IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Comparative Analysis Of Weak Signal Conditioning Circuit

Srikanta S, Dr. K.P. Lakshmi
MTech Student, Professor
Department of Electronics & Communication Engineering,
VLSI Design and Embedded Systems,
BMSCE, Bengaluru, India.

Abstract: This paper compares three distinct approaches to signal amplification and conditioning for piezoelectric sensors and light intensity measurement. The first approach addresses the challenge of amplifying weak charge signals from piezoelectric plates in shape detection, proposing a compact, high-integration charge amplifier circuit with strong anti-interference capabilities. This design, validated through Multisim simulations and actual tests, demonstrates good passband flatness and less than 2% theoretical error, highlighting its feasibility and reliability. The second approach presents a novel charge amplifier for piezoelectric sensors, particularly beneficial in quasi-static applications. By eliminating the need for extremely large resistors and utilizing a simple analog and linear feedback network with general-purpose JFET operational amplifiers, the proposed circuit significantly reduces output offset voltage and implementation costs. Experimental results show a low-cutoff frequency of 0.2 Hz and a gain of 20.5 dB, with a minimal output offset voltage and a relative error of 2.1%. The third approach evaluates different signal conditioning circuits for light intensity measurement using LDR and photodiode sensors. It emphasizes the importance of accurate light measurement for various applications and highlights the performance of instrumentation amplifiers for fixed lux ranges and active low-pass filters for variable lux ranges. This comparative analysis underscores the advancements in signal conditioning solutions tailored to specific applications, enhancing measurement accuracy and efficiency.

***Index Terms* – Signal conditioning, piezoelectric, simulation, low-level signals, filters.**

I. INTRODUCTION

The field of piezoelectric sensors has seen significant advancements in recent years due to their broad applications in various industries, including medical, automotive, and consumer electronics. Piezoelectric sensors convert mechanical stress into electrical signals, which are often weak and require effective amplification and conditioning for accurate measurement and analysis. However, existing methods face challenges in terms of integration, noise resistance, and cost-effectiveness. Recent studies have proposed various solutions to address these challenges. For instance, a high-integration charge amplifier circuit with strong anti-interference capabilities has been developed, demonstrating feasibility and reliability through simulations and practical tests. In the comparison of three papers, each addressing distinct aspects of measurement systems, several key differences and similarities emerge. In tackling the complex task of adjusting the delicate charge signal generated by piezoelectric plates during shape detection. Highlighting the limitations of traditional charge amplifying circuits, particularly their large size, the author has designed a compact, highly integrated, and robust charge signal amplifying circuit. This innovative circuit boasts enhanced anti-interference capabilities and cost-effectiveness. Comparative analyses between Multisim simulations and real circuit tests reveal superior flatness in the passband, with a theoretical error margin under 2% [1].

These advancements are particularly significant in fields like automotive, home appliances, and aerospace. Where aluminum's properties are critical, and the rolling process often leads to uneven residual stress distribution in sheets. The new design offers a more efficient and practical solution compared to bulky, inefficient conventional charge amplifiers. In contrast, the author goes into the specifics of charge amplifiers, or current integrators, which produce an output voltage proportional to the integrated value of the input current or total injected electrical charge [2]. These amplifiers are crucial in various measurement systems, including interfaces for piezoelectric sensors, indirect electric field strength measurements, and bio-signal measurements. To address the issue of output offset voltage caused by the input currents of operational amplifiers, the author suggests using JFET op-amps, which typically exhibit better performance in reducing this offset. The author focuses on the measurement of light intensity using different sensors, with a particular emphasis on light-dependent resistors (LDRs) and photodiodes. The author discusses the necessity of maintaining appropriate light levels for various applications, such as poultry housing, commercial greenhouses, TV cameras, and reading lights in bedrooms. LDRs, which change resistance based on light exposure, are highlighted for their sensitivity to light intensity and their varying resistance with light wavelength [3]. Despite their widespread use, LDRs are sometimes replaced by more advanced devices like photodiodes and photo-transistors due to their nonlinear characteristics and sensitivity variations. Collectively, these papers emphasize the importance of precise measurement and the technological advancements in charge amplifiers and light intensity sensors [1]-[3].

II. ANALYSIS AND DESIGN OF A WEAK CHARGE SIGNAL AMPLIFIER CIRCUIT

A. Charge signal amplification:

The signal, originating from charged particles traveling through a detector, is incredibly weak, almost lost in the ambient noise. To make this tiny signal discernible, the scientists employ a technique known as charge signal amplification. This process begins with the initial interaction of charged particles with a detector medium, which generates a small electrical pulse. However, this pulse is so minuscule that it would be impossible to measure directly with any degree of accuracy. Therefore, the signal must be amplified to be useful. The amplification process involves several stages, each ultra-carefully designed to enhance the signal while minimizing the introduction of additional noise. First, the initial electrical pulse is fed into a preamplifier, a sensitive device that boosts the signal without significantly distorting it. This is akin to turning up the volume on a quiet conversation without adding background static. Following the preamplifier, the signal may pass through a series of further amplifiers, each stage progressively increasing the signal strength. Along the way, filters may be employed to strip away any residual noise, ensuring that what emerges is a clear, strong representation of the original particle interaction. This amplified signal can then be processed and analyzed, revealing valuable information about the particle’s properties and, in the case of our scientist, potentially unlocking new secrets about the universe. Through this elegant dance of amplification, what begins as a barely detectable whisper becomes a powerful, understandable voice. The piezoelectric sensor must undergo impedance transformation, amplification, and filtering to ensure accuracy and reliability.

B. Charge conversion circuit:

In this setup, a charge source is configured in parallel with a capacitor to emulate the behavior of a piezoelectric sensor, connected to a charge conversion circuit. The charge conversion circuit, as described by the author [2], operates as amplifier (op-amp) and a well-insulated capacitor at its core. This design includes a feedback resistor and capacitor, both possessing high resistance values, which serve dual purposes: providing DC feedback to the circuit and mitigating zero drift. an integrative circuit featuring a high-gain operational amplifier.
The equivalent circuit can be visualized as an AC current source paralleled by a capacitor and resistor, all connected across the differential inputs of an op-amp. The negative feedback loop in this configuration consists of a feedback resistor and capacitor, functioning as a filter circuit. Notably, the

op-amp employed in this setup is a JFET, chosen for its advantageous properties in such applications [1].

In the face of the challenging task of adjusting the delicate charge signal produced by the piezoelectric plate during shape detection, the author confronts the drawbacks of typical charge amplifying circuits, particularly their large size. In response, the author innovatively designed a compact, high-integration, and robust charge signal amplifying circuit with enhanced anti-interference capabilities and improved cost-effectiveness. Emphasizing these improvements, the author conducted a comparative analysis between Multisim simulations and actual circuit tests, demonstrating superior flatness in the passband with a theoretical error margin of less than 2%. The significance of this advancement is underscored in various fields such as automotive, home appliances, and aerospace, where aluminum's exceptional properties make it a vital raw material. The rolling manufacture of aluminum plates often results in uneven residual stress distribution within the sheets. Compared to other well-known charge amplifiers available on the market, which are often bulky and inefficient in space utilization, the author's design offers a more efficient and practical solution.

C. Charge Signal Amplifying Design

The piezoelectric shape measuring roll is fundamental to the effective detection of aluminum materials using piezoelectric sensors. When a load is applied to the piezoelectric force sensor in a specific direction, it generates electrical charges within the piezoelectric material. These sensors are crucial for measuring non-electrical physical quantities such as acceleration, velocity, and force. During the measurement process, the tension within the aluminum plate is transformed into radial pressure by the direction roller, producing a very weak signal. Before this data can be acquired, the signal integral circuit, emphasizing its construction around a high-gain operational amplifier and a well-insulated capacitor at its core. To ensure proper functionality, the circuit incorporates a feedback resistor and capacitor with high resistance values, which are crucial for providing DC feedback and minimizing zero drift. Furthermore, the author delves into the foundational principles of the Miller effect and Kirchhoff's current law to elucidate the circuit's operation. When the charge generated by the piezoelectric sensor passes through this charge conversion circuit, the output voltage can be derived from these fundamental laws. The setup effectively converts the sensor's charge output into a usable voltage signal, with the JFET op-amp ensuring high input impedance and low noise, thus enhancing the accuracy and stability of the measurement [2].

D. Filter circuit design:

Designing an effective filter circuit is crucial in charge amplifiers to mitigate interference from external environmental noise, thereby enhancing the measurement accuracy of the system [1]. The appropriate filter design is essential following the charge conversion circuit to ensure that external noise is effectively filtered out. Filters can be classified into types such as Butterworth, Chebyshev, and Bessel based on their response characteristics. Among these, Butterworth filters are renowned for their maximum flatness, exhibiting no ripple in both the passband and stopband, earning them the nickname "maximum flat filters." The Sallen-Key topology is employed for designing active filters due to its high input impedance and the ease of configuring gain. Given that the signal generated by the piezoelectric sensor is a low-frequency signal, a stable passband is achieved by designing a bandpass filter composed of high-pass and low-pass filters in series. This configuration does not demand high-performance operational amplifiers; hence, a general-purpose op-amp, LF356N, is utilized in this study. The Butterworth filter is chosen for its optimal performance, and the circuit is structured in the Sallen-Key form with a gain set to 1. Demonstrating the practical implementation of these concepts to achieve a robust and effective filter circuit.

III. A NOVEL LOW OUTPUT OFFSET VOLTAGE CHARGE AMPLIFIER FOR PIEZOELECTRIC SENSORS

New design proves particularly advantageous in quasi-static applications. Traditional charge amplifiers in such applications typically require extremely large feedback resistors, often in the giga-ohm range. In contrast, the proposed amplifier eliminates the need for such large resistors, significantly reducing the output offset voltage compared to conventional designs. Additionally, this innovative circuit can be implemented using general-purpose JFET operational amplifiers instead of costly electrometer operational amplifiers, leading to a substantial reduction in implementation costs. The proposed charge amplifier was assembled using a general-purpose JFET op-amp to capture and amplify the output voltage from a Minisense100 piezoelectric vibration sensor. In the conducted experiments, the amplifier achieved a low-cutoff frequency of 0.2 Hz and gain of 20.5 dB. The output offset voltage was measured at 210 μV. Furthermore, the amplifier demonstrated a relative error of just 2.1% when measuring very small vibrations (±0.015g), compared to a reference vibration meter. This highlights the amplifier's precision and effectiveness in practical applications.

The frequency response of the modified prototype, illustrated in Fig. 12, highlights significant improvements in performance. When utilizing the LF411 op-amp, the output offset voltage of the prototype measured 210 μV, compared to 3.1 mV when the LF411 was replaced with the LF351. Experimental measurements of the output voltage noise revealed peak-to-peak values of 5.78 mV for the LF411 and 8.74 mV for the LF351. These findings underscore the effectiveness of the new proposed method for quasi-static applications. By modifying the conventional charge amplifier and incorporating bias-current compensation to achieve a low-cutoff frequency of 0.2 Hz, the circuit requires a feedback resistor of 27.5 GΩ. Additionally, to maintain a flat frequency response within the passband, resistors R1 and R2 in the bias current compensated charge amplifier must each be 80 MΩ. These high resistance values, however, lead to a substantial increase in the output DC offset voltage, reaching approximately 2 V and 12 mV, respectively. This experiment demonstrates the prototype's enhanced capability and practicality for quasi-static applications, offering a significant reduction in output offset voltage and noise, which are critical for precise measurements [2]. Here the author introduces a novel charge amplifier designed for piezoelectric sensors, aimed at significantly reducing output offset voltage, particularly in quasi-static applications [2]. This new design offers low output offset voltage and minimal offset temperature drift, presenting a notable structural advantage. Unlike conventional charge amplifiers and their variants, which require extremely large and costly resistors (in the range of giga-ohm's and tera-ohm's) for quasi-static applications, the proposed topology utilizes a straightforward analog and linear feedback network that can be constructed using general-purpose components. For experimental validation, the new charge amplifier was assembled using a general-purpose JFET op-amp. Comparative analysis between the conventional and proposed circuits revealed that the new amplifier exhibits a substantially lower output offset voltage in quasi-static applications. Moreover, achieving a similar low offset voltage with conventional charge amplifiers necessitates the use of expensive electrometer op-amps, making the new design more cost-effective for quasi-static applications. Consequently, the implementation cost of the charge amplifier is significantly reduced while maintaining superior performance [2].

IV. COMPARISON OF SIGNAL CONDITIONING CIRCUITS FOR LIGHT INTENSITY MEASUREMENT

Light is essential for our ability to see, perceive, and enjoy various forms of visual communication. Insufficient lighting can lead to several issues such as lack of interest, difficulty concentrating, drowsiness, and perceived laziness. Additionally, inadequate lighting can cause eyestrain, headaches, indigestion, and irritability. In residential homes, living rooms serve multiple purposes including relaxation, family entertainment, and social gatherings, each requiring different lighting techniques. Study rooms, where detailed visual tasks and skilled work are performed, also necessitate appropriate and sufficient lighting. Therefore, measuring light intensity is crucial to maintaining the required LUX levels for various environments. Using a light meter is the most accurate method for measuring light intensity at a specific location. Commercial light meters incorporate various signal conditioning circuits, and selecting the appropriate circuit is a key task for instrumentation engineers. This paper evaluates the performance of different signal conditioning circuits, focusing on their linearity, sensitivity, and accuracy [3].

The signal conditioning circuit utilizing an instrumentation amplifier is highly effective for resistive sensors like LDRs, RTDs, and strain gauges, which produce small resistance changes in response to variations in physical parameters such as light, temperature, or force [3]. One method to measure these resistance changes is to apply a constant current through the sensor and measure the resulting voltage output. An instrumentation amplifier, a specialized differential amplifier with input buffer amplifiers, eliminates the need for input impedance matching, making it ideal for measurement and test equipment. These amplifiers are characterized by very low DC offset, low drift, low noise, high open-loop gain, high common-mode rejection ratio, and high input impedances, making them essential for circuits requiring high accuracy and stability both in the short and long term.

The signal conditioning process involves manipulating an analog signal to meet the requirements for subsequent processing stages. In the study described changes in the LDR's resistance due to varying light intensity result in changes in the output voltage of a bridge circuit. This output is then amplified by the instrumentation amplifier connected to the bridge, producing a corresponding voltage variation. The experiment showed that by limiting the input voltage, the output voltage variation remains linear within a specific range. The instrumentation amplifier used in the project has a gain of 10, and the bridge circuit is highly sensitive, ensuring that the output voltage accurately reflects the sensitivity of the bridge. This setup highlights the effectiveness of instrumentation amplifiers in achieving precise signal conditioning for resistive sensors [3].

In conclusion, this paper presents a performance evaluation of two signal conditioning circuits for light intensity measurement, implemented using hardware circuits [3]. The findings indicate that for applications requiring high accuracy, linearity, and sensitivity within a fixed lux range, the Signal Conditioning Circuit using an Instrumentation Amplifier is superior to other circuits. However, if the requirement is to measure light intensity across a variable lux range, it is recommended to use a signal conditioning circuit incorporating an active low-pass filter. These insights guide the selection of appropriate signal conditioning circuits based on specific measurement needs.

V. CONCLUSION.

The comparative analysis of the three papers reveals distinct advancements in the fields of charge amplification and light intensity measurement, each tailored to specific applications and challenges. The development of a compact and cost-effective charge amplifier circuit using the LMC6081 precision CMOS operational amplifier and the general-purpose LF356 for filtering and sensitivity adjustments are highlights. This design offers stability and good passband flatness, effectively addressing the limitations of traditional charge amplifiers in terms of size and cost [1]. The introduction of a novel charge amplifier for piezoelectric sensors, focusing on reducing output offset voltage in quasi-static applications without relying on extremely large resistors. By utilizing a simple analog and linear feedback network with general-purpose JFET op-amps, the proposed circuit significantly lowers implementation costs while maintaining low offset voltage and temperature drift [2]. The evaluation of the performance of two signal conditioning circuits for light intensity measurement, concluding that instrumentation amplifiers offer superior accuracy, linearity, and sensitivity for fixed lux ranges, while active low-pass filters are recommended for variable lux ranges [3]. These studies collectively underscore the importance of tailored signal conditioning solutions in enhancing measurement accuracy and efficiency across various domains.

VI. REFERENCES

[1] Shaoliang wei and Qiang Shao "Analysis and Design of weak charge Signal amplifier Circuit" 2023 IEEE 6th Information Technology, Networking,Electronic and Automation Control Conference (ITNEC) DOI: 10.1109/ITNEC56291.2023.10082158

[2] Emad Alnasser "A Novel Low Output Offset Voltage Charge Amplifier for Piezoelectric Sensors ." 2020 IEEE Sensors Journal; DOI: 10.1109/JSEN.2020.2970839

[3] Nagaraju Duggirala, chede kireet "Comparison of Signal Conditioning Circuits For Light Intensity Measurement" DOI: 10.15449/wjes.2014.2007

[4] Daniel monagle, Eric A. Ponce, steven b Leeb "Rule the Joule: An energy management design guide for self powered sensors" IEEE Sensors Journal (Volume: 24, Issue: 1, 01 January 2024) DOI: 10.1109/JSEN.2023.3336529.

[5] J.Y. Yao, L, Yan, "Status and development of cold rolling production of aluminum sheet and foil and its process lubricants in China" Petroleum Products Application Research, vol. 39, issue 3, pp. 5-9, 202

[6] E. Alnasser, "A Novel Low Output Offset Voltage Charge Amplifier for Piezoelectric Sensors," IEEE Sensors Journal, vol. 20, issue. 10, pp. 5360-5367, May15, 2020

[7] Y.F. Ren, Y.Q. Wei, X.Z. Jia, "Design of a conditioning circuit for weak charge signals," Instrumentation Technology and Sensors, vol. 03, pp. 86-90,2019

[8] P. Giannelli, G. Calabrese, G. Frattini, M. Granato, and L. Capineri, "A buffered single-supply charge amplifier for high-impedance piezoelectric sensors," IEEE Trans. Instrum. Meas., vol. 68, no. 2, pp. 368–376, Feb. 2019.

[9] N. Aupetit, "Signal conditioning for shock sensors," STMicroelectronics, Geneva, Switzerland, Appl. Note AN4708, Aug. 2015.

[10] J. H. Huijsing, "Instrumentation Amplifiers: A Comparative Study on Behalf of Monolithic Integration", IEEE Transactions on Instrumentation and Measurement, Vol IM-25, No. 3, pp. 227-231, September 1976

[11] J. R. Riskin, A User's Guide to IC Instrumentation Amplifiers, Analog Devices, 1993