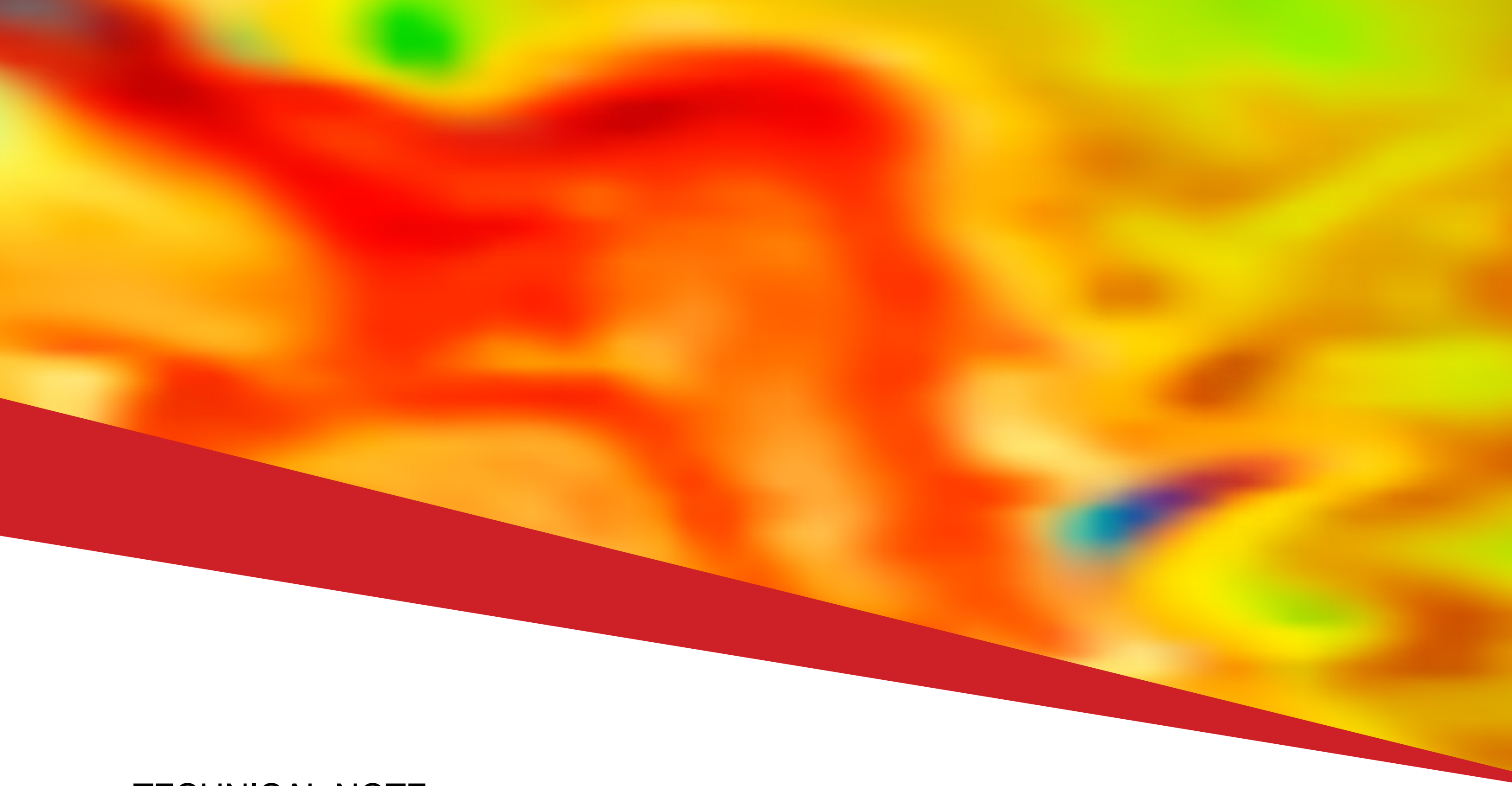


TECHNICAL NOTE

Noise Mitigation Strategies for Infrared Detection

By Columbine Robinson, Applications Engineer, Hamamatsu Corporation

When it comes to infrared measurements, a lock-in amplifier paired with a pulsed light source is an essential tool to increase SNR for low light applications. The goal of this tech note is to highlight the advantages of using a lock-in amplifier with Hamamatsu's InAsSb detector and LEDs.

HAMAMATSU

PHOTON IS OUR BUSINESS

TABLE OF CONTENTS

HAMAMATSU

PHOTON IS OUR BUSINESS

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. Black body radiation increases with temperature. This means that if the ambient temperature changes, the noise also changes as well as a detector's sensitivity. Often these measurements are in environments with changing ambient temperature, which makes it challenging to know if the change in signal is coming from the desired measurement source or a change in ambient temperature. One way to mitigate this is to use a lock-in amplifier (LIA) in conjunction with a pulsed light source. A lock-in amplifier typically uses a reference signal with a specific frequency to pass signals of this frequency and reject noise signals other than the reference frequency.

The amount of noise measured by the lock-in amplifier is determined by the measurement bandwidth. The lock-in amplifier does not narrow its detection bandwidth until after the phase-sensitive detectors. In a lock-in amplifier, the equivalent noise bandwidth of the low pass filter, determined by the time constant, sets the detection bandwidth. The measured noise is shown in Equation 1.

$$V_{noise}(rms) = 0.13\sqrt{R}\,\sqrt{ENBW}\ \text{nV}$$

R: input resistor
ENBW: equivalent noise bandwidth of low pass filter (time constant)

Equation 1: *Lock-in amplifier noise*

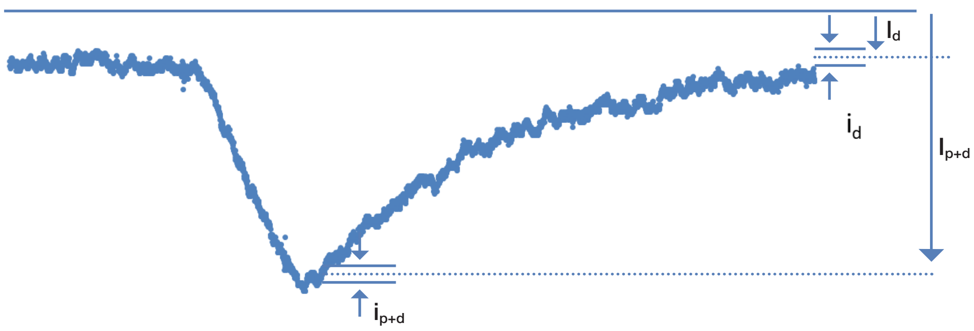
We must also consider shot noise, which is shown in Equation 2.

$$I_{noise}(rms) = \sqrt{2qI\Delta f}$$

q: electron charge
I: rms AC current or DC current
Δf: bandwidth

Equation 2: *Shot noise*

To calculate the signal-to-noise ratio (SNR) of the bare detector, we must consider I_p and i_{p+d} (see Figure 1).



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)

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

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

Figure 1: *SNR Calculation*

In our experiment, we input the signal from the detector as well as a reference pulse from the LED driver to the lock-in amplifier. The low pass filter time constant and rolloff will determine the detector's bandwidth at the output at a frequency of $f = f_{sig} – f_{ref}$. Input noise near f_{ref} will appear as noise at the output with a bandwidth of DC to the detection bandwidth. The noise is the standard deviation (root of the mean of the squared deviations).

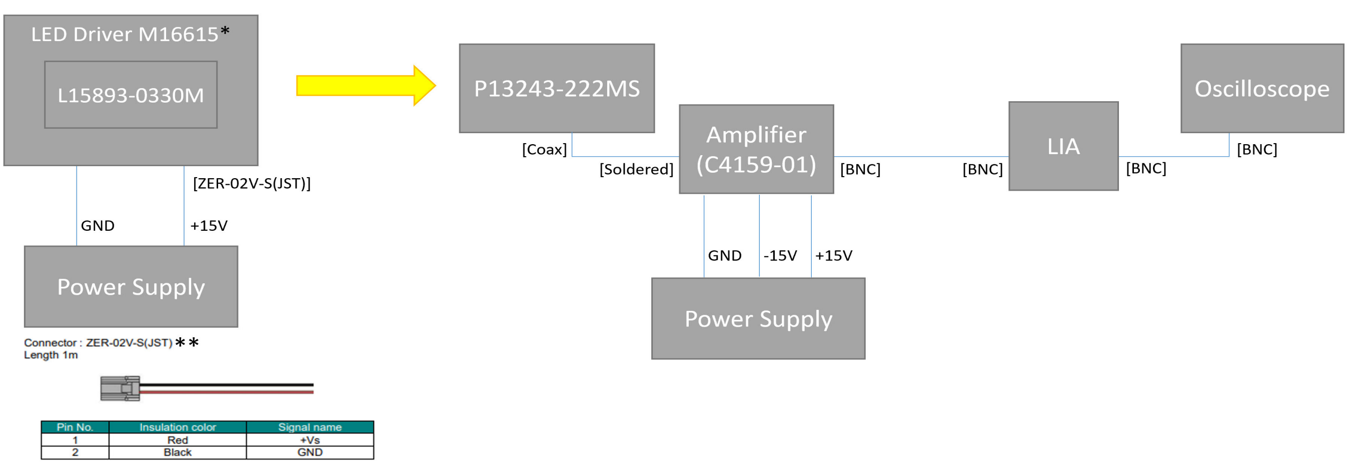
Please note that we did not use any lenses in our experiment; lenses would increase the light collection.

MEASUREMENT SETUP

The following table lists the major equipment and settings we used in our experiment, and the measurement setup is shown in Figure 2. 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, 54.38 mm, and 104.38 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	No cooling applied
Amplifier	C4159-01	Set at LOW gain (10^6)
SR810 lock-in amplifier (LIA)		• Time constant of 1 s, 12 dB • Sensitivity of 20 mV
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 2: *Measurement setup*

MEASUREMENT RESULTS

1: Varying Distance (varying light levels)

Figure 3 shows the signal from the detector without the lock-in amplifier, and we calculated the SNR as follows.

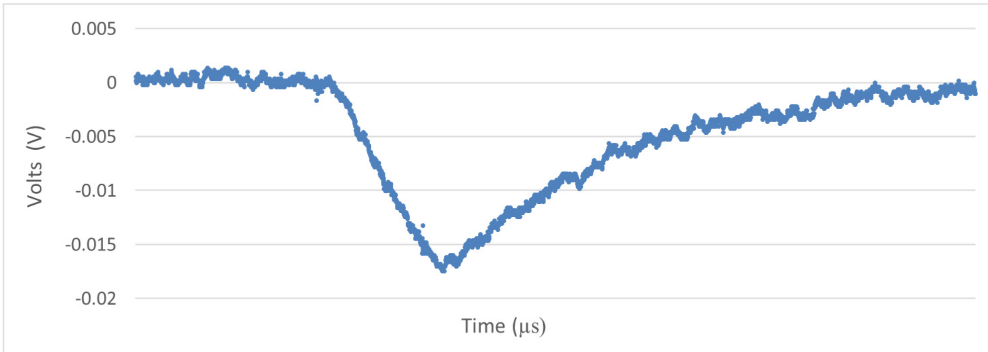


Figure 3: *LED pulse from detector at room temperature*

$$I_p\ (rms) = 0.36\text{ mV} - -16.47\text{ mV} = 16.83\text{ mV}$$

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

$$SNR = 16.83\text{ mV} / 0.43\text{ mV} = 39.1$$

To determine the SNR using the LIA, we must compare the signals passed through the LIA when the LED is on and when the LED is off (see Figure 4).

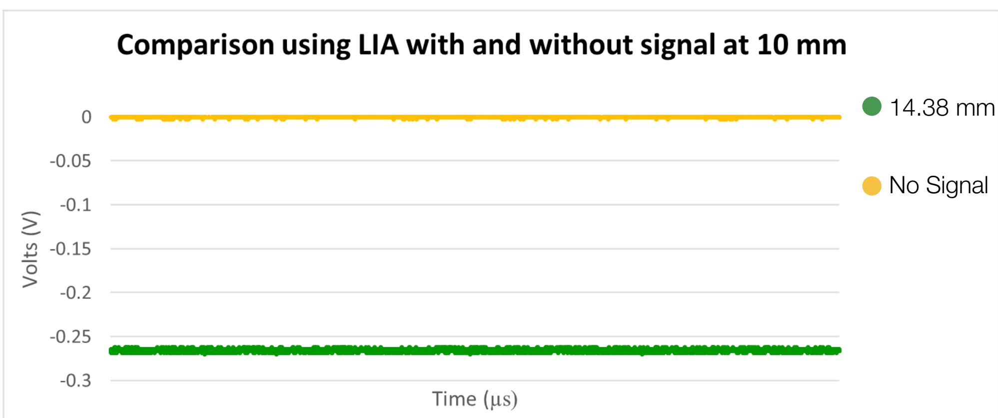


Figure 4: *LIA at 14.38 mm*

As mentioned previously, the noise is the standard deviation of the signal. SNR is calculated as follows:

SNR = 268 mV / 1.3 mV = 206.2

The LIA has improved the SNR by 5.3-fold.

At 50 mm, the signal from the detector is undetectable (see Figure 5).

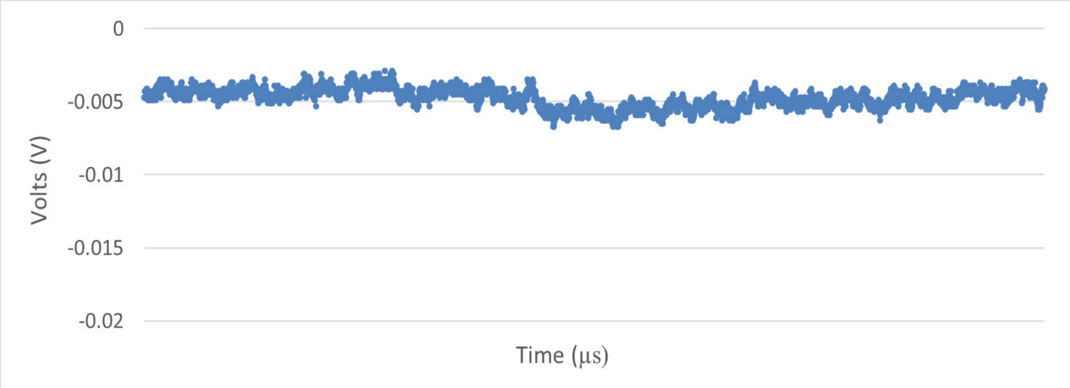


Figure 5: *LED pulse from detector at a distance of 54.38 mm*

However, with the help of the lock-in amplifier, measurements out to 100 mm are possible (see Figure 6).

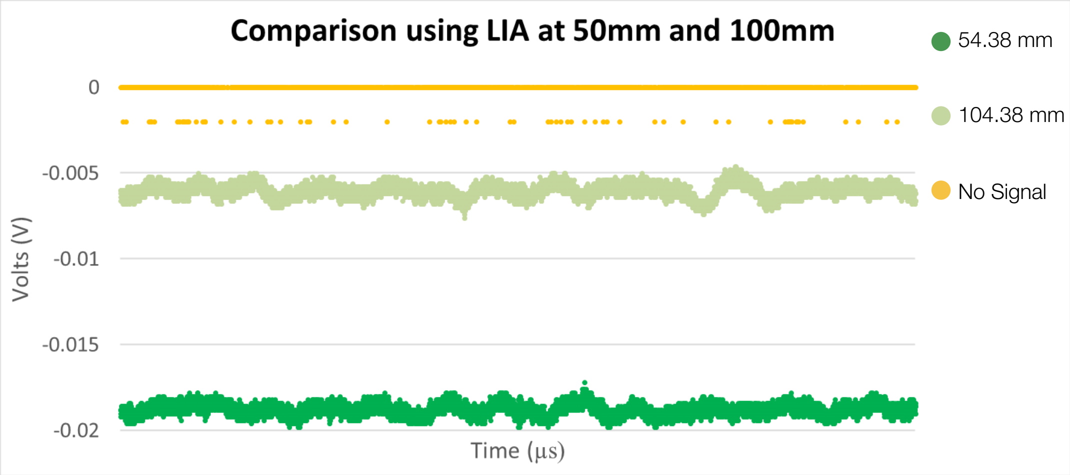


Figure 6: *LIA at 54.38 mm and 104.38 mm*

SNR at 54.38 mm = 18.7 mV / 0.4 mV = 46.8

SNR at 104.38 mm = 6.8 mV / 0.4 mV = 17.0

2: Varying Temperature

In a simulated hot environment, the detector's dark current increases (highlighted in red in Figure 7).

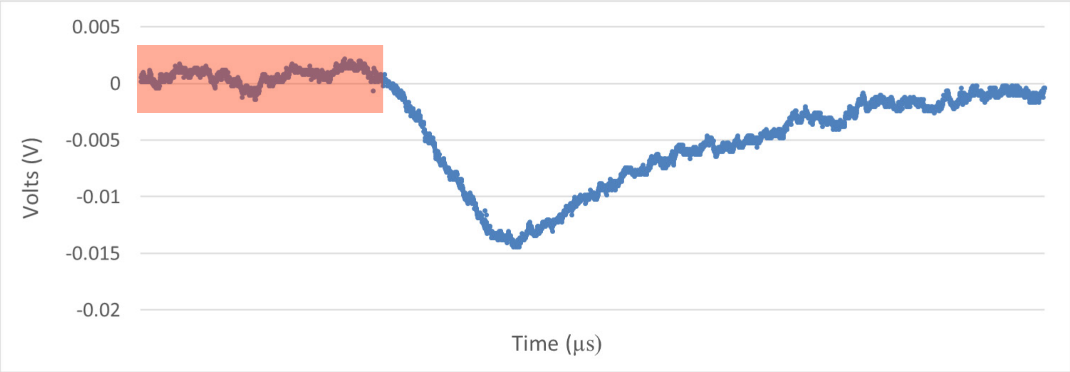


Figure 7: *LED pulse from detector in hot environment*

The SNR is calculated as follows:

$$I_p\,(_{rms}) = 0.71\text{ mV} - -13.04\text{ mV} = 13.75\text{ mV}$$

$$i_{p+d}\,(_{rms}) = 0.70\text{ mV}$$

$$SNR = 13.75\text{ mV} / 0.70\text{ mV} = 19.6$$

However, the lock-in amplifier signal is not affected by an increase in the temperature (see Figure 8).

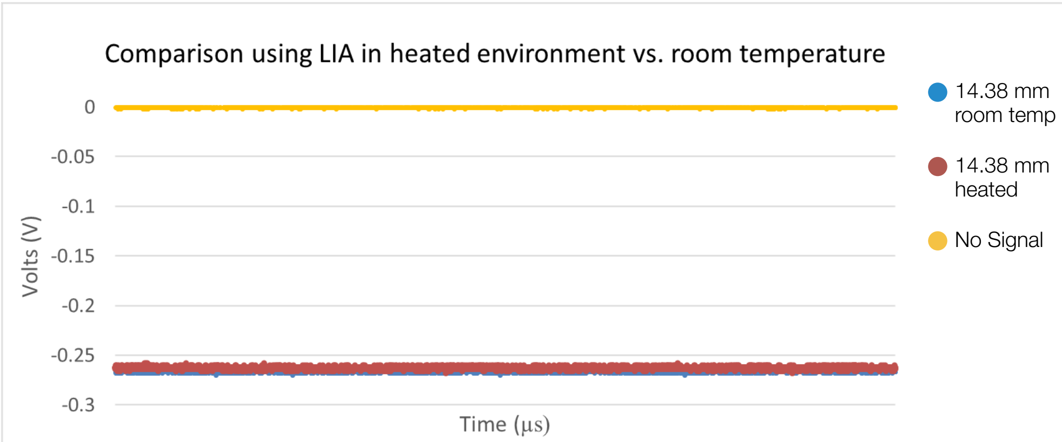


Figure 8: *Comparison using LIA in heated environment vs. room temperature*

Distance (mm)	Readout	SNR
14.38	C4159-01	39.1
14.38	LIA	206.2
54.38	C4159-01	0
54.38	LIA	46.8
104.38	LIA	17.0

Table 2: *Summary of SNR with and without LIA*

DISCUSSION

We have shown the benefits of using a lock-in amplifier in combination with a pulsed light source. A lock-in amplifier has the potential to increase SNR by 5.3-fold and, in some situations, allow the detection of a signal that is not detectable without it. This means the potential for detecting small gas concentrations or resolving small temperature changes has substantially increased.

We have also shown that the LIA measurement is not affected by ambient temperature changes. This is critical to many applications where the ambient temperature changes or cannot be well controlled.

The benefits of using a lock-in amplifier in combination with a pulsed light source:

- **Increase SNR by 5.3X**
- **Ability to detect signals that would not be detectable otherwise**
- **The LIA measurement is not affected by ambient temperature changes**

REFERENCES

1. Compound Semiconductor Photosensors Catalog, Cat. No. KIRD9004E01 April 2021
2. Introduction to Photodetectors Webinar, Slawomir Piatek, 2020
3. Evaluation Kit for LED M16615 Operation Manual, Doc. No. K11-B6G175 December 2021
4. C4159-01 Operation Manual, DWG. NO. K02-B6G020, June 2020
5. About Lock-In Amplifiers, Application Note #3, thinkSRS.com
6. Model SR810 DSP Lock-In Amplifier, Stanford Research Systems, Revision 1.8 (01/2005)
7. Consultations from Yuji Iwai and Slawomir Piatek

Hamamatsu Corporation
Published June, 2023

EQUIPMENT LIST

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