A SIMPLE LOW-COST PHOTODIODE RADIATION DETECTOR FOR MONITORING IN PROCESS PET RADIOCHEMISTRY

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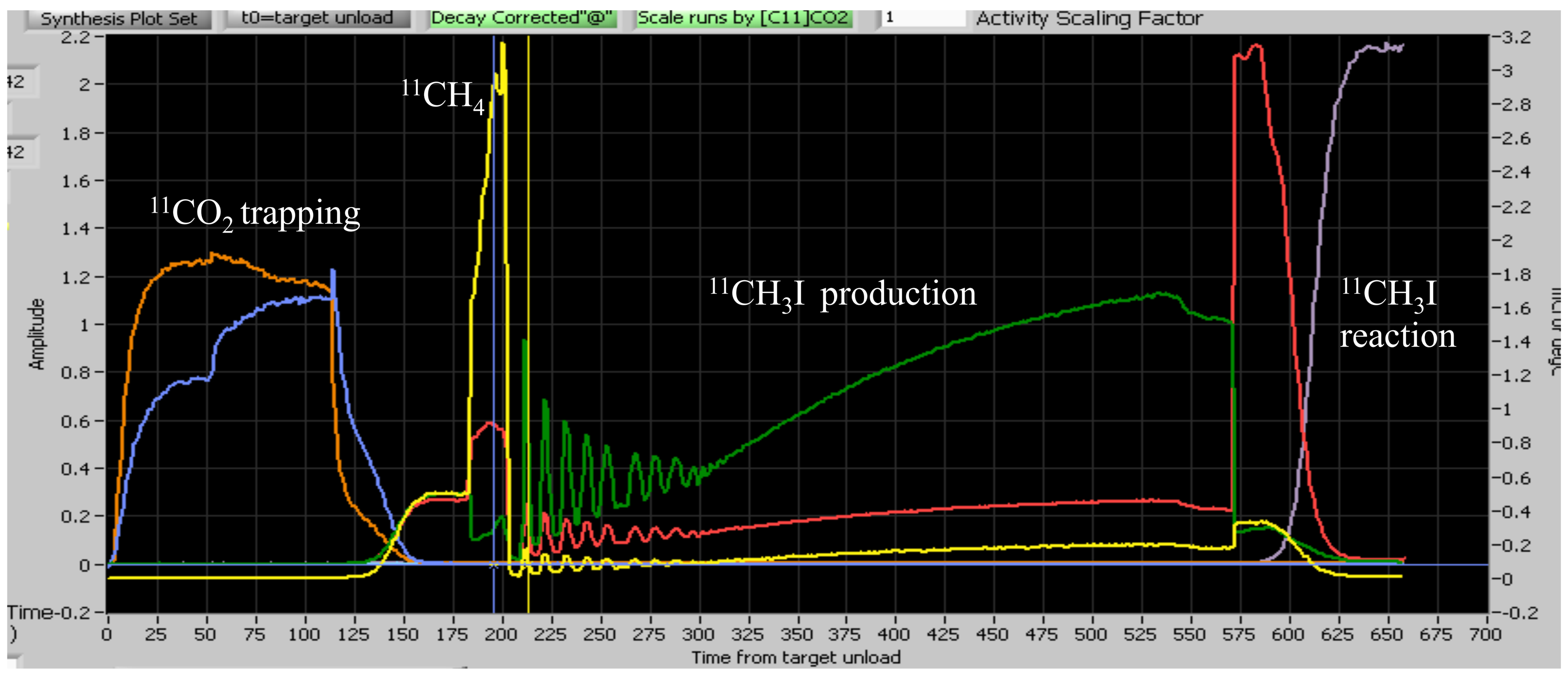
Introduction

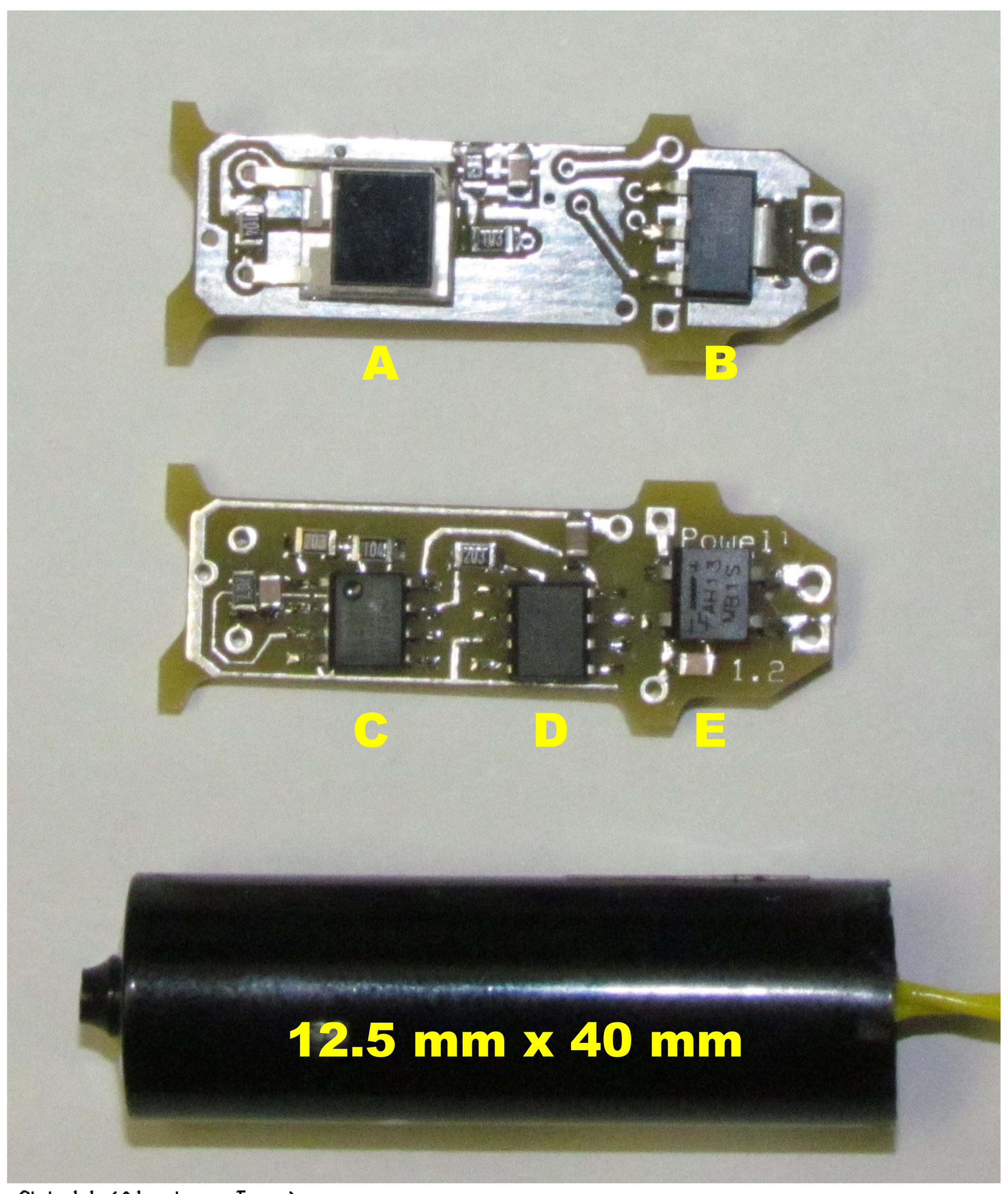
We have found that placing radiation detectors throughout our radiochemistry synthesis rigs is advantageous for determining the progress of radioisotopes through the system, delineating thresholds and triggering steps in a sequence, monitoring radiochromatographic separations, providing process feedback and adjustment, and determining maintenance needs, in addition to troubleshooting. In our carbon-11 synthesis module we monitor no less than nine radiation detectors during a typical synthesis[1]. Often we find that the more points of feedback we have the better we are able to maintain high and consistent yields and overall system reliability. Photodiodes are routinely used as inexpensive and compact radiation detectors for work in radiochemistry[2,3]. However, additional issues arise if the detectors are not simple to use and easily wired up for low-noise operation. In addition, it is important that detectors are insensitive to temperature fluctuations, given their nearness to chemical reaction vessels.



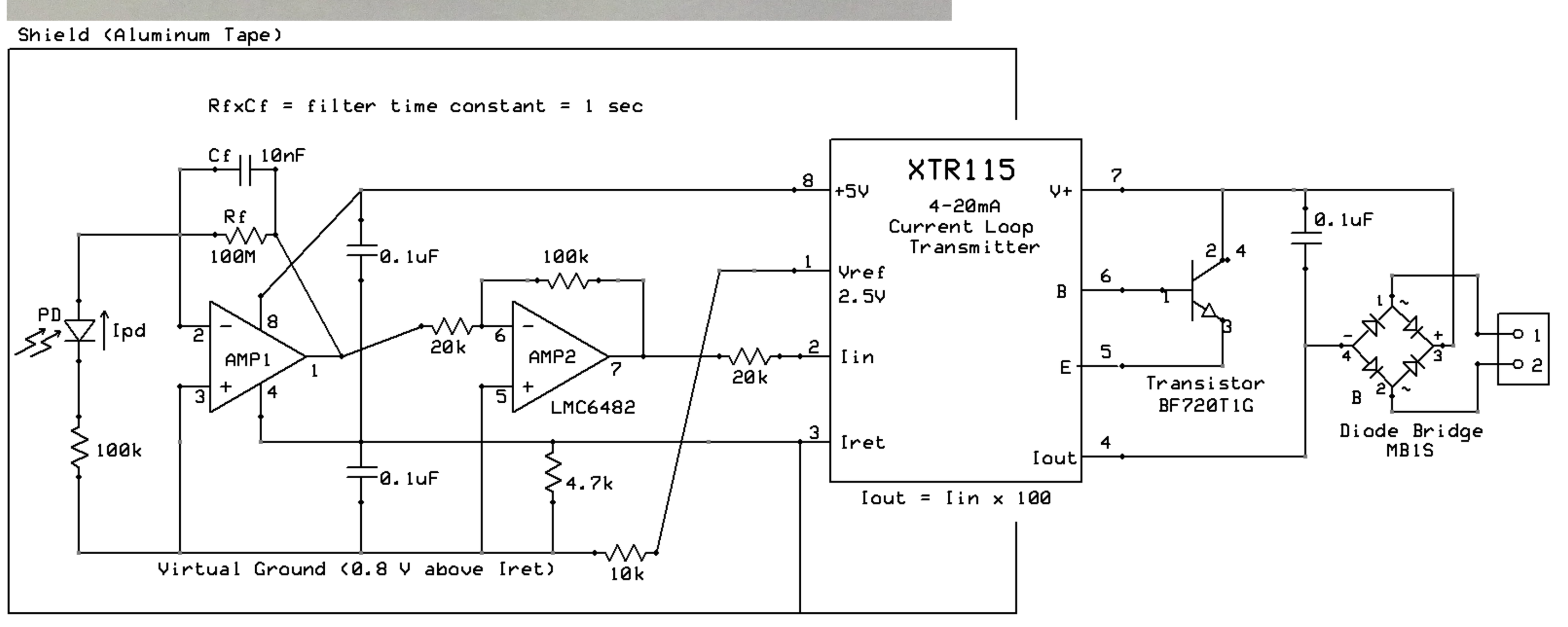
Portion of the LabVIEW control screen from the LBNL in-house built gas phase carbon-11 methyl iodide production rig depicting 6 of the 9+ radiation detectors employed in the system.

Detector Details

Our compact, low-noise, design is based on off-the-self amplifier and two-wire 4-20 mA transmitter chips and can easily be connected to standard analog input electronics with only a single twisted pair of wires. The photodiode and all electronics fit into a small epoxy-sealed package shaped as a 12.5 mm diameter cylinder that is 40mm long, allowing the detector to be placed within a few centimeters of the radiation source.



Photograph of assembled detector printed circuit board front and back along with epoxy encapsulated final assembly. Upper image shows (A) Hamamatsu S6967 Photodiode (active area 5.5x4.8mm) and (B) BF720T1G Transistor. Middle image shows (C) LMC6462 dual OpAmp, (D) Texas Instruments XTR115U Current Loop transmitter, and (E) MB1S diode bridge. Bottom image depicts the potted detector 12.5mm dia x 40mm long (20-3001 epoxy from Epoxies, Etc.). Circuit boards ordered online from from ExpressPCB.com.



Detector circuit diagram: The design is based on the XTR115 Current Loop Transmitter. This chip provides a 5 volt supply that powers a two-stage amplifier (LMC6482). The first stage converts current in the photodiode (Hamamatsu S6967) into a voltage across a large resister (100MΩ); the second stage provides additional amplification to better match the input of the XTR115. A precision reference voltage from the XTR115 is used as a "virtual ground" for the front-end circuit. The photodiode detector is not biased. An RC filter on the first stage, with a time constant of 1 second, effectively averages the signal. Required power is 12 to 24 volts.

Results

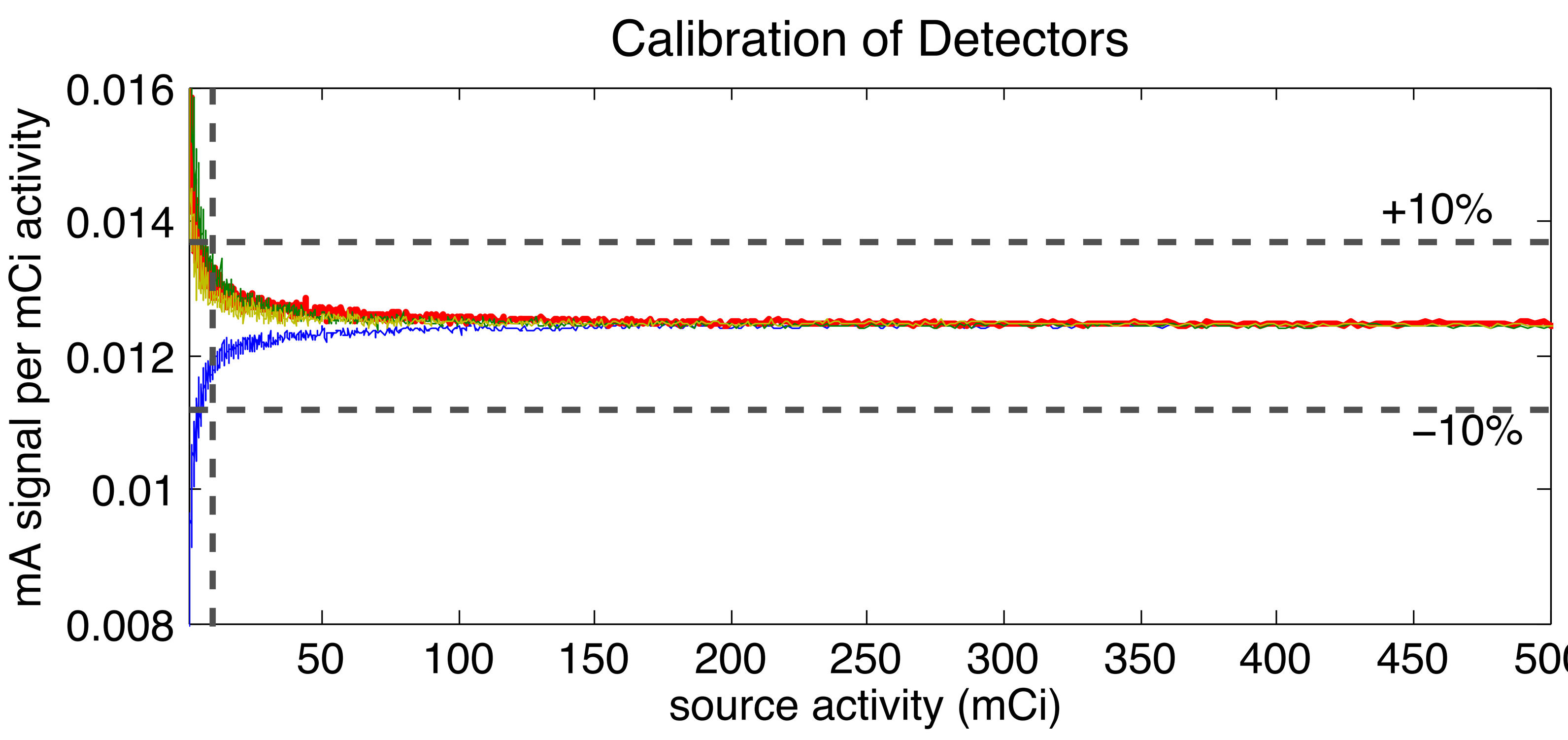
Placed at 4.5 cm from a radiation source, approximately 3.2 pA of current is seen in the photodiode per 1 mCi (37 MBq) of carbon-11 (using a Hamamatsu S6967 PIN Photodiode; active area 5.5x4.8 mm). This is amplified and converted into an output signal of about 8 µA. Maximum signal of 20 mA is thus reached for about 2 Ci (74 GBq) at this distance.

Noise Analysis: By observing the decay of a sample of carbon-11 over time, it was possible to measure the noise level as a function of detector signal. The Signal-to-Noise Ratio (SNR) was found to be proportional to the square root of the signal, consistent with the main noise source being due to the statistics of the interacting gamma rays. The measured SNR/sqrt(Signal) was about 16 $pA^{-1/2}$. For 1 pA this is the level of noise that would be produced by a rate of interacting photons of $16^2 = 256$ over the integration time of the detector (which is effectively 1 second). This indicates that the average photon interacting with the detector produces 1 pA/256 = 0.004pA = 24k electron-hole pairs. In silicon each electron-hole pair requires 3.64 eV of energy, indicating an energy deposition of about 90 keV.
Using the 0.004 pA per gamma estimate from above, and the measured detector signal for a known source and distance, it is possible to estimate the fraction of each 511 keV gamma ray that interacts in the active volume of the detector. This is about 1.1%.

Electronic noise is at an output level of 0.25 µA (0.1 pA in the detector) and thus is dominated by the statistical photon noise described above.

Temperature Effects: We observed fluctuations in the "zero" baseline over periods of tens of minutes. When the temperature was held constant at 20.5±1°C, these fluctuations were less than 1 µA, but temperature variations from 25 to 45°C produced shifts of from 5-50 µA (varying by individual detector; mostly below 20 µA). Actual conditions inside a working hotcell will be between these extremes; we have observed typical baseline shifts of 1-10 µA.

Sensitivity: The measurement sensitivity of the detectors depends on their use. We define sensitivity as the level at which measurement uncertainty is 10%. If the detectors can be "zeroed" (i.e. have their baseline readings measured at zero radioactivity) near the time of the measurement, so that baseline fluctuations are minimal, then sensitivity of better than 1 mCi at 45 mm can be achieved. Overa longer period between zeroing and the measurement, with typical temperature variations in a hotcell, sensitivity might be more like 5 mCi at 45 mm. And near sources of significant temperature variation (heaters or liquid nitrogen) the sensitivity could be 10 mCi at 45 mm or worse.



Decay of a sample of Carbon-11 observed by four detectors in close geometry (~3cm). Shown as signal per mCi (with the four detectors aligned in output). Baseline shifts over this multi-hour experiment of ±6 µA cause the deviations at low activity levels. These deviations exceeded 10% at 5-10 mCi.

Conclusion, References, & Acknowledgements

The radiation detectors described herein are low-cost, easy to construct, and reliable. We are able to incorporate a large number into our radiosynthetic processes due to these favorable properties.

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3. Carroll and Ramsey Associates, Berkeley, CA 94710, www.carroll-ramsey.com.

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