PALMER Wahl INSTRUMENTATION GROUP

170 Years of Continued Innovation

The Evolution of Thermal Imaging Cameras

The World’s Finest Manufacturers of Temperature, Pressure & Humidity, Test and Calibration Instruments

May, 2007

What is a Thermal Imager?

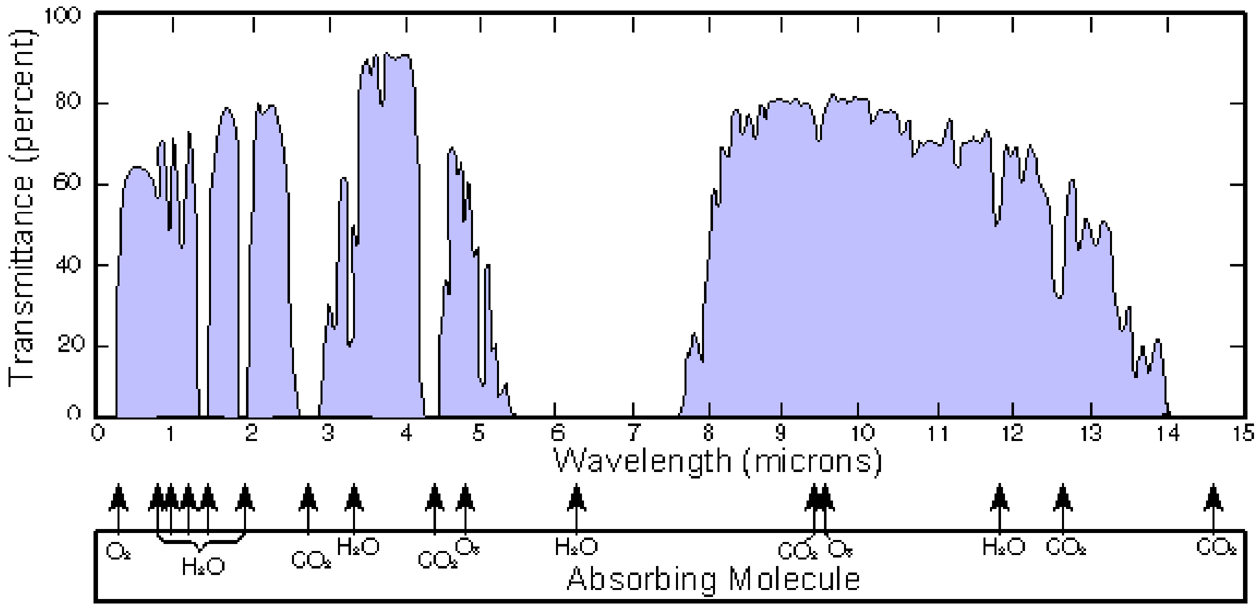
- In simplest terms, a thermal imager operates like the human eye, but is much more powerful.
- Infrared energy from the environment travels through a lens and is registered on a detector.
- The thermal imager measures very small relative temperature differences and converts otherwise invisible heat patterns into clear, visible images that are seen through either a viewfinder or monitor.
- Thermal imagers cannot see through walls, glass or other solid objects, but they can detect heat that has transferred to the surface of an object.

Infrared Imaging Spectra

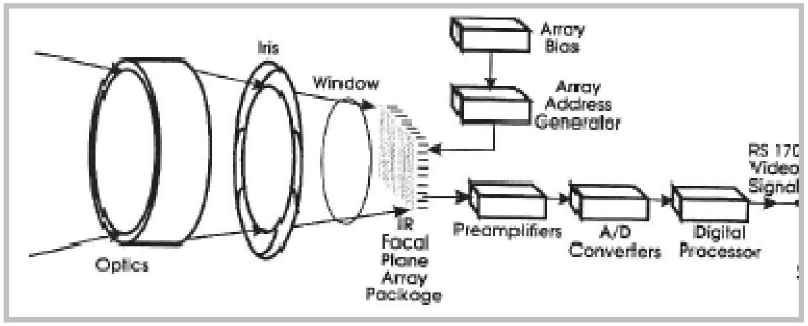
Thermal Imaging systems collect light at wavelengths longer than visible light but shorter than 1 mm. The IR spectrum is divided in the following ranges:

- Near Infrared (NIR), 0.75 µm to 1.4 µm
- Short Wave Infrared (SWIR), 1.4 µm to 3 µm
- Mid Wave Infrared (MWIR), 3 µm to 5 µm
- Long Wave Infrared (LWIR), 8 µm to 12 µm
- Very Long Wave Infrared (VLWIR), 12 µm to 25 µm
- Far Wave Infrared (FWIR), 25 µm to 1 mm

Wavelength Absorbtion

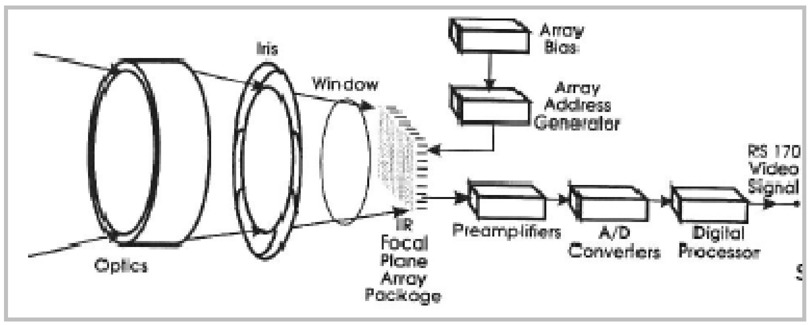


How a Thermal Imager Works



- A special lens focuses the infrared light emitted by all of the objects in view.
- The focused light is scanned by the infrared-detector elements creating electric impulses.

How a Thermal Imager Works



- The impulses are sent to a signal-processing unit, that translates the information from the elements into data for the display.
- The signal-processing unit sends the information to the display, where it appears as various colors depending on the intensity of the infrared emission.

History of Thermal Imager Development

- 1947 – US military developed the first infrared line scanner (one image took an hour to produce).
- 1966 – First real-time commercial thermal imager.
- 1990s – Introduction of high resolution, uncooled focal plane arrays.
- Now – Introduction of high resolution, uncooled Thermal Imagers at affordable prices.

Detector Types

There are two distinctive detector technologies:

- **Direct detection (photon counting)**
- **Thermal detection**

Direct detection translates the photons directly into electrons. The charge accumulated, the current flow, or the change in conductivity are proportional to the radiance of objects in the scenery viewed. This category contains many detectors: PbSe, HgCdTe, InSb, PtSi, etc. Except for thermal imagers, working in the SWIR range, all infrared cameras based on the direct detection technology are detectors cooled to cryogenic temperatures, close to -200°C.

Detector Types - 2

Thermal detection uses secondary effects, such as the relation between conductivity, capacitance, expansion and detector temperature. The following detectors are included in this category: bolometers, thermocouples, thermopiles, pyroelectric detectors etc. They do not require cryogenic temperatures

Detector Generations

Four distinct generations of thermal imagers have been designed, based on IR detector technologies developed during the last 30 years, and classified according to the number of elements contained in each group.

1st generation thermal imagers contain single element detectors, or detectors with only a few elements. A two-dimensional mechanical scanner was usually used in order to generate a two-dimensional image.

2nd generation thermal imagers are vector detectors, usually containing 64 or more elements. The two-dimensional scanner was somehow simplified in the vertical direction, to include only the interlace motion.

Detector Generations - 2

3rd generation thermal imagers contain two-dimensional arrays with several columns of elements. These thermal imagers still scan in one direction and perform a Time Delay Integration (TDI) of the signal in the scanning direction in order to improve the signal-to-noise ratio.

4th generation thermal imagers contain two-dimensional array detectors that do not require any scanning mechanism for acquiring the two-dimensional picture.

Early Detector Materials

Early PFA detectors (known as Photon detectors) consisted of materials like:

- Lead Selenide - PbSe
- Mercury Cadmium Teluride - HgCdTe
- Indium Antimonide - InSb
- Platinum Silicide - PtSi

Early Detector Materials

These detectors typically needed to be cooled to very cold temperatures to achieve maximum performance and relied on costly cryogenic refrigeration units (Dewars) to achieve -200°C (-328°F) operating temperatures.

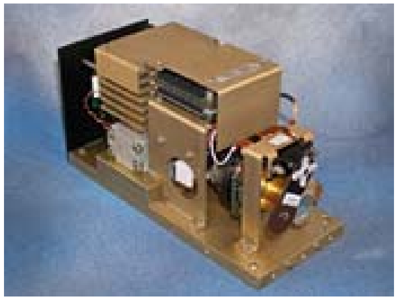
Early Detector Materials

Newer photon type infrared sensors were developed that operated at elevated temperatures that allowed solid-state thermal electric coolers and sterling coolers to be used.

Early Detector Materials

Thermal Imagers based on cryogenically-cooled or thermal electric-cooled detectors have the following drawbacks:

- High electrical power consumption – Short battery life.
- A relatively long cooling down time, usually more than a few minutes.
- Limited MTBF time resulting from the cooler lifetime - usually a few thousand hours.
- Larger size and weight.
- More expensive ($35k – $100k)

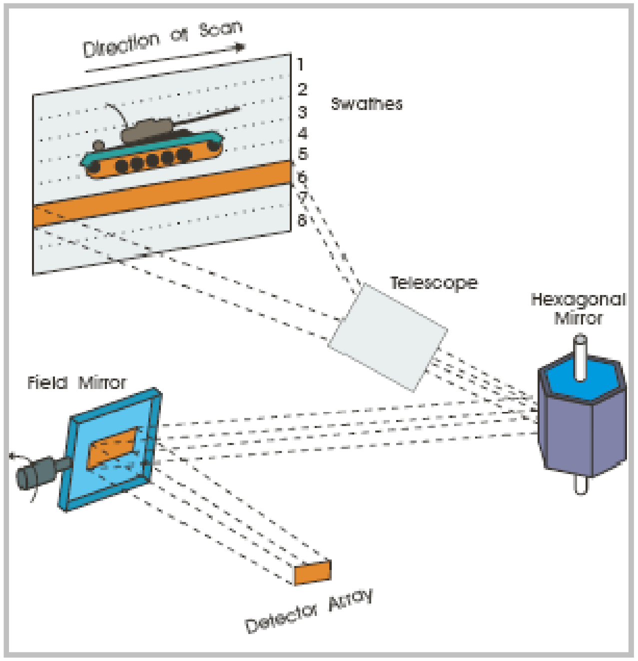


Detector Advancements

Thermal imagers have been designed based on IR detector technologies and classified according to the number of elements contained in each group.

- Early generation thermal imagers typically contained single element detectors, or detectors with only a few elements (1 x 3). A two-dimensional mechanical scanner was usually used in order to generate a two-dimensional image.

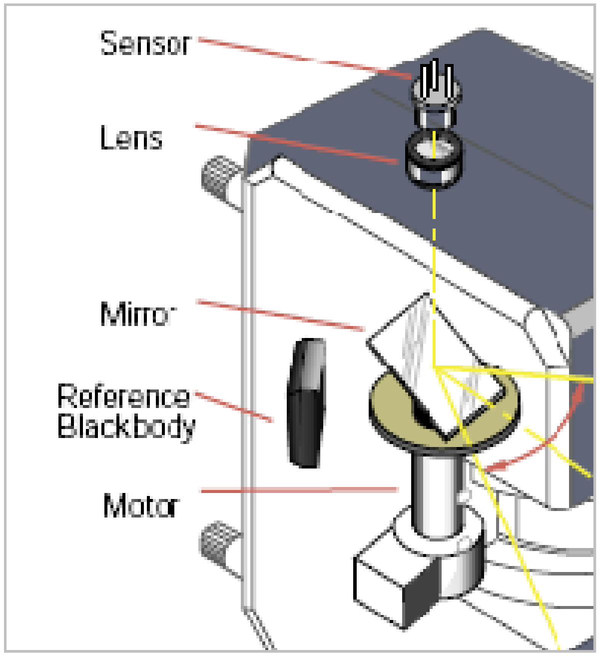
Detector Advancements



Detector Advancements

- 2nd generation thermal imagers contained two-dimensional arrays with several columns of elements (12 x 12). These thermal imagers still required scanning in one direction and complex electronics to improve the signal-to-noise ratio.

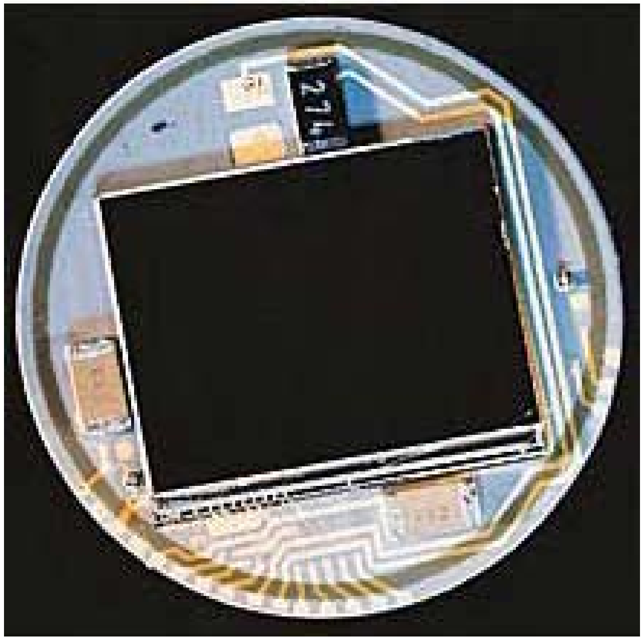
Detector Advancements



Detector Advancements

- Today's generation thermal imagers contain two-dimensional array detectors (160 x 120, 320 x 240, 640 x 480) that do not require any scanning mechanism for acquiring the two-dimensional picture. These are called infrared focal plane arrays (FPA)

Detector Advancements



320x240 pixels detector array mounted onto a carrier substrate.
The total size of the chip is 11 x 14 mm.

Cooling Technology

There are two main cooling technologies:

Cooled thermal imagers technology implemented in cameras based on a detector cooled to a temperature close to 77 degrees Kelvin (about -200°C) or lower.

Uncooled thermal imagers technology implemented in detectors usually stabilized to temperatures between -30°C to +30°C or not stabilized at all.

Cooling Technology - 2

Cooled Thermal Imagers Advantages

Systems based on the InSb cryogenically-cooled detectors have the following advantages:

The InSb detector collects the light in the3 µm to 5 µm spectral band providing a better spatial resolution because the wavelength is much shorter than the 8 µm to 12 µm spectral band. InSb detector elements are usually smaller in size compared to the microbolometer detector elements . For the same required spatial resolution, InSb detectors require lenses with shorter focal lengths.

Cooling Technology - 3

Thermal imagers based on InSb detectors have very good sensitivity (low NEDT* values) even for a relatively high f number. Thermal imaging cameras with long focal lengths have relatively acceptable physical dimensions. (*Noise Equivalent Temperature Difference).

Cooled Thermal Imagers Disadvantages

System based on the InSb, cryogenically-cooled detectors have the following drawbacks:

Higher electrical power consumption compared to uncooled thermal imagers
- A relatively long cooling down time, usually more than a few minutes
- Limited MTBF time resulting from the cooler lifetime - usually a few thousand hours
- More expensive

Cooling Technology - 4

Uncooled Thermal Imagers Advantages

Uncooled microbolometer detectors have the following advantages:

Collect the light in the 8 μm to 12 μm spectral band. This spectral band provides a better penetration through smoke, smog, dust, water vapor etc. because the wavelength is much longer than the 3 μm to 5 μm spectral band.

They are small and lightweight. For applications requiring relatively short ranges, the physical dimensions of the camera are even smaller. This property enables, for example, the mounting of uncooled microbolometer thermal imagers on helmets.

Cooling Technology - 5

Provide real video output immediately after power on.

Low power consumption relative to cooled detector thermal imagers.

Very long MTBF.

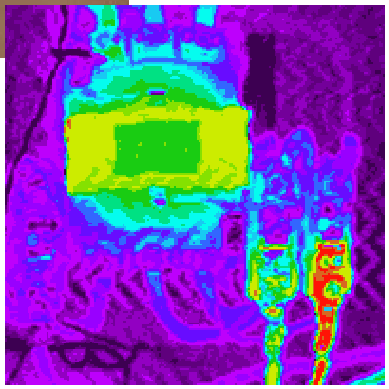
Less expensive compared to cameras based on cooled detectors.

Uncooled Thermal Imagers Disadvantages
The main drawback of thermal imaging cameras based on uncooled microbolometer detectors is that they require low f# optics.

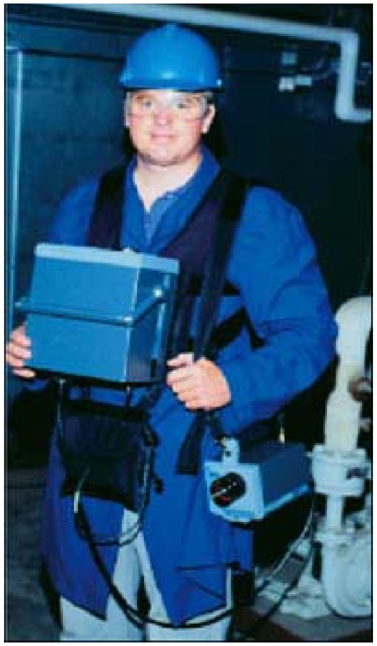
(f# = ratio of focal length to diameter of optics).

Thermal Imagers Based On Earlier Technology

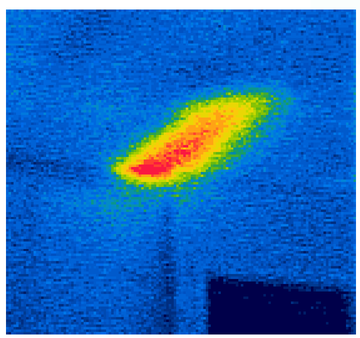
Thermal Imagers Based On Earlier Technology



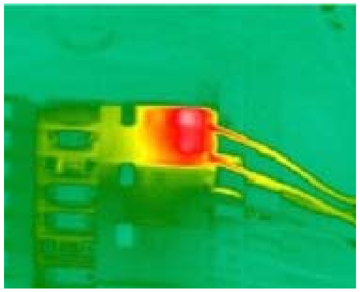
Thermal Imagers Based On Earlier Technology



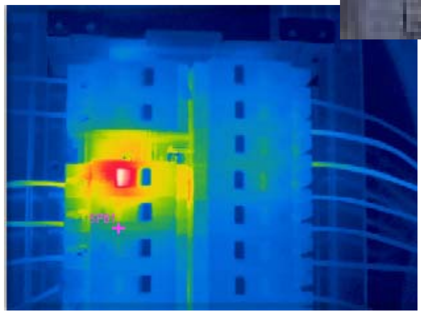
Thermal Imagers Based On Earlier Technology



Thermal Imagers Based On Earlier Technology



Thermal Imagers Based On Earlier Technology



New Detector Development

During the 80’s the Department of Defense gave both Honeywell and Texas Instruments (TI) large classified contracts to develop uncooled infrared sensor technology.

The military wanted a sensor that had very short turn-on time.

Both programs were very successful.

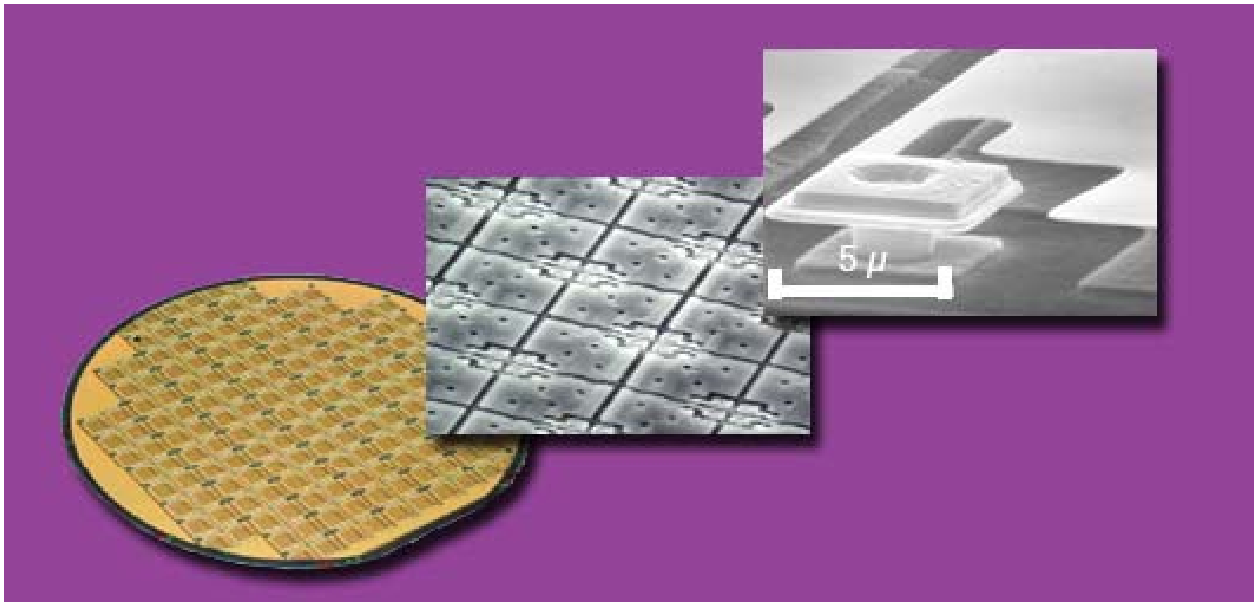
New Detector Development

In 1992 the US Government de-classified the use of this technology for commercial products but maintained control of the technology.

TI developed commercial imagers with their sensor technology and Honeywell licensed their microbolometer sensor technology to other companies.

New Detector Development

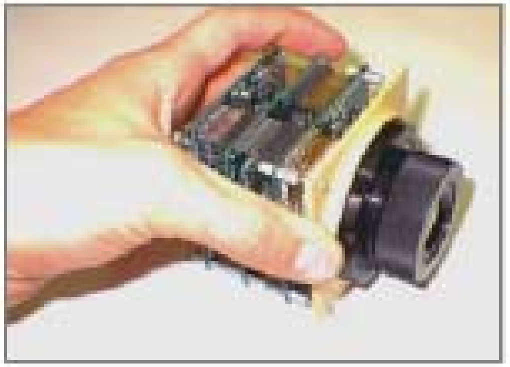
A microbolometer FPA is a 2-dimensional array of small temperature-sensitive electrical resistors.

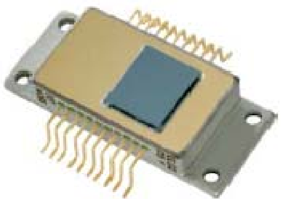


New Detector Development

Microbolometer detectors can be operated at room temperature and therefore do not require cooling.

This is a distinct advantage as the inconvenience of liquid gasses, or high cost of closed cycle Sterling coolers is avoided.





New Detector Development

Uncooled microbolometer detectors have the following advantages:

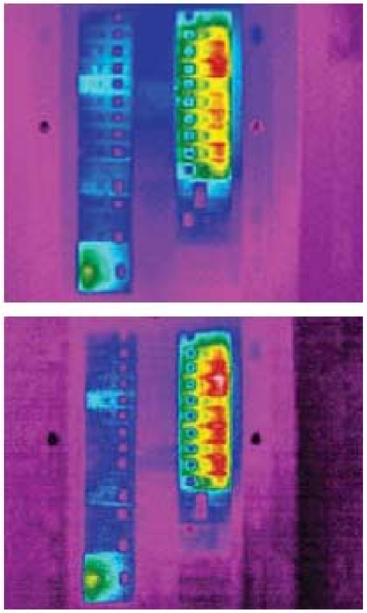
- Collect the infrared in the 8 μm to 14 μm spectral band. This spectral band provides a better penetration through smoke, smog, dust, water vapor etc.
- They are small and lightweight. The physical dimensions of a thermal imaging camera can now be smaller.

New Detector Development

Continued - Uncooled microbolometer detectors have the following advantages:

- Provide real video output immediately after power on.
- Low power consumption relative to cooled detector thermal imagers. Longer battery life.
- Very long MTBF.
- Less expensive compared to cameras based on cooled detectors. ($6k - $50k)

New Detector Development



Comparison of two images, one taken with a 320x240 camera (top) and the other with a 160x120 camera (bottom) – Snell Infrared

New Detector Development

160 x 120 microbolometer Image

Other Technology Advancements

The FPA detector, especially the uncooled microbolometer may be a significant breakthrough in technology but without advancements in the optics, electronics, and microprocessor technologies it would not have been possible to develop today's cameras.

Other Technology Advancements

Optics

- The development of smaller optics with low f # was required for microbolometer thermal imagers.

Other Technology Advancements

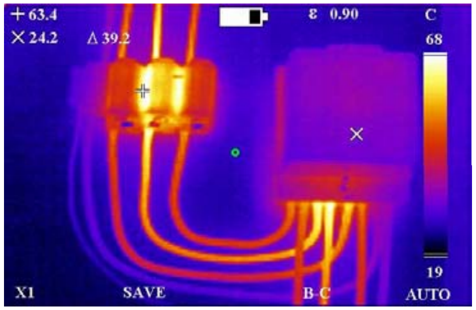
Electronics / Microprocessors

- Advanced 14 bit digital signal processing is required to produce defect-free images from uncooled arrays.
- Sensitivity, signal-to-noise and image acquisition speed has improved.

Other Technology Advancements

Continued - **Electronics / Microprocessors**

- Some cameras provide temperature data at each image pixel. Multiple cursors can be positioned to each pixel with the corresponding temperature read out on the screen or display.



Other Technology Advancements

Continued - **Electronics / Microprocessors**

- Today images are digitized, stored, manipulated, processed onboard the camera. Removable SD or PCMCIA cards can store up to 1000 radiometric infrared images for recall, analysis or archiving.

Other Technology Advancements

Continued - **Electronics / Microprocessors**

- Some cameras can record and store operator voice text commentary and playback with each image.

Other Technology Advancements

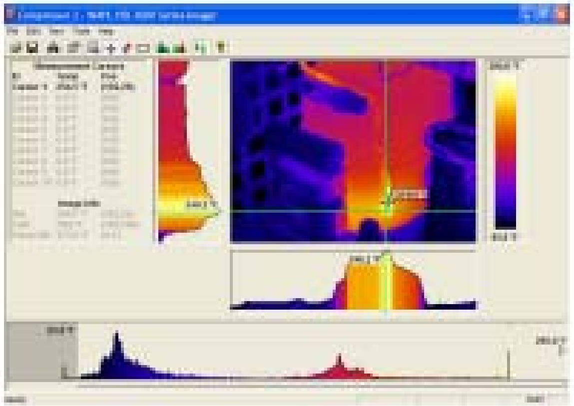
Batteries

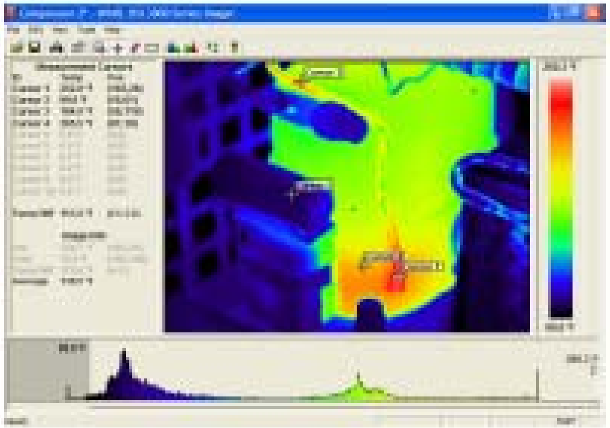
- New high performance, long life Li-Ion batteries for four hours of continuous use on a single charge.

Other Technology Advancements

Computers & Software

- Intuitive Windows based software for reporting, archiving and analyzing thermal images and loaded on laptop computers and pocket PC.





Today's Thermal Imagers

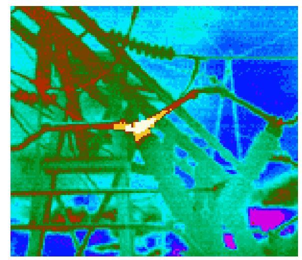
Today's Thermal Imagers

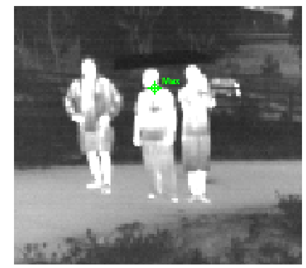
Today's Thermal Imagers

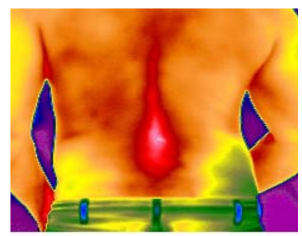
Today’s Thermal Imagers

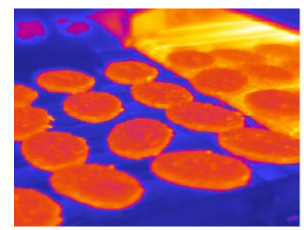
Expanding Applications For Thermal Imagers

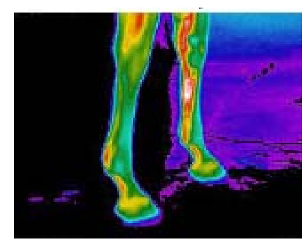
- Surveillance
- Fire Fighting
- Research & Development
- Manufacturing Process Control
- Automotive Driving-Assistance
- Non-Destructive Testing
- Predictive Maintenance
- Energy Audits
- Roofing/Insulation Inspection
- Water/Mold Damage
- Veterinary/Human Medical
- SARS/Bird Flu Screening











The Future

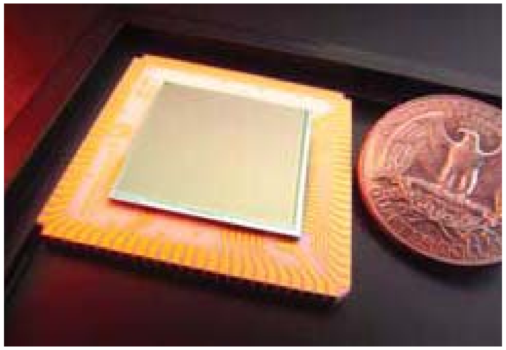
Clearly, uncooled infrared FPAs represent a revolution in infrared thermal imaging cameras.

It is expected that the technology will continue to develop, particularly in the area of improved detector performance and reduced noise equivalent temperature difference and electronics.

The Future

As costs continue to decrease and production volumes rise, the price of solid state uncooled, lightweight systems should continue to drop.

Expect to see larger arrays (640 x 480, 1024 x 1024) and even smaller, lightweight cameras using less power.



The Future

Cameras integrating Infrared, Visual and Blended Images. Allowing live infrared images to be overlaid directly onto the visual camera pictures.

Wireless network communication and connectivity. Ability to transfer or store thermal and visual images, sound and data in the field directly to desk PCs.

The End