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Design of an Inline JFET Buffer for High-Impedance Piezoelectric Sensor Signal Conditioning

Purushottam Chawke[1], Divya Kalamkar[2]

[1]Assistant professor, Electronics and Telecommunication, G.H Raisoni college of Engineering and Management
[2]Student, Electronics and Telecommunication, G.H Raisoni College of Engineering and Management

Abstract
Accurate measurement of transient pressure signals during blast events is essential for analyzing structural response under extreme loading. Quartz-based piezoelectric sensors are widely used due to their high sensitivity and fast response; however, their inherently high output impedance leads to signal attenuation and distortion when interfaced directly with conventional data acquisition systems.
This paper presents the design and analysis of an inline JFET-based voltage follower for effective signal conditioning of piezoelectric sensors. A low-noise N-channel JFET (2SK209) is configured as a source follower to provide high input impedance and low output impedance, ensuring minimal signal loading and improved transmission through BNC interfaces. Multiple circuit configurations were implemented and experimentally evaluated to study the effects of biasing, stability, and impedance matching.
Results show that while JFET-based buffering preserves signal characteristics, proper biasing and interfacing are critical for achieving stable and detectable outputs. Supporting simulations validate the expected behavior of the proposed design. The study highlights key challenges in sensor interfacing and provides insights for improving reliable acquisition of high-frequency transient pressure signals.

Keywords: piezoelectric sensor, quartz sensor, JFET buffer, voltage follower, high input impedance, signal conditioning, impedance matching, data acquisition.

1. Introduction

Blast events are characterized by the rapid release of energy, resulting in the propagation of high-pressure shock waves through the surrounding medium. These shock waves produce sudden and significant variations in pressure, temperature, and density, which impose extreme dynamic loads on nearby structures. Understanding the behavior of structures under such conditions is essential for applications in defense, aerospace, and protective engineering. Among the various parameters involved, pressure is the most critical, as it directly governs the magnitude and distribution of forces acting on a structure.
Accurate measurement of blast-induced pressure is therefore fundamental to evaluating structural response and improving design methodologies. However, capturing such measurements is challenging due to the extremely short duration and high-frequency nature of the pressure transients. Conventional sensing and measurement systems often fail to accurately record these rapid variations, leading to incomplete or distorted data.

Piezoelectric pressure sensors, particularly quartz-based sensors, are widely employed in dynamic measurement applications due to their high sensitivity, fast response time, and stability. Despite these advantages, a major limitation arises from their inherently high output impedance. When interfaced directly with standard data acquisition systems, this can result in signal attenuation, distortion, and susceptibility to noise, especially during the critical positive pressure phase of a blast.
To address these challenges, appropriate signal conditioning techniques are required to ensure effective impedance matching and preservation of signal integrity. Among the available approaches, the use of field-effect transistor (FET)-based buffer circuits offers a practical solution due to their high input impedance and low noise characteristics. In particular, JFET-based voltage follower configurations are well suited for interfacing with high-impedance sources such as piezoelectric sensors.
In this work, an inline JFET-based buffer circuit is designed and analyzed for improving the acquisition of transient pressure signals from a piezoelectric sensor. The study focuses on evaluating different circuit configurations, understanding their limitations, and identifying key factors affecting signal transmission and detection. The objective is to develop an effective interfacing approach that enables reliable capture of blast-induced pressure signals for further analysis and application in structural safety and design.

2. Literature Review

Blast wave characterization and its interaction with structures have been extensively studied in both classical and modern literature. Foundational work such as Explosive Shocks in Air by Kinney and Graham [12] provides a comprehensive understanding of shock wave propagation, pressure–time profiles, and structural response. Standardized guidelines such as UFC 3-340-02 [13] further establish design principles for structures subjected to blast loading. Advanced studies have explored complex blast scenarios, including near-field pressure prediction using computational fluid dynamics [14] and experimental characterization in confined geometries [15]. Additionally, the effects of wave reflection, angle of incidence, and pressure amplification mechanisms have been investigated in [16], [17] and [18], contributing to a more realistic understanding of blast loading conditions.
Accurate measurement of blast-induced pressure remains a significant challenge due to the transient and high-frequency nature of shock waves. Recent research has focused on improving sensor systems, calibration techniques, and signal processing methods. For instance, enhanced measurement systems incorporating neural network-based approaches have been proposed in [2], while calibration methodologies based on bar pressure sensors are discussed in [3]. The importance of sensor calibration and transient response analysis has been further emphasized in [4], [7], and [8], where shock tube-based methods and dynamic calibration techniques are used to characterize high-frequency sensor behavior. Additionally, signal processing approaches for improving dynamic calibration accuracy have been presented in [9], highlighting the challenges associated with extracting reliable information from transient signals.
Piezoelectric sensors are widely used for dynamic pressure measurement due to their fast response, high sensitivity, and suitability for transient applications. Studies in [10] and [11] demonstrate their effectiveness in capturing high-frequency forces and shock wave loads. The response of sensors under transient and blast conditions has also been investigated in [6], providing insights into their behavior under extreme environments. Furthermore, advancements in sensor materials and fabrication techniques, such as screen-printed PVDF-based piezoelectric transducers, have been explored for unsteady pressure measurements [5], offering flexible and cost-effective alternatives.
Despite these advancements, a key limitation of piezoelectric sensors is their inherently high output im

pedance, which complicates direct interfacing with data acquisition systems. High-frequency transient signals are highly susceptible to attenuation, distortion, and noise due to impedance mismatch and transmission losses. While most existing research emphasizes sensor design, calibration, and signal processing, comparatively less attention has been given to front-end analog interfacing techniques for preserving signal integrity at the hardware level.

Field-effect transistors (FETs), particularly junction field-effect transistors (JFETs), provide a promising solution to this challenge due to their high input impedance and low noise characteristics. The fundamental operation and characteristics of JFETs are discussed in [1], highlighting their suitability for high-impedance signal interfacing. However, their application as inline buffer circuits for piezoelectric pressure sensing in high-frequency blast environments remains relatively underexplored.

Therefore, this work focuses on bridging this gap by investigating the design and implementation of a JFET-based inline voltage follower for effective signal conditioning. The study aims to enhance signal interfacing and transmission, enabling reliable acquisition of transient pressure signals in blast measurement applications.

3. System Architecture and Proposed Methodology

The objective of this work is to develop an effective signal acquisition system for measuring transient pressure generated during blast events using a piezoelectric sensor. Due to the high output impedance of the sensor and the high-frequency nature of the signal, a carefully designed interfacing architecture is required to ensure accurate and reliable data capture.

The overall system consists of four main stages: the piezoelectric pressure sensor, the inline JFET-based buffer circuit, the signal transmission interface, and the signal conditioning and data acquisition unit. The piezoelectric sensor acts as the primary sensing element, converting the applied dynamic pressure into an electrical charge signal. This signal, however, is characterized by very low amplitude and high output impedance, making it highly susceptible to loading effects and noise if directly connected to measurement systems.

To address this issue, an inline buffer stage is introduced immediately after the sensor. In this work, a JFET-based voltage follower configuration is proposed and implemented as the buffering element. The input signal from the sensor is applied to the gate terminal of the JFET, while the output is taken from the source terminal. Due to the reverse-biased gate junction, the JFET presents an extremely high input impedance, thereby minimizing loading on the sensor. Simultaneously, the source follower configuration provides a low output impedance, enabling efficient signal transfer to subsequent stages.

The buffered signal is then transmitted through a BNC cable to the signal conditioning unit. At this stage, proper impedance matching becomes critical to prevent signal reflections, attenuation, and distortion, particularly for high-frequency transient signals.

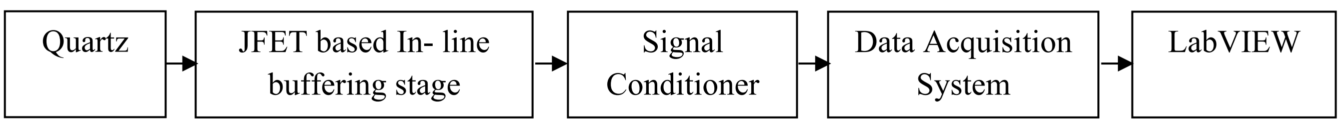

Figure 1: Block Diagram

The signal conditioning unit is responsible for further processing, scaling, and preparing the signal for acquisition by the data acquisition system. The final output is a pressure–time waveform that represents the transient behavior of the blast event. The proposed methodology involves iterative design and testing of multiple JFET-based circuit configurations to achieve stable operation and optimal signal transmission. Different biasing techniques, including self-biasing and voltage divider biasing, are explored to establish a suitable operating point for the JFET. Each configuration is experimentally evaluated based on parameters such as voltage levels, stability, and output detectability at the signal conditioning stage.

In addition to hardware implementation, simulation studies are carried out to validate the expected behaviour of the JFET buffer circuit and to analyze its response under transient input conditions. The combined approach of experimental analysis and simulation enables a comprehensive understanding of the system performance and helps in identifying limitations related to signal amplitude, impedance mismatch, and interfacing constraints.

Overall, the proposed architecture focuses on improving signal integrity at the front-end level, ensuring that the weak and high-frequency signals generated by the piezoelectric sensor are preserved and accurately transmitted to the measurement system. This approach is essential for reliable acquisition of transient pressure data in blast-related applications.

4. Design Approach and Circuit Implementation

The primary challenge in interfacing piezoelectric pressure sensors with measurement systems arises from their inherently high output impedance and low signal amplitude. Direct connection to data acquisition systems often leads to signal attenuation, distortion, and poor signal-to-noise ratio. To address this, a front-end buffering stage is required to preserve signal integrity while enabling efficient transmission.

In this work, a voltage follower (buffer) configuration is implemented using a Junction Field-Effect Transistor (JFET). Compared to conventional operational amplifier-based buffers, the JFET offers significant advantages for this application, including extremely high input impedance, low noise characteristics, and simpler biasing requirements. These properties make it well suited for handling high-frequency transient signals generated by piezoelectric sensors.

An N-channel JFET (2SK209) is selected as the core active device due to its suitability for low-noise, small-signal applications. The device is configured in a source follower topology, where the input signal is applied at the gate and the output is taken from the source. The drain is connected to the supply voltage, establishing the necessary current flow. In this configuration, the output voltage follows the input voltage with a small offset defined by the gate-to-source voltage, resulting in near-unity gain.

The key advantage of this configuration lies in its impedance transformation capability. The gate terminal draws negligible current due to reverse biasing of the PN junction, ensuring minimal loading on the sensor. At the same time, the source provides a low output impedance, allowing the signal to be transmitted effectively through BNC cables to the signal conditioning unit. This impedance matching is critical for preserving high-frequency signal components and minimizing transmission losses.

To achieve stable operation, appropriate biasing of the JFET is essential. Different biasing techniques were explored, including self-biasing using a source resistor and voltage divider biasing at the gate. The source resistor establishes a negative feedback mechanism, stabilizing the operating point by automatically adjusting the gate-to-source voltage based on the drain current. In improved configurations, a voltage divider network is introduced at the gate to provide a more defined biasing condition and enhance stability.

In addition to hardware implementation, simulation studies were carried out using LTSpice to validate

In addition to hardware implementation, simulation studies were carried out using LTSpice to validate the proposed circuit design. The simulated circuit consists of a JFET-based source follower configuration with appropriate biasing resistors and coupling capacitors to replicate practical operating conditions. A sinusoidal input signal, representing a low-amplitude transient signal from a piezoelectric sensor, is applied at the gate terminal.

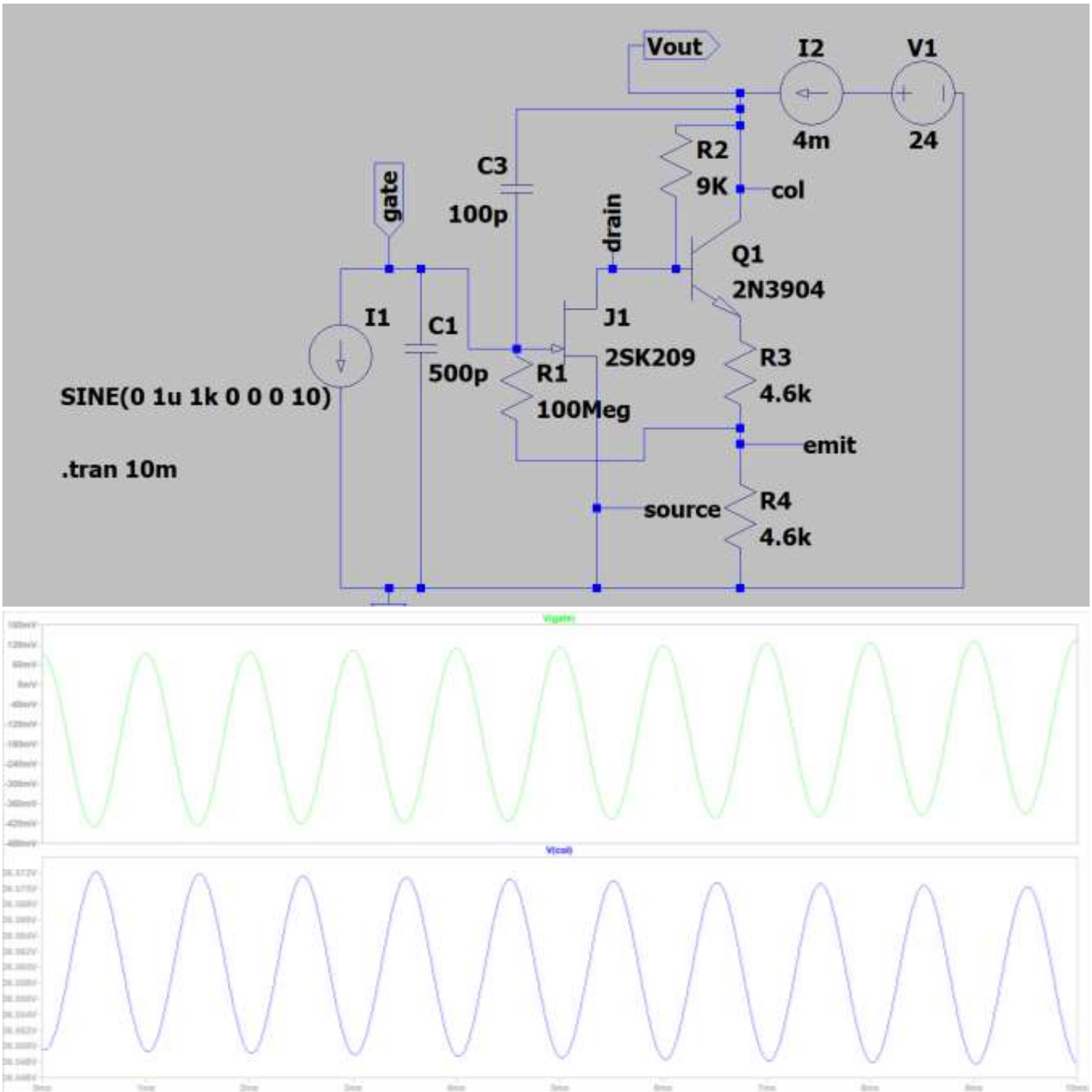

Figure 2: Circuit diagram implementation in Simulation with its waveforms

As shown in Figure 2, the upper waveform represents the input signal applied at the gate, while the lower waveform represents the output taken from the source terminal. It can be observed that the inverted output waveform closely follows the input signal with a consistent phase and waveform shape, confirming the expected operation of the voltage follower configuration.

A slight DC offset is observed in the output signal, which corresponds to the gate-to-source voltage (V_{GS}) of the JFET. This behavior is characteristic of source follower circuits, where the output voltage tracks the input with a small voltage drop. Importantly, no significant distortion or attenuation is observed, indicating that the circuit effectively preserves the signal characteristics.

The simulation also demonstrates that the circuit is capable of responding to rapid signal variations within the millisecond range, validating its suitability for high-frequency transient applications such as blast pressure measurement. The presence of coupling capacitors ensures proper AC signal transfer while maintaining biasing conditions, and the resistor network establishes a stable operating point for the JFET. These results confirm that the proposed JFET-based buffer circuit performs as expected under ideal conditions, providing high input impedance and effective signal tracking. When compared with experimental observations, where a measurable output was not consistently obtained, it can be inferred that the limitations are primarily due to practical factors such as extremely low sensor signal amplitude, impedance mismatches, and constraints of the signal conditioning unit, rather than deficiencies in the circuit design itself.

5. Results and Discussion

The performance of the proposed JFET-based voltage follower was evaluated using LTSpice simulation to verify its ability to buffer low-amplitude input signals. The simulation results, as shown in Figure X, include both the input signal applied at the gate terminal and the corresponding output obtained from the source terminal.

The input waveform is a sinusoidal signal with small amplitude, representing the output of a piezoelectric sensor. The output waveform closely follows the input signal in shape and frequency, confirming the expected operation of the source follower configuration. This indicates that the circuit successfully maintains signal integrity without introducing noticeable distortion.

A DC offset is observed in the output signal, which is consistent with the inherent behaviour of a JFET source follower. This offset corresponds to the gate-to-source voltage (V_{GS}), resulting in the output being slightly lower than the input signal. Despite this offset, the waveform tracking remains accurate, demonstrating near-unity gain performance.

Additionally, the simulation shows that the circuit responds effectively to rapid signal variations, indicating its suitability for high-frequency transient applications. The high input impedance of the JFET ensures minimal loading on the input source, while the low output impedance enables efficient signal transfer.

Overall, the simulation results validate the theoretical design of the JFET-based buffer circuit, confirming its capability to preserve and transmit low-amplitude signals with minimal distortion. These findings support its application in interfacing high-impedance sensors such as piezoelectric pressure sensors for transient signal measurement.

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