Sallen-Key_High_Pass_Filter -- Overview

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Sallen-Key High Pass Filter

Objectives:

After performing this lab exercise, learner will be able to:

- Understand & analyze working of Sallen-Key topology of active filters
- Design & build a Sallen-Key high pass filter using opamp
- Establish relationship between input and output signal - prepare a Bode plot for the filter circuit
- Practice working with measuring equipment and laboratory tools like digital oscilloscope, signal generator, multimeter and power supply
- Use digital oscilloscope to debug/analyze the circuit

Equipment:

To perform this lab experiment, learner will need:

- Digital Storage Oscilloscope (TBS1000B-Edu from Tektronix or any equivalent)
- Power Supply (2231A-30-3 Power Supply from Keithley or any equivalent power supply capable of supplying +/- 10V DC)
- Signal generator (AFG1000 from Tektronix or equivalent) for providing AC input to circuit
- Multimeter
- Electronic Components
  - Opamp 741 / TL082 or equivalent - as single IC or as part of any analog circuit kit (like ASLK board from TI)
  - Resistor (2 x 1K ohms)
  - Capacitor (2 x 0.1 uF)
- BNC cables
- Breadboard and connecting wires

Theory / Key Concepts:

Before performing this lab experiment, it is important to learn following concepts:

- An opamp is a high-gain differential amplifier with very high input impedance. Very high open-loop gain allow for creating amplifiers with stable gain using feedback.
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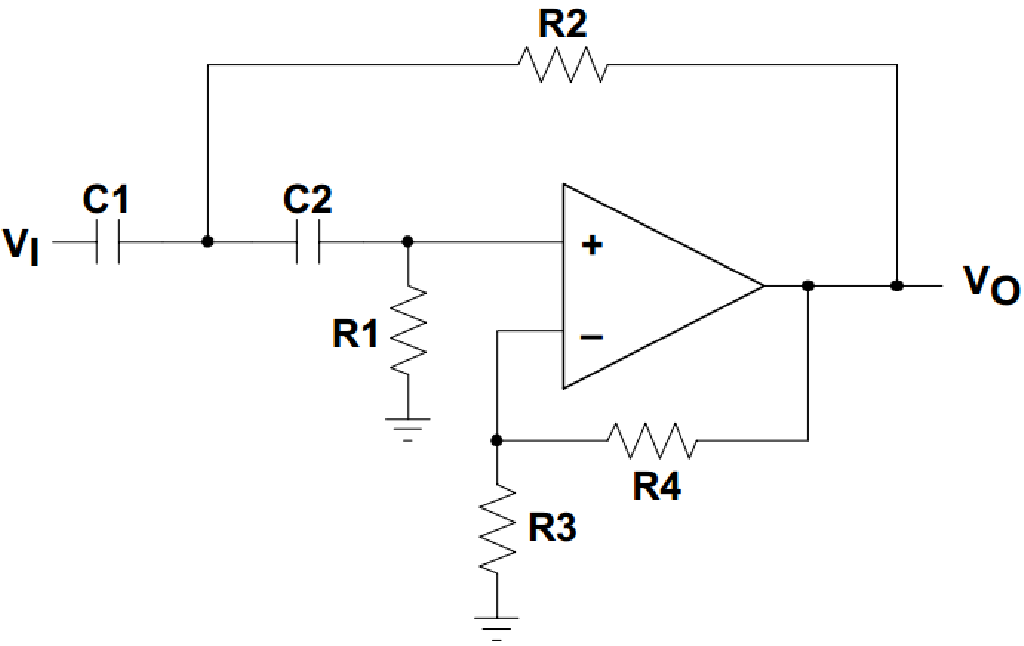
- A high-pass filter is an electronic circuit that attenuates signals with a frequency lower than a certain value and passes signals of higher frequencies.
  - The 'certain' frequency after which the atteneuation ends is called as 'cut-off frequency' of the filter.
  - Range of frequencies below cut-off frequency is called stop band and higher frequency ranges are called pass band.
- At cut-off frequency, the signal amplitude is 0.707 times of its value in the passband i.e., the signal level is 3dB below the passband value.
- Professors R.P. Sallen and E.L. Key described a new filter topology in 1955, which was named after them, the Sallen-Key filters.
- An active Sallen-Key filter can be cascaded easily to make higher order filters. The opamp provides the buffering buffering between cascaded stages.
- Sallen-Key filter gives the flexibility of modifying the filter characteristics (cut-off frequency and Q) using R, C values and amplifier gain. This makes filter design easy.

Circuit Design:

Learner can use the theoretical design rules to calculate the circuit component values:

- A generic Sallen-Key high pass filter circuit is shown below with filter parameters:



Where:

- K = amplifier gain = 1 + (R4 / R3)
- Transfer function = V_0/V_i

$$= \frac{K(s^2(R1R2C1C2))}{s^2(R1R2C1C2) + s(R2C2 + R2C1 + R1C2(1 - K)) + 1}$$

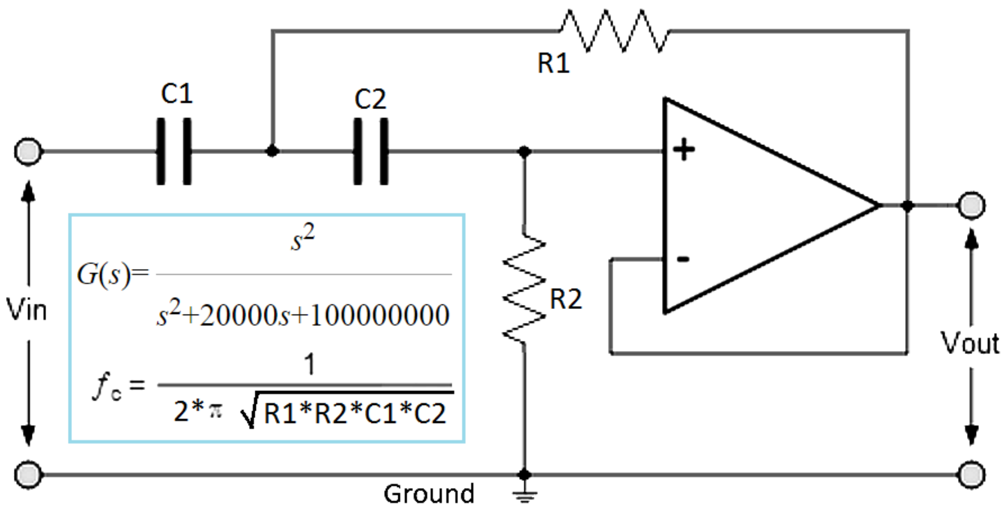
- Cut-off frequency =

$$fc = \frac{1}{2\pi\sqrt{R1R2C1C2}}$$

and

$$Q = \frac{\sqrt{R1R2C1C2}}{R2C2 + R2C1 + R1C2(1 - K)}$$

- We can simplify the filter design by choosing R1 = R2 = R = 1k Ohms and C1 = C2 = C = 0.1uF. The opamp gain is kept unity (R4 = 0 and R3 = infinty).



- This makes
  - Amplifier gain K =1

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- With the given R and C values, the cut-off frequency will be 1592 Hz, Q = 1/2 and K (opamp amplifier gain) = 1

Sallen-Key_High_Pass_Filter -- Procedures

Step 1

Check Your Understanding:

Before performing this lab experiment, learners can check their understanding of key concepts by answering these?

- What will be the slope of magnitude response in the stop band of a Sallen-Key high-pass filter?
    - -20dB / decade
    - 0 dB / decade
    - -40dB / decade
    - +20dB / decade

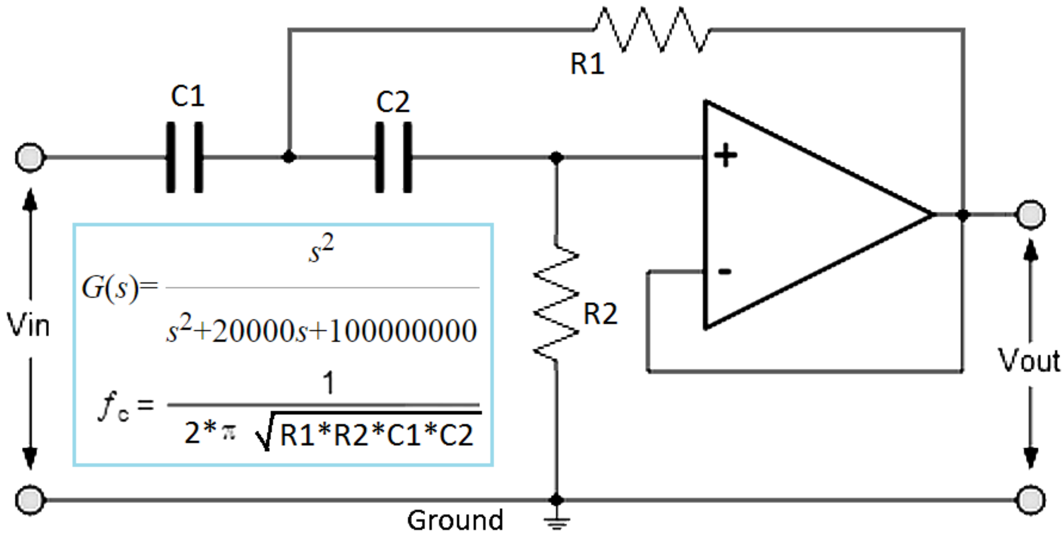
- How will the phase respones for Sallen-Key high pass filter vary with frequency of input signal?
    - Phase will vary from 0 to 90 degrees as frequency goes low to high
    - Phase will vary from 0 to -90 degrees as frequency goes low to high
    - Phase will vary from 0 to -180 degrees as frequency goes low to high
    - Phase will vary from 180 to 0 degrees as frequency goes low to high

- The response of the filter circuit will produce any overshoot or oscillation for:
    - Q > 0.5
    - Q = 0.5
    - Q < 0.5
    - Q = infinity

Step 2

Circuit diagram / Connection Details

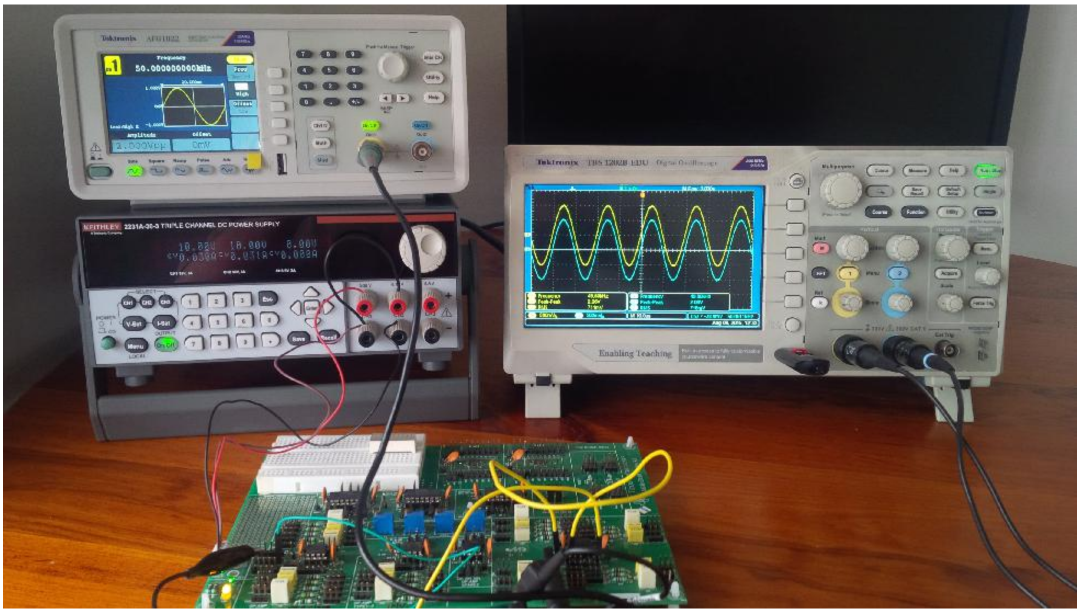
- Using the jumper / connecting wires prepare the circuit as shown below - Choose C1 = C2 = 0.1uF & R1 = R2 = 1k ohm.
- When using the ASLK board, you will have to use additional R and C (not available on board) on the small breadboard provided



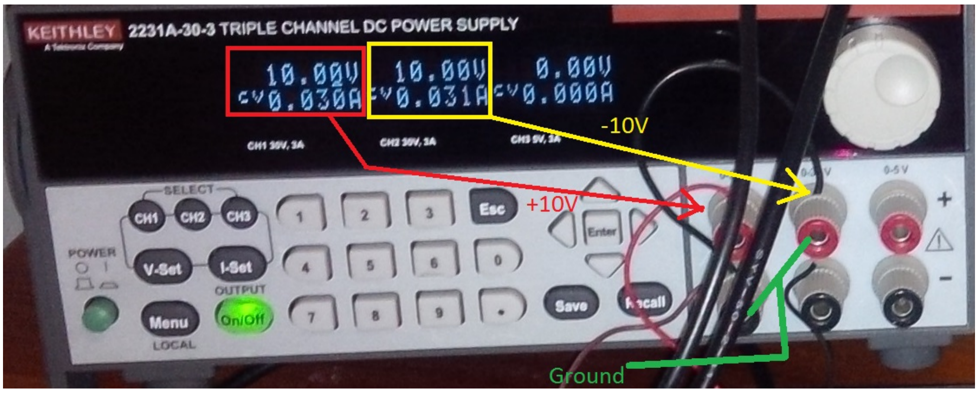
Step 3

Experiment Setup

- Make the arrangement as shown in figure below -



- Turn on the DC power supply, ensure that +/- 10V is applied to ASLK /Opamp circuit
    - You can use '2 channels' of 2231A DC power supply in independent mode and combine negative one channel with positive of other to be treated as common or ground point



- Use signal from AFG/signal generator to feed to opamp input
- Probe at input and output pins of the filter to view the signal on oscilloscope - View input on channel 1 and output on channel 2

Step 4

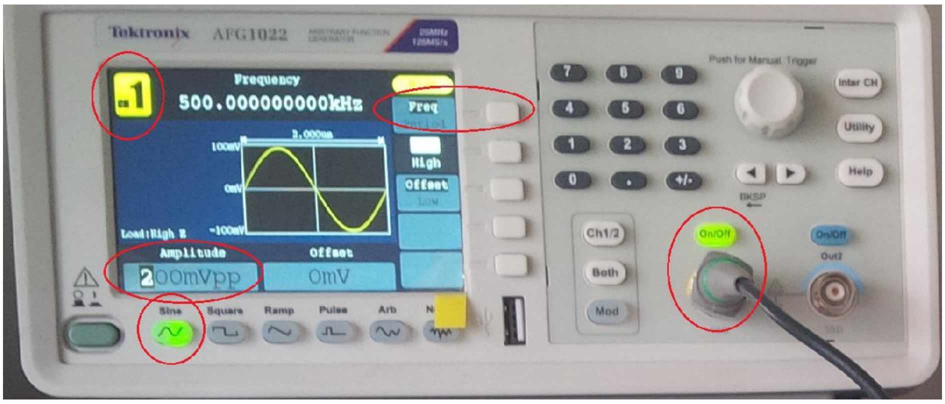
Make the Circuit Work

- Use signal from AFG/signal generator to feed to opamp input
- Set sinusoidal signal from channel 1 of the AFG
  - amplitude = 1 V_{pp}
  - frequency = 10K Hz
- Autoset the oscilloscope to see both input and output waveforms

Step 5

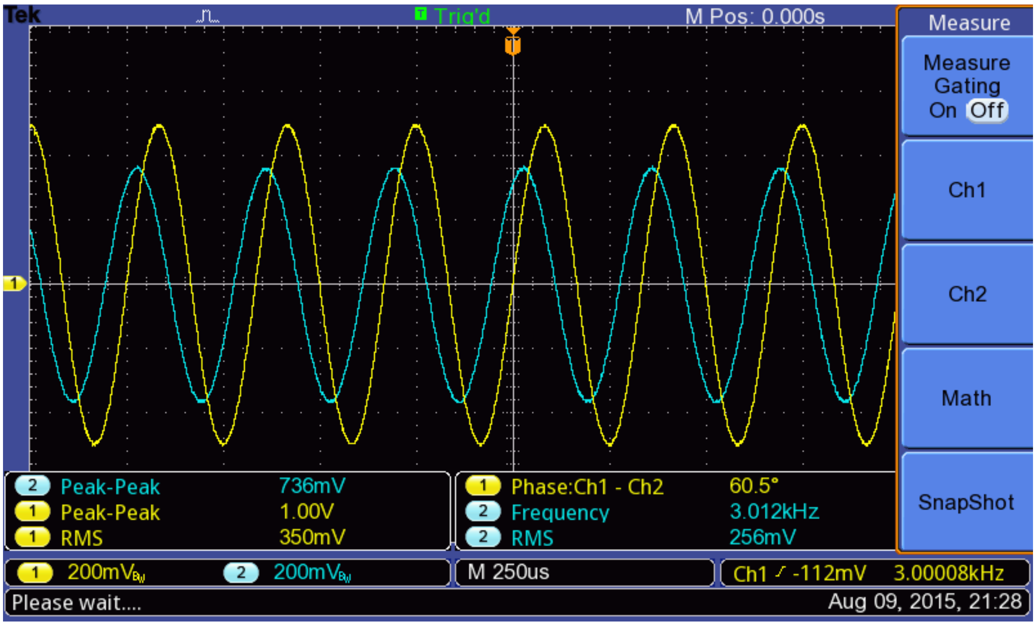
Taking the Measurements

- Set input
  - Sinusoidal, 1V peak-to-peak amplitude
  - 100 Hz frequency
  - Continous mode (on AFG)
  - enable the channel 1 output on AFG



- Autoset the oscilloscope to optimally see both input and output signal
- Set up following measurements:
  - On Ch1 - V_{pp}, V_{rms}, Frequency
  - On Ch2 - V_{pp}, V_{rms}, and Phase (between Ch1 and Ch2)

- Keeping the amplitude of the sinusoid input fixed at 1V peak-to-peak, vary its frequency from 100Hz to 100kHz. You may take more readings near cut-off frequency.
- Tabulate the measurements. You can also capture screenshot for each measurement set.



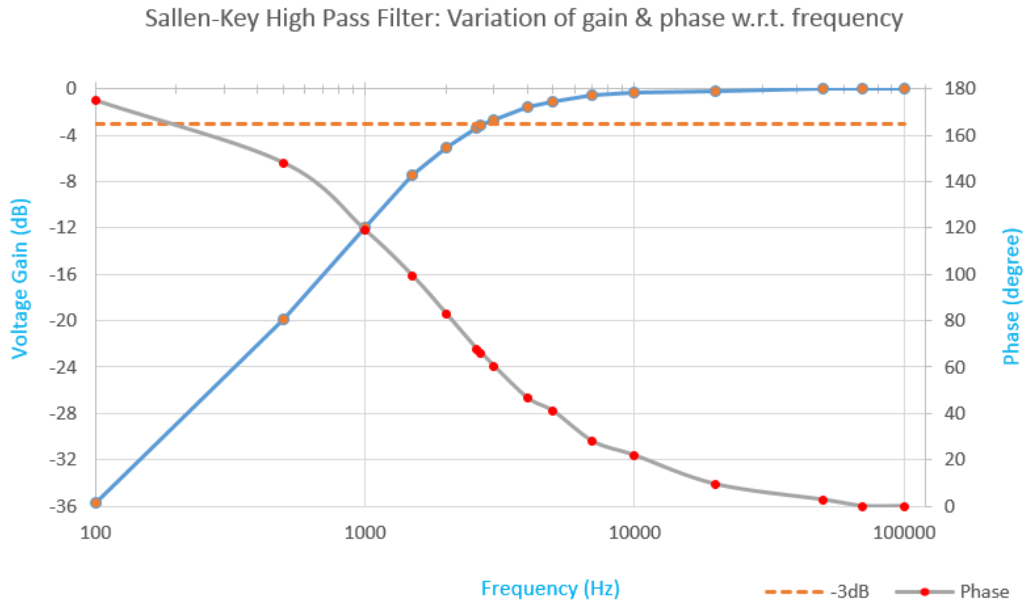
Step 6

Analyzing the Result

- The observation table would look like as shown below. Calculate voltage gain (observed from measurements) and its decible equivalent.

#	Frequency (Hz)	INPUT		OUTPUT		Phase Difference (Degrees)	Voltage Gain	Voltage Gain (dB)
		Vpp (V)	Vrms (mV)	Vpp (V)	Vrms (mV)			
1	100	0.976	342	0.016	2.55	175.00	0.02	-35.71
2	500	0.992	345	0.1	26.5	148.00	0.10	-19.93
3	1,000	1.020	353	0.256	85.9	119.00	0.25	-12.01
4	1,500	1.000	355	0.424	143	99.30	0.42	-7.45
5	2,000	0.984	345	0.552	192	82.90	0.56	-5.02
6	2,600	1.020	354	0.696	238	67.60	0.68	-3.32
7	2,700	1.020	354	0.712	243	66.00	0.70	-3.12
8	3,000	1.000	351	0.736	256	60.50	0.74	-2.66
9	4,000	0.968	334	0.808	276	46.60	0.83	-1.57
10	5,000	0.984	338	0.864	297	40.80	0.88	-1.13
11	7,000	0.992	342	0.928	318	27.80	0.94	-0.58
12	10,000	1.000	342	0.960	332	21.80	0.96	-0.35
13	20,000	1.020	347	0.992	341	9.36	0.97	-0.24
14	50,000	1.000	345	1.000	345	2.69	1.00	0.00
15	70,000	1.000	345	1.000	345	0.00	1.00	0.00
16	100000	1.000	345	1.000	345	0.00	1.00	0.00

- Prepare Bode plot - plot voltage gain and phase against frequency.



- Find out the cut-off frequency from the plot (where the gain drops to -3dB from its passband value)

Step 7

Conclusion

The analysis of the observed results confirm that (As expected):

- The voltage gain of the filter circuit increses to 1 (0 dB) as input frequency is increased
- The attenuation roll-off is -40dB/decade as it is a 2nd order filter
- The cut-off frequency (where gain is -3dB or 3dB down from its passband value) is 2800Hz.
- At the estimated (calculated from R and C values) cut-off frequency of 1592 Hz, the gain is down by ~ 6dB and phase is -90 degrees. (Positive sign in the phase signifies, output leads input)