



Prof. Mor M. Peretz

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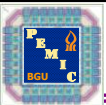
[1]

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Analog Electronic Circuits

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Lesson #2 Outline

- Basic OpAmp circuits
 - Summing, difference, integrator, differentiator
- Basic feedback
 - Feedback definition
 - OpAmp as feedback system
 - Non-inverting and inverting cases
- Static limitations
 - DC errors
 - Bias current, Offset voltage
 - Correction for offsets
 - Output voltage swing, input voltage range
- Dynamic limitations
 - Open-loop response
 - Gain-Bandwidth product



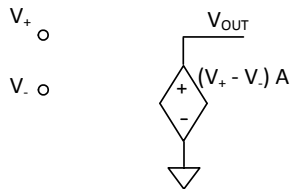
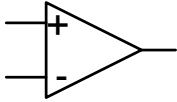
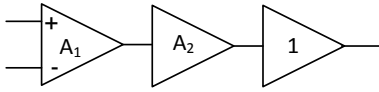
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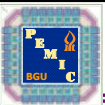
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OpAmp characteristics



Ideal OpAmp primary features:

- Differential inputs
- Output product as function inputs $(V_+ - V_-) A$
 $A = A_1 A_2 A_3$
- Infinite gain $A \rightarrow \infty$
- Infinite Bandwidth $BW \rightarrow \infty$
- Infinite input resistance $R_{in} \rightarrow \infty$
- Zero output resistance $R_{out} \rightarrow 0$



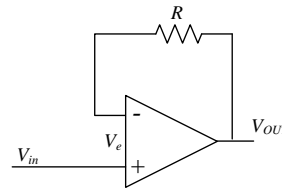
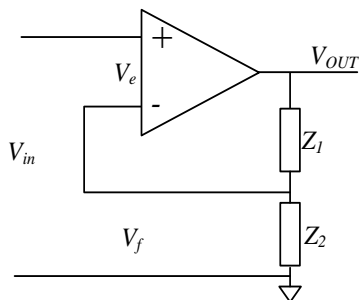
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Non-inverting Amp





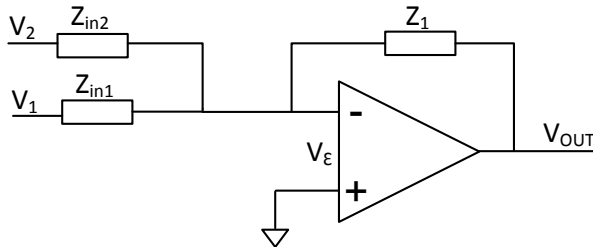
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Summing Amp



$$V_{out} = - \left[V_1 \left(\frac{Z_1}{Z_{in1}} \right) + V_2 \left(\frac{Z_1}{Z_{in2}} \right) \right]$$



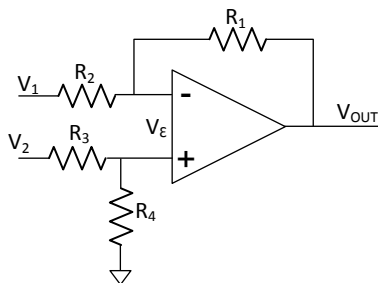
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Difference Amp



$$V_{out_1} = -V_1 \left(\frac{R_1}{R_2} \right)$$

$$V_{out_2} = V_2 \left(\frac{R_4}{R_3 + R_4} \right) \left(1 + \frac{R_1}{R_2} \right)$$

$$\frac{R_2}{R_1} = \frac{R_3}{R_4}$$

$$V_{out} = \frac{R_1}{R_2} (V_2 - V_1)$$



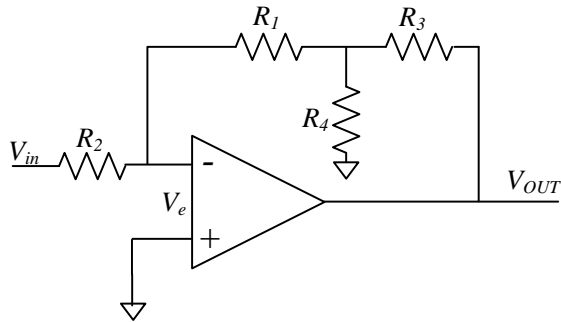
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Feedback forces zero error state



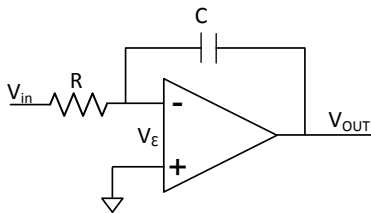
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Integrator Amp



$$V_{out} = \frac{1}{SC} / \frac{1}{R} V_{in} = \frac{1}{SCR} V_{in}$$



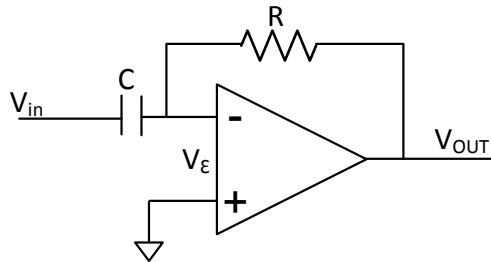
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Differentiator Amp



$$V_{out} = SC/RV_{in} = SCR V_{in}$$



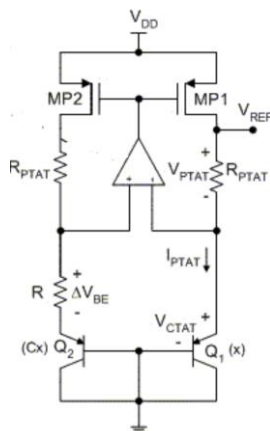
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Voltage reference by OpAmp (Bandgap)





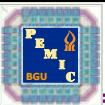
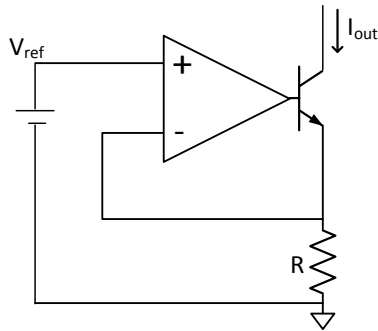
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Current source by OpAmp



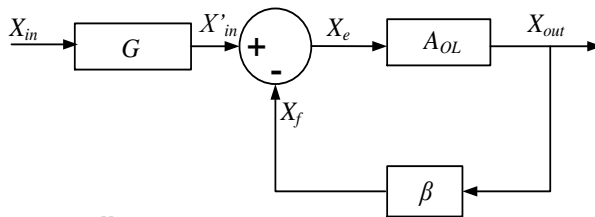
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Negative Feedback



$$A_{CL} = \frac{X_{out}}{X_{in}} = G \frac{A_{OL}}{1 + \beta A_{OL}}$$

$$A_{CL} \Big|_{\beta A_{OL} \gg 1} = \frac{G}{\beta}$$

$$A_{CL} \Big|_{\beta A_{OL} \ll 1} = G A_{OL}$$

$$A_{OL} = \frac{X_{out}}{X_e}$$

$$G = \frac{X'_{in}}{X_{in}} \Big|_{X_{out}=0} = \frac{X_e}{X_{in}} \Big|_{X_{out}=0}$$

$$\beta = \frac{X_f}{X_{out}} \Big|_{X_{in}=0} = \frac{X_e}{X_{out}} \Big|_{X_{in}=0}$$



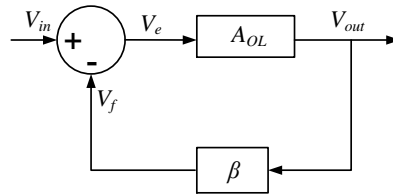
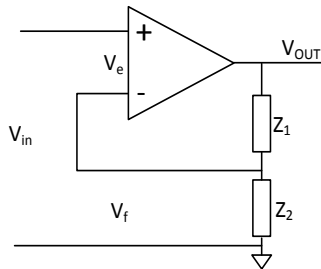
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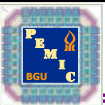
Feedback Non-inverting Amp



$$G = \left. \frac{V_e}{V_{in}} \right|_{V_{out}=0} = 1$$

$$\beta = \left. \frac{V_e}{V_{out}} \right|_{V_{in}=0} = \frac{Z_2}{Z_1 + Z_2}$$

$$A_{CL} |_{\beta A_{OL} \gg 1} = \frac{G}{\beta} = \frac{1}{\frac{Z_2}{Z_1 + Z_2}} = \frac{Z_1 + Z_2}{Z_2} = 1 + \frac{Z_1}{Z_2}$$



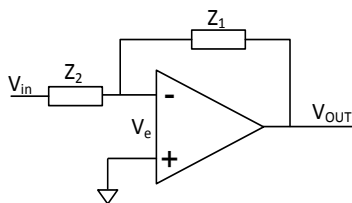
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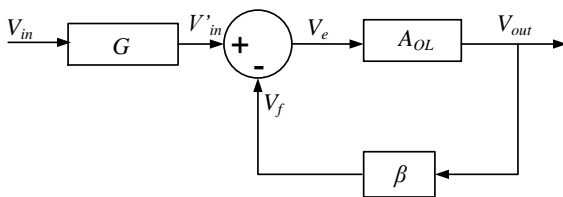
Feedback Inverting Amp



$$G = \left. \frac{V_e}{V_{in}} \right|_{V_{out}=0} = -\frac{Z_1}{Z_1 + Z_2}$$

$$\beta = \left. \frac{V_e}{V_{out}} \right|_{V_{in}=0} = \frac{Z_2}{Z_1 + Z_2}$$

$$A_{CL} |_{\beta A_{OL} \gg 1} = \frac{G}{\beta} = -\frac{\frac{Z_1}{Z_1 + Z_2}}{\frac{Z_2}{Z_1 + Z_2}} = -\frac{Z_1}{Z_2}$$





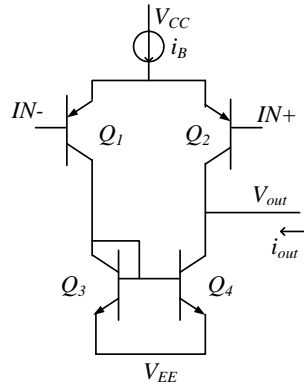
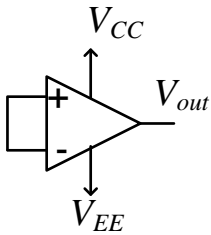
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Static limitations Input stage



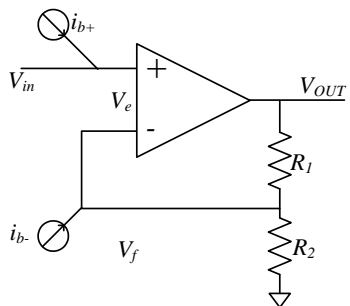
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Bias current Non-inverting Amp





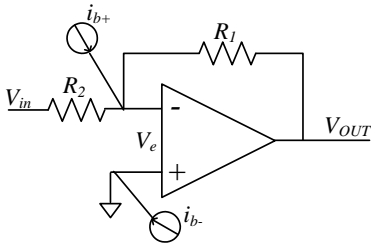
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Bias current Inverting Amp



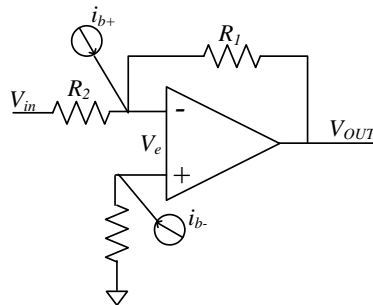
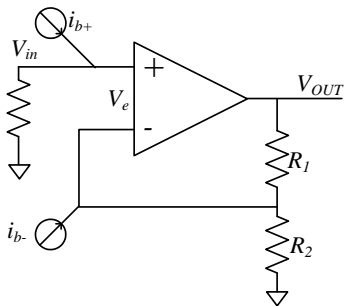
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Bias current Correction





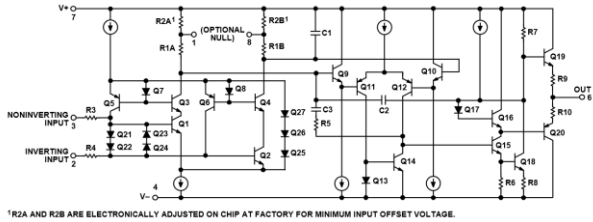
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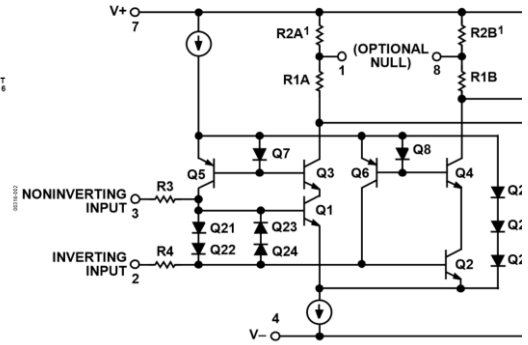
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Bias current Input bias cancellation



*R2A AND R2B ARE ELECTRONICALLY ADJUSTED ON CHIP AT FACTORY FOR MINIMUM INPUT OFFSET VOLTAGE.

OP-07 (Analog Devices)



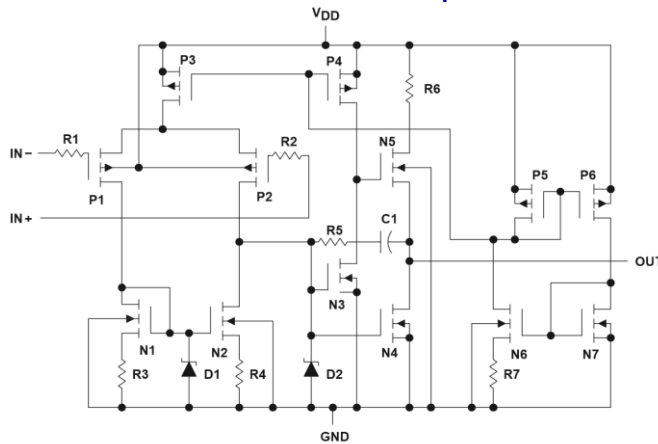
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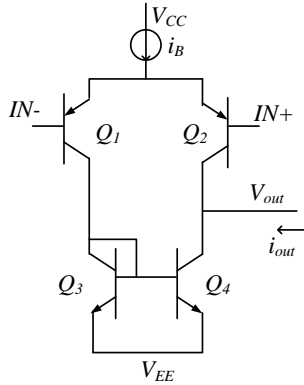
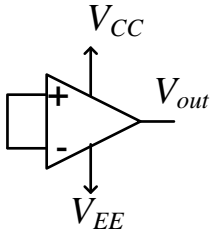
Bias current Low bias input



TL08x (Texas Instruments)



Static limitations Offset voltage



$$\beta = \frac{V_e}{V_{out}} \Big|_{V_{in}=0} = \frac{Z_2}{Z_1 + Z_2}$$

$$i_{out} = g_m(V_+ - V_-)$$

$$g_m = \frac{i_B}{2V_T}$$

$$i_{C1} + i_{C2} = i_B$$

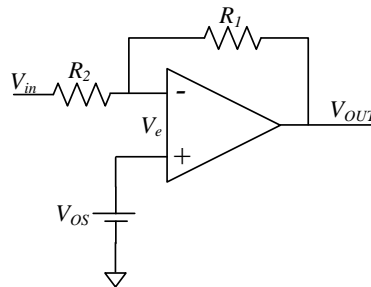
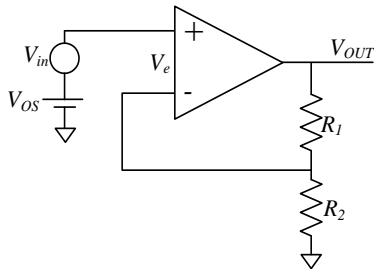
$$i_C = I_S e^{\left(\frac{V_{BE}}{V_T}\right)}$$

$$\frac{i_{C1}}{i_{C2}} = \frac{I_{S1}}{I_{S2}} e^{\left(\frac{V_{BE1} - V_{BE2}}{V_T}\right)}$$

$$I_{S1} = I_{S2}, V_{E1} = V_{E2} \quad ; \quad \frac{i_{C1}}{i_{C2}} = e^{\left(\frac{V_+ - V_-}{V_T}\right)}$$



Offset voltage





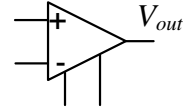
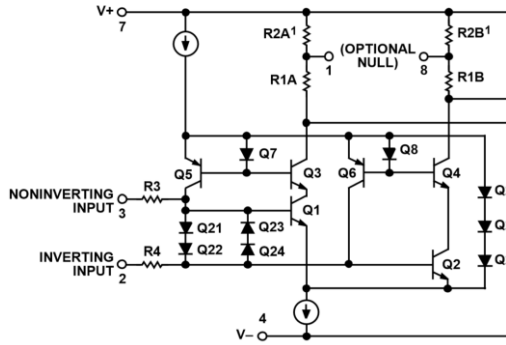
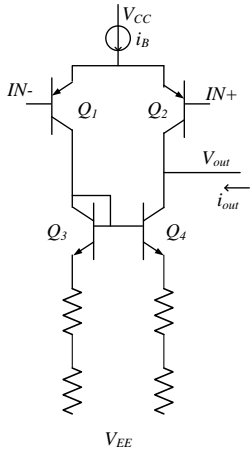
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Offset voltage Correction



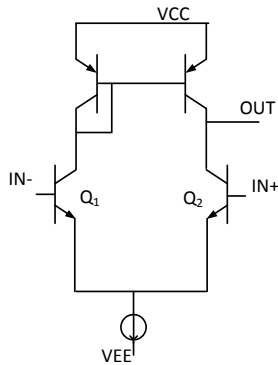
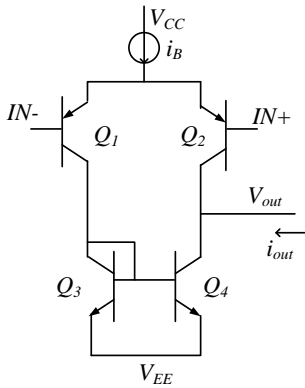
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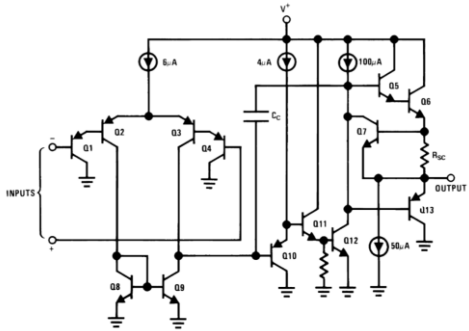
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Maximum ratings (Basic)

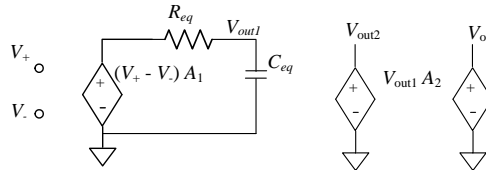
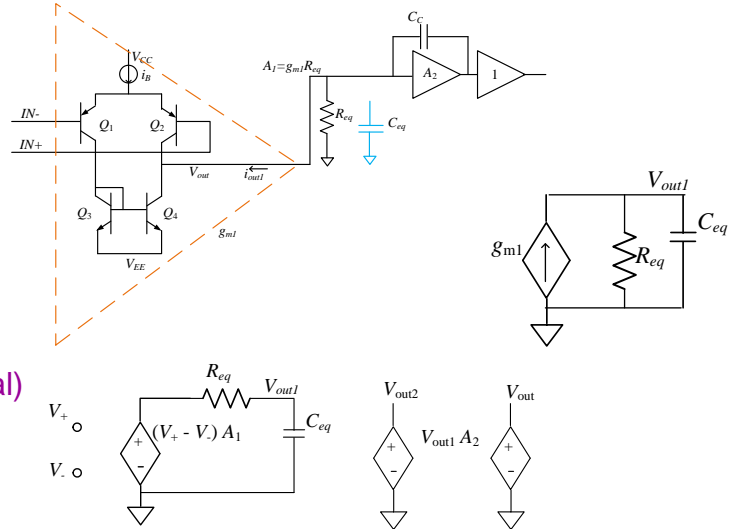




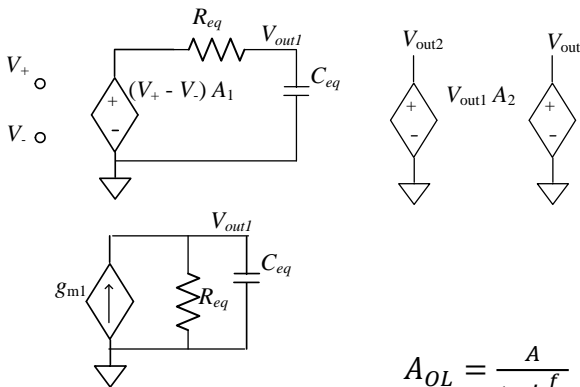
Open-loop response



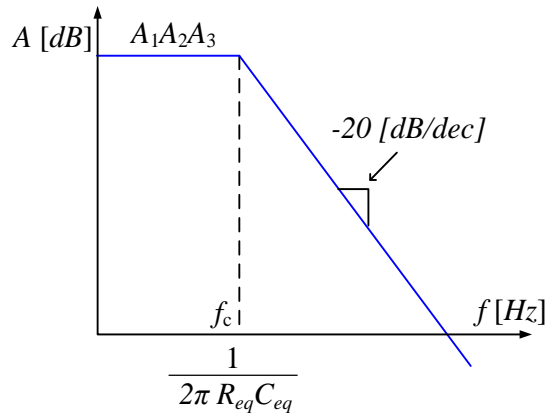
LM324 (Texas Instruments, National)



Open-loop response



$$A_{OL} = \frac{A}{1 + j\frac{f}{f_c}}$$





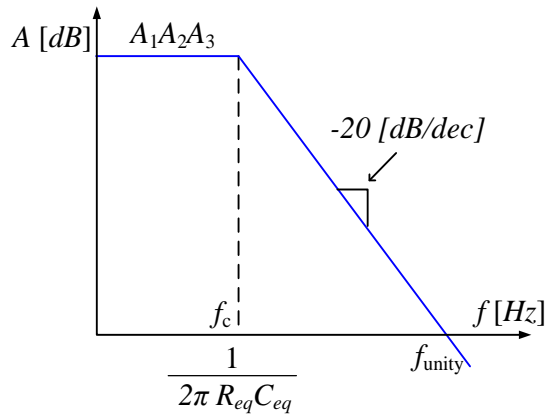
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Gain-Bandwidth Product - GBW



$$A_{CL} = G \frac{A_{OL}}{1 + \beta A_{OL}}$$

$$\beta = 1, G = 1$$

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL}}$$

$$GBW = f_{unity}$$