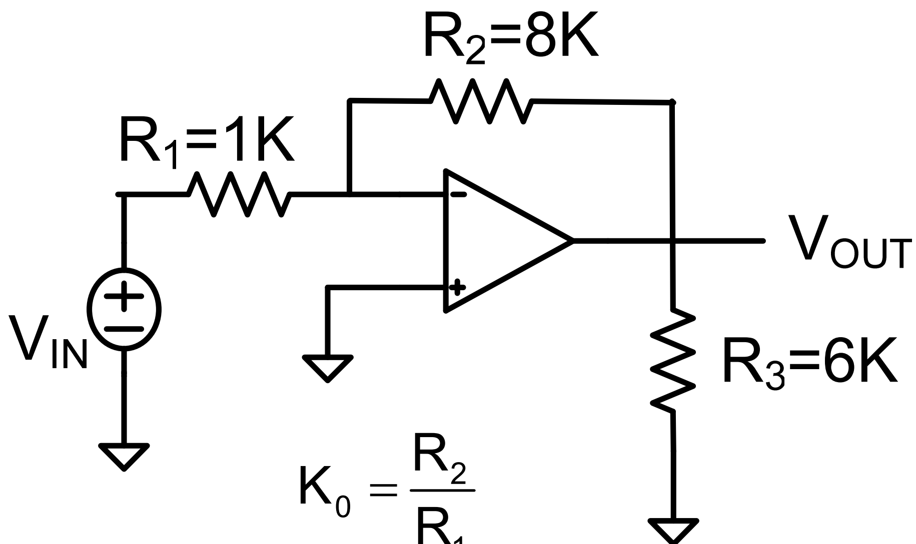
EE 230
Lecture 18

Nonideal Op Amp Characteristics

- Output Saturation
- Slew Rate
- Offset Voltage

Quiz 12

The operational amplifier has a GB of 20MHz. Determine the 3dB bandwidth of the closed-loop amplifier.



$$K_0 = \frac{R_2}{R_1}$$

And the number is ?

1 3 8

5 4

?

2 6

9 7

Quiz 12

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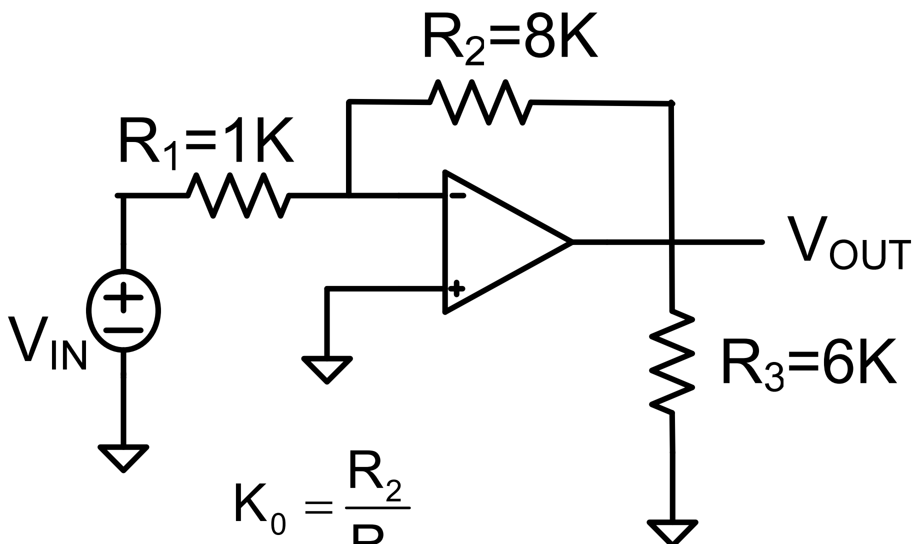


$$K_0 = \frac{R_2}{R_1}$$

Solution:

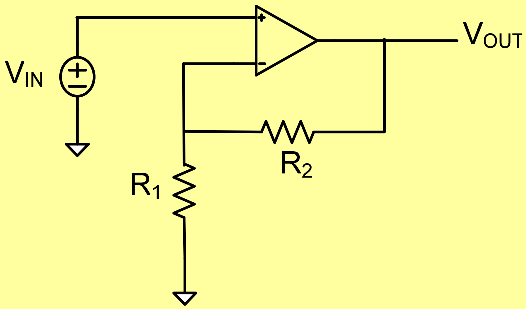
$$(1+K_0)BW = GB$$

$$BW = \frac{GB}{1+K_0} = \frac{20MHz}{9} = 2.2MHz$$

Review from Last Lecture

Gain, Bandwidth and GB

Summary of Effects of GB on Basic Inverting and Noninverting Amplifiers

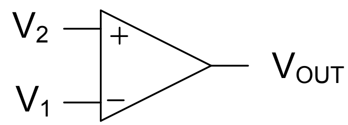


Basic Noninverting Amplifier

$$K_0 = 1 + \frac{R_2}{R_1}$$

$$BW = \frac{GB}{K_0}$$

$$A_{FB}(s) = \frac{K_0}{1 + s\frac{K_0}{GB}}$$

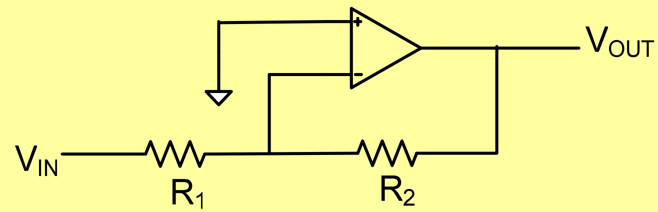


$$A_1(s) = \frac{GB}{s + BW_A}$$

$$GB = A_0 \bullet BW_A$$

$$A(s) = \frac{GB}{s}$$

Adequate model for most applications

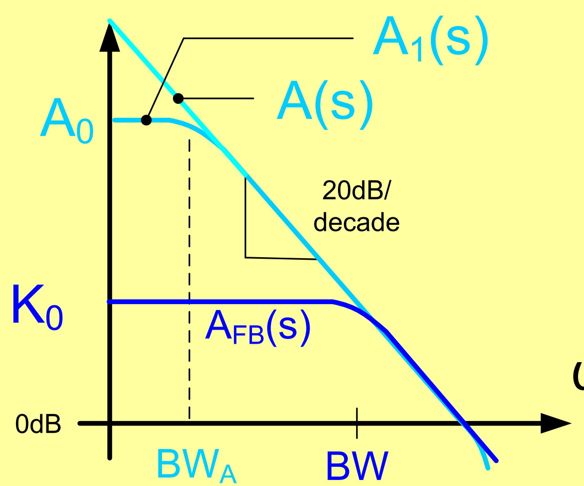


Basic Inverting Amplifier

$$K_0 = \frac{R_2}{R_1}$$

$$BW = \frac{GB}{1 + K_0}$$

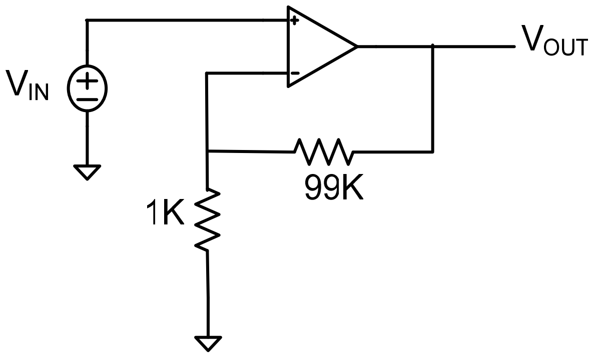
$$A_{FB}(s) = -\frac{K_0}{1 + s\frac{(1 + K_0)}{GB}}$$



Review from Last Lecture

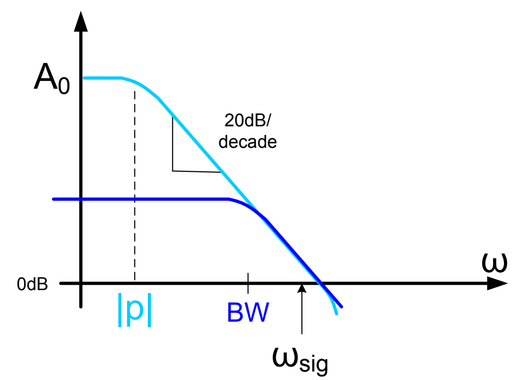
Example:

If the input to the amplifier is .01sin(2π10000t), determine the actual and desired output if the op amp is the LMP2231 biased with +/- 2.5V supplies.



$$V_{OUTDesired} = \sin(2\pi \bullet 10000t)$$

$$\omega_{SIG} = 2\pi \bullet 10000$$



$$A_{FB}(s) = \frac{100}{1+\frac{100}{2\pi \bullet 10000}s}$$

$$A_{FB}(j\omega) = \frac{100}{1+\frac{100}{2\pi \bullet 130000}j(2\pi \bullet 10000)}$$

$$A_{FB}(j\omega) = \frac{100}{1+j7.7}$$

$$\left|A_{FB}(j\omega)\right| = \frac{100}{\sqrt{1+7.7^2}} = 12.9$$

$$\angle A_{FB}(j\omega) = -\tan^{-1}\left(\frac{j7.7}{1}\right) = -82.6^o$$

$$V_{OUT} = .01*12.9\sin(2\pi \bullet 10000t - 82.6^o)$$

$$V_{OUT} = .12\sin(2\pi \bullet 10000t - 82.6^o)$$

Measurement of GB

Most direct: measure A_o $\Rightarrow$ $GB = A_o \omega_b$

measure ω_b

A_o is difficult to measure (and exact value usually not of concern)

ω_b is difficult to measure (and exact value seldom of concern)

Direct method of determining GB is not practical

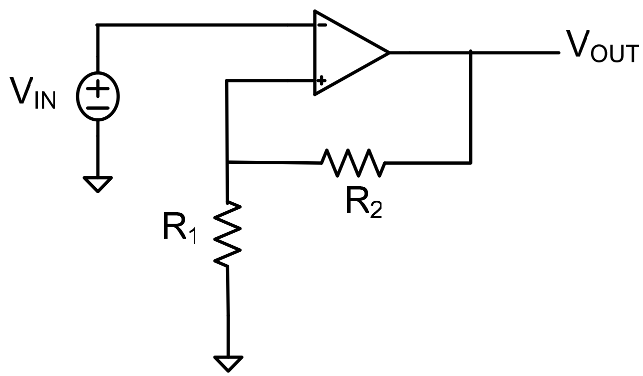
If a circuit is adversely affected be a parameter, then this circuit is often useful for measuring that parameter provided relationship between performance and parameter is determined/known.

Strategy for Measuring GB

1. Build FB noninverting amplifier with gain K_o

2. Measure BW

3. $GB=(K_0)(BW)$



Keep gain (K_0) quite large (maybe 100) and amplitude small enough so there is no SR distortion. With large K_0, frequency where gain drops 3dB will be small enough that it can be accurately measured.

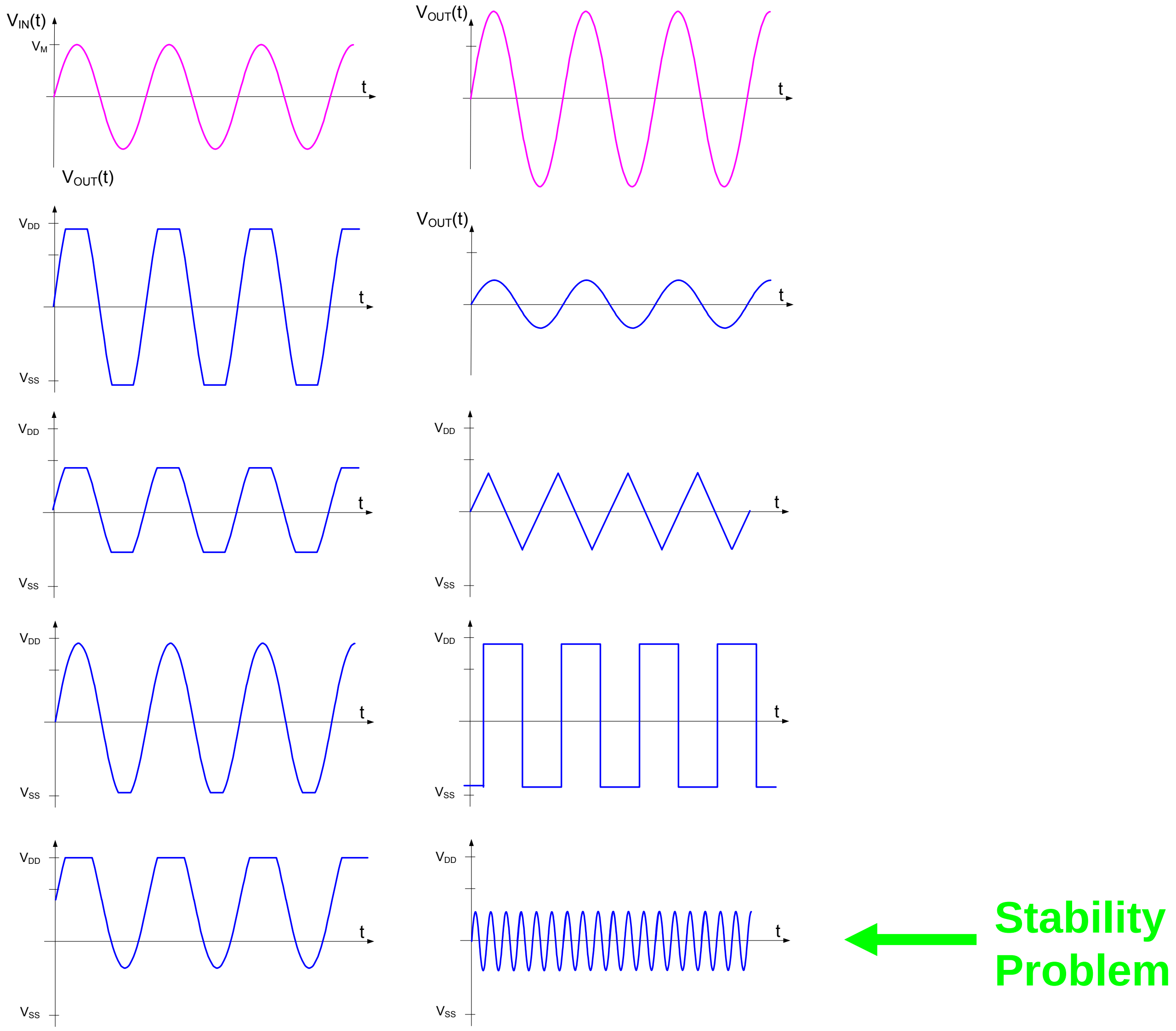
Determination of proper Op Amp orientation

Put in frequency dependent model for op amp $A(s)=\frac{GB}{s}$

in the OVERALL CIRCUIT and determine which orientation of the op amp has all poles in LHP

- In almost all op amp circuits of interest, there will be a unique op amp orientation that will provide a stable circuit
- This can be somewhat tedious if there are several op amps because they must all be oriented correctly
- Experience is useful at providing guidance on how to orient the op amps
- An unstable circuit can be embedded in a larger circuit that is stable and a stable circuit can be embedded in a larger circuit and make it unstable so can not consider only the stability of a subcircuit but rather must consider the overall circuit
- One of the major reasons the concept of stability was discussed in this course was to have a method of correctly orienting the op amps in op amp circuits

Stability Problems



Nonideal Op Amp Characteristics

Critical Parameters

- Gain-Bandwidth Product (GB)
- Offset Voltage
- Input Voltage Range
- Output Voltage Range
- Output Saturation Current
- Slew Rate

Usually Less Critical Parameters

- DC voltage gain , A_0
- 3dB Bandwidth, BW

$GB = A_0 BW$

- Common Mode Rejection Ratio (CMRR)
- Power Supply Rejection Ratio (PSRR)
- R_{IN} and R_{OUT}
- Bias Currents
- Full Power Bandwidth
- Compensation

Output Saturation

- Output Voltage Saturation

  Maximum or minimum output voltage that an op amp can provide

- Output Current Saturation

  Maximum output current that an op amp can source or sink

Both parameters usually given in a data sheet

Output voltage saturation often 0.6V to 1.2V below and above supply voltages though some op amps provide rail-to-rail outputs

Maximum sourcing and sinking currents usually the same

Output Saturation

Output Voltage Saturation

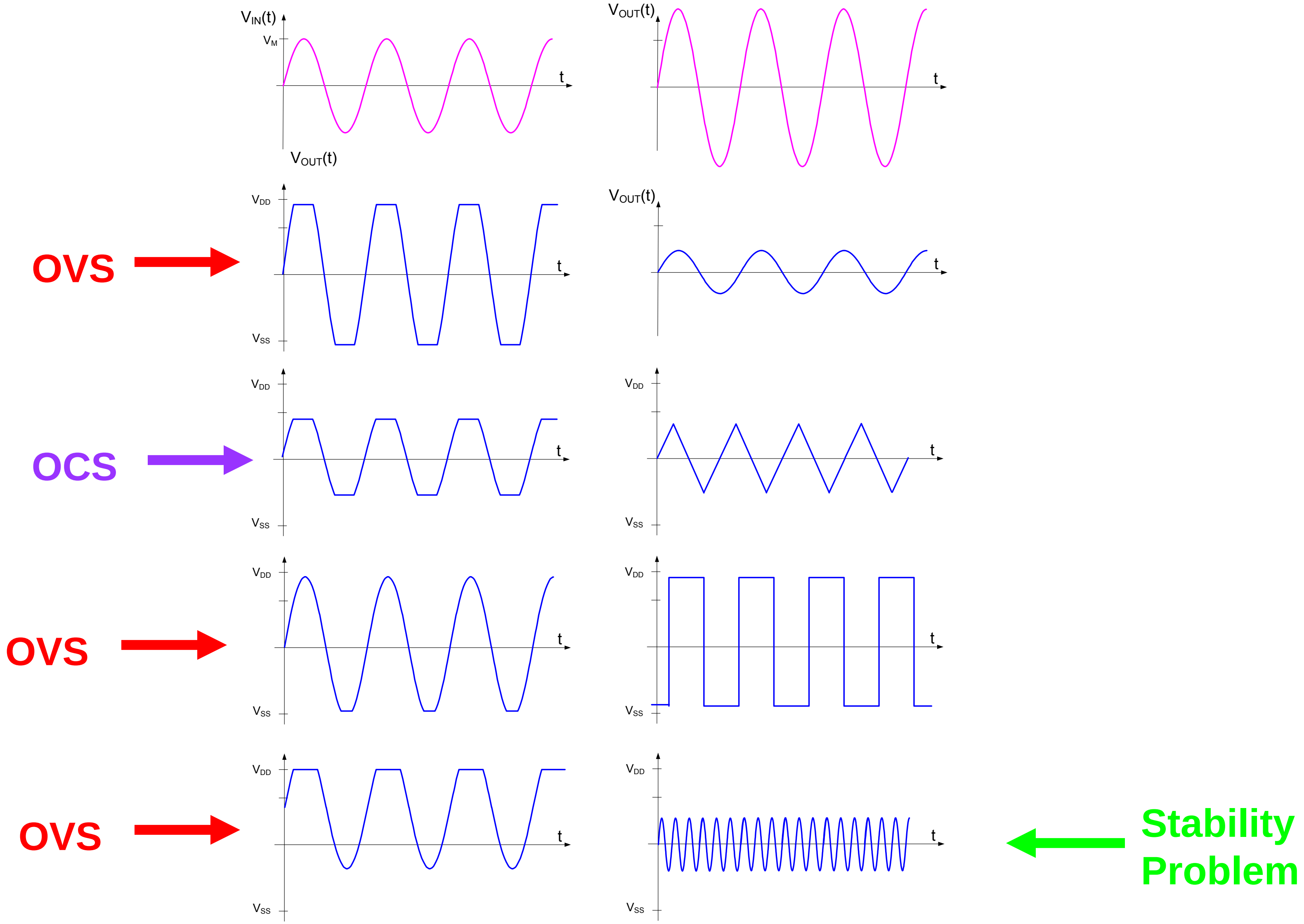
Output voltage saturation usually results in clipping if attempts to exceed the limit are made

The clipping will usually be near the upper and lower rails

If the load is removed and clipping still occurs, it is usually in indication of output voltage saturation

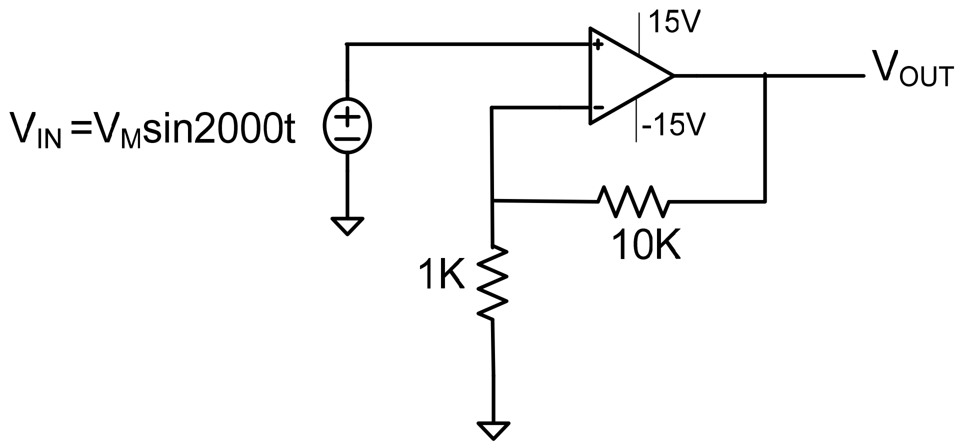
If clipping occurs at approximately the value specified in a data sheet, likely a problem with output voltage saturation

Output Saturation



Output Saturation

Output Voltage Saturation



Example: The op amp is biased with +/- 15 V power supplies and the output saturation voltages are bounded away from the supplies by 1.2V. Determine the maximum input voltage that can be applied without output saturation.

Must keep magnitude of V_{OUT} less than 13.8V

$$13.8V \geq V_M\left(1+\frac{R_2}{R_1}\right)$$

$$13.8V \geq V_M\left(1+\frac{10K}{1K}\right)$$

$$1.25V \geq V_M$$

Output Saturation

Output Current Saturation

Output voltage saturation usually results in clipping at levels below the output voltage limits if attempts are made to exceed the output current limits

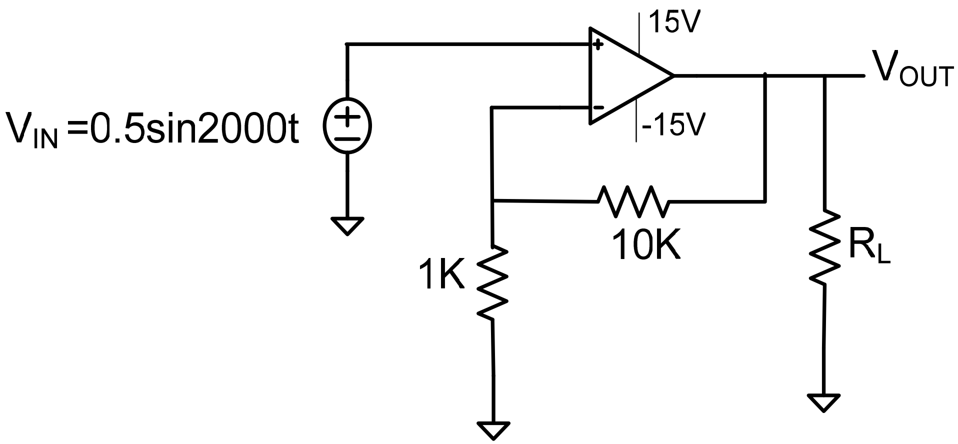
The maximum output current is often listed at the short-circuit output current in a data sheet

In most designs, the major consumer of the output current is the load

If capacitive loads are present, the current requirements to drive the capacitor can get large at higher frequencies and this can become the major consumer of output current

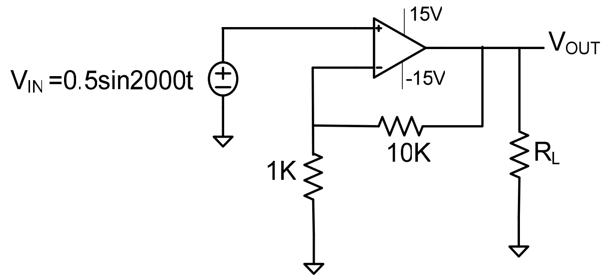
Output Saturation

Output Current Saturation



Example: The op amp is biased with +/- 15 V power supplies. Determine the minimum load that can be applied to avoid output current saturation if the input amplitude is fixed at 0.5V peak and the op amp is a 741.

Output Current Saturation



National Semiconductor

August 2000

LM741 Operational Amplifier

LM741
Operational Amplifier

General Description

The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

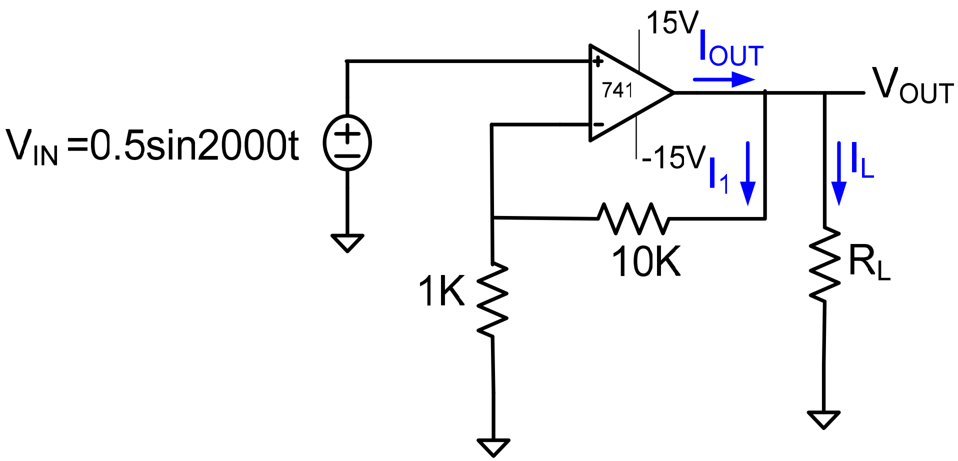
The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0°C to +70°C temperature range, instead of −55°C to +125°C.

Features

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Output Voltage Swing	$V_S = \pm 20V$										
	$R_L \geq 10\ k\Omega$	±16									V
	$R_L \geq 2\ k\Omega$	±15									V
	$V_S = \pm 15V$										
	$R_L \geq 10\ k\Omega$				±12	±14		±12	±14		V
	$R_L \geq 2\ k\Omega$				±10	±13		±10	±13		V
Output Short Circuit Current	$T_A = 25°C$	10	25	35		25			25		mA
	$T_{AMIN} \leq T_A \leq T_{AMAX}$	10		40							mA
Common-Mode Rejection Ratio	$T_{AMIN} \leq T_A \leq T_{AMAX}$										
	$R_S \leq 10\ k\Omega$, $V_{CM} = \pm 12V$				70	90		70	90		dB
	$R_S \leq 50\Omega$, $V_{CM} = \pm 12V$	80	95								dB

Output Saturation

Output Current Saturation



Example: The op amp is biased with +/- 15 V power supplies. Determine the minimum load that can be applied to avoid output current saturation if the input amplitude is fixed at 0.5V peak and the op amp is a 741.

$$V_{OUTMAX}=0.5*11=5.5V$$

$$I_{OUTMAX} \geq I_{1MAX} + I_{LMAX}$$

$$25mA \geq \frac{5.5-0.5}{10K} + \frac{5.5}{R_L}$$

$$25mA \geq 0.5mA + \frac{5.5}{R_L}$$

$$R_L \geq 224\Omega$$

Note: In most situations, the load current will dominate the feedback currents

Nonideal Op Amp Characteristics

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- Gain-Bandwidth Product (GB)
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Usually Less Critical Parameters

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- 3dB Bandwidth, BW

$GB = A_0 BW$

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Slew Rate

The slew rate of an op amp is the maximum rate of change that can occur in the output voltage of an op amp

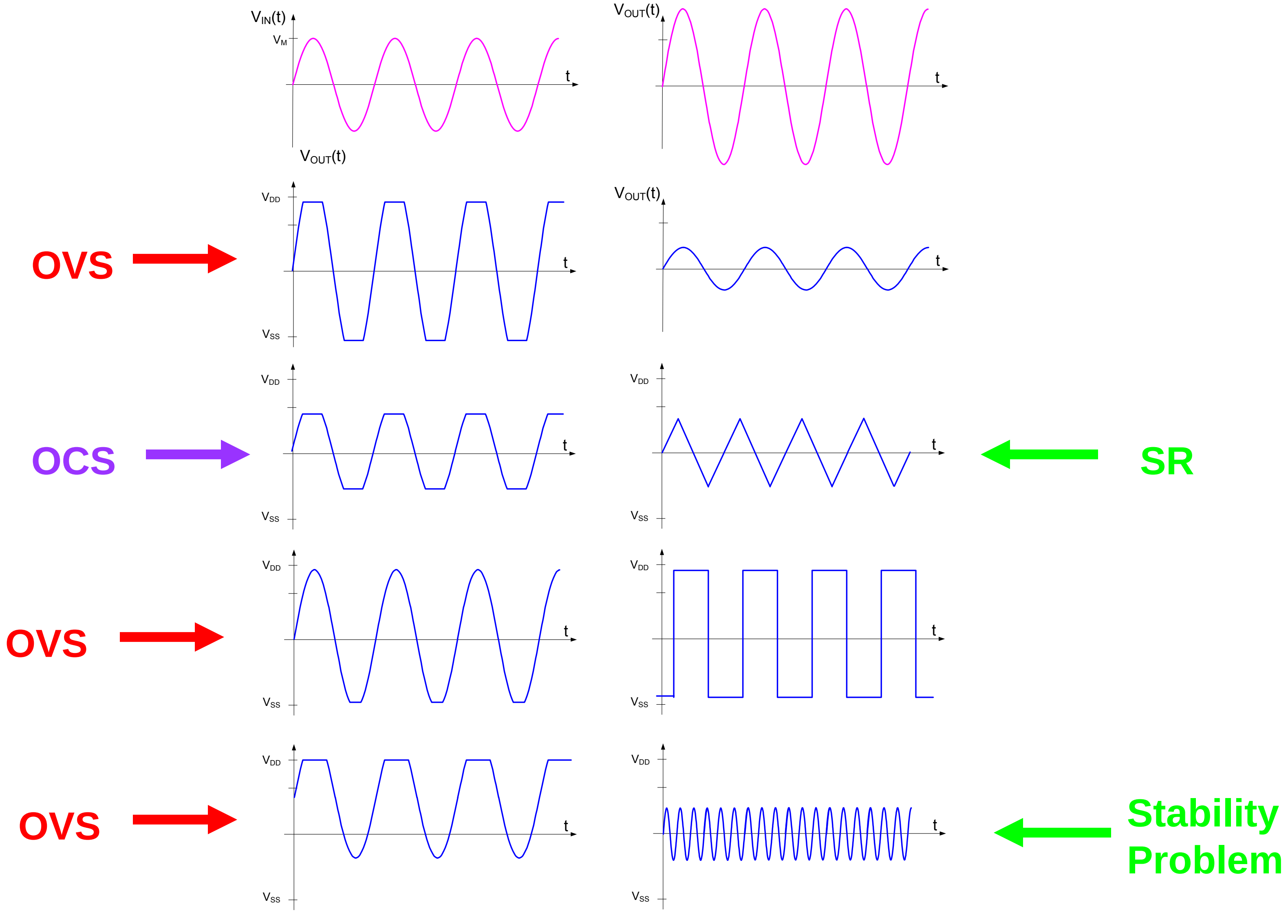
Usually the positive going slew rate and the negative going slew rate are the same

Slew rate is usually specified in the units of V/μsec

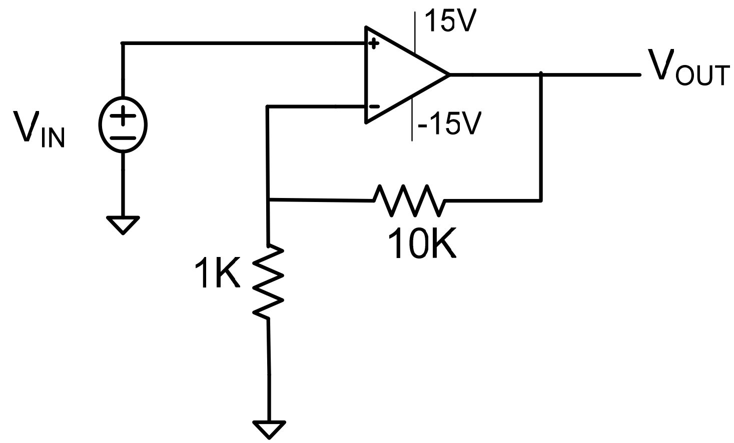
Slewing can occur in any circuit for any type of input waveform

Slew is usually most problematic at higher frequencies when large output excursions are desired

Output Saturation

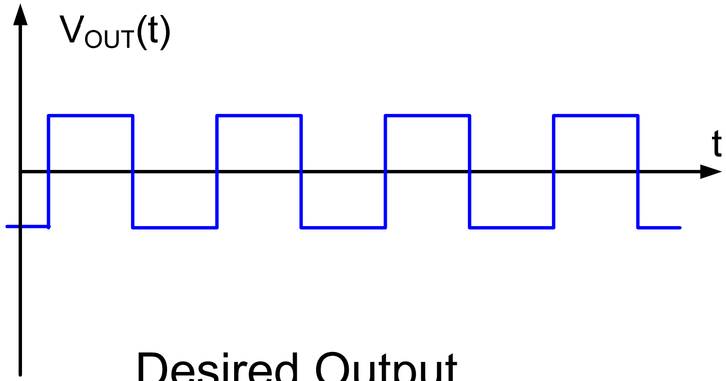


Slew Rate

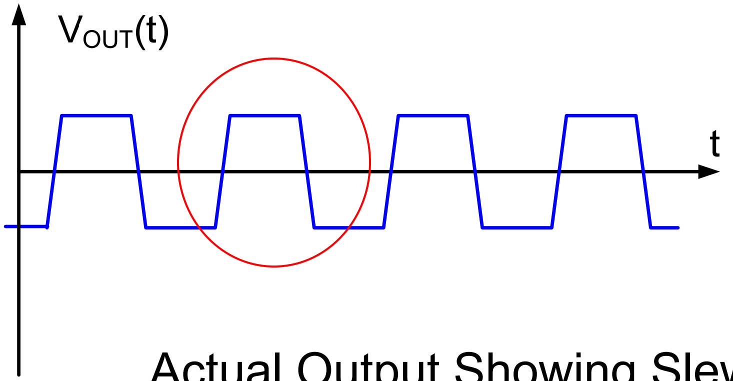


If V_{IN} is a square wave, this circuit will always exhibit slew rate limitations

Assume V_{IN} is a rather low amplitude, low frequency square wave

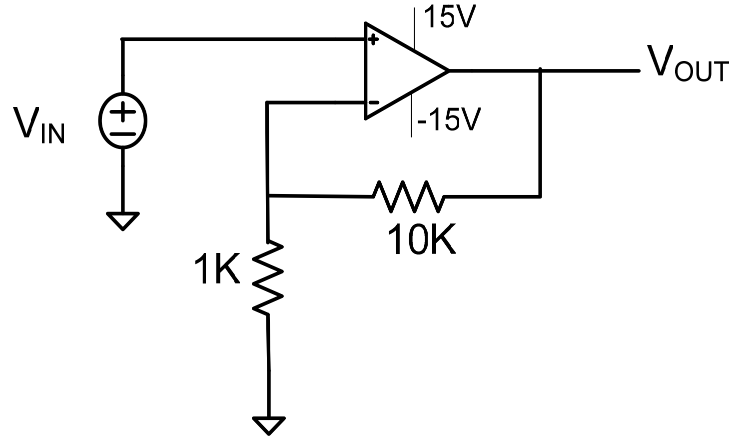


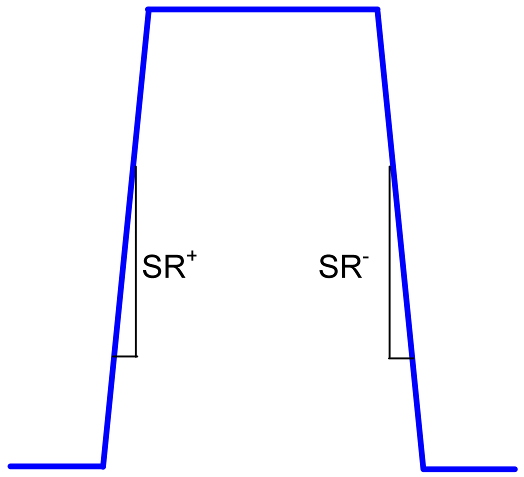
Desired Output



Actual Output Showing Slew

Slew Rate



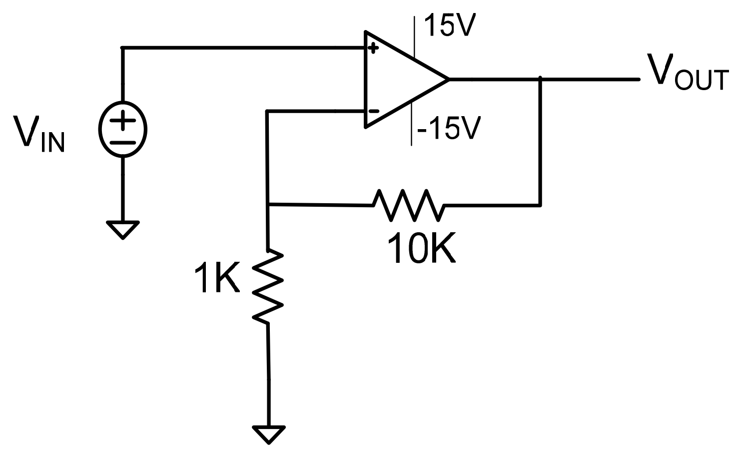


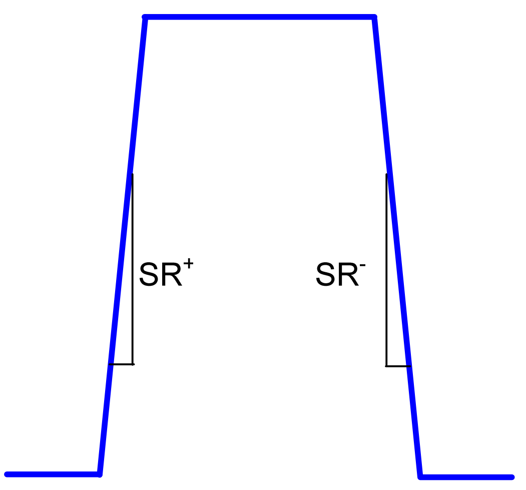
SR is the slope of either the positive or negative going output transition

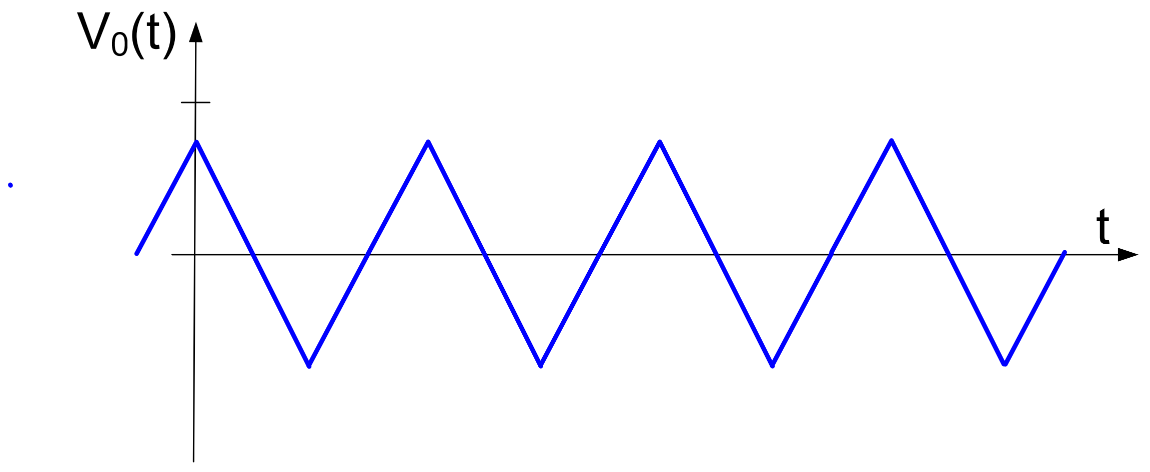
In some situations, the output will be always in slew resulting in the triangular waveform

This is a good circuit for measuring the SR of an Op Amp

Slew Rate



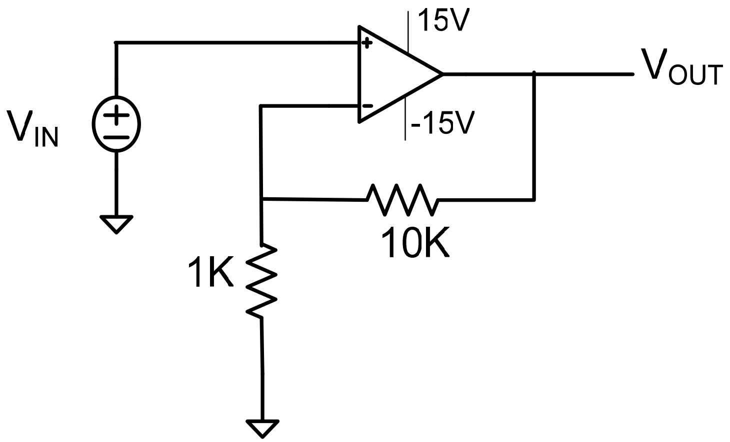


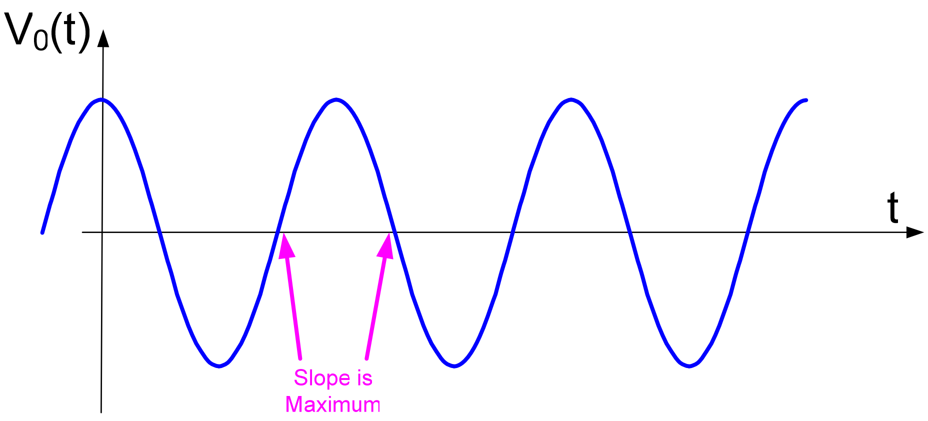


Output stays in slew for entire transition

Slew limits the level of the output

Slew Rate





Example: Determine the maximum frequency of a sinusoidal input of amplitude V_M=0.1V that can be applied if a 741 Op Amp is used if SR distortion must be avoided.

If no slew and no GB limitations,

$$V_{OUT} = 11 \bullet V_M \sin\omega t$$

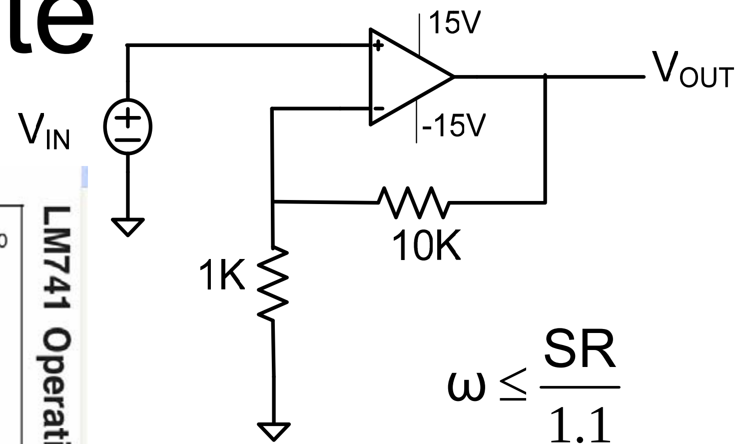
$$\frac{dV_{OUT}}{dt} = 11 \bullet V_M \omega \cos\omega t$$

This slope is a maximum at the zero crossings and thus

$$\left|\frac{dV_{OUT}}{dt}\right|_{MAX} = \left|11 \bullet V_M \omega \cos\omega t\right|_{t=0} \le SR$$

$$11 \bullet V_M \omega \le SR \quad \longrightarrow \quad \omega \le \frac{SR}{11 \bullet V_M} = \frac{SR}{1.1}$$

Slew Rate



$$\omega \le \frac{SR}{1.1}$$

National Semiconductor

August 2000

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Features

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Bandwidth (Note 6)	T_A = 25˚C	0.437	1.5								MHz
Slew Rate	T_A = 25˚C, Unity Gain	0.3	0.7			0.5			0.5		V/µs

$$\omega \le \frac{0.5E6}{1.1} = 450 Krad/\sec$$

$$f \le 71.6 KHz$$

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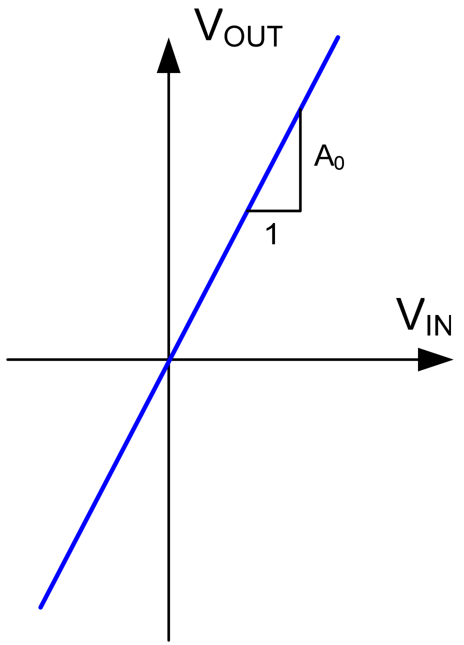
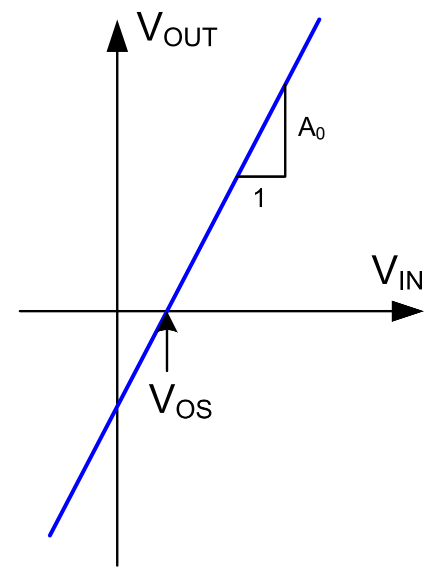
Offset Voltages



Ideal OA transfer characteristics



Actual typical OA transfer characteristics

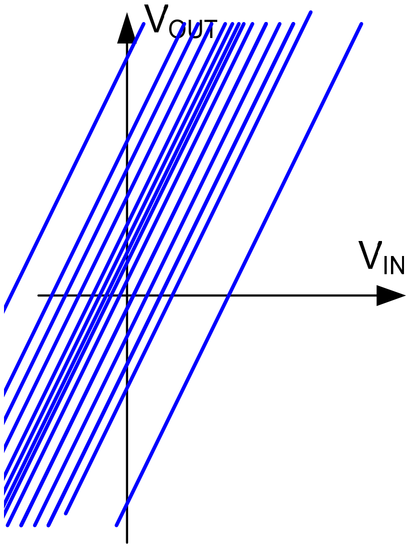
A_0 is the dc gain of the Op Amp and is very large

V_{OS} is called the input offset voltage (or just offset voltage) and represents the dc shift from the ideal crossing at the origin

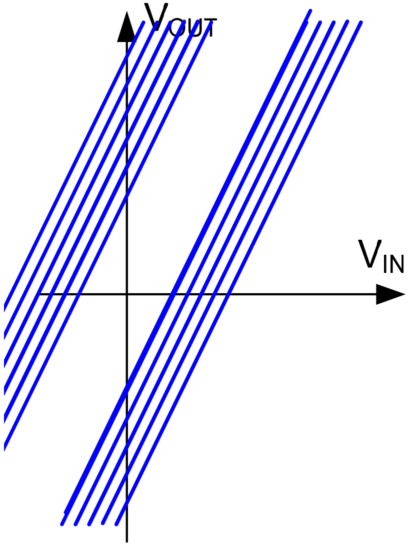
V_{OS} is a random variable at the design stage and varies from one device to another after fabrication

Can be positive or negative

Offset Voltages

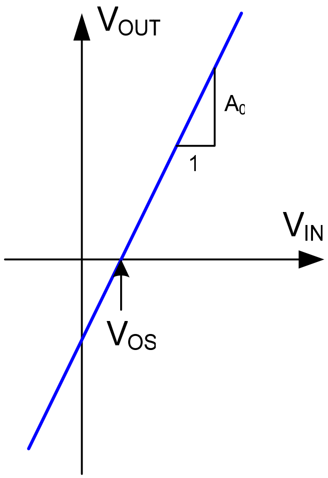


Typical distribution of transfer characteristics after fabrication

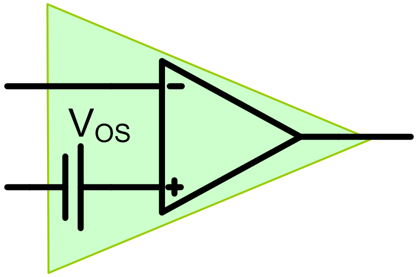


Distribution of commercial parts if premium parts have been removed

Offset Voltages



Model: $V_{OUT} = A_0 \left(V_{IN} - V_{OS} \right)$



Can be modeled with a dc voltage source in series with either terminal
Polarity of the source is not known on batch since can be positive or negative
Polarity of offset voltage for each individual op amp can be measured

End of Lecture 18