EE 435

Lecture 21

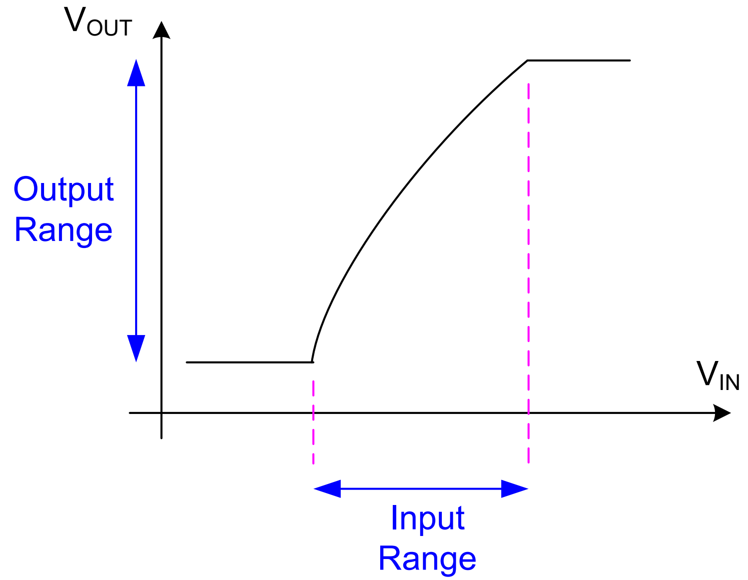
Linearity of Bipolar and MOS Differential Pairs

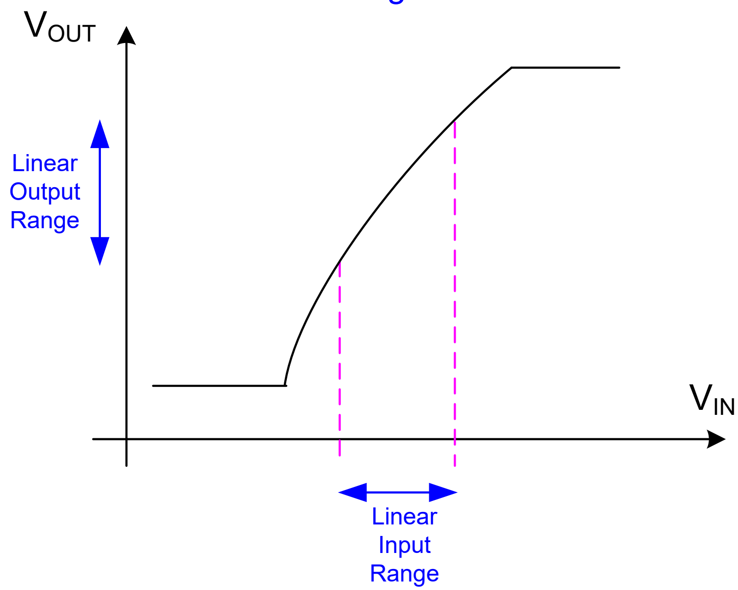
Linearity of Common Source Amplifier

Offset Voltages

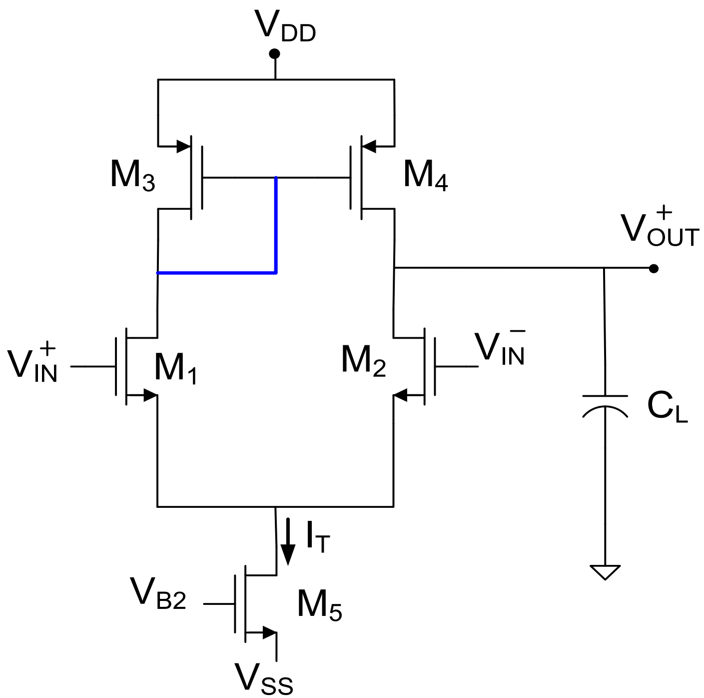
Review from last lecture

Signal Swing and Linearity

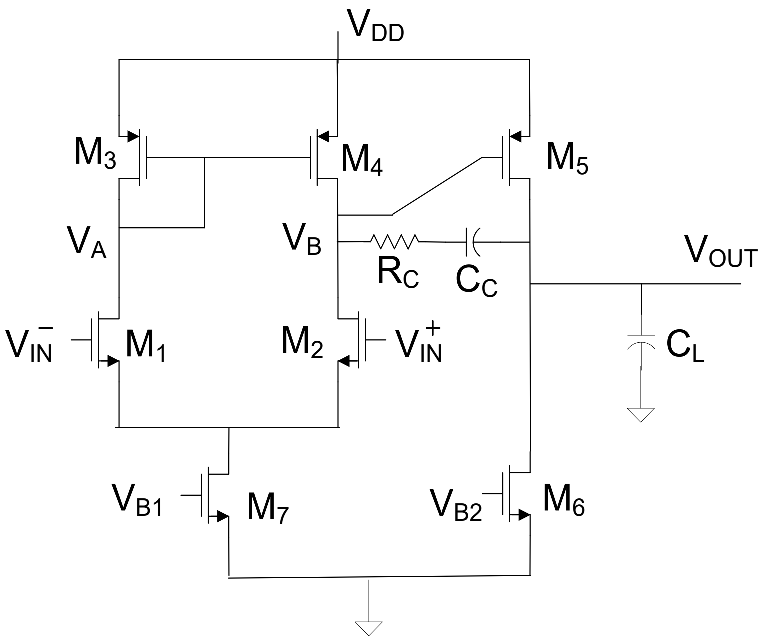




Linearity of Amplifiers



Single-Stage



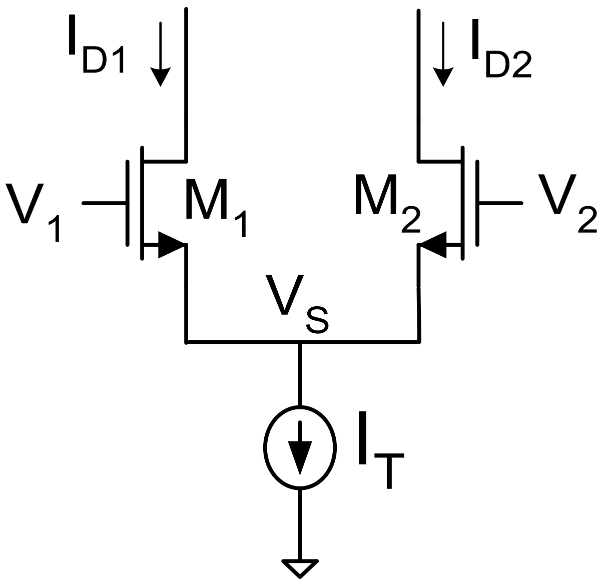
Two-Stage

Linearity of differential pair of major concern

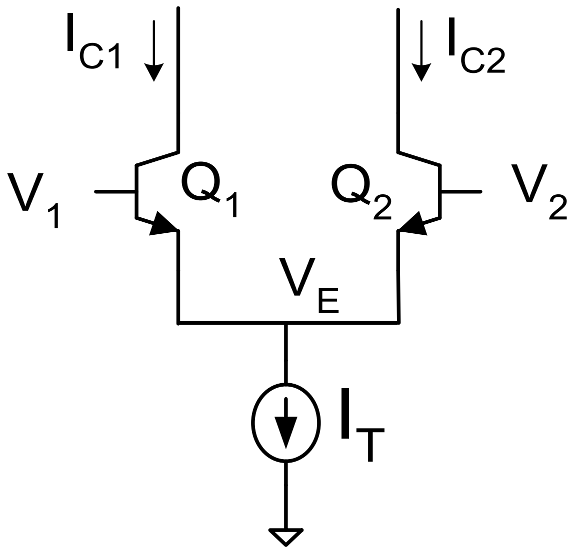
Linearity of common-source amplifier is of major concern (since signals so small at output of differential pair)

Review from last lecture

Differential Input Pairs



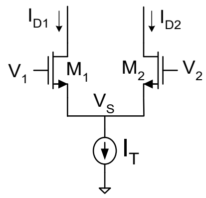
MOS Differential Pair



Bipolar Differential Pair

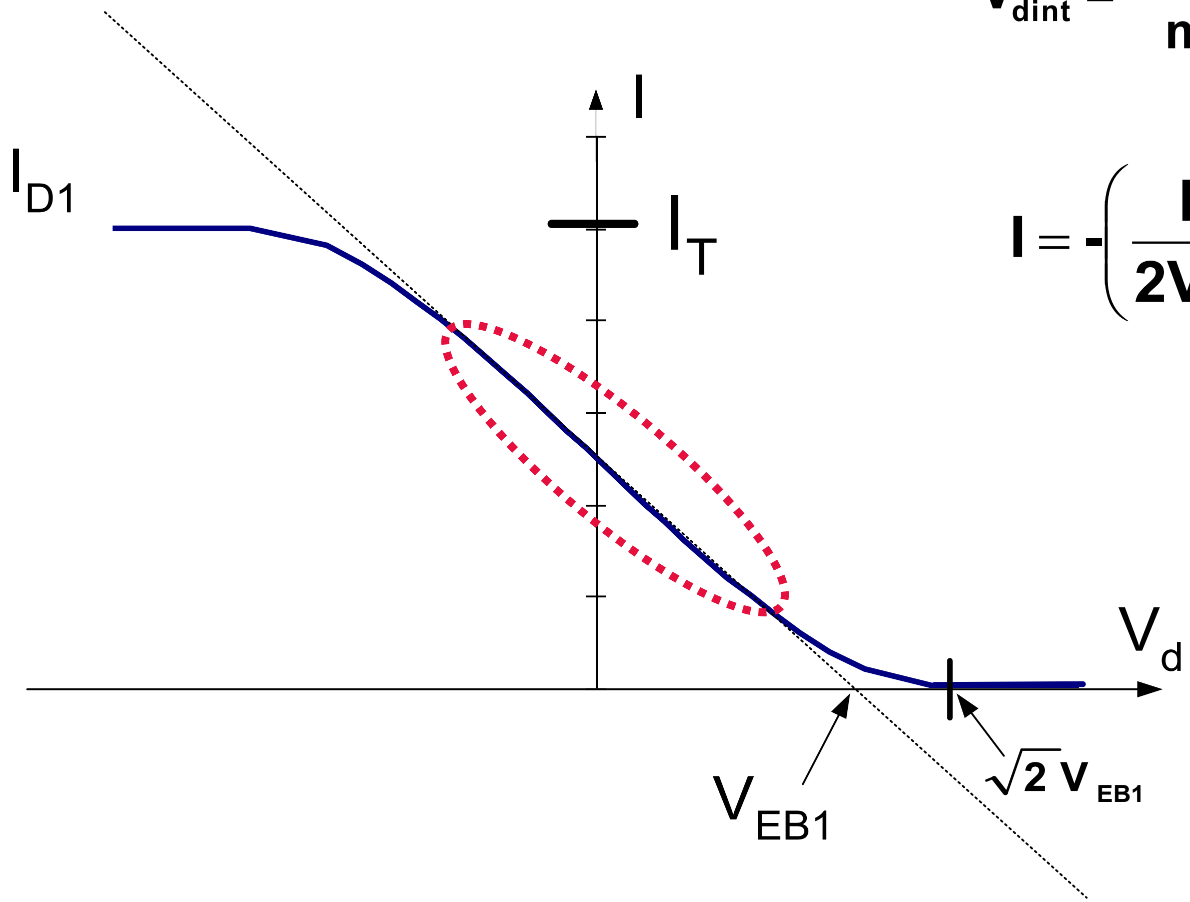
Review from last lecture

How linear is the amplifier ?



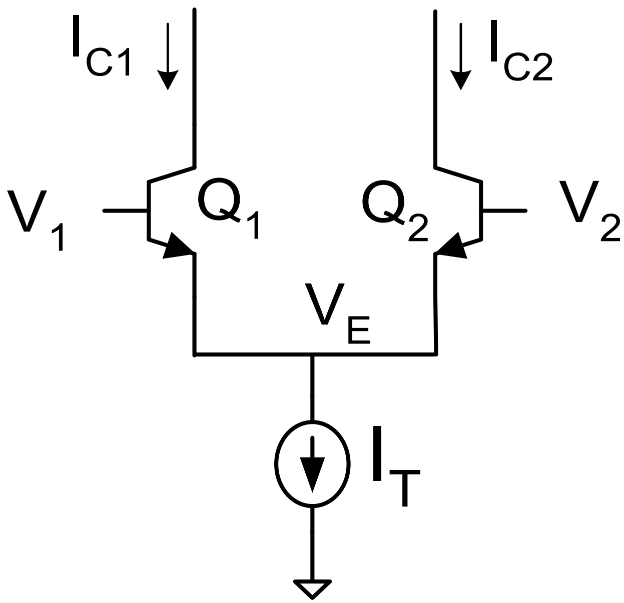
$$V_{dint} = -\frac{h}{m} = -\frac{I_T}{2m} = V_{EB1}$$

$$I = -\left(\frac{I_T}{2V_{EB1}}\right)V_d + \frac{I_T}{2}$$



Review from last lecture

Bipolar Differential Pair



$$V_d = V_t\left(\ln\left(\frac{I_{C2}}{J_S A_{E2}}\right) - \ln\left(\frac{I_{C1}}{J_S A_{E1}}\right)\right) \overset{A_{E1}=A_{E2}}{=} V_t \ln\left(\frac{I_{C2}}{I_{C1}}\right)$$

$$V_d = V_t \ln\left(\frac{I_T - I_{C1}}{I_{C1}}\right)$$

$$V_d = V_t \ln\left(\frac{I_{C2}}{I_T - I_{C2}}\right)$$

$$V_d = V_2 - V_1$$

At $I_{C1}=I_{C2}=I_T/2$, $V_d=0$

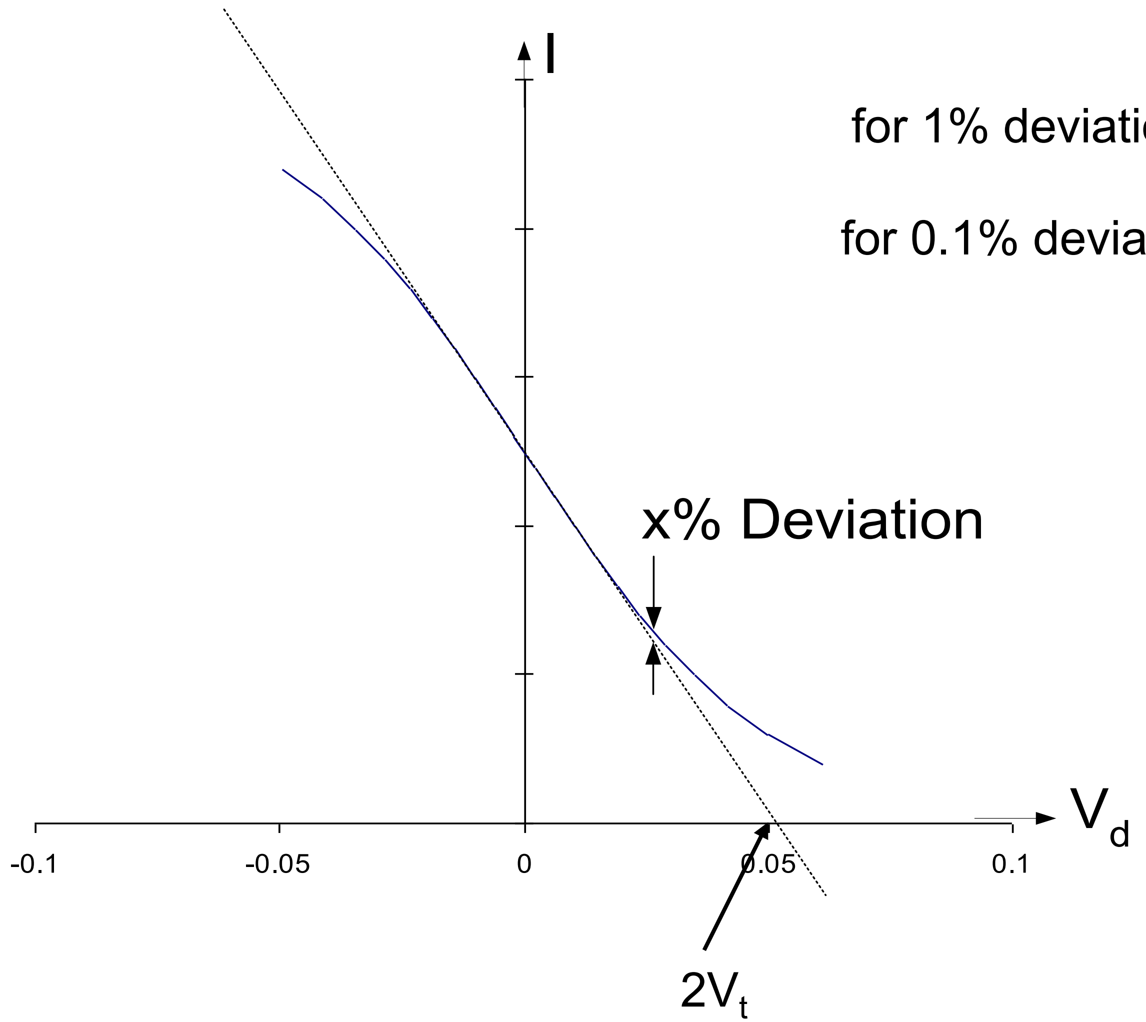
As I_{C1} approaches 0, V_d approaches infinity

As I_{C1} approaches I_T, V_d approaches minus infinity

Transition much steeper than for MOS case

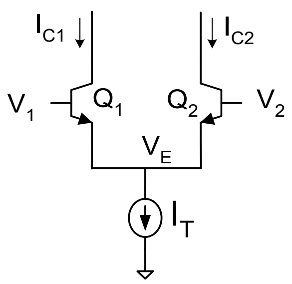
Review from last lecture

Signal Swing and Linearity of Bipolar Differential Pair

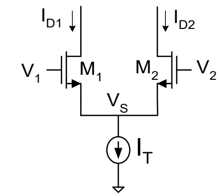


for 1% deviation, V_d=.56V_t

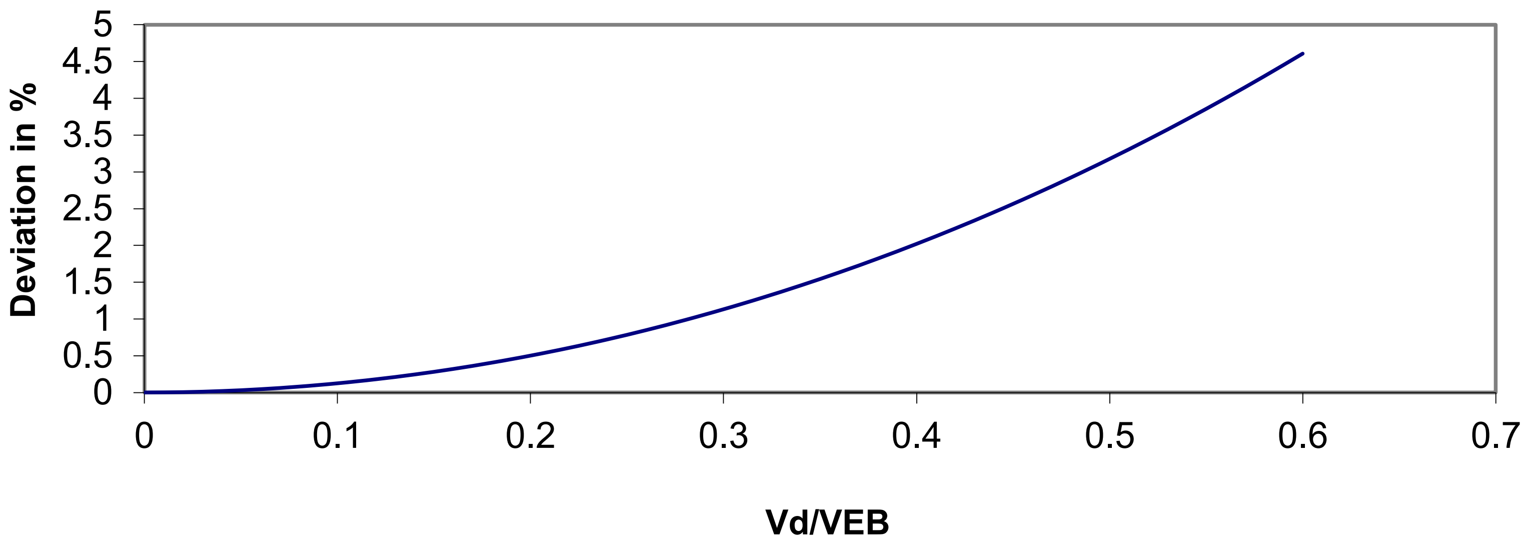
for 0.1% deviation, V_d=.27V_t



How linear is the amplifier ?



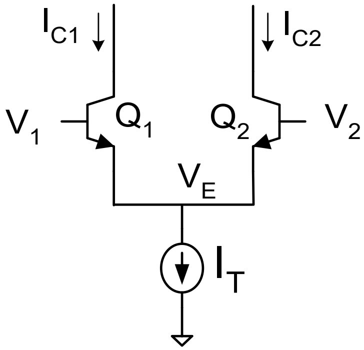
Deviation from Linear



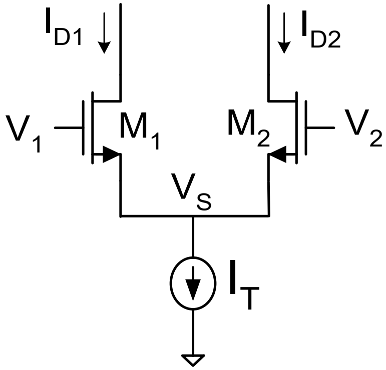
Vd/VEB	θ	Vd/VEB	θ	Vd/VEB	θ
0.02	0.005	0.22	0.607	0.42	2.23
0.04	0.020	0.24	0.723	0.44	2.45
0.06	0.045	0.26	0.849	0.46	2.68
0.08	0.080	0.28	0.985	0.48	2.92
0.1	0.125	0.3	1.13	0.5	3.18
0.12	0.180	0.32	1.29	0.52	3.44
0.14	0.245	0.34	1.46	0.54	3.71
0.16	0.321	0.36	1.63	0.56	4.00
0.18	0.406	0.38	1.82	0.58	4.30
0.2	0.501	0.4	2.02	0.6	4.61

Review from last lecture

Comparison of Distortion in BJT and MOSFET Pairs



$$V_d = V_m \sin(\omega t)$$



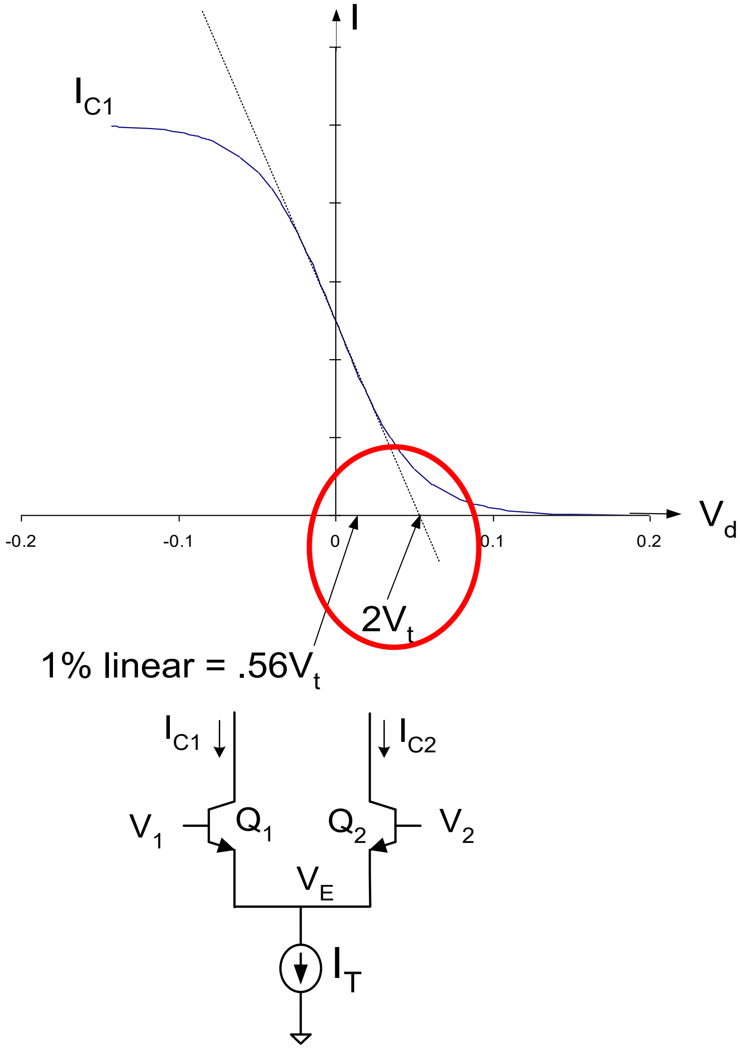
$$THD = -20\log\left(48\left(\frac{V_t}{V_m}\right)^2 - 3\right)$$

$$THD = -20\log\left(32\left(\frac{V_{EB1}}{V_m}\right)^2 - 3\right)$$

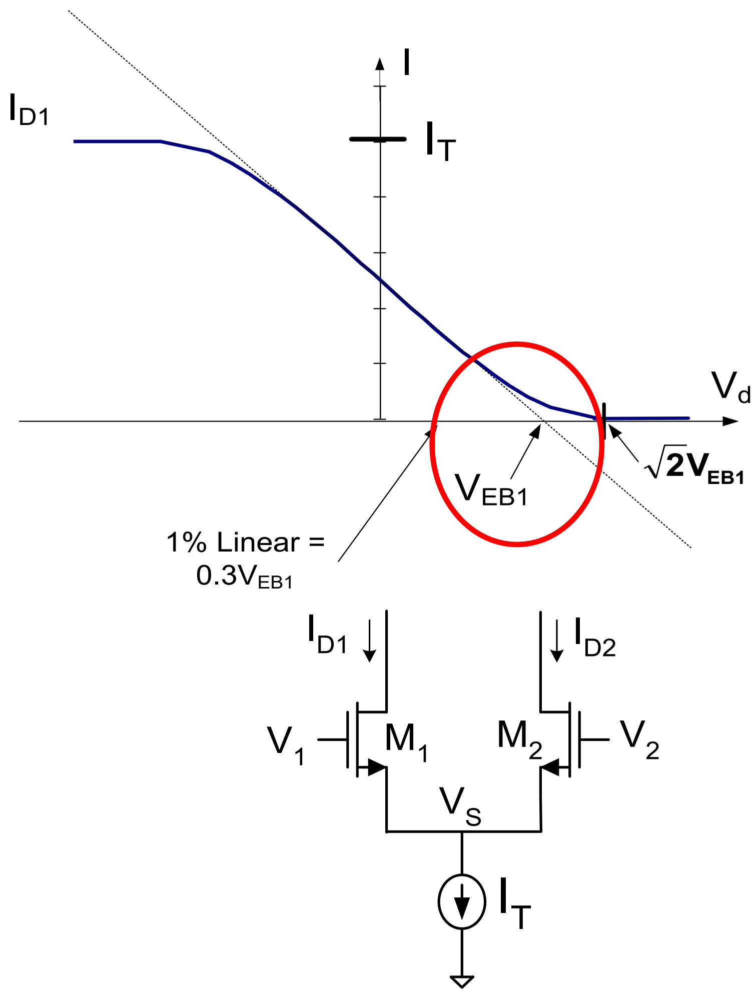
V_m/V_t	THD (dB)
2.5	-13.4049
1	-33.0643
0.5	-45.5292
0.25	-57.6732
0.1	-73.6194
0.05	-85.6647
0.025	-97.7069
0.01	-113.625

V_m/V_{EB1}	THD (dB)
2.5	-6.52672
1	-29.248
0.5	-41.9382
0.25	-54.1344
0.1	-70.0949
0.05	-82.1422
0.025	-94.1849
0.01	-110.103

Linearity and Signal Swing Comparison of Bipolar/MOS Differential Pair

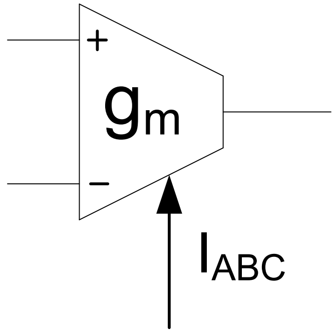


Signal swing determined by V_t



Signal swing determined by V_{EB}

Applications as a programmable OTA with I_{ABC}



The current-dependence of the g_m of the differential pair (single transistor) is often used to program the transconductance of an OTA with the tail bias current I_{ABC}

MOS

$$g_m = \sqrt{I_{ABC}}\sqrt{\mu C_{OX}\frac{W}{L}}$$

Two decade change in current for every decade change in g_m

$$g_m = uC_{OX}\frac{W}{L}V_{EB}$$

BJT

$$g_m = \frac{I_{ABC}}{2V_t}$$

One decade change in current for every decade change in g_m

What change in signal swing if programmed with I_{ABC}?

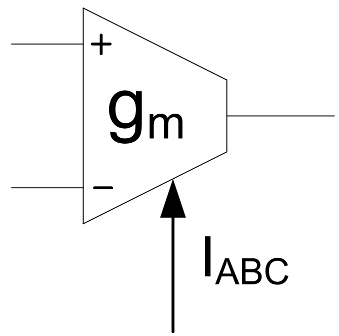
One decade decrease in signal swing for every decade decrease in g_m

No change in signal swing when g_m Is changed

Limited g_m adjustment possibility

Large g_m adjustment possible

Applications as a programmable OTA with I_{ABC}



MOS

$$g_m = \sqrt{I_{ABC}}\sqrt{\mu C_{OX}\frac{W}{L}}$$

BJT

$$g_m = \frac{I_{ABC}}{2V_t}$$

One decade decrease in signal swing for every decade decrease in g_m

No change in signal swing when g_m Is changed

Assume a MOS transconductor has an acceptable signal swing (as determined by linearity) with V_{EB}=1V (maybe p-p signal swing is V_{EB})

What would be the acceptable signal swing (with the same linearity) if g_m were tuned by one decade with I_{ABC}?

$$V_{EB1} = \sqrt{I_{DQ}}\sqrt{\frac{2L}{\mu C_{OX}W}} \qquad V_{EB2} = \sqrt{\frac{I_{DQ}}{100}}\sqrt{\frac{2L}{\mu C_{OX}W}} = \frac{1}{10}\sqrt{I_{DQ}}\sqrt{\frac{2L}{\mu C_{OX}W}} = \frac{V_{EB1}}{10}$$

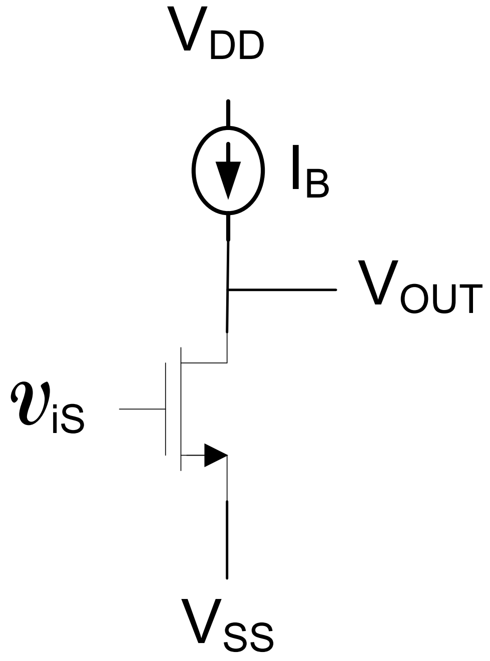
Signal swing would be reduced by a factor of 10

Signal Swing and Linearity Summary

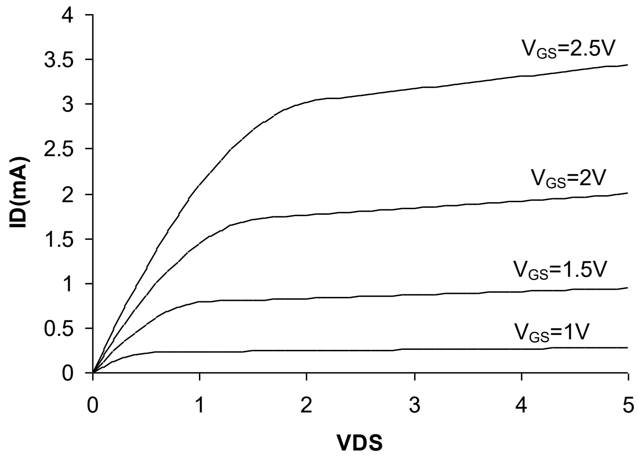
- Signal swing of MOSFET can be rather large if V_{EB} is large but this limits gain
- Signal swing of MOSFET degrades significantly if V_{EB} is changed for fixed W/L
- Bipolar swing is very small but independent of g_m
- Multiple-decade adjustment of bipolar g_m is practical
- Even though bipolar input swing is small, since gain is often very large, this small swing does usually not limit performance in feedback applications

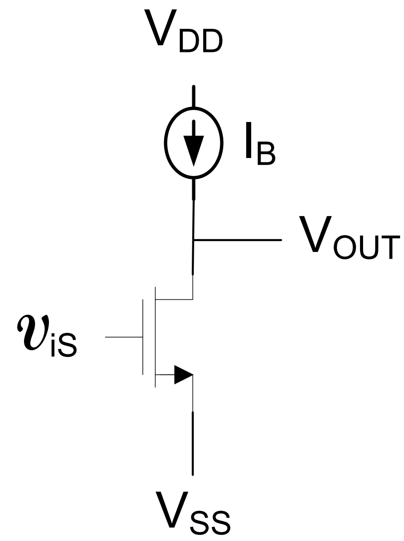
Linearity of Common-Source Amplifier

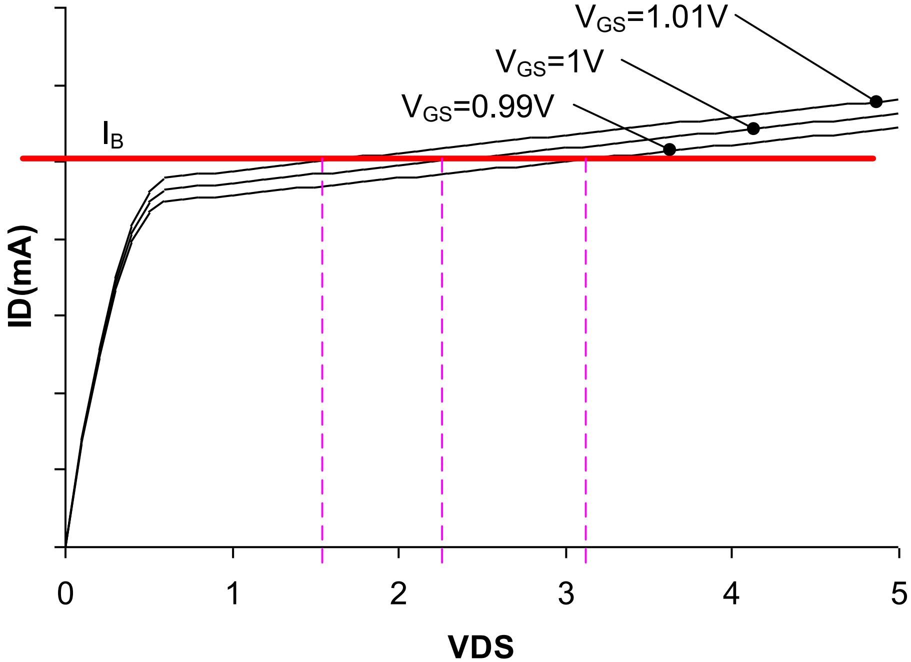
For convenience, will consider situation where current source biasing I_B is ideal



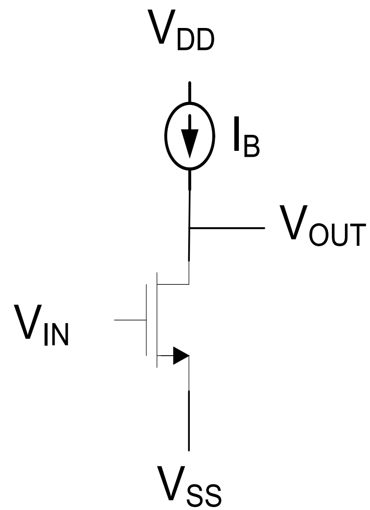
Linearity of Common-Source Amplifier







Linearity of Common-Source Amplifier



$$V_{IN} = V_{INQ} + v_{iS}$$

V_{INQ}: Quiescent Input
v_{iS}: Signal Input

$$V_{OUT} = V_{OQ} + v_{OS}$$

V_{OQ}: Quiescent Output
v_{OS}: Signal Output

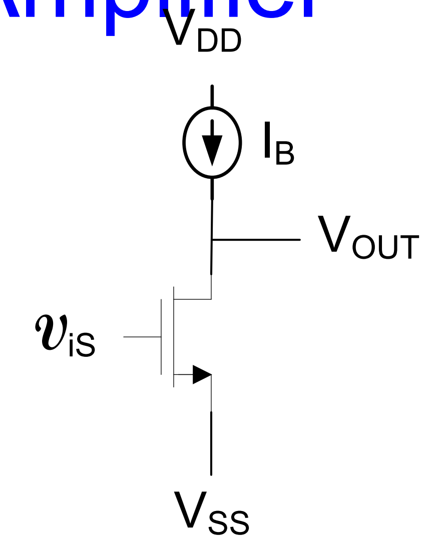
$$I_B = \frac{\mu C_{OX} W}{2L}(V_{IN}-V_{SS}-V_{TH})^2\left(1+\lambda\left[V_{OUT}-V_{SS}\right]\right)$$

$V_{EB} = V_{INQ} - V_{SS} - V_{TH}$ strictly for notational convenience define $\beta = \frac{\mu C_{OX} W}{2L}$

$$I_B = \beta(v_{iS}-V_{EB})^2\left(1+\lambda\left[v_{OS}+V_{OQ}-V_{SS}\right]\right)$$

$$v_{OS} = V_{SS}-V_{OQ}-\frac{\left(\frac{I_B}{\beta V_{EB}^2\left(1-\frac{v_{iS}}{V_{EB}}\right)^2}\right)-1}{\lambda}$$

Linearity of Common-Source Amplifier



$$v_{OS} = V_{SS} - V_{OQ} - \frac{\left(\frac{I_B}{\beta V_{EB}^2\left(1-\frac{v_{iS}}{V_{EB}}\right)^2}\right)-1}{\lambda}$$

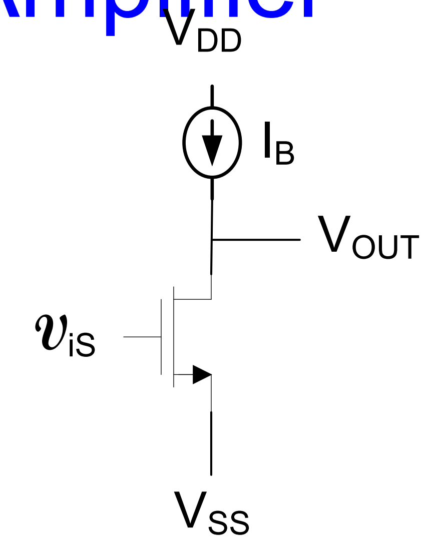
Recall for x small $\frac{1}{1+x} \simeq 1-x$

$$v_{OS} \cong V_{SS} - V_{OQ} - \frac{\left(\frac{I_B\left(1+\frac{v_{iS}}{V_{EB}}\right)^2}{\beta V_{EB}^2}\right)-1}{\lambda}$$

$$v_{OS} \cong V_{SS} - V_{OQ} - \frac{I_B}{\lambda\beta V_{EB}^2}\left(1+2\frac{v_{iS}}{V_{EB}}+\left(\frac{v_{iS}}{V_{EB}}\right)^2\right)-\frac{1}{\lambda}$$

$$v_{OS} \cong \left[V_{SS} - V_{OQ} - \frac{1}{\lambda}\left(\frac{I_B}{\beta V_{EB}^2}+1\right)\right] - \frac{I_B}{\lambda\beta V_{EB}^2}\left(2\frac{v_{iS}}{V_{EB}}+\left(\frac{v_{iS}}{V_{EB}}\right)^2\right)$$

Linearity of Common-Source Amplifier



$$v_{OS} \cong \left[V_{SS}-V_{OQ}-\frac{1}{\lambda}\left(\frac{I_B}{\beta V_{EB}^2}+1\right)\right]-\frac{I_B}{\lambda\beta V_{EB}^2}\left(2\frac{v_{iS}}{V_{EB}}+\left(\frac{v_{iS}}{V_{EB}}\right)^2\right)$$

but
$$\left[V_{SS}-V_{OQ}-\frac{1}{\lambda}\left(\frac{I_B}{\beta V_{EB}^2}+1\right)\right] \cong 0$$

$$I_B \cong \beta(V_{EB})^2$$

Thus

$$v_{OS} \cong -\left(2\frac{v_{iS}}{\lambda V_{EB}}+\frac{1}{\lambda}\left(\frac{v_{iS}}{V_{EB}}\right)^2\right)$$

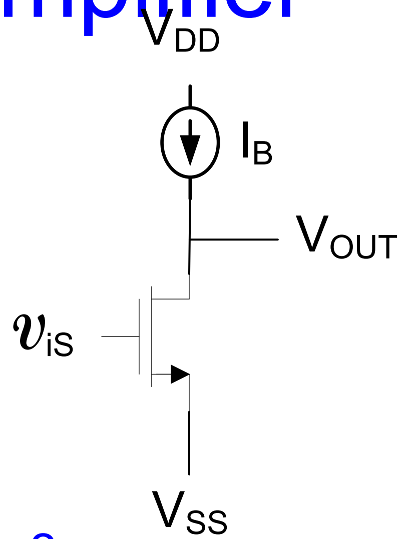
$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS}+\frac{1}{2V_{EB}}v_{iS}^2\right)$$

Is this a linear or nonlinear relationship?

What are the dominant harmonics in the distortion of this amplifier?

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$



What are the dominant harmonics in the distortion of this amplifier?

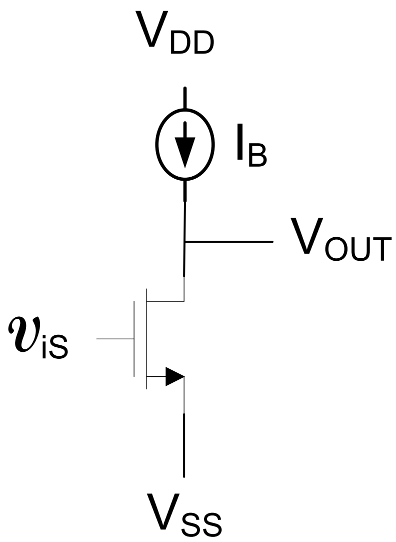
Consider input $V_m \sin(\omega t)$

Recall $$\sin^2 x = \frac{1-\cos 2x}{2}$$

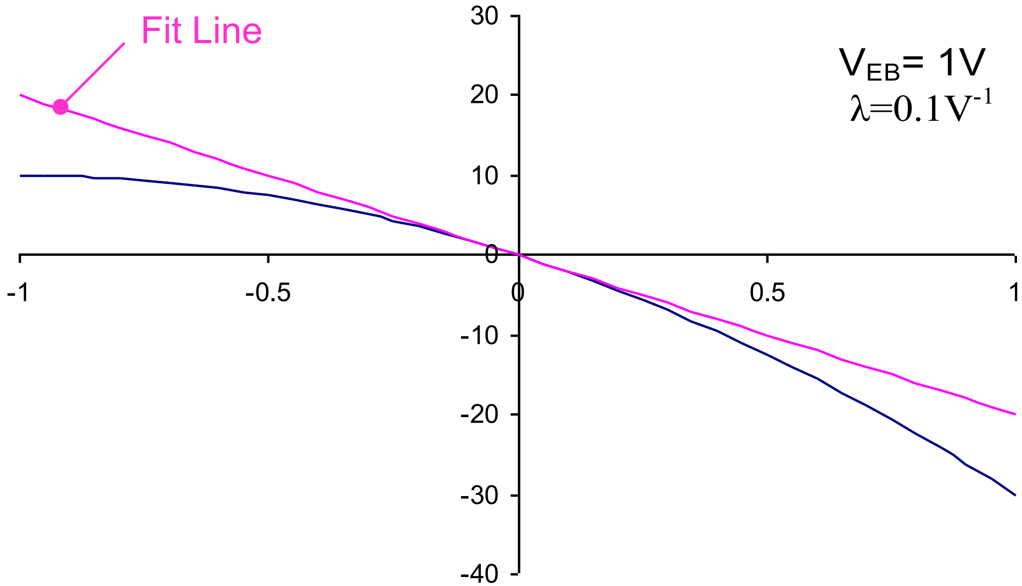
- Output will have components at ω and 2ω
- Dominant distortion is 2nd-order distortion
- This is in contrast to the differential pair that had dominantly 3rd order distortion
- Can readily obtain expression for THD

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$



Is this a linear or nonlinear relationship?



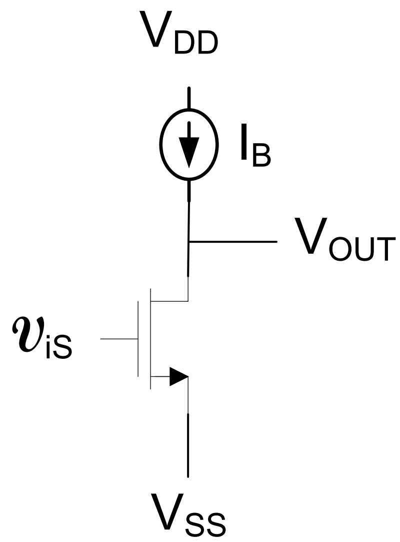
when v_{iS} = -V_{EB} (the minimum value of v_{iS} to maintain saturation operation)

the error in V_{OS} will be V_{EB}/2 which is -50% !

Is this a linear or nonlinear relationship?

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$



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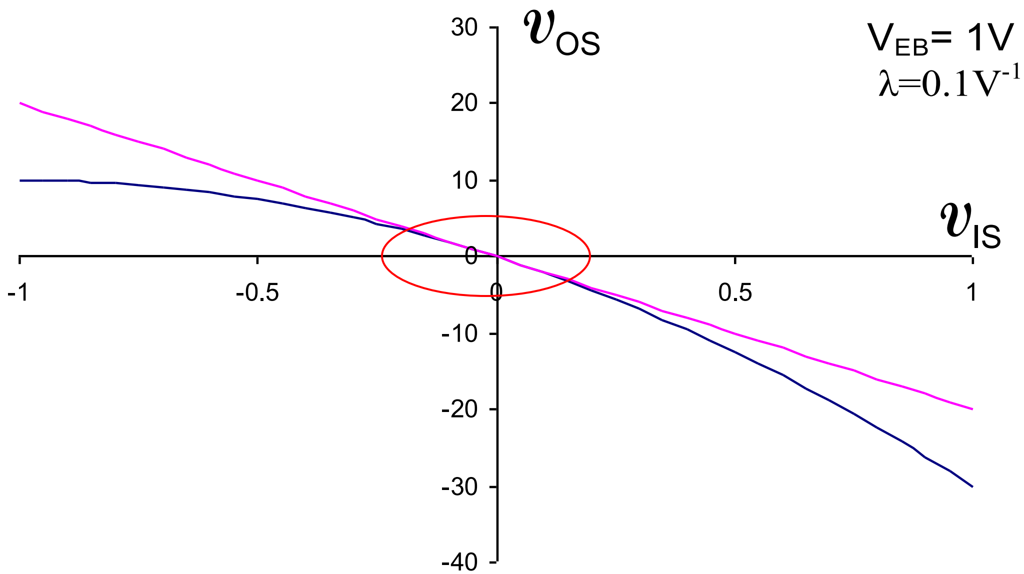
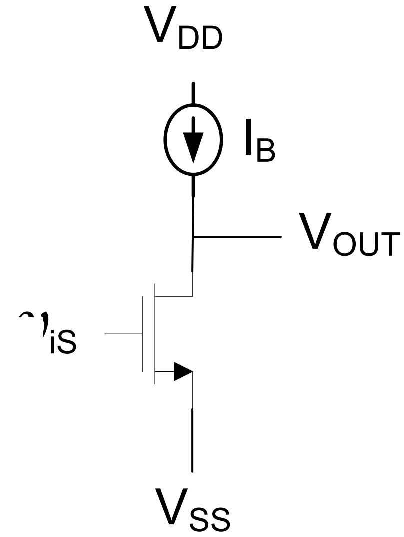


Note this is a reasonably high gain amplifier and could be larger for smaller V_{EB}

Over what output voltage range are we interested?

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$



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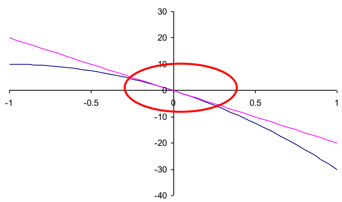
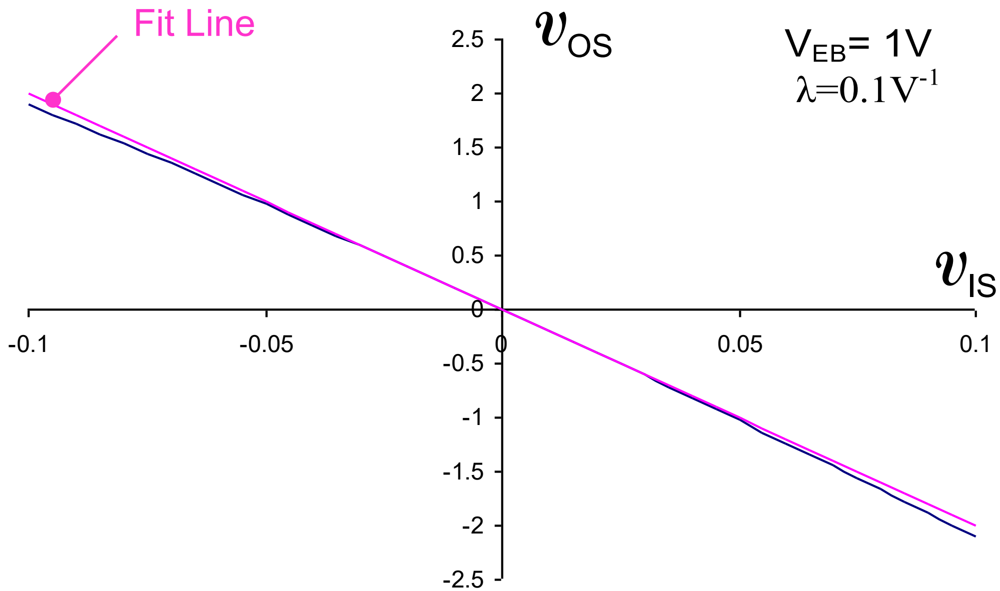


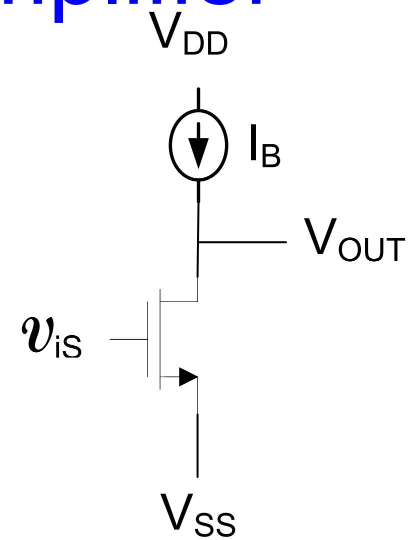


Linearity is reasonably good over practical input range

Practical input range is much less than V_{EB}

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$



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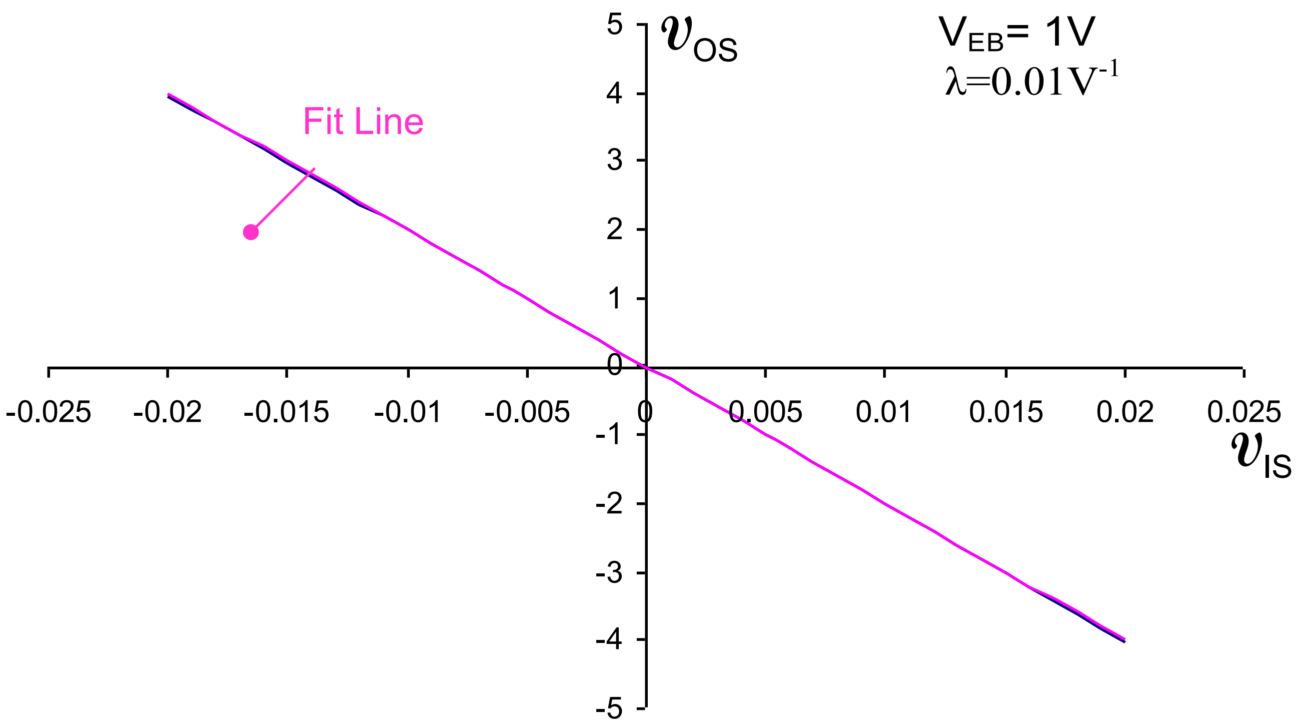


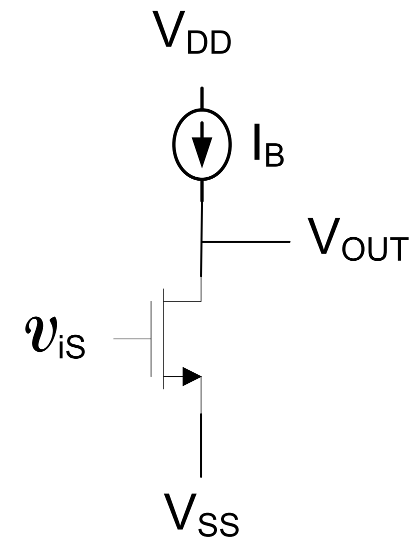
λ=0.01V^{-1} more realistic in many processes or for longer L

Can't "see" nonlinearity in this plot

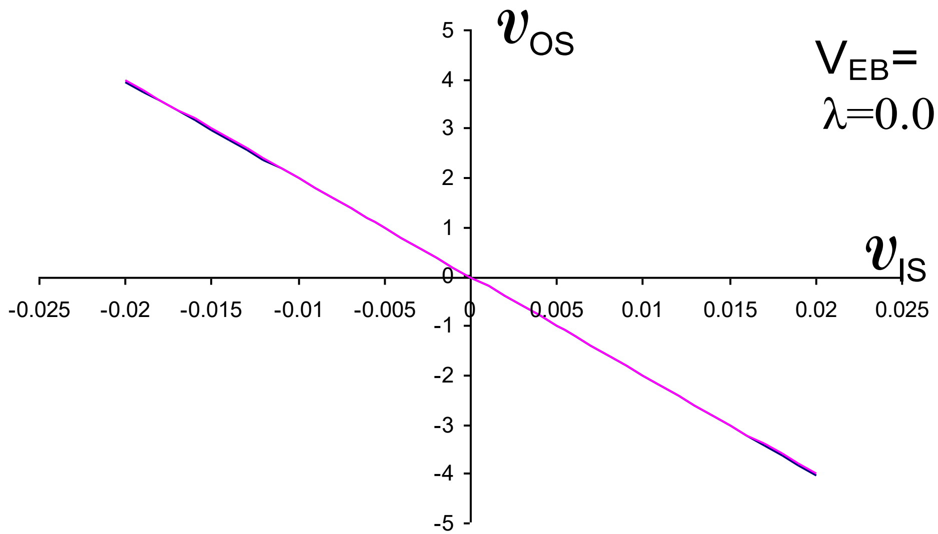
Appears to be dependent upon dc gain of amplifier ??

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}}v_{iS}^2\right)$$



Is this a linear or nonlinear relationship?



Will look at difference between output and ideal output as defined by fit lie

$$v_{FIT} \cong -\frac{2}{\lambda V_{EB}}v_{iS}$$

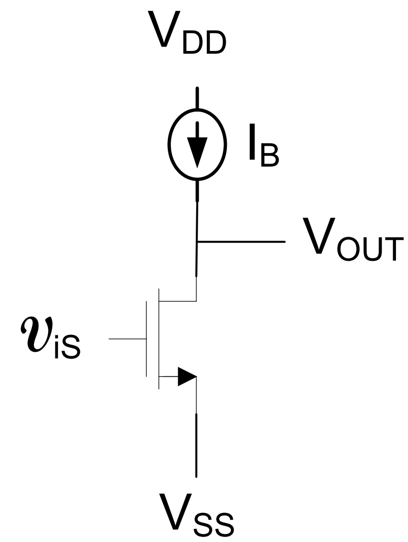
$$\varepsilon = v_{FIT} - v_{OS}$$

$$\varepsilon \cong \frac{1}{\lambda V_{EB}^2}v_{iS}^2$$

Appears to be highly dependent upon dc gain of amplifier ??

Linearity of Common-Source Amplifier

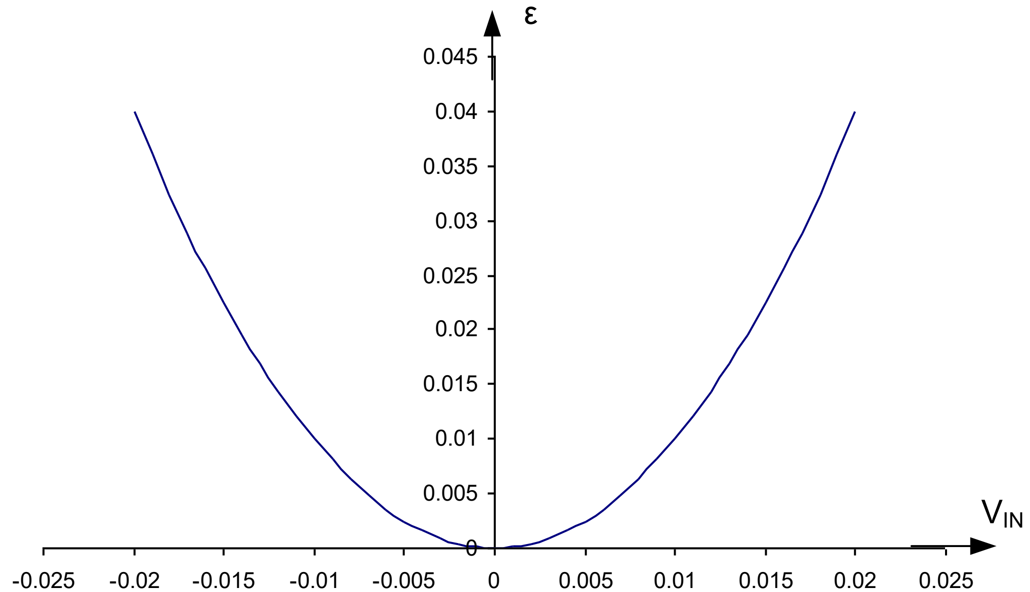
$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS}+\frac{1}{2V_{EB}}v_{iS}^2\right)$$



Is this a linear or nonlinear relationship?

$$\varepsilon \cong \frac{1}{\lambda V_{EB}^2}v_{iS}^2$$

V_{EB}= 1V
λ=0.01V^{-1}

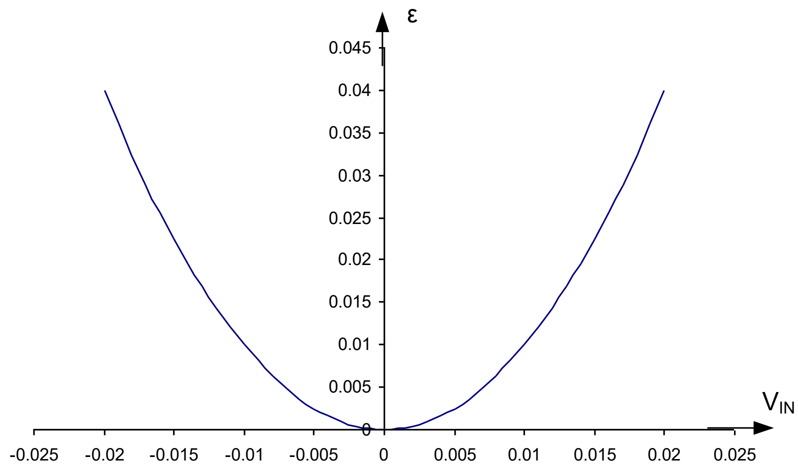


Appears to be highly dependent upon dc gain of amplifier ??

Linearity of Common-Source Amplifier

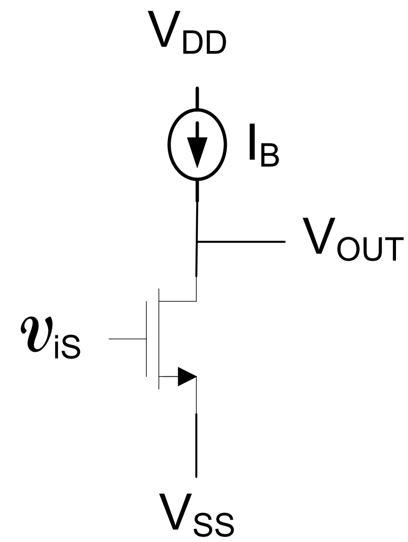
$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}}v_{iS}^2\right)$$

Is this a linear or nonlinear relationship?



V_{EB}= 1V

$\lambda=0.01V^{-1}$



$$\varepsilon_{PCT} \cong \frac{\varepsilon}{v_{FIT}}100\% = \left[\frac{\frac{1}{\lambda V_{EB}^2}v_{iS}^2}{\frac{2v_{iS}}{\lambda V_{EB}}}\right]100\% = \left(\frac{100\%}{2V_{EB}}\right)v_{iS}$$

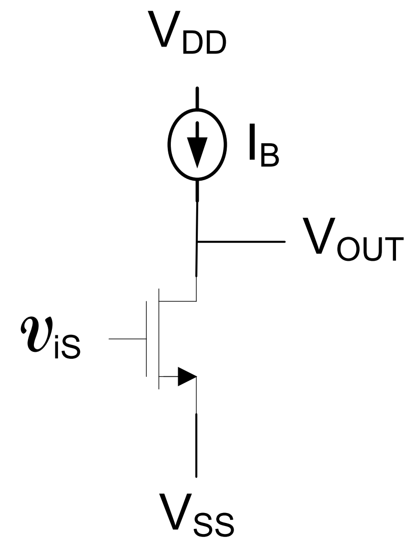
$$\varepsilon_{PCT} \cong \left(-\frac{\lambda \bullet 100\%}{4}\right)v_{OS}$$

Appears to be highly dependent upon dc gain of amplifier ??

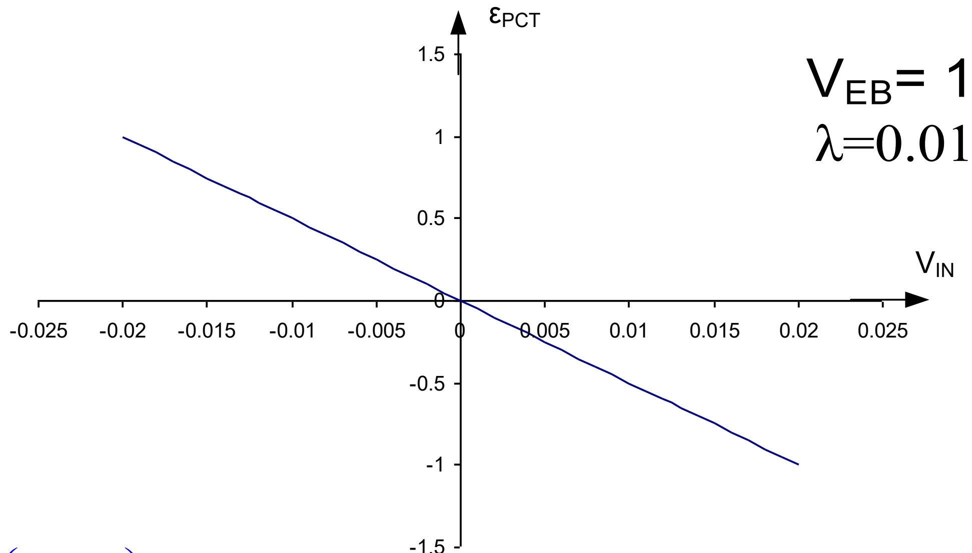
Relative error in output independent of gain of amplifier !

Linearity of Common-Source Amplifier

$$v_{OS} \cong -\frac{2}{\lambda V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}}v_{iS}^2\right)$$



Is this a linear or nonlinear relationship?



V_{EB}= 1V

$\lambda = 0.01\text{V}^{-1}$

$$\varepsilon_{PCT} \cong \left(\frac{100\%}{2V_{EB}}\right)v_{iS}$$

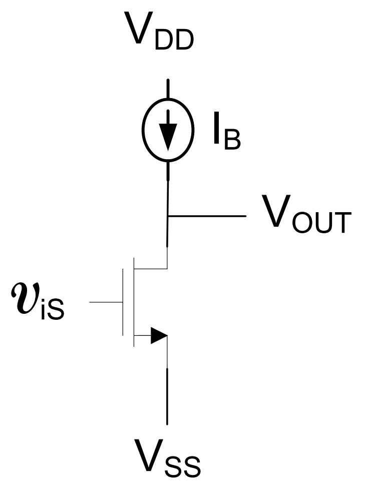
or, in terms of v_{OS},

$$\varepsilon_{PCT} \cong \left(-\frac{\lambda \bullet 100\%}{4}\right)v_{OS}$$

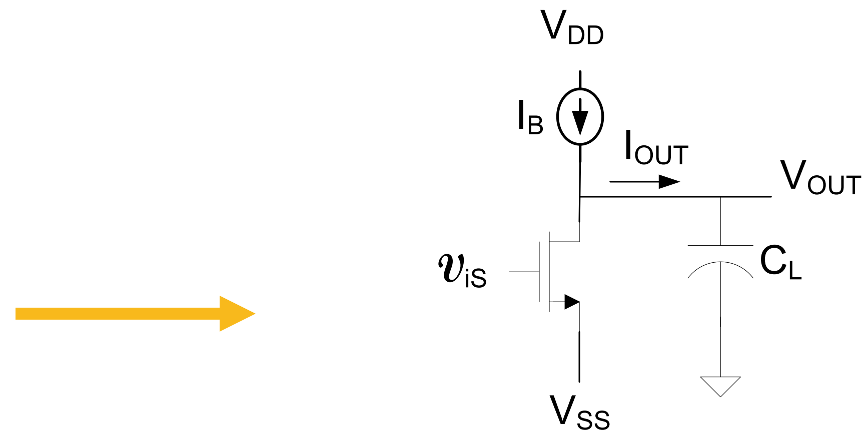
1% deviation for this example occurs at $\left|v_{OS}\right| \cong 0.01\frac{4}{\lambda} \cong 4\text{V}$

In spite of square-law nonlinearity in MOSFET, linearity of CS amplifier is quite good provided MOSFET remains in saturation region !!

Linearity of Common-Source Amplifier

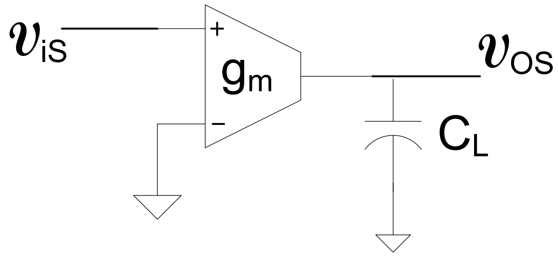


High-Gain Amplifier



Transconductance Amplifier

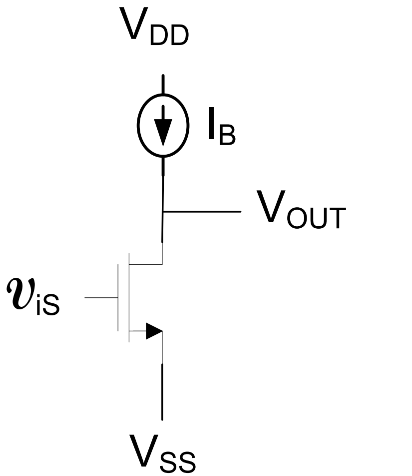
The transconductance amplifier driving a load C_L is performing as an integrator



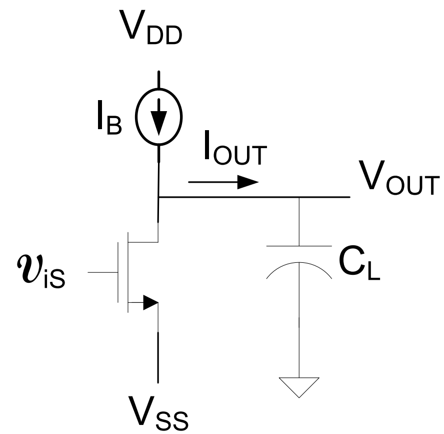
Integrators often used in filters where at frequencies of most interest $|v_{OS}|$ is comparable to $|v_{iS}|$

Is this common-source amplifier linear or nonlinear?

Linearity of Common-Source Amplifier



High-Gain Amplifier



Transconductance Amplifier

$$I_{OUT} = I_B - I_D$$

$$I_{OUT} = I_B - \beta(v_{iS} + V_{EB})^2\left(1+\lambda\left[V_{OS}+V_{OQ}-V_{SS}\right]\right)$$

$$I_{OUT} = \left[I_B - \beta(V_{EB})^2\left(1+\lambda\left[V_{OQ}-V_{SS}\right]\right)\right] - \beta\left(v_{iS}^2 + 2v_{iS}V_{EB}\right)\left(1+\lambda\left[V_{OS}+V_{OQ}-V_{SS}\right]\right)$$

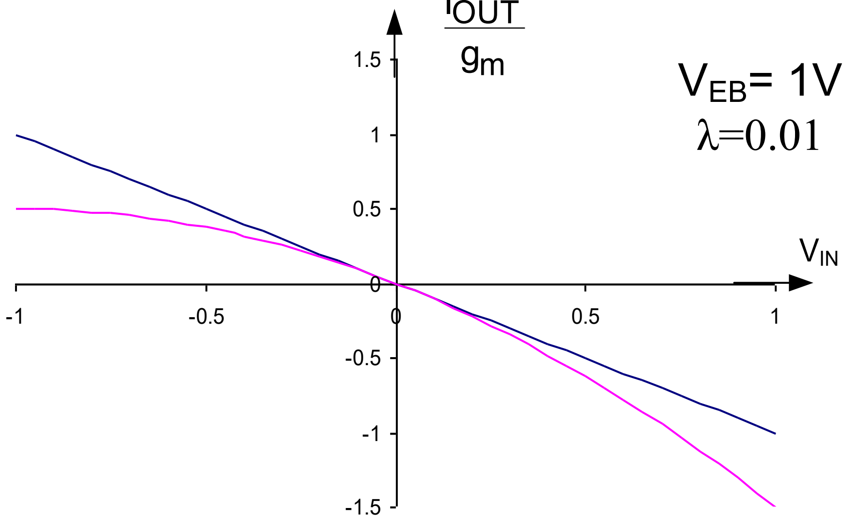
$$I_{OUT} \cong -\beta\left(v_{iS}^2 + 2v_{iS}V_{EB}\right)$$

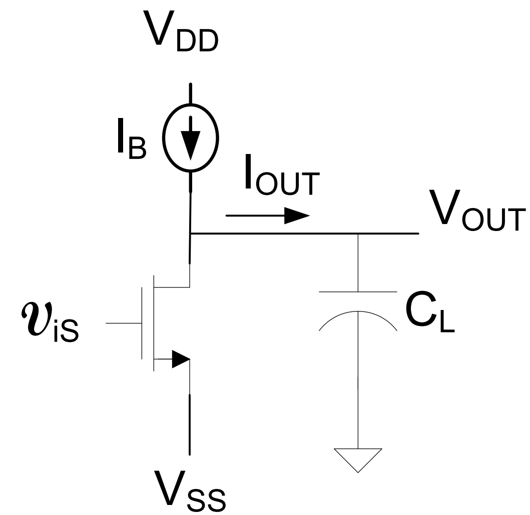
$$I_{OUT} \cong -\frac{2I_B}{V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}}v_{iS}^2\right)$$

Is this a linear or nonlinear relationship?

Linearity of Common-Source Amplifier

As an OTA





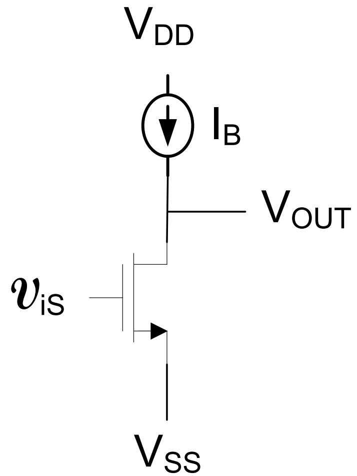
$$g_m = \frac{2I_B}{V_{EB}}$$

$$I_{OUT} \cong -\frac{2I_B}{V_{EB}}\left(v_{iS} + \frac{1}{2V_{EB}} v_{iS}^2\right)$$

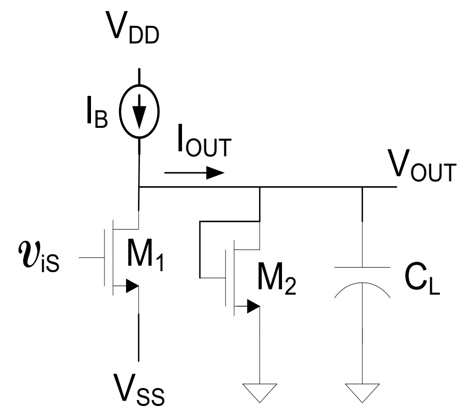
Is this a linear or nonlinear relationship?

At v_{IS}=-V_{EB}, the error in I_{OUT} will be -50% !

Linearity of Common-Source Amplifier



High-Gain Amplifier

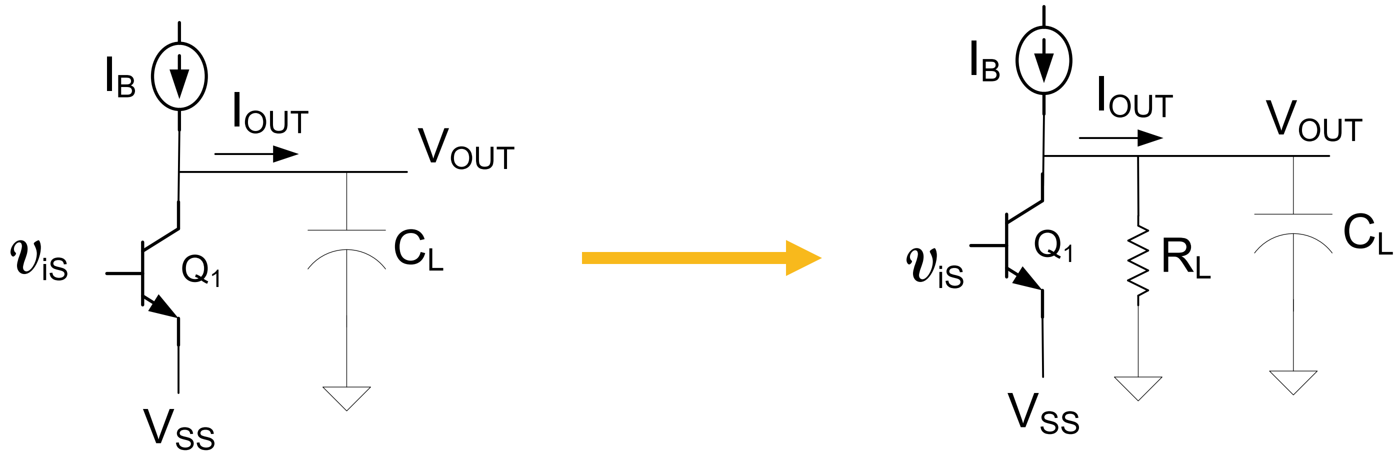


Transconductance Amplifier

Is this common-source amplifier linear?

- Reasonably linear if used in high-gain applications and V_{EB} is large (e.g. if $A_V=g_m/g_o=2/((\lambda V_{EB})=100$ and Vo=1V, Vin=10mV)
- Highly nonlinear when used in low-gain applications though linearity dependent upon g_m

Linearity of Common-Emitter Amplifier



High-Gain Amplifier

Transconductance Amplifier

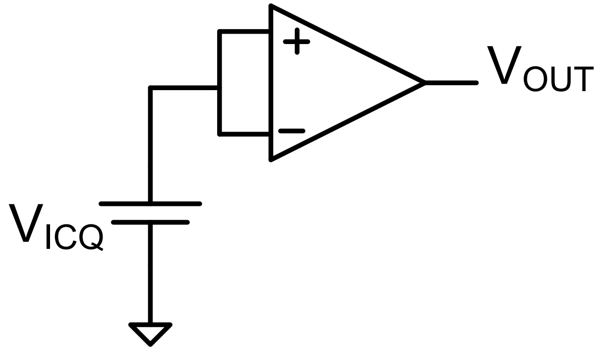
Is this common-emitter amplifier linear?

- Very linear if used in high-gain applications
  (e.g. if $A_V=g_m/g_0=V_{AF}/V_t=4000$ and $V_o=1V$, $V_{in}=250uV$)
- Highly nonlinear when used in low-gain applications but not dependent upon g_m
- Bipolar OTAs (e.g. current mirror op amp) can operate over multiple decades of gain with low-level signals but no degradation with gain

Offset Voltage

Two types of offset voltage:

- Systematic Offset Voltage
- Random Offset Voltage

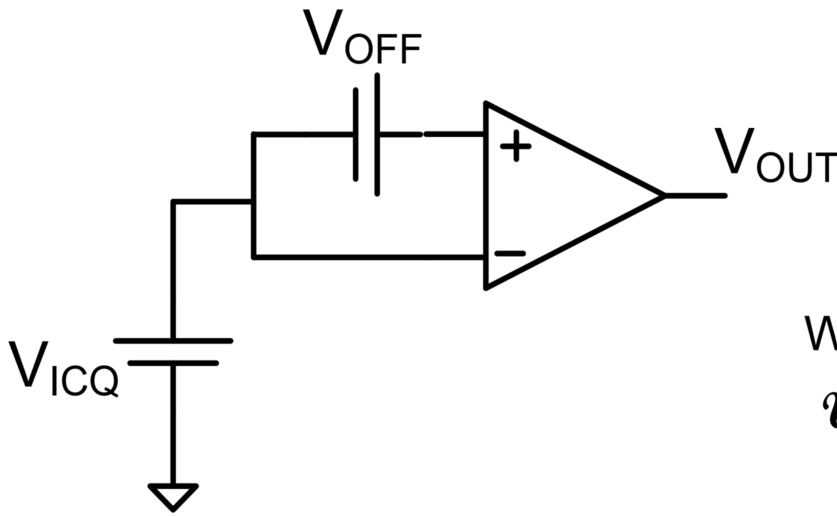


Definition: The output offset voltage is the difference between the desired output and the actual output when V_{id}=0 and V_{ic} is the quiescent common-mode input voltage.

$$V_{OUTOFF} = V_{OUT} - V_{OUTDES}$$

Note: V_{OUTOFF} is dependent upon V_{ICQ} although this dependence is usually quite weak and often not specified

Offset Voltage



When operating linearly

$$v_{OUT} = A_D v_D + A_C v_C$$

Definition: The input-referred offset voltage is the differential dc input voltage that must be applied to obtain the desired output when V_{ic} is the quiescent common-mode input voltage.

V_{OFF} is usually related to the output offset voltage by the expression

$$V_{OFF} = \frac{V_{OUTOFF}}{A_D}$$

V_{OFF} is dependent upon V_{ICQ} although this dependence is usually quite weak and often not specified

V_{OFF} almost always large enough to force open-loop op amp out of linear mode for good op amps

Offset Voltage

Note: Our definition differs from that of most others

From Wikipedia March 3, 2024

The **input offset voltage** (V_{os}) is a parameter defining the differential DC voltage required between the inputs of an amplifier, especially an operational amplifier (op-amp), to make the output zero (for voltage amplifiers, 0 volts with respect to ground or between differential outputs, depending on the output type).[1]

From Analog Devices MT-037 Tutorial

Ideally, if both inputs of an op amp are at exactly the same voltage, then the output should be at zero volts. In practice, a small differential voltage must be applied to the inputs to force the output to zero. This is known as the input offset voltage, V_{OS}

Offset Voltage: The differential voltage which must be applied to the input of an op amp to produce zero output.

Offset Voltage

Note: Our definition differs from that of most others

From Texas Instruments Application Note: SLOA059 – March 2001

Input Offset Voltage Defined

The input offset voltage is defined as the voltage that must be applied between the two input terminals of the op amp to obtain zero volts at the output. Ideally the output of the op amp should be at zero volts when the inputs are grounded.

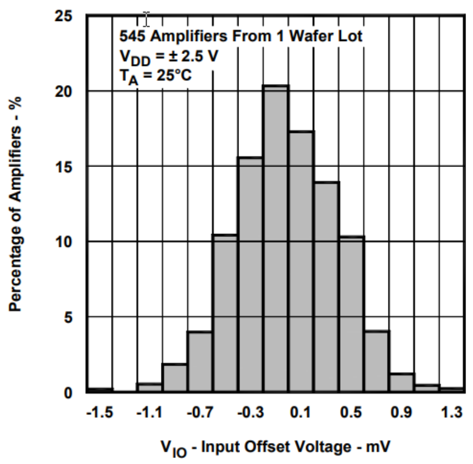


Figure 3. Distribution of V_{IO} for the TLV2721

Implicit in the definition of V_{OS} by most others is that the desired output voltage of an op amp is 0v when the differential input is 0V

Offset Voltage

Note: Our definition differs from that of most others

Implicit in the definition of V_{OS} by most others is that the desired output voltage of an op amp is 0v when the differential input is 0V

Note: Difference in definition of offset is usually insignificant once an op amp has been designed

So, if difference in definition of offset is insignificant, is there any reason to define it differently and to emphasize the difference or emphasize that there is no significant difference?

- Pointing out difference may simplify analytical formulation of offset
- Emphasize using a Degree of Freedom to achieve target offset voltage is typically not justifiable

Offset Voltage

From Analog Devices   MT-037 Tutorial

- **Ranges:**
  - **Chopper Stabilized Op Amps:** **<1µV**
  - **General Purpose Precision Op Amps:** **50-500µV**
  - **Best Bipolar Op Amps:** **10-25µV**
  - **Best JFET Input Op Amps:** **100-1,000µV**
  - **High Speed Op Amps:** **100-2,000µV**
  - **Untrimmed CMOS Op Amps:** **5,000-50,000µV**
  - **DigiTrim™ CMOS Op Amps:** **<100µV-1,000µV**

Figure 1: Typical Op Amp Input Offset Voltage

These ranges probably are applicable to catalog op amps

Offset Voltage

From Analog Devices MT-037 Tutorial

INPUT OFFSET VOLTAGE DRIFT AND AGING EFFECTS

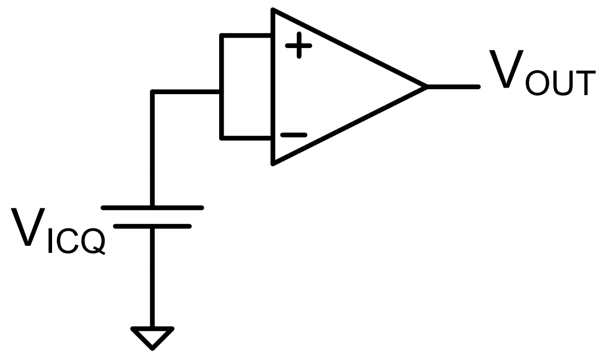
Input offset voltage varies with temperature, and its temperature coefficient is known as *TCV_{OS}*, or more commonly, *drift*. Offset drift is affected by offset adjustments to the op amp, but when the offset voltage of a bipolar input op amp has been minimized, the drift may be as low as 0.1 µV/°C (typical value for OP177F). More typical drift values for a range of general purpose precision op amps lie in the range 1-10 µV/°C. Most op amps have a specified value of TCV_{OS}, but some, instead, have a second value of maximum V_{OS} that is guaranteed over the operating temperature range. Such a specification is less useful, because there is no guarantee that TCV_{OS} is constant or monotonic.

The offset voltage also changes as time passes, or *ages*. Aging is generally specified in µV/month or µV/1000 hours, but this can be misleading. Since aging is a "drunkard's walk" phenomenon, it is proportional to the *square root* of the elapsed time. An aging rate of 1 µV/1000 hour therefore becomes about 3 µV/year (not 9 µV/year).

Offset Voltage

Two types of offset voltage:

- Systematic Offset Voltage
- Random Offset Voltage



After fabrication it is impossible (difficult) to distinguish between the systematic offset and the random offset in any individual op amp

Measurements of offset voltages for a large number of devices will provide mechanism for identifying systematic offset and statistical characteristics of the random offset voltage

Systematic Offset Voltage

Offset voltage that is present if all device and model parameters assume their nominal value

Easy to simulate the systematic offset voltage

Almost always the designer’s responsibility to make systematic offset voltage very small

Generally easy to make the systematic offset voltage small

Random Offset Voltage

- Due to random variations in process parameters and device dimensions
- Random offset is actually a random variable at the design level but deterministic after fabrication in any specific device
- Distribution naturally nearly Gaussian (could be un-naturally manipulated)

  Has zero mean

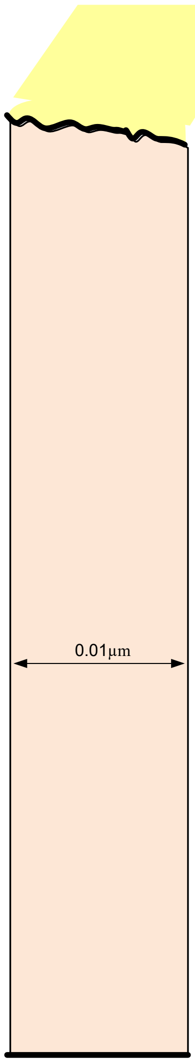
  Characterized by its standard deviation or variance

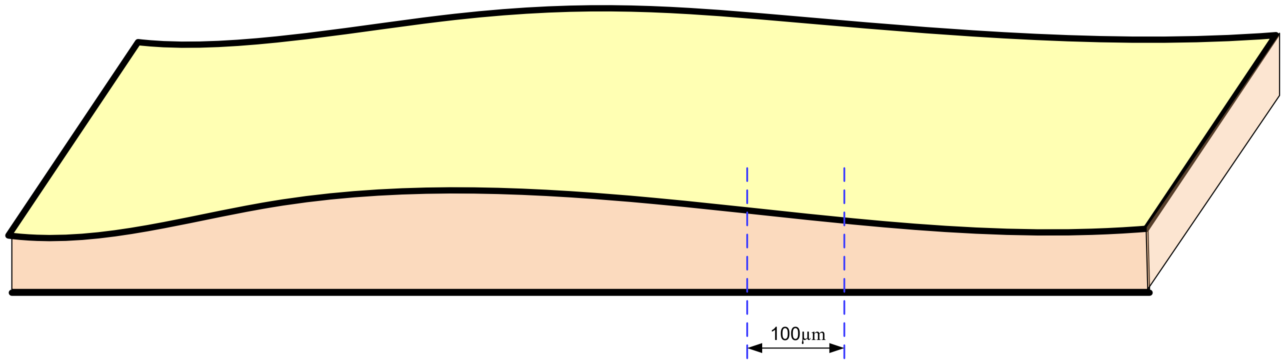
  Often strongly layout dependent

  Due to both local random variations and correlated gradient effects

  - Will consider both effects separately
  - Gradient effects usually dominate if not managed
  - Good methods exist for driving gradient effects to small levels

Gradient and Local Random Effect





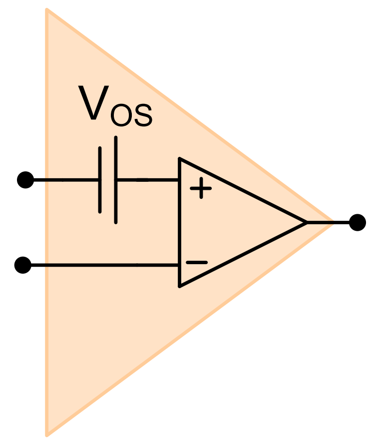
Gradient Effects : Locally Appear Linear

- Magnitude and Direction of Gradients are random
- Highly Correlated over Short Distances

Local Random Effects :
Vary Locally With No Correlation

- **Both Contribute to Offset**
- **Both are random variables**
- **If Not Managed, Both Can Cause Large Offsets**
- **Strategies for minimizing their effects are different**
- **Will refer to the local random effects as “random” and the random gradient effects as “gradient” effects**

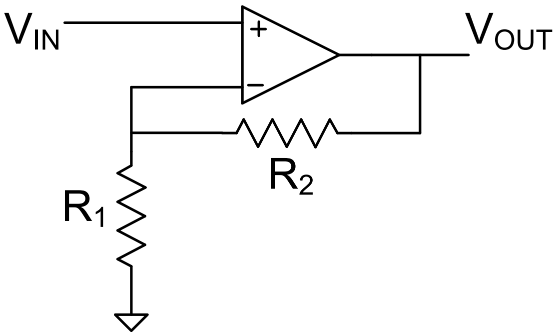
Offset Voltage



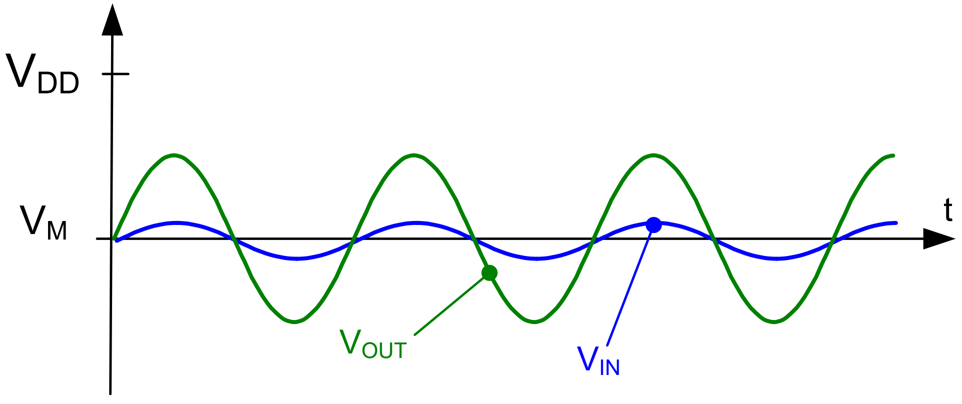
Can be modeled as a dc voltage source in series with the input

Offset Voltage

Effects of Offset Voltage - <u>an example</u>

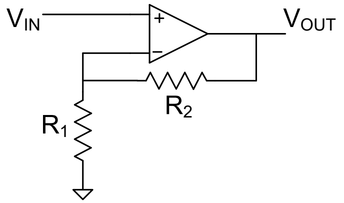


Desired I/O relationship

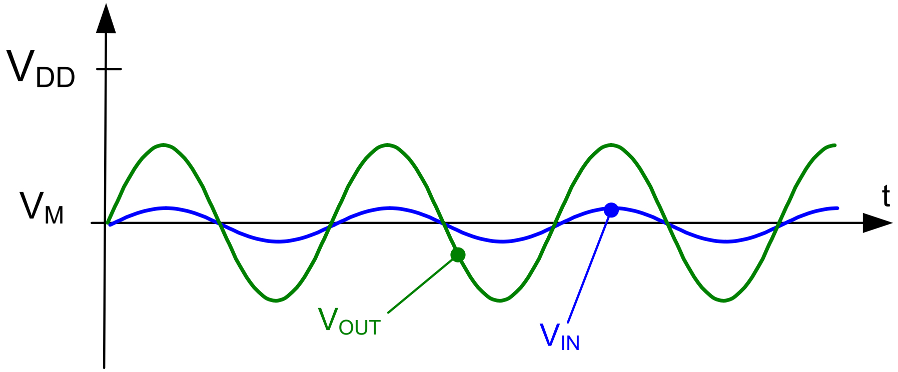


Offset Voltage

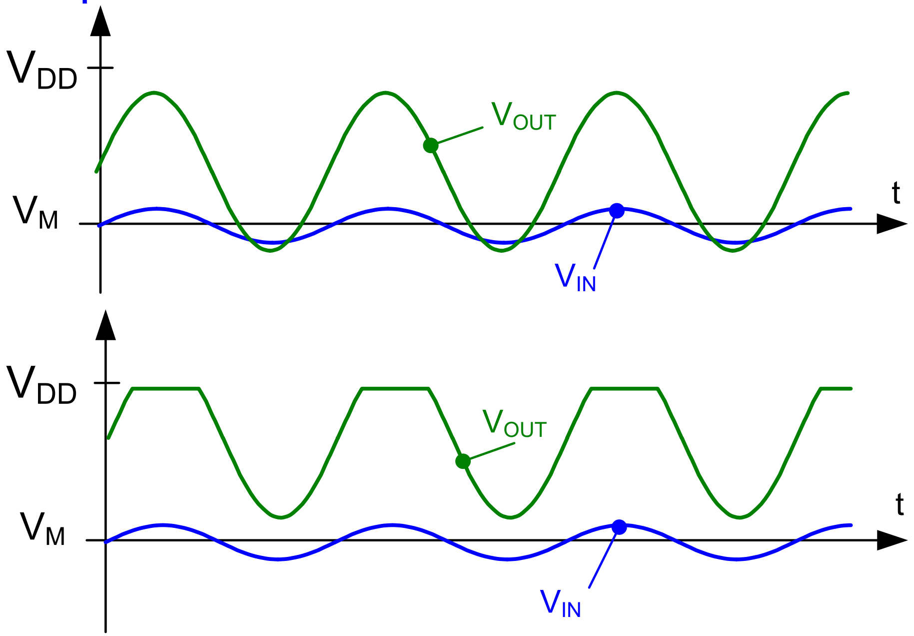
Effects of Offset Voltage - <u>an example</u>



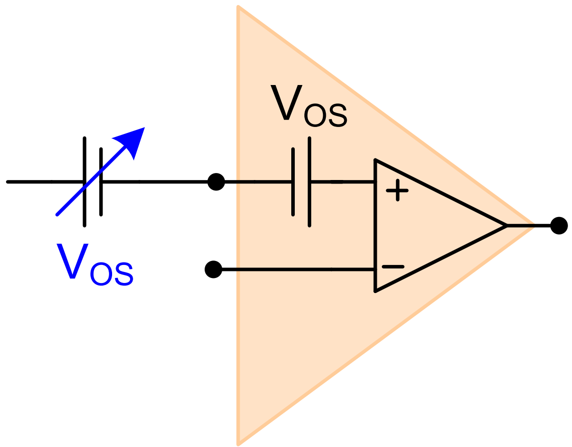
Desired I/O relationship



Actual I/O relationship due to offset



Offset Voltage



Effects can be reduced or eliminated by adding equal amplitude opposite DC signal (many ways to do this)

Widely used in offset-critical applications

Comes at considerable effort and expense for low offset

Prefer to have designer make V_{OS} small in the first place

Effects of Offset Voltage

- Deviations in performance will change from one instantiation to another due to the random component of the offset

- Particularly problematic in high-gain circuits

- A major problem in many other applications

- Not of concern in many applications as well

Stay Safe and Stay Healthy !

End of Lecture 21