Design of a Single Power Supply Op-Amp Circuit for the Photodiode Readout of the Electron Ion Collider's Detection of Internal Reflected Light Detector

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This note discusses the design and test results for a single power supply version of the Electron Ion Collider's (EIC) Detection of Internal Reflected Light (DIRC) Detector.

A transimpedance amplifier (op-amp) circuit, combined with a low-pass RC filter, to convert the current response of the photodiodes to 0–5 V DC has been designed [1]. Previous design and simulation used an ideal op-amp in the circuit for ease of simulation. However, real op-amps require power supplies that also act as references for the op-amp's output. Typically, a positive and negative power supply with an output of about ±12 V DC is used. For applications where only positive voltage output signals are expected (as with the EIC DIRC photodiode readout), the circuit can be modified to use only one positive power supply.

Changing the circuit to use only one +12 V DC power supply reduces the hazard class of the circuit's enclosure to the lowest hazard class, class 1, since typically, the positive and negative voltage come from a single 120 V AC to ±12 V DC converter, which would make the circuit enclosure a class 2 hazard. While a class 1 hazard level can be achieved with separate +12 V DC and -12 V DC wall-mounted power supplies, using only one +12 V DC supply enables reducing the necessary size of the enclosure used to house the circuit board.

When a single power supply is used (positive voltage reference input connected to +12 V DC and the negative voltage reference input connected to ground, or 0 V), with no current input, the output will settle close to 0 V, but never actually reach zero. This situation will cause the op-amp output to become saturated as the op-amp will try to drive its output to 0 V, but will be unable to do so because its negative voltage reference input is ground. When this happens, the op-amp's response to a change in the input current will be delayed, causing the output voltage to behave like the voltage drop over a charging capacitor. This undesirable behavior can be prevented by biasing the op-amp, connecting its non-inverting input to a low, millivolt-level voltage source.

For the EIC DIRC circuit design, Fig. 1, this is done by using a potentiometer as a voltage divider. With this configuration, the wiper terminal of the potentiometer is connected to the op-amp's non-inverting input and the +12 V DC and ground connected to the other two terminals. Using a potentiometer instead of fixed-value resistors has the advantage of allowing the bias voltage to be tuned.

The downside to using a single-supply configuration for the op-amp is that when there is no current input, the output signal will be offset by the voltage seen at the device's non-inverting input. Fortunately, this offset is easily accounted since it can be measured and tuned precisely using the potentiometer.

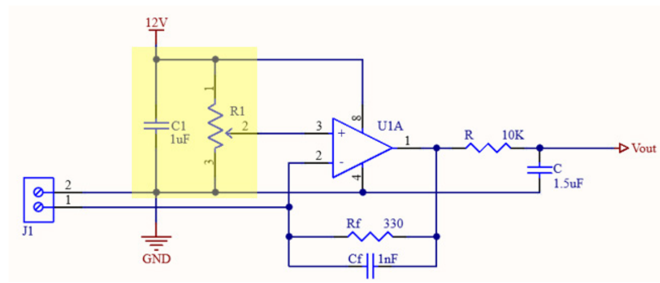

FIG. 1. Single-supply, op-amp configuration for the EIC DIRC photodiode readout circuit. The yellow portion sets the voltage at the non-inverting input of the op-amp, R1 is a potentiometer, C1 is a power-decoupling capacitor to filter out power supply instability.

For the EIC DIRC photodiode readout circuit, the maximum expected current from the photodiode is 15 mA, which induces a 4.95 V output from the op-amp [1]. With these expected values, the voltage at the non-inverting op-amp input will be set to 50 mV using the potentiometer voltage divider, resulting in an output of 50 mV with 0 mA input current and an output of 5 V with 15 mA input current.

Once the circuit was designed and tested in software, the circuit was breadboarded, Fig. 2. For this physical circuit, a 1.8-MΩ potentiometer was used for R1. To test the circuit, a current was provided by a Krohn-Hite Model 523 Precision DC source and measured for verification by a Keithley 6517B electrometer; the output of the op-amp was measured also using a Keithley 6517B electrometer. For the test, the current was increased from 0 mA to 15 mA in 1 mA steps and a measurement taken of the corresponding output voltage. Test results are shown in Fig. 3.

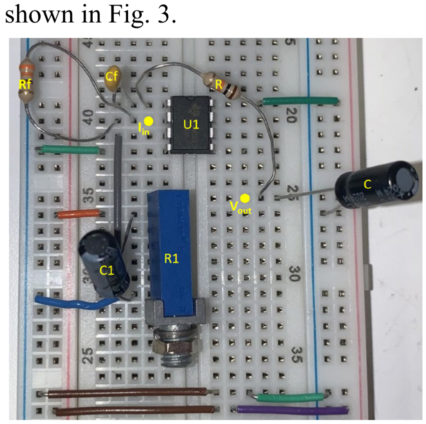

FIG. 2. Photo of op-amp circuit breadboard. Labeled parts match Fig. 1. Yellow dots note where input current I_{in} was supplied and output voltage V_{out} was read.

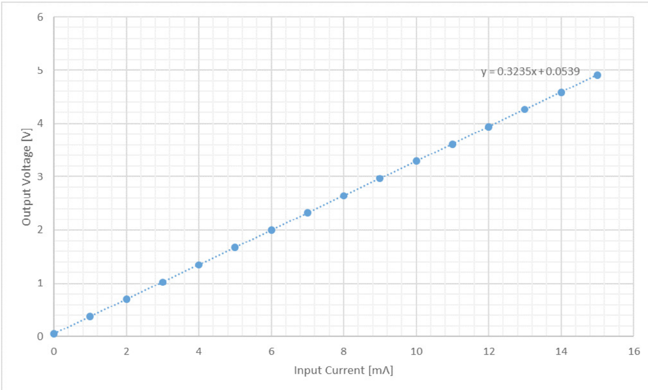

FIG. 3. Plot of test results. The dashed, blue line is a linear fit of the data points with the equation displayed on the plot.

In summary, a single power supply version of the op-amp circuit that will be used in the EIC DIRC laser acceptance tests was designed and prototyped. A single-supply version of the circuit will be used rather than the typical dual power supply version to allow the circuit's enclosure to be the lowest hazard class possible and to reduce the number of external power supplies required for the circuit. When the circuit was prototyped on a breadboard, it behaved as expected and converted the 0–15 mA input current to a 0–5 V voltage, matching the design specifications previously determined.

[1] T. Lemon, et al., *Design and Simulation of the Photodiode Readout Circuit for the Quartz Bar Acceptance Tests for the Electron-Ion Collider's Detection of Internally Reflected Cherenkov Light Detector*, DSG Note 2023-14, 2023.