EE105
Microelectronic Devices and Circuits
Multi-Stage Amplifiers

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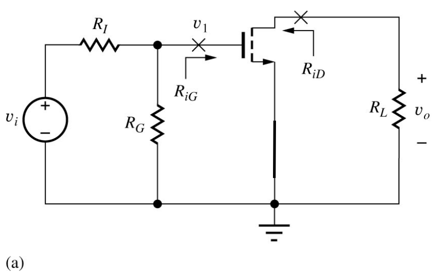
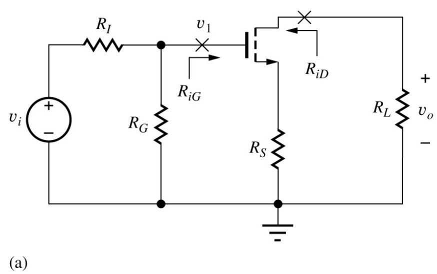
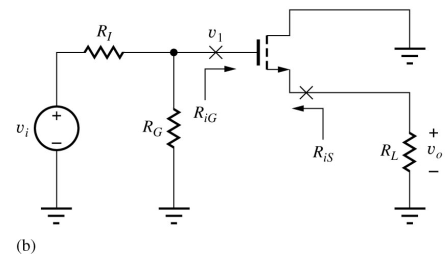
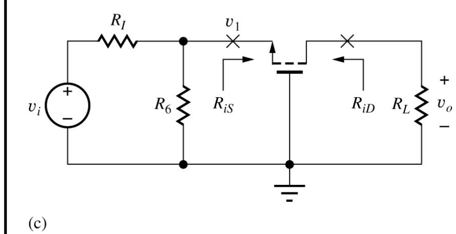
Terminal Gain and I/O Resistances of MOS Amplifiers

Common Source (CS)	CS with Degeneration	Common Drain (CD)	Common Gate (CG)
			
$A_{V,t}=-g_mR_L$ $R_i=\infty$ $R_o=r_o$ $A_{I,t}=\infty$	$A_{V,t}=-\dfrac{g_mR_L}{1+g_mR_S}$ $R_i=\infty$ $R_o=\left[r_o\left(1+g_mR_E\right)\right]$ $A_{I,t}=\infty$ Without degeneration: Simply set $R_S=0$	$A_{V,t}=\dfrac{R_L}{\dfrac{1}{g_m}+R_L}$ $R_i=\infty$ $R_o=\dfrac{1}{g_m}$ $A_{I,t}=\infty$	$A_{V,t}=g_mR_L$ $R_i=\dfrac{1}{g_m}$ $R_o=\left[r_o\left(1+g_mR_E\right)\right]$ $A_{I,t}\approx 1$

For the gain, R_i, R_o of the whole amplifier, you need to include voltage/current dividers at input and output stages

Summary of MOS Single-Transistor Amplifiers

MOS	Common Source (CS)	Common Source with Deg.	Common Drain (CD)	Common Gate (CG)
R_i				Small
R_o	Large	Very Large	Small	Large
A_V	Moderate	Small	~ 1	Moderate
f_H	Small	Moderate	Large	Large

BSAC

Single Stage Amplifier Cannot Meet All Requirements

- For example, a general purpose operational amplifier requires
  - High input resistance ~ 1MΩ
  - Low output resistance ~ 100Ω
  - High voltage gain ~ 100,000
- No single transistor amplifier can satisfy all spec's
- Cascading multiple stages of amplifiers offers a path towards the design

Multistage Amplifiers

- Usually
  - An input stage to provide required input resistance
  - Middle stage(s) to provide gain
  - An output stage to provide required output resistance or drive external loads
- More gain !
  - Gain/stage limited, especially in nanoscale devices
- Improve Bandwidth
  - De-couple high impedance nodes from large capacitors
- DC coupling (no passive elements to block the signal)
  - Use amplifiers to naturally "level shift" signal

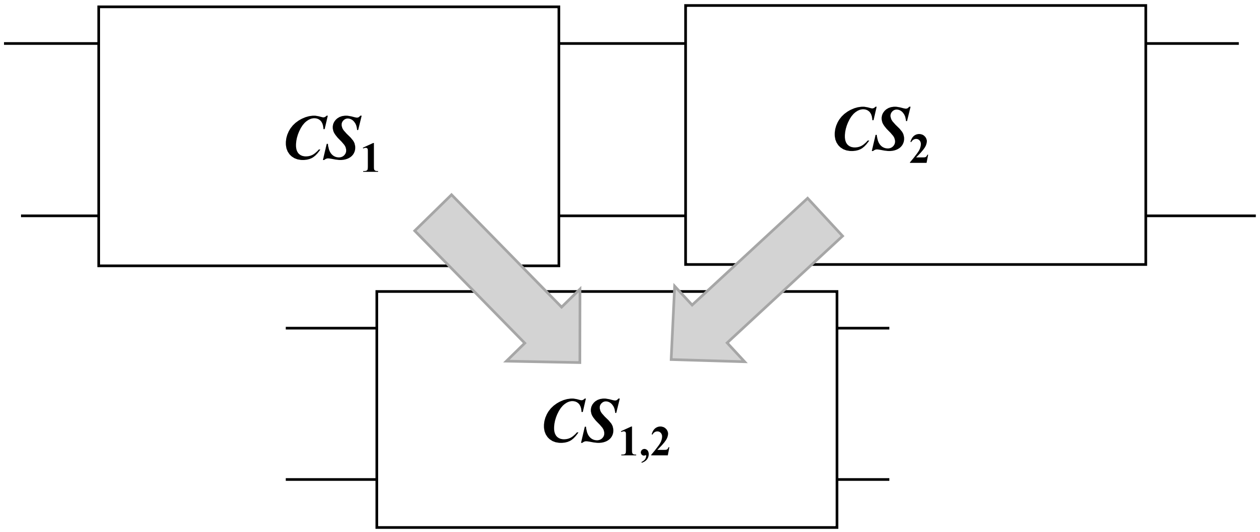
Impedance "Match"

- On-chip circuits often use "voltage/current" matching to minimize loading
- Keep in mind the input resistance and output resistance of each type of stage so that the loading does not create an undesired effect

	Ideal R_{in}	Ideal R_{out}
Voltage Amplifier		0
Current Amplifier	0	
Transconductance Amplifier		
Transresistance Amplifier	0	0

Two-Stage Voltage Amplifier

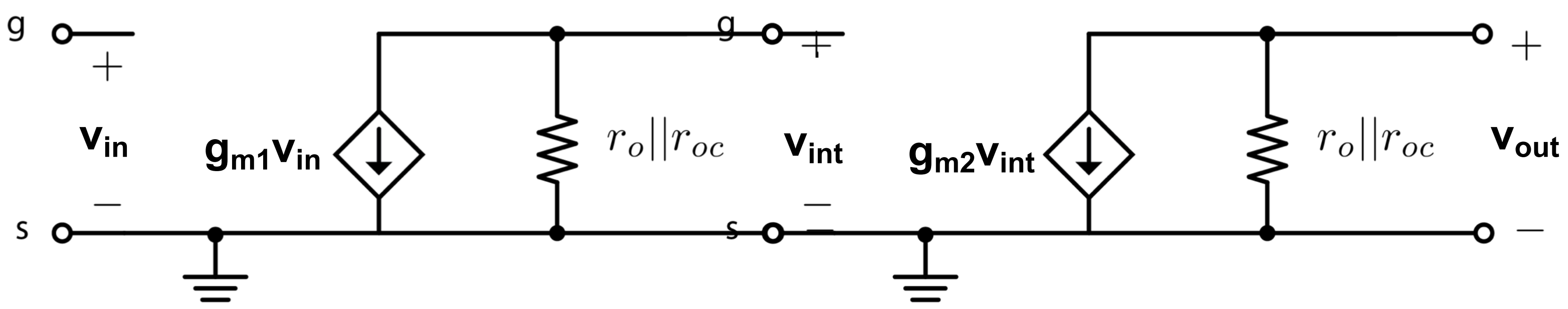
- Boost gain by cascading Common-Source stages



Can combine into a single 2-port model

Results of new 2-port: $R_{in} = R_{in1}$, $R_{out} = R_{out2}$

CS Cascade Analysis



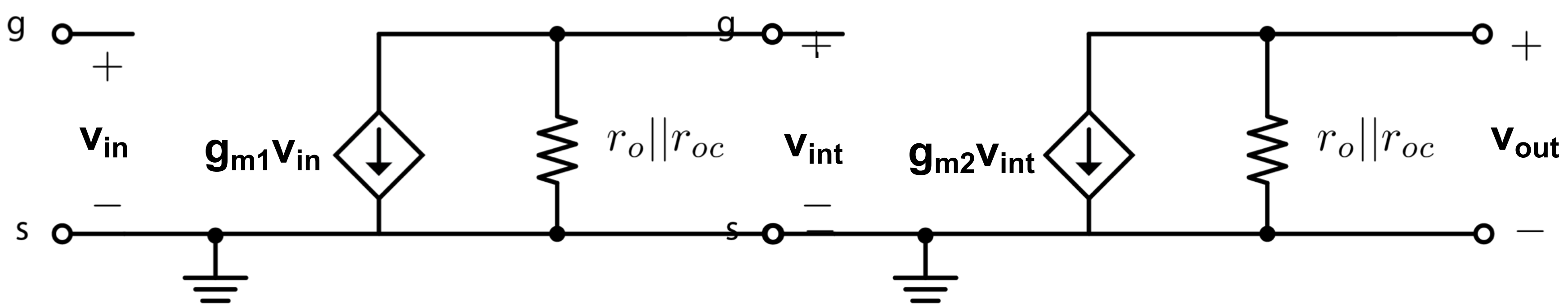
Results of new 2-port:

$R_{in} = R_{in1} =$

$R_{out} = R_{out2} =$

$A_V = v_{out}/v_{in} =$

CS Cascade Bandwidth



Two time constants:

$\tau_1 =$

$\tau_2 =$

Bandwidth Extension

- **Common Source stage has high gain, but low bandwidth**
- **Note that Miller effect is the culprit**
- **Follower stage can buffer source resistance from Miller cap**

Bandwidth Extension Using Source Follower (SF)