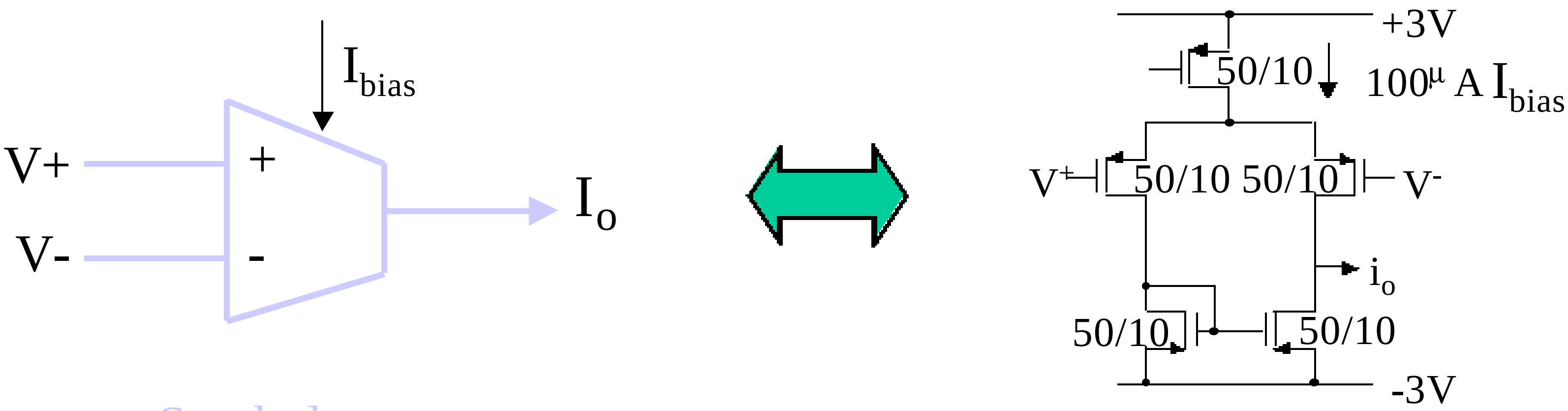


Symbol

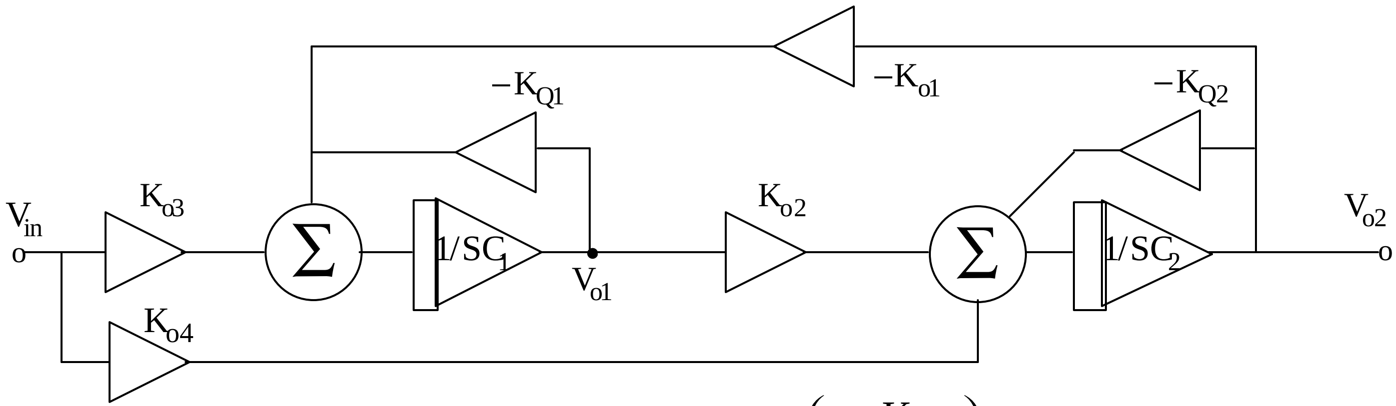
(a)

A simple CMOS implementation

Second-Order OTA-C (Gm-C) Filters

- A canonic filter structure
- A low frequency high-Q low pass architecture
- A General Biquad Structure for multiple purposes
- OTA Non-idealities effects on filter performance

The OTA-Biquadratic Architectures are based on State-Variable Structures



$$\frac{V_{o2}}{V_{in}} = \frac{\dfrac{K_{o3}K_{o2}}{S^2C_1C_2} + \dfrac{K_{o4}}{SC_2}\left(1 + \dfrac{K_{Q1}}{SC_1}\right)}{1 + \left(\dfrac{K_{Q1}}{SC_1} + \dfrac{K_{Q2}}{SC_2}\right) + \left(\dfrac{K_{Q1}K_{Q2}}{S^2C_1C_2} + \dfrac{K_{o1}K_{o2}}{S^2C_1C_2}\right)}$$

$$H_1(S) = \frac{V_{o2}}{V_{in}} = \frac{K_{o3}K_{o2} + K_{o4}K_{Q1} + SK_{o4}/C_1}{S^2C_1C_2 + S(K_{Q1}C_2 + K_{Q2}C_1) + (K_{Q1}K_{Q2} + K_{o1}K_{o2})} \quad (1a)$$

$$H_1(0) = \frac{K_{Q1}K_{o4} + K_{o3}K_{o2}}{K_{Q1}K_{Q2} + K_{o1}K_{o2}} \quad (1b)$$

$$\omega_o^2 = \frac{K_{Q1}K_{Q2} + K_{o1}K_{o2}}{C_1C_2} \quad (1c)$$

$$\frac{\omega_o}{Q} = BW = \frac{K_{Q1}}{C_1} + \frac{K_{Q2}}{C_2} \quad (1d)$$

Particular Cases

$$K_{o1} = K_{o3} \quad , \quad K_{o2} = K_{Q2}$$
$$K_{Q1} = 0 \quad , \quad K_{o4} = 0$$

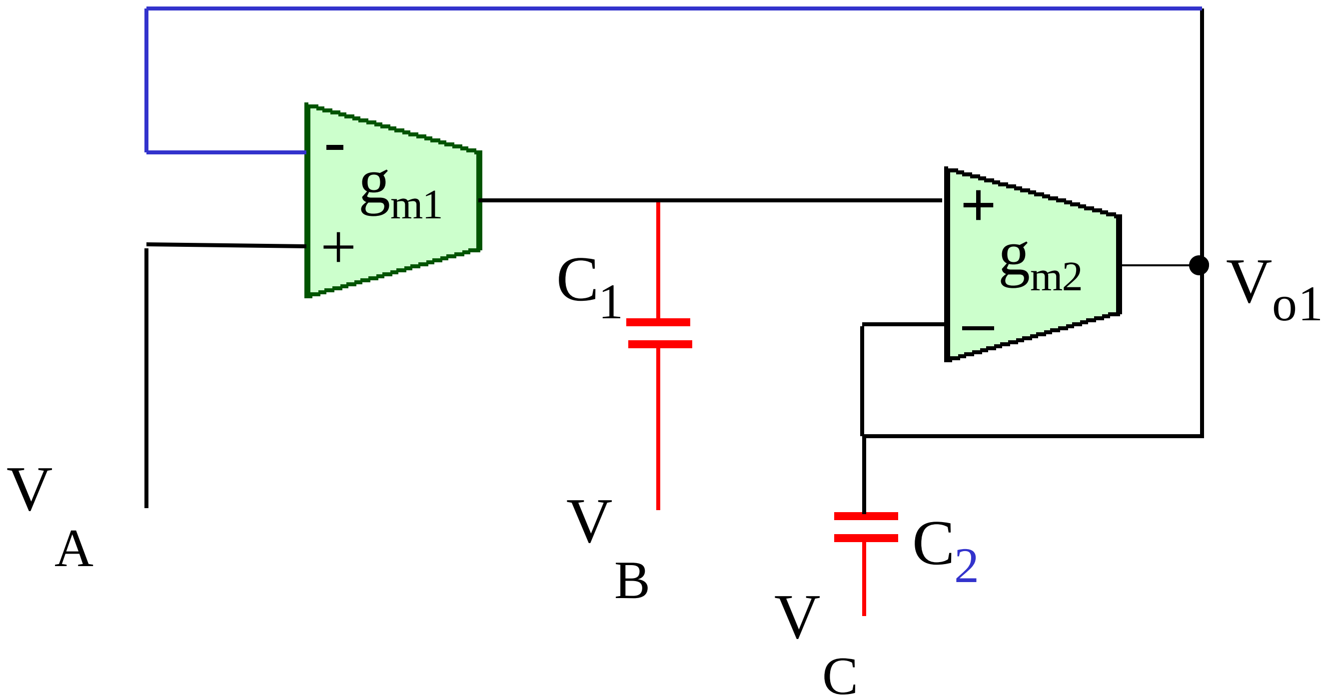
From (1a)

$$H_1(S) = \left. \frac{K_{o1}K_{o2} / C_1C_2}{S^2 + SK_{Q2} / C_2 + K_{o1}K_{o2} / C_1C_2} \right|_{\substack{K_{o1}=g_{m1} \\ K_{o2}=g_{m2}}} = \frac{g_{m1}g_{m2}}{S^2C_1C_2 + SC_1g_{m2} + g_{m1}g_{m2}} \qquad (2)$$

Next an implementation of (2) with three input signals follow.

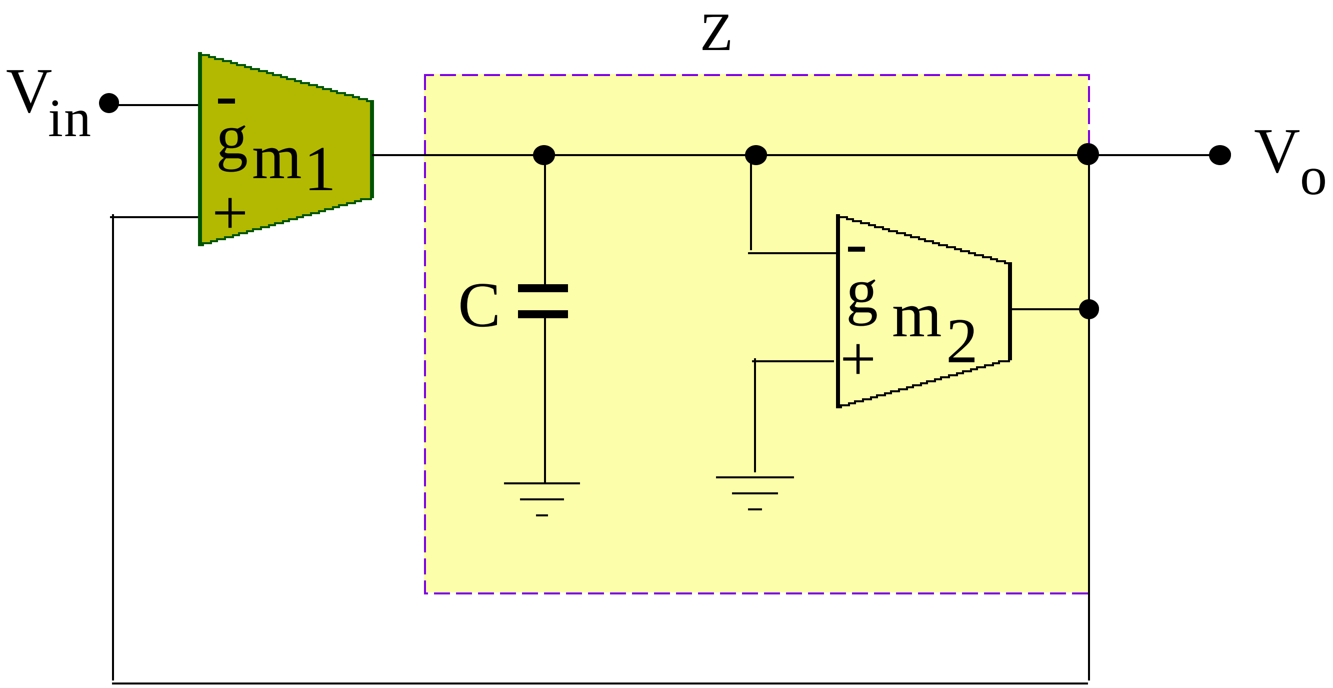
Note that injecting signal through the capacitors yield BP and HP filters. The drawback is that the injecting signal must be generated by ideal voltage sources.

Canonic OTA-C Biquad



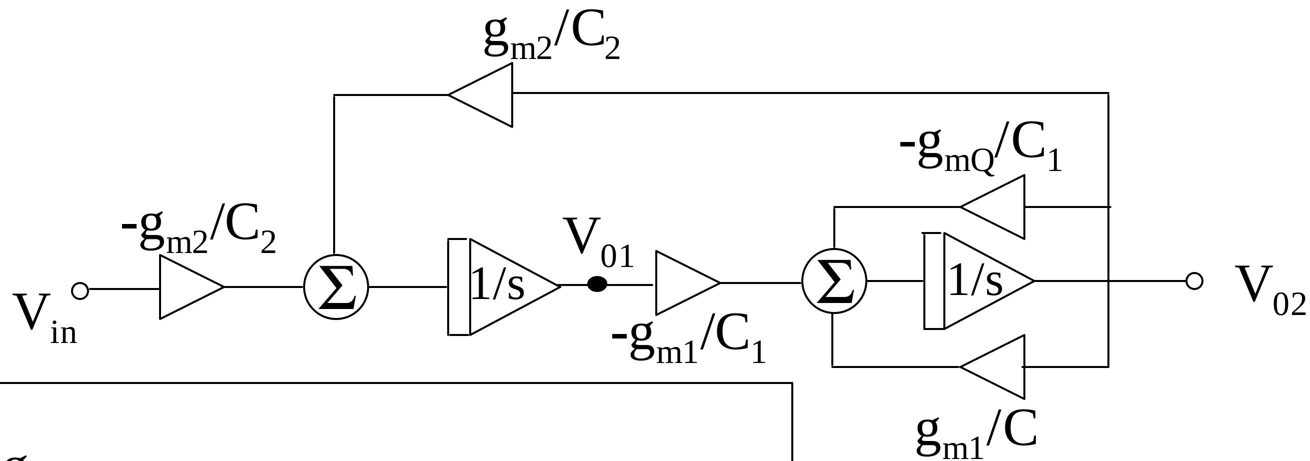
$$V_{01} = \frac{s^2 C_1 C_2 V_C + s C_1 g_{m2} c V_B + g_{m1} g_{m2} V_A}{s^2 C_1 C_2 + s C_1 g_{m2} + g_{m1} g_{m2}}$$

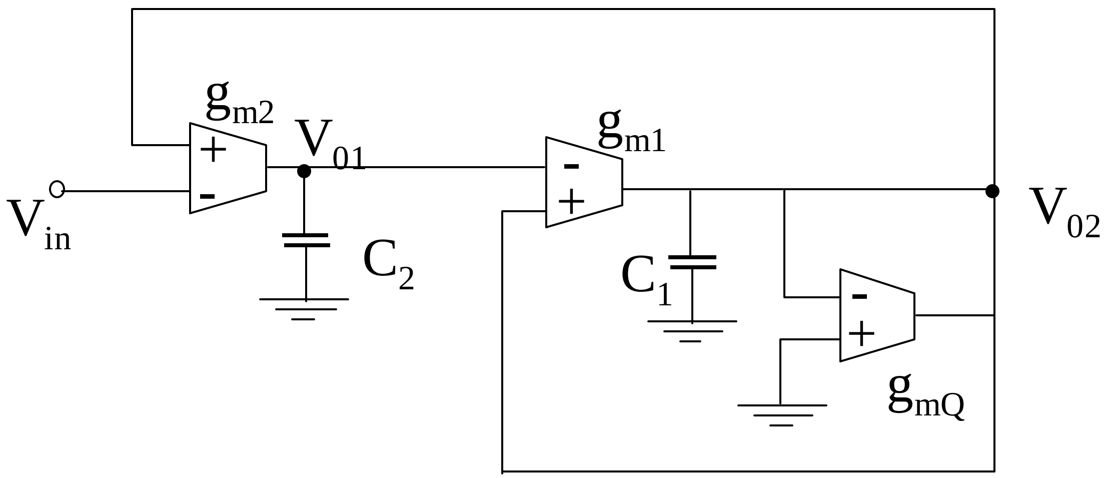
Lossy Integrator With Positive Feedback



$$\frac{V_o}{V_{in}} = \frac{-g_{m_1} Z}{1 - g_{m_1} Z} = -\frac{g_{m_1}}{sC + (g_{m_2} - g_{m_1})}$$

Low-Frequency, High-Q OTA-C Biquad



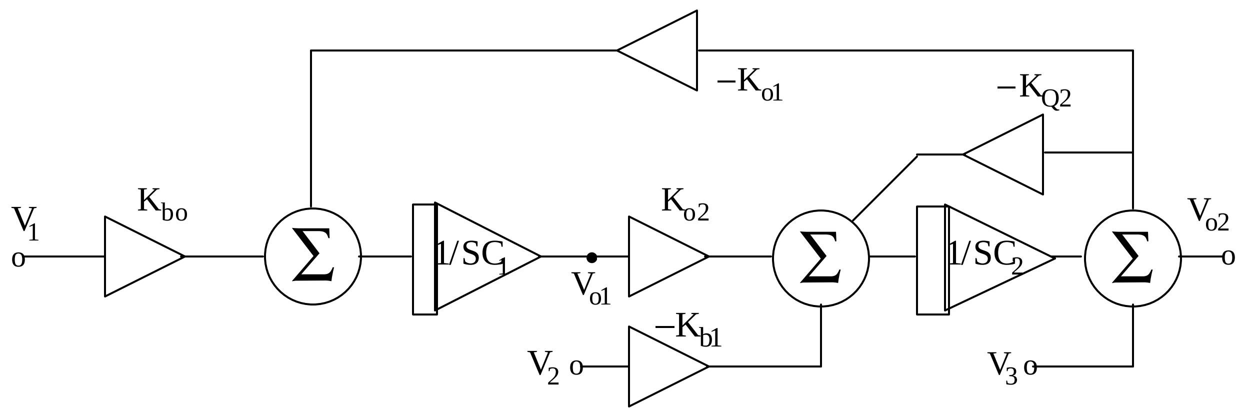


$$\frac{V_{02}}{V_{in}} = \frac{g_{m1}g_{m2}/C_1C_2}{s^2 + s(g_{mQ} - g_{m2})/C_1 + g_{m1}g_{m2}/C_1C2} = \frac{g_{m1}g_{m2}/C_1C_2}{D(s)}$$

LP

$$\frac{V_{01}}{Vin} = \frac{g_{m1}/C_2(s + (g_{m2} - g_{mQ})/C_1)}{D(s)}$$

Resonator



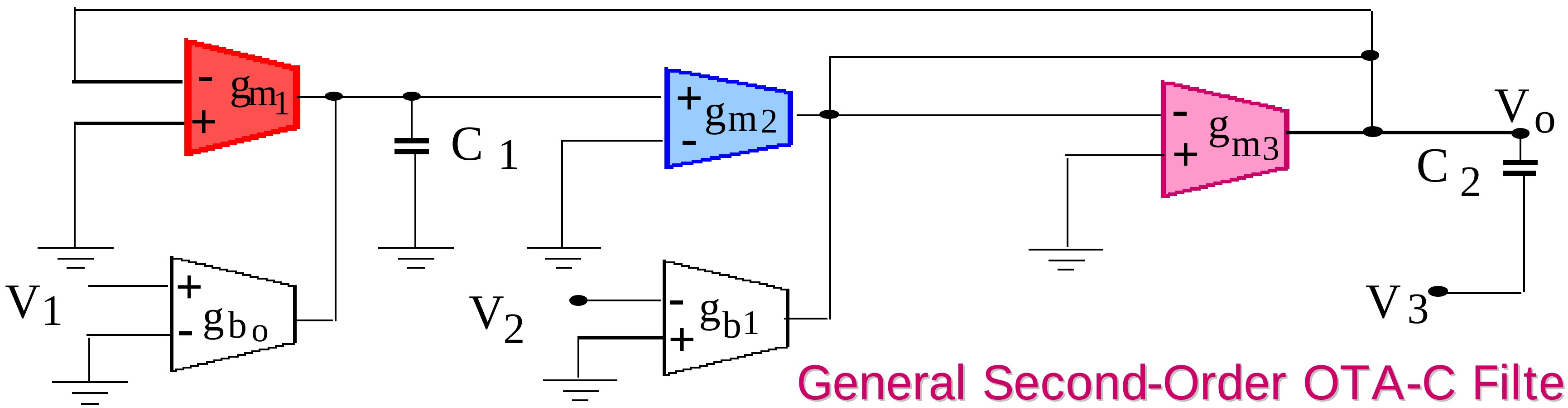
For $V_1 = V_2 = V_3 = V_{in}$

$$H_1(s) = \frac{V_{o1}}{V_{in}} = \frac{K_{bo}K_{o2}/S^2C_1 - K_{b1}/SC_2 + 1}{1 + \frac{K_Q}{SC_2} + \frac{K_{o1}K_{o2}}{S^2C_1C_2}} = \frac{S^2 - SK_{b1}/C_2 + K_{bo}K_{o2}/C_1C_2}{S^2 + SK_Q/C_2 + K_{o1}K_{o2}/C_1C_2}$$

$$\omega_o^2 = \frac{K_{o1}K_{o2}}{C_1C_2} \quad , \quad \frac{\omega_o}{Q} = \frac{K_Q}{C_2} \quad , \quad Q = \frac{1}{K_Q}\sqrt{\frac{K_{o1}K_{o2}C_2}{C_1}}$$

$$H_1(0) = \frac{K_{bo}}{K_{o1}} \quad , \quad \omega_z^2 = \frac{K_{bo}K_{o2}}{C_1C_2} \quad , \quad \frac{\omega_z}{Q_z} = \frac{K_{b1}}{C_2}$$

$$S_K^{\omega_o} = \frac{2\omega_o}{2K}\frac{K}{\omega_o} \quad , \quad S_{K_{o1},\,K_{o2}}^{\omega_o} = \frac{1}{2} \quad , \quad S_{\frac{K_Q}{C_2}}^{\frac{\omega_o}{Q}} = 1$$



General Second-Order OTA-C Filter

For $V_1=V_2=V_3$

$$H(s)=\frac{s^2 - s\frac{g_{b1}}{C_2}+\frac{g_{bo}g_{m2}}{C_1C_2}}{s^2+s\frac{g_{m3}}{C_2}+\frac{g_{m1}g_{m2}}{C_1}}$$

$$\omega_o^2=\frac{g_{m1}g_{m2}}{C_1C_2} \quad ; \quad \omega_z^2=\frac{g_{bo}g_{m2}}{C_1C_2}$$

$$\frac{\omega_o}{Q}=\frac{g_{m3}}{C_2} \quad ; \quad \frac{\omega_z}{Q_z}=\frac{g_{b1}}{C_2}$$

$$|H(0)|=\frac{g_{bo}}{g_{m1}} \quad ; \quad |H(\infty)|=1$$

Non-idealities effects on OTA-C Biquads

Input parasitic capacitance of OTAs, for ungrounded terminals create unwanted zeroes.

The transconductance gain "g_m" is not only a function of bias current, but it is frequency dependent and can be characterized by one dominant pole. i.e., $g_m = g_{mo} /(1 + s / \omega_p)$

One figure of merit in OTA-C filters is the excess phase, that is the additional phase added to the ideal phase. Next we illustrate this with an example

OTA Specifications in Open Loop

Let

$$BW_I = \frac{g_{m3}}{C_2} \quad ; \quad Q_I = \frac{C_2\,\omega_o}{g_{m3}}$$

If

$$g_{mi}(s) = \frac{g_{moi}}{1 + s/\omega_{p_i}} \cong g_{mi}\left(1 - s/\omega_{p_i}\right) \quad , \quad i = 1, 2, \cdots 5$$

$$\phi_E \triangleq \omega_o/\omega_p$$

Then

$$\omega_{oa}^2 = \frac{\omega_o^2}{1 + \dfrac{\omega_o^2}{\omega_{p_1}\,\omega_{p_2}} - \dfrac{BW_I}{\omega_{p3}}} \quad ; \quad \omega_o^2 = \frac{g_{mo1}\,g_{mo2}}{C_1\,C_2}$$

$$BW_a = \frac{BW_I - 2\,\dfrac{\omega_o^2}{\omega_{p_1}\,\omega_{p2}}}{1 - \dfrac{BW_I}{\omega_{p3}} + \dfrac{1}{\omega_{p_1}\,\omega_{p_2}\,C_1\,C_2}} \cong BW_I - 2\,\phi_{E_1}\,\phi_{E_2}$$

$$Q_a = \frac{\omega_{oa}}{BW_a} \cong \frac{Q_I}{1 - \dfrac{2\omega_o}{\omega_p}\,Q_I} = \frac{Q_I}{1 - 2\,\phi_{E_1} Q_I}$$

A_o DC Gain Effect

$$Q_a = \frac{Q}{1 + \frac{2Q}{A_o}}$$

Q	Q_a
1	1.03617
2	2.1501
4	4.6492
5	6.0573
10	15.36
20	66.27

For $f_E = 1^o$

Stability Requires

$Q < 28.64$

Q	Q
1	0.996
5	4.902
10	9.6
50	41.667

For A = 500

$Q_a \uparrow \quad A_o \downarrow$

$Q_a \uparrow \quad f_E \uparrow$

References

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