
# APPLICATION STORY

## THE CHALLENGE OF MEASURING HEAT AT HIGH SPEEDS

*How do you measure the heat of an object that is moving fast or changing temperature rapidly? Traditional temperature measurement tools such as thermocouples or spot pyrometers don't offer the resolution or speed needed to fully characterize high speed thermal applications. These tools are impractical for measuring an object in motion – or at the very least, provide an incomplete picture of an object's thermal properties.*

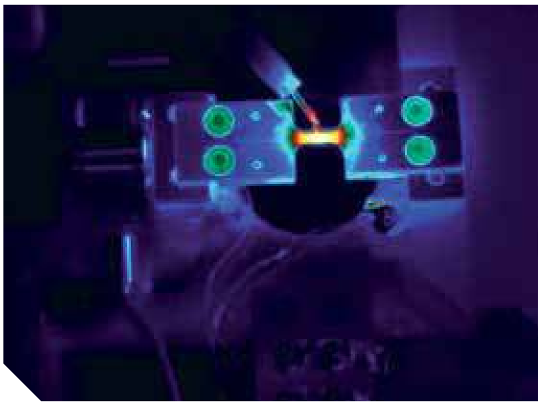
*In contrast, an infrared camera can measure temperature across an entire scene, capturing thermal readings for each pixel. Infrared cameras can offer fast, accurate, non-contact temperature measurement. By choosing the correct type of camera for your application, you will be able to gather reliable measurements at high speeds, produce stop-motion thermal images, and generate compelling research data.*

*Stop motion image of FA-18 Hornets from a FLIR InSb cooled thermal camera*

### SPOT VS. BROAD AREA MEASUREMENT

Measuring temperature across a broad area, instead of spot by spot, can help researchers and engineers make better-informed decisions about the systems they're testing. Since thermocouples and thermistors require contact, they only provide data from one location at a time. In addition, small test subjects can only fit a few thermocouples at one time. Attaching them may actually change the temperature reading by acting as a heat sink. Non-contact measurement is possible with a pyrometer – also called an infrared (IR) thermometer—but just like thermocouples, pyrometers only measure a single point.

Infrared cameras produce images from the radiation emitted by objects above absolute zero. By providing a temperature measurement for each pixel, researchers are able to see and measure temperature across a scene without contact. Because IR cameras offer more data than thermocouples or pyrometers and can track changes in temperatures over time, they work well for research and engineering purposes.



*Thermal image of a traditional thermocouple*

## COOLED VS. UNCOOLED INFRARED DETECTORS

There are two types of infrared detectors: thermal and quantum. Thermal detectors such as microbolometers react to incident radiant energy which heats the pixels and creates a change in temperature that is reflected in a change in resistance. These cameras do not require cooling and cost less than quantum detector cameras.

Cooled quantum detectors are made from Indium Antimonide (InSb), Indium Gallium Arsenide (InGaAs), or Strained Layer Superlattice. These detectors are photovoltaic, meaning photons strike the pixels and are converted into electrons that are stored in an integration capacitor. The pixel is electronically shuttered by opening or shorting the integration capacitor.

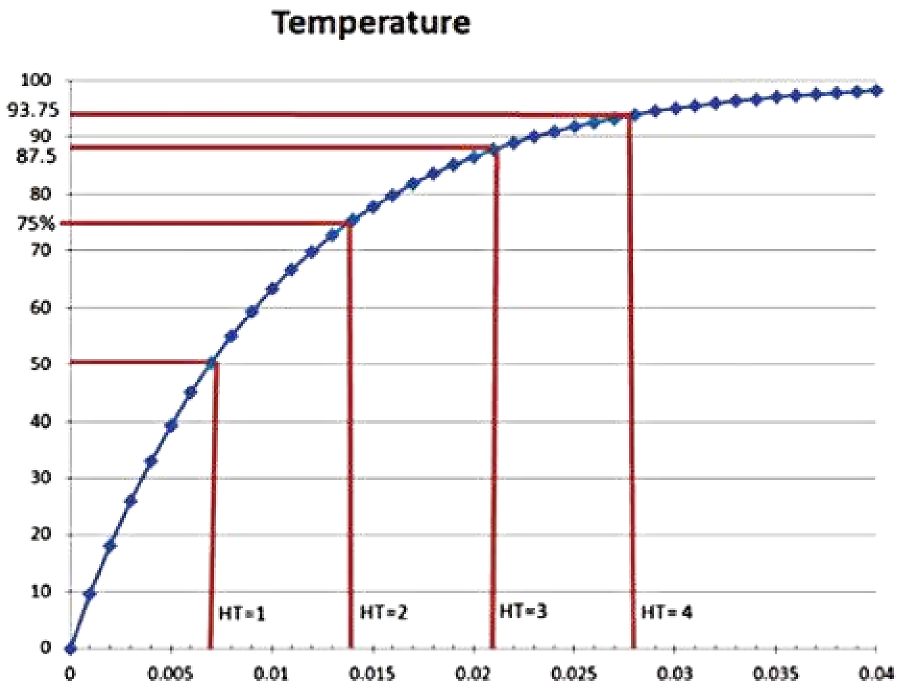


*Figure 1 - System response of 0°C to 100°C transition, tau = 10 ms, half time = 7 ms*

"Quantum detectors are intrinsically faster than microbolometers – and the main reason for that is the microbolometers have to change temperature," explains Dr. Robert Madding, President of RPM Energy Associates. A pioneer in the infrared industry, Dr. Madding has more than 35 years of experience in infrared thermography applications and training.

Instead of changing the temperature of the pixels, "quantum detectors add their energy to electrons in the semiconductor, elevating them above the detector energy bandgap into the conduction band," says Dr. Madding. "This can be measured as a change in detector voltage or current, depending on detector design. It can occur very fast."

For an InSb camera such as the FLIR X6900sc, the typical integration times when measuring object between -20°C to 350°C can be as low as 0.48 μs. These incredibly short "snap-shot speeds" make it possible to freeze motion for images and to accurately measure very fast transients.

In contast, the pixels of an uncooled camera such as the FLIR T1030sc are made from a material whose resistance changes significantly with temperature. Again, each pixel physically heats up or cools down. Its resistance varies with temperature and can be measured and mapped back to the target temperature via a calibration process.

The snap-shot speed, or "time constant", for a modern microbolometer camera is generally between 8-12 ms. However, this doesn't mean the sensor's pixels can be read out every 8 to 12 ms. The rule of thumb for a first order system responding to step input is it takes five time constants to reach a steady state.

## TIME CONSTANTS AND A THOUGHT EXPERIMENT

The following thought experiment offers an easy way to understand a microbolometer's time constant and how it impacts high speed temperature measurement.

Consider two buckets of water: one is full of well- stirred ice water at 0°C; the other is filled water at a rapid boil (100°C). We point a microbolometer camera at the ice water to get a reading. Then, we instantaneously switch to the boiling water (a 100°C step input) and plot the resulting temperature.

For this graph, we're using half-steps of roughly 7 ms each so we can follow the progression over the five time constants more closely. After a half-time constant, the microbolometer reports 50°C – or half the actual temperature of the boiling water. After

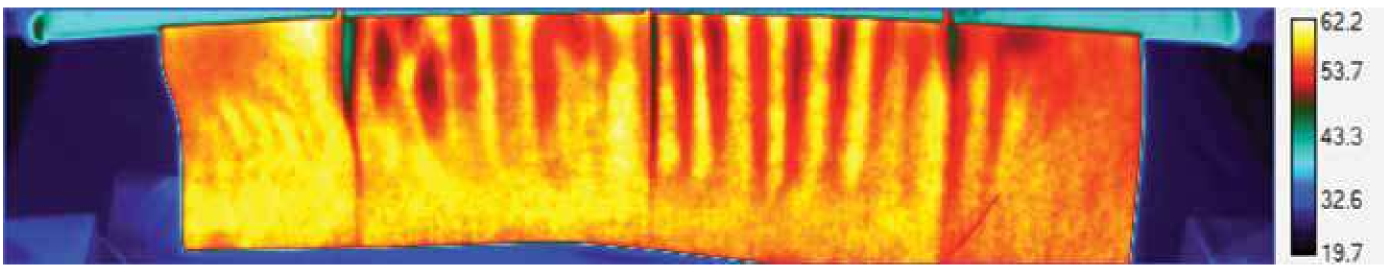


*Figure 2 - Thermal image of paper leaving heated rollers*

another 7 ms, the microbolometer reports a temperature of 75°C. It increases by half again after another half-time constant to 87.5°C, and so on, getting closer to 100°C with each half-step.

Now, consider the temperature reading at a full step, between 8-12 ms. On the graph, you can see the microbolometer read the temperature of the boiling water at around 60°C – an error of 40°C. The camera is still accurately reporting the temperature of the pixel. The problem is that the pixel itself did not have enough time to reach the temperature of the scene it was measuring. It still needs about four more time constants to reach a stable temperature.

## REAL WORLD DATA

Now let's look at the difference between a quantum detector's integration time and a microbolometer's time constant in terms of measuring mechanical systems. Our first example is a printing process that was required to uniformly heat a sheet of paper across its width and length to 60°C. The paper spooled out of rollers at 50 inches/second.

Both a cooled quantum detector camera and a microbolometer camera were used to capture side by side data. Figure 3 shows that the data from the two types of cameras looks dramatically different. The data from the microbolometer shows a big, relatively steady bump in temperature along the length. The data from the quantum detector camera shows significant variations in temperature over time. The variations indicate that the heated roller assembly cooled down due to contact with the paper over the first revolution. The bang-bang controller sensed the temperature drop and turned the heater controller fully on again in response. As a result, the roller heated up until the set point was reached, shut off, and then the process repeated. This one graph was enough to convince the R&D engineer of two things – a photon counting camera was required for testing the product and that a PID control system must be implemented on the heated roller if the desired design objectives were to be met.

For our second example, the goal was to freeze the motion of a tire rotating at 40 mph. As you would expect, the exposure time for the uncooled microbolometer camera wasn't fast enough, causing the wheel spokes to appear almost transparent. (See Figure 4)

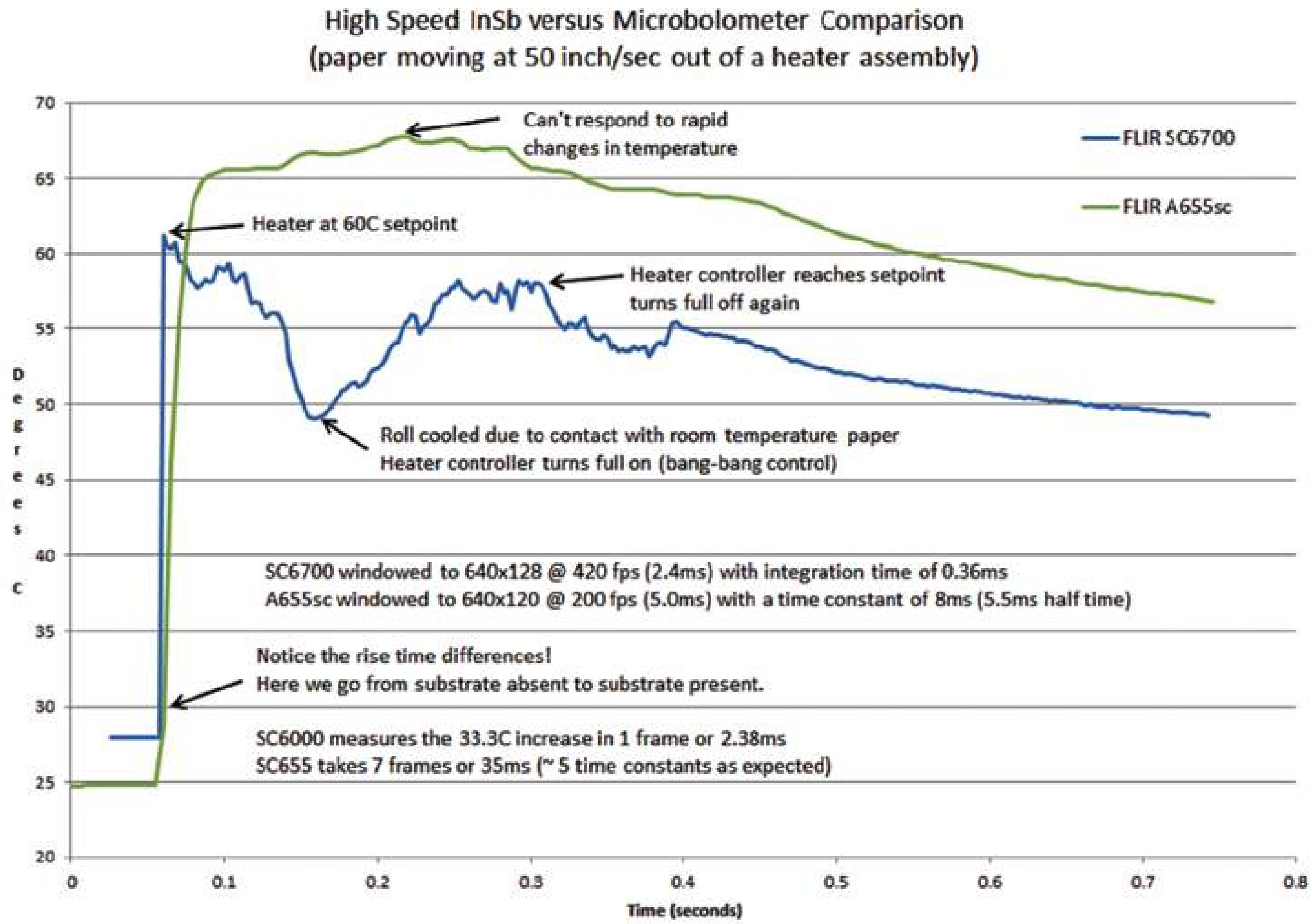



*Figure 3 - Photon-counting quantum detector versus microbolometer for thermal transients*

Note how the fast integration time offered by the cooled camera stopped the motion of the wheel spokes, allowing for accurate measurement of the caliper as well as areas of corrosion on the rotor. In contrast, the spokes were moving too fast to be recorded by the uncooled camera. Any temperature measurements would be too low due to interference from the blurred spokes.

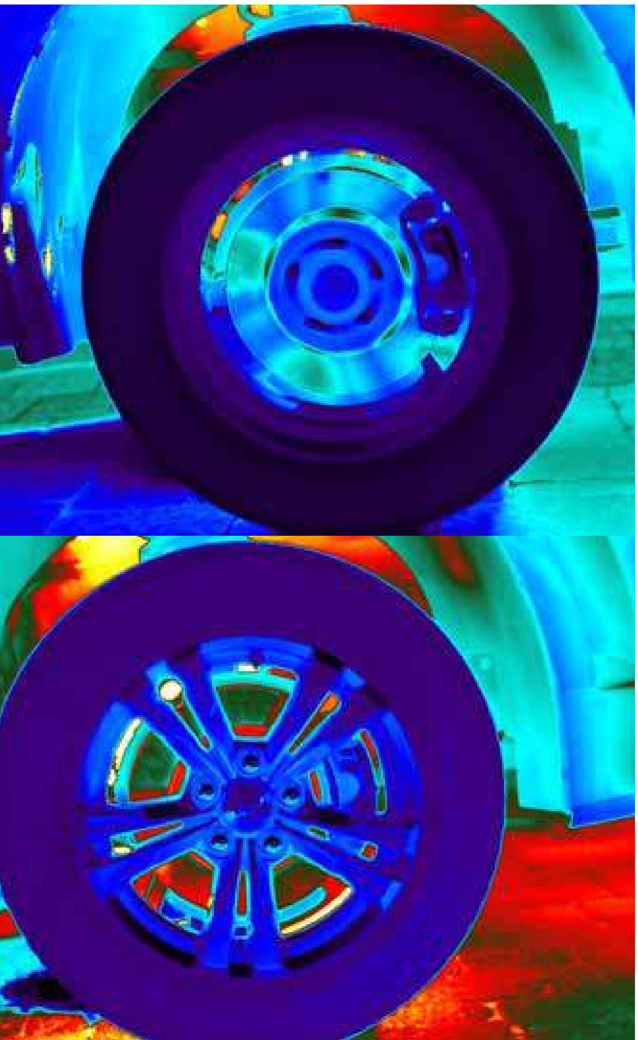
## BEYOND STOP-MOTION PERFORMANCE

Besides snap-shot speed, quantum detector cameras have an additional advantage over microbolometers: they can offer a higher resolution and frame recording speed. For example, the FLIR X6900sc captures full-frame 640 x 512 imagery at a rate of 1000 frames per second. While many of the latest microbolometer cameras offer a similar 640 x 480 resolution, the full resolution frame speed is only 30 fps. On the other hand, the fact that microbolometer cameras are uncooled means they can offer the ease of portability and handheld use. This can be an advantage for many applications. The X6900sc and similar cooled cameras are not inherently portable, but they include features such as the ability to synchronize and trigger remotely.

## GET THE RIGHT TOOL FOR THE JOB

As you can see, it's important to use the correct thermal detector for the job. Traditional forms of temperature measurement are not practical for moving or smaller devices and simply do not provide enough information to tell the full story of how products are responding thermally. IR cameras offer the ability to capture hundreds of thousands of points of accurate non-contact temperature measurement in every image, but it's important to choose the correct detector for your application. If you choose a detector with an inherently slow response and then read it out at a high frame rate, you may end up with bad data. In general, microbolometers can be used for frame rates up to 50 fps. For tests with fast thermal transients or frame rate requirements, it's usually best to select a higher performance cooled quantum detector camera.

*Figure 4 – Tire rotating at 40 mph recorded with a microbolometer camera (left) and with a quantum detector camera (right)*



*Cooled or uncooled, FLIR has a thermal camera for all needs*

For more information about thermal imaging cameras or about this application, please visit:

www.flir.com/research

The images displayed may not be representative of the actual resolution of the camera shown.
Images for illustrative purposes only.
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