High Bandwidth Differential Amplifier for Shock Experiments

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Introduction and Motivation

We developed a high bandwidth differential amplifier for gas gun shock experiments/applications. The circuit has a bandwidth > 1 GHz, and is capable of measuring signals of $\leq 1.5V$ with a common mode rejection of 250V. Conductivity measurements of gas gun targets are measured by flowing high currents through the targets. The voltage is measured across the target using a technique similar to a four-point probe. Because of the design of the current source and load, the target voltage is approximately 250V relative to ground. Since the expected voltage change in the target is < 1V, the differential amplifier must have a large common mode rejection. High pass filters suppress internal ringing of operational amplifiers. Results of bench tests are shown.

Motivations for Electrical Conductivity Experiments

- Electrical conductivity a function of pressure.
- Bulk property of material
- Transport property of materials (Useful for studying planetary interiors, modeling dynamo)
- Useful for observing phase changes (some materials change electrical conductivity with phase change)
- Electrical conductivity in free electron metals is directly proportional to thermal conductivity, according to the Wiedemann-Franz Law

$$\frac{\kappa}{\sigma} = LT$$

where κ is the thermal conductivity, σ is the electrical conductivity, and T is the temperature in Kelvin. L is the proportionality constant known as the Lorenz number, equal to $2.44 \times 10^{-8} W\Omega K^{-2}$.

Determining Conductivity from a Differential Amplifier

If the current (I) through a rectangular sample is known (as in a 4 point probe measurement), the conductivity is calculated by

$$\sigma = G \frac{\ell}{A}$$

where σ is the conductivity, ℓ is the length of the sample, G is the conductance, V is the voltage, and A is the cross-sectional area of the sample. The conductance (G) is the inverse of the resistance (R)

$$G = \frac{1}{R} = \frac{I}{V}$$

and the conductivity σ is then calculated as

$$\sigma = \frac{I\ell}{VA}$$

If the sample is not rectangular, the conductivity σ is calculated as

$$\sigma = C_1 \frac{I}{V}$$

where C_1 is a constant of the shape and can be calculated by electromagnetic wave codes.

Experimental Setup

Figure 1. Two-Stage Gas Gun*

Figure 3. Experimental Setup for Conductivity Experiments*

Figure 2. Shock wave in the target*

Figure 1 shows a two-stage gas gun used in shock experiments. The gas gun propels an impactor to the target. When the impactor hits the target, it sends a shock wave into the target. Based on the design of the impactor and target, the shock wave reverberates through the target, causing a rapid increase in pressure (Figure 2). The electrical conductivity, which is a function of pressure, is measured by supplying a steady current through the sample. The voltage over the sample is measured using the differential amplifier (Figure 3).

*adapted from Ref. [3]

Amplifier Design

Circuit Design Must Meet Needs for High Speed Gas Gun Shock

- The High Explosives Application Facility (HEAF) at LLNL operates a 2-stage gas gun for shock experiments
 - Shock time: 10's of ns
 - Shock pressures >1 Mbar
- Differential voltage measurement required
- Circuit Capabilities:
 - Response speed: 10 ns
 - Bandwidth: up to 500 MHz
 - Gain: 1-4
 - Input Voltage Requirements: Full differential input
 - Input Voltage Differential: 50-100 mV
 - Input "DC" Voltage: 250 V
 - Output Voltage: 25-1000 mV
 - Must be able to withstand significant EMP

Figure 4. Image of the Two-Stage Gas Gun at HEAF at LLNL

Figure 5. Block diagram of the differential amplifier. First, the common mode voltage is stripped off, allowing for the differential voltage to be measured. If necessary the signal is amplified, although that reduces the bandwidth of the differential amplifier. (See Figure 6.)

Figure 6. The Op-Amps used in the differential amplifier have a gain-bandwidth product of 1600 MHz. The highest bandwidth is achieved with a gain of 1, with the bandwidth inversely proportional to the gain.

Bench Test Setup

Figure 7. Block diagram of the impulse response bench test. The signal from a pulsar was split 50/50. One leg was then split again, with 20% of the signal used to signal the scope. The resulting differential is 10% of the initial voltage of the pulse.

Figure 8. Photo of Bench Test Setup

Figure 9. Block diagram of DC response bench test. Two high voltage power supplies are used to demonstrate the ability of the differential amplifier's ability to reject the common mode voltage.

Bench Test Results

Bench test results show 10 ns and 50 mV pulses are detectable

Figure 10. The differential amplifier is able to detect a 10 ns wide pulse. The second peak in the trigger trace is due to reflections from the high impedance of the amplifier input and does not appear in the amplifier trace. Periodic oscillation is one of the characteristics of the Op-Amp based on the gain-bandwidth product.

Figure 11. The differential amplifier is able to detect a 50 mV signal with a 50 ns pulse width. Improvements in the board design should permit us to improve the detection level.

Circuit tested at 30 V shows good Common Mode Rejection

Figure 12. Temporal Resolution of Differential Amplifier

Figure 13. The circuit is able to linearly track the differential even with a large common mode voltage input (>30V).

Conclusion and Future Work

The differential amplifier meets most of the specifications required for the gas gun electrical conductivity experiments. Further improvements in the circuit manufacture, as well as the use of surface mount components, should reduce the noise level of the circuit, which will improve the detectable signal level. The circuit will also be powered by batteries, which should make it resistant to the EMP of the gas gun. This will be tested in ride-along experiments on the gas gun.

Future Work

- Test the circuit at higher voltages (>250 V).
- Perform a full scale bench test with a dummy load (no dynamic change in conductivity).
- Implement the amplification stage to increase the gain (present design is set for gain=1).
- Measure the bandwidth for various amplifications.

References

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Poster Information

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