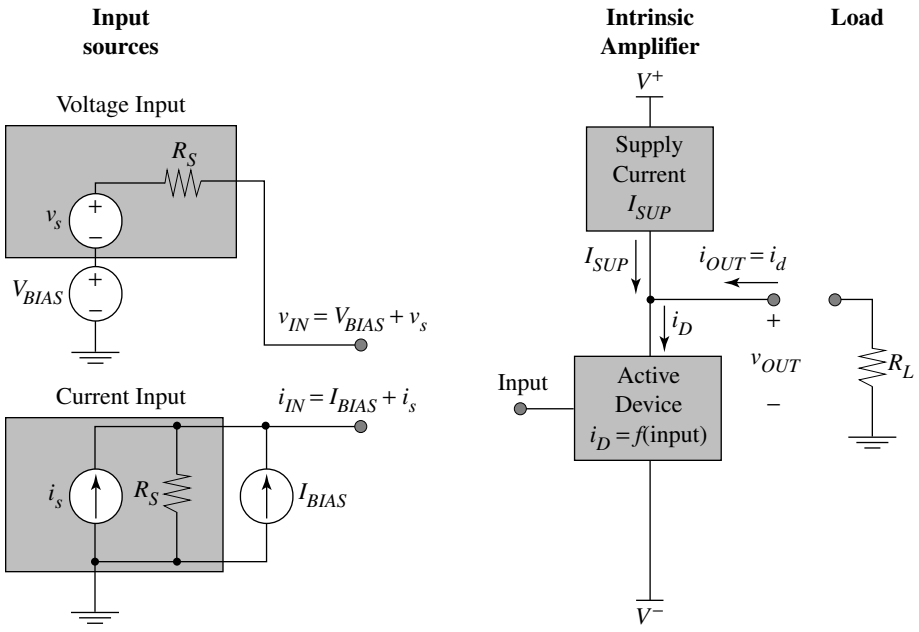
I. Transistor Amplifiers

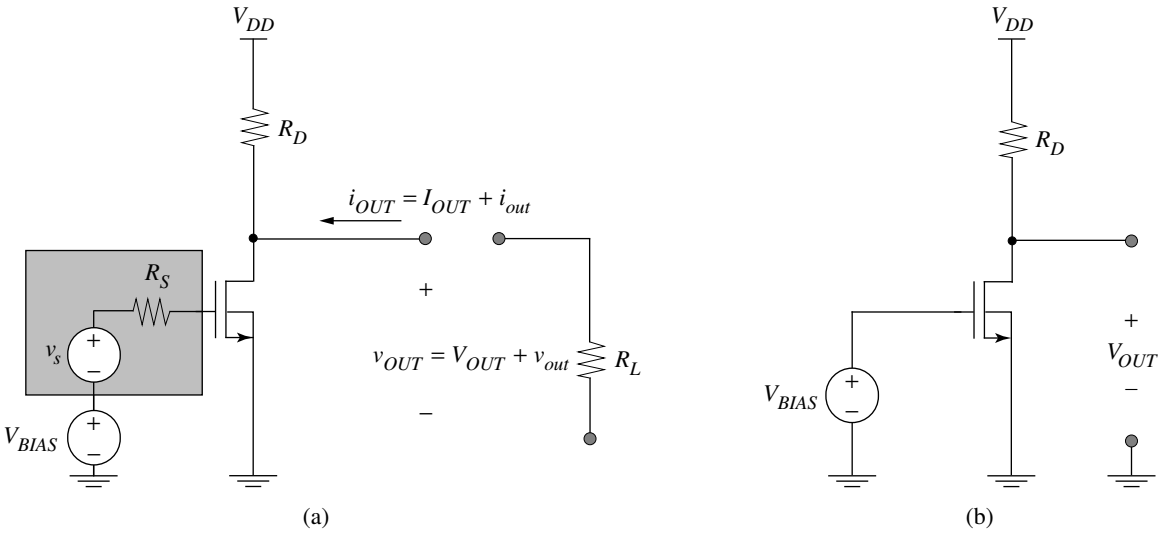
A. Amplifier Terminology:



- Total input voltage = $V_{BIAS} + v_s = v_{IN}$
- Total input current = $I_{BIAS} + i_s = i_{IN}$
- Source resistance R_S is <u>only</u> associated with small signal sources
- Total output voltage = $v_{OUT} = V_{OUT} + v_{out}$
- Total output current = $i_{OUT} = I_{OUT} + i_{out}$
- Choose $I_D = I_{SUP}$ ----> DC output current, $I_{OUT} = 0$, $V_{OUT} = 0$
- $i_{out} = i_D - I_{SUP} = i_d$
- $v_{out} = -i_{out} R_L = i_d R_L$

II. Common-Source Amplifier

A. Topology



- Full amplifier includes DC bias voltage, V_{BIAS}, small signal voltage and associated source resistance, R_S, and load resisitance, R_L
- To compute V_{BIAS} remove v_s, R_S and R_L

B. Biasing the CS Amplifier

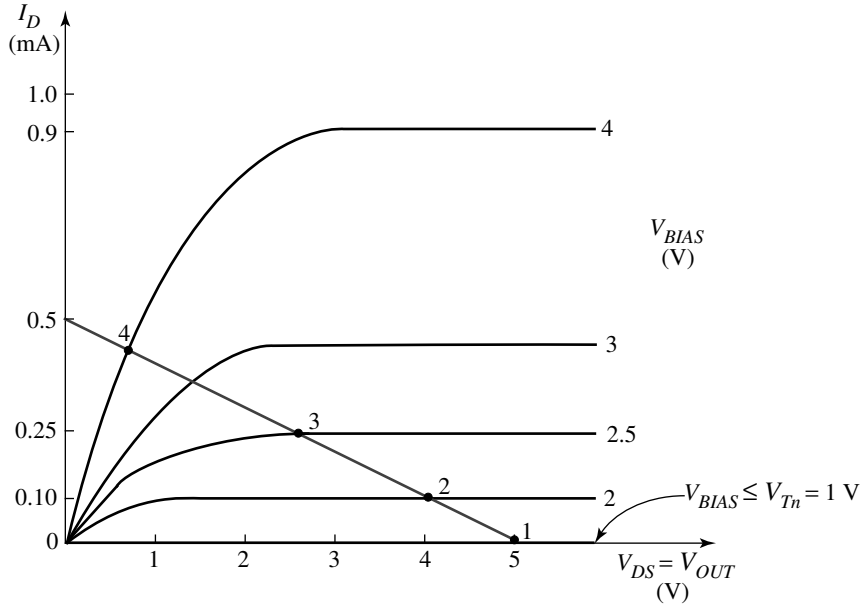
- Find V_{BIAS} such that V_{OUT} is "centered" $V_{OUT} = 2.5\text{V}$

$$V_{OUT} = V_{DD} - I_D R_D$$

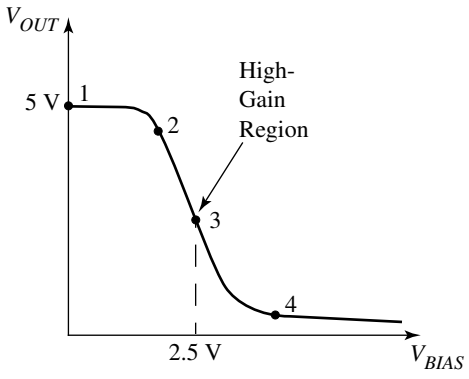
$$I_D = \frac{W}{2L}\mu_n C_{ox}(V_{GS} - V_{Tn})^2 = \frac{W}{2L}\mu_n C_{ox}(V_{BIAS} - V_{Tn})^2$$

- Solve both equations OR

- We can find the operating point graphically by plotting the NMOS characteristics and the with a load line
- $I_D = 250\ \mu A$, $V_{BIAS} = 2.5V$, $V_{OUT} = 2.5V$



(a)

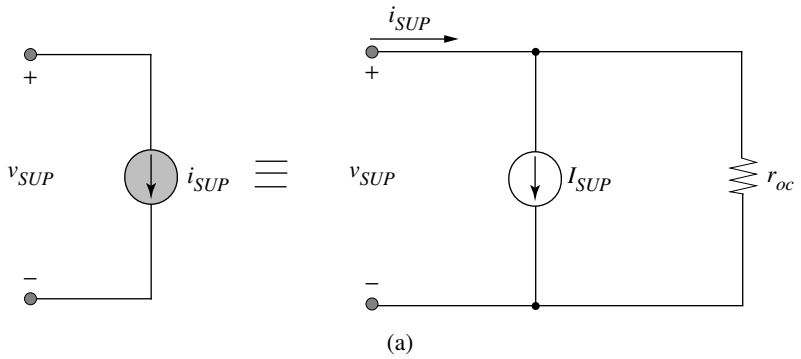


(b)

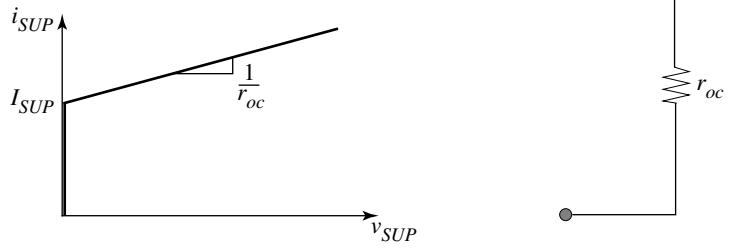
- Low voltage gain since limited by value of R_D

III. Common-Source Amplifier - Current Source Supply

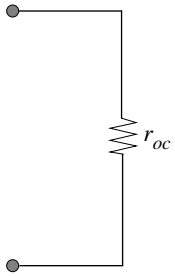
A.Current Source Supplies



(a)



(b)



(c)

- Large-signal model:

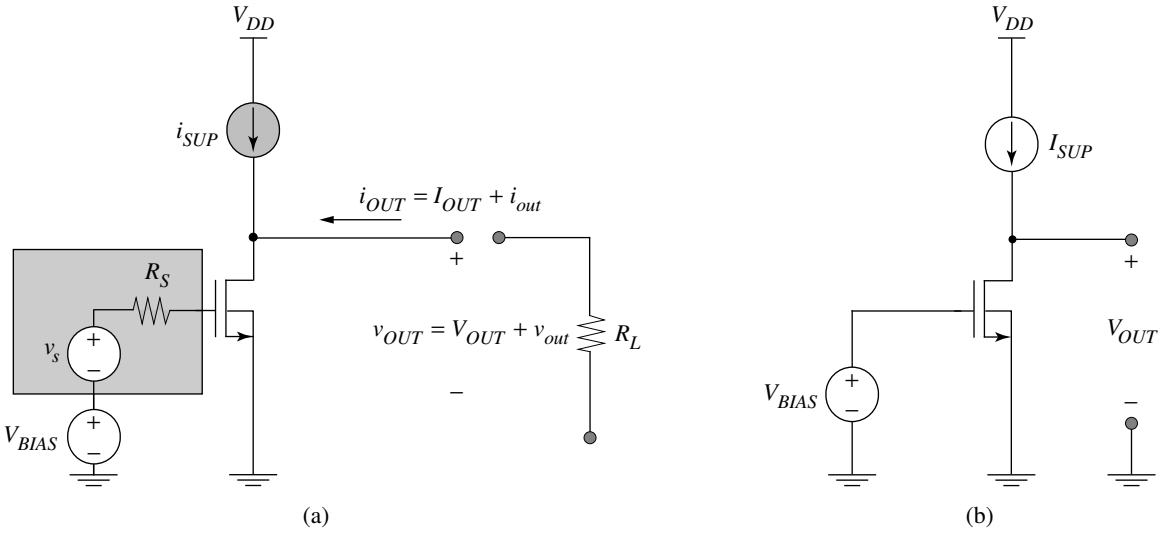
$$i_{SUP} = 0 \text{ for } V_{SUP} < 0$$

$$i_{SUP} = I_{SUP} + v_{SUP}/r_{oc} \text{ for } V_{SUP} > 0$$

- Small-signal model: I_{SUP}=0 & V_{SUP}=0

$$i_{sup}=v_{sup}/r_{oc}$$

B. Large Signal Analysis - CS Amplifier

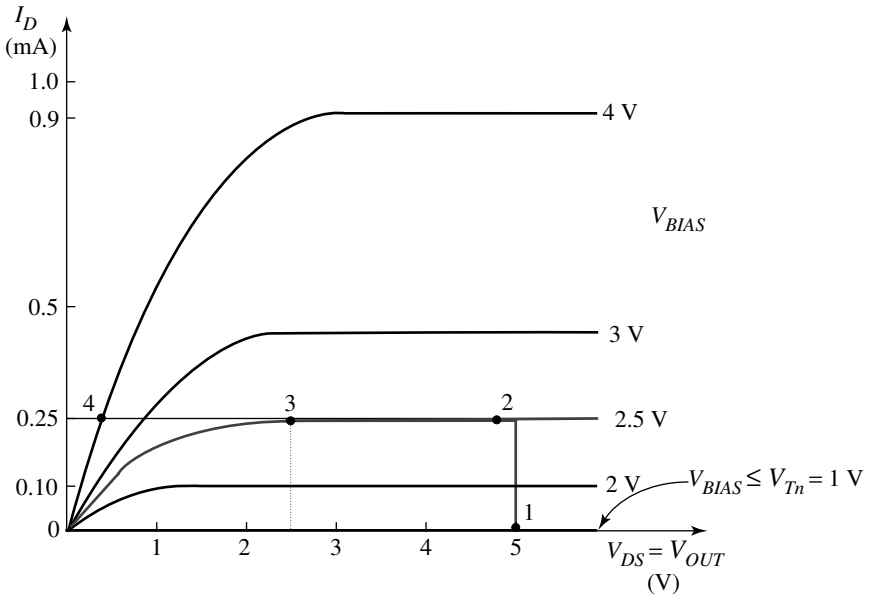


- Find V_{BIAS} such that V_{OUT} is "centered"
- This occurs by forcing $I_D = I_{SUP}$ when MOS transistor in saturated

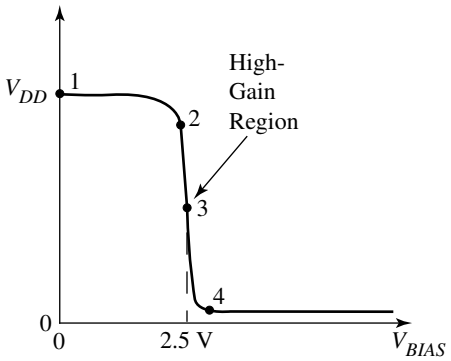
$$I_{SUP} = I_D = \frac{W}{2L}\mu_n C_{ox}(V_{GS} - V_{Tn})^2 = \frac{W}{2L}\mu_n C_{ox}(V_{BIAS} - V_{Tn})^2$$

$$V_{BIAS} = V_{Tn} + \sqrt{\frac{I_{SUP}}{\frac{W}{2L}\mu_n C_{ox}}}$$

- We can find the operating point graphically by plotting the NMOS characteristics and with a load line



(a)

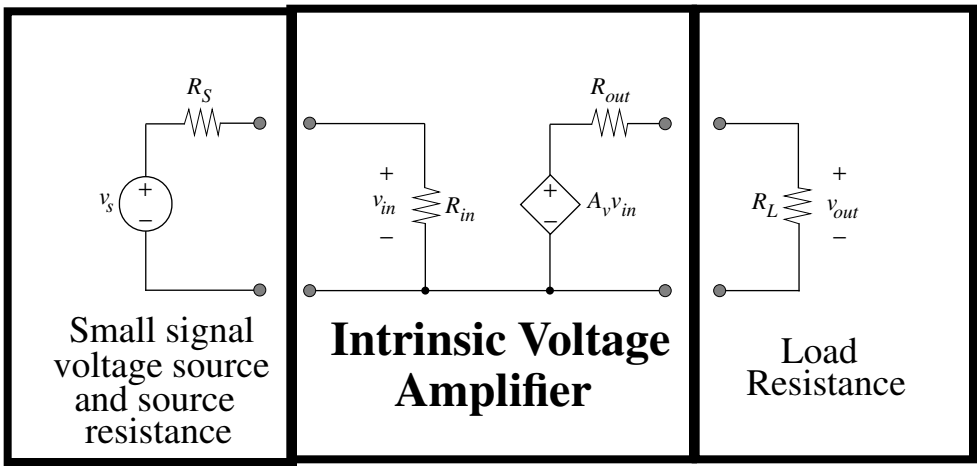


(b)

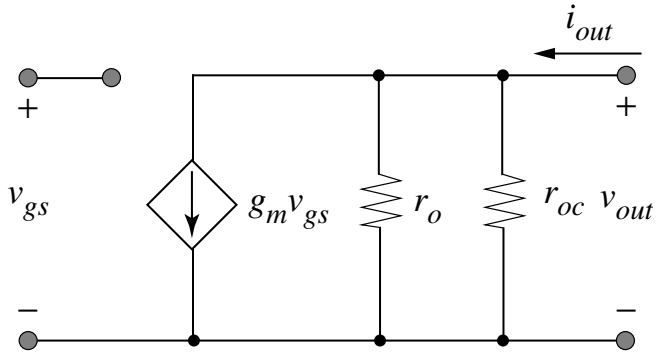
- The range of input bias voltage, V_{BIAS} for which the current source and the transistor are in their constant-current regions is *extremely* small. We will address this issue later.
- Load line for current source supply (idealized characteristics)
- Determine small-signal model at high gain operating point

IV. Two-Port Amplifier Small-Signal Models

A. Introduction



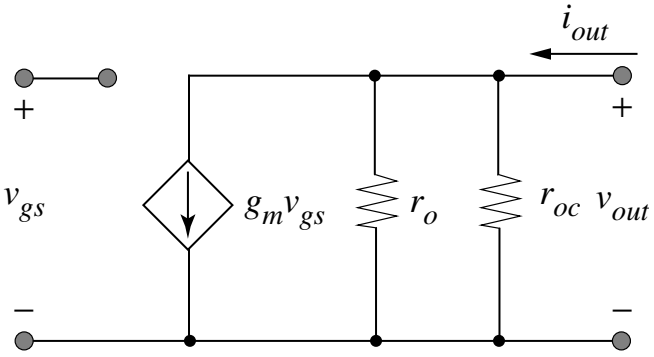
- Look at small signal model of the "intrinsic" or "unloaded" CS amplifier
- Remove R_S and R_L
- Find R_{in}, R_{out}, A_v



B. Method to find two-port small-signal model Parameters

- Find intrinsic voltage gain - apply perfect test voltage source (no RS) and calculate output voltage
- $A_v = v_{out}/v_t$

(a) A_v

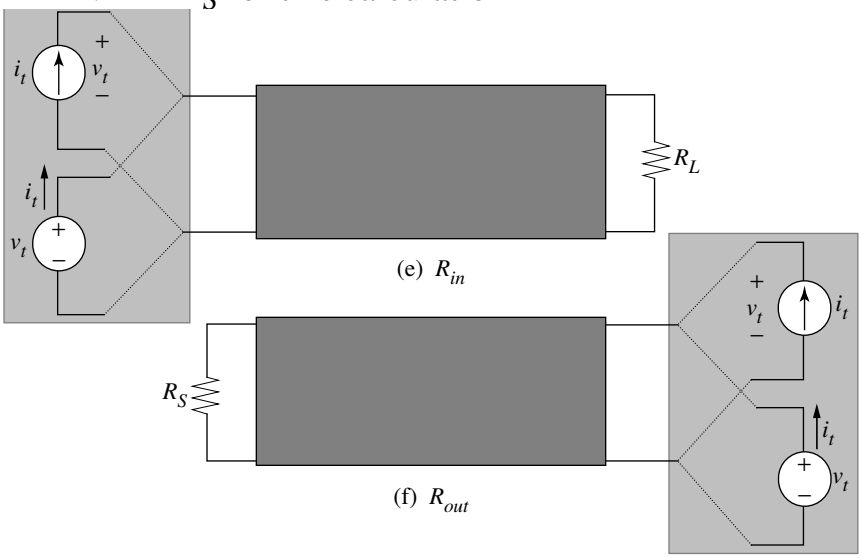


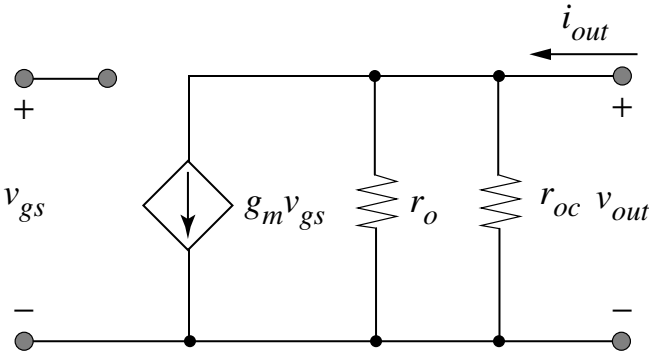
$$A_v = -g_m (r_o \parallel r_{oc})$$

$$g_m = \sqrt{2\frac{W}{L}\mu_n C_{ox} I_D}$$

$$r_o = \frac{1}{\lambda I_D}$$

- Find R_{in} by applying a test voltage or current source at the input and calculating the resulting current or voltage across the test source
- LEAVE in R_L for this calculation
- Find R_{out} by applying a test voltage or current source at the output and calculating the resulting current or voltage across the test source
- LEAVE in R_S for this calculation

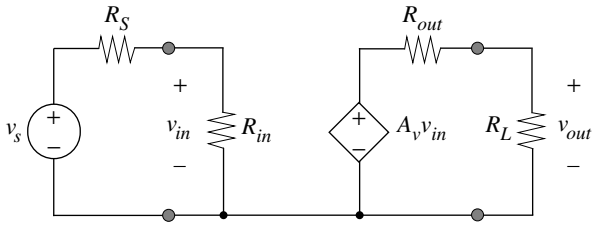




R_{in} --->∞ and $R_{out} = r_o \| r_{oc}$

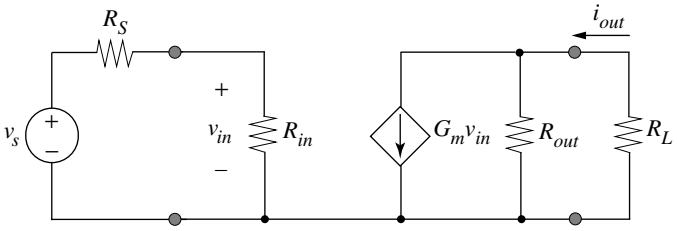
C. Effect of Source and Load Resistances

- Voltage Amplifier



$$\frac{v_{out}}{v_s} = \left(\frac{R_{in}}{R_{in}+R_S}\right) \quad A_v \quad \left(\frac{R_L}{R_L+R_{out}}\right)$$

- Transconductance Amplifier



$$\frac{i_{out}}{v_s} = \frac{R_{in}}{R_{in}+R_s}\, G_m \, \frac{R_{out}}{R_L+R_{out}} \text{ where } G_m = g_m$$

- In both cases we want R_{in} to be large since controlled generator is voltage controlled
- We want $\boldsymbol{R_{out}}$ **small if voltage output**
- We want $\boldsymbol{R_{out}}$ **large if current output**
- $R_{out} = R_L$ to have maximum power out (current *and* voltage)

D. CS amplifier circuit parameter dependencies on device parameters and supply current

Device Parameters	Circuit Parameters			
	A_V	G_m	R_{in}	R_{out}
	$-g_m(r_o \| r_{oc})$	g_m	∞	$r_o \| r_{oc}$
I_{SUP}	$\downarrow$	$\uparrow$	–	$\downarrow$
W	$\uparrow$	$\uparrow$	–	–
$\mu_n C_{ox}$	$\uparrow$	$\uparrow$	–	–
$L \propto 1/\lambda_n$	$\uparrow$	$\downarrow$	–	$\uparrow$

Arrows indicate which direction to change device parameters to *increase* circuit parameter values.