# SELECTION GUIDE FOR PbS & PbSe INFRARED DETECTORS

Most infrared (IR) systems consist of three major components:

- a source of energy (S),
- a detector (D) and
- an optical system (T) which controls the energy transfer from source to detector.

Each of these components is, among other things, a function of wavelength (I), and the overall conversion of useful energy (E) through the system can thus be expressed as:

$$E = K f_{\Delta\lambda} S_\lambda \bullet T_\lambda \bullet D_\lambda \bullet d\lambda$$

where K is a constant.

The ultimate purpose of most IR systems is to detect source emission in the presence of background or unwanted radiation. This can usually be achieved through:

1. spectral discrimination,
2. spatial discrimination,
3. temporal discrimination, or
4. any combination of these.

To an IR system designer, it is, therefore, of paramount importance to fully understand, characterize and specify each major component of the system (including the background) by their wavelength and temperature characteristics, size and performance variation with time and/or frequency.

## DETECTOR SELECTION

The detector is the most critical component of any IR system since it is the singular device which converts optical energy into useful electrical signal.

Due to their reliability, cost effectiveness and performance, Cal Sensors lead sulfide (PbS) and lead selenide (PbSe) are the detectors of choice for many commercial applications in the IR wavelength region between 1 µm and 6 µm.

Cal Sensors PbS and PbSe are chemically deposited, thin film, photoconductive IR detectors that require a bias voltage to measure resistance drop when exposed to IR radiation.

It is important to note that virtually all PbS/PbSe characteristics vary with temperature. Detectors also exhibit typical 1/$f$ noise. For optimum performance, detector temperature should be stabilized and incident radiation should be chopped.

Careful system design considerations for these applications should include the following list of detector selection criteria. Important characteristics of lead salt detectors, in general, and ones unique to those manufactured by Cal Sensors, are also included under each section.

Detector parameters which have to be characterized and specified in detail include:

### Spectral Response -
### To define the wavelength range of interest

Typical spectral response of standard PbS and PbSe detectors is shown below.
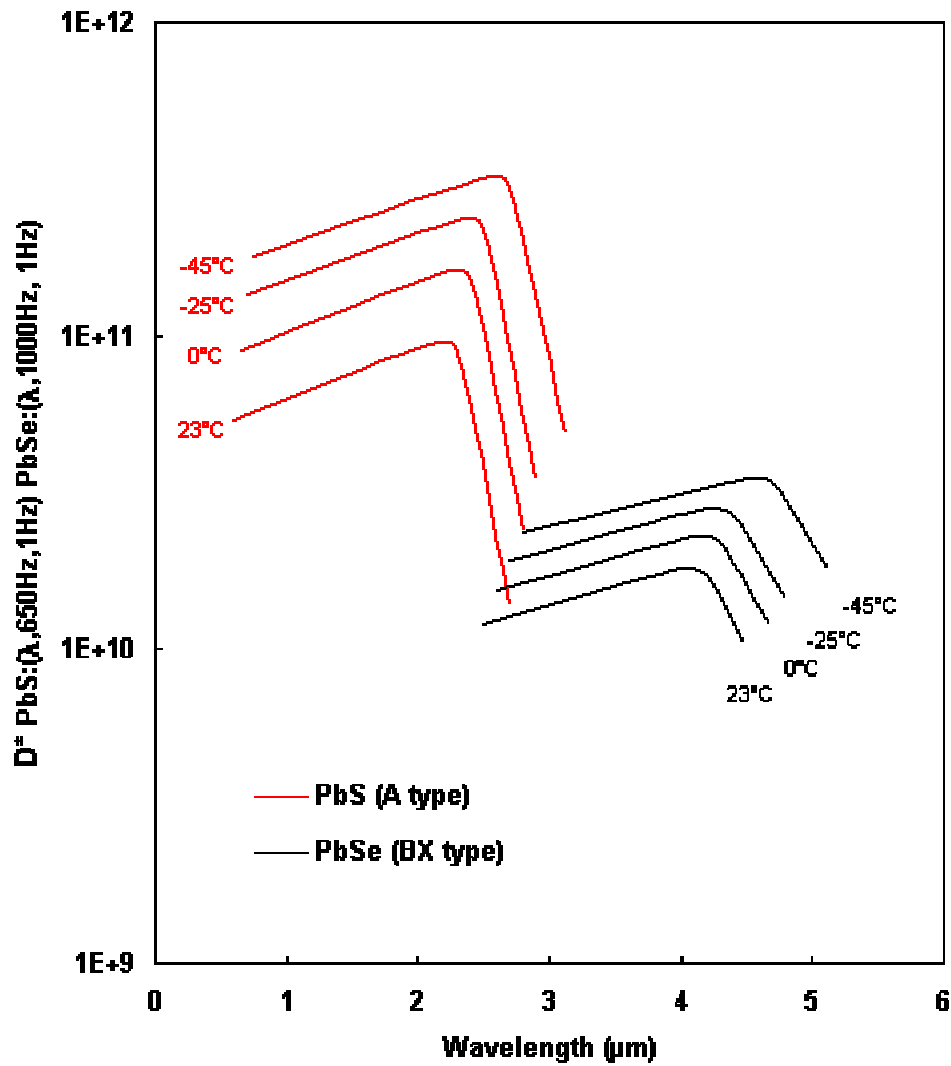
By altering controlled chemical deposition parameters, Cal Sensors can consistently produce detectors with very high peak detectivity or extended wavelength response at a given operating temperature. Cooling shifts both the spectral response and cutoff wavelength of PbS and PbSe detectors to longer wavelengths.

## Detectivity --
## To define detector signal-to-noise ratio (S/N)

Cooling the detector increases detectivity. See Figure below for typical D* vs. temperature characteristics of PbS/PbSe detectors.
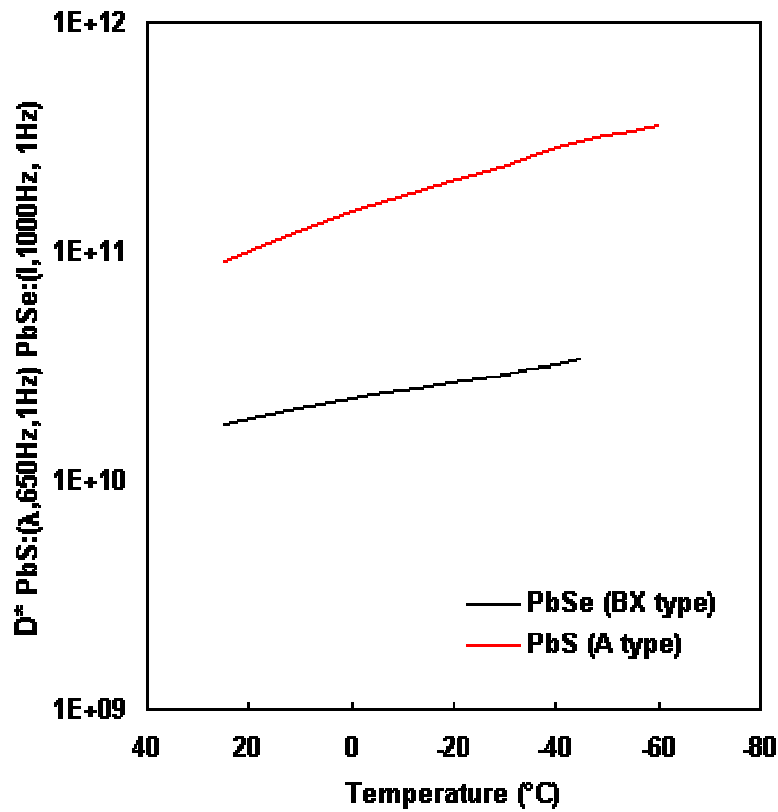
## Responsivity --
## To define detector electrical signal output

Cooling increases detector responsivity. The typical variation of responsivity vs. temperature of PbS/PbSe detectors is shown below.
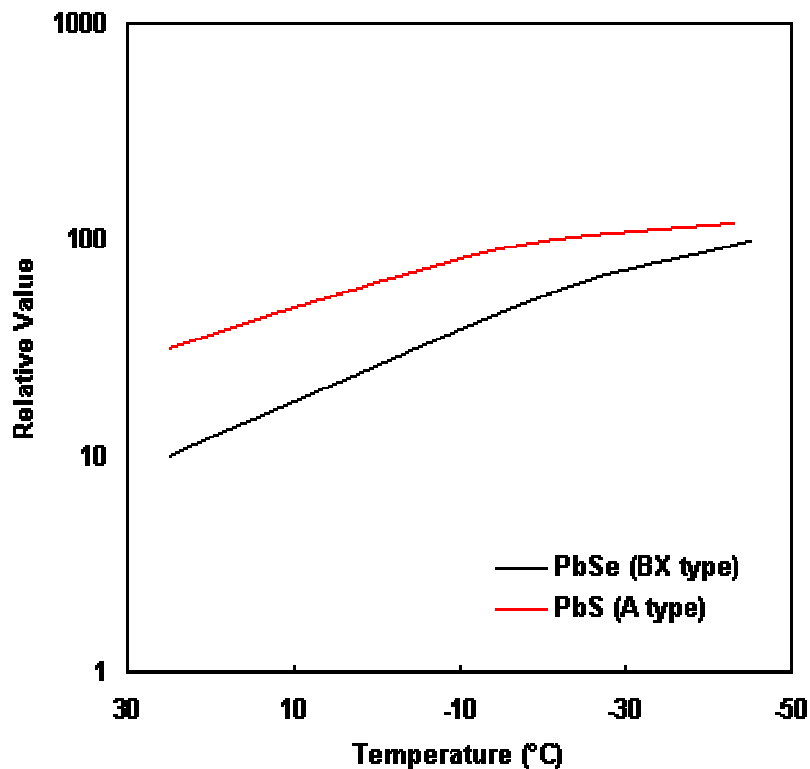
## Detector operating temperature and/or method of cooling (or heating) --
## To stabilize detector temperature and/or to increase detector S/N or spectral response

For a number of applications both PbS and PbSe detectors provide more than adequate sensitivity while operating at room temperature (uncooled). Since all detector characteristics vary with temperature, a method of cooling or heating must be provided to stabilize detector performance at system operating conditions. Cooling the detector improves detectivity, responsivity, and spectral response. Among the various cooling devices available, solid state thermoelectric (TE) coolers are the most cost effective and reliable (See TE cooling section below).

# Detector Response Speed and Frequency Response --
## To determine system frequency and response time

Both PbS and PbSe detector time constants increase (i.e., response speeds decrease) with a decrease in temperature (see figure below). By customizing deposition parameters, detectors with faster (decreased) time constants, at a given operating temperature, can be produced. A number of readily available PbS chemistries, characterized by their time constants at +23¼C, are shown in the Figure below (e.g., PbS with a time constant of less than 100 µsec at room temperature, is shown in the figure as PbS 100 µsec).
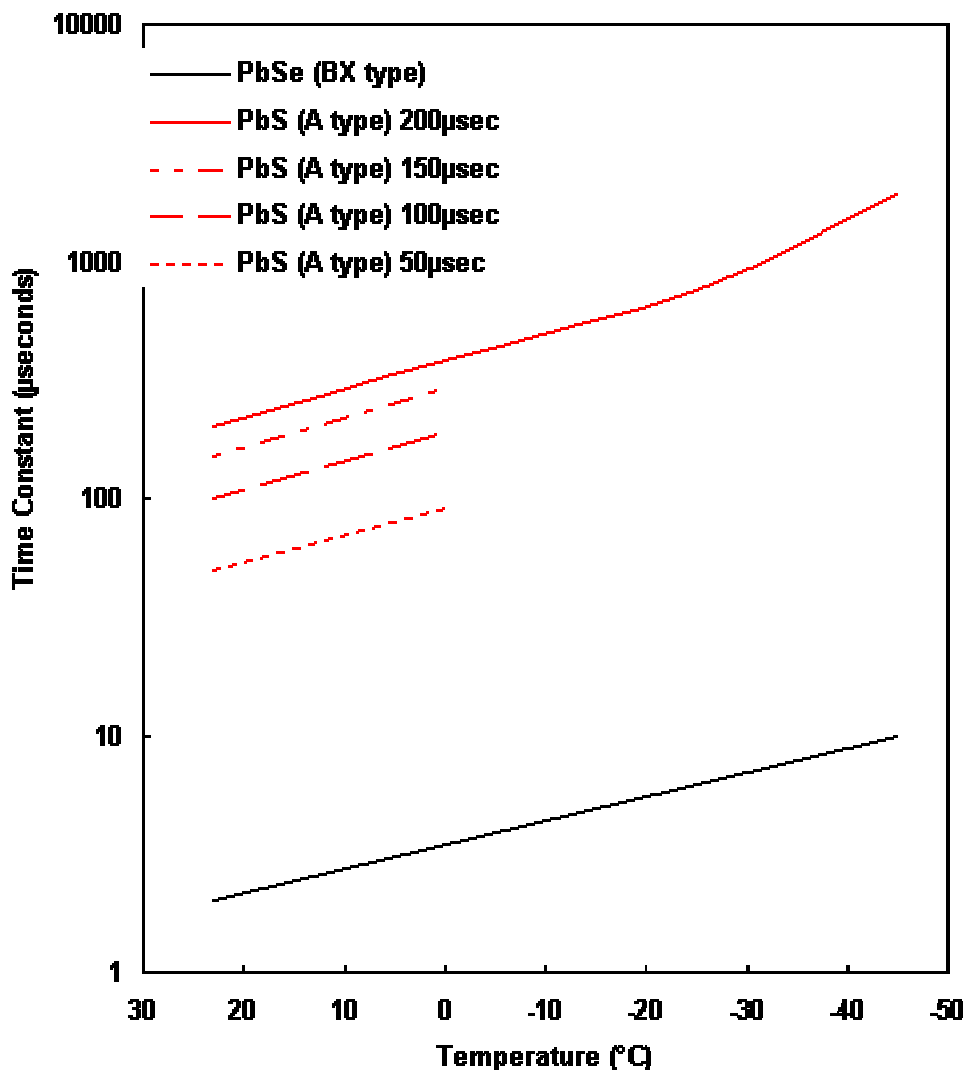
At a given chopping frequency ($f$), detector responsivity ($R_f$) is related to its responsivity at 0 Hz ($R_0$) as follows:
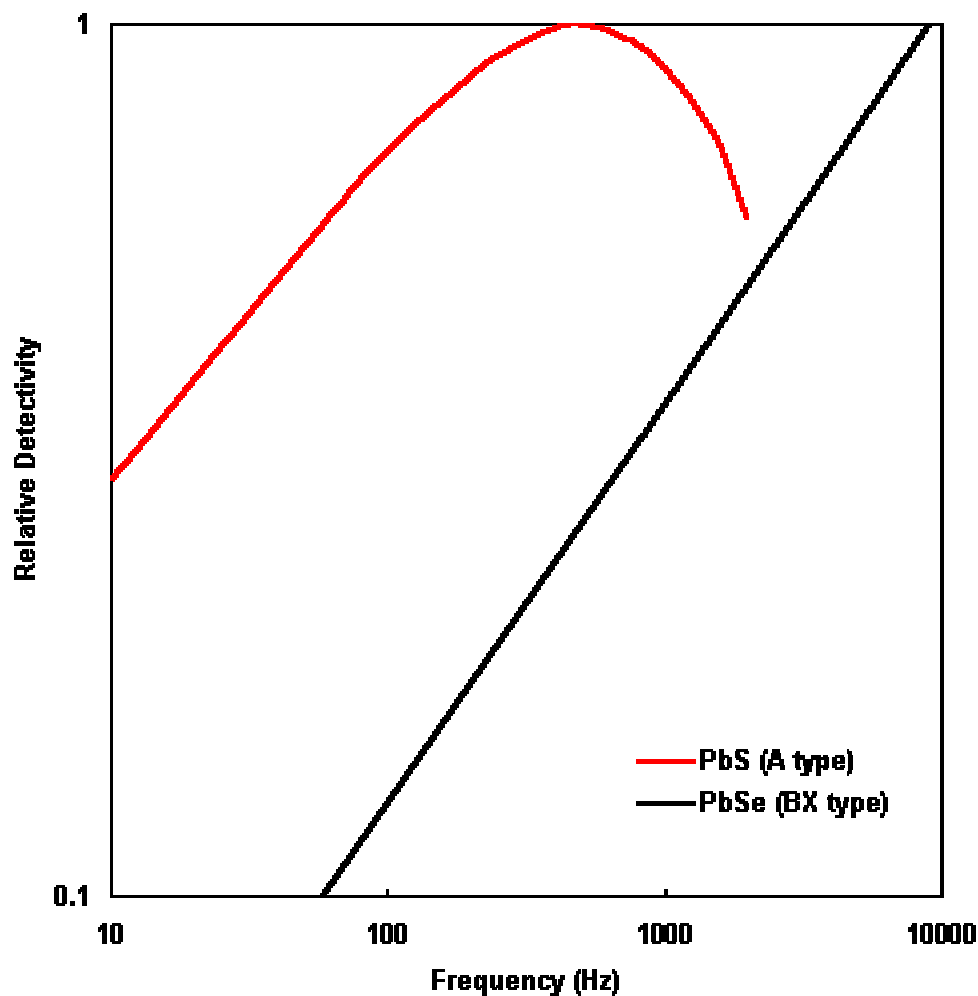
$$R_f = \frac{R_0}{(1+4\pi^2 f^2 \tau^2)^{1/2}}$$

where $t$ is the detector time constant.

PbS and PbSe detectors exhibit typical 1/$f$ noise, and accordingly, at a given chopping frequency, detectivity, D*($f$)can be expressed as:
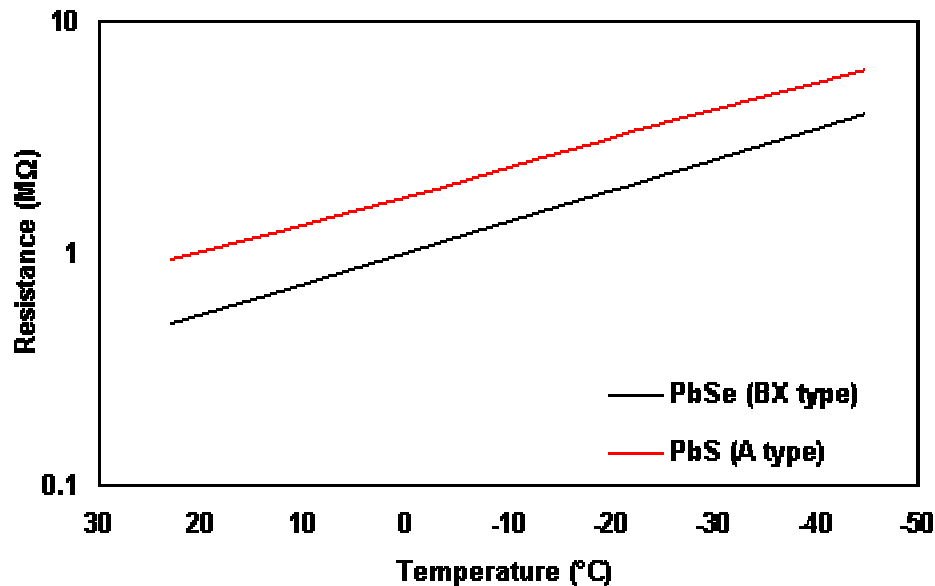
$$D^*(f) = \frac{Kf^{1/2}}{(1+4\pi^2 f^2 \tau^2)^{1/2}}$$

Typical frequency response of PbS/PbSe detectors is shown below:

## Detector Dark Resistance at Operating Temperature --
## To insure compatibility with signal processing electronics

Cooling increases detector dark resistance. The relative change in dark resistance with temperature for selected PbS and PbSe chemistries is shown below.



## Detector Bias --
## To define bias required from signal processing electronics

In general, signal is linearly related to bias voltage (up to approximately the detector maximum bias voltage). At low bias, PbS/PbSe detector noise shows relatively little dependence on voltage. After a given voltage value is reached, noise is linearly related to voltage. The typical variation of signal, noise and S/N of PbSe detectors with bias is shown in the figure below. Larger detector areas require higher bias voltage to reach this range.

Detector noise is a function of the inverse of the chopping frequency. Therefore, at decreasing chopping frequencies further decreased voltage bias may yield acceptable signal to noise ratios.
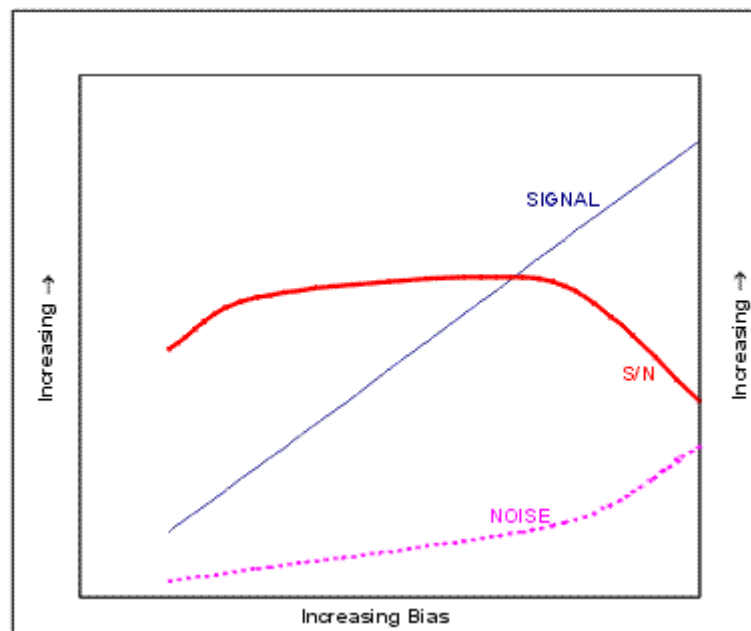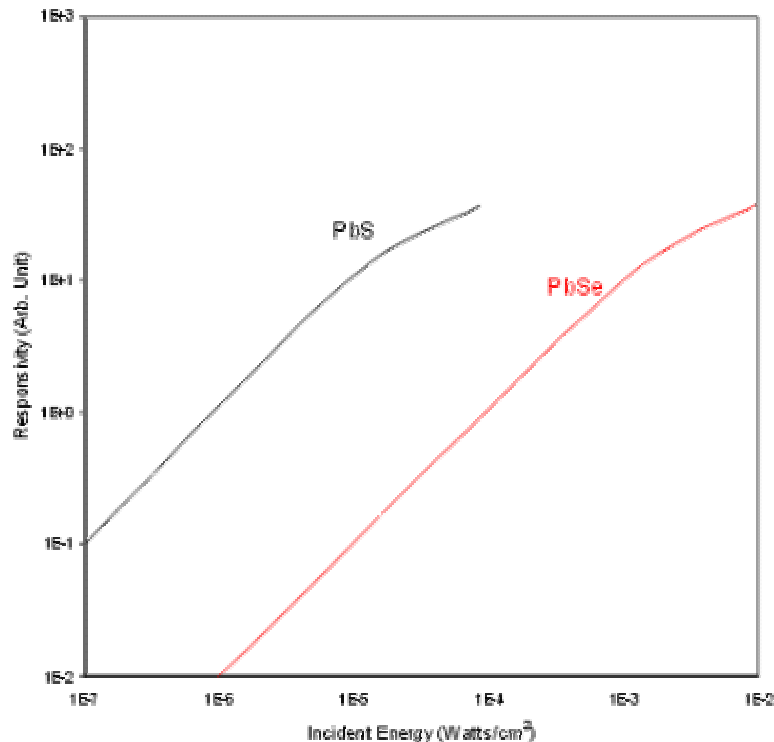
For routine detector testing, Cal Sensors uses the typical bias and amplification circuit shown below.
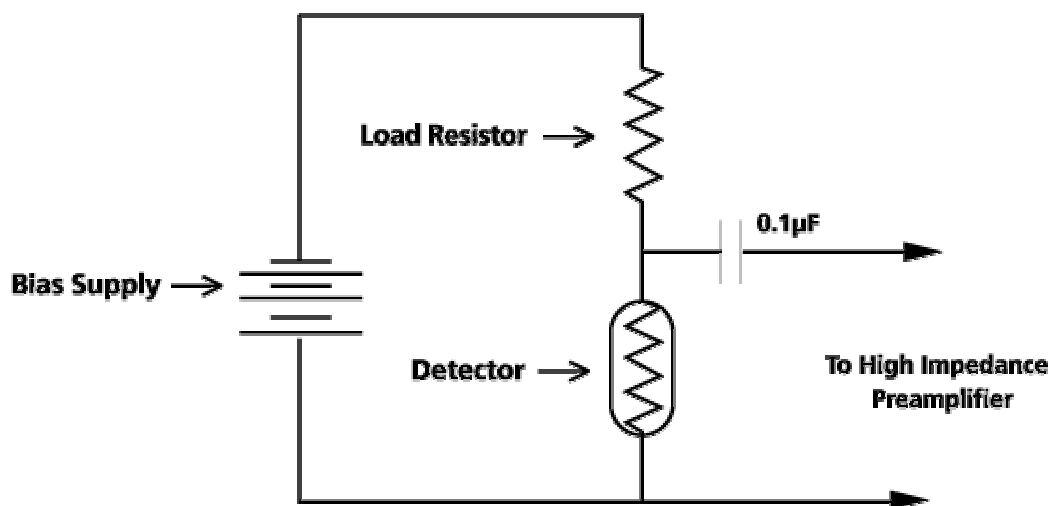
## Detector Linearity --
## To define the range of incident radiation over which signal is linear to irradiance

PbS and PbSe detector signal output is linear with incident radiation in the range $10^{-7}$ W/cm$^2$ to $10^{-3}$ W/cm$^2$ (See below).



## Effective (active) Area/Size of Detector Elements, and Number and Spacing of Elements in an Array -- To define system resolution and to maximize S/N

Cal Sensors offers a wide range of standard PbS/PbSe single element detector sizes and arrays. Detector active area and /or array configuration are not limited to those shown in this catalog. Single element square and rectangular detectors with dimensions of from 0.1 mm to 10 mm, quadrant detectors, and high density staggered and linear arrays are routinely being produced in volume.

## Detector Field of View --
## To limit background and/or improve signal to noise

The field of view (FOV) for standard detectors is usually determined by the package aperture. Unless very cold background temperatures are involved, restricting detector FOV will not substantially improve detectivity. However, should the need arise, custom apertures can be installed either inside or outside the detector packages. Please contact our application engineers for specific FOV information.

## Detector Package --
## To protect the detector elements from harsh environmental conditions and provide for the packaging of integral coolers, filters and detector electronics

A number of standard packages available. See the PbS and PbSe sections for specifications and illustrations.

Cal Sensors offers a variety of TO-style and other packages for the detector(s), cooler, integral optical filter(s) and detector signal processing electronics.

TO-style and other standard semiconductor packages are of welded construction, hermetically sealed and typically backfilled with a dry, inert gas selected to reduce convective heat load on coolers and ensure moisture and/or contaminant free operation. Standard packages are generally provided with sapphire windows but can be supplied with antireflection (AR) coated silicon or germanium windows and/or customer specified spectral filters. Detectors and arrays are also installed and tested in numerous custom designed and customer specified packages.

## Thermoelectric Cooling --
## To provide reliable and cost-effective cooling and temperature stabilization

For most commercial applications requiring the spectral response and performance of cooled PbS and PbSe detectors, the most efficient method of cooling involves the use of miniature solid state thermoelectric (TE) coolers. Cal Sensors TE cooled PbS and PbSe detectors are rugged, produced in volume, and have for many years performed maintenance free in a wide variety of customer systems.

Thermoelectric coolers operate on the principle known as the "Peltier effect," which describes the property of certain semiconductor materials to transfer heat in the direction of electrical current applied to them. n - p type material elements of these semiconductors are sandwiched between ceramic plates and connected in series to form a one stage cooler. Cooler stages are also "cascaded" to form multi stage coolers. (See Figure below)
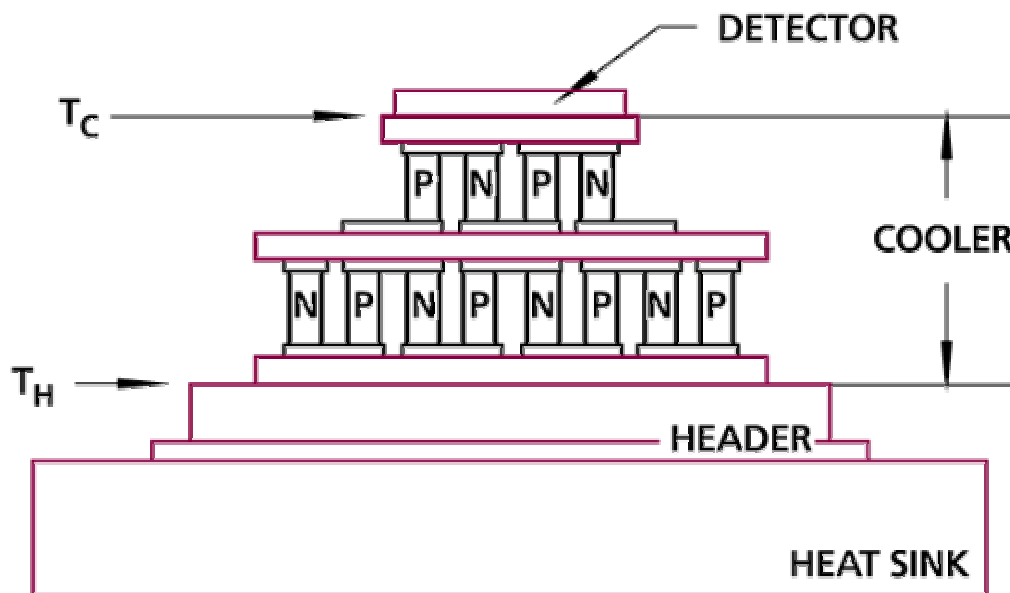
In TE cooled detectors, cooler performance can be characterized by the required input power to achieve the $\Delta T$ required where $\Delta T$ = $T_H$ - $T_C$, $T_H$ is the ambient or heat sink temperature and $T_C$ is the cold plate temperature (See Fig. below).

These characteristics are primarily a function of cooler material, number of n - p element pairs, number of cooler stages, and the active, as well as, passive (convective, conductive and radiative) heat load (Q) on the cooler. The typical relationship between input cooler power, heat load and $\Delta T$ is shown below.
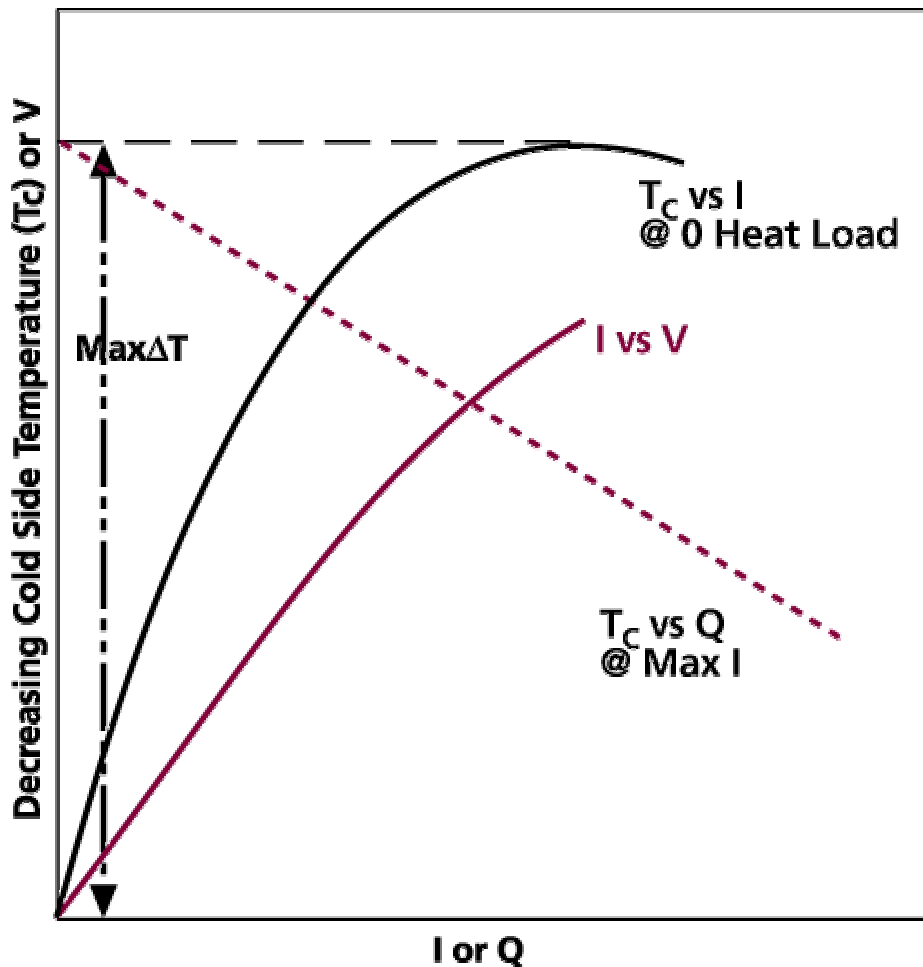


It is important to note that the application of input current (I) beyond the maximum rated value of a given cooler, will cause heating of the cooler cold plate. In a TE cooled detector this can result in thermal run-away and detector damage. The use of a thermistor with the TE cooled detector is recommended and careful consideration should be given to the thermistor set point resistance in the cooler controller/power supply. It is also important to emphasize that TE coolers are d.c. devices and if the indicated polarity is not observed, catastrophic damage can result instantly to the detector.

Cooler power must not be applied when the detector assembly is not properly mounted on a heat sink.

Detectors (and thermistors), and TE coolers in Cal Sensors packages are mounted in close thermal contact with the cooler cold plate and package headers, respectively. To insure proper thermal transfer, the detector header must be installed in close thermal contact to an appropriate heat sink external to the detector package.

The highest (hottest) system ambient temperature should usually be used to determine the $\Delta T$ needed from the TE cooler. Cal Sensors specifies and tests TE cooled detectors at or near the maximum or rated input cooler power, with the detectors mounted on an infinite (water cooled) heat sink maintained @ +25°C ± 1°C. It should be noted that at higher heat sink/system ambient temperatures, and a given cooler power, $\Delta T$ will increase. This increase depends on the type of cooler, but for most of the "standard" coolers used, $\Delta T_{hot}$ = $\Delta T$ 25°C + 0.4 ($T_{hot}$ - 25°C), where $T_{hot}$ is the higher system ambient temperature.

Cal Sensors offers many package/cooler options. Detectors offered include those mounted on 1-, 2-, 3-.and 4- stage TE coolers. TE cooled detectors usually contain a calibrated or uncalibrated thermistor (See Fig. below). Thermistor leads can be connected externally in a tight servo loop with controller/power supply circuitry to control input power and maintain set point temperature.
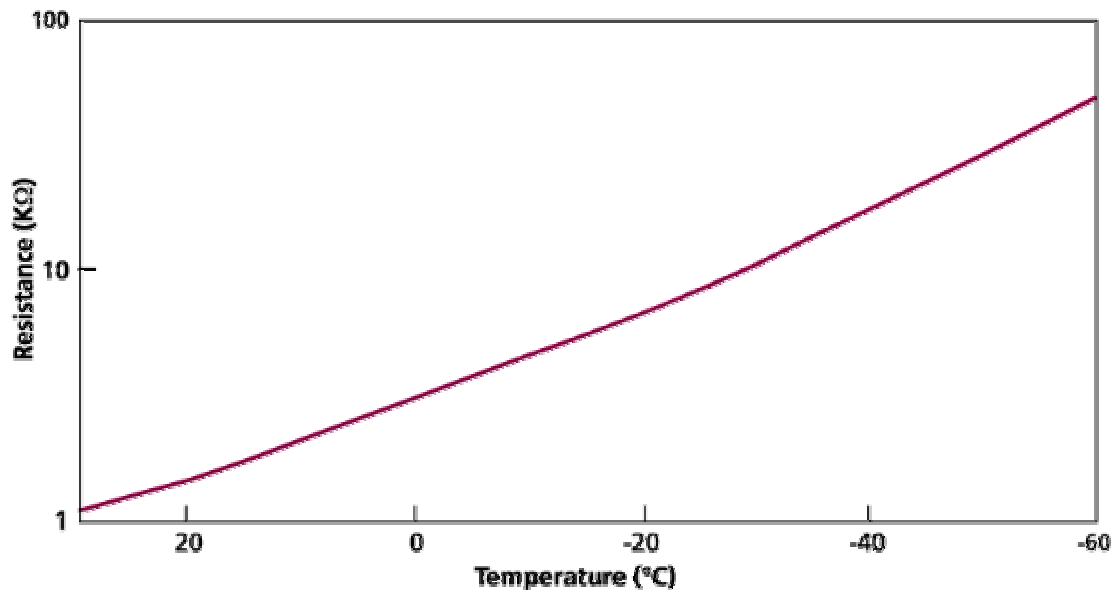


## Multi-Color Detectors --
## For systems operating in two or more wavelength regions

Cal Sensors produces multi-color detectors which can provide advantageous detector design alternatives. Multi-color detectors can generally be classified into two types: coaxial and coplanar (See multi-color section for more information).

Coaxial multi-color detectors are ideal for systems operating in both the visible and IR, and typically consist of a silicon photodiode mounted in close proximity above a cooled or uncooled PbS or PbSe detector. The silicon diodes are coated to provide maximum IR energy throughput. Custom Si/PbS and Si/PbSe detectors are built on request.

Coplanar multi-color detectors typically consist of two or more PbS or PbSe detectors mounted side by side on a TE cooler cold plate (or package header). Spectral filters are then mounted into carefully designed filter holders, which are in close proximity above each detector. Filter holders are designed and built to minimize optical cross talk (noise) between channels.

## Arrays --
## For spectrometric or imaging systems

Cal Sensors' in-house capability for design, fabrication and packaging provides custom solutions to virtually any PbS or PbSe detector array requirement (See array section for more information).

Multi-element detector assemblies include quadrant, as well as, high density staggered or linear, cooled or uncooled arrays.

Custom arrays and packages of virtually any configuration can readily be built on request, although this may involve the nominal additional cost of designing and producing non recurrent tooling (photomasks) needed to define active areas and electrodes, and may extend standard delivery times.

## Detector Accessories --
## For optimum detector performance and system interface

Application of input cooler power generates heat in a TE cooled detector. To avoid damage, the TE cooled detector should be mounted securely on an adequate **heat sink**. The heat must then be dissipated through the bottom of the package header and the external heat sink. The entire bottom surface of the header (excluding the feedthroughs) must be in intimate thermal contact with a flat mating surface area of the heat sink where a non-conductive thermal compound has been applied. For optimum performance, a copper or aluminum heat sink, capable of dissipating at least twice the input cooler power, should be used.

A **temperature controller/power supply** is necessary to stabilize and control the operating temperature of a TE cooled detector over a range of ambient system temperatures. The detector must contain a thermistor, and the controller should be designed so that the thermistor is in a tight servo loop with the amplifier in the controller. After careful consideration of the TE cooler capability, heat sink temperature, and the anticipated range of ambient temperatures (See TE cooling section above) the resistance value of the set point resistor can be chosen. Input power to the TE cooler should be from a d.c. supply with less than 10% ripple.

**Preamplifiers** for either PbS or PbSe detectors must accommodate high input impedance and provide a low noise, low impedance interface to the system electronics. They must provide the desired gain, frequency response, and be stable over the ambient temperature range. To minimize noise, preamplifiers should be designed with a low frequency cut off, reduced microphonics, and protection against electro magnetic interference (EMI).