TECHNICAL NOTE

Tradeoffs and Considerations of Cooling InAsSb Detectors

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When it comes to infrared measurements, it is a common misperception that cooling is a requirement. Cooling adds cost, bulk, and complexity (TEC, heatsink, temperature controller, power), so it is important to only include cooling if absolutely necessary.

The goal of this technical note is to guide customers through the decision-making process of whether to include cooling in their system, using examples of Hamamatsu's InAsSb detectors and LEDs.

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INTRODUCTION

Problem statement: Infrared light measurements can be quite challenging since the desired signals that one wants to measure can be extremely small in high noise environments. The reason that there is so much noise in the infrared region is that all objects give off black body radiation. Cooling is often times added to infrared detectors to increase sensitivity, but Hamamatsu offers proprietary multistage infrared detectors that are designed to operate at room temperature.

Photovoltaic Detector Noise

Let us first consider the components of noise. The photovoltaic detector noise (i) is equal to the square root of Johnson noise (ij) squared plus the shot noise (iSD) due to dark current, including the photocurrent generated by background light, squared.

$$i = \sqrt{i_j^{\,2} + i_{SD}^{\,2}}$$

Equation 1: *Photovoltaic Detector Noise*

Johnson Noise

Johnson noise is expressed in the following equation:

$$i_j = \sqrt{\frac{4kTB}{R_{sh}}}$$

k: Boltzmann's constant
T: absolute temperature of element
B: noise bandwidth
R_{sh}: shunt resistance

Equation 2: *Johnson Noise*

The controllable variables of Johnson noise are temperature, bandwidth, and shunt resistance. Hamamatsu offers InAsSb detectors with a proprietary multistage structure that leads to a high shunt resistance. These detectors have a shunt resistance on the order of 30,000-200,000 Ω, whereas a traditional InAsSb detector has a shunt resistance on the order of 10 Ω. This, in turn, reduces Johnson noise and makes room temperature measurements possible. If the required sensitivity is high, one can further reduce shunt resistance with cooling. A plot of shunt resistance as a function of chip temperature is shown in Figure 1.

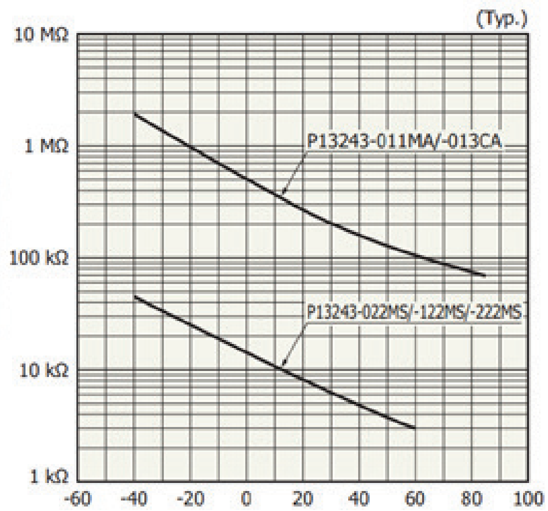


Figure 1: *Shunt resistance vs. chip temperature*

Shot Noise

Shot noise is expressed in the following equation:

$$i_{SD} = \sqrt{2qI_DB}$$

q: electron charge
I_D: dark current
B: noise bandwidth

Equation 3: *Shot Noise*

However, we do not need to consider dark current because InAsSb detectors are meant to be operated in photovoltaic mode (no biasing). An InAsSb detector's signal is based on photosensitivity. A plot of photosensitivity at different ambient temperatures as a function of wavelength is shown in Figure 2.

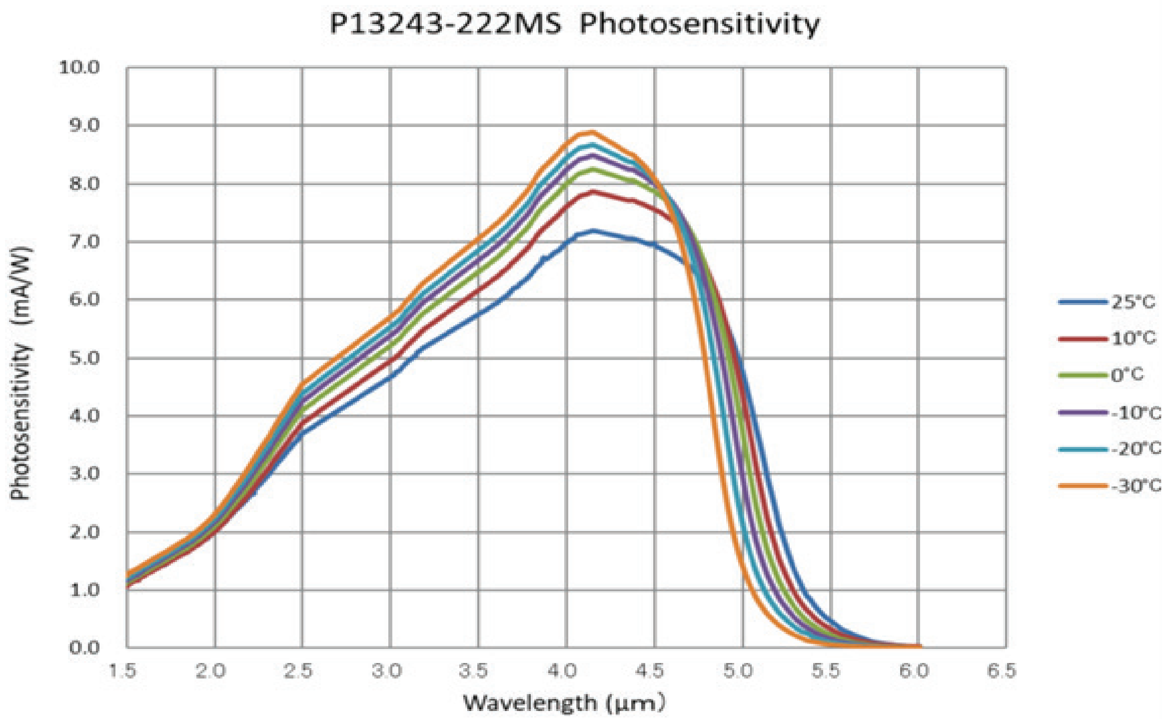


Figure 2: *P13243-222MS InAsSb detector's photosensitivity at different ambient temperatures*

It is important to note that if one chooses not to include cooling, the sensitivity will change with different ambient temperatures. Therefore, it is important to monitor ambient temperatures with a reference channel or thermistor. Even if cooling is used, a cooled detector, if DC coupled, will still experience offset changes with changes in ambient temperature.

By cooling the detector, we increase the detector's photosensitivity. Because Johnson noise is temperature dependent however, we reduce the noise and therefore increase the signal-to-noise ratio (SNR).

To calculate SNR, we must consider I_p and i_{p+d} (see Figure 3) on the following page.

InAsSb photovoltaic detector - P13243-222MS

LEARN MORE ABOUT
InAsSb Photovoltaic Detector

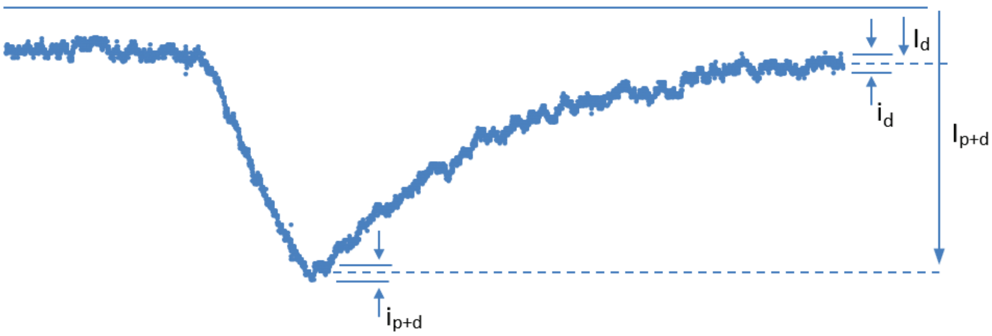


Figure 3: *SNR calculation*

I_d: mean value of noise component

i_d (rms): AC component of noise

I_{p+d}: mean value of signal (noise component included)

i_{p+d} (rms): AC component of signal (noise component included)

$$I_p = I_{p+d} - I_d$$

$$SNR = I_p / i_{p+d}$$

SNR Calculation

In our experiment, we took data from the P13243-222MS InAsSb detector (featuring 2-stage cooling ability) connected to the C4159-01 amplifier, with and without cooling. We used a pulsed 3.3 μm LED as the infrared source. We calculated the SNR with and without cooling, and then calculated the limits to determine the least amount of detectable light in both scenarios.

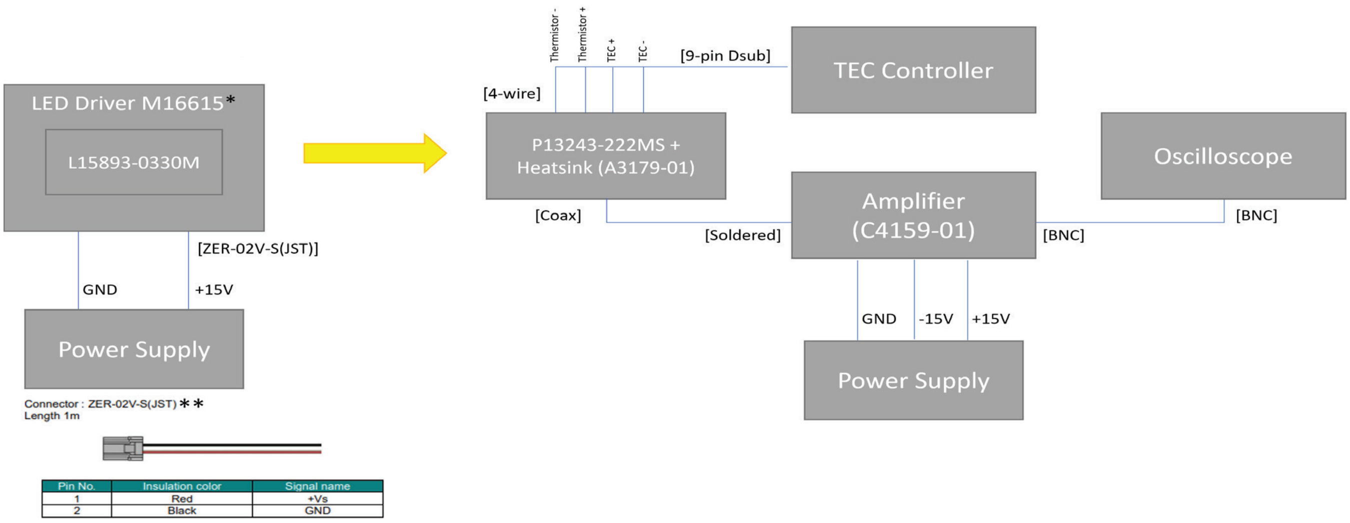
We chose to use the P13243-222MS without cooling rather than one of our detectors with a band pass filter to get a true comparison. However, Hamamatsu offers room temperature detectors with band pass filters specifically at the absorption wavelengths of methane and CO_2, which will reduce noise since the detector can only detect light at that specific wavelength.

MEASUREMENT SET-UP

The following table lists the major equipment and settings we used in our experiment, and the measurement setup is shown in Figure 4. For more details, see the Equipment List on the last page.

Major Equipment and Setup Notes

Equipment	Hamamatsu Part Number	Setup Notes
3.3 μm LED	L15893-0330M	• Pulsed at 1 kHz, 1000 μs using LED driver • Placed 14.38 mm from the InAsSb detector (The LED is a distance of 1.08 mm from the package, and the detector is a distance of 3.3 mm.)
LED driver	M16615	
LED power supply		
InAsSb detector	P13243-222MS	2-stage cooled detector connected to heatsink and amplifier
Heatsink	A3179-01	
Amplifier	C4159-01	Set at LOW gain (10^6)
TEC controller		
Power supply		
Oscilloscope		• Bandwidth-limited to 20 MHz • Set to AC coupling
BNC cable		Connected the BNC cable signal to the InAsSb detector's pin 1 (anode), which produces an inverted pulse. To produce a non-inverted pulse, connect the BNC cable signal to pin 2 (cathode).
Heat gun		Used to simulate a hot environment (60°C)
Other equipment		See the Equipment List on the last page for more details.



*Please refer to "Evaluation kit for LED M16615 Operation Manual" Doc. No. K11-B6G175.
**Found in LED Driver Manual, page 6.

Figure 4: *Measurement setup*

MEASUREMENT RESULTS

In our room temperature measurement, we calculated the SNR as follows.

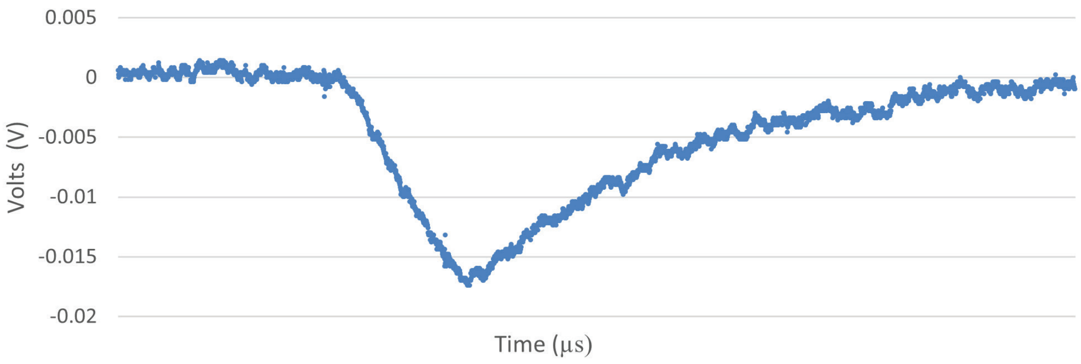


Figure 5: *LED pulse from uncooled detector at room temperature*

I_p (rms) = 0.36 mV - -16.47 mV = 16.83 mV

i_{p+d} (rms) = 0.43 mV

SNR = 16.83 mV / 0.43 mV = 39.1

A general rule of thumb is that to be detectable a signal must be three times that of the noise. In this scenario, the noise is 0.43 mV. Therefore, to be detectable, the signal should be at least 1.29 mV. At room temperature, the detector's sensitivity at 3.3 μm is 5.3 mA/W. The amplifier provides a gain of 10^6 V/A on the low setting. We then cooled the detector to -15°C. We calculated the SNR as follows.

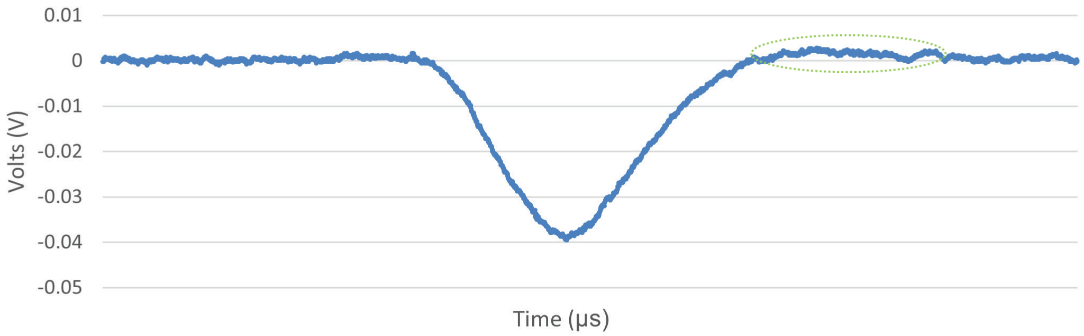


Figure 6: *LED pulse from detector cooled to -15°C*

I_p (rms) = 0.30 mV - -38.64 mV = 38.94 mV

i_{p+d} (rms) (rms)= 0.44 mV

SNR = 38.94 mV / 0.44 mV = 88.5

**Note: The overshoot (highlighted in green) is due to the amplifier being slower than the detector.*

The cooled detector has similar noise levels; however, the sensitivity has increased (6.1 mA/W), which leads to an increase in SNR.

We then simulated a heated environment and calculated the SNR without cooling.

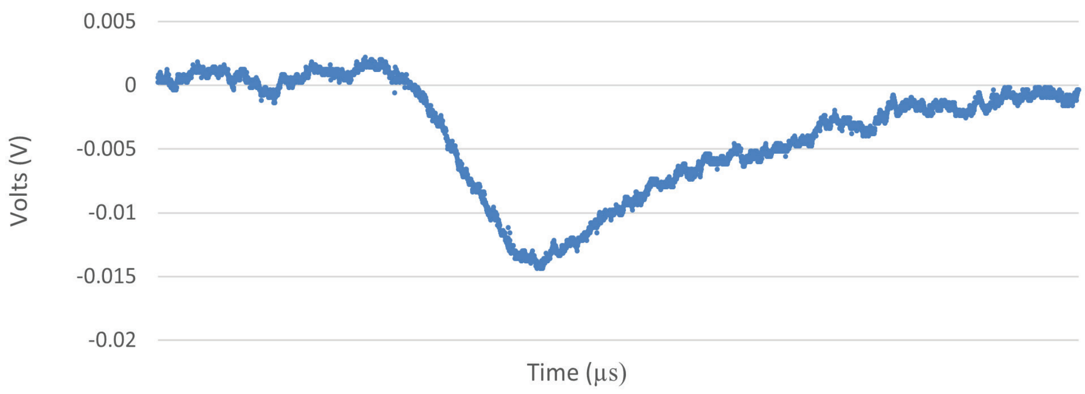


Figure 7: *LED pulse from uncooled detector in hot environment*

I_p (rms) = 0.71 mV - -13.04 mV = 13.75 mV

i_{p+d} (rms) = 0.70 mV

SNR = 13.75 mV / 0.70 mV = 19.6

In a heated environment, the noise is higher.

We then used cooling with the simulated heated environment and calculated the SNR.

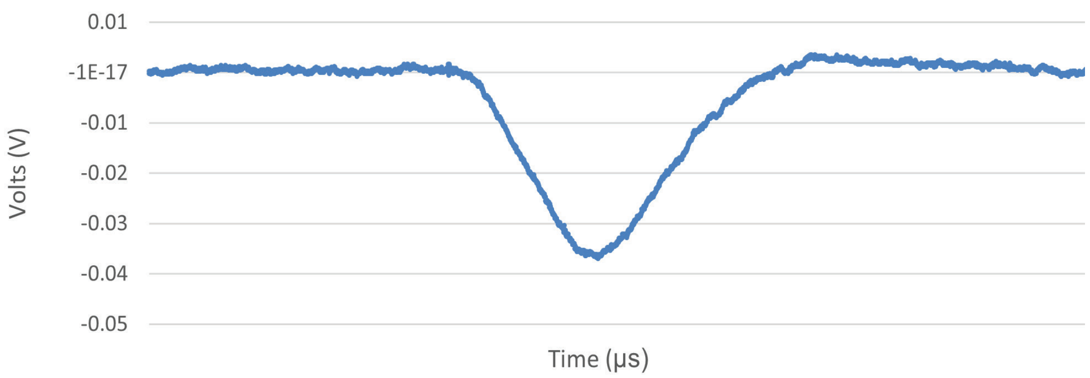


Figure 8: *LED pulse from cooled detector in hot environment*

I_p (rms) = 0.40 mV - -35.94 mV = 36.34 mV

i_{p+d} (rms) (rms)= 0.45 mV

SNR = 36.34 mV / 0.45 mV = 80.8

With cooling, noise levels are brought down while the signal is increased.

Temperature (°C)	SNR
25	39.1
-15 wrt ambient	88.5
60	19.6
-15 wrt 60 ambient	80.8

Table 2: *Summary of SNR at different temps*

DISCUSSION

By exposing the uncooled detector to a hot environment, the SNR is reduced from 39.1 to 19.6 (48.8%). Additionally, we see a background noise increase, highlighted in red (see Figures 9 and 10).

With cooling, we do not see this effect on the dark current (see Figures 11 and 12).

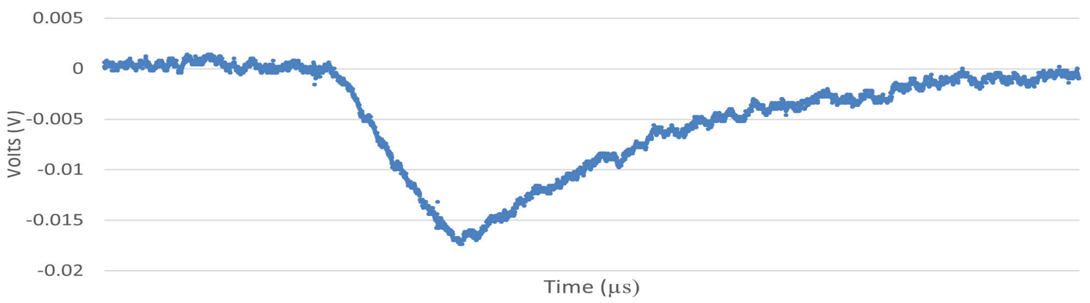


Figure 9: *LED pulse from uncooled detector at room temperature environment*

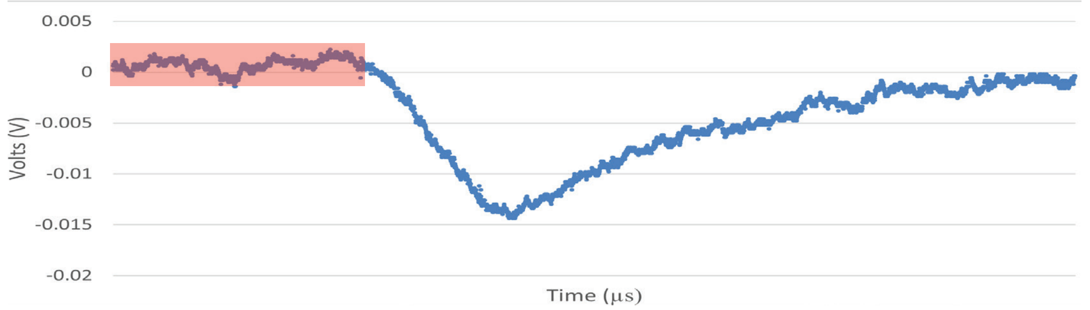


Figure 10: *LED pulse from uncooled detector in hot environment*

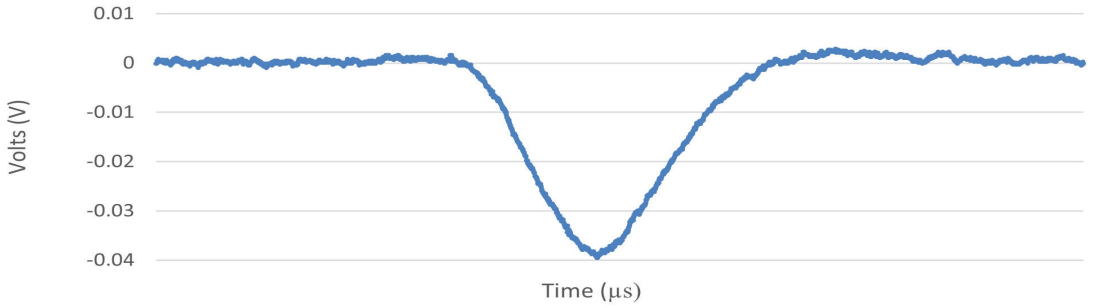


Figure 11: *LED pulse from cooled detector in room temperature environment*

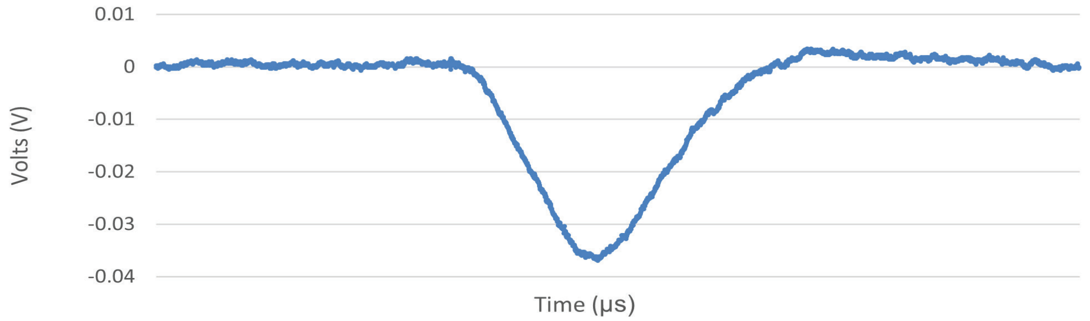


Figure 12: *LED pulse from cooled detector in hot environment*

The amplitude of the pulse in a hot environment has decreased slightly (38.94 mV to 36.34 mV, 93.6%). However, this is less than the decrease in signal with the uncooled detector (16.83 mV to 13.75 mV, 81.7%). Additionally, the noise remains roughly the same with the cooled detector in a heated environment, which leads to very little change in the SNR (88.5 to 80.8).

The benefits of cooling include:

- **Increasing the signal-to-noise ratio by a factor of 2.3**
- **Mitigating an increase in background noise**
- **Maintaining roughly the same SNR even in a heated environment**

As mentioned before, Hamamatsu's P13243 series has a proprietary multistage structure that allows them to perform at room temperature. This structure also increases shunt resistance. Therefore, one should keep in mind that some applications may not require cooling. In addition, if we were to compare a cooled detector to a non-multistage room temperature detector, we would see an even greater increase in SNR.

REFERENCES

1. Compound Semiconductor Photosensors Catalog, Cat. No. KIRD9004E01 April 2021
2. Evaluation Kit for LED M16615 Operation Manual, Doc. No. K11-B6G175 December 2021
3. C4159-01 Operation Manual, DWG. NO. K02-B6G020, June 2020
4. Introduction to Photodetectors Webinar, Slawomir Piatek, 2020
5. TEC2000 Thermoelectric Temperature Controller Instruction Manual, Doc. Number 2135-K01, Rev E 7-20-2001
6. Consultations from Yuji Iwai and Slawomir Piatek

Hamamatsu Corporation
Published April, 2023

The following equipment can be used for the experiment described in this technical note.

* Or similar alternative with similar specifications
(Hamamatsu's C1103-04 temperature controller is available.)

** Includes coax cable (18 gauge wire, 1.50 – GEV Fujikura DIA)
4-conductor cable (T-VSV Bando Densen, 18 gauge wire, 2464C BIOS-CL3-AWG18-X)

Description	Part Number	Supplier
Cooled InAsSb Detector	P13243-222MS	Hamamatsu
Heatsink Assembly Kit**	A3179-01	Hamamatsu
Preamplifier	C4159-01	Hamamatsu
Oscilloscope*	DPO 4054	Tektronix
Temperature Controller*	TEC2000	Thorlabs
MIR LED Driver	M16615	Hamamatsu
3.3 µm LED	L15893-0330M	Hamamatsu
Power supply (2)*	E3630A	Agilent

Optional Opto-Mechanical Parts

Description	Part Number	Supplier
Aluminum Breadboard, 300 mm x 450 mm x 12.7 mm, M6 Taps	MB6045/M	Thorlabs
Ø12.7 mm Post Holder, Spring-Loaded Hex-Locking Thumbscrew, L=50 mm, 5 Pack	PH50/M-P-5	Thorlabs
Ø12.7 mm Optical Post, SS, M4 Setscrew, M6 Tap, L = 40 mm, 5 Pack	TR40/M-P-5	Thorlabs
Dovetail Optical Rail, 300 mm, Metric	RLA300/M	Thorlabs
Dovetail Rail Carrier, 1.00" x 1.00" (25.4 mm x 25.4 mm), 1/4" (M6) Counterbore (2)	RC1	Thorlabs
Kinematic Self-Centering Mount, Ø0.15" (Ø3.8 mm) to Ø1.7" (Ø43 mm)	KS1SC	Thorlabs
M6 x 1.0 Stainless Steel Cap Screw, 10 mm Long, 25 Pack	SH6MS10	Thorlabs
M6 x 1.0 Stainless Steel Cap Screw, 20 mm Long, 25 Pack	SH6MS20	Thorlabs
M6 x 1.0 Stainless Steel Setscrew, 12 mm Long, 25 Pack	SS6MS12	Thorlabs