Lecture 2 - C

Analog Signal Conditioning

EE 521: Instrumentation and Measurements

Lecture Notes Update on September 13, 2009

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Contents

1 Integrators and Differentiators

Integrators

See Figure 1

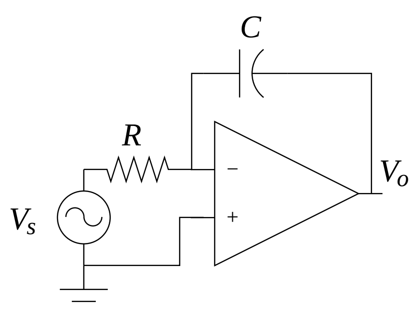

Figure 1: Integrator

- Drifts if there is dc or average levels in the signal.
- Will also drift due to current biases in the op-amp.

Differentiator

See Figure 2

- dc or average levels in the signal and op-amp biases pose no issues.
- High frequency issues.

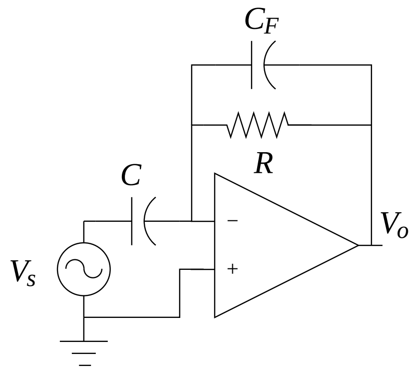

Figure 2: Practical differentiator

2 Active Filters

Common Filter Types

See Figure 3. Few remarks.

- Used to improve SNR.
- Reduce coherent interference.
- Required in systems with analog-to-digital converters.
- Used for smoothing.
- A measure of quality for bandpass filters is the Q factor defined as

$$Q = \frac{CenterFreq.}{Bandwidth} \tag{1}$$

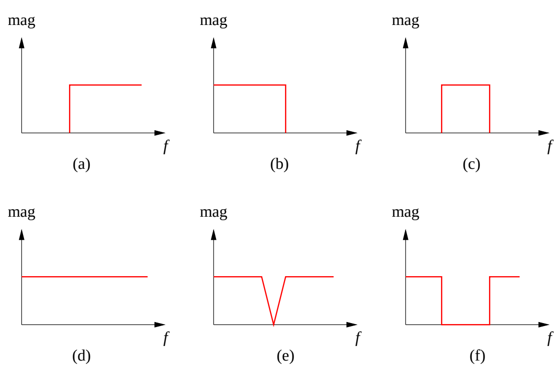

Figure 3: Sample of ideal filters: (a) lowpass; (b) highpass; (c) bandpass; (d) allpass; (e) notch; (f) bandstop

2 - C.5

2.1 Sallen-Key

Active Filters - Generalized Circuit

Analysis of the Sallen-Key Architecture http://focus.ti.com/lit/an/sloa024b/sloa024b.pdf See Figure 4. 2 - C.6

Non-Ideal Transfer Function

$$\frac{V_o}{V_s} = \left(\frac{c}{d}\right)\left[\frac{1}{1+\frac{1}{A_D(f)b}-\frac{d}{b}}\right] \tag{2}$$

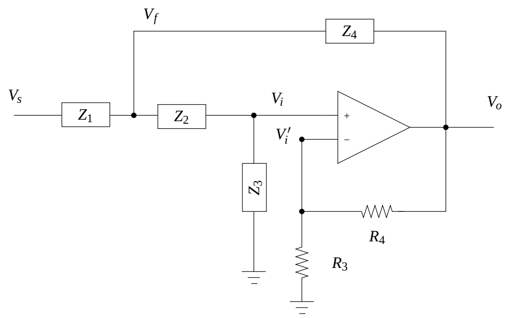

Figure 4: Generalized Sallen-Key Circuit

where

$$b = \frac{R_3}{R_3 + R_4}$$

$$c = \frac{Z_2Z_3Z_4}{Z_2Z_3Z_4 + Z_1Z_2Z_4 + Z_1Z_2Z_3 + Z_2Z_2Z_4 + Z_2Z_2Z_1}$$

$$d = \frac{Z_1Z_2Z_3}{Z_2Z_3Z_4 + Z_1Z_2Z_4 + Z_1Z_2Z_3 + Z_2Z_2Z_4 + Z_2Z_2Z_1}$$

2 - C.7

Ideal Transfer Function

$$\frac{1}{A_D(f)b} \approx 0$$

$$\frac{V_o}{V_s} = \frac{K}{\frac{Z_1Z_2}{Z_3Z_4} + \frac{Z_1}{Z3} + \frac{Z_2}{Z_3} + \frac{Z_1(1-K)}{Z_4} + 1} \quad (3)$$

where

$$K = \frac{R_3 + R_4}{R_3} \quad (4)$$

2 - C.8

Quadratic Form

$$s^2/\omega_n^2 + s_2\zeta/\omega_n + 1$$

where ω_n is the natural frequency and ζ is the damping factor. Also, $Q = 1/(2\zeta)$. 2 - C.9

Low-Pass Filter

$$Z_1 = R_1, \quad Z_2 = R_2, \quad Z_3 = \frac{1}{sC_1}, \quad Z_4 = \frac{1}{sC_2}, \quad K = 1 + \frac{R_4}{R_3} \quad (5)$$

$$\frac{V_o}{V_s} = \frac{K}{s^2(R_1R_2C_1C_2) + s(R_1C_1 + R_2C_1 + R_1C_2(1-K)) + 1} \quad (6)$$

let

$$\omega_n^2 = \frac{1}{R_1R_2C_1C_2}, \quad \zeta^2 = \frac{R_1R_2C_1C_2}{(R_1C_1 + R_2C_1 + R_1C_2(1-K))^2}$$

2 - C.10

High-Pass Filter

$$Z_1 = \frac{1}{sC_1}, \quad Z_2 = \frac{1}{sC_2}, \quad Z_3 = R_1, \quad Z_4 = R_2, \quad K = 1 + \frac{R_4}{R_3} \tag{7}$$

$$\frac{V_o}{V_s} = \frac{K(s^2(R_1R_2C_1C_2))}{s^2(R_1R_2C_1C_2) + s(R_2C_2 + R_2C_1 + R_1C_2(1-K)) + 1} \tag{8}$$

let

$$\omega_n^2 = \frac{1}{R_1R_2C_1C_2}, \quad \zeta^2 = \frac{R_1R_2C_1C_2}{(R_2C_2 + R_2C_1 + R_1C_2(1-K))^2}$$

2 - C.11

Bandpass Filter

$$Z_1 = R_1, \quad Z_2 = \frac{1}{sC_1}, \quad Z_3 = R_2, \quad Z_4 = R_3||C_2, \quad K = 1 + \frac{R_4}{R_3} \tag{9}$$

2 - C.12

2.2 Biquad Active Filters

Biquad Active Filter

See Figure 5.

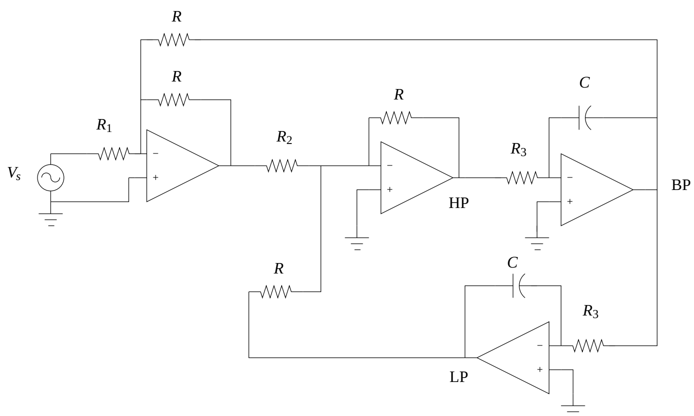

Figure 5: Biquad Active Filter

2 - C.13

Notch filter

See Figure 6

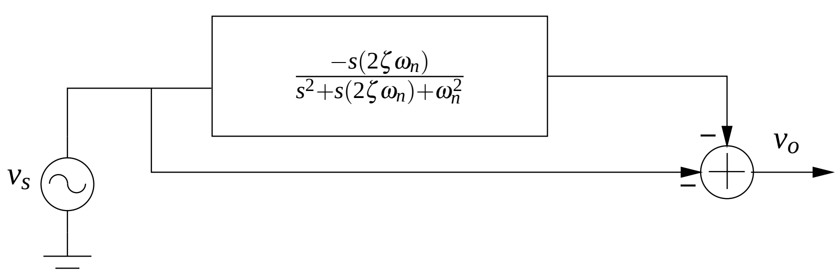

Figure 6: Biquad notch filter

2 - C.14

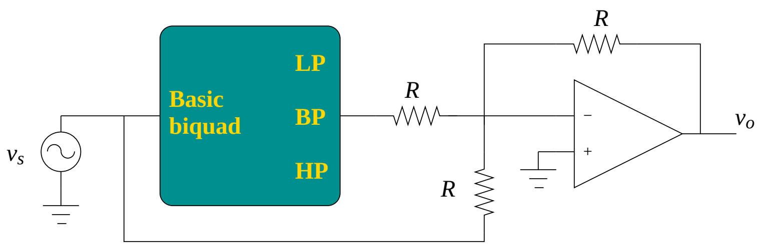

Figure 7: Biquad notch filter

Biquad notch filter

See Figure 7
where $R_1 = R$. 2 - C.15

Biquad allpass filter

See Figure 8

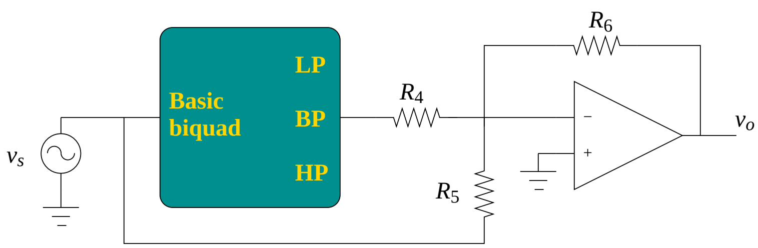

Figure 8: Biquad allpass filter

where $R_1 = R$, $R_5 = 2R_4$, and $R_6 = R_5$. 2 - C.16

2.3 Generalized Impedance Converter Active Filters

Generalized Impedance Converter (GIC)

See Figure 9.

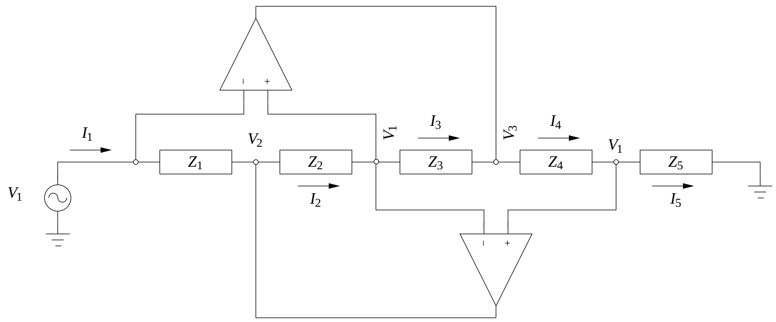

Figure 9: Generalized Sallen-Key Circuit

2 - C.17

GIC driving point impedance

$$Z_{11}(s) = V_1/I_1 = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4} \tag{10}$$

- If $Z_2 = 1/(sC_2)$ and the rest of the Zs are resistors

$$Z_{11} = s(C_2 R_1 R_3 / R_4) \tag{11}$$

where the equivalent inductance is given by

$$L_{eq} = C_2 R_1 R_3 / R_4 \tag{12}$$

- If Z_1 and Z_5 are made capacitors, then

$$Z_{11} = -1/(Ds^2) \tag{13}$$

where the D element is

$$D = C_1 C_5 R_2 R_4 / R_3 \tag{14}$$

2 - C.18

Filter examples using GIC

- Bandpass filter

$$V_o/V_s = \frac{sL_{eq}/R}{s^2 C I_{eq} + (sL_{eq}/R) + 1} \tag{15}$$

- Low-pass filter

$$V_o/V_s = \frac{1}{s^2 RD + sRC + 1} \tag{16}$$

2 - C.19

Bandpass Filter

See Figure 10

2 - C.20

Low-pass Filter

See Figure 11

2 - C.21

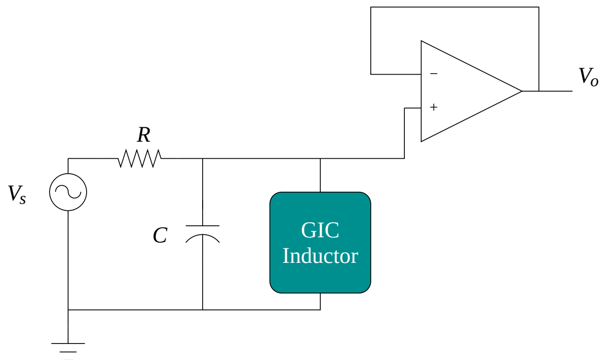

Figure 10: Bandpass filter using GIC

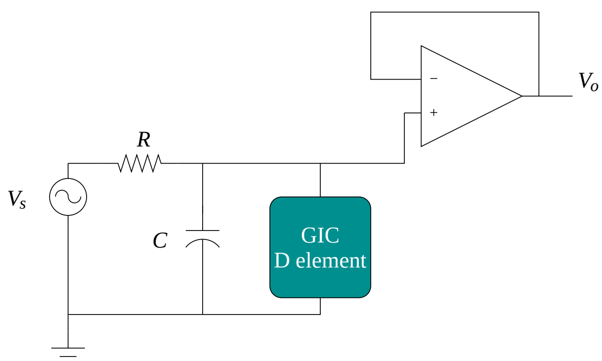

Figure 11: Lowpass filter using GIC