Design of an Active Band-Pass Filter for the Analysis of Electromyographic Signals Derived from the Median Nerve, Using Genetic Algorithms

Article *in* International Journal of Applied Engineering Research · September 2021

CITATIONS
0

READS
162

3 authors, including:

Diego Alejandro Barragan Vargas
Francisco José de Caldas District University
7 PUBLICATIONS **4** CITATIONS
SEE PROFILE

Ricardo Galan
Hospital Militar Central
14 PUBLICATIONS **127** CITATIONS
SEE PROFILE

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 7 (2021) pp. 552-562

Design of an Active Band-Pass Filter for the Analysis of Electromyographic Signals Derived from the Median Nerve, Using Genetic Algorithms

Diego Alejandro Barragán Vargas 1, Dr. Roberto Ferro Escobar 2, Ricardo Galán Suarez 3

[1]**Department of Electronic Engineering, Universidad Distrital Francisco José de Caldas. Bogotá-Colombia.*

[2]**Department of Electronic Engineering, Universidad Distrital Francisco José de Caldas. Bogotá-Colombia .*

[3]** Central Military Hospital. Bogotá-Colombia.*

Abstract

In this paper we propose the design of a second order band pass active filter of Sallen Key topology by means of a software developed in MATLAB of a genetic algorithm whit multiobjective optimization, with the purpose of minimizing the sensitivities of the passive components, such as the different resistors and capacitors, in order to reduce the noise and have a measurement signal more faithful to the original, annex to the above, it is intented to minimize the error in the components necessary to filter the signal, with respect to conventional methods that are generally used. As a future work, it is desired to develop a superficial electromyographic device with low sensitivity in its components for the measurement of electrical parameters that are associated with the behavior of the healthy median nerve and with carpal tunnel syndrome, to generate a database and with it different algorithms of analysis of prevention and prediction.

Keywords: Band pass filter, operational amplifier, genetic algorithm, sensitivity.

1. Introduction

An electronic filter is a circuit that selects or attenuates a frequency or a range of frequencies, that is, those that pass signals present in certain bands and block signals from other frequency bands, these filters can be divided into two large classes that are known as active filters and passive filters, depending or not on controlled sources and active components, as in the case of operational amplifiers [1]. For the interest of this article, active filters will be analyzed, due to their continuous use in biomedical electronics, since they are necessary for the suppression of noise and amplification of the signal to be studied, it is important to take into account that the implementation of These filters present many options, highlighting designs with topologies of resistors, capacitors and operational amplifiers (active RC filters) [2] [3].

The selection of the discrete components of the RC filters is very important, since the correct operation of the filter in the frequency bands to be attenuated or allowed to pass will depend on this, generally for ease of design equal values are proposed for some components [4-6], this simplifies the process, however it compromises and limits the freedom of design, which is why the use of genetic algorithms was considered, taking into account that they are heuristic search and optimization methods. In this document we will proceed to design an active band pass filter that takes into account the sensitivities of the components, for this the article [7] that only analyzes an active bi-quadratic low pass filter was taken as a guide. make a comparison with the classic designs that are exposed in the literature to observe the final result of the signal. Filter design is important in biomedical fields such as electromyography, which is a technique used in the functional study of the neuromuscular system, its main objective is the reception of electrical signals produced by a living being [8-10], for Therefore, it is of vital importance to deepen the concept of the devices used and in the same way a review of the different technologies implemented [11], in order to observe in this way the impact of the filters to be designed and with this, take into account factors relevant, such as noise, which greatly affect the desired capture signal [12].

The article was organized as follows: in section 2 the second order high pass filter was shown, in section 3 the second order low pass filter was explained, in section 4 the design of the filters was described with the genetic algorithms, in section 5 the filters were designed in the traditional way, in section 6 the results of the algorithm's behavior and a simulation of the components in MATLAB were shown, making the respective comparison with the traditional design simulation, where detailed the respective information obtained, in section 7 an analysis of the results obtained was carried out and in section 8 the respective conclusions and future work to be carried out were given.

2. Materials and Methods

2.1. High Pass Filter

A high pass filter allows all frequencies above its cutoff frequency to pass through without attenuation [1] [16], in this case a filter with Sallen Key topology will be analyzed as shown in the following figure:

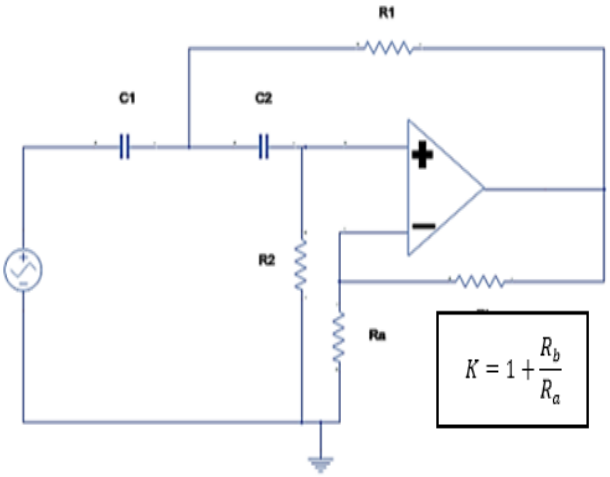

Figure 1. Sallen Key high pass filter

Where:

$$R_a = R \;\; y \;\; R_b = (k-1)R \qquad (1)$$

The transfer function of the high pass filter for this case is:

$$\frac{V_{sal}}{V_{ent}} = \frac{ks^2}{s^2+\left(\frac{1}{C_1R_2}+\frac{1}{C_2R_2}+\frac{(1-K)}{C_1R_1}\right)s+\frac{1}{C_1C_2R_1R_2}} \qquad (2)$$

Having:

$$H(s) = \frac{H_0 s^2}{s^2+\frac{w_n}{Q}s+w^2{}_n} \qquad (3)$$

The cutoff frequency is:

$$w_0 = \sqrt{\frac{1}{R_1R_2C_1C_2}} \qquad (4)$$

The quality factor is given by:

$$\boldsymbol{Q} = \frac{\sqrt{C_1C_2R_1R_2}}{C_1R_1+C_2R_1+C_2R_2(1-k)} \qquad (5)$$

And the profit is given by:

$$G = \frac{R_2}{R_1} \qquad (6)$$

The sensitivity for the filters is:

$$S_{X_i}^F = \frac{dF/F}{dX_i/X_i} \qquad (7)$$

Therefore, the sensitivity for the Sallen Key high pass filter is:

$$S_K^{W_0} = 0 \qquad (8)$$

$$S_{R_1}^{W_0} = S_{R_2}^{W_0} = S_{C_1}^{W_0} = S_{C_2}^{W_0} = -1/2 \qquad (9)$$

$$S_{R_1}^{Q} = \frac{\sqrt{R_1}}{2}\left(\frac{\sqrt{C_1C_2R_2}[C_2R_2(1-K)-R_1(C_1+C_2)]}{\sqrt{C_1C_2R_1R_2}[R_1[C_1+C_2]+C_2R_2(1-k)]}\right) \qquad (10)$$

$$S_{R_2}^{Q} = \frac{\sqrt{R_2}[\sqrt{C_1C_2R_1}R_1(C_1+C_2)-\sqrt{C_1C_2R_1}C_2(1-k)]}{2\sqrt{C_1C_2R_1R_2}[R_1(C_1+C_2)+C_2R_2(1-k)^2]} \qquad (11)$$

$$S_K^{Q} = \frac{kC_2R_2}{R_1(C_1+C_2)+C_2R_2(1-k)} \qquad (12)$$

2.2. Low Pass Filter

A Sallen Key low pass filter [17] will be used, as shown in figure 2:

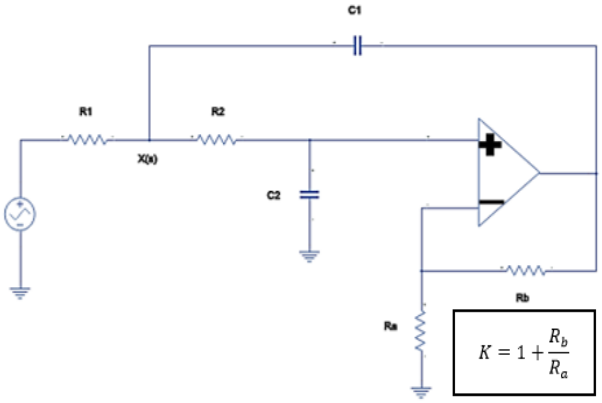

Figure 2. Sallen Key Low Pass Filter

The transfer function for the low pass filter in this case is:

$$\frac{V_{ent}}{V_{sal}} = \frac{\frac{K}{R_1R_2C_1C_2}}{s^2+\left[\frac{C_2(R_1+R_2)+(1-K)R_1C_1}{R_1R_2C_1C_2}\right]s+\frac{1}{R_1R_2C_1C_2}} \qquad (13)$$

Having:

$$H(s) = \frac{kw_c{}^2}{s^2+\frac{w_c}{Q}s+w_c{}^2} \qquad (14)$$

The cutoff frequency is:

$$w_c = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}} \quad (15)$$

The quality factor is given by:

$$Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_2(R_1+R_2)+(1-k)R_1 C_1} \quad (16)$$

Therefore, the sensitivity for the Sallen Key low pass filter is:

$$S_K^{W_0} = 0 \quad (17)$$

$$S_{R_1}^{W_0} = S_{R_2}^{W_0} = S_{C_1}^{W_0} = S_{C_2}^{W_0} = -1/2 \quad (18)$$

$$S_{R_1}^{Q} = \frac{C_2(R_2-R_1)+C_1(1-k)(R_1-2)}{2[C_2(R_1+R_2)+R_1 C_1(1-k)]} \quad (19)$$

$$S_{R_2}^{Q} = \frac{C_2(R_1-R_2)+(1-k)R_1 C_1}{C_2(R_1+R_2)+(1-k)R_1 C_1} \quad (20)$$

$$S_K^{Q} = \frac{R_1 C_1 K}{C_2(R_1+R_2)+(1-k)R_1 C_1} \quad (21)$$

2.3. Filter Design Using Genetic Algorithms

The algorithm must find the values of the passive elements of the filter, since these random values will be set at the beginning to initialize the parameters and therefore the population, to observe and evaluate the sensitivities that depend on the values of the minimum elements and errors in gain, pole frequencies, and quality factor that are less than a specified maximum error. The multiobjective optimization problem that must be solved by the genetic algorithm was proposed in accordance with what was suggested in the article [6], although it differs in the proposed form of the algorithm and in the parameters since a simple genetic algorithm was performed with the primary and secondary parameters, this can be represented by the following expression:

$$minF(y) = S_{R_1}^{Q}, S_{R_2}^{Q}, S_{R_3}^{Q} \quad (22)$$

Subject to:

$$Error_G(y) \leq Emax \quad (23)$$

$$Error_{Wp}(y) \leq Emax \quad (24)$$

$$Error_{Qp}(y) \leq Emax \quad (25)$$

Where Emax is defined as the maximum tolerable design error of the filter characteristics.

Having:

$$Error_G(y) = \left|\frac{G(y)-G_H}{G_H}\right| \quad (26)$$

$$Error_{Wp}(y) = \left|\frac{W_p(y)-W_{pH}}{W_{pH}}\right| \quad (27)$$

$$Error_{Qp}(y) = \left|\frac{Q_p(y)-Q_{pH}}{Q_{pH}}\right| \quad (28)$$

With the conditions of the problem raised, the following steps were taken into account:

- **Population initialization:** It consists of the random generation of an initial population of individuals who are the solutions to the problem [18]. For this case study where the evaluation of a Sallen Key low pass filter and another Sallen Key high pass filter is carried out for the generation of a band pass filter, each individual represents a possible filter configuration characterized by the respective values of resistances and capacitors, where a chromosome made up of five genes is used, as shown below:

Figure 3 Structure of the generated chromosomes

In the code generated in Matlab, this part was proposed as follows for the two filters:

```
clear all
close all
clc
%% Population Initialization
inputs = 5; % Number of entries
% Resistors in K_Ohms
R1=15*rand(1,1);   % Resistor 1
R2=100*rand(1,1); % Resistor 2
k=20*rand(1,1);     % Resistor 3
C1=0.1*rand(1,1); % Capacitor 1 in uF
C2=0.2*rand(1,1); % Capacitor 2 in uF
% Total number of Parameters
totpar = 2*inputs;
scale=15;
```

Where the secondary parameters depend on the equations

obtained and for the case of the high pass filter they were:

```
% Filter secondary parameters
G=R2/R1;
Wp=sqrt(1/(R1*R2*C1*C2));
Qp=(sqrt(C1*C2*R1*R2)/(R1*(C1+C2)+C2*R2*(1-k)));
S1=(sqrt(R1)/2)*(((sqrt(C1*C2*R2)*C2*R2*(1-k))-(sqrt(C1*C2 * R2)*R1*(C1+C2)))/(sqrt(C1*C2*R1*R2)*(R1*(C1+C2)+C2*R2* (1-k))));
S2=((sqrt(R2)/2)*((sqrt(C1*C2*R1)*R1*(C1+C2)-sqrt(C1*C2 * R1)*C2*(1-k))/(sqrt(C1*C2*R1*R2)*(R1*(C1+C2)+C2*R2*(1-k)^2))));
S3=((k*C2*R2)/(R1*(C1+C2)+C2*R2*(1-k)));
```

Then the algorithm parameters were generated in code having:

```
% Genetic Algorithm Parameters
Ngen=500; % Number of Generations
npop=30;    %  Population size
press=0.01; % Pressure factor selection
ipop=60;    % Population mean size
pcross=0.7;%  Crossover probability
pmut=0.03;%  Mutation Probability
pop=2*scale*(rand(npop,totpar)-0.5);
x = [R1, R2, k, C1, C2];
```

- **Evaluation:** For each generation, the individuals of the present population are evaluated according to a predefined quality criterion that is known as the fitness function, in this article a process similar to that proposed in the article [6] is followed, in which weighted sums methods are used, having:

$$f(y) = (W_1|S_{R_1}^Q| + W_2|S_{R_2}^Q| + W_3|S_{R_3}^Q|) \quad (29)$$

Where the Wi represents the weights assigned to each of the filter sensitivities that must be minimized, in this problem we do not want to give priority to any special weight, so we have:

$$f(y) = \frac{1}{3}(|S_{R_1}^Q| + |S_{R_2}^Q| + |S_{R_3}^Q|) \quad (30)$$

In the Matlab code this part was raised as follows:

```
% Evolutionary Cycle
for gen =1:Ngen
for i =1:npop% Evaluation of Individuals
% Sensitivity Calculation - Fitness Function
sen=(1/3)*(abs(S1*rand(1,1))+abs(S2*rand(1,1))+abs(S3*rand(1,1)));
fobj=sen;
end;
%Subject to:
% Gain error
EG = abs(((G*sen)-G)/G);
% Pole frequency error
EW = abs(((Wp*sen)-Wp)/Wp);
% Quality factor error
EQ = abs(((Qp*sen)-Qp)/Wp);
outpop(gen,1:3)=[ EG EW EQ];
qpop = [  EG EW EQ gen]
```

- **Selection:** To generate the next generation of the population, individuals are selected according to their fitness value, for this the roulette method was used, which considers that the probability that an individual is chosen for the crossing is proportional to its fitness value. The roulette selection method was described by Hassoun as "the stochastic version of survival of the fittest", this technique is one of the most used and consists of assigning a segment of the roulette to individuals based on their fitness and the total fitness of the current population and when spinning the roulette as many times as selections are required, the procedure to follow for this is as follows:

  - **First:** Calculate the target value f (xi) for each chromosome x (i).
  - **Second:** Calculate the total target value for the population:

$$F = \sum_{i=1}^{I} f(x_i) \quad \forall \quad i = 1,2,3,..,I \quad (31)$$

  - **Third:** Calculate the selection probability pk for each chromosome xi:

$$p_i = \frac{f(x_i)}{F} \qquad i = 1,2,3,\dots,I \qquad (32)$$

  - **Fourth:** Calculate the cumulative probability pi for each chromosome xi:

$$q_i = \sum_{i=1}^{I} p_i \qquad i = 1,2,\dots,I \qquad (33)$$

After the selection, it is done as follows: I repetitions:

- First: Generate a random number p in a range [0,1].
- Second: Choose the i-th chromosome xi such that qi-1 <p≤ qi.

Carrying out this part in Matlab we have:

```
% Qualification of Individuals
Efficiency = (1 - press) * (EG - fobj)/max([EG - EW, eps]) + press; %
Roulette selection
Wheel = cumsum(Efficiency);
for j=1:ipop
% Selection of the first couple
Shoot = rand(1,1)*max(Wheel);
Index = 1;
while((Wheel(Index)<Shoot)&(Index<length(Wheel)))
Index = Index + 1;
End
indiv1(j,:) = pop(Index,:);
findiv1(j)  = fobj(Index);
Iindiv1(j)  = Index;
% Selection of the second partner
Shoot = rand(1,1)*max(Wheel);
Index = 1;
while((Wheel(Index)<Shoot)&(Index<length(Wheel)))
Index = Index + 1;
end
indiv2(j,:)= pop(Index,:);
findiv2(j) = fobj(Index);
Iindiv2(j) = Index;
End
```

- **Crossover:** The uniform method was used in which each gene in the child is obtained by copying the corresponding gene from one of the parents, according to a randomly generated binary crossover mask [13] [19]. The code in Matlab made for this part was:

```
% Crossover
for j=1:ipop
if (pcross>rand(1,1))
pind = ceil((totpar-1)*rand(1,1) + 1);
x1 = [indiv1(j,1:pind) indiv2(j,pind+1:totpar)];
x2 = [indiv2(j,1:pind) indiv1(j,pind+1:totpar)];
indiv1(j,:) = x1;
indiv2(j,:) = x2;
end
end
```

- **Mutation:** In this part the uniform random mutation operator is used, which considers that each gene has the same probability of being mutated [14] [15]. The code in Matlab made for this part was:

```
%Mutation
for j=1:ipop
if (pmut>rand(1,1))
pind= ceil((totpar-1)*rand(1,1)+1);
vind=2*(rand(1,1)-0.5)*scale;
indiv1(j,pind)=vind;
end
if (pmut>rand(1,1))
pind= ceil((totpar-1)*rand(1,1)+1);
vind=2*(rand(1,1)-0.5)*scale;
indiv2(j,pind)=vind;
end
end
poplast=pop;
```

- **Stop condition:** The cycle is repeated until the stop condition is satisfied, which consists of reaching a maximum number of generations. The code generated in Matlab was:

```
%New population
for j=1:npop
indexsel= ceil((ipop-1)*rand(1,1)+1);
if rand(1,1) > 0.5
pop(j,:)=indiv1(indexsel,:);
else
pop(j,:)=indiv2(indexsel,:);
end
```

```
end
Wheel = 0;
end
% Obtaining the best individual from the final population
for i =1:npop
w=poplast(i,:);
% Sensitivity calculation Fitness function
sen=(1/3)*(abs(S1*rand(1,1))+abs(S2)+abs(S3));
fobj(i,1)=sen;
end
x= x
figure
plot(outpop);
```

2.4. Filter Design Using the Classic Method

The classical method advises to match some components to facilitate the design. The analysis process generated to obtain the components in the respective filters is shown below, taking into account that the band pass filter will be focused at frequencies from 20Hz to 500Hz.

2.4.1. High-Pass Filter Design

The cutoff frequency for this filter is 20Hz, for ease of design and commercial use 1uF capacitors are used, having C1 = C2, where a quality factor Q = 2 and a resistance R2 = 20KΩ will be left, having:

$$W_o{}^2 = \frac{1}{R_1 R_2 C_1 C_2} \qquad (34)$$

Solving for R1 we have:

$$R_1 = \frac{1}{R_2 C_1 C_2 W^2{}_o} = 3{,}17K\Omega \qquad (35)$$

Now we will proceed to clear and find K from equation 4 having:

$$K = 1 - \left[\frac{\sqrt{C_1 C_2 R_1 R_2} - QR_1[C_1 + C_2]}{QC_2 R_2}\right] \qquad (36)$$

Where replacing the values you get:

$$K = 1{,}118 \qquad (37)$$

Now we assume that Ra = 10KΩ to find Rb, having:

$$R_b = R_a(K - 1) = 2{,}358K\Omega \qquad (38)$$

Having with this all the necessary values of the components for the high pass filter.

2.4.2. Low-Pass Filter Design

The cutoff frequency of this filter is 500Hz, for ease of design 0.1uF capacitors are used, an R2 = 20KΩ and a quality factor Q = 2 will be used, having:

$$R_1 = \frac{1}{R_2 C_1 C_2 W^2{}_o} = 506{,}6\Omega \qquad (39)$$

Now we proceed to calculate K having:

$$K = 1 - \frac{1}{R_1 C_1}\left[\frac{\sqrt{R_1 R_2 C_1 C_2}}{Q} - C_2(R_1 + R_2)\right] \qquad (40)$$

Where replacing the values you get:

$$K = 3918{,}47 \qquad (41)$$

Now we assume that Ra = 100Ω to find Rb, having:

$$R_b = R_a(K - 1) = 391{,}7K\Omega \qquad (42)$$

Having with this all the necessary values of the components for the low pass filter.

3. Results

3.1. Simulation of Design Filters Using Genetic Algorithms.

It is important to note that the vector x generated in Matlab contains the elements in the following order:

x = [R1, R2, k, C1, C2]; (42)

When calculating the respective components with the aforementioned steps, it was obtained:

x =7.1884 96.8165 15.6808 0.8864 0.1450

We proceed to show the simulation of the Sallen Key high pass filter, having:

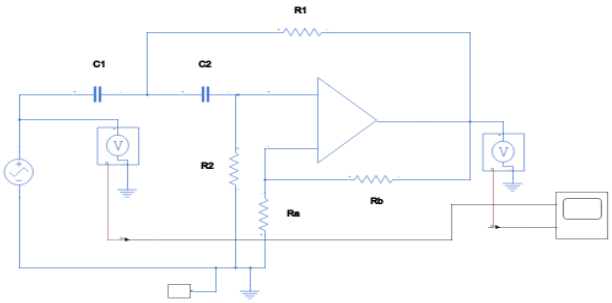

Figure 4. Sallen key high pass filter

Where we proceeded to test with a frequency below 20Hz which is the cutoff frequency, observing that the signal was attenuated for the lower frequencies (in this case it was attenuated 67 times, it was tested with 5Hz) as shown below:

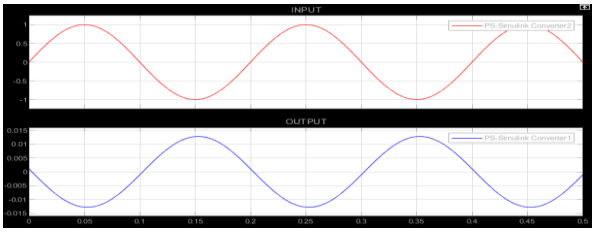

Figure 5. Input signal (Red) and output signal (blue)

Now we proceed to show the values of the vector x obtained for the Sallen Key low-pass filter having:

x = [R1, R2, k, C1, C2]; (43)

Having that the values are:

x=0.8749 81.5882 7,3657 0.3208 0.0035

We now proceed to show the simulation for the Sallen Key low pass filter having:

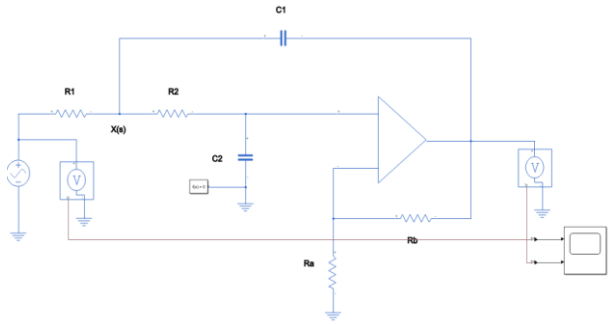

Figure 6. Sallen Key low-pass filter

Where we proceeded to test with a frequency above 500Hz which is the cutoff frequency, observing that the signal was attenuated for higher frequencies as shown below:

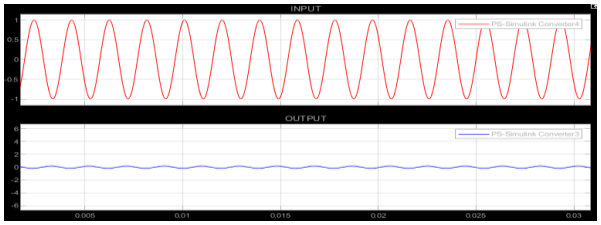

Figure 7. Input signal (Red) and output signal (Blue)

3.2. FILTER SIMULATION CLASSIC DESIGN

We proceed to show the simulation of the Sallen Key high pass filter, having:

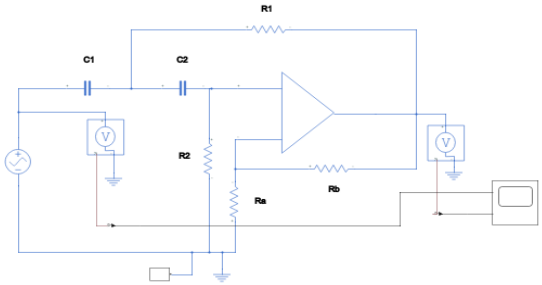

Figure 8. Sallen Key High Pass Filter

Where we proceeded to test with a frequency below 20Hz which is the cutoff frequency, observing that the signal was attenuated for the lower frequencies (in this case it was attenuated 2 times, it was tested with 5Hz) as shown below:

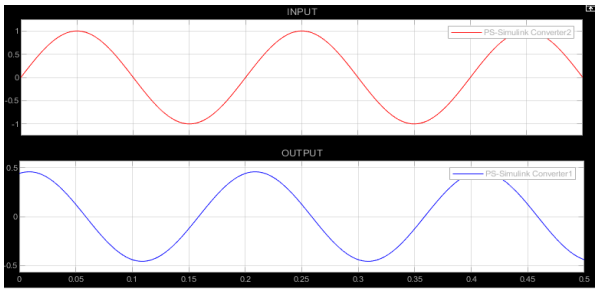

Figure 9. Input signal (Red) and output signal (Blue)

We now proceed to show the simulation for the Sallen Key low pass filter having:

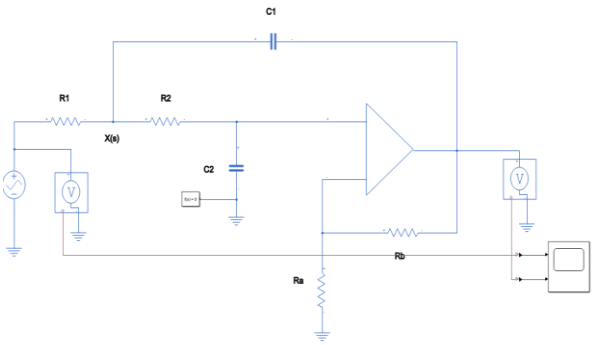

Figure 10. Sallen Key Low Pass Filter

Where we proceeded to test with a frequency above 500Hz which is the cutoff frequency, observing that the signal was attenuated for higher frequencies as shown below:

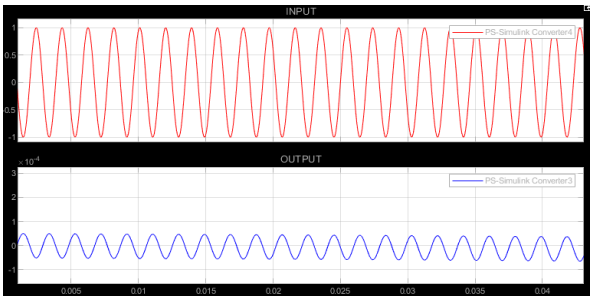

Figure 11. Input signal (Red) and output signal (Blue)

4. Analysis and Discussions Results

After generating the respective calculations to find the components of the designs, the sensitivities of the designs are reviewed having:

4.1. Sensitivity of Filters Designed by Genetic Filter

The vector qpop contains the values of the respective errors and the number of generations iterated to obtain the minimum value of sensitivity.

qpop= [EG EW EQ gen] (44)

We proceed to show first the qpop vector of the Sallen Key high-pass filter:

qpop= 0.6051 0.6051 0.0369 500.0000

The figure showing the sensitivities of the components is presented below:

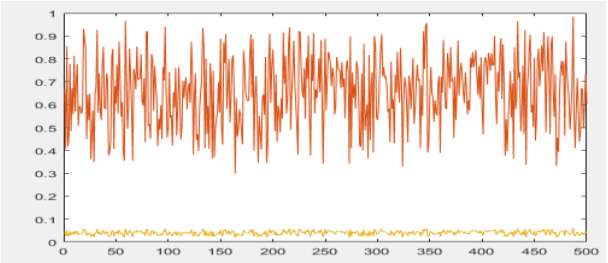

Figure 12. Sensitivity of the resistors in the high pass filter

Now we proceed to show the qpop vector of the Sallen Key low-pass filter, having:

qpop= 0.3147 0.3147 0.1834 500.0000

The figure showing the sensitivities of the components is presented below:

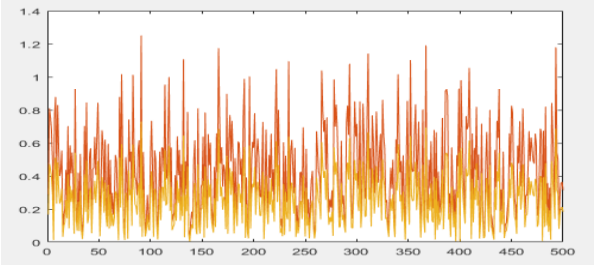

Figure 13. Sensitivities of the resistors in the low-pass filter

4.2. SENSITIVITY OF FILTERS DESIGNED IN THE CLASSIC WAY.

We proceed to show the values of the vector qpop, having:

qpop= 0.7395 0.7395 1.2455 500.0000

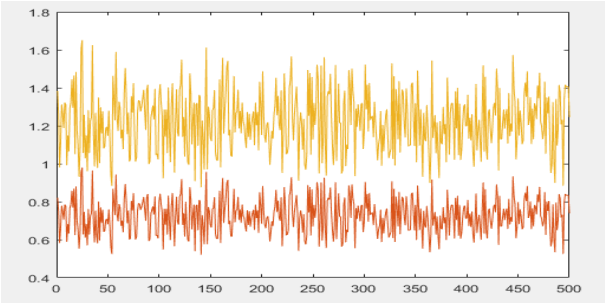

Figure 14. Sensitivity of the resistors in the high pass filter

Now we proceed to show the qpop vector of the Sallen Key low-pass filter, having:

qpop= 0.5033 0.5033 22.5881 500.0000

The figure showing the sensitivities of the components is presented below:

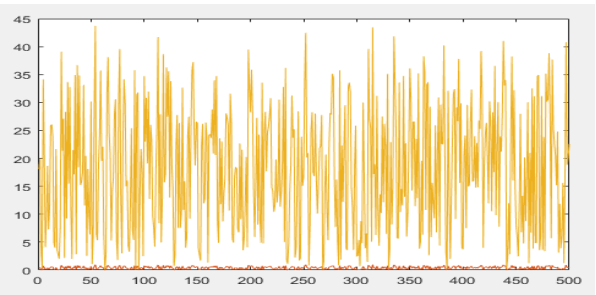

Figure 15. Sensitivity of the resistors in the low pass filter

Carrying out the respective comparison between the sensitivities of the design with genetic algorithms with respect to the classical design, a considerable decrease in the variation of the sensitivity is observed, which is reflected in the errors displayed in the qpop vector, which confirms that the filters have been optimized and These can considerably reduce the noise of the electromyographic signals obtained from the median nerve. A frequency analysis is carried out by means of the Bode diagram.

4.3. High Pass Filter Body Diagram

- **Classic Design**

The transfer function is:

$$H(s) = \frac{1{,}118s^2}{s^2+62{,}7760s+15772{,}87} \quad (45)$$

The bode plot of (45) is:

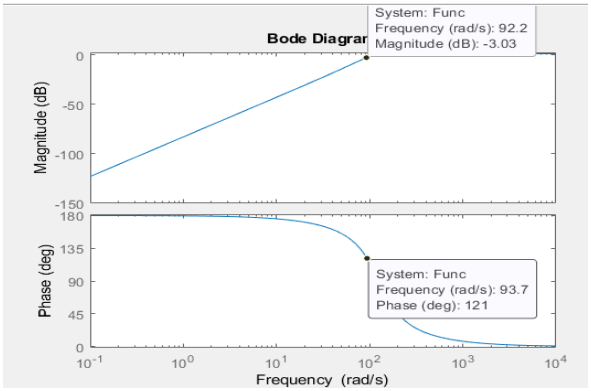

Figure 16. Diagram of the classic design high pass filter winery

- **Genetic Algorithm**

The transfer function is:

$$H(s) = \frac{15{,}6808s^2}{s^2-2221{,}144s+11180{,}135} \quad (46)$$

The bode plot of (46) is:

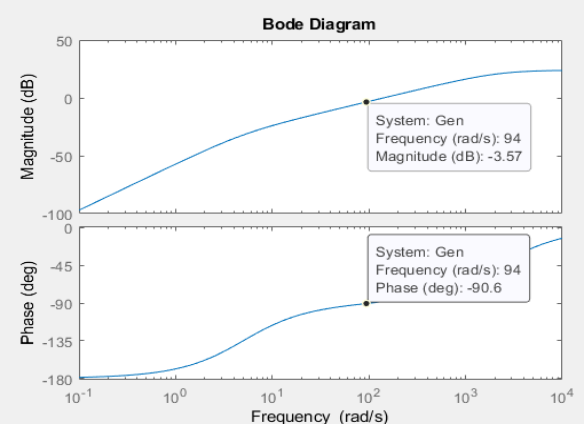

Figure 17. Diagram of the high pass filter design with AG

4.4. Low Pass Filter Body Diagram

- **Classic Design**

The transfer function is:

$$H(s) = \frac{378405053{,}3}{s^2+1569{,}44s+9869719{,}7} \quad (47)$$

The bode plot of (47) is:

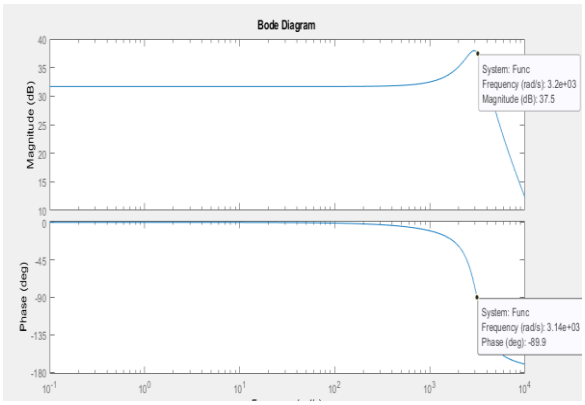

Figure 18. Low pass filter winery diagram classic design

- **Genetic Algorithm**

The transfer function is:

$$H(s) = \frac{91902413{,}89}{s^2-18691{,}01s+12477078{,}06} \quad (48)$$

The Bode plot of (48) is:

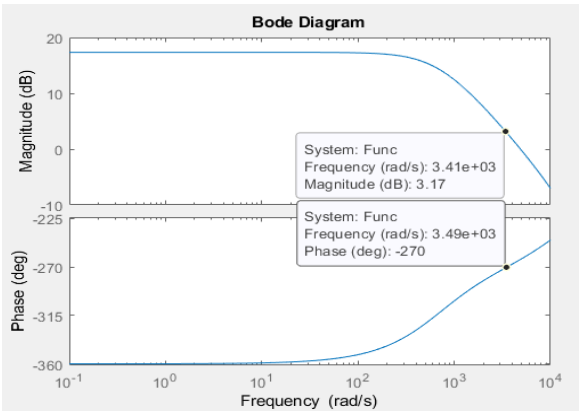

Figure 19. Low pass filter bode diagram AG

5. CONCLUSIONS

- A greater variability was observed in the change in the sensitivity of the filters with the classic design, with respect to the filters of the design with genetic algorithm, this can be evidenced in figures 12 to 15, where the genetic filters have a lower variation, in the case of the genetic high-pass filter, the variation of the sensitivities present in the resistors are between 0 and 16, while in the classic design they are between 0 and 30; In the case of the genetic low-pass filter, the variation in resistive sensitivities is between 1 and 0, while in the classical design it is between 0 and 40.
- The errors obtained with the genetic algorithm are less than those obtained with the classic design, this can be observed in the qpop matrix, because in the genetic design the errors are an average of 10%, while in the classic design the error is found by about 41% on the average of the three errors.
- The Roulette algorithm is sometimes not the most suitable for making the selection since it gives a greater weight to the individual with a greater probability of obtaining suitable characteristics.
- As future work, it is desired to develop a superficial electromyographic device with low sensitivity in its components for the measurement of the electrical parameters that are associated with the behavior of the healthy median nerve and with carpal tunnel syndrome, to generate a database and with it different algorithms of prevention and prediction analysis.

References

[1] F. Miyara, "Filtros activos". [Online]. Disponible en: https://www.fceia.unr.edu.ar/enica3/filtros-t.pdf, accedido: 09,10,2020.

[2] C. A. Corral, "Designing rc active filters with standard-component values". [Online]. Disponible en: https://www.edn.com/designing-rc-active-filters-with-standard-component-values/, accedido: 09,11,2020.

[3] R. F. Boylestad, "Electrónica: Teoría de circuitos y dispositivos electrónicos". País de Publicación: México. Editorial: Prentice HALL, ISBN: 978-607-442-292-4, 2009, pp. 607-610.

[4] H. G. Dimopoulos, "Analog Electronic Filters: Theory, design and Synthesis". País de publicación: Estados Unidos. Editorial: Springer, ISBN: 978-94-007-2189-0, 2012, pp. 403-427.

[5] R. Raut and S. Swamy, "Modern Analog Filter Analysis and design". País de Publicación: Singapur. Editorial: WYLEY VCH, ISBN: 978-3-527-40766-8, 2010, pp. 103-130.

[6] S. Franco, "Diseño con amplificadores operacionales y circuitos integrados analógicos ". País de Publicación: México. Editorial: MC GRAW HILL, ISBN:978-970-10-4595-5, 2005, pp. 111-217.

[7] M. A. Lovay, E. A. Romero, and G. M. Peretti, "Genetic algorithms applied to the design of robust biquadratic filters", International Journal Numerical Modelling. Vol 32, 2018. Doi: https://doi.org/10.1002/jnm.2531

[8] T. Talamillo, "Guía EMG y SNG," Revista *Enfermería Docente*. Vol. 93, pp. 11–16, 2011. Disponible en: http://www.sspa.juntadeandalucia.es/servicioandaluzdesalud/huvvsites/default/files/revistas/ED-093-05.pdf

[9] W. A. A. Anaya, J. D. C. Santos, I. C. N. Martinez, "USO DE LA ELECTROMIOGRAFÍA DE SUPERFICIE COMO MÉTODO DE EVALUACIÓN EN LA MECÁNICA DEGLUTORIA", Revista Signos Fónicos. Vol.3, No. 2, pp. 6,2017. Disponible en: http://revistas.unipamplona.edu.co/ojs_viceinves/index.php/CDH/article/view/2918

[10] A. Ramírez, D. A- Garzón, "Análisis de sensibilidad por la colocación de los electrodos en la electromiografía de superficie (semg)", Revista Ingeniería Universidad Facultad de Antioquia. No. 46, pp. 70-79, 2008. Disponible en: http://www.scielo.org.co/pdf/rfiua/n46/n46a07.pdf

[11] J. Nolasco, J. Mendoza, … C. U.-P., and U. 2018, "Implementación de una Interfaz por Computadora para el Control de Movimiento del Robot i-SOBOT Aplicando Electromiografía (EMG)", *Revista Pistas Educativas.* No. 113, 2015. Disponible en: http://www.itcelaya.edu.mx/ojs/index.php/pistas/article/viewFile/326/315

[12] W. F. U. Rojas, F. M. Santa, "Implementación de un electromiógrafo con interfaz USB", Revista Tecnura. Vol. 16, no. 33, pp. 117-130,2012. Disponible en: http://www.scielo.org.co/pdf/tecn/v16n33/v16n33a08.pdf

[13] S. de Greiff, J. C. Rivera, "Optimización de portafolios de inversión con costos de transacción utilizando un algoritmo génetico multiobjetivo: caso aplicado a la bolsa de valores de Colombia". Journal of Management and Economics for Iberoamerica, vol 34, N° 136, pp 74-87, 2018, doi: https://doi.org/10.18046/j.estger.2018.146.2812.

[14] H. A. Uribe, L. G. Torres, I. Z. Félix, Z. S. Hernández, "Diseño e implementación de un algoritmo genético para la predicción de una variable", Research in Computing Science, pp 187-197,2019. Disponible en: https://www.rcs.cic.ipn.mx/2019_148_8/Diseno%20e%20implementacion%20de%20un%20algoritmo%20genetico%20para%20la%20prediccion%20de%20una%20variable.pdf

[15] C. P. Navarro, S. G. Reyna, G. A. González, M. O. Yepez, S. B. Jimenez, M. R. Huerta, C. L. Ramírez, "Algoritmos genéticos aplicados a la optimización de características en la clasificación de arritmias cardiacas utilizando los clasificadores KNN y naive Bayes". Research in Computing Science, pp 55-68,2017. Disponible en: https://rcs.cic.ipn.mx/2017_134/Algoritmos%20

geneticos%20aplicados%20a%20la%20optimizacion%20de%20caracteristicas%20en%20la%20clasificacion.pdf

[16] K. V. Cartwrigtht, E. J. Kaminsky. “Finding the minimum input impedance of a second-order unity-gain Sallen Key low-pass filter without calculus”. Journal Physics Education. Vol 7. No. 4. 2013. Disponible en: https://scholarworks.uno.edu/cgi/viewcontent.cgi?article=1124&context=ee_facpubs

[17] E. Benedicto Ortega Rosales and F. Sandoval Ibarra, "A 100Hz Low-Pass 2nd Order Sallen-and-Key Active Filter: A Design Proposal," in IEEE Latin America Transactions, vol. 12, no. 2, pp. 73-77, March 2014, doi: 10.1109/TLA.2014.6749520.

[18] M. J. T. Mateos, C. López-Pujalte and A. M. Cañavate, "Decision Support System based on Competitive Intelligence and Genetic Algoritms," 2020 15th Iberian Conference on Information Systems and Technologies (CISTI), Seville, Spain, 2020, pp. 1-7, doi: 10.23919/CISTI49556.2020.9141060.

[19] A. V. Andreichikov, A. A. Zudinov, A. A. Nasyrov and I. S. Kravchuk, "Genetic Algoritms for the Synthesis of Innovative Engineering Solutions," 2019 International Conference "Quality Management, Transport and Information Security, Information Technologies" (IT&QM&IS), Sochi, Russia, 2019, pp. 452-458, doi: 10.1109/ITQMIS.2019.8928382.