High_Pass_Filter_1st_Order -- Overview

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1st Order High Pass Filter

Objectives:

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

- Understand and comprehend working of opamp
- Comprehend basics of filtering circuits using resistor & capacitor
- Design & build a 1st order 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 (1K ohms)
  - Capacitor (0.1 uF)
- BNC cables
- Breadboard and connecting wires

Theory / Key Concepts:

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

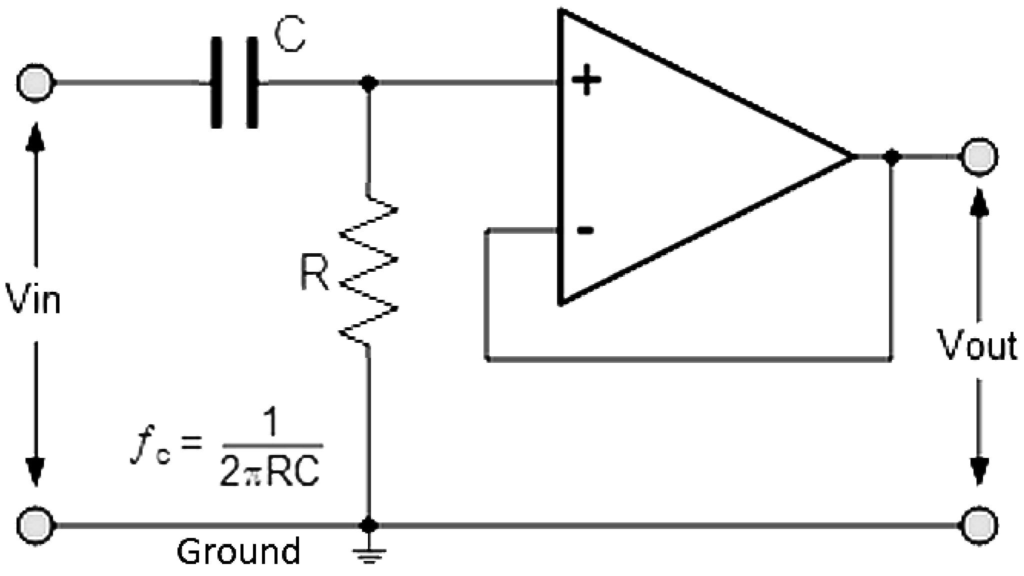
- An opamp is a high-gain differential amplifier with very high input impedance. Very high open-loop gain allow for creating amplifiers with stable gain using feedback.
- A high-pass filter is an electronic circuit that attenuates signals with a frequency lower than a certain value and passes signals 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.
- A simple R, C filter makes a 1st order filter of cut-off frequency:

$$f_c = \frac{1}{2.\Pi.R.C}$$

- Filter characteristics is usually shown by a Bode plot which is a graph of the frequency response of the system. A Bode plot show magnitude and phase variation w.r.t. input signal frequency.
- High-pass filter is used for eliminating low-frequency motion artefacts / noise from the medical signal like ECG.

Circuit Design:

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



- Choosing R = 1k Ohms and C = 0.1uF, cut-off frequency will be 1592 Hz

High_Pass_Filter_1st_Order -- Procedures

Step 1

Check Your Understanding:

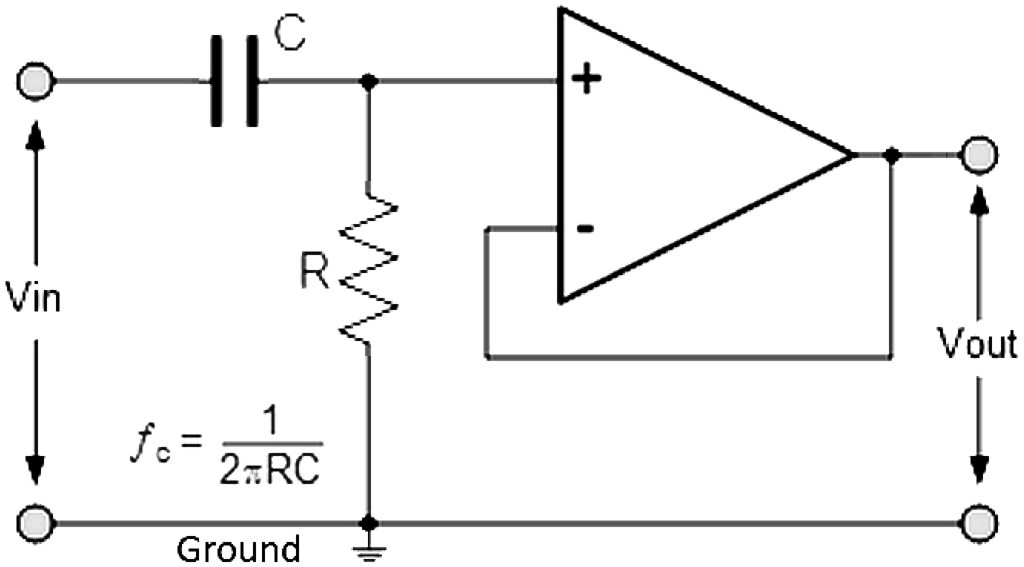
Before performing this lab experiment, learners can check their understanding of key concepts by answering these?

- What will be the effect of a high-pass filter with cut-off frequency of 1kHz, on a sinusoid of 35kHz?
  - Signal will be amplified
  - Signal will be attenuated
  - Signal amplitude will remain same
  - Signal will be rectified
- If 1V peak-to-peak, 10kHz sinusoid is applied to a high-pass filter of cut-off frequency 10kHz, the amplitude of the filter output will be?
  - 1.707 V_{pp}
  - 1.414 V_{pp}
  - 1.000 V_{pp}
  - 0.707 V_{pp}
- A high-pass filter also behaves as:
  - A differentiator circuit
  - An integrator circuit
  - A rectifier circuit
  - A logrithmic amplifier circuit

Step 2

Circuit diagram / Connection Details

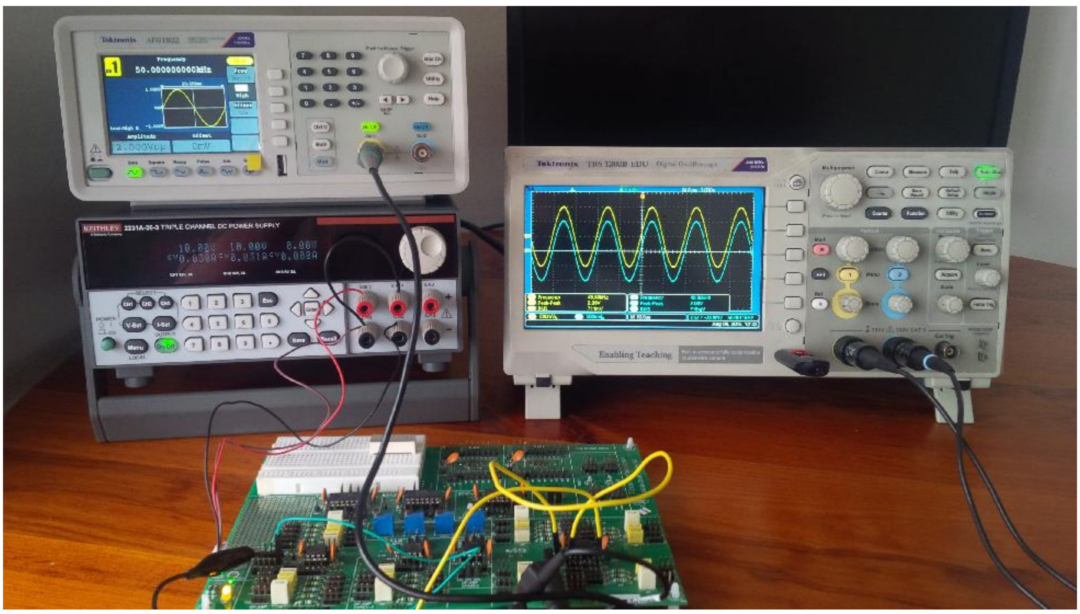
- Using the jumper / connecting wires prepare the circuit as shown below - Choose C = 0.1uF & R = 1k ohm:



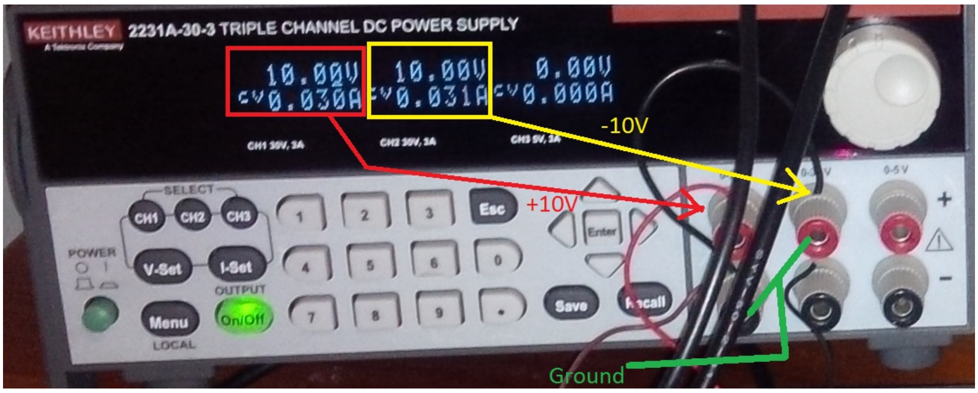
Step 3

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

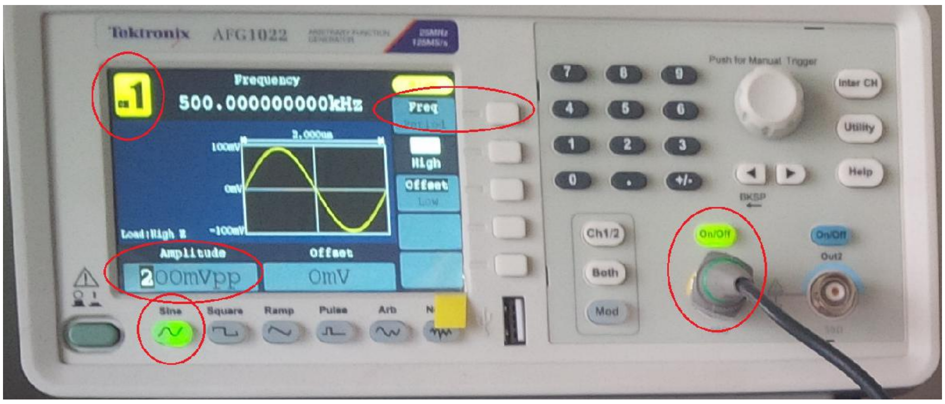
Make the Circuit Work

- 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 = 50 kHz
- Autoset the oscilloscope to see both input and output waveforms

Step 5

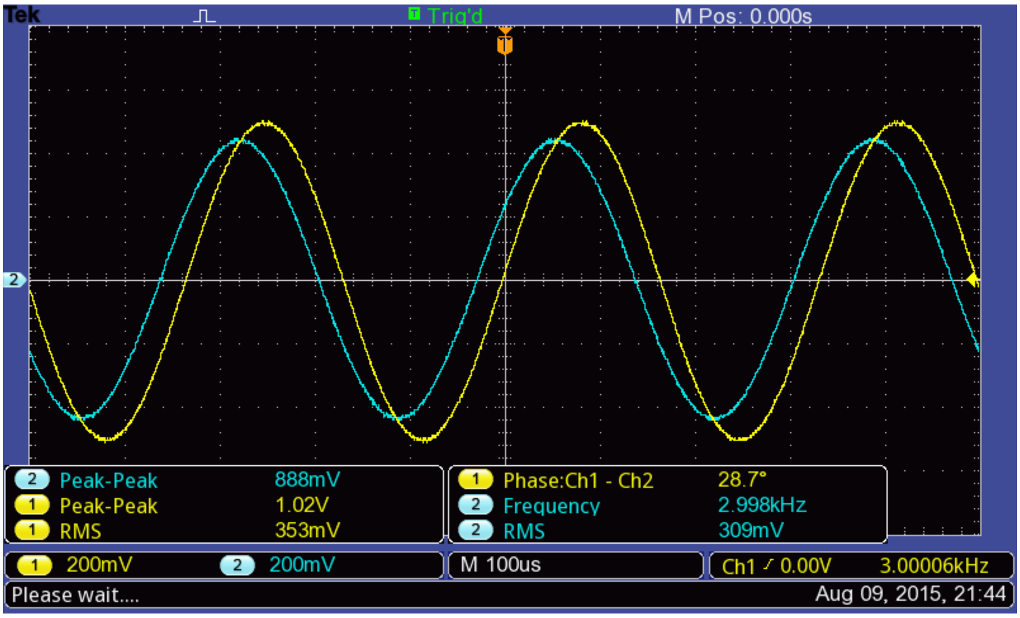
Taking the Measurements

- Set input
  - Sinusoidal, 1V peak-to-peak amplitude
  - 50 kHz 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 50Hz to 50kHz. You may take more readings near cut-off frequency.
- Tabulate the measurements. You can also capture screenshot for each measurement set.



Step 6

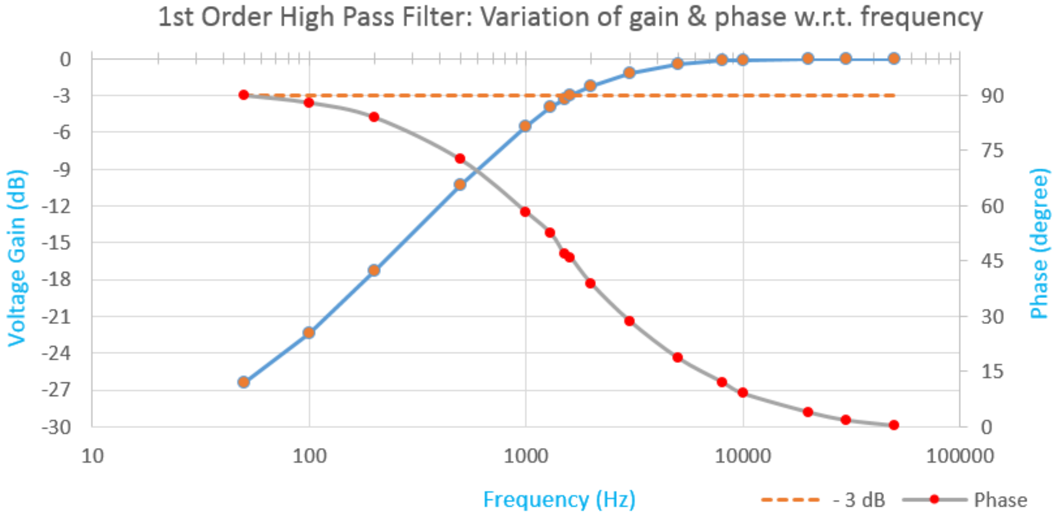
Analyzing the Result

- 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	50	1.000	349	0.048	10.9	90.00	0.05	-26.375
2	100	1.000	349	0.076	21.7	88.00	0.08	-22.384
3	200	1.000	349	0.136	42.8	84.00	0.14	-17.329
4	500	1.000	348	0.304	102.0	72.50	0.30	-10.343
5	1,000	1.020	355	0.536	185.0	58.30	0.53	-5.589
6	1,300	1.000	349	0.632	217.0	52.50	0.63	-3.986
7	1,500	1.000	347	0.680	235.0	46.80	0.68	-3.350
8	1,600	1.010	352	0.712	246.0	46.00	0.70	-3.037
9	2,000	1.010	351	0.776	272.0	38.80	0.77	-2.289
10	3,000	1.020	353	0.888	309.0	28.70	0.87	-1.204
11	5,000	1.000	349	0.952	331.0	18.70	0.95	-0.427
12	8,000	1.000	351	0.984	343.0	12.10	0.98	-0.140
13	10,000	1.000	342	0.984	336.0	9.00	0.98	-0.140
14	20,000	1.000	342	1.000	321.0	3.93	1.00	0.000
15	30,000	1.000	343	1.000	342.0	1.72	1.00	0.000
16	50,000	1.010	347	1.000	342.0	0.24	0.99	-0.086

** POSITIVE phase signifies that output leads input

- 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 increases towards '1' as input frequency is increased
- The cut-off frequency (where gain is -3dB or 3dB down from its passband value) is 1600Hz. Which is quite close to estimated (calculated from R and C values) value of 1592 Hz.
- The phase at cut-off frequency is 45 degrees.