User's manual
FLIR A310 ex

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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

One or several of the following patents and/or design patents may apply to the products and/or features. Additional pending patents and/or pending design patents may also apply.

000279476-0001; 000439161; 000499579-0001; 000653423; 000726344; 000859020; 001106306-0001; 001707738; 001707746; 001707787; 001776519; 001954074; 002021543; 002058180; 002249953; 002531178; 0600574-8; 1144833; 1182246; 1182620; 1285345; 1299699; 1325808; 1336775; 1391114; 1402918; 1404291; 1411581; 1415075; 1421497; 1458284; 1678485; 1732314; 2106017; 2107799; 2381417; 3006596; 3006597; 466540; 483782; 484155; 4889913; 5177595; 60122153.2; 602004011681.5-08; 6707044; 68657; 7034300; 7110035; 7154093; 7157705; 7237946; 7312822; 7332716; 7336823; 7544944; 7667198; 7809258 B2; 7826736; 8,153,971; 8018649 B2; 8212210 B2; 8289372; 8354639 B2; 8384783; 8520970; 8565547; 8595689; 8599262; 8654239; 8680468; 8803093; D540838; D549758; D579475; D584755; D599,392; D615,113; D664,580; D664,581; D665,004; D665,440; D677298; D710,424 S; DI6702302-9; DI6903617-9; DI7002221-6; DI7002891-5; DI7002892-3; DI7005799-0; DM/057692; DM/061609; EP 2115696 B1; EP2315433; SE 0700240-5; US 8340414 B2; ZL 201330267619.5; ZL01823221.3; ZL01823226.4; ZL02331553.9; ZL02331554.7; ZL200480034894.0; ZL200530120994.2; ZL200610088759.5; ZL200630130114.4; ZL200730151141.4; ZL200730339504.7; ZL200820105768.8; ZL200830128581.2; ZL200880105236.4; ZL200880105769.2; ZL200930190061.9; ZL201030176127.1; ZL201030176130.3; ZL201030176157.2; ZL201030595931.3; ZL201130442354.9; ZL201230471744.3; ZL201230620731.8.

1.8 EULA Terms

- You have acquired a device ("INFRARED CAMERA") that includes software licensed by FLIR Systems AB from Microsoft Licensing, GP or its affiliates ("MS"). Those installed software products of MS origin, as well as associated media, printed materials, and "online" or electronic documentation ("SOFTWARE") are protected by international intellectual property laws and treaties. The SOFTWARE is licensed, not sold. All rights reserved.
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1.9 EULA Terms

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2 Notice to user

2.1 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://www.infraredtraining.com/community/boards/

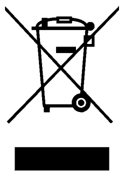
2.2 Calibration

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.

2.3 Accuracy

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

2.4 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.

2.5 Training

To read about infrared training, visit:

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

2.6 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 and notifications, go to the Download tab at:

http://support.flir.com

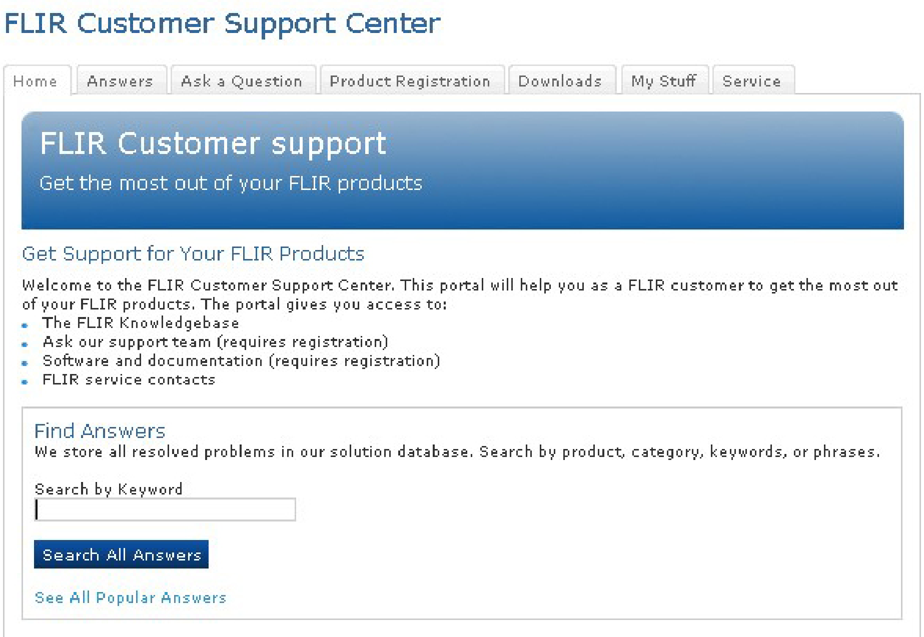
It only takes a few minutes to register online. In the download area you will also find the latest releases of manuals for our other products, as well as manuals for our historical and obsolete products.

2.7 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 Customer help



3.1 General

For customer help, visit:

http://support.flir.com

3.2 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, 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

3.3 Downloads

On the customer help site you can also download the following:

- 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.

4 Safety information

CAUTION

Do not point the infrared camera (with or without the lens cover) at strong energy sources, for example, devices that cause laser radiation, or the sun. This can have an unwanted effect on the accuracy of the camera. It can also cause damage to the detector in the camera.

CAUTION

Applicability: Cameras with an automatic shutter that can be disabled.

Do not disable the automatic shutter in the camera for a long time period (a maximum of 30 minutes is typical). If you disable the shutter for a longer time period, damage to the detector can occur.

5 What is FLIR A310 ex?

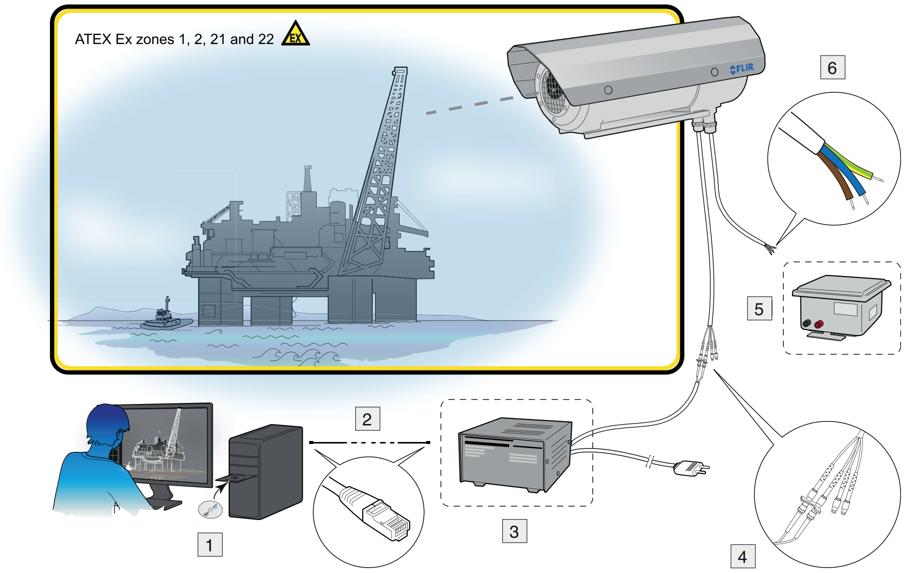
Explosive atmospheres need to be protected from ignition sources by selecting equipment and protective systems that meet the requirements of the ATEX product directives and similar regulations.

The FLIR A310 ex is an ATEX-proof solution, with a thermal imaging camera mounted in an enclosure, making it possible to monitor critical and other valuable assets in explosive atmospheres. Process monitoring, quality control, and fire detection in potentially explosive locations are typical applications for the FLIR A310 ex.

Key features:

- Thermography monitoring and early fire detection in explosion hazard areas.
- Enclosures for infrared cameras in classification zones 1, 2, 21, and 22.
- ATEX certified to the latest standards.
- Rated to protection class IP67.
- Plug and play installation, with the enclosure delivered ready for use.

6 Typical system overview



1. Thermovision System Tools & Utilities CD-ROM.
2. Ethernet cable.[1]
3. Optical-to-Ethernet converter.[1]
4. FC connectors from the camera housing (including two spares).
5. 24 V DC power supply.[1]
6. Pigtail cable from housing. The color coding of the pigtail cable is:
   - Brown: positive +.
   - Blue: negative –.
   - Green/yellow: earth.

1. Not supplied with the camera unit.

7 Typical system setup procedure

1. Unpack the camera unit from the cardboard box.
2. Install the camera unit at the intended location. It is the responsibility of the installer to meet all applicable safety standards required by the authorities of the region in which the unit will be operating in.
3. Connect the camera unit to an external power supply.[2] The unit requires 24 V DC in. The color coding of the pigtail cable is:
   - Brown: positive +.
   - Blue: negative –.
   - Green/yellow: earth.

   > **Note**
   > The external power supply must not be inside the classified zone.

4. Connect the camera unit to an optical-to-Ethernet converter.[2]

   > **Note**
   > The optical-to-Ethernet converter must not be inside the classified zone.

5. Install the Thermovision System Tools & Utilities CD-ROM on a computer connected to the network. This will install the following software:
   - FLIR IP Config.
   - FLIR IR Monitor.
   - FLIR IR Camera Player.
6. Start FLIR IP Config to identify the unit in the network and automatically assign or manually set IP addresses, etc. For more information, see the FLIR IP Config manual on the User Documentation CD-ROM or on the *Help* menu in FLIR IP Config.
7. Start FLIR IR Monitor to control the camera, e.g., laying out measurement tools and setting up alarms. For more information, see the FLIR IR Monitor manual on the User Documentation CD-ROM or on the *Help* menu in FLIR IR Monitor.

2. Not supplied with the camera unit.

8 IRCamSafeEX-AXB/C Ex d enclosures for infrared cameras

Note
Section 8 in this manual is a translation of the German manual from the manufacturer of the enclosure, dated 2012-05-16, revision 1.1. In the event that any question should arise about the correctness of the translation, the German version is the authoritative version.

8.1 General information

8.1.1 Manufacturer

AT-Automation Technology GmbH
Hermann-Bössow-Strasse 6–8
23843 Bad Oldesloe
Germany

Telephone: +49 4531 88011-0
Fax: +49 34531 88011-20
Internet: www.AutomationTechnology.de

8.1.2 Introduction

The IRCamSafeEX-AXB/C[3] series is a range of protective enclosures for infrared cameras. The enclosures are designed for use with infrared cameras from the FLIR A3XX/SC3XX[4] and A615/SC6XX[5] series. There are two types of protective enclosure, distinguished by the letter code in the product name: AXB[5] and AXC. Both enclosure types are designed to be used in explosive atmospheres resulting from flammable gases. The AXC model can also be used in explosive atmospheres resulting from combustible dusts.

The protective enclosures comply with the applicable explosion protection guidelines and are certified as a complete unit with all attachments, so the cameras do not need to be recertified following installation.

8.1.3 Labeling

AXB[5] enclosure model

AXC enclosure model

3. Comment from FLIR Systems: AXB not supported.
4. Comment from FLIR Systems: Only FLIR A310 supported.
5. Comment from FLIR Systems: Not supported.

AT – Automation Technology GmbH
Hermann-Bössow-Straße 6 – 8 • D-23843 Bad Oldesloe • Germany
Phone: +49 4531 88011-0 • www.AutomationTechnology.de

Model:	IRCamSafeEX-AXC	
Serial No.:	000005	Year: 2012
Power:	115VAC/230VAC/24VDC, $60W_{max.}$	
Certificate:	ZELM 12 ATEX XXXX	T_{amb} -20°C/+40°C
II 2G Ex d IIC T6 Gb II 2D Ex tb IIIC T85° Db		IP67
CE 0820		

WARNUNG / WARNING / ADVERTENCIA / ATTENTION !

NICHT UNTER SPANNUNG ÖFFNEN / DE-ENERGIZE BEFORE OPENING
DESENERGIZAR ANTES DE ABRIR / NE PAS OUVIRIR SOUS TENSION

NACH DEM ABSCHALTEN 10 MINUTEN WARTEN VOR DEM ÖFFNEN.

8.2 General safety instructions

The operating instructions contain important safety instructions that must be observed when carrying out assembly, operation and maintenance work. Failure to observe the safety instructions may endanger people, the plant, and the environment.

Hazard caused by unauthorized work on the device

Assembly, installation, commissioning, operation, and maintenance work may only be performed by personnel who are authorized and trained to do so.

Before assembly/commissioning:

- Read the operating instructions.
- Ensure that assembly and operating personnel are provided with adequate training.
- Ensure that the personnel in charge fully understand the contents of the operating instructions.
- National assembly and installation regulations apply (e.g. IEC/EN 60079-14).

If anything is unclear:

- Contact the manufacturer.

When operating the devices:

- Ensure that the operating instructions are available at the site of operation at all times.
- Observe the safety instructions.
- Observe national safety and accident prevention regulations.
- Only operate the device according to its performance data.
- Maintenance work or repairs that are not described in the operating instructions must not be performed without the manufacturer's prior consent.
- Any damage to the device may nullify the explosion protection.
- Any additions or modifications to the device that impair the explosion protection are prohibited.
- Only install and operate the device if it is dry, clean, and in perfect condition.

8.3 Use and intended area of application

The protective enclosures are certificated for use with infrared cameras in potentially explosive atmospheres categorized as zones 1 and 2. The AXC enclosure model can also be used in potentially explosive atmospheres categorized as zones 21 and 22.

Only use the device in line with its intended use

Failure to use the device in line with its intended use will render the manufacturer's liability and warranty void.

Only use the device in line with the operating conditions stipulated in these operating instructions.

In potentially explosive atmospheres, the device must only be operated according to these operating instructions.

8.3.1 Permitted attachments

The following camera and lens combinations can be used.

Camera	Lens	AXB model[6]	AXC model
A3XX[7] SC3XX[6]	Without ancillary lens	X	X
	45° ancillary lens, focal length = 10 mm	X	X
	15° ancillary lens, focal length = 30 mm[6]	X	X
	6° ancillary lens, focal length = 76 mm[6]	X	X
	90° ancillary lens, focal length = 4 mm[6]	X	X
A615[6] SC6XX[6]	15° lens, focal length = 41.3 mm	X	X
	25° lens, focal length = 24.6 mm	X	X
	45° lens, focal length = 13.1 mm	X	X

<u>Installation work must only be carried out by specialist personnel</u>

The attachments must be assembled by the manufacturer or by personnel authorized by the manufacturer.

8.3.2 Permitted cable glands and connectors

There are two pressure-resistant, flameproof cable glands to connect the power supply line and the data transmission line. Alternatively, pressure-resistant, flameproof connector systems can be used. The cable glands and connectors are preassembled by the manufacturer. The enclosure can also be supplied by the manufacturer with the connection cables already connected.

The following EX cable glands can be used with the protective enclosure.

Manufacturer	Reference	Size	Sheath diameter A1 (mm)	Maximum number of single wires
Stahl	8163/2-20S/16-PXSS2K-M20	20s/16	3.1–8.7	15
Stahl	8163/2-20S-PXSS2K-M20	20s	6.1–11.7	15
Stahl	8163/2-20-PXSS2K-M20	20	6.5–14.0	15
Stahl	8163/2-20S/16-PX2K-M20	20s/16	6.1–11.5	15
Stahl	8163/2-20S-PX2K-M20	20s	9.5–15.9	15
Stahl	8163/2-20-PX2K-M20	20	12.5–20.9	15
Hummel	EXIOS Barrier 1.606.2000.50	20-1	6–12	8

6. Comment from FLIR Systems: Not supported.
7. Comment from FLIR Systems: Only FLIR A310 supported.

Manufacturer	Reference	Size	Sheath diameter A1 (mm)	Maximum number of single wires
Hummel	EXIOS Barrier 1.606.2000.51	20-2	9–16	10
Hummel	EXIOS Barrier 1.606.2000.52	20-3	12.5–20.5	15

The following EX connector systems can be used with the protective enclosure.

Manufacturer	Description	Reference
Stahl	Connector plug for power supply terminal 2-pin + PE	8591/16.-06-3.00
Stahl	Ethernet connector, 4-pin	8591/467-01-3022
Hawke	Panel jack for power supply terminal, 4-pin	N-BR1-M-B-P-X-0-3-X-A
Hawke	Panel jack for Ethernet connection, 8-pin	N-BR1-M-C-P-X-0-8-X-A

Installation work must only be carried out by specialist personnel

The cable glands and the connectors for the enclosure must be assembled by the manufacturer or personnel authorized by the manufacturer.

8.3.3 Construction with preassembled connection cables

Connection 1 (data link) is equipped with a fiber-optic connection cable that has the following properties:

- Four-core fiber-optic breakout cable for outdoor use: AT-V(ZN)Y(ZN)Y 4G50/125 OM2, or 62.5/125 OM1 (e.g. Helukabel 803348 with a sheath diameter of 8.5 mm).
- Four LC connectors preassembled on the enclosure interior. Inside length of a single wire: 450 mm.
- The second terminal side is not assembled and can be spliced.
- Typical length: 5 m[8].

Connection 2 (electrical power supply) is equipped with a three-core copper cable (e.g. Helukabel 37264) that has the following properties:

- Sheath diameter: 9.8 mm.
- Core cross-section: 3 × 1.5 mm², fine wire.
- Typical length: 5 m[8]. It can be assembled with a connector (Stahl 8570/12-306).

Customer-specific lengths and free-end cable assemblies are available on request.

8.4 Compliance with applicable standards

The protective enclosures comply with the following standards and guidelines:

- Directive 94/9/EC.
- EN 60079-0:2009: “Explosive atmospheres—Part 0: Equipment—General requirements.”
- EN 60079-1:2007: “Explosive atmospheres—Part 1: Equipment protection by flameproof enclosures ‘d’.”
- EN 60079-14:2009: “Explosive atmospheres—Part 14: Electrical installations design, selection and erection.”
- EN 60079-17:2008: “Explosive atmospheres—Part 17: Electrical installations inspection and maintenance.”
- EN 60079-31:2009: “Explosive atmospheres—Part 31: Equipment dust ignition protection by enclosure ‘t’.”

8. Comment from FLIR Systems: 4 m (13.1 ft.)

8.5 Technical data

General technical data:

- Normal operating conditions temperature range T_a: –20°C to +40°C.
- Protection class: IP67.
- Weight: 6.7 kg (without camera and lens).
- Total capacity: 5.06 L.
- External dimensions (excluding canopy and connections), diameter × length: 170 mm × 408 mm.
- Enclosure material: aluminum.
- Surface: powder coated.
- Material for infrared transparent window: germanium; anti-reflective coating on both sides; hard carbon coating on the exterior.
- Maximum power of auxiliary heater: 16 W.
- Operating voltage: 115 V AC 60 Hz/230 V AC 50 Hz/24 V DC.
- Maximum electrical connected load: 60 W.
- Integrated controller:
  - Four-port switch with two 100Base-FX fiber-optic lucent connectors or two RJ45 (10/100) uplinks.
  - Suitable for ring topology to reduce the amount of cabling required.
  - Two internal temperature sensors, humidity sensor, and pressure sensor.
  - Switchable camera power supply and auxiliary heating via Modbus TCP/IP.
  - Web interface for configuration.

Explosion protection data:

- For use in potentially explosive atmospheres categorized as zones 1 and 2.
- Type of protection: flameproof enclosure “d.”
- Maximum surface temperature in line with temperature class T6: maximum 85°C.
- ATEX marking—AXB[9] model:
  - Gas explosion protection: II 2G Ex d IIB T6 Gb.
- ATEX marking—AXC model:
  - Gas explosion protection: II 2G Ex d IIC T6 Gb.
  - Dust explosion protection: II 2D Ex tb IIIC T85° Db IP67.
  - Inspection document: ZELM 12 ATEX 0485 X.

9. Comment from FLIR Systems: Not supported.

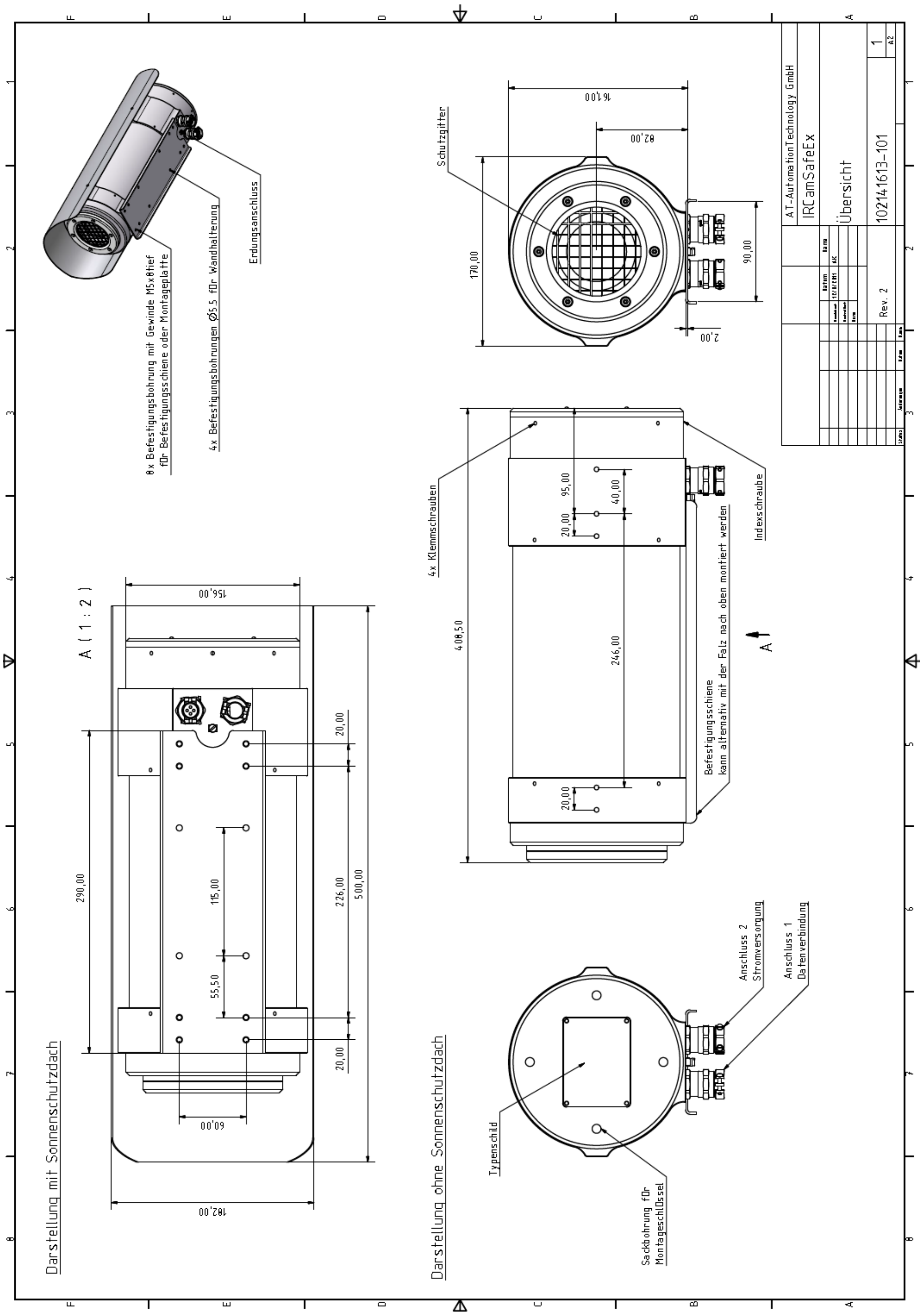


Figure 8.1 Overview of IRCamSafeEX-AXB/C (all measurements in mm) — subject to change without notice.

8.6 Transport, storage, and disposal

Transport:

The device should transported in its original packaging and must not be able to move within the packaging. Handle the device with care; do not drop it.

Storage:

Store the device in its original packaging in a dry place.

Disposal:

All components must be disposed of in a manner that does not harm the environment and in line with legal requirements.

8.7 Assembly and disassembly

Before assembly, check that the ambient temperature range and the protection class on the rating plate meet the requirements for the assembly area.

The fastening bores used to install the enclosure are depicted in Figure 1. The eight M5 threads for the protective enclosure can be used to attach the protective enclosure to the mounting plate. Alternatively, a mounting rail can be used to attach the enclosure to a wall bracket. When assembling the enclosure, ensure that the screws are tightly fastened: use a maximum torque of 3.5 Nm for the M5 fastening screw threads. Use locking washers to prevent the fastening screws from becoming loose.

Note
It is advisable to attach the sun canopy to the protective enclosure if the device is going to be used outdoors.

8.8 Installation

Installation work must only be carried out by specialist personnel

Installation work may only be performed by personnel who have been authorized and trained to do so. All applicable national regulations in the country in which the product is used must be observed (e.g. EN 60079-14). The manufacturer or personnel authorized by the manufacturer must assemble the cable glands or the connectors for the enclosure and install the connection lines.

Hazard caused by live parts

Ensure that all supply lines are disconnected from the mains electricity supply and that they cannot be switched on inadvertently.

Hazard caused by incorrect cable glands

Explosion protection is no longer guaranteed if incorrect cable glands are used. Only use cable glands that are suitable for the required protection type and that are specifically listed by the manufacturer as suitable for the enclosure you are using. See the section “Permitted cable glands and connectors.”

Hazard caused by faulty cable anchorage

When using cable glands, explosion protection is no longer guaranteed if the cable anchorage is faulty. Install cables and lines securely. Observe the instructions for cable feed-through.

Hazard caused by damaged threads

If a thread is damaged, there is no guarantee that the joint is flameproof. Remove and replace the enclosure cover carefully. Any enclosure cover or enclosure with damaged threads must be replaced immediately.

Hazard caused by defective sealing

The level of explosion protection afforded largely depends on compliance with the IP protection class. When carrying out any work on or involving the enclosure, ensure that all seals are positioned correctly and are in perfect condition.

8.8.1 Installing the connection lines

8.8.1.1 Lines

The quality of the supply pipe used must meet the thermal and mechanical requirements in the area of application. The cables must comply with the applicable guidelines for direct entry into flameproof enclosures in EN 60079-14. Cable glands must be sealed with a sealing compound to waterproof the individual wires.

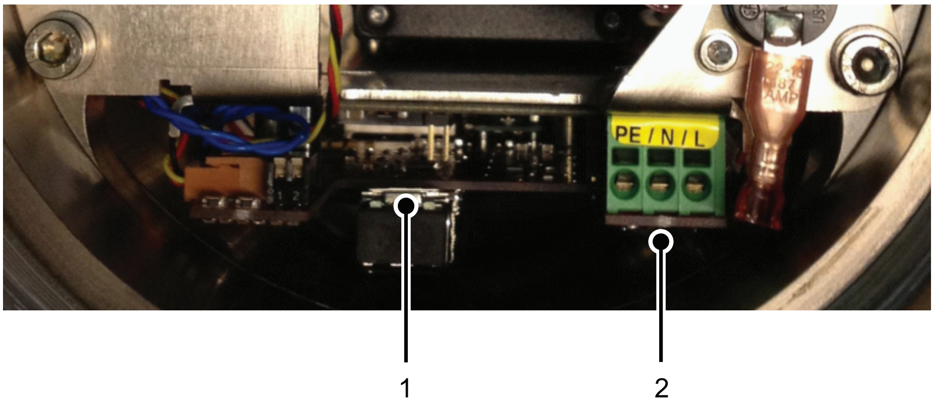


Figure 8.2 Connections on the controller board. 1, fiber-optic lucent; 2, supply line connection

8.8.1.2 Unscrewing the rear enclosure cover

1. Unscrew 1 × enclosure index screw.
2. Unscrew 4 × enclosure locking screws.
3. Position the assembly wrench on the rear cover and unfasten the enclosure cover.
4. Carefully remove the enclosure cover.

8.8.1.3 Installing the connection lines

1. Feed the connection lines with all external insulation through the cable glands into the terminal compartment.
2. Ensure that the cable diameter matches the clamping cross-section on the cable gland. Ensure that the cable gland is sealed using a sealing compound in line with the instructions for cable glands.
3. Tighten the hexagonal nuts for the cable gland so that the terminal compartment is sealed and the cable anchorage at the connection points is secure.
4. The tightening torque required can be found in the instructions for the components.
5. Install the connection lines in the terminal compartment so that:
   - The permitted minimum bending radii values for each wire cross-section are reached.
   - Mechanical damage to the cable insulation is avoided.

Incorrect installation

- **Please observe the thread sizes for the cable glands in the operating instructions.**
- **The connection line must meet the applicable requirements, and the cross-section dimensions must be sufficient. The diameter must comply with the cable gland requirements.**
- **Suitable lines must be selected and installed in such a way that the maximum permitted wire temperatures are not exceeded.**

- **The permitted ambient temperatures for the assembled components must not be exceeded.**
- **When stripping the insulation, ensure that the wire insulation reaches the clamps.**
- **When stripping the insulation, ensure that the wire is not damaged.**
- **The switch assembly may only be installed in dry and clean conditions.**

8.8.1.4 Locking the rear enclosure cover

1. Check that the O rings are positioned correctly and are in perfect condition.
2. Check that the thread for the rear cover is clean and in perfect condition. The cover must be replaced if the thread is damaged.
3. Check that assembly paste is applied to the thread (e.g. Teflon paste).
4. Apply new drying agent.
5. Carefully position the enclosure cover and manually screw it down.
6. Position the assembly wrench on the rear cover and screw the enclosure cover down until the index position is reached.
7. Screw in and tighten 1 × enclosure index screw.
8. Screw in and tighten 4 × enclosure locking screws.

8.8.1.5 Installing the earth connection

The earth connection is suitable for fine-wire cables up to 1.5 mm^2 and single-wire cables up to 2.5 mm^2. Place the stripped end of the earth cable in the earth connection and tighten the M4 screw for the earth connection to a maximum torque of 1.2 Nm.

8.9 Commissioning

Before commissioning

- Ensure that the device is not damaged.
- Ensure that the device has been installed in line with the instructions.
- Ensure that the protective window grid has been fitted correctly.
- Check the cable glands for any damage and ensure they are secured.
- Check that screws and nuts are fastened securely.
- Check that the power supply and data cable are installed correctly; check the cable sheaths for any damage.
- Check the tightening torques.
- If necessary, ensure that any unused cable glands have been sealed with stoppers approved in line with Directive 94/9/EC.

Steps during commissioning

1. Turn on the mains voltage.
2. Configure the Ethernet connection to the protective enclosure controller using the EDS Configurator tool.
3. Load the website for the protective enclosure controller and, if necessary, configure the network switch settings.
4. Check and configure the Ethernet connection to the infrared camera using the FLIR IP Config tool.
5. Start the monitor software.
6. Check the camera image.
7. Check the sensor values (temperature, humidity, pressure) for the protective enclosure controller.

8.10 Maintenance

Operators of electrical systems in potentially explosive atmospheres must ensure that the system is kept in proper working order and is operated correctly. The operator must also monitor the system and carry out maintenance and repair work as required. Maintenance work and troubleshooting must only be performed by specialist personnel. In particular, when carrying out maintenance work, it must be ensured that the parts essential for maintaining the type of protection and the features offered by the system are in proper working order. The specified safety instructions must be consulted before performing any maintenance work/troubleshooting.

Hazard caused by live parts

Disconnect the device from the mains electricity supply before carrying out any maintenance work. Secure the device against being switched on inadvertently.

Hazard caused by opening the enclosure or cable connections

Before opening the enclosure or cable connections, disconnect the device and any connected fiber-optic units, and secure them against being switched on inadvertently.

Installation work must only be carried out by specialist personnel

Installation work must only be performed by personnel who have been authorized and trained to do so. All applicable national regulations in the country in which the device is used must be observed (e.g. EN 60079-17).

8.10.1 Regular maintenance work

The type and scope of checks to be performed can be found in the applicable national regulations (e.g. IEC/EN 60079-17). Maintenance work must be scheduled in such a way that any faults requiring attention are identified in good time.

When performing maintenance work:

- Check the device for any visible signs of damage such as mechanical damage, warping, or corrosion.
- Check that cable glands and lines are installed securely.
- Check that screws and nuts are fastened securely.
- Check the cable glands/connectors for damage.
- Observe the maintenance instructions for the cable glands/connectors used according to their respective operating instructions.
- Check that the temperature of the location is not exceeding or falling below the permitted temperatures set out in IEC/EN 60079-0.
- Check that the device is performing as intended.

8.10.2 Cleaning

The enclosure can be cleaned with a cloth, brush, vacuum cleaner, or other similar product. If it is necessary to remove the protective grid to clean the viewing window, the device must first be disconnected from the mains electricity supply. The window can be cleaned with water or with isopropanol (provided that this is permitted in the relevant area).

Hazard caused by missing safety devices

Before removing the protective grid, disconnect the device and any connected fiber-optic units, and secure them against being switched on inadvertently.

8.11 Fittings and replacement parts

Reference	Order number
O-ring for enclosure cover	102141613-14
M4x6 enclosure index screw ISO 4027	102141613-19
M4x6 enclosure locking screw ISO 4026	102141613-18

Reference	Order number
M20x2 cable connection seal	102141613-33
M5x12 protective grid fastening screw DIN 6912	102141613-17
Sun canopy	102141613-11
Mounting rail	102141613-12
M5x8 screw for mounting rail	102141613-31
Drying agent	102141613-32
Assembly wrench for rear cover with SW32 connection	102141613-50

Cable connections and connectors may only be replaced after consultation with and approval from the manufacturer.

Use of incorrect accessories and replacement parts

Failure to use the correct accessories and replacement parts will render the manufacturer's liability and warranty void. Use only original accessories and replacement parts from AT-Automation Technology GmbH.

8.12 EC-type examination certificate

1. Ergänzung

(Ergänzung gemäß EG-Richtlinie 94/9 Anhang III Ziffer 6)

ZELM ex

zur EG-Baumusterprüfbescheinigung

ZELM 12 ATEX 0485 X

Gerät:	**Kameragehäuse IRCamSafeEx Typ AXB**
Hersteller:	**AT Automation Technology GmbH**
Anschrift:	**Hermann Bössow Straße 6–8, D–23843 Bad Oldesloe**

Beschreibung der Ergänzung

Die 1. Ergänzung betrifft die Einführung eines alternativen Typs des Kameragehäuses IRCamSafeEx. Die alternative Ausführung ist für den Einsatz in gas- und staubexplosionsgefährdeten Bereichen der Gruppen IIC bzw. IIIC vorgesehen. Die alternative Ausführung des Kameragehäuses erhält die Typenbezeichnung:

IRCamSafeEx Typ AXC

Die Kennzeichnung für das Kameragehäuse IRCamSafeEx Typ AXC lautet:

Ex **II 2G Ex d IIC T6 Gb und**

II 2D Ex tb IIIC T85°C Db

Die besonderen Bedingungen werden wie folgt erweitert:

6. Die Schutzart des Gehäuses ist von der ordnungsgemäßen Installation und Auswahl der eingesetzten Kabelverschraubung abhängig. Es dürfen nur die vom Hersteller installierten Kabelverschraubungen mit zutreffender separater EG-Baumusterprüfbescheinigung verwendet werden. Bei der Installation sind die Angaben in der Betriebsanleitung zu beachten.

Die elektrischen Daten, sowie alle übrigen Daten und die besonderen Bedingungen bleiben unverändert und gelten auch für diese 1. Ergänzung.

Das Betriebsmittel darf künftig auch unter Berücksichtigung dieser 1. Ergänzung gefertigt werden.

Seite 1 von 2

EG-Baumusterprüfbescheinigungen ohne Unterschrift und ohne Stempel haben keine Gültigkeit. Diese EG-Baumusterprüfbescheinigung darf nur unverändert weiterverbreitet werden. Auszüge oder Änderungen bedürfen der Genehmigung der Prüf- und Zertifizierungsstelle ZELM ex.

ZELM ex
Prüf- und Zertifizierungsstelle
Siekgraben 56 D-38124 Braunschweig

1. Ergänzung
zur EG-Baumusterprüfbescheinigung ZELM 11 ATEX 0469 X

ZELM ex

Prüfbericht Nr.

ZELM Ex 0411225918

Grundlegende Sicherheits- und Gesundheitsanforderungen

Die grundlegenden Sicherheits- und Gesundheitsanforderungen werden weiterhin erfüllt durch Übereinstimmung mit folgenden Normen:

EN 60079-0:2009 **EN 60079-1:2007** **EN 60079-31:2009**

Braunschweig, 10.05.2012

ZELM ex

Zertifizierungs-stelle

Zertifizierungsstelle ZELM ex
Dipl.-Ing. Harald Zelm

Seite 2 von 2

ZELM ex
Prüf- und Zertifizierungsstelle
Siekgraben 56 · D-38124 Braunschweig

8.13 EC declaration of conformity

EG-Konformitätserklärung
EC-Declaration of Conformity
Déclaration de Conformité CE

AT – Automation Technology GmbH • Hermann-Bössow-Strasse 6 – 8 • D-23843 Bad Oldesloe, Germany
erklärt in alleiniger Verantwortung, declares in its sole responsibility, déclare sous sa seule responsabilité

dass das Produkt that the product que le produit	**IRCamSafeEX-AXB** **IRCamSafeEX-AXC**
Kennzeichnung, marking, marquage (-AXB): **Kennzeichnung**, marking, marquage (-AXC):	Ex **II 2G Ex d IIB T6 Gb** Ex **II 2G Ex d IIC T6 Gb** Ex **II 2D Ex tb IIIC T85° Db**
mit der EG-Baumusterprüfbescheinigung: under EC-Type Examination Certificate: avec Attestation d'examen CE de type:	**ZELM 12 ATEX 0485 X** **(ZELM Ex e.K.** **Siekgraben 56, 38124 Braunschweig)**
Kenn-Nr. der benannten Stelle: Notified Body number: No de l'organisme de certification:	**0820**

auf das sich diese Erklärung bezieht, mit den folgenden Normen oder normativen Dokumenten übereinstimmt
which is the subject of this declaration, is in conformity with the following standards or normative documents
auquel cette déclaration se rapporte, est conforme aux normes ou aux documents normatifs suivants

Bestimmungen der Richtlinie Terms of the directive Prescription de la directive	**Nummer sowie Ausgabedatum der Norm** Number and date of issue of the standard Numéro ainsi que date d'émission de la norme
94/9/EG: ATEX-Richtlinie 94/9/EC: ATEX Directive 94/9/CE: Directive ATEX	EN 60079-0: 2009 EN 60079-1: 2007 EN 60079-14: 2009 EN 60079-17: 2008 EN 60079-28: 2007 EN 60079-31: 2009
2006/95/EG: Niederspannungsrichtlinie 2006/95/EC: Low Voltage Directive 2006/95/CE: Directive Basse Tension	
2004/108/EG: EMV-Richtlinie 2004/108/EC: EMC Directive 2004/108/CE: Directive CEM	

Bad Oldesloe, 16. Mai. 2012 **Ort und Datum** Place and Date Lieu et date	**Dr. Andrè Kasper** **Leiter Qualitätssicherung** Director Quality Management Dept. Directeur Dept. Assurance de Qualité

9 Technical data

9.1 Online field-of-view calculator

Please visit http://support.flir.com and click the FLIR A310 ex camera for field-of-view tables for all lens–camera combinations in this camera series.

9.2 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.

9.3 FLIR A310 ex 25°

P/N: 71001-1103
Rev.: 17786

Introduction

The FLIR A310 ex is an ATEX-proof solution, with a thermal imaging camera mounted in an enclosure, making it possible to monitor critical and other valuable assets in explosive atmospheres. Process monitoring, quality control, and fire detection in potentially explosive locations are typical applications for the FLIR A310 ex.

- Thermographic monitoring and early fire detection in explosion–hazard area.
- Enclosures for infrared cameras in Ex zones 1, 2, 21, and 22.
- ATEX certified.
- Protection class IP67.
- Plug and play installation, enclosure is delivered ready-for-use.
- Available with additional options.

The certification comprises the whole system, which includes the enclosure as well as all components built inside of it, such as the infrared camera, heater, and integrated controller. This means that no additional certification is required for operation.

The integrated controller is equipped with two fiber optic and two Ethernet ports. This enables a flexible network integration in star ring topologies.

Furthermore, the integrated controller features several digital I/O channels and sensors for temperature, humidity, and pressure. Among other functions, the I/O channels enable the user to switch on/off the camera and the heater via remote control. Access is accomplished through an integrated web interface or Modbus TCP/IP.

Explosion-proof housing

General data	
Ambient temperature range for operation	–20°C to +40°C
Protection class	IP67
Weight	6.7 kg (without camera and lens)
Empty volume	5.06 l
External dimensions (without sun shield)	D = 170 mm, L = 408 mm
Housing material	Nickel-plated aluminium
Surface	Powder coated
Protection window	Germanium, double-sided AR Coated, externally with additional hard-carbon layer
Maximum power of the additional heater	16 W
Operating voltage	24 V DC
Maximum electric connection power	60 W
Power cable	Helukabel 37264
Length of power cable	4 m (13 ft.)
Power cable configuration	Pigtail
Integrated controller	4-port switch with 2 × fiber-optic LC 100Base-FX or 2 × RJ45(10/100) up-links, ring-topology support for reduced cabling effort, 2 × internal temperature sensors, air humidity and pressure sensor, digital output module controllable via Modbus TCP/IP or web interface to enable turning the heater on/off
Ethernet medium	Multi-mode breakout fiber AT-V(ZN)Y(ZN)Y 4G50/125 OM2
Length of Ethernet cable	4 m (13 ft.)
Ethernet configuration	Pigtail with FC connector

Explosion protection-specific data	
For use in EX zone	1, 2, 21, and 22
Ignition protection category	Flame-proof enclosure “d”
Maximum surface temperature (according to temperature class T6)	Maximum 85°C
ATEX certification (version -AXC)	EX-Protection Gas: II 2G Ex d IIC T6 Gb, EX-Protection Dust: II 2D Ex tb IIIC T85° Db
Verification certificate	ZELM 12 ATEX 0485 X

Camera system

Imaging and optical data	
IR resolution	320 × 240 pixels
Thermal sensitivity/NETD	< 0.05°C @ +30°C (+86°F) / 50 mK
Field of view (FOV)	25° × 18.8°
Minimum focus distance	0.4 m (1.31 ft.)
Focal length	18 mm (0.7 in.)
Spatial resolution (IFOV)	1.36 mrad
Lens identification	Automatic
F-number	1.3
Image frequency	30 Hz
Focus	Automatic or manual (built in motor)
Zoom	1–8× continuous, digital, interpolating zooming on images

Detector data	
Detector type	Focal Plane Array (FPA), uncooled microbolometer
Spectral range	7.5–13 µm
Detector pitch	25 µm
Detector time constant	Typical 12 ms

Measurement	
Object temperature range	–20 to +120°C (–4 to +248°F) 0 to +350°C (+32 to +662°F)
Accuracy	±2°C (±3.6°F) or ±2% of reading

Measurement analysis	
Spotmeter	10
Area	10 boxes with max./min./average/position
Isotherm	1 with above/below/interval
Measurement option	Measurement Mask Filter Schedule response: File sending (ftp), email (SMTP)
Difference temperature	Delta temperature between measurement functions or reference temperature
Reference temperature	Manually set or captured from any measurement function
Atmospheric transmission correction	Automatic, based on inputs for distance, atmospheric temperature and relative humidity
Optics transmission correction	Automatic, based on signals from internal sensors

Measurement analysis	
Emissivity correction	Variable from 0.01 to 1.0
Reflected apparent temperature correction	Automatic, based on input of reflected temperature
External optics/windows correction	Automatic, based on input of optics/window transmission and temperature
Measurement corrections	Global and individual object parameters

Alarm	
Alarm functions	6 automatic alarms on any selected measurement function, Digital In, Camera temperature, timer
Alarm output	Digital Out, log, store image, file sending (ftp), email (SMTP), notification

Set-up	
Color palettes	Color palettes (BW, BW inv, Iron, Rain)
Set-up commands	Date/time, Temperature°C/°F

Storage of images	
Storage media	Built-in memory for image storage
File formats	Standard JPEG, 16-bit measurement data included

Ethernet	
Ethernet	Control, result and image
Ethernet, type	100 Mbps
Ethernet, standard	IEEE 802.3
Ethernet, configuration	Pigtail with FC-connector (fiber)
Ethernet, communication	TCP/IP socket-based FLIR proprietary
Ethernet, video streaming	MPEG-4, ISO/IEC 14496-1 MPEG-4 ASP@L5
Ethernet, image streaming	16-bit 320 × 240 pixels @ 7-8 Hz - Radiometric
Ethernet, protocols	Ethernet/IP, Modbus TCP, TCP, UDP, SNTP, RTSP, RTP, HTTP, ICMP, IGMP, ftp, SMTP, SMB (CIFS), DHCP, MDNS (Bonjour), uPnP

Shipping information

- Infrared camera with lens, in explosion-proof housing
- Cardboard box
- Printed documentation
- User documentation CD-ROM
- Utility CD-ROM

EAN-13	7332558008355
UPC-12	845188008703
Country of origin	Sweden

9.4 FLIR A310 ex 45°

P/N: 71001-1104
Rev.: 17787

Introduction

The FLIR A310 ex is an ATEX-proof solution, with a thermal imaging camera mounted in an enclosure, making it possible to monitor critical and other valuable assets in explosive atmospheres. Process monitoring, quality control, and fire detection in potentially explosive locations are typical applications for the FLIR A310 ex.

- Thermographic monitoring and early fire detection in explosion–hazard area.
- Enclosures for infrared cameras in Ex zones 1, 2, 21, and 22.
- ATEX certified.
- Protection class IP67.
- Plug and play installation, enclosure is delivered ready-for-use.
- Available with additional options.

The certification comprises the whole system, which includes the enclosure as well as all components built inside of it, such as the infrared camera, heater, and integrated controller. This means that no additional certification is required for operation.

The integrated controller is equipped with two fiber optic and two Ethernet ports. This enables a flexible network integration in star ring topologies.

Furthermore, the integrated controller features several digital I/O channels and sensors for temperature, humidity, and pressure. Among other functions, the I/O channels enable the user to switch on/off the camera and the heater via remote control. Access is accomplished through an integrated web interface or Modbus TCP/IP.

Explosion-proof housing

General data	
Ambient temperature range for operation	–20°C to +40°C
Protection class	IP67
Weight	6.7 kg (without camera and lens)
Empty volume	5.06 l
External dimensions (without sun shield)	D = 170 mm, L = 408 mm
Housing material	Nickel-plated aluminium
Surface	Powder coated
Protection window	Germanium, double-sided AR Coated, externally with additional hard-carbon layer
Maximum power of the additional heater	16 W
Operating voltage	24 V DC
Maximum electric connection power	60 W
Power cable	Helukabel 37264
Length of power cable	4 m (13 ft.)
Power cable configuration	Pigtail
Integrated controller	4-port switch with 2 × fiber-optic LC 100Base-FX or 2 × RJ45(10/100) up-links, ring-topology support for reduced cabling effort, 2 × internal temperature sensors, air humidity and pressure sensor, digital output module controllable via Modbus TCP/IP or web interface to enable turning the heater on/off
Ethernet medium	Multi-mode breakout fiber AT-V(ZN)Y(ZN)Y 4G50/125 OM2
Length of Ethernet cable	4 m (13 ft.)
Ethernet configuration	Pigtail with FC connector

Explosion protection-specific data	
For use in EX zone	1, 2, 21, and 22
Ignition protection category	Flame-proof enclosure “d”
Maximum surface temperature (according to temperature class T6)	Maximum 85°C
ATEX certification (version -AXC)	EX-Protection Gas: II 2G Ex d IIC T6 Gb, EX-Protection Dust: II 2D Ex tb IIIC T85° Db
Verification certificate	ZELM 12 ATEX 0485 X

Camera system

Imaging and optical data	
IR resolution	320 × 240 pixels
Thermal sensitivity/NETD	< 0.05°C @ +30°C (+86°F) / 50 mK
Field of view (FOV)	45° × 33.8
Minimum focus distance	0.20 m (0.66 ft.)
Focal length	9.66 mm (0.38 in.)
Spatial resolution (IFOV)	2.59 mrad
Lens identification	Automatic
F-number	1.3
Image frequency	30 Hz
Focus	Automatic or manual (built in motor)
Zoom	1–8× continuous, digital, interpolating zooming on images

Detector data	
Detector type	Focal Plane Array (FPA), uncooled microbolometer
Spectral range	7.5–13 µm
Detector pitch	25 µm
Detector time constant	Typical 12 ms

Measurement	
Object temperature range	–20 to +120°C (–4 to +248°F) 0 to +350°C (+32 to +662°F)
Accuracy	±2°C (±3.6°F) or ±2% of reading

Measurement analysis	
Spotmeter	10
Area	10 boxes with max./min./average/position
Isotherm	1 with above/below/interval
Measurement option	Measurement Mask Filter Schedule response: File sending (ftp), email (SMTP)
Difference temperature	Delta temperature between measurement functions or reference temperature
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Atmospheric transmission correction	Automatic, based on inputs for distance, atmospheric temperature and relative humidity
Optics transmission correction	Automatic, based on signals from internal sensors

Measurement analysis	
Emissivity correction	Variable from 0.01 to 1.0
Reflected apparent temperature correction	Automatic, based on input of reflected temperature
External optics/windows correction	Automatic, based on input of optics/window transmission and temperature
Measurement corrections	Global and individual object parameters

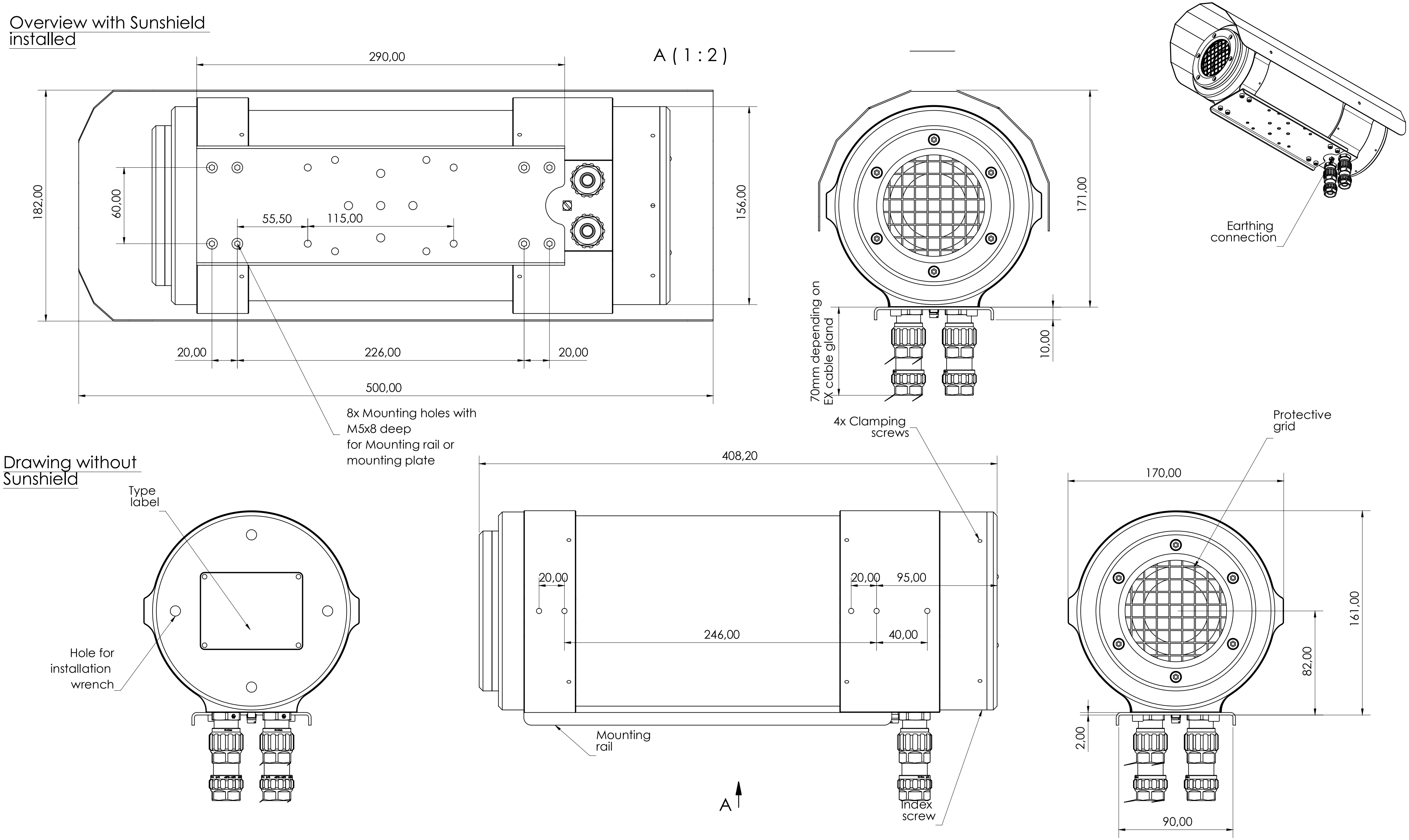
Alarm	
Alarm functions	6 automatic alarms on any selected measurement function, Digital In, Camera temperature, timer
Alarm output	Digital Out, log, store image, file sending (ftp), email (SMTP), notification

Set-up	
Color palettes	Color palettes (BW, BW inv, Iron, Rain)
Set-up commands	Date/time, Temperature°C/°F

Storage of images	
Storage media	Built-in memory for image storage
File formats	Standard JPEG, 16-bit measurement data included

Ethernet	
Ethernet	Control, result and image
Ethernet, type	100 Mbps
Ethernet, standard	IEEE 802.3
Ethernet, configuration	Pigtail with FC connector
Ethernet, communication	TCP/IP socket-based FLIR proprietary
Ethernet, video streaming	MPEG-4, ISO/IEC 14496-1 MPEG-4 ASP@L5
Ethernet, image streaming	16-bit 320 × 240 pixels @ 7-8 Hz - Radiometric
Ethernet, protocols	Ethernet/IP, Modbus TCP, TCP, UDP, SNTP, RTSP, RTP, HTTP, ICMP, IGMP, ftp, SMTP, SMB (CIFS), DHCP, MDNS (Bonjour), uPnP

Shipping information	
• Infrared camera with lens, in explosion-proof housing • Cardboard box • Printed documentation • User documentation CD-ROM • Utility CD-ROM	
EAN-13	7332558008362
UPC-12	845188008710
Country of origin	Sweden



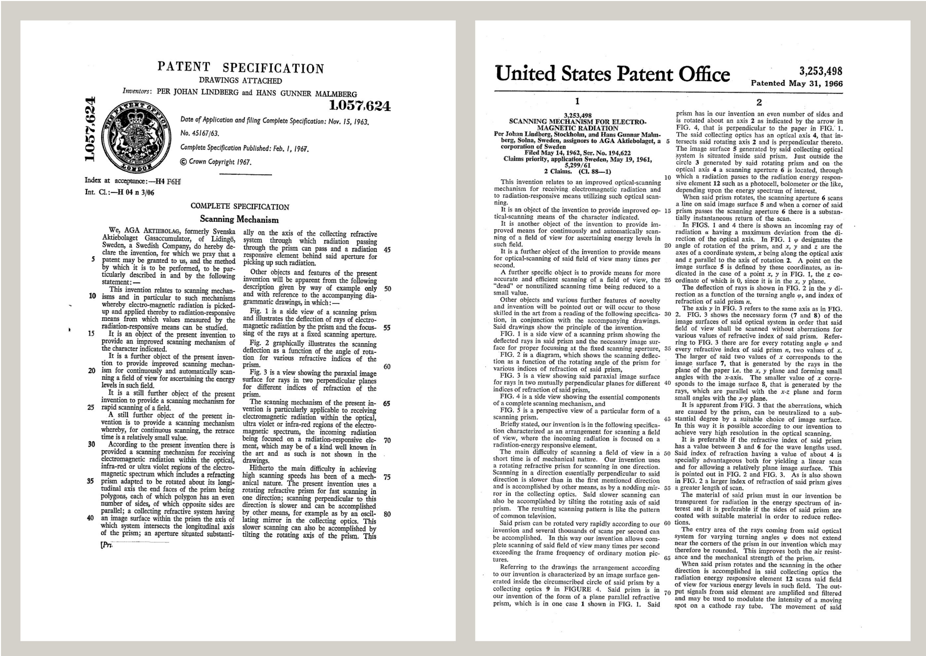
All dimensions in mm

Drawn	H. ÖSTLING
Date	2014-04-14
Check	JAMA
Modified by	H. ÖSTLING
Modified	2014-05-15
General tolerances	ISO 2768-mK
Surface treatment	Weatherding/Surface treatment
Scale	2:1
Sheet	1(1)
Size	A0
Designation	Basic Dimensions A3xxEx
Drawing No.	T128183
Rev	A

FLIR

11 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. In November 2007, Extech Instruments was acquired by FLIR Systems.


PATENT SPECIFICATION
DRAWINGS ATTACHED
1.057.624
COMPLETE SPECIFICATION
Scanning Mechanism

United States Patent Office
3,253,498
Patented May 31, 1966
SCANNING MECHANISM FOR ELECTRO-MAGNETIC RADIATION

Figure 11.1 Patent documents from the early 1960s

The company has sold more than 258,000 infrared cameras worldwide for applications such as predictive maintenance, R & D, non-destructive testing, process control and automation, and machine vision, among many others.

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 11.2 LEFT: Thermovision Model 661 from 1969. 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. RIGHT: FLIR One, which was launched in January 2014, is a slide-on attachment that gives iPhones thermal imaging capabilities. 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.

11.1 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.

11.2 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.

11.3 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.

11.4 A few images from our facilities

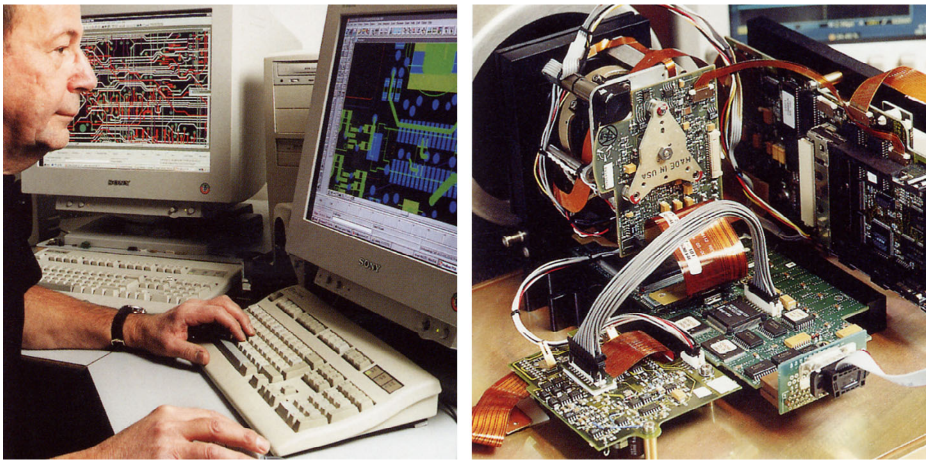


Figure 11.3 LEFT: Development of system electronics; RIGHT: Testing of an FPA detector

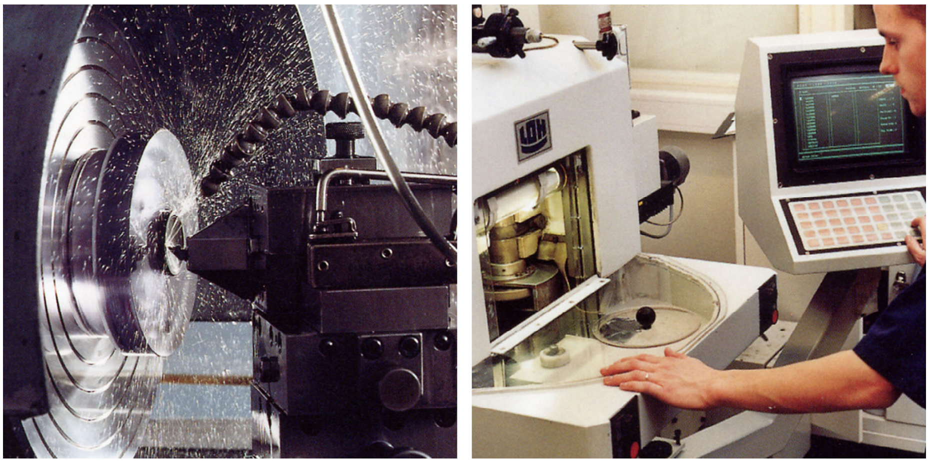


Figure 11.4 LEFT: Diamond turning machine; RIGHT: Lens polishing

12 Glossary

absorption (absorption factor)	The amount of radiation absorbed by an object relative to the received radiation. A number between 0 and 1.
atmosphere	The gases between the object being measured and the camera, normally air.
autoadjust	A function making a camera perform an internal image correction.
autopalette	The IR image is shown with an uneven spread of colors, displaying cold objects as well as hot ones at the same time.
blackbody	Totally non-reflective object. All its radiation is due to its own temperature.
blackbody radiator	An IR radiating equipment with blackbody properties used to calibrate IR cameras.
calculated atmospheric transmission	A transmission value computed from the temperature, the relative humidity of air and the distance to the object.
cavity radiator	A bottle shaped radiator with an absorbing inside, viewed through the bottleneck.
color temperature	The temperature for which the color of a blackbody matches a specific color.
conduction	The process that makes heat diffuse into a material.
continuous adjust	A function that adjusts the image. The function works all the time, continuously adjusting brightness and contrast according to the image content.
convection	Convection is a heat transfer mode where a fluid is brought into motion, either by gravity or another force, thereby transferring heat from one place to another.
dual isotherm	An isotherm with two color bands, instead of one.
emissivity (emissivity factor)	The amount of radiation coming from an object, compared to that of a blackbody. A number between 0 and 1.
emittance	Amount of energy emitted from an object per unit of time and area (W/m^2)
environment	Objects and gases that emit radiation towards the object being measured.
estimated atmospheric transmission	A transmission value, supplied by a user, replacing a calculated one
external optics	Extra lenses, filters, heat shields etc. that can be put between the camera and the object being measured.
filter	A material transparent only to some of the infrared wavelengths.
FOV	Field of view: The horizontal angle that can be viewed through an IR lens.
FPA	Focal plane array: A type of IR detector.
graybody	An object that emits a fixed fraction of the amount of energy of a blackbody for each wavelength.
IFOV	Instantaneous field of view: A measure of the geometrical resolution of an IR camera.

image correction (internal or external)	A way of compensating for sensitivity differences in various parts of live images and also of stabilizing the camera.
infrared	Non-visible radiation, having a wavelength from about 2–13 μm.
IR	infrared
isotherm	A function highlighting those parts of an image that fall above, below or between one or more temperature intervals.
isothermal cavity	A bottle-shaped radiator with a uniform temperature viewed through the bottleneck.
Laser LocatIR	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
laser pointer	An electrically powered light source on the camera that emits laser radiation in a thin, concentrated beam to point at certain parts of the object in front of the camera.
level	The center value of the temperature scale, usually expressed as a signal value.
manual adjust	A way to adjust the image by manually changing certain parameters.
NETD	Noise equivalent temperature difference. A measure of the image noise level of an IR camera.
noise	Undesired small disturbance in the infrared image
object parameters	A set of values describing the circumstances under which the measurement of an object was made, and the object itself (such as emissivity, reflected apparent temperature, distance etc.)
object signal	A non-calibrated value related to the amount of radiation received by the camera from the object.
palette	The set of colors used to display an IR image.
pixel	Stands for *picture element*. One single spot in an image.
radiance	Amount of energy emitted from an object per unit of time, area and angle ($W/m^2/sr$)
radiant power	Amount of energy emitted from an object per unit of time (W)
radiation	The process by which electromagnetic energy, is emitted by an object or a gas.
radiator	A piece of IR radiating equipment.
range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
reference temperature	A temperature which the ordinary measured values can be compared with.
reflection	The amount of radiation reflected by an object relative to the received radiation. A number between 0 and 1.
relative humidity	Relative humidity represents the ratio between the current water vapour mass in the air and the maximum it may contain in saturation conditions.
saturation color	The areas that contain temperatures outside the present level/span settings are colored with the saturation colors. The saturation colors contain an ‘overflow’ color and an ‘underflow’ color. There is also a third red saturation color that marks everything saturated by the detector indicating that the range should probably be changed.

span	The interval of the temperature scale, usually expressed as a signal value.
spectral (radiant) emittance	Amount of energy emitted from an object per unit of time, area and wavelength ($W/m^2/\mu m$)
temperature difference, or difference of temperature.	A value which is the result of a subtraction between two temperature values.
temperature range	The current overall temperature measurement limitation of an IR camera. Cameras can have several ranges. Expressed as two blackbody temperatures that limit the current calibration.
temperature scale	The way in which an IR image currently is displayed. Expressed as two temperature values limiting the colors.
thermogram	infrared image
transmission (or transmittance) factor	Gases and materials can be more or less transparent. Transmission is the amount of IR radiation passing through them. A number between 0 and 1.
transparent isotherm	An isotherm showing a linear spread of colors, instead of covering the highlighted parts of the image.
visual	Refers to the video mode of a IR camera, as opposed to the normal, thermographic mode. When a camera is in video mode it captures ordinary video images, while thermographic images are captured when the camera is in IR mode.

13 Thermographic measurement techniques

13.1 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

13.2 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.

13.2.1 Finding the emissivity of a sample

13.2.1.1 Step 1: Determining reflected apparent temperature

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

13.2.1.1.1 Method 1: Direct method

Follow this procedure:

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

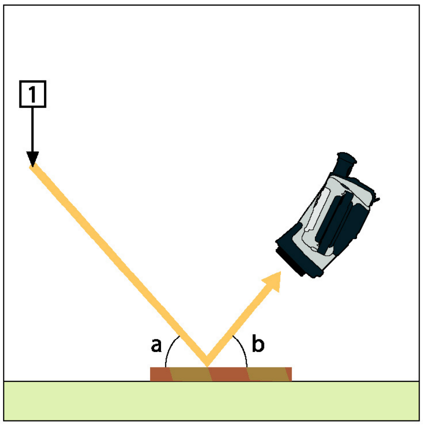


Figure 13.1 1 = Reflection source

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

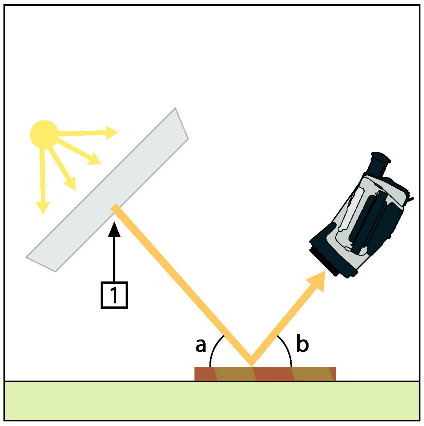


Figure 13.2 1 = Reflection source

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

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

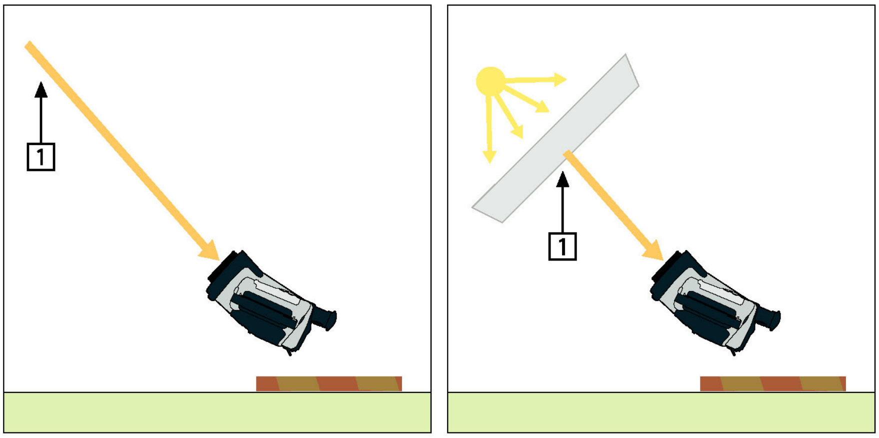


Figure 13.3 1 = Reflection source

Note
Using a thermocouple to measure reflected apparent temperature is not recommended for two important reasons:

- A thermocouple does not measure radiation intensity
- A thermocouple requires a very good thermal contact to the surface, usually by gluing and covering the sensor by a thermal isolator.

13.2.1.1.2 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.

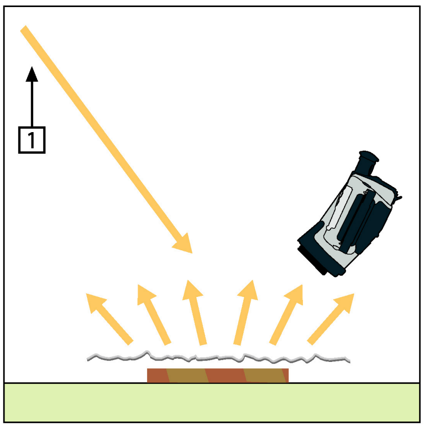


Figure 13.4 Measuring the apparent temperature of the aluminum foil.

13.2.1.2 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.

13.3 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.

13.4 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.

13.5 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%.

13.6 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

14 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.

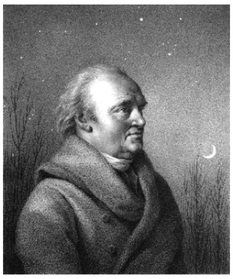


Figure 14.1 Sir William Herschel (1738–1822)

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 14.2 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 14.3 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 14.4 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.

15 Theory of thermography

15.1 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.

15.2 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.

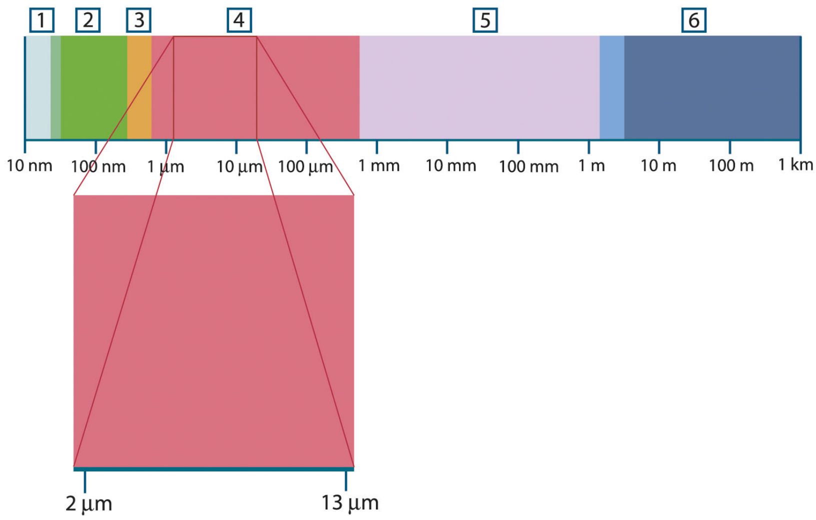


Figure 15.1 The electromagnetic spectrum. 1: X-ray; 2: UV; 3: Visible; 4: IR; 5: Microwaves; 6: Radiowaves.

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:

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

15.3 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.

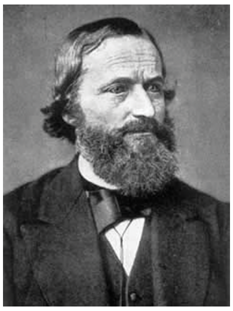


Figure 15.2 Gustav Robert Kirchhoff (1824–1887)

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.

15.3.1 Planck's law

Figure 15.3 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.

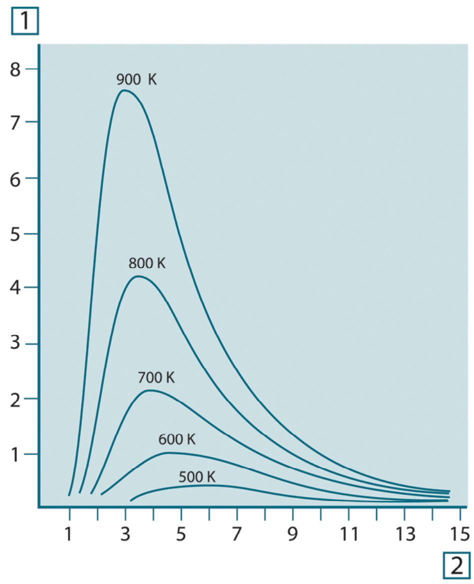


Figure 15.4 Blackbody spectral radiant emittance according to Planck's law, plotted for various absolute temperatures. 1: Spectral radiant emittance (W/cm^2 × 10^3(μm)); 2: Wavelength (μm)

15.3.2 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.

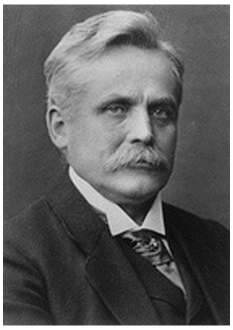


Figure 15.5 Wilhelm Wien (1864–1928)

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.

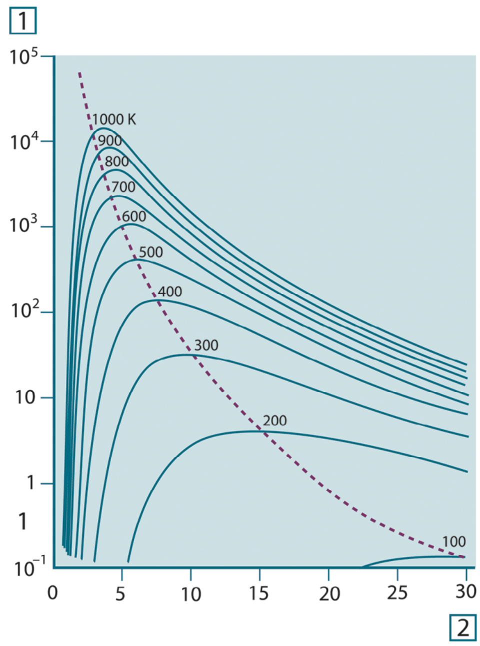


Figure 15.6 Planckian curves plotted on semi-log scales from 100 K to 1000 K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law. 1: Spectral radiant emittance (W/cm² (μm)); 2: Wavelength (μm).

15.3.3 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 15.7 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.

15.3.4 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:

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

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.

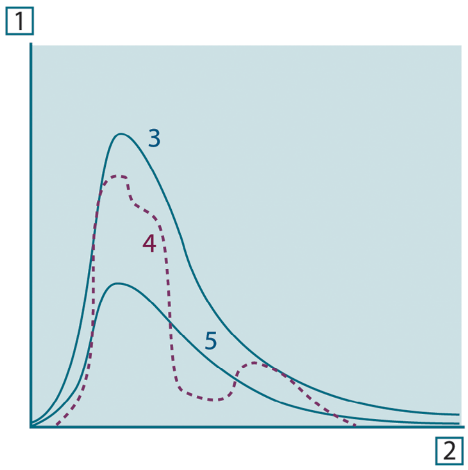


Figure 15.8 Spectral radiant emittance of three types of radiators. 1: Spectral radiant emittance; 2: Wavelength; 3: Blackbody; 4: Selective radiator; 5: Graybody.

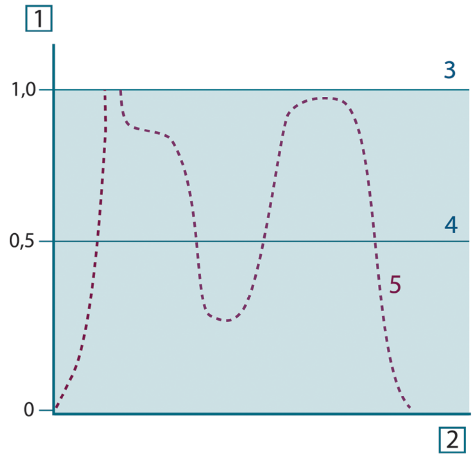


Figure 15.9 Spectral emissivity of three types of radiators. 1: Spectral emissivity; 2: Wavelength; 3: Blackbody; 4: Graybody; 5: Selective radiator.

15.4 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.

16 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.

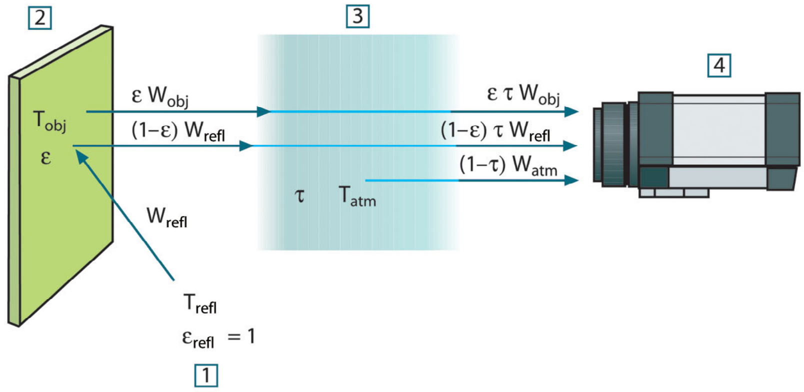


Figure 16.1 A schematic representation of the general thermographic measurement situation.1: Surroundings; 2: Object; 3: Atmosphere; 4: Camera

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 16.1 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.

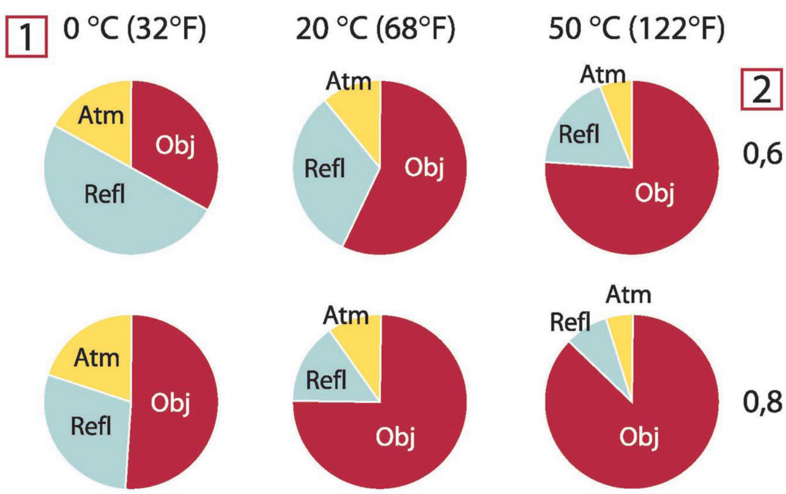


Figure 16.2 Relative magnitudes of radiation sources under varying measurement conditions (SW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: $\tau = 0.88$; T_{refl} = 20°C (+68°F); T_{atm} = 20°C (+68°F).

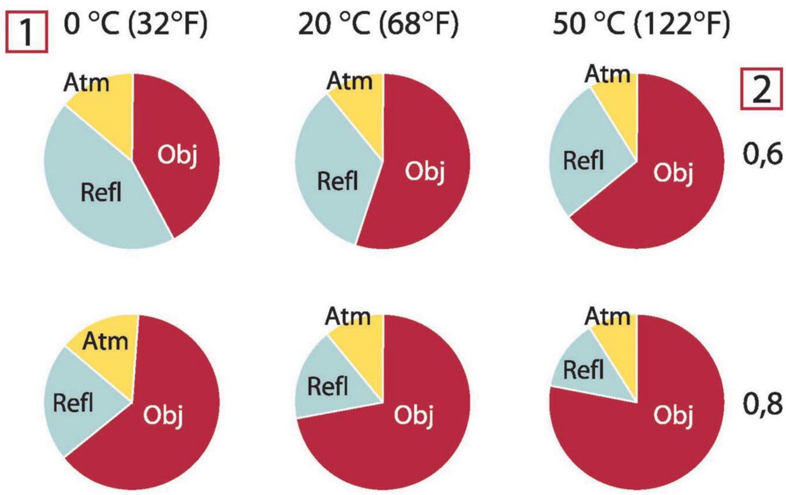


Figure 16.3 Relative magnitudes of radiation sources under varying measurement conditions (LW camera). 1: Object temperature; 2: Emittance; Obj: Object radiation; Refl: Reflected radiation; Atm: atmosphere radiation. Fixed parameters: $\tau = 0.88$; $T_{refl} = 20°C$ (+68°F); $T_{atm} = 20°C$ (+68°F).

17 Emissivity tables

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

17.1 References

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13. ITC Technical publication 29.

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.

17.2 Tables

Table 17.1 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
Aluminum	anodized, light gray, dull	70	SW	0.61	9
Aluminum	anodized, light gray, dull	70	LW	0.97	9

Table 17.1 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	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
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

Table 17.1 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	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
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

Table 17.1 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
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
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

Table 17.1 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
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, care-fully 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
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

Table 17.1 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 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
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

Table 17.1 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
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
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

Table 17.1 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
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
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

Table 17.1 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
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
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

Table 17.1 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
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
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

Table 17.1 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	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

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