EE230: Experiment 5
Observing frequency response of a filter in time domain

Hitesh Kandala, 180070023

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1 Overview of the experiment

1.1 Aim of the experiment

The aim of the experiment is to observe frequency response of a High pass filter by implementing a sweep sine wave generator.

1.2 Theory

To measure frequency response, we need sweep sine wave generator (that generates sinusoidal signal whose frequency can be varied linearly keeping amplitude constant) as shown below.

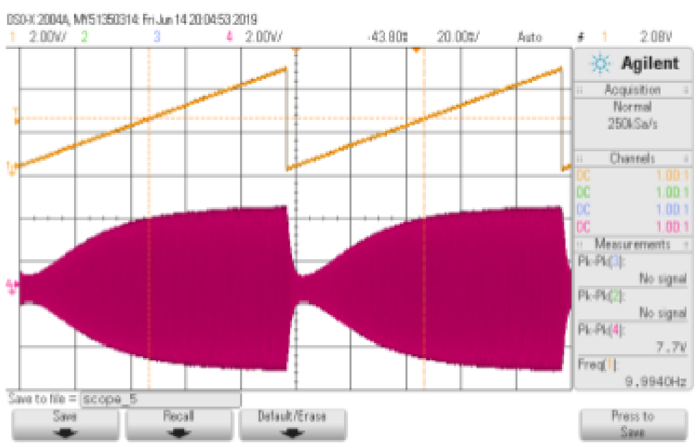


Figure 1: HIGH PASS FILTER

Oscillators are circuits that produce periodic waveforms without any input signal. Fig. 2 demonstrates a basic negative feedback system in which V_{IN} is the input voltage, V_{OUT} is the output voltage from the amplifier block with gain A and β as the feedback factor, that is fed back to the summing junction. E represents the error signal that is equal to the summation of the feedback factor and the input voltage.

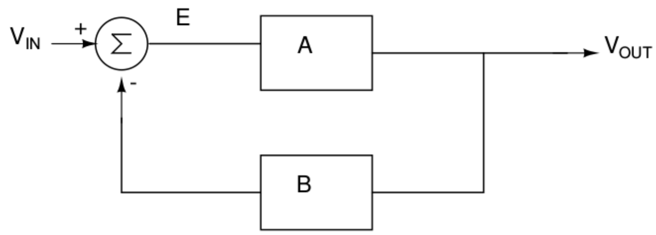


Figure 2: Block diagram of feedback network

$$E = V_{IN} - \beta V_{OUT} \tag{1}$$

$$V_{OUT} = AE = A(V_{IN} - \beta V_{OUT}) \tag{2}$$

$$A_f = \frac{V_{OUT}}{V_{IN}} = \frac{A}{1 + A\beta} \tag{3}$$

When A$\beta = 1\angle - 180^o$, the denominator term becomes 0 and the gain with feedback, becomes infinite. This means infinitesimal signal can provide an output voltage. When the condition for loop gain and phase shift is satisfied, the circuit produces output without an input signal. This is *Barkhausen Criterion* for sustained oscillations.

In practical circuits, however, it is found that for the loop gain Aβ, even if made equal to unity, the oscillations die out exponentially as the devices used for amplification are nonlinear in nature and cause the gain to reduce from their nominal value resulting in oscillations to cease. Hence; the loop gain Aβ is made slightly greater than one to build up oscillations. The growing oscillations are then limited by the non-linearity of the circuit elements. The automatic gain control circuits are also often used to stabilise the amplitude of oscillations to result in less distortion.

1.2.1 Wien Bridge Oscillator

The Wien bridge oscillator is one of the simplest oscillators. Fig.2 shows the basic Wien bridge circuit configuration. OPAMP is used as the amplifying device and the Wien Bridge is used as the feedback element.

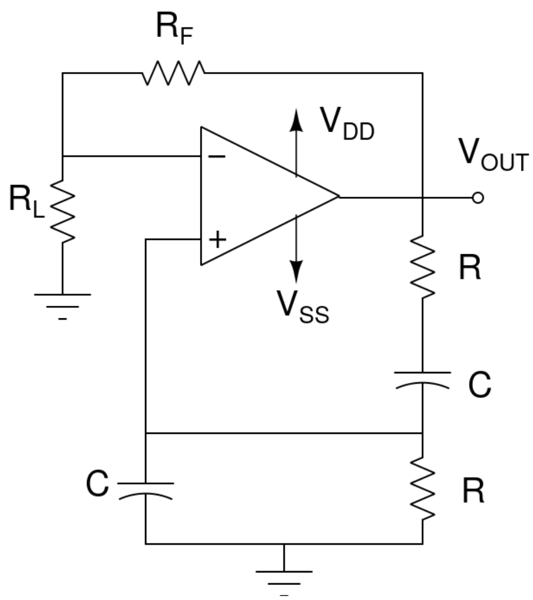


Figure 3: Wien Bridge Oscillator

The OPAMP is used in non-inverting mode that provides a phase shift of 0^o . One can expect that the phase shift introduced by the feedback network also to be equal to 0^o at the frequency of oscillations. The frequency of oscillations is,

$$f = \frac{1}{2\pi RC} \tag{4}$$

This condition comes from solving for V_f i.e. the feedback voltage

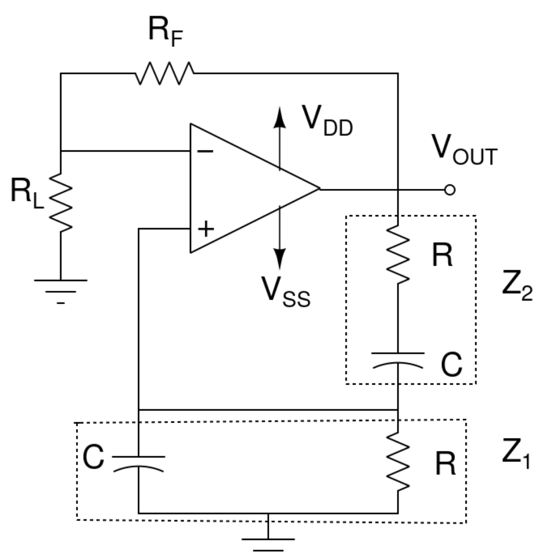


Figure 4: Analysis of Wien Bridge Oscillator

The feedback voltage is given by,

$$V_f = \frac{Z_1}{Z_1 + Z_2} V_{OUT} \tag{5}$$

where,

$$Z_1 = \frac{R}{1+RCS} \tag{6}$$

$$Z_2 = R + \frac{1}{CS} \tag{7}$$

Substituting these values in Eq. 5 we get,

$$V_f = \frac{\frac{R}{1+RCS}}{\frac{R}{1+RCS} + R + \frac{1}{CS}} V_{OUT} \tag{8}$$

Substituting the value of S = $j\omega$ and simplifying we get,

$$V_f = \frac{j\omega RC}{1 + 3j\omega RC - \omega^2 R^2 C^2} V_{OUT} \tag{9}$$

To ensure phase shift of 0^o by the feedback network, $1 - \omega^2 R^2 C^2 = 0$, which leads to

$$\omega = \frac{1}{RC} \rightarrow f = \frac{1}{2\pi RC} \tag{10}$$

This happens for

$$V_f = \frac{V_{OUT}}{3} \tag{11}$$

This implies that the non-inverting gain of the amplifier should be slightly greater than 3 so that the loop gain condition is satisfied.

2 Experimental results

Procedure

- The oscillating part of the Wein Bridge Oscillator was assembled and Bode plots of amplitude and frequency response were plotted with frequency ranging from 100Hz to 30kHz for $10V_{p-p}$ sine wave input.
- The Wien Bridge Oscillator was constructed. potentiometer at R_5 was adjusted to get sustained sinusoidal oscillations at the output.
- We then aimed to vary R_1 and R_2 with voltage. For this we set up a different circuit with an LDR and op-amp, and measure R_{out} of LDR with changes in input voltage.
- To generate sweep we connected $LED - LDR's$ in place of R_1 and R_2 of Wien Bridge Oscillator.Hence, now the frequency was dependent on resistance controlled by input frequency.
- A negative feedback loop was added so the the amplitude remains same with variation in frequency caused due to non-idealities of OP-AMP.
- We now connect this Sweep Generator to the second order Sallen Key high pass filter circuit and observe voltage wave-forms on the DSO.

2.1 Non-inverting Feedback Network of Wien Bridge Oscillator

Observations and Inferences

The feedback network is shown below:

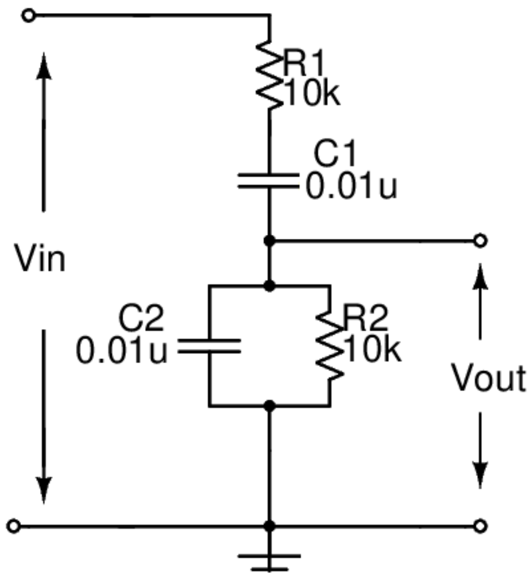
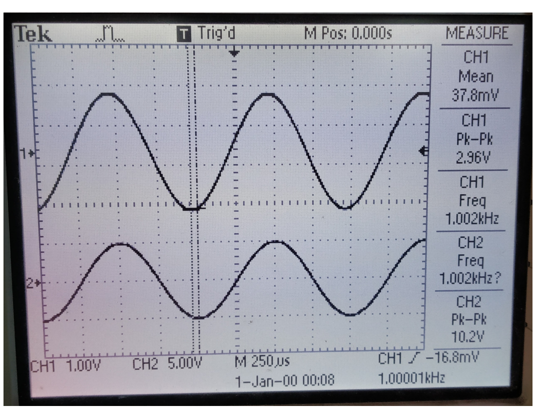


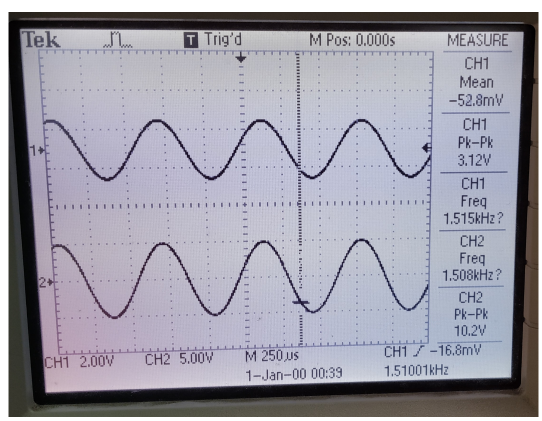
Figure 5: Positive feedback network of Wien Bridge Oscillator

The V_{out} vs V_{in} relation is given by equation 3,

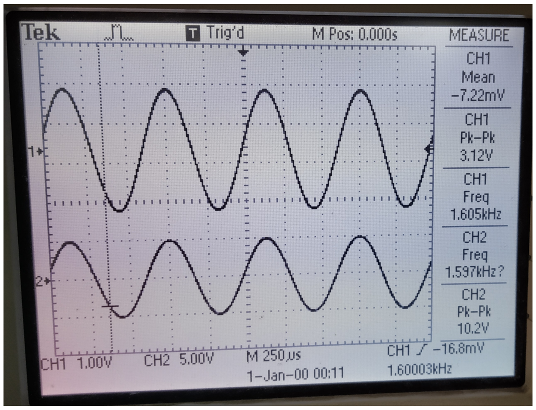
The waveform of V_{out} for different frequencies on application of a 10 V_{p-p} sine wave input is shown below:



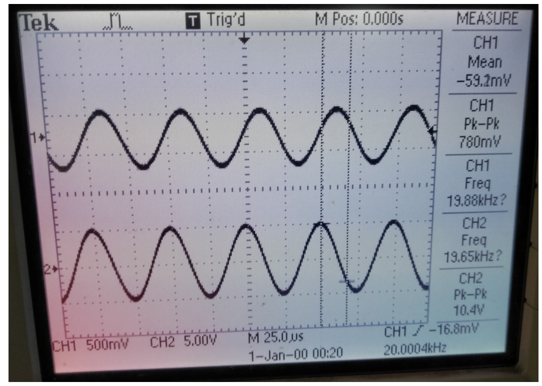
(a) f = 1kHz



(b) f = 1.51kHz



(a) f = 1.6kHz



(b) f = 20kHz

The magnitude Bode plot obtained for the above circuit is as plotted below:

ω(kHz)	V_{out} (V)	$V_{in}(V)$
0.1	0.632	10.2
0.5	2.32	10.2
0.9	2.88	10.2
1	2.96	10.2
1.2	3.04	10.2
1.4	3.12	10.2
1.53	3.12	10.2
1.59	3.12	10.2
1.8	3.12	10.2
2.2	3.04	10.2
3	2.88	10.6
10	1.44	10.6
15	1.02	10.4
20	0.78	10.4
30	0.512	10.4

Table 1: Observation Table

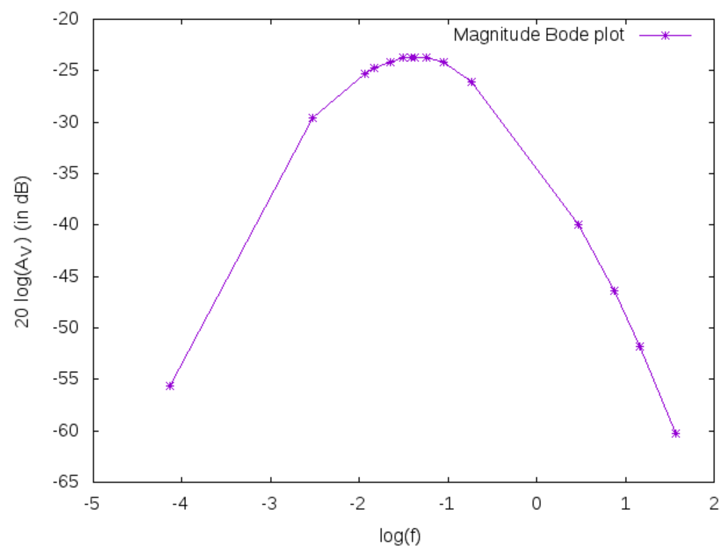


Figure 8: amplitude response

The corresponding phase Bode plot is shown below.

ω(kHz)	Δt (V)	ϕ deg
0.1	1800	64.8
0.5	220	39.6
1	40	14.4
1.59	0	0
1.8	-10	-6.48
3	-26	-28.08
10	-18	-64.8
15	-12	-64.8
20	-10	-72
30	-7	-75.6

Table 2: Observation Table

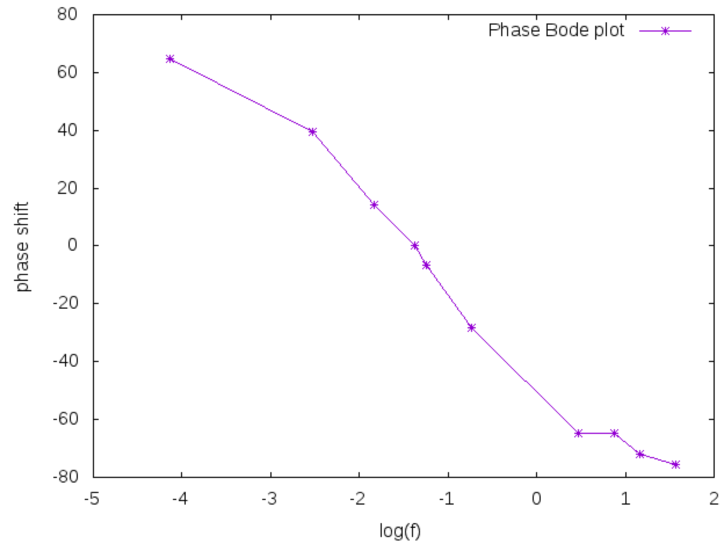


Figure 9: phase response

∗ The maximum gain obtained from magnitude bode plot is 0.305 at the frequency of 1.59kHz.

∗ The phase difference between V_{in} and V_{out} for maximum gain is 0.

2.2 Wien Bridge Oscillator

Observations and Inferences

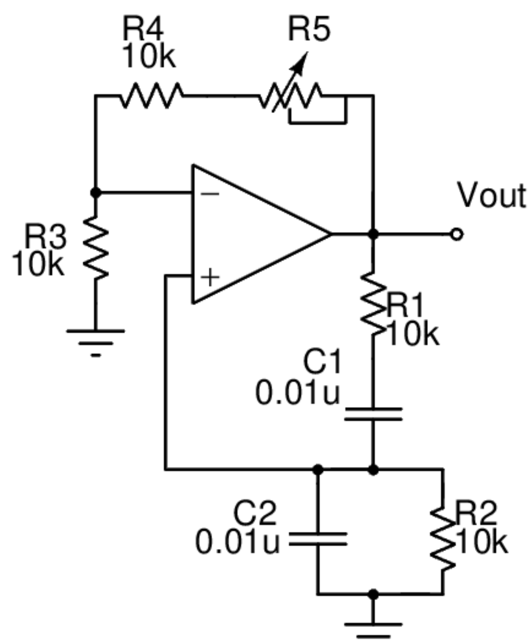


Figure 10: Circuit of wien bridge oscillator

The op-amp used in the above circuit is TL084 and the ideal values of the passive elements used are $R_1 = R_2 = 10k\Omega$, $C_1 = C_2 = 0.01\mu F$, $R_3 = R_4 = 10k\Omega$, $R_5 = 100k\Omega$ pot with +12V and -12V supply.

Therefore the theoretical value of frequency of the Wien Bridge Osclillator is

$$f = \frac{1}{2\pi RC} \tag{12}$$
$$= \frac{1}{2\pi \times 10k \times 0.01\mu F} \tag{13}$$
$$= 1.591kHz \tag{14}$$

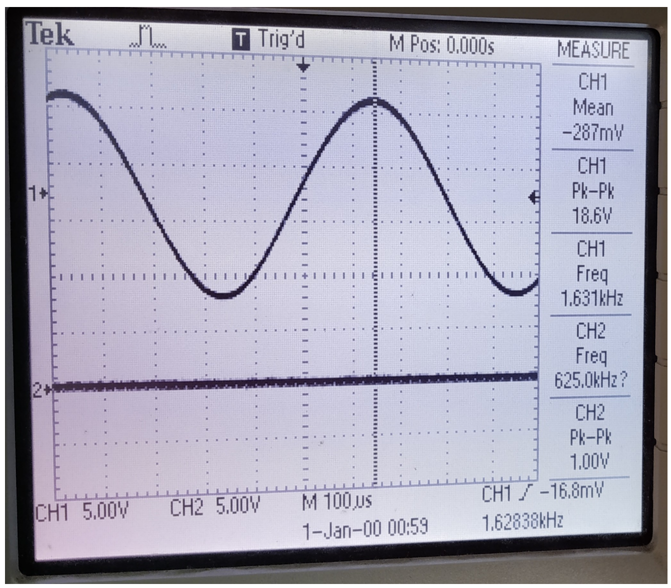


Figure 11: Wien Bridge stable oscillation waveform

The actual values of the resistances used are $R_1 = 9.78k\Omega$, $R_2 = 9.68k\Omega$, $R_3 = 9.79k\Omega$, $R_4 = 9.74k\Omega$.

Therefore, the approximate experimental frequency of oscillator is

$$f = \frac{1}{2\pi RC} \tag{15}$$
$$= \frac{1}{2\pi \times 9.78k \times 0.01\mu F} \tag{16}$$
$$= 1.627kHz \tag{17}$$

This almost matches the observed value i.e. 1.628kHz as can be seen in the above figure.

2.3 Wien Bridge Oscillator as voltage controlled oscillator

To make the Wien Bridge Oscillator work as voltage controlled oscillator, we design a circuit based on the op-amp TL084 and a LED-LDR pair as shown in fig. 13.

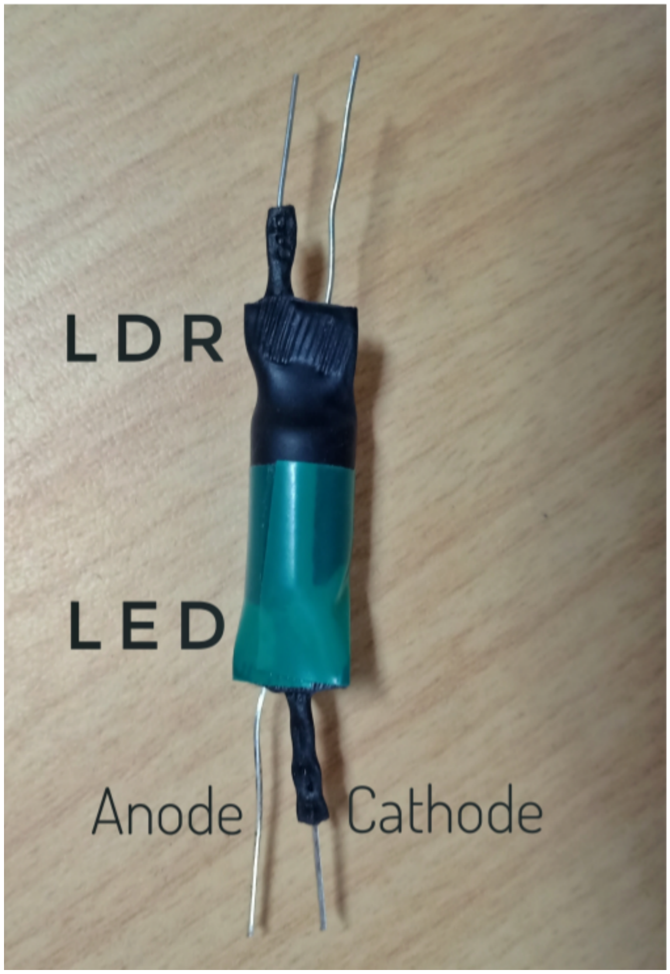


Figure 12: LED-LDR pair

A photoresistor or LDR is an active component whose resistance decreases with respect to receiving luminosity on the component's sensitive surface. As, more current flows due to increase in input voltage, more illumination is observed in LED which in turn reduces the output resistance in non-linear fashion.

We plan to use this circuit for varying both R_1 and R_2 simultaneously (in the feedback network of the Wien Bridge Oscillator) in accordance with control voltage V_C, hence controlling its frequency as it is inversely proportional to resistances' value.

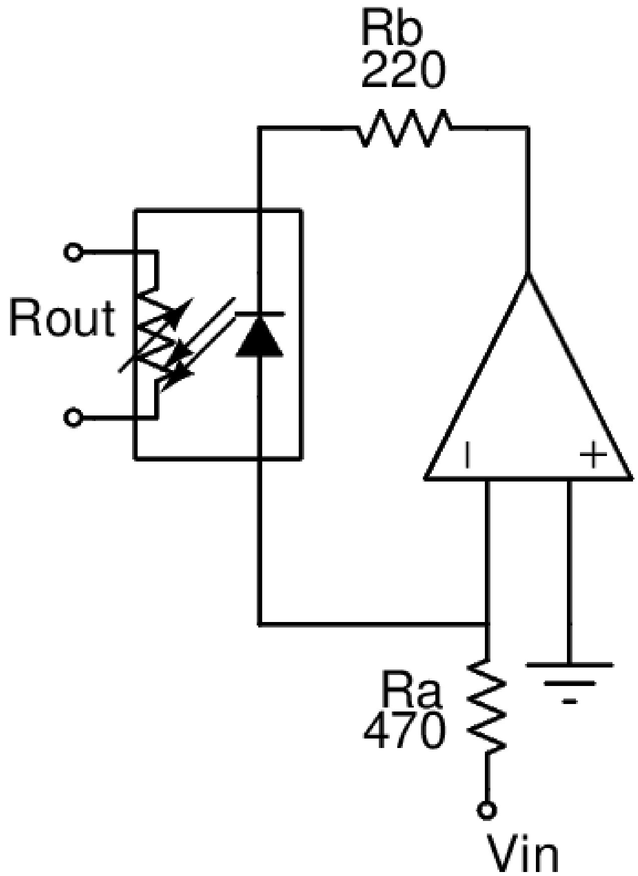


Figure 13: LED-LDR pair circuit for varying R$_{out}$

The graph of R_{out} vs V_{in} as we vary V_{in} is plotted below:

$V_{in}(V)$	$R_{out}(k\Omega)$
0	96
0.1	12.4
0.2	6.6
0.3	4.7
0.5	3.0
1.0	1.9
1.5	1.6
2.0	1.4
2.5	1.2
3.0	1.1
3.5	1.1

Table 3: Observation Table

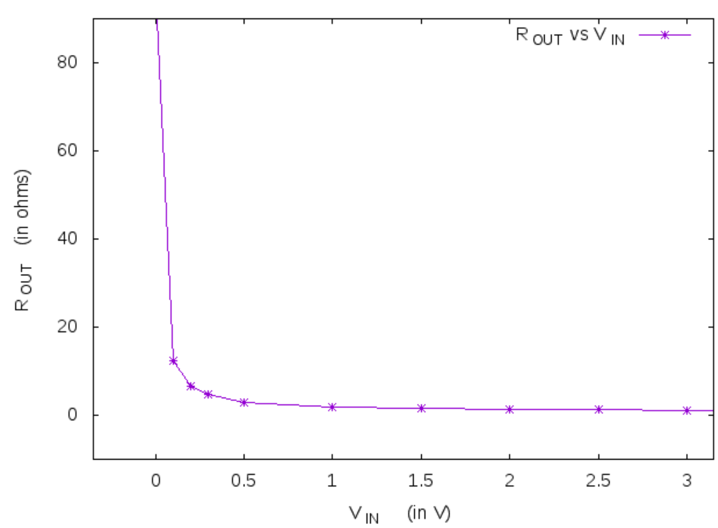


Figure 14: Variation of R$_{out} with change in V_{IN}$

2.4 Sweep Generator

Here, finally we combine the circuits of wien bridge oscillator and the LED-LDR to get the desired sine sweep generator.

Since the two LED's are connected in series, the current flowing through them will be the same. Now as V_{in} increases, both R_1 and R_2 decrease such that the magnitude of both are equal to each other. As R_1 and R_2 decrease, the frequency of the Wien Bridge Oscillator increases.

The final circuit is as shown below, we use here 3 LED-LDR pair circuits. Two of these circuits are for varying the resistors present in the feedback network of the oscillator. The third circuit is used because as the frequency changes, the amplitude of the output waveform is likely to decrease, so we vary this third additional resistor to increase the gain and maintain a fixed amplitude of the output.

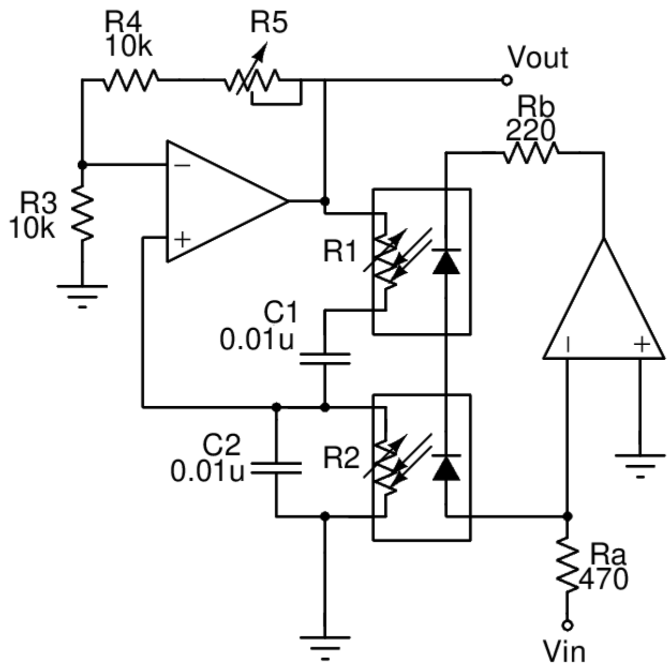
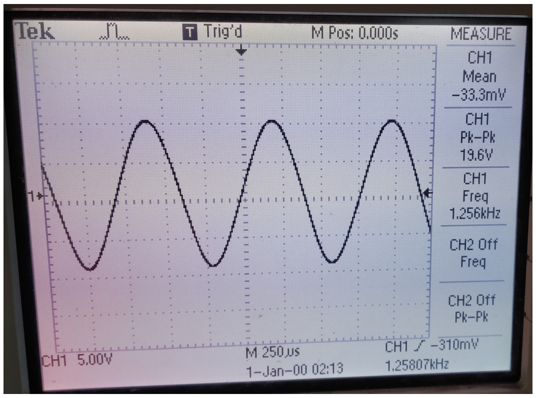
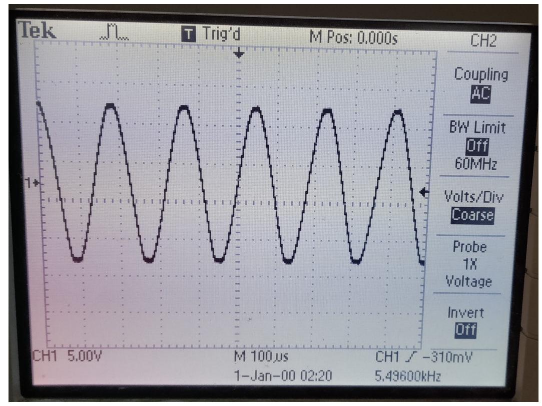


Figure 15: Sweep Generator

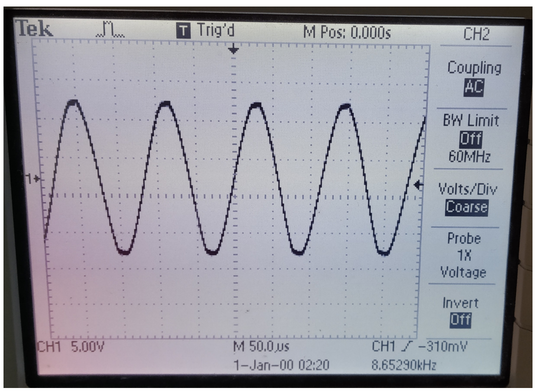
To verify whether our proposed circuit changes frequency on varying the input voltage, we note the waveform for $V_c = 0V$, $0.5V$, $1V$, and $1.5V$.



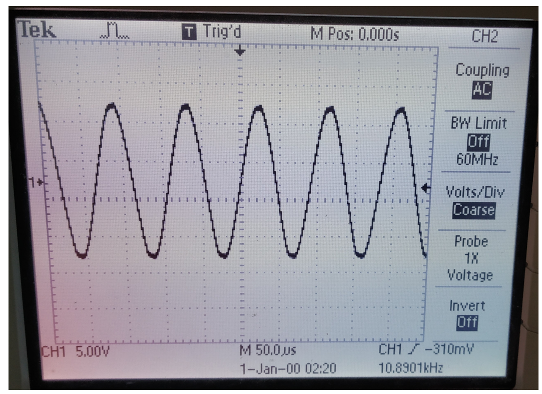
(a) $V_C = 0V$



(b) $V_C = 0.5V$



(a) $V_C = 1V$



(b) $V_C = 1.5V$

2.5 Sweep Generator and High Pass Filter

The circuit of Sallen Key High pass filter is shown below.

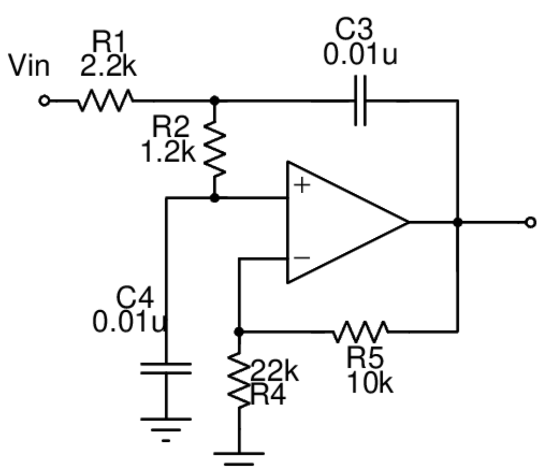


Figure 18: High Pass Filter

The maximum and minimum frequencies obtained at the output of the Sweep Generator was 3kHz and 10.3kHz

The final circuit joining the sweep generator with the high pass filter is shown below.

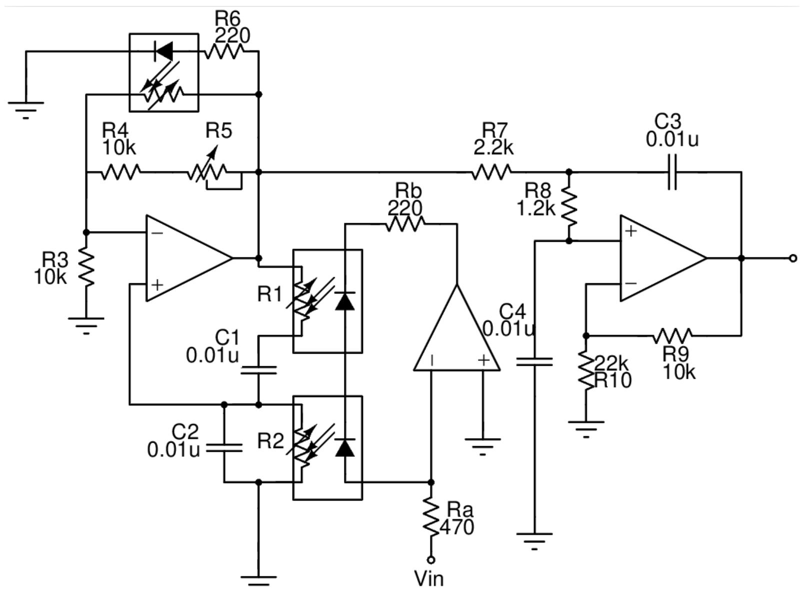
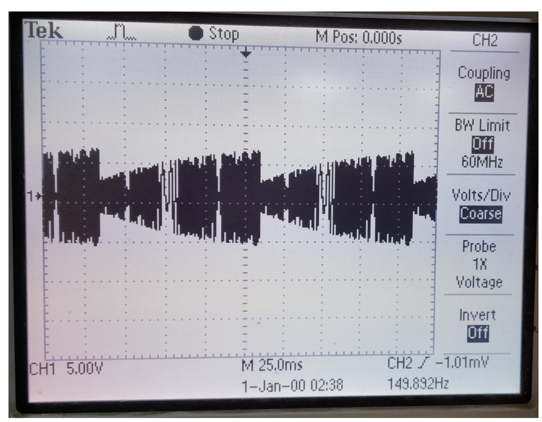


Figure 19: Sweep generator with High Pass Filter

The output waveform obtained on DSO, on connecting our sine sweep generator to the input of a second order Sallen Key High pass filter is shown below:

(a) Ramp signal



(b) Frequency Response of ramp signal

3 In-Lab Circuit

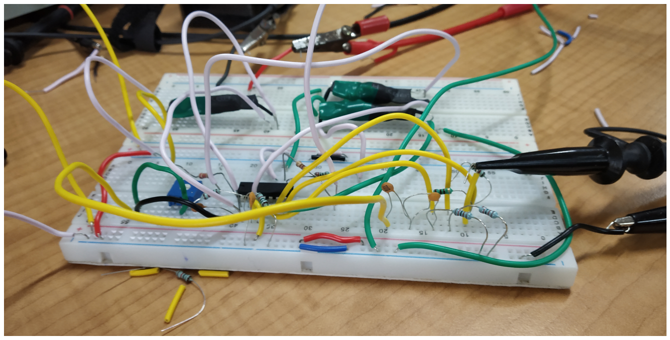


Figure 21: Bread-board circuit of Sweep generator with High Pass Filter

References

[1] Experiment Handout
http://wel.ee.iitb.ac.in/teaching_labs/WEL%20Site/ee230/Labsheets-2020/Handouts/lab5_handout_observing_frequency_response_of_a_filter_in_time_domain_modified_14_02_2020.pdf

[2] Supporting material for Wien Bridge Oscillator and High Pass Filter
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[3] Data-sheet of op-amp TL084
https://www.ti.com/lit/ds/symlink/tl082b.pdf?HQS=TI-null-null-alldatasheets-df-pf-SEP-wwe