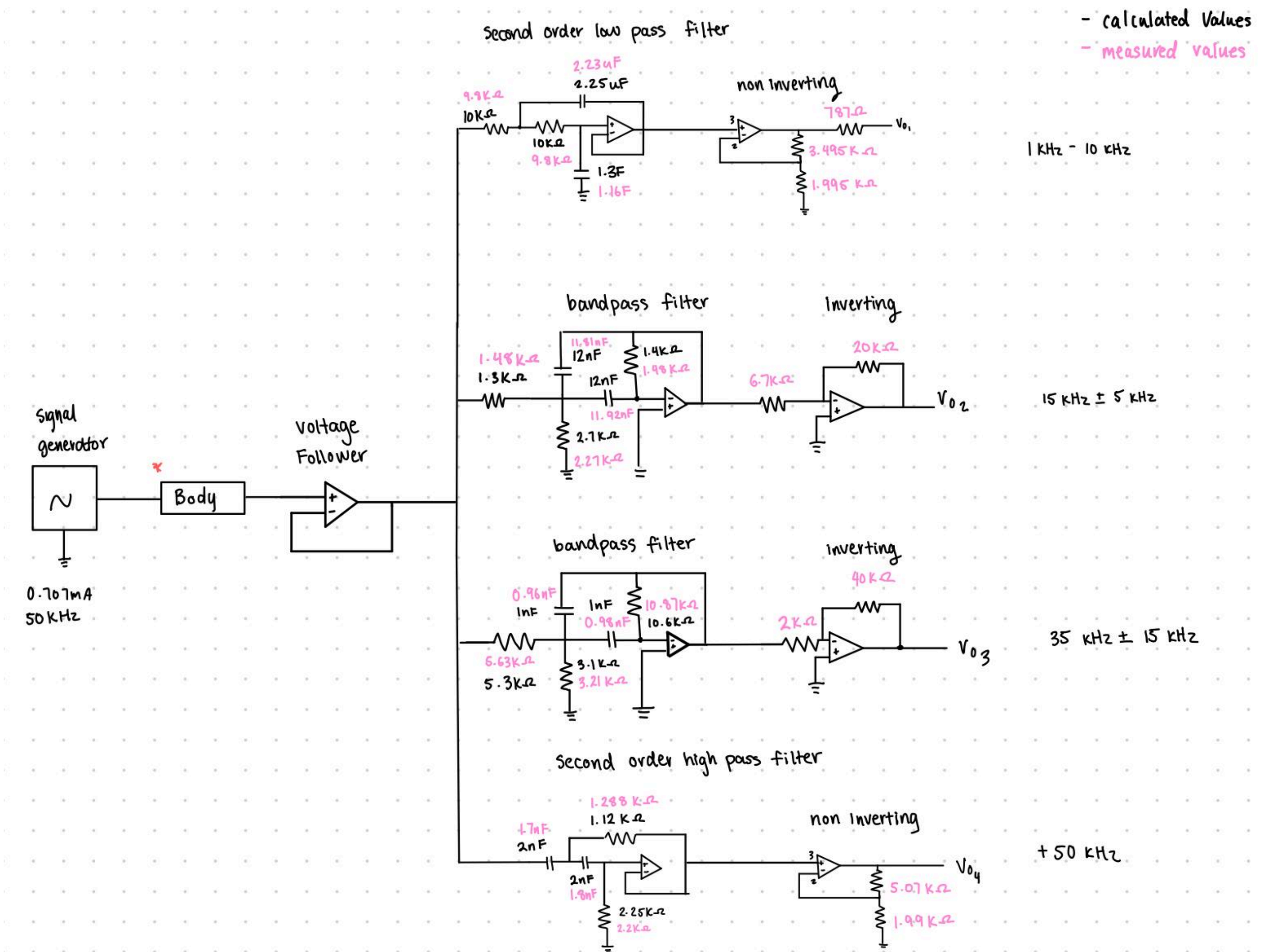
Circuit Schematics



Some Notes:

Low Pass Filter Components and Their Functions

1. **R1R_1R1 (Input Resistor):**
   - **Function:** Controls the input impedance and sets the initial conditions for the filter. It works with C3C_3C3 to create the first RC (resistor-capacitor) network.
   - **Effect of Change:**
     - **Increase:** Reduces the overall cutoff frequency, slowing the filter's response to high frequencies.
     - **Decrease:** Increases the cutoff frequency, allowing higher frequencies to pass through.
2. **R2R_2R2 (Feedback Resistor):**

- **Function:** Forms part of the second RC network with C4C_4C4 and determines the feedback loop's behavior.
- **Effect of Change:**
  - **Increase:** Reduces feedback, making the circuit less responsive to high frequencies and potentially increasing gain.
  - **Decrease:** Increases feedback, allowing more high-frequency content to influence the output.

3. **C3C_3C3 (Capacitor in Series):**
   - **Function:** Works with R1R_1R1 to create a high-pass stage (within the low-pass filter), setting the initial cutoff frequency of the filter.
   - **Effect of Change:**
     - **Increase (higher capacitance):** Lowers the cutoff frequency, blocking more high-frequency signals.
     - **Decrease (lower capacitance):** Raises the cutoff frequency, allowing more high-frequency signals.
4. **C4 (Feedback Capacitor):**
   - **Function:** Works with R2R_2R2 in the feedback loop to set the overall filter's response and ensure stability. This capacitor helps shape the second-order characteristics.
   - **Effect of Change:**
     - **Increase:** Lowers the cutoff frequency and sharpens the roll-off rate, making the filter more selective.
     - **Decrease:** Raises the cutoff frequency, allowing more high-frequency signals to pass.

Summary of Changes

- **Resistors (R1,R2R_1, R_2R1,R2)**: Primarily affect the cutoff frequency and the amount of feedback.
- **Capacitors (C3,C4C_3, C_4C3,C4)**: Control the cutoff frequency and the roll-off steepness.
- **Op-Amp:** Determines the amplification quality and stability of the filter.

How It Filters High Frequencies:

1. At **low frequencies**, C3C_3C3 and C4C_4C4 act like open circuits (high reactance), allowing the op-amp to amplify the signal with minimal attenuation.
2. At **high frequencies**, C3C_3C3 and C4C_4C4 act like short circuits (low reactance), diverting the signal away from the op-amp input and increasing negative feedback, which attenuates the output.

Step-by-Step Signal Flow:

1. **Input Signal:** ViV_iVi enters the circuit and passes through R1R_1R1, encountering C3C_3C3 which blocks high frequencies.

2. **Amplification:** The filtered signal reaches the op-amp, which amplifies the low-frequency components.
3. **Feedback Loop:** R2R_2R2 and C4C_4C4 adjust the op-amp's gain, suppressing high-frequency signals and ensuring stability.
4. **Output Signal:** The resulting VoV_oVo is a low-pass filtered version of ViV_iVi, with high-frequency components attenuated.

In Summary:

As the frequency increases:

1. C4C_4C4 provides a low-impedance path for the high-frequency components.
2. This increases the strength of the negative feedback.
3. The increased feedback reduces the op-amp's gain for high-frequency signals, effectively filtering them out.

Orion's 3 Rules for designing w/ Op Amps

1. Use the formula to determine if the output will swing positive or negative ($V_{out} = k(V^+ - V^-)$)
2. No current goes into the + and - terminals
3. If there is a component connecting Vout and V- (called feedback) then there is a virtual short between "+" and "-"
    a. If one of the input voltages are known, the other one will also be known
    b. common to see one of the inputs set to a known voltage, such as Vin or ground
    c. If there is no feedback then V+ ≠ V-.

Purpose of adding the voltage follower

The voltage follower right after the "Body" is essential for:
- Preventing signal distortion caused by loading effects.
- Preserving the amplitude of the signal.
- Ensuring efficient signal transfer to the filters by providing impedance matching.
- Isolating the "Body" from downstream circuit effects, maintaining signal integrity.

Component Calculations

Low-Pass Filter (1 - 10 kHz)

$f_0 = 5\text{kHz}$

Set $R_1 = R_2 = 10\text{k}\Omega$

$C_1 = C_2$

$$\omega_0^2 = \frac{1}{R_1R_2C_1C_2} \Rightarrow (2\pi f_0)^2 = \frac{1}{R_1R_2C_1C_2}$$

High-Pass (50+ kHz) $f_0 = 50\text{kHz}$ C_3 & $C_4 = 2\text{nF}$ $Q = 0.707$

$$\omega_0^2 = \frac{1}{R_1R_2C_3C_4} \qquad \frac{\omega_0}{Q} = \frac{R_1C_3(1-G) + C_4(R_1+R_2)}{R_1R_2C_3C_4}$$

$$\frac{2\pi f_0}{Q} = \frac{\frac{1}{C_1} + \frac{1}{C_2}}{R_4}$$

$$R_4 = \frac{Q(1/C_1 + 1/C_2)}{2\pi f_0} = \frac{0.707 \times \frac{2}{2\times10^{-9}}}{2\pi(50{,}000)}$$

$= 2250.45\ \Omega$

$= 2.25\ \text{k}\Omega$

$$R_3 = \frac{1}{4\pi^2(50{,}000)^2(2250)(2\times10^{-9})^2}$$

$= 1125.79\ \Omega$

$= 1.12\ \text{k}\Omega$

Bandpass: 15kHz ± 5 kHz

$f_0 = 15\text{kHz}$ $\Delta f = 10\text{kHz}$ $C_2 = C_4 = 12\text{nF}$ $G = 1$ $Q = \frac{f_0}{\Delta f} = \frac{15}{10} = 1.5$

$$R_1 = \frac{Q}{G2\pi f_0 C_4} = \frac{1.5}{2\pi(15000)(12\times10^{-9})} = 1326.29\Omega = 1.33\text{k}\Omega$$

$$R_5 = \frac{Q(C_2+C_4)}{2\pi f_0 C_2C_4} = \frac{1.5(2)(12\times10^{-9})}{2\pi(15000)(12\times10^{-9})^2} = 2652.58\Omega = 2.65\text{k}\Omega$$

$$R_3 = \frac{1}{(2\pi f_0)^2R_5C_2C_4 - \frac{1}{R_1}} = \frac{1}{(2\pi(1500))^2(2652.58)(12\times10^{-9})^2 - \frac{1}{1326.29}} = 1388.79\Omega = 1.39\text{k}\Omega$$

$R_1 = 1.3\text{k}\Omega$ $R_5 = 2.7\text{k}\Omega$ $R_3 = 1.4\text{k}\Omega$

Bandpass: 35kHz ± 15kHz

$f_0 = 35\text{kHz}$ $\Delta f = 30\text{kHz}$ $C_2 = C_4 = 1\text{nF}$ $G = 1$ $Q = \frac{f_0}{\Delta f} = \frac{35}{30} = \frac{7}{6}$

$$R_1 = \frac{Q}{G2\pi f_0 C_4} = \frac{7/6}{2\pi(35000)(1\times10^{-9})} = 5305.16\Omega = 5.3\text{k}\Omega$$

$$R_5 = \frac{Q(C_2+C_4)}{2\pi f_0 C_2C_4} = \frac{7/6(2)(1\times10^{-9})}{2\pi(35000)(1\times10^{-9})^2} = 10610.33\Omega = 10.6\text{k}\Omega$$

$$R_3 = \frac{1}{(2\pi f_0)^2R_5C_2C_4 - \frac{1}{R_1}} = \frac{1}{(2\pi(35000))^2(10610.33)(1\times10^{-9})^2 - \frac{1}{5305.16}} = 3080.43 = 3.1\text{k}\Omega$$

$R_1 = 5.3\text{k}\Omega$ $R_5 = 10.6\text{k}\Omega$ $R_3 = 3.1\text{k}\Omega$

Second Order Low-Pass
Vin = 5.4 V

Frequency (kHz)	Vout	Experimental dB Gain
1	12.5	7.290325063701758
5	12.5 V	7.290325063701758
7	12.1	7.0078322098696315
10	10.3 V	5.608869297644075
15	6.0 V	0.9151498112135013
20	3.8 V	-3.0522032641231682
25	2.6 V	-6.348408237043012
50	1.2	-13.064250275506875

Bandpass Filter (15kHz ± 5kHz)
Vin = 5.2 V

Frequency (kHz)	Vout	Experimental dB Gain
5	5.6	0.6436936674280247
10	7.2	2.826583055929386
12	7.4	3.0645675219235406
14	7.2	2.826583055929386
16	7	2.581893927589153
18	6.6	2.07081183814139
20	6.2	1.5277669172690942
25	5.4	0.3278083237633877
30	4.6	-1.064910239064503
50	3	-4.777641778302735

Bandpass Filter (35kHz ± 15kHz)
Vin = 5.3 V

Frequency (kHz)	Vout	Experimental dB Gain
10	3.5	-3.6041565050102675
20	5.9	0.9315228408271043
25	6.7	2.035978662000749
30	7	2.416443408269356
35	6.8	2.164660862108945
40	6.5	1.7727497408413304
45	6	1.0775076156570915

50	5.6	0.478243148108227 27
60	5.1	-0.3341138700570535
70	4.6	-1.2303607583843004

Second Order high-pass filter

Vin = 4.90V

Frequency (kHz)	Vout	Experimental dB Gain
30	3.8	-2.2082496682340715
40	5.71	1.3288005643466878
45	5.9	1.6131186322726108
50	5.5	1.003332189314603
55	5.3	0.6815957914455066
60	5	0.17547848615010309
65	4.7	-0.36196444185592436
70	4.4	-0.9348680708465247
80	3.9	-1.9826294600402905

Bode Plot