TO DESIGN AND SYUDY THE HIGH PASS, LOW PASS AND BAND PASS FILTER CIRCUIT.

APPARATUS REQUIRED

1. Bread Board
2. Signal Generator
3. Resistors
4. Capacitors
5. Jumper Wires
6. Oscilloscope

THEORY

RC filters are fundamental circuits in electronics, using combinations of resistors (R) and capacitors (C) to selectively pass or block signals based on their frequency. These filters exploit the frequency-dependent nature of capacitive reactance, which decreases with increasing frequency, thereby allowing precise control over the frequency response of the circuit.

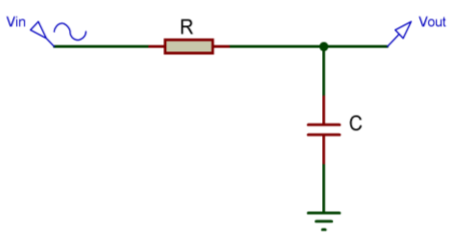
Low Pass Filter:

A low pass filter allows frequencies below a specific cutoff frequency (f_c) to pass with minimal attenuation while attenuating signals with frequencies above f_c. This is achieved due to the frequency-dependent impedance of the capacitor, which becomes smaller at higher frequencies. The cutoff frequency is defined as the frequency where the output signal power drops to half its maximum value (or the voltage drops to 70.7% of its maximum value).

Mathematically, the cutoff frequency is given by:

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

At frequencies much lower than f_c, the capacitor acts as an open circuit, allowing signals to pass with minimal loss. As the frequency approaches and exceeds f_c, the capacitor effectively shorts the output to ground, leading to signal attenuation. The filter's roll-off rate beyond the cutoff is 20 dB/decade,



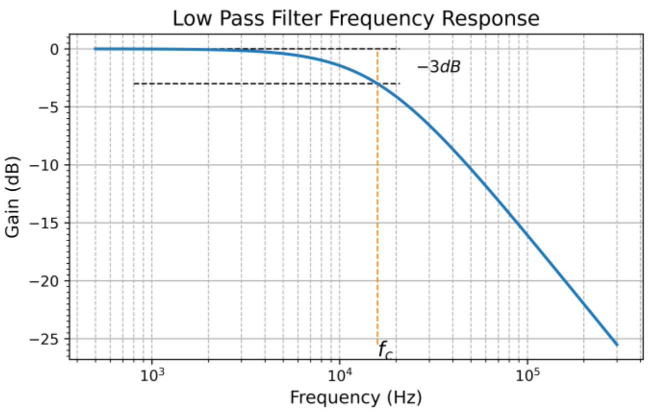


Figure 1: Low pass filter circuit (left) and a typical semi-log plot of voltage gain v/s frequency curve for low pass filter (right).

typical for a first-order filter. The output voltage (V_{out}) at a given frequency f is related to the input voltage (V_{in}) by the following formula:

$$V_{out} = \frac{1}{\sqrt{1 + (2\pi f RC)^2}} \cdot V_{in} \tag{2}$$

This equation shows that the output voltage decreases as the frequency increases, particularly beyond the cutoff frequency f_c.

High Pass Filter:
A high pass filter allows frequencies above the cutoff frequency to pass while attenuating those below it. The cutoff frequency is the same as in the low pass filter as in equation (1).

For frequencies much higher than f_c, the capacitor behaves like a short circuit, allowing high-frequency signals to pass with minimal attenuation. For frequencies much lower than f_c the capacitor acts as an open circuit, blocking low-frequency signals. The roll-off rate below the cutoff is also 20 dB/decade.

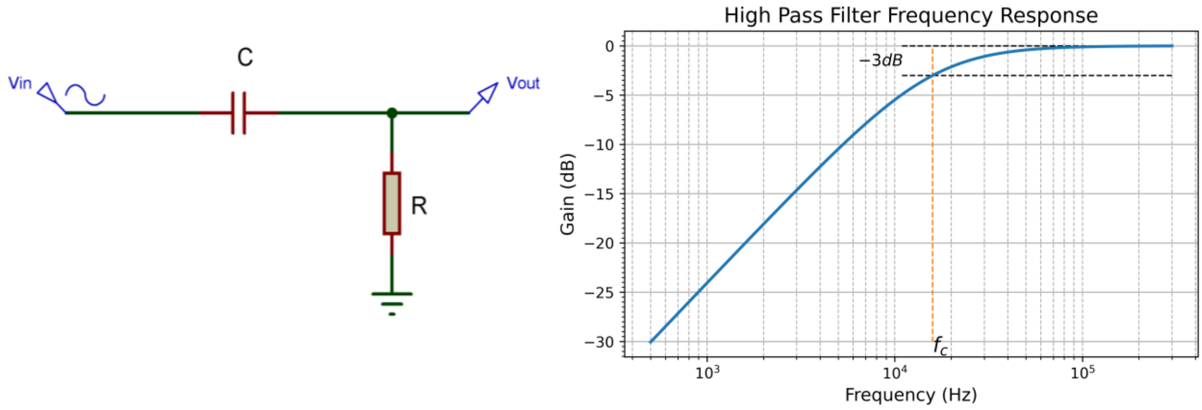


Figure 2: High pass filter circuit (left) and a typical semi-log plot of voltage gain v/s frequency curve for High pass filter (right).

The output voltage (V_{out}) at a given frequency f is related to the input voltage (V_{in}) by the following formula:

$$V_{out} = \frac{2\pi f RC}{\sqrt{1 + (2\pi f RC)^2}} \cdot V_{in} \tag{3}$$

This equation shows that the output voltage increases as the frequency increases, particularly beyond the cutoff frequency f_c.

Band Pass Filter:
A band pass filter allows frequencies within a defined range (bandwidth) to pass, while attenuating frequencies outside this range. A simple RC band pass filter can be constructed by cascading a high pass filter with a low pass filter. The lower and upper cutoff frequencies, f_L and f_H, determine the passband, calculated as equation (1) for different value of R and C, and the bandwidth (BW) is defined as:

$$BW = f_H - f_L \tag{4}$$

For band pass $f_H > f_L$ and the center frequency (f_0) of the band pass filter, where the signal experiences maximum gain, is approximately the geometric mean of the two cutoff frequencies:

$$f_0 = \sqrt{f_H \cdot f_L} \tag{5}$$

Band pass filters are essential in applications requiring frequency selectivity, such as radio tuning, where only a specific range of frequencies needs to be passed while others are attenuated.

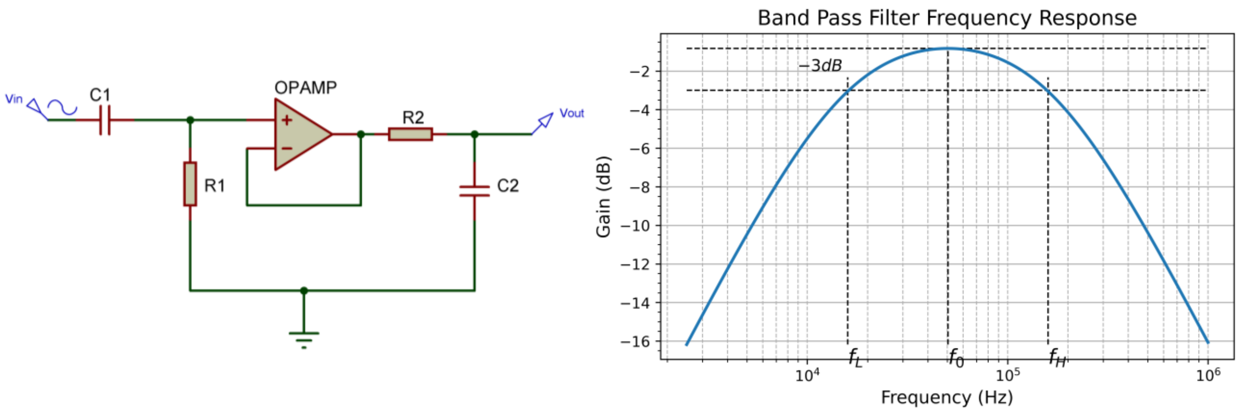


Figure 3: Band pass filter circuit (left) and a typical semi-log plot of voltage gain v/s frequency curve for Band pass filter (right).

The output voltage (V_{out}) at a given frequency f is related to the input voltage (V_{in}) by the following formula:

$$V_{out} = \frac{2\pi f R_1 C_1}{\sqrt{(1 + (2\pi f R_1 C_1)^2)(1 + (2\pi f R_2 C_2)^2)}} \cdot V_{in} \tag{6}$$

This equation shows that the output voltage increases as the frequency increases, and decreases after certain frequency.

OBSERVATION

Table 1: The observation table of the low pass filter for $Vin = 6\,Vpp, R = 1K\Omega\,, C = 10\,nF.$

SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$(dB)	SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$ (dB)
1	300	5.2	-1.24	41	26000	2.5	-7.60
2	400	5.2	-1.24	42	28000	2.4	-7.96
3	500	5.2	-1.24	43	30000	2.3	-8.33
4	600	5.2	-1.24	44	32000	2.2	-8.71
5	700	5.2	-1.24	45	34000	2.1	-9.12
6	800	5.2	-1.24	46	36000	2	-9.54
7	900	5.2	-1.24	47	38000	1.9	-9.99
8	1000	5.2	-1.24	48	40000	1.8	-10.46
9	1200	5.2	-1.24	49	45000	1.7	-10.95
10	1400	5.2	-1.24	50	50000	1.48	-12.16
11	1600	5.2	-1.24	51	55000	1.36	-12.89
12	1800	5.2	-1.24	52	60000	1.24	-13.69
13	2000	5.2	-1.24	53	65000	1.16	-14.27
14	2500	5.2	-1.24	54	70000	1.08	-14.89
15	3000	5.2	-1.24	55	75000	1	-15.56
16	3500	5.2	-1.24	56	80000	0.96	-15.92
17	4000	5.2	-1.24	57	85000	0.92	-16.29
18	4500	5	-1.58	58	90000	0.84	-17.08
19	5000	5	-1.58	59	95000	0.8	-17.50
20	5500	5	-1.58	60	100000	0.76	-17.95
21	6000	4.8	-1.94	61	110000	0.72	-18.42
22	6500	4.8	-1.94	62	120000	0.66	-19.17

23	7000	4.8	-1.94
24	7500	4.6	-2.31
25	8000	4.6	-2.31
26	8500	4.6	-2.31
27	9000	4.4	-2.69
28	10000	4.4	-2.69
29	11000	4.2	-3.10
30	12000	4	-3.52
31	13000	4	-3.52
32	14000	4	-3.52
33	15000	3.8	-3.97
34	16000	3.6	-4.44
35	17000	3.4	-4.93
36	18000	3.3	-5.19
37	19000	3.2	-5.46
38	20000	3.1	-5.74
39	22000	2.9	-6.32
40	24000	2.7	-6.94

63	130000	0.62	-19.72
64	140000	0.58	-20.29
65	150000	0.54	-20.92
66	160000	0.5	-21.58
67	170000	0.46	-22.31
68	180000	0.42	-23.10
69	190000	0.4	-23.52
70	200000	0.38	-23.97
71	220000	0.34	-24.93
72	240000	0.32	-25.46
73	260000	0.3	-26.02
74	280000	0.28	-26.62
75	300000	0.26	-27.26

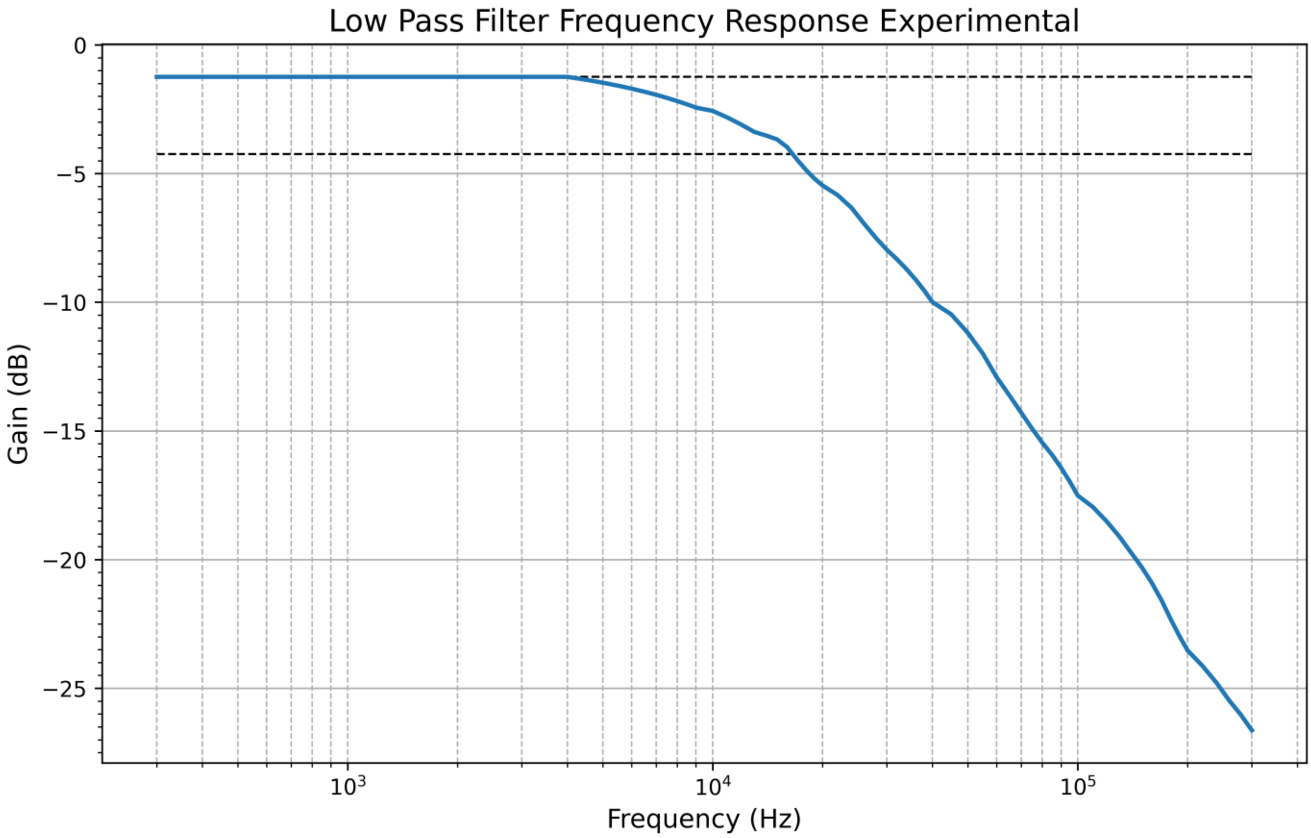


Figure 4: Experimental semi-log plot of voltage gains v/s frequency for Low Pass Filter.

Cut off Frequency

$R = 1K\Omega, C = 10\ nF$

Theoretical cutoff frequency $(fc_{th}) = \frac{1}{2\pi RC} = \frac{1}{2\times\pi\times1\times10^3\times10\times10^{-9}} = 15915.49\ Hz$

Error:

$$\Delta fc_{th} = fc_{th}\sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta c}{C}\right)^2} = 15915.49\sqrt{\left(\frac{50}{1000}\right)^2 + \left(\frac{2}{10}\right)^2} = 15915.49 \times 0.20$$

$$= 3281.06\ Hz$$

$\therefore fc_{th} = (15915.49 \pm 3183.09)\ Hz$

From graph:

Experimental cutoff frequency $(fc_{exp}) =$

Table 2: The observation table of the High pass filter for $Vin = 6\ Vpp, R = 100\Omega\ , C = 10\ nF$.

SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$ (dB)
1	1000	0.036	-44.437
2	1100	0.04	-43.5218
3	1200	0.044	-42.694
4	1300	0.048	-41.9382
5	1400	0.052	-41.243
6	1500	0.056	-40.5993
7	1600	0.06	-40
8	1700	0.064	-39.4394
9	1800	0.064	-39.4394
10	1900	0.068	-38.9128
11	2000	0.072	-38.4164
12	2200	0.084	-37.0774
13	2400	0.088	-36.6734
14	2600	0.096	-35.9176
15	2800	0.104	-35.2224
16	3000	0.108	-34.8945
17	3200	0.112	-34.5787
18	3400	0.116	-34.2739
19	3600	0.128	-33.4188
20	3800	0.14	-32.6405
21	4000	0.15	-32.0412
22	4500	0.16	-31.4806
23	5000	0.17	-30.954
24	5500	0.2	-29.5424
25	6000	0.21	-29.1186
26	6500	0.23	-28.3285
27	7000	0.25	-27.6042
28	7500	0.28	-26.6199
29	8000	0.29	-26.3151
30	8500	0.3	-26.0206
31	9000	0.31	-25.7358

SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$ (dB)
50	34000	1.24	-13.6946
51	36000	1.2	-13.9794
52	38000	1.3	-13.2842
53	40000	1.4	-12.6405
54	45000	1.6	-11.4806
55	50000	1.7	-10.954
56	55000	1.8	-10.4576
57	60000	2.1	-9.11864
58	65000	2.2	-8.71457
59	70000	2.4	-7.9588
60	75000	2.5	-7.60422
61	80000	2.6	-7.26356
62	85000	2.7	-6.93575
63	90000	2.8	-6.61986
64	95000	2.8	-6.61986
65	100000	3	-6.0206
66	110000	3.2	-5.46003
67	120000	3.4	-4.93345
68	130000	3.6	-4.43697
69	140000	3.6	-4.43697
70	150000	3.8	-3.96735
71	160000	4	-3.52183
72	170000	4	-3.52183
73	180000	4.2	-3.09804
74	190000	4.4	-2.69397
75	200000	4.6	-2.30787
76	220000	4.6	-2.30787
77	240000	4.6	-2.30787
78	260000	4.8	-1.9382
79	280000	4.8	-1.9382
80	300000	5	-1.58362

32	9500	0.34	-24.9334	81	320000	5.2	-1.24296
33	10000	0.36	-24.437	82	340000	5.2	-1.24296
34	11000	0.4	-23.5218	83	360000	5.4	-0.91515
35	12000	0.44	-22.694	84	380000	5.4	-0.91515
36	13000	0.46	-22.3079	85	400000	5.4	-0.91515
37	14000	0.5	-21.5836	86	450000	5.4	-0.91515
38	15000	0.56	-20.5993	87	500000	5.6	-0.59926
39	16000	0.58	-20.2945	88	550000	5.6	-0.59926
40	17000	0.6	-20	89	600000	5.8	-0.29447
41	18000	0.62	-19.7152	90	650000	5.8	-0.29447
42	19000	0.72	-18.4164	91	700000	5.8	-0.29447
43	20000	0.76	-17.9468	92	750000	5.8	-0.29447
44	22000	0.8	-17.5012	93	800000	5.8	-0.29447
45	24000	0.84	-17.0774	94	850000	5.8	-0.29447
46	26000	0.88	-16.6734	95	900000	5.8	-0.29447
47	28000	1	-15.563	96	950000	5.8	-0.29447
48	30000	1.08	-14.8945	97	1000000	5.8	-0.29447
49	32000	1.2	-13.9794				

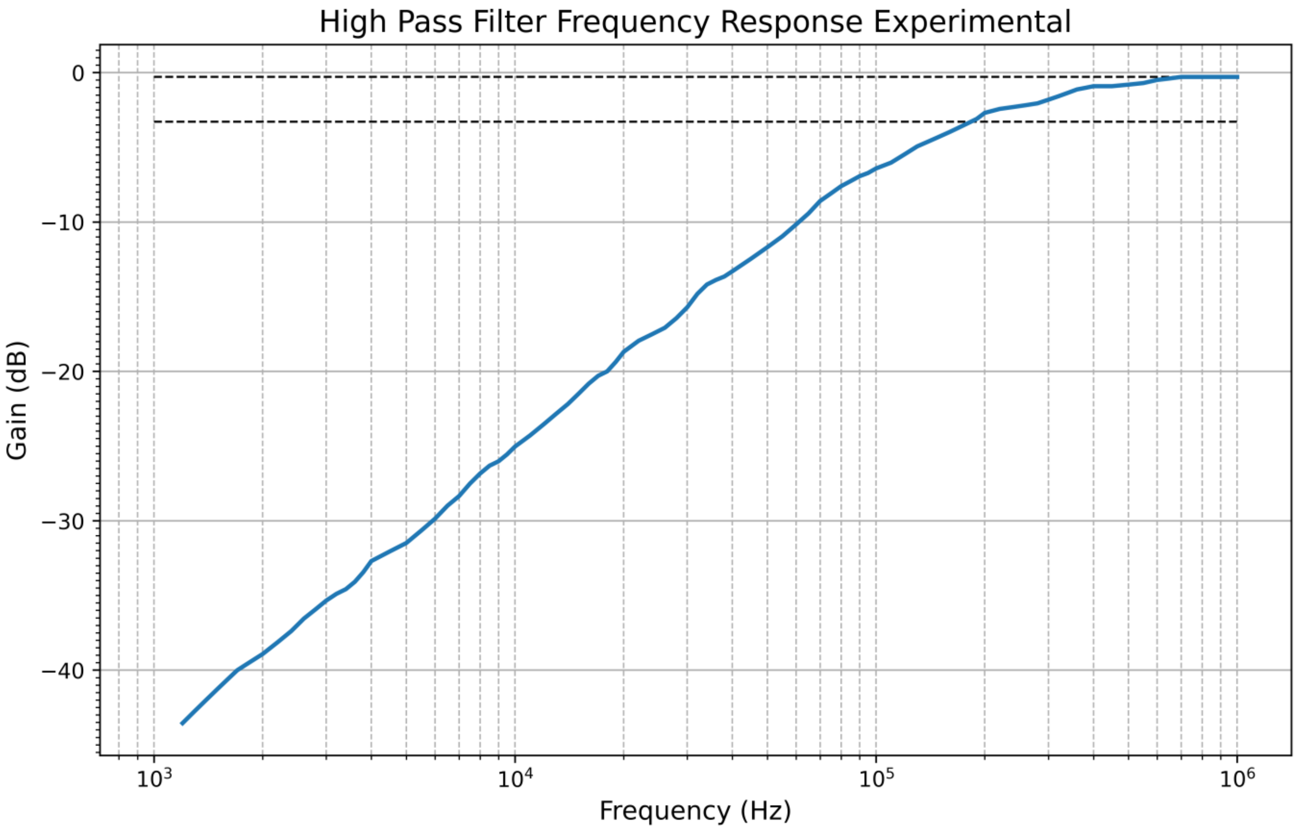


Figure 5: Experimental semi-log plot of voltage gains v/s frequency for High Pass Filter.

Cut off Frequency

$R = 100\ \Omega, C = 10\ nF$

Theoretical cutoff frequency $(fc_{th}) = \frac{1}{2\pi RC} = \frac{1}{2\times\pi\times100\times10\times10^{-9}} = 159154.94\ Hz$

Error:

$$\Delta fc_{th} = fc_{th}\sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta c}{C}\right)^2} = 159154.94\sqrt{\left(\frac{5}{100}\right)^2 + \left(\frac{2}{10}\right)^2} = 159154.94 \times 0.20$$

$$= 32810.63\ Hz$$

$\therefore fc_{th} = (159154.49 \pm 32810.63)\ Hz$

From graph:

Experimental cutoff frequency $\left(fc_{exp}\right) =$

Table 3: The observation table of the Band pass filter for $Vin = 6\,Vpp, R_1 = 1000\Omega\,, C_1 = 10\,nF, R_2 = 100\Omega\,, C_1 = 10\,nF$.

SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$ (dB)
1	1000	0.38	-23.9674
2	1100	0.4	-23.5218
3	1200	0.44	-22.694
4	1300	0.48	-21.9382
5	1400	0.52	-21.243
6	1500	0.56	-20.5993
7	1600	0.6	-20
8	1700	0.64	-19.4394
9	1800	0.68	-18.9128
10	1900	0.72	-18.4164
11	2000	0.76	-17.9468
12	2200	0.8	-17.5012
13	2400	0.92	-16.2873
14	2600	0.96	-15.9176
15	2800	1.04	-15.2224
16	3000	1.12	-14.5787
17	3200	1.2	-13.9794
18	3400	1.2	-13.9794
19	3600	1.3	-13.2842
20	3800	1.4	-12.6405
21	4000	1.5	-12.0412
22	4500	1.7	-10.954
23	5000	1.8	-10.4576
24	5500	2	-9.54243
25	6000	2.1	-9.11864
26	6500	2.3	-8.32847
27	7000	2.4	-7.9588
28	7500	2.6	-7.26356
29	8000	2.7	-6.93575
30	8500	2.8	-6.61986
31	9000	3	-6.0206
32	9500	3.1	-5.73579

SN	Frequency (Hz)	Vo(pp) (V)	Gain = $20log(Vo/Vin)$ (dB)
50	34000	5.2	-1.24296
51	36000	5.4	-0.91515
52	38000	5.4	-0.91515
53	40000	5.4	-0.91515
54	45000	5.4	-0.91515
55	50000	5.4	-0.91515
56	55000	5.4	-0.91515
57	60000	5.4	-0.91515
58	65000	5.4	-0.91515
59	70000	5.4	-0.91515
60	75000	5.4	-0.91515
61	80000	5.2	-1.24296
62	85000	5.2	-1.24296
63	90000	5.2	-1.24296
64	95000	5.2	-1.24296
65	100000	5	-1.58362
66	110000	5	-1.58362
67	120000	4.8	-1.9382
68	130000	4.6	-2.30787
69	140000	4.4	-2.69397
70	150000	4.4	-2.69397
71	160000	4.2	-3.09804
72	170000	4	-3.52183
73	180000	4	-3.52183
74	190000	3.8	-3.96735
75	200000	3.6	-4.43697
76	220000	3.6	-4.43697
77	240000	3.2	-5.46003
78	260000	3	-6.0206
79	280000	2.8	-6.61986
80	300000	2.8	-6.61986
81	320000	2.7	-6.93575

33	10000	3.2	-5.46003
34	11000	3.4	-4.93345
35	12000	3.6	-4.43697
36	13000	3.8	-3.96735
37	14000	4	-3.52183
38	15000	4.2	-3.09804
39	16000	4.2	-3.09804
40	17000	4.4	-2.69397
41	18000	4.6	-2.30787
42	19000	4.6	-2.30787
43	20000	4.6	-2.30787
44	22000	4.8	-1.9382
45	24000	4.8	-1.9382
46	26000	5	-1.58362
47	28000	5	-1.58362
48	30000	5.2	-1.24296
49	32000	5.2	-1.24296

82	340000	2.5	-7.60422
83	360000	2.4	-7.9588
84	380000	2.3	-8.32847
85	400000	2.2	-8.71457
86	450000	2	-9.54243
87	500000	1.8	-10.4576
88	550000	1.6	-11.4806
89	600000	1.5	-12.0412
90	650000	1.4	-12.6405
91	700000	1.3	-13.2842
92	750000	1.2	-13.9794
93	800000	1.2	-13.9794
94	850000	1.16	-14.2739
95	900000	1.04	-15.2224
96	950000	1	-15.563
97	1000000	0.96	-15.9176

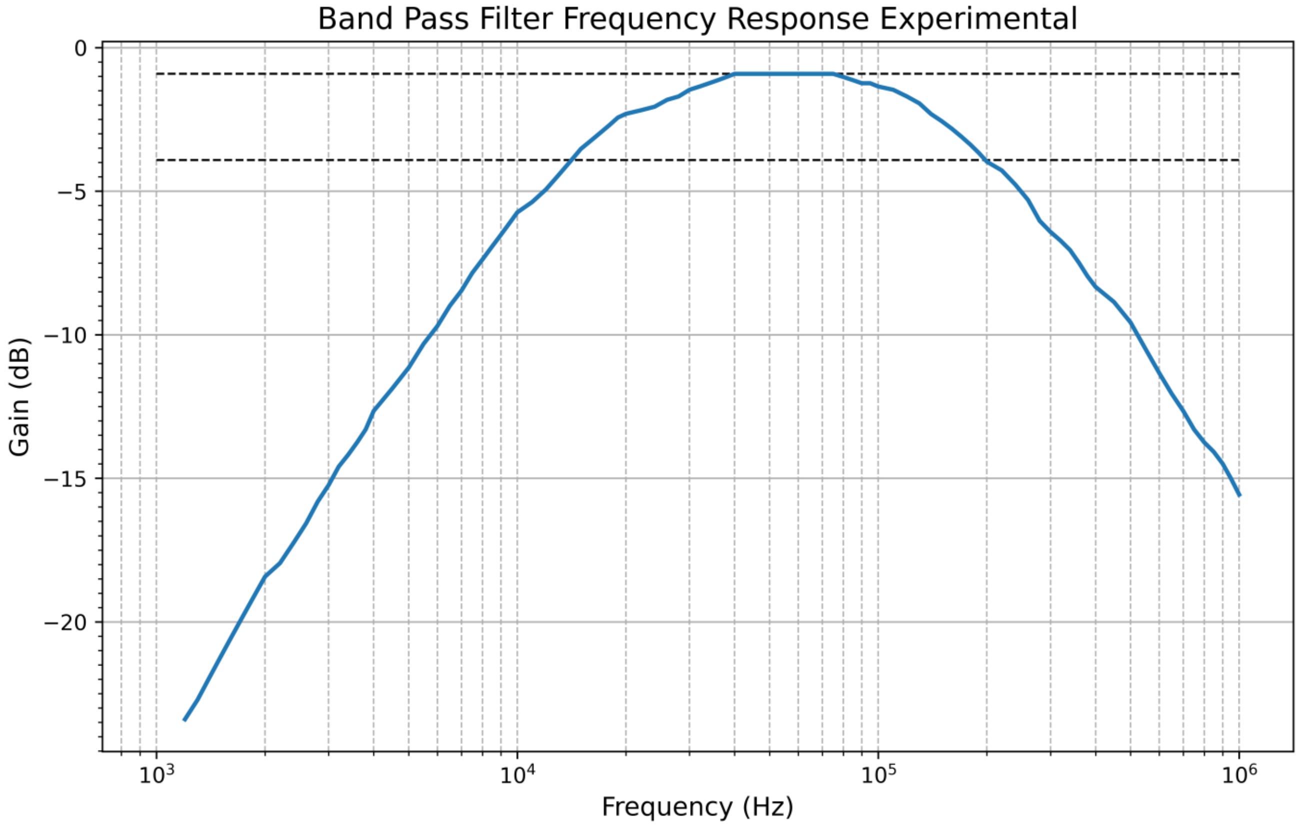


Figure 6: Experimental semi-log plot of voltage gains v/s frequency for Band Pass Filter.

Cut off Frequencies

$R_1 = 1K\Omega, C_1 = 100\ nF, R_2 = 10K\Omega, C_2 = 10\ nF$

Theoretical cutoff frequencies:

$$f_L = \frac{1}{2\pi R_1 C_1} = \frac{1}{2 \times \pi \times 1 \times 10^3 \times 10 \times 10^{-9}} = 15915.49\ Hz$$

$$f_H = \frac{1}{2\pi R_2 C_2} = \frac{1}{2 \times \pi \times 1 \times 10^2 \times 10 \times 10^{-9}} = 159154.94\ Hz$$

Error:

$$\Delta f_L = f_L\sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta C}{C}\right)^2} = 15915.49\sqrt{\left(\frac{5}{100}\right)^2 + \left(\frac{2}{10}\right)^2} = 15915.49 \times 0.20 = 3281.06\ Hz$$

$\therefore f_L = (15915.49 \pm 3183.09)\ Hz$

$$\Delta f_H = f_H\sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\frac{\Delta c}{C}\right)^2} = 159154.94\sqrt{\left(\frac{5}{100}\right)^2 + \left(\frac{2}{10}\right)^2} = 159154.94 \times 0.20 = 32810.63\ Hz$$

$\therefore f_H = (159154.94 \pm 32810.63)\ Hz$

Bandwidth $(BW) = f_H - f_L = 159154.94 - 15915.49 = 143239.45\ Hz$
And $\Delta BW = \sqrt{(\Delta f_L)^2 + (\Delta f_H)^2} = \sqrt{3281.06^2 + 32810.63^2 =}$ 32974.26 Hz
$\therefore BW = (143239.45 \pm 32964.67)\ Hz$

Center frequency $(f_0) = \sqrt{f_H \cdot f_L} = \sqrt{159154.94 \times 15915.49} = 50329.2\ Hz$

And $\Delta f_0 = f_0 \cdot \frac{1}{2}\sqrt{\left(\frac{\Delta f_L}{f_L}\right)^2 + \left(\frac{\Delta f_H}{f_H}\right)^2} = 50329.2 \times \frac{1}{2} \times \sqrt{\left(\frac{3281.06}{15915.49}\right)^2 + \left(\frac{32810.63}{159154.94}\right)^2} = 7336.67\ Hz$

$\therefore f_0 = (50329.2 \pm 7336.67)\ Hz$
From graph:
Experimental lower cutoff frequency $(f_L) =$
Experimental upper cutoff frequency $(f_H) =$
Bandwidth $(BW) =$
Center frequency $(f_0) =$

RESULT

1. **Low-Pass Filter:**
   Cutoff Frequency: Observed at approximately ………………………… Hz.
   Frequency Response: Output voltage was high for low frequencies and started attenuating as the frequency increased, beyond ………………………… Hz.
   Roll-Off Rate: Measured to be approximately ………………………… dB/decade, consistent with theoretical values for the first-order filter.
2. **High-Pass Filter:**
   Cutoff Frequency: Observed at approximately ………………………… Hz.
   Frequency Response: Output voltage was low for frequencies below ………………………… Hz and increased for frequencies above it.
   Roll-Off Rate: Similar to the low-pass filter, observed attenuation rate is approximately ………………………… dB/decade.
3. **Band-Pass Filter:**
   Center Frequency: Observed at ………………………… Hz.
   Bandwidth: Measured at ………………………… Hz.
   Frequency Response: Output voltage peaked at the center frequency and attenuated for frequencies above and below the passband.

CONCLUSION

The experimental observations for all three filters (low-pass, high-pass, and band-pass) align closely with the theoretical expectations, verifying their respective frequency-selective behaviors:

Low-pass filters attenuate high frequencies, passing lower frequencies effectively.
High-pass filters do the opposite, attenuating lower frequencies and passing higher frequencies.
Band-pass filters allow frequencies within a specific range to pass, attenuating frequencies outside this range.
The cutoff frequencies, roll-off rates, and bandwidth were consistent with the designed component values (resistors and capacitors). Small deviations from theoretical predictions may be attributed to:

- Non-idealities in components.
- Measurement inaccuracies.
- Parasitic effects in the circuit.

The experiment successfully demonstrated how filters can be applied in practical scenarios like audio signal processing, communication systems, and noise reduction.

…………………………
(Signature)