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Application Note

Design considerations for PbS/PbSe infrared detector electronics

1. Photo resistive PbS and PbSe detectors

Polycrystalline lead sulfide (PbS) detectors are sensitive to electromagnetic radiation between the wavelengths of 1 and 3 µm and therefore applicable for near infrared (NIR) applications. Lead selenide (PbSe) detectors extend into the mid infrared (MIR), covering a broader wavelength range from 1 to 5 µm.

Both detector types utilize the photoconductive effect where exposure to infrared radiation causes a decrease of the resistance of the active area as a function of the radiation intensity. There are some peculiar characteristics that need to be considered when working with PbS and PbSe detectors, especially by users more accustomed to photodiodes.
Photoresistors are passive devices which unlike photodiodes cannot be operated in photovoltaic mode as they don't generate a photocurrent of their own. For detector operation they always require a bias voltage. The second key difference can already be deduced from their name: they behave like resistors, not diodes. Consequently, there is no p-n junction, no junction capacitance, and no polarity.

2. Converting resistance change to voltage change

To evaluate the response of a photoresistor, the resistance change has to be converted into a voltage or a current change. The converted change can then be amplified and digitized for further processing.
There are several ways to design a front-end for photoresistors that can achieve this conversion, such as voltage dividers, inverted amplifiers or differential amplifiers.
Internal evaluation has shown that trinamiX PbS and PbSe detectors perform best when used in a voltage divider setup (fig. 1). This is based on thermal and current noise analysis of these circuits. For the current noise all three circuits show similar performance regarding carrier-to-noise-ratio (CNR). However, in cases where thermal noise dominates, the CNR performance of the voltage divider circuit is better than the other options.
Based on this advantage and its simplicity the voltage divider is the recommended circuit for the evaluation of PbS and PbSe detectors.

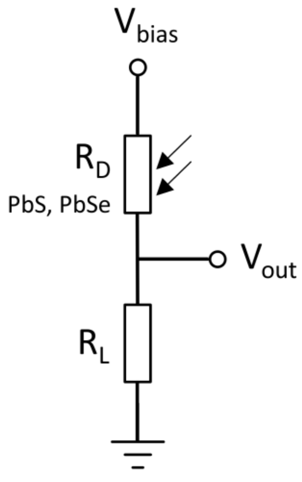


Figure 1: Voltage divider

3. PbS/PbSe read-out circuit

The building blocks of an exemplary read-out circuit based on a voltage divider setup is depicted in fig. 2. It consists of a modulated light source, an analog front-end and the digital processing circuit.

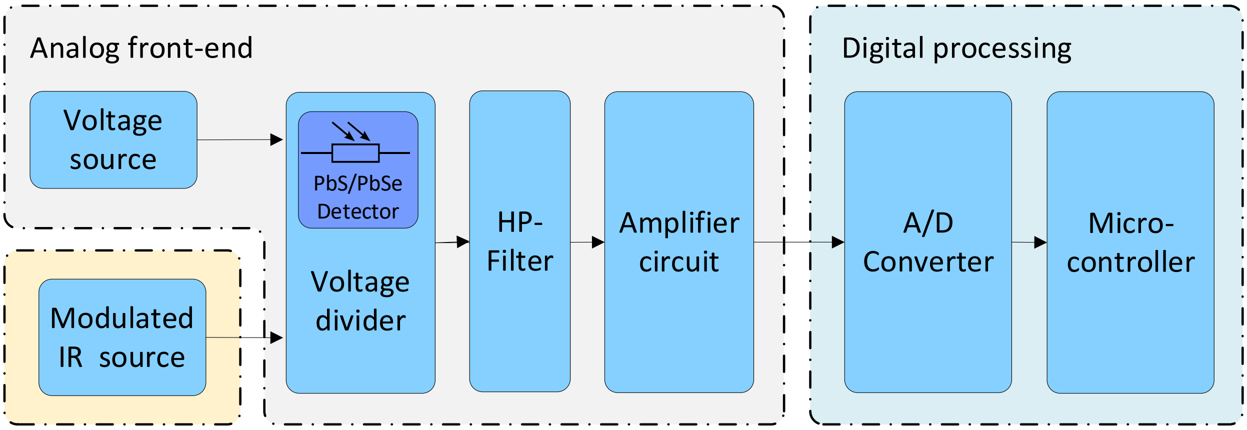


Figure 2: Exemplary PbS/PbSe circuit building blocks

3.1. Modulated IR source

For the presented front-end electronics to work the detector signal needs to be modulated. The main advantage of modulation is that the detector signal can easily be separated from background radiation and other disturbances.
Depending on the application there are several options when it comes to light sources. An overview is depicted in table 1.

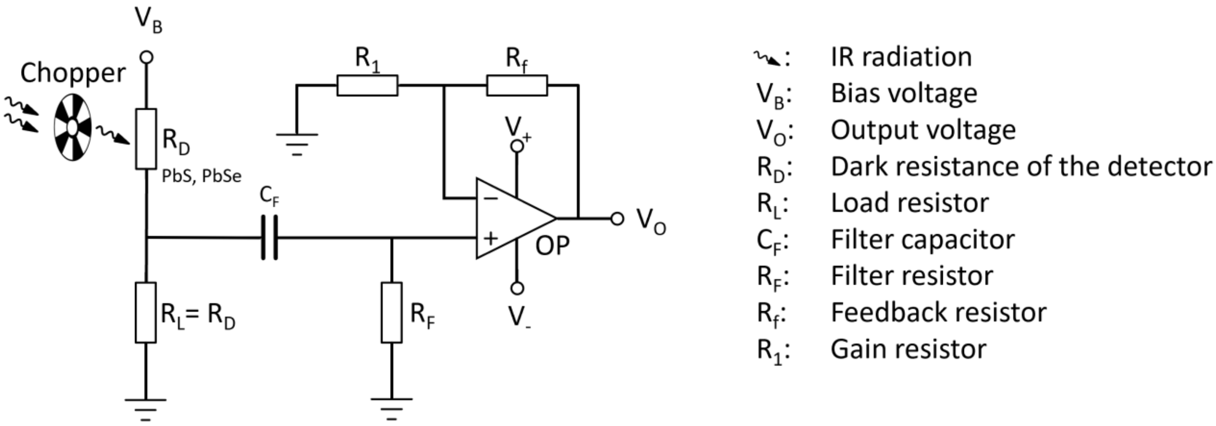
Table 1: Comparison of IR sources

IR source	Wavelength range	Modulation frequency	Price	Lifespan
LEDs	VIS/NIR/ MIR (≤4.7µm)	Up to several kHz	High	High
Incandescent bulbs	VIS/NIR/MIR	Up to 10Hz	Low	Low to medium
MEMS thermal emitters	NIR/MIR	Up to 15Hz	High	Medium to high

The main advantage of using LEDs is that they can be easily modulated via PWM from low frequencies such as 1 Hz up to higher frequencies of several hundred Hz. The modulation frequency, whether with LEDs or any other kind of source, should be chosen according to the application and be as high as possible. This is based on the fact that PbS and PbSe are prone to pink noise which decreases with increasing modulation frequency. PbSe can work with higher modulation frequencies as opposed to PbS because of its significantly lower time constant (typ. 4 µs vs 200 µs).

When choosing a modulation frequency, it is also important to make sure that it is not the same, multiple of or close to the power-line frequency of the location where the detector module will be used in. For most of the world this frequency is either 50hz or 60Hz. Choosing these frequencies or multiples of them will cause the circuit to couple in more outside noise.
A significant disadvantage of LEDs as IR light sources is however their limited wavelength range. There are only a handful options in the range of 2-5 µm, whether broadband or narrowband. Furthermore, the available ones can be quite expensive. As alternatives incandescent bulbs or MEMS based thermal emitters can be used as broadband IR light sources which have good coverage of both the PbS and PbSe range. Their disadvantage however is that electrically they can only be modulated at low frequencies of only 10-15hz. Going higher reduces the modulation depth significantly and in the case of incandescent bulbs, electrical modulation may negatively affect their lifespan.
The main differentiation between the MEMS based emitters and incandescent bulbs are that the bulbs are lower in cost but also have a lower lifespan.

In cases where a higher modulation frequency with incandescent sources are needed, mechanical chopper wheels can be used. They can be easily adapted to have a wide range of frequencies and come with the advantage of a high modulation depth no matter the IR source. Choppers can also be used when measuring radiation sources that have a continuous IR output such as incandescent lamps or blackbody radiators. The



main disadvantage of using choppers is, that they introduce moving parts into the measurement system which make it more prone to failure and prevent miniaturization.

3.2. Analog front-end

The analog front-end (fig. 3) is responsible for acquiring the detector response and preparing it for further digital processing. In the following chapters each block of the analog front-end will be explored in detail.

Figure 3: Analog front-end for PbS/PbSe

Bias voltage

As already stated, photoresistors like PbS and PbSe detectors need a bias voltage to work. The signal of the PbS/PbSe detectors increase proportionally with the bias voltage. However, the detectors have a rated maximum electric field intensity (V/mm) which if exceeded causes a significant increase in noise. As the signal level increase proportionally to the bias voltage and no additional information can be extracted from simply increasing the bias voltage, it is recommended to use as low a voltage as possible to bias the detectors. It is also important to note that since the rated maximum is based on field intensity, the applicable bias is tied to the detector geometry. Typical electric field intensity that trinamiX detectors work with range from 5V/mm to 50V/mm.

From a circuit design standpoint, the bias should be as noise free and stable as possible. To achieve this voltage references in combination with operational amplifiers that have low-noise and low-drift are recommended to generate the required bias. trinamiX evaluation kits use voltage references with an accuracy of ≤0.1%, temperature drift of ≤0.8 ppm/C° and noise of ~3 µV_{pp}/V.

Voltage divider

As the name suggests, a voltage divider (fig 1.) divides the applied voltage over its two resistors, one being the load resistor (R_L) and the other being the dark resistance (R_D) of the PbS/PbSe detector. R_D in this case is the resistance of the detector when not exposed to any radiation.

How much voltage from the source gets applied to each resistor is dependent on its resistance values. The output voltage of the divider circuit can then be calculated using the following equation.

$$V_{Bias} = \frac{R_L}{R_D + R_L} V_{in}$$

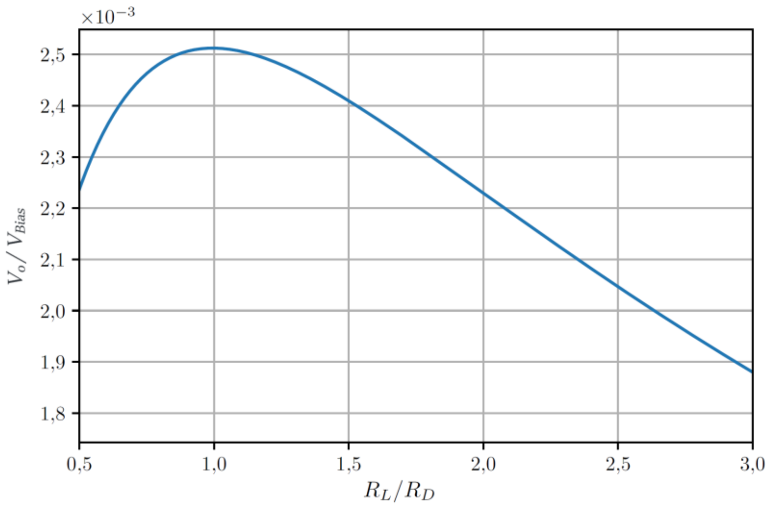


Figure 4: Change of output voltage in relation to the ratio of R_L/ R_D

Since radiation exposure causes the photoresistor resistance to reduce, the output voltage also experiences a change. For the highest detection performance, R_L should be chosen carefully as figure 4 shows that a 1:1 ratio of R_L to R_D leads to the maximum achievable output voltage. To further improve the performance metal electrode leadless face (MELF) resistors are recommended as load resistors. They have better long-term stability and lower noise then standard thin-film or thick-film resistors.

High pass filter

With a voltage divider the detector signal always has a DC offset. This is due to the applied bias voltage. Compared to the bias voltage the AC response of the detector as a result of the modulated light source is very small. Usually the AC signal is in milli volts range while the Bias can go up to 10s of volts. To separate the AC signal and preventing a saturation of the amplifier stage, analog filtering is needed.
As an additional benefit, the filters can be configured in a way that they also suppress unwanted frequencies from electronic components other than the analog front end and the environment. In the PbS and PbSe case a RC high pass filter designed to cut off the DC part and pass through the AC detector signal can be used. If desired, filters of higher magnitude can be applied to achieve steeper cut-off slopes. For additional filtering of higher frequencies, the high pass filter can be extended to a band pass filter.
The reference designs from trinamiX use only a high pass to reduce the offset. Cutting off unwanted frequencies on an analog circuit level is mostly unnecessary since trinamiX evaluation boards rely on fast Fourier transformation (FFT) algorithm for the data analysis. This algorithm allows to specifically target the frequency components (e.g. at the modulation frequency) of interest while neglecting other frequency components.

Amplifier

The detector signal after the voltage divider and filtering is usually in the range of a few millivolts. To prepare this for digitization the signal should be conditioned to utilize the maximum resolution of the ADC. This can be achieved by using an operational amplifier in a non-inverting configuration. The amplification can then be adjusted via the feedback and gain resistor (R_f and R_1). Generally, it is recommended to use resistors in the 1kΩ to 1MΩ range for the operational amplifier circuit. Low resistor values (<1kΩ) would require the OPAMP to provide high currents to achieve the necessary voltage drops for the amplifier to operate properly. However usually OPAMPs are only rated for 10’s of milliamps at most. High resistor values (>1MΩ) on the other hand can introduce more noise into the circuit.
Note that PbSe typically has an order of magnitude lower responsivity than PbS and therefore needs higher amplification to achieve the same signal strength as PbS.

3.3. Digital Processing

In the first stage of the digital processing, the amplified signals have to be digitized by an ADC. It is recommended to use either fully differential or pseudo-differential input modes for best noise performance and high resolution. If the ADC analog inputs don't have sufficient protection from voltage and current spikes, a serial resistor and a voltage clipper can be added between the amplifier output and the ADC input.

Once the signals have been processed by the ADC they can be transferred to the micro-controller via a serial bus. If the use case allows for it, then the analog signal can also be directly connected to the ADC inputs of the micro controller. Here the most important part to watch out for in the built-in micro-controller ADCs is their resolution. Usually this does not exceed 12-bit.

The current trinamix single-pixel evaluation kit uses a 16-bit ADC while the multi-pixel kit uses a 24-bit ADC, making sure that customers have sufficient resolution to evaluate their applications with. This in turn can provide answers whether the target application can work with internal micro-controller ADCs with lower resolution or not.
Once the data is processed by the controller it can be visualized with the help of a graphical user interface if desired. TrinamiX evaluation kits make use of either a LabVIEW or C# based GUI to depict the measured signals on a PC.

Appendix

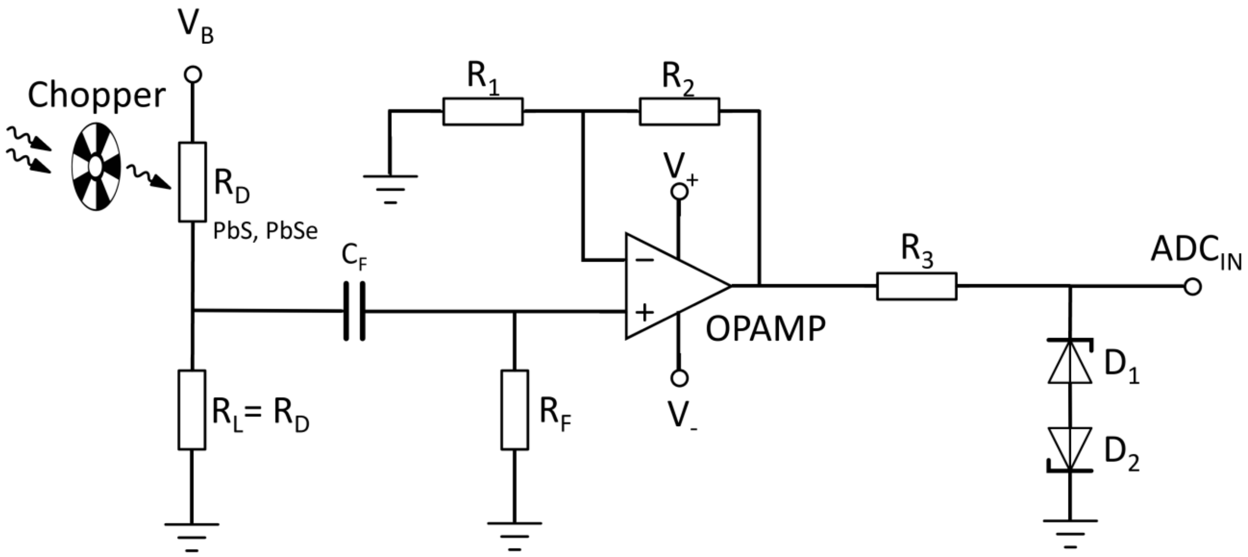


Table: Exemplary circuit values

Component	Value	Note
Optical Chopper	20 Hz	Incandescent lamp
Dark resistance R_D	1 MΩ	typ. for trinamiX PbS/PbSe
Load resistance R_L	1 MΩ	MELF package
High pass capacitor C_F	10 nF	$f_{cut\text{-}off}$ = 1.6 Hz
High pass resistor R_F	10 MΩ	
Gain resistor R_1	1 kΩ	4x Amplification for PbS
Feedback resistor R_2	3 kΩ	
Operational Amp.	-	OPA172
Current limit. resistor R_3	649 Ω	I_{LIM} = 5mA
Voltage clipper D_1, D_2	1 V	Zener diode cut-off above/below ±1 V
Bias voltage V_B	10 V	-
OP-AMP V_+	10.8 V	4.5 V to 36 V
OP-AMP V_-	GND	-

About trinamiX:

trinamiX GmbH develops and sells cutting-edge 3D vision and infrared sensing solutions for use in both consumer electronics devices and industrial designs. The company's products enable humans and machines to better capture data, with the goal of understanding the world around us. This results in improved decision-making as well as stronger biometric security. trinamiX, based in Ludwigshafen, Germany was founded in 2015 as a wholly owned subsidiary of BASF SE. The company employs 170 people worldwide. Further information on: www.trinamixsensing.com.

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