Low_Pass_Filter_1st_Order -- Overview

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1st Order Low 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 low 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:

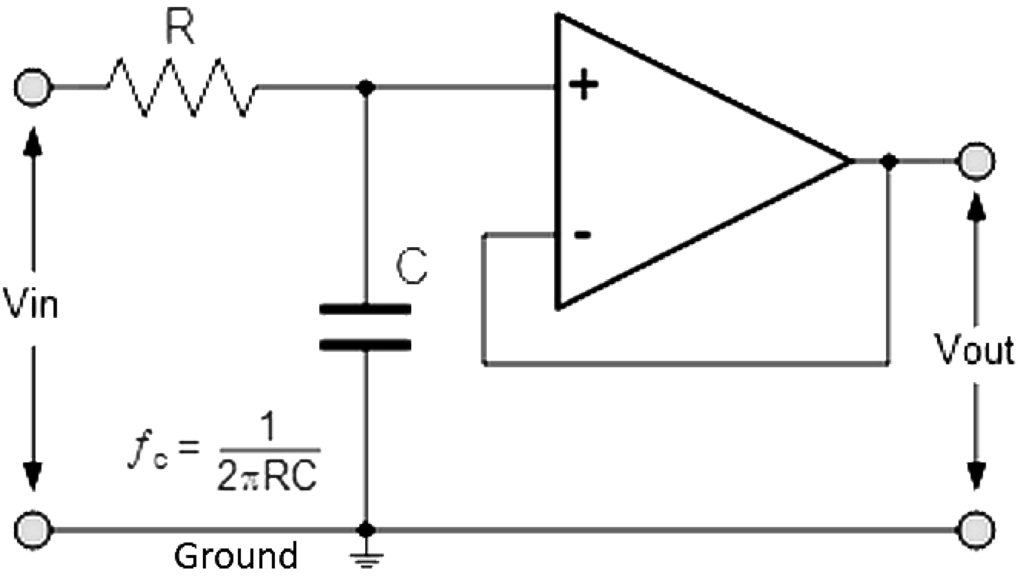
- An opamp is a high-gain differential amplifier with very high input impedance. Very high open-loop gain allow for creating amplifiers with stable gain using feedback.
- A low pass filter is an electronic circuit that passes signals with a frequency lower than a certain value and attenuates signals of higher frequencies.
  - The 'certain' frequency after which the atteneuation starts is called as 'cut-off frequency' of the filter.
  - Range of frequencies below cut-off frequency is called pass-band and higher frequency ranges are called stop 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.
- Low pass filter is used for eliminating high-frequency noise from the system.

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

Low_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 low-pass filter with cut-off frequency of 10kHz, on a sinusoid of 35kHz?
  - Signal will be amplified
  - Signal will be attenuated
  - Signal amplitude will remain same
  - Signal will be rectified

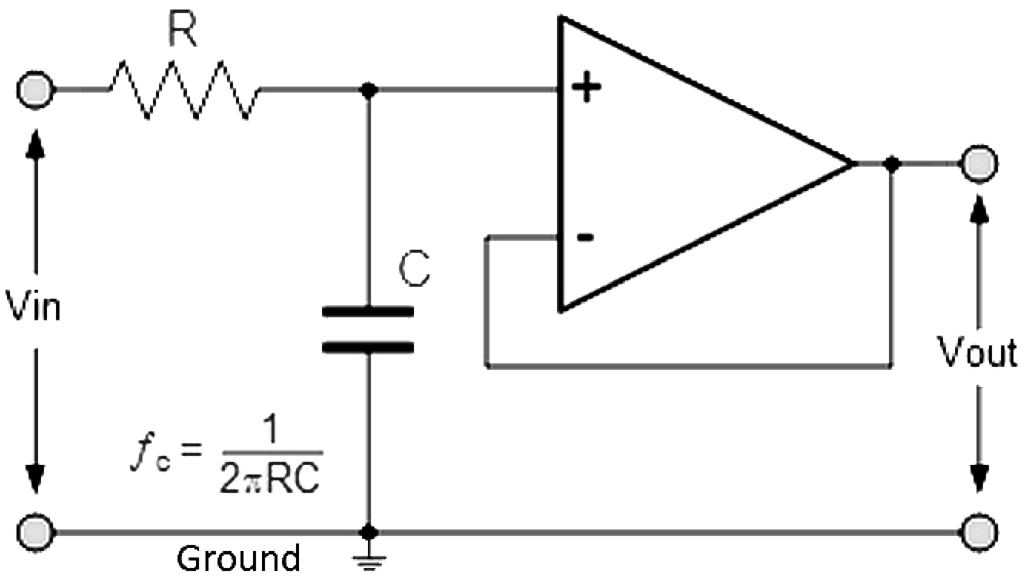
- If 1V peak-to-peak, 10kHz sinusoid is applied to a low-pass filter of cut-off frequency 10kHz, the amplitude of the filter output will be?
  - 1.707 V_{pp}
  - 1.414 V_{pp}
  - 1.000 V_{pp}
  - 0.707 V_{pp}

- A low-pass filter also behaves as:
  - A differentiator circuit
  - An integrator circuit
  - A rectifier circuit
  - A logrithmic amplifier circuit

Step 2

Circuit diagram / Connection Details

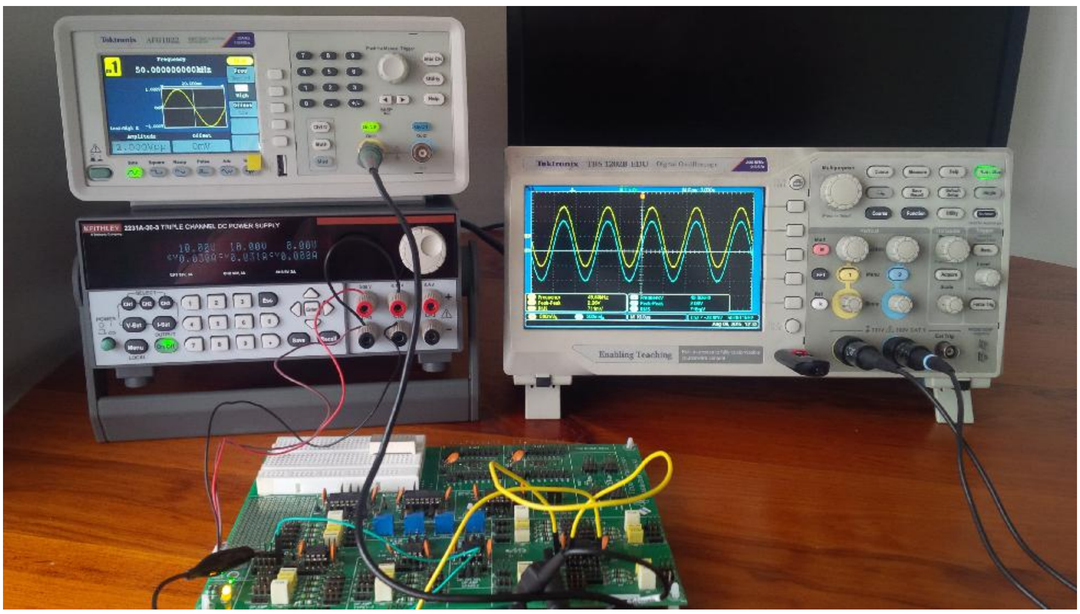
- Using the jumper / connecting wires prepare the circuit as shown below - Choose C = 0.1uF & R = 1k ohm:



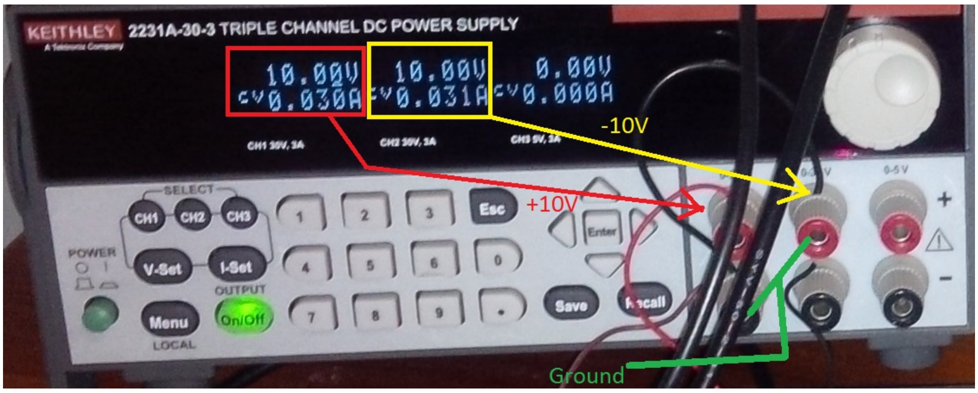
Step 3

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

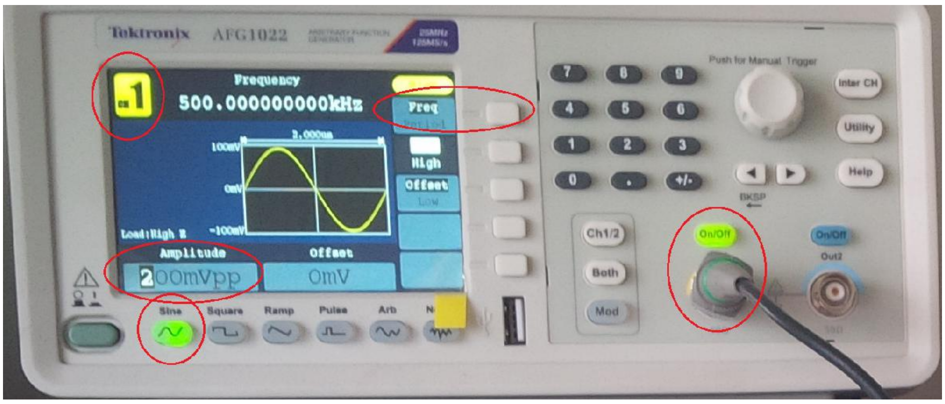
Make the Circuit Work

- 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 Hz
- Autoset the oscilloscope to see both input and output waveforms

Step 5

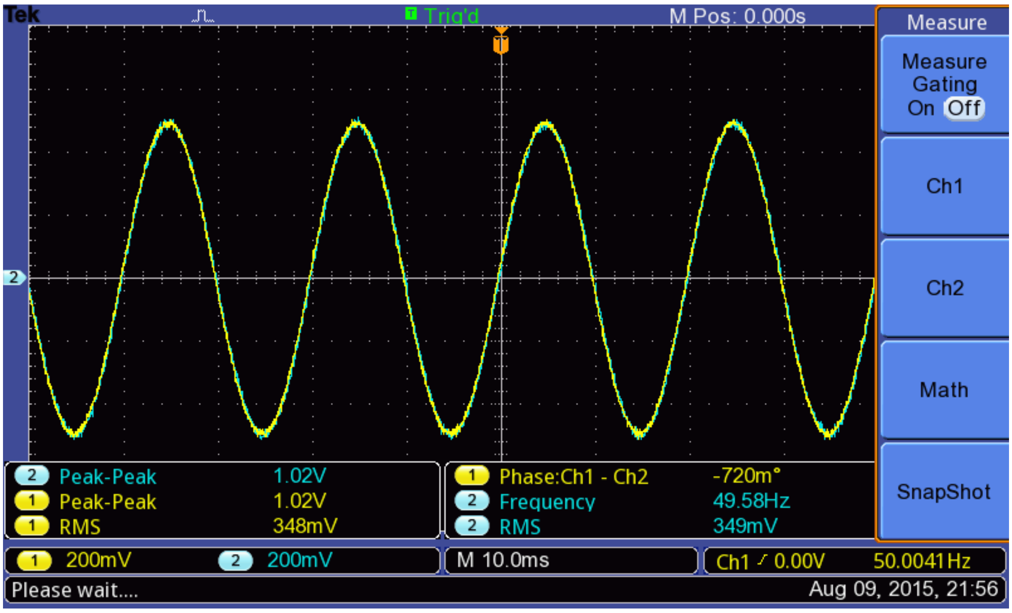
Taking the Measurements

- Set input
  - Sinusoidal, 1V peak-to-peak amplitude
  - 50 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 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

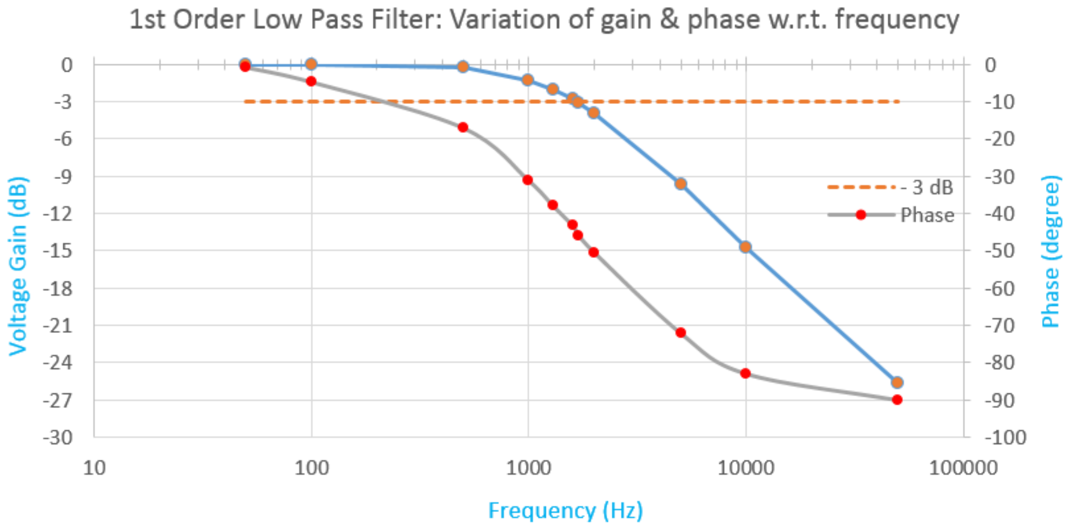
Analyzing the Result

- 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	1.020	348	1.020	349.0	-0.72	1.00	0.00
2	100	1.020	348	1.020	349.0	-4.68	1.00	0.00
3	500	1.020	351	0.992	336.0	-17.00	0.97	-0.24
4	1,000	1.010	348	0.872	297.0	-31.10	0.86	-1.28
5	1,302	1.010	354	0.800	277.0	-38.00	0.79	-2.02
6	1,601	1.000	348	0.728	249.0	-43.30	0.73	-2.76
7	1,702	1.000	343	0.704	242.0	-45.90	0.70	-3.05
8	2,004	1.010	351	0.640	222.0	-50.40	0.63	-3.96
9	5,000	1.000	347	0.328	110.0	-72.00	0.33	-9.68
10	10,000	1.000	349	0.184	58.0	-82.90	0.18	-14.70
11	50,000	1.000	351	0.052	12.8	-90.00	0.05	-25.68

** MINUS sign in the phase signifies that output lags 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 reduces as input frequency is increased
- The cut-off frequency (where gain is -3dB or 3dB down from its passband value) is 1700Hz. 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. (minus sign in the phase signifies, output lags input)