

Optically Isolated Current-to-Voltage Converter for an Electron Optics System

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A simple, inexpensive, optically isolated current-to-voltage converter circuit has been developed for the measurement of bipolar currents in the range of 10 pA to 1 μ A on the biased elements of an electron optics system at voltages up to 3.5 kV. The design takes advantage of low-leakage, low-power CMOS operational amplifiers as well as linear optocouplers to create a low-noise battery-powered front end with an expected battery life of 3 years using a single 9 V lithium battery.

A common problem in electron optics is the measurement of low-level currents on optical elements that are biased in the range of hundreds to thousands of volts. When steering and focusing a charged particle beam, it is often necessary to monitor currents on several system elements sequentially as the beam transmission is optimized by adjustment of electrode voltages. This is the case with our Scanning Electron Microscope with Polarization Analysis (SEMPA) electron optics, where eight separate aperture currents are monitored during alignment.¹ Historically, the ammeter function of a commercial battery-powered electrometer has been used for this measurement. Tuning requires that the electrometer be connected to each aperture in turn; a laborious and time consuming task since the bias voltages must be turned off during each connection change. A scheme for switching the currents through the electrometer was considered but this would have required the fabrication of a custom mechanical switch to maintain leakage currents at an acceptable level. Space and cost constraints prevented us from using a separate electrometer for each aperture. Instead, we developed a small, low-cost, single channel optically isolated current-to-voltage (I/V) converter board. Eight of these boards are used in a dedicated aperture current monitoring system. The boards accommodate bipolar currents in the range of 1 nA to 350 nA, with bias voltages up to 1500 V. In order to maintain low noise operation, battery power is favored over DC-DC converter power for the circuit's front end. To achieve acceptable battery life the low power front end uses CMOS operational amplifiers and linear optocouplers.

Figure 1 shows a simplified schematic of the optically isolated current-to-voltage converter. The circuit's input reference level is established by V_{bias} which sets the electrode potential through the input op-amp. The central components of the circuit are two linear optocouplers.² Each optocoupler contains a Light Emitting Diode (LED) whose light output impinges upon an input photodiode and an identical, electrically isolated, output photodiode. The purpose of the input photodiode is to provide a feedback current that is proportional to the LED's output flux. This feedback signal is used in an op-amp servo loop to linearize the LED's output flux and stabilize it against variations with time and temperature. The servoing action causes the input photodiode current to exactly equal the input current, I_{in} . The LED illumination also generates an identical "mirror" current³, I_{out} , in the output photodiode. I_{out} is converted to a voltage on the ground referenced side of the circuit by the output op-amp. Bipolar capability is

provided by operating the input op-amp at ± 4.5 V and using a matched pair of optocouplers. The LEDs and photodiodes of the optocouplers are connected in an antiparallel configuration, so that negative input currents activate the LED in the lower optocoupler in figure 1 and positive input currents activate the LED in the upper device.⁴ To maintain isolation, the input and output op-amps are operated from separate sources of power. A 9 V battery, in conjunction with an active polarity splitter (not shown), powers the input op-amp and a ± 15 V power supply powers the output op-amp. The optocoupler has an input to output isolation rating of 3500 V. The LED-Dual-Photodiode current mirror technique has been used in at least two commercial isolation amplifiers.⁵ The type of linear optocoupler used here allows one to build custom isolation circuits by making available only the essential isolation elements without the input and output circuitry normally found in an isolation amplifier.

The current mirror is usable over an input range of 10 pA to 300 μ A. The low end of the input range is limited by photodiode dark current which is held to less than 10 pA by the zero volt bias inherent in the inverting op-amp configuration. The high end of the input range is limited by the maximum allowable LED current of 60 mA. Since our application measures currents of 350 nA or less we limited the LED current to 100 μ A, and the input current range to ± 1 μ A. The error in the circuit's current to voltage conversion is $\pm 1\%$ for input currents between 1 nA and 1 μ A, and 10% for input currents between 100 pA and 1 nA. Operating the LED at 100 μ A maximizes battery life, but comes at the expense of bandwidth. At these currents the optocouplers have a 3 dB bandwidth of 2 kHz, whereas at a LED current of 10 mA and photodiode current of 100 μ A the device is specified to have a bandwidth of 200 kHz. In our application the bandwidth is further limited to a few hertz since tuning is done manually and the output signals are displayed on an analog meter.

The basic current mirror scheme is expanded in the final design to include output stage I/V converter gain switching and remote offset voltage adjustment. The converters are coupled to the electron optics using coaxial cables with grounded shields in a "high-low" connection scheme, i.e "high" to the electrode and "low" to the bias voltage, V_{bias} . In this configuration the circuit sinks or sources all of the electron optic element's current. The dual CMOS op-amp used

in the front end features low input bias current (10 fA) and requires only $32 \mu\text{A}$ of power supply current.⁶ One of the two op-amps in the package is used to servo the LED currents. The op-amp inputs are protected from electrical discharge damage by low leakage clamping diodes⁷ and current-limiting resistors. The second op-amp (not shown) is used in a polarity splitter configuration to create the $\pm 4.5 \text{ V}$ power required for bipolar operation from a single 9 V lithium battery.⁸ Long battery life is assured by low LED currents, low op-amp power requirements, and the use of a transistor output optocoupler (not shown) which disconnects the battery from the circuit whenever the system power is turned off. Battery protection is provided by an automatic resetting 100 mA fuse.⁹ Each of the eight boards has a separate front panel offset trimmer to cancel any errors caused by cable leakage, and the output I/V converter gain for each board is selected as either 10 mV/nA or 100 mV/nA by a front panel toggle switch. The final output voltages are monitored by an analog meter with built-in range switching down to 10 mV full scale.¹⁰

The optically isolated current-to-voltage converter boards have performed reliably and have been effective in making the SEMPA optics much easier to tune. The combination of small size (92 mm x 165 mm) and self powered front end also make the design useful for other charged particle optics systems. In addition, the electrometer outputs could be easily read into a computer using A/D converters, and these signals could be used as the basis of a computer controlled automatic tuning system.

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¹ M.R. Scheinfein, J. Unguris, M.H. Kelley, D.T. Pierce, and R.J. Celotta, Rev. Sci. Instrum. **61**(10), 2501 (1990).

² Part number IL300 Linear Optocoupler, Siemens Components, Inc., Optoelectronics Division, 19000 Homestead Road, Cupertino, CA 95014

³ I_{out} is actually equal to the input photodiode current multiplied by the device's transfer gain which may vary between 0.56 and 1.61. The parts are sorted and labeled with a code that indicates their transfer gain in a +/-5% bin.

⁴ "Designing Linear Amplifiers Using the IL300 Optocoupler" Appnote 50 by Bob Krause, Siemens Components, Inc., Optoelectronics Division, 19000 Homestead Road, Cupertino, CA 95014

⁵ Part numbers 3650, ISO100 Optically-Coupled Linear Isolation Amplifier, Burr-Brown Corporation, P.O. Box 11400, Tucson, AZ 85734-1400

⁶ Part number LMC6062AIN, Precision CMOS Dual Micropower Operational Amplifier, National Semiconductor Corporation, P.O. Box 58090, Santa Clara, CA 95052-8090

⁷ Part number PAD1, Low-Leakage Pico-Amp Diode, Siliconix, P.O. Box 54951, Santa Clara, CA 95056

⁸ Lithium 9-Volt "Transistor" Battery, Ultralife Batteries Inc., 19 Fairfield Place, West Caldwell, NJ 07006

⁹ Part number RXE010 PolySwitch, Raychem Corporation, PolySwitch Division, 300 Constitution Drive, Menlo Park, CA 94025-1164

¹⁰ Model number PM-502B DC Millivoltmeter, Millivac Instruments, Inc., P.O. Box 997, Schenectady, NY 12301-0997

Figure Captions

Figure 1. Simplified schematic of the optically isolated current to voltage converter

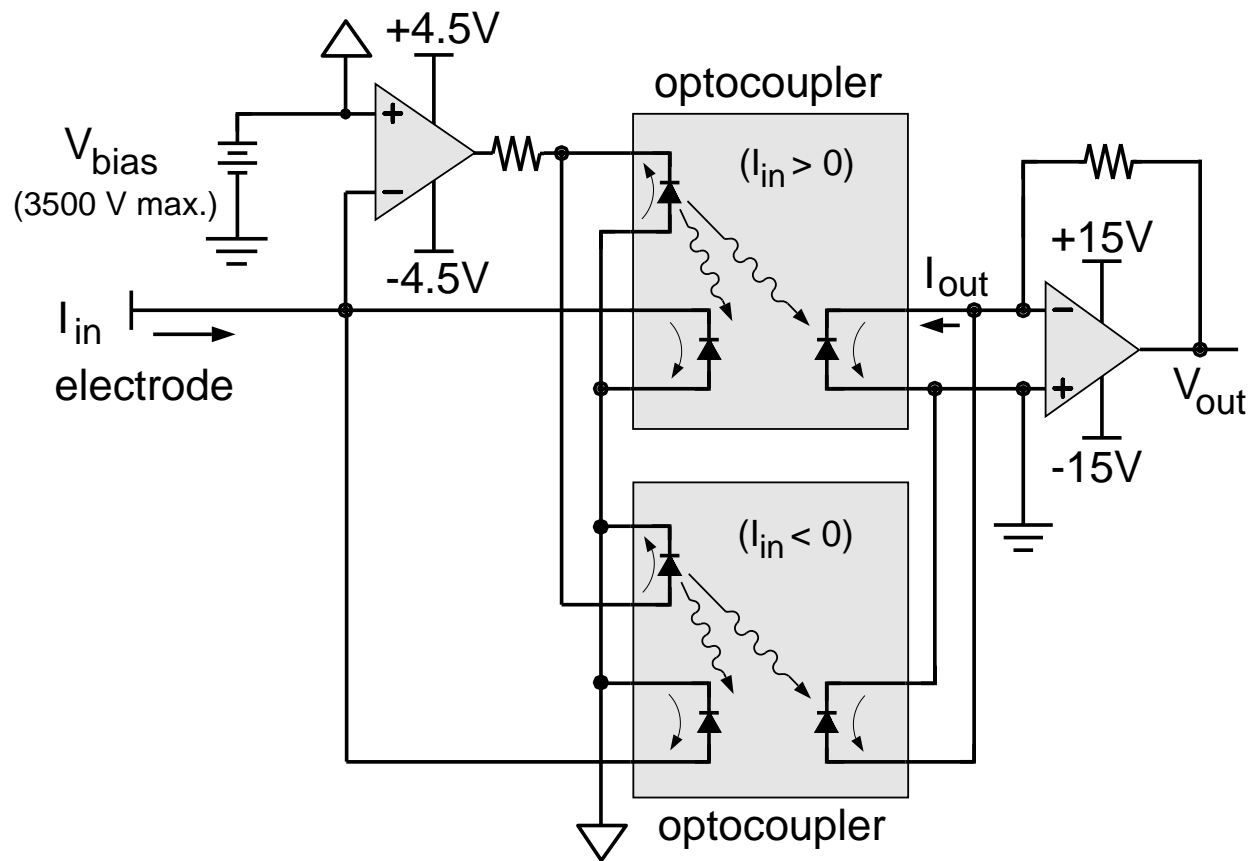


Figure 1