

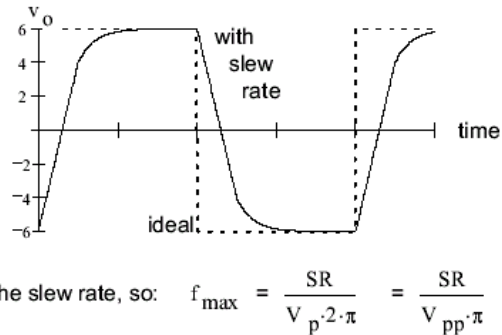
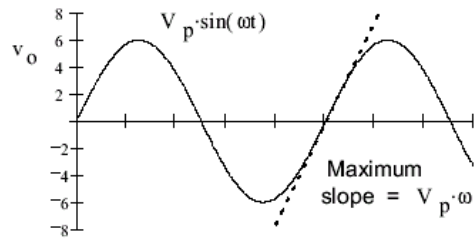
Op Amps output voltage can only change so fast. The maximum rate of change is called slew rate (SR)

**Slew Rate continued**

A square wave:

ing step function:

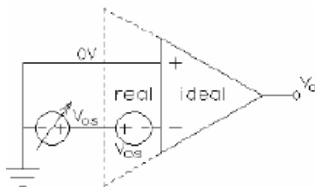
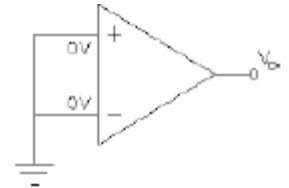
What if your output is a sine wave?



must be less than the slew rate, so:  $f_{max} = \frac{SR}{V_p \cdot 2 \cdot \pi} = \frac{SR}{V_{pp} \cdot \pi}$

**DC Imperfections:**

**Offset Voltage (V<sub>os</sub>)** The voltage for the output below should be zero, but almost always is not. The value when both inputs are grounded is called the voltage offset, V<sub>os</sub>. To compensate for this offset =>



a fixed voltage can be placed at the input as shown below. Several op amps have an extra terminal in the package (offset null terminal) that can be adjusted so that the output will read zero when the inputs are both grounded. This value is also affected by temperature and so can not always be compensated.

**Input bias currents (I<sub>B1</sub>, I<sub>B2</sub>, ave=I<sub>B</sub>)** The real op amp has currents as seen below. ( $V_o = I_{B1} \cdot R_f$ )

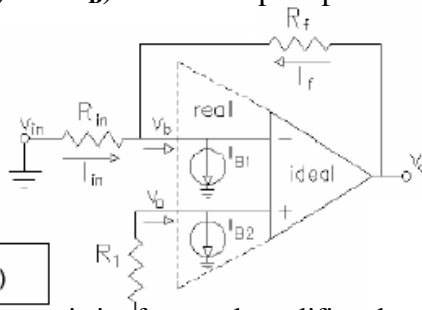
**The cure (if I<sub>B1</sub> = I<sub>B2</sub>):**

if  $v_o = 0$

$v_b = (R_f \parallel R_{in}) I_{B1}$

if  $R_1 = (R_f \parallel R_{in})$

then  $v_a = (R_f \parallel R_{in}) I_{B2}$



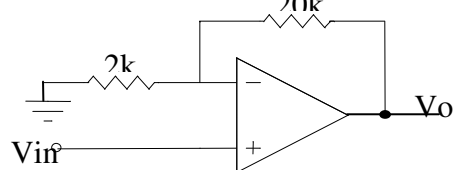
To reduce input bias current affect=> *match impedances seen at each terminal to be the same.*

**Example 16:** make  $R_1 = (R_f \parallel R_{in})$

You are given the following characteristics for a real amplifier along with the circuit below.

Op amp Characteristics:

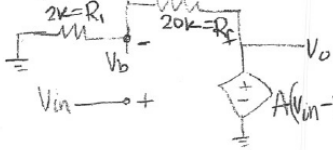
Input offset voltage:	$V_{ios} = 4.0\text{mV}$	Open-loop gain:	$A_o = 100\text{dB}$
Input offset current:	$I_{os} = 200\text{nA}$	Unity-gain bandwidth:	$f_T = 2\text{MHz}$
Input bias current:	$I_{iB} = 600\text{nA}$	Output swing limits:(within 2V of supply)	$\pm 15\text{V}$
Input resistance:	$R_i = 1\text{M}\Omega$	Slew rate:	$4\text{V}/\mu\text{s}$
Output resistance:	$R_o = 50\Omega$		



- What is the voltage gain of the circuit? Ignore  $R_i$  and  $R_o$  and only consider the finite gain,  $A_o$ .
- For small input signals, what is the 3db bandwidth of the circuit (in Hz)?
- For an output signal of 10Vpp, considering the slew rate effect, what is the limiting frequency of the circuit?
- What is the maximum peak-to-peak output you can get without clipping?
- Find the effect of the input offset voltage ( $v_{in} = 0\text{V}$ ). (i.e. find output value when input = 0)
- How should the circuit be modified to minimize the effect of the input bias current? Show the modification on the schematic above and find the value of any added parts.

**ECE2280 FUNDAMENTALS OF ELECTRICAL ENGINEERING**

(a) Ignore  $R_i$  since it is large and  $R_o$  since it is small.



$$V_b = V_{in} = \frac{V_o(R_i)}{R_i + R_f}$$

$$A(V_{in} - V_b) = V_o$$

$$\frac{V_o}{A} = \left[ V_{in} - \frac{V_o(R_i)}{R_i + R_f} \right] \Rightarrow V_o \left[ \frac{1}{A} + \frac{R_i}{R_i + R_f} \right] = V_{in}$$

$$\therefore \frac{V_o}{V_{in}} = \frac{1}{\frac{1}{A} + \frac{R_i}{R_i + R_f}} \quad \left\{ \text{when } A \gg \text{ then } \frac{V_o}{V_{in}} = \left[ \frac{R_i + R_f}{R_i} \right] \right\}$$

$$A = 100\text{dB} = 10^{100/20} = 100\text{kV/V}$$

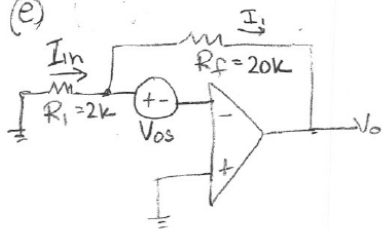
$$\frac{V_o}{V_{in}} = \frac{1}{\frac{1}{100\text{k}} + \frac{2\text{k}}{22\text{k}}} = 10.999 \quad \text{without } A \Rightarrow \frac{V_o}{V_{in}} = 11\text{V}$$

$$(b) f_c = \frac{f_T}{\text{gain}} = \frac{2\text{MHz}}{10.999} \approx 182\text{kHz}$$

$$(c) f_{\text{max}} = \frac{SR}{V_{pp} \cdot \pi} = \frac{4\text{V}/\mu\text{s}}{10\text{V} \cdot \pi} = 127\text{kHz}$$

$$(d) 2(\pm 15\text{V}) = 30\text{V}_{pp}$$

(e)



$$I_{in} = \frac{-V_{os}}{R_i} = I_1$$

$$\frac{V_{os} - V_o}{R_f} = \frac{-V_{os}}{R_i}$$

$$R_f V_{os} \left( \frac{1}{R_f} + \frac{1}{R_i} \right) = \frac{V_o}{R_f} = V_{os} \left( 1 + \frac{R_f}{R_i} \right) = 4\text{m} \left( 1 + \frac{20\text{k}}{2\text{k}} \right) = 44\text{mV}$$

(f) Both terminals should have the same  $R$  seen by that terminal  $\Rightarrow (-)$  terminal sees  $(R_i || R_f) = 1.82\text{k}$

