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Systematic Design and Modelling of Single Lead Electrocardiography using Filter Order 3 to Reduce Noise Using Spektrum Analysis Based on Fast Fourier Transform Approach

Anita Miftahul Maghfiroh, Singgih Yudha Setiawan, Levana Forra Wakidi
Department of Electromedical Engineering, Poltekkes Kemenkes Surabaya, Jl. Pucang Jajar Timur No. 10, Surabaya, 60245, Indonesia
Corresponding author: singgih yudha setiawan (e-mail: singgihyudha91@gmail.com).

ABSTRACT Electrocardiography (EKG) is a method commonly used to measure the performance of the human heart through the heart's electrical activity. To obtain the ECG signal, a lead is carried out using electrodes attached to the skin surface which are recorded in the frequency range 0.05-150Hz. The characteristics of the ECG signal consist of the PR interval, QRS complex and QT interval, from these waveforms doctors can diagnose a disease. However, to get a quality ECG signal, there are often disturbances, such as interference with the 50Hz frequency from electrical grids, respiratory movements, or it could also be caused by the ECG processing algorithm, so it is feared that an error will occur in the diagnosis. From these problems, an appropriate ECG filter is needed to reduce the error rate in generating a wave and maintain signal quality so that it can be accepted clinically. This study aims to design an ECG using a 3rd order filter. The ECG input signal is amplified by an instrument amplifier with 100-fold gain, then a filter process is carried out using a 3rd order Low pass filter to reduce noise interference and then a notch filter is used to ward off the 50Hz network frequency. The results of making a 3rd order filter are able to reduce noise and be able to detect ECG signals properly. It is hoped that this research can be used as a reference for filter design for EKG production and can be utilized in clinical use.

INDEX TERMS Elektrocardiografi, high pass filter, low pass filter, notch filter

I. INTRODUCTION

Electrocardiography (EKG) is a method commonly used to measure the performance of the human heart through the heart's electrical activity. Heart performance monitoring is one of the vital signs that cannot be ignored, the normal heart rate measurement range is between 60-100 BPM, while the unit of measure is expressed as Beats Per Minute (BPM). An electrocardiographic signal (ECG) is a biomedical signal that is non-stationary and has a frequency that changes with time according to cardiac physiological events. Electrocardiography (EKG) has an important role in the process of monitoring and preventing heart attacks. The ECG signal is obtained by tapping using electrodes attached to the surface of the skin and recorded in the frequency range 0.05-150Hz [1][2]. The characteristics of the ECG signal consist of the PR interval, QRS complex and QT interval [3][4]. From these waveforms the doctor can diagnose the patient's condition if there are abnormalities in heart function. In order to get a good ECG signal, there are often disturbances that can be fatal in the diagnosis results, such as interference with the 50Hz frequency from electrical networks, respiratory movements or it could also be caused by the EKG processing algorithm. From these problems, an appropriate ECG filter is needed to reduce the error rate in generating a wave and maintain signal quality so that it can be accepted clinically [5][6][7]. Charles e. Kossmann et al., said that the system performance, linear, ity andoutput deviation should not be more than 5% from peak to peak output. As well as component frequencies between 0.05Hz – 100Hz [8]. Limei Xiu et al have made an EKG with low-power instrumentation, which can be operated at a power of

2.5V – 5.5V by providing an amplifier gain of 40db and having a common-mode rejection ratio (CMMR) of 100db [9]. The advantage of this tool is that it can be used in a portable manner, however, in this study the output of the ECG signal was not explained. R. D. Zuhroini et al, EKG instrumentation has been made with a cut off frequency between 0.05Hz – 110Hz [10][11]. The advantage of this tool is that it can display a 2-channel ECG signal, but the error rate for the resulting ECG signal is quite large, which is around 7.14%. Several researchers have also developed low-cost EKG instrumentation so that it can be used in a portable way [12][13][14][15], however, there is still noise interference so it is equipped with a digital filter which has quite heavy computation. Jayant et al. to get rid of interference from electric grids by removing it using an IIR filter, the research explained that the IIR filter is digitally able to block the 50Hz frequency. However, the IIR filter used is only up to the 2nd order [16]. Martin J. Burke et al have also developed a low power preamplifier so that it can be used portable [17][18]. The amplifier created provides a gain of 43dB in -3dB bandwidth 0.05Hz – 2kHz. This research can reduce motion artifacts but there is still noise in the ECG signal. Mahesh s. Chavan et al have also made a 12-channel ECG instrumentation with an input impedance of 20 MΩ and a frequency response of 0.01Hz – 100Hz with a Gain amplifier of 1000x [19][20]. This system is equipped with a digital filter to reduce the resulting noise, but in this study the computation used is quite heavy and the output signal results still contain noise interference. Anita Miftah et al have made ECG instrumentation by comparing a single supply bio-amplifier with a bi-polar supply with pretty good signal output results and the resulting performance is in accordance with medical standards [21][22][23]. However, the weakness of this study is that the output of the ECG instrumentation is still displayed on an oscilloscope, making it difficult for researchers to directly see the signal output because they have to be connected to an oscilloscope. From several previous studies, researchers have not found any discussion of the analog filter order used and no explanation of the frequency spectrum produced by the ECG signal. Therefore the purpose of this study is to make ECG instrumentation using a 3rd order filter to reduce noise and determine the frequency spectrum of the ECG signal using a fast fourier transform (FFT) [24][25][26].

II. MATERIALS AND METHODS

A. *EXPERIMENTAL SETUP*

In this study, the AD620 IC was used to design ECG instrumentation with a gain of 100x and a filter with a bandwidth frequency of 0.05Hz – 100Hz. In making a high pass filter circuit using order 1 with a cut off frequency of 0.05Hz. Meanwhile, the low pass filter (LPF) circuit uses order 3 with a cut-off frequency of 100Hz.

1) MATERIALS AND TOOLS

The materials and tools used in this study were the manufacture of ECG instrumentation using lead II leads. The input signal used is the ECG Simulator Brand Fluke type MPS450 then the signal is displayed on the oscilloscope. Furthermore, the data is stored via sd-card and processed using the FFT program to determine the frequency spectrum of the ECG signal.

2) EXPERIMENT

In this experiment data acquisition was carried out, by inputting the ECG signal using the ECG simulator which then output the signal displayed on the oscilloscope. Furthermore, it is stored on an SD-Card or flash and then the data is processed off-line to determine the frequency spectrum of the ECG signal using FFT.

3) METHODS

In this study the FFT method was used to determine the frequency spectrum of the ECG signal. Fast Fourier Transform (FFT) divides a signal into different frequencies in a complex exponential function [27]. Fast Fourier Transform (FFT) is an algorithm for calculating discrete Fourier transforms quickly and efficiently. Because the signals in the communication system are continuous, the results can be used for the Fourier transform. FFT is an algorithm used to calculate Discrete Fourier Transform (DFT) quickly and efficiently. DFT calculations directly require arithmetic operations of 0 (N2) or have the order of N2, while calculations with FFT will require operations of 0 (NlogN). DFT is expressed in Eq. (1) and Eq. (2) [28].

$$\begin{aligned} X(k) &= \sum_{n=0}^{N-1} x(n) W_N^{nk} \\ &= \sum_{r=0}^{N/4-1} x(4r) W_N^{k(4r)} + \sum_{r=0}^{N/4-1} x(4r+1) W_N^{k(4r+1)} \\ &\quad + \sum_{r=0}^{N/4-1} x(4r+2) W_N^{k(4r+2)} + \sum_{r=0}^{N/4-1} x(4r+3) W_N^{k(4r+3)} \\ &= \sum_{r=0}^{N/4-1} x(4r) W_N^{k(4r)} + \sum_{r=0}^{N/4-1} x(4r+1) W_N^{k} W_{N/4}^{kr} \\ &\quad + \sum_{r=0}^{N/4-1} x(4r+2) W_N^{2k} W_{N/4}^{kr} + \sum_{r=0}^{N/4-1} x(4r+3) W_N^{3k} W_{N/4}^{kr} \\ &= X_0(k) + X_1(k) W_N^{k} + X_2(k) W_N^{2k} + X_3(k) W_N^{3k} \end{aligned} \tag{1}$$

where $k = 0,1,\dots,N-1. W_N = e^{-j2\pi/N}$.

Due to the symmetrical property of twiddle factors, we get the Equations that:

$$\begin{cases} X(k) = X_0(k) + X_1(k)W_N^k + X_2(k)W_N^{2k} + X_3(k)W_N^{3k} \\ X(k + N/4) = X_0(k) - jX_1(k)W_N^k - X_2(k)W_N^{2k} + jX_3(k)W_N^{3k} \\ X(k + N/2) = X_0(k) - X_1(k)W_N^k + X_2(k)W_N^{2k} - X_3(k)W_N^{3k} \\ X(k + 3N/4) = X_0(k) + jX_1(k)W_N^k - X_2(k)W_N^{2k} - jX_3(k)W_N^{3k} \end{cases} \quad (2)$$

where $k = 0 \sim N/4, W_N = e^{-j2\pi/N}$.

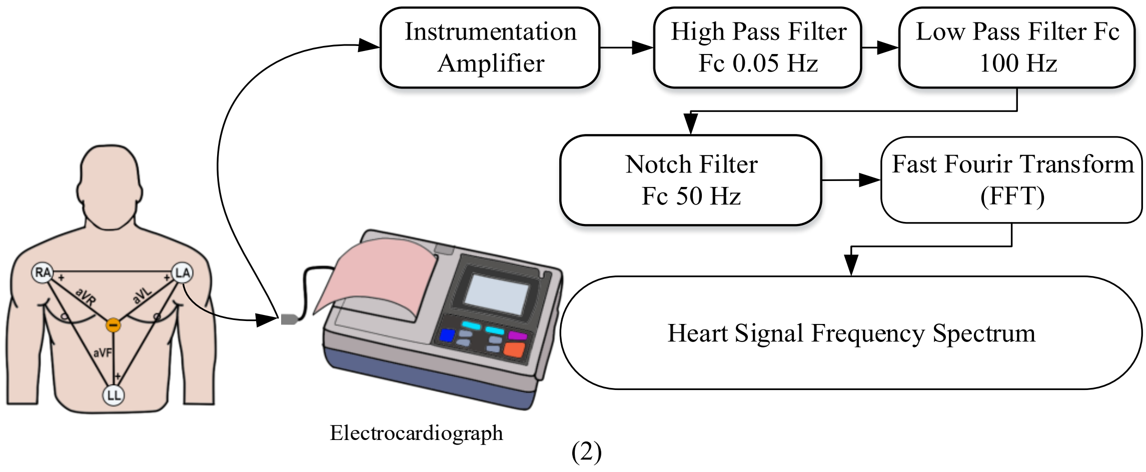


FIGURE 1. ECG instrument system design with single lead II leads. The filter used is a 1st order HPF with a cut off frequency of 0.5 Hz and a 3rd order LPF with a cut off frequency of 100 Hz. The notch filter is used to reduce interference from the 50 Hz power grid. The ECG signal output is then processed using the FFT to determine the frequency spectrum of the ECG signal.

B. THE DIAGRAM BLOCK

On FIGURE 1 explained about the design of ECG instrumentation. In this study, the instrumentation amplifier used the AD620 IC with a gain of 100x. The output of the instrumentation amplifier still contained noise, so a first-order analog high-pass filter with a cut-off frequency of 0.05 Hz and a third-order low-pass filter with a cut-off frequency of 100 Hz were needed. Furthermore, to reduce the 50 Hz frequency interference from the power grid, a notch filter circuit with a 50 Hz cut-off frequency is needed. The output of ECG instrumentation in the form of an electrocardiogram signal is processed using the FFT to determine the frequency spectrum of the ECG signal.

C. ECG INSTRUMENTATION MANUFACTURING

In this research, there are several circuits made for ECG instrumentation including instrumentation amplifier circuits, 1st order high pass filters, 2nd order low pass filters and notch filter circuits. In making the amplifier instrumentation circuit this research used the Ad620 IC [29] with a gain of 100 times and produces a gain of 60 dB described in FIGURE 2. The gain produced by instrumentation amplifier is based on Eq. (3)

$$G = \frac{49.4\,K\Omega}{R_G} + 1 \quad (3)$$

where G is the gain while RG is the resistance value used to determine the Gain.

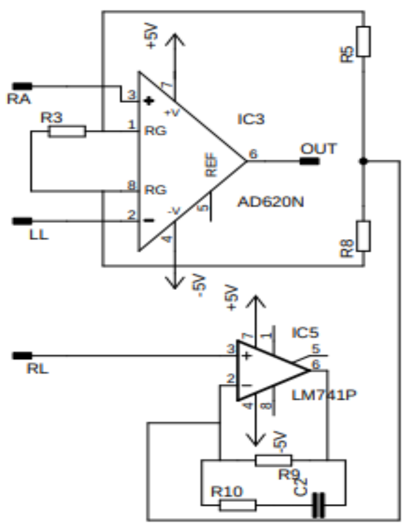
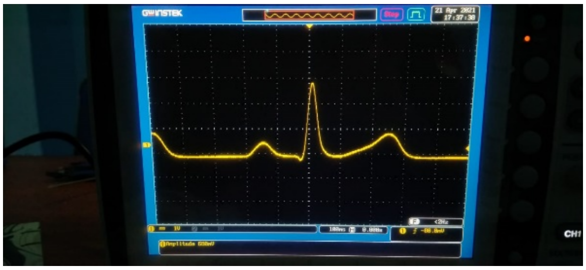


FIGURE 2. Instrumentation amplifier circuit design using IC AD620 with Gain 100 times.

The output of the instrumentation amplifier still contains noise, so a filter is needed to reduce the noise. On FIGURE 3 explained about the instrumentation of a 1st order high pass filter with a cut off frequency of 0.05 Hz.



The way to determine the calculation of R and C is based on Eq. (4).

FIGURE 3. Instrumentation high pass filter orde 1 dengan frekuensi cut off 0,05 Hz

$$f_c = \frac{1}{2\pi RC} \quad (4)$$

Where f_c is cut off frequency, R is resistance value, and C is Capacitor value.

The output of the 0.05Hz HPF filter as the input of the low pass filter with a cut off frequency of 100 Hz uses order 3 which is described in FIGURE 4. where the circuit is built from two filter circuits, which consist of one 2nd order LPF circuit and one 1st order LPF circuit.

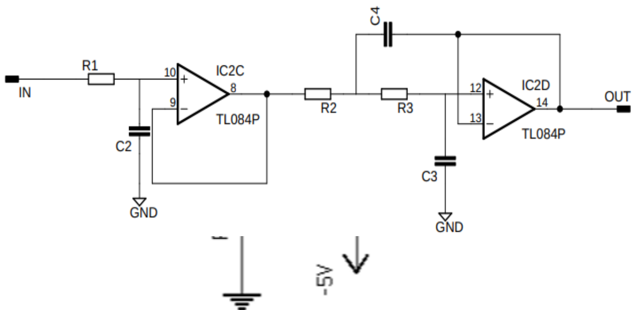


FIGURE 4. Instrumentation low pass filter with a cut off frequency of 100Hz yang terdiri dari 1 rangkaian orde 2 dan orde 1.

The Notch Filter circuit in this study is used to remove the 50 Hz frequency grid noise in the supply voltage and that generated by the oscilloscope. The Notch Filter circuit is shown as follows FIGURE 5. The C1 value used is 1 µF, RA = 1kΩ and the cut-off frequency (fc) is 50 Hz. Center frequency value ωr, quality factor (Q), R2, R1 and RB values are calculated by Eq. (6)-(10).

$$\omega_r = 2.\pi.fc \quad (6)$$

$$Q = \frac{\omega_r}{B} \quad (7)$$

$$R2 = \frac{2}{BC} \quad (8)$$

$$R1 = \frac{R_2}{4.Q^2} \quad (9)$$

$$RB = 2\,.\,Q^2.R_a \quad (10)$$

FIGURE 7. ECG signal display on oscilloscope

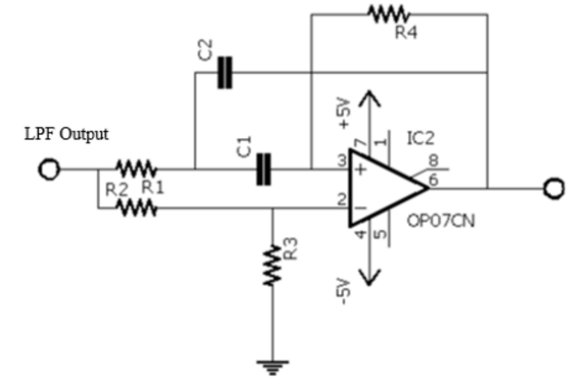


FIGURE 5. Instrumentation notch filter dengan frekuensi cut off 50 Hz

III. RESULT

From the results of measurement, testing and data collection on each instrumentation, measurements have been carried out 5 times, then the average value and the resulting standard deviation are calculated. Then the results of the average are plotted in a graph to test the suitability of the filter that has been designed. Meanwhile, to get the frequency spectrum of the ECG signal, ECG data is collected with the input used is the ECG simulator, the data displayed on the oscilloscope is stored, then the frequency domain is calculated using the FFT method..

A. TEST RESULTS FOR MAKING ECG INSTRUMENTATION

On FIGURE 6 it is explained that the input signal used is the ECG Simulator with a sensitivity setting of 1. Furthermore, the ECG signal output is displayed on the oscilloscope.

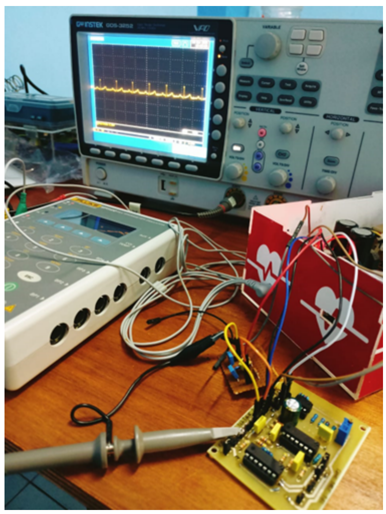


FIGURE 6. The ECG instrumentation test displayed on the oscilloscope with the input signal used is the ECG Simulator

ECG instrumentation results are described in FIGURE 7. From the figure, it is obtained that the output signal is quite clean with the use of order 1 HPF and order 3 LPF with a bandwidth frequency of 0.05 Hz – 100 Hz.

To find out the performance of each instrumentation, data collection was carried out 5 times and then the average and standard deviation were calculated. TABLE 1 is the result of data collection instrumentation amplifier with an input voltage of 1 Volt - 5 Volts.

TABLE 1
Measurement of the performance of the AD620 instrumentation amplifier was carried out 5 times with an input voltage of 1 Volt – 5 Volts

Mean Amplitude (Volt)	
Input	Output AD620
1	6.08
1.1	6.8
1.2	7.2
1.3	7.52
1.4	8
1.5	8.2
1.6	8.2
1.7	8.2
1.8	8.2
1.9	8.2
2	8.2
2.1	8.2
2.2	8.2
2.3	8.2
2.4	8.2
2.5	8.2
2.6	8.2
2.7	8.2
2.8	8.2
2.9	8.2
3	8.2
3.5	8.2
4	8.2
4.5	8.2
5	8.2

Based on TABLE 1 It is known that at an input voltage of 1 Volt - 5 Volts the output voltage is stable at an input voltage of 1.5 Volts with an output voltage of 8.2 Volts. For more details explained in the graph FIGURE 8.

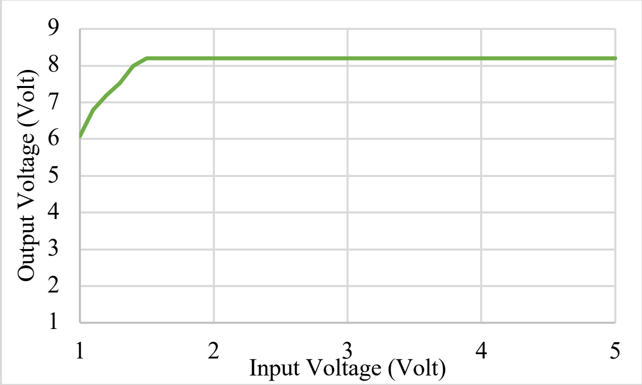


FIGURE 8. Graph of calculating the average output of the AD620 instrumentation amplifier

To test the high pass filter circuit, a frequency input test is carried out using a function generator starting from 0.1 Hz – 10 Hz as shown in Fig. FIGURE 9.

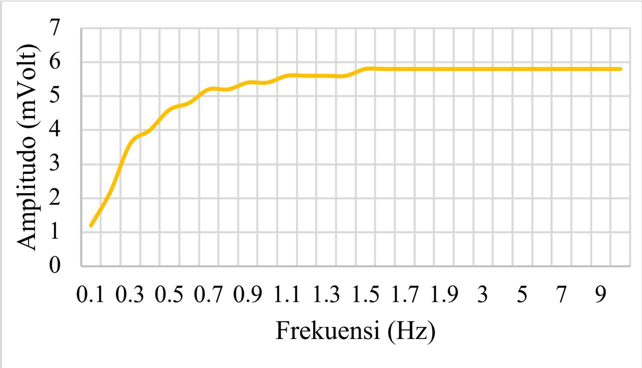


FIGURE 9. Graph of the frequency response of the high pass filter with a cut off frequency of 0.05 Hz

From explanation FIGURE 9 a graphic image of the frequency response of the high pass filter on input frequencies less than 0.5 Hz starts to be muted and on input frequencies above 0.5 Hz high frequencies are passed. Next on FIGURE 10 explained about the graph of the low frequency response of the filter with a cut off frequency of 100 Hz.

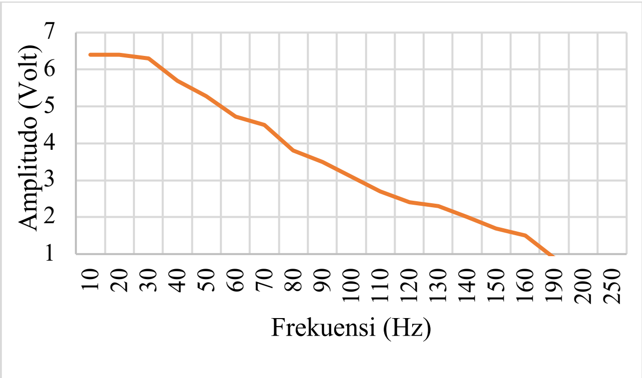


FIGURE 10. Graph of low pass filter frequency response with cut frequency off 100 Hz

From explanation FIGURE 10 obtained a graph of the frequency response of the low pass filter with a cut-off frequency of 100 Hz. Filter testing by giving input frequencies ranging from 10 Hz – 250 Hz. Input frequencies less than 100 Hz low frequencies are passed and at input frequencies above 100 Hz high frequencies begin to be muted. Meanwhile, to get rid of the 50 Hz frequency disturbance, this research uses a notch filter circuit. FIGURE 11 is a graphic explanation of the frequency response of the notch filter with a cut-off frequency of 50 Hz.

On FIGURE 11 shows the measurement results of the notch filter, the measurement is carried out by providing an input frequency of 10Hz to 250Hz, from these results it is known that the output of the notch filter shows a cut off frequency response at 50 HZ.

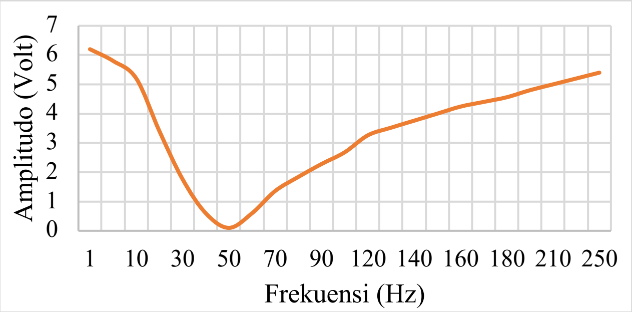


FIGURE 11. Nocth filter frequency response graph with a cut off frequency of 50 Hz

B. ECG Frequency Spectrum Results using FFT

The results of the ECG signal data collection in the form of CSV data were tested using the FFT to determine the frequency response generated by the ECG signal. FIGURE 12 is the result of ECG signal and frequency spectrum.

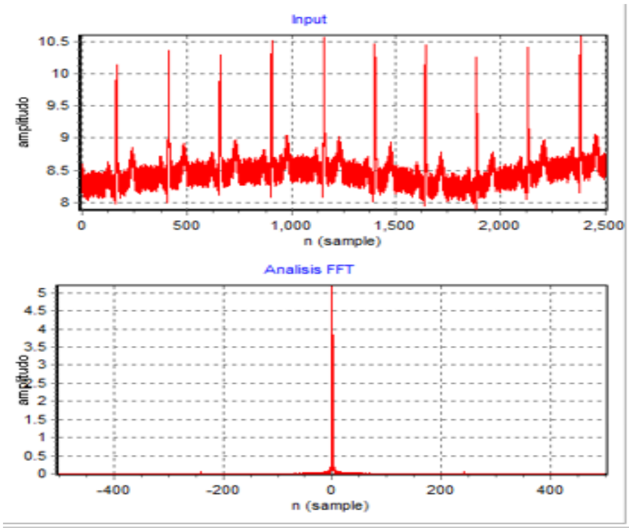


FIGURE 12. ECG signal searching for the frequency spectrum using FFT

Result of FIGURE 12 shows that the results of the frequency spectrum of the ECG signal are in the highest frequency range at a frequency of 0 – 100 Hz. Above the frequency of 100 Hz the frequency has started to be suppressed and the signal spectrum information begins to disappear.

IV. DISCUSSION

From the results of the tests that have been carried out, the average value of the instrumentation amplifier is known that at an input voltage of 1 Volt - 5 Volts the output voltage is stable at an input voltage of 1.5 Volts with a resulting output voltage of 8.2 Volts. Whereas in the filter test on the HPF with input frequencies between 0.1 Hz – 10 Hz, the high pass filter frequency response is obtained at input frequencies less than 0.5 Hz, high frequencies begin to be muted and at input frequencies above 0.5 Hz, high frequencies are passed. While the results of the 3rd order LPF test with an input frequency of 10 Hz – 250 Hz, it is obtained that the input frequency is less than 100 Hz, the low frequency is passed and the input frequency above 100 Hz, the high frequency begins to be muted. The results of the notch filter test on the input frequency of 50 Hz were successfully pushed over. Jayant et al to get rid of interference from the power grid by removing it using an IIR filter [16], The study explained that the digital IIR filter is able to block the 50Hz frequency. To obtain diagnostic quality Roberta Dozio et al. designed 2nd-order and 3rd-order analog high-pass filters to eliminate distortion in the ECG recording [30]. In this study it was explained that the removal of distortion was still not optimal because the order used was only up to order-3.

In this study, a 3rd order filter was made for the ECG signal filtering process. The contribution of this study can be used as a reference for choosing the right filter to reduce noise interference in ECG signals. The weakness in this study is that the signal display output still uses an oscilloscope, so it is less effective when carrying out data acquisition.

V. CONCLUSION

The purpose of this research is to design an ECG using a 3rd order filter. From the results of tests and measurements, it can be concluded that a 3rd order filter can be used to reduce noise so that the ECG signal can be produced in accordance with FIGURE 7. The results of the frequency spectrum of the ECG signal obtained the highest frequency range at a frequency of 0-100 Hz. Above the frequency of 100 Hz, the frequency has started to be suppressed and the signal spectrum information starts to be lost. For future research, the researcher will add a digital filter to eliminate artefact interference caused by subject movement.

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