

EE 435

Lecture 2:

Basic Op Amp Design

- Single Stage Low Gain Op Amps

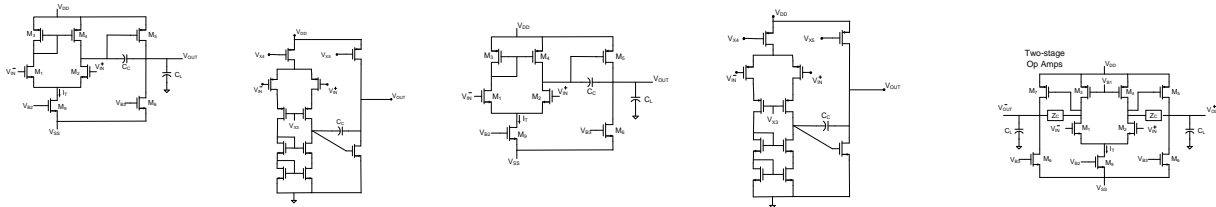
Review from last lecture:

Will Attempt in the Course to Follow, as Much as Possible, the Following Approach

Understand



Synthesize



Analyze (if not available from the Understand step)

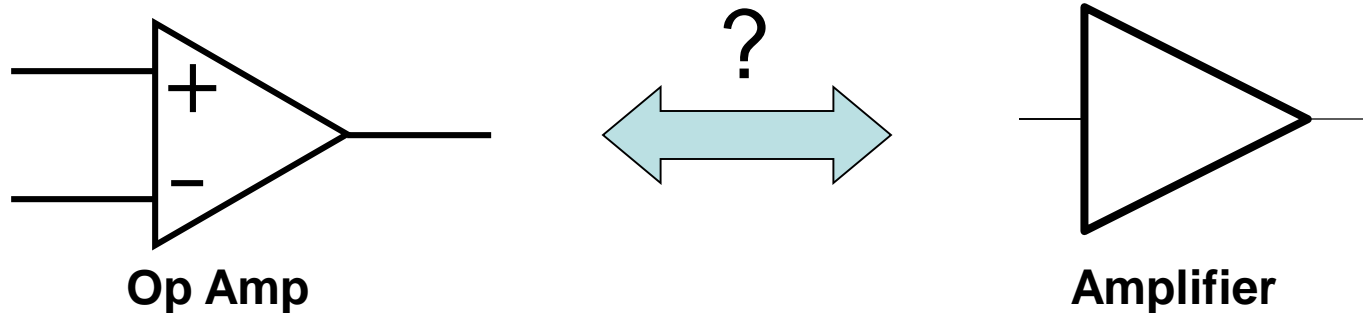
Modify, Extend, and Create



Simulate and Verify

Review from last lecture:

How does an amplifier differ from an operational amplifier?

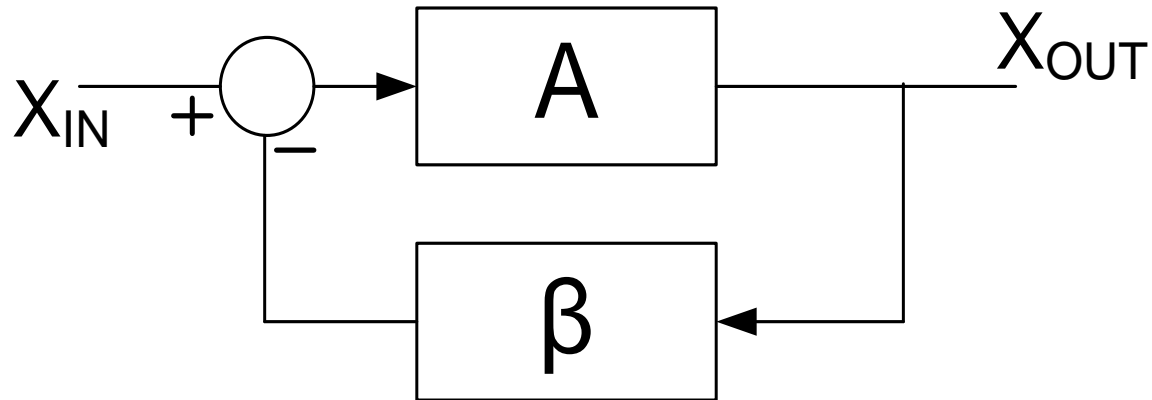


Amplifier used in open-loop applications

Operational Amplifier used in feedback applications

Review from last lecture:

Why are Operational Amplifiers Used?



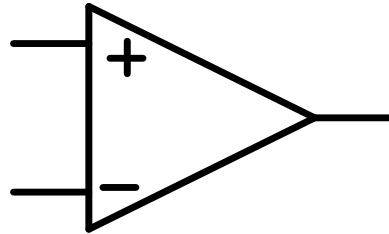
Input and Output Variables intentionally designated as “X” instead of “V”

$$\frac{X_{out}}{X_{in}} = A_F = \frac{A}{1 + A\beta} = \underset{\approx}{A \rightarrow \infty} \frac{1}{\beta}$$

Op Amp is Enabling Element Used to Build Feedback Networks !

Review from last lecture:

What is an Operational Amplifier?



Textbook Definition:

- Voltage Amplifier with Very Large Gain
 - Very High Input Impedance
 - Very Low Output Impedance
- Differential Input and Single-Ended Output

This represents the Conventional Wisdom !

Does this correctly reflect what an operational amplifier really is?

Review from last lecture:

What Characteristics are Really Needed for Op Amps?

$$A_F = \frac{A}{1 + A\beta} \approx \frac{1}{\beta} \quad A_{VF} = \frac{-A\beta_1}{1 + A\beta} \approx \frac{-\beta_1}{\beta}$$

1. Very Large Gain

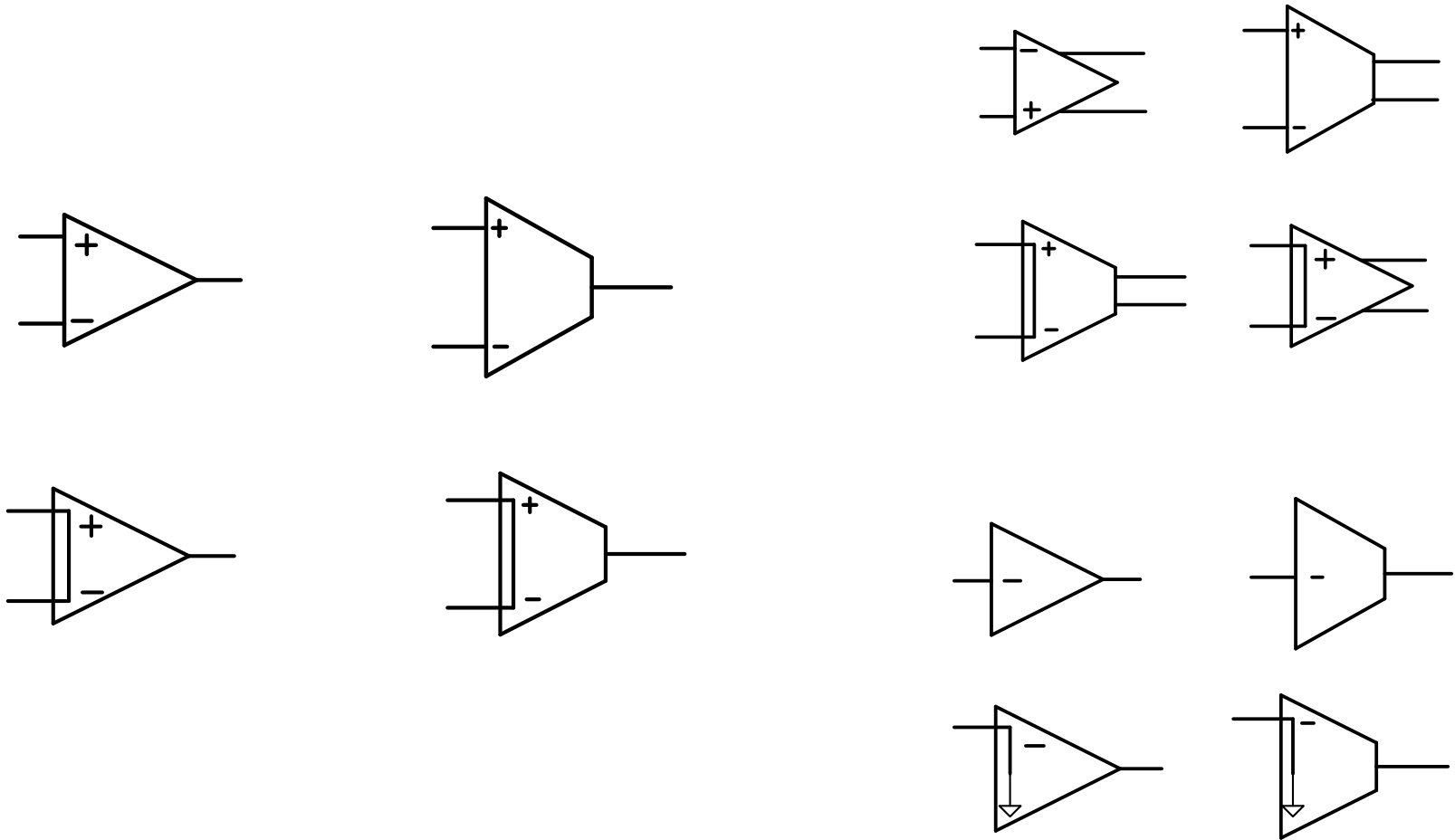
To make A_F (or A_{VF}) insensitive to variations in A

To make A_F (or A_{VF}) insensitive to nonlinearities of A

2. Port Configurations Consistent with Application

Review from last lecture:

Port Configurations for Op Amps



(Could also have single-ended input and differential output though less common)

Review from last lecture:

What Characteristics do Many Customers and Designers Assume are Needed for Op Amps?

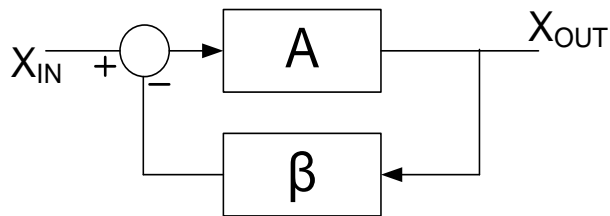
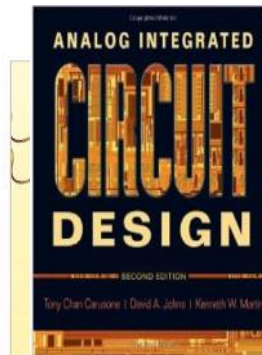
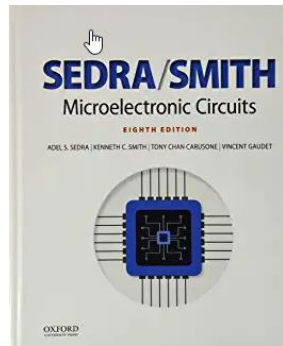
1. Very Large Voltage Gain

and ...

2. Low Output Impedance
3. High Input Impedance
4. Large Output Swing
3. Large Input Range
4. Good High-frequency Performance
5. Fast Settling
6. Adequate Phase Margin
7. Good CMRR
8. Good PSRR
9. Low Power Dissipation
10. Reasonable Linearity
11. . . .

What is an Operational Amplifier?

Lets see what the experts say !




Conventional Wisdom does not provide good guidance on what an amplifier or an operational amplifier should be!

What are the implications of this observation?

Conventional Wisdom Does Not Always Provide Correct Perspective – even in some of the most basic or fundamental areas !!

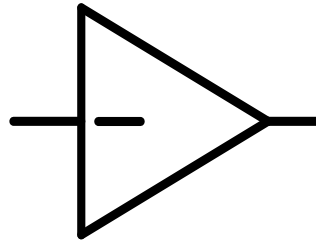
- Just because its published doesn't mean its correct
- Just because famous people convey information as fact doesn't mean they are right
- Keep an open mind about everything that is done and always ask whether the approach others are following is leading you in the right direction

Basic Op Amp Design Outline

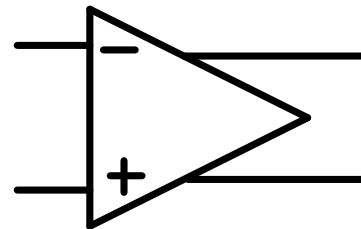
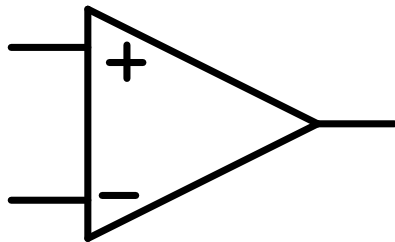
- Fundamental Amplifier Design Issues
-  • Single-Stage Low Gain Op Amps
- Single-Stage High Gain Op Amps
- Two-Stage Op Amp
- Other Basic Gain Enhancement Approaches

Single-Stage Low-Gain Op Amps

-  • Single-ended input



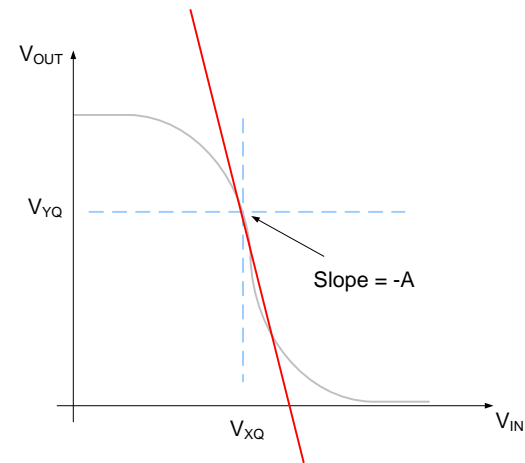
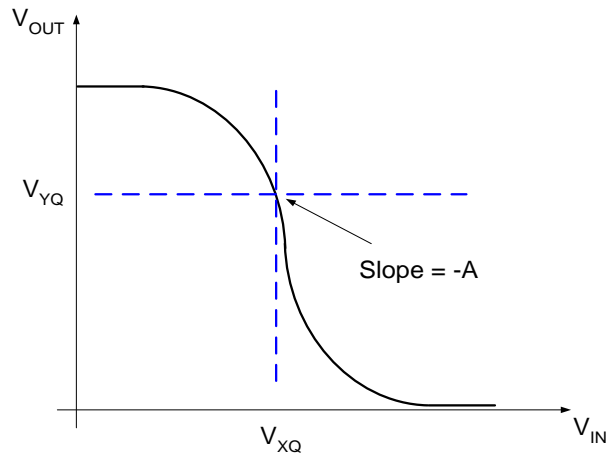
- Differential Input



(Symbol not intended to distinguish between different amplifier types)

Single-ended Op Amp (Inverting Amplifier)

Consider:



Assume Q-point at $\{V_{XQ}, V_{YQ}\}$

$$\mathbf{V_{OUT} = f(V_{IN})}$$

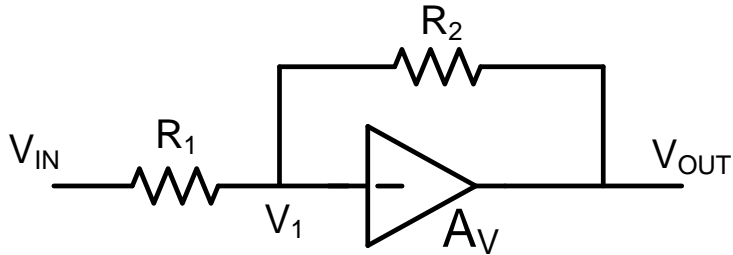
$$V_{OUT} \cong (-A)(V_{IN} - V_{XQ}) + V_{YQ}$$

When operating near the Q-point, the linear and nonlinear model of the amplifier are nearly the same

If the gain of the amplifier is large, V_{XQ} is a characteristic of the amplifier

Single-ended Op Amp (Inverting Amplifier)

(assume the feedback network does not affect the relationship between V_1 and V_{OUT})

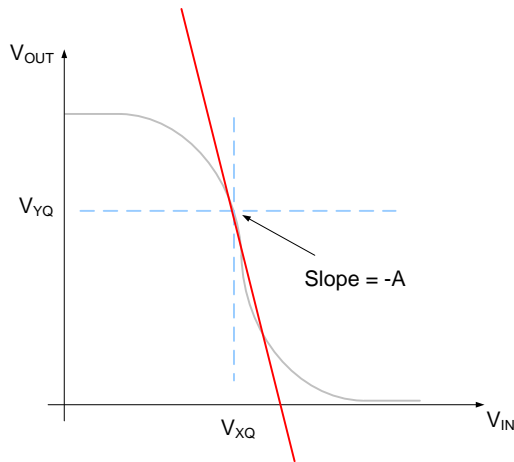


$$\left. \begin{aligned} V_O &= (-A)(V_1 - V_{XQ}) + V_{YQ} \\ V_1 &= \frac{R_1}{R_1 + R_2} V_O + \frac{R_2}{R_1 + R_2} V_{IN} \end{aligned} \right\}$$

Eliminating V_1 we obtain:

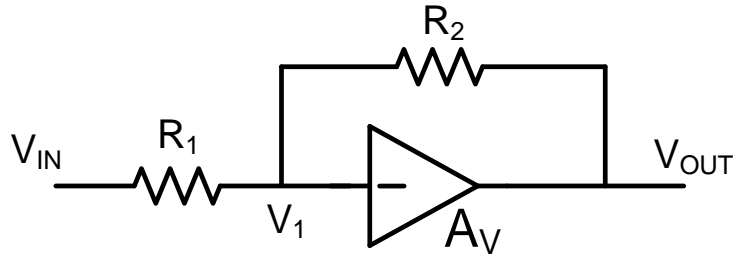
$$V_O = (-A) \left(\frac{R_1}{R_1 + R_2} V_O + \frac{R_2}{R_1 + R_2} V_{IN} - V_{XQ} \right) + V_{YQ}$$

If we define V_{iSS} (small-signal) by $V_{IN} = V_{INQ} + V_{iSS}$



$$V_O = \left(\frac{-A \left(\frac{R_2}{R_1 + R_2} \right)}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) (V_{iSS} + V_{INQ}) + \left(\frac{A}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) V_{XQ} + \left(\frac{1}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) V_{YQ}$$

Single-ended Op Amp Inverting Amplifier



$$V_O = \left(\frac{-A \left(\frac{R_2}{R_1 + R_2} \right)}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) (V_{ISS} + V_{INQ}) + \left(\frac{A}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) V_{XQ} + \left(\frac{1}{1 + A \left(\frac{R_1}{R_1 + R_2} \right)} \right) V_{YQ}$$

But if A is large, this reduces to

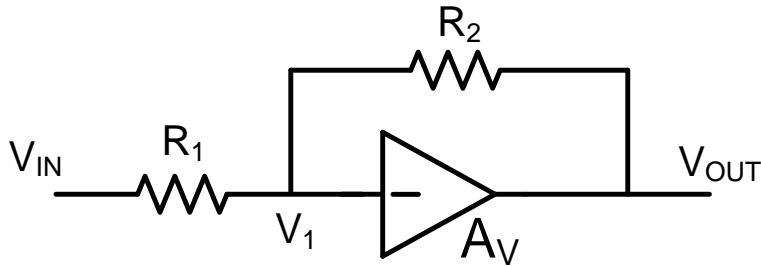
$$V_O = -\frac{R_2}{R_1} V_{ISS} + V_{XQ} + \frac{R_2}{R_1} (V_{XQ} - V_{INQ})$$

Note that as long as A is large, if V_{INQ} is close to V_{XQ}

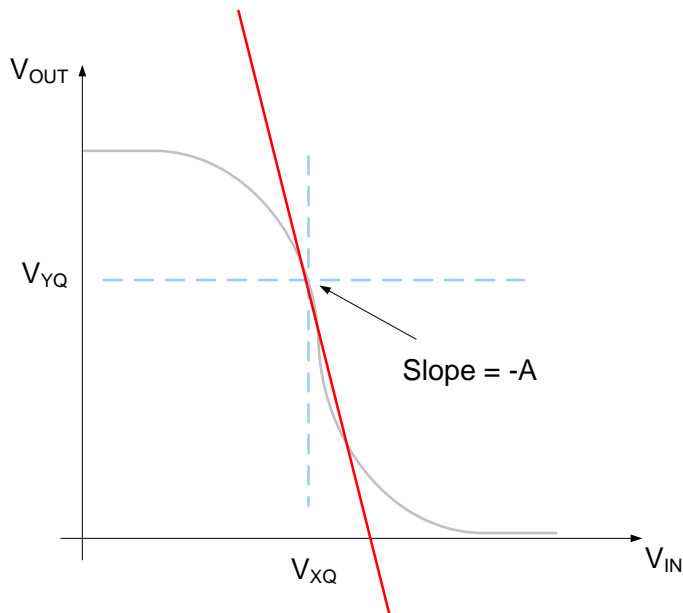
$$V_O \cong -\frac{R_2}{R_1} V_{ISS} + V_{XQ}$$

Single-ended Op Amp Inverting Amplifier

(assume the feedback network does not affect the relationship between V_1 and V_{OUT})



$$\left. \begin{aligned} V_O &= (-A)(V_1 - V_{XQ}) + V_{YQ} \\ V_1 &= \frac{R_1}{R_1 + R_2} V_O + \frac{R_2}{R_1 + R_2} V_{IN} \end{aligned} \right\}$$

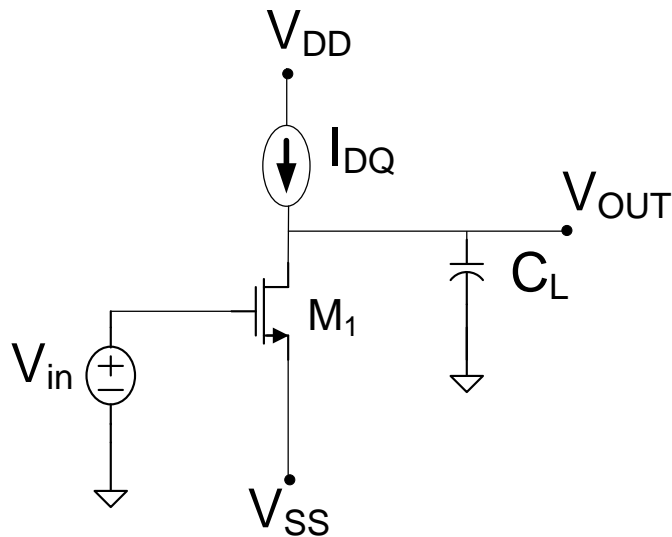


Summary:

$$V_O = -\frac{R_2}{R_1} V_{iss} + V_{XQ} + \frac{R_2}{R_1} (V_{XQ} - V_{inQ})$$

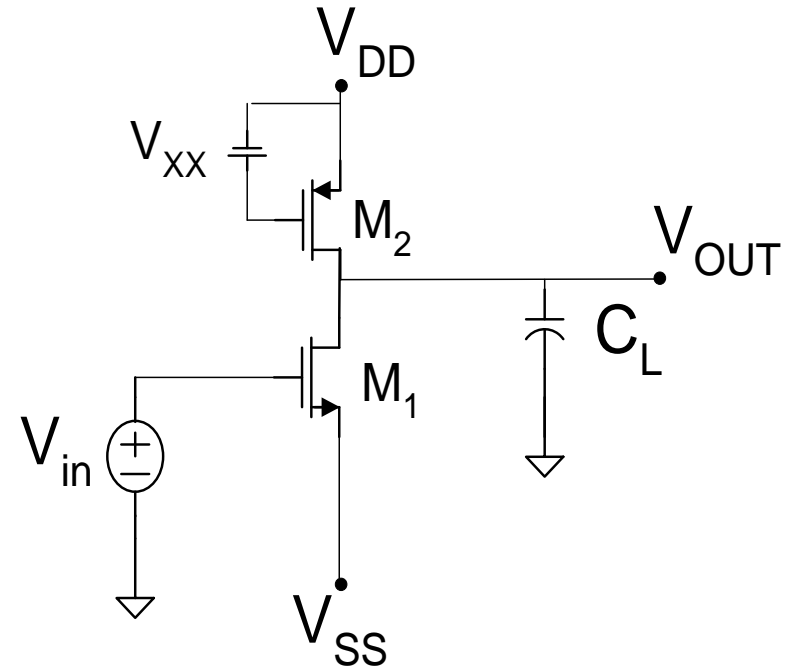
What type of circuits have the transfer characteristic shown?

Single-stage single-input low-gain op amp



Basic Structure

Have added the load capacitance to include frequency dependence of the amplifier gain



Practical Implementation

This is the common-source amplifier with current source biasing discussed in EE 330

This is not a new idea !



Gene Taatjes
JULY 1973

AN-88
CMC

CMOS LINEAR APPLICATIONS

PNP and NPN bipolar transistors have been used for many years in "complementary" type of amplifier circuits. Now, with the arrival of CMOS technology, complementary P-channel/N-channel MOS transistors are available in monolithic form. The MM74C04 incorporates a P-channel MOS transistor and an N-channel MOS transistor connected in complementary fashion to function as an inverter.

Due to the symmetry of the P- and N-channel transistors, negative feedback around the complementary pair will cause the pair to self bias itself to approximately 1/2 of the supply voltage. Figure 1 shows an idealized voltage transfer characteristic curve of the CMOS inverter connected with negative feedback. Under these conditions the inverter is biased for operation about the midpoint in the linear segment on the steep transition of the voltage transfer characteristic as shown in Figure 1.

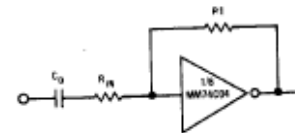
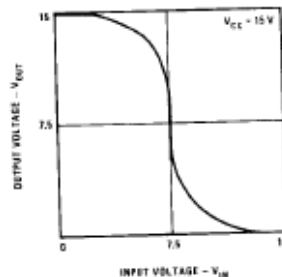


FIGURE 2. A 74CMOS Inverter Biased for Linear Mode Operation.

The power supply current is constant during dynamic operation since the inverter is biased for Class A operation. When the input signal swings near the supply, the output signal will become distorted because the P-N channel devices are driven into the non-linear regions of their transfer characteristics. If the input signal approaches the supply voltages, the P- or N-channel transistors become saturated and supply current is reduced to essentially zero and the device behaves like the classical digital inverter.

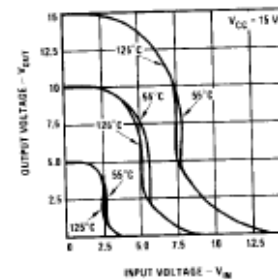
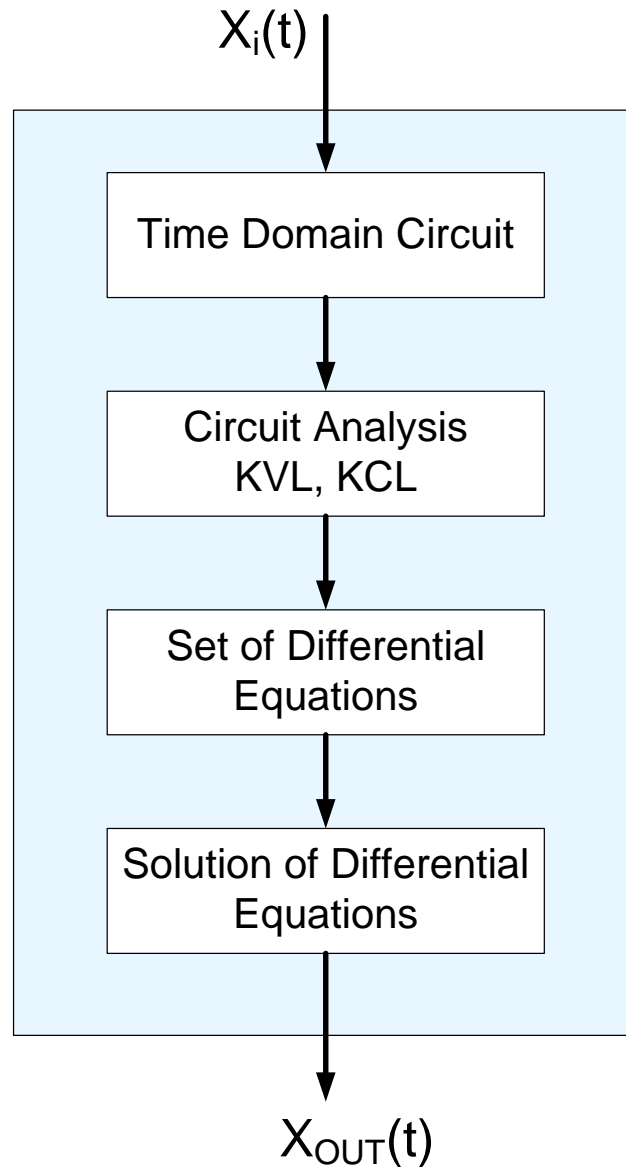


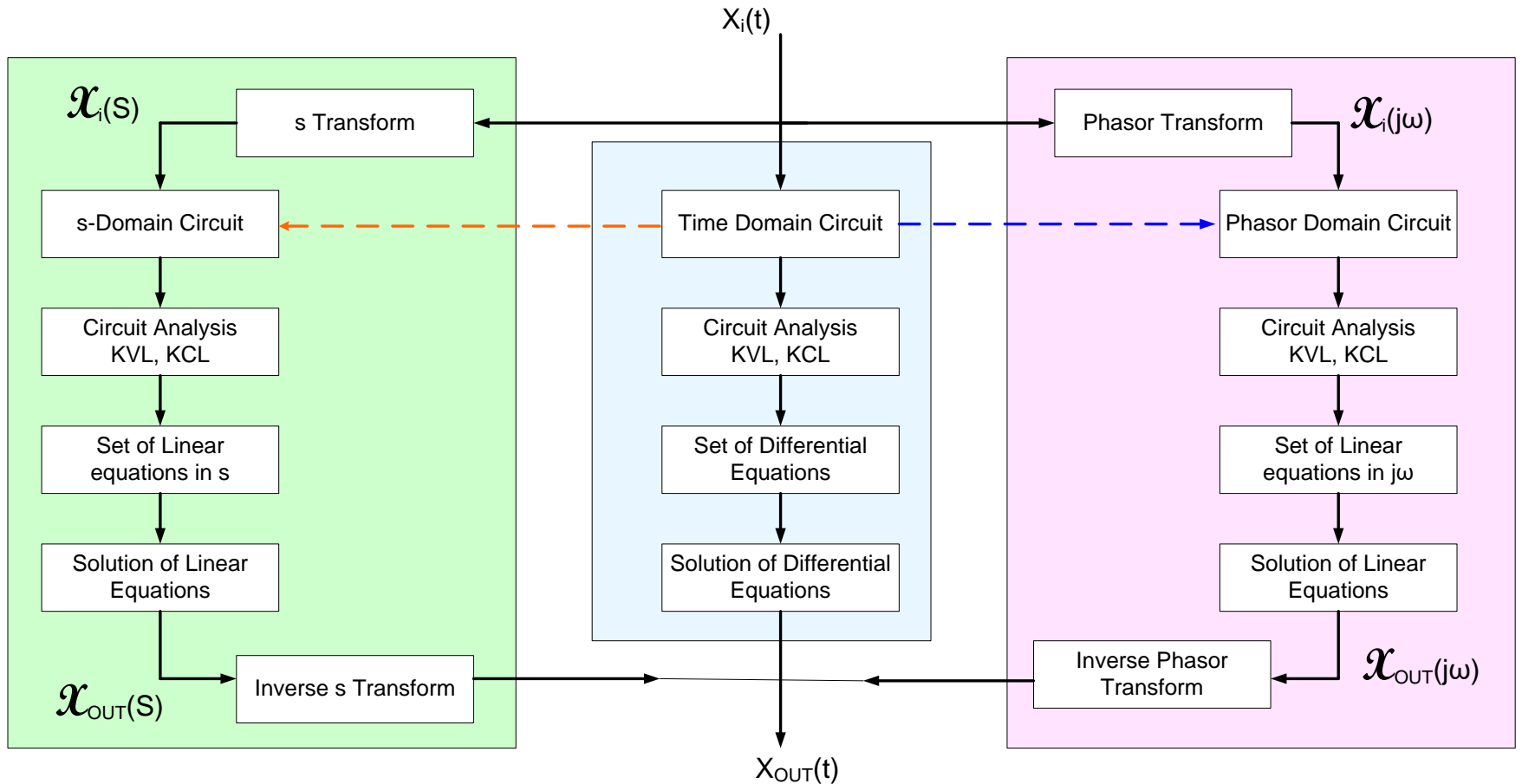
FIGURE 3. Voltage Transfer Characteristics for an Inverter Connected as a Linear Amplifier.

Review of ss steady-state analysis

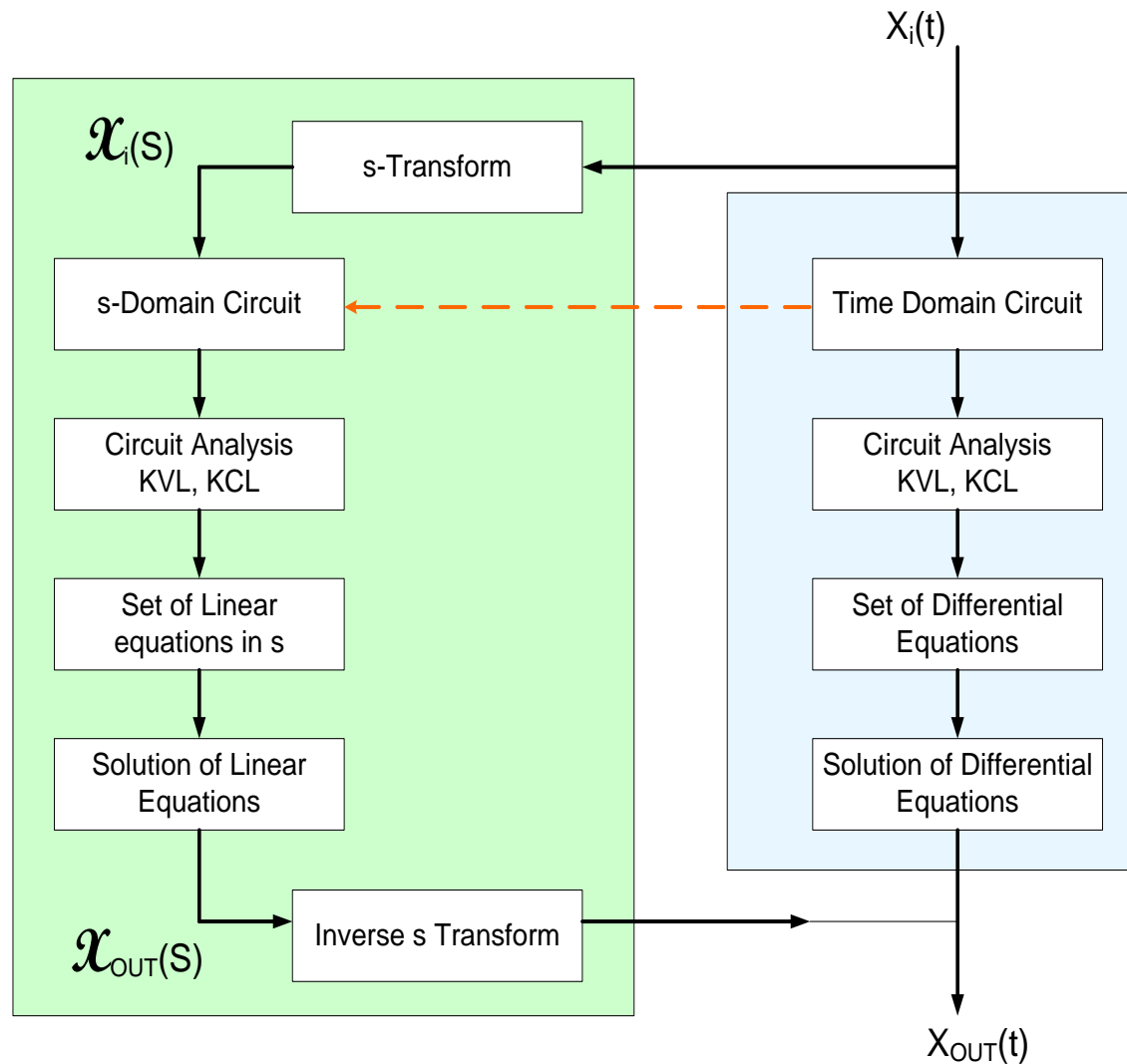
Standard Approach to Circuit Analysis



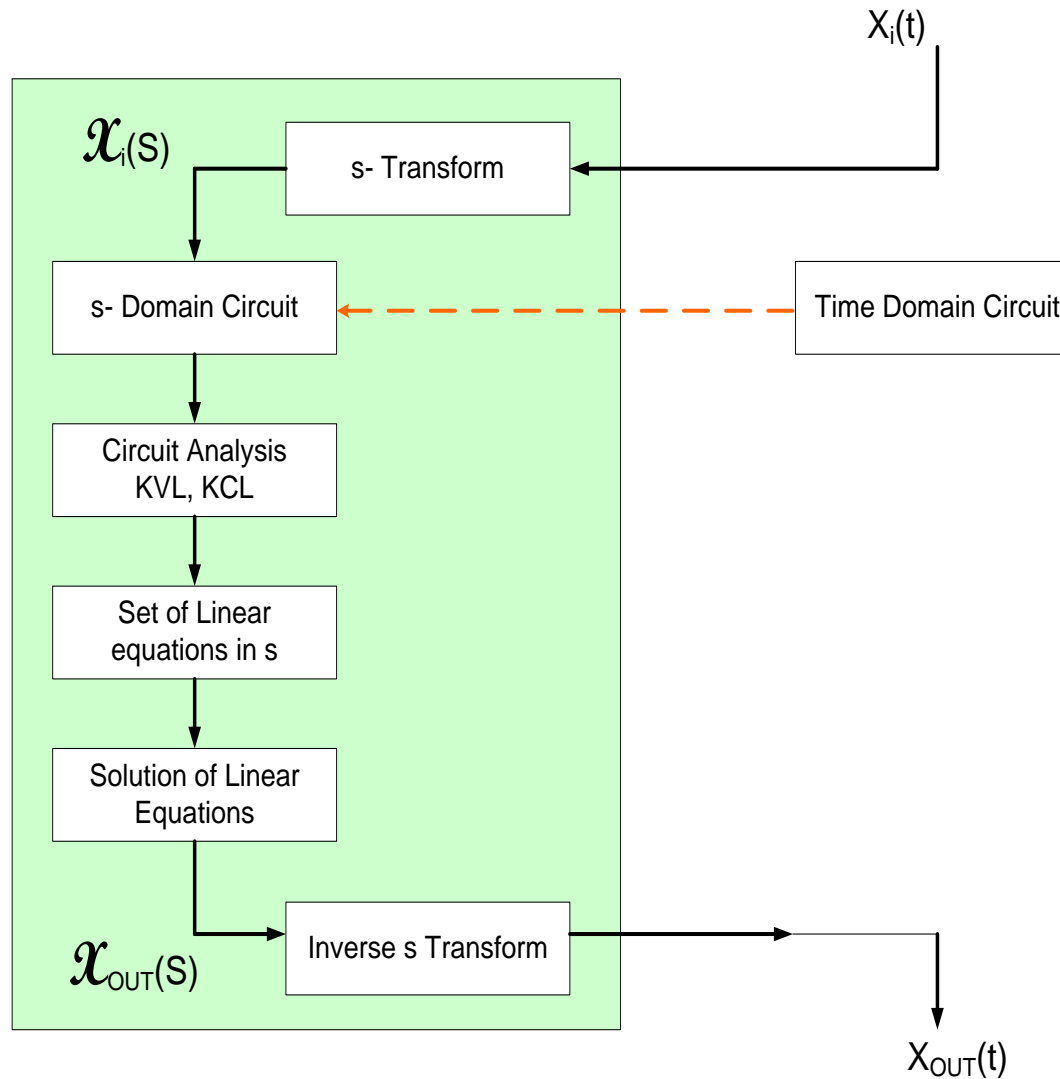
Time, Phasor, and s- Domain Analysis



Time and s- Domain Analysis

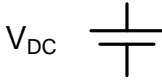
















s- Domain Analysis



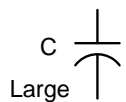


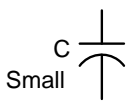
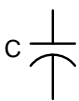

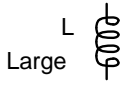


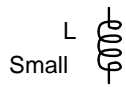





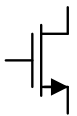
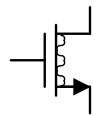
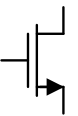
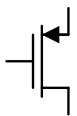
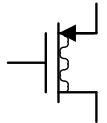
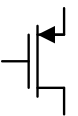
Review of ss steady-state analysis

Dc and small-signal equivalent elements

	Element	ss equivalent	dc equivalent
dc Voltage Source	V_{DC} 		V_{DC} 
ac Voltage Source	V_{AC} 	V_{AC} 	
dc Current Source	I_{DC} 		I_{DC} 
ac Current Source	I_{AC} 	I_{AC} 	
Resistor	R 	R 	R 


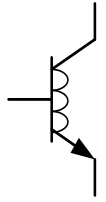
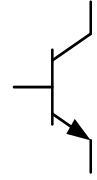

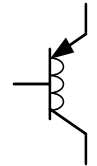
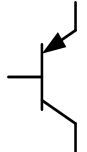






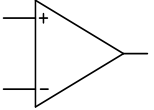
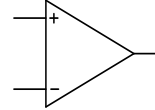
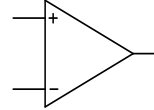
Review of ss steady-state analysis

Dc and small-signal equivalent elements

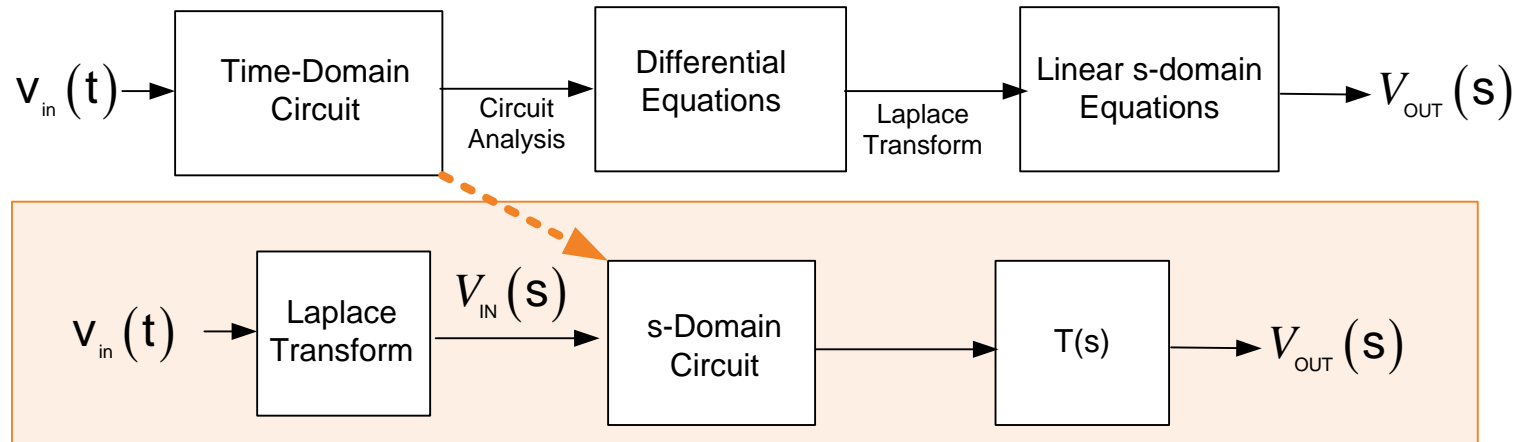
	Element	ss equivalent	dc equivalent
Capacitors	<p>C</p>  <p>Large</p>		
	<p>C</p>  <p>Small</p>		
Inductors	<p>L</p>  <p>Large</p>		
	<p>L</p>  <p>Small</p>		
Diodes			 <p>Simplified</p>
MOS transistors			 <p>Simplified</p>
			 <p>Simplified</p>

Review of ss steady-state analysis

Dc and small-signal equivalent elements

	Element	ss equivalent	dc equivalent
Bipolar Transistors			 Simplified
			 Simplified
Dependent Sources			
			
			

Summary of Sinusoidal Steady-State Analysis Methods for Linear Networks



Transfer Function of Time-Domain Circuit:

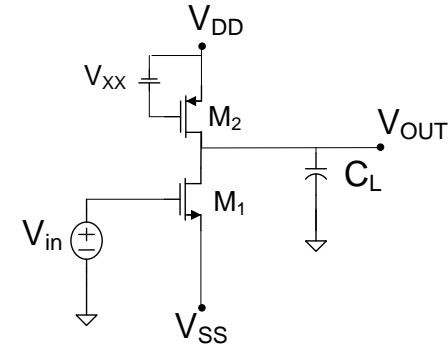
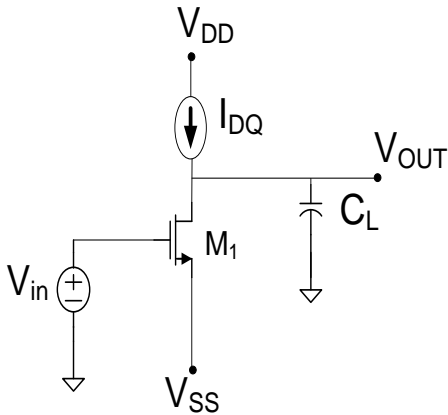
$$T(s) = \frac{V_{OUT}(s)}{V_{IN}(s)}$$

Key Theorem:

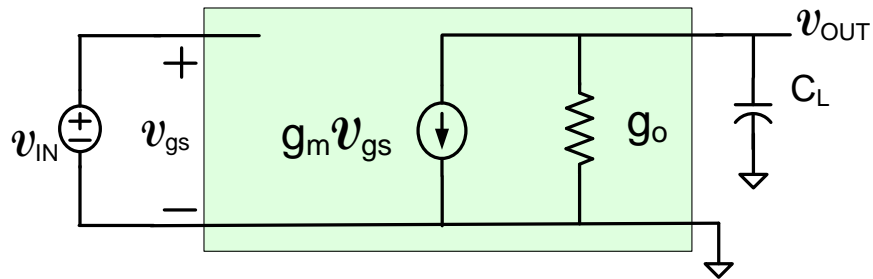
If a sinusoidal input $V_{IN} = V_M \sin(\omega t + \theta)$ is applied to a linear system that has transfer function $T(s)$, then the steady-state output is given by the expression

$$v_{out}(t) = V_M |T(j\omega)| \sin(\omega t + \theta + \angle T(j\omega))$$

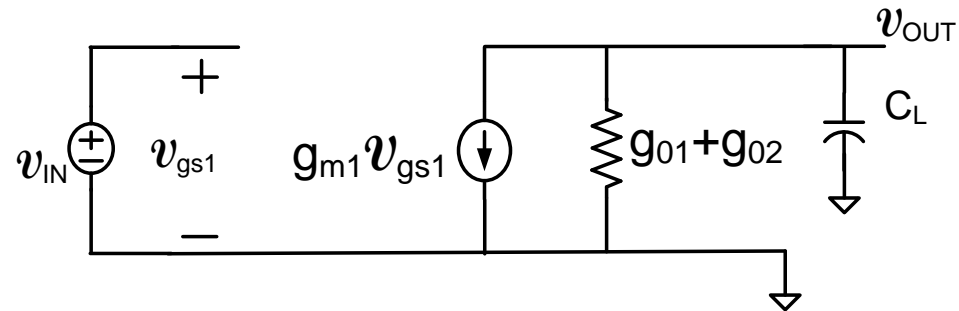
Two single-stage single-input low-gain op amps



Small Signal Models



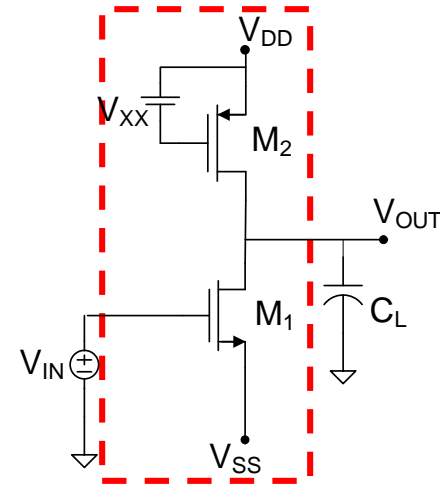
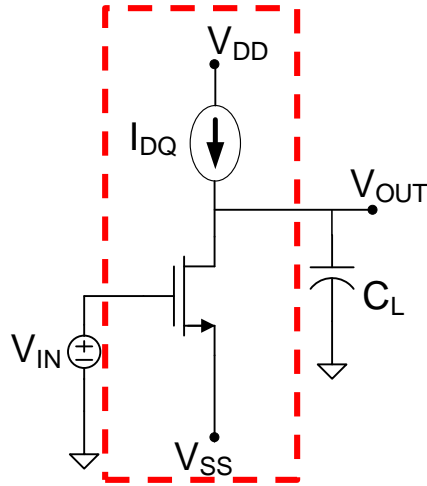
$$A_V = \frac{-g_m}{sC_L + g_o}$$



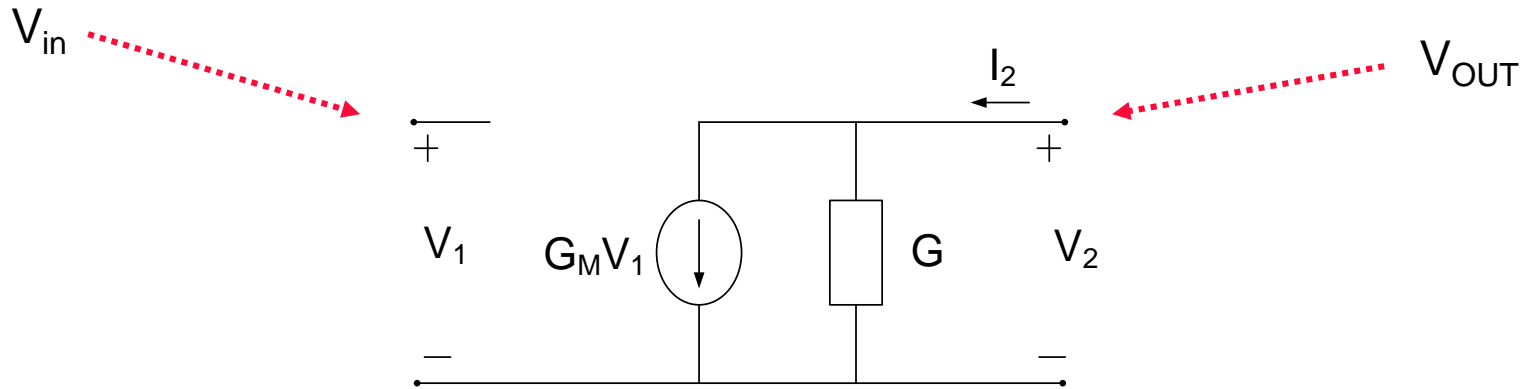
$$A_V = \frac{-g_{m1}}{sC_L + g_{o1} + g_{o2}}$$

dc Voltage gain is ratio of overall transconductance gain to output conductance

Two single-stage single-input low-gain op amps



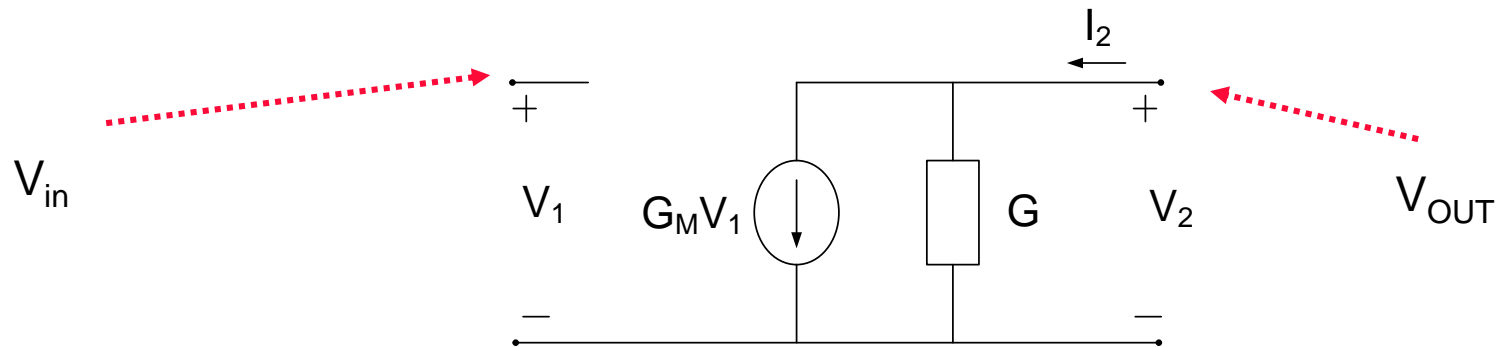
Observe in either case the small signal equivalent circuit is a two-port of the form:



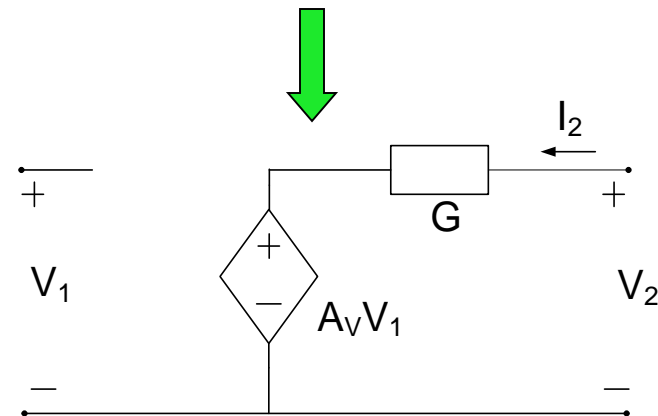
All properties of the circuit are determined by G_M and G

General single-stage single-input low-gain op amp

Small Signal Model of the op amp (unilateral with $R_{IN}=\infty$)



Alternate equivalent small signal model obtained by Norton to Thevenin transformation

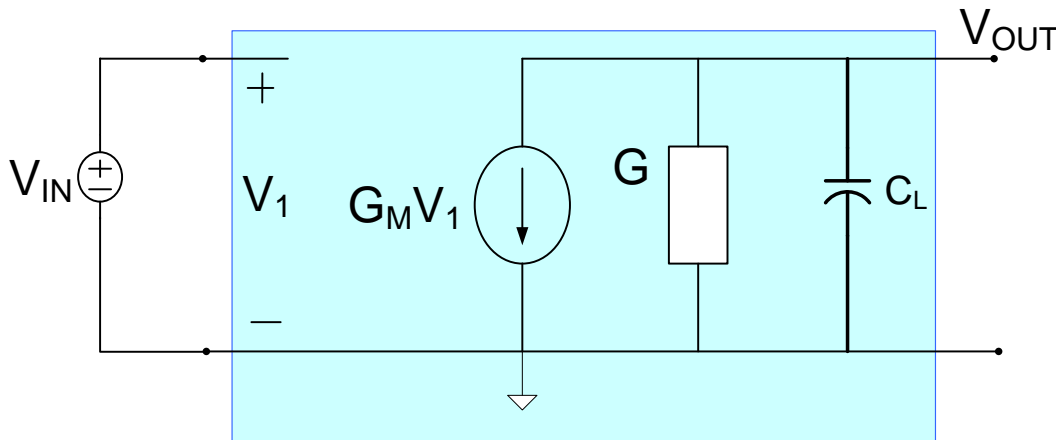


$$A_V = -\frac{G_M}{G}$$

All properties of the circuit are determined by A_V and G

General single-stage single-input low-gain op amp

Small Signal Model of the op amp with C_L (unilateral with $R_{IN}=\infty$)



$$A_V = \frac{-G_M}{sC_L + G}$$

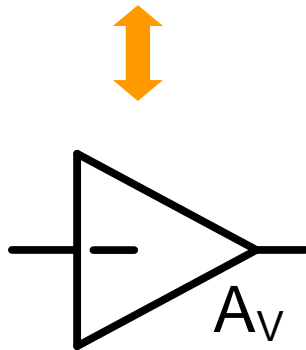
$$A_{V0} = \frac{-G_M}{G}$$

3dB (actually half-power) bandwidth:

$$BW = \frac{G}{C_L}$$

$$GB \stackrel{\text{def}}{=} |A_{V0} \cdot BW|$$

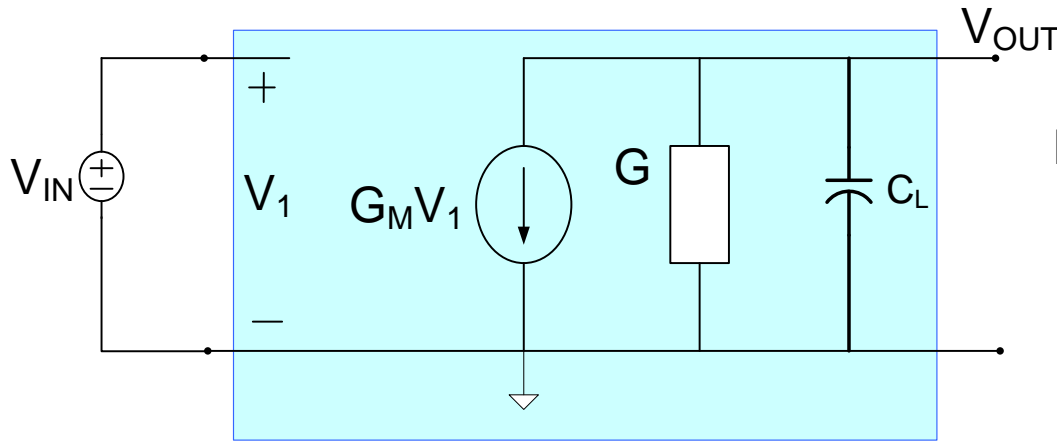
$$GB = \left(\frac{G_M}{G} \right) \left(\frac{G}{C_L} \right) = \frac{G_M}{C_L}$$



Analysis is general and applies to any single-stage single-input op amp (unilateral with $R_{IN}=\infty$)

GB and A_{V0} are two of the most important parameters in an op amp

Single-stage single-input low-gain op amp



By inspection from General Analysis

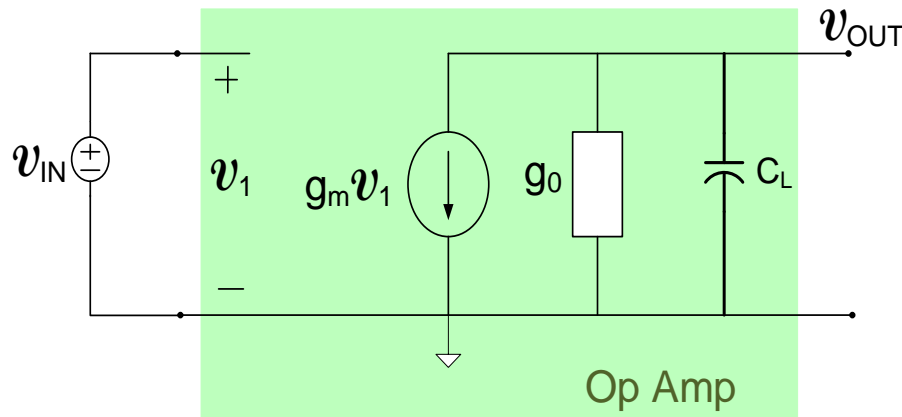
$$A_V = \frac{-g_m}{sC_L + g_o}$$

$$A_{V0} = \frac{-g_m}{g_o}$$

$$BW = \frac{g_o}{C_L}$$

$$GB = \left(\frac{g_m}{g_o} \right) \left(\frac{g_o}{C_L} \right) = \frac{g_m}{C_L}$$

for common-source amplifier



The parameters g_m and g_o give little insight into design

How do we design an amplifier with a given architecture in general or this architecture in particular?

What is the design space?

Generally V_{SS} , V_{DD} , C_L (and possibly V_{OUTQ}) will be fixed

Must determine $\{W_1, L_1, I_{DQ}$ and $V_{INQ}\}$

Thus there are 4 design variables

But W_1 and L_1 appear as a ratio in almost all performance characteristics of interest

and I_{DQ} is related to V_{INQ} , W_1 and L_1 (this is a constraint)

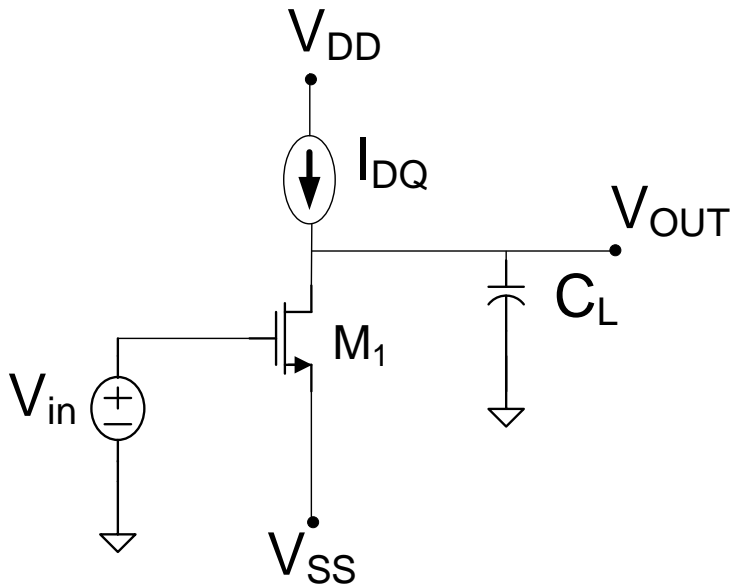
$$I_{DQ} = \mu C_{ox} \frac{W}{L} (V_{INQ} - V_{SS} - V_{TH})^2$$

Thus the 3-dimensional design space generally has only two independent variables (or two degrees of freedom), so can consider any two

$$\left\{ \frac{W_1}{L_1}, I_{DQ} \right\}$$

Thus design or “synthesis” with this architecture involves exploring the two-dimensional design space

$$\left\{ \frac{W_1}{L_1}, I_{DQ} \right\}$$



How do we design an amplifier with a given architecture in general or this architecture in particular?

What is the design space?

Generally V_{SS} , V_{DD} , C_L (and possibly V_{OUTQ}) will be fixed

1. Determine the design space

Must determine $\{W_1, L_1, I_{DQ} \text{ and } V_{INQ}\}$

2. Identify the constraints

Thus there are 4 design variables

But W_1 and L_1 appear as a ratio in almost all performance characteristics of interest

3. Determine the entire set of unknown variables and the Degrees of Freedom

and I_{DQ} is related to V_{INQ} , W_1 and L_1

4. Determine an appropriate parameter domain

Thus the design space generally has only two independent variables or **two degrees of freedom**

(Parameter domains for characterizing the design space are not unique!)

$$\left\{ \frac{W_1}{L_1}, I_{DQ} \right\}$$

Thus design or “synthesis” with this architecture involves exploring the two-dimensional design space

5. Explore the resultant design space with the identified number of Degrees of Freedom

$$\left\{ \frac{W_1}{L_1}, I_{DQ} \right\}$$

How do we design an amplifier with a given architecture ?

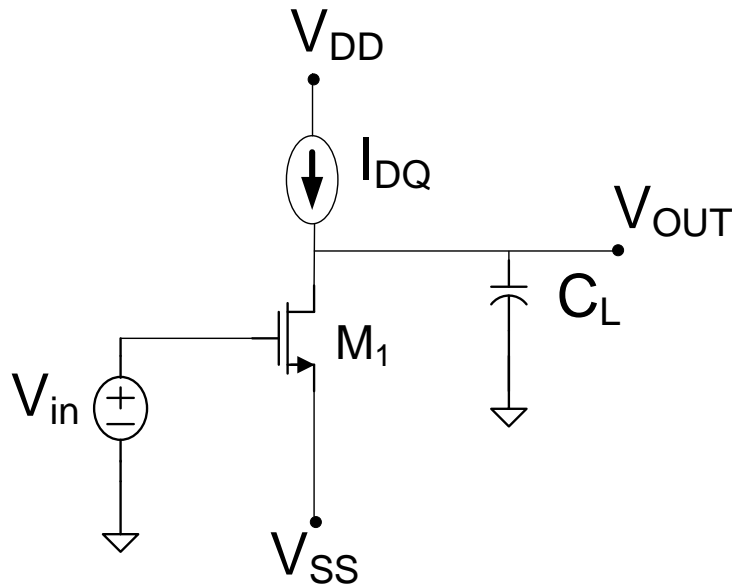
1. Determine the design space
2. Identify the constraints
3. Determine the entire set of unknown variables and the Degrees of Freedom
4. Determine an appropriate parameter domain
5. Explore the resultant design space with the identified number of Degrees of Freedom

Parameter Domains for Characterizing Amplifier Performance

- Should give insight into design
- Variables should be independent
- Should be of minimal size
- Should result in simple design expressions
- **Most authors give little consideration to either the parameter domain or the degrees of freedom that constrain the designer**

Parameter Domains for Characterizing Amplifier Performance

Consider basic op amp structure



$$A_v = \frac{-g_m}{sC_L + g_0}$$

$$A_{v0} = \frac{-g_m}{g_0}$$

$$GB = \frac{g_m}{C_L}$$

Small signal parameter domain :

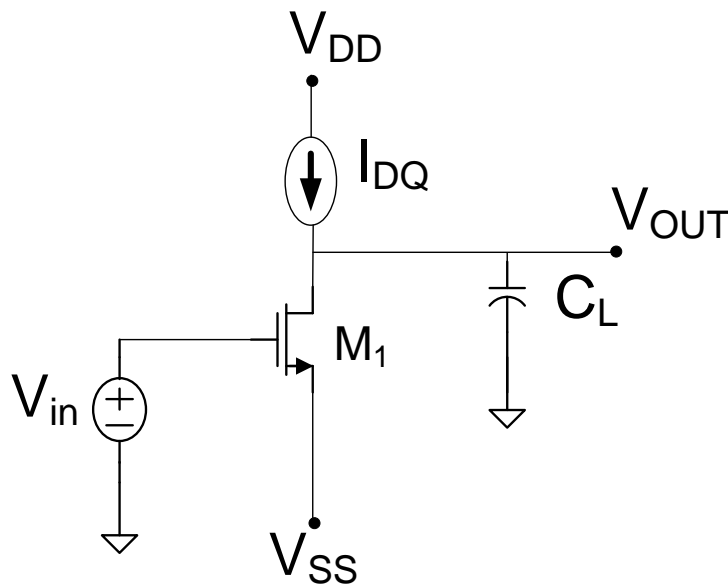
$$\{g_m, g_0\}$$

Degrees of Freedom: 2

Small signal parameter domain
obscures implementation issues

Parameter Domains for Characterizing Amplifier Performance

Consider basic op amp structure



$$A_v = \frac{-g_m}{sC_L + g_0}$$

$$A_{v0} = \frac{-g_m}{g_0}$$

$$GB = \frac{g_m}{C_L}$$

What parameters does the designer really have to work with?

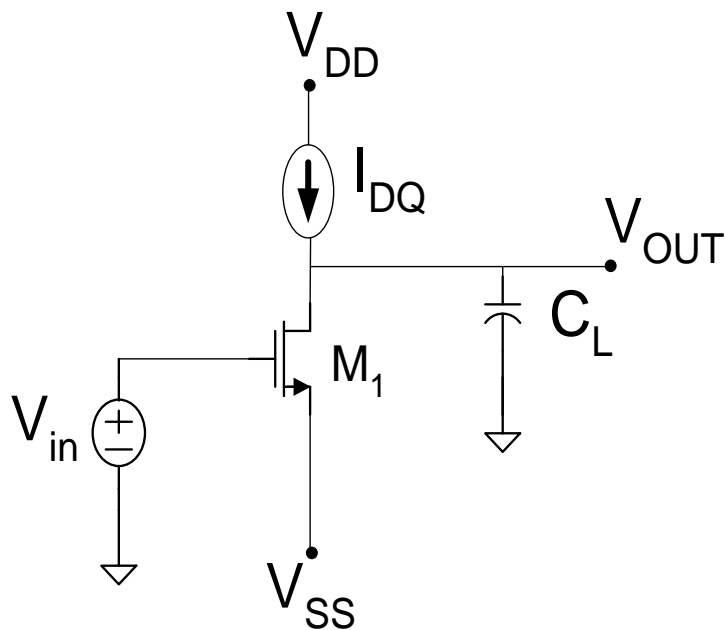
$$\left\{ \frac{W}{L}, I_{DQ} \right\}$$

Degrees of Freedom: 2

Call this the natural parameter domain

Parameter Domains for Characterizing Amplifier Performance

Consider basic op amp structure (not generic !)



Natural parameter domain

$$\left\{ \frac{W}{L}, I_{DQ} \right\}$$

$$GB = \frac{g_m}{C_L}$$

$$A_{v0} = \frac{-g_m}{g_o}$$

How do performance metrics A_{v0} and GB relate to the natural domain parameters?

$$g_m = \frac{2I_{DQ}}{V_{EB}} = \frac{\mu C_{OX} W}{L} V_{EB} = \sqrt{2\mu C_{OX} \frac{W}{L} I_{DQ}}$$

$$g_o = \lambda I_{DQ}$$

Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

$$A_V = \frac{-g_m}{sC_L + g_0}$$

Small signal parameter domain : $\{g_m, g_0\}$

$$A_{V0} = \frac{-g_m}{g_0} \quad GB = \frac{g_m}{C_L}$$

Natural design parameter domain: $\left\{ \frac{W}{L}, I_{DQ} \right\}$

$$A_{V0} = \frac{\sqrt{2\mu C_{OX} \frac{W}{L}}}{\lambda \sqrt{I_{DQ}}} \quad GB = \frac{\sqrt{2\mu C_{OX} \frac{W}{L}} \sqrt{I_{DQ}}}{C_L}$$

- Expressions very complicated
- Both A_{V0} and GB depend upon both design parameters
- Natural parameter domain gives little insight into design and has complicated expressions

Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

Small signal parameter domain :

$$\{g_m, g_0\}$$

$$A_{v0} = \frac{-g_m}{g_0}$$

$$GB = \frac{g_m}{C_L}$$

Natural design parameter domain:

$$\left\{ \frac{W}{L}, I_{DQ} \right\}$$

$$A_{v0} = \left[\frac{\sqrt{2\mu C_{OX}}}{\lambda} \right] \left[\frac{\sqrt{\frac{W}{L}}}{\sqrt{I_{DQ}}} \right]$$

$$GB = \left[\frac{\sqrt{2\mu C_{OX}}}{C_L} \right] \left[\sqrt{\frac{W}{L}} \sqrt{I_{DQ}} \right]$$

Process
Dependent

Architecture
Dependent

Process
Dependent

Architecture
Dependent

Key Observation !

Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

Small signal parameter domain : $\{g_m, g_0\}$

$$A_{v0} = \frac{-g_m}{g_0} \quad GB = \frac{g_m}{C_L}$$

Natural design parameter domain:

$$\left\{ \frac{W}{L}, I_{DQ} \right\}$$

$$A_{v0} = \left[\frac{\sqrt{2\mu C_{OX}}}{\lambda} \right] \left[\frac{\sqrt{\frac{W}{L}}}{\sqrt{I_{DQ}}} \right] \quad GB = \left[\frac{\sqrt{2\mu C_{OX}}}{C_L} \right] \left[\sqrt{\frac{W}{L}} \sqrt{I_{DQ}} \right]$$

Alternate parameter domain:

$$\{P, V_{EB}\}$$

$$P = \text{Power} = V_{DD} I_{DQ}$$

$$V_{EB} = \text{excess bias} = V_{GSQ} - V_T$$

$$A_{v0} = -\frac{g_M}{g_0} = -\left(\frac{2I_{DQ}}{V_{EB}}\right)\left(\frac{1}{\lambda I_{DQ}}\right) = -\frac{2}{\lambda V_{EB}} \quad GB = \frac{g_M}{C_L} = \left(\frac{2I_{DQ}}{V_{EB}}\right)\frac{1}{C_L} = \left[\frac{2}{V_{DD} C_L}\right] \frac{P}{V_{EB}}$$

Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

Small signal parameter domain : $\{g_m, g_0\}$

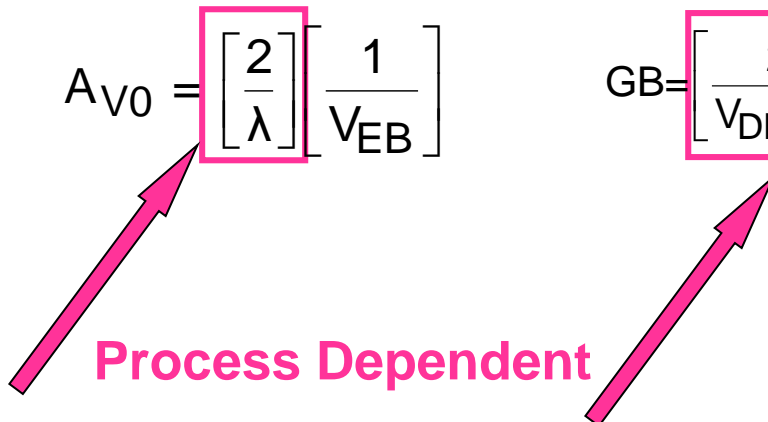
$$A_{V0} = \frac{-g_m}{g_0} \quad GB = \frac{g_m}{C_L}$$

Natural design parameter domain: $\left\{ \frac{W}{L}, I_{DQ} \right\}$

$$A_{V0} = \left[\frac{\sqrt{2\mu C_{OX}}}{\lambda} \right] \left[\frac{\sqrt{\frac{W}{L}}}{\sqrt{I_{DQ}}} \right] \quad GB = \left[\frac{\sqrt{2\mu C_{OX}}}{C_L} \right] \left[\sqrt{\frac{W}{L}} \sqrt{I_{DQ}} \right]$$

Alternate parameter domain: $\{P, V_{EB}\}$

$$A_{V0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right] \quad GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$



Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

Small signal parameter domain : $\{g_m, g_0\}$

$$A_{v0} = \frac{-g_m}{g_0} \quad GB = \frac{g_m}{C_L}$$

Natural design parameter domain: $\left\{ \frac{W}{L}, I_{DQ} \right\}$

$$A_{v0} = \left[\frac{\sqrt{2\mu C_{OX}}}{\lambda} \right] \frac{\sqrt{\frac{W}{L}}}{\sqrt{I_{DQ}}} \quad GB = \left[\frac{\sqrt{2\mu C_{OX}}}{C_L} \right] \sqrt{\frac{W}{L}} \sqrt{I_{DQ}}$$

Alternate parameter domain:

$\{P, V_{EB}\}$

$$A_{v0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right] \quad GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$

Architecture Dependent

Parameter Domains for Characterizing Amplifier Performance

Degrees of Freedom: 2

Small signal parameter domain :

$$\{g_m, g_0\}$$

$$A_{V0} = \frac{-g_m}{g_0}$$

$$GB = \frac{g_m}{C_L}$$

Natural design parameter domain:

$$\left\{ \frac{W}{L}, I_{DQ} \right\}$$

$$A_{V0} = \left[\frac{\sqrt{2\mu C_{OX}}}{\lambda} \right] \frac{\sqrt{\frac{W}{L}}}{\sqrt{I_{DQ}}}$$

$$GB = \left[\frac{\sqrt{2\mu C_{OX}}}{C_L} \right] \sqrt{\frac{W}{L}} \sqrt{I_{DQ}}$$

Alternate parameter domain:

$$\{P, V_{EB}\}$$

$$A_{V0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right]$$

$$GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$

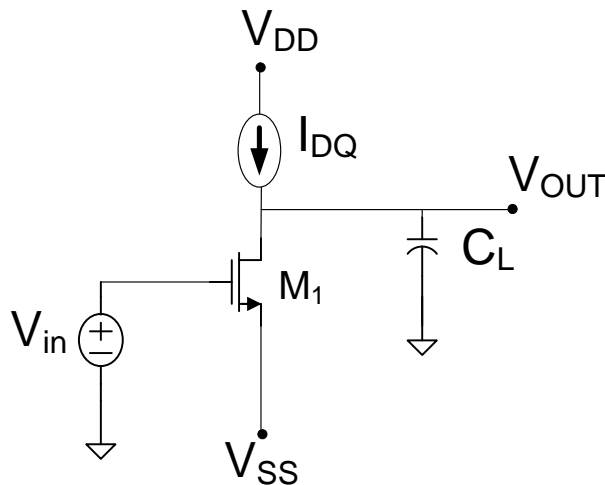
- Alternate parameter domain gives considerable insight into design
- Easy to map from alternate parameter domain to natural parameter domain
- Alternate parameter domain provides modest parameter decoupling
- $A_{V0} \left[\frac{\lambda}{2} \right]$ and $GB \left[\frac{V_{DD} C_L}{2} \right]$ figures of merit for comparing different architectures

Parameter Domains for Characterizing Amplifier Performance

- Design often easier if approached in the alternate parameter domain
- **How does one really get the design done, though? That is, how does one get back from the alternate parameter domain to the natural parameter domain?**

Alternate parameter domain:

$$\{P, V_{EB}\}$$



$$W = ?$$

$$L = ?$$

$$I_{DQ} = ?$$

$$V_{INQ} = ?$$

Parameter Domains for Characterizing Amplifier Performance

- Design often easier if approached in the alternate parameter domain
- **How does one really get the design done, though? That is, how does one get back from the alternate parameter domain to the natural parameter domain?**

Alternate parameter domain: $\{P, V_{EB}\}$

Natural design parameter domain: $\left\{\frac{W}{L}, I_{DQ}\right\}$

$$I_{DQ} = \frac{P}{V_{DD} - V_{SS}} \quad \frac{W}{L} = \frac{P}{(V_{DD} - V_{SS}) \mu C_{OX} V_{EB}^2}$$

To complete design:

Arbitrarily pick W or L

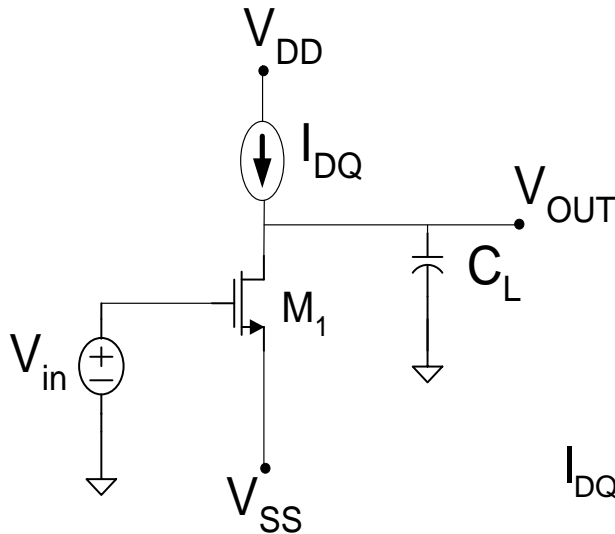
Satisfy constraint -
$$V_{INQ} = V_{SS} + V_T + \sqrt{I_{DQ} \frac{2}{\mu C_{OX}} \frac{L}{W}}$$

Design With the Basic Amplifier Structure

Consider basic op amp structure

Alternate parameter domain: $\{P, V_{EB}\}$

Degrees of Freedom: 2



$$A_{V0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right]$$

$$GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$

$$I_{DQ} = \frac{P}{V_{DD} - V_{SS}}$$

$$\frac{W}{L} = \frac{2P}{V_{DD} \mu C_{OX} V_{EB}^2}$$

$$V_{INQ} = V_{SS} + V_T + \sqrt{I_{DQ} \frac{2}{\mu C_{OX}} \frac{L}{W}}$$

What are the design requirements?

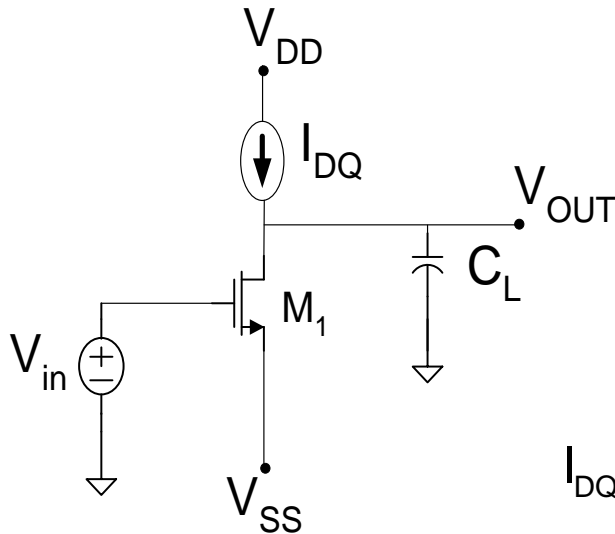
Depends on application !

Design With the Basic Amplifier Structure

Consider basic op amp structure

Alternate parameter domain: $\{P, V_{EB}\}$

Degrees of Freedom: 2



$$A_{V0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right]$$

$$GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$

$$I_{DQ} = \frac{P}{V_{DD} - V_{SS}}$$

$$\frac{W}{L} = \frac{2P}{V_{DD} \mu C_{OX} V_{EB}^2}$$

$$V_{INQ} = V_{SS} + V_T + \sqrt{I_{DQ} \frac{2}{\mu C_{OX}} \frac{L}{W}}$$

What if the design requirement dictates that $V_{INQ}=0$?

- Increase the number of constraints from 1 to 2
- Decrease the Degrees of Freedom from 2 to 1

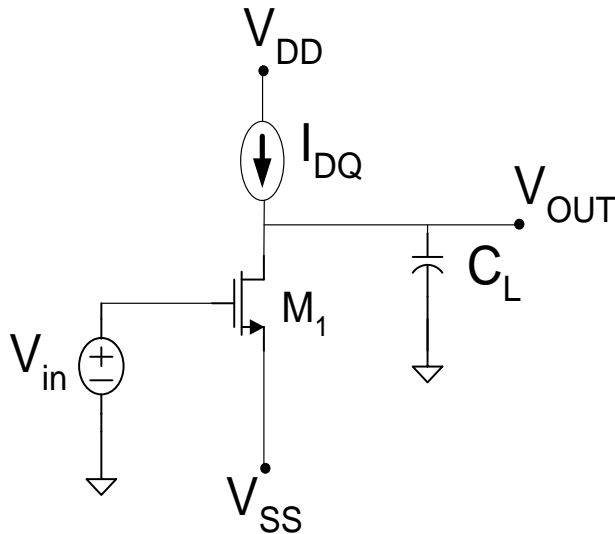
Question: How can one meet two or more performance requirements with one design degree of freedom with this circuit?

Design With the Basic Amplifier Structure

Consider basic op amp structure

Alternate parameter domain: $\{P, V_{EB}\}$

Degrees of Freedom: 2



$$A_{V0} = \left[\frac{2}{\lambda} \right] \left[\frac{1}{V_{EB}} \right]$$

$$GB = \left[\frac{2}{V_{DD} C_L} \right] \left[\frac{P}{V_{EB}} \right]$$

$$I_{DQ} = \frac{P}{V_{DD}}$$

$$\frac{W}{L} = \frac{P}{V_{DD} \mu C_{OX} V_{EB}^2}$$

$$V_{INQ} = V_{SS} + V_T + \sqrt{I_{DQ} \frac{2}{\mu C_{OX}} \frac{L}{W}}$$

But what if the design requirement dictates that $V_{INQ} = 0$?

Question: How can one meet two or more performance requirements with one design degree of freedom with this circuit?

Degrees of Freedom: 1

Luck or Can't



Stay Safe and Stay Healthy !

End of Lecture 2