Sensor System for Infrared Spectroscopy - Introduction

Outline of the Problem

Infrared spectroscopy, particularly in the near and mid-infrared region is an important field that requires specialized sensors. The industry continues to grow with new applications developing as the sensor technology becomes available. In many cases the science required for spectroscopic analysis is understood and the implementation waits only for the supporting technology to be developed. Trends are, as always, towards smaller, lower cost systems with improved performance.

The implementation of such a spectroscopic system involves several subsystems and areas of specialization.

- Optics
    - The fundamental purpose of the optical component in a spectroscopic system is to disperse the optical input spatially by wavelength. The geometry of this dispersive aspect needs to be compatible with the sensor array being used.
- Sensor
    - The sensor is the component which converts an optical input to an electrical output. The sensor typically incorporates an array of detector elements with some low level multiplexing and biasing electronics. In addition to the geometric design of the detector elements many other parameters need to be considered including operating temperature, spectral sensitivity, stability, responsivity, noise, and speed (both readout speed and detector response speed). Obviously the primary consideration is spectral sensitivity since the sensor must cover the wavelengths of interest.
- Electronics
    - The system electronics are responsible for providing the various drive signals required by the sensor as well as handling the multiplexed output and converting it to a standard computer interface. In addition it would be advantageous if the electronics provided control of auxiliary functions such as temperature stabilization of the detector. All electronic functions should be provided with no additional system noise.
- Software
    - With the availability of modern computing systems most spectroscopic applications require software development for implementation. This may be high level PC programming or low level microcontroller code. A straightforward software development path is essential in modern spectroscopic systems.

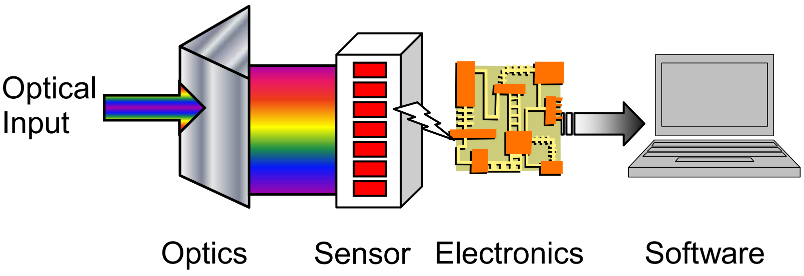


Figure 1
Spectrometer Subsystems

Innovation of Solution

It would be advantageous to incorporate as many of these subsystems as possible into a single spectroscopic solution while maintaining the flexibility necessary to be applicable to a wide range of applications. Since the optical performance and layout is very specific to the particular application the Optics subsystem will not be included in the solution. The remaining subsystems – Sensor, Electronics and Software can all be tightly integrated and be relatively independent of the optical design. Of course the sensor material selection will be determinative of the spectral range covered.

Since the goal is to address infrared spectroscopy, and specifically near to mid infrared, only detector materials with response in the 1µm to 6µm region will be considered. Of these detectors, there are a number which typically operate at very cold temperatures. These include InSb, InAs and HgCdTe. Since the design goal parameters include "small" and "low cost" these detector materials will not be considered due to the size and cost of their cooling systems. Thermal detectors using Pyroelectric or Bolometric materials could be considered because of their broad wavelength response, however they have low sensitivity and slow response speed compared to photon detectors so they would be inappropriate for a general purpose spectroscopic system. The detector materials that remain for consideration are InGaAs photodiodes (both standard and extended) and lead salt photoconductors (PbS and PbSe). All of these detectors have reasonable cooling requirements and good response times. Standard InGaAs photodiodes have excellent sensitivity and speed, but are limited in upper wavelength sensitivity to 1.7µm and therefore can not be considered for a general purpose solution even in the near infrared. Extended InGaAs photodiodes have reasonable sensitivity, but still only extend to 2.6µm. The remaining alternatives, PbS and PbSe photoconductors have characteristics that make them excellent candidates. PbS has detectivity values that are at least as good as Extended InGaAs with sensitivity to 3µm. PbSe is approximately an order of magnitude less sensitive than PbS, but has sensitivity to 5µm. Since both materials are similar photoconductors, they could be used interchangeably within the system to provide sensitivity through the broad range of 1µm to 5µm.The primary challenge in implementing a PbS or PbSe spectroscopic system is that because these detectors operate in the photoconductive mode they have large dark currents. Often these dark currents are dealt with by modulating the incident radiation and then filtering out the DC component. This scheme works well but adds the complexity of source modulation. A better solution would be to develop electronics sophisticated enough to deal with the dark current electronically.

The selection of the detector material determines many of the features of the electronics interface. In a general sense the electronics needs to interface with the sensor, perform as much correction as possible and present the output through a standard computer interface. In addition the electronics should perform any control functions, such as temperature control. If the detector array is to contain a significant number of pixels, the multiplexing electronics should be contained within the detector package to improve performance and minimize package pin count. Since the goal is an integrated spectroscopic system, the hardware architecture is influenced by the desire for simple software interaction.

The software interface should not be language specific to afford the broadest usability. This is most easily implemented as a library of functions to control and interface with the detector array. This also implies that the interface hardware is most easily implemented in a microcontroller based architecture.

Technical Realization

Cal Sensors, Inc. has produced PbS and PbSe photoconductors for over 20 years and has recently developed arrays that are specifically designed to cover the near and mid infrared spectrum at reasonable cost with high sensitivity. Each sensor consist of 256 photoconductive elements housed in an industry standard 28 pin package which also contains a Peltier cooler and thermistor for thermal stabilization and internal integrating multiplexers. Interface electronics and software are also provided to easily transfer data via USB to a computer.

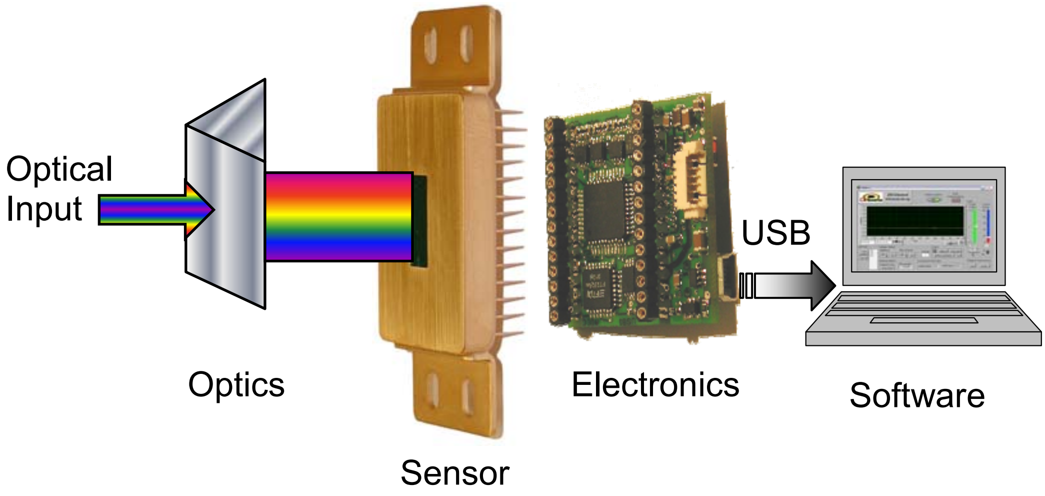


Figure 2
System Implementation

Theory of Operation

Sensor: Detector and Multiplexing Electronics

The array pixels are designed to easily interface with standard dispersive optics. Two geometrically identical photoconductive arrays were developed so the entire 1µm to 5µm region can be covered by selecting either PbS (1µm to 3µm) or PbSe (1µm to 5µm). The 256 pixels are 40 microns wide and 450 microns tall and are spaced at 50 microns. Internal to the sensor is a thermoelectric cooler, thermal sensing element for temperature feedback and stabilization, and an integrated circuit specifically designed to interface with photoconductive elements. The process for manufacturing the photonductive film involves wet chemical deposition onto a substrate and then delineation of the elements. This process is relatively straightforward, using standard photolithographic techniques, and can produce arrays of high pixel functionality, often 100%. This is not quite as easily achieved with other detector manufacturing techniques and is an advantage for these detectors.

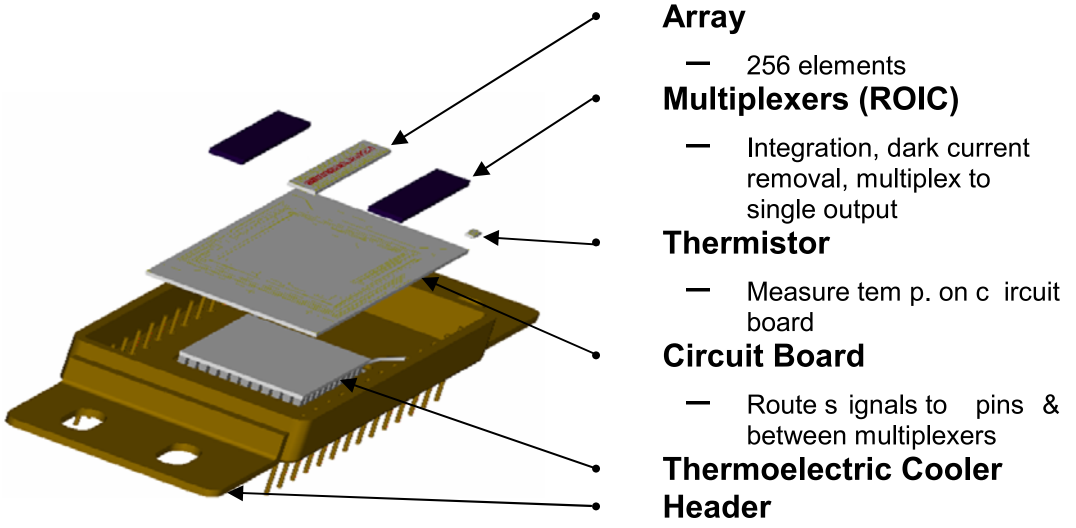


Figure 3
Sensor Implementation

Figure 4 shows the operation of the sensor. The bias voltage on the photoconductive detector generates a current that varies depending on the number of photons on the detector surface. The charge from this current is collected in a capacitor called the Charge Well. When the detector is not illuminated the current is called "Dark Current". This dark current can be referenced and subtracted from all of the pixels, a process generally referred to as First Order, or Offset Correction. Because the resistance of each element in the array is not identical, a global offset correction is typically not satisfactory in reducing the dark current to levels that provide adequate dynamic range. To further improve the offset correction each pixel is provided with a D/A converter which when provided with a digital correction value will individually adjust the offset correction value of that pixel. The number of bits available in the D/A converter will determine the resolution of the correction available. The implemented scheme provides 8 bits of correction, which is typically adequate for the pixel-to-pixel non-uniformities encountered.

Once the dark current is subtracted from the pixels the remaining current represents the difference in current between the dark state and the illuminated state, which is the signal current. Since this detector array is intended for spectroscopic applications, integration is required for applications involving low incident radiation. The signal current will collect on the charge well for a specified amount of time, implementing signal integration. In order to offer the maximum flexibility and dynamic range both the integration time and the well size are adjustable by sending the sensor digital values to the IC. The integration time is hardware limited to a minimum of 10µS and a maximum of 218mS. In practical operation the maximum integration time is limited by the uniformity of the array after correction. Even with good uniformity and dark current correction the differences in pixel offsets are amplified as the integration time increases. The result is that the dynamic range of the array is reduced as the integration time increases. In practice the integration time may be increased until the system reaches the minimum required dynamic range. At the end of the integration time the voltages on the 256 charge wells are captured on a sample-and-hold and the charge wells are reset to start another integration cycle. The electronics allows for read after integrate or read during integrate operation.

The 256 signal voltages are time division multiplexed onto a single output pin which will contain a stream of analog voltage levels which are proportional to the number of incident photons on each pixel. The readout timing is controlled by a pixel clock which can operate up to 2MHz allowing for a 7.8mS frame rate.

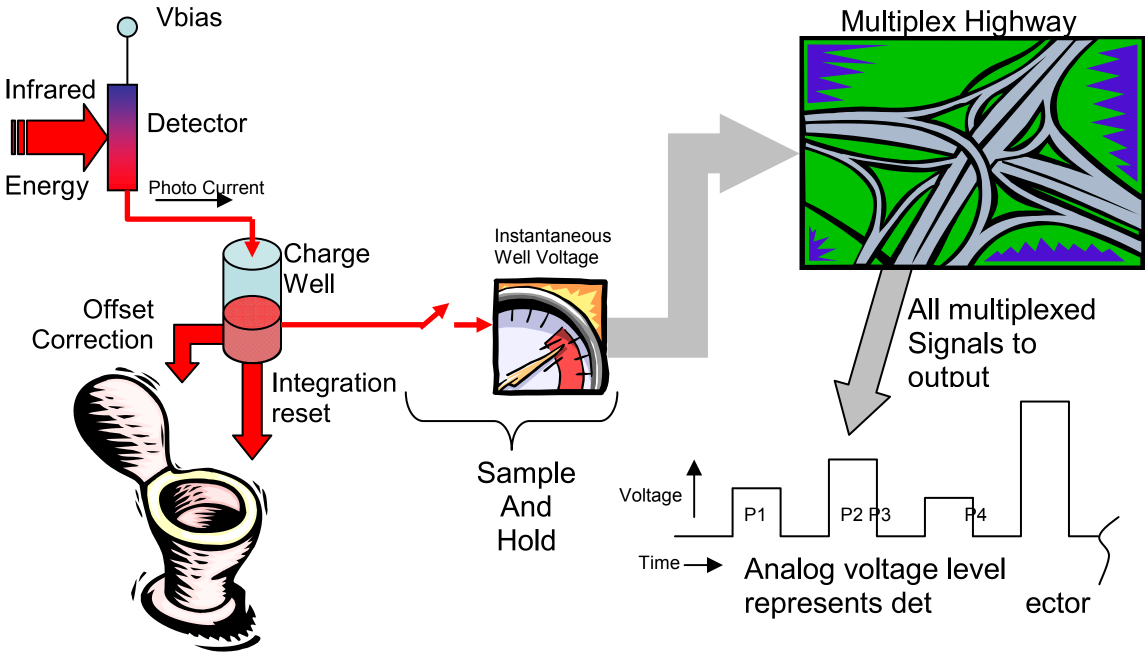


Figure 4
Sensor Operation Diagram

Interface Electronics

The task of the interface electronics is to simplify the interface between the controlling computer and the sensor and has been implemented on a small board that plugs directly into the sensor header and provides connections for the USB interface as well as system and thermoelectric cooler power.

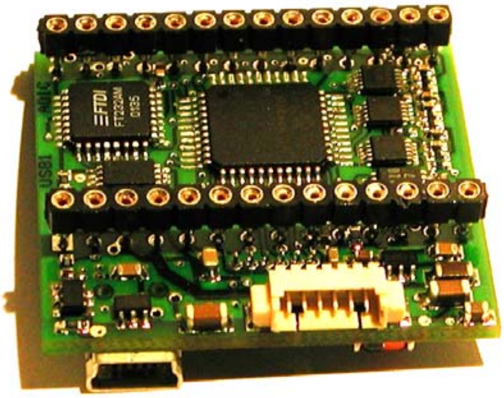


Figure 5
Interface Electronics

The following functions are provided by the interface electronics:

- Sensor (detector and multiplexer IC) control and interface
- Thermoelectric cooler control
- Digitization of the analog detector signal output stream
- USB command based interface
    - Analog conversion of digital control voltages
    - Command based interface structure for simple software integration

The sensor IC requires numerous timing signals to operate. A microcontroller based architecture has been selected to implement the required functions. This makes generation of the timing signals simple and easily modified through the firmware interface port. All control software as well as the sensor calibration coefficients are stored in on-board non-volatile memory. This also facilitates restoration of the sensor coefficients through the startup sequence so the process can be transparent to the spectroscopic system.

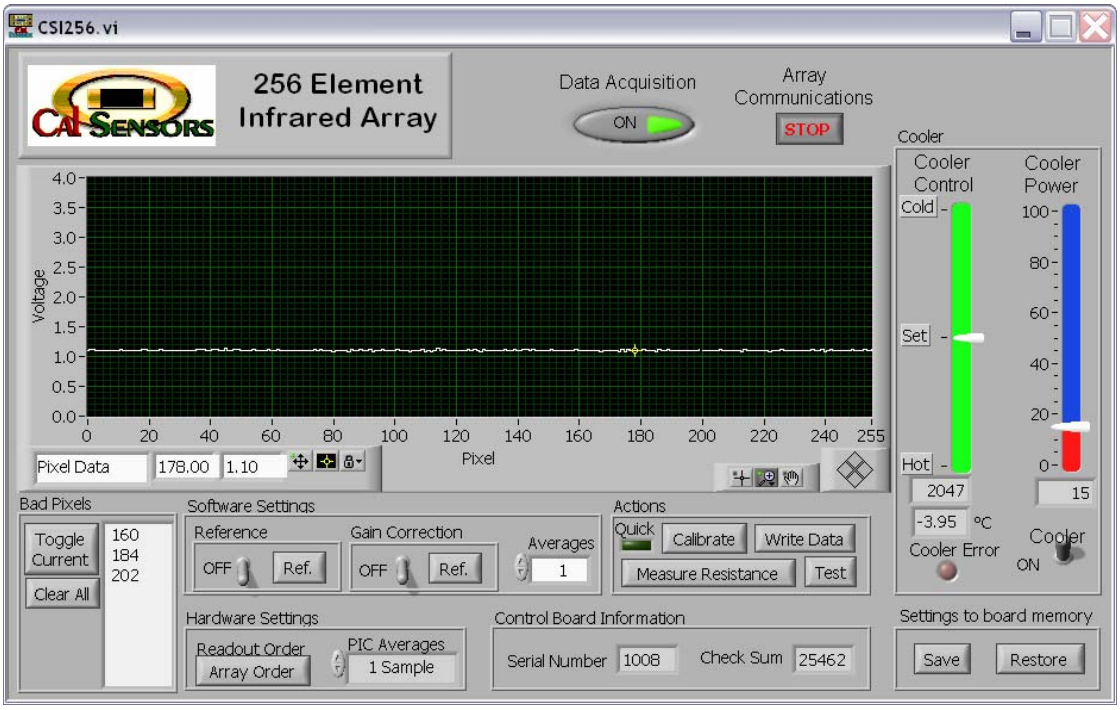
The thermal stability of the photoconductive array is critical for DC operation. The resistance of a lead salt photoconductor varies by approximately 3% per °C. The sensor provides thermal control and monitoring elements so the microcontroller is able to monitor the detector temperature by placing the thermistor within a bridge network with a fixed resistor to set the control resistance. The microcontroller then issues a pulse width modulated signal to a FET which controls the current of the thermoelectric cooler contained in the sensor package. The efficiency of this system does not require any heatsinking of the FET and the microcontroller synchronizes the timing of the high current drive pulses with the pixel clock to eliminate any noise that would result if the system were run asynchronously.

The sensor provides a multiplexed analog output stream as previously described. The interface electronics accepts this analog stream by generating a pixel clock which is synchronized with a 14 bit A/D converter and provides a digital representation of the photon input on each pixel. The conversion rate is 100k samples/second, which sets the maximum digital sample rate of the system and is sufficient for most spectroscopic systems.

The interface electronics is command based and a USB interface architecture was selected to facilitate straightforward system hardware/software interface. Digital signals enter through the USB interface and are converted to analog if necessary before communication with the sensor IC. Conversely analog signals from the sensor are digitized for communication through the USB interface to the host computer. The microcontroller responds to a digital command structure to implement all sensor IC functions as well as thermoelectric cooler control and several auxiliary functions.

Software

The spectrometer developer requires a sensor system that will supply information about the incident, wavelength dispersed photons on each pixel. A high level of hardware abstraction releases the developer from having to understand the photon-to-data conversion process and allows concentration on the development of system optics and the software necessary to implement the target system. To this end a software interface library was developed to implement all functions required to control and operate the infrared sensor through the interface electronics. A balance between low level control and high level abstraction was the goal and was achieved through customer feedback through the development process. The library can be accessed through any popular Microsoft Windows development language, as well as through National Instrument's LabView. A LabView application has been developed and is supplied with the system to easily take data from the array. Setup is as simple as installing the USB drivers and running the application software.



Pixel Data 178.00 1.10

Bad Pixels: 160, 184, 202

Averages 1

PIC Averages 1 Sample

Serial Number 1008

Check Sum 25462

Cooler Control 2047

-3.95 °C

Cooler Power 15

Figure 6
Application Software

Results

The goal of this project was to develop a core system that would facilitate the rapid development of infrared spectrometer systems to address the growing market and to eliminate the need for experts in spectroscopy to become experts in detectors and their associated interface hardware. With the addition of the appropriate optics and some software customization an infrared spectrometer can easily be developed in the 1µm to 5µm infrared range. Two geometrically identical photoconductive arrays have been developed and cover this entire spectrum. To aid in the electronics hardware design a novel interface board is available that incorporates a microcontroller which controls all interface to the internal multiplexers and performs temperature stabilization control and signal digitization. This board accepts commands and transfers data through a standard USB interface. The software interface is implemented through a library of functions and is demonstrated in a Lab View application. The sensor system is currently available in production quantities from Cal Sensors, Inc. for shipment worldwide.

Important Note:

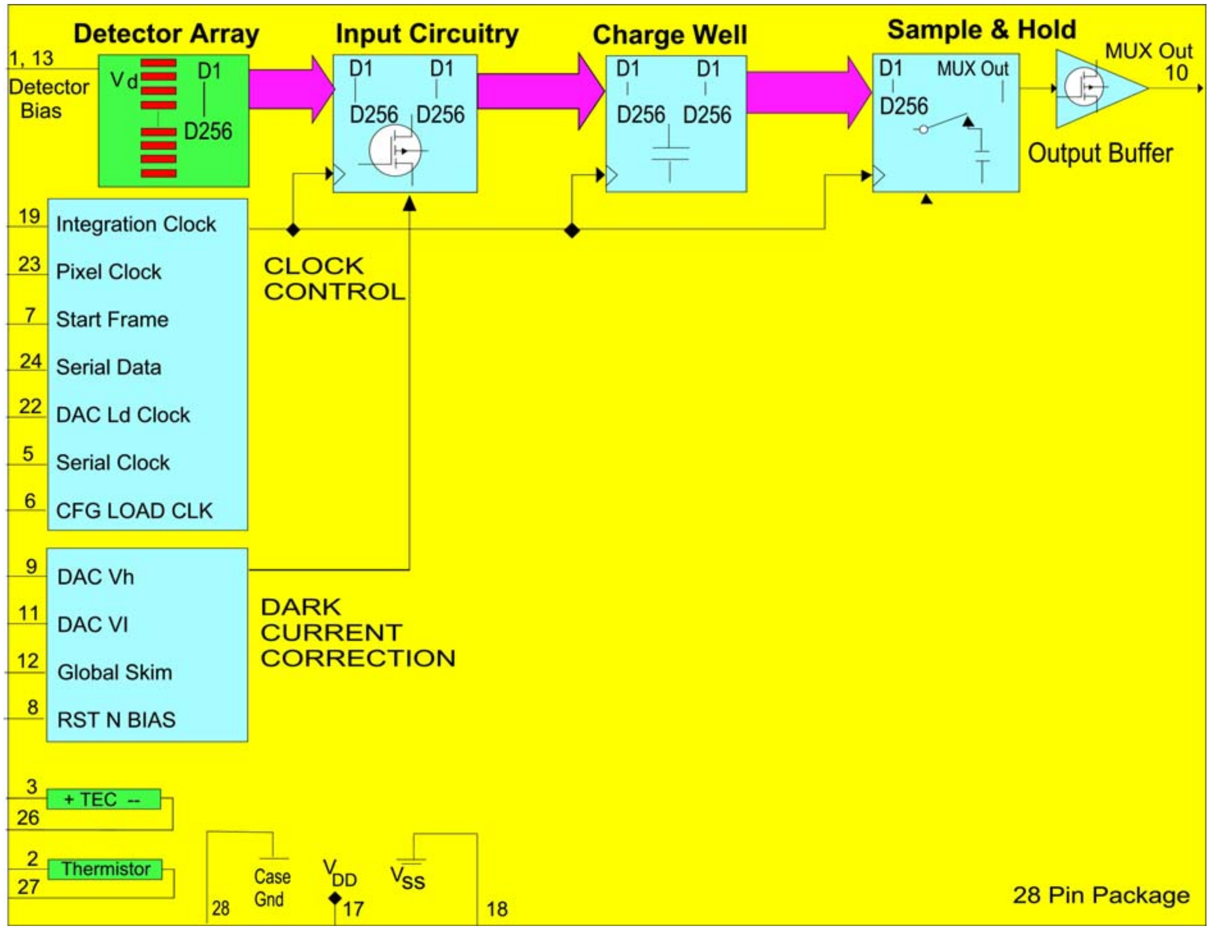
During further technical development an important change has been made. A new 256 channel multiplier did replace in 2008 the two 128 channel multipliers. The advantage is a more homogeneous signal and a simplification of the read-out.

All following information in this product file is related to the new version with one 256 channel multiplexer.

256 Element PbS and PbSe Arrays

256 Element PbS Multiplexed Array Performance

Parameter	
Operating Wavelength Range:	1 to 3 Microns (PbSe)
Operating Temperature:	-4ºC (TEC stabilized)
Number of Elements:	256 detector elements
Element Size:	Pixel width 40 microns, pixel height 450 microns, and pixel pitch 50 microns
Peak Detectivity:	D* (PbS): 1x10^{11} (cm√Hz$^{0.5}$W^{-1}) @-4ºC
Response Uniformity (pixel-to-pixel):	±10% of array signal mean (PbS)
Integration Range:	.01ms to 200ms (on board)
Pixel Clock:	2MHz max.
Linearity:	90%
Pixel Operability:	98%
Detector Rise Time:	<1ms
Input Power Requirement:	12 VDC main, 5VDC @1.5A cooler

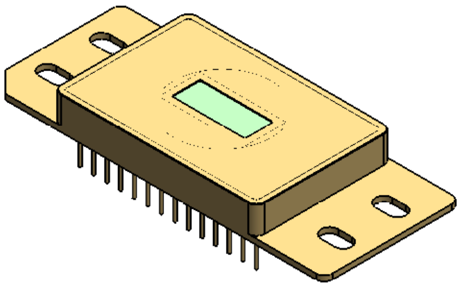


NOTES:

1. SEE SHEET 2 FOR MECHANICAL OUTLINE AND DIMENSIONS.

REVISIONS

REV	DESCRIPTION	DRN	DATE
A	ADDED DETAILS TO PART # IN DWG TITLE	PDM	10-01-07
B	PIN LENGTH WAS: .230, PIN DIAMETER TOLERANCE TIGHTENED	PDM	07-17-08
C	RESTORED ESD HANDLING NOTE	PDM	07-21-08



PIN FUNCTIONS

PIN NO.	FUNCTION	PIN NO.	FUNCTION
1	DETECTOR BIAS	15	NC
2	THERMISTOR A	16	NC
3	TEC (+)	17	Vdd
4	NC	18	Vss
5	SERIAL CLK	19	INT CLK
6	CFG LOAD CLK	20	NC
7	FRAME START	21	NC
8	RST N BIAS	22	DAC LD CLK
9	DAC Vh	23	PIXEL CLK
10	MUX OUT	24	SERIAL DATA
11	DAC VI	25	NC
12	GLOBAL SKIM	26	TEC (-)
13	DET BIAS	27	THERMISTOR B
14	NC	28	CASE

ESD HANDLING REQUIRED ⬡C

CSI CONFIDENTAL AND
PROPRIETARY INFORMATION

THIRD ANGLE PROJECTION

MATERIAL:

FINISH:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

+/- TOLERANCES

XX = .01
XXX = .005
XXXX = .0005
XXXXX = .00005

DO NOT SCALE DRAWING

APPROVALS	NAME	INIT.	DATE
DRAWN	ROYAL	JLR	04-11-06
CHECKED	W.WHITEHORN		
ENG APPR.	J.ELLIOTT		
MFG APPR.	R.ASKER		
Q.A.	L.SNYDER		

CAL SENSORS, INC.

TITLE: **OUTLINE & MOUNTING**
⟨A⟩ AT1-(.45mm x .04mm) 28T-256 M1

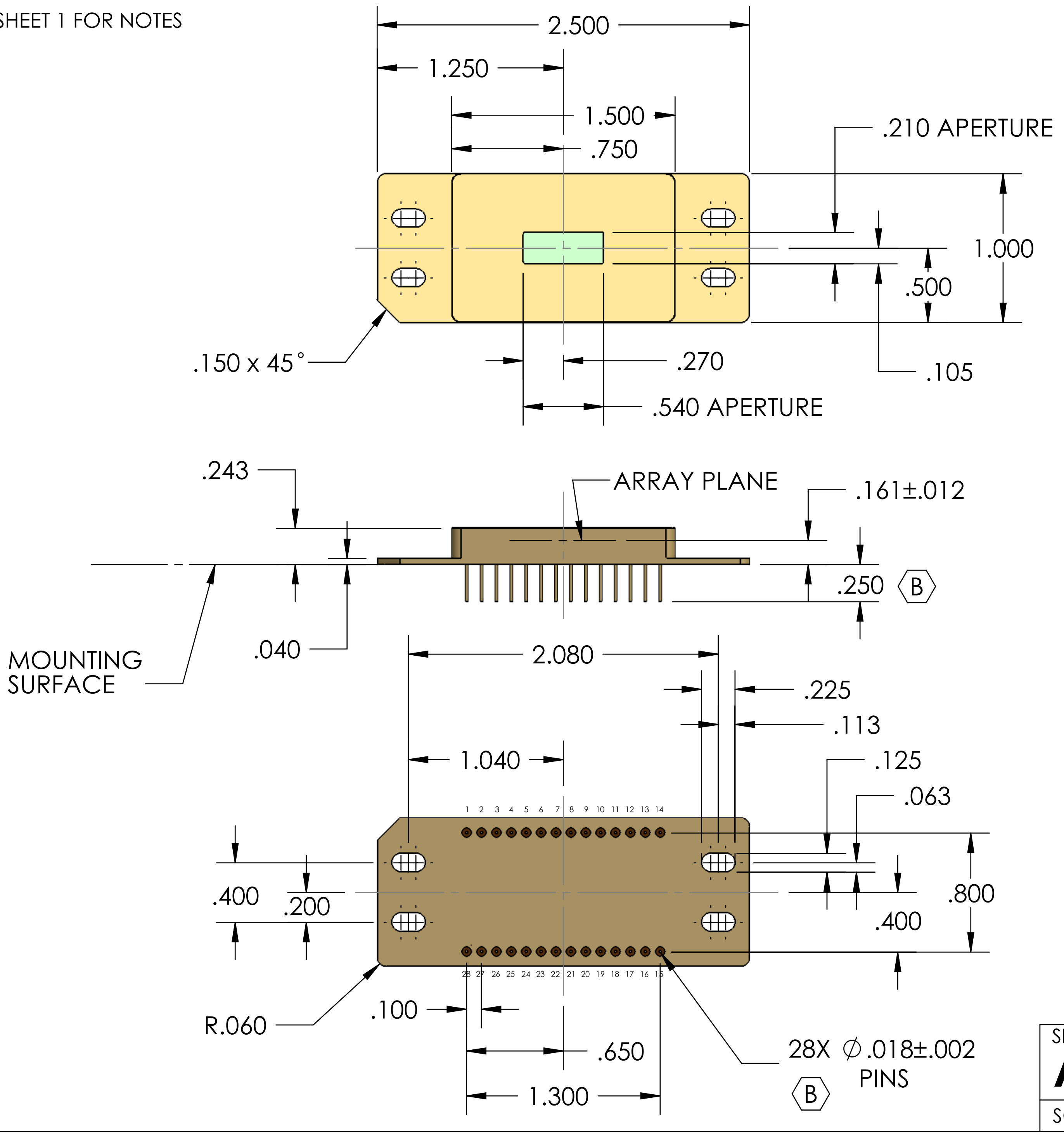
SIZE **A**
DWG. NO. 63065
REV C

SCALE: 1:1
UNCLASSIFIED

5 4 3 2 1

SEE SHEET 1 FOR NOTES

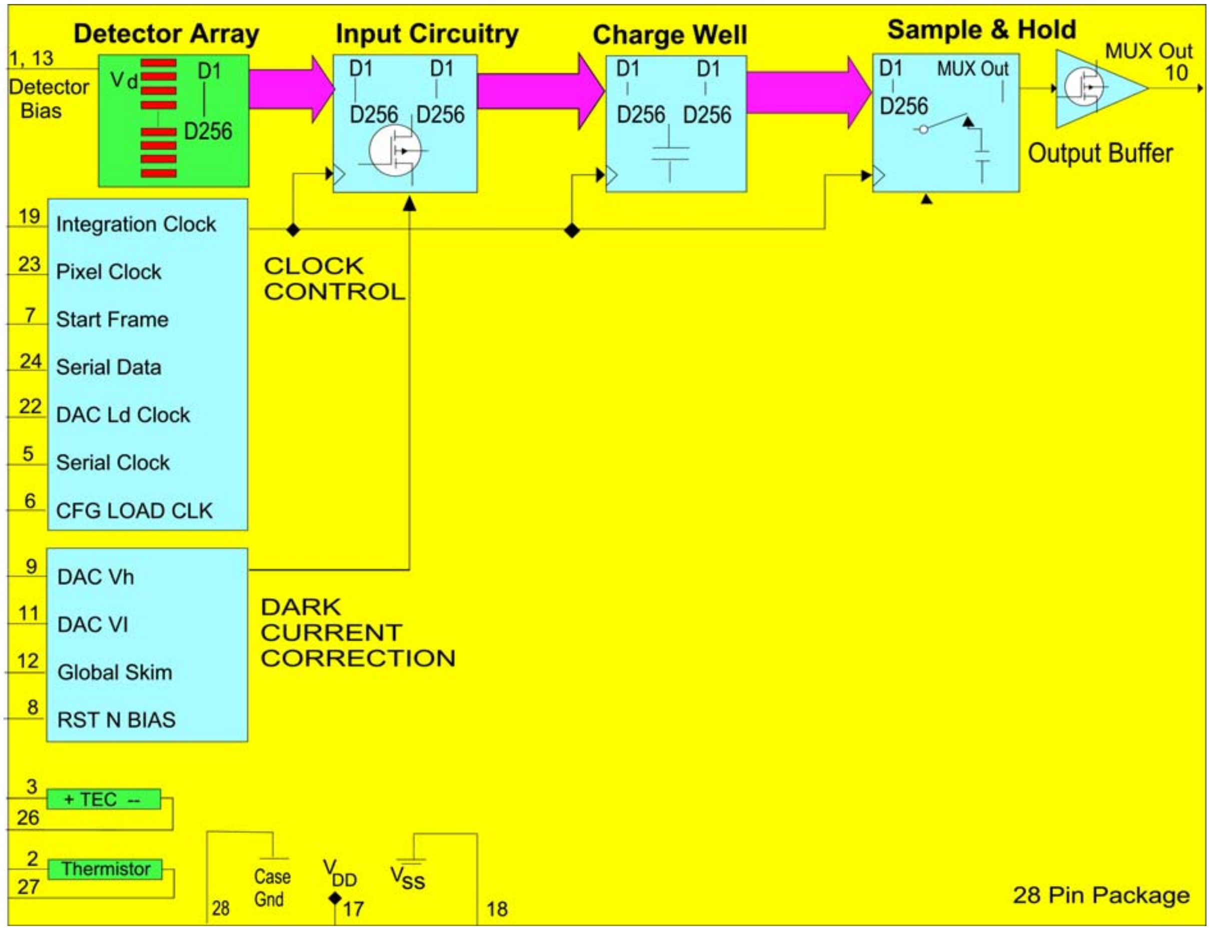
SEE SHEET 1 FOR REVISIONS



SIZE	DWG. NO.	REV
A	63065	C
SCALE: 1:1	UNCLASSIFIED	

256 Element PbSe Multiplexed Array Performance

Parameter	
Operating Wavelength Range:	1 to 5 Microns (PbSe)
Operating Temperature:	-4ºC (TEC stabilized)
Number of Elements:	256 detector elements
Element Size:	Pixel width 40 microns, pixel height 450 microns, and pixel pitch 50 microns
Peak Detectivity:	D* (PbSe): 1x10^{10} cm√Hz /W) @-4ºC
Response Uniformity (pixel-to-pixel):	±15% of array signal mean (PbSe)
Integration Range:	.01ms to 100ms (on board)
Pixel Clock:	2MHz max.
Linearity:	90%
Pixel Operability:	98%
Detector Rise Time:	<10µS
Input Power Requirement:	12 VDC main, 5VDC @1.5A cooler

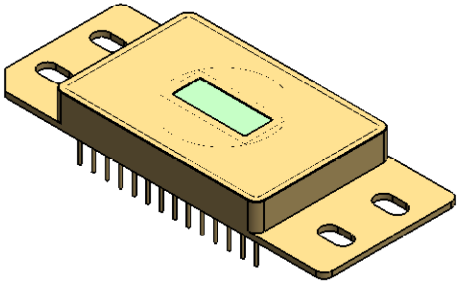


NOTES:

1. SEE SHEET 2 FOR MECHANICAL OUTLINE AND DIMENSIONS.

REVISIONS

REV	DESCRIPTION	DRN	DATE
A	PIN LENGTH WAS: .230, PIN DIAMETER TOLERANCE TIGHTENED	PDM	07-17-08
B	RESTORED ESD HANDLING NOTE	PDM	07-21-08



PIN NO.	FUNCTION	PIN NO.	FUNCTION
1	DETECTOR BIAS	15	NC
2	THERMISTOR A	16	NC
3	TEC (+)	17	Vdd
4	NC	18	Vss
5	SERIAL CLK	19	INT CLK
6	CFG LOAD CLK	20	NC
7	FRAME START	21	NC
8	RST N BIAS	22	DAC LD CLK
9	DAC Vh	23	PIXEL CLK
10	MUX OUT	24	SERIAL DATA
11	DAC VI	25	NC
12	GLOBAL SKIM	26	TEC (-)
13	DET BIAS	27	THERMISTOR B
14	NC	28	CASE

ESD HANDLING REQUIRED ⟨B⟩

CSI CONFIDENTAL AND
PROPRIETARY INFORMATION

THIRD ANGLE PROJECTION

MATERIAL:

FINISH:

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
+/- TOLERANCES
XX = .01
XXX = .005
XXXX = .0005
XXXXX = .00005

DO NOT SCALE DRAWING

APPROVALS	NAME	INIT.	DATE
DRAWN	ROYAL	JLR	08-08-07
CHECKED	W.WHITEHORN		
ENG APPR.	J.ELLIOTT		
MFG APPR.	R.ASKER		
Q.A.	L.SNYDER		

CAL SENSORS, INC.

TITLE: **OUTLINE & MOUNTING**
BXT1-(.45mm x .04mm) 28T-256 M1

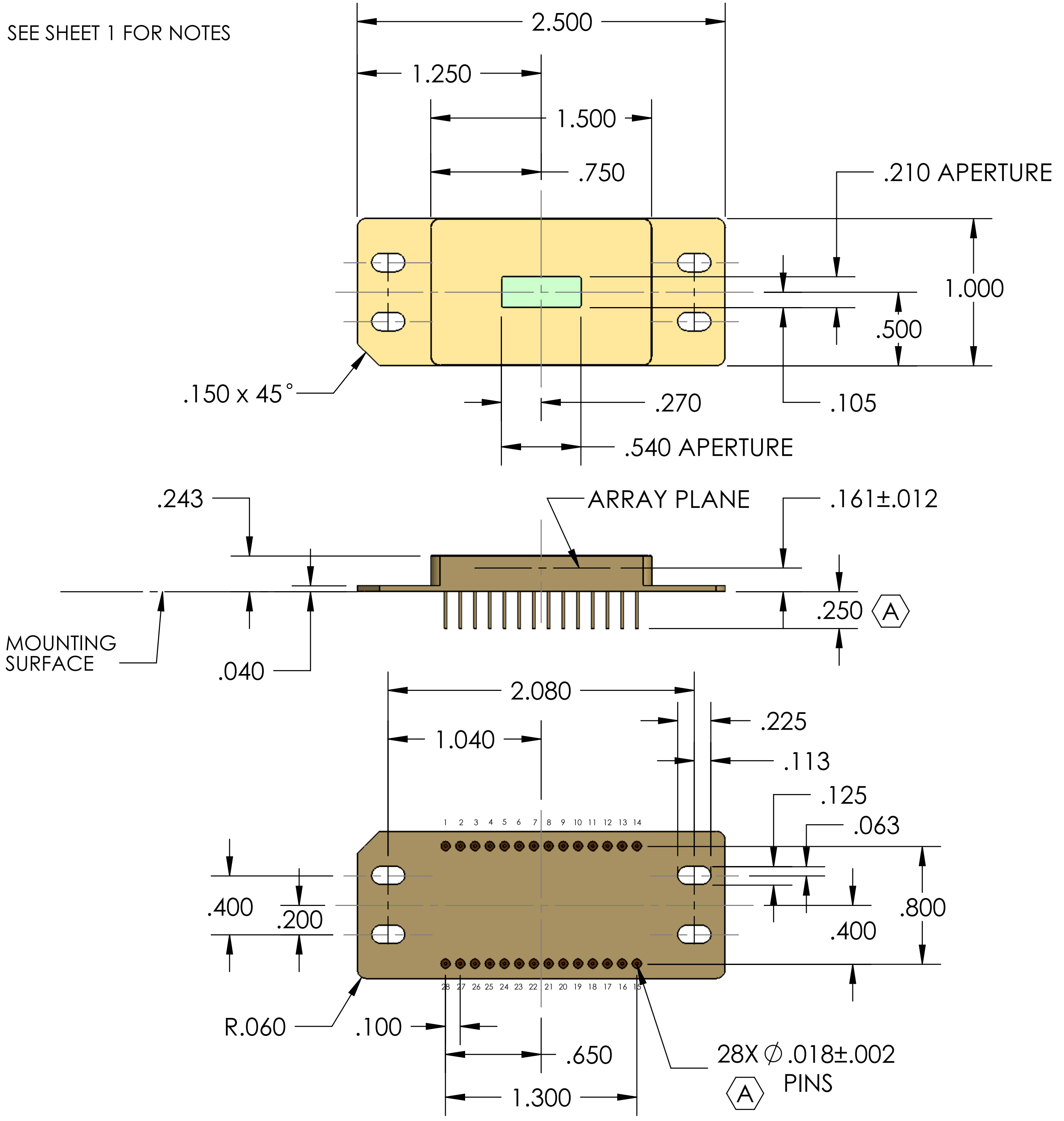
SIZE	DWG. NO.	REV
A	63068	B

SCALE: 1:1 UNCLASSIFIED

5 4 3 2 1

SEE SHEET 1 FOR NOTES

SEE SHEET 1 FOR REVISIONS



SIZE	DWG. NO.	REV
A	63068	B
SCALE: 1:1	UNCLASSIFIED	

5 4 3 2 1

LIRA^{5S}
256 Element Multiplexed Arrays for Thermography and Thermal Imaging

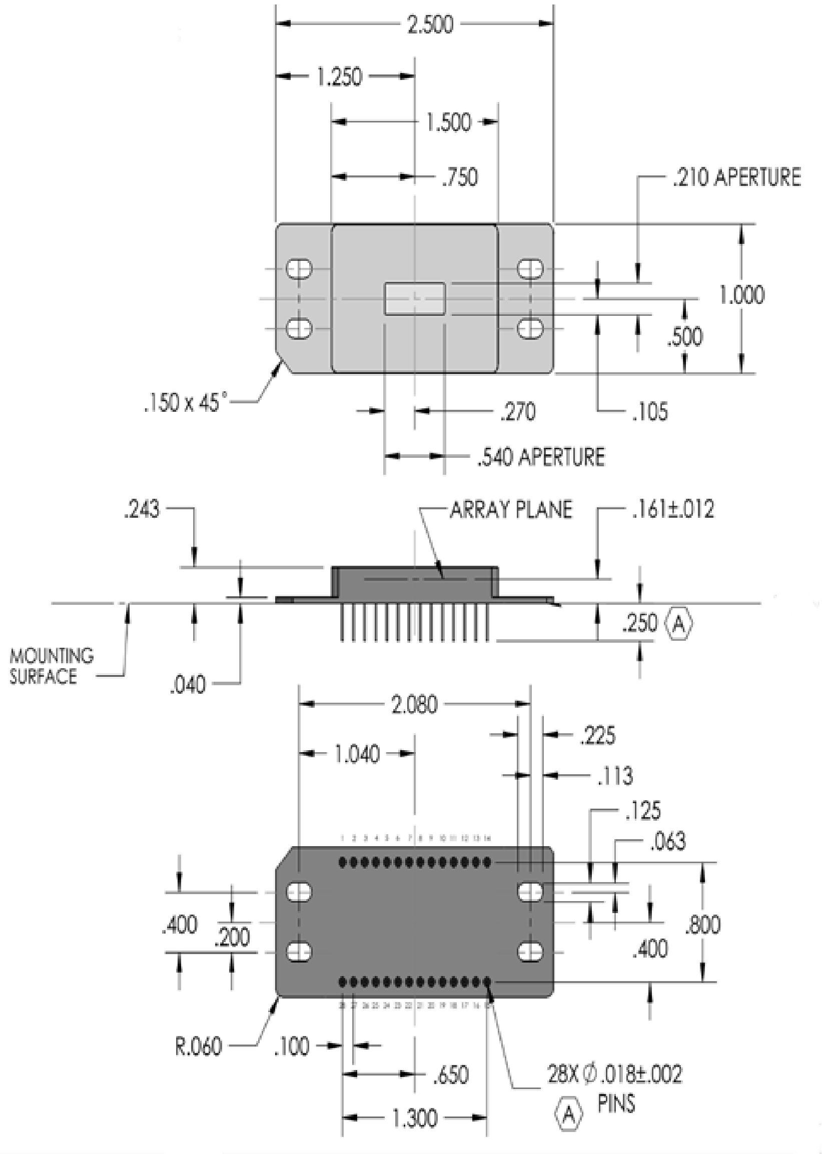
Lead Selenide (PbSe) 1-5 µm

PbSe Multiplexed Array Features:

- The low profile package features a detector with square pixels on 50 micron centers.
- The internal electronics provide variable integration and dark current correction
- Temperature stabilization is achieved using an internal thermoelectric cooler and thermistor.
- This product is designed for thermography and thermal imaging applications in the 1 to 5 micron wavelength region.
- The internal multiplexer includes a serial readout up to 4 MHz and a global plus 8 bit per pixel dark current correction.
- Signal integration is variable with adjustable well size and can be generated before or during readout.
- The array package is supplied with a compact USB controller board (optional) for easy computer interface.
- Can be supplied as a development system.

256 Element PbSe Multiplexed Array Performance

Parameter:	**Typical Performance:**
Operating Wavelength Range:	1 to 5 Microns
Number of Elements:	256 detector elements
Element Size:	Pixel size 40 microns square, and pitch 50 microns
Peak Detectivity:	D*: 1.0 x 10^{10} (Jones)
Resistance Uniformity (pixel-to-pixel):	±15% of array signal mean
Integration Range:	.01mS to 200mS (on board)
Pixel Clock:	2MHz max. for 4 MHz data output
Linearity:	90%
Pixel Operability:	98% minimum
Detector Rise Time:	<10µS
Input Power Requirement:	7 VDC mux, 8VDC cooler 1.7A max

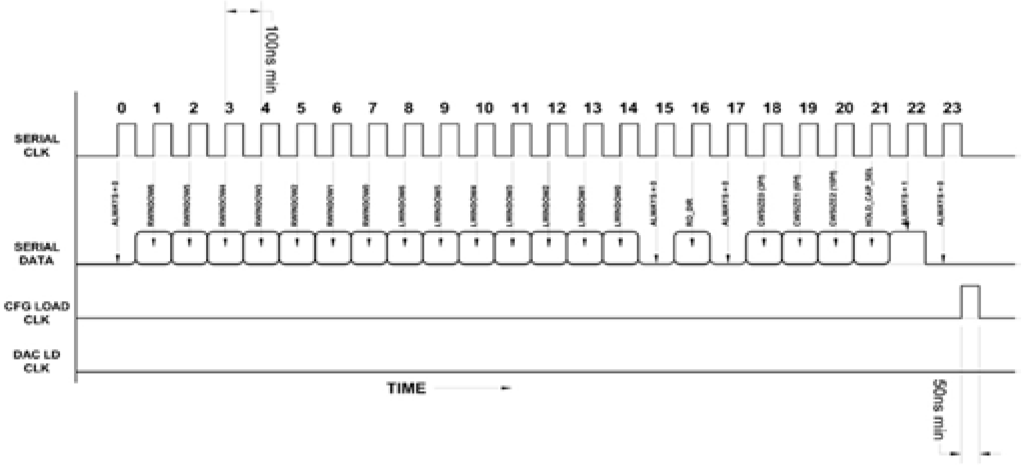


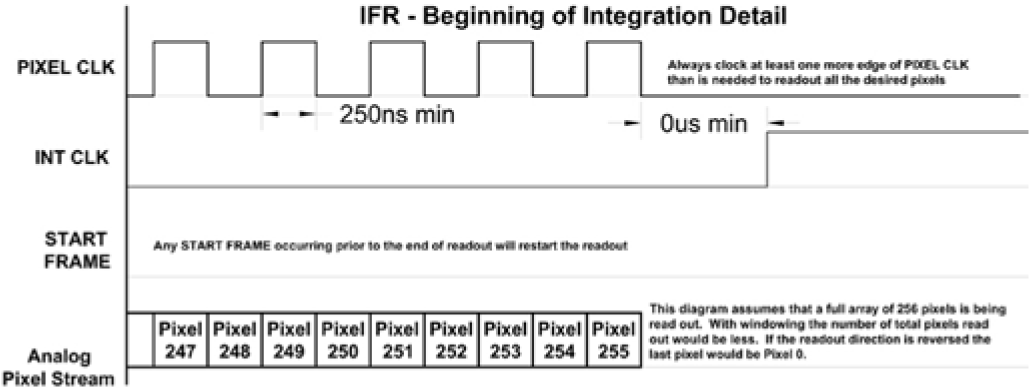
PIN FUNCTION

1	DETECTOR BIAS
2 T	HERMISTOR A
3 T	EC (+)
4	NC
5	SERIAL CLK
6	CFG LOAD CLK
7	FRAME START
8	N BIAS RST
9	DAC Vh
10	MUX OUT
11	DAC VI
12	GLOBAL SKIM
13	DET BIAS
14	NO CONNECTION
15	NO CONNECTION
16	NO CONNECTION
17	Vdd
18	Vss
19	INT CLK
20	NC
21	NC
22	DAC LOAD CLK
23	PIXEL CLK
24	SERIAL DATA
25	NC
26	TEC (-)
27	THERMISTOR B
28	CASE

System Timing Diagrams

Serial Control Register Timing Diagram

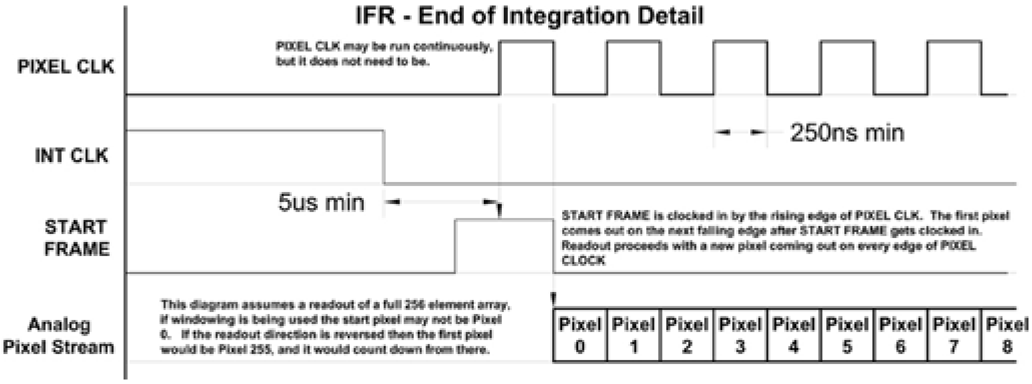



IFR - Beginning of Integration Detail

Always clock at least one more edge of PIXEL CLK than is needed to readout all the desired pixels

Any START FRAME occurring prior to the end of readout will restart the readout

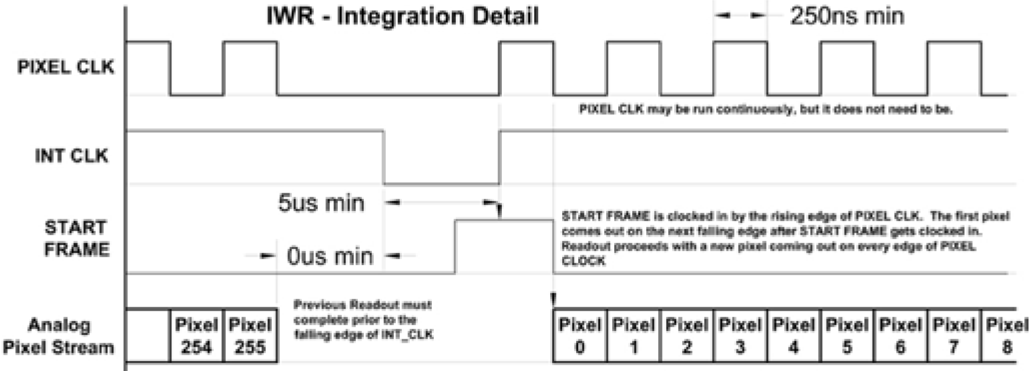
This diagram assumes that a full array of 256 pixels is being read out. With windowing the number of total pixels read out would be less. If the readout direction is reversed the last pixel would be Pixel 0.


IFR - End of Integration Detail

PIXEL CLK may be run continuously, but it does not need to be.

START FRAME is clocked in by the rising edge of PIXEL CLK. The first pixel comes out on the next falling edge after START FRAME gets clocked in. Readout proceeds with a new pixel coming out on every edge of PIXEL CLOCK

This diagram assumes a readout of a full 256 element array, if windowing is being used the start pixel may not be Pixel 0. If the readout direction is reversed then the first pixel would be Pixel 255, and it would count down from there.


IWR - Integration Detail

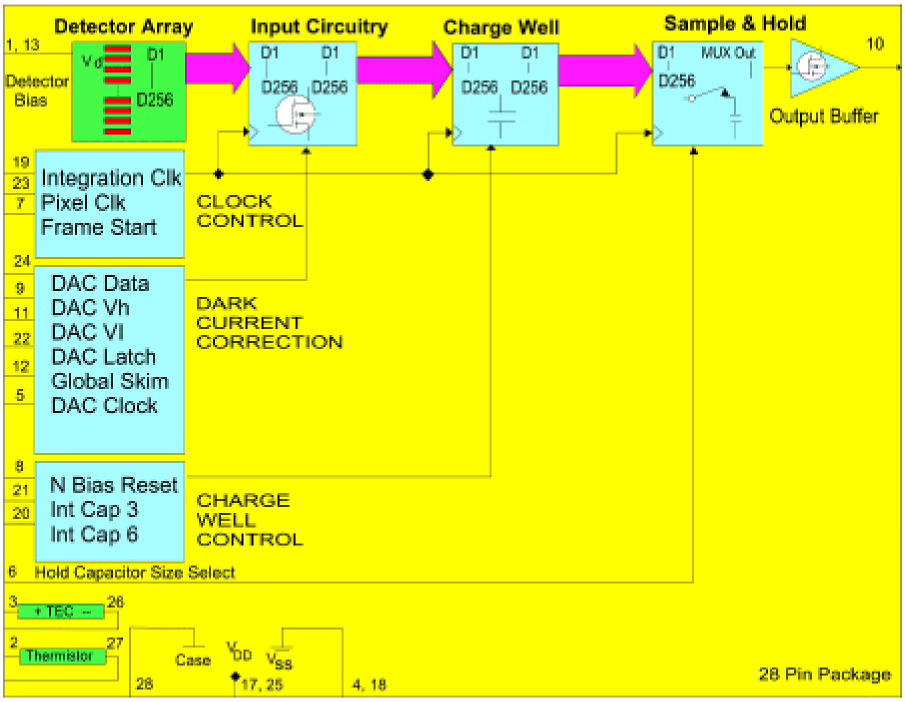
PIXEL CLK may be run continuously, but it does not need to be.

START FRAME is clocked in by the rising edge of PIXEL CLK. The first pixel comes out on the next falling edge after START FRAME gets clocked in. Readout proceeds with a new pixel coming out on every edge of PIXEL CLOCK

Previous Readout must complete prior to the falling edge of INT_CLK

This diagram assumes a readout of a full 256 element array, if windowing is being used the start pixel may not be Pixel 0. If the readout direction is reversed then the first pixel would be Pixel 255, and it would count down from there.

Cal Sensors 256 Element Multiplexed Array
Functional Diagram



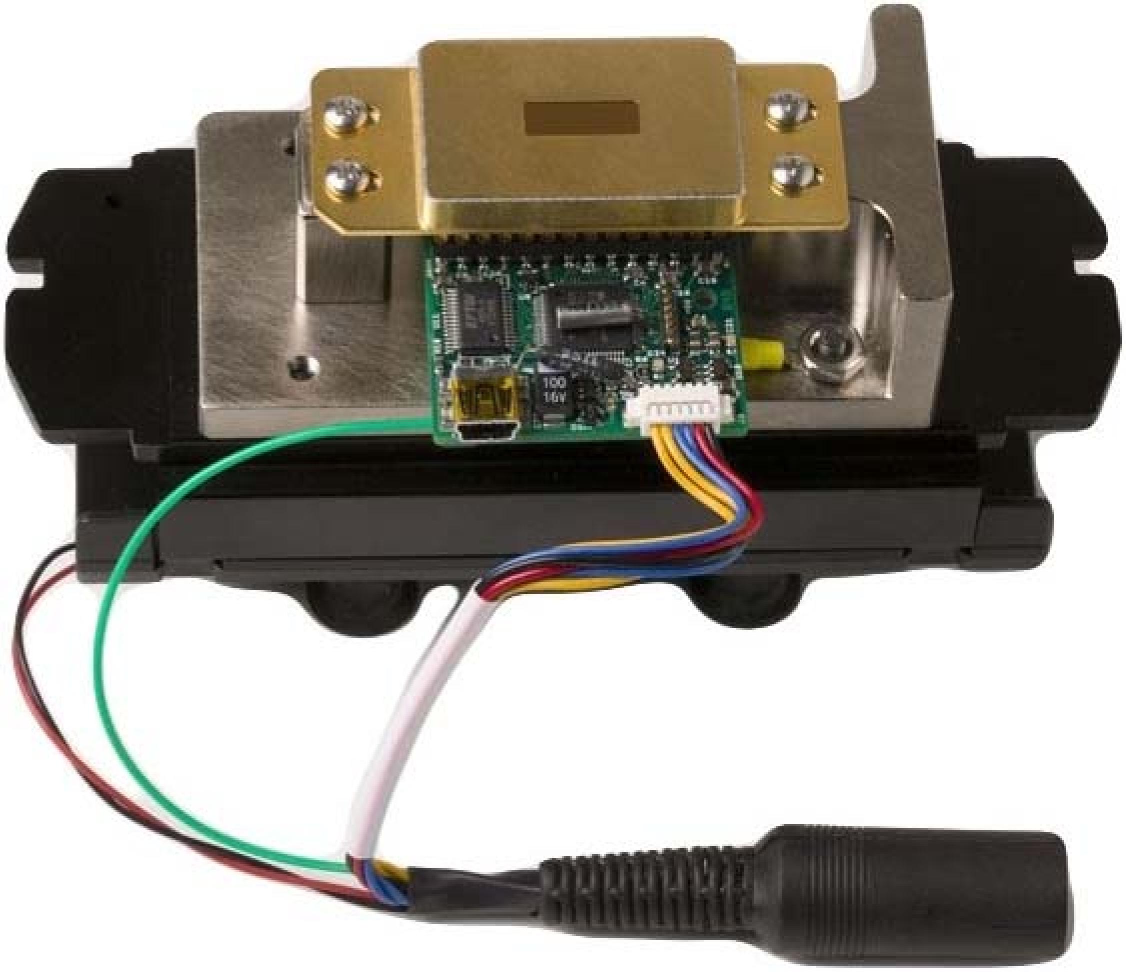
USB Interface Board Features & Specification

- USB interface to controller
  Can be controlled by software commands with supplied driver
- Simple command structure interface
- On-board microcontroller controls all multiplexed array functions
  Cooler control to set point temperature
  All multiplexed timing and control voltages
  Detector bias voltage
  A/D converter control
  Storage of all control and correction coefficients in no-volatile memory
  Automatic reload at power-up
- 16 bit A/D converter at 500k samples/sec
- Efficient, high current PWM cooler drive FET requires no additional heatsinking
  Synchronization with A/D conversion ensures low noise
- Simple power requirements
  12V@100 mA
  4 to 6 volts @1.5A
- Small size: 2.1” x 1.4” x 0.4”
- Direct interface to standard 28 pin package

06/09 / V1 / HW / cal/ lira5s.doc

256 Element Array

Development System User's Manual



CSI 8073 (9/08)

Germany and other countries: LASER COMPONENTS GmbH, Phone: +49 8142 2864 0, Fax: +49 8142 2864 11, info@lasercomponents.com
Great Britain: LASER COMPONENTS (UK) Ltd., Phone: +44 1245 491 499, Fax: +44 1245 491 801, info@lasercomponents.co.uk
France: LASER COMPONENTS S.A.S., Phone: +33 1 3959 5225, Fax: +33 1 3959 5350, info@lasercomponents.fr

Section

1

Cal Sensors

256 Element Array Development System User's Manual

1. Getting Started

The purpose of the development system is to provide our customers with a convenient method to gain experience using the Cal Sensors 256 Element Multiplexed Array. The components of the development system can then be used within the customer's system, saving development time and expense. The development system consists of the following items:

1) 256 Element Array

2) USB Interface Electronics Board

3) Copper mounting block

4) Heatsink with integrated fan1

5) USB cable

6) Power supply module (12V @ 1A, 5V @ 4A)

7) Cal Sensors Array Controller Software and USB driver.

Before You Start

System Precautions

The development system has been designed to be robust enough to be used in a laboratory environment; however the following precautions must be observed:

- Both the USB Interface Electronics Board and the array itself are ESD sensitive. Please exercise typical ESD handling precautions. Use a grounded outlet with the power supply module.

- The thermal design of this system is not intended to be operated at extreme ambient temperatures. Ensure that the thermoelectric cooler does not overheat and the detector itself does not exceed min/max temperature ratings noted on page sixteen of this manual.

Minimum System Requirements

- Windows Operating System (The software should work on Windows 98 or greater, although it has not been tested on all configurations.)
- Pentium processor, or equivalent
- 32MB of memory
- 5MB of hard drive space
- CD-ROM (for installation only)
- 256-color at 1024 x 768 minimum resolution.
- One available USB port

Section

2

Cal Sensors

256 Element Array Development System User's Manual

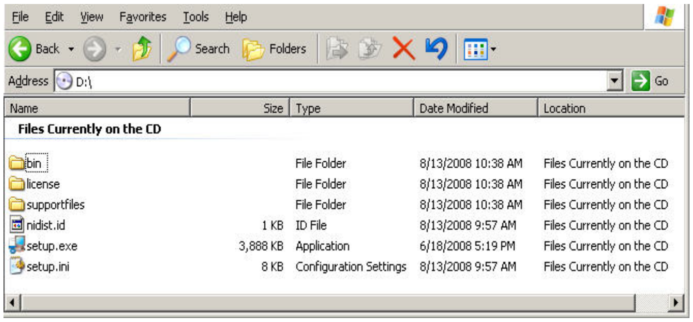
2. Software

Installation

To install the CSI256 CDROM application software follow these steps:

1. Open or explore the contents of the Cal Sensors Array CDROM media.

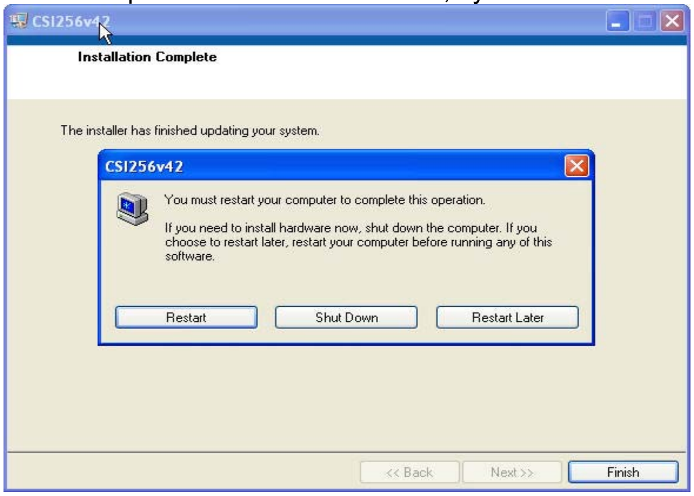
2. Run the Setup.exe program and follow the instructions.



Files Currently on the CD

Name	Size	Type	Date Modified	Location
bin		File Folder	8/13/2008 10:38 AM	Files Currently on the CD
license		File Folder	8/13/2008 10:38 AM	Files Currently on the CD
supportfiles		File Folder	8/13/2008 10:38 AM	Files Currently on the CD
nidist.id	1 KB	ID File	8/13/2008 9:57 AM	Files Currently on the CD
setup.exe	3,888 KB	Application	6/18/2008 5:19 PM	Files Currently on the CD
setup.ini	8 KB	Configuration Settings	8/13/2008 9:57 AM	Files Currently on the CD

3. After completion of the installation, you must restart your computer.



Installation Complete

The installer has finished updating your system.

You must restart your computer to complete this operation.

If you need to install hardware now, shut down the computer. If you choose to restart later, restart your computer before running any of this software.

4. The CSI256 application program is now installed. It uses the ADICLib_256R4.dll to interface with the array, which is installed in the standard Windows System (or System32) directory.

5. The Cal Sensors 256 Array interface board uses a standard Windows Dynamic Link Library (dll) to access all of the operational functions. This means that custom software can be developed in a variety of languages. An application written with LabView is included to demonstrate many of the array functions. The installation media also includes a DLL directory with information for using the DLL, including a help file that lists all of the DLL functions. The DLL directory also includes a copy of the ADICLib_256R4.dll file.

<u>The first time you use the development system you will need to install the USB drivers. To do this, follow these instructions:</u>

1. With the computer on and the USB cable from the MUX Controller Board disconnected from the computer, apply power to the controller board by plugging in the power supply module and then plug the USB cable into the computer.

2. The "Found New Hardware" wizard will pop up requesting to connect to Windows Update. Select "No, not at this time" and click NEXT.

Welcome to the Found New Hardware Wizard

Windows will search for current and updated software by looking on your computer, on the hardware installation CD, or on the Windows Update Web site (with your permission).

Read our privacy policy

Can Windows connect to Windows Update to search for software?

○ Yes, this time only
○ Yes, now and every time I connect a device
● No, not this time

Click Next to continue.

3. Choose "Install from a list or specific location (Advanced)" and click Next.

This wizard helps you install software for:

ADIC Linear Mux Array Controller

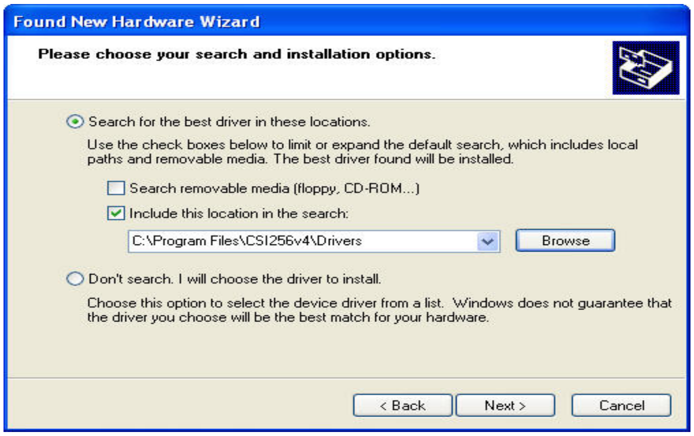
If your hardware came with an installation CD or floppy disk, insert it now.

What do you want the wizard to do?

○ Install the software automatically (Recommended)
● Install from a list or specific location (Advanced)

Click Next to continue.

4. Select “Search for the best driver in these locations.”, and check “Include this location in the search:”. Browse to “C:\Program Files\CSI256v4\Drivers” directory and click NEXT.



Please choose your search and installation options.

● Search for the best driver in these locations.

Use the check boxes below to limit or expand the default search, which includes local paths and removable media. The best driver found will be installed.

☐ Search removable media (floppy, CD-ROM...)

☑ Include this location in the search:

C:\Program Files\CSI256v4\Drivers

○ Don't search. I will choose the driver to install.

Choose this option to select the device driver from a list. Windows does not guarantee that the driver you choose will be the best match for your hardware.

5. You may receive a notice that the driver “has not passed Windows Logo testing…” Please click on “Continue Anyway”. Click “Finish” to complete the hardware driver installation wizard. There will now be an “ADIC Linear MUX Array Controller” entry under the “Universal Serial Bus Controllers” heading in the Windows Device Manager.

Please wait while the wizard installs the software...

The software you are installing for this hardware:

ADIC Linear Array Controller R4

has not passed Windows Logo testing to verify its compatibility with Windows XP. (Tell me why this testing is important.)

Continuing your installation of this software may impair or destabilize the correct operation of your system either immediately or in the future. Microsoft strongly recommends that you stop this installation now and contact the hardware vendor for software that has passed Windows Logo testing.

6. Once the program has completed installing the driver, click FINISH to proceed to operation of the software.

Completing the Found New Hardware Wizard

The wizard has finished installing the software for:

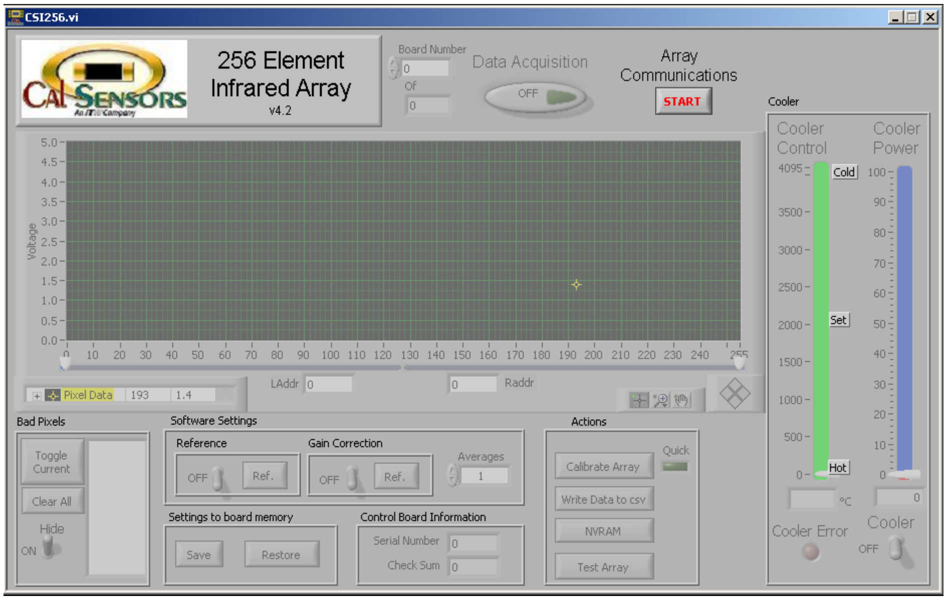
ADIC Linear Array Controller R4

Click Finish to close the wizard.

Operation

The CSI256 application is simple to operate since all controls operate like real-world objects. The application is written using National Instruments LabView and utilizes all of the primary functions in the control DLL.

When the application starts all of the controls are disabled, except for the Array Communications button. Make sure the array is powered and plugged into the USB port on your computer, then press the Start button.



Board Number 0 Of 0

Pixel Data 193 1.4

LAddr 0

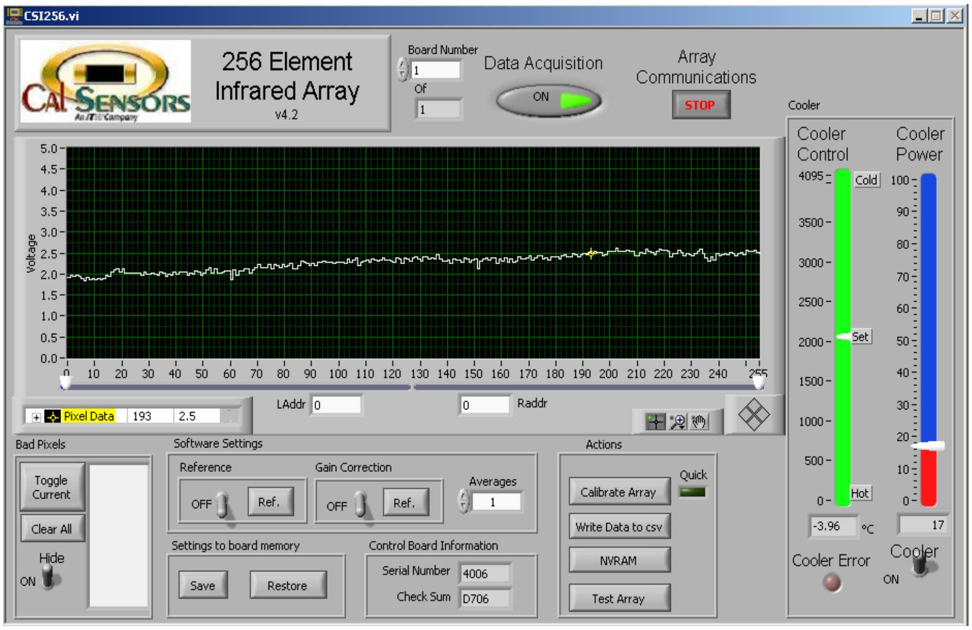
Raddr 0

Averages 1

Serial Number 0

Check Sum 0

After communications are established with the controller board all of the application controls become enabled and the Windows Close button becomes disabled. The figure below shows the active application acquiring data with the cooler on.



Board Number 1 Of 1

Pixel Data 193 2.5

LAddr 0

Raddr 0

Averages 1

-3.96 °C

17

Serial Number 4006

Check Sum D706

Software Control Descriptions

- DATA ACQUISITION: Continuously acquire data by pressing the Data Acquisition button. Press it again to turn off data acquisition.

- ARRAY COMMUNICATIONS: Starts or stops communication with the array. If no array is currently available an error message is displayed. The close window icon is only enabled when the array communications is Off.

- PIXEL DATA GRAPH: The data display can be manipulated (zoom, scale, etc.) by using the control selectors at the bottom of the graph. Right clicking on the graph elements also brings up a menu to control the graph settings. The data range of the Y axes can be changed by double clicking on the axis data values and typing in new min and max limits. The default Y axis data range is 0V to 5V, which corresponds to the array output limits.

- MULTI-BOARD INTERFACE: This feature set (located to the left of the DATA ACQUISITION button) allows the user to connect multiple Array devices to the software by communicating through separate USB ports.

SOFTWARE SETTINGS

- SOFTWARE REFERENCE: You may set the current input data as a reference by clicking the Ref. button. To subtract the reference from the displayed reading switch the Reference On.

- SOFTWARE GAIN CORRECTION: You may correct the gain of the current input data by clicking the Gain Correction Ref. button and then turning the switch to On. This multiplies each pixel by an amount to make the display uniform under illumination. Typically you would do this after establishing a Reference, if you are using that function.

- SOFTWARE AVERAGING: You may display the average of a number of readings by entering that number in the Averages box.

CONTROL BOARD INFORMATION

- SERIAL NUMBER: The control board serial number is displayed.

- CHECK SUM: The firmware check sum is displayed. This indicates the firmware version.

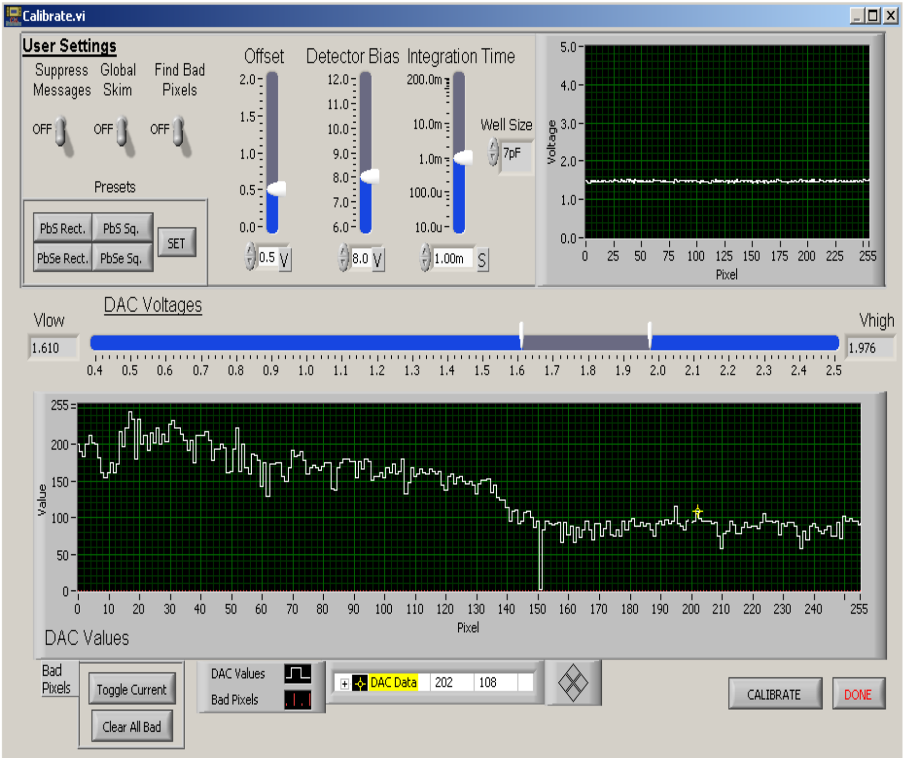
SETTINGS TO BOARD MEMORY

- SAVE / RESTORE SETTINGS: The current calibration settings may be saved to the non-volatile RAM on the controller board by pressing Save. The software does an automatic Restore when it is started. A manual restore may be performed by pressing Restore. All DAC, global skim, well size, bias and bad pixel settings that were previously saved will be restored.

THERMOELECTRIC COOLER

- COOLER: Turn the cooler on by clicking on the Cooler switch. The Cooler Control indicator will move towards the set point and the Cooler Power indicator will show the percentage of full power being supplied to the cooler. If the software senses a cooler error, such as insufficient heatsinking, the cooler power will be shut down and the Cooler Error light illuminated. Correct the problem and turn the cooler back on to reset the error.

- CALIBRATION: To calibrate the array from the main screen press the calibrate array button. This brings up the calibration window.



Calibrate.vi

Suppress Messages: OFF

Global Skim: OFF

Find Bad Pixels: OFF

Offset: 0.5 V

Detector Bias: 8.0 V

Integration Time: 1.00m S

Well Size: 7pF

Vlow: 1.610

Vhigh: 1.976

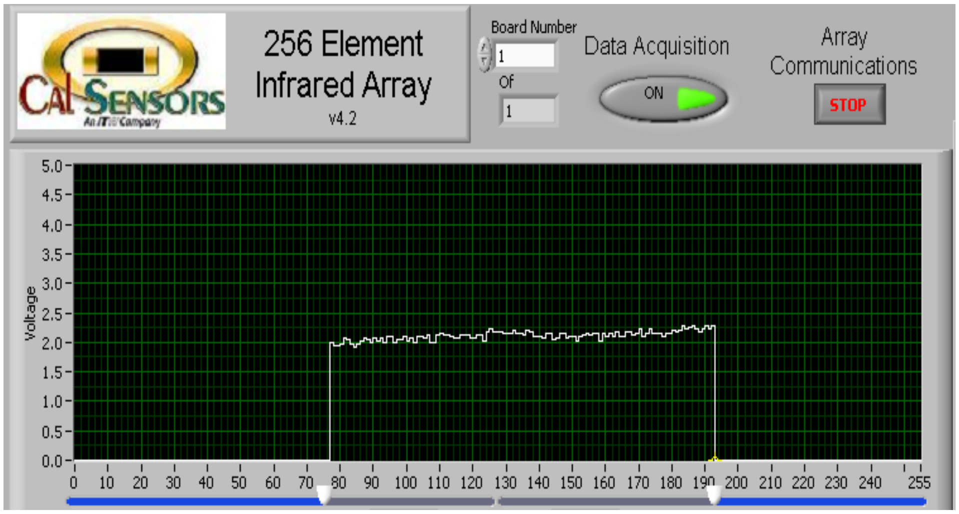
DAC Data: 202, 108

Adjust the User Settings to their desired values. Preset Values may be recalled by pressing one of the Preset buttons. Preset values may be set by pressing the SET button and corresponding detector type. After the appropriate settings have been selected, cover the array and press the Calibrate button. The software then cycles through the calibration sequence, displaying progress messages (assuming Suppress Messages is Off) and setting correction values for each pixel. Upon completion the DAC voltages for each pixel are displayed in the graph, as well as the High and Low voltage range and the Global Skim value if Global Skim was turned on before calibration. Bad pixels can be marked in this window as they were in the main window. After calibration is finished click OK to return to the main window.

If the Quick option is selected in the main window by clicking the LED, the array will be calibrated with the current settings without calling the calibration window. Be sure to cover the array to obtain an accurate calibration.

WINDOWING

- A subset of the entire array can be read out by adjusting the right and left white arrows on the pixel graph.



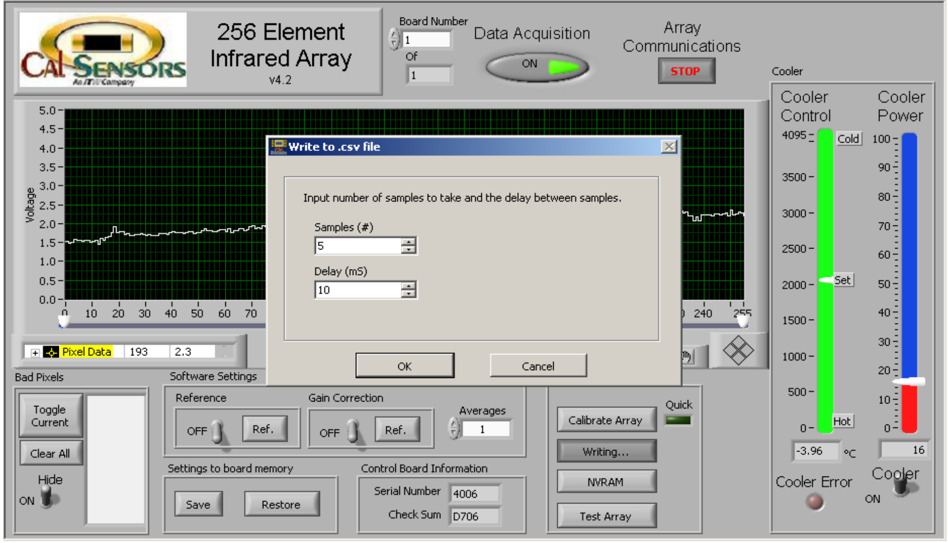
BAD PIXELS

- TOGGLE CURRENT / CLEAR ALL: A bad pixel can be marked or unmarked by moving the data cursor (yellow crosshair) to the pixel and clicking on Toggle Current. The bad pixel will appear in the Bad Pixel List. All bad pixels can be cleared by clicking on Clear All. To select the current pixel, select the data cursor and drag it to the new position. You may also type the pixel number into the data legend, which shows the data value of the selected pixel. There are also options to change the data cursor appearance.

- HIDE: Toggles whether to hide or show the bad pixels. When Hide is selected a bad pixel is given a value of the average of the two adjacent pixels.

ACTIONS

- WRITE DATA TO CSV: To write a series of data samples at defined intervals to a file using the comma separated values (.csv) format, Maximum samples 65,000. click the Write Data button and enter the information as requested.



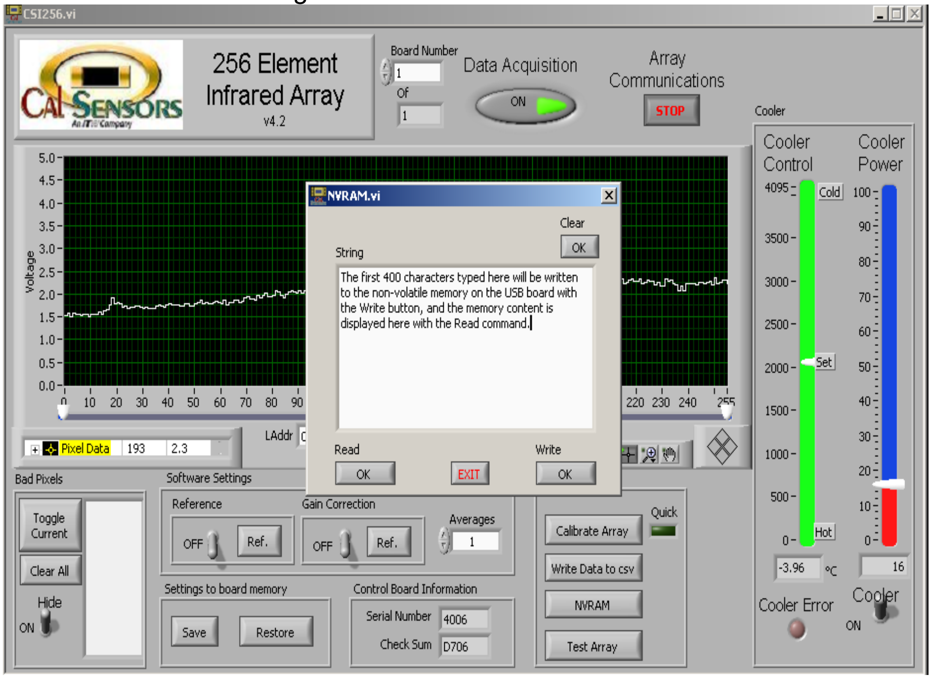
Write to .csv file

Input number of samples to take and the delay between samples.

Samples (#): 5

Delay (mS): 10

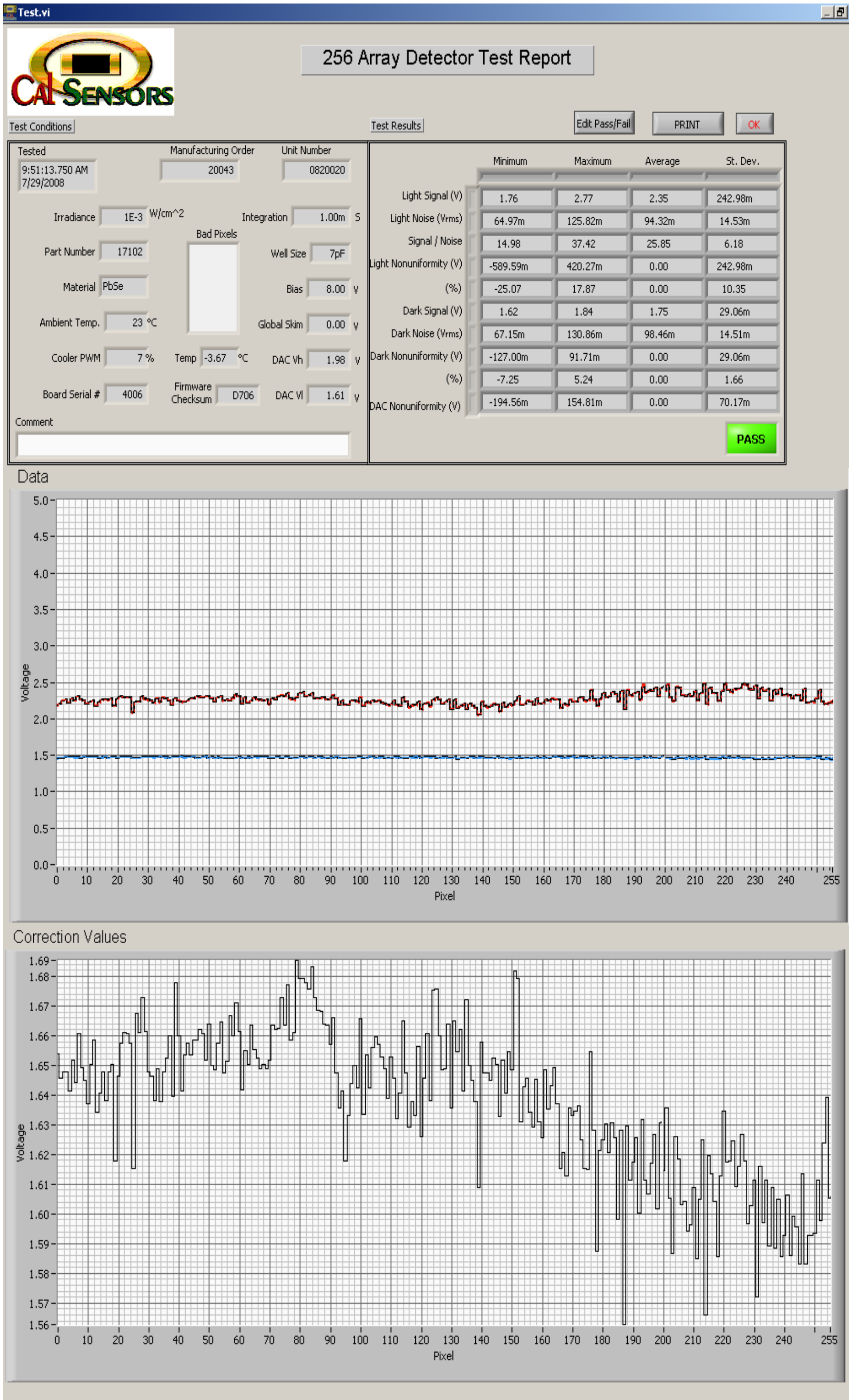
- NVRAM: Provides access to 400 bytes of data that can be stored in the non-volatile memory on the USB interface board. This is useful for storing system setup or calibration parameters. This function is intended only to demonstrate the usage of the NVRAM functions.



NVRAM.vi

String: The first 400 characters typed here will be written to the non-volatile memory on the USB board with the Write button, and the memory content is displayed here with the Read command.

- TEST ARRAY: This function facilitates testing of the array under known input conditions. After the button is pressed you will be asked for the part serial number and other test conditions. Press OK after the information is entered and you will be asked to cover the array. Pressing OK will initiate the gathering of 100 data samples. You will then be asked to uncover the array, exposing it to the calibrated illumination that you specified, and again 100 data samples will be gathered. Once all the data is gathered the test data sheet will be displayed with both basic and calculated results. You may enter a comment in the appropriate section, and print the data sheet on the system default printer by pressing Print. Close the window when testing is complete to return to the main window. A test report example is shown on the following page.



256 Array Detector Test Report

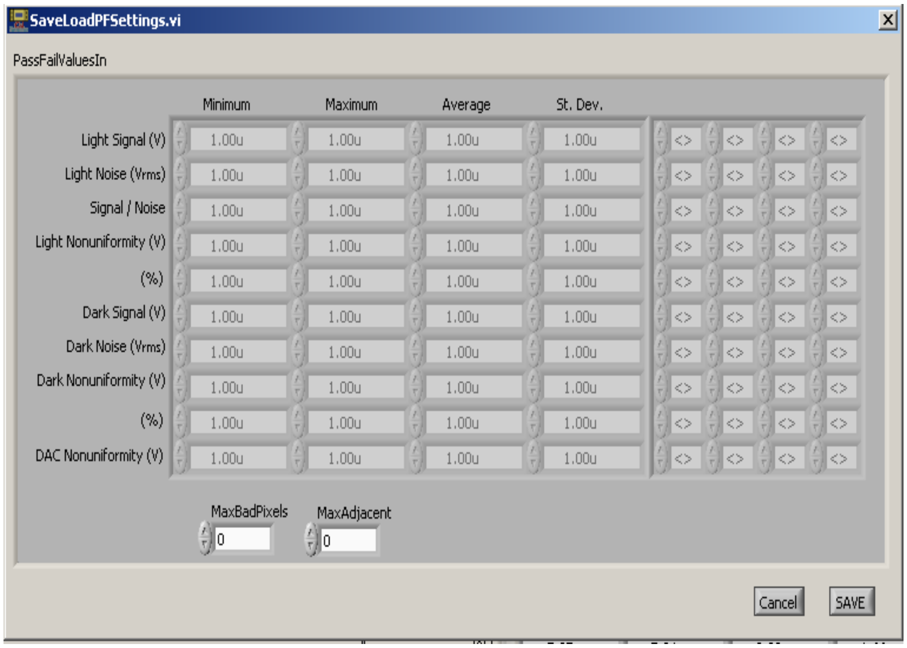
Tested: 9:51:13.750 AM 7/29/2008
Manufacturing Order: 20043
Unit Number: 0820020
Irradiance: 1E-3 W/cm^2
Integration: 1.00m S
Part Number: 17102
Bad Pixels:
Well Size: 7pF
Material: PbSe
Bias: 8.00 V
Ambient Temp.: 23 °C
Global Skim: 0.00 V
Cooler PWM: 7 %
Temp: -3.67 °C
DAC Vh: 1.98 V
Board Serial #: 4006
Firmware Checksum: D706
DAC Vl: 1.61 V
Comment:

	Minimum	Maximum	Average	St. Dev.
Light Signal (V)	1.76	2.77	2.35	242.98m
Light Noise (Vrms)	64.97m	125.82m	94.32m	14.53m
Signal / Noise	14.98	37.42	25.85	6.18
Light Nonuniformity (V)	-589.59m	420.27m	0.00	242.98m
(%)	-25.07	17.87	0.00	10.35
Dark Signal (V)	1.62	1.84	1.75	29.06m
Dark Noise (Vrms)	67.15m	130.86m	98.46m	14.51m
Dark Nonuniformity (V)	-127.00m	91.71m	0.00	29.06m
(%)	-7.25	5.24	0.00	1.66
DAC Nonuniformity (V)	-194.56m	154.81m	0.00	70.17m

Data

Correction Values

- EDIT PASS/FAIL: This feature gives the user the ability to change and save custom Pass/Fail criteria within the test function. Each of the test parameters can be adjusted to provide Min/Max, Average, and Standard Deviation test criteria.



	Minimum	Maximum	Average	St. Dev.				
Light Signal (V)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Light Noise (Vrms)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Signal / Noise	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Light Nonuniformity (V)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
(%)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Dark Signal (V)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Dark Noise (Vrms)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
Dark Nonuniformity (V)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
(%)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>
DAC Nonuniformity (V)	1.00u	1.00u	1.00u	1.00u	<>	<>	<>	<>

MaxBadPixels: 0
MaxAdjacent: 0

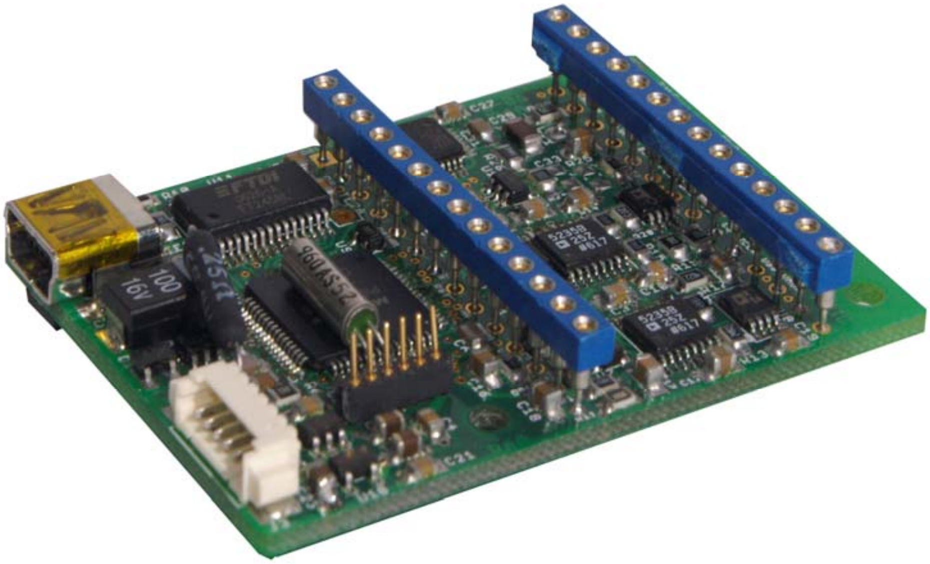
Cal Sensors

256 Element Array Development System User's Manual

3. Interface Electronics Board

General Description

The interface electronics board contains a microcontroller that supplies all timing and cooler control for the system along with USB interface circuitry and a current switch for powering the cooler. System control is provided by sending commands over the USB interface. The cooler is controlled by Pulse Width Modulating the supplied cooler current based on feedback from the thermistor. The set temperature is determined by a resistor located on the Interface Electronics Board. This set temperature is approximately -4° C.



Power connection

Power to the Interface Electronics Board is supplied through a six pin connector. Power supplied to this board also supplies power to the detector array and the thermoelectric cooler.

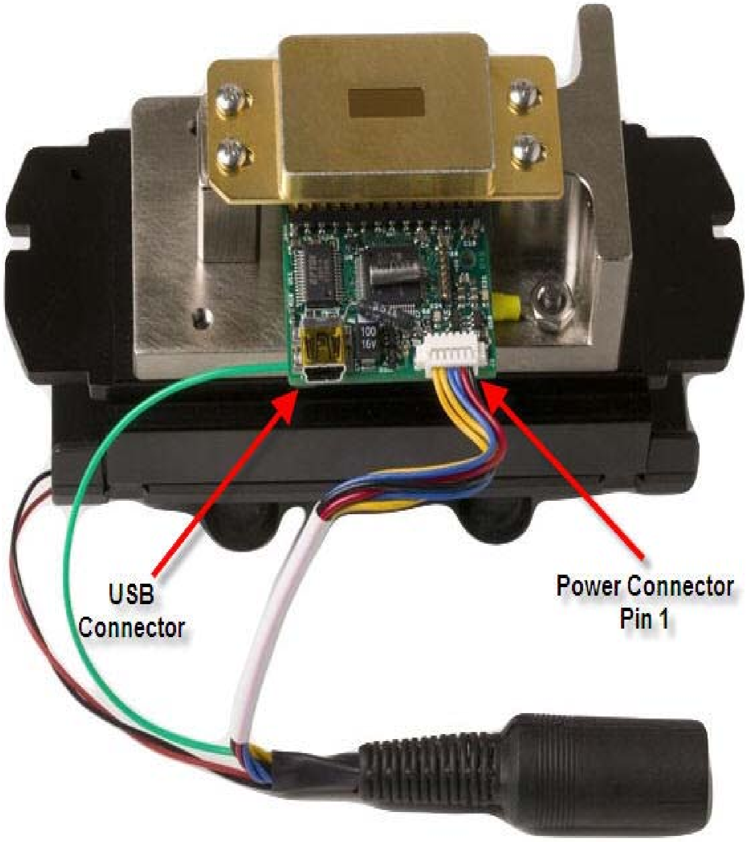
Connector Pin Out:

Pin 1: BLACK Wire - Ground Return for +12V power (100mA)
Pin 2: RED Wire - +12VDC @ 100mA System Power
Pin 3 & 4: BLUE Wire - Ground Return for TEC Power (approx 2A)
Pin 5 & 6: YELLOW Wire - +5VDC* @ 2 Amps TEC Power

In addition, the Development System powers the system's fan from the twelve volts power supply. This requires an additional 500 milliamps for a total of 600 milliamps on the twelve volt supply.

** This voltage can be reduced to provide greater cooler control stability if the PWM value is below 15%.*

Note that the Ground Returns for both the +12V power and the TE power (pins 1, 3 and 4) must be connected together at the system common ground point otherwise damage may result to the controller board.



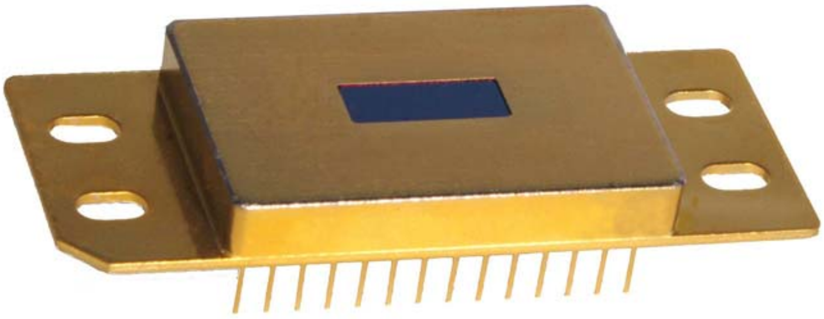
Cal Sensors

256 Element Array Development System User's Manual

4. Detector Array

General Description

The Cal Sensors PbS/PbSe array has 256 elements in a linear configuration. Each element is 40 microns wide and 450 microns high on 50 micron center-to-center spacing. The 28 pin array package contains the 256 element linear array, integrating multiplexers, a thermoelectric cooler, and a thermistor for temperature control.

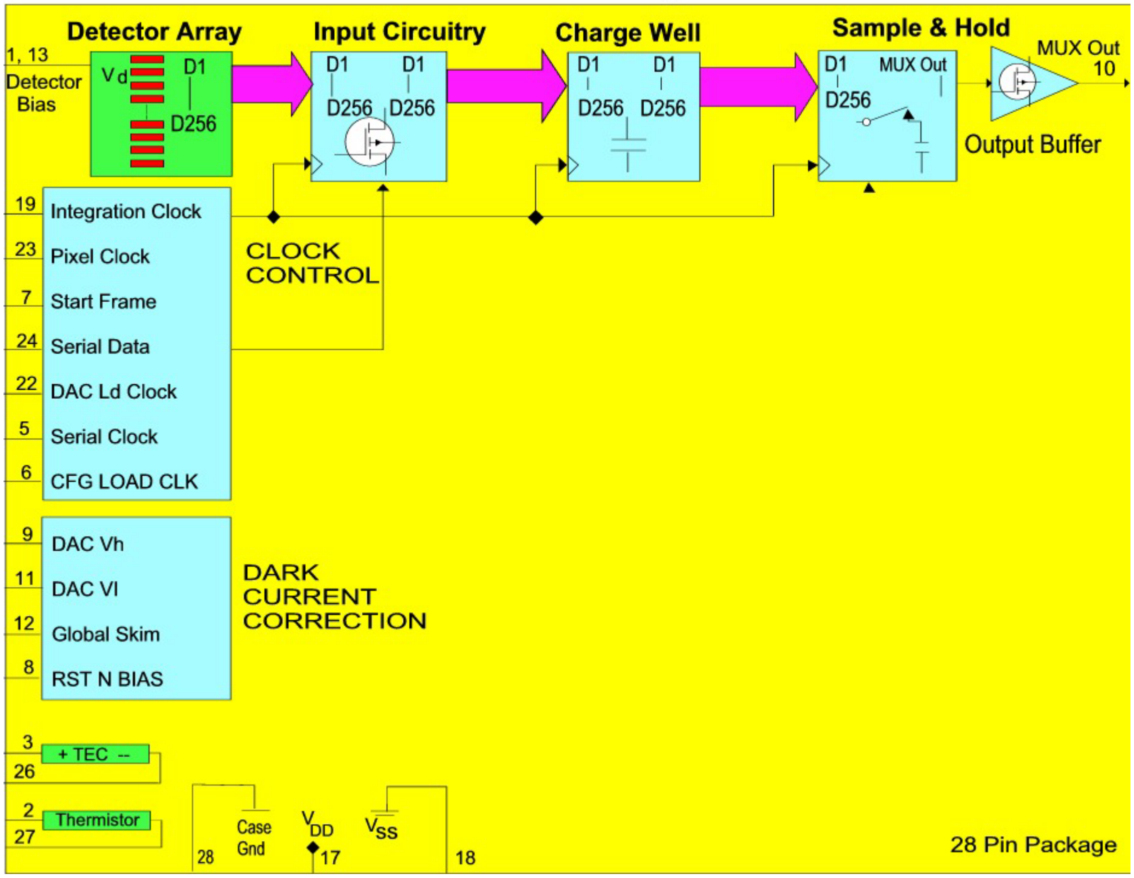


Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Power Supply Voltage	V_{DD}	7	V
Input Voltage (any pin)	V_{PINMAX}	V_{DD} + 0.7V Vss - 0.7V	V
Operating Temperature	T_{OP}	PbS -40 to +65 PbSe -40 to +55	°C
Storage Temperature	T_{stg}	PbS -40 to +65 PbSe -40 to +55	°C
Detector Current	I_{dmax}	6	µA

Functional Block Diagram

Cal Sensors 256 Element Multiplexed Array
Functional Diagram

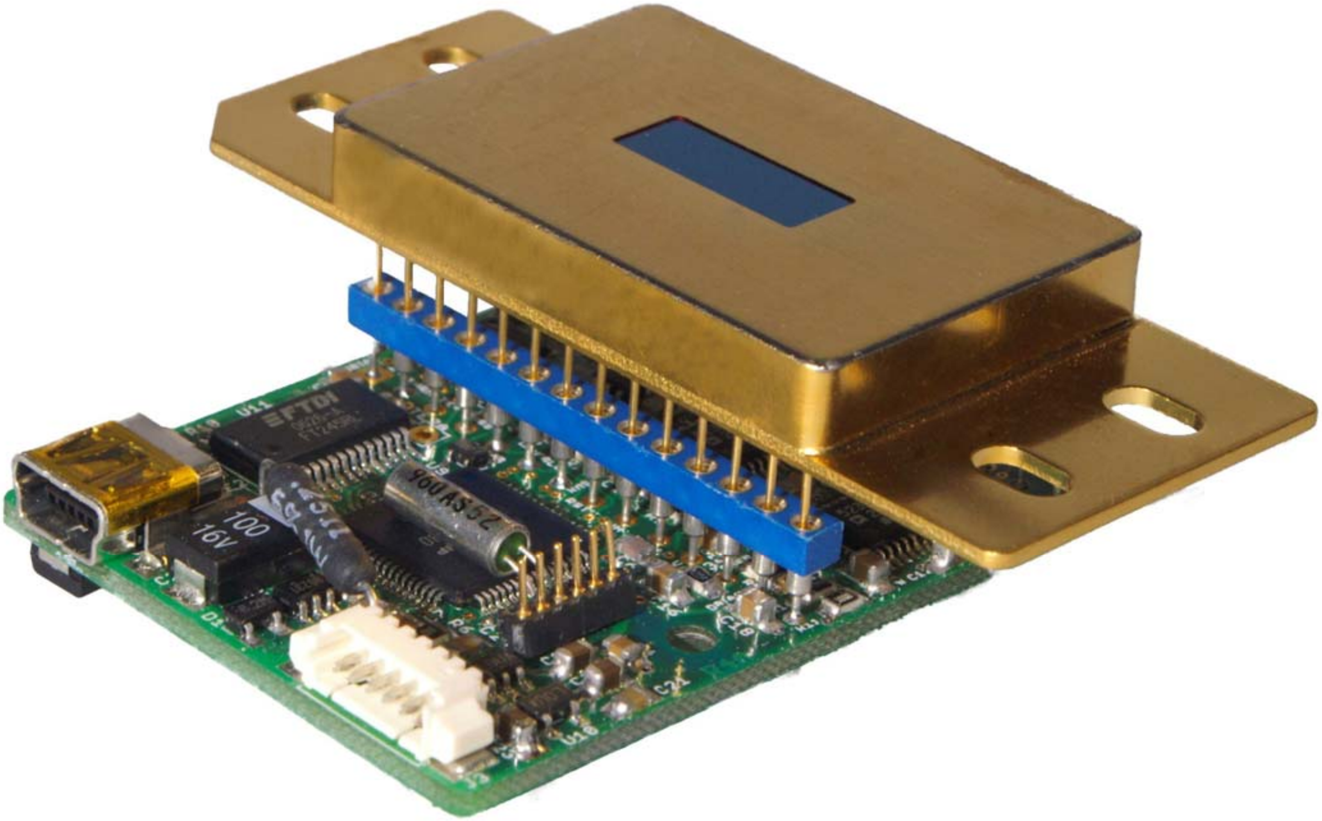


CalSensors

LASER COMPONENTS

256 Element Array

Programming Manual



CSI 8085 (8/08)

Section

1

Cal Sensors

256 Element Array Programming Manual

1. Introduction

The purpose of this manual is to provide our customers with the basic operating principles of the Cal Sensors 256 Element Multiplexed Array as interfaced through the Electronics Interface Board. With this information and the ADIC Library Documentation the user will be able to write code to operate the array in a variety of programming languages. The ADIC Library Documentation provides detailed information on each function, as well as information regarding specific language interfacing, error code definitions and documentation on working with multiple arrays on a single computer.

The 256 Element Array package can be interfaced to directly without the interface board, but requires a significant amount of digital logic and various voltages. The interface board simplifies the operation of the array by providing all necessary voltages, timing and thermoelectric cooler control functions. The array interface is then accomplished by sending commands over a USB interface using a standard Windows dynamic linked library (dll).

This manual will first discuss the operation of the array, then the operation of the interface board.

Section

2

Cal Sensors

256 Element Array Programming Manual

2. Array – Principles of Operation

Introduction

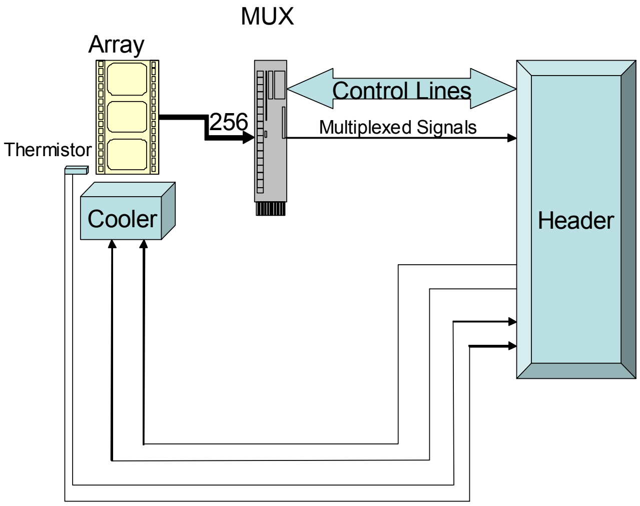
The array consists of the following items, all housed within an industry standard 28 pin package:

1. Thermoelectric cooler – used for thermal stabilization. **Note: Sufficient heatsinking must be provided to prevent damage to the array.**

2. Thermistor – used to provide feedback to control the temperature of the thermoelectric cooler.

3. Multiplexing Interface IC – used to condition the array output and multiplex all 256 channels onto a single output line.

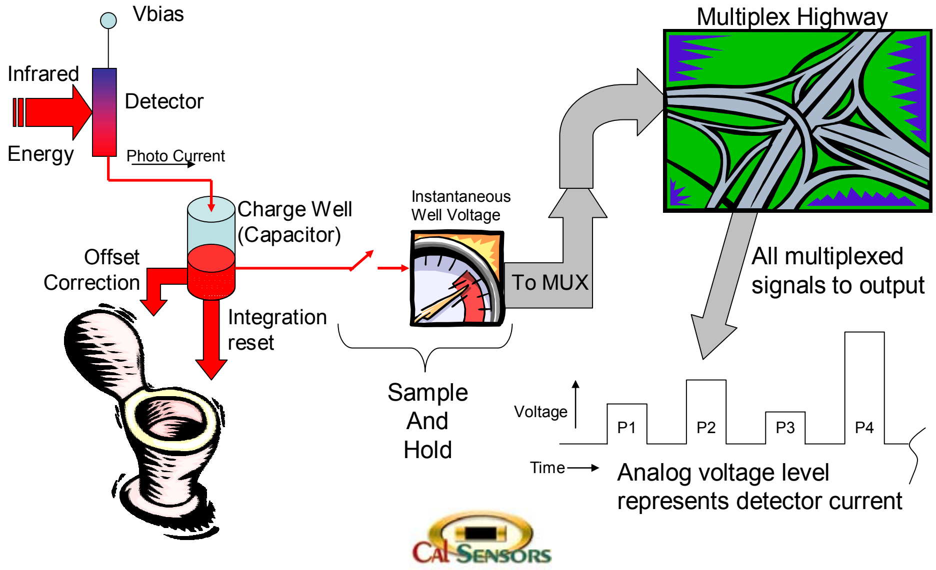
4. 256 Element Photoconductive Infrared Array – used to convert infrared photons into an electrical output.



- Figure 1 - Array Functional Block Diagram

Operation

A simplified pictorial representation of the array operation is shown in Figure 2. This should be referred to throughout the following discussion.



• Figure 2 - Array Operation

Summary

Each pixel has a bias voltage applied, generating a current which is collected in a charge well (capacitor). The offset current is subtracted from the incoming current, leaving only the signal current on the charge well. The signal current accumulates on the charge well for the integration period, at which time the voltage is sampled, the charge on the capacitor is removed and the accumulation cycle starts again. The value from all 256 sample-and-hold circuits are multiplexed onto a single line and sent out.

Detailed Description

Each detector element has a bias voltage, Vbias, applied to it. The nature of photoconductive detectors is that they change resistance with incident photons. With an applied bias voltage the electrical current out of a photoconductive detector will consist of two parts. There will be an amount of current that exists when the element has no incident radiation (dark current) and a different amount of current when the element is exposed to the “signal” radiation. A higher bias voltage will produce more overall current. The “signal” current therefore can be determined by subtracting a known dark current from the total current coming from the detector element.

The difficulty with Lead Salt photoconductors (PbS and PbSe) is that the dark current is typically quite large compared to the signal current. In addition the bulk resistance of the film changes significantly with changing temperature. To stabilize the temperature the Cal Sensors array contains a thermoelectric cooler and a thermistor, which is strategically located. With feedback from the thermistor, the cooler current can be modulated to accurately control the temperature of the detector array.

With the variability due to temperature removed the task of the multiplexer is to determine the dark current for each pixel and eliminate it so the signal current can be collected. This is performed through a calibration process where the array element is covered, removing all signal photons, and the output current is measured. This dark current can then be "skimmed" from the total current revealing the signal current. In this system there are actually two methods to remove the dark current. The first is Global Skim, where a fixed amount is skimmed from all 256 channels. The second is an individual correction for each pixel, typically required to accommodate the resistance variability of the photoconductive elements. This individual correction is always used, whereas Global Skim is often not used. Both global and individual dark current corrections are included as Offset Correction in Figure 2.

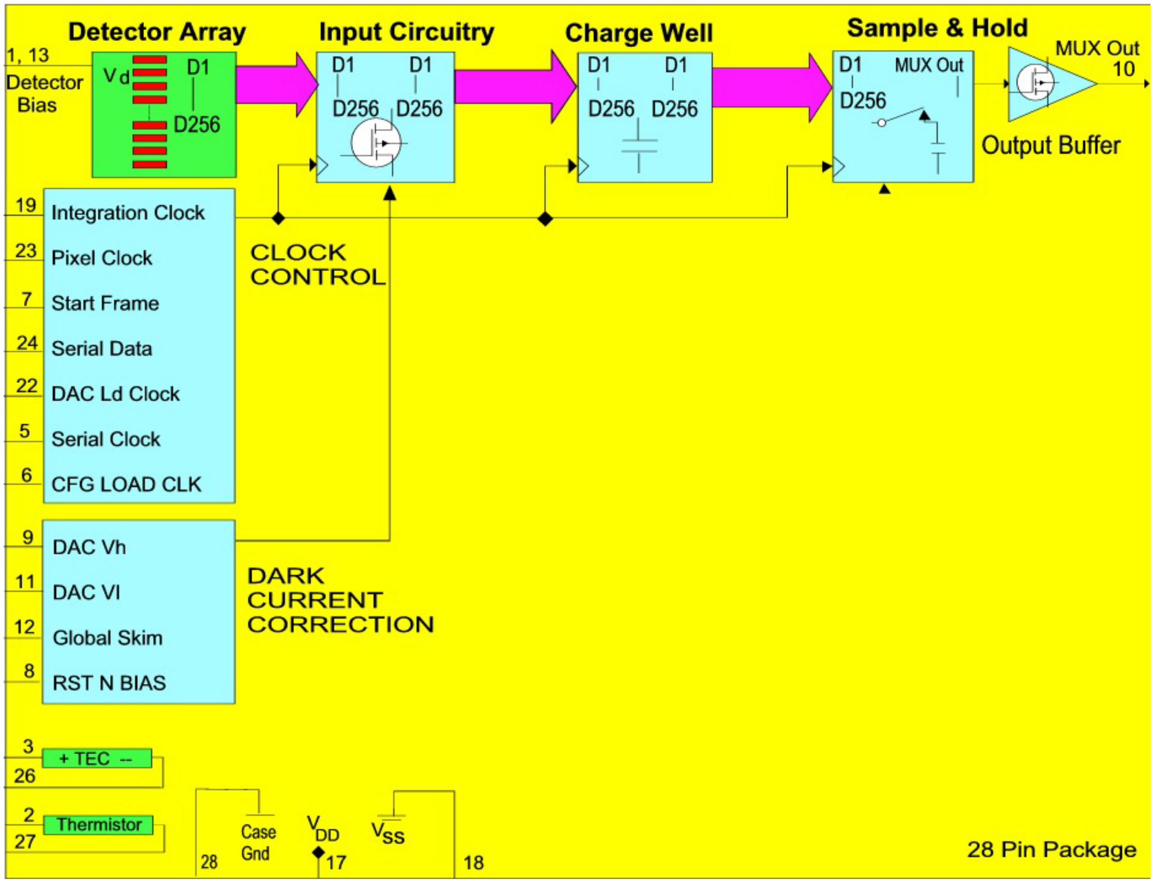
The individual pixel correction is implemented through a series of 256 digital to analog converters (DACs). All of the DACs operate between a high and low voltage (DAC Vh and DAC Vl). Each 8 bit DAC divides this voltage range into 256 steps and applies the appropriate correction to each pixel depending on the individual dark currents. The process of determining the DAC correction values for each pixel is referred to as Calibration. The correction values are dependent on other settings (integration time, bias voltage, etc.) so these values must be set and all signal radiation blocked prior to performing a calibration. In theory, if the temperature of the array and all other factors remain constant, a given calibration would never need to be repeated. In practice, because of changing temperature and other factors, the calibration process will need to be repeated at some interval. This needs to be performed more or less often depending on the stability or resolution required by a particular application.

The resulting signal current is accumulated on the charge well capacitor. The size of this capacitor can be set to 1pF, 4pF, 7pF, 10pF, 11pF, 14pF, 17pF or 20pF. Decreasing the charge well size effectively increases the gain of the system, in that the resultant voltage on the charge well after a certain integration time will be greater with a smaller capacitor. Since the total charge accumulated depends on bias voltage, detector resistance, dark current subtraction accuracy and integration time it is important to select a capacitor size that can accommodate the charge accumulation without "filling up", otherwise signal clipping will occur.

Once the integration time is completed the charge well is sampled and the resulting voltage held in a sample-and-hold circuit. This sampled voltage is proportional to the signal photons on the detector element. After the sampling is accomplished, the charge well is reset and the charge accumulation repeats. The resulting 256 voltage levels are multiplexed at a fixed clock rate onto the single output line.

Figure 3 shows the array pin assignments with the associated functional block diagram. Many of the pins are associated with clocking and control functions and require digital logic to implement. For systems that already contain digital logic or microcontroller functions this may be practical to provide. Many systems, however, are computer based and need to interface through standard ports. This functionality is provided by the Interface Electronics Board described in the next section.

Cal Sensors 256 Element Multiplexed Array
Functional Diagram



- Figure 3 - Array Pin Functions

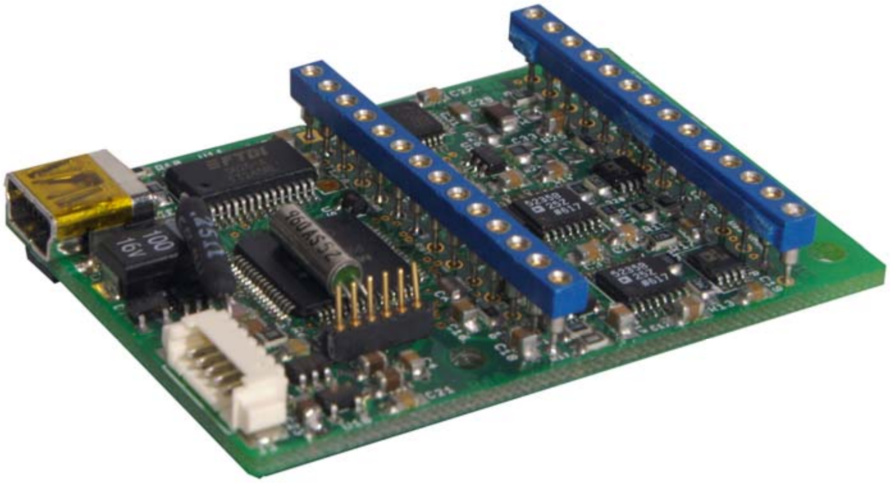
Cal Sensors

256 Element Array Programming Manual

3. Interface Board – Principles of Operation

General Description

The interface electronics board contains a microcontroller that supplies all timing and cooler control for the system along with USB interface circuitry and a current switch for powering the cooler. System control is provided by sending commands over the USB interface. The cooler is controlled by Pulse Width Modulating the supplied cooler current based on feedback from the thermistor. The set temperature is determined by a resistor located on the Interface Electronics Board. This set temperature is approximately -4° C.



Features

- Standard USB interface using Windows dynamic linked library for interface functions.
- Small size (1.4” x 2.1”)
- 10 bit linear precision array voltage settings, providing all of the required array voltages from a single 12V input.
- 16bit output signal digitization at 500K samples/second
- Non-volatile storage of array settings and user data
- High efficiency thermoelectric control to fixed temperature
- Generation of all required timing and control signals

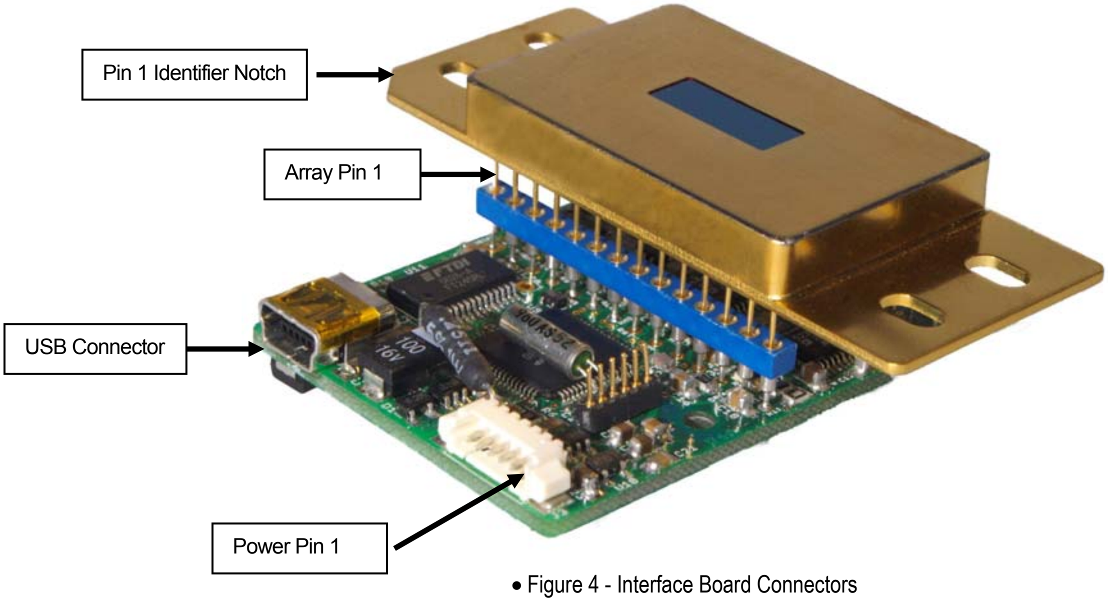
Power connection

Power to the Interface Electronics Board is supplied through a six pin connector. Power supplied to this board also supplies power to the detector array and the thermoelectric cooler.

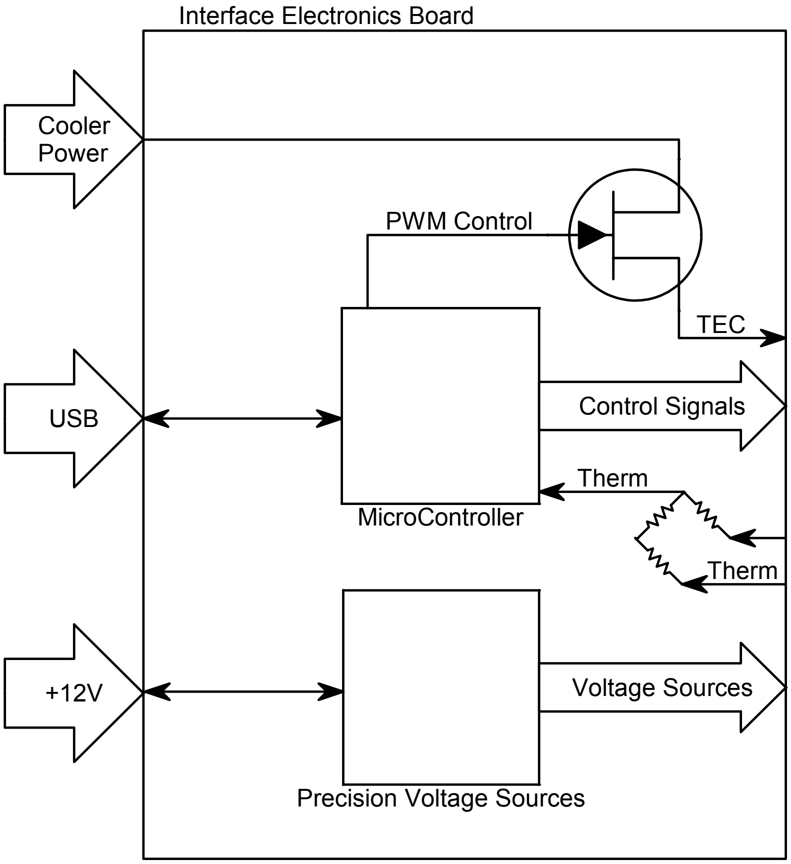
Connector Pin Assignment:

Pin 1: BLACK Wire - Ground Return for +12V power (100mA)
Pin 2: RED Wire - +12VDC @ 100mA System Power
Pin 3 & 4: BLUE Wire - Ground Return for TEC Power (approx 2A)
Pin 5 & 6: YELLOW Wire - +5VDC @ 2 Amps TEC Power

Note that the Ground Returns for both the +12V power and the TE power (pins 1, 3 and 4) must be connected together at the system common ground point otherwise damage may result to the controller board.



- Figure 4 - Interface Board Connectors



- Figure 5 - Interface Board Block Diagram

Section

4

Cal Sensors

256 Element Array Programming Manual

4. Operation

Overview

Because of the high level of functional integration contained in the Interface Electronics Board, the operation of the array is simply a matter of supplying mechanical connection (including heatsinking), electrical connection (power and USB) and then sending the appropriate commands from the host computer. Therefore, this section is primarily a description of how to implement the software commands. Since a standard Windows interface library is provided any standard programming language may be used. Cal Sensors provides an application written in National Instrument's LabView with the Development System. Because of the generic nature of the interface library no particular programming language will be targeted in this section. Specific language implementations are shown in the ADIC Library Documentation, and that document should be referred to for details on each of the library commands.

Functions

ArrayAdd	SaveE2Block
ArrayPercentDiff	SendAllCoeff
ArraySubtract	SetConversionRef
CloseDevice	SetConversionRef_Brd
DoCalibrate	SetDacGSkim
Flux_P	SetDacReferences
Flux_W	SetDacReferences_Brd
GetBoard_Handle	SetDacVH
GetData	SetDacVL
GetData2	SetDetBias
GetDeviceHandle	SetGlobalSkimVal
GetNumBoards	SetGlobalSkimVal_Brd
GetQuery3	SetIntegration
HideBadPixels	SetMuxSize
HideBadPixels_Brd	SetWellSize
MarkBadPixel	StoreAll
ReadE2Block	SuppressCalStat
ReadPWM	SuppressErrors
ReadTemp	SyncPC
RestoreAll	TECoolerPower

Several of these functions simply perform calculations that are convenient for a particular application.

Calculation Functions

ArrayAdd	Adds two single dimension arrays.
ArrayPercentDiff	Percent difference between two single dimension arrays.
ArraySubtract	Subtracts two single dimension arrays.
Flux_P	Integrates Plank's blackbody equation in Photons/(sec•cm^2•sr).
Flux_W	Integrates Plank's blackbody equation in Watts/(cm^2•sr).

The remainder of the functions are involved with controlling the array. Many of these have default conditions that are usually left at their default value, so there is another subset of functions that are most commonly used for systems that use a single array connected to a computer.

Common Functions

CloseDevice	Closes communication with the device. This should always be the last command sent.
DoCalibrate	Calibrates the array, setting the DAC coefficient array of correction values for each pixel. In the default condition Global Skim will not be used and DAC Vh and Vl will be determined.
GetData	Reads the digital data values for each pixel.
GetDeviceHandle	Returns an address to the device used in all other function calls. This should always be the first command sent.
MarkBadPixel	Sends the bad pixel map to the board. The board will not use values from bad pixels, instead returning the average of the two adjacent pixels with GetData.
RestoreAll	Restores settings from the non-volatile RAM on the board previously saved with the StoreAll command.
SetDetBias	Sets the bias level for the array.
SetIntegration	Sets the integration time for the array.
SetMuxSize	Sets the size of the Mux. This should always be set to 256.
SetWellSize	Sets the charge well to 1pF, 4pF, 7pF or 10pF.
StoreAll	Stores array settings to non-volatile RAM on the board.
TECoolerPower	Turns on or off the cooler. When on the temperature of the array will be held to the set point, (approximately -4°C),

Before any functions are called up, there are several data structures that need to be established. These structures are passed to various functions and should be initialized before us in a function. Most functions are passed the Device Handle (obtained from GetDeviceHandle) and return a status variable which is 1 if the function completes successfully. Please see the appendix of ADIC Library Documentation for a list of error codes.

Also note that there are specific functions that deal with multiple attached boards. Please refer to the ADIC Library Documentation under the section Working With Multiple Controller Boards.

Data Structures

coeffArray	The 256 element array of DAC correction coefficients.
bPixMapArray or bpMap	The 256 element array of bad pixels. Should be 1 at bad pixel locations, otherwise all 0.
MxData	The 256 element array of pixel values returned from GetData.
BaseSettings	A 16 element array containing array settings. BaseSettings(0) = Integration Time BaseSettings(1) = NOT USED, value will ALWAYS be 0 BaseSettings(2) = Global Skim value BaseSettings(3) = NOT USED, value will ALWAYS be 0 BaseSettings(4) = DACVh value BaseSettings(5) = NOT USED, value will ALWAYS be 0 BaseSettings(6) = DACVl value BaseSettings(7) = NOT USED, value will ALWAYS be 0 BaseSettings(8) = NOT USED, value will ALWAYS be 0 BaseSettings(9) = Detector Bias BaseSettings(10) = Mux Size BaseSettings(11) = Direction Flag BaseSettings(12) = Number of Bad Pixels BaseSettings(13) = Integration Well Size BaseSettings(14) = Left wndow address BaseSettings(15) = Right window address

Sequence of Events

The standard sequence of events when interacting with the array is as follows:

1. Call GetDeviceHandle to get the device handle. An error will be returned if there are no devices attached, they are not powered up or there is some other communication problem. **Note: The USB drivers must be installed on any system using the array before any communication is possible.**
2. Initialize and place all zeros in the bad pixel array.
3. Set the mux size to 256 using SetMuxSize.
4. Set a well size using SetWellSize. (10pF is a good start.)
5. Set the integration time using SetIntegration. (500µS is a good start.)
6. Set the detector bias using SetDetBias. (7V is a good start.)
7. Call TECoolerPower with a teStatus of 1 if required to turn the cooler on.
    a. Note: Ensure that the array has sufficient heatsinking prior to issuing this command.
    b. Wait until the temperature has stabilized before calibrating.
8. Call DoCalibrate making sure the parameters passed have all been initialized.
    a. Remember to cover the array during calibration.
    b. A value of 1.0 is a good starting point for arraySetVal.
9. Call GetData as necessary making sure the parameters passed have all been initialized.
10. If the cooler has been turned on call TECoolerPower with a teStatus of 0 to turn the cooler off.
11. At the end of communications call CloseDevice.

If the array status was previously stored with the StoreAll command, steps 3 – 6 may be skipped by calling RestoreAll.

DoCalibrate

Since calibration is one of the most important functions, it is important to understand the process being performed by the interface board. The DoCalibrate function looks at the current being generated by each pixel and attempts to calculate values for all DACs that will make all outputs equal to a target output voltage. The actual target correction value is set by arraySetVal, which is passed to DoCalibrate. Intuitively the correction target should be as low as possible to provide the greatest range of output values. Since the multiplexer cannot operate at the lower voltage rail there must be some minimum voltage that allows the full range of DAC correction values. Typically an array can be calibrated with target values as low as 0.50V or 0.75V.

If pixels are marked as bad in the bPixMapArray sent to DoCalibrate, their values are not used to calculate the DAC values. If there is a bad pixel that is not marked typically the DAC Vh or DAC Vl will be at the rail and the bad pixel will be either very high or low. The correction for this is to mark the pixel bad and perform another calibration.

Changes in array parameters such as bias or well size will typically require a re-calibration. Changes in array operating temperature will also require a re-calibration.

Conclusion

With the Interface Electronics Board, operating the Cal Sensors 256 Element Array becomes simply a process of issuing commands through a standard USB port. This manual has provided the hardware and software details necessary to operate the array within this environment. Please refer to the DLL library description in the ADIC Library Documentation for detailed library information.

Recent Developments in Photoconductive Infrared Arrays

Purpose

The infrared region from 1µm to 5µ is an area of interest for both spectroscopic and thermographic applications. Lead sulphide (PbS) and lead selenide (PbSe) are intrinsically photoconductive materials that cover this important spectral region and have a long history of development and manufacturing. They have several advantages over competing materials, but because of their nature, they have several challenges that need to be addressed. This paper will outline the application of several established technologies that have been applied to make PbS and PbSe arrays compatible with modern infrared array applications. An implementation will be shown that takes advantage of these techniques to produce a second generation array.

Problem Discussion

Selection of Detector Material

Comparison of detector materials

A variety of detector materials can be considered for the small, low powered, low cost systems required today. Of these detectors, there are a number which typically operate at very cold temperatures to reduce thermally generated free carriers and achieve adequate performance. These include InSb, InAs and HgCdTe. These detector materials cannot be considered unless the system performance requirements warrant the increased size, cost and complexity. Thermal detectors using pyroelectric or bolometric materials could be considered because of their broad wavelength response, however they have low sensitivity and slow response speed compared to photon detectors so they would be inappropriate for a general purpose spectroscopic or thermometric system. The detector materials that remain for consideration are InGaAs photodiodes (both standard and extended) and lead salt photoconductors (PbS and PbSe). All of these detectors have reasonable cooling requirements and good response times. Standard InGaAs photodiodes have excellent sensitivity and speed, but are limited in upper wavelength sensitivity to 1.7µm and therefore can not be considered for a general purpose solution even in the near infrared. Extended InGaAs photodiodes have reasonable sensitivity, but still only extend to 2.6µm. The remaining alternatives, PbS and PbSe photoconductors have characteristics that make them excellent candidates. PbS has detectivity values that are at least as good as Extended InGaAs with sensitivity to 3µm. PbSe is approximately an order of magnitude less sensitive than PbS, but has sensitivity to 5µm.

History of lead salt photoconductors

Lead salt photoconductors have a long history of development. The photoconductive properties of lead sulfide (PbS) were discovered in 1933 by Kutzscher at the University of Berlin, although his work was performed in great secrecy and not publicly known until after 1945(1). Lead sulfide was also produced by Cashman (Northwestern University) and Gudden (University of Prague) and implemented for various military applications at that time and indicated good sensitivity to 3µm. Robert Cashman was also working with other lead salt compounds and showed that lead selenide (PbSe) also had promise as a photoconductor to 5µm, which was particularly important because of the 3 µm – 5µm atmospheric transmission window. Commercial production of PbS began around 1943 in Germany, 1944 in the United States (Northwestern University) and 1945 in England (Admiralty Research Laboratory).

PbS and PbSe have a long history of development and have taken advantage of advances in manufacturing techniques to continue to be important detectors for infrared sensing. Advances in photolithography in the 1960s provided the methodology to create arrays of photoconductive materials, thereby advancing the number of applications available to these detectors particularly in the area of spectroscopy.

Issues and Solutions

Principals of photoconductivity

Photoconductors are essentially resistors whose conductivity changes with incident photons. A photon with energy greater than the material's band-gap energy is absorbed in the photoconductive material to produce electron-hole pairs, which increases the conductivity of the material. To measure the incident radiation a simple voltage divider bias circuit is typically used. The current through the load resistor, and therfore the voltage across the load resistor varies with incident radiation. In practice the photoconductive change is small compared to the bulk resistance of the material, so differentiating the signal can be difficult. An AC coupled circuit is often used and the radiation source is modulated by mechanical (chopper) or electronic (pulsed source) means. Besides providing the ability to easily distinguish the photocurrent, this method has the added advantage of minimizing the detector noise, including 1/f noise inherant in these detector materials, by use of a band pass filter or lock-in amplifier centered at the modulation frequency. The disadvantage of the modulated source method is the size and complexity of modulating the source and the fact that slow or steady state radiation changes cannot be detected.

Because of the nature of photoconductive materials there are several issues that need to be addressed to insure a successful product. This is particularly important in applications that require high sensitivity such as reflective spectroscopy or precision thermography.

Thermal Coefficient of Resistance

Photoconductive detectors have a bulk resistance which is temperature dependent. For lead salt photoconductive films this temperature dependency is typically on the order of 3%/°C. The problem is that if the bulk resistance is changing due to temperature variations it can be indistinguishable from the photoconductive signal. Modulation of the signal radiation can help address this issue, but this requires extra hardware and is not an option where modulation is not compatible or desired in the system solution.

Several schemes have been developed to attempt to compensate for the change in detector resistance and responsivity that occur as the temperature of the film changes. Some of these schemes include elements, such as per-detector thermal compensation elements, that are not compatible with large pixel count arrays. The most simplistic approach is to hold the detector temperature constant as the ambient temperature changes. Fortunately advances in Peltier cooling technology and cooler control design make it relatively easy to include a thermoelectric cooler, temperature sensing device, and control electronics(2)(3)into any system solution. The solution chosen for this development was a thermoelectric cooler with a surface area large enough to encompass both the detector array and the interfacing electronics chip. Holding both the detectors and the electronics in an isothermal condition insures maximum stability in the device. Locating the sensing element as close to the center of the isothermal surface as possible improves the feedback to the control circuit.

“Dark” Current

As previously discussed, in the typical bias arrangement there is a bias or “dark” current generated by the bias voltage being applied across the bulk (dark) resistance of the photoconductor. Because the change in resistance due to photon generated carriers is small compared to the bulk resistance of the film, the signal current change is commensurately small. In order to detect the incident photons on the film, the bias current must be disposed of in some manner. This is often done, again, by modulating the signal radiation and then AC coupling the resultant signal, which is effective but can lead to issues particularly in arrays where timing between elements is often critical.

Because the detector resistance can be held relatively constant by thermal stabilization of the detector, a bias current subtraction scheme can be used. The advantage of bias current subtraction is that the source does not need to be modulated and a true DC signal system can be implemented. Subtracting a constant current from all of the array elements however does not provide adequate solution because the film fabrication process cannot guarantee highly uniform element-to-element resistances. A scheme has been developed where both global and per-pixel subtraction of the bias current can be performed. Figure 1 shows data from an array with particularly wide resistance variation, both before dark current correction (Uncalibrated) and after correction using an 8 bit D/A converter on each pixel. The nearly flat calibrated line shows the effectiveness of this process. This dark current subtraction scheme allows DC operation of the array, eliminating any mechanical or electronic chopping.

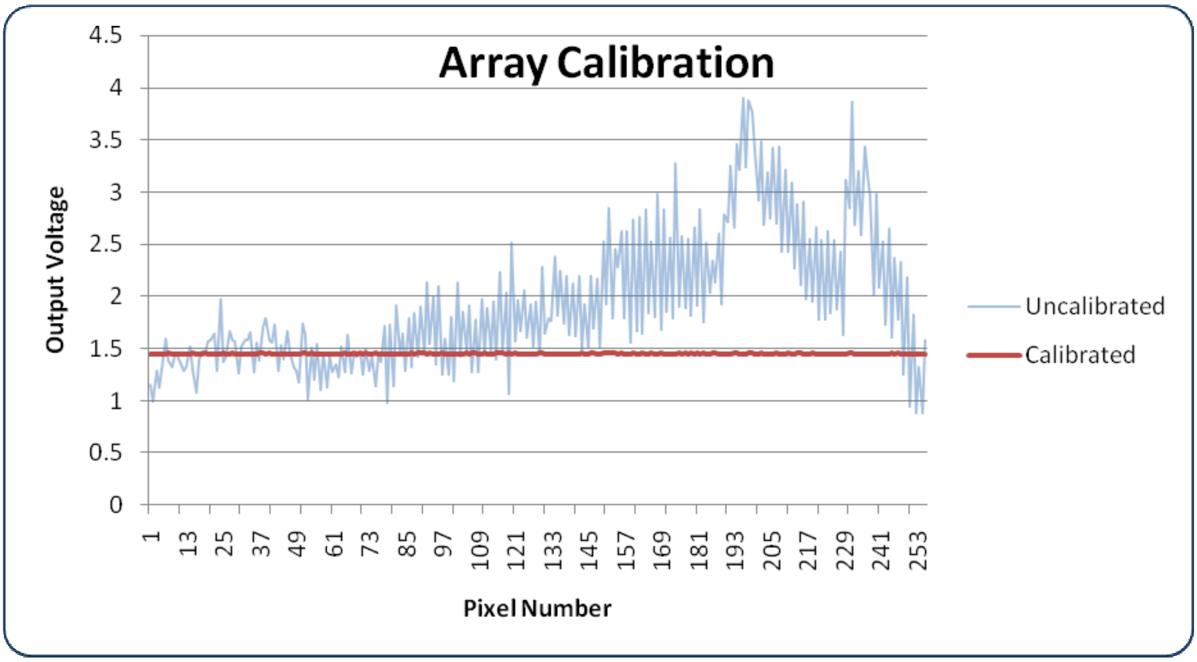


Figure 1 - Effectiveness of Per Pixel Dark Current Subtraction

Environmental Sensitivity

Wet chemically deposited PbS and PbSe photo conductive films are poly crystalline in structure. The materials used in their fabrication produce films that are hygroscopic, sensitive to UV radiation, and mechanically fragile. The film characteristics can also change or be destroyed at high temperature or with condensing moisture.

The solution is to insure that the components are hermetically maintained in an inert environment. Proper selection of the backfill gas can also help with the thermal load presented to the thermoelectric cooler. Vacuum packaging is also an option, but is not required for the reasonable operating temperatures used by lead salt photoconductors and the complexity is usually avoided.

Small Geometries

Single element detectors produced from wet chemically deposited photoconductive films have traditionally been delineated by standard photolithographic techniques. Current array geometries are typically 40µm x 450µm for spectroscopic arrays and 40µm x 40 µm for thermographic arrays, both with inter-element gaps of 10µm. These geometries are compatible with most infrared optical systems and provide enough photon collection area to produce reasonable signals. Although these geometries do not push the limits of photolithographic techniques, with traditional deposition methods the polycrystalline films and substrate surface finishes the topographies make fine photolithography difficult. In addition the films are sensitive to undercutting which can occur with photolithographic etching and increases the resistance variability in arrays with small geometries.

Ion milling provides a method of delineation with finer detail in these situations(4) and eliminates some of the disadvantages of photolithography.

Implementation

A key to success in producing robust products is the application of proven processes. The balance is between pushing the technical envelope to increase product usefulness and making sure the applied technologies are mature enough to yield consistency and reliability in the end application. This is a second generation implementation that refines the initial work done on lead salt photoconductive arrays implemented only for spectroscopic applications. This second generation implementation enhances the previous design and expands the application base to thermography and thermal imaging with a 40µm x 40µm pixel option.

The implementation consists of the following elements that address the stated detector issues:

- A chemically deposited detector array which uses a combination of photolithography and ion milling to produce the required geometries in both rectangular and square pixel configurations.
- A dedicated second generation silicon chip to handle the electronic interface to the array and provide other features and enhancements.
- An industry standard package capable of housing the critical components in a hermetic environment with a UV/Visible filtering window.
- A thermoelectric cooler with physical, thermal and electrical characteristics matched to the package and thermal load.
- A thermal sensing element carefully positioned to provide the optimal feedback to a control circuit.

Figure 2 and Figure 3 show the design concept, which considers all of the aspects of the design. 3D modelling was important to capture the physical, electrical and thermal aspects of the design. The manufacturability of the design to produce a good cost/performance ratio was also a primary consideration and is shown implemented design is shown in Figure 4. The detector pixels can be either rectangular for spectroscopic applications, or square for thermographic applications. The entire design, including the interface IC, can accommodate either configuration thereby providing a universal solution.

A key component is a second generation readout interface chip (ROIC) which has been developed by ADIC, Inc. (Longwood, FL, USA). This chip provides the following features:

- Both global and 8 bit per pixel dark current subtraction
- 4MHz data readout speed
- Signal integration with selectable charge well size
- Input circuitry specifically designed to interface with PbS and PbSe photoconductors.
- Advanced functionality including:
    - Data windowing
    - Bidirectional readout
    - Read while or after integration
    - Single supply operation

Although a seemingly simple component, the lid assembly provides hermetic sealing, UV/Visible blocking for both the silicon chip and detector array with good transmission over the wavelengths of interest, and an optical aperture so careful design and material selection is critical. Figure 5 shows the fully packaged array, including an AR coated silicon window. The geometry of the window is such that the welding fixture provides the alignment necessary to insure that background radiation is rejected while not vignetting the array elements.

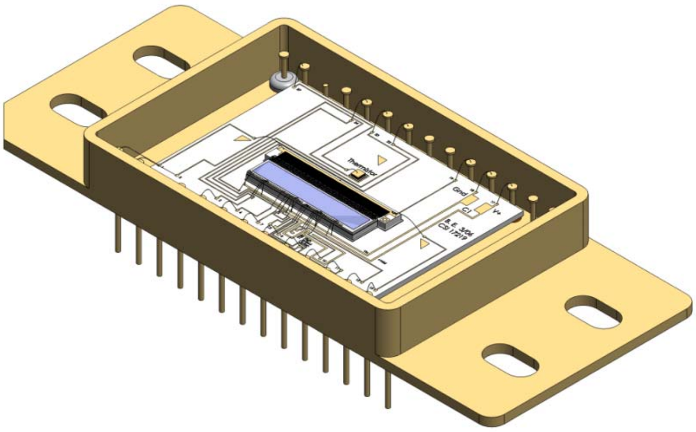


Figure 2 - Design Concept

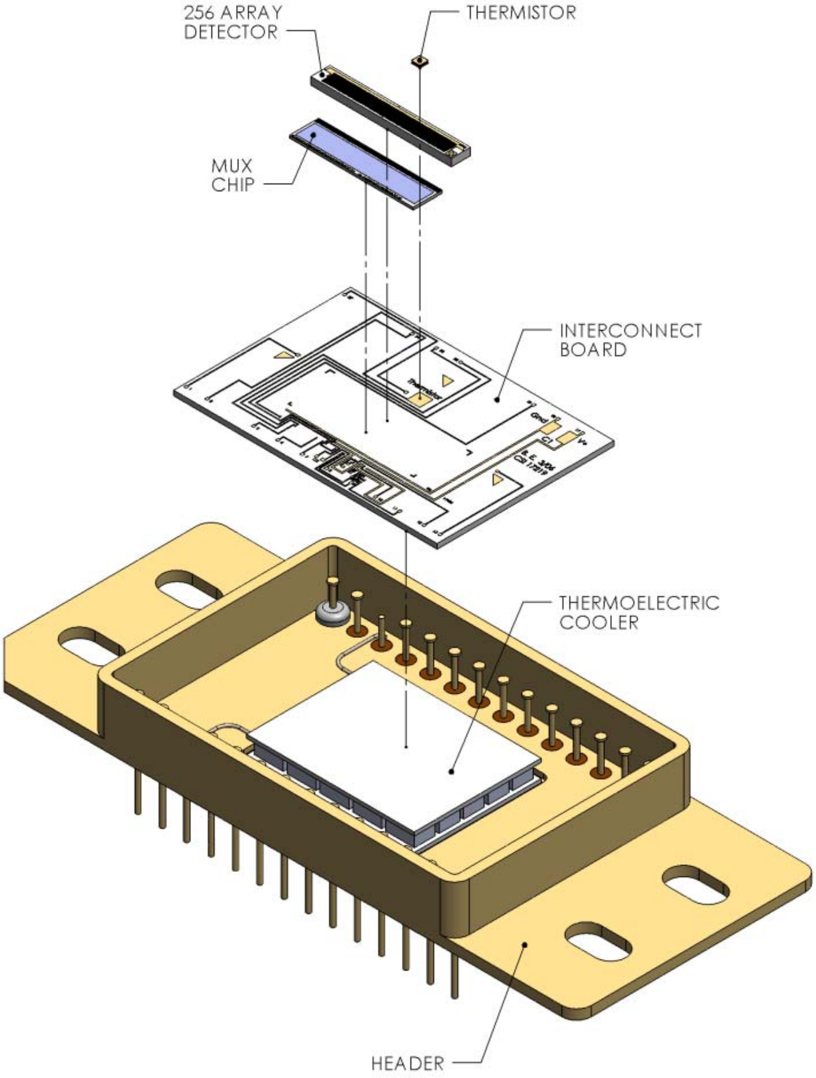


Figure 3 - Design Concept, Exploded

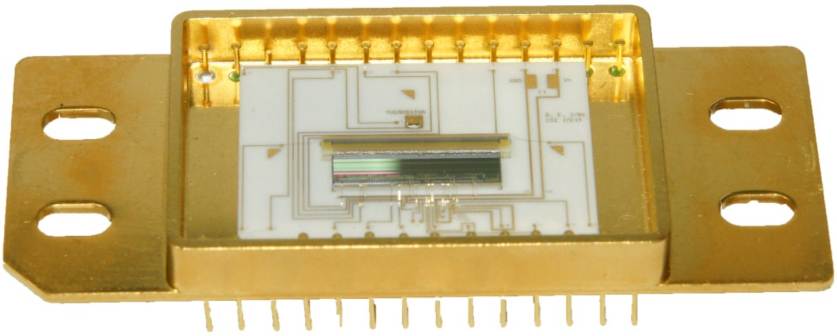


Figure 4 - Design Realization, Internal

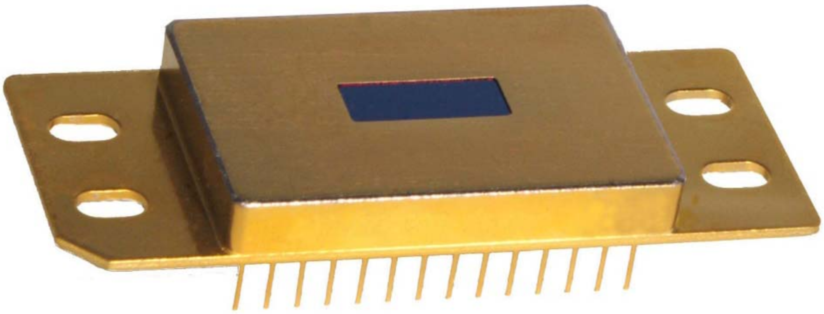


Figure 5 - Design Realization, Packaged

Conclusion

Lead salt photoconductive films are a mature technology that have shown general usefulness as detectors in the near and mid infrared regions in both spectroscopic and thermographic applications. Advances in integrated circuit design, photolithography, ion milling, hermetic sealing and thermoelectric cooling can be applied to produce detector array assemblies that take advantage of the benefits of photoconductive arrays while compensating for their various characteristics. These issues and their solutions have been presented in theory and practice, showing an economically producible detector array package for easy implementation in both spectroscopic and thermographic applications.

Bibliography

1. **Rogalski, Antoni.** *Infrared Photon Detectors.* Bellingham : SPIE, 1995.

2. **Woodward, W. Stephen.** Thermoelectric-cooler unipolar drive achieves stable temperatures. *EDN.* 3. December 2007, S. 98.

3. *Study of a Silicon Photodetector Thermal Stabilization using a Peltier Cell.* **E. Foschi, C. Guandalini, G. Levi, L. Quadrani, C. Sbarra, M. Zuffa.** Grenoble : Proceedings of the COMSOL Users Conference, 2007.

4. **MITTAL, V., et al.** Ion beam milling of n-type mercury cadmium telluride for photoconductive devices. *SPIE Proceedings.* 16. September 1997, S. 799 - 802.