Low Noise Amplification for Optical Detector Arrays

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Abstract - **Detection of low intenisty light pulses is accomplished using a three stage amplifier design. A highly sensitive input stage provides a large gain and buffers the sensor from the following stages. An integration stage averages the input signal and holds the output value during data collection. Low impedance output drive capability and noise immunity are provided by a third stage. The combination of these three stages produces a system capable of detecting photocurrent signals in the range of 10-100 nA.**

I. Introduction

The prototype instrument excites the sample with a pulse of excitation light and analyzes the scattered light for fluorescence markers indicating the presence of microbes. A pulsed xenon lamp. This provides a "white" light source which is filtered to produce the excitation wavelengths. Emission light is collected and filtered using a reflective optic assembly [see C. Estes and L. Powers, these proceedings]. The filtered emission wavelengths are detected by an array of photomultiplier tubes (PMTs), and amplified to a level readable by a standard analog to digital (A/D) converter. This data is analyzed using a neural network [see B. Wade, C. Estes, and L. Powers, these proceedings]. This system is capable of detecting even low levels of microbial contamination [see C. Lloyd, H.-Y. Mason, M. Dice, C. Estes, A. Duncan, B. Wade, W. Ellis, Jr. and L. Powers, these proceedings].

II. Design requirements

The requirements for the amplifier circuitry are determined by three factors: the bandwidth of the light source, the output characteristics of the PMT, and the input characteristics of the A/D converters on board the microcontroller. To reduce coupling from high frequency digital signals, the pre-amplifiers are built on a separate printed circuit board from the power supply and digital subsystems. In order to maximize the sensitivity of the instrument, noise and interference have been reduced to the minimum levels for the required gain and bandwidth. The primary sources of noise in a photocurrent pre-amplifier are thermal noise from the load resistor and shot noise from the PMT itself. The magnitudes of both noise sources are directly proportional to bandwidth. The design is comprised of three stages as shown in Figure 1.

III. Gain stage

The pulsed xenon light source used for this design has an output rise time of approximately 10us and a half max width of approximately 20µs. Therefore the amplifier will require a slew rate of 2V/µs and a minimum bandwidth of 100 KHz. The first stage of the amplifier provides most of the gain. A typical PMT output current from a low concentration of cells is in the range of 10 - 100 nA. Since the A/D converters use a 5V scale reference, the amplifier must provide a minimum of $5x10^8$ V/A gain.

A load resistor can be used to provide a maximum gain of $3.0x10^5$, as determined by the required bandwidth. An op-amp configured as a non-inverting amplifier is used as a buffer between the load resistor and the next stage of the circuit. To avoid loss of signal at the input, this op-amp must have a maximum input bias current of less than 10% of the smallest input signal over the entire operating temperature range. Several available low input bias op-amps are suitable for this application. The AD549, manufactured by Analog Devices, meets the requirements with a minimum slew rate of 3V/µs and a maximum input bias current of 250 fA. To reduce system noise, the bandwidth is chosen as the minimum possible for the given signal (with a small allowance for drift and tolerances).

To reduce offsets due to leakage currents, the inputs of the AD549 are surrounded by a guard trace. This trace is tied to the inverting input, which has a relatively low impedance path to ground. This diverts leakage currents to ground with a minimal offset voltage at the input.

IV. Integrator

The second stage of the amplifier integrates the signal over the width of the lamp output pulse. This serves as an averaging function and acts as a sample and hold circuit to maintain the output during the A/D converter settling and acquisition time. The IVC102 single chip integrator, manufactured by Texas Instruments, provides a well designed integrator in a single package. Integration and reset control are handled by a pair of logic level control lines. The IVC102 serves as an excellent hold circuit due to its low (1nV/µs) droop rate. The single chip design also allows for a compact circuit layout.

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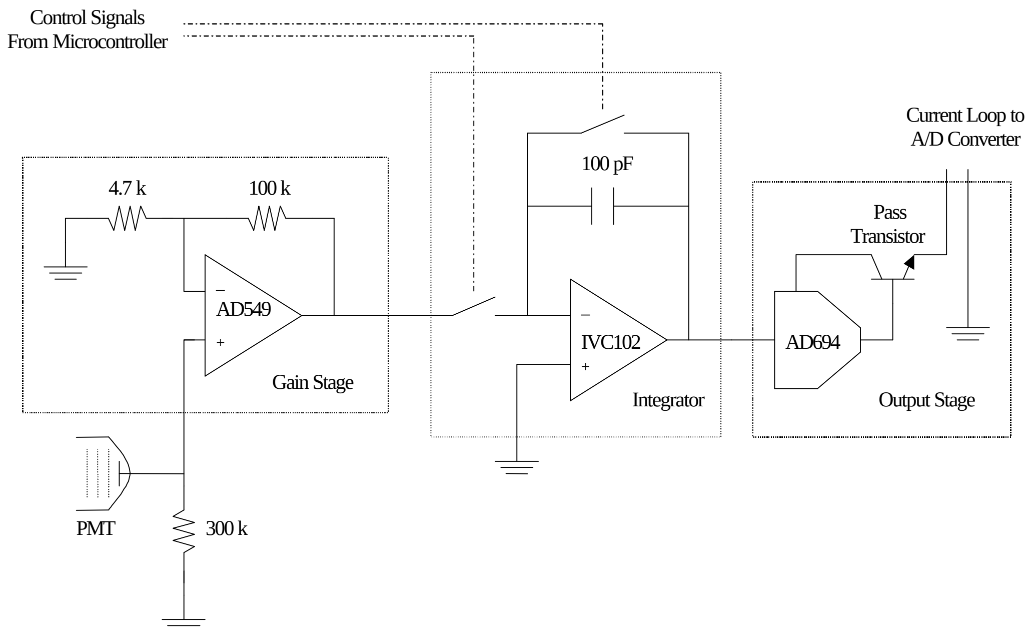

Fig. 1. Simplified Schematic Diagram

To reduce the effect of the electromagnetic pulse from the lamp, integration is started approximately 25µs after the leading edge of the lamp trigger signal. At this point, the signal pulse is near its peak magnitude and the electromagnetic interference from the lamp has decayed to nearly zero.

V. Output Stage

The microcontroller selected for this design uses a single A/D converter multiplexed to 8 input channels by a set of sample and hold circuits. This presents the output of the pre-amplifier with a low impedance. The input also exhibits a significant parallel capacitance. In order to minimize settling time, the output stage of the pre-amplifier is designed to have a low output impedance and maximum stability for driving a capacitive load. This circuit uses an AD694 to convert the 0-10V output of the integrator to a 0-16 mA current loop. Drift due to heat buildup is reduced by using an external pass transistor to source the output current. A load resistor converts this current to a voltage at the A/D converter input. Using a current loop to transmit the signal between printed circuit boards has the added benefit of lower susceptibility to electromagnetic interference. With the low output impedance of this design, the limiting factor for the settling time of the A/D input is the slew rate of the AD694.

VI. Conclusions

In summary, this system provides an effective means of measuring small photocurrent signals. One example is shown in Figure 2 for cells suspended in microdroplets on a reflective surface.

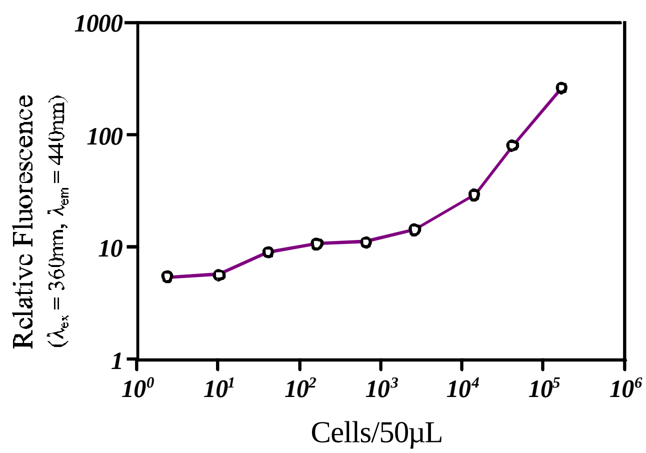

Fig. 2. Cells in 50µL droplets