PH-211
Electronics Lab.

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Experiment No - 6.
Experiment Name - Filters.
Date - 11/09/2023

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Filter Circuits

Aim: To construct and study (a) the voltage gain as a function of frequency for low pass filter, (b) the voltage gain as a function of frequency for high pass filter and phase shift as well as cutoff frequency.

Equipments: DC power supply, (+/-) 15 Volts, bread board, CRO, DMM, function generator.

→ Formulae

(a) low pass filter.

$$A_v = \frac{A_{max}}{\sqrt{1+(f/f_c)^2}}$$

$A_{max} = 1 + \frac{R_f}{R_i}$ (gain of non-inverting amplifier).

$f_c = \frac{1}{2\pi RC}$ (cutoff frequency)

f = operational frequency.

A_v = voltage gain.

(b) high pass filter

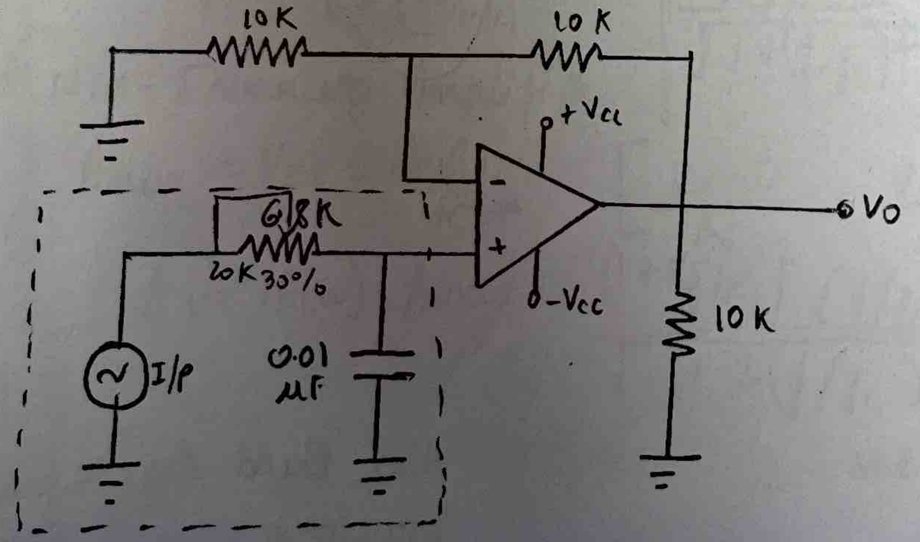
$$A_v = \frac{A_{max}\ (f/f_c)}{\sqrt{1+(f/f_c)^2}}$$

$$A_{max} = 1 + \frac{R_f}{R_1}$$

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

Circuit diagram and Analysis.

(a) low pass filter.



low pass Filter

Non-inverting Amplifier

Analysis: $\frac{V_{in} - V_+}{R} = \frac{V_+ - 0}{1/sC}$ $(s = +j\omega)$.

$\Rightarrow V_+ = \frac{V_{in}(1/sC)}{1 + \frac{1}{sC}} \Rightarrow \frac{V_+}{V_{in}} = \frac{1}{1 + sRC}$

$A(\omega) = \left|\frac{V_+}{V_{in}}\right| = \left|\frac{1}{1 + j\omega RC}\right| = \frac{1}{\sqrt{1 + (\omega RC)^2}}$

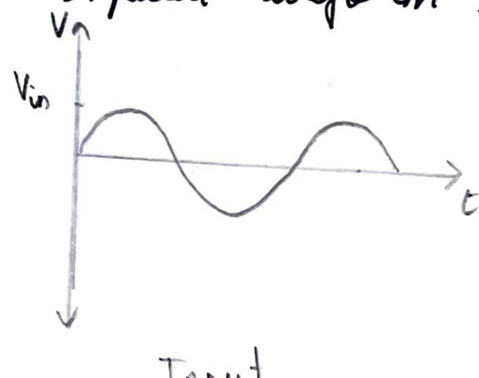
$\omega_c = \frac{1}{RC} \rightarrow$ Cutoff frequency.

$|A(\omega)| = \frac{1}{\sqrt{1 + \left(\frac{\omega}{\omega_c}\right)^2}} = \frac{1}{\sqrt{1 + (f/f_c)^2}}$

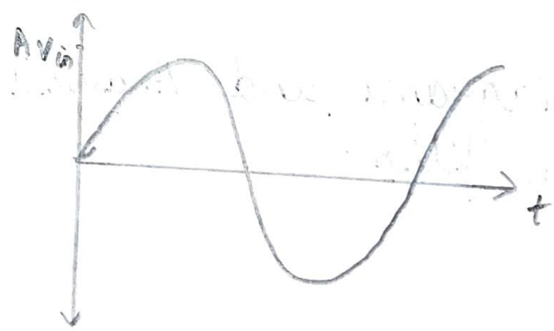
Non-Inverting Amplifier : $A_{max} = \frac{V_o}{V_+} = 1 + \frac{R_f}{R_i}$ $\left[\because \frac{V_- - 0}{R_1} = \frac{V_o - V_-}{R_f}\right]$

$A_v = |A(\omega)|\, A_{max} = \frac{1 + R_f/R_i}{\sqrt{1 + (f/f_c)^2}}$

→ Expected Waveform .



Input



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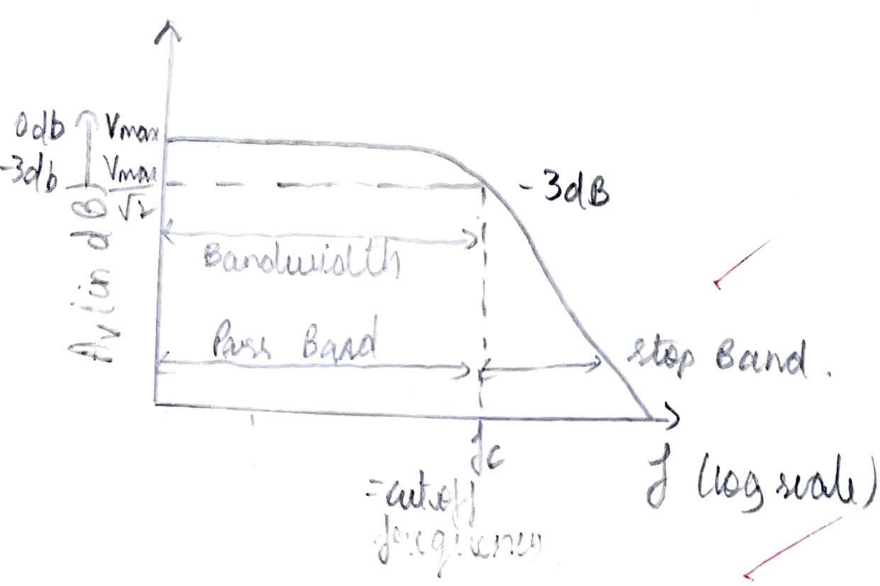
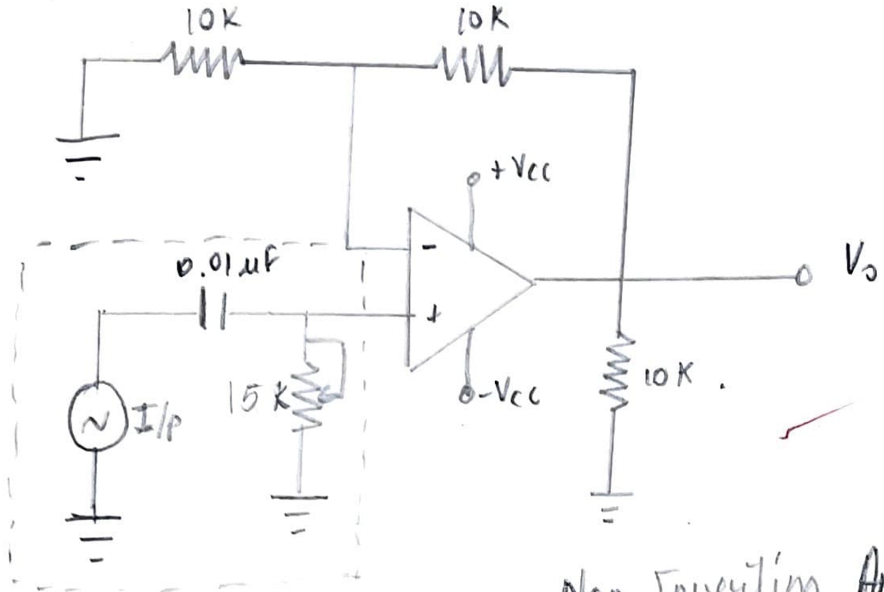


Mid Band Region Waveform

It allows low frequencies to pass

2) High Pass filter



high pass filter — Non Inverting Amplifier

Analysis: $\frac{V_{in}-V_-}{SC} = \frac{V_+ - 0}{R}$ $\quad (S = j\omega)$

$\Rightarrow V_+ = \frac{V_{in}}{1+\frac{1}{SRC}} \quad \Rightarrow \frac{V_+}{V_{in}} = \frac{j\omega RC}{1+j\omega RC}$.

$|A(\omega)| = \left|\frac{V_+}{V_{in}}\right| = \frac{\omega RC}{\sqrt{1+(\omega RC)^2}} \quad \left(\omega_c = \frac{1}{RC}\right)$

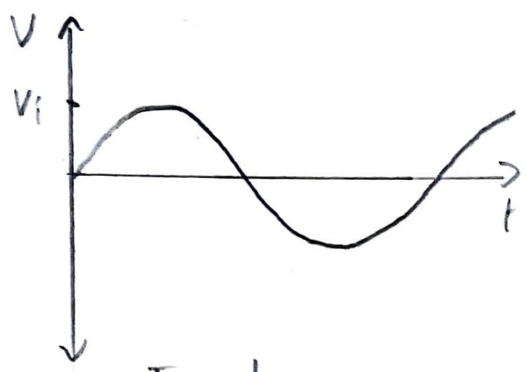
$= \frac{\omega/\omega_c}{\sqrt{1+(\omega/\omega_c)^2}} = \frac{f/f_c}{\sqrt{1+(f/f_c)^2}}$

→ Non-Inverting Amplifier

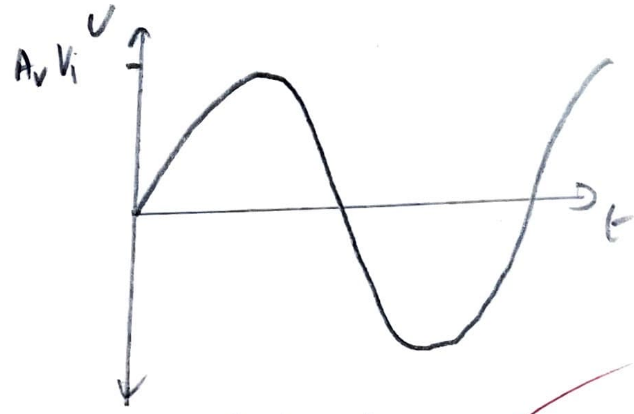
$A_{max} = \frac{V_0}{V_1} = 1+\frac{R_f}{R_i} \quad \left[\frac{V_- - 0}{R_i} = \frac{V_0 - V_-}{R_f}\right]$

$A_v = |A(\omega)|\, A_{max} = \frac{(1+R_f/R_i)\,(f/f_c)}{\sqrt{1+(f/f_c)^2}}$

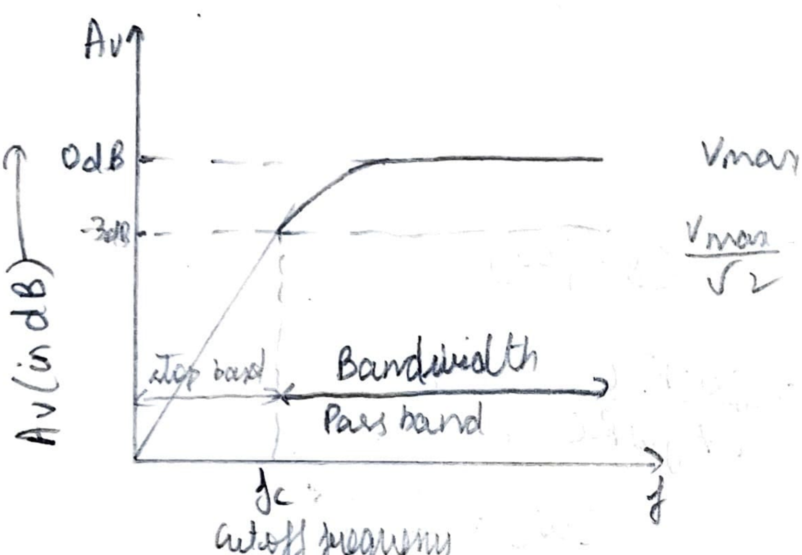
→ Expected Waveform



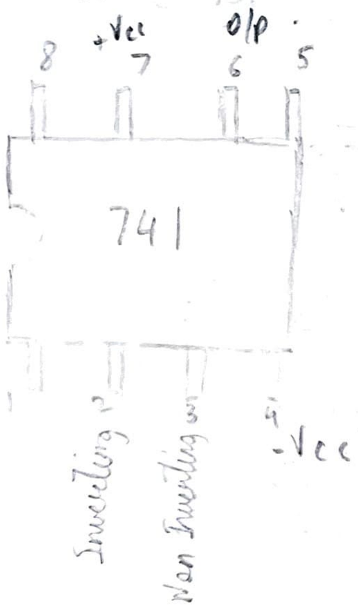
Input



Output



It allows high frequencies to pass



IP = $\frac{10}{10}$

Observation Table

low pass filter

Biasing Voltage = ±15V

S No	Frequency	Vin (V)	Vout	$A_V = 20\log\left(\frac{V_{out}}{V_{in}}\right)$ (dB)	A_V	Phase shift
1	5 Hz	1.5 V	3.0 V	~~6.02~~ 6.02	2	-1.0°
2	10 Hz	1.5 V	3.0 V	6.02	2	-2.5°
3	20 Hz	1.5V	3.0V	6.02	2	-1.8°
4	30 Hz	1.5 V	3.0V	6.02	2	-2.2°
5	100 Hz	1.5 V	3.0	6.02	2	3.0°
6	200 Hz	1.5 V	3.0	6.02	2	5.0°
7	300 Hz	1.5V	3.0	6.02	2	7.2°
8	500 Hz	1.5 V	3.0	6.02	2	13.5°
9	1KHz	1.5 V	2.8	5.42	1.87	25°
10	2 KHz	1.5 V	2.3	3.71	1.53	44°
11	3KHz	1.5 V	1.8	1.58	1.2	54°
12	5 KHz	1.5 V	1.3	-1.24	0.87	64°
13	10 KHz	1.5 V	690mV	-6.74	0.46	80°
14	20 KHz	1.5 V	370mV	-12.16	0.25	90°
15	30 KHz	~~25~~ 1.5V	250mV	-15.56	0.16	83°
16	50KHz	1.5 V	160mV	-19.44	0.11	88°
17	100 KHz	1.5V	96mV	-23.87	0.64	92°
18	200 KHz	1.5V	60mV	-27.96	0.04	101°/-79°
19	500 KHz	1.5V	44mV	-30.65	0.029	-177°/+177°
20	1 MHz	1.5V	40mV	-31.48	0.026	-179°/+179°

→ first write Av

→ then Av (in dB)

(b) high pass filter. Biasing Voltage = ±15V

$A_v (\text{in dB}) = 20 \log \frac{V_{out}}{V_{in}}$

S No	Frequency	V_{in}	V_{out}	A_v = ~~$20\log\left(\frac{V_{out}}{V_{in}}\right)$~~	A_v.	phase shift (ϕ)
1	5 Hz	5V	85mV	~~-37.72~~ 0.013	~~0.013~~ -37.72	~~74.5°~~ -108°
2	10 Hz	5.0V	114mV	0.023	-32.84	-95°
3	20 Hz	5.0V	206mV	0.041	-27.72	-95°
4	30 Hz	5.0V	296mV	0.059	-24.55	-91°
5	100 Hz	5.0V	1.0V	0.2	-13.80	-82°
6	200 Hz	5.0V	2.0V	0.4	-7.96	-79°
7	300 Hz	5.0V	2.8V	0.56	-5.04	-73°
8	500 Hz	5.0V	4.6V	0.92	-0.72	-64°
9	1 KHz	5.0V	7.2V	1.44	3.161	-44°
10	2 KHz	5.0V	9.1V	~~1.42~~ 1.82	5.20	-26°
11	3 KHz	5.0V	9.8V	1.96	5.85	-17°
12	5 KHz	5.0V	10.2V	2.04	6.19	-10°
13	10 KHz	5.0V	10.4V	2.08	6.36	-5°
14	20 KHz	5.0V	10.4V	2.08	6.36	0.7°
15	30 KHz	5.0V	10.4V	2.08	6.36	4.9°
16	50 KHz	5.0V	8.4V	1.68	4.50	35.1°
17	100 KHz	5.0V	4.4V	0.88	-1.11	66.8°
18	200 KHz	5.0V	2.1V	0.42	-7.54	81.9°
19	500 KHz	5.0V	880mV	0.176	-15.09	92.1°
20	1 MHz	5.0V	480mV	0.096	-20.35	-11.9°

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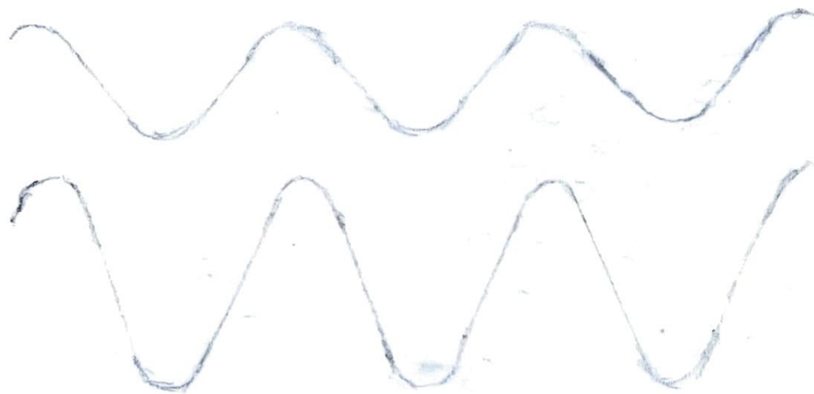
(a) Low Pass Filter

V_{INPUT}

V_{OUTPUT}



Frequency = 500 Hz

At saturation

Phase shift = 13.5°

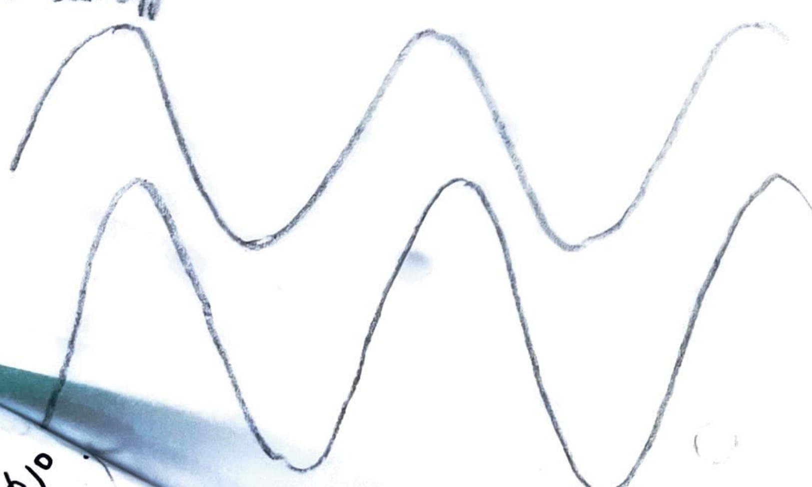
V_{in} = 1.5 V V_{cc} = ±15 V

V_{out} = 3.0 V

A_v = 2.0

A_v (in dB) = 6.02

At cutoff



(Cutoff Region)

frequency = 1000 Hz

phase Diff = 44.0°

V_{in} = 1.5 V

V_{out} = 2.30V

AV = 1.53 (3.71 dB

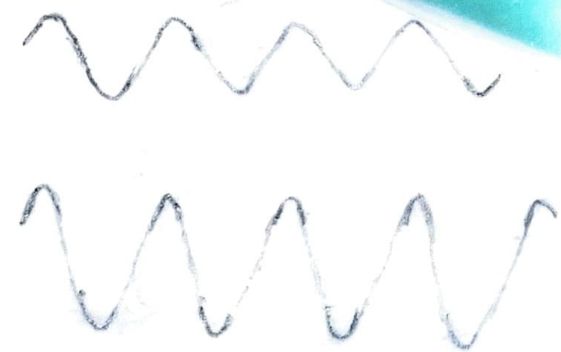
V_{cc} = ± 15 V

(b) High Pass Filter

At saturation

V_{in}

V_{out}



frequency = 10 kHz

V_{in} = 5.0 V

V_{out} = 10.4 V

V_{cc} = ±15

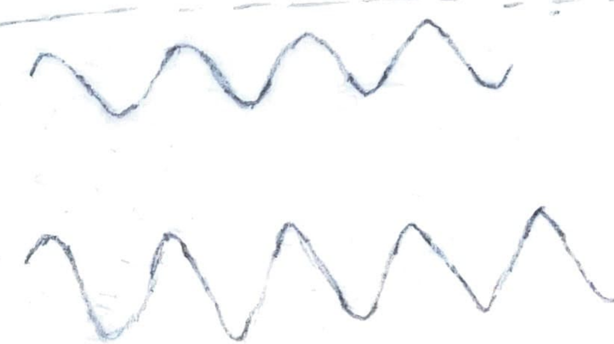
A_v = 2.08

A_v(in dB) = 6.36

phase shift = -5°

V_{in}

V_{out}



At Cutoff

frequency = 1KHz

V_{in} = 5.0V

V_{out} = 7.28V

A_v = 1.

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Calculation

(a) Low Pass Filter

from the graph

Cutoff frequency (f_c) = 2.3 KHz

Theoritical $f_c = \frac{1}{2\pi RC} = 2340.5\ Hz$.

$A_{max} = 1 + \frac{R_f}{R_1} = 2$

$45°\ \phi$ at $f = 2.3\ KHz$

$A_{V_1} = 1.44$

$V_{max} = 3V$

$\frac{V_{max}}{\sqrt{2}} = 2.12V$

∴ allowed frequency band for low pass filter is $= f_H - f_L$

$f_H = 2.3 KHz$

$f_L = 5\ Hz$

$= 2.3\ KHz - 5\ Hz$

$= 2.295\ KHz$

(b) High Pass filter

from the graph

Cutoff frequency = 1.0 KHz

Theoritical $f_c = \frac{1}{2\pi RC} = 1.06\ KHz$

$A_{max} = 1 + \frac{R_f}{R_1} = 2$

$45°\ \phi$ at $f = 1\ KHz$

$A_{V_1} = 1.37$

$V_{max} = 10.4V$

$\frac{V_{max}}{\sqrt{2}} = 7.35V$

∴ allowed frequency band for high pass filter is $= f_H - f_L$

$f_H = 30\ KHz$

$f_L = 1\ KHz$

$= 30\ KHz - 1\ KHz$

$= 29\ KHz$

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Result

1. The cutoff frequency for low pass filter is 2.3 KHz
2. The allowed frequency band for it is 2.295 KHz
3. Cutoff frequency for high pass filter is 1 KHz
4. The allowed frequency band for it is 29 KHz.
5. The theoritical v/s Actual values is

	Theoritical	Actual
low pass	$f_c = 2340.5\ Hz$ $f_H - f_L = 2340.5\ Hz$	$f_c = 2.3\ KHz$. $f_H - f_L = 2.295\ KHz$. $A_{max} = 2$. $V_{max} = 3V$ $A_{V_1} = 1.44$ $\frac{V_{max}}{\sqrt{2}} = 2.12V$
High pass	$f_c = 1.06\ KHz$.	$f_c = 1\ KHz$ $f_H - f_L = 29\ KHz$. $V_{max} = 10.4V$ $A_{max} = 2$ $\frac{V_{max}}{\sqrt{2}} = 7.35V$ $A_V = 1.37$

Precautions :

1. Make sure that all connection are tight -
2. Do not apply two large biasing voltage to the op-amp
3. Switch off the power supply when handling the circuit.
4. Wait for the values is oscilloscope to reach equilibrium
5. Ensure the ground is connected between the powersupply and breadboard.

Discussion

1. There is a phase shift in all the these circuits
2. phase difference increases with the increase in frequency.
3. Breakdown for low pass filter was observed for 1.4 MHz
4. Breakdown for high pass filter was observed for 1800KHz ~~increase and then~~
5. Vout for low pass filter was observed to remain constant and then decrease
6. Vout for High pass filter was observed to increase first then remain constant and then decrease.

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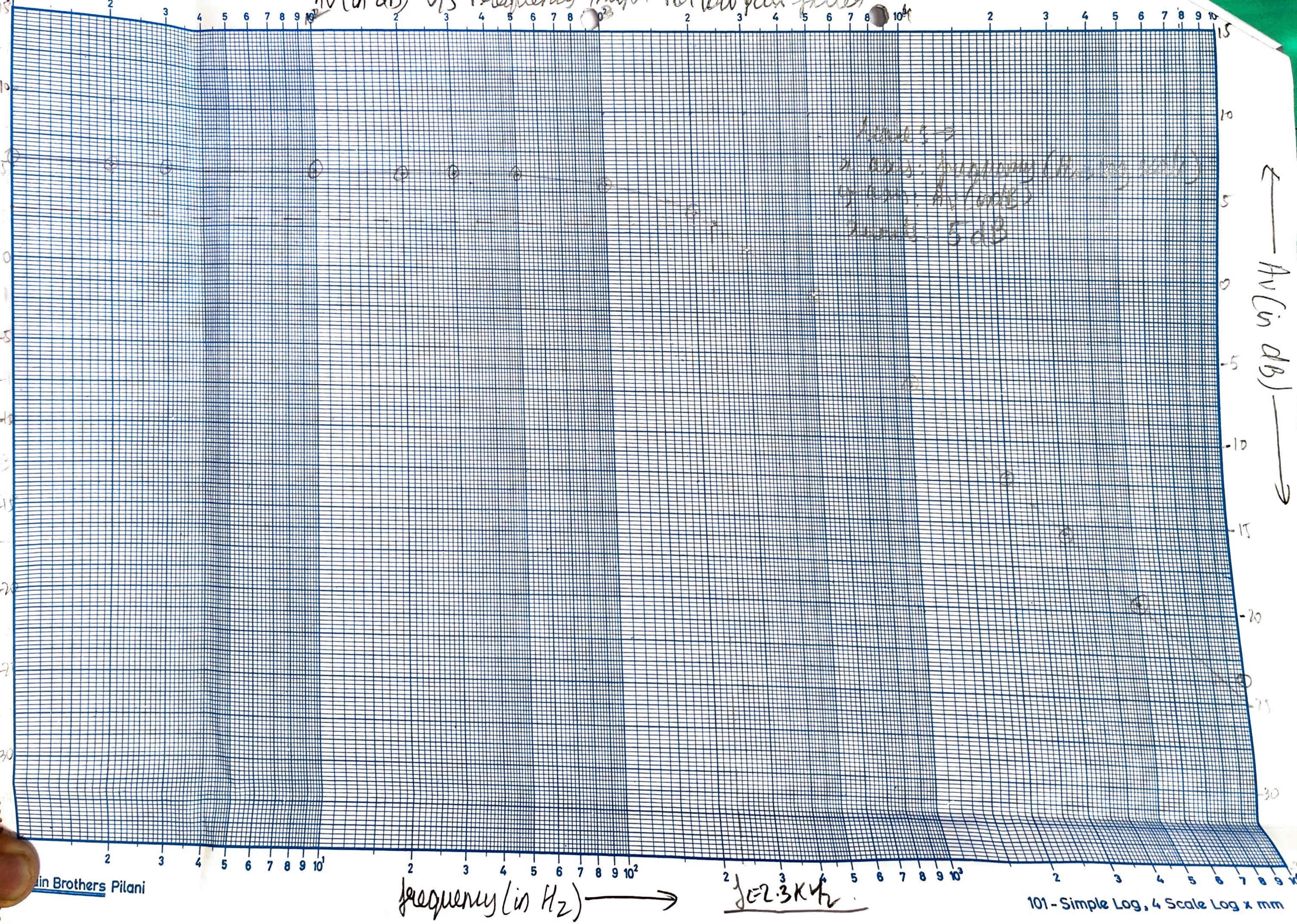
Av (in dB) v/s Frequency Graph for lowpass filter



Av(in dB) v/s Frequency Graph for high pass filter