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

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A laser test station has been built [1] for the acceptance test of the quartz crystals for the Detection of Internally Reflected Cherenkov light (DIRC) detector of the Electron-Ion Collider (EIC). This note discusses the circuit developed to measure the photodiode current response, which quantifies the reflectivity of the crystals.

The acceptance test for the EIC-DIRC detector's quartz bars will aid selection of bars whose reflectivity of the laser light that traversed through the bar is greater than 99%.

For the test, Thorlabs SM1PD2A photodiodes—key specifications are listed in Table I—will be used to quantify the laser beam power before and after passing through the quartz bar. The photodiode's current response to the laser light will be converted to a voltage in the 0–5 V range by a transimpedance operation amplifier (op-amp), and then measured using the ADS1115 analog digital converter (ADC).

	Parameter	Symbol	Value
325-nm Wavelength	photodiode responsivity	R_{325}	0.15 A/W
	laser power	P_{325}	14 mW
	maximum I expected ($I_{325} = R_{325} \times P_{325}$)	I_{325}	2.1 mA
442-nm Wavelength	photodiode responsivity	R_{442}	0.25 A/W
	laser power	P_{442}	44 mW
	maximum I expected ($I_{442} = R_{442} \times P_{442}$)	I_{442}	11 mA
Combined wavelength	maximum I considered ($I_{total} = I_{325} + I_{442}$ + safety margin)	I_{total}	15 mA

TABLE I. Specifications and parameters for test station photodiode and laser.

The advantages of using an op-amp are that the input impedance from the photodiode does not affect the op-amp's voltage output because the two inputs of the op-amp are virtually shorted to ground and the ADC after the op-amp does not affect the current-to-voltage conversion because the op-amp output is isolated from its input.

The input portion of the circuit, Fig. 1, models the photodiode characteristics with an ideal current source and an ideal diode. The photodiode's junction impedance is modeled by a 1.75-nF capacitor and a 20-MΩ resistor. All components are in parallel and connected to the op-amp with appropriately sized feedback resistor R_f and feedback capacitor C_f.

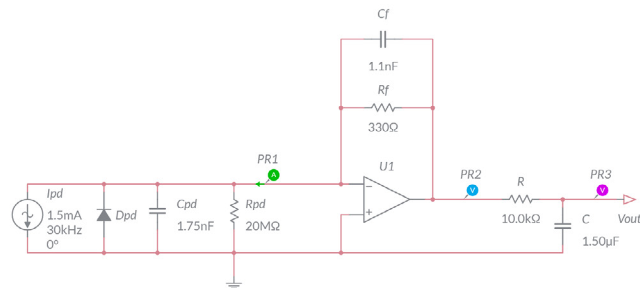

FIG. 1. Op-amp circuit schematic used in Multisim Live to simulate and verify the circuit behavior. PR1, PR2, and PR3 indicate locations of Multisim Live simulation probes.

To achieve the desired gain, R_f is determined using

$$R_f = (V_{out\ max} - V_{out\ min})/I_{total} \tag{1}$$

for $V_{out\ max} = 5$ V, $V_{out\ min} = 0$ V, and $I_{total} = 15$ mA, $R_f = 330\ \Omega$.

The value of C_f to stabilize the op-amp output is determined using

$$C_f \leq \sqrt{((C_{cm} + C_{Diff} + C_{pd})/(2\pi R_f B))} \tag{2}$$

Substituting the values of C_{cm}, C_{Diff}, C_{pd}, and B from Table II, and $R_f = 330\ \Omega$, Eq. 2 gives $C_f = 1.1$ nF.

Parameter	Symbol	Value
Common-mode capacitance	C_{cm}	1.5 pF
Differential capacitance	C_{Diff}	0.1 pF
Photo diode capacitance	C_{pd}	1.75 nF
Gain bandwidth product	B	700 kHz

TABLE II. Parameters of the LM358P op-amp selected for the EIC-DIRC photodiode readout circuit.

To reduce the effects of noise in the laser power—specified by the manufacturer to be ±10% of the laser's output power and to have a lower frequency limit f of 30 KHz—at the output to be less than 180 µV, the resolution of the ADC, a low-pass filter is implemented.

The laser power varying by ±10% as specified corresponds to a 0.495 V peak noise in the transimpedance amplifier voltage output. For the low-pass filter using V_{in} = 0.495 V, V_{out} = 180 µV, f = 30 KHz, and R = 10 kΩ,

$$C \leq (\sqrt{((V_{in})^2 - (V_{out})^2)})/(2\pi V_{out} f R) \quad (3)$$

gives for the low-pass filter's capacitor C 1.5 µF.

Figure 2 is Multisim Live simulation's current response of the circuit with all photodiode characteristics taken into consideration and modeled with the 1.5-mA, 30-kHz noise and the 15-mA maximum current.

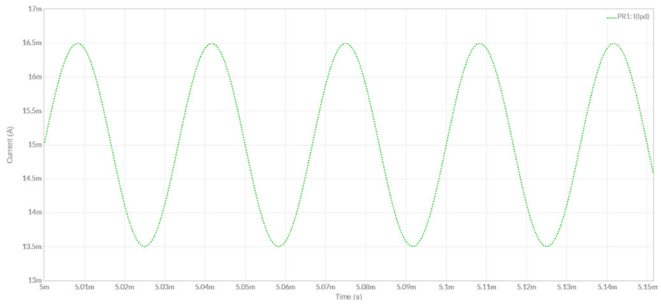

FIG. 2. Current output from the photodiode model, including the noise in the laser's power measured at PR1 (Fig. 1).

Figure 3 shows Multisim Live simulation's voltage outputs after the op-amp (blue line) and after the low-pass RC filter (pink line).

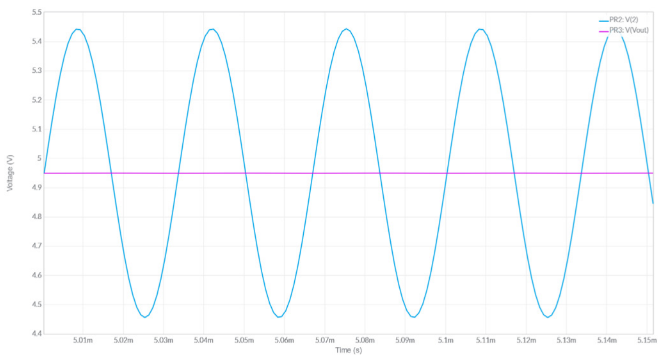

FIG. 3. Plot of the unfiltered voltage output of the op-amp (blue) measured at PR2 (Fig. 1) and the output of the low-pass RC filter (pink) measured at PR3 (Fig. 1). The oscillation on the pink line cannot be seen as it is about four orders of magnitude smaller than 4.95 V.

The output voltage of the op-amp has an oscillation with a peak amplitude of ~500 mV around the 4.95-V offset (blue line in Fig. 3), indicating the noise at the input is passed to the output voltage, however the amplitude of the noise is reduced to less than 180 µV by the RC filter. The phase shift between the op-amp's input current and the voltage output of the low-pass filter is not necessary to be considered, as this happens to the noise signal.

In summary, to read the photodiode current response induced by the reflected laser light, an op-amp circuit with an RC filter was designed. The circuit was modeled and simulated in Multisim Live, verifying its ability to convert the photodiode current in the 0–15 mA range to a voltage signal in the 0–5 V range.

[1] T. Lemon, et al., *Design and Features of the EIC-DIRC Laser Lab's Laser Interlock System*, DSG Note 2023-01, 2023.