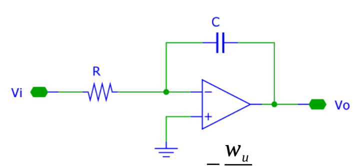
Implementation Issues

- Component spread
- Sensitivity
- Tuning
- Noise
- Finite Gain
- Finite Bandwidth
- …

Finite Bandwidth



$$-\frac{w_u}{s}$$

$$\frac{V_o}{V_i} = \underbrace{-\frac{w_o}{s}}_{\text{ideal}} \underbrace{\frac{w_u}{w_o + w_u}}_{\text{DC gain error}} \underbrace{\frac{1}{1 - \frac{s}{w_o + w_u}}}_{\text{pole}}$$

$$\text{with} \qquad w_o = \frac{1}{RC}$$

- Model finite bandwidth only
- DC gain infinite (keep things manageable & stand a chance to actually learn something from the calculation)
- Errors:
  - DC Gain: minor problem
  - Pole: → phase shift
- What's the effect on a filter?

Effect on Filter Response

Ideal Integrator $H_{\text{int\_ideal}} = -\frac{w_o}{s}$

Actual Integrator $H_{\text{int\_actual}} \cong -\frac{w_o}{s}\frac{1}{1+\frac{s}{p_2}}$ with $p_2 = -w_u - w_o \cong -w_u$

Ideal Filter $H_{\text{filter\_ideal}}(s)\Big|_{s=p_{\text{ideal}}} \to \infty$

Actual Filter $H_{\text{filter\_actual}}\left(s\left(1+\frac{s}{p_2}\right)\right)\Big|_{s=p_{\text{actual}}} \to \infty$

Hence: $p_{\text{ideal}} = p_{\text{actual}}\left(1+\frac{p_{\text{actual}}}{p_2}\right)$

Solve for p_{actual}!

Solving for p_{actual}

$p_{\text{ideal}} = a_i + jb_i$

$p_{\text{actual}} = a_a + jb_a$

$p_2 = -a_2$

$|b_i| >> |a_i|$ (high Q)

$|b_a| >> |a_a|$

$|a_2| >> |a_i|, |a_a|$

$$a_i + jb_i = (a_a + jb_a)\left(1+\frac{a_a + jb_a}{a_2}\right)$$

$$a_i = a_a\left(1+\frac{a_a}{a_2}\right) - \frac{b_a^2}{a_2}$$

$$\cong a_a - \frac{b_a^2}{a_2}$$

$$a_a \cong a_i + \frac{b_a^2}{a_2} = a_i\left(1+\frac{b_a}{a_i}\frac{b_a}{a_2}\right)$$

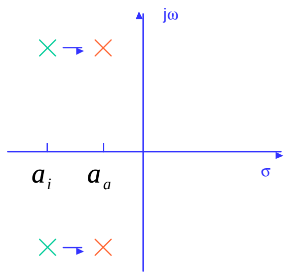
$$\cong a_i\left(1-2Q_i\frac{b_a}{b_i}\frac{b_a}{a_2}\right) \quad \text{using} \quad \frac{b}{a} = -2Q$$

$$\cong a_i\left(1-2Q_i\frac{b_a}{a_2}\right) \quad \text{assuming} \quad b_a \approx b_i$$

$$\cong a_i\left(1-2Q_i\frac{w_{\text{corner}}}{a_2}\right)$$

Effect of Finite Amplifier Bandwidth

$$a_a \cong a_i\left(1-2Q_i\frac{w_{\text{corner}}}{a_2}\right)$$



Example:

$$Q=10,\quad f_{\text{corner}}=1\text{MHz},\quad f_u=100\text{MHz}$$

$$a_a \cong a_i\left(1-2\times 10\frac{1\text{ MHz}}{100\text{ MHz}}\right)=0.8a_i$$

To reduce a < 1% (and, hence increase Q by < 1%) need

$$f_u > 200Qf_{\text{corner}}$$

Solution:

- Very fast amplifier, or
- Compensation circuit

Q enhancement → peaking in response (or instability)

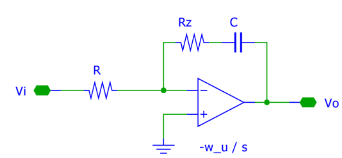
Pole-Zero Cancellation

$$H=-\frac{1+sR_zC}{sRC\left(1+\frac{s}{w_u}\right)+\frac{s}{w_u}\left(1+sR_zC\right)}$$

$$=\underbrace{-\frac{1}{sRC}}_{\text{ideal response}}\;\underbrace{\frac{1+sR_zC}{1+\frac{s}{w_u}+\frac{1}{w_uRC}\left(1+sR_zC\right)}}_{\text{error, should be 1}}$$

$$=-\frac{w_o}{s}\frac{1+sR_zC}{1+\frac{w_o}{w_u}+\frac{s}{w_u}\left(1+\frac{R_z}{R}\right)}$$

$$=-\frac{w_o}{s}\frac{1}{1+\frac{w_o}{w_u}}\frac{1+sR_zC}{1+s\frac{\left(1+\frac{R_z}{R}\right)}{w_u\left(1+\frac{w_o}{w_u}\right)}}$$



Need $\frac{\left(1+\frac{R_z}{R}\right)}{w_u\left(1+\frac{w_o}{w_u}\right)}=R_zC$

$$\Rightarrow R_z \cong \frac{1}{w_uC} \qquad \text{assuming} \quad w_u >> w_o$$