E4215: Analog Filter Synthesis and Design
Integrator nonidealities

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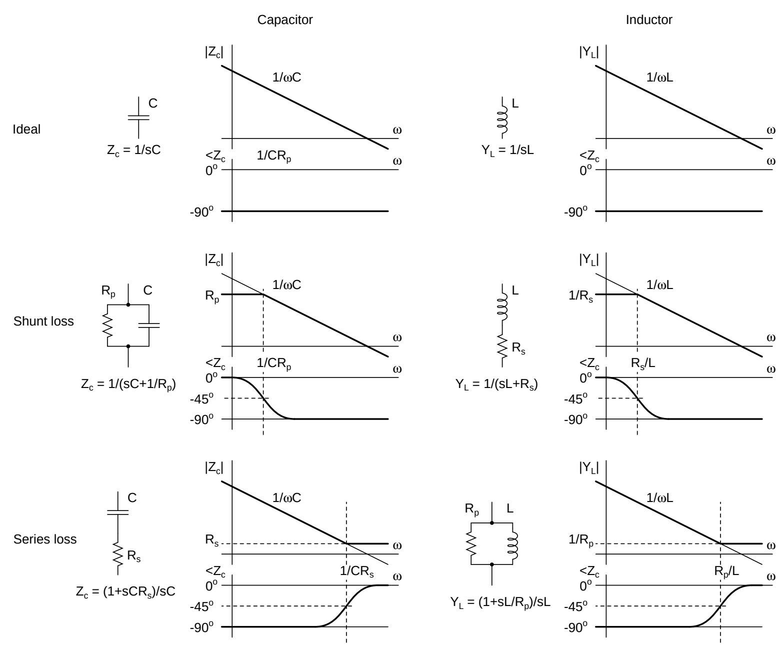

Figure 1: Capacitor and Inductor as integrators. Effect of series and shunt losses on the transfer function.

- Ideal integration: I-V in a capacitor or V-I in an inductor.

$$Z_C = \frac{1}{sC} \qquad Y_L = \frac{1}{sL}$$

- Shunt loss in a capacitor or series loss in an inductor: Low frequency limitation.

$$Z_C = \frac{1}{sC + 1/R_p} \qquad Y_L = \frac{1}{sL + R_s}$$

- Series loss in a capacitor or shunt loss in an inductor: High frequency limitation.

$$Z_C = \frac{1 + sCR_s}{sC} \qquad Y_L = \frac{1 + sL/R_p}{sL}$$

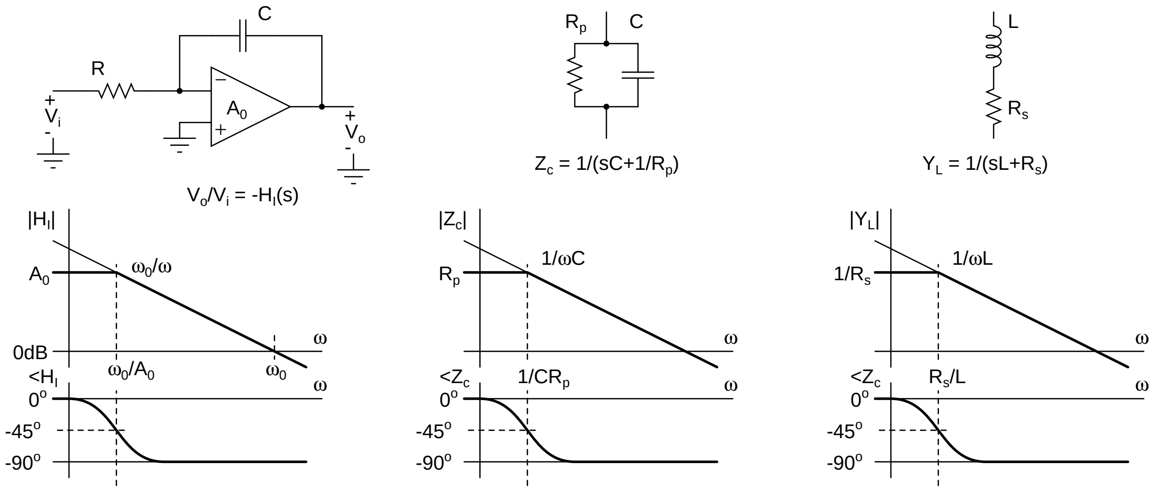

Figure 2: (a) Active integrator using an opamp with a finite dc gain, (b) Equivalent lossy capacitor (c) Equivalent lossy inductor

- Ideal integrator

$$\frac{V_o(s)}{V_i(s)} = -H_I(s) = -\frac{\omega_0}{s}$$

- Integrator using an opamp with a finite gain

$$\frac{V_o(s)}{V_i(s)} = -H_I(s) = -\frac{1}{s/\omega_0 + 1/A_0}$$

Note the similarity to a capacitor with a shunt loss or an inductor with a series loss.

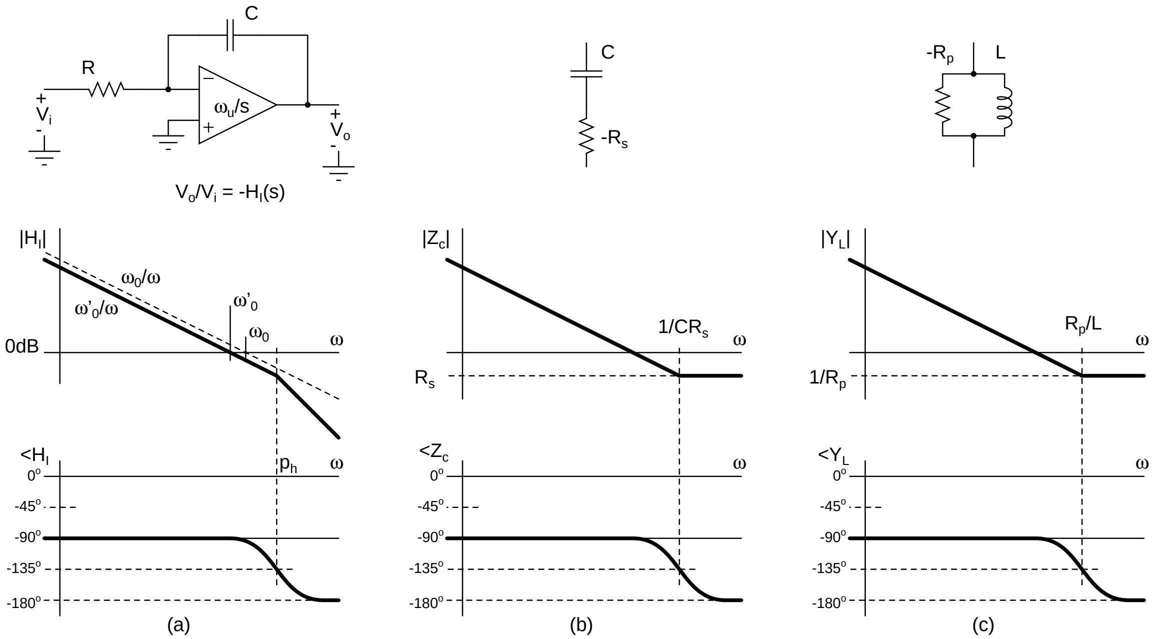

Figure 3: (a) Active integrator using an opamp with a finite unity gain frequency, (b) Capacitor with a negative series loss (c) Inductor with a negative shunt loss

- Ideal integrator

$$\frac{V_o(s)}{V_i(s)} = -H_I(s) = -\frac{\omega_0}{s} = -\frac{1}{sCR}$$

- Integrator using an opamp with a finite gain

$$\begin{aligned}
\frac{V_o(s)}{V_i(s)} &= -H_I(s) \\
&= -\frac{\omega_0'}{s}\frac{1}{1+s/p_h} \\
&= -\frac{\omega_0'}{s}\left(1-\frac{s}{p_h}\right) \qquad \left|\frac{\omega}{p_h}\right| \ll 1
\end{aligned}$$

$$\omega_0' = \frac{\omega_0}{1+\omega_0/\omega_u} \quad , \quad p_h = \omega_u + \omega_0$$

Note the similarity of phase response to a capacitor with a series negative loss or an inductor with a shunt negative loss.