EE230: Analog Circuits Lab
Lab - 7

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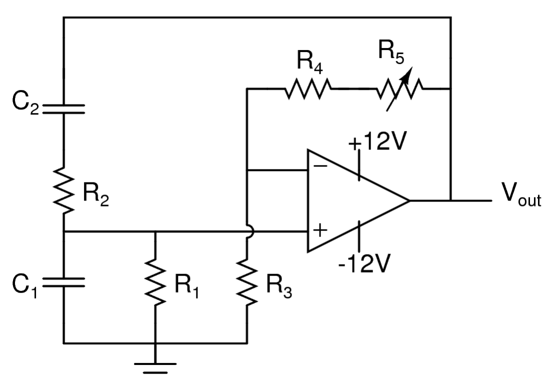
1 Wien Bridge Oscillator

1.1 Aim of the experiment

The aim of this experiment was to design a Wein Bridge Oscillator and observe it's frequency response.

1.2 Design

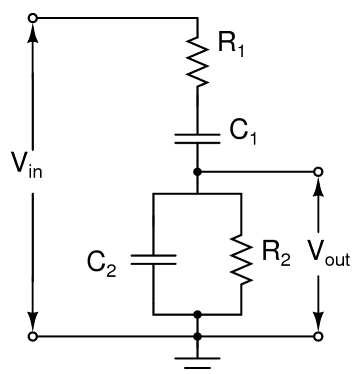
The design of the Wein Bridge Oscillator is shown below.



TL084 OpAmp IC was used for the circuit
±12V was used as supply voltages for the OpAmp

1.3 Experimental results

(a) Before building the Wein Bridge Oscillator, the following circuit was built and analysed:



here, $R_1 = R_2 = 10\text{k}\Omega$
and, $C_1 = C_2 = 10\text{nF}$

analysing the above circuit, by KVL:

$$V_{out} = \frac{V_{in}}{R_1 + \frac{1}{sC_1} + (\frac{R_2 \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}})} (\frac{R_2 \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}})$$

substituting $R_1 = R_2 = R$ and $C_1 = C_2 = C$ and simplifying:

$$V_{out} = \frac{V_{in}.sRC}{s^2R^2C^2 + 3sRC + 1}$$

thus, the gain G is given by:

$$G = \frac{V_{out}}{V_{in}} = \frac{sRC}{s^2R^2C^2 + 3sRC + 1}$$

substituting $s = j\omega$:

$$G = \frac{V_{out}}{V_{in}} = \frac{jRC\omega}{3jRC\omega + 1 - \omega^2R^2C^2}$$

thus,

$$|G| = |\frac{V_{out}}{V_{in}}| = \frac{RC\omega}{\sqrt{9R^2C^2\omega^2 + (1-\omega^2R^2C^2)^2}}$$

maximum gain occurs when $1 - \omega^2R^2C^2 = 0$ or,

$$\omega = \frac{1}{RC}$$

or,

$$f = \frac{1}{2\pi RC}$$

for the used circuit components, $f \approx 1.6kHz$
thus, at maximum gain, the gain is purely real; hence, there is no phase difference between V_{in} and V_{out} when the gain is maximum.

now, a $10V_{pp}$ sinusoidal input with varying frequency was applied to the circuit, the observed peak-to-peak V_{out} and the phase between them ϕ are tabulated below:

freq.	$V_{out(pk-pk)}$	ϕ
100Hz	1.34V	89.71°
200Hz	2.52V	80.41°
500Hz	5.28V	64.40°
750Hz	6.80V	50.81°
1kHz	8.00V	38.53°
2kHz	9.40V	20.12°
5kHz	9.80V	7.2°
10kHz	9.90V	2.02°
20kHz	9.90V	-1.15°
30kHz	9.90V	-4.76°

The observations are explained by the relation between V_{out} and V_{in} derived above.

(b) A Wein bridge oscillator generates sine waves using an OpAmp and a bridge network with resistors and capacitors.

1. **Phase Shift and Frequency Determination:**
    - Bridge and feedback networks introduce a phase shift.

- Circuit is designed for 0° total phase shift at the oscillation frequency.

2. **Op-Amp Operation:**
   - Op-amp amplifies the phase-shifted voltage difference.
   - Positive feedback sustains oscillations.
3. **Oscillation Initiation:**
   - Small disturbances initiate oscillations.
   - Feedback ensures stable sine wave output.
4. **Frequency Adjustment:**
   - Component values (R_f, C_f, R_1, R_2, C_1, C_2) determine frequency.
   - Fine-tuning for desired frequency.

(c) Deriving the frequency of oscillation of the Wein Bridge Oscillator: the voltage at the inverting terminal V_-:

$$V_- = \frac{V_{out} R_3}{R_4 + R_5 + R_3}$$

the voltage at the inverting terminal V_+:

$$V_+ = \frac{V_{out}}{R_2 + \frac{1}{sC_2} + (\frac{R_1 \frac{1}{sC_1}}{R_1 + \frac{1}{sC_1}})} (\frac{R_1 \frac{1}{sC_1}}{R_1 + \frac{1}{sC_1}})$$

simplifying,

$$V_+ = \frac{V_{out} R_1 C_2 s}{s^2 C_1 C_2 R_1 R_2 + s(R_1 C_2 + R_2 C_2 + R_1 C_1) + 1}$$

the voltage at the inverting and non-inverting terminal are equal or, $V_+ = V_-$

$$\frac{R_3}{R_4 + R_5 + R_3} = \frac{R_1 C_2 s}{s^2 C_1 C_2 R_1 R_2 + s(R_1 C_2 + R_2 C_2 + R_1 C_1) + 1}$$

substituting $s = j\omega$:

$$\frac{R_3}{R_4 + R_5 + R_3} = \frac{j R_1 C_2 \omega}{j\omega(R_1 C_2 + R_2 C_2 + R_1 C_1) + 1 - \omega^2 C_1 C_2 R_1 R_2}$$

the LHS is real, thus, the RHS must also be real
thus, $1 - \omega^2 C_1 C_2 R_1 R_2 = 0$
or,

$$\omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

or,

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

The circuit for the Wein Bridge Oscillator was built as shown above.
Values of the components used:
$R_1 = R_2 = R_3 = R_4 = 10\text{k}\Omega$
$R_5 = 20\text{k}\Omega$ pot.
$C_1 = C_2 = 10\text{nF}$
thus, the frequency of oscillations for this design is given by:

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = 1.59kHz$$

and, the peak-to-peak of V_{out}:

$$V_{out} = V_{sat.} - (-V_{sat.}) = +12V - (-12V) = +24V$$

(d) R_5 was adjusted suitably to obtain sustained oscillations.
The waveform observed on the DSO is shown:

The observed value of the frequency of oscillations:

$$f_o = 1.731kHz$$

and that of the peak-to-peak V_{out} is

$$V_{out} = 19.00V$$

(e) For $R_1 = R_2$ =5kΩ, the theoretical value of the oscillation frequency using the above formula is given by:

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} = 3.183kHz$$

The observed value of the frequency of oscillation in this case:

$$f_o = 3.32kHz$$

If R_1 and R_2 are not equal, the frequency will be

$$f_o = \frac{1}{2\pi\sqrt{R_1 R_2}C}$$

1.4 Conclusion and Inference

Thus, we successfully built and analysed the working of a Wein Bridge Oscillator. We also understood the effect of varying component values on the oscillations.

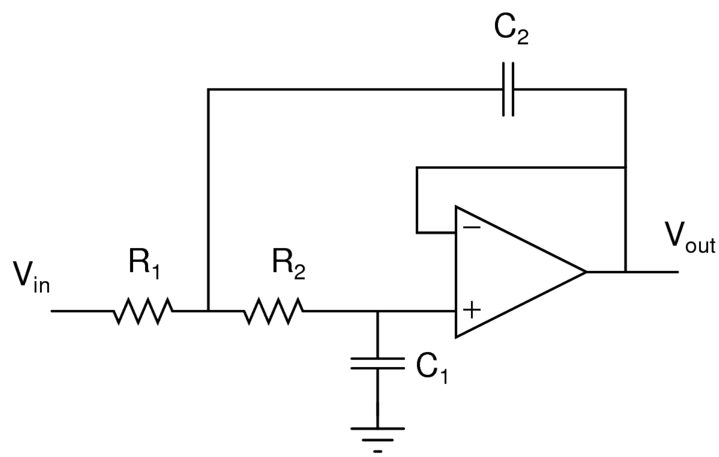
1.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

2 Sallen-Key (2-pole) Active Low-pass Filter

2.1 Aim of the experiment

The aim of this experiment was to design and analyse a Sallen-Key filter. We were required to bulid a Butterworth and a Chebyshev filter.



2.2 Design

The circuit for a Sallen-Key filter is shown in the figure below:

where, $R_2 \ = mR$ and $R_1 = R$

$C_2 = C$ and $C_1 = C$

now, the filter's cut-off frequency can be determined using the formula:

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}}$$

where, FSF is the Frequency Scaling Factor

also, the filter's Quality Factor Q is given by:

$$Q = \frac{\sqrt{mn}}{m+1}$$

using these expressions, we derive suitable values of m and n to obtain the desired cut-off frequency.

2.3 Experimental results

(a) **Butterworth Filter**

We have to design a Butterworth Filter with FSF=1, a cut-off frequency of $1kHz$ and quality factor of $\frac{1}{\sqrt{2}}$.

Circuit values: $R_2 = R = 18.4k\Omega$ and $C_1 = C = 0.01\mu$F

now, to derive values of m and n to set R_1 and C_2

we have,

$$Q = \frac{\sqrt{mn}}{m+1} = \frac{1}{\sqrt{2}}$$

simplifying,

$$m^2 + 2m + 1 = 2mn$$

also,

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} = 1kHz$$

simplifying this further gives,

$$mn = 0.748$$

thus, solving for m and n gives:

$$m = 0.223$$

and

$$n = 3.35$$

thus, we have

$$R_1 = mR = 4.1k\Omega$$

$$R_2 = R = 18.4k\Omega$$

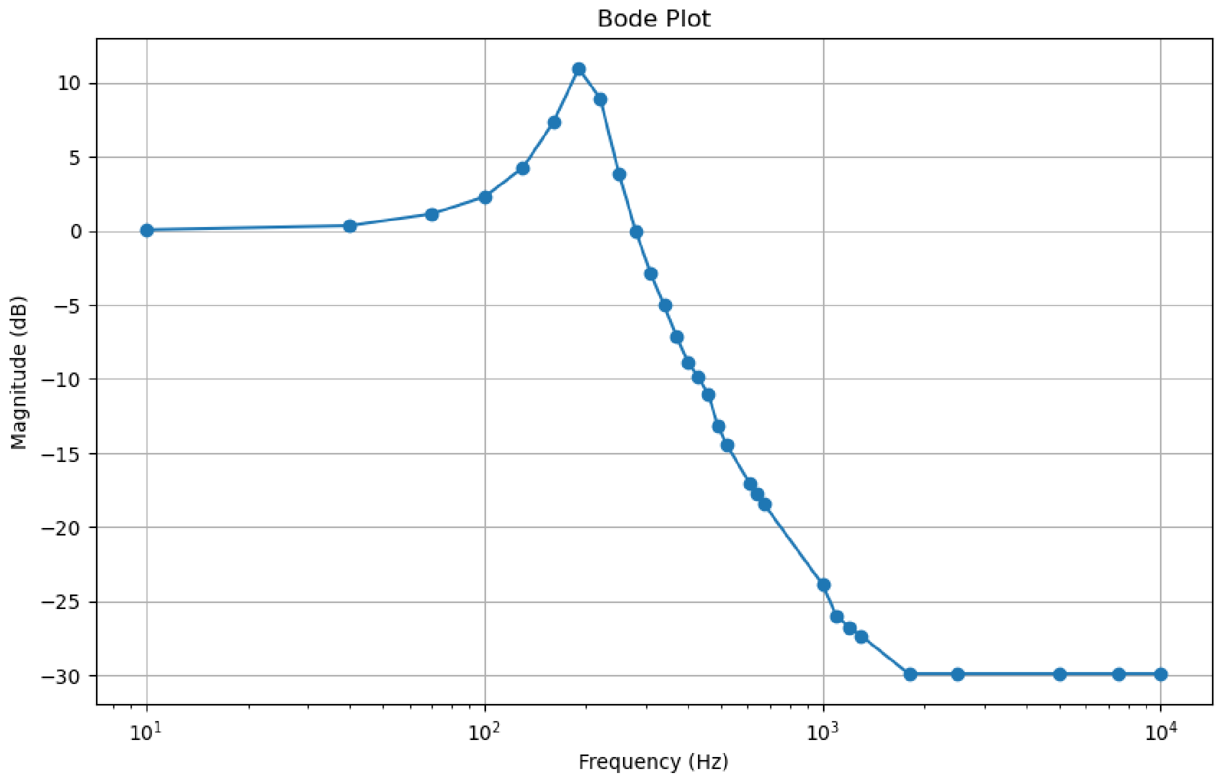
$$C_1 = C = 0.01\mu F$$

$$C_2 = nC = 0.0335\mu F$$

The frequency response of the filter, the frequency and observed peak-to-peak output voltages on applying a $1V_{pp}$ input are tabulated in the next page.

freq.	$\lvert V_{out(pk-pk)} \rvert$
10Hz	1.008V
40Hz	1.04V
70Hz	1.14V
100Hz	1.30V
130Hz	1.63V
160Hz	2.32V
190Hz	3.52V
220Hz	2.80V
250Hz	1.56V
280Hz	1.00V
310Hz	0.72V
340Hz	0.56V
370Hz	0.44V
400Hz	0.36V
430Hz	0.32V
460Hz	0.28V
490Hz	0.22V
520Hz	0.19V
610Hz	0.14V
640Hz	0.13V
670Hz	0.12V
1.0kHz	0.064V
1.1kHz	0.050V
1.2kHz	0.046V
1.3kHz	0.043V
1.8kHz	0.032V
2.5kHz	0.032V
5.0kHz	0.032V
7.5kHz	0.032V
10.0kHz	0.032V

The Bode Plot of the Butterworth filter, based on the tabulated values is shown below:



(b) **Chebyshev Filter**

We have to design a Chebyshev Filter with $FSF = 0.8414$, a cut-off frequency of $1kHz$ and quality factor of 1.3049.

Circuit values: $R_2 = R = 7.32k\Omega$ and $C_1 = C = 0.01\mu$F

now, to derive values of m and n to set R_1 and C_2

we have,

$$Q = \frac{\sqrt{mn}}{m+1} = 1.3049$$

also,

$$f_c \times FSF = \frac{1}{2\pi RC\sqrt{mn}} = 1kHz \times 0.8414$$

thus, solving for m and n gives:

$$m = 0.98$$

and

$$n = 6.81$$

thus, we have

$$R_1 = mR = 7.18k\Omega$$

$$R_2 = R = 7.32k\Omega$$

$$C_1 = C = 0.01\mu F$$

$$C_2 = nC = 0.0681\mu F$$

The frequency response of the filter, the frequency and observed peak-to-peak output voltages on applying a $1V_{pp}$ input are tabulated from the next page:

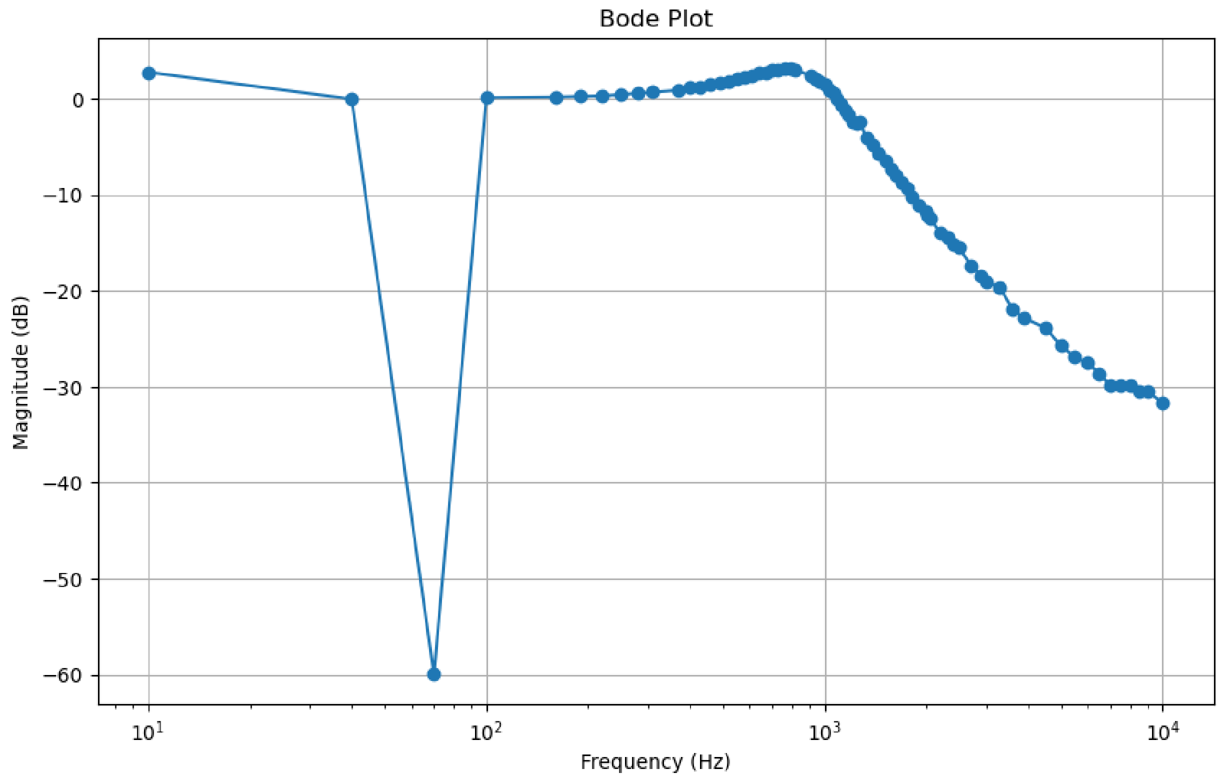
freq.	$\lvert V_{out(pk-pk)} \rvert$
10Hz	1.38V
40Hz	1.00V
70Hz	1.008m
100Hz	1.016V
160Hz	1.024V
190Hz	1.032V
220Hz	1.040V
250Hz	1.056V
280Hz	1.072V
310Hz	1.086V
370Hz	1.112V
400Hz	1.144V
430Hz	1.160V
460Hz	1.192V
490Hz	1.216V
520Hz	1.240V
550Hz	1.272V
580Hz	1.304V
610Hz	1.326V
640Hz	1.360V
670Hz	1.380V
700Hz	1.416V
730Hz	1.424V
760Hz	1.432V
790Hz	1.440V
820Hz	1.424V
910Hz	1.32V
940Hz	1.28V
970Hz	1.24V
1kHz	1.19V

1.03kHz	1.12V
1.06kHz	1.072V
1.09kHz	1.008V
1.12kHz	0.944V
1.15kHz	0.88V
1.18kHz	0.832V
1.21kHz	0.764V
1.24kHz	0.752V
1.27kHz	0.762V
1.33kHz	0.630V
1.39kHz	0.576V
1.45kHz	0.520V
1.51kHz	0.48V
1.57kHz	0.432V
1.63kHz	0.4V
1.69kHz	0.368V
1.75kHz	0.344V
1.81kHz	0.312V
1.90kHz	0.280V
1.99kHz	0.260V
2.02kHz	0.248V
2.05kHz	0.240V
2.2kHz	0.2V
2.3kHz	0.192V
2.4kHz	0.176V
2.5kHz	0.168V
2.7kHz	0.136V
2.9kHz	0.120V
3.0kHz	0.112V
3.3kHz	0.104V
3.6kHz	0.080V

3.9kHz	0.072V
4.5kHz	0.064V
5.0kHz	0.052V
5.5kHz	0.045V
6.0kHz	0.042V
6.5kHz	0.037V
7.0kHz	0.032V
7.5kHz	0.032V
8.0kHz	0.032V
8.5kHz	0.030V
9.0kHz	0.030V
10.0kHz	0.026V

Table. Frequency Response of the Chebyshev Filter

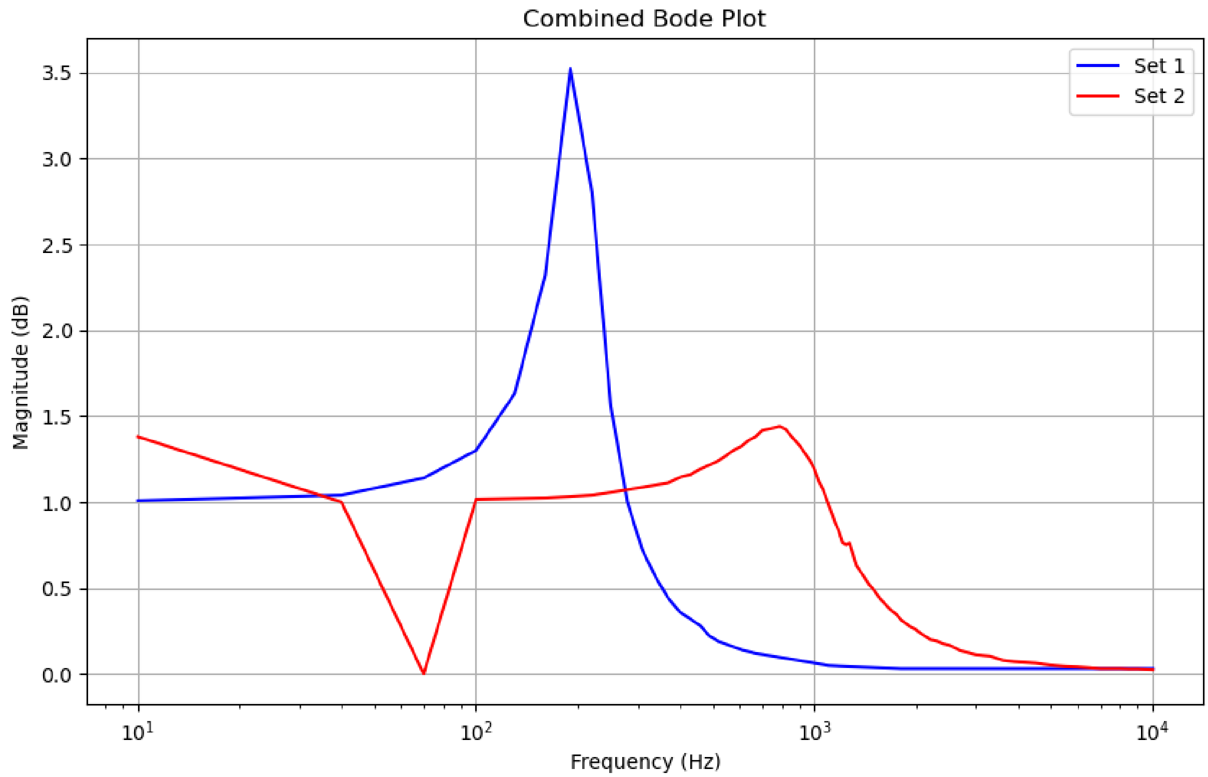
The Bode Plot of the Chebyshev filter, based on the tabulated values is shown on the next page:



2.4 Conclusion and Inference

Thus, we successfully designed a Butterworth and Chebyshev filter of the required frequency and analysed it's frequency response.

The combined Bode Plot of both the filters is shown below:



From the above graph, we can infer the following:

- The Butterworth filter shows a smooth, monotonic decrease, while the Chebyshev filter shows ripples in the pass-band.
- The Chebyshev filter has a steeper roll-off.

2.5 Experiment completion status

All parts of this experiment were successfully completed in the lab.

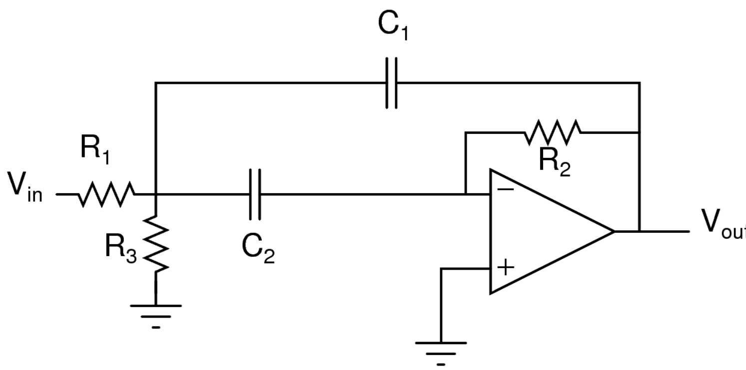
3 Multiple-feedback Active Band-Pass Filter

3.1 Aim of the experiment

The aim of this experiment was to design and build a Multiple-feedback Active Band-Pass Filter.

3.2 Design

The circuit for the Band-Pass filter is shown in the figure below.



now, the center frequency of the filter can be determined by the formula:

$$f_c = \frac{1}{2\pi C}\sqrt{\frac{R_1 + R_3}{R_1 R_2 R_3}}$$

the filter's Quality Factor Q is given by:

$$Q = \pi f_o C R_2$$

also, the Bandwidth of the filter is given by:

$$BW = \frac{f_o}{Q}$$

3.3 Experimental results

(a) Circuit values:
$R_1 = 68k\Omega$, $R_2 = 180k\Omega$ and $R_3 = 2.7k\Omega$
$C_1 = C_2 = C = 0.01\mu\text{F}$

(b) Thus, for the above circuit values,
the calculated center frequency of the filter:

$$f_c = \frac{1}{2\pi C}\sqrt{\frac{R_1 + R_3}{R_1 R_2 R_3}} \approx 736.13Hz$$

the filter's Quality Factor Q is given by:

$$Q = \pi f_o C R_2 \approx 4.16$$

also, the Bandwidth of the filter is given by:

$$BW = \frac{f_o}{Q} = \frac{736.13}{4.16} \approx 176.95Hz$$

3.4 Conclusion and Inference

Thus, we analyse the filter response of a Multiple-feedback
Active Band-Pass filter.

3.5 Experiment completion status

I was able to set up the circuit successfully, but didn't have time to take down the readings due to a component malfunction while performing the second experiment.