Active Filter Design

TE201414 - Rangkaian Elektronika

Program Studi Teknik Elektro

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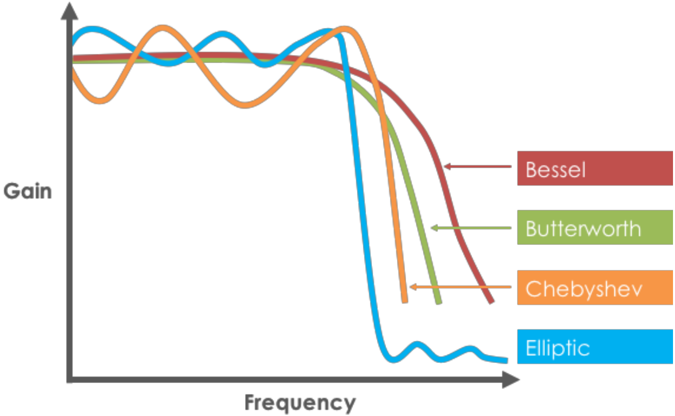
Filter Design

several things should be specified while designing analog active filter:

- Frequency response bode plot
- Cut off frequency
- Intended attenuation
- Filter order
- Circuit
- Value of the resistance and capacitance

Kind of Filter

approximation digital filter



Butterworth filter as approximation for analog filter with op-amp

Filter Order

assume that cut off frequency, and intended attenuation at certain frequency are f_c, A_v, and f respectively.
normalized frequency can be calculated by dividing f to f_c (low-pass filter)

$$\omega = \frac{f}{f_c}$$

and (high-pass filter)

$$\omega = \frac{f_c}{f}$$

filter order with Butterworth attenuation

$$A_v(\omega)_{dB} \leq 10 \log(1 + \omega^{2n})$$

Example 1

Design a filter that have cut off frequency at $500Hz$ and attenuation $-10dB$ at $1000Hz$!
based on case above, the filter required is low pass filter. then:

$$\omega = \frac{f}{f_c} = \frac{1000}{500} = 2$$

Butterworth attenuation filter:

$$A_v(\omega)_{dB} \leq 10log(1+\omega^{2n})$$

$$10dB \leq 10\log(1+2^{2n})$$

$$1 \leq \log(1+2^{2n})$$

$$10^1 \leq 1+2^{2n}$$

$$9 \leq 2^{2n}$$

Example 1

logaritmic basis 2

$$log_2 9 \leq 2n \rightarrow \frac{log 9}{log 2} \geq 2n$$

$$\frac{0.95}{0.301} \leq 2n$$

$$n \geq 3.15$$

filter order to approach the required specification is

$$n = 4$$

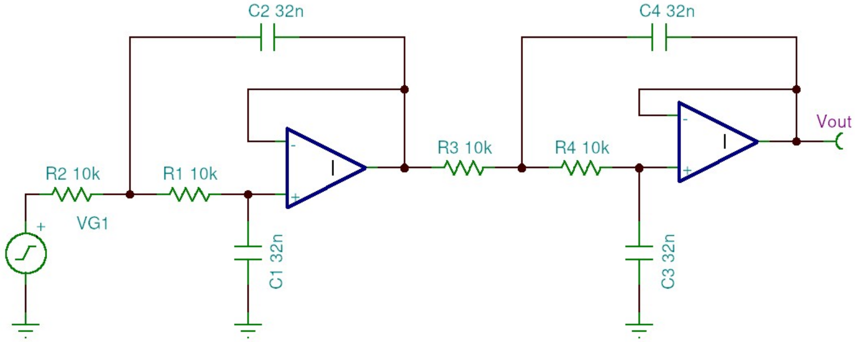
find the R-C value, assume that $R = 10k\Omega$:

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

$$500 = \frac{1}{2\pi 10^4 C} \rightarrow C = 3.2 * 10^{-8} F$$

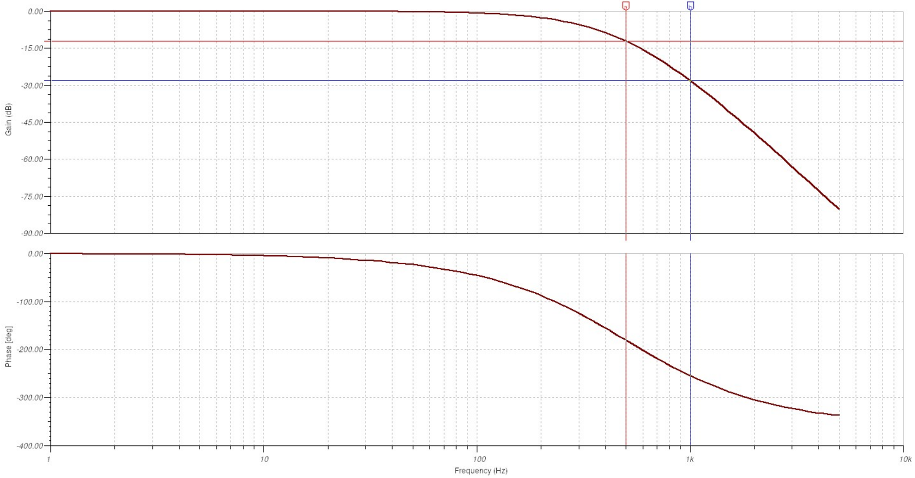
Example 1

Low-pass filter circuit

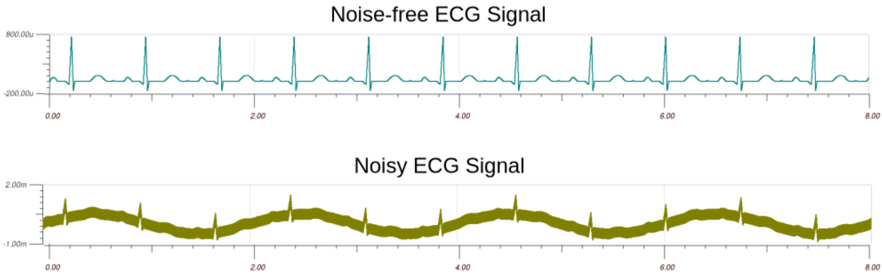


Example 1

Bode plot diagram



Example 2



a noisy ecg signal is given above. ecg signal has frequency band between $3-10Hz$. noises has 2 component, high frequency and low frequency. the frequency of noise are at $1kHz$ and $0.5Hz$. the amplitude of $1kHz$ noise is $500\mu V$ peak-peak. $0.5Hz$ noise is $1mV$ peak-peak. design a filter circuit that attenuate the HF noise amplitude to $5\mu V$ peak-peak and LF noise to $10\mu V$ peak-peak.

Example 2

based on the problem above there are 2 noise components present on ECG signal. filter required for attenuating both noise frequency is band pass filter.

- lower frequency (high pass filter):

filter order:

$$A_v(\omega)_{dB} \leq 10\log(1+\omega^{2n})$$

$$A_v(\omega)|_{dB} = 20\log\frac{V_{out}}{V_{in}} = 20\log\frac{10uV}{1mV} = -40dB$$

$$\omega = \frac{f_c}{f} = \frac{3}{0.5} = 6$$

$$40 \leq 10\log(1+6^{2n})$$

$$4 \leq \log(1+6^{2n})$$

$$10^4 \leq 1+6^{2n}$$

Example 2

$1 << 10^4$, then:

$$10^4 \leq 6^{2n}$$

$$2n \geq \log_6 10^4$$

$$2n \geq \frac{\log 10^4}{\log 6}$$

$$2n \geq \frac{4}{\log 2 + \log 3}$$

$$2n \geq \frac{4}{0.301 + 0.477}$$

$$2n \geq 5.14$$

$$n \geq 2.57$$

filter order required is 3.

Example 2

assume that resistor has same value and capacitor has same value. assume resistor value is $1k\Omega$.

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

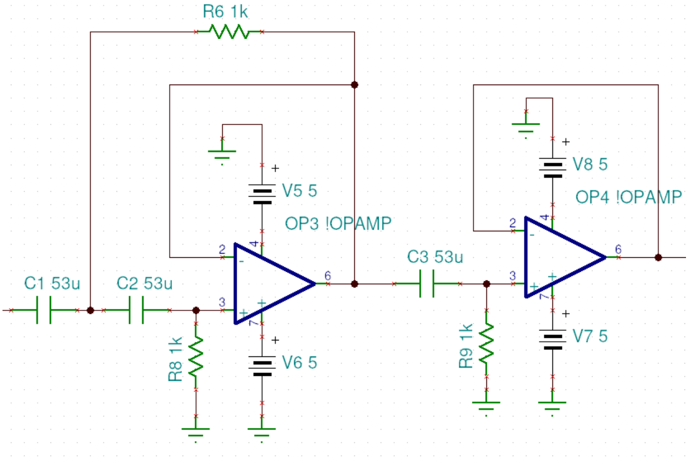
$$C = \frac{1}{2\pi R f_c}$$

$$C = \frac{1}{2\pi 10^3 3}$$

$$C = 53\mu F$$

3rd order high pass filter (attenuate frequency lower than 3Hz)

Example 2



- higher frequency (low pass filter):

Example 2

filter order:

$$A_v(\omega)_{dB} \leq 10\log(1+\omega^{2n})$$

$$A_v(\omega)|_{dB} = 20\log\frac{V_{out}}{V_{in}} = 20\log\frac{5uV}{500uV} = -40dB$$

$$\omega = \frac{f}{f_c} = \frac{10^3}{10} = 100$$

$$40 \leq 10\log(1+100^{2n})$$

$$4 \leq \log(1+100^{2n})$$

$$10^4 \leq 1+100^{2n}$$

$1 << 10^4$, then:

$$10^4 \leq 100^{2n}$$

$$2n \geq \frac{\log 10^4}{\log 100}$$

Example 2

$$2n \geq \frac{4}{2}$$
$$n \geq 1$$

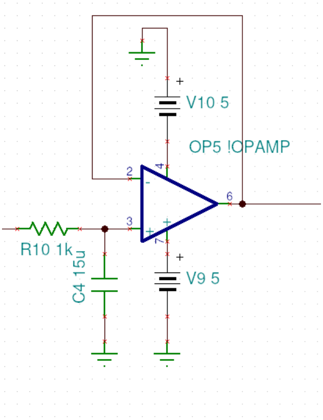
filter order required is 1.

assume that resistor has same value and capacitor has same value. assume resistor value is $1k\Omega$.

$$f_c = \frac{1}{2\pi RC}$$
$$C = \frac{1}{2\pi R f_c}$$
$$C = \frac{1}{2\pi 10^4 10}$$
$$C = 15\mu F$$

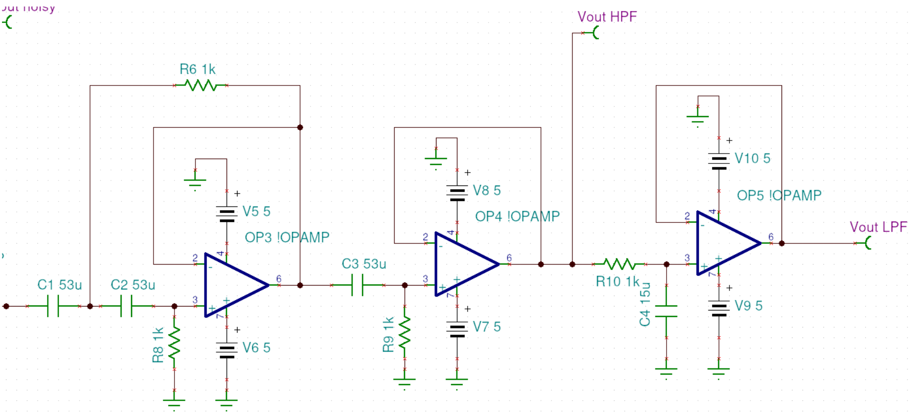
1st order low pass filter (attenuate frequency higher than 10Hz)

Example 2



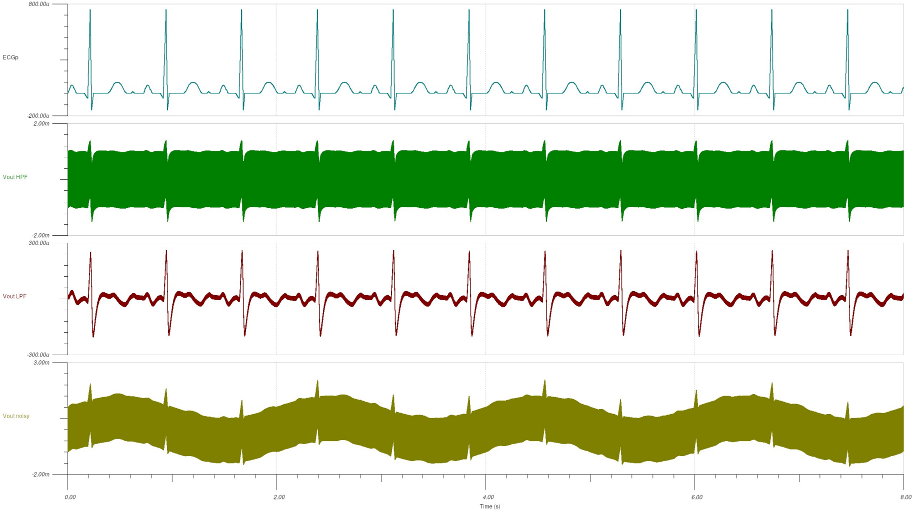
- complete circuit

Example 2

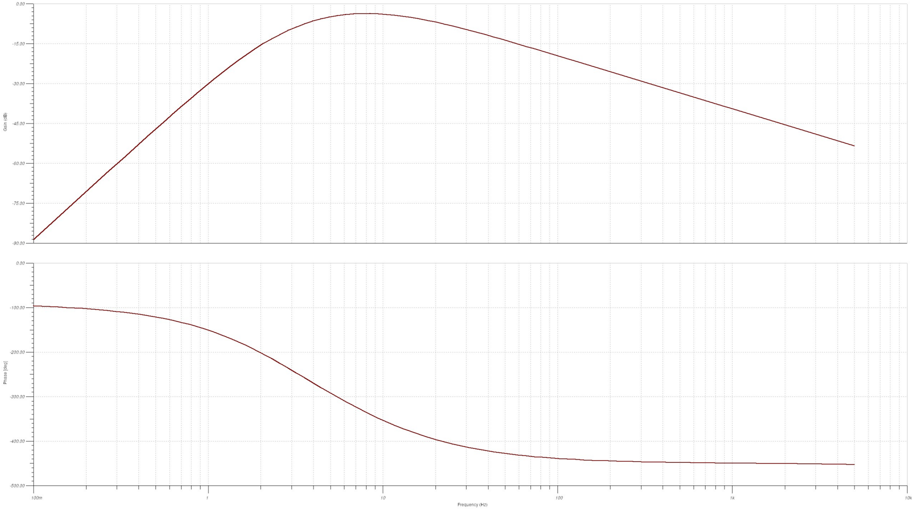


Vout HPF
R6 1k
V10 5
V8 5
OP5 !OPAMP
V5 5
OP4 !OPAMP
Vout LPF
OP3 !OPAMP
C3 53u
R10 1k
C1 53u
C2 53u
C4 15u
V9 5
V7 5
R9 1k
R8 1k
V6 5

Example 2


800.00u
ECGp
-200.00u
2.00m
Vout HPF
-2.00m
300.00u
Vout LPF
-300.00u
3.00m
Vout noisy
-2.00m
0.00
2.00
4.00
6.00
8.00
Time (s)

Example 2



0.00
-15.00
-30.00
-45.00
-60.00
-75.00
-90.00
Gain (dB)
0.00
-100.00
-200.00
-300.00
-400.00
-500.00
Phase [deg]
100m
1
10
100
1k
10k
Frequency (Hz)

References

Floyd,T.L., Fundamentals of Analog Circuits, Prentince Hall, .
Malvino,A., Electronic Principle, McGrawHill, 2016.
Boylestad, R.L., Nashelsky,L., Electronics Devices and Circuit Theory, Pearson, 2014.

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