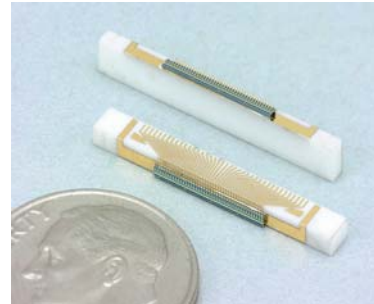


# Application Note

## Bias and Amplification Circuits for Direct-Readout InGaAs Photodiode Arrays



### 1 Introduction

Goodrich's SUI team (Sensors Unlimited, Inc.) offers a variety of standard and custom InGaAs linear photodiode arrays, including both multiplexed and direct-readout types. Direct-readout arrays incorporate no multiplexer, and one output connection is provided for each photodiode. A direct-readout array is functionally the same as a collection of individual photodiodes, but with the cost and size advantages of monolithic integration within a single semiconductor chip. Typically, a direct-readout array contains between eight and sixty-four individual InGaAs PIN photodiodes. Direct-readout arrays may be provided in the form of chips on ceramic submount, in windowed hermetic packages, or in custom packaging to suit particular applications.

Typically, customers connect each photodiode of a direct-readout array to a separate amplifier circuit. This note provides some guidance for the design of these external amplification circuits.

### 2 Direct-Readout Array Configurations

The most common direct-readout array design is a common-cathode arrangement: the n-type semiconductor substrate forms the cathode of all photodiodes in the array, with each photodiode anode connected to an individual wire-bonding

pad. Common-anode arrays, and arrays with separate anode and cathode connections to each pixel, can also be produced on special order.

Devices supplied in a hermetic package can have a separate case ground pin that is electrically isolated from the array. Connecting this pin to the zero reference ("ground") of the external amplification circuit reduces the EMI susceptibility of the photodiode circuit. Packaged arrays may also include an internal thermistor for monitoring the temperature of the detector array, allowing for correction of the temperature variation of dark current and spectral response.

### 3 Electrical Crosstalk in Direct-Readout Arrays

When light strikes the active area of a single photodiode within an array, the electrical contacts of that photodiode do not collect 100% of the photo-generated carriers. Some carriers, particularly those generated outside of the depletion region, diffuse away from the generation point and are collected by the electrical contacts of neighboring photodiodes. This effect is the primary origin of low-frequency crosstalk in direct-readout arrays. Because of the monolithic structure of direct-readout arrays, such lateral carrier diffusion cannot be completely eliminated. For a typical array with a pixel pitch of 250 microns, the crosstalk between

adjacent pixels will be within the range of -35 to -45 dB, depending upon the optical wavelength and the size and position of the light spot within the photodiode active area.

The amount of crosstalk is determined primarily by the distance between each photodiode and the illuminated areas of the neighboring photodiodes; crosstalk varies inversely with this distance. Crosstalk is therefore minimized when the photodiode pitch (center to center spacing) is large and the light is focused to a small spot within each photodiode. Varying only the width of the photodiode active areas while keeping the photodiode pitch constant has very little effect on crosstalk, since this does not change the distance that photo-generated carriers must diffuse in order to be collected by a neighboring photodiode. For applications that require extremely low crosstalk, arrays can be fabricated with special structures that block carrier diffusion between adjacent photodiodes.

Guard ring structures are sometimes requested in order to reduce crosstalk in direct-readout arrays. In common-cathode arrays, guard rings are p-type diffusions like the photodiode anodes, but forming a single electrical node laid out in a lattice geometry surrounding each of the active pixels. When all of the incident light falls completely within the active area(s) of one or more pixels, the presence of a guard ring has no effect on crosstalk, since the guard ring does not alter the diffusion distance. The main benefit of a guard ring is to prevent any stray light that may strike the array in the space between pixels from generating a photocurrent in nearby pixels. Thus, for a fixed pixel pitch, adding a guard ring can increase the modulation transfer function (MTF) of the array, at the cost of reducing the fill factor.

When a guard ring is used, crosstalk is sensitive to the bias voltage applied to the guard ring; guard rings should always be biased at zero volts with respect to the common cathode, or reverse-biased by a few volts. Usually the guard bias should be the same as the photodiode bias. A guard ring should never be allowed to "float", as this causes a large increase in crosstalk.

#### 4 Amplification Circuits

The photodiodes in a direct-readout array are high-impedance devices, and yield the best linearity and largest dynamic range when

operated as current sources. Therefore, the best external amplifier circuit for most applications is a linear transimpedance (current to voltage) amplifier, utilizing one operational amplifier and a few passive components for each photodiode. In general, the transimpedance configuration has both bandwidth and noise advantages over the combination of a load resistor and a voltage amplifier. Transimpedance amplifier circuits are discussed in detail in standard references such as *The Art of Electronics 2<sup>nd</sup> Edition* (Horowitz & Hill, Cambridge University Press, 1989) and *Photodiode Amplifiers* (Graeme, McGraw-Hill, 1995). Manufacturers of operational amplifiers such as Analog Devices, Burr-Brown / Texas Instruments, Linear Technology, Maxim, and National Semiconductor also publish many useful application notes dealing with various transimpedance amplifier considerations, such as bandwidth, noise, and frequency compensation.

Proper operational amplifier selection and circuit design are critical. It will generally be found that the dynamic range, noise, and bandwidth performance of a photodiode array will be limited mainly by the external amplifier circuit parameters and not by the fundamental properties of the photodiodes. As with any measurement circuit, the bandwidth should be wide enough to pass the required signal information but no wider. Excess circuit bandwidth only adds noise and reduces dynamic range without conferring any benefit. For applications where maximum bandwidth is required, very careful consideration must be given to noise gain peaking effects as discussed in *Graeme* (cited above).

Operational amplifier specifications such as input bias current, voltage noise density, offset voltage, and offset voltage drift should be carefully considered in relation to the performance demands of the application. In most cases, good results will be obtained using operational amplifiers with less than 1 nA of input bias current, less than 20 nV/ $\sqrt{\text{Hz}}$  of input voltage noise, less than 100  $\mu\text{V}$  of offset voltage, and less than 5  $\mu\text{V}/^\circ\text{C}$  of offset voltage drift.

For maximum dynamic range in applications such as average optical power monitoring, a logarithmic amplifier may be advantageous. Since logarithmic amplifiers produce an output proportional to the logarithm of the input current,

they allow more precise measurements over a larger dynamic range than linear amplifiers, for a given bandwidth and level of thermal and quantization noise. However, log amplifier circuits typically require more analog circuit design expertise than linear amplifier circuits in order to obtain satisfactory results, and the cost per channel is significantly greater for log amplifiers.

## 5 Detector Biasing

One of the most important considerations for proper operation of a direct-readout array is selecting a bias voltage for the photodiodes (and for the guard ring if present). In most applications, applying a bias of zero volts between the common cathode and each anode will produce the lowest dark current and noise. Zero bias is easy to achieve using the transimpedance amplification circuit.

Applying a non-zero reverse bias to the photodiodes has several effects. First, it increases dark current, and therefore the shot noise of the dark current. This may limit the dynamic range of the circuit if optical powers of the order of one nanoamp per pixel or less are to be measured. A non-zero reverse bias slightly reduces the photodiode capacitance, improving the high-frequency response somewhat. Increasing the reverse bias also increases the linearity at high optical input power levels. If a reverse bias circuit is used, the bias should not exceed ten volts, and one to five volts will usually be sufficient to obtain the maximum frequency response and high-power linearity.

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If you need further technical support, please contact our sales department via email [sui\\_support@goodrich.com](mailto:sui_support@goodrich.com) or call us at 609-520-0610.

**About Goodrich's SUI Team:** Founded in 1991, SUI (Sensors Unlimited, Inc.) is the leading manufacturer of indium gallium arsenide (InGaAs) PIN and avalanche photodiode arrays that are used in shortwave and near infrared imaging for military, industrial, spectroscopic, machine vision, and telecommunications applications. SUI provides InGaAs photodiode array processing as a foundry service and designs custom readout integrated circuits for unique imaging applications within its ISO 9001 certified facility. For more information, visit [www.oss.goodrich.com/sui](http://www.oss.goodrich.com/sui).