EMITOR: Jurnal Teknik Elektro

Analysis of Second-Order HPF and LPF Circuit Simulations as Digital Signal Amplification Filters

Florentius Budi Setiawan*, Paskal Kariman, Leonardus Heru Pratomo, Slamet Riyadi
Fakultas Teknik Program Studi Teknik Elektro – Universitas Katolik Soegijapranata
Semarang, Indonesia
*f.budi.s@unika.ac.id

Abstract – *The writing of this paper focuses on describing and relating simple modeling and analysis to the simulation of High-PassFilter (HPF) and Lowpass filter (LPF) designs using Op-Amp, which previously used an analog system and then converted into a digital system using input and output digital gain processing frequency which aims to strengthen the sinusoidal signal contained in the HPF and LPF systems. Filter is defined as an electrical network that is designed to pass alternating current that is increased at a predetermined frequency and blocks all alternating current that is increased at a predetermined frequency. Frequency also has types, namely analog, digital, active and passive. Analog filters are used for analog signals, digital are used for signals using digital techniques, passive filters such as resistors, capacitors, inductors, and active such as transistors or op-amps. In general, the understanding of HPF is that it passes high frequencies at the cut-off frequency and dampens low frequencies. Furthermore, LPF also has different characteristics, namely, passing low frequencies and dampening high frequencies. Currently related to digital signal processing, it can be said to be a method of manipulating, analyzing and interpreting signals, which is used to process the removal of noise or interference on several unwanted components of the signal. By knowing these characteristics, what the author did was carry out a simulation aimed at helping to obtain optimal frequency output.*

Keywords – *High-Pass Filter (HPF); Low-Pass Filter (LPF); Digital Signal Processing; Op-Amp Simulation; Frequency Response.*

I. Introduction

These days, filters are frequently used in everyday life on gadgets like radios, televisions, and cell phones. An apparatus that attenuates undesirable frequencies while permitting acceptable frequencies to pass is called a filter. Filters are a vital part of electronic equipment. Analogue and digital filters are separated out. In general, communication systems and signal processing employ filters [1]. Filters can alternatively be categorised according to their digital or analogue nature, or according to their frequency response, in which case they are classified as Low Pass or High Pass filters [2].

Analog filters are characterized by their circuits, which include components such as Resistors, Inductors, and Capacitors (R-L-C) [3]. The working system of analog filters is where the analog signal is continuous over time [4]. The form of the analog signal is sinusoidal, where, when the voltage versus time graph is plotted, the output result is sinusoidal [5]. However, this signal is very susceptible to noise or disturbances, which can easily lead to the loss of information in the signal [5]. Examples of analog filter applications include analog televisions, film cameras, cassettes, TV remotes, speedometers, pressure gauges, analog phones, and analog radios.

In contrast, digital filters are found in Integrated Circuits (ICs) or microcontrollers. One advantage of analog filters is that there is no need to dismantle the circuit to pass the required signal values, but this can be done through computerization of the filter [4]. A digital filter is defined as allowing frequencies that are not continuous over time. Digital filters are typically used in the processing of voice signals and telecommunications [6].

The form of the digital signal is square wave and has discrete characteristics, only having distinct values [7]. Filters themselves can be either active or passive. The difference between them is that active filters have resistances such as inductors and capacitors. Active filters contain Op-amps or transistors but also include

The manuscript was received on October 11, 2023, revised on May 29, 2024, and published online on July 26, 2024. Emitor is an accredited Journal of Electrical Engineering at the – Universitas Muhammadiyah Surakarta, holding a Sinta 3 accreditation. It is accessible at https://journals2.ums.ac.id/index.php/emitor/index.

resistances such as inductors and capacitors [8].

Active filters themselves can be referred to as Active High Pass Filters (Active HPF), where this filter circuit will pass input signals along with frequencies above it and will attenuate frequencies below its cut-off frequency and also include an amplification circuit, namely an Operational Amplifier (Op-amp). The use of active filters themselves requires a supply voltage to activate the components used [9].

While passive filters depend on the type of element predetermined by their operation [10]. For example, an RC filter is generally only used for audio or also for low frequencies. The principles of operation of low pass and high pass filters, as well as op-amp circuits, are methods the author uses in the process of smoothing digital signals. The function of the low pass filter will be used to smooth the signal where this type of filter will attenuate the output of high frequencies and will allow low frequencies to pass. Meanwhile, the high pass filter type will be used to attenuate low frequencies and allow high frequencies that are present in the sinusoidal signal. Certainly, passive filters themselves have advantages and disadvantages, where the disadvantage of active filters lies in their larger size compared to active filters. Whereas the advantage is that they can be used for higher frequencies [11].

Therefore, based on the results of the research from the system that has been simulated in the digital system as filtering. The purpose of writing this paper is to smooth out the problems of disturbances found in the output part of the system that has been measured. By performing simulations on the PowerSimulator (Psim) software, which has been developed for the simulation of High Pass Filter (HPF) and Lower Pass Filter (LPF). This paper is structured as follows; the introduction is presented in section (I). An explanation of the purpose of the writing is aimed at section (II). Providing the design method and circuit form of the system with PowerSimulator (Psim) is aimed at section (III). Performing analysis on the output results is aimed at section (IV), and finally, conclusions along with existing references.

II. Research Methods

i. High Pass Filter (HPF)

In this paper, the type of High Pass Filter (HPF) implemented or simulated is a second-order High Pass Filter. A high pass filter is one of the filters that uses passive components, such as resistors and capacitors, or also resistors and inductors. For High Pass Filters using resistors and capacitors, it is referred to as an RC High Pass Filter, and High Pass Filters using resistors and inductors are known as RL High Pass Filters [12]. As the name suggests (high pass), it allows high frequencies to pass through and attenuates the cut-off frequency. High pass filters also weaken all output voltages at the cut-off frequency.

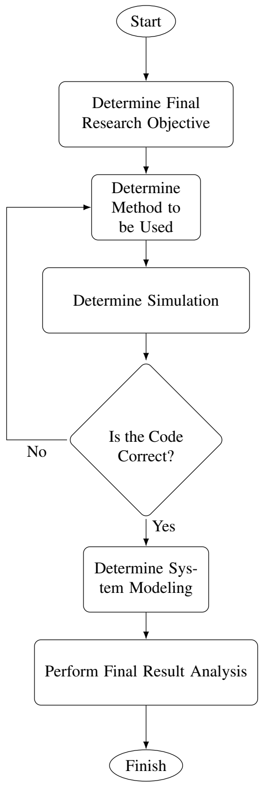


Figure 1: Flowchart of the Design Process

The calculations in the high pass filter are developments based on the amplification components used, such as operational amplification (Op-amp). We can find or calculate the magnitude of the cut-off frequency in the high pass filter using the following formula [13]. The calculations in the high pass filter are developments based on the amplification components used, such as operational amplifiers (Op-amp). We can find or calculate the magnitude of the cut-off frequency in the high pass filter using the following formula:

$$f.c = \frac{1}{2\pi\sqrt{R \cdot C}} = \frac{1}{2\pi\sqrt{R_1 \cdot R_2 \cdot C_2}} \quad (1)$$

ii. Low Pass Filter (LPF)

A Low Pass Filter (LPF) is a circuit in which the output voltage remains DC until the desired cut-off frequency. As the frequency increases above the cut-off, the output voltage is increasingly attenuated, implying that as the frequency rises, the voltage falls. Thus, it can be concluded that a low pass filter operates at frequencies lower than its cut-off frequency and attenuates frequencies higher than the cut-off frequency.

To determine the cut-off frequency of a low pass filter, the formula can be used as equation 1. Generally, the method for determining the cut-off frequency of each filter is similar, but what distinguishes them is the use of an Op-amp [14] for control of the amplification. The use of a Low Pass Filter itself is an active filter where the output value will remain the same or stable even under load, the purpose of which is to prevent voltage reduction before the load [15].

iii. Operational Amplifier

An operational amplifier (Op-amp) is a key component used for amplification in High Pass Filter (HPF) and Low Pass Filter (LPF) circuits. An Op-amp is essentially a signal amplifier for digital signals. It comprises capacitors, resistors, diodes, and transistors.

The entire Op-amp circuit within an Integrated Circuit (IC) package is categorized into several types, including Single, Dual, and Quad Op-amps [16]. Op-amps are a type of electronic amplifier that operates on direct current and offers very high amplification [14].

Op-amps have two primary configurations: closed loop and open loop. The closed-loop configuration serves to reduce gain, aimed at minimizing excess noise and avoiding poor responses. In contrast, the open-loop configuration is used for amplification, thereby allowing the output voltage to approach the supply voltage, V_{cc}. The initial input voltage of the amplifier is very small, and the amplifier works by converting this small voltage into a significantly higher output voltage [17].

iv. Digital Signal Processing (DSP)

Currently, digital signal processing (DSP) has become a fundamental part in creating, processing, transmitting, and storing a vast amount of information in various forms such as audio, video, text, and images [18]. Digital signal processing involves the manipulation of digital signals using software, allowing these signals to be continuously managed in terms of frequency, space, time, and other dimensions.

The ADC (Analog to Digital Converter) functions to convert analog signals to digital, whereas the DAC (Digital to Analog Converter) converts digital signals back to analog [19]. The components of this system are defined as follows:

1. DAC: Digital to Analog Converter
2. ADC: Analog to Digital Converter
3. DSP: Digital Signal Processing

The advantages of using digital signal processing include programmability and improved control accuracy [18]. Digital signal processing is divided into linear and non-linear operations. Non-linear signals are associated with non-linear systems as well.

v. Power Simulator (Psim)

The Power Simulator (Psim) software is a tool used for designing and obtaining simulation results in low-current electrical circuits. Psim produces output signals that are equivalent to the actual hardware output. In other words, measurements performed in Psim will mirror those that occur in reality. Based on the brief overview of Psim software, the author has chosen this software as a tool for conducting preliminary analysis in this research.

When planning a framework on a specific topic, several steps are undertaken. These range from performing simulations on the software to determining the circuit configurations for the designated methods. These methods are grouped into several parts to ensure the research objectives are clearly understood. The methods are explained as follows:

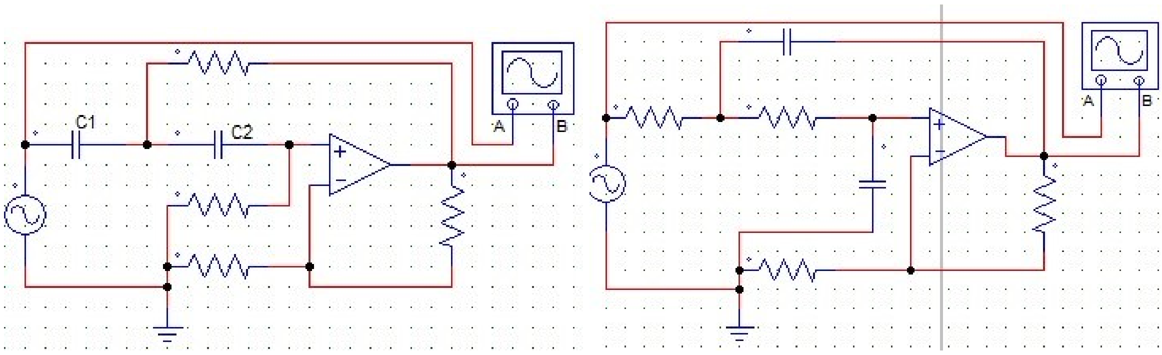
1. **Method Section (Understanding)**: This part involves understanding HPF and LPF, the circuit configurations, the components involved, and the characteristics of HPF and LPF.
2. **Experimental Section (Simulation)**: Simulations of HPF, LPF, and BSF circuits are performed in this section. It includes designing the framework for planning. These simulations are carried out using Power Simulator (Psim).
3. **Addition Section (Signal Amplification)**: As relevant to the discussion topic, this section involves enhancing the input of each circuit. Amplification aims to optimize voltage and produce a quality output signal for each circuit. An operational amplifier is used in the simulations for power amplification. The operational amplifier (Op-amp) system is integrated into a single circuit (Integrated Circuit, IC) [20].
4. **Final Section (Analysis and Conclusion)**: After understanding and simulating the circuits, analysis is performed on each circuit. This section also focuses on the output voltage and optimal frequency of each circuit.

vi. Circuit Layouts in Simulation

This section demonstrates the circuit configurations used in the Power Simulator (Psim) simulations.

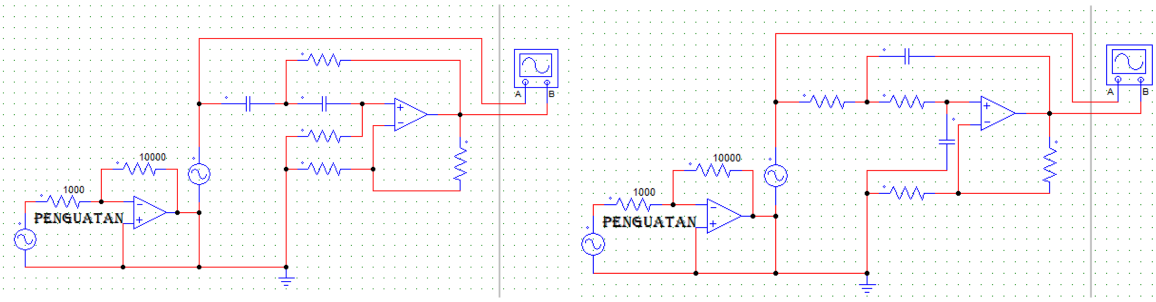
The circuits shown are unamplified configurations aimed to improve output voltage and frequency wave quality. These are second-order circuits.

In the amplified configurations, resistors of 1000 and 10000 ohms and an operational amplifier are used.



(a) **(b)**

Figure 2: (a) Second-Order HPF Circuit and (b) Second-Order LPF Circuit



(a) **(b)**

Figure 3: (a) Second-Order HPF Circuit After Amplification and (b) Second-Order LPF Circuit After Amplification

The amplification achieved in these circuits is tenfold. The calculation for the gain is as follows:

$$\text{Gain}(A_v) = \frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_f}{R_in} \quad (2)$$

Applying this to the circuits in the simulation:

$$V_{\text{out}} = -\frac{R_f}{R_in} = -\frac{10000}{1000} = -10 \quad (3)$$

Table 1 below lists the components and materials used in the simulations:

Component	Specification
Voltage to Op-Amp	±12 Volt DC
Op-Amp Type	TL082
Capacitors	22 & 4 nf
Resistors	750, 5200, 150, & 10k ohm
Cut-off Frequency	40 kHz

Table 1: Table 1: Components and materials used in the simulations

III. Results and Discussion

i. Simulation Results for HPF and LPF Responses

This section presents the simulation results of the High Pass Filter (HPF) and Low Pass Filter (LPF) responses from Psim, both before and after amplification.

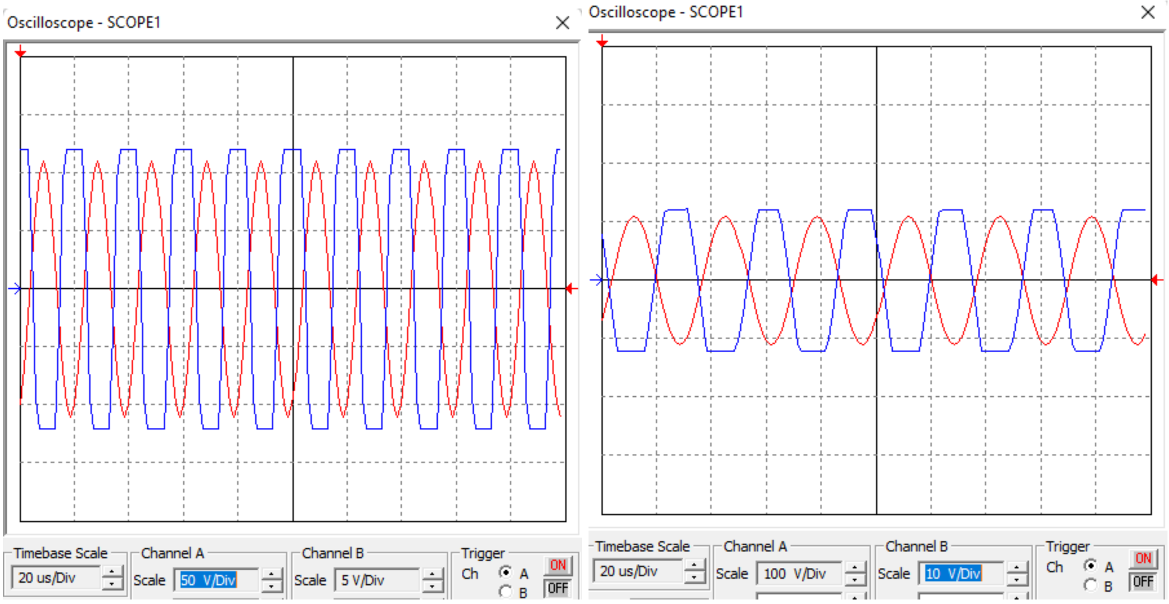
Following the simulations, a detailed discussion is conducted on the HPF and LPF circuits before and after amplification, to determine and utilize the optimal sinusoidal signal for digital signal processing.

ii. Analysis of High Pass Filter (HPF)

In the simulation results, the output signal of the HPF can be seen in Figure 9 (not shown here), where the blue line represents the output signal and the red line represents the input signal. The designated cut-off frequency was 40 kHz, while the measurements conducted on the software showed a cut-off at 50 kHz. The response of the HPF before amplification is box-shaped with a maximum output voltage of 5V/div, whereas the input voltage operates maximally at 20V/div (shown in Figure 9). This voltage is the maximum present in the circuit. However, after amplification, the resulting output voltage reaches up to 50V/div (shown in Figure 11). This increase is due to the amplification. The input voltage also increased tenfold, from initially 20V/div to 200V/div for the maximum output voltage (shown in Figure 11).

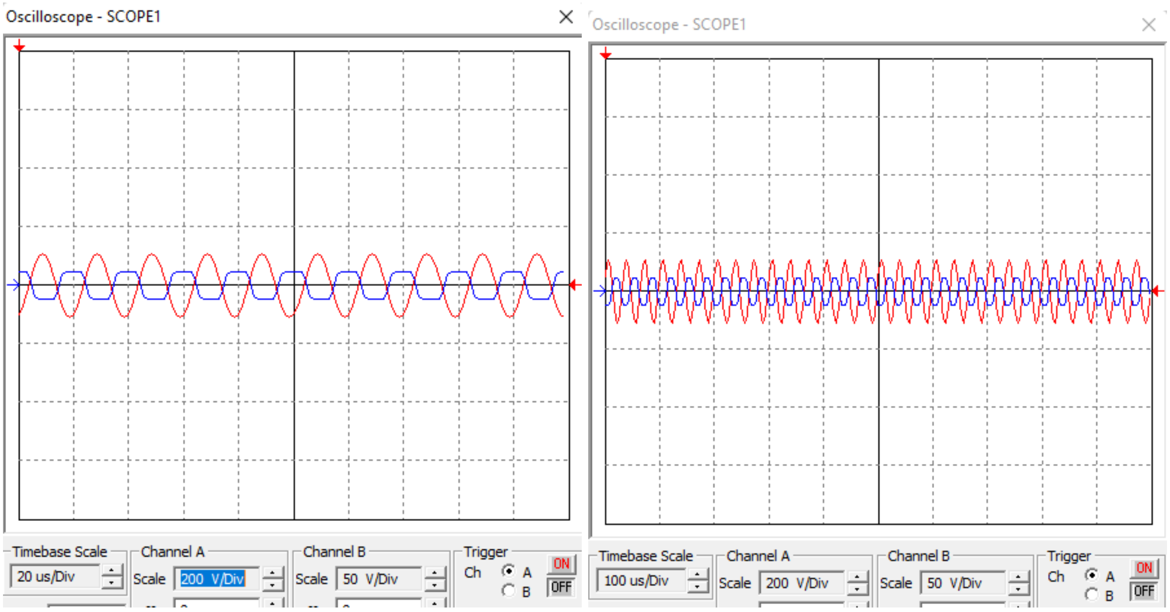
iii. Analysis of Low Pass Filter (LPF)

This section focuses on the significant amplification effects observed in the Low Pass Filter (LPF) simulations. In Figure 10, the blue wave represents the output



(a) **(b)**

Figure 4: (a) HPF Response Before Amplification and (b) LPF Response Before Amplification



(a) **(b)**

Figure 5: (a) Simulation Results of the HPF Response After Amplification and (b) Simulation Results of the LPF Response After Amplification

from the LPF circuit, and the red wave represents the input. Initially, the output shape of the LPF circuit was square and only measured a maximum of 5V/div, with a maximum input voltage of 20V/div (as shown in Figure 11). However, after amplification, the signal quality and voltage of the circuit improved significantly. The signal shape transformed into a typical digital (sinusoidal) signal. The output voltage also experienced a tenfold increase, from initially 5V/div to 50V/div, and the input voltage increased similarly, from 20V/div to 200V/div (as shown in Figure 12). These simulations were conducted with a cut-off frequency set at 40kHz, and measurements were taken at 30kHz.

IV. Conclusion

The simulation results of HPF and LPF, based on the input-output action model, show a good relationship between input and output signals and voltages. Specifically, the output signal characteristics of the LPF simulations demonstrated a harmonious relationship with the input signals, resembling the desired system input signal harmonics. Similarly, the HPF also displayed harmonious output relative to its input signals. The LPF required the most amplification, especially in its second-order configuration, as evidenced in Figures 12 and 10. Post-amplification, with the same frequency of 30kHz, the output signal quality markedly improved. It is concluded that the HPF operates maximally at 5V/div before amplification and reaches up to 50V/div post-amplification. Similarly, the LPF exhibits comparable changes in signal shape and output voltage.

This research underscores that even with tenfold amplification, the circuits continue to perform excellently and provide robust signal responses. The implication of this study is to acknowledge that these filter circuits also possess order, and further research could explore beyond the second order, possibly into third order or higher.

Acknowledgment

We extend our deepest gratitude to God Almighty for blessing us with health and opportunity. We also thank the author's parents for providing facilities and support for all activities and endeavors, and to Professor Florentius from Soegijapranata Catholic University, Semarang, for imparting valuable knowledge in the course on digital signal processing. Your prayers and support are greatly appreciated. It is hoped that this paper will enhance understanding of the simulation of op-amp HPF and LPF as filters in the amplification of digital signals.

References

[1] R. Hidayat, Syafruddin, and G. D. Ramady, "Desain low pass filter butterworth dengan komponen aktif voltage controlled voltage source," *Isu Teknol. Stt Mandala*, vol. 15, no. 2, pp. 31–36, 2020. [Online]. Available: https://www.ejournal.sttmandalabdg.ac.id/index.php/JIT/article/view/185

[2] T. Niagawan, "Perancangan tapis butterworth untuk merestorasi citra digital," 2018. [Online]. Available: http://eprints.unram.ac.id/id/eprint/2742

[3] A. I. Muslim, "Filter analog dan aplikasi filter analog," 2022. [Online]. Available: https://www.academia.edu/88005041

[4] F. Roy, "Pengertian filter analog dan filter digital," eduidea.id. [Online]. Available: https://eduidea.id/pengertian-filter-analog-dan-filter-digital/

[5] F. H. Utomo, "Pengertian sinyal analog dan digital beserta contohnya," kelasplc.com. [Online]. Available: https://www.kelasplc.com/pengertian-sinyal-analog-dan-digital-beserta-contohnya/

[6] A. A. V. Addina, "Implementasi filter finite impuls response (fir) pada dsk tms320c6713 transceiver menggunakan teknik windowing," *J. Jartel*, vol. 6, no. 1, pp. 1–8, 2018.

[7] R. Alfita and R. V. Nahari, "Pengolahan sinyal digital."

[8] A. Kurniawan, "Filter analog," 2023. [Online]. Available: https://www.researchgate.net/publication/367253145_Filter_Analog

[9] A. Gintings, I. Yuniantoro, and S. Harlan, "Filter pasif rc dan filter aktif op amp lm741 sebagai pengatur nada dalam sistem penguat audio, sebuah catatan," *Ensains*, vol. 2, no. 3, pp. 195–200, 2019.

[10] A. Taking, "Analisa rangkaian active high pass filter orde 1 dan orde 2 topology sallenkey," 2022. [Online]. Available: https://repository.ubt.ac.id/flipbook/baca.php?bacaID=9077

[11] S. Fuada, G. Alisrobia, M. Hasanah, M. C. Yustina, and D. Rahmawati, "Penggunaan virtual lab. circuit wizard untuk simulasi rangkaian high pass filter pasif," *J. Ilm. Teknol. Inf. Terap.*, vol. 9, no. 2, pp. 197–206, 2023.

[12] F. Trisnawati and S. D. Ramdan, "High pass filter," *Repoteknologi.id*, vol. 1, no. 3, pp. 1–8, 2021. [Online]. Available: http://repoteknologi.id/index.php/repoteknologi/article/view/68/54

[13] B. A. Ananditya, "Analisis sederhana simulasi op-amp hpf dan lpf sebagai filter pengolahan isyarat digital," 2021. [Online]. Available: https://www.researchgate.net/publication/357803097_Analisis_Sederhana_Simulasi_Op-Amp_HPF_dan_LPF_sebagai_Filter_Pengolahan_Isyarat_Digital

[14] P. N. Lidyaza, D. Darmawan, and A. Qurthobi, Eds., *Karakterisasi Kadar Air Batubara Berdasarkan Pengukuran Nilai Kapasitansi*, vol. 5, no. 3, 2018. [Online]. Available: https://openlibrarypublications.telkomuniversity.ac.id/index.php/engineering/article/view/7198/7082

[15] R. M. Yasin, A. N. Aziz, and H. Hartono, "Rancang bangun sistem kontrol berbasis biopotensial mata (studi kasus: Mengontrol aplikasi berbasis android)," *J. Teras Fis.*, vol. 1, no. 1, pp. 9–22, 2018.

[16] D. Denisenko, N. Prokopenko, and N. Butyrlagin, "Differential difference amplifiers in the second order low-sensitive all-pass active rc-filters," in *International Conference on Computation, Automation and Knowledge Management (ICCAKM)*, 2020, pp. 275–279.

[17] M. I. Pangestu, D. P. Pamungkas, and R. Wulaningrum, "Sistem pakar diaknosis kerusakan amplifier dengan metode case based reasoning (cbr)," *Semin. Nas. Inov. Teknol.*, vol. 5, no. 1, pp. 231–236, 2021.

[18] B. Murtianta and D. Susilo, "Penguat kelas d frekuensi tetap orde 2," *J. Edukasi Elektro*, vol. 6, no. 1, pp. 24–31, 2022.

[19] A. Mustofa, *Pengolahan Sinyal Digital*. Universitas Brawijaya Press, 2018.

[20] E. P. Sitohang, D. J. Mamahit, and N. S. Tulung, "Rancang bangun catu daya dc menggunakan mikrokontroler atmega 8535," *J. Tek. Elektro dan Komput.*, vol. 7, no. 2, pp. 135–142, 2018.