow i_d = \frac{\left(g_m r_o v_{gs} - (1+g_{mb} r_o) v_{out}\right)}{(r_o+R)}$$

The Common Drain Amplifier: Input Resistance

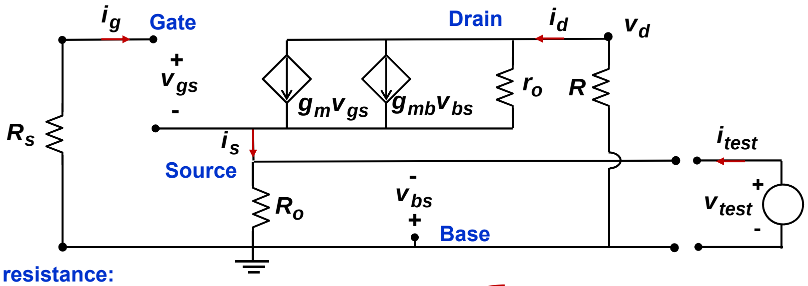


Input resistance:

$$R_{in} = \frac{v_{test}}{i_{test}} = \infty$$

→ Large

The Common Drain Amplifier: Output Resistance



Output resistance:

$$i_{test} = \frac{v_{test}}{R_o} - i_d$$

$$= \frac{v_{test}}{R_o} - \frac{\left(g_m r_o v_{gs} - (1+g_{mb} r_o) v_{test}\right)}{(r_o + R)}$$

$$= \frac{v_{test}}{R_o} + \frac{(g_m r_o + 1 + g_{mb} r_o)}{(r_o + R)} v_{test}$$

$$\Rightarrow \frac{1}{R_{out}} = \frac{i_{test}}{v_{test}} = \frac{1}{R_o} + \frac{(g_m + g_{mb}) r_o + 1}{(r_o + R)}$$

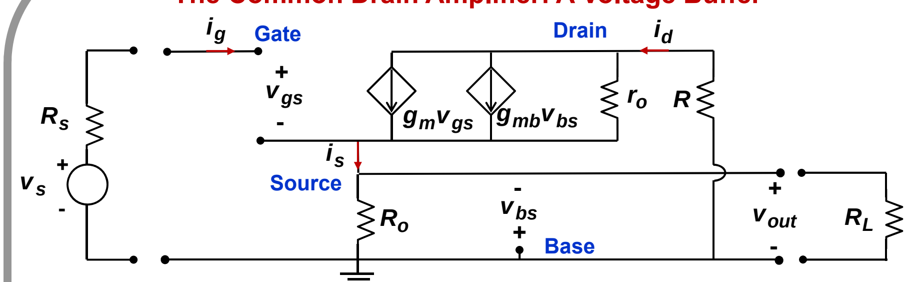
$$i_d = g_m v_{gs} - g_{mb} v_{test} + \frac{v_d - v_{test}}{r_o}$$

$$= g_m v_{gs} - g_{mb} v_{test} + \frac{-i_d R - v_{test}}{r_o}$$

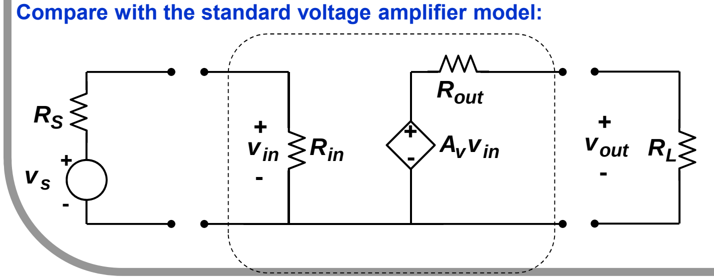
$$\Rightarrow i_d = \frac{\left(g_m r_o v_{gs} - (1+g_{mb} r_o) v_{test}\right)}{(r_o + R)}$$

R_{out} can be small if:
$r_o >> R$
$(g_m+g_{mb})\, r_o >> 1$
and/or if R_o is small

The Common Drain Amplifier: A Voltage Buffer



Compare with the standard voltage amplifier model:



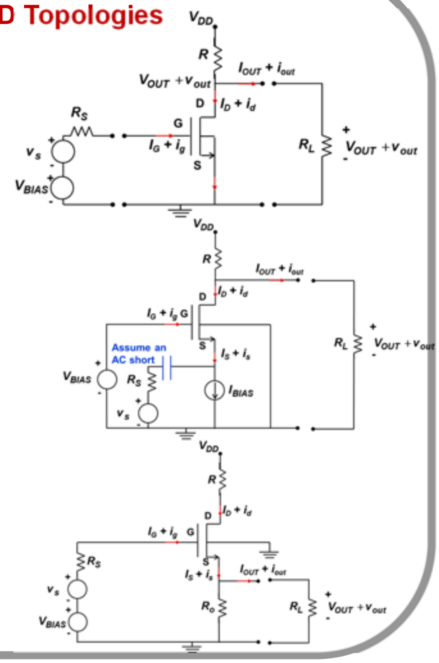
R_{out} can be small

R_{in} is large

A_v 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