Passive High-Pass Filter

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***Abstract*—This report presents the design, analysis, and implementation of a passive third-order LC high-pass filter.**

***Index Terms*—**

I. Introduction

In physiological signal acquisition systems, such as ECG, EMG, or EEG, filtering is critical to isolate the desired biosignals from low-frequency noise and interference, including motion artifacts and baseline drift. A high-pass filter is particularly useful for eliminating these unwanted low-frequency components while preserving the integrity of higher-frequency biomedical signals. The third-order filter offers enhanced selectivity and steeper roll-off compared to lower-order designs, making it suitable for applications requiring precise frequency discrimination.

The ladder or Pi configuration of the filter illustrated in Fig. 1 is a common design choice for high-pass filters, as it provides a compact and efficient layout.

II. Methodology

A. Design Process

From "Table A-1 Element values for low-pass single-resistance-terminated lossless-ladder realizations" in *Introduction to the Theory and Design of Active Filters* [1], the following values are given for a 3rd-order butterworth low-pass filter with a 1 rad/s bandwidth terminated with a resistance of $R = 1\Omega$:

$$\begin{aligned} L_1 &= 1.5000 \\ C_2 &= 1.3334 \\ L_3 &= 0.5000 \end{aligned} \tag{1}$$

To transform the low-pass filter into a high-pass filter, the inductors become capacitors with $C = 1/L$ and the capacitors become inductors with $L = 1/C$. The values for the high-pass filter are thus:

$$\begin{aligned} C_1' &= \frac{1}{L_1} = 0.6667 \\ L_2' &= \frac{1}{C_2} = 0.7500 \\ C_3' &= \frac{1}{L_3} = 2.0000 \end{aligned} \tag{2}$$

To denormalize the filter such that the cutoff frequency is $f_c = 1$ kHz or $\omega_c = 2\pi f_c = 3141.59$ rad/s and with a load resistance of $R_L = 1$ kΩ, the component values should be scaled accordingly:

$$\begin{aligned} C_1'' &= \frac{C_1'}{R\omega_c} = 106.10 \text{ nF} \\ L_2'' &= \frac{RL_2'}{\omega_c} = 119.37 \text{ mH} \\ C_3'' &= \frac{C_3'}{R\omega_c} = 318.31 \text{ nF} \end{aligned} \tag{3}$$

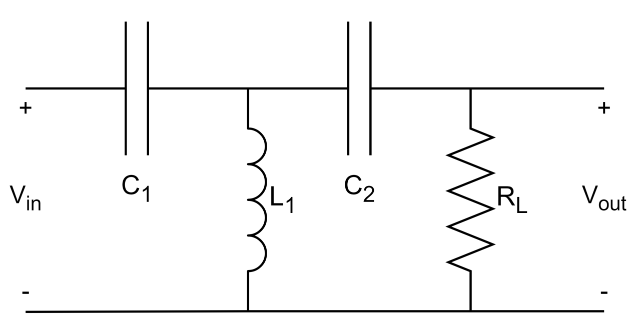

Fig. 1: Passive High-Pass Filter

B. Experimental Setup

To explore the difficulties of working with inductors, the single inductor in the design was built with two inductors in series, L_{11} and L_{12}. They were placed orthogonally to each other to minimize the coupling between them as shown in Fig. 2. To keep the circuit compact and simple, the components values were chosen to match the design values as closely as possible, however, given the available components and the coupling between the inductors, the measured values are not identical to the design values. The component values are shown in Table I.

The frequency response of the filter was measured by collecting the input and output voltages at octave intervals from 2 Hz to 20 MHz using the oscilloscope's function generator and probes connected to the input and output. The interval at which the expected cutoff frequency is located was measured with more detail, collecting data at 0.1 kHz intervals from 1 kHz to 2 kHz.

The roll-off rate was calculated as the maximum derivative of the gain with respect to frequency.

C. Simulation

The circuit was simulated using LTSpice to compare the measured results with the expected behavior of the filter. The simulation was set up to match the experimental mea-

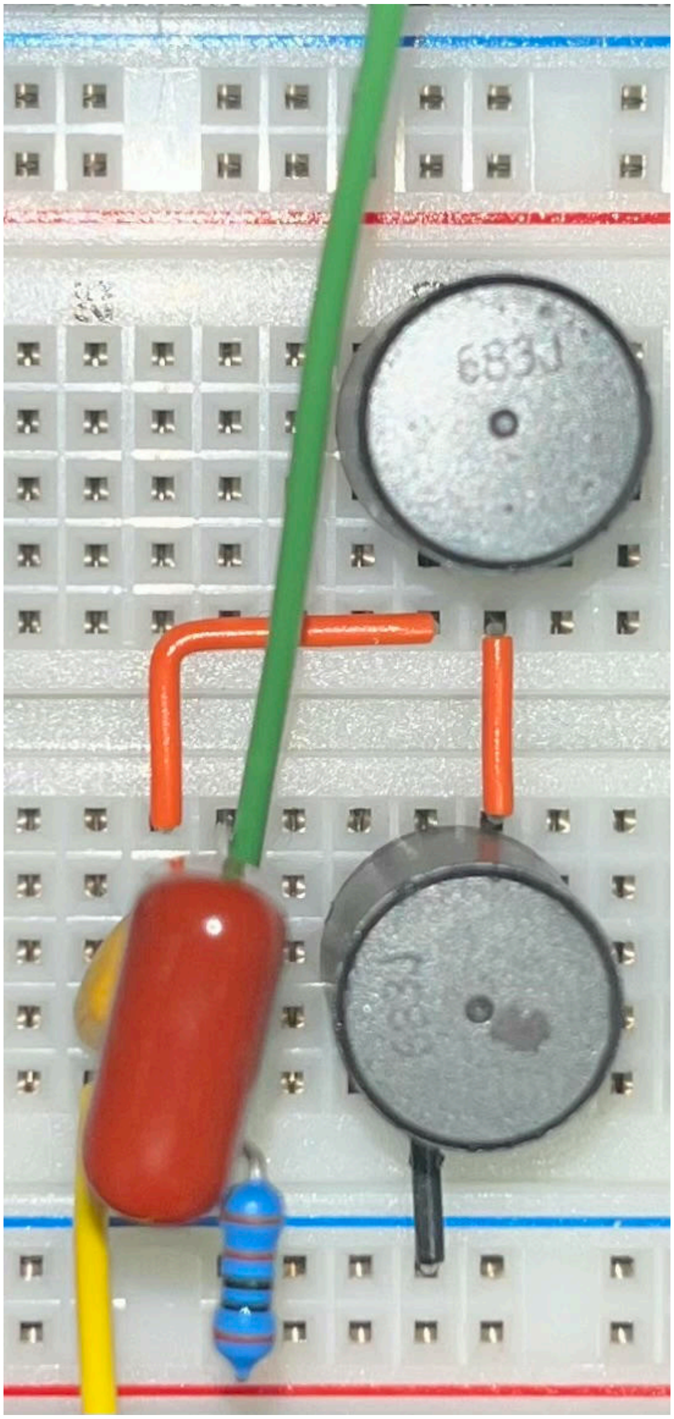

Fig. 2: Experimental Circuit: input at yellow wire, output at green wire. L_{11} is the top inductor with its pins direction facing southeast, L_{12} is the bottom inductor with its pins direction facing southwest.

sured component values, including the inductor's winding resistance.

III. Results and Discussion

A. *Frequency Response*

The collected measurements are given in Table II, and the frequency response is plotted in Fig. 3 with the simulated

TABLE I: Component Values

Component	Design	Ideal	Measured
C_1	106.10 nF	100 nF	93.9543 nF
C_2	318.31 nF	330 nF	354.231 nF
L_{11}	NA	68 mH	68.5271 mH
L_{12}	NA	68 mH	68.4791 mH
L_1	119.37 mH	NA	225.395 mH
R_{ind}	0 Ω	NA	104.016 Ω
R_L	1 kΩ	1kΩ	0.99853 kΩ

response for comparison. The measured frequency response crosses the -3 dB line at 1.218 kHz, which is only slightly lower than the simulated cutoff frequency of 1.419 kHz. The experimental frequency response also shows a plateau below 100 Hz which is likely due to the limited accuracy of the oscilloscope at low voltages, which is close to 110 mV at the output in this range. There is also an increase in the gain at high frequencies past around 1 MHz where Table II shows that the output does not deviate significantly, instead the input voltage appears to fall off.

B. *Roll-off Rate*

For a third-order filter, the expected roll-off rate is $20 \times 3 = 60$ dB / decade, which is consistent with the simulated roll-off rate shown in Fig. 4. However, the measured roll-off rate was found to be approximately 46.01 dB / decade, which is closer to the expected 40 dB / decade for a second-order filter. This may be again due to the oscilloscope's limited accuracy at low voltages, as Fig. 4 shows, the measured roll-off rate only begins to increase after 100 Hz, where at which point the simulated roll-off rate is already over 50 dB. The derivative values are given in Table III.

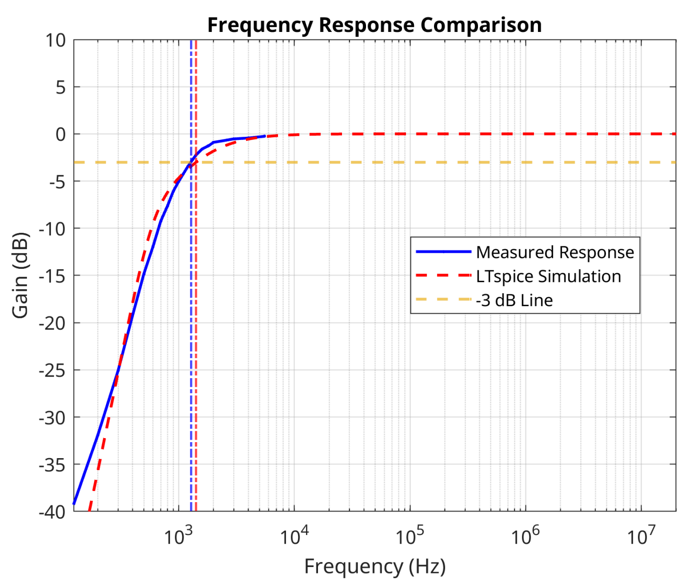

Fig. 3: Frequency Response

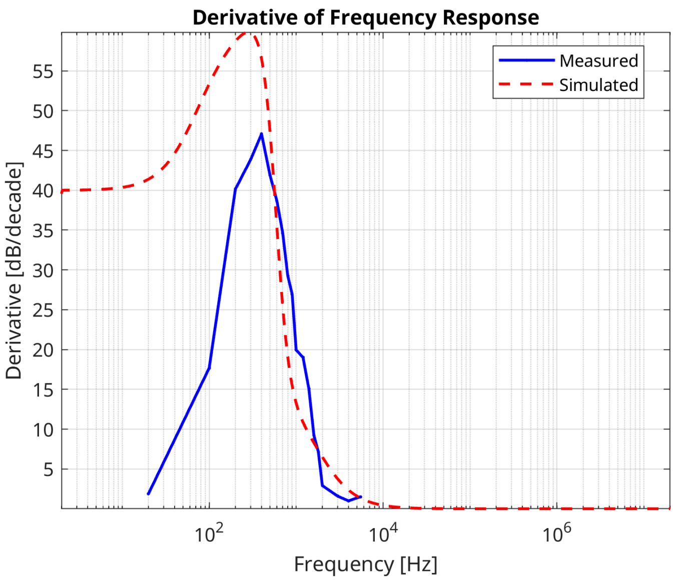

Fig. 4: Gain Derivative

IV. Appendix

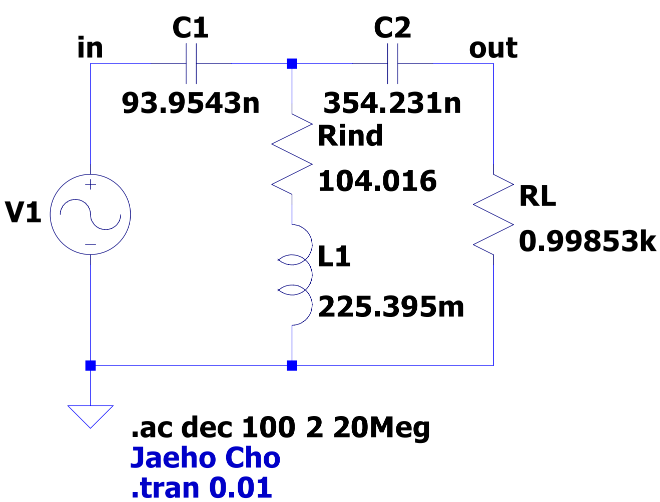

Fig. 5: LTSpice Schematic

TABLE II: Measured Frequency Response Values

f [Hz]	V_{in} [dB/decade]	V_{out} [dB/decade]	A_{linear}	A_{dB} [dB]
20	21.3	0.11	0.01	-45.74
100	21.3	0.16	0.01	-42.49
200	21.3	0.54	0.03	-31.92
300	21.3	1.19	0.06	-25.06
400	21.3	2.33	0.11	-19.22
500	21.3	3.86	0.18	-14.84
600	21.3	5.39	0.25	-11.94
700	21.1	7.28	0.35	-9.24
800	21.1	8.76	0.42	-7.64
900	21.1	10.5	0.5	-6.06
1000	20.9	11.7	0.56	-5.04
1200	20.7	13.9	0.67	-3.46
1400	20.7	15.9	0.77	-2.29
1600	20.3	16.9	0.83	-1.59
1800	20.3	17.5	0.86	-1.29
2000	20.3	18.3	0.9	-0.9
3000	20.3	19.1	0.94	-0.53
4000	20.3	19.3	0.95	-0.44
5500	20.3	19.7	0.97	-0.26

TABLE III: Gain Derivative Values

f [Hz]	Measured [dB/decade]	Simulated [dB/decade]
20	1.87	41.39
100	17.68	53.35
200	40.13	58.72
300	43.86	59.78
400	47.06	56.51
500	41.91	47.41
600	38.68	35.39
700	34.65	25.46
800	29.29	19.14
900	26.94	15.47
1000	19.96	13.28
1200	19	10.86
1400	15.07	9.4
1600	9.21	8.28
1800	7.15	7.34
2000	2.92	6.52
3000	1.59	3.76
4000	0.99	2.36
5500	1.52	1.34

References

[1] L. P. Huelsman and P. E. Allen, *Introduction to the Theory and Design of Active Filters*. New York: McGraw-Hill, 1980.