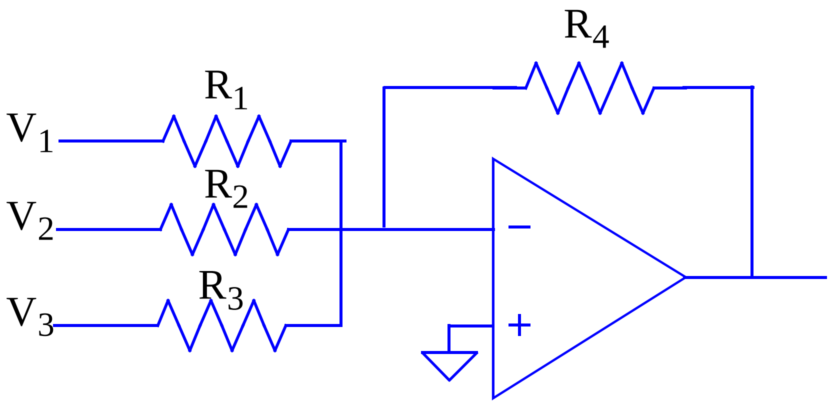
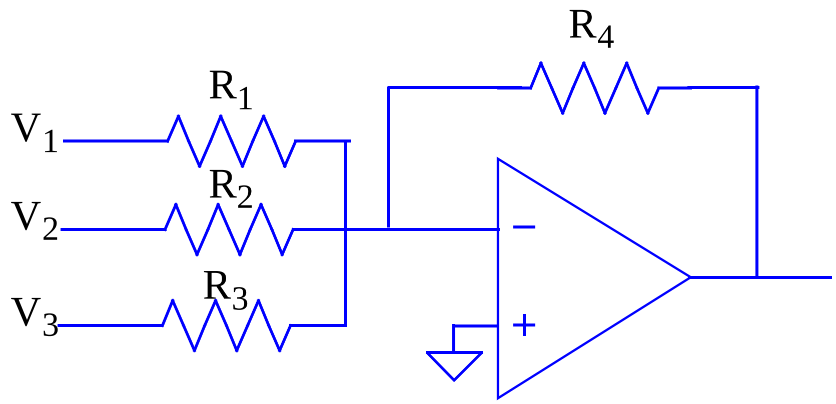
Summing Amplifier Revisited

- Superposition can be used to easily evaluate summing amplfiers with infinite open loop gain



Summing Amplifier Revisited

- Can we solve for the summing amplifier gain the same way when the open loop gain is finite?

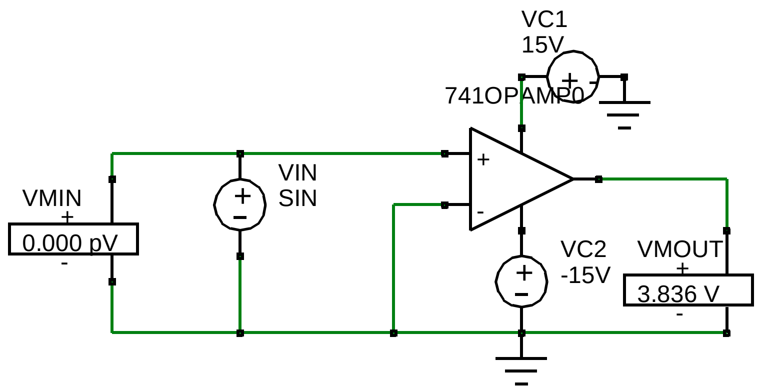


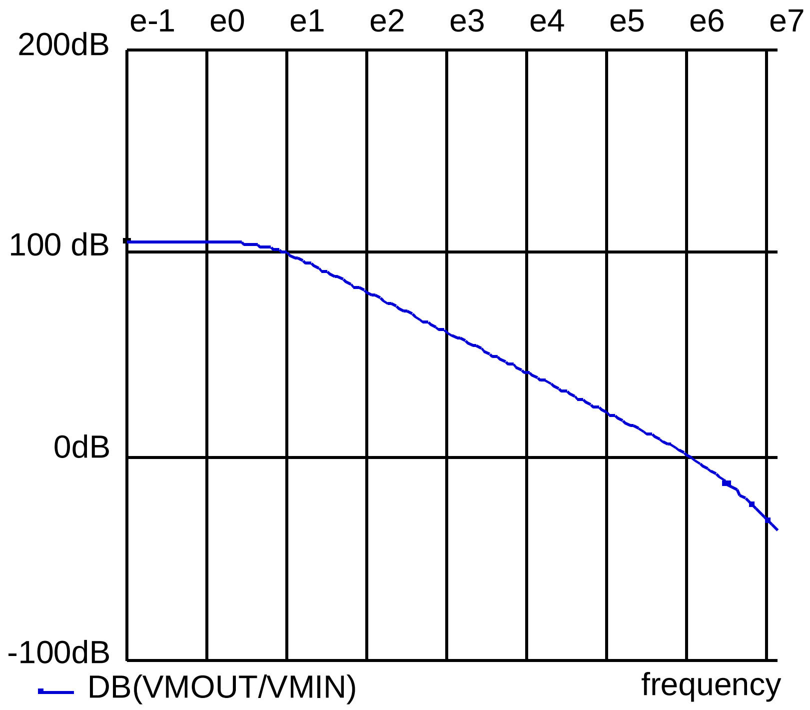
Other Opamp Nonidealities

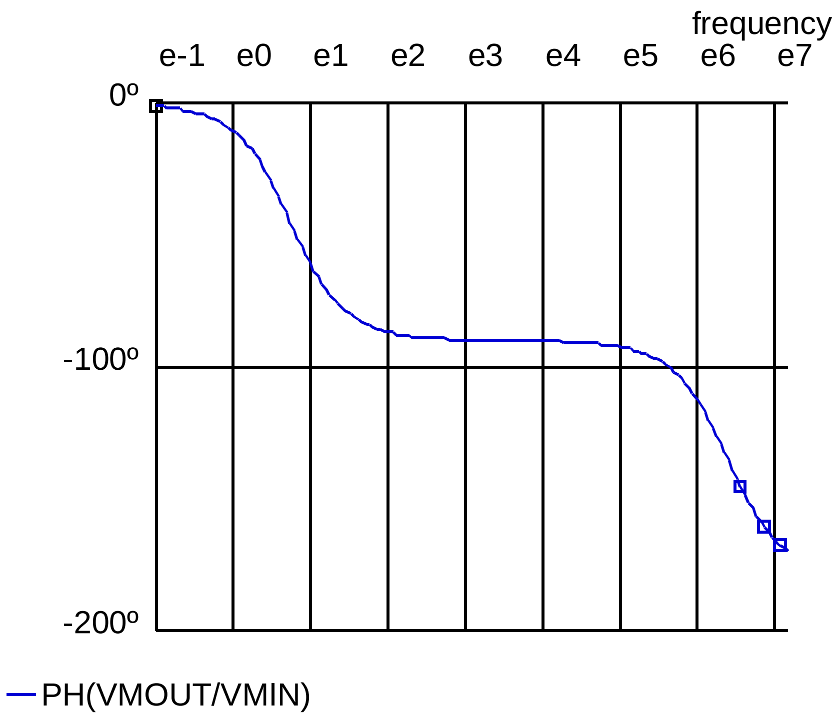
- The open loop gain is generally so large that we can neglect its impact on the closed-loop circuit gain
- But a significant nonideality that we cannot ignore is the finite open-loop gain as a function of frequency
- Parasitic capacitance causes the gain to fall off at high frequency (can't make ω_H infinite for any amplifier!)
- The gain may be designed to change with frequency to enure stability ---- compensation

741 Opamp

- One of the most popular, general purpose opamps are the 741-type

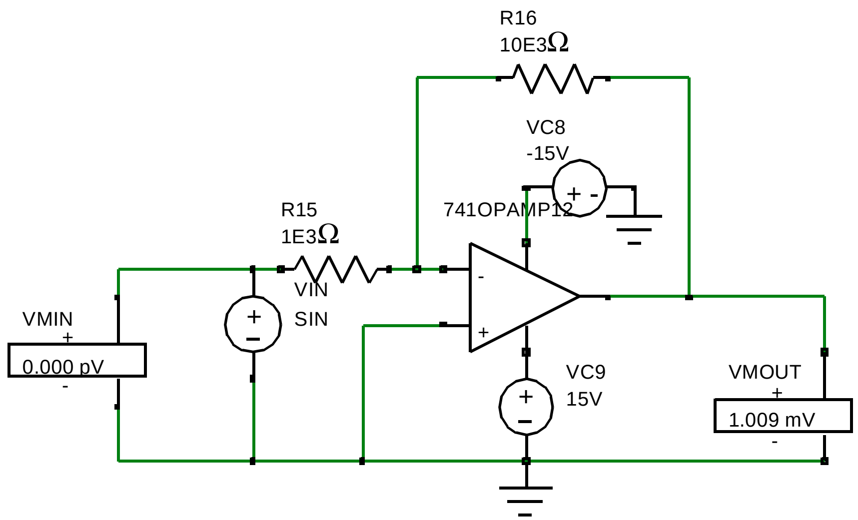


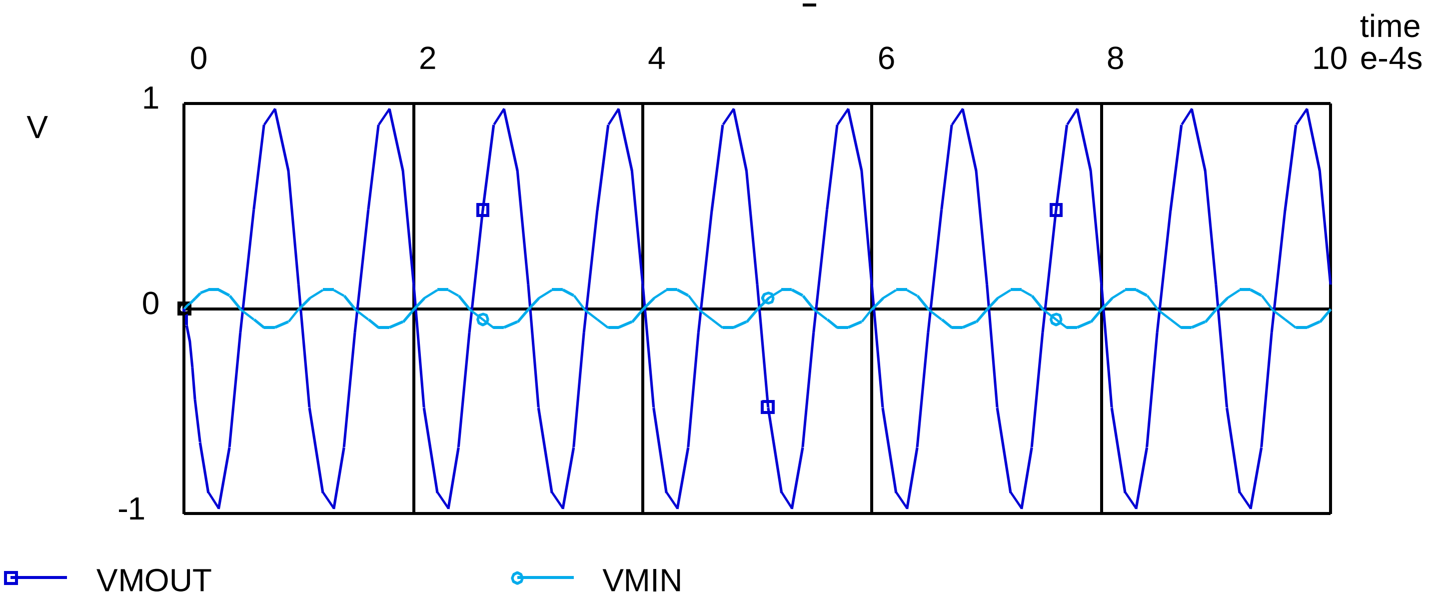




741 Opamp Example

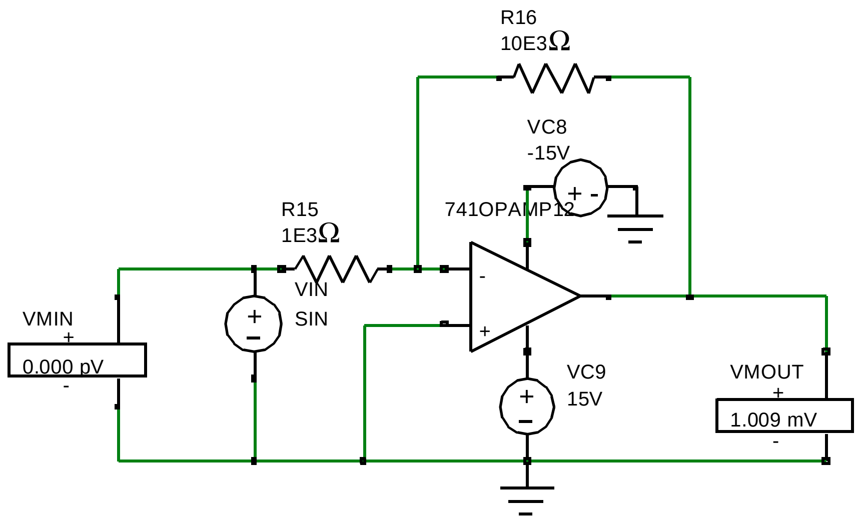
- A gain of 10, or 20dB is possible at 10kHz:

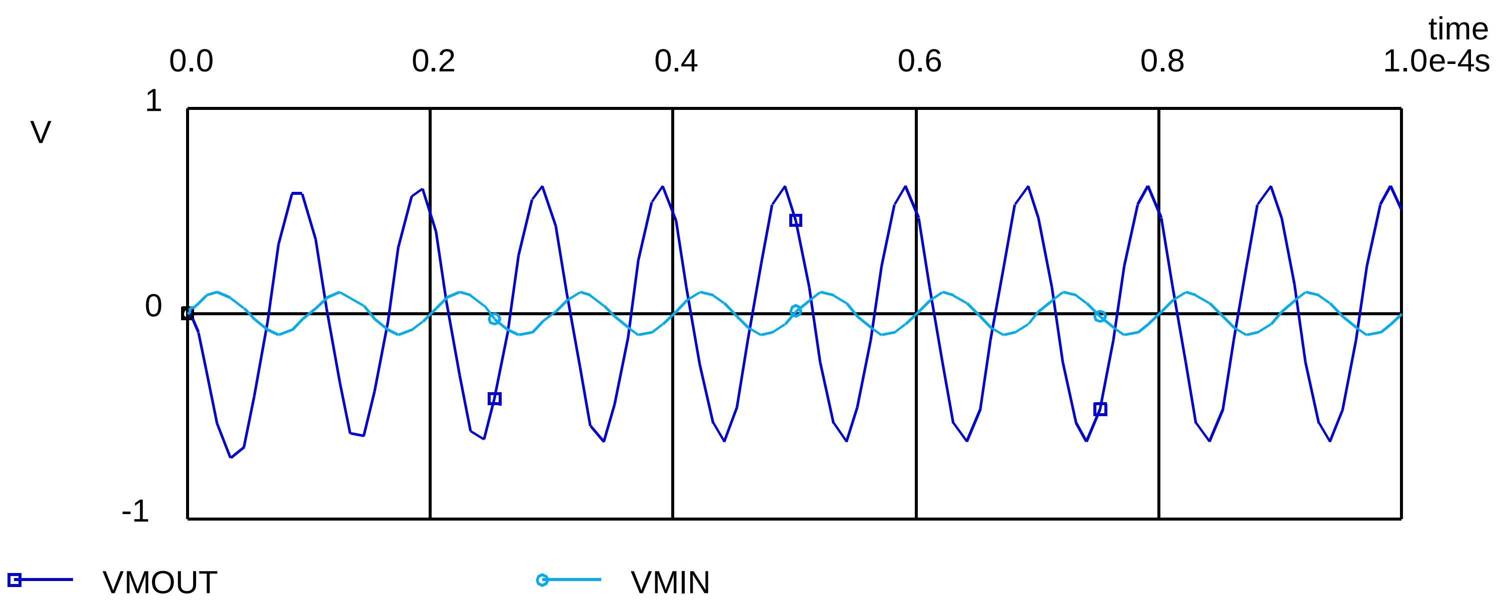




741 Opamp Example

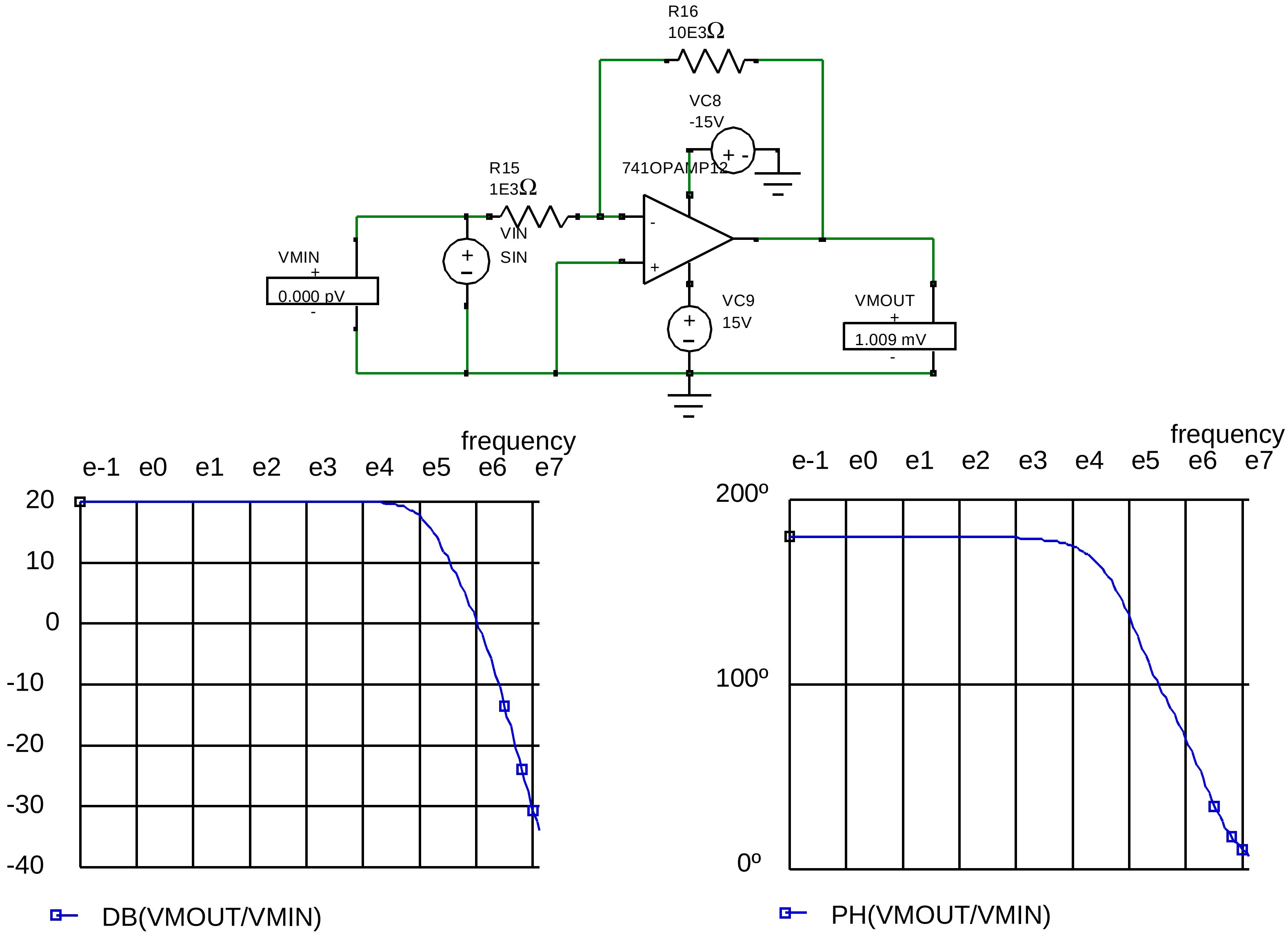
- But <u>not</u> at 100kHz:





741 Opamp Example

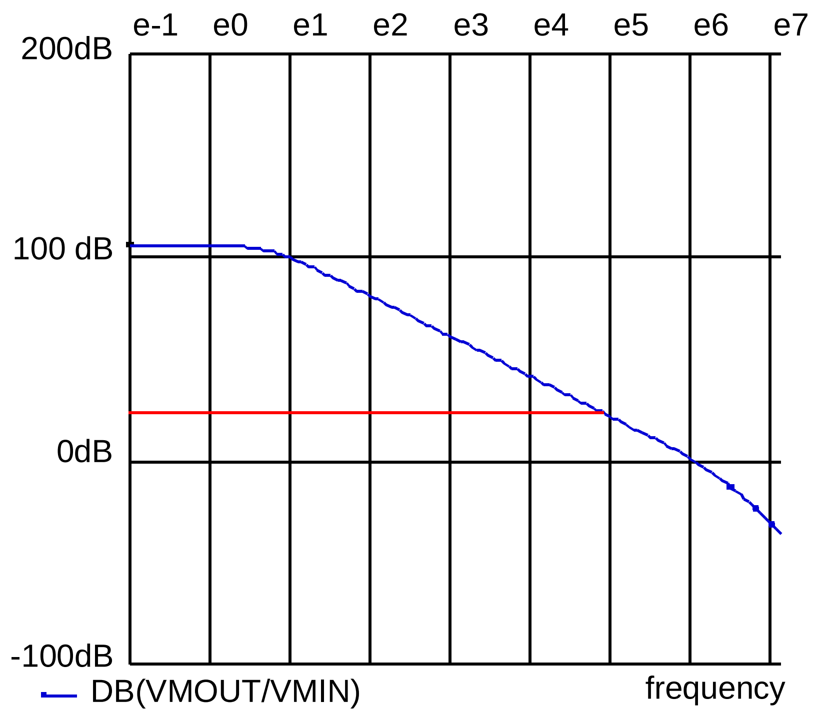
- This decrease in gain is evident from a frequency domain analysis



Gain as a Function of Frequency

- Will the closed-loop gain (with feedback) will always be less than or equal to the open loop gain as a function of frequency?

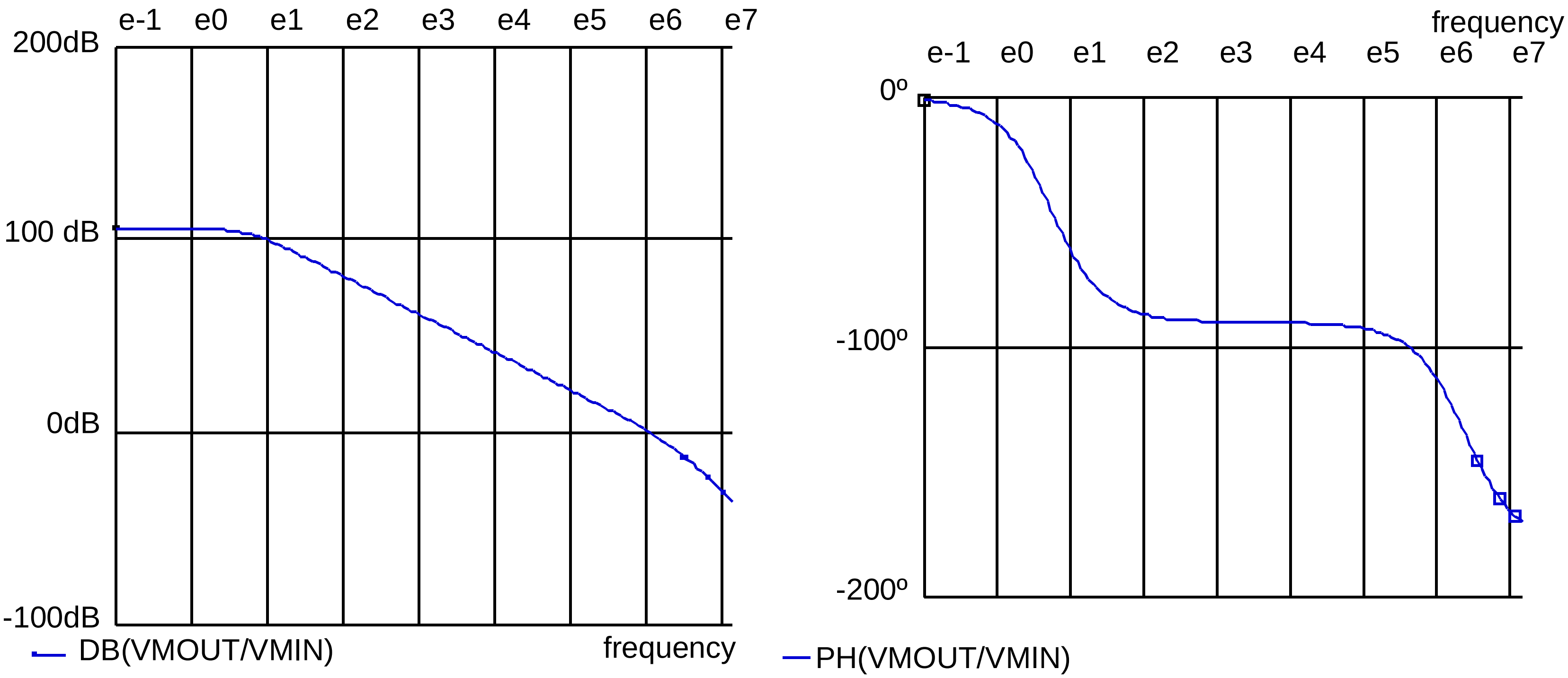
open loop gain



Gain as a Function of Frequency

- We can assume that the close-loop response will follow the open loop characteristic beyond the frequency at which they intersect if the load capacitance and input terminal capacitances are small
- Why are the other capacitors a factor?

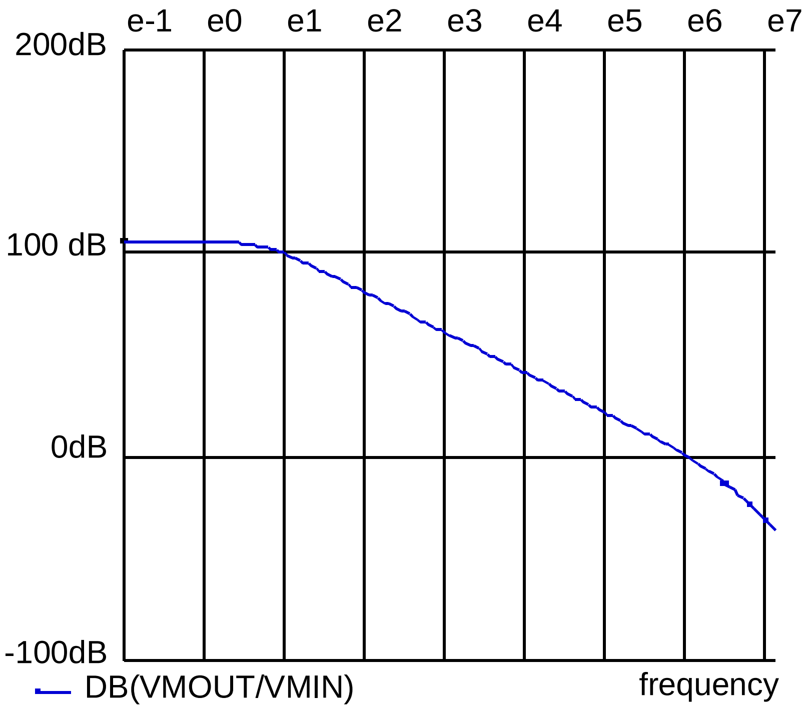
741 Open Loop Characteristics

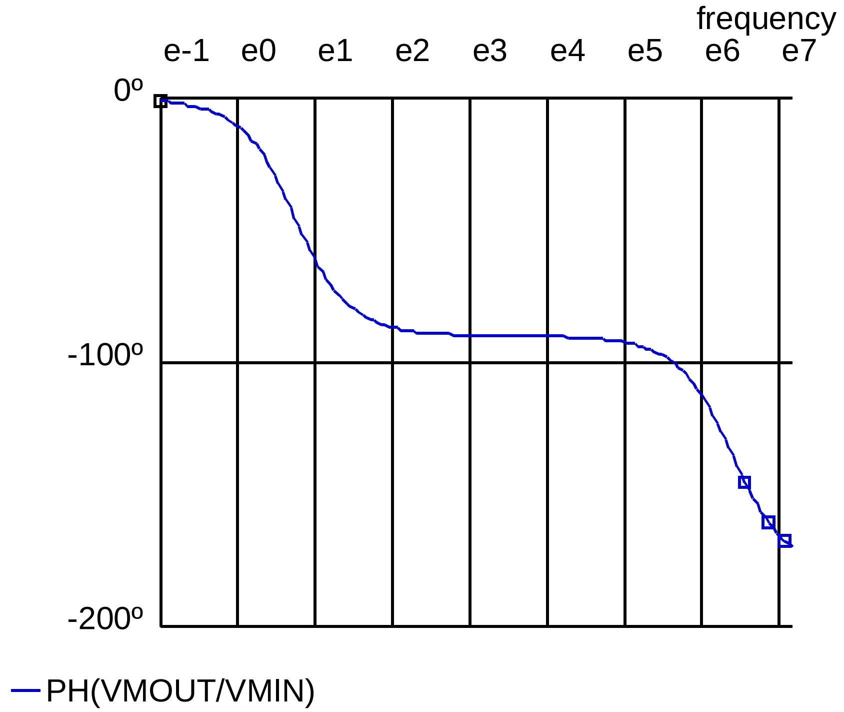


Gain as a Function of Frequency

- It is important that the open loop characteristic has a phase shift of less than 180º (a change in gain of less than 40dB per decade) at the point of intersection with the closed-loop characteristic --- why?

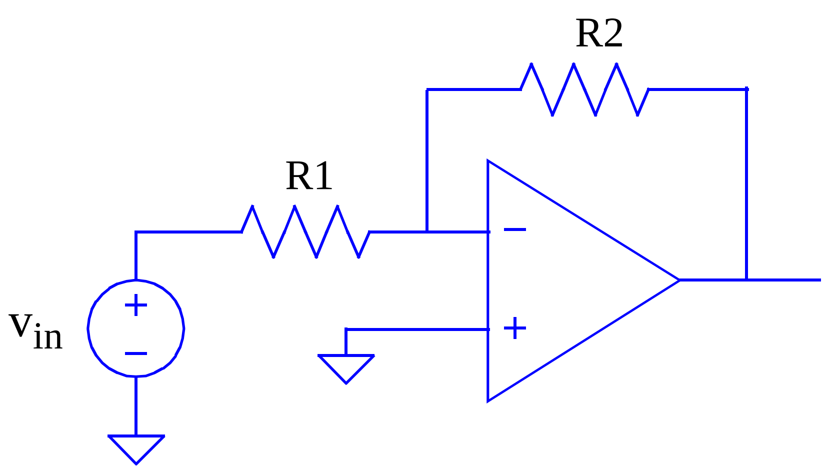
741 Open Loop Characteristics





Stability

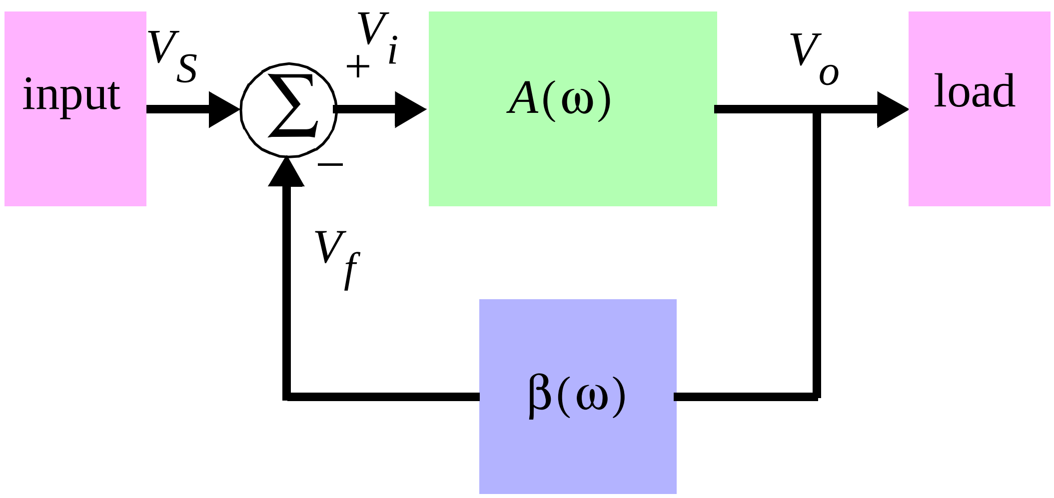
- If the open loop gain has a phase shift of 180º, and we connect the opamp with negative feedback (which represents another phase shift of 180º), then the total phase shift will be 360º which is like positive feedback



$$v_o(s) = -A(s)v_1$$

Feedback

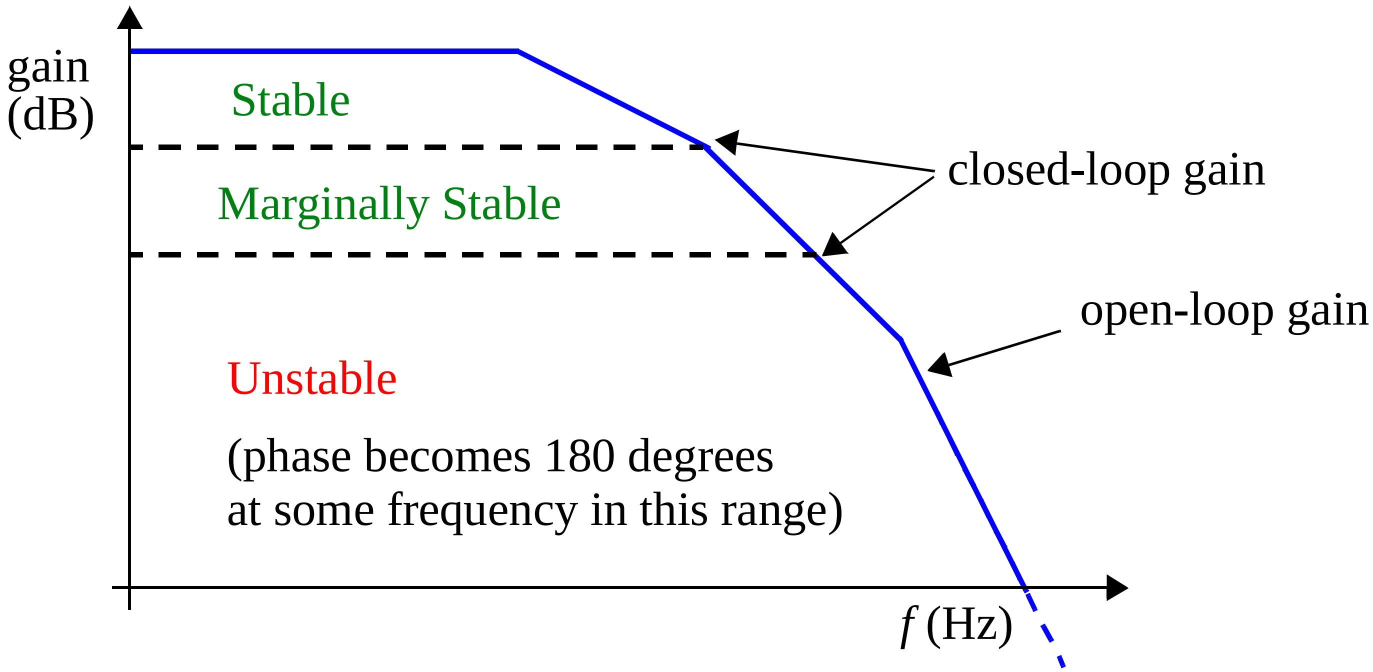
- The feedback can further complicate matters if it is also a function of frequency



$$A_f(\omega) = \frac{A(\omega)}{1 + \beta(\omega)A(\omega)}$$

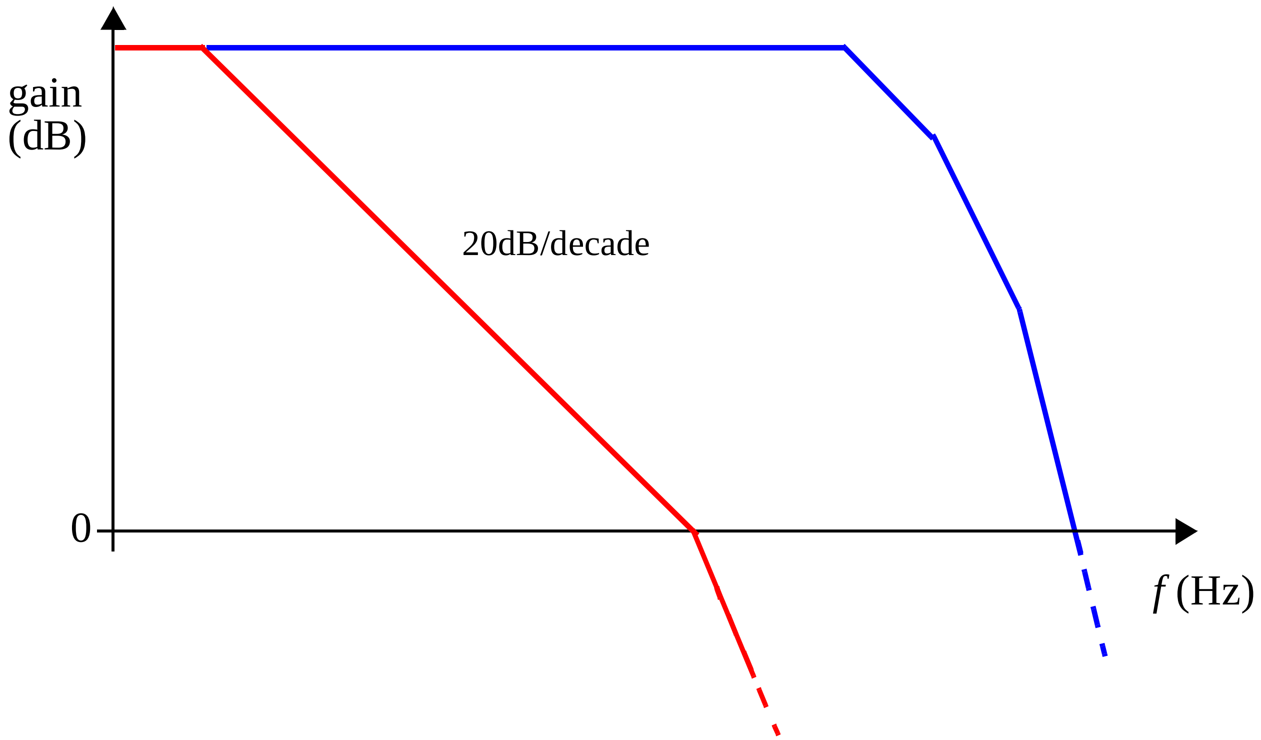
Stability

- The circuit will be unstable with this positive feedback
- What causes the gain characteristic to exhibit these unwanted phase shifts?



Internal Compensation

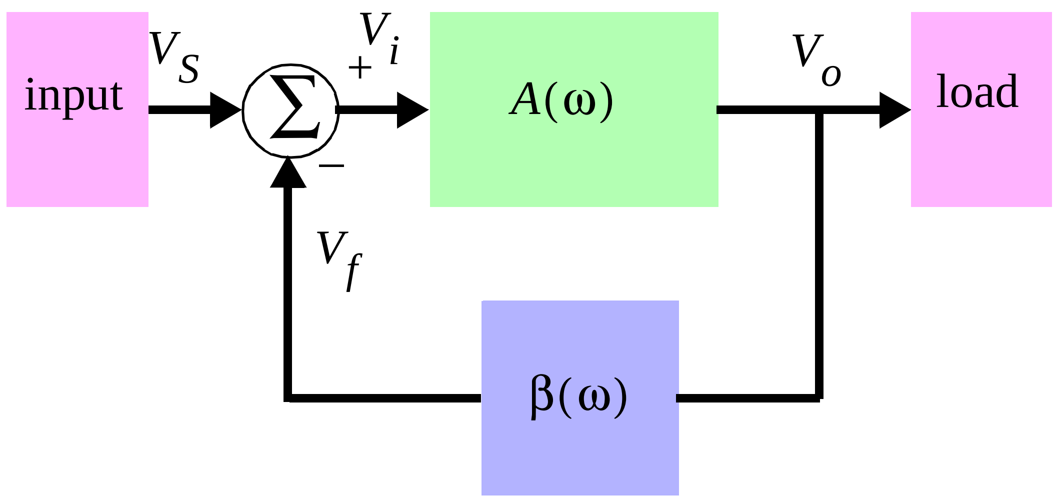
- Compensation capacitors are added to purposely place a low frequency (dominant) pole so that the change in gain will be 20dB/decade up until the unity gain frequency
- Why isn't the phase a concern beyond this frequency?



- Sacrifices gain for stability

Feedback

- Most feedback we've considered has no phase shift (resistors), so compensation will ensure stability
- However, frequency dependent feedback can pose a problem even for compensated opamps

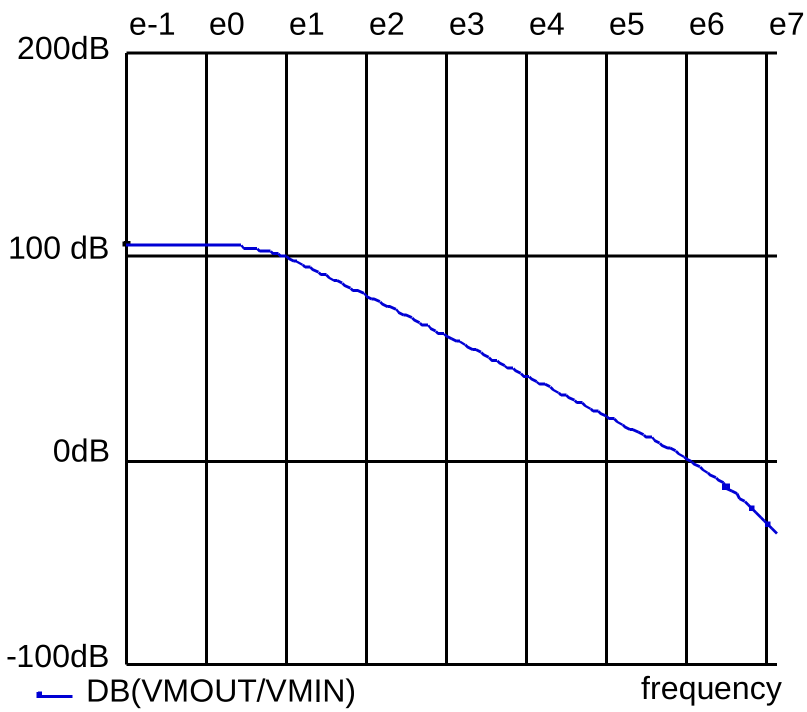


$$A_f(\omega) = \frac{A(\omega)}{1 + \beta(\omega)A(\omega)}$$

Modeling Gain as a Function of Frequency

- With compensation, the frequency response appears like a STC

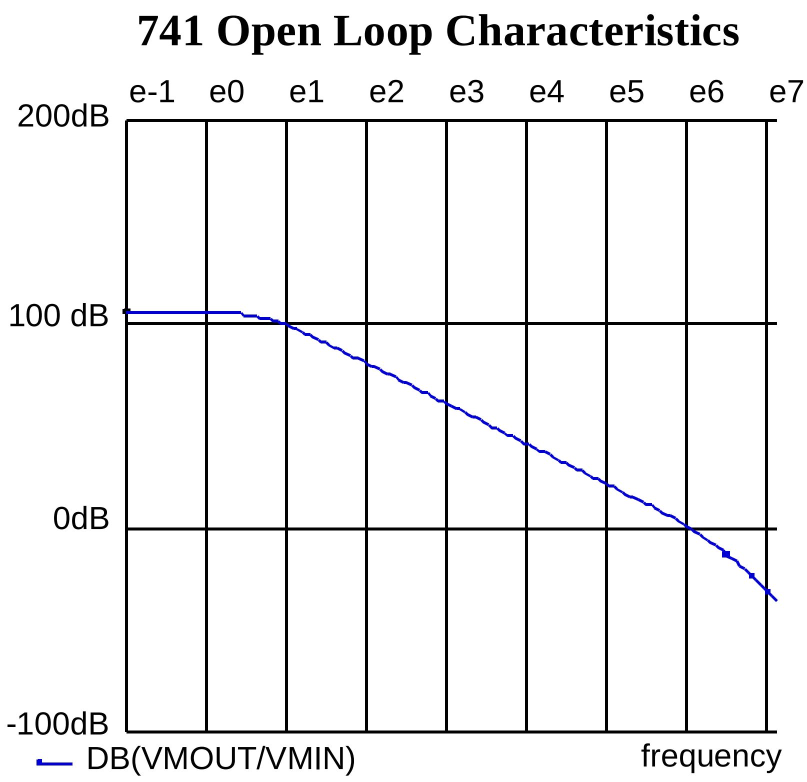
741 Open Loop Characteristics



$$A(s) = \frac{A_o}{1 + s/\omega_b}$$

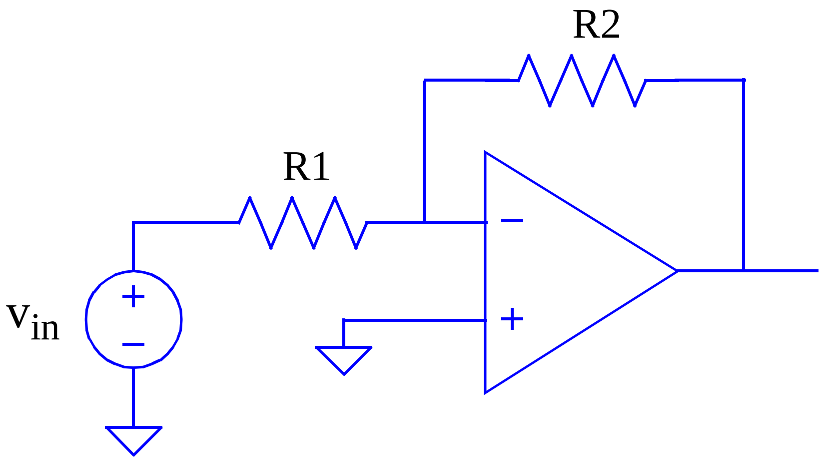
Unity Gain Bandwidth

- We can easily solve for the frequency, ω_t, at which the gain is 0dB



Frequency Dependence of Gain

- Using these expressions for gain as a function of frequency we can approximate the inverting amplifier circuit gain as a function of frequency



$$\frac{V_o}{V_i} = \frac{-\frac{R_2}{R_1}}{1 + \frac{\left(1 + \frac{R_2}{R_1}\right)}{A(s)}}$$

$$A(s) = \frac{A_o}{1 + s/\omega_b}$$

$$\frac{V_o}{V_i} = \frac{-\frac{R_2}{R_1}A_o}{A_o + \left(1 + \frac{R_2}{R_1}\right) + \frac{s}{\omega_b}\left(1 + \frac{R_2}{R_1}\right)}$$

Frequency Dependence of Gain

- We can assume that the closed-loop gain is much smaller than the dc open loop gain

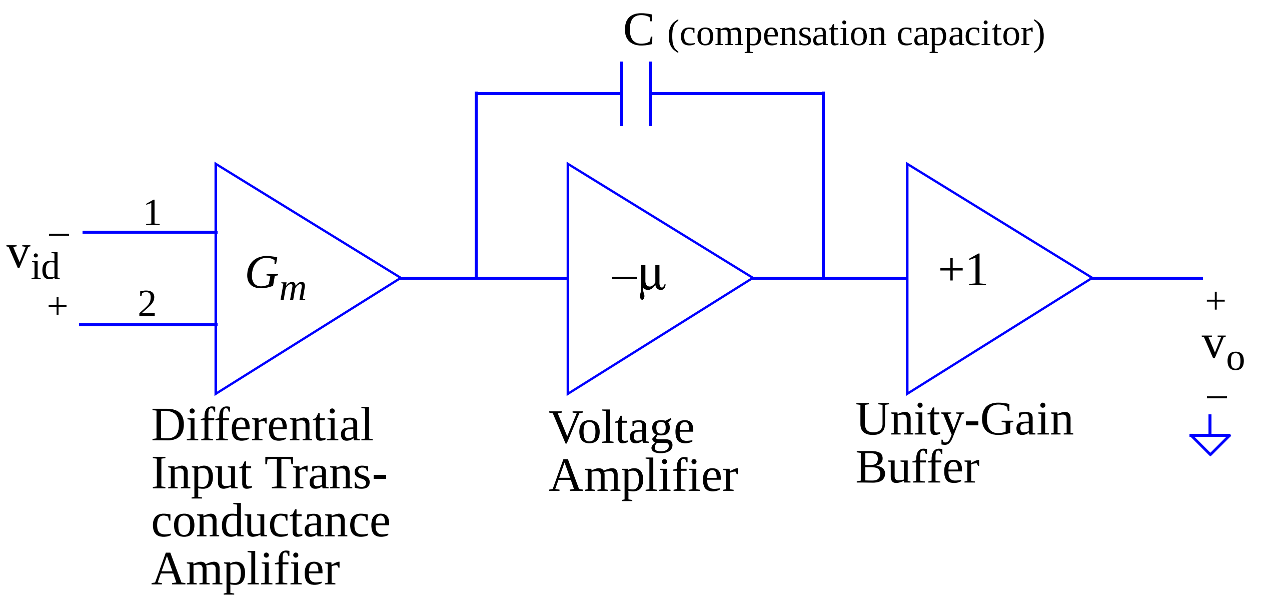
$$\frac{V_o}{V_i} = \frac{-\frac{R_2}{R_1}A_o}{A_o + \left(1 + \frac{R_2}{R_1}\right) + \frac{s}{\omega_b}\left(1 + \frac{R_2}{R_1}\right)}$$

Frequency Dependence of Gain

- Does this result seem correct?

Opamp Macromodels

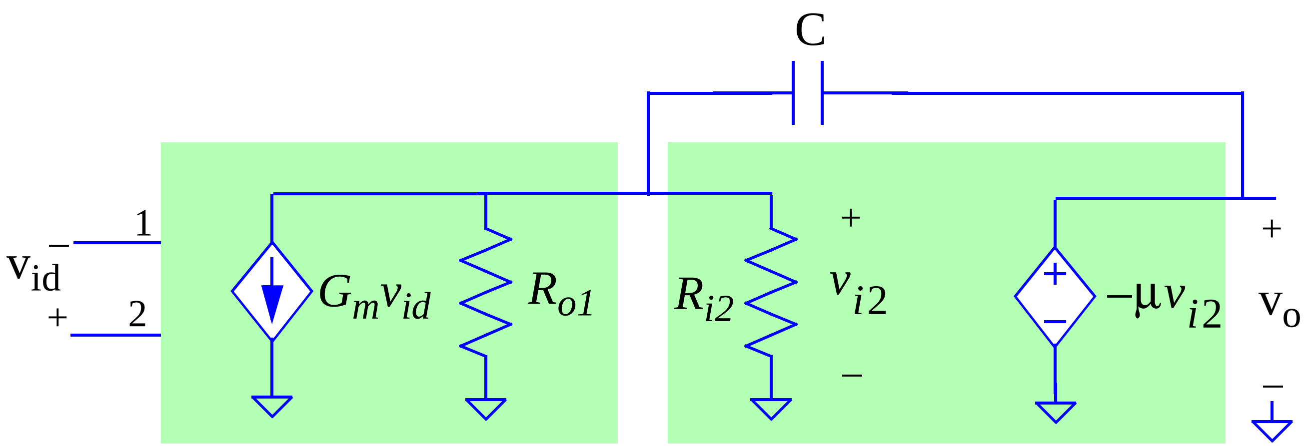
- We can model the frequency dependence of the gain using a macromodel for the opamp
- Internal structure of an opamp:



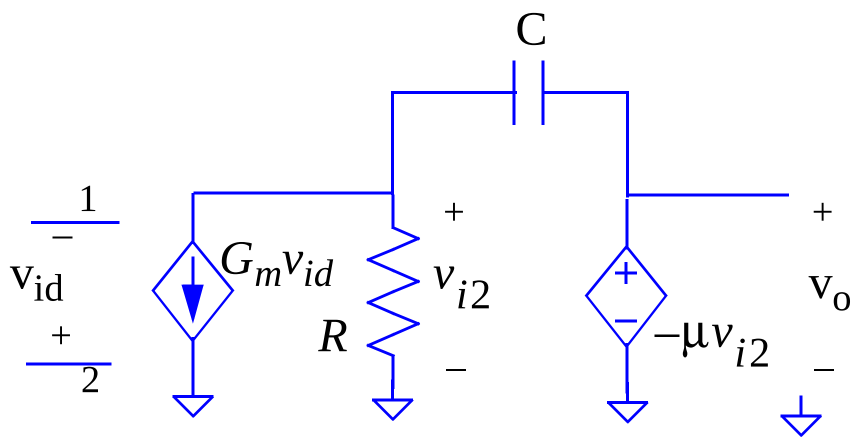
- We'll build all of these transistor level components later in the course

Opamp Macromodels

- We can model the first two stages (the last is trivial) using controlled sources, R's and C's:

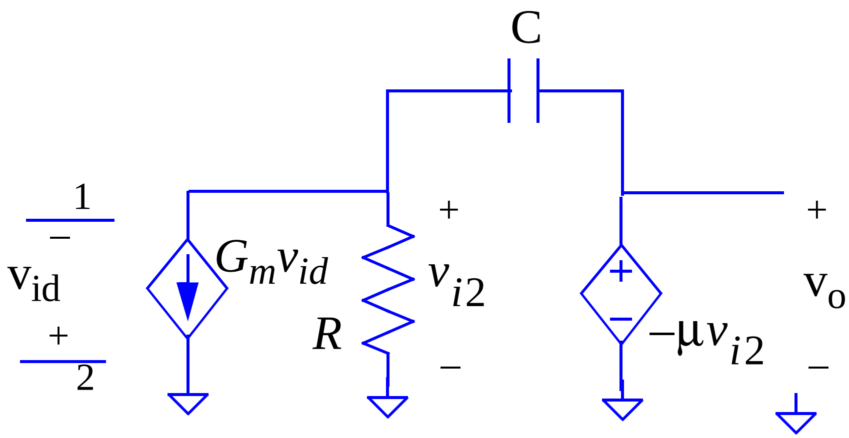


- Which we can simplify by combining the parallel R's

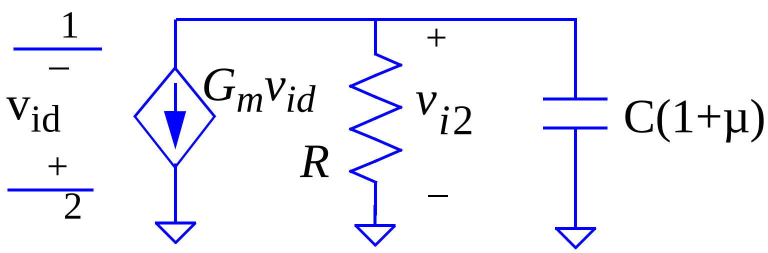


Opamp Macromodel

- This circuit has the same STC form as a compensated opamp



Opamp Macromodel

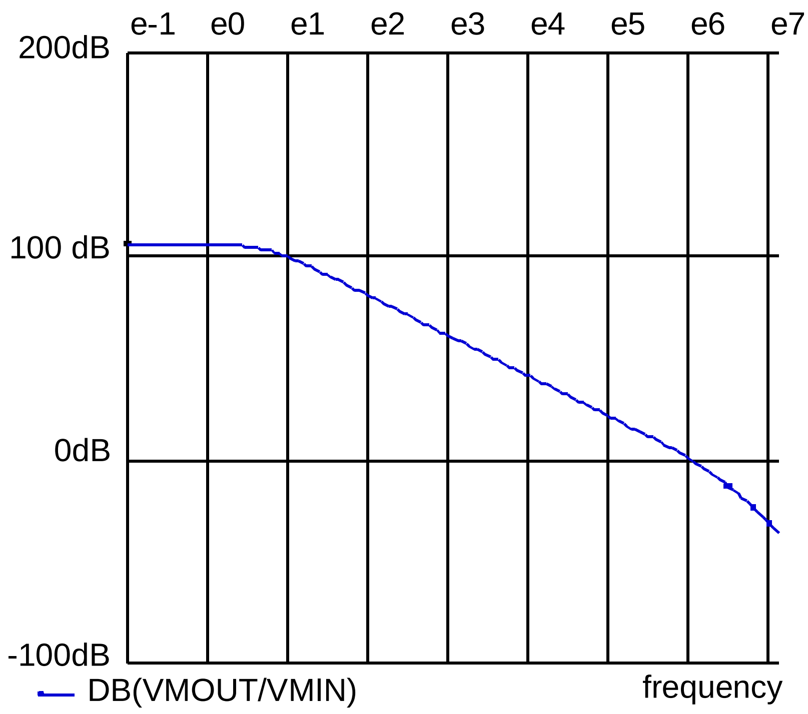


Opamp Macromodel

- The parameters for a 741 macromodel are:

$$G_m = 0.19\frac{mA}{volt} \quad \mu = 529 \quad R_{i2} = 4M\Omega \quad R_{o1} = 6.7M\Omega \quad C = 30pF$$

741 Open Loop Characteristics



Macromodel