I recently purchased a Seek RevealPro Thermal Camera, which boasts a 320 x 240 thermal sensor with >15 Hz frame rate at an incredibly affordable price.

One of the only issues that I have with this camera is that it comes with a fixed 32° field-of-view lens\(^1\). This is OK for general thermal inspection, but it’s a real disadvantage when trying to use the camera for close-up work to assess dissipation on printed circuit boards or identifying a faulty or undersized component. On the opposite side of the distance range, the 32° FOV lens makes it difficult to see and measure the temperature of objects at a distance, or of smaller objects at normal distances.

\(^1\) My other issues are that it does not support a tethered mode, and that it does not capture video, only stills.
I thus decided to build magnifying (“macro”) and close-up (“telephoto” - Figure 1) converters for the RevealPro. I’m passing along information on my designs in hopes that others will find it useful.

**Lenses Suitable for Thermal Imaging**

First things first – Thermal cameras measure the intensity of infrared light at around 10 µm. This is because objects emit blackbody radiation peaking at around that wavelength in accordance with **Wien’s displacement law**. However, normal glass doesn’t transmit light at those wavelengths, so the lenses used in thermal imaging must be made of either Germanium or Zinc Selenide (Figure 2) which allow radiation in the 10 µm range to pass through.

![Figure 2](image.png)

*Figure 2 - Normal glass doesn’t transmit light at those wavelengths, so the lenses used in thermal imaging must be made of either germanium or Zinc Selenide which allow radiation in the 10 µm range to pass through. Germanium lenses are opaque to visible light and have a glassy-gray metallic look. Zinc Selenide has a very broad transmission range (600 nm - 16.0 µm) giving them a dark orange tint in the visible range.*

Germanium (Ge) lenses are most commonly used for thermal imaging applications because of their broad transmission range (2.0 - 16 µm – see Figure 3) in the spectral region of interest. Germanium lenses are opaque to visible light and have a glassy-gray metallic look. They are inert to air, water, alkalis, and most acids. Germanium has an index of refraction of 4.004 at 10.6 µm, and its transmission properties are highly temperature sensitive.
Zinc Selenide (ZnSe) is much more commonly used with CO₂ lasers. It has a very broad transmission range (600 nm - 16.0 µm, see Figure 4). Because of low absorption in the red portion of the visible spectrum, ZnSe lenses are commonly used in optical systems that combine CO₂ lasers (which commonly operate at 10.6 µm), with inexpensive visible-red HeNe or semiconductor alignment lasers.
New infrared lenses can be purchased from Thorlabs, Edmund Optics, and other optical component suppliers. As you can imagine, these lenses are not cheap – Ø1/2" Ge plano-convex lenses from Thorlabs are priced at around $140, while ZnSe lenses are around $160. Ø1" Ge lenses sell for around $240, while ZnSe at this diameter cost around $300. Surplus finds or Far-East offerings are thus best to make the macro and telephoto adapters. ZnSe lenses from China can be bought on eBay® for around $60.

“Macro” Adapter
A “macro” magnifying converter is simply a convex or plano-convex lens placed in front of the thermal camera’s lens. As shown in Figure 5, IR light rays from the object enter the convex lens in parallel but are refracted by the lens so that they converge as they exit, and create a “virtual image” on the camera’s sensor. This image appears to be larger than the object itself because of simple geometry since the light rays back trace back in straight lines to the virtual image, which is farther from the camera than the object, and thus appears bigger.
As shown in Figure 6, a simple Ge or ZnSe plano-convex lens allows the camera to be placed much closer to the object under examination, providing magnification that is inversely proportional to the lens' focal length. The upper-left pane of the figure shows the heatsink vents of my laptop as imaged by the Seek RevealPRO's fixed lens. The fixed focus of the RevealPRO requires a minimum distance of around 6”. Placing plano-convex lenses of decreasing focal lens in front of the camera allows larger and larger magnifications of the image, revealing details that are completely lost with the unaided camera.
diy “Macro” and “Telephoto” Adapters for Thermal Cameras

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“Telephoto” Converter

Imaging an object at a distance with a thermal camera requires a simple telescope made with lenses that work in the 10 µm range. A basic refracting telescope that has two optical elements, an objective and an eyepiece. The objective is a large lens that collects light from a distant object and creates an image of that object in the focal plane. The eyepiece is just a magnifying glass through which the thermal camera can view the virtual image.

As shown in Figure 7, there are two basic configurations for a refractive telescope: A Keplerian telescope has a converging lens eyepiece and a Galilean telescope has a diverging lens eyepiece. The image as viewed through the Keplerian telescope is inverted, while that produced by a Galilean telescope is upright. The telescope by itself is not an image forming system. Rather, the thermal camera attached to the telescope ultimately forms the image through its own optics.

Figure 7 – Refractive telescopes have two common configurations: A Keplerian telescope has a converging lens eyepiece and a Galilean telescope has a diverging lens eyepiece. The image as viewed through the Keplerian telescope is inverted, while that produced by a Galilean telescope is upright.
I was able to find a Ø1” Ge plano-convex lens with a focal length of 50 mm (similar to a Thorlabs LA9659-E3) and a Ø1/2” Ge plano-convex lens with a focal length of 15 mm (similar to a Thorlabs LA9410-E3) to make my Keplerian telephoto converter. The magnification is thus:

\[
\text{Magnification}_{\text{Keplerian}} = \frac{f_o}{f_e} = \frac{50 \text{ mm}}{15 \text{ mm}} = 3.33
\]

Telephoto adapters of other magnifications are easy to design using the simple formulas shown above. Please note that the main lens tube’s length may need to be changed, since the distance between the lenses should be close to \( f_0 + f_e \).

As shown in Figure 8 through Figure 10, I housed my telephoto converter in an optical tube made with Thorlab’s SM1 and SM05 tube components. I placed the objective lens at the front of a SM1V05 adjustable lens tube to allow focusing by making it possible to adjust the distance between the lenses. An external SM1 ring is used to lock the focus. Table 1 lists all of the materials needed to build the telephoto converter. Using brand-new parts from Thorlabs you can expect to spend around $466. If you use ZnSe lenses from eBay® and new parts for the housing you’ll probably spend around $200.
**Figure 9 — My Keplerian ×3.33 telephoto converter showing objective and eyepiece lenses.**

**Table 1 — Bill of materials for the Keplerian ×3.33 telephoto converter**

<table>
<thead>
<tr>
<th>Thorlabs Part Number</th>
<th>Description</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA9659-E3</td>
<td>Ø1” Ge Plano-Convex Lens, f = 50 mm, AR-Coated: 7-12 µm</td>
<td>$241.74</td>
</tr>
<tr>
<td>LA9410-E3</td>
<td>Ø1/2” Ge Plano-Convex Lens, f = 15 mm, AR-Coated: 7-12 µm</td>
<td>$139.74</td>
</tr>
<tr>
<td>SM1V05</td>
<td>Ø1” Adjustable Lens Tube, 0.31” Travel Range</td>
<td>$30.25</td>
</tr>
<tr>
<td>SM1L15</td>
<td>SM1 Lens Tube, 1.50” Thread Depth, One Retaining Ring Included</td>
<td>$15.70</td>
</tr>
<tr>
<td>SM1A1</td>
<td>Adapter with External SM05 Threads and Internal SM1 Threads</td>
<td>$20.60</td>
</tr>
<tr>
<td>SM05L03</td>
<td>SM05 Lens Tube, 0.30” Thread Depth, One Retaining Ring Included</td>
<td>$13.80</td>
</tr>
<tr>
<td>SM1RR</td>
<td>SM1 Retaining Ring for Ø1” Lens Tubes and Mounts</td>
<td>$4.50</td>
</tr>
<tr>
<td><strong>Total with new germanium lenses</strong></td>
<td></td>
<td><strong>$466.33</strong></td>
</tr>
<tr>
<td><strong>Housing only</strong></td>
<td></td>
<td><strong>$84.85</strong></td>
</tr>
</tbody>
</table>
The enclosure for the telescope doesn’t need to be as fancy as mine. PVC pipes with some arrangement for focusing (e.g. lens mounted on threaded cap) will work perfectly OK. However, I really like Thorlabs’ SM Tubes because they are relatively inexpensive and perfectly suited for the construction of this type of optical instruments. In addition, the threaded side of the eyepiece’s SM05L03 sits perfectly against the retainer ring of the Seek RevealPRO’s lens (Figure 11).
I'm very pleased with the results. Figure 12 shows some sample images of the telephoto converter in use. The left panes show the image captured through the Seek RevealPRO's fixed lens. The right panes show the same scene using the ×3.33 telephoto converter of Figure 9. I added an orange rectangle to the images on the left panes to indicate the region magnified by the telephoto converter. The rectangle's dimensions are 1/3.33 those of the image frame, demonstrating that the magnification achieved by the telephoto converter is indeed ×3.33.

Of course, the lens systems used in the Seek RevealPRO and the telephoto converter are extremely simple, so distortions and vignetting are to be expected. As shown in Figure 13, vignetting is most apparent when using the telephoto converter to image subjects at a large distance. Nevertheless, details that cannot be seen with the unaided camera are very apparent using the telephoto converter.
Figure 12 – Sample images demonstrating the Keplerian telephoto adapter with the Seek RevealPRO thermal camera. On left panes are the scenes imaged through the unaided camera. On the right panes are the same scenes through the ×3.33 telephoto converter. The dimensions on the orange rectangle on the left panes is exactly 1/3.33 the size of the RevealPRO’s frame, showing that the telephoto converter indeed has a magnification of ×3.33.
Attaching the Converter Lenses to a Camera

Macro and telephoto converters are easily used when hand-held in front of a camera. However, for a more stable solution you may want to consider permanently attaching a Thorlabs SM05NT ($6.58) SM05 Locking Ring (ID 0.535”-40, 0.75” OD) to your camera’s lens mount so that you can quickly mount macro or telephoto converters in front of the camera’s lens without affecting its original functionality.

For my application, I needed the camera and telephoto converter to remain at a fixed location referenced to the device on which I was performing a thermal analysis, so I post-mounted the camera and telephoto converter on a small aluminum optical breadboard as shown in Figure 14.
Figure 14 - For my application, I needed the camera and telephoto converter to remain at a fixed location referenced to the device on which I was performing a thermal analysis, so I post-mounted the Seek RevealPRO camera and telephoto converter on a small aluminum optical breadboard.

Sources
Seek - www.thermal.com
Thorlabs – www.thorlabs.com
Edmund Industrial Optics - www.edmundoptics.com

Note: I am not affiliated in any way with these companies.

Further Reading and Experiments
For more interesting experiments on physics and photography of the unseen world, please look through my books (click here for my books on Amazon.com):
and go to my websites:

www.diyPhysics.com and www.UVIRimaging.com
APPENDIX – Step-by-Step Instructions for Building the Telephoto Converter

(Also available as an Instructable at: https://www.instructables.com/id/Diy-Thermal-Camera-Telephoto-Converter/)

Step 1 – Remove Ring from SM1L15 Tube
Using your fingers or a spanner wrench (e.g. Thorlabs SPW602 which sells for $26.75) remove the SM1 retainer ring that comes inside the SM1L15 tube.

Step 2 – Prepare Components for the Assembly of the Objective Lens
Prepare the components that you’ll need for the assembly of the objective lens:

- SM1V05 adjustable lens tube
- Two SM1 retainer rings (one of them comes from the SM1L15 lens tube as shown in prior step)
- Ø1" Ge Plano-Convex Lens, f = 50 mm, AR-Coated: 7-12 µm (or similar)
Step 3 – Insert SM1 Retainer Ring into SM1V05 to a Depth of 6mm

Using a spanner wrench or your fingers, insert one retainer ring into the SM1V05 adjustable lens tube to a depth of approximately 6mm. This may need to change depending on the lens that you chose as your objective. The idea is to allow the lens to sit sufficiently behind to make it possible to use a retainer ring on the other side of the lens.

Step 4 – Insert Objective Lens and Outer Retainer Ring

Insert the objective lens with its convex side facing outward and then fix in place using the second retainer ring. Be careful not to over-tighten, since this may damage the lens! If you use tweezers or other tool instead of a spanner wrench be careful not to scratch the lens.
Step 5 – Prepare Components for Eyepiece

Prepare the components that you’ll use to assemble the eyepiece:

- SM05L03 lens tube
- SM5 retainer ring (removed from SM05L03 tube)
- Ø1/2" Ge Plano-Convex Lens, f = 15 mm, AR-Coated: 7-12 µm (or similar)

Step 6 – Assemble Eyepiece

Assemble the eyepiece by inserting the eyepiece lens into the SM05L03 tube. The convex side should face the external threads (down in the following picture). Fix the lens in position with the SM05 retainer ring. Preferably, use a SM05 spanner wrench (e.g. Thorlabs SPW603, which sells for $24.50) to insert and tighten the SM05 retainer ring. **Be careful not to over-tighten, since this may damage the lens!** If you use tweezers or other tool instead of a spanner wrench be careful not to scratch the lens.
Step 7 – Mount Eyepiece to SM1-to-SM05 Adapter
Screw the eyepiece lens assembly onto a SM1A1 SM1-to-SM05 adapter.

Step 8 – Final Assembly
Finally, screw the eyepiece lens assembly (mounted on the SM1A1 adapter) and the objective lens assembly onto the SM1L15 lens tube. This completes the assembly of the Keplerian telephoto converter.

Step 9 – Use the Telephoto Converter
Place the telephoto converter in front of the thermal camera’s lens and start exploring! You should focus the lens by turning the objective lens assembly until the sharpest image of your subject is obtained. The external SM1 ring that comes with the SM1V05 adjustable lens tube can be used to lock the focus setting.

You may want to consider permanently attaching a Thorlabs SM05NT ($6.58) SM05 Locking Ring (ID 0.535”-40, 0.75” OD) to your camera’s lens mount so that you can quickly mount macro or telephoto converters in front of the camera’s lens without affecting its original functionality.
Lastly, remember that a Keplerian telescope inverts the image, so you will see the thermal picture upside-down on your camera’s screen. It takes just a little bit of practice to get used to the fact that pointing the camera with the telephoto converter installed needs movements in the opposite direction of the image.