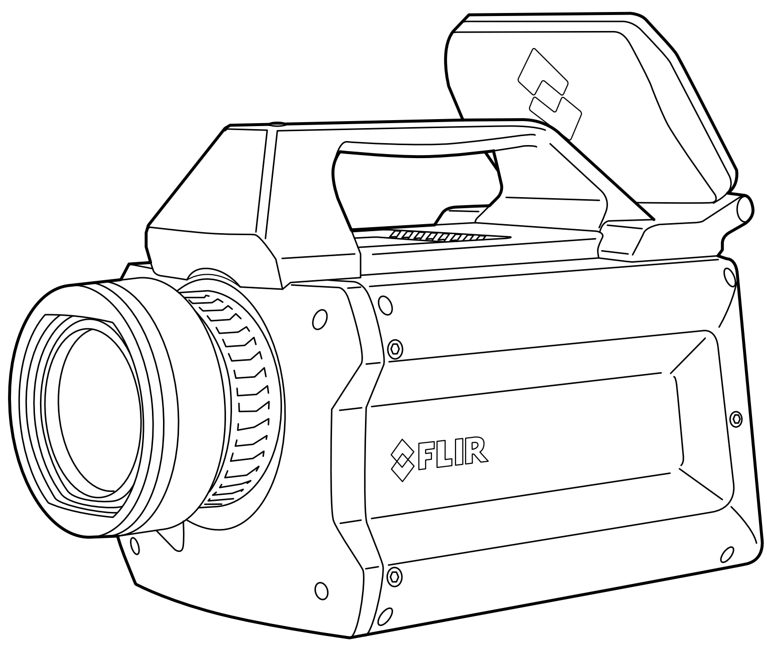
User’s manual
FLIR X6520sc series



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1 Disclaimers

1.1 Legal disclaimer

All products manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of one (1) year from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction.

Uncooled handheld infrared cameras manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of two (2) years from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction, and provided that the camera has been registered within 60 days of original purchase.

Detectors for uncooled handheld infrared cameras manufactured by FLIR Systems are warranted against defective materials and workmanship for a period of ten (10) years from the delivery date of the original purchase, provided such products have been under normal storage, use and service, and in accordance with FLIR Systems instruction, and provided that the camera has been registered within 60 days of original purchase.

Products which are not manufactured by FLIR Systems but included in systems delivered by FLIR Systems to the original purchaser, carry the warranty, if any, of the particular supplier only. FLIR Systems has no responsibility whatsoever for such products.

The warranty extends only to the original purchaser and is not transferable. It is not applicable to any product which has been subjected to misuse, neglect, accident or abnormal conditions of operation. Expendable parts are excluded from the warranty.

In the case of a defect in a product covered by this warranty the product must not be further used in order to prevent additional damage. The purchaser shall promptly report any defect to FLIR Systems or this warranty will not apply.

FLIR Systems will, at its option, repair or replace any such defective product free of charge if, upon inspection, it proves to be defective in material or workmanship and provided that it is returned to FLIR Systems within the said one-year period.

FLIR Systems has no other obligation or liability for defects than those set forth above.

No other warranty is expressed or implied. FLIR Systems specifically disclaims the implied warranties of merchantability and fitness for a particular purpose.

FLIR Systems shall not be liable for any direct, indirect, special, incidental or consequential loss or damage, whether based on contract, tort or any other legal theory.

This warranty shall be governed by Swedish law.

Any dispute, controversy or claim arising out of or in connection with this warranty, shall be finally settled by arbitration in accordance with the Rules of the Arbitration Institute of the Stockholm Chamber of Commerce. The place of arbitration shall be Stockholm. The language to be used in the arbitral proceedings shall be English.

1.2 Usage statistics

FLIR Systems reserves the right to gather anonymous usage statistics to help maintain and improve the quality of our software and services.

1.3 Changes to registry

The registry entry HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Control\Lsa \LmCompatibilityLevel will be automatically changed to level 2 if the FLIR Camera Monitor service detects a FLIR camera connected to the computer with a USB cable. The modification will only be executed if the camera device implements a remote network service that supports network logons.

1.4 U.S. Government Regulations

This product may be subject to U.S. Export Regulations. Please send any inquiries to exportquestions@flir.com.

1.5 Copyright

1.6 Quality assurance

The Quality Management System under which these products are developed and manufactured has been certified in accordance with the ISO 9001 standard.

FLIR Systems is committed to a policy of continuous development; therefore we reserve the right to make changes and improvements on any of the products without prior notice.

1.7 Patents

000439161; 000653423; 000726344; 000859020; 001707738; 001707746; 001707787; 001776519; 001954074; 002021543; 002021543-0002; 002058180; 002249953; 002531178; 002816785; 002816793; 011200326; 014347553; 057692; 061609; 07002405; 100414275; 101796816; 101796817; 101796818; 102334141; 1062100; 11063060001; 11517895; 1226865; 12300216; 12300224; 1285345; 1299699; 1325808; 1336775; 1391114; 1402918; 1404291; 1411581; 1415075; 1421497; 1458284; 1678485; 1732314; 17399650; 1880950; 1886650; 2007301511414; 2007303395047; 2008301285812; 2009301900619; 20100060357; 2010301761271; 2010301761303; 2010301761572; 2010305959313; 2011304423549; 2012304717443; 2012306207318; 2013302676195; 2015202354035; 2015304259171; 204465713; 204967995; 2106017; 2107799; 2115696; 2172004; 2315433; 2381417; 2794760001; 3006596; 3006597; 303330211; 4358936; 483782; 484155; 4889913; 4937897; 4995790001; 5177595; 540838; 579475; 584755; 599392; 60122153; 6020040116815; 602006006500.0; 6020080347796; 6020110003453; 615113; 615116; 664580; 664581; 665004; 665440; 67023029; 6707044; 677298; 68657; 69036179; 70022216; 70028915; 70028923; 70057990; 7034300; 710424; 7110035; 7154093; 7157705; 718801; 723605; 7237946; 7312822; 7332716; 7336823; 734803; 7544944; 7606484; 7634157; 7667198; 7809258; 7826736; 8018649; 8153971; 8212210; 8289372; 8340414; 8354639; 8384783; 8520970; 8565547; 8595689; 8599262; 8654239; 8680468; 8803093; 8823803; 8853631; 8933403; 9171361; 9191583; 9279728; 9280812; 9338352; 9423940; 9471970; 9595087; D549758.

1.8 Third-party licenses

1.8.1 GNU Lesser General Public License (LGPL)

http://www.gnu.org/licenses/lgpl-2.1.en.html

(Retrieved May 27, 2015)

1.8.2 Fonts (Source Han Sans)

https://github.com/adobe-fonts/source-han-sans/blob/master/LICENSE.txt

(Retrieved May 27, 2015)

1.8.3 Fonts (DejaVu)

http://dejavu-fonts.org/wiki/License

(Retrieved May 27, 2015)

2 Safety information

For best results and user safety, the following warnings and precautions should be followed when handling and operating the camera.

- Do not open the camera body for any reason. Disassembly of the camera (including removal of the cover) can cause permanent damage and will void the warranty.
- Great care should be exercised with your camera optics. Refer to section 12.1.2 *Infrared lens*, page 61 for lens cleaning.
- Operating the camera outside of the specified input voltage range or the specified operating temperature range can cause permanent damage.
- Do not image extremely high-intensity radiation sources, e.g., the sun, lasers, or arc welders.
- The camera is a precision optical instrument and should not be exposed to excessive shock and/or vibration.
- The camera contains static-sensitive electronics and should be handled appropriately.
- Do not put any item on the external cooling intake, to maintain the cooling of the camera.

3 Notice to user

3.1 User-to-user forums

Exchange ideas, problems, and infrared solutions with fellow thermographers around the world in our user-to-user forums. To go to the forums, visit:

http://forum.infraredtraining.com/

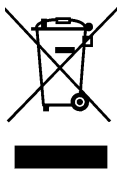
3.2 Calibration

We recommend that you send in the camera for calibration once a year. Contact your local sales office for instructions on where to send the camera.

3.3 Accuracy

For very accurate results, we recommend that you wait 5 minutes after you have started the camera before measuring a temperature.

3.4 Disposal of electronic waste



As with most electronic products, this equipment must be disposed of in an environmentally friendly way, and in accordance with existing regulations for electronic waste.

Please contact your FLIR Systems representative for more details.

3.5 Training

To read about infrared training, visit:

- http://www.infraredtraining.com
- http://www.irtraining.com
- http://www.irtraining.eu

3.6 Documentation updates

Our manuals are updated several times per year, and we also issue product-critical notifications of changes on a regular basis.

To access the latest manuals, translations of manuals, and notifications, go to the Download tab at:

http://support.flir.com

It only takes a few minutes to register online. In the download area you will also find the latest releases of manuals for our other products, as well as manuals for our historical and obsolete products.

3.7 Important note about this manual

FLIR Systems issues generic manuals that cover several cameras within a model line.

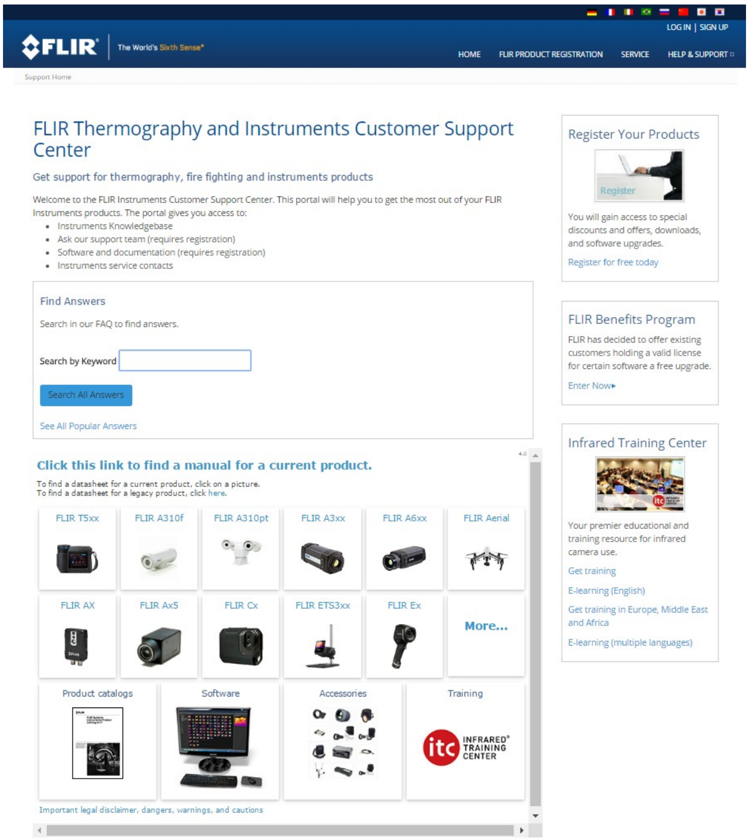
This means that this manual may contain descriptions and explanations that do not apply to your particular camera model.

3.8 Note about authoritative versions

The authoritative version of this publication is English. In the event of divergences due to translation errors, the English text has precedence.

Any late changes are first implemented in English.

4 Customer help



4.1 General

For customer help, visit:

http://support.flir.com

4.2 Submitting a question

To submit a question to the customer help team, you must be a registered user. It only takes a few minutes to register online. If you only want to search the knowledgebase for existing questions and answers, you do not need to be a registered user.

When you want to submit a question, make sure that you have the following information to hand:

- The camera model
- The camera serial number
- The communication protocol, or method, between the camera and your device (for example, SD card reader, HDMI, Ethernet, USB, or FireWire)
- Device type (PC/Mac/iPhone/iPad/Android device, etc.)
- Version of any programs from FLIR Systems
- Full name, publication number, and revision number of the manual

4.3 Downloads

On the customer help site you can also download the following, when applicable for the product:

- Firmware updates for your infrared camera.
- Program updates for your PC/Mac software.
- Freeware and evaluation versions of PC/Mac software.
- User documentation for current, obsolete, and historical products.
- Mechanical drawings (in *.dxf and *.pdf format).
- Cad data models (in *.stp format).
- Application stories.
- Technical datasheets.
- Product catalogs.

5 Introduction

5.1 Camera system components

The FLIR X6520sc infrared camera and its accessories are delivered in a transport case that typically contains the items below.

- FLIR X6520sc camera with removable LCD touchscreen.
- Portfolio that includes important information on the camera:
  - Packing list.
  - Factory acceptance report.
  - Calibration curves (if applicable).
  - Camera files on a CD-ROM.
  - Optical cleaning tissue.
  - A set of user instructions.
  - Filter-holding tool.
  - Micro SD card with an SD adapter.
- Camera power supply.
- Camera cables:
  - Power supply.
  - Gigabit Ethernet (GigE) with locks.
  - 50 Ω coaxial cable for sync (yellow colored).
  - 50 Ω coaxial cable for triggering (orange colored).
  - 50 Ω coaxial cable for lock-in (green colored).
  - 75 Ω coaxial cable for general purposes (blue colored).
  - LCD extender cable (with right-angle USB connectors).
- LCD connector protective cap.

There may also be additional items that you have ordered such as software or CDs.

5.2 System overview

The FLIR X6520sc infrared camera system has been developed by FLIR to meet the needs of the research community. The camera makes use of an advanced 640 × 512 readout circuit (ROIC), mated to a mercury cadmium telluride (MCT) detector to cover the 3.7–4.8 µm mid-wave infrared band.

The FLIR X6520sc is a stand-alone imaging camera that interfaces to host PCs using standard interfaces, including GigE and Camera Link Base.

5.2.1 View from the front—bayonet mount

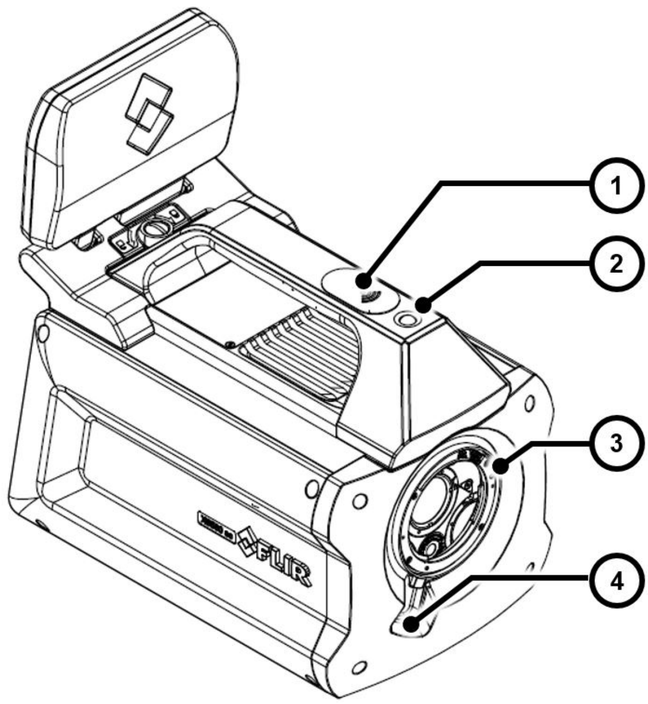


Figure 5.1 View from the front—bayonet mount.

1. Wi-Fi antenna.
2. Global status LED.
3. Lens bayonet interface.
4. Lens release latch.

5.2.2 View from the rear

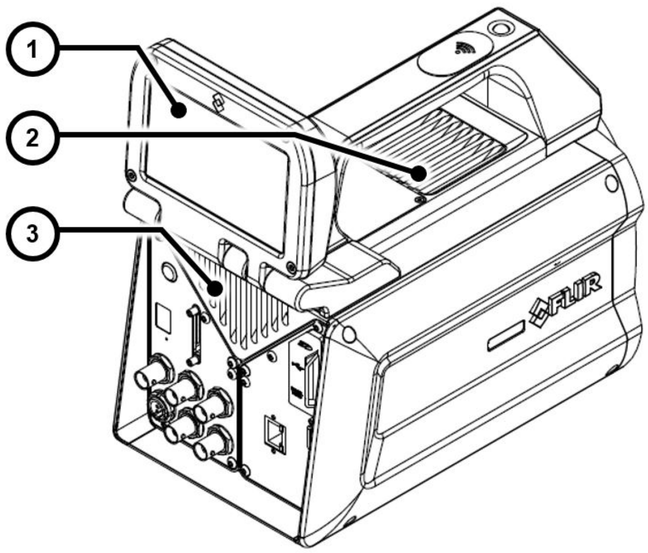


Figure 5.2 View from the rear.

1. Removable touch screen LCD.
2. External cooling intake.
3. External cooling exhaust.

5.2.3 Back panel

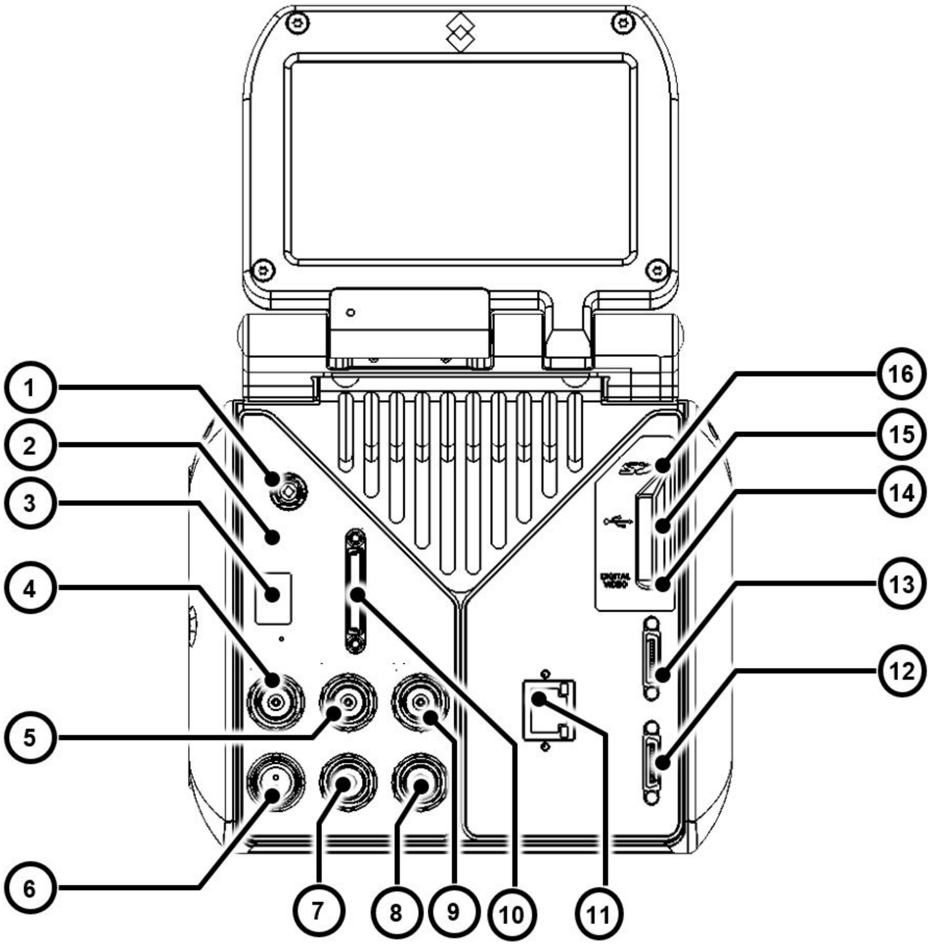


Figure 5.3 Camera back panel description.

1. Power button.
2. Status LED.
3. Infrared remote sensor.
4. Sync In.
5. Sync Out.
6. Power In.
7. Lock-in In.
8. General-purpose IO.
9. Trigger In.
10. Auxiliary port.
11. GigE Vision.
12. Camera Link Base.
13. Camera Link Medium.
14. Digital video interface.
15. USB .
16. Micro SD card.

5.3 Key features

- **Fast frame rate**
  The FLIR X6520sc series has an adjustable frame rate. Windowing allows a subset of the total image to be selectively read out with a user-adjustable window size. The sub-sample windows can be arbitrarily chosen and are easily defined.
- **14-bit image data**
  The FLIR X6520sc camera streams out 14-bit thermal images.
- **Outstanding measurement accuracy**
  The high accuracy of ±1°C or ±1% produces sensitive thermal images. The FLIR X6520sc detects temperature differences smaller than 25 mK (18 mK typical).
- **CNUC calibration**
  CNUC is a proprietary calibration process that provides beautiful imagery and measurement stability. CNUC allows for flexible integration time adjustments without the need to perform non-uniformity corrections. CNUC calibration also produces accurate measurement stability regardless of exposure of the camera to ambient temperature variations.
- **Hypercal**
  Hypercal ensures the best measurement range with the highest sensitivity. Simply set the desired lower and upper temperature limits, and the camera will automatically adjust to the appropriate integration (exposure) time.
- **Auto-exposure**
  The camera automatically adjusts its temperature range to best fit the thermal scene.
- **Presets**
  Up to eight presets and their associated parameters, e.g., integration time, frame rate, window size, and window location, are available for instant selection with a single command. These presets can be used in Dynamic Range Extension (DRX) mode (also called “superframing”), which allows the acquisition of thermal data from up to four user-defined temperature ranges simultaneously, then merges those streams into a single real-time data stream that spans all four temperature ranges, effectively extending dynamic range from 14 bit to 16 bit.
- **Multiple triggering modes and synchronizing interfaces**
  The FLIR X6520sc camera provides different interfaces to support maximum flexibility for synchronizing the camera to external events, as well as synchronizing external events to the camera:
  - Sync In (TTL).
  - Sync Out.
  - Trigger In.
- **Multiple video outputs**
  The FLIR X6520sc camera features multiple independent and simultaneous video:
  - Digital 14-bit video—Camera Link Base.
  - Digital 14-bit video—GigE.
  - Digital video—DVI format 1080p30 digital output.
- **Wide range of interchangeable lenses**
  The FLIR X6520sc camera has an advanced high-performance optical design. The lenses feature a professional bayonet mount with a lock. Each lens is identified through the bayonet connector. A temperature probe is also integrated into the lens, for improved measurement accuracy and drift compensation.
- **Ultrasonic smart lenses (USLs)**
  FLIR lenses with a bayonet mount are equipped with the latest motorization technology, using ultrasonic motors that provide fast response and precise positioning.
- **Motorized filter wheel**

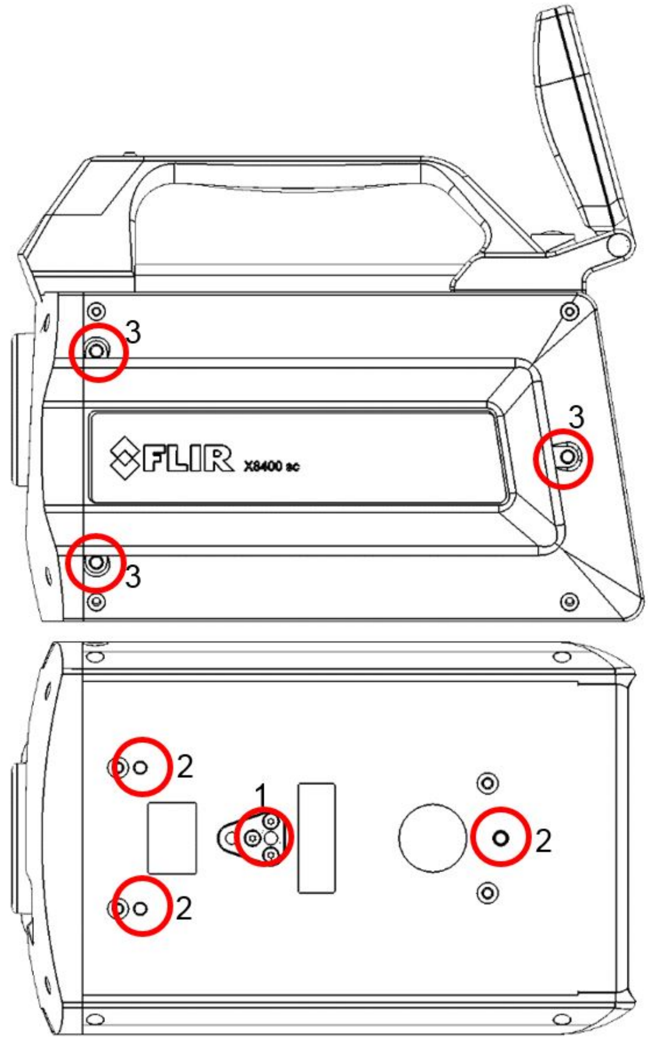
The FLIR X6520sc camera has a four-slot motorized filter wheel with automatic filter recognition and measurement parameter adjustment. The removable filter holders contain an integrated temperature probe for improved measurement accuracy.

- **Removable touch screen LCD**
  The detachable touch screen LCD provides you with on-site thermal image feedback. The LCD screen also provides camera information, adjustment controls, and ResearchIR Max acquisition control. The LCD touch screen can be removed from the FLIR X6520sc camera when the camera needs to be installed in a hard to reach location. Simply position the camera and control it at a distance.
- **Wi-Fi**
  The camera includes a Wi-Fi interface, which enables it to be controlled by a smart phone (iPhone) or a tablet (iPad).
- **Video color palettes**
  The FLIR X6520sc camera supports a selection of standard and user-defined color palettes (or grayscale) for DVI video.
- **Configuration management**
  Save your camera configuration to the SD card (e.g., when loaning your camera to your colleague). To use a configuration saved on an SD card, simply insert the SD card.
- **Global-status LED**
  Located on the top of the camera, the global-status LED provides instant system status, including the ResearchIR Max status (a green light indicates fully acquired). The back panel LEDs instantly inform you about the camera status.

6 Installing the camera

6.1 Mounting the camera

The camera can be operated installed either on a workbench or mounted on a tripod or custom mount. A standard photo mount (¼-20 UNC) or 3 × M5 mounting holes on the camera base as well as 3 × M5 mounting holes on the left side of the camera are provided.



1. ¼-20 UNC mount.
2. Camera base M5 mounting holes.
3. Camera left side M5 mounting holes.

6.2 Powering the camera

6.2.1 Power supply

The camera is powered through the red power connector (6 in Figure 5.3 *Camera back panel description.*, page 11) on the back panel. When the 24 V DC power supply provided with the camera (PN X1159) is connected, the power button (1 in Figure 5.3 *Camera back panel description.*, page 11) blinks slowly, indicating that the camera is receiving power.

Refer to section 11 *Technical data*, page 58 for the power supply technical data.

6.2.2 Power button

The power button (1 in Figure 5.3 *Camera back panel description.*, page 11) is located behind the touch screen LCD. Open the touch screen LCD to its maximum extension to access the button.

Note Keep the LCD screen opened or detach it when the camera is being operated to prevent the external cooling vent from being blocked.

A short press on the power button starts the camera.

To turn off the camera:

- A short press on the power button starts the camera shutdown procedure. The camera is switched off a few seconds later.
- A long press on the power button forces the camera to turn off immediately, bypassing the shutdown procedure.

6.2.3 Camera boot-up and cooling down

When the camera is turned on, its Stirling cooler starts first. Stirling coolers produce noise. A high volume of noise is normal for advanced cooled thermal cameras.

The camera requires up to 7 minutes to reach the detector temperature of 80 K. In parallel, the camera performs a built-in test of its components and initializes the internal software and interfaces.

The camera is ready to use when all the status LEDs on the back panel are green (2 in Figure 5.3 *Camera back panel description.*, page 11).

6.3 Adjusting the field of view

Once the camera is installed and operating, its field of view is adjusted to suit the thermal scene being imaged. This adjustment is done by selecting a suitable lens for the desired field of view, and then fine tuning the camera position to the scene.

Use of the LCD screen is helpful during this procedure.

6.3.1 LCD screen

The FLIR X6520sc includes a detachable touch screen LCD that provides instant thermal image feedback. The LCD screen also provides camera information, adjustment controls, and ResearchIR Max acquisition control.

In the LCD screen examples below, the camera measurement configuration and temperature range have been adapted to the thermal scene. If the camera is not correctly set up for the scene, the image can become saturated.

The temperature range of the camera can be automatically adjusted using the auto-exposure button on the touch screen. For more information, see section 8.2.2 *Auto-exposure*, page 36.

If the thermal scene does not match the configuration measurement (i.e., the spectral filter on the filter wheel), it is necessary to select the correct configuration measurement in ResearchIR Max. For more information, see section 6.4.4 *Measurement configuration*, page 22.

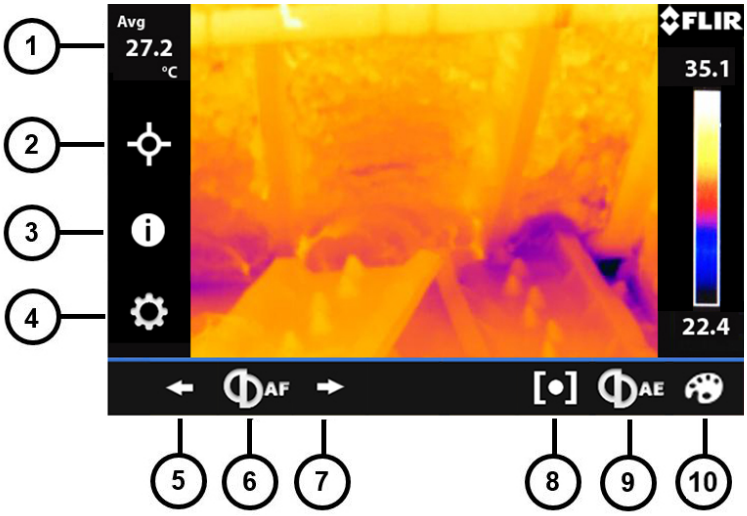


Figure 6.1 LCD touch screen.

1. Image statistics.
2. Add spot tool: center, cold, or hot.
3. Camera information.
4. Measurement configuration.
5. Adjust the near focus (not available for all lenses).
6. Autofocus (not available for all lenses).
7. Adjust the far focus (not available for all lenses).
8. Start acquisition in ResearchIR Max.
9. Auto-exposure.
10. Change the color palette.

6.3.1.1 Detaching the touch screen LCD

The LCD screen can be detached from the camera and used remotely when the camera is mounted in a hard to reach location.

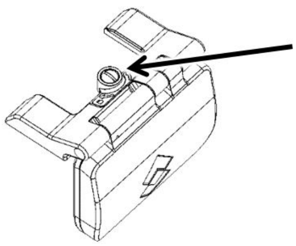
Note

- The camera can still be operated without the LCD screen connected.
- The LCD screen can be detached and attached while the camera is in operation.

6.3.1.2 Procedure

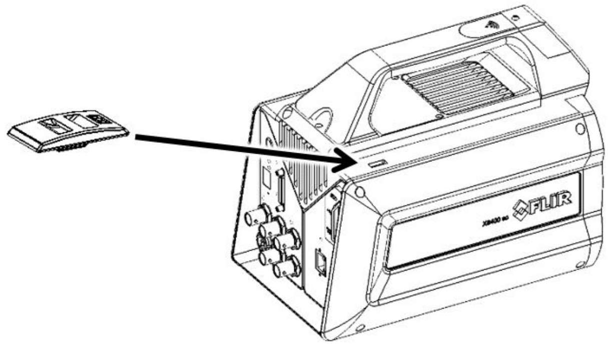
Follow the procedure below to install and detach the LCD screen from the camera:

1. Remove the LCD screw using a flat screwdriver or a coin.



2. Gently lift up the screen to disconnect it from the camera, being careful of the USB connector.

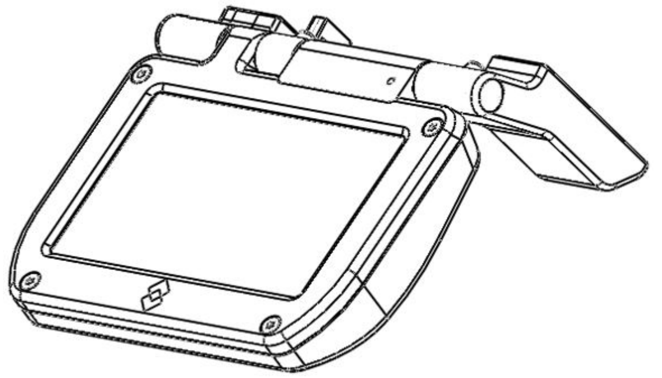
3. Place the provided protective cap on the camera, to avoid dust or water entering the camera.



6.3.1.3 General

When detached, the LCD screen can be connected to the camera using the provided right-angled USB extender cable. An additional USB cable can be added to extend the length. The efficiency of operating the camera in this way is highly dependent on the quality of the additional USB cable and the environment in which the camera is being used.

The screen has been designed for ease of use on a workbench, as shown in the figure below.



The screen automatically detects its orientation, and flips the interface accordingly. The orientation can be locked in the ResearchIR Max camera user interface (see section 6.4.8 *Advanced camera controls*, page 25).

6.3.2 Lens

A large range of lenses is available for the FLIR X6520sc. The lenses feature a professional bayonet mount with a lock. Each lens is identified through the bayonet connector. A temperature probe is also integrated into the lens. This probe is used by the camera to compensate for thermal drifts.

Note FLIR is continuously extending its range of available optics. Contact your FLIR sales representative for more information on newly available optics.

6.3.2.1 Installing an infrared lens

Note

- The detector is a very sensitive sensor. It must not be directed toward strong visible light, e.g., sunlight.
- Do not touch the lens surface when you install the lens. If this happens, clean the lens according to the instructions in section 12.1.2 *Infrared lens*, page 61.
- Do not touch the filter surface when you install the lens. If this happens, clean the filter according to the instructions in section 12.1.2 *Infrared lens*, page 61.

6.3.2.1.1 Procedure—bayonet mount

Follow the procedure below to install an infrared lens with a bayonet mount:

1. If present, remove the installed lens or the protection in front of the detector/filter wheel.
2. Align the red index mark on the lens with the red index mark on the bayonet ring.
3. Carefully push the infrared lens into the bayonet ring.
4. Rotate the infrared lens 30° clockwise (looking at the front of the lens).
5. The camera automatically identifies the lens and selects the measurement configuration corresponding to the lens, if loaded into the camera memory. For more information, see section 6.4.4 *Measurement configuration*, page 22.

6.3.2.2 Removing an infrared lens

Note

- The detector is a very sensitive sensor. It must not be directed toward strong light, e. g., sunlight.
- Do not touch the lens surface when you install the lens. If this happens, clean the lens according to the instructions in section 12.1.2 *Infrared lens*, page 61.
- Lenses can be heavy, so take care not to be surprised by their weight. Some lenses weight several hundred grams.
- When you have removed the infrared lens, put the lens caps on the lens to protect it from dust and fingerprints.

6.3.2.2.1 Procedure—bayonet mount

Follow the procedure below to remove an infrared lens with a bayonet mount:

1. Pull forward the release button for the infrared lens (4 in Figure 5.1 *View from the front—bayonet mount.*, page 10).
2. Rotate the infrared lens 30° counterclockwise (looking at the front of the lens).
3. Carefully pull out the infrared lens from the bayonet mount.
4. Install the protective cap or a new optic on the camera, to avoid visible light striking the detector.

6.3.2.3 Lens identification

FLIR X6520sc lenses with a bayonet mount have a unique identifier. The camera reads the lens identifier and automatically selects the measurement configuration corresponding to the lens, if loaded into the camera memory. For more information, see section 6.4.4 *Measurement configuration*, page 22.

The lens connected to the camera is displayed in ResearchIR Max and on the LCD screen.

6.3.2.4 Adjusting the camera focus

Note Do not touch the lens surface when you adjust the camera focus. If this happens, clean the lens according to the instructions in section 12.1.2 *Infrared lens*, page 61.

Camera focus can be done manually by rotating the focus ring on the lens:

- For far focus, rotate the focus ring counterclockwise (looking at the front of the lens).
- For near focus, rotate the focus ring clockwise (looking at the front of the lens).

For some lenses, you can also adjust the camera focus by doing the following:

- Using the focus control buttons on the LCD screen (see Figure 6.1 *LCD touch screen.*, page 16).
- Using the focus control buttons in ResearchIR Max.

6.3.2.5 Autofocus

The FLIR X6520sc features powerful and fast autofocus using the USL technology in lenses with a bayonet mount.

Note Autofocus is not available in lenses with an M80 mount and not in all lenses with a bayonet mount.

Autofocus can be started by:

- Using the autofocus button on the LCD screen (see Figure 6.1 *LCD touch screen.*, page 16).
- Using the autofocus button in ResearchIR Max.
- Using the infrared remote controller (see section 7.4 *Infrared remote*, page 34).

6.3.2.6 Using an extension ring

Note

- The detector is a very sensitive sensor. It must not be directed toward strong visible light, e.g., sunlight.
- Do not touch the lens surface when you install the lens. If this happens, clean the lens according to the instructions in section 12.1.2 *Infrared lens*, page 61.
- Using extension rings requires a good understanding of their radiometric effects and the resulting measurement errors. The Infrared Training Center (ITC) offers courses and training. For more information on any training you require, contact your FLIR sales representative or ITC at www.infraredtraining.com.

Extension rings can be added between the camera and the infrared lens in order to change the minimum focus distance and thus the field of view of the camera. It is possible to use more than one extension ring at the same time.

Refer to the specification sheet for your infrared lens for available extension ring sizes and other data.

Depending on the extension ring, automatic lens identification may not function. This means you must manually select the measurement configuration using the FLIR ResearchIR Max software.

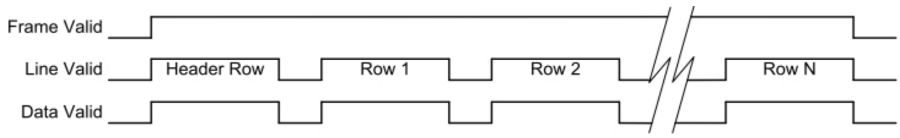
6.4 Setting the camera parameters

6.4.1 Connection to the computer

The camera can be connected to a computer using either Camera Link or GigE. Although it is possible to use both interfaces in parallel, only one of these should be used send commands to the camera. The second computer should be used only to retrieve images.

6.4.1.1 *Connection through the Camera Link interface*

Camera Link is a standard data interface for high-end visible and infrared cameras. The FLIR X6520sc uses a Camera Link Base interface in a single-tap, 16-bit configuration. In terms of ports, the A and B ports are used, with bit A0 being the LSB of the data transferred, and bit B7 being the MSB. The header row uses the entire 16-bit value while the pixel data has a 14-bit range, with the upper MSBs masked to 0.



The camera is connected to the computer using one camera link cable (refer to section 11 *Technical data*, page 58 for cable reference and Camera Link information). Connect the cable to connector 12 in Figure 5.3 *Camera back panel description.*, page 11.

The Camera Link mode is selected using the ResearchIR Max camera control panel interface (refer to section 6.4.8 *Advanced camera controls*, page 25). It should always be set to Base for the FLIR X6520sc.

Note

- Various connector notations can be found for Camera Link medium frame grabbers (0&1, 1&2, A&B). Make sure to connect camera connector 1 to the first port of the frame grabber.
- ResearchIR Max software supports a variety of frame grabbers. Contact your FLIR sales representative for more information on compatibility.

6.4.1.2 *Connection through the GigE interface*

The FLIR X6520sc features a GigE connection. The GigE interface can be used for image acquisition and/or camera control. The GigE interface is GigE Vision compliant.

GigE is available when the camera is in Base mode only. Refer to section 6.4.8 *Advanced camera controls*, page 25 for mode selection.

Note

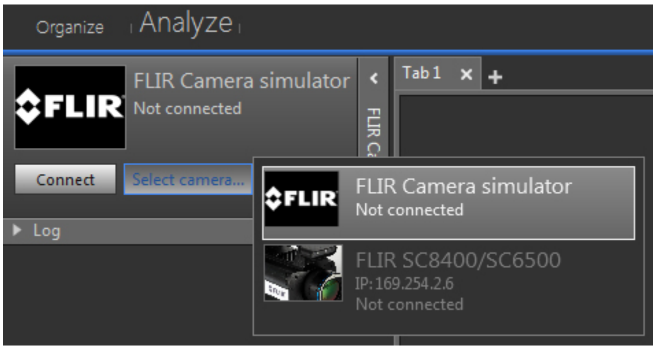
- Use only the high-quality Ethernet cable provided with the camera or a CAT 6 equivalent cable.
- The GigE driver installation procedure must be followed exactly. Contact your FLIR local support if required.

6.4.2 Connection to FLIR ResearchIR Max

Note Refer to section 6.4.1 *Connection to the computer*, page 19 to make sure that the camera is correctly connected to the computer.

6.4.2.1 *General*

The FLIR X6520sc interfaces with the FLIR ResearchIR Max software. FLIR ResearchIR Max is a powerful image acquisition and analysis tool. Refer to the ResearchIR Max user manual for operating instructions. FLIR X6520sc specific camera control is described in this document.



6.4.2.2 Procedure

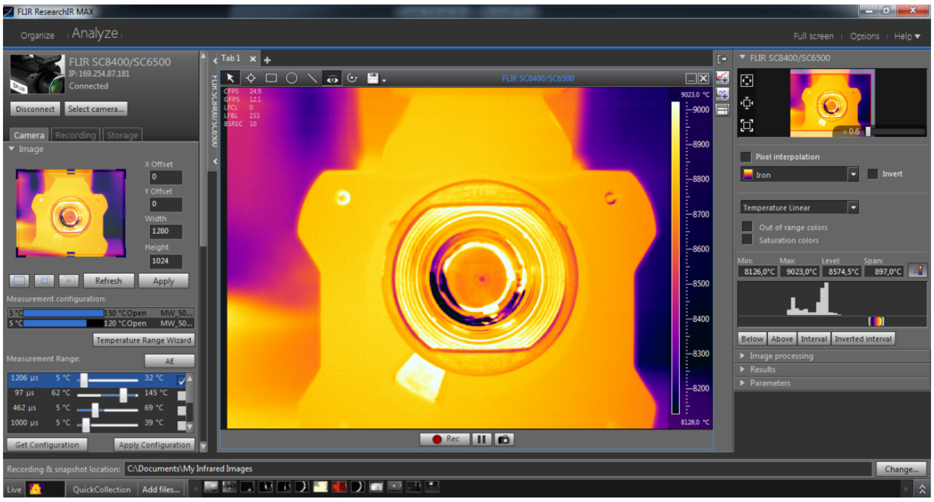
Follow the procedure below to select and connect the camera:

1. Click the *Select camera* button.
2. Select the FLIR X6520sc camera.

   The camera's IP address is displayed when connected using GigE.

   The Camera Link port is displayed when connected using Camera Link.
3. Click the *Connect* button to activate the camera connection.

Once connected, the camera control interface is populated with the camera parameters, and the live image is displayed on the current tab.



6.4.3 Image size adjustment

6.4.3.1 General

The FLIR X6520sc can be set up to use only part of the detector. This allows the camera can be operated at higher frame rates. The selection is done through the upper part of the camera control panel.

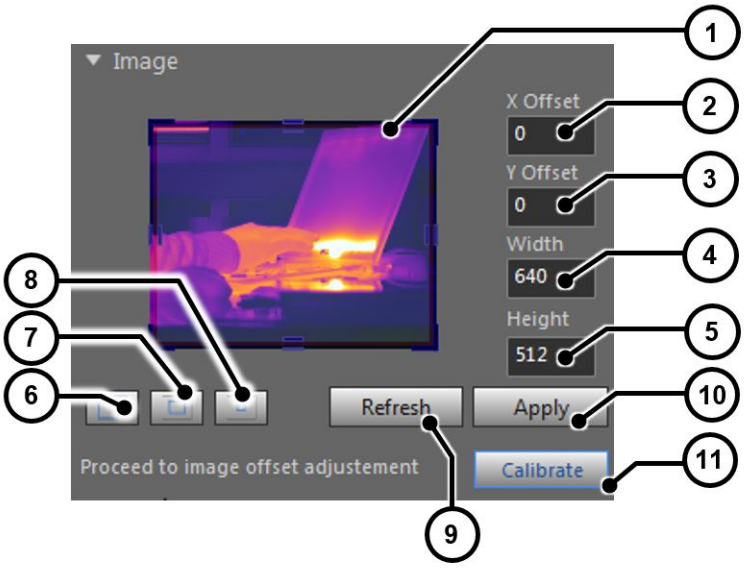


Figure 6.2 Image size adjustment

1. Preview window. The window size can be selected by dragging the handles. The entire box can be dragged to set the location.
2. The *X* offset can be manually set in this field.
3. The *Y* offset can be manually set in this field.
4. The window width can be manually set in this field.
5. The window height can be manually set in this field.
6. Set the window size to full detector size (640 × 512).
7. Set the window size to half detector size (320 × 256 centered).
8. Set the window size to quarter detector size (160 × 128 centered).
9. Refresh the preview window with the last acquired image from the camera.
10. Apply the settings to the camera.
11. If needed, calibrate the image against a homogeneous reference target (also called “1 point NUC”).

6.4.4 Measurement configuration

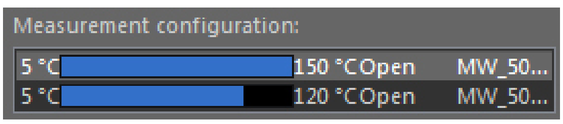
6.4.4.1 General

A measurement configuration is a combination of optical setup (lens and spectral filter), integration mode setting, and Camera Link setting.

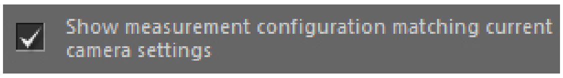
The measurement configurations available in the camera are displayed in the FLIR ResearchIR Max interface. Each configuration is described with minimum and maximum calibrated temperatures, the lens and filter type, the integration mode (ITR or IWR), and the Camera Link setting (Base/Medium).

For lenses with automatic identification (see section 6.3.2.3 *Lens identification*, page 18), the camera automatically selects the measurement configuration corresponding to the lens.

You can also select the measurement configuration manually. Take care to select the measurement configuration corresponding to the lens, filter, integration mode setting (ITR or IWR), and the Camera Link setting (Base or Medium) in use. The configuration is selected by clicking on it. It is then highlighted in light gray. Once selected, the camera is automatically set to this configuration.



It is possible to deactivate the configuration filter by unchecking the check box shown below.



When unchecked, all configurations available in the camera are listed. It is then possible to select a configuration that does not match the current optical and detector setup. This is useful for advanced users when, for instance, using an infrared lens for which no calibration files are available: in this example, the camera will provide temperature data even if the calibration does not apply to the lens.

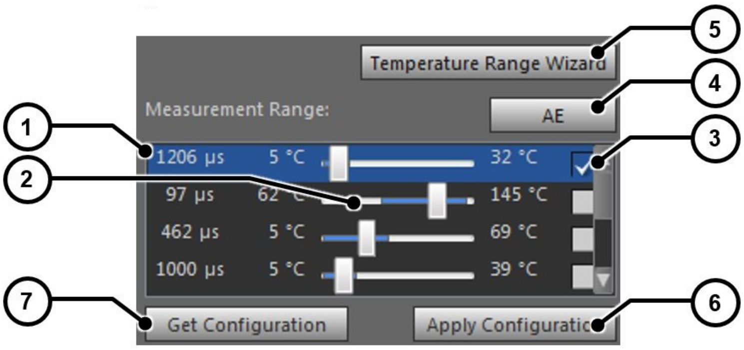
Note

- Only one measurement configuration is valid at a time.
- Make sure you select a configuration that matches the temperature of the scene to be measured. If not, your measurements will be incorrect because they will be outside the limits of the calibration.

6.4.5 Temperature range adjustment

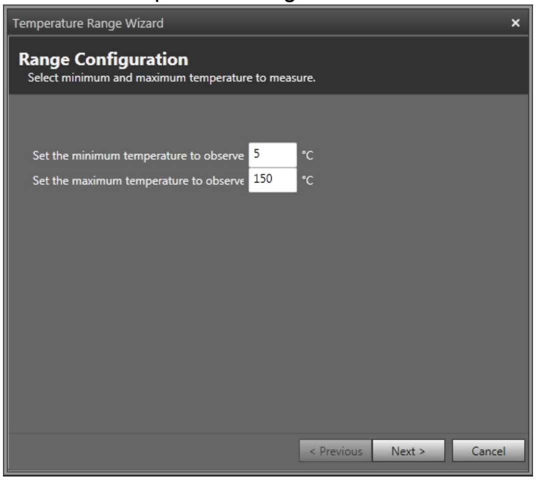
6.4.5.1 General

The temperature range is defined by the minimum and maximum temperatures that can be measured for a given integration time.

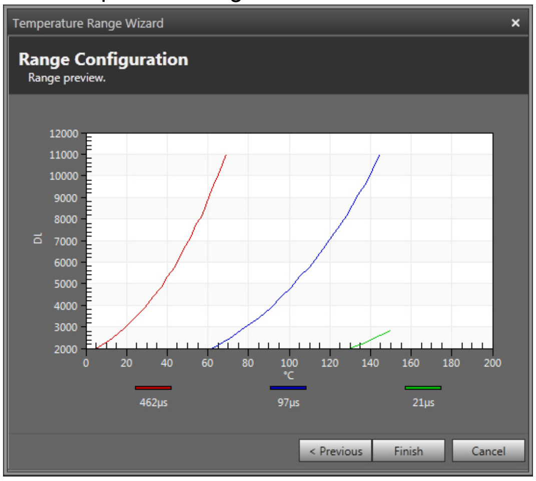


1. Integration time for the range. Double click on the integration time to manually enter a value. The range is indicated in red and will be applied to the camera after clicking on the *Apply Configuration* button.
2. Drag the range slider to adjust the integration time. The corresponding lower and upper temperatures of the range are displayed. The range is indicated in red and will be applied to the camera after clicking on the *Apply Configuration* button.
3. Activate the range by checking the box. If more than one range is activated, the camera enters superframing mode, selecting each range in turn. Refer to section 8.6 *Dynamic range extension—superframing*, page 39 for more information on superframing.
4. The FLIR X6520sc features an automatic exposure control that automatically selects the best integration time for the current thermal scene. Refer to section 8.2.2 *Auto-exposure*, page 36 for more information on auto-exposure.
5. The temperature range wizard automates the selection of integration times and superframing.

5.1. Select the temperature range to measure.



5.2. The wizard automatically calculates the best integration times to cover the desired temperature range.



Click on the *Finish* button to set up the camera accordingly.

6. Apply the temperature range configuration to the camera.
7. Read the actual camera configuration.

6.4.6 Frame frequency

6.4.6.1 General

The frame rate is the number of images taken by the camera per second. Achievable frame rates are based on the camera settings, the camera overhead, and the integration settings.

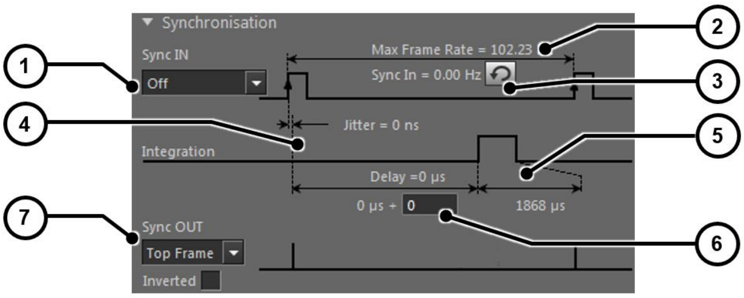
6.4.7 Synchronizing the camera to an external signal

6.4.7.1 General

Note Refer to section 8.7 *Camera synchronization*, page 40 for detailed information on synchronization.

The camera can be synchronized to an external signal. This is useful in, for example, brake disk testing. A signal from the testing machine will synchronize the camera to the disk speed.

Synchronization parameters are set through the ResearchIR Max user interface:



1. Activate/deactivate external synchronization. Select the active edge and input impedance.
2. Based on the camera configuration (e.g., the window size, integration time, or integration mode), the maximum allowable Sync In frequency is displayed.
3. The actual Sync In signal frequency is measured by the camera and displayed here. If the Sync In frequency is higher than the maximum allowable frame rate, a warning message is displayed. In this case, the input signal is under-sampled.
4. The jitter on the Sync In signal, which is typically one pixel clock, is displayed here.
5. The integration time length is displayed here. The integration time is defined in the measurement range panel.
6. A delay between the Sync In signal and the start of integration time can be defined here.
7. Several camera signals can be routed to the Sync Out connector. The polarity of these signals is also defined here.

6.4.8 Advanced camera controls

6.4.8.1 General

This section describes the *Advanced Camera Controls*.

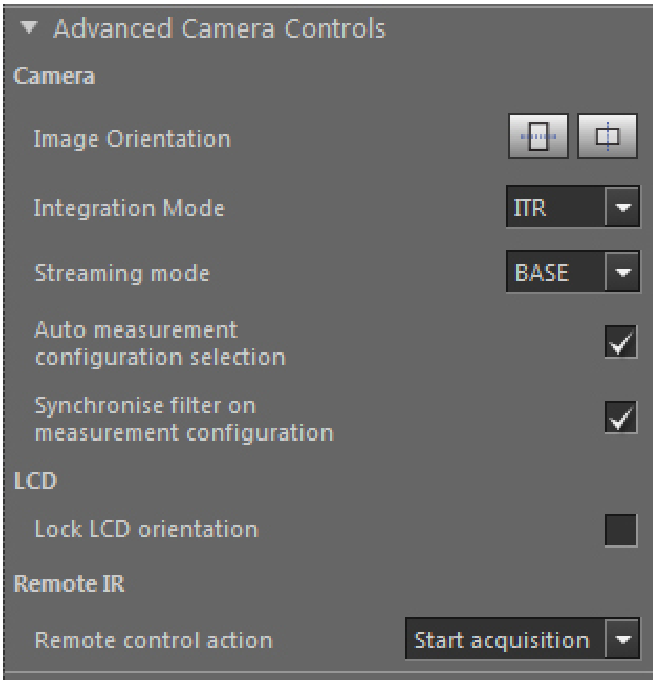
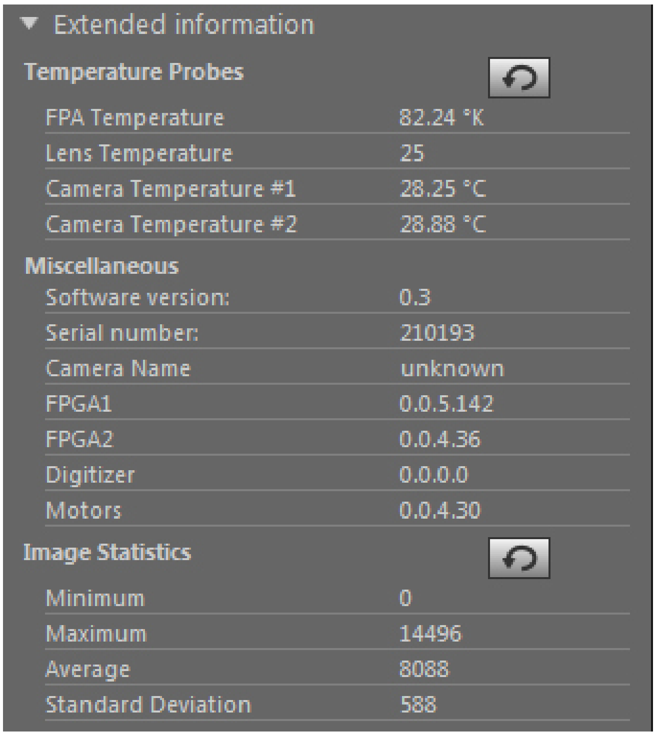


Image Orientation	Select the orientation of the image at the detector level. This impacts digital radiometric outputs as well as video outputs.
Integration Mode	Select between integrate then read (ITR) and integrate while read (IWR). (IWR mode is not available in all camera models.) Refer to section 8.5 *Frame rate and integration modes*, page 37 for more information about these modes. The integration mode impacts the available measurement ranges, depending on the calibration configuration of the camera.
Streaming Mode	Select Base or Medium. For more information, see section 6.4.1.1 *Connection through the Camera Link interface*, page 20. The streaming mode should always be set to Base for the FLIR X6520sc.
Auto measurement configuration selection	When this option is checked, the camera automatically searches the measurement configuration corresponding to the exact optical path (filter + lens) and detector configuration. If no measurement configuration is available in the camera, selecting this option will have no effect. For lenses with the M80 mount (no automatic lens identification), this setting has no effect.
Synchronize filter on measurement configuration	When this option is checked (default), the filter corresponding to the selected measurement configuration is automatically placed by the filter wheel in front of the detector. Deactivating this option should be reserved for advanced setups where the user requires a different spectral filter for a measurement configuration.
Lock LCD orientation	Freeze the LCD screen automatic orientation.
Remote control action	Select the action associated with the infrared remote controller. Refer to section 7.4 *Infrared remote*, page 34 for more information on the infared remote.

6.4.9 Extended camera information

6.4.9.1 General

Extended camera information can be found in the *Extended information* section in the ResearchIR Max camera tab.



Temperature Probes	The camera is equipped with various temperature probes that are used for improving measurement accuracy or for camera diagnostics. Click the refresh button to update the temperature values.
Miscellaneous	This section lists the firmware version information, the model, and the serial number of the camera
Image Statistics	The image statistics as measured by the camera are shown here. Click the refresh button to update the statistics values.

7 Operation

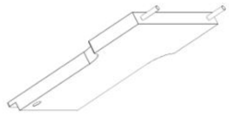
7.1 Filter wheel

The FLIR X6520sc includes a four-slot filter wheel. Each slot can hold a 1 in. (2.5 cm) diameter filter with a thickness of up to 2.5 mm. An identification system has been implemented so that the camera recognizes the inserted slot and automatically adjusts the measurement configuration.

7.1.1 Removing an optical filter holder

Note

- This operation is undertaken close to the detector window. Take extreme care not to touch or scratch the detector window. Contact FLIR service if you require assistance with this operation.
- The detector is a very sensitive sensor. It must not be directed toward strong light, e. g., sunlight. It is better to remove filters with the camera turned on, as the detector, when cooled, is less sensitive to visible light.
- A filter holder tool is provided with the camera.



- Do not touch the filter surface when you install the filter. If this happens, clean the filter according to the manufacturer's instructions.

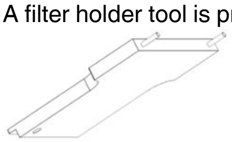
Follow the procedure below to remove a filter holder from the camera filter wheel:

1. Select the measurement configuration range corresponding to the filter to be used. This places the filter in front of the detector, allowing access to it.
2. If there is no measurement configuration range corresponding to the filter, switch off the camera and manually rotate the wheel to place the filter to be removed in front of the detector.
3. Gently insert the two pins of the filter holder tool into the corresponding holes.
4. Rotate the filter holder counterclockwise to release the holder from the wheel.
5. Gently remove the holder from the camera, and store it in its case.

7.1.2 Installing an optical filter holder

Note

- This operation is undertaken close to the detector window. Take extreme care not to touch or scratch the detector window. Contact FLIR service if you require assistance with this operation.
- The detector is a very sensitive sensor. It must not be directed toward strong light, e. g., sunlight. It is best to remove filters with the camera turned on, as the detector, when cooled, is less sensitive to visible light.
- A filter holder tool is provided with the camera.



- Do not touch the filter surface when you install the filter. If this happens, clean the filter according to the manufacturer's instructions.

Follow the procedure below to install a filter holder in the camera filter wheel:

1. Select the measurement configuration range using the filter to be used. The corresponding filter slot is placed in front of the detector allowing access to it.
2. If there is no measurement configuration range corresponding to the filter, switch off the camera and manually rotate the wheel to place the appropriate filter slot in front of the detector.

3. Gently insert the two pins of the filter holder tool into the corresponding holes of the holder to install.
4. Insert the filter holder, making sure that the two slots in the holder are in line with the two springs on the filter wheel.
5. Rotate the filter holder clockwise until the springs are correctly maintaining the holder.

7.1.3 Filter holder identification

Each filter holder is identified by a combination of magnets glued onto the filter holder. FLIR provides standard filter configurations with corresponding identification numbers (IDs). At start-up, the camera scans the filter wheel and identifies the inserted holders. If equipped with a lens with a bayonet mount, the camera also adjusts the measurement configuration in accordance with the identified filter holders.

The IDs 40 to 58 are reserved for customer-defined holders.

7.1.4 Creating a custom filter holder

Note

- Filters are fragile. Handle them with great care.
- Do not touch the filter surface when you install the filter. If this happens, clean the filter according to the manufacturer's instructions.
- Wear gloves or finger tips to handle the filter.

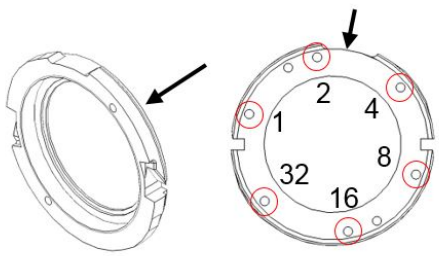
7.1.4.1 General

You can configure a filter holder to use your own spectral filter. You need an empty holder (P/N SC8_SC6_FILT_HOLD—contact your FLIR representative for more information on blank filter holders).

7.1.4.2 Procedure

Follow the procedure below to assemble a filter within a filter holder:

1. Select a holder ID within the range 40 to 58. This will be used by the camera to identify your filter.
2. Convert this number to binary. For example, 40 is 101000.
3. The magnets provided with the empty holder are glued to the holder in accordance with the binary code. For every "1" in the binary code, a magnet is glued in the appropriate hole in the holder (see the figure below), with the north pole of the magnet facing into the hole. For example, for binary code 101000, you need to place a magnet at positions 8 and 32.

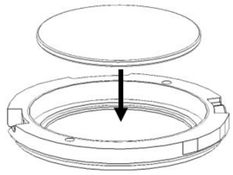


Binary code	1	0	1	0	0	0
Magnet requirement	Yes	No	Yes	No	No	No
Magnet position/value	32	16	8	4	2	1

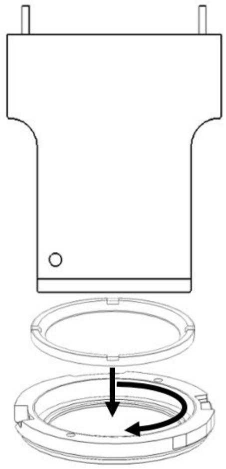
The use of Loctite Hysol 3430 A&B glue is recommended.

Note The Microsoft Windows calculator in programmer mode provides an easy way to convert decimal numbers into binary code.

4. Place your filter in the holder. Take care to ensure correct filter orientation, to avoid errors in the radiometric measurement. Contact your filter provider for this information.



5. Gently insert the threaded filter ring, and tighten it using the filter tool. Take great care not to damage the filter with the tool.

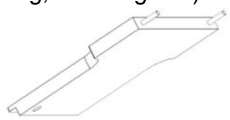


7.1.5 Installing two filters in the filter holder

You can install two filters in the filter holder.

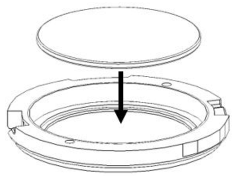
Note

- The total thickness of the two filters must not exceed 2 mm.
- The order in which you install the filters will not affect their performance. However, to avoid narcissus effects, it is recommended that the filters are installed with the least reflective side downwards in the filter holder (i.e., toward the detector).
- Filters are fragile. Handle them with the great care.
- Do not touch the filter surface when you install the filters. If this happens, clean the filter according to the manufacturer's instructions.
- Wear gloves or finger tips to handle the filters
- A set of filter holder equipment (filter holder, centering ring, filter spacer, threaded filter ring, and magnets) and a filter holder tool are provided with the camera.

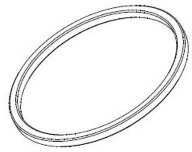


Follow the procedure below to install two filters in the filter holder.

1. Create a custom filter ID, as described in section 7.1.4 *Creating a custom filter holder*, page 29.
2. Place the first filter in the holder.

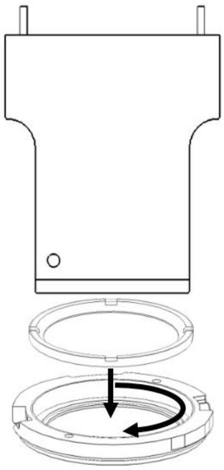


3. Place the centering ring into the holder.



4. Clean the visible filter surface.
5. Place the filter spacer on top of the first filter.

6. Place the second filter into the holder. Make sure it seats correctly on top of the filter spacer and is centered with the centering ring.
7. Gently insert the threaded filter ring and tighten it using the filter tool. Take great care not to damage the filter with the tool.



7.1.6 Adding a custom filter parameter into the camera

7.1.6.1 General

Up to two filters can be mounted in a slot. A slot is defined in the camera's slot.ini file, and a filter's definition is stored in a text file in the camera.

Slot.ini file is a text file containing the holder identification and the corresponding filter numbers.

```
[Holder XXX]
F1 = FYYYY
F2 = FZZZZ
```

Where XXX is the unique identifier of the slot, and YYYY and ZZZZ are filter numbers referring to the existing FYYYY.txt and FZZZZ.txt files, respectively.

For instance, for a holder defined by ID 42 in which the filter F3221 is mounted, the following should be added to the slot.ini file:

```
[Holder 42]
F1 = F3221
F2 = F9999
```

For a holder defined by ID 45 in which the filters F3221 and F1518 are mounted, the following should be added to the slot.ini file:

```
[Holder 45]
```

```
F1 = F3221
F2 = F1518
```

Note

- Refer to section 9.2 *USB connection*, page 47 to access the camera files through the USB connection.
- Refer to section 7.1.7 *Filter definition file description*, page 32 for the description of the filter definition.

7.1.6.2 Procedure

1. Connect your camera to your computer using the USB port.
2. Edit the file Slot.ini file located in the location FlashFS/filters/.
3. Save and close the file Slot.ini.
4. If the filter definition files for the added holder are not present in FlashFS/filters/, they have to be created.
5. Repeat steps 2 to 4 for all filters and holders to be added.
6. Reboot the camera (a short press on the power button) to apply the modification.

7.1.7 Filter definition file description

7.1.7.1 General

Filter definition files contain identification and spectral information for the corresponding filters. This information is used by the camera and ResearchIR Max to adjust measurement configurations.

Filter definition files must contain all the sections described below. The values in each section must not be longer than the specified number of characters. It may be easier to copy an existing filter file and modify it.

#reference max 20 char [reference] **F1201**	The filter reference. This reference is used in the Slot.ini file and must start with the capital letter “F.”
#name max 20 char [name] **NA_4094_4388_60%**	The user-friendly name that is displayed in the ResearchIR Max user interface. FLIR uses the following naming convention, but it can be freely modified. XX_YYYY_ZZZZ_WW% • XX : type of filter (NA, narrow; LP, low pass; HP, high pass; BP, band pass) • YYYY: cut-in (in nm) • ZZZZ: cut-off (in nm) • WW: average transmission
#application max 20 char [application] **Blue CO_2 filter**	Application in which the filter is used. This name is displayed on the camera’s LCD screen.
#band max 10 char [band] **MW**	BB: broadband midwave (1.5–5 µm) MW: midwave (3–5 µm) If unknown, enter “N/A.”
#material max 20 char [material] **Silicon**	Filter substrate If unknown, enter “N/A.”
#type max 20 char [type] **Narrow**	Type of filter (narrow, band pass, high pass, low pass) If unknown, enter “N/A”.
#peak in µm [peak] **4.22**	Peak transmission If unknown, enter “0.”

#cuton in nm [cuton] **4094**	Filter cut-in (in nm) If unknown, enter "0."
#cutoff in nm [cutoff] **4388**	Filter cut-off (in nm) If unknown, enter "0."
#transmission in % [transmission] **60**	Average filter transmission (in %) If unknown, enter "0."
#tolerance in % [tolerance] **0.3**	Filter spectral tolerance If unknown, enter "0."
#[thickness] in mm [thickness] **0.5**	Filter substrate thickness If unknown, enter "0".
#spectral response max 160 char [spectral response] 1:0;3,94:0,01;3,95:0,02;3,96:0,07; **4,04:0,04;4,06:0,01;4,08:0;6:0**	Spectral response curve definition The wavelength and corresponding transmission (the maximum is 1) are separated by a colon. Pairs of values are separated by a semicolon. If unknown, enter "N/A."

7.2 Camera configuration file management

7.2.1 CNUC file management

7.2.1.1 General

Note

- CNUC files are related to the measurement configurations available for the camera. Refer to section 6.4.4 *Measurement configuration*, page 22.
- Accessing camera files exposes the camera system files. Do not erase or modify files other than the configuration files.

CNUC files are accessible by an FTP connection to the camera. Refer to section 9.2 *USB connection*, page 47 to connect to camera files.

7.2.1.2 Procedure

1. Connect your camera to your computer through the USB port.
2. You can add or delete camera calibration files directly in the directory FlashFS/nuc/.
3. Reboot the camera to apply the modification

7.3 Camera Wi-Fi application

7.3.1 General

Note Refer to section 9.1 *Wi-Fi connection*, page 46 to set up a Wi-Fi connection to the camera.

A web application is available when using Wi-Fi to connect to the camera. This application allows image recording to be started and stopped in ResearchIR Max.

7.3.2 Procedure

1. Connect your device (smartphone or computer) to your camera.
2. On a web browser, go to http://169.254.242.23.
3. Control the ResearchIR Max recording from the web page.

7.3.3 Camera web page description

1. Indicates camera status:
   - *Ready*: The camera is running properly and providing infrared images.
   - *Not Ready*: The camera is not providing infrared images. Check the camera status LEDs for detailed information.
2. Indicates ResearchIR Max connection status:
   - *Connected*: ResearchIR Max is connected to the camera and ready to acquire an image sequence.
   - *Not Connected*: No sequence acquisition is possible. Check ResearchIR Max status on the computer.
3. Indicates the current sequence recording status:
   - *Blank*: Recording is not in progress in ResearchIR Max.
   - *Recording*: ResearchIR Max is currently recording an image sequence.
4. Press the start/stop acquisition button to start or stop the image sequence acquisition in ResearchIR Max.

7.4 Infrared remote

7.4.1 General

The FLIR X6520sc can be controlled with the provided infrared remote or any XLR camera remote control using the Nikon protocol.

The actions available are as follows:

- Start acquisition in ResearchIR Max.
- Trigger 1 point NUC calibration.
- Trigger auto-exposure.
- Trigger autofocus (not available for all lenses).

7.4.2 Procedure

Follow the procedure below to select the infrared remote action:

1. Connect the camera to ResearchIR Max.
2. In the camera tab, under *Advanced Camera Control*, select the infrared remote action.

8 Radiometric measurement

8.1 Non-uniformity correction (NUC)

8.1.1 General

NUC refers to the process by which the camera electronics correct for the differences in the pixel-to-pixel response of each individual pixel in the detector array. The camera can create (or allow for the user to load) a NUC table that consists of a unique gain and offset coefficients and a bad pixel indicator for each pixel. The table is then applied in the digital processing pipeline as shown in Figure 8.1. The result is corrected data, where each pixel responds consistently across the detector input range, creating a uniform image.

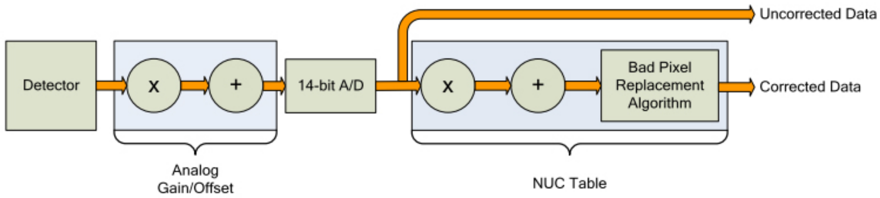


Figure 8.1 Digital process showing the application of NUC tables.

To create the NUC table, the camera images either one or two uniform temperature sources. The source is an external source provided by the user. The source should be uniform and large enough to overfill the camera's field of view. By analyzing the pixel data from these constant sources, the non-uniformity of the pixels can be determined and corrected. There are two types of processes that are used to create the NUC table: one point and two point.

8.1.2 CNUC

8.1.2.1 General

CNUC is a proprietary calibration process. A camera calibrated with CNUC allows for flexible integration time adjustments without the need to perform NUCs. Additionally, the CNUC calibration produces accurate measurement stability regardless of the camera's exposure to ambient temperature variations.

A CNUC correction is valid for a specific optical configuration comprising a lens and spectral filters combination. CNUC corrections are generated by FLIR service offices where advanced calibration benches are available. Contact your FLIR representative for CNUC correction on new spectral filters or infrared lenses.

The CNUC process generates a gain and offset map based on the camera's internal parameters and environmental probes.

8.1.3 Two-point correction process

8.1.3.1 General

The two-point correction process builds a NUC table that contains individually computed gain and offset coefficients for each pixel, as shown in Figure 8.2. Two uniform sources are required for this correction: one source at the low end of the usable detector input range, and a second source at the upper end.

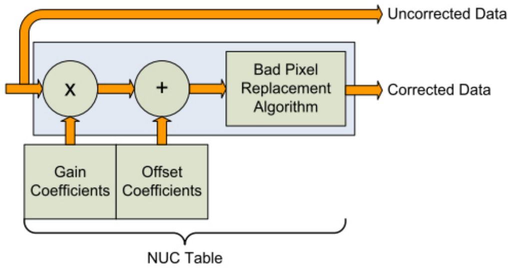


Figure 8.2 Two-point correction.

8.1.4 One-point correction (offset correction)

8.1.4.1 General

The NUC correction is strongly dependent on the optical path in front of the detector, and on the detector setup itself. Often, any change in the camera or detector settings will require a new NUC. However, this change is mainly in the offset response of the image while the gain component stays constant. An offset update simply computes a new offset coefficient using the existing gain coefficient and corrects the image non-uniformity. An offset update requires only one uniform source, usually set at a temperature on the lower edge of the operational range.

One-point correction is done when clicking the calibrate button in the ResearchIR Max camera tab (11 in Figure 6.2 *Image size adjustment*, page 22).

8.2 Temperature calibration

8.2.1 Hypercal

8.2.1.1 General

Hypercal is a proprietary temperature measurement process that complements CNUC. With Hypercal, for any integration time selected, the camera produces accurate measurement within ±1°C or ±1% over the configured measurement range. Therefore, it makes the selection of the optimal measurement range for a given thermal scene an easy task.

Note ±1°C or ±1% accuracy is standard for the FLIR X6520sc, unless explicitly specified otherwise. Typically, calibration on custom spectral filters or custom optical configurations have higher-accuracy tolerances.

8.2.2 Auto-exposure

8.2.2.1 General

Because the dynamic range of a natural thermal scene can be larger than the range of the camera, some images taken by the camera may be saturated. When an image is in the bottom part of the dynamic range, the sensitivity is affected; therefore, the integration time has to be increased. Conversely, when an image is in the higher part of the dynamic range and saturated, the integration time has to be decreased.

When activated, the camera will search for the highest integration time for which the image dynamic range is contained in the upper part of the linearity domain of the detector.

Auto-exposure can be started from ResearchIR Max (see section 6.4.5 *Temperature range adjustment*, page 23) or from the LCD screen (see Figure 6.1 *LCD touch screen.*, page 16).

Note

- The auto-exposure process looks for the best integration time for the actual thermal scene. It may be the case that this preferred integration time is not achievable because it is limited by the camera's frame rate. In this case, the auto-exposure process is stopped, and the preferred integration is not applied.

The auto-exposure process is not designed to handle multiple integration times.

8.3 Bad pixel replacement

8.3.1 General

Once an NUC has been carried out, bad pixels can be detected and replaced. This is done by replacing the bad pixels by the median value of the eight neighboring pixels.

There are three kinds of bad pixels:

- Bad pixels relative to the *gain* of the non-uniformity correction. In this case the system will consider a pixel as bad if the gain coefficient from the NUC is lower or higher than the predefined percentage. For instance, if the threshold is 25%, the system will determine a pixel as bad if the gain is <0.75 but >1.25.
- Bad pixels relative to the *offset* of the NUC. In this case the system will consider a pixel as a bad if the offset coefficient from the NUC table is lower or higher than the predefined threshold. For instance, if the threshold is 30% and if the range of digitization is 16 384 digital levels (DL), the system will determine a pixel as bad if the offset is <–4915 DL but >4915 DL.
- Bad pixels relative to its level of root-mean-square (RMS) *noise*. In this case the system will consider a pixel as bad if the RMS noise is lower or higher than the predefined threshold. For instance, if the threshold is 3.5 and the mean and standard deviation of the noise image are, respectively, 5.0 and 1.0, the system will determine a pixel as bad if the RMS noise is >8.5. With the absolute threshold, the system considers a pixel as bad if its value is higher than this threshold.

8.4 Camera file management

8.4.1 Procedure

1. Connect your camera to a computer using the USB port.
2. You can add or delete camera calibration files directly in the directory FlashFS/nuc/.
3. Reboot the camera to apply the modification

Note

If you are using Microsoft Windows 7:

- The camera must be connected to the computer using USB.
- The USB drivers must be correctly installed.

8.5 Frame rate and integration modes

8.5.1 General

The frame rate is the number of images taken by the camera per second. The integration time is the "exposure time"—the period of time for which the camera views the scene. Achievable frame rates are based on the camera settings, the camera overhead, and the integration settings. A brief review of the processes that occur during a frame is needed to understand how to determine maximum achievable frame rates.

There are two basic integration modes: integrate then read (ITR) and integrate while read (IWR). ITR is the most basic behavior of the camera and shows the process most clearly.

Note

- An NUC update is recommended any time an adjustment is made to either the frame rate or the integration time, regardless of the integration mode.
- The IWR mode is not available in all camera models.

8.5.2 The ITR process

As seen in Figure 8.3, the frame generation process begins with a frame synchronization (Frame Sync). The camera then integrates the set amount of time, goes through a fixed dead time, transmits data, goes through a second fixed dead time, and then is ready to start the process over again. The figure shows that the camera first completes the integration process and then reads the data out, hence the term “integrate then read.”

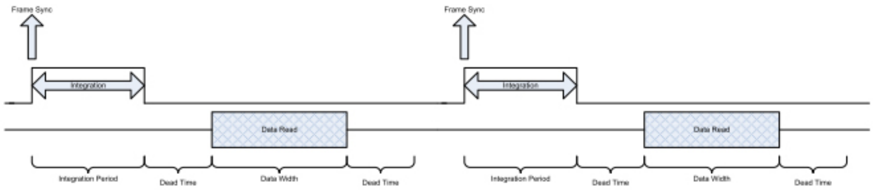


Figure 8.3 The ITR frame generation process.

All timings for the frame generation process are based on a 50 MHz clock, yielding a resolution of 160 ns. The minimum integration time for the FLIR X6520sc is two clock cycles or 320 ns.

Table 8.1 gives the method for computing the maximum frame rate for the ITR process.

Table 8.1 ITR maximum frame rate calculations

Data width	[8 + number of columns + number of columns × number of rows)]/50 M
Dead time	246.32 µs
Integration time	User defined; [320 ns ≤ integration time ≤ 11 minutes]
Frame rate	1/[integration time + data width + dead time]

Table 8.2 shows the ITR calculations for a typical frame setting of 640 × 512 with an integration period of 2.0 ms.

Table 8.2 ITR maximum frame rate calculations, 640 × 512, 2.0 ms integration time

Data width	[8 + 640 + 640 × 512]/50 M = 0.006566
Dead time	246.32 µs
Integration time	0.002
Frame rate	1 / [0.006566 + 0. 00024632 + 0.002] = 1/ [0.0088129] = 113.47

8.5.3 The IWR process

The integration and the data readout periods can be thought of as two separate processes. However, they are linked by certain timing requirements. This means that the camera can integrate for a period, then starts the data readout for that integration period, and during that readout starts the integration period for the next frame. This process is thus termed “integrate while read,” and can greatly speed up frame rates, as seen in Figure 8.4. The drawback to this process is that it injects a fixed pattern noise into the data, which can be removed by performing an NUC on the data.

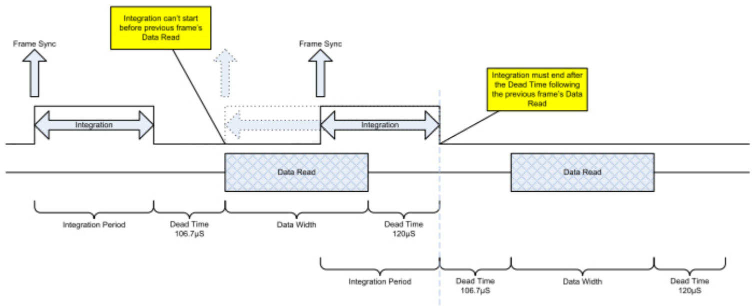


Figure 8.4 The IWR frame generation process.

The integration period cannot end before the previous frame data is read. The integration period cannot begin until after the previous frame's data read starts. Therefore, the calculation used to compute the maximum IWR frame rate depends on the integration and data read period. These calculations are shown in Table 8.1.

Table 8.1 IWR maximum frame rate calculations

Data width	[4 + number of columns + number of columns × number of rows)]/50 M
Dead time	249.28 µs
Integration time	User defined; [320 ns ≤ integration time ≤ 11 minutes]
Frame rate	Integration time < data width + dead time : 1/[data width + dead time] Integration time > data width + dead time : 1/[Integration time + dead time]

Table 8.2 shows the IWR calculations for a typical frame setting of 640 × 512 with an integration period of 2.0 ms.

Table 8.2 IWR maximum frame rate calculations, 640 × 512, 2.0 ms integration time

Data width	[4 + 640 + 640 × 512]/50 M = 0.00656648
Dead time	249.28 µs
Integration time	0.002
Frame rate	Integration time < data width + dead time: 1/[0. 00656648 + 0. 00024928] = 1/[0.00681576] = 146.72

8.5.4 Procedure

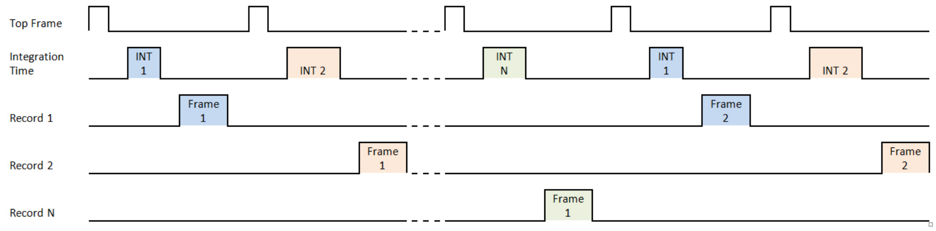
Note The IWR mode is not available in all camera models.

Follow the procedure below to select the camera integration mode (ITR or IWR):

1. Connect the camera to ResearchIR Max
2. In the camera tab, under *Advanced Camera Control*, select the integration mode.

8.6 Dynamic range extension—superframing

The main purpose of superframing is to capture a large dynamic range event with various integration times. Consider a rocket launch as an example. During the launch, a short integration time would be needed to monitor the plume of the rocket. However, such a short integration time would not yield adequate images across the the rocket body. If the integration time was increased to yield adequate images across the rocket body and its plume, the plume would saturate the detector. Superframing cycles through up to eight different integration periods. Below is a timing graph explaining the link between the recorded frame and the integration time in superframing mode.



Refer to section 6.4.5 *Temperature range adjustment*, page 23 to set up superframing.

8.7 Camera synchronization

The FLIR X6520sc can be synchronized to an external signal. The synchronization applies to the timing of an individual frame. The camera features a Sync In connector (4 in Figure 5.3 *Camera back panel description.*, page 11) and a Sync Out connector (5 in Figure 5.3 *Camera back panel description.*, page 11).

The FLIR X6520sc makes use of frame synchronizations to control the generation of image data. The generation of a frame consists of two phases: integration and data readout. Depending on the timing between these two events, you have two basic integration modes: ITR and IWR. In ITR mode, integration and data readout occur sequentially. The complete frame time is the combined total of the integration time plus the readout time. In IWR mode, the integration phase of the current frame occurs during the readout phase of the previous frame. In other words, the ITR and IWR refer to whether or not the camera will overlap the data readout and integration periods. In ITR mode, the data is not overlapped, which means lower frame rates, but this process provides a less noisy image. IWR mode can achieve much faster frame rates, but with a slight increase in noise.

On frame synchronization, the camera immediately integrates, followed by data read out.

Note

- When using an external frame synchronization and preset sequencing, or superframing, the external frame synchronization should be set to comply with the ITR frame rate limits. If the external synchronization rate is too fast, the camera will ignore synchronizations that occur before the camera is ready.
- If the frame rate is too low, the image quality may deteriorate. Contact your FLIR representative if you have questions about low frame rates for your specific camera model.
- Synchronization is different from triggering. The latter is described in section 8.8 *Trigger In*, page 43.
- The IWR mode is not available in all camera models.

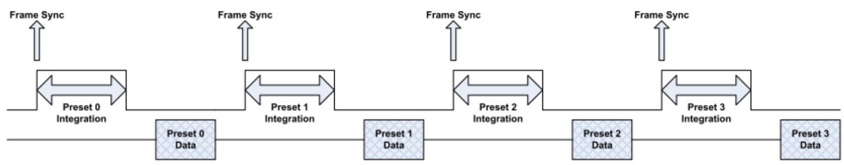


Figure 8.5 Frame synchronization—ITR mode.

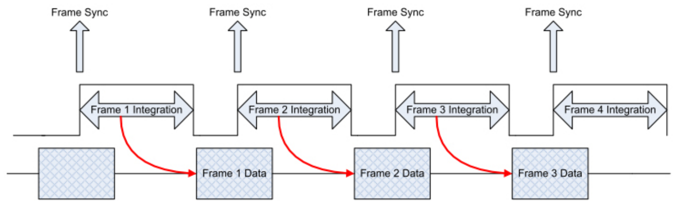


Figure 8.6 Frame synchronization—IWR mode.

8.7.1 Sync In

8.7.1.1 General

The Sync In signal is supplied to the camera by connector 4 in Figure 5.3 *Camera back panel description.*, page 11. The minimum pulse width is 300 ns.

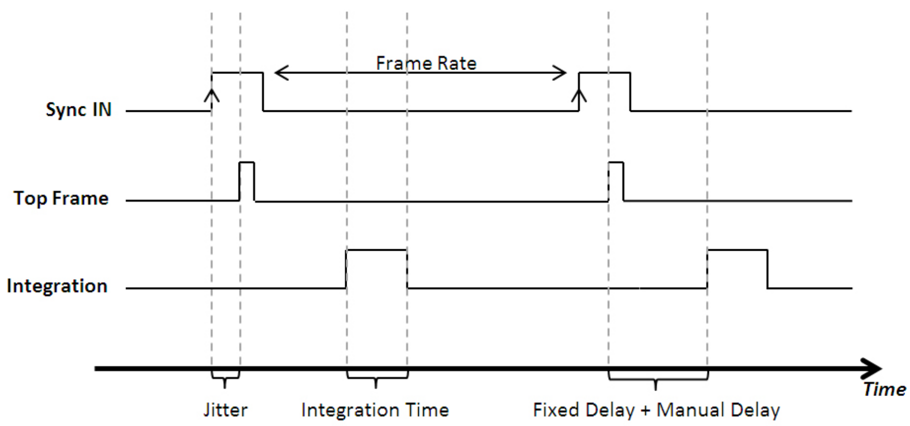
The Sync In setup is described in section 6.4.7 *Synchronizing the camera to an external signal*, page 24.

8.7.1.2 Characteristics

Name	Value
Amplitude	Rising-edge TTL, 0/+5 V
High-state minimum voltage	>3.5 V
Low-state maximum voltage	<0.5 V
Polarity	User selectable
Maximum frequency[1]	Maximum frame rate of the camera for a given detector configuration[2]
Minimum pulse width	300 ns
Impedance	User selectable. 50 Ω/10 MΩ
Protection	Voltage peaks (500 V/<1 ns) Overvoltage (15 V) Reversed polarity
Connector type	Coaxial BNC jack

1. Some cameras also have a minimum frequency (unspecified). Contact your FLIR representative for more information.
2. Example: If the detector is working at 100 in full frame, then the maximum frequency will be 100.

8.7.1.3 Chronogram



Name	Value	Notes
Jitter	20 ns	1 pixel clock (50 M)
Fixed delay	690 ns	Propagation through the back panel card + propagation from the FPGA to the detector
Manual delay	–	Set by the user
Integration Time	–	Set by the user

8.7.1.4 LED description

LED status	Description
Off	No signal detected. Check the connection and signal levels.
Green	Signal detected and the signal voltage is correct but the signal is continuous.
Orange	Signal detected but the signal voltage is **incorrect**.
Blinking green	Signal detected. LED is blinking at the signal frequency. Signal voltage is **correct**.
Blinking orange	Signal detected. LED is blinking at the signal frequency. Signal voltage is **incorrect**.

8.7.2 Sync Out

8.7.2.1 General

The Sync Out signal is synchronous with the Sync In or the frame rate (if Sync In is not selected). It can be used to synchronize other events with the camera. It is a TTL signal.

The Sync Out setup is described in section 6.4.7 *Synchronizing the camera to an external signal*, page 24.

8.7.2.2 Characteristics

Name	Value
Amplitude	TTL signal 0/+5 V
Max frequency	Maximum frame rate of the camera for a given detector configuration[1]
Impedance	High impedance
Minimum pulse width	300 ns
Protection	Voltage peaks (500 V/<1 ns) Overvoltage (15 V) Reversed polarity
Connector	Coaxial BNC jack

1. Example: If the detector is working at 100 in full frame, then the maximum frequency will be 100.

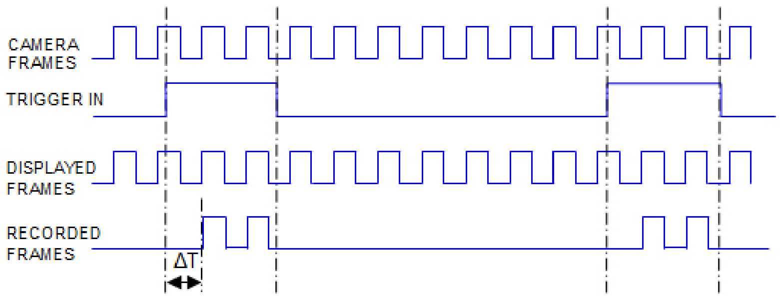
8.7.2.3 *LED description*

LED status	Description
Off	No signal.
Blinking Green	Signal ready to use. LED is blinking at the signal frequency.
Green	Signal not **usable**. Signal voltage is 5 V continuous.

8.8 Trigger In

8.8.1 General

Trigger In is used to tag images in the camera so that they are recorded by the software. The status of the Trigger In signal at the start of integration is added to the frame header sent to the recording software.



ΔT is a jitter of one frame period maximum. The Trigger In signal must be at least one frame period long. All frames are sent to the computer. ResearchIR Max will start or stop acquisition based on the Trigger In signal. This is configured in the start and stop conditions on the ResearchIR Max recording tab (left panel).

When to use this configuration

- To capture a fugitive event. The camera will acquire images, but the software only records the frame of interest.
- When a precise start for the recording time is required.
- When only a few frames are needed to be recorded

When NOT to use this configuration

- When it is needed to trigger each acquisition. In that situation, it is preferable to use the Sync In input.

8.8.2 Characteristics

Name	Value
Amplitude	Rising edge TTL, 0/+5 V
High-state minimum voltage	>3.5 V
Low-state maximum voltage	<0.5 V
Minimum pulse width	One frame period
Impedance	User selectable. 50 Ω/10 MΩ

Name	Value
Protection	Voltage peaks (500 V/<1 ns) Overvoltage (15 V) Reversed polarity
Connector type	Coaxial BNC jack

8.8.3 LED description

LED status	Description
Off	No signal detected. Check the connection and signal levels.
Green	Signal detected and the signal voltage is correct but the signal is continuous.
range	Signal detected. Signal voltage is **incorrect**.
Blinking green	Signal detected. LED is blinking at the signal frequency. Signal voltage is **correct**.
Blinkingorange	Signal detected. LED is blinking at the signal frequency. Signal voltage is **incorrect**.

8.9 Lock-in

8.9.1 General

The lock-in technique is commonly used in thermography to improve the sensitivity of the camera and to extract from the thermal signal the thermal effects corresponding to an external excitation in the object under evaluation.

The FLIR X6520sc features a lock-in signal input BNC connector on the back panel of the camera (7 in Figure 5.3 *Camera back panel description.*, page 11).

The value of the signal is digitalized during the integration of the infrared image and embedded within it. It is then recorded by ResearchIR Max and stored in the sequence file image headers. Files recorded with ResearchIR Max can subsequently be exploited with FLIR Thesa software. Contact your FLIR representative for further information.

Note When conducting lock-in experiments it is highly recommended to place a large non-polarized capacitor (e.g., 1 µF 100 V or 1 µF 63 V) in series with the input.

8.9.2 Characteristics

Name	Value
Amplitude	150 mV < $V_{\text{lock-in}}$ < 10 V
Frequency	10 mHz < F_{lockin}< 6 kHz
Maximum signal offset sweep rate	Half-amplitude per period
Impedance	High *Z*
Protection	Peak voltage 500 V Clamping voltage 150 V Rated voltage 24 V Electrostatic discharge (ESD) contact 8 kV ESD air 15 kV
Connector type	Coaxial BNC jack

8.10 IRIG-B

The FLIR X6520sc features an IRIG-B input BNC connector (colored blue) on the back panel of the camera (8 in Figure 5.3 *Camera back panel description.*, page 11).

The value of the signal is digitalized during the integration of the infrared image and embedded within it. It is then recorded by ResearchIR Max and stored in the sequence file image headers.

The supported IRIG-B formats are IRIG-B12x. The signal should be 3:1, 3 Vpp maximum at 50 Ω or 6 Vpp for high impedance input.

9 Interfaces

9.1 Wi-Fi connection

9.1.1 General

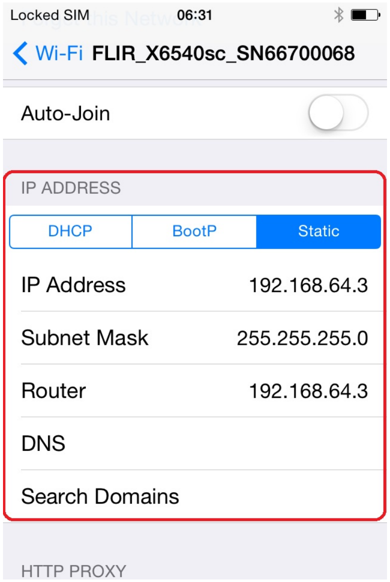
It is possible to connect to the FLIR X6520sc using the camera's integrated Wi-Fi and a peer-to-peer (*ad hoc*) WLAN network. This connection allows control of image acquisition in ResearchIR Max from the camera (same functions as on the LCD screen).

9.1.2 Procedure

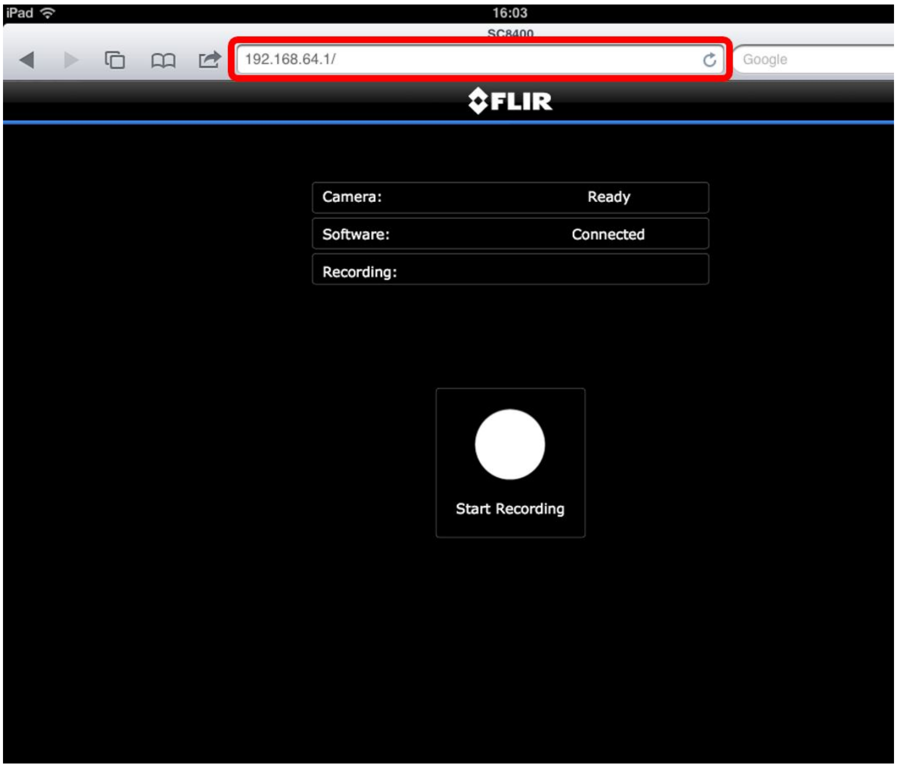
Follow the procedure below to set up the peer-to-peer WLAN network:

1. Connect the camera.

2. Enter the password: 1234567890.
3. Configure the advanced parameters.



4. Connect to http://192.168.64.1/



9.2 USB connection

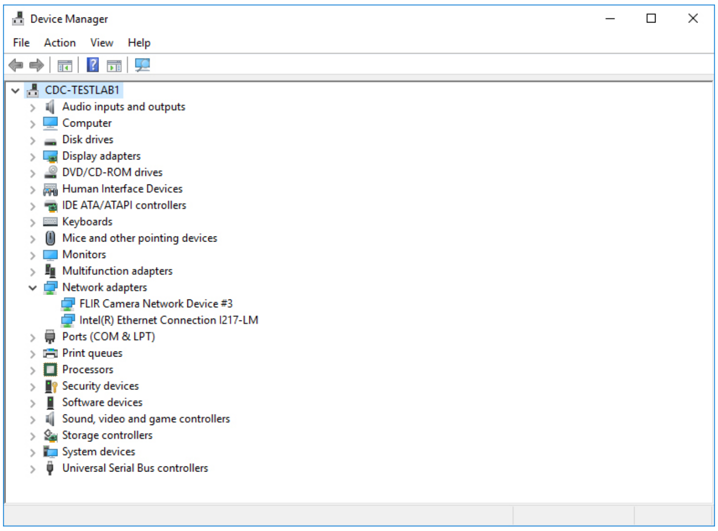
9.2.1 General

The camera features a USB connector that is used to access to the camera's internal file system. Once connected, the connection allows:

- Access to the camera memory, to upload configuration and CNUC files.
- Access to the camera registry with the Res.NET utility (provided on request, see section 4 *Customer help*, page 7).

The USB connection requires a FLIR USB driver on the camera and also on the computer. Depending on the camera, there are two scenarios:

1. **The camera has a newer FLIR USB driver**
   When the FLIR ReseachIR Max software is installed on the computer, a valid FLIR USB driver is automatically installed on the computer. When this FLIR USB driver is installed, *FLIR Camera Network Device* is listed under *Network adaptors* in Windows Device Manager. No manual installation of a USB driver is required, but you need to configure the network interface (see section 9.2.3 *Configuration of the network interface*, page 52).



2. **The camera has a legacy FLIR USB driver**
   Installation of the driver *FLIR X8400sc - X6500sc – USB.inf* is required on the computer. For more information, see section 9.2.2 *USB driver installation*, page 48. After installing the driver, you need to configure the network interface (see section 9.2.3 *Configuration of the network interface*, page 52).

Note

- The connection type to the camera is RDNIS over a USB connection.
- The following operating systems are supported:
  - Microsoft Windows 7 32 and 64 bit
  - Microsoft Windows Vista 32 and 64 bit
  - Microsoft Windows XP SP2

9.2.2 USB driver installation

This section applies to cameras with the legacy FLIR USB driver. Installation of the driver *FLIR X8400sc - X6500sc – USB.inf* is required on the computer. Contact your FLIR service centre or visit http://support.flir.com to download the driver.

9.2.2.1 First time installation

9.2.2.1.1 General

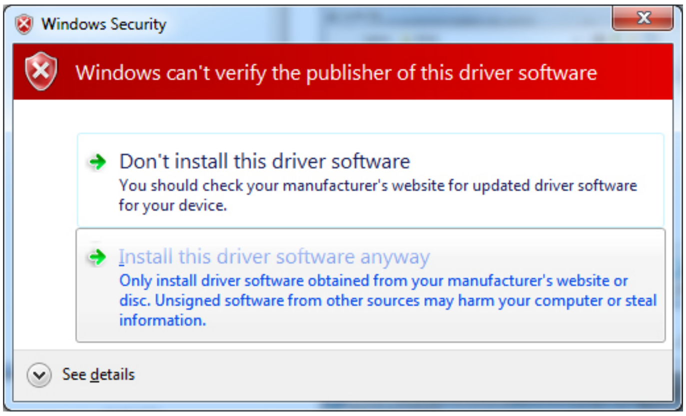
When the camera is connected to the computer by a USB cable for the first time, Windows detects the camera and prompts you to select the driver.

9.2.2.1.2 Procedure

Follow the procedure below to install the USB driver:

1. Connect the camera to the computer using the USB cable.
2. At the Windows prompt, select the *FLIR X8400sc - X6500sc – USB.inf* file.

3. Allow installation of the driver, despite it not being Microsoft trusted software.



4. Configure the network interface by following the procedure in section 9.2.3 *Configuration of the network interface*, page 52.

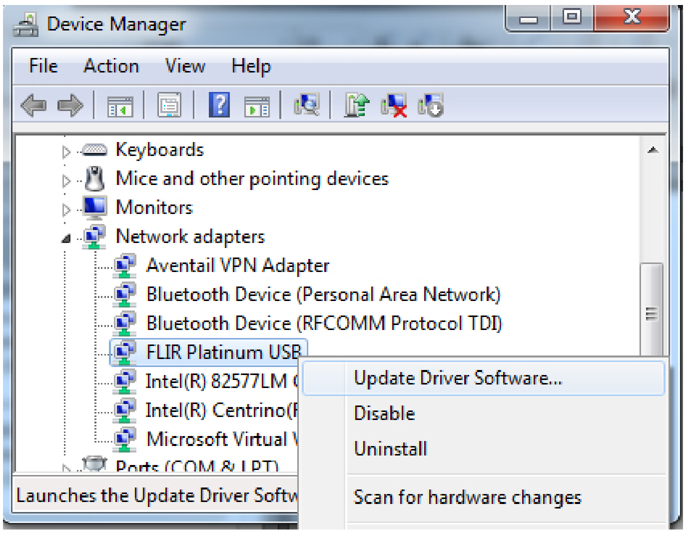
9.2.2.2 Replacing an existing driver

9.2.2.2.1 General

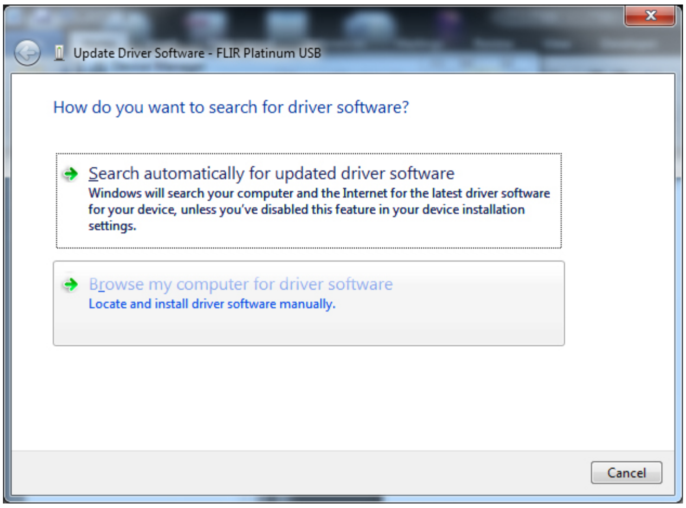
When the USB driver has already been installed, follow the procedure below to update the driver.

9.2.2.2.2 Procedure

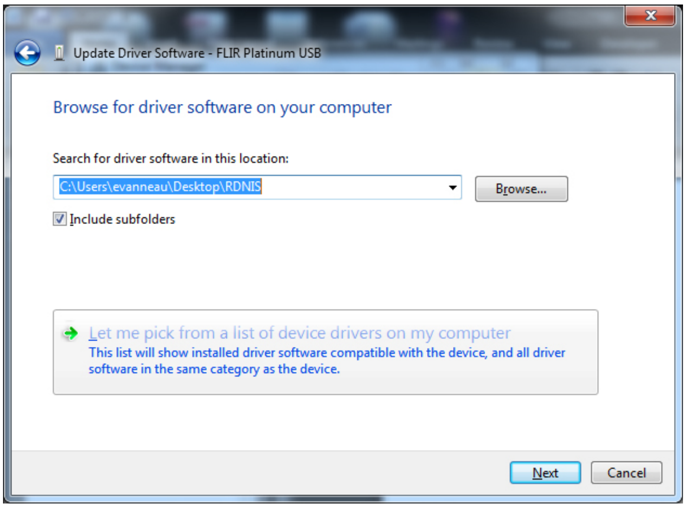
1. Disable the Ethernet connection between the camera and the computer.
2. Connect the camera to the computer with the USB cable.
3. Open Control Panel > Device Manager.
4. Under *Network adapters*, find the device named FLIR Platinum USB.
5. Right-click and select *Update Driver Software*.



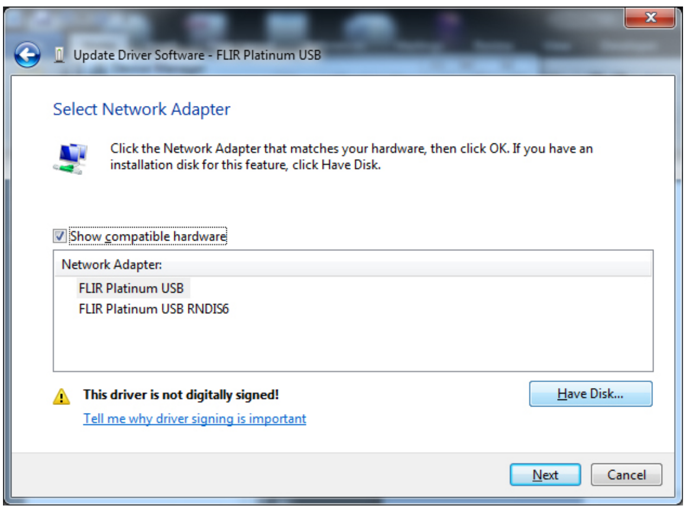
6. Select *Browse my computer for driver software*.



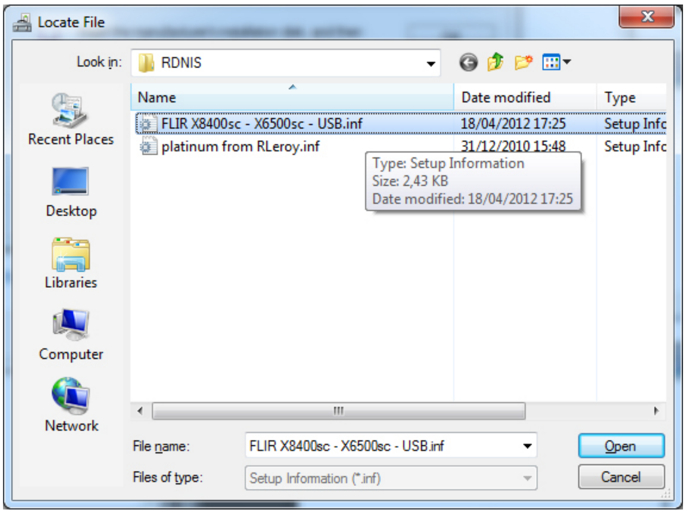
7. Select *Let me pick from a list of device on my computer*.



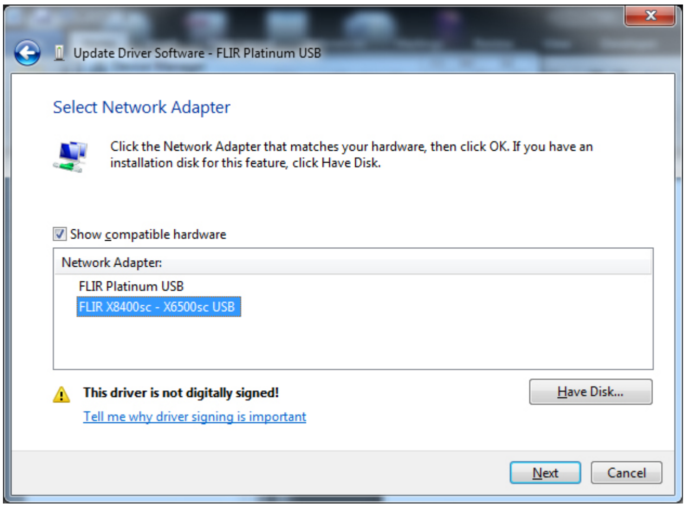
8. Click the *Have Disk…* button.



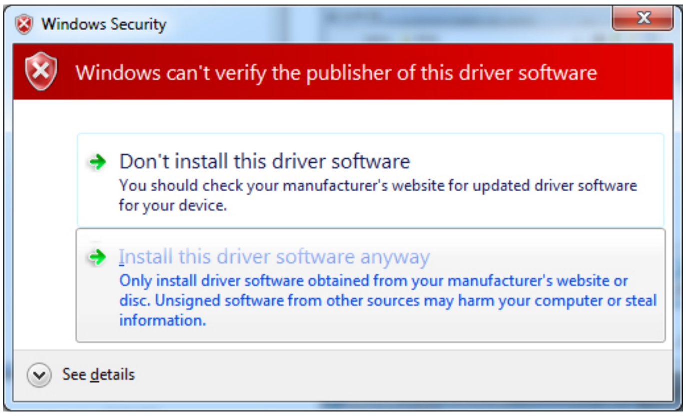
9. Browse and select the file *FLIR X8400sc - X6500sc – USB.inf* file.



10. Select Driver X8400sc – X6500sc – USB, and click the *Next* button.

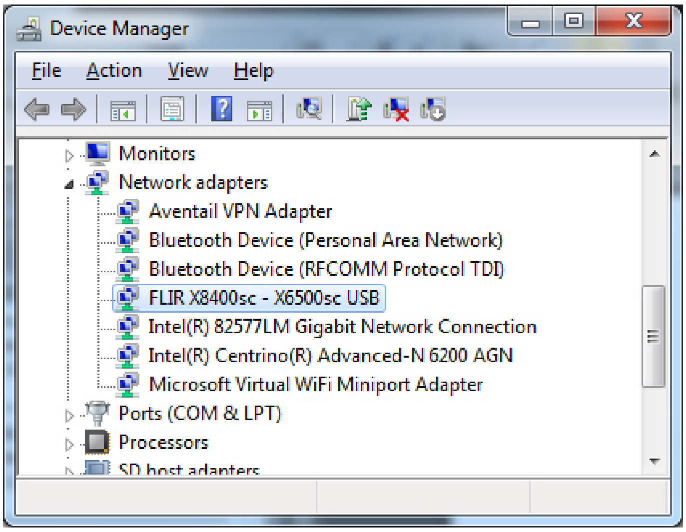


11. Click *Install this driver software anyway*. The driver is now installing. If the installation does not progress correctly, try unplugging the USB cable from the computer.



12. Restart the computer.

13. Device Manager now shows the new device FLIR X8400sc – X6500sc.

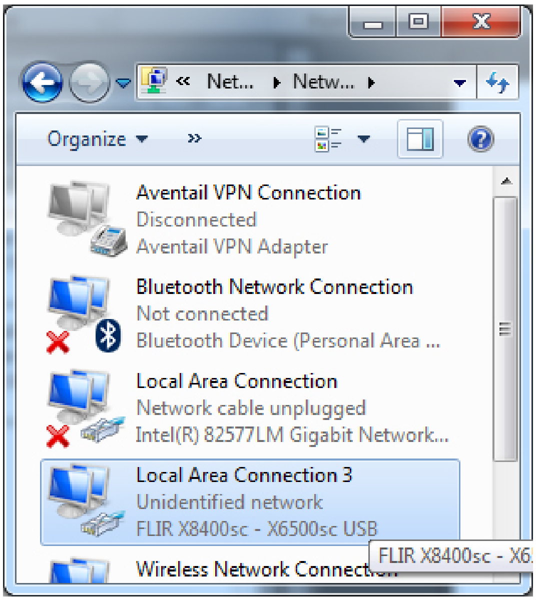


14. Configure the network interface by following the procedure in section 9.2.3 *Configuration of the network interface*, page 52.

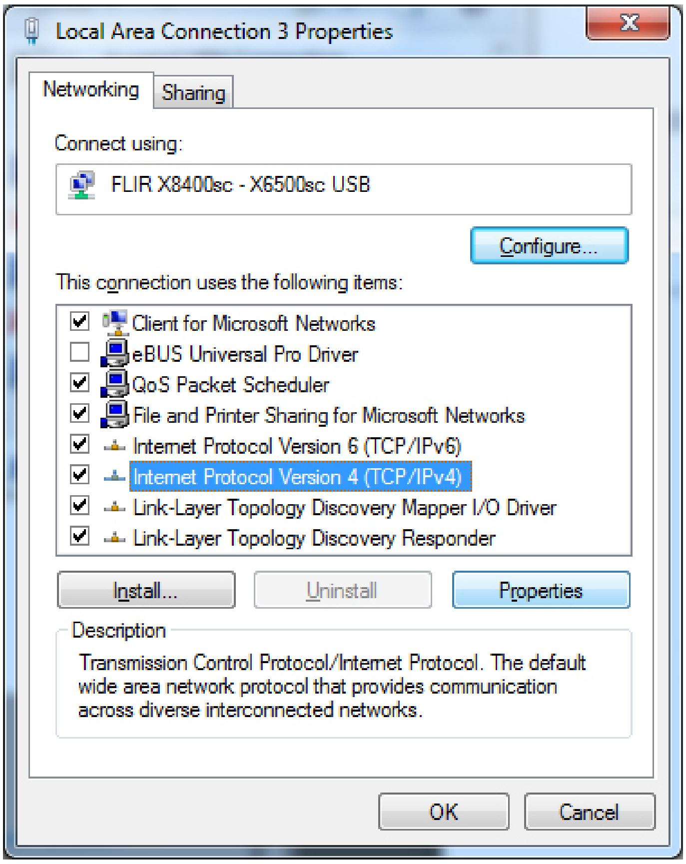
9.2.3 Configuration of the network interface

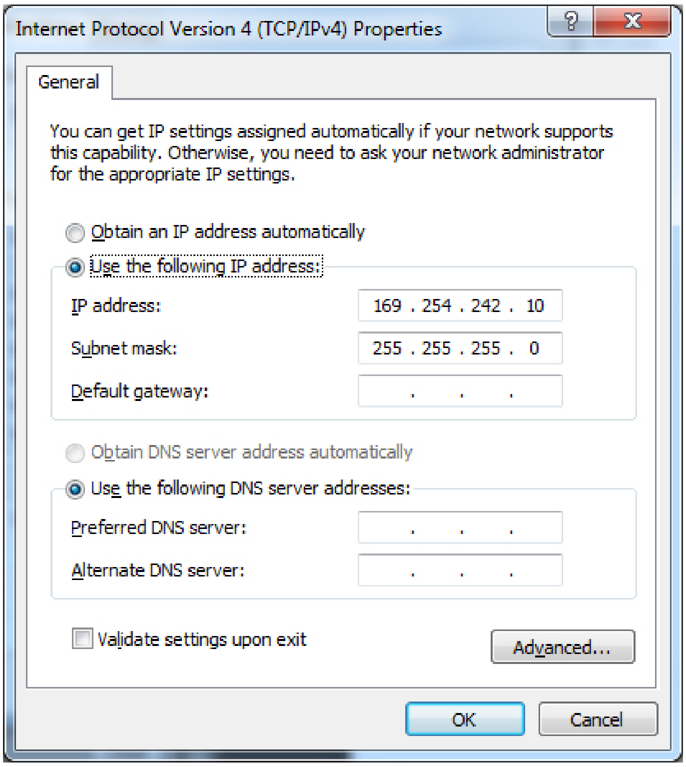
9.2.3.1 Procedure

1. Go to Network Connections: open the Control Panel, click *Network and Internet*, click *View network status and tasks*, and click *Change adapter settings*.



2. Right-click on the FLIR X8400sc – X6500sc connection and click *Properties*, then select Internet Protocol V4 and click the *Properties* button.





3. Set the IP address to 169.254.242.10 and the subnet mask to 255.255.255.0.

   Click the *OK* button.
4. The camera can now be accessed:

   - Use Windows Explorer to access camera files such as CNUC, lens, and filter ID descriptors.
   - Use ResNet to access the camera registry. ResNet is an internal tool. Contact your FLIR service department for more information.

9.2.4 Accessing the camera files with Windows Explorer

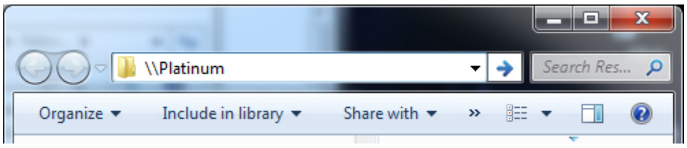
9.2.4.1 General

Note

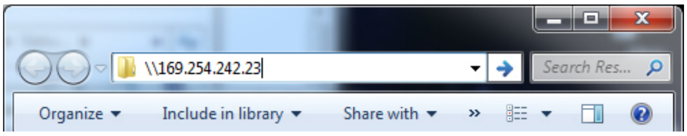
- The camera must be connected to the computer using the USB cable.
- The USB drivers must be correctly installed.

When the camera is connected to the computer with the USB cable (the Ethernet connection to the camera must be disabled), type the address of the camera in Window Explorer. The address can be in the form of:

- The camera’s IP address: 169.254.242.23.



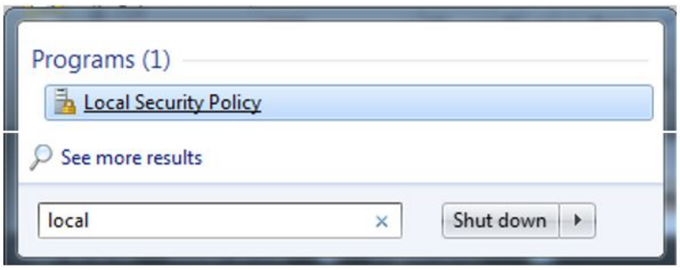
- The camera’s SMB name: Platinum.



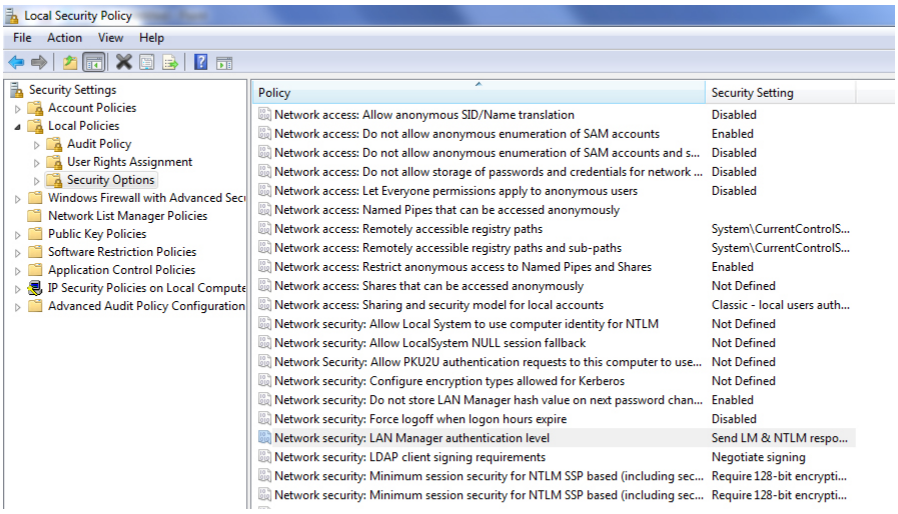
9.2.4.2 Procedure

The Windows 7 default configuration needs to be modified to allow correct display of the camera files in Windows Explorer:

1. Open the Local Security Policy control panel. It can be easily found by typing “Local” in the Windows Start Menu search field.



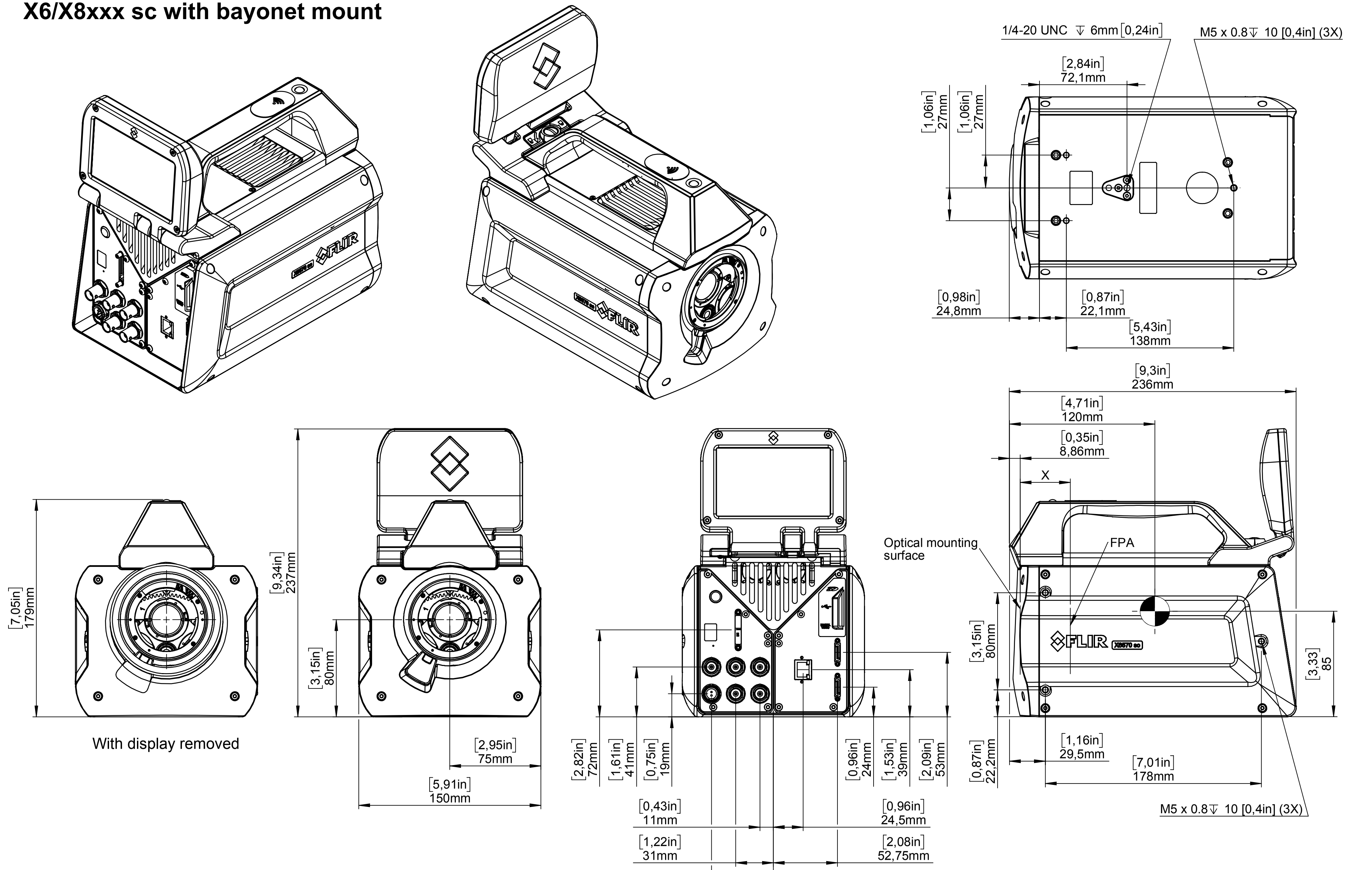
2. Set the LAN Manager authentication level to “Send LM & NTLM responses.”



10 Mechanical drawings

[See next page]

X6/X8xxx sc with bayonet mount



Model name	X	Weight
X6520sc	41.28 mm [1,625 in]	4800 g ± 5 %
X6530sc	41.28 mm [1,625 in]	4800 g ± 5 %
X6540sc	41.28 mm [1,625 in]	4800 g ± 5 %
X6550sc	41.28 mm [1,625 in]	4800 g ± 5 %
X6580sc	41.28 mm [1,625 in]	4800 g ± 5 %
X8400sc	47.90 mm [1,886 in]	5100 g ± 5 %

Modified	Check	Drawn by
2017-02-07	FRGU	R&D Instruments

Denomination: X6/X8xxx - Basic dimension

Size: A3 | Scale: 1:3 | Sheet: 1(2)

Drawing No.: T130229 | Rev: A

FLIR

11 Technical data

11.1 Note about technical data

FLIR Systems reserves the right to change specifications at any time without prior notice. Please check http://support.flir.com for latest changes.

11.2 Note about authoritative versions

The authoritative version of this publication is English. In the event of divergences due to translation errors, the English text has precedence.

Any late changes are first implemented in English.

11.3 FLIR X6520sc

P/N: 80601-0101
Rev.: 42028

Detector/image	
Sensor material	MCT
Image size	640 × 512
Pitch	15 µm
Aperture	f/4
Windowing	320 × 256/160 × 128
Arbitrary size windowing (down to)	132 × 8
Arbitrary size windowing (steps)	Horizontal: ≥32, steps of 4 pixels. Vertical: ≥8, steps of 1 pixel
Maximum frame rate (full frame)	146 Hz
Maximum frame rate[1]	• 146 Hz @ 640 × 512 IWR • 528 Hz @ 320 × 256/IWR • 1510 Hz @ 160 × 128/IWR • 3699 Hz @ 132 × 8/IWR
Integration time range	80 ns to 20 000 µs
Integration time step	80 ns
Integration time mode	IWR/ITR
Shutter	No
Digital output	GigE/Camlink base
Cooler type	Closed-cycle (rotary) Stirling rooler
Cooling temperature	80 K
Operability	>99%

Mechanical/environmental	
Dimensions(L × W × H) (without lens)	• 233 mm × 150 mm × 178 mm (9.17 in. × 5.91 in. × 7.01 in.) (without LCD) • 233 mm × 150 mm × 221 mm (9.17 in. × 5.91 in. × 8.70 in.) (with LCD)
Weight without lens	• 4.350 kg (9.590 lb.) without LCD • 4.800 kg (10.580 lb.) with LCD
Power supply	24 V DC
Power consumption (cooldown/stab)	48 W/35 W
Operational temperature	–20°C/+50°C (–4°F/122°F)
Shock	Operational 6 ms, 25*g*, IEC 68-2-29
Vibration	Operational 2*g*, IEC 68-2-26

Radiometry	
Spectral range	3.7–4.8 µm
Thermal sensitivity/NETD	<25 mK
CNUC/Hypercal	Yes
Temperature measurement accuracy	±1°C (1.8°F) or ±1%

1. Some cameras also have a minimum frame rate, unspecified. Contact your FLIR representative for more information.

Radiometry	
Maximum temperature without filter	150°C (300°F)
Filter wheel	4 slots for 1 in. filter up to 2.5 mm thick
Filter holding	Bayonet

Timings and signals	
Optical interface	USL bayonet
SYNC IN	TTL, singled ended, BNC >300 ns pulse width
SYNC IN jitter	20 ns
SYNC IN active edge	Falling or rising edge
Analog signals	1 × (0/+10V), BNC
TRIGGER IN	TTL, singled ended, BNC >300 ns pulse width
Video output	DVI 1080p30
Waveform generator	Sinus/triangle/square TTL 0–5 V. Frequency: 0.001 Hz to 250 kHz

GigE	
GigE Vision	Yes
Genicam	On specific configuration only

Camera link	
Connector type	1 × Mini MDR26
Wi-Fi type	802.11g

Lenses	
Available optics	• L1008 MW 50 2.0 640 × 512 • L1009 MW 25 2.0 640 × 512 • L1019 MW 100 2.0 640 × 512 • L1114 MW Close up X3

Supplies & accessories:

- T198970; Lens MW 1x f/3.0 WD30

12 Maintenance and service

12.1 Cleaning the camera

12.1.1 Camera housing, cables, and other items

12.1.1.1 Liquids

Use one of these liquids:

- Warm water
- A weak detergent solution

12.1.1.2 Equipment

A soft cloth

12.1.1.3 Procedure

Follow this procedure:

1. Soak the cloth in the liquid.
2. Twist the cloth to remove excess liquid.
3. Clean the part with the cloth.

> ⚠ **CAUTION**
>
> Do not apply solvents or similar liquids to the camera, the cables, or other items. This can cause damage.

12.1.2 Infrared lens

12.1.2.1 Liquids

Use one of these liquids:

- A commercial lens cleaning liquid with more than 30% isopropyl alcohol.
- 96% ethyl alcohol (C_2H_5OH).

12.1.2.2 Equipment

Cotton wool

> ⚠ **CAUTION**
>
> If you use a lens cleaning cloth it must be dry. Do not use a lens cleaning cloth with the liquids that are given in section 12.1.2.1 above. These liquids can cause material on the lens cleaning cloth to become loose. This material can have an unwanted effect on the surface of the lens.

12.1.2.3 Procedure

Follow this procedure:

1. Soak the cotton wool in the liquid.
2. Twist the cotton wool to remove excess liquid.
3. Clean the lens one time only and discard the cotton wool.

> ⚠ **WARNING**
>
> Make sure that you read all applicable MSDS (Material Safety Data Sheets) and warning labels on containers before you use a liquid: the liquids can be dangerous.

> ⚠ **CAUTION**
>
> - Be careful when you clean the infrared lens. The lens has a delicate anti-reflective coating.
> - Do not clean the infrared lens too vigorously. This can damage the anti-reflective coating.

12.2 Cooler maintenance

12.2.1 General

The microcooler is designed to provide maintenance-free operation for many thousands of hours. The microcooler contains pressurized helium gas.

After several thousand hours of operation the gas pressure decreases, and cooler service is required to restore cooler performance. The cooler also contains micro ball bearings, which may exhibit wear by becoming louder.

12.2.2 Signs to watch for

The FLIR Systems microcooler is equipped with a closed-loop speed regulator, which adjusts the cooler motor speed to regulate the detector temperature.

Typically, the cooler runs at maximum speed for 7–10 minutes (depending on model), and then slows to about 40% of maximum speed. As the gas pressure degrades, the motor continues at maximum speed for longer and longer periods to attain operating temperature

Eventually, as the helium pressure decreases, the motor will lose the ability to achieve and/or maintain operating temperature. When this occurs, the camera must be returned to FLIR Systems Customer Service Department for service.

13 Quality

13.1 Quality assurance

The quality management system under which this product is developed and manufactured has been certified in accordance with the ISO 9001 standard. FLIR Systems is committed to a policy of continuous development; therefore, we reserve the right to make changes and improvements to the product described in this manual without prior notice.

13.2 For the US market

Important instructions and notices for the user

Modification of this device without the express authorization of FLIR Systems Advanced Thermal Solutions may void the user's authority under FCC rules to operate this device.

Note This equipment generates, uses, and can radiate radio-frequency energy, and if not installed and used in accordance with the instructions it may cause harmful interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference, in which case the user at their own expense will be required to take whatever measures may be required to correct the interference.

13.3 For the Canadian market

Industry Canada Notice

This Class A digital apparatus complies with Canadian standard ICES-003.

Note d'industrie Canada

Cet appareil numérique de Classe A est conforme à la norme NMB-003 du Canada.

13.4 For the whole world

Proper disposal of electrical and electronic equipment (EEE)

The European Union (EU) has enacted Waste Electrical and Electronic Equipment Directive 2002/96/EC (WEEE), which aims to prevent EEE waste from arising; to encourage reuse, recycling, and recovery of EEE waste; and to promote environmental responsibility.

In accordance with these regulations, all EEE products labeled with the "crossed out wheeled bin" either on the product itself or in the product literature must not be disposed of in regular rubbish bins, mixed with regular household or other commercial waste, or by other regular municipal waste collection means. Instead, and in order to prevent possible harm to the environment or human health, all EEE products (including any cables that came with the product) should be responsibly discarded or recycled.

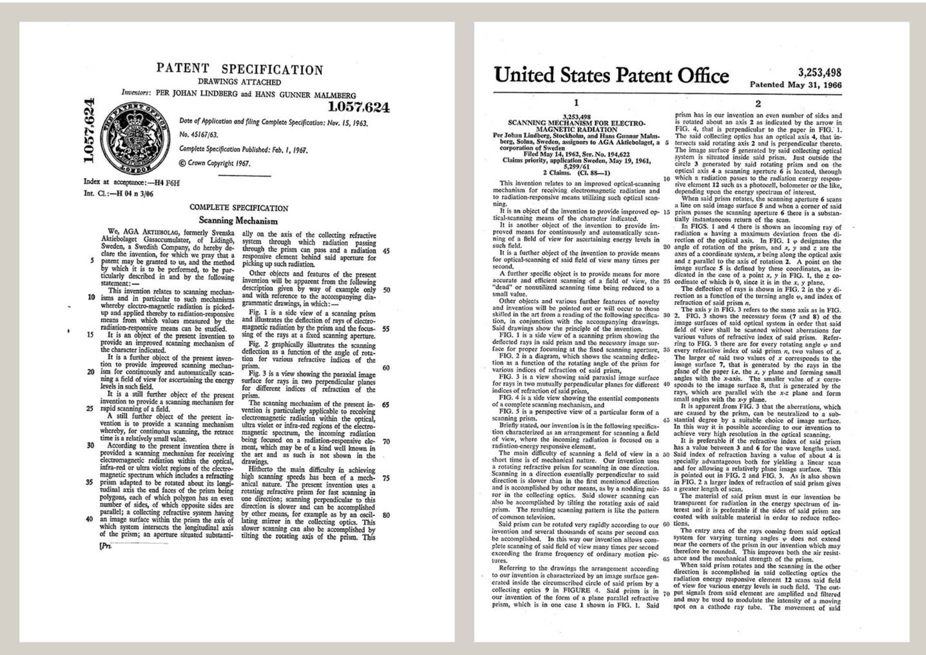
To identify a responsible disposal method where you live, contact your local waste collection or recycling service, your original place of purchase or product supplier, or the responsible government authority in your area. Business users should contact their supplier or refer to their purchase contract.

14 About FLIR Systems

FLIR Systems was established in 1978 to pioneer the development of high-performance infrared imaging systems, and is the world leader in the design, manufacture, and marketing of thermal imaging systems for a wide variety of commercial, industrial, and government applications. Today, FLIR Systems embraces five major companies with outstanding achievements in infrared technology since 1958—the Swedish AGEMA Infrared Systems (formerly AGA Infrared Systems), the three United States companies Indigo Systems, FSI, and Inframetrics, and the French company Cedip.

Since 2007, FLIR Systems has acquired several companies with world-leading expertise in sensor technologies:

- Extech Instruments (2007)
- Ifara Tecnologías (2008)
- Salvador Imaging (2009)
- OmniTech Partners (2009)
- Directed Perception (2009)
- Raymarine (2010)
- ICx Technologies (2010)
- TackTick Marine Digital Instruments (2011)
- Aerius Photonics (2011)
- Lorex Technology (2012)
- Traficon (2012)
- MARSS (2013)
- DigitalOptics micro-optics business (2013)
- DVTEL (2015)
- Point Grey Research (2016)
- Prox Dynamics (2016)



PATENT SPECIFICATION

DRAWINGS ATTACHED

Inventors: PER JOHAN LINDBERG and HANS GUNNER MALMBERG

1,057,624

Date of Application and filing Complete Specification: Nov. 15, 1963.

No. 45167/63.

Complete Specification Published: Feb. 1, 1967.

© Crown Copyright 1967.

Index at acceptance:—H4 F6H

Int. Cl.:—H 04 n 3/06

COMPLETE SPECIFICATION

Scanning Mechanism

We, AGA AKTIEBOLAG, formerly Svenska Aktiebolaget Gasaccumulator, of Lidingö, Sweden, a Swedish Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to scanning mechanisms and in particular to such mechanisms whereby electro-magnetic radiation is picked-up and applied thereby to radiation-responsive means from which values measured by the radiation-responsive means can be studied.

United States Patent Office

3,253,498

Patented May 31, 1966

3,253,498

SCANNING MECHANISM FOR ELECTROMAGNETIC RADIATION

Per Johan Lindberg, Stockholm, and Hans Gunnar Malmberg, Solna, Sweden, assignors to AGA Aktiebolaget, a corporation of Sweden

Filed May 14, 1962, Ser. No. 194,622

Claims priority, application Sweden, May 19, 1961, 5,299/61

2 Claims. (Cl. 88—1)

This invention relates to an improved optical-scanning mechanism for receiving electromagnetic radiation and to radiation-responsive means utilizing such optical scanning.

It is an object of the invention to provide improved optical-scanning means of the character indicated.

It is another object of the invention to provide improved means for continuously and automatically scanning of a field of view for ascertaining energy levels in such field.

Figure 14.1 Patent documents from the early 1960s

FLIR Systems has three manufacturing plants in the United States (Portland, OR, Boston, MA, Santa Barbara, CA) and one in Sweden (Stockholm). Since 2007 there is also a manufacturing plant in Tallinn, Estonia. Direct sales offices in Belgium, Brazil, China, France, Germany, Great Britain, Hong Kong, Italy, Japan, Korea, Sweden, and the USA —together with a worldwide network of agents and distributors—support our international customer base.

FLIR Systems is at the forefront of innovation in the infrared camera industry. We anticipate market demand by constantly improving our existing cameras and developing new ones. The company has set milestones in product design and development such as the introduction of the first battery-operated portable camera for industrial inspections, and the first uncooled infrared camera, to mention just two innovations.

Figure 14.2 1969: Thermovision Model 661. The camera weighed approximately 25 kg (55 lb.), the oscilloscope 20 kg (44 lb.), and the tripod 15 kg (33 lb.). The operator also needed a 220 VAC generator set, and a 10 L (2.6 US gallon) jar with liquid nitrogen. To the left of the oscilloscope the Polaroid attachment (6 kg (13 lb.)) can be seen.

Figure 14.3 2015: FLIR One, an accessory to iPhone and Android mobile phones. Weight: 90 g (3.2 oz.).

FLIR Systems manufactures all vital mechanical and electronic components of the camera systems itself. From detector design and manufacturing, to lenses and system electronics, to final testing and calibration, all production steps are carried out and supervised by our own engineers. The in-depth expertise of these infrared specialists ensures the accuracy and reliability of all vital components that are assembled into your infrared camera.

14.1 More than just an infrared camera

At FLIR Systems we recognize that our job is to go beyond just producing the best infrared camera systems. We are committed to enabling all users of our infrared camera systems to work more productively by providing them with the most powerful camera–software combination. Especially tailored software for predictive maintenance, R & D, and process monitoring is developed in-house. Most software is available in a wide variety of languages.

We support all our infrared cameras with a wide variety of accessories to adapt your equipment to the most demanding infrared applications.

14.2 Sharing our knowledge

Although our cameras are designed to be very user-friendly, there is a lot more to thermography than just knowing how to handle a camera. Therefore, FLIR Systems has founded the Infrared Training Center (ITC), a separate business unit, that provides certified training courses. Attending one of the ITC courses will give you a truly hands-on learning experience.

The staff of the ITC are also there to provide you with any application support you may need in putting infrared theory into practice.

14.3 Supporting our customers

FLIR Systems operates a worldwide service network to keep your camera running at all times. If you discover a problem with your camera, local service centers have all the equipment and expertise to solve it within the shortest possible time. Therefore, there is no need to send your camera to the other side of the world or to talk to someone who does not speak your language.

15 Terms, laws, and definitions

Term	Definition
Absorption and emission[2]	The capacity or ability of an object to absorb incident radiated energy is always the same as the capacity to emit its own energy as radiation
Apparent temperature	uncompensated reading from an infrared instrument, containing all radiation incident on the instrument, regardless of its sources[3]
Color palette	assigns different colors to indicate specific levels of apparent temperature. Palettes can provide high or low contrast, depending on the colors used in them
Conduction	direct transfer of thermal energy from molecule to molecule, caused by collisions between the molecules
Convection	heat transfer mode where a fluid is brought into motion, either by gravity or another force, thereby transferring heat from one place to another
Diagnostics	examination of symptoms and syndromes to determine the nature of faults or failures[4]
Direction of heat transfer[5]	Heat will spontaneously flow from hotter to colder, thereby transferring thermal energy from one place to another[6]
Emissivity	ratio of the power radiated by real bodies to the power that is radiated by a blackbody at the same temperature and at the same wavelength[7]
Energy conservation[8]	The sum of the total energy contents in a closed system is constant
Exitant radiation	radiation that leaves the surface of an object, regardless of its original sources
Heat	thermal energy that is transferred between two objects (systems) due to their difference in temperature
Heat transfer rate[9]	The heat transfer rate under steady state conditions is directly proportional to the thermal conductivity of the object, the cross-sectional area of the object through which the heat flows, and the temperature difference between the two ends of the object. It is inversely proportional to the length, or thickness, of the object[10]
Incident radiation	radiation that strikes an object from its surroundings
IR thermography	process of acquisition and analysis of thermal information from non-contact thermal imaging devices
Isotherm	replaces certain colors in the scale with a contrasting color. It marks an interval of equal apparent temperature[11]
Qualitative thermography	thermography that relies on the analysis of thermal patterns to reveal the existence of and to locate the position of anomalies[12]
Quantitative thermography	thermography that uses temperature measurement to determine the seriousness of an anomaly, in order to establish repair priorities[12]

2. Kirchhoff's law of thermal radiation.
3. Based on ISO 18434-1:2008 (en).
4. Based on ISO 13372:2004 (en).
5. 2nd law of thermodynamics.
6. This is a consequence of the 2nd law of thermodynamics, the law itself is more complicated.
7. Based on ISO 16714-3:2016 (en).
8. 1st law of thermodynamics.
9. Fourier's law.
10. This is the one-dimensional form of Fourier's law, valid for steady-state conditions.
11. Based on ISO 18434-1:2008 (en)
12. Based on ISO 10878-2013 (en).

Term	Definition
Radiative heat transfer	Heat transfer by the emission and absorption of thermal radiation
Reflected apparent temperature	apparent temperature of the environment that is reflected by the target into the IR camera[13]
Spatial resolution	ability of an IR camera to resolve small objects or details
Temperature	measure of the average kinetic energy of the molecules and atoms that make up the substance
Thermal energy	total kinetic energy of the molecules that make up the object[14]
Thermal gradient	gradual change in temperature over distance[13]
Thermal tuning	process of putting the colors of the image on the object of analysis, in order to maximize contrast

13. Based on ISO 16714-3:2016 (en).
14. Thermal energy is part of the internal energy of an object.

16 Thermographic measurement techniques

16.1 Introduction

An infrared camera measures and images the emitted infrared radiation from an object. The fact that radiation is a function of object surface temperature makes it possible for the camera to calculate and display this temperature.

However, the radiation measured by the camera does not only depend on the temperature of the object but is also a function of the emissivity. Radiation also originates from the surroundings and is reflected in the object. The radiation from the object and the reflected radiation will also be influenced by the absorption of the atmosphere.

To measure temperature accurately, it is therefore necessary to compensate for the effects of a number of different radiation sources. This is done on-line automatically by the camera. The following object parameters must, however, be supplied for the camera:

- The emissivity of the object
- The reflected apparent temperature
- The distance between the object and the camera
- The relative humidity
- Temperature of the atmosphere

16.2 Emissivity

The most important object parameter to set correctly is the emissivity which, in short, is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody of the same temperature.

Normally, object materials and surface treatments exhibit emissivity ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has a higher emissivity. Oil-based paint, regardless of color in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity 0.97 to 0.98.

Non-oxidized metals represent an extreme case of perfect opacity and high reflexivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low – only increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

16.2.1 Finding the emissivity of a sample

16.2.1.1 Step 1: Determining reflected apparent temperature

Use one of the following two methods to determine reflected apparent temperature:

16.2.1.1.1 Method 1: Direct method

Follow this procedure:

1. Look for possible reflection sources, considering that the incident angle = reflection angle (a = b).

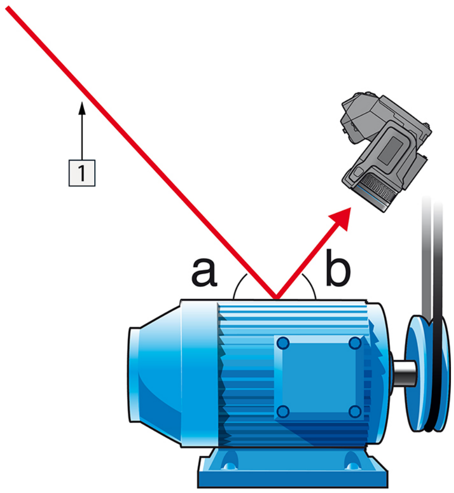


Figure 16.1 1 = Reflection source

2. If the reflection source is a spot source, modify the source by obstructing it using a piece if cardboard.

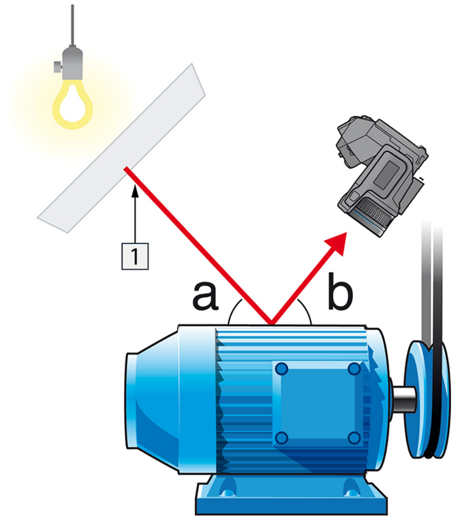


Figure 16.2 1 = Reflection source

3. Measure the radiation intensity (= apparent temperature) from the reflection source using the following settings:
   - Emissivity: 1.0
   - D_{obj}: 0

   You can measure the radiation intensity using one of the following two methods:

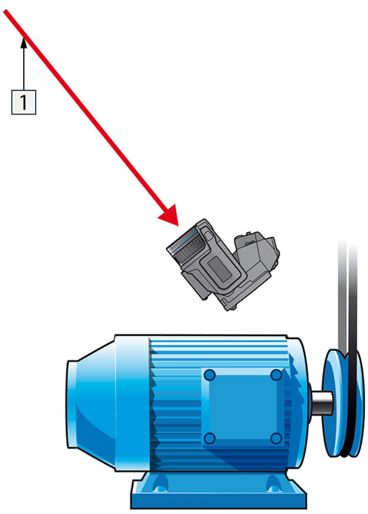


Figure 16.3 1 = Reflection source

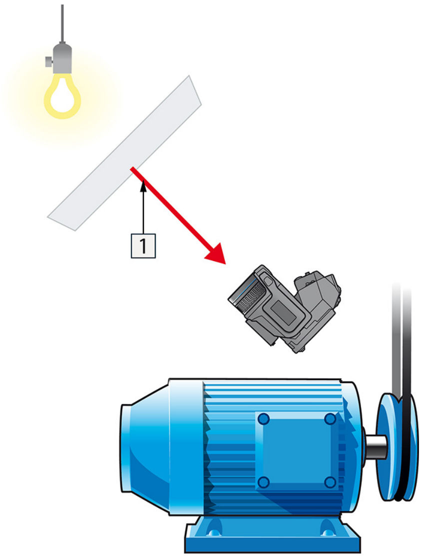


Figure 16.4 1 = Reflection source

You can not use a thermocouple to measure reflected apparent temperature, because a thermocouple measures *temperature*, but apparent temperatrure is *radiation intensity*.

16.2.1.1.2 Method 2: Reflector method

Follow this procedure:

1. Crumble up a large piece of aluminum foil.
2. Uncrumble the aluminum foil and attach it to a piece of cardboard of the same size.
3. Put the piece of cardboard in front of the object you want to measure. Make sure that the side with aluminum foil points to the camera.
4. Set the emissivity to 1.0.

5. Measure the apparent temperature of the aluminum foil and write it down. The foil is considered a perfect reflector, so its apparent temperature equals the reflected apparent temperature from the surroundings.

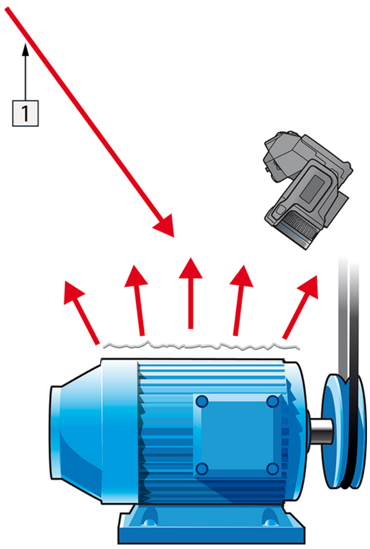


Figure 16.5 Measuring the apparent temperature of the aluminum foil.

16.2.1.2 Step 2: Determining the emissivity

Follow this procedure:

1. Select a place to put the sample.
2. Determine and set reflected apparent temperature according to the previous procedure.
3. Put a piece of electrical tape with known high emissivity on the sample.
4. Heat the sample at least 20 K above room temperature. Heating must be reasonably even.
5. Focus and auto-adjust the camera, and freeze the image.
6. Adjust *Level* and *Span* for best image brightness and contrast.
7. Set emissivity to that of the tape (usually 0.97).
8. Measure the temperature of the tape using one of the following measurement functions:
    - *Isotherm* (helps you to determine both the temperature and how evenly you have heated the sample)
    - *Spot* (simpler)
    - *Box Avg* (good for surfaces with varying emissivity).
9. Write down the temperature.
10. Move your measurement function to the sample surface.
11. Change the emissivity setting until you read the same temperature as your previous measurement.
12. Write down the emissivity.

Note

- Avoid forced convection
- Look for a thermally stable surrounding that will not generate spot reflections
- Use high quality tape that you know is not transparent, and has a high emissivity you are certain of
- This method assumes that the temperature of your tape and the sample surface are the same. If they are not, your emissivity measurement will be wrong.

16.3 Reflected apparent temperature

This parameter is used to compensate for the radiation reflected in the object. If the emissivity is low and the object temperature relatively far from that of the reflected it will be important to set and compensate for the reflected apparent temperature correctly.

16.4 Distance

The distance is the distance between the object and the front lens of the camera. This parameter is used to compensate for the following two facts:

- That radiation from the target is absorbed by the atmosphere between the object and the camera.
- That radiation from the atmosphere itself is detected by the camera.

16.5 Relative humidity

The camera can also compensate for the fact that the transmittance is also dependent on the relative humidity of the atmosphere. To do this set the relative humidity to the correct value. For short distances and normal humidity the relative humidity can normally be left at a default value of 50%.

16.6 Other parameters

In addition, some cameras and analysis programs from FLIR Systems allow you to compensate for the following parameters:

- Atmospheric temperature – *i.e.* the temperature of the atmosphere between the camera and the target
- External optics temperature – *i.e.* the temperature of any external lenses or windows used in front of the camera
- External optics transmittance – *i.e.* the transmission of any external lenses or windows used in front of the camera

17 About calibration

17.1 Introduction

Calibration of a thermal camera is a prerequisite for temperature measurement. The calibration provides the relationship between the input signal and the physical quantity that the user wants to measure. However, despite its widespread and frequent use, the term "calibration" is often misunderstood and misused. Local and national differences as well as translation-related issues create additional confusion.

Unclear terminology can lead to difficulties in communication and erroneous translations, and subsequently to incorrect measurements due to misunderstandings and, in the worst case, even to lawsuits.

17.2 Definition—what is calibration?

The International Bureau of Weights and Measures[15] defines *calibration*[16] in the following way:

an operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.

The calibration itself may be expressed in different formats: this can be a statement, calibration function, calibration diagram[17], calibration curve[18], or calibration table.

Often, the first step alone in the above definition is perceived and referred to as being "calibration." However, this is not (always) sufficient.

Considering the calibration procedure of a thermal camera, the first step establishes the relation between emitted radiation (the quantity value) and the electrical output signal (the indication). This first step of the calibration procedure consists of obtaining a homogeneous (or uniform) response when the camera is placed in front of an extended source of radiation.

As we know the temperature of the reference source emitting the radiation, in the second step the obtained output signal (the indication) can be related to the reference source's temperature (measurement result). The second step includes drift measurement and compensation.

To be correct, calibration of a thermal camera is, strictly, not expressed through temperature. Thermal cameras are sensitive to infrared radiation: therefore, at first you obtain a radiance correspondence, then a relationship between radiance and temperature. For bolometer cameras used by non-R&D customers, radiance is not expressed: only the temperature is provided.

17.3 Camera calibration at FLIR Systems

Without calibration, an infrared camera would not be able to measure either radiance or temperature. At FLIR Systems, the calibration of uncooled microbolometer cameras with a measurement capability is carried out during both production and service. Cooled cameras with photon detectors are often calibrated by the user with special software. With this type of software, in theory, common handheld uncooled thermal cameras could be calibrated by the user too. However, as this software is not suitable for reporting

15. http://www.bipm.org/en/about-us/ [Retrieved 2017-01-31.]
16. http://jcgm.bipm.org/vim/en/2.39.html [Retrieved 2017-01-31.]
17. http://jcgm.bipm.org/vim/en/4.30.html [Retrieved 2017-01-31.]
18. http://jcgm.bipm.org/vim/en/4.31.html [Retrieved 2017-01-31.]

purposes, most users do not have it. Non-measuring devices that are used for imaging only do not need temperature calibration. Sometimes this is also reflected in camera terminology when talking about infrared or thermal imaging cameras compared with thermography cameras, where the latter are the measuring devices.

The calibration information, no matter if the calibration is done by FLIR Systems or the user, is stored in calibration curves, which are expressed by mathematical functions. As radiation intensity changes with both temperature and the distance between the object and the camera, different curves are generated for different temperature ranges and exchangeable lenses.

17.4 The differences between a calibration performed by a user and that performed directly at FLIR Systems

First, the reference sources that FLIR Systems uses are themselves calibrated and traceable. This means, at each FLIR Systems site performing calibration, that the sources are controlled by an independent national authority. The camera calibration certificate is confirmation of this. It is proof that not only has the calibration been performed by FLIR Systems but that it has also been carried out using calibrated references. Some users own or have access to accredited reference sources, but they are very few in number.

Second, there is a technical difference. When performing a user calibration, the result is often (but not always) not drift compensated. This means that the values do not take into account a possible change in the camera's output when the camera's internal temperature varies. This yields a larger uncertainty. Drift compensation uses data obtained in climate-controlled chambers. All FLIR Systems cameras are drift compensated when they are first delivered to the customer and when they are recalibrated by FLIR Systems service departments.

17.5 Calibration, verification and adjustment

A common misconception is to confuse *calibration* with *verification* or *adjustment*. Indeed, calibration is a prerequisite for *verification*, which provides confirmation that specified requirements are met. Verification provides objective evidence that a given item fulfills specified requirements. To obtain the verification, defined temperatures (emitted radiation) of calibrated and traceable reference sources are measured. The measurement results, including the deviation, are noted in a table. The verification certificate states that these measurement results meet specified requirements. Sometimes, companies or organizations offer and market this verification certificate as a "calibration certificate."

Proper verification—and by extension calibration and/or recalibration—can only be achieved when a validated protocol is respected. The process is more than placing the camera in front of blackbodies and checking if the camera output (as temperature, for instance) corresponds to the original calibration table. It is often forgotten that a camera is not sensitive to temperature but to radiation. Furthermore, a camera is an *imaging* system, not just a single sensor. Consequently, if the optical configuration allowing the camera to "collect" radiance is poor or misaligned, then the "verification" (or calibration or recalibration) is worthless.

For instance, one has to ensure that the distance between the blackbody and the camera as well as the diameter of the blackbody cavity are chosen so as to reduce stray radiation and the size-of-source effect.

To summarize: a validated protocol must comply with the physical laws for *radiance*, and not only those for temperature.

Calibration is also a prerequisite for *adjustment*, which is the set of operations carried out on a measuring system such that the system provides prescribed indications corresponding to given values of quantities to be measured, typically obtained from measurement standards. Simplified, adjustment is a manipulation that results in instruments that measure correctly within their specifications. In everyday language, the term “calibration” is widely used instead of “adjustment” for measuring devices.

17.6 Non-uniformity correction

When the thermal camera displays ”Calibrating…” it is adjusting for the deviation in response of each individual detector element (pixel). In thermography, this is called a ”non-uniformity correction” (NUC). It is an offset update, and the gain remains unchanged.

The European standard EN 16714-3, Non-destructive Testing—Thermographic Testing—Part 3: Terms and Definitions, defines an NUC as “Image correction carried out by the camera software to compensate for different sensitivities of detector elements and other optical and geometrical disturbances.”

During the NUC (the offset update), a shutter (internal flag) is placed in the optical path, and all the detector elements are exposed to the same amount of radiation originating from the shutter. Therefore, in an ideal situation, they should all give the same output signal. However, each individual element has its own response, so the output is not uniform. This deviation from the ideal result is calculated and used to mathematically perform an image correction, which is essentially a correction of the displayed radiation signal. Some cameras do not have an internal flag. In this case, the offset update must be performed manually using special software and an external uniform source of radiation.

An NUC is performed, for example, at start-up, when changing a measurement range, or when the environment temperature changes. Some cameras also allow the user to trigger it manually. This is useful when you have to perform a critical measurement with as little image disturbance as possible.

17.7 Thermal image adjustment (thermal tuning)

Some people use the term “image calibration” when adjusting the thermal contrast and brightness in the image to enhance specific details. During this operation, the temperature interval is set in such a way that all available colors are used to show only (or mainly) the temperatures in the region of interest. The correct term for this manipulation is “thermal image adjustment” or “thermal tuning”, or, in some languages, “thermal image optimization.” You must be in manual mode to undertake this, otherwise the camera will set the lower and upper limits of the displayed temperature interval automatically to the coldest and hottest temperatures in the scene.

18 History of infrared technology

Before the year 1800, the existence of the infrared portion of the electromagnetic spectrum wasn't even suspected. The original significance of the infrared spectrum, or simply ‘the infrared’ as it is often called, as a form of heat radiation is perhaps less obvious today than it was at the time of its discovery by Herschel in 1800.

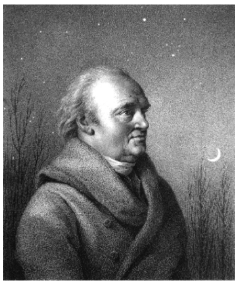


Figure 18.1 Sir William Herschel (1738–1822)

The discovery was made accidentally during the search for a new optical material. Sir William Herschel – Royal Astronomer to King George III of England, and already famous for his discovery of the planet Uranus – was searching for an optical filter material to reduce the brightness of the sun’s image in telescopes during solar observations. While testing different samples of colored glass which gave similar reductions in brightness he was intrigued to find that some of the samples passed very little of the sun’s heat, while others passed so much heat that he risked eye damage after only a few seconds’ observation.

Herschel was soon convinced of the necessity of setting up a systematic experiment, with the objective of finding a single material that would give the desired reduction in brightness as well as the maximum reduction in heat. He began the experiment by actually repeating Newton’s prism experiment, but looking for the heating effect rather than the visual distribution of intensity in the spectrum. He first blackened the bulb of a sensitive mercury-in-glass thermometer with ink, and with this as his radiation detector he proceeded to test the heating effect of the various colors of the spectrum formed on the top of a table by passing sunlight through a glass prism. Other thermometers, placed outside the sun’s rays, served as controls.

As the blackened thermometer was moved slowly along the colors of the spectrum, the temperature readings showed a steady increase from the violet end to the red end. This was not entirely unexpected, since the Italian researcher, Landriani, in a similar experiment in 1777 had observed much the same effect. It was Herschel, however, who was the first to recognize that there must be a point where the heating effect reaches a maximum, and that measurements confined to the visible portion of the spectrum failed to locate this point.

Figure 18.2 Marsilio Landriani (1746–1815)

Moving the thermometer into the dark region beyond the red end of the spectrum, Herschel confirmed that the heating continued to increase. The maximum point, when he found it, lay well beyond the red end – in what is known today as the ‘infrared wavelengths’.

When Herschel revealed his discovery, he referred to this new portion of the electromagnetic spectrum as the ‘thermometrical spectrum’. The radiation itself he sometimes referred to as ‘dark heat’, or simply ‘the invisible rays’. Ironically, and contrary to popular opinion, it wasn't Herschel who originated the term ‘infrared’. The word only began to appear in print around 75 years later, and it is still unclear who should receive credit as the originator.

Herschel’s use of glass in the prism of his original experiment led to some early controversies with his contemporaries about the actual existence of the infrared wavelengths. Different investigators, in attempting to confirm his work, used various types of glass indiscriminately, having different transparencies in the infrared. Through his later experiments, Herschel was aware of the limited transparency of glass to the newly-discovered thermal radiation, and he was forced to conclude that optics for the infrared would probably be doomed to the use of reflective elements exclusively (i.e. plane and curved mirrors). Fortunately, this proved to be true only until 1830, when the Italian investigator, Melloni, made his great discovery that naturally occurring rock salt (NaCl) – which was available in large enough natural crystals to be made into lenses and prisms – is remarkably transparent to the infrared. The result was that rock salt became the principal infrared optical material, and remained so for the next hundred years, until the art of synthetic crystal growing was mastered in the 1930’s.

Figure 18.3 Macedonio Melloni (1798–1854)

Thermometers, as radiation detectors, remained unchallenged until 1829, the year Nobili invented the thermocouple. (Herschel’s own thermometer could be read to 0.2 °C (0.036 °F), and later models were able to be read to 0.05 °C (0.09 °F)). Then a breakthrough occurred; Melloni connected a number of thermocouples in series to form the first thermopile. The new device was at least 40 times as sensitive as the best thermometer of the day for detecting heat radiation – capable of detecting the heat from a person standing three meters away.

The first so-called ‘heat-picture’ became possible in 1840, the result of work by Sir John Herschel, son of the discoverer of the infrared and a famous astronomer in his own right. Based upon the differential evaporation of a thin film of oil when exposed to a heat pattern focused upon it, the thermal image could be seen by reflected light where the interference effects of the oil film made the image visible to the eye. Sir John also managed to obtain a primitive record of the thermal image on paper, which he called a ‘thermograph’.

Figure 18.4 Samuel P. Langley (1834–1906)

The improvement of infrared-detector sensitivity progressed slowly. Another major breakthrough, made by Langley in 1880, was the invention of the bolometer. This consisted of a thin blackened strip of platinum connected in one arm of a Wheatstone bridge circuit upon which the infrared radiation was focused and to which a sensitive galvanometer responded. This instrument is said to have been able to detect the heat from a cow at a distance of 400 meters.

An English scientist, Sir James Dewar, first introduced the use of liquefied gases as cooling agents (such as liquid nitrogen with a temperature of –196°C (–320.8°F)) in low temperature research. In 1892 he invented a unique vacuum insulating container in which it is possible to store liquefied gases for entire days. The common ‘thermos bottle’, used for storing hot and cold drinks, is based upon his invention.

Between the years 1900 and 1920, the inventors of the world ‘discovered’ the infrared. Many patents were issued for devices to detect personnel, artillery, aircraft, ships – and even icebergs. The first operating systems, in the modern sense, began to be developed during the 1914–18 war, when both sides had research programs devoted to the military exploitation of the infrared. These programs included experimental systems for enemy intrusion/detection, remote temperature sensing, secure communications, and ‘flying torpedo’ guidance. An infrared search system tested during this period was able to detect an approaching airplane at a distance of 1.5 km (0.94 miles), or a person more than 300 meters (984 ft.) away.

The most sensitive systems up to this time were all based upon variations of the bolometer idea, but the period between the two wars saw the development of two revolutionary new infrared detectors: the image converter and the photon detector. At first, the image converter received the greatest attention by the military, because it enabled an observer for the first time in history to literally ‘see in the dark’. However, the sensitivity of the image converter was limited to the near infrared wavelengths, and the most interesting military targets (i.e. enemy soldiers) had to be illuminated by infrared search beams. Since this involved the risk of giving away the observer’s position to a similarly-equipped enemy observer, it is understandable that military interest in the image converter eventually faded.

The tactical military disadvantages of so-called 'active’ (i.e. search beam-equipped) thermal imaging systems provided impetus following the 1939–45 war for extensive secret military infrared-research programs into the possibilities of developing ‘passive’ (no search beam) systems around the extremely sensitive photon detector. During this period, military secrecy regulations completely prevented disclosure of the status of infrared-imaging technology. This secrecy only began to be lifted in the middle of the 1950’s, and from that time adequate thermal-imaging devices finally began to be available to civilian science and industry.

19 Theory of thermography

19.1 Introduction

The subjects of infrared radiation and the related technique of thermography are still new to many who will use an infrared camera. In this section the theory behind thermography will be given.

19.2 The electromagnetic spectrum

The electromagnetic spectrum is divided arbitrarily into a number of wavelength regions, called *bands*, distinguished by the methods used to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum. They are all governed by the same laws and the only differences are those due to differences in wavelength.

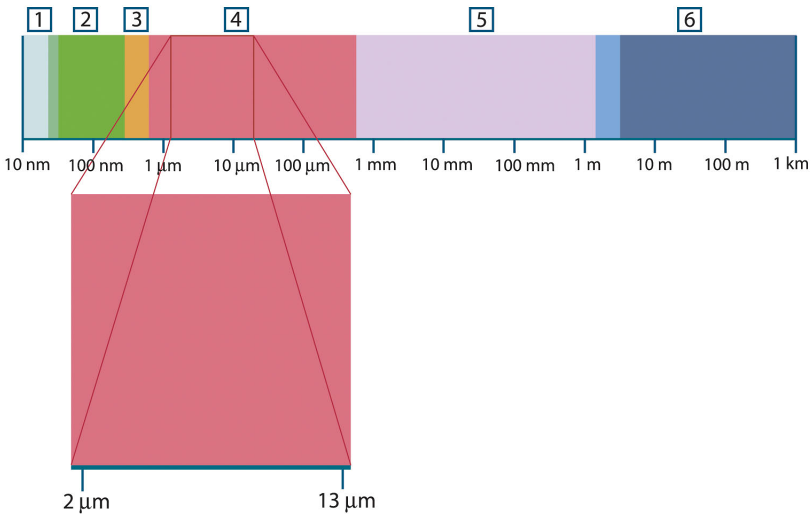


Figure 19.1 The electromagnetic spectrum. 1: X-ray; 2: UV; 3: Visible; 4: IR; 5: Microwaves; 6: Radiowaves.

Thermography makes use of the infrared spectral band. At the short-wavelength end the boundary lies at the limit of visual perception, in the deep red. At the long-wavelength end it merges with the microwave radio wavelengths, in the millimeter range.

The infrared band is often further subdivided into four smaller bands, the boundaries of which are also arbitrarily chosen. They include: the *near infrared* (0.75–3 µm), the *middle infrared* (3–6 µm), the *far infrared* (6–15 µm) and the *extreme infrared* (15–100 µm). Although the wavelengths are given in µm (micrometers), other units are often still used to measure wavelength in this spectral region, *e.g.* nanometer (nm) and Ångström (Å).

The relationships between the different wavelength measurements is:

$$10\ 000\ \text{Å} = 1\ 000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}$$

19.3 Blackbody radiation

A blackbody is defined as an object which absorbs all radiation that impinges on it at any wavelength. The apparent misnomer *black* relating to an object emitting radiation is explained by Kirchhoff's Law (after *Gustav Robert Kirchhoff*, 1824–1887), which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

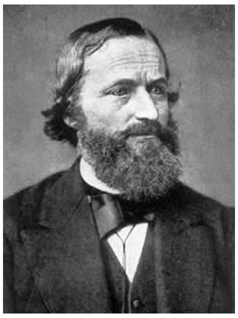


Figure 19.2 Gustav Robert Kirchhoff (1824–1887)

The construction of a blackbody source is, in principle, very simple. The radiation characteristics of an aperture in an isotherm cavity made of an opaque absorbing material represents almost exactly the properties of a blackbody. A practical application of the principle to the construction of a perfect absorber of radiation consists of a box that is light tight except for an aperture in one of the sides. Any radiation which then enters the hole is scattered and absorbed by repeated reflections so only an infinitesimal fraction can possibly escape. The blackness which is obtained at the aperture is nearly equal to a blackbody and almost perfect for all wavelengths.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a *cavity radiator*. An isothermal cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are determined solely by the temperature of the cavity. Such cavity radiators are commonly used as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as a FLIR Systems camera for example.

If the temperature of blackbody radiation increases to more than 525°C (977°F), the source begins to be visible so that it appears to the eye no longer black. This is the incipient red heat temperature of the radiator, which then becomes orange or yellow as the temperature increases further. In fact, the definition of the so-called *color temperature* of an object is the temperature to which a blackbody would have to be heated to have the same appearance.

Now consider three expressions that describe the radiation emitted from a blackbody.

19.3.1 Planck's law

Figure 19.3 Max Planck (1858–1947)

Max Planck (1858–1947) was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W_{\lambda b} = \frac{2\pi hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)} \times 10^{-6} [Watt / m^2, \mu m]$$

where:

$W_{\lambda b}$	Blackbody spectral radiant emittance at wavelength λ.
c	Velocity of light = 3 × 10^8 m/s
h	Planck's constant = 6.6 × 10^{-34} Joule sec.
k	Boltzmann's constant = 1.4 × 10^{-23} Joule/K.
T	Absolute temperature (K) of a blackbody.
λ	Wavelength (μm).

Note The factor 10^{-6} is used since spectral emittance in the curves is expressed in Watt/m^2, μm.

Planck's formula, when plotted graphically for various temperatures, produces a family of curves. Following any particular Planck curve, the spectral emittance is zero at λ = 0, then increases rapidly to a maximum at a wavelength λ_{max} and after passing it approaches zero again at very long wavelengths. The higher the temperature, the shorter the wavelength at which maximum occurs.

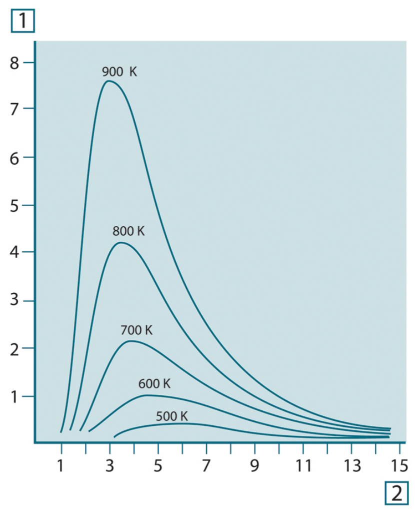


Figure 19.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. 1: Spectral radiant emittance (W/cm^2 × 10^3(μm)); 2: Wavelength (μm)

19.3.2 Wien's displacement law

By differentiating Planck's formula with respect to λ, and finding the maximum, we have:

$$\lambda_{\max} = \frac{2898}{T}[\mu m]$$

This is Wien's formula (after *Wilhelm Wien*, 1864–1928), which expresses mathematically the common observation that colors vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the color is the same as the wavelength calculated for λ_{max}. A good approximation of the value of λ_{max} for a given blackbody temperature is obtained by applying the rule-of-thumb 3 000/T μm. Thus, a very hot star such as Sirius (11 000 K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27 μm.

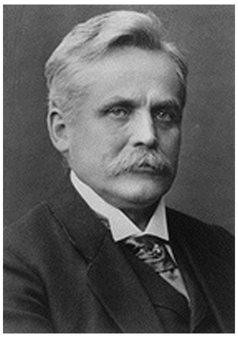


Figure 19.5 Wilhelm Wien (1864–1928)

The sun (approx. 6 000 K) emits yellow light, peaking at about 0.5 µm in the middle of the visible light spectrum.

At room temperature (300 K) the peak of radiant emittance lies at 9.7 µm, in the far infrared, while at the temperature of liquid nitrogen (77 K) the maximum of the almost insignificant amount of radiant emittance occurs at 38 µm, in the extreme infrared wavelengths.

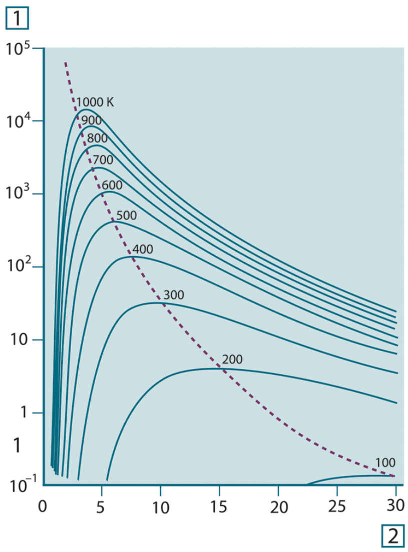


Figure 19.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. 1: Spectral radiant emittance (W/cm² (µm)); 2: Wavelength (µm).

19.3.3 Stefan-Boltzmann's law

By integrating Planck's formula from λ = 0 to λ = ∞, we obtain the total radiant emittance (W_b) of a blackbody:

$$W_b = \sigma T^4 \ [\mathrm{Watt/m^2}]$$

This is the Stefan-Boltzmann formula (after *Josef Stefan*, 1835–1893, and *Ludwig Boltzmann*, 1844–1906), which states that the total emissive power of a blackbody is proportional to the fourth power of its absolute temperature. Graphically, W_b represents the area below the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval λ = 0 to λ_{max} is only 25% of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

Figure 19.7 Josef Stefan (1835–1893), and Ludwig Boltzmann (1844–1906)

Using the Stefan-Boltzmann formula to calculate the power radiated by the human body, at a temperature of 300 K and an external surface area of approx. 2 m^2, we obtain 1 kW. This power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

19.3.4 Non-blackbody emitters

So far, only blackbody radiators and blackbody radiation have been discussed. However, real objects almost never comply with these laws over an extended wavelength region – although they may approach the blackbody behavior in certain spectral intervals. For example, a certain type of white paint may appear perfectly *white* in the visible light spectrum, but becomes distinctly *gray* at about 2 µm, and beyond 3 µm it is almost *black*.

There are three processes which can occur that prevent a real object from acting like a blackbody: a fraction of the incident radiation α may be absorbed, a fraction ρ may be reflected, and a fraction τ may be transmitted. Since all of these factors are more or less wavelength dependent, the subscript λ is used to imply the spectral dependence of their definitions. Thus:

- The spectral absorptance α_λ= the ratio of the spectral radiant power absorbed by an object to that incident upon it.
- The spectral reflectance ρ_λ = the ratio of the spectral radiant power reflected by an object to that incident upon it.
- The spectral transmittance τ_λ = the ratio of the spectral radiant power transmitted through an object to that incident upon it.

The sum of these three factors must always add up to the whole at any wavelength, so we have the relation:

$$\alpha_\lambda + \rho_\lambda + \tau_\lambda = 1$$

For opaque materials $\tau_\lambda = 0$ and the relation simplifies to:

$$\varepsilon_\lambda + \rho_\lambda = 1$$

Another factor, called the emissivity, is required to describe the fraction ε of the radiant emittance of a blackbody produced by an object at a specific temperature. Thus, we have the definition:

The spectral emissivity ε_λ= the ratio of the spectral radiant power from an object to that from a blackbody at the same temperature and wavelength.

Expressed mathematically, this can be written as the ratio of the spectral emittance of the object to that of a blackbody as follows:

$$\varepsilon_\lambda = \frac{W_{\lambda o}}{W_{\lambda b}}$$

Generally speaking, there are three types of radiation source, distinguished by the ways in which the spectral emittance of each varies with wavelength.

- A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$
- A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1

- A selective radiator, for which ε varies with wavelength

According to Kirchhoff's law, for any material the spectral emissivity and spectral absorptance of a body are equal at any specified temperature and wavelength. That is:

$$\varepsilon_\lambda = \alpha_\lambda$$

From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_\lambda = 1$):

$$\varepsilon_\lambda + \rho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfectly reflecting material (*i.e.* a perfect mirror) we have:

$$\rho_\lambda = 1$$

For a graybody radiator, the Stefan-Boltzmann formula becomes:

$$W = \varepsilon \sigma T^4 \text{ [Watt/m}^2\text{]}$$

This states that the total emissive power of a graybody is the same as a blackbody at the same temperature reduced in proportion to the value of ε from the graybody.

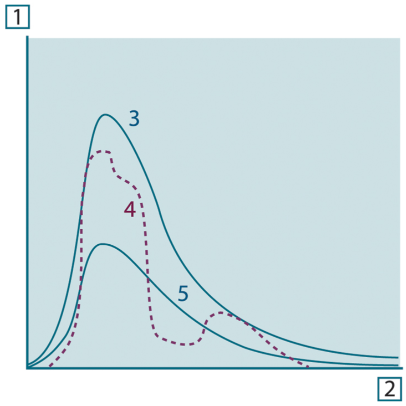


Figure 19.8 Spectral radiant emittance of three types of radiators. 1: Spectral radiant emittance; 2: Wavelength; 3: Blackbody; 4: Selective radiator; 5: Graybody.

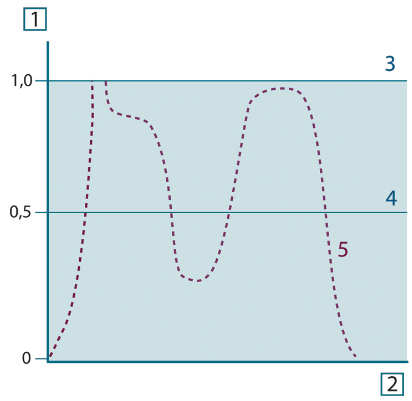


Figure 19.9 Spectral emissivity of three types of radiators. 1: Spectral emissivity; 2: Wavelength; 3: Blackbody; 4: Graybody; 5: Selective radiator.

19.4 Infrared semi-transparent materials

Consider now a non-metallic, semi-transparent body – let us say, in the form of a thick flat plate of plastic material. When the plate is heated, radiation generated within its volume must work its way toward the surfaces through the material in which it is partially absorbed. Moreover, when it arrives at the surface, some of it is reflected back into the interior. The back-reflected radiation is again partially absorbed, but some of it arrives at the other surface, through which most of it escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker they must all be added up when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as:

$$\varepsilon_\lambda = \frac{(1-\rho_\lambda)(1-\tau_\lambda)}{1-\rho_\lambda\tau_\lambda}$$

When the plate becomes opaque this formula is reduced to the single formula:

$$\varepsilon_\lambda = 1-\rho_\lambda$$

This last relation is a particularly convenient one, because it is often easier to measure reflectance than to measure emissivity directly.

20 The measurement formula

As already mentioned, when viewing an object, the camera receives radiation not only from the object itself. It also collects radiation from the surroundings reflected via the object surface. Both these radiation contributions become attenuated to some extent by the atmosphere in the measurement path. To this comes a third radiation contribution from the atmosphere itself.

This description of the measurement situation, as illustrated in the figure below, is so far a fairly true description of the real conditions. What has been neglected could for instance be sun light scattering in the atmosphere or stray radiation from intense radiation sources outside the field of view. Such disturbances are difficult to quantify, however, in most cases they are fortunately small enough to be neglected. In case they are not negligible, the measurement configuration is likely to be such that the risk for disturbance is obvious, at least to a trained operator. It is then his responsibility to modify the measurement situation to avoid the disturbance e.g. by changing the viewing direction, shielding off intense radiation sources etc.

Accepting the description above, we can use the figure below to derive a formula for the calculation of the object temperature from the calibrated camera output.

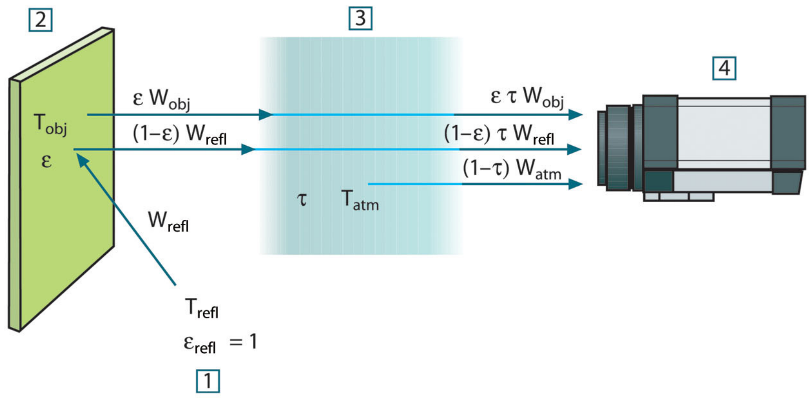


Figure 20.1 A schematic representation of the general thermographic measurement situation.1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera

Assume that the received radiation power W from a blackbody source of temperature T_{source} on short distance generates a camera output signal U_{source} that is proportional to the power input (power linear camera). We can then write (Equation 1):

$$U_{source} = CW(T_{source})$$

or, with simplified notation:

$$U_{source} = CW_{source}$$

where C is a constant.

Should the source be a graybody with emittance ε, the received radiation would consequently be εW_{source}.

We are now ready to write the three collected radiation power terms:

1. *Emission from the object* = $\varepsilon\tau W_{obj}$, where ε is the emittance of the object and τ is the transmittance of the atmosphere. The object temperature is T_{obj}.

2. *Reflected emission from ambient sources* = $(1 – \varepsilon)\tau W_{refl}$, where $(1 – \varepsilon)$ is the reflectance of the object. The ambient sources have the temperature T_{refl}.
   It has here been assumed that the temperature T_{refl} is the same for all emitting surfaces within the halfsphere seen from a point on the object surface. This is of course sometimes a simplification of the true situation. It is, however, a necessary simplification in order to derive a workable formula, and T_{refl} can – at least theoretically – be given a value that represents an efficient temperature of a complex surrounding.

   Note also that we have assumed that the emittance for the surroundings = 1. This is correct in accordance with Kirchhoff's law: All radiation impinging on the surrounding surfaces will eventually be absorbed by the same surfaces. Thus the emittance = 1. (Note though that the latest discussion requires the complete sphere around the object to be considered.)
3. *Emission from the atmosphere* = $(1 – \tau)\tau W_{atm}$, where $(1 – \tau)$ is the emittance of the atmosphere. The temperature of the atmosphere is T_{atm}.

The total received radiation power can now be written (Equation 2):

$$W_{tot} = \varepsilon\tau W_{obj} + (1-\varepsilon)\tau W_{refl} + (1-\tau)W_{atm}$$

We multiply each term by the constant C of Equation 1 and replace the CW products by the corresponding U according to the same equation, and get (Equation 3):

$$U_{tot} = \varepsilon\tau U_{obj} + (1-\varepsilon)\tau U_{refl} + (1-\tau)U_{atm}$$

Solve Equation 3 for U_{obj} (Equation 4):

$$U_{obj} = \frac{1}{\varepsilon\tau}U_{tot} - \frac{1-\varepsilon}{\varepsilon}U_{refl} - \frac{1-\tau}{\varepsilon\tau}U_{atm}$$

This is the general measurement formula used in all the FLIR Systems thermographic equipment. The voltages of the formula are:

Table 20.1 Voltages

U_{obj}	Calculated camera output voltage for a blackbody of temperature T_{obj} i.e. a voltage that can be directly converted into true requested object temperature.
U_{tot}	Measured camera output voltage for the actual case.
U_{refl}	Theoretical camera output voltage for a blackbody of temperature T_{refl} according to the calibration.
U_{atm}	Theoretical camera output voltage for a blackbody of temperature T_{atm} according to the calibration.

The operator has to supply a number of parameter values for the calculation:

- the object emittance ε,
- the relative humidity,
- T_{atm}
- object distance (D_{obj})
- the (effective) temperature of the object surroundings, or the reflected ambient temperature T_{refl}, and
- the temperature of the atmosphere T_{atm}

This task could sometimes be a heavy burden for the operator since there are normally no easy ways to find accurate values of emittance and atmospheric transmittance for the actual case. The two temperatures are normally less of a problem provided the surroundings do not contain large and intense radiation sources.

A natural question in this connection is: How important is it to know the right values of these parameters? It could though be of interest to get a feeling for this problem already here by looking into some different measurement cases and compare the relative magnitudes of the three radiation terms. This will give indications about when it is important to use correct values of which parameters.

The figures below illustrates the relative magnitudes of the three radiation contributions for three different object temperatures, two emittances, and two spectral ranges: SW and LW. Remaining parameters have the following fixed values:

- $\tau = 0.88$
- T_{refl} = +20°C (+68°F)
- T_{atm} = +20°C (+68°F)

It is obvious that measurement of low object temperatures are more critical than measuring high temperatures since the 'disturbing' radiation sources are relatively much stronger in the first case. Should also the object emittance be low, the situation would be still more difficult.

We have finally to answer a question about the importance of being allowed to use the calibration curve above the highest calibration point, what we call extrapolation. Imagine that we in a certain case measure U_{tot} = 4.5 volts. The highest calibration point for the camera was in the order of 4.1 volts, a value unknown to the operator. Thus, even if the object happened to be a blackbody, i.e. $U_{obj} = U_{tot}$, we are actually performing extrapolation of the calibration curve when converting 4.5 volts into temperature.

Let us now assume that the object is not black, it has an emittance of 0.75, and the transmittance is 0.92. We also assume that the two second terms of Equation 4 amount to 0.5 volts together. Computation of U_{obj} by means of Equation 4 then results in U_{obj} = 4.5 / 0.75 / 0.92 – 0.5 = 6.0. This is a rather extreme extrapolation, particularly when considering that the video amplifier might limit the output to 5 volts! Note, though, that the application of the calibration curve is a theoretical procedure where no electronic or other limitations exist. We trust that if there had been no signal limitations in the camera, and if it had been calibrated far beyond 5 volts, the resulting curve would have been very much the same as our real curve extrapolated beyond 4.1 volts, provided the calibration algorithm is based on radiation physics, like the FLIR Systems algorithm. Of course there must be a limit to such extrapolations.

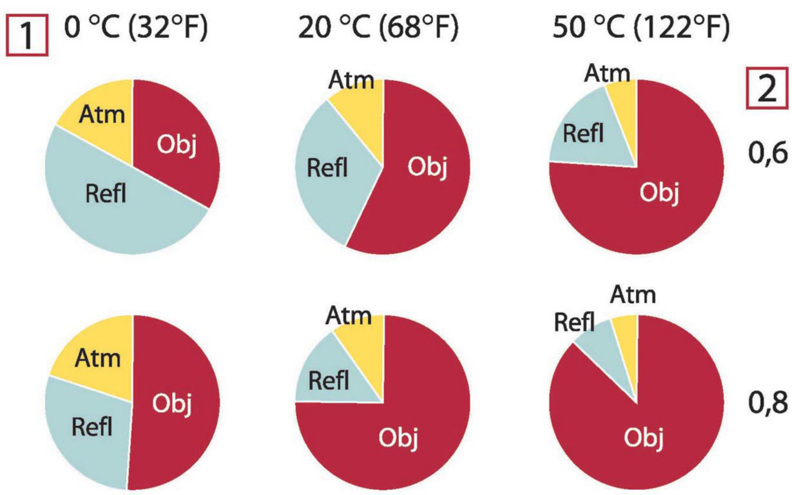


Figure 20.2 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: $\tau = 0.88$; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

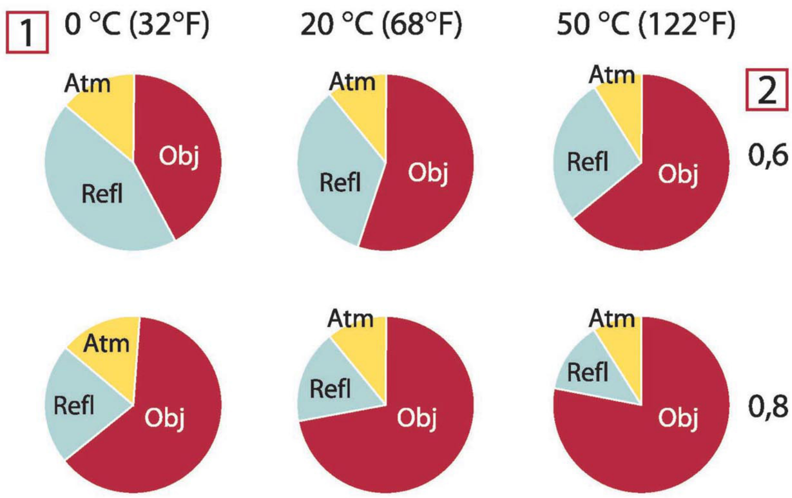


Figure 20.3 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: $\tau = 0.88$; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

21 Emissivity tables

This section presents a compilation of emissivity data from the infrared literature and measurements made by FLIR Systems.

21.1 References

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Note The emissivity values in the table below are recorded using a shortwave (SW) camera. The values should be regarded as recommendations only and used with caution.

21.2 Tables

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference

1	2	3	4	5	6
3M type 35	Vinyl electrical tape (several colors)	< 80	LW	≈ 0.96	13
3M type 88	Black vinyl electrical tape	< 105	LW	≈ 0.96	13
3M type 88	Black vinyl electrical tape	< 105	MW	< 0.96	13
3M type Super 33 +	Black vinyl electrical tape	< 80	LW	≈ 0.96	13
Aluminum	anodized sheet	100	T	0.55	2
Aluminum	anodized, black, dull	70	SW	0.67	9
Aluminum	anodized, black, dull	70	LW	0.95	9

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized, light gray, dull	70	LW	0.97	9
Aluminum	as received, plate	100	T	0.09	4
Aluminum	as received, sheet	100	T	0.09	2
Aluminum	cast, blast cleaned	70	SW	0.47	9
Aluminum	cast, blast cleaned	70	LW	0.46	9
Aluminum	dipped in HNO_3, plate	100	T	0.05	4
Aluminum	foil	27	10 µm	0.04	3
Aluminum	foil	27	3 µm	0.09	3
Aluminum	oxidized, strongly	50–500	T	0.2–0.3	1
Aluminum	polished	50–100	T	0.04–0.06	1
Aluminum	polished plate	100	T	0.05	4
Aluminum	polished, sheet	100	T	0.05	2
Aluminum	rough surface	20–50	T	0.06–0.07	1
Aluminum	roughened	27	10 µm	0.18	3
Aluminum	roughened	27	3 µm	0.28	3
Aluminum	sheet, 4 samples differently scratched	70	SW	0.05–0.08	9
Aluminum	sheet, 4 samples differently scratched	70	LW	0.03–0.06	9
Aluminum	vacuum deposited	20	T	0.04	2
Aluminum	weathered, heavily	17	SW	0.83–0.94	5
Aluminum bronze		20	T	0.60	1
Aluminum hydroxide	powder		T	0.28	1
Aluminum oxide	activated, powder		T	0.46	1
Aluminum oxide	pure, powder (alumina)		T	0.16	1
Asbestos	board	20	T	0.96	1
Asbestos	fabric		T	0.78	1
Asbestos	floor tile	35	SW	0.94	7
Asbestos	paper	40–400	T	0.93–0.95	1
Asbestos	powder		T	0.40–0.60	1
Asbestos	slate	20	T	0.96	1
Asphalt paving		4	LLW	0.967	8
Brass	dull, tarnished	20–350	T	0.22	1
Brass	oxidized	100	T	0.61	2
Brass	oxidized	70	SW	0.04–0.09	9

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Brass	oxidized	70	LW	0.03–0.07	9
Brass	oxidized at 600°C	200–600	T	0.59–0.61	1
Brass	polished	200	T	0.03	1
Brass	polished, highly	100	T	0.03	2
Brass	rubbed with 80-grit emery	20	T	0.20	2
Brass	sheet, rolled	20	T	0.06	1
Brass	sheet, worked with emery	20	T	0.2	1
Brick	alumina	17	SW	0.68	5
Brick	common	17	SW	0.86–0.81	5
Brick	Dinas silica, glazed, rough	1100	T	0.85	1
Brick	Dinas silica, refractory	1000	T	0.66	1
Brick	Dinas silica, unglazed, rough	1000	T	0.80	1
Brick	firebrick	17	SW	0.68	5
Brick	fireclay	1000	T	0.75	1
Brick	fireclay	1200	T	0.59	1
Brick	fireclay	20	T	0.85	1
Brick	masonry	35	SW	0.94	7
Brick	masonry, plastered	20	T	0.94	1
Brick	red, common	20	T	0.93	2
Brick	red, rough	20	T	0.88–0.93	1
Brick	refractory, corundum	1000	T	0.46	1
Brick	refractory, magnesite	1000–1300	T	0.38	1
Brick	refractory, strongly radiating	500–1000	T	0.8–0.9	1
Brick	refractory, weakly radiating	500–1000	T	0.65–0.75	1
Brick	silica, 95% SiO_2	1230	T	0.66	1
Brick	sillimanite, 33% SiO_2, 64% Al_2O_3	1500	T	0.29	1
Brick	waterproof	17	SW	0.87	5
Bronze	phosphor bronze	70	SW	0.08	9
Bronze	phosphor bronze	70	LW	0.06	9
Bronze	polished	50	T	0.1	1
Bronze	porous, rough	50–150	T	0.55	1
Bronze	powder		T	0.76–0.80	1
Carbon	candle soot	20	T	0.95	2
Carbon	charcoal powder		T	0.96	1
Carbon	graphite powder		T	0.97	1

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Carbon	graphite, filed surface	20	T	0.98	2
Carbon	lampblack	20–400	T	0.95–0.97	1
Chipboard	untreated	20	SW	0.90	6
Chromium	polished	50	T	0.10	1
Chromium	polished	500–1000	T	0.28–0.38	1
Clay	fired	70	T	0.91	1
Cloth	black	20	T	0.98	1
Concrete		20	T	0.92	2
Concrete	dry	36	SW	0.95	7
Concrete	rough	17	SW	0.97	5
Concrete	walkway	5	LLW	0.974	8
Copper	commercial, burnished	20	T	0.07	1
Copper	electrolytic, carefully polished	80	T	0.018	1
Copper	electrolytic, polished	–34	T	0.006	4
Copper	molten	1100–1300	T	0.13–0.15	1
Copper	oxidized	50	T	0.6–0.7	1
Copper	oxidized to blackness		T	0.88	1
Copper	oxidized, black	27	T	0.78	4
Copper	oxidized, heavily	20	T	0.78	2
Copper	polished	50–100	T	0.02	1
Copper	polished	100	T	0.03	2
Copper	polished, commercial	27	T	0.03	4
Copper	polished, mechanical	22	T	0.015	4
Copper	pure, carefully prepared surface	22	T	0.008	4
Copper	scraped	27	T	0.07	4
Copper dioxide	powder		T	0.84	1
Copper oxide	red, powder		T	0.70	1
Ebonite			T	0.89	1
Emery	coarse	80	T	0.85	1
Enamel		20	T	0.9	1
Enamel	lacquer	20	T	0.85–0.95	1
Fiber board	hard, untreated	20	SW	0.85	6
Fiber board	masonite	70	SW	0.75	9
Fiber board	masonite	70	LW	0.88	9
Fiber board	particle board	70	SW	0.77	9
Fiber board	particle board	70	LW	0.89	9
Fiber board	porous, untreated	20	SW	0.85	6

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Glass pane (float glass)	non-coated	20	LW	0.97	14
Gold	polished	130	T	0.018	1
Gold	polished, carefully	200–600	T	0.02–0.03	1
Gold	polished, highly	100	T	0.02	2
Granite	polished	20	LLW	0.849	8
Granite	rough	21	LLW	0.879	8
Granite	rough, 4 different samples	70	SW	0.95–0.97	9
Granite	rough, 4 different samples	70	LW	0.77–0.87	9
Gypsum		20	T	0.8–0.9	1
Ice: See Water					
Iron and steel	cold rolled	70	SW	0.20	9
Iron and steel	cold rolled	70	LW	0.09	9
Iron and steel	covered with red rust	20	T	0.61–0.85	1
Iron and steel	electrolytic	100	T	0.05	4
Iron and steel	electrolytic	22	T	0.05	4
Iron and steel	electrolytic	260	T	0.07	4
Iron and steel	electrolytic, carefully polished	175–225	T	0.05–0.06	1
Iron and steel	freshly worked with emery	20	T	0.24	1
Iron and steel	ground sheet	950–1100	T	0.55–0.61	1
Iron and steel	heavily rusted sheet	20	T	0.69	2
Iron and steel	hot rolled	130	T	0.60	1
Iron and steel	hot rolled	20	T	0.77	1
Iron and steel	oxidized	100	T	0.74	4
Iron and steel	oxidized	100	T	0.74	1
Iron and steel	oxidized	1227	T	0.89	4
Iron and steel	oxidized	125–525	T	0.78–0.82	1
Iron and steel	oxidized	200	T	0.79	2
Iron and steel	oxidized	200–600	T	0.80	1
Iron and steel	oxidized strongly	50	T	0.88	1
Iron and steel	oxidized strongly	500	T	0.98	1
Iron and steel	polished	100	T	0.07	2
Iron and steel	polished	400–1000	T	0.14–0.38	1
Iron and steel	polished sheet	750–1050	T	0.52–0.56	1
Iron and steel	rolled sheet	50	T	0.56	1
Iron and steel	rolled, freshly	20	T	0.24	1
Iron and steel	rough, plane surface	50	T	0.95–0.98	1
Iron and steel	rusted red, sheet	22	T	0.69	4
Iron and steel	rusted, heavily	17	SW	0.96	5

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Iron and steel	rusty, red	20	T	0.69	1
Iron and steel	shiny oxide layer, sheet,	20	T	0.82	1
Iron and steel	shiny, etched	150	T	0.16	1
Iron and steel	wrought, carefully polished	40–250	T	0.28	1
Iron galvanized	heavily oxidized	70	SW	0.64	9
Iron galvanized	heavily oxidized	70	LW	0.85	9
Iron galvanized	sheet	92	T	0.07	4
Iron galvanized	sheet, burnished	30	T	0.23	1
Iron galvanized	sheet, oxidized	20	T	0.28	1
Iron tinned	sheet	24	T	0.064	4
Iron, cast	casting	50	T	0.81	1
Iron, cast	ingots	1000	T	0.95	1
Iron, cast	liquid	1300	T	0.28	1
Iron, cast	machined	800–1000	T	0.60–0.70	1
Iron, cast	oxidized	100	T	0.64	2
Iron, cast	oxidized	260	T	0.66	4
Iron, cast	oxidized	38	T	0.63	4
Iron, cast	oxidized	538	T	0.76	4
Iron, cast	oxidized at 600°C	200–600	T	0.64–0.78	1
Iron, cast	polished	200	T	0.21	1
Iron, cast	polished	38	T	0.21	4
Iron, cast	polished	40	T	0.21	2
Iron, cast	unworked	900–1100	T	0.87–0.95	1
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	LW	≈ 0.96	12
Krylon Ultra-flat black 1602	Flat black	Room temperature up to 175	MW	≈ 0.97	12
Lacquer	3 colors sprayed on Aluminum	70	SW	0.50–0.53	9
Lacquer	3 colors sprayed on Aluminum	70	LW	0.92–0.94	9
Lacquer	Aluminum on rough surface	20	T	0.4	1
Lacquer	bakelite	80	T	0.83	1
Lacquer	black, dull	40–100	T	0.96–0.98	1
Lacquer	black, matte	100	T	0.97	2
Lacquer	black, shiny, sprayed on iron	20	T	0.87	1
Lacquer	heat–resistant	100	T	0.92	1
Lacquer	white	100	T	0.92	2
Lacquer	white	40–100	T	0.8–0.95	1
Lead	oxidized at 200°C	200	T	0.63	1
Lead	oxidized, gray	20	T	0.28	1

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Lead	oxidized, gray	22	T	0.28	4
Lead	shiny	250	T	0.08	1
Lead	unoxidized, polished	100	T	0.05	4
Lead red		100	T	0.93	4
Lead red, powder		100	T	0.93	1
Leather	tanned		T	0.75–0.80	1
Lime			T	0.3–0.4	1
Magnesium		22	T	0.07	4
Magnesium		260	T	0.13	4
Magnesium		538	T	0.18	4
Magnesium	polished	20	T	0.07	2
Magnesium powder			T	0.86	1
Molybdenum		1500–2200	T	0.19–0.26	1
Molybdenum		600–1000	T	0.08–0.13	1
Molybdenum	filament	700–2500	T	0.1–0.3	1
Mortar		17	SW	0.87	5
Mortar	dry	36	SW	0.94	7
Nextel Velvet 811-21 Black	Flat black	–60–150	LW	> 0.97	10 and 11
Nichrome	rolled	700	T	0.25	1
Nichrome	sandblasted	700	T	0.70	1
Nichrome	wire, clean	50	T	0.65	1
Nichrome	wire, clean	500–1000	T	0.71–0.79	1
Nichrome	wire, oxidized	50–500	T	0.95–0.98	1
Nickel	bright matte	122	T	0.041	4
Nickel	commercially pure, polished	100	T	0.045	1
Nickel	commercially pure, polished	200–400	T	0.07–0.09	1
Nickel	electrolytic	22	T	0.04	4
Nickel	electrolytic	260	T	0.07	4
Nickel	electrolytic	38	T	0.06	4
Nickel	electrolytic	538	T	0.10	4
Nickel	electroplated on iron, polished	22	T	0.045	4
Nickel	electroplated on iron, unpolished	20	T	0.11–0.40	1
Nickel	electroplated on iron, unpolished	22	T	0.11	4
Nickel	electroplated, polished	20	T	0.05	2
Nickel	oxidized	1227	T	0.85	4
Nickel	oxidized	200	T	0.37	2
Nickel	oxidized	227	T	0.37	4

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Nickel	oxidized at 600°C	200–600	T	0.37–0.48	1
Nickel	polished	122	T	0.045	4
Nickel	wire	200–1000	T	0.1–0.2	1
Nickel oxide		1000–1250	T	0.75–0.86	1
Nickel oxide		500–650	T	0.52–0.59	1
Oil, lubricating	0.025 mm film	20	T	0.27	2
Oil, lubricating	0.050 mm film	20	T	0.46	2
Oil, lubricating	0.125 mm film	20	T	0.72	2
Oil, lubricating	film on Ni base: Ni base only	20	T	0.05	2
Oil, lubricating	thick coating	20	T	0.82	2
Paint	8 different colors and qualities	70	SW	0.88–0.96	9
Paint	8 different colors and qualities	70	LW	0.92–0.94	9
Paint	Aluminum, various ages	50–100	T	0.27–0.67	1
Paint	cadmium yellow		T	0.28–0.33	1
Paint	chrome green		T	0.65–0.70	1
Paint	cobalt blue		T	0.7–0.8	1
Paint	oil	17	SW	0.87	5
Paint	oil based, average of 16 colors	100	T	0.94	2
Paint	oil, black flat	20	SW	0.94	6
Paint	oil, black gloss	20	SW	0.92	6
Paint	oil, gray flat	20	SW	0.97	6
Paint	oil, gray gloss	20	SW	0.96	6
Paint	oil, various colors	100	T	0.92–0.96	1
Paint	plastic, black	20	SW	0.95	6
Paint	plastic, white	20	SW	0.84	6
Paper	4 different colors	70	SW	0.68–0.74	9
Paper	4 different colors	70	LW	0.92–0.94	9
Paper	black		T	0.90	1
Paper	black, dull		T	0.94	1
Paper	black, dull	70	SW	0.86	9
Paper	black, dull	70	LW	0.89	9
Paper	blue, dark		T	0.84	1
Paper	coated with black lacquer		T	0.93	1
Paper	green		T	0.85	1
Paper	red		T	0.76	1
Paper	white	20	T	0.7–0.9	1
Paper	white bond	20	T	0.93	2
Paper	white, 3 different glosses	70	SW	0.76–0.78	9

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Paper	white, 3 different glosses	70	LW	0.88–0.90	9
Paper	yellow		T	0.72	1
Plaster		17	SW	0.86	5
Plaster	plasterboard, untreated	20	SW	0.90	6
Plaster	rough coat	20	T	0.91	2
Plastic	glass fibre laminate (printed circ. board)	70	SW	0.94	9
Plastic	glass fibre laminate (printed circ. board)	70	LW	0.91	9
Plastic	polyurethane isolation board	70	LW	0.55	9
Plastic	polyurethane isolation board	70	SW	0.29	9
Plastic	PVC, plastic floor, dull, structured	70	SW	0.94	9
Plastic	PVC, plastic floor, dull, structured	70	LW	0.93	9
Platinum		100	T	0.05	4
Platinum		1000–1500	T	0.14–0.18	1
Platinum		1094	T	0.18	4
Platinum		17	T	0.016	4
Platinum		22	T	0.03	4
Platinum		260	T	0.06	4
Platinum		538	T	0.10	4
Platinum	pure, polished	200–600	T	0.05–0.10	1
Platinum	ribbon	900–1100	T	0.12–0.17	1
Platinum	wire	1400	T	0.18	1
Platinum	wire	500–1000	T	0.10–0.16	1
Platinum	wire	50–200	T	0.06–0.07	1
Porcelain	glazed	20	T	0.92	1
Porcelain	white, shiny		T	0.70–0.75	1
Rubber	hard	20	T	0.95	1
Rubber	soft, gray, rough	20	T	0.95	1
Sand			T	0.60	1
Sand		20	T	0.90	2
Sandstone	polished	19	LLW	0.909	8
Sandstone	rough	19	LLW	0.935	8
Silver	polished	100	T	0.03	2
Silver	pure, polished	200–600	T	0.02–0.03	1
Skin	human	32	T	0.98	2
Slag	boiler	0–100	T	0.97–0.93	1
Slag	boiler	1400–1800	T	0.69–0.67	1
Slag	boiler	200–500	T	0.89–0.78	1

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Slag	boiler	600–1200	T	0.76–0.70	1
Snow: See Water					
Soil	dry	20	T	0.92	2
Soil	saturated with water	20	T	0.95	2
Stainless steel	alloy, 8% Ni, 18% Cr	500	T	0.35	1
Stainless steel	rolled	700	T	0.45	1
Stainless steel	sandblasted	700	T	0.70	1
Stainless steel	sheet, polished	70	SW	0.18	9
Stainless steel	sheet, polished	70	LW	0.14	9
Stainless steel	sheet, untreated, somewhat scratched	70	SW	0.30	9
Stainless steel	sheet, untreated, somewhat scratched	70	LW	0.28	9
Stainless steel	type 18-8, buffed	20	T	0.16	2
Stainless steel	type 18-8, oxi-dized at 800°C	60	T	0.85	2
Stucco	rough, lime	10–90	T	0.91	1
Styrofoam	insulation	37	SW	0.60	7
Tar			T	0.79–0.84	1
Tar	paper	20	T	0.91–0.93	1
Tile	glazed	17	SW	0.94	5
Tin	burnished	20–50	T	0.04–0.06	1
Tin	tin–plated sheet iron	100	T	0.07	2
Titanium	oxidized at 540°C	1000	T	0.60	1
Titanium	oxidized at 540°C	200	T	0.40	1
Titanium	oxidized at 540°C	500	T	0.50	1
Titanium	polished	1000	T	0.36	1
Titanium	polished	200	T	0.15	1
Titanium	polished	500	T	0.20	1
Tungsten		1500–2200	T	0.24–0.31	1
Tungsten		200	T	0.05	1
Tungsten		600–1000	T	0.1–0.16	1
Tungsten	filament	3300	T	0.39	1
Varnish	flat	20	SW	0.93	6
Varnish	on oak parquet floor	70	SW	0.90	9
Varnish	on oak parquet floor	70	LW	0.90–0.93	9
Wallpaper	slight pattern, light gray	20	SW	0.85	6
Wallpaper	slight pattern, red	20	SW	0.90	6
Water	distilled	20	T	0.96	2

Table 21.1 T: Total spectrum; SW: 2–5 µm; LW: 8–14 µm, LLW: 6.5–20 µm; 1: Material; 2: Specification; 3:Temperature in °C; 4: Spectrum; 5: Emissivity: 6:Reference (continued)

1	2	3	4	5	6
Water	frost crystals	–10	T	0.98	2
Water	ice, covered with heavy frost	0	T	0.98	1
Water	ice, smooth	0	T	0.97	1
Water	ice, smooth	–10	T	0.96	2
Water	layer >0.1 mm thick	0–100	T	0.95–0.98	1
Water	snow		T	0.8	1
Water	snow	–10	T	0.85	2
Wood		17	SW	0.98	5
Wood		19	LLW	0.962	8
Wood	ground		T	0.5–0.7	1
Wood	pine, 4 different samples	70	SW	0.67–0.75	9
Wood	pine, 4 different samples	70	LW	0.81–0.89	9
Wood	planed	20	T	0.8–0.9	1
Wood	planed oak	20	T	0.90	2
Wood	planed oak	70	SW	0.77	9
Wood	planed oak	70	LW	0.88	9
Wood	plywood, smooth, dry	36	SW	0.82	7
Wood	plywood, untreated	20	SW	0.83	6
Wood	white, damp	20	T	0.7–0.8	1
Zinc	oxidized at 400°C	400	T	0.11	1
Zinc	oxidized surface	1000–1200	T	0.50–0.60	1
Zinc	polished	200–300	T	0.04–0.05	1
Zinc	sheet	50	T	0.20	1

A note on the technical production of this publication

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