Band-Pass Filter
A comprehensive analysis

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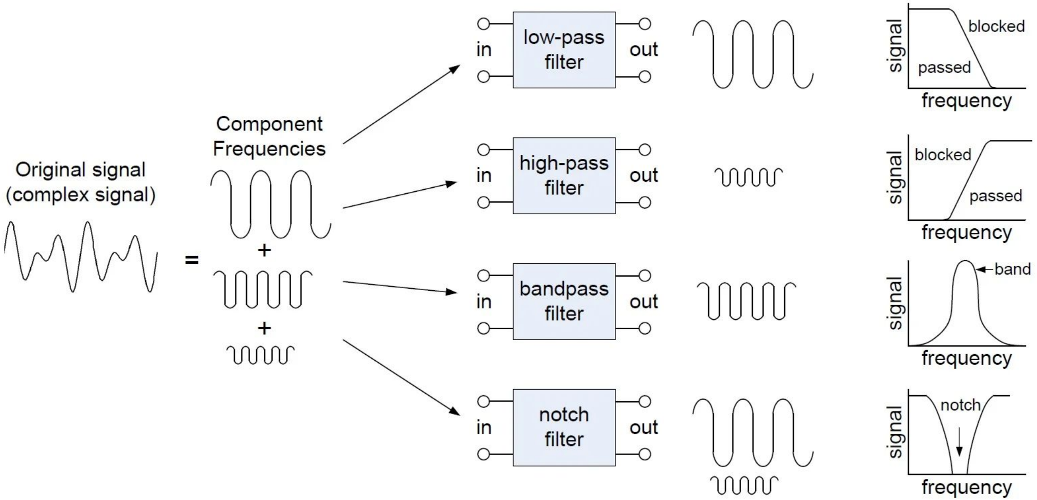
Four Major Types of Filters

The four primary types of filters include the low-pass filter, the high-pass filter, the band-pass filter, and the notch filter (or the band-reject or band-stop filter). Take note, however, that the terms "low" and "high" do not refer to any absolute values of frequency, but rather they are relative values with respect to the cutoff frequency.



Some Technical Terms for better understanding

- **-3dB Frequency (f_3dB)**

The -3dB frequency is also referred to as the cutoff frequency, and it is the frequency at which the output power is reduced by one-half, or at which the output voltage is the input voltage multiplied by $1/\sqrt{2}$.

- **Center frequency (f_0)**

The center frequency, a term used for bandpass and notch filters, is a central frequency that lies between the upper and lower cutoff frequencies. Also called peak frequency.

- **Bandwidth (β)**

The bandwidth is the width of the *passband*, and the passband is the band of frequencies that do not experience significant attenuation when moving from the input of the filter to the output of the filter.

- **Stopband frequency (f_s)**

This is a particular frequency at which the attenuation reaches a specified value.

Quality factor (**Q**)

The Q factor is a dimensionless parameter that indicates the energy losses within a resonant element. The Q factor of an element relates to the losses, this links directly in to the bandwidth of a resonator with respect to its centre frequency.

Mathematically,

$$Q = 2\pi f \frac{\text{Total stored energy}}{\text{Power Losses}}$$

For both band-pass and notch filters,

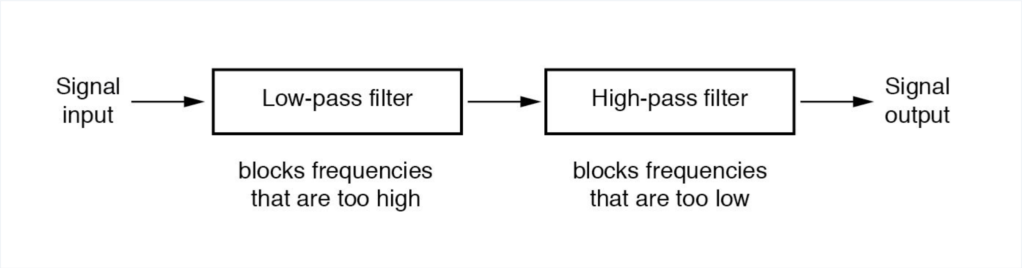
$$Q = f_0 / (f_2 - f_1)$$

Overview

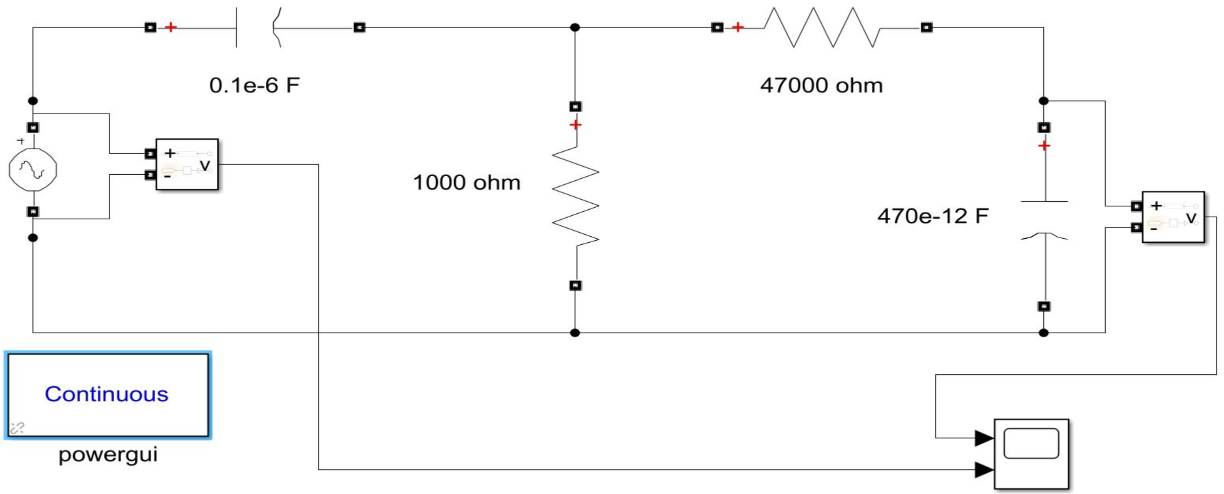
A **band-pass filter**(**BPF**) is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range.

An example of an analogue electronic band-pass filter is an RLC circuit (a resistor–inductor–capacitor circuit). These filters can also be created by combining a low-pass filter with a high-pass filter.

Creating a bandpass filter from a low-pass and high-pass filter can be illustrated using block diagrams:

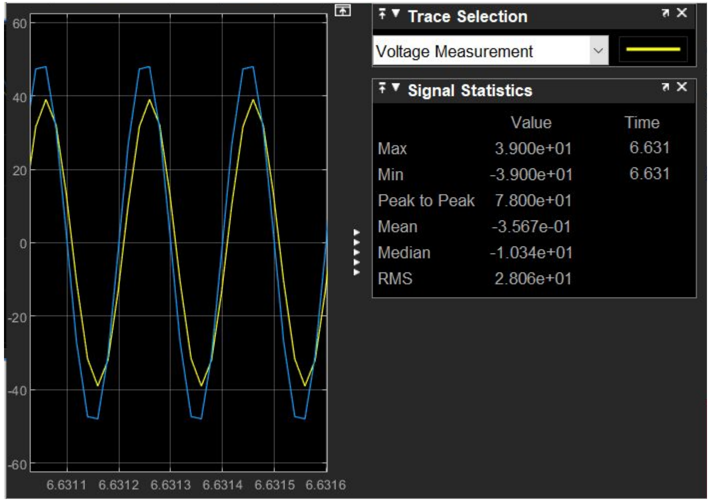


2nd-order Passive Band-Pass filter



Matlab simulation

Analysis of matlab simulation of basic bandpass filter



Low cut-off frequency: 1591.1Hz **High cut-off frequency**: 7204.84Hz

$F_1 = 1/(2\pi * R_1 * C_1)$ $F_2 = 1/(2\pi * R_2 * C_2)$

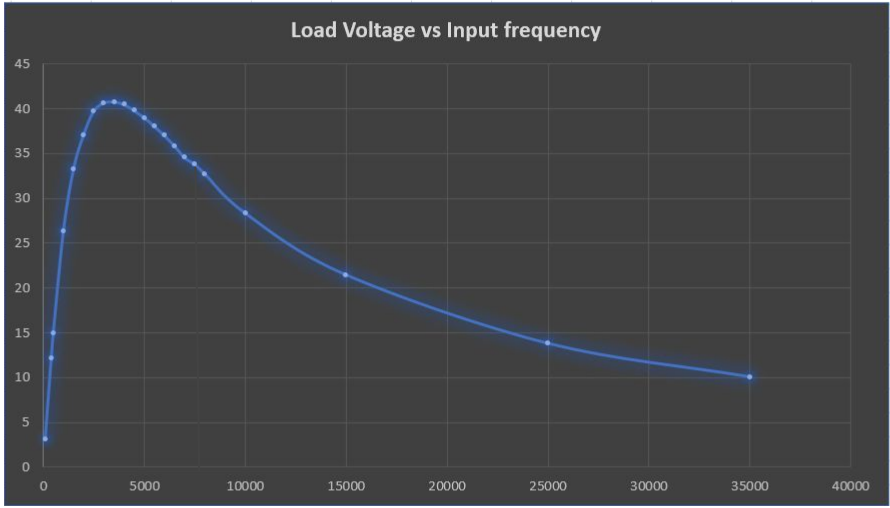
Bandwidth: 5613.74 Hz Q-factor: $F_{center} / (F_2 - F_1)$

$F_2 - F_1$

The 1 graph shows an input of 5000 Hz.
The 2 graph shows an input of 500 Hz.

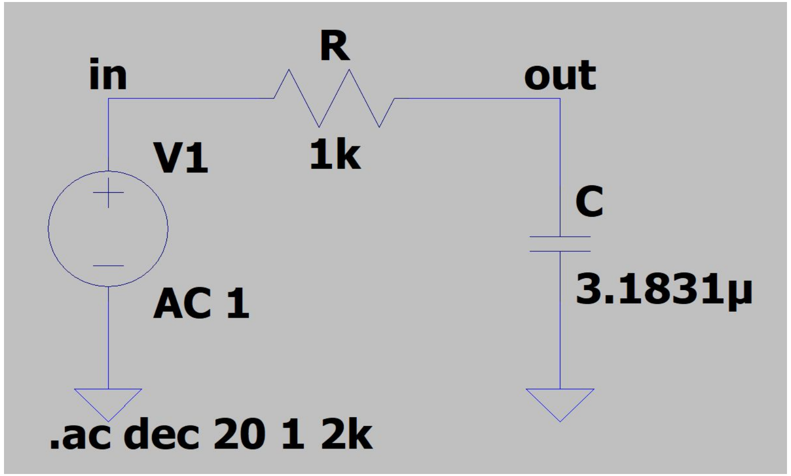
Observations:

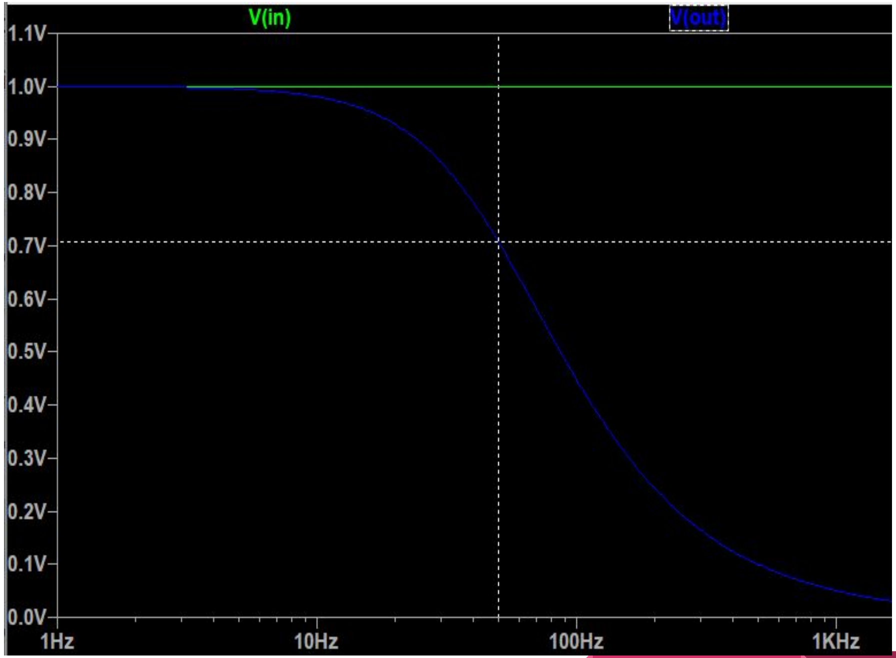
Input Frequency(Hz)	Output Voltage (V)	Input Frequency (Hz)	Output Voltage (V)
100	3.13	5000	39
400	12.15	5500	38.05
500	14.92	6000	37.01
1000	26.3	6500	35.86
1500	33.21	7000	34.55
2000	37.08	7500	33.79
2500	39.7	8000	32.74
3000	40.62	10000	28.36
3500	40.77	15000	21.46
4000	40.46	25000	13.81
4500	39.8	35000	10.07



Plotting the values in the table, we get the above graph

RC Low Pass Filter

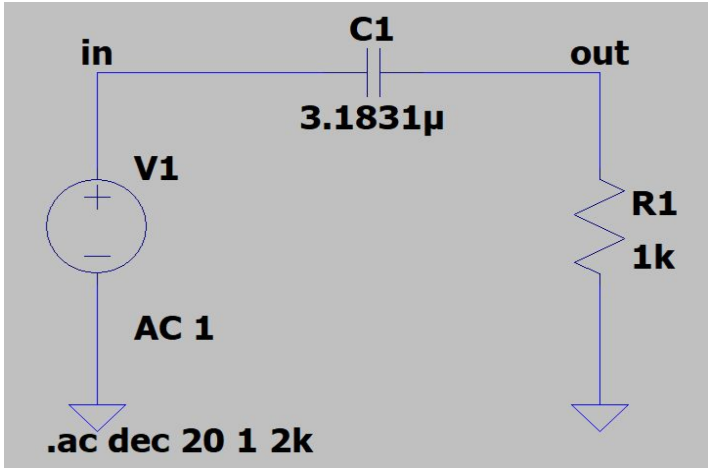


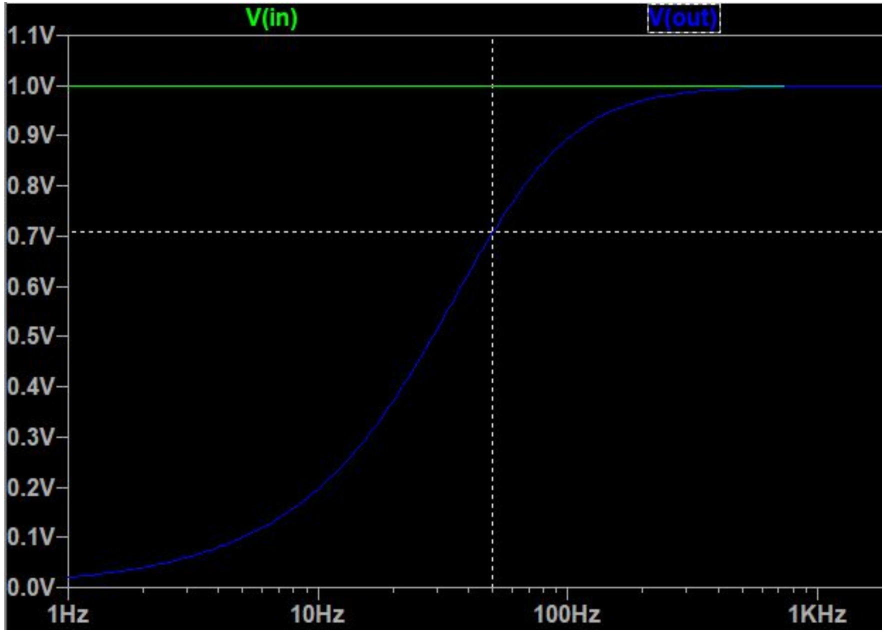


Input Voltage : 1V
Cutoff Voltage : 708.51306mV
Cutoff Frequency : 49.808743Hz

$f_c = 1/2\pi RC$

RC High Pass Filter

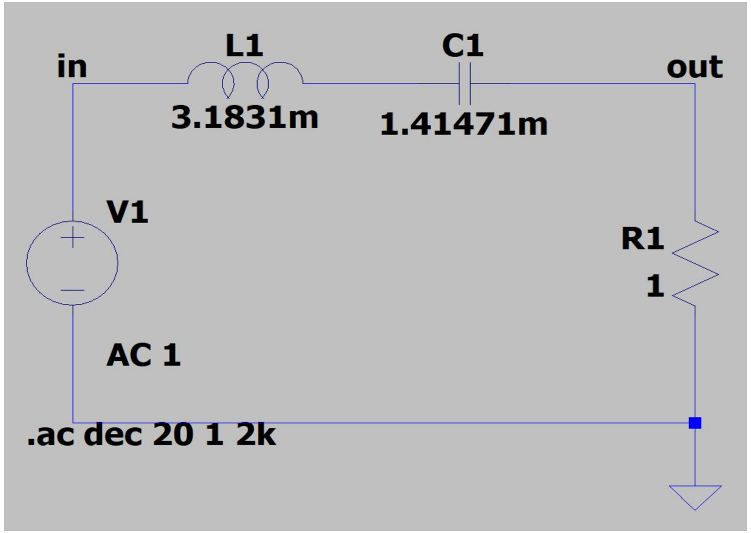


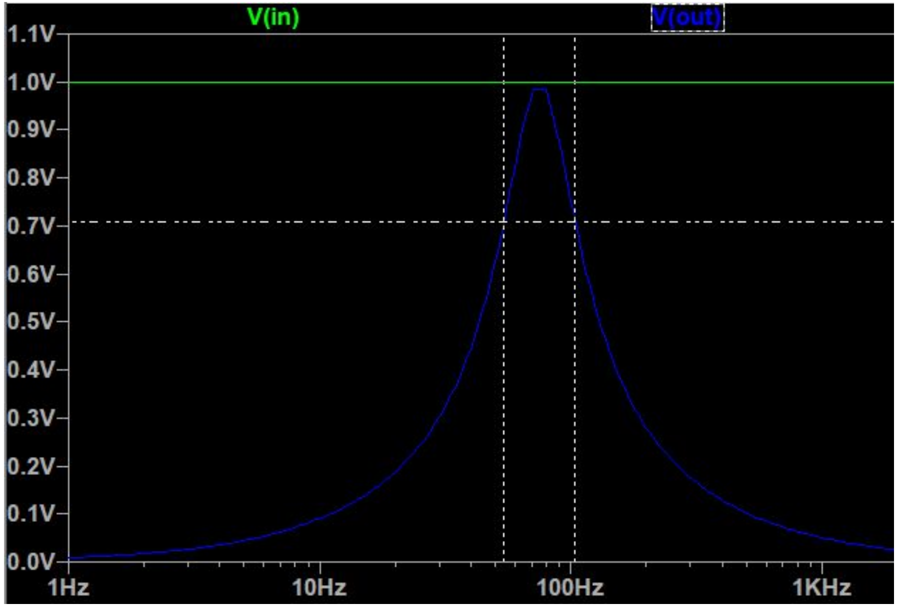


Input Voltage : 1V
Cutoff Voltage : 707.18648mV
Cutoff Frequency : 50.019634Hz

$f_c = 1/2\pi RC$

Series RLC Bandpass Filter

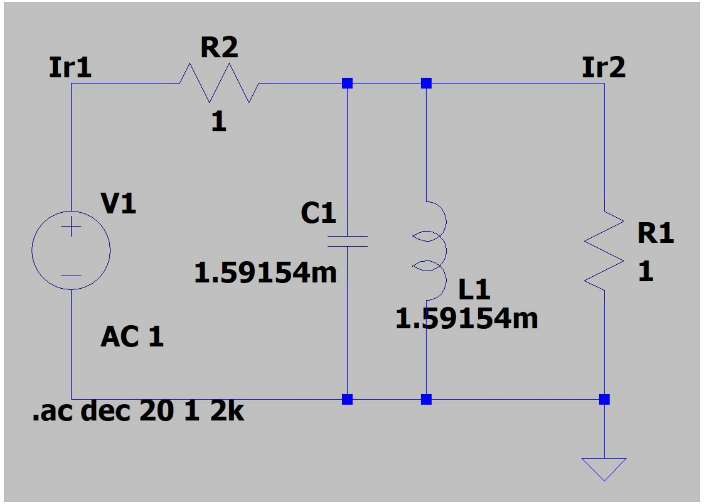


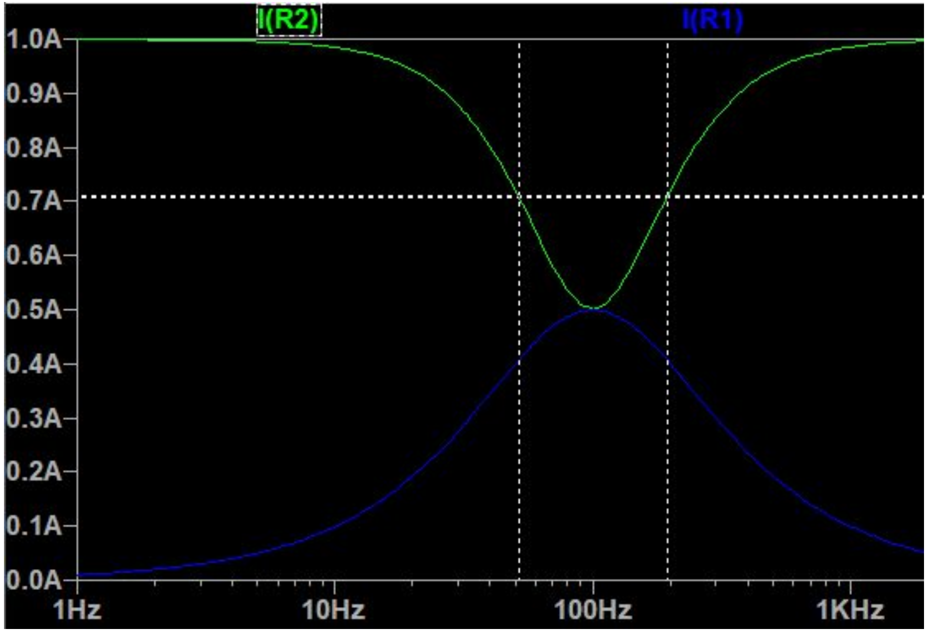


Input Voltage : 1v
Cutoff Voltage : 707.93066mV
Lower Cutoff Frequency f_1 : 54.066407Hz
Upper Cutoff Frequency f_2 : 104.31416Hz
Peak Frequency f_0 : 79.100749

$f_0 = 1/2\pi\sqrt{LC}$
Bandwidth $\Delta f = R/2\pi L = 50$Hz

Parallel RLC Bandstop Filter



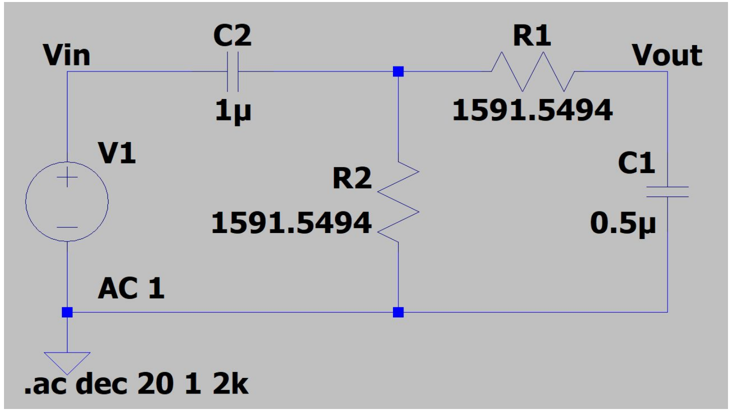


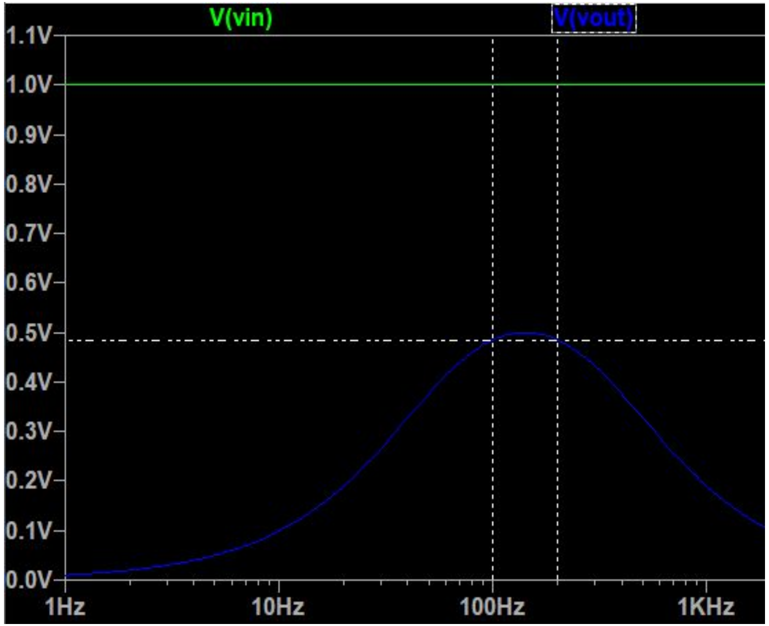
Input Voltage : 1v
Cutoff Current : 707.45751mA
Lower Cutoff Frequency f_1 : 51.739224Hz
Upper Cutoff Frequency f_2 : 194.37771Hz
Peak Frequency f_0 : 100Hz

$f_0 = 1/2\pi\sqrt{LC}$

Bandwidth $\Delta f = 1/2\pi RC = 150$Hz

RC Bandpass Filter

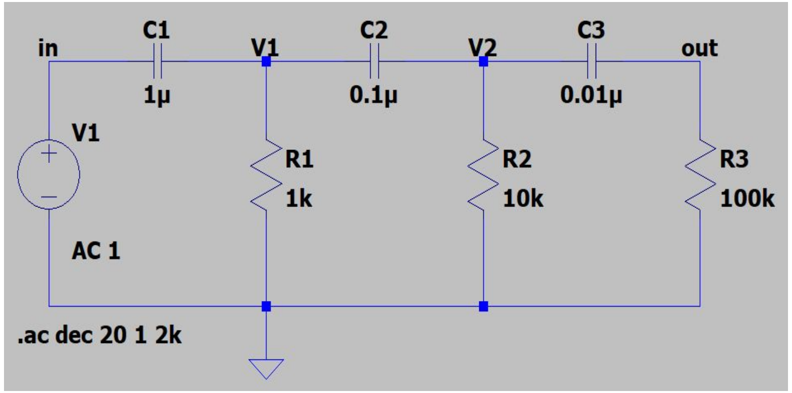


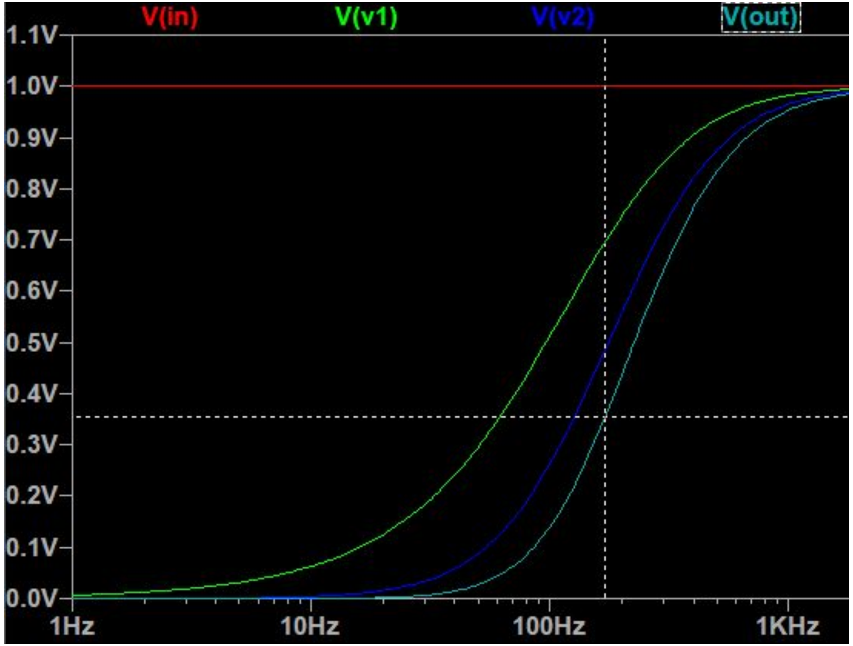


Input Voltage : 1V
Cutoff Voltage : 485.10742mV
Lower Cutoff Frequency f_1 : 100.05351Hz
Upper Cutoff Frequency f_2 : 200.10423Hz
Peak Frequency f_0 : 141.4213 Hz

$f_0 = \sqrt{f_1 f_2} = 141.4213$ Hz
Bandwidth $\Delta f = f_2 - f_1 = 100$Hz

Cascaded RC High Pass Filter

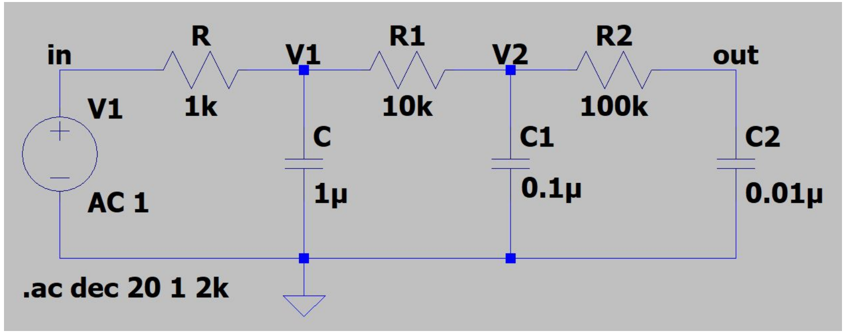


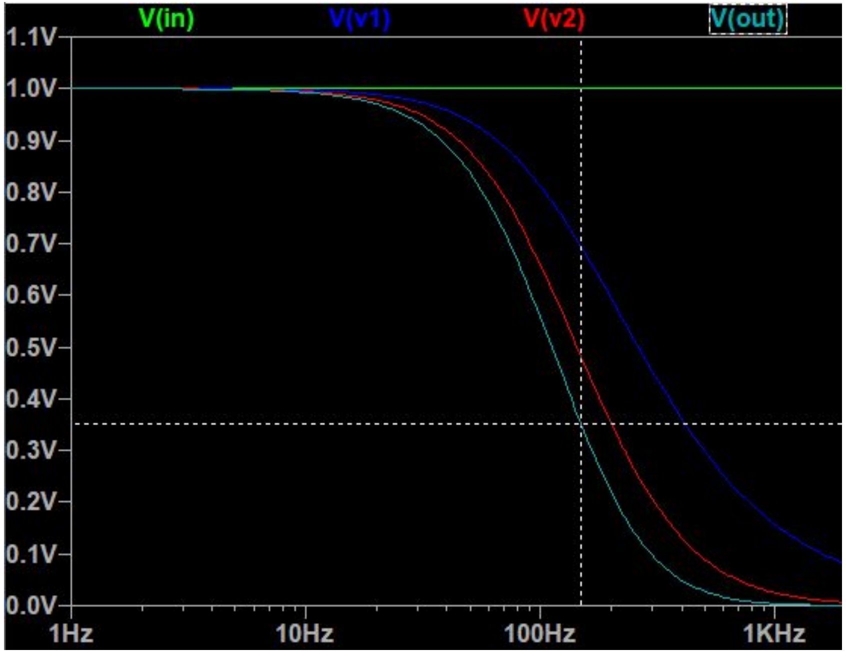


Input Voltage : 1V
Cutoff Voltage : 353.44195mV
Cutoff Frequency : 170.32121Hz

$f_c = 1/2\pi(R_1C_1 \ldots\ldots R_nC_n)$^1/n

Cascaded RC Low Pass Filter



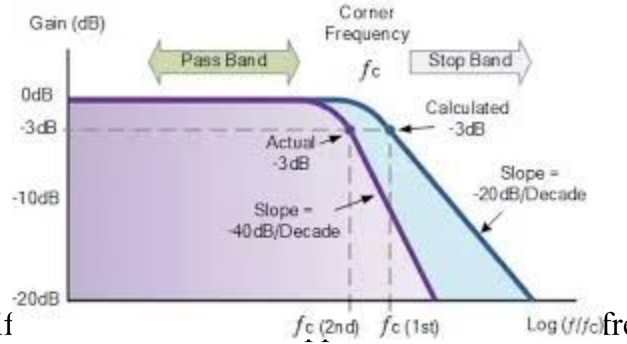


Input Voltage : 1V
Cutoff Voltage : 352.74528mV
Cutoff Frequency : 149.4122Hz

$f_c = 1/2\pi(R_1C_1........R_nC_n)$^1/n

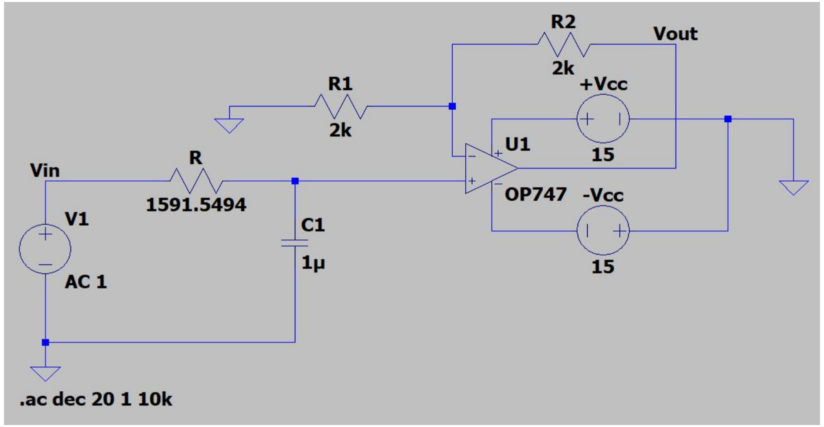
An ideal bandpass filter would have a completely flat passband (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the passband. Additionally, the transition out of the passband would have brickwall characteristics.

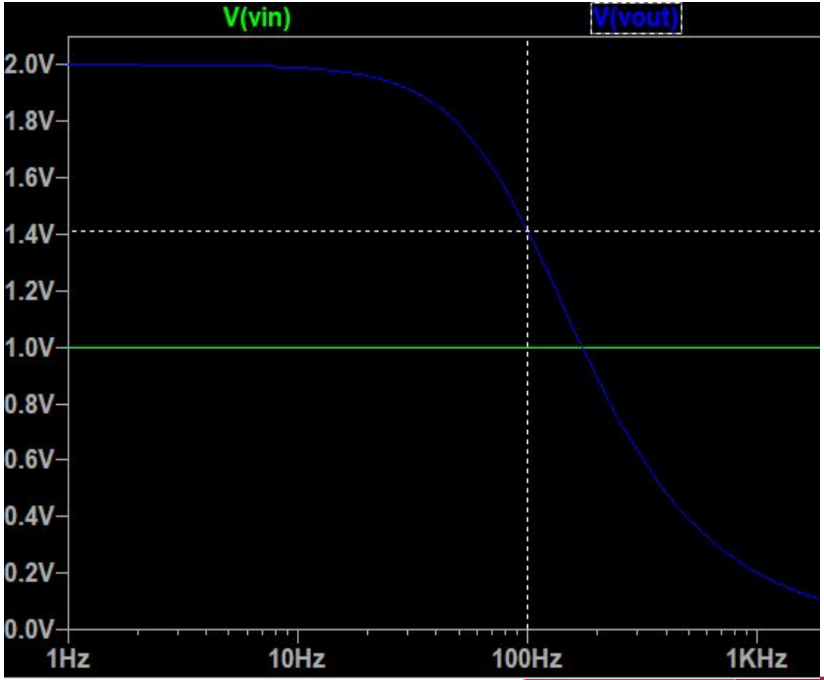
In practice, no bandpass filter is ideal. The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended passband where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band *ripple*.



The bandwidth of the filter is simply the dif frequencies.

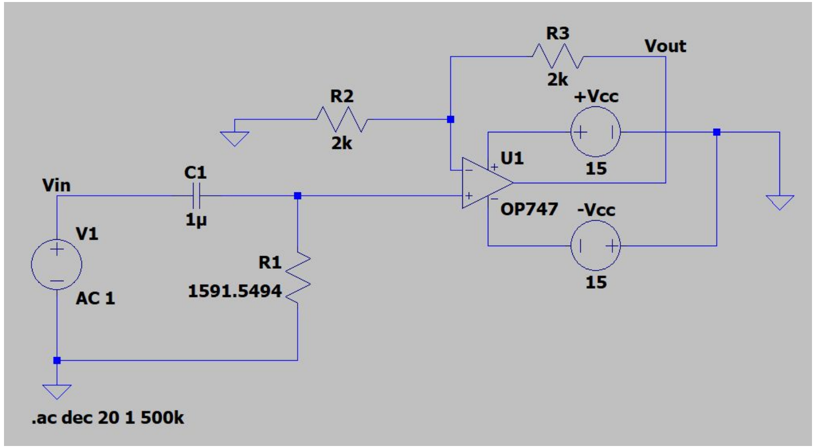
Active RC Low Pass Filter

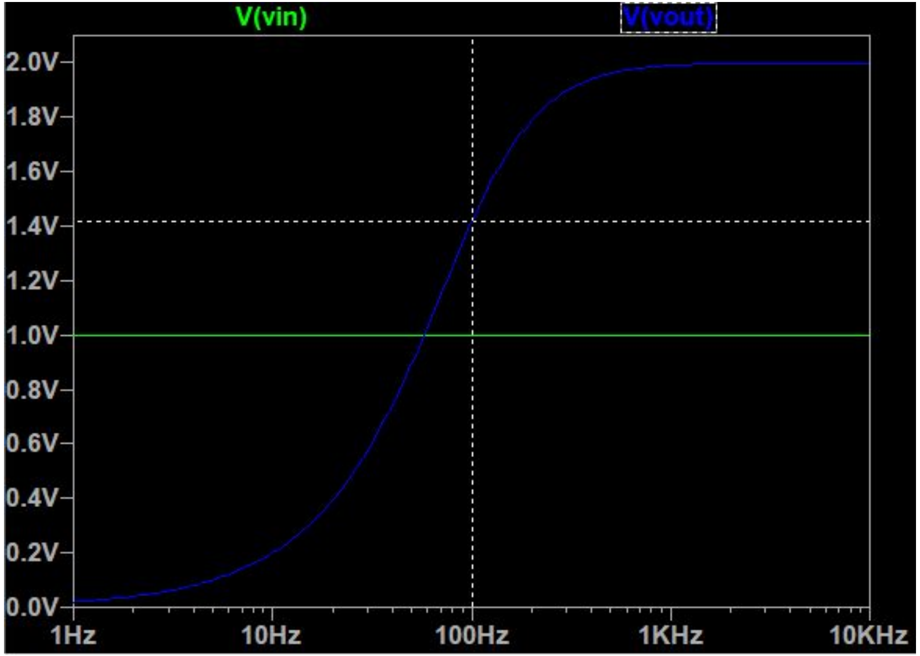




Input Voltage : 1V
Gain : $1+ R_2/R_1 = 2$
Cutoff Voltage : Gain xVin/√2 = 1.4142 V
Cutoff Frequency : 1/2πRC = 100 Hz

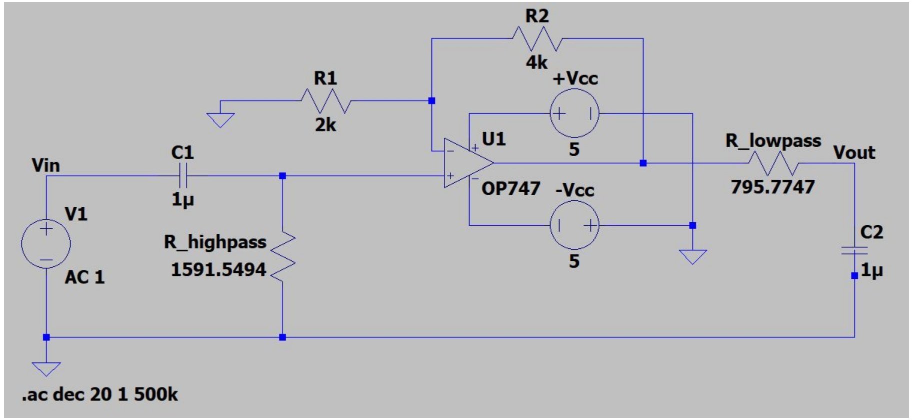
Active RC High Pass Filter

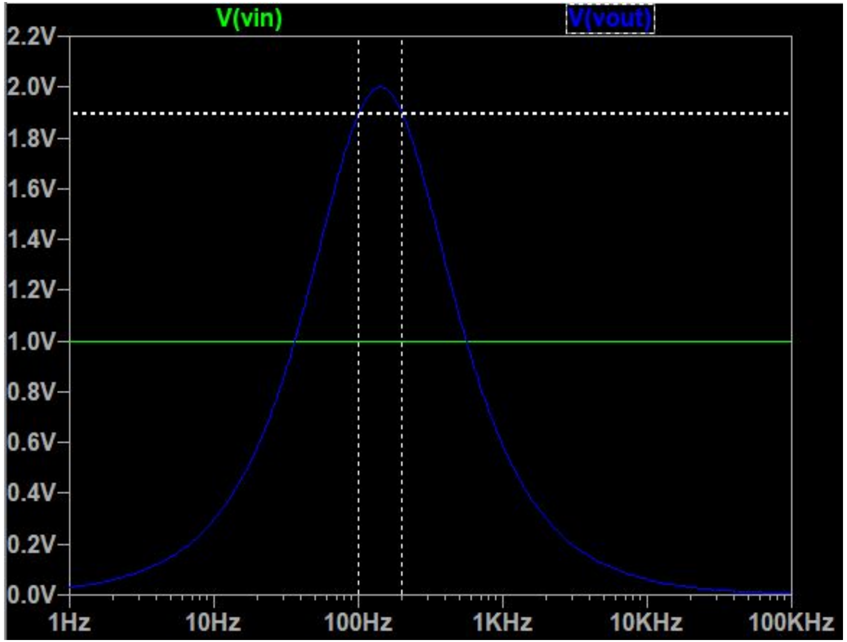




Input Voltage : 1V
Gain : 1+ R_3/R_2 = 2
Cutoff Voltage : Gain xVin/√2 = 1.4142 V
Cutoff Frequency : 1/2πRC = 100 Hz

Active RC Bandpass Filter





Input Voltage :1V
Gain :1+ R_2/R_1 = 3
Cutoff Voltage : Gain xVin/√2 = 1.9178 V
Lower Cutoff Frequency f_1 : $1/2\pi R_h C$ = 99.903947Hz
Upper Cutoff Frequency f_2 : $1/2\pi R_l C$ = 200.70108Hz

Peak Frequency $f_0=\sqrt{f_1 f_2}$ =141.4213
Bandwidth $\Delta f = f_2 - f_1$ = 100Hz

Conclusion

- Normal 1st order circuits may not provide ideal characteristics of a filter.
- On introduction of cascaded filters, the size of the circuit increased and the cutoff voltage/current also decreased a lot. But, more ideality(brick wall characteristics) were observed in the bode plot.
- As the technology advanced we switched from big suitcase sized radios to small transistor radios that could easily fit inside pockets. This was possible by the introduction of op-amps to filter circuits and making active filters.
- This project was successful in studying and analysing the early models of frequency filters.

References

- https://www.allaboutcircuits.com/technical-articles/an-introduction-to-filters/
- https://www.electronics-tutorials.ws/filter/filter_5.html
- https://www.electrical4u.com/band-pass-filter/
- https://en.wikipedia.org/wiki/Filter_(signal_processing)

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Thank You