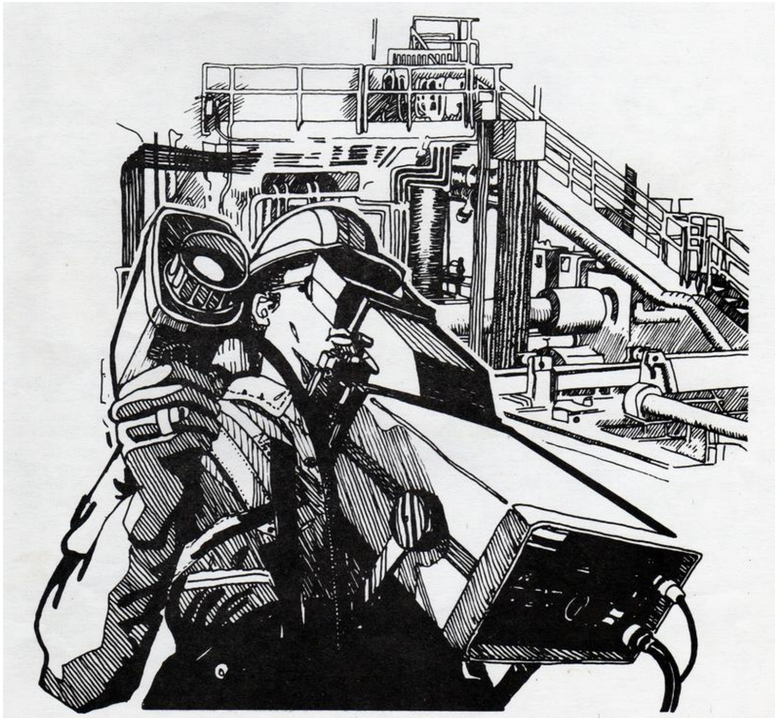
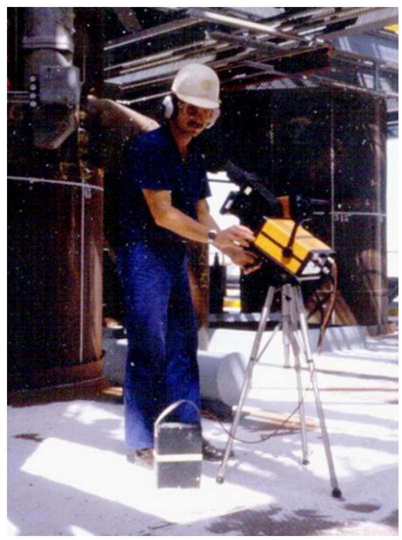
Manual AGA Thermovision 750



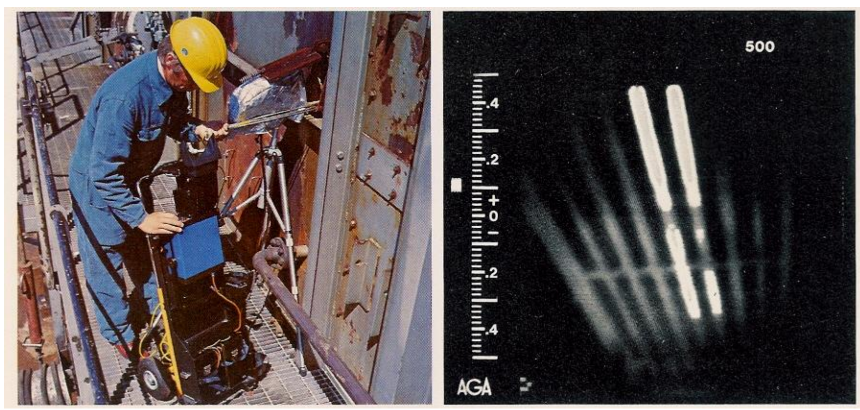
O site Termonautas traz a seus leitores e estudantes o Manual de Operação do AGA Thermovision 750 (1975 -1980), excelente exemplo de um dos clássicos da história da termografia.

Esse foi o modelo de entrada para muitos termografistas (onde me incluo), tendo sido utilizados durante boa parte da década de 80.

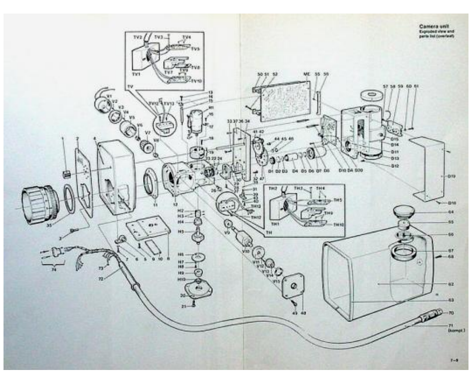


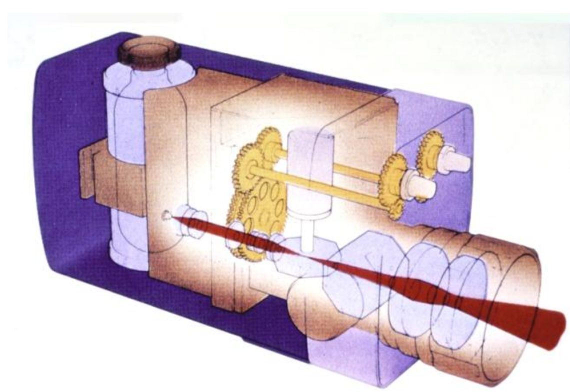
Eram equipamentos sensíveis a onda média (2 a 5,6 micrometros), com detectores resfriados a nitrogênio líquido, muito robustos e confiáveis, construídos para ciclos de vida superiores a 10 anos.

Havia uma versão denominada Petroscanner, produzida especialmente para a inspeção de fornos de processo, que foi muito importante na introdução da termografia nas empresas petroquímicas.



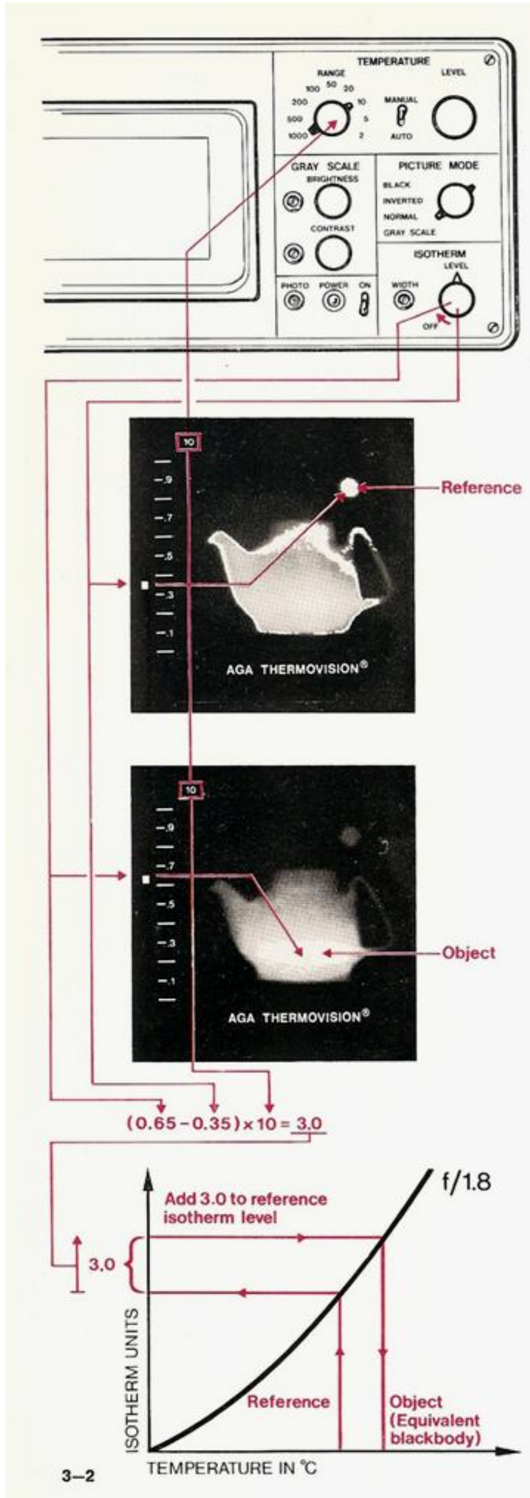
Diferentemente da documentação distribuída atualmente, seus componentes e princípios de construtivos eram muito mais explícitos. Esse manual era acompanhado por um volumoso manual de manutenção que era entregue aos clientes, do qual incluímos ao final do manual um esquema tipo vista explodida da unidade de câmera.

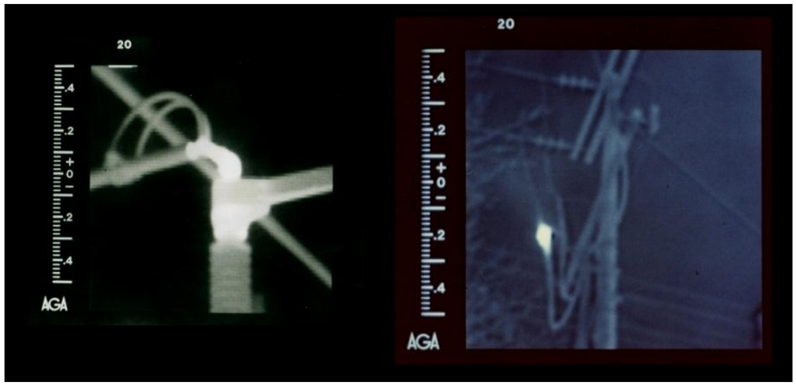




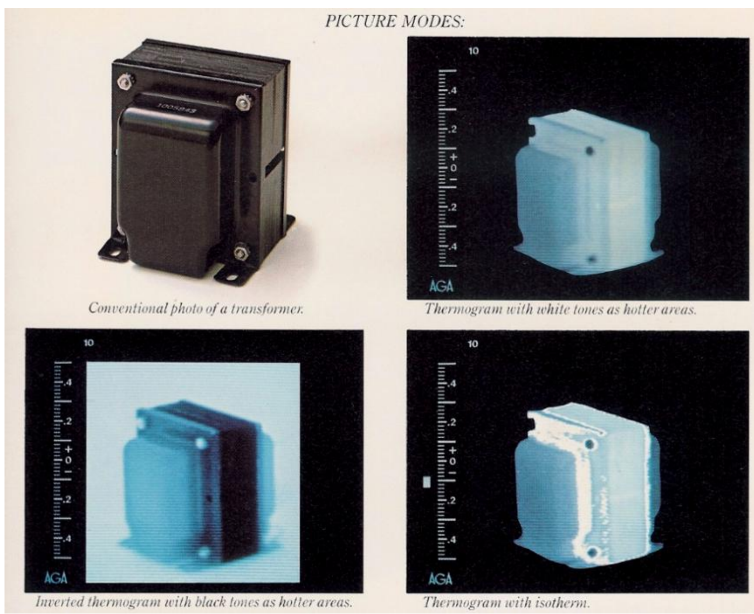
Os equipamentos da série 700 da AGA foram os derradeiros a realizar medições comparativas de temperatura, ou seja, sem a indicação da temperatura do objeto medido.

O termografista determinava a diferença entre a radiação recebida de uma referência de temperatura conhecida e a do corpo a ser medido. Nesse método utilizam-se as curvas de calibração do equipamento segundo o método explicado na Seção 3 do manual.





As imagens eram em preto e branco (escala de cinza direta ou invertida) apresentadas em um CRT (tubo de raios catódicos), o que era problemático quando se inspecionava locais de elevado campo magnético. O registro era realizado por uma câmera fotográfica Polaroid.



Conventional photo of a transformer.

Thermogram with white tones as hotter areas.

Inverted thermogram with black tones as hotter areas.

Thermogram with isotherm.

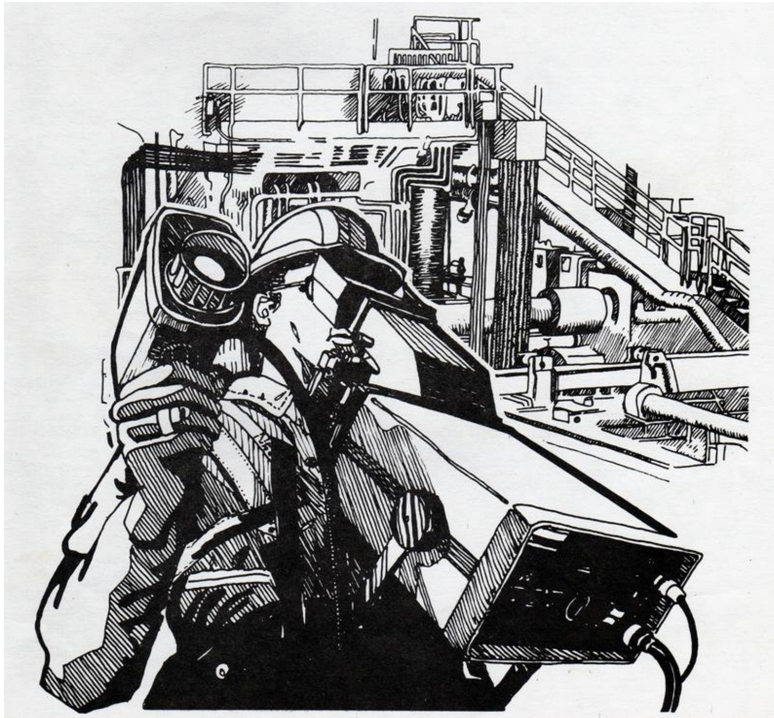
Enfim, uma viagem à tecnologia dos anos 70, a mesma que construiu os Ônibus Espaciais Norte-americanos (que por sinal utilizaram equipamentos desse tipo em seus primeiros voos – ver o artigo 68 - A Termografia e os Ônibus Espaciais)

Boa leitura a todos.

Attílio Bruno Veratti

Termografista Nível III ABENDI

Manual AGA Thermovision 750

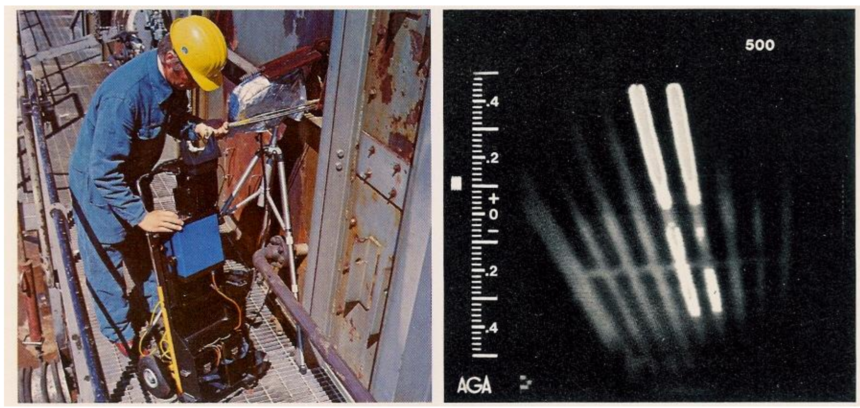


El sitio Termonautas trae a sus lectores y estudiantes el Manual de Operación de AGA Thermovision 750 (1975 - 1980), excelente ejemplo de uno de los clásicos en la historia de la termografía.

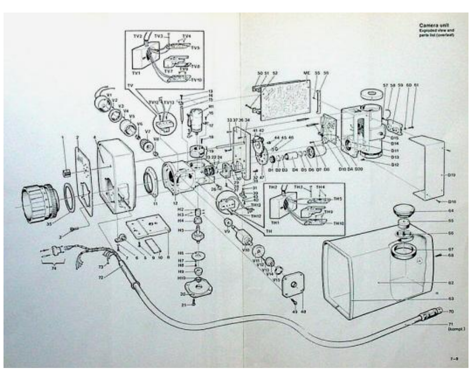
Este fue el modelo de inicio para muchos termógrafos (donde me incluyo), habiendo sido utilizado durante buena parte de la década de los 80.

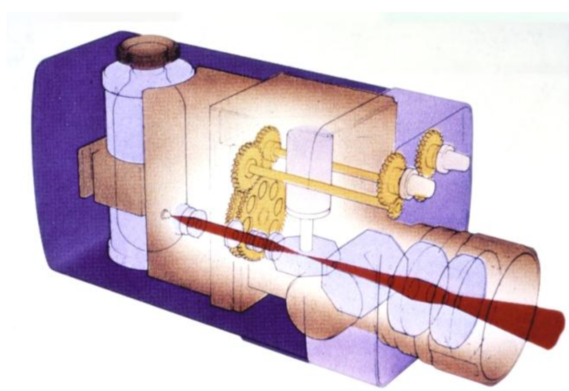
Eran equipos sensibles a la onda media (2 a 5.6 micrómetros), con detectores enfriados por nitrógeno líquido, muy robustos y confiables, construidos para ciclos de vida superiores a 10 años.

Había una versión denominada Petroscanner, producida especialmente para la inspección de hornos de proceso, que fue muy importante en la introducción de la termografía en las empresas petroquímicas.



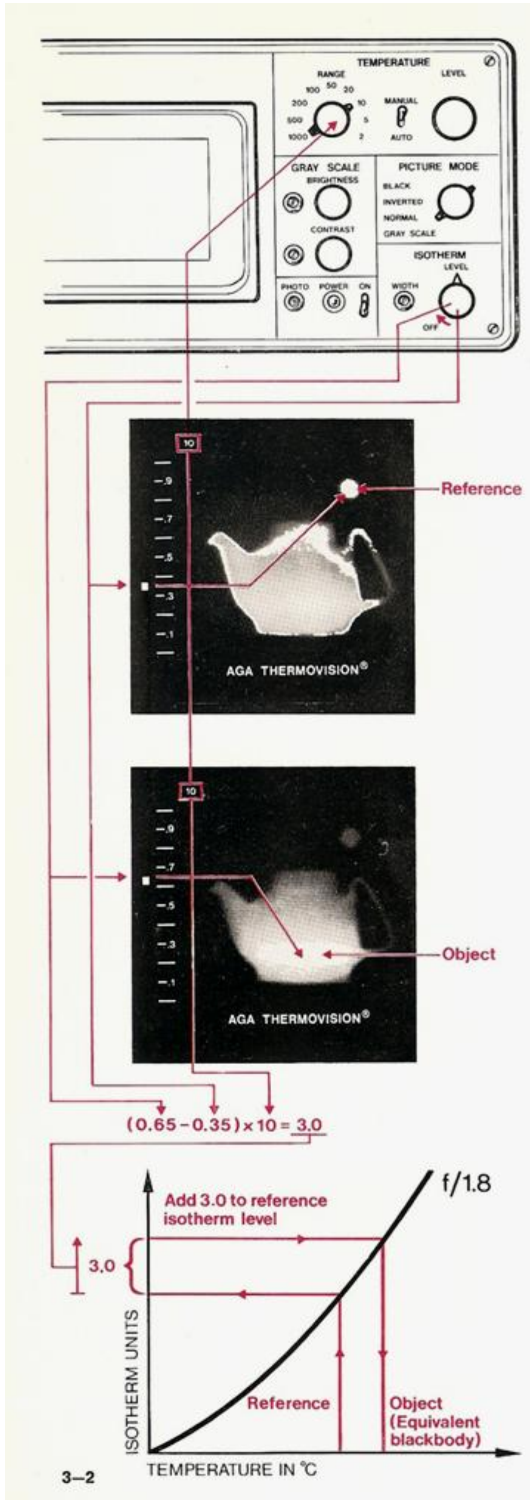
A diferencia de la documentación distribuida actualmente, sus componentes y principios de construcción eran mucho más explícitos. Este manual estaba acompañado de un voluminoso manual de mantenimiento, del cual incluimos, de la parte final de dicho manual, un esquema tipo vista en despiece de la unidad de la cámara.

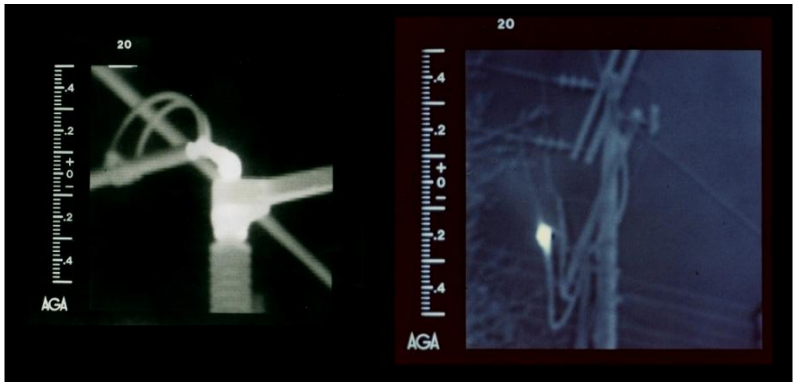




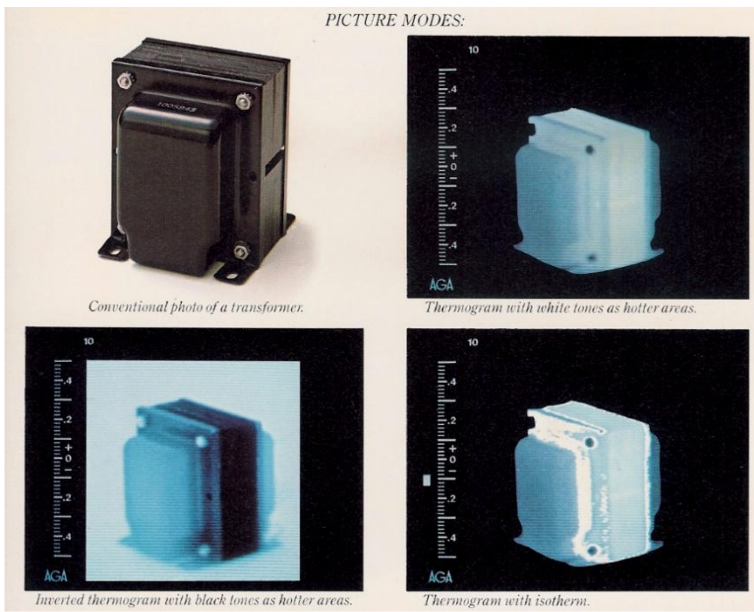
Los equipos de la serie 700 de AGA fueron los últimos en realizar mediciones por comparación de temperatura, es decir, sin la indicación en el monitor de la temperatura del objeto medido.

El termógrafo determinaba la diferencia entre la radiación recibida de una referencia de temperatura conocida y la del cuerpo a ser medido. En este método se utilizaban las curvas de calibración del equipo siguiendo el procedimiento explicado en la Sección 3 del manual.





Las imágenes eran en blanco y negro (escala de grises directa o invertida) y presentadas en un CRT (tubo de rayos catódicos), lo que era problemático cuando se inspeccionaban lugares con elevado campo magnético. El registro era realizado por una cámara fotográfica Polaroid.



PICTURE MODES:

Conventional photo of a transformer.

Thermogram with white tones as hotter areas.

Inverted thermogram with black tones as hotter areas.

Thermogram with isotherm.

En conclusión, un viaje a la tecnología de los años 70, la misma que construyo los Transbordadores Espaciales Norteamericanos (que por cierto, utilizaron equipos de este tipo en sus primeros vuelos - ver el artículo 68 - La Termografía y los Transbordadores Espaciales).

Buena lectura a todos.

Erandy Flores

Termógrafa Nivel III ITC

AGA Thermovision® 750 Operating Manual

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SECTION 1
Introduction

BACKGROUND TO AGA THERMOVISION

All objects emit heat (i.e. infrared radiation) which is constantly being absorbed and re-emitted by ourselves and everything around us. 'Thermography' is the term used to describe the process of making this thermal radiation visible and capable of interpretation.

The pioneer commercial instrument capable of providing live thermal-picture display was the AGA Thermovision system, first introduced in 1965. The new, lightweight Model 750 Thermovision equipment is designed especially for carry-around viewing applications—convenient wherever a compact and completely portable, live thermal picture display is a requirement.

AGA Thermovision is the registered trademark of AGA Infrared Systems AB, a company within the AGA Group of Sweden, whose main activity is the development and manufacturing of professional thermal imaging equipment for both medical and industrial thermography applications.

FEATURES

- Lightweight, hand-held IR-camera unit and portable display.
- Carry-around chest harness for viewing the display while standing, walking, etc.
- Portable equipment-mount comprising integrated tripod, display platform and camera panorama head, for fixed-location viewing.
- Portable nickel-cadmium battery pack, rechargeable from power supply/charger unit.
- Interchangeable camera front lenses & extension rings for different fields-of-view, from tele to wide-angle and close-up.
- Aperture selection on front of camera gives 8 temperature viewing ranges, from —20 to +900°C.
- Camera accepts holders for IR filters to provide selective spectral response and/or extend temperature viewing range to over 2000°C.
- High-speed refractive prism scanner provides 25 picture-fields per second (for flicker-free viewing) with 4:1 field interlacing for raster-free picture display.
- Simultaneous temperature-range-setting digit display in picture.
- Photo-recording attachment, with exposure control which triggers preset picture illumination to correspond with type of film used, and electronically synchronized timing for precise 1 or 4 picture-field exposures.
- Separate power supply unit for ac-powered system operation.
- Remote camera operation possible up to 30 metres from display unit with standard interconnection cables.

SPECIFICATIONS

System

Operating temperature range:	—15 to +55°C
Storage temperature range:	—20 to +70°C
Power requirements:	8—15 V DC, 21 W or 100—240 V AC ±10 %, 45—450 Hz single-phase, 35 VA

IR-camera unit

Type

Cat. No. 556 191 001—Lightweight hand-held, realtime electro-optical prism scanning, with interchangeable front lenses, temperature-range aperture selection and exchangeable spectral-range filters.

Optics

Normal front lens (20°×20° fov):	AGA IR-Lens Si 33/1:1.8/20°
Range of focus:	0.5 m — infinity
Scanned area at 0.5 m:	0.15×0.13 m
Instantaneous field:	3.4 mrad (0.2°) at 50 % contrast
Tele front lens (7°×7° fov):	AGA IR-Lens Ge 99/1:1.8/7°
Range of focus:	1 m — infinity
Scanned are at 1 m:	9.8×8.4 cm
Instantaneous field:	1.1 mrad (0.06°) at 50 % contrast
Close-up viewing:	Lens-extension rings available
Lens mount:	Threaded, standard M44×1 mm
Focusing:	Manual
Apertures:	Eight f/stops, selectable on camera front
Camera mount:	Photographic-standard UNC 1/4″ and 3/8″ threaded mounting holes provided in base
IR filters:	Provision for inserting standard 'gray' and spectral-range filters in special holders

IR detector

Type:	Indium antimonide (InSb) photovoltaic
Spectral range:	2—5.6 μm
Cooling:	Liquid-nitrogen dewar, 2 hours between refillings

Dimensions

See illustration	
Camera-to-display cable:	1.1 m, attached
Extension cables:	10 m. (Up to 3 extension cables can be connected together, for a total possible camera-to-display distance of 31.1 m)
Weight:	
Camera unit, without front lens:	1.5 kg
Normal front lens (20°×20° fov):	0.18 kg
Tele front lens (7°×7° fov):	0.6 kg

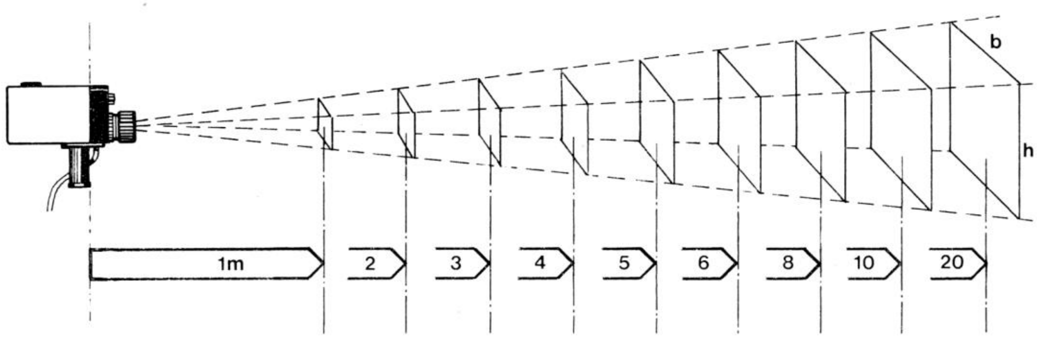
Display unit

Type

Cat. No. 556 191 002—Battery-operated lightweight portable, TV-type thermal picture display, with isotherm display, temperature measurement controls and automatic preset-exposure photo recording.

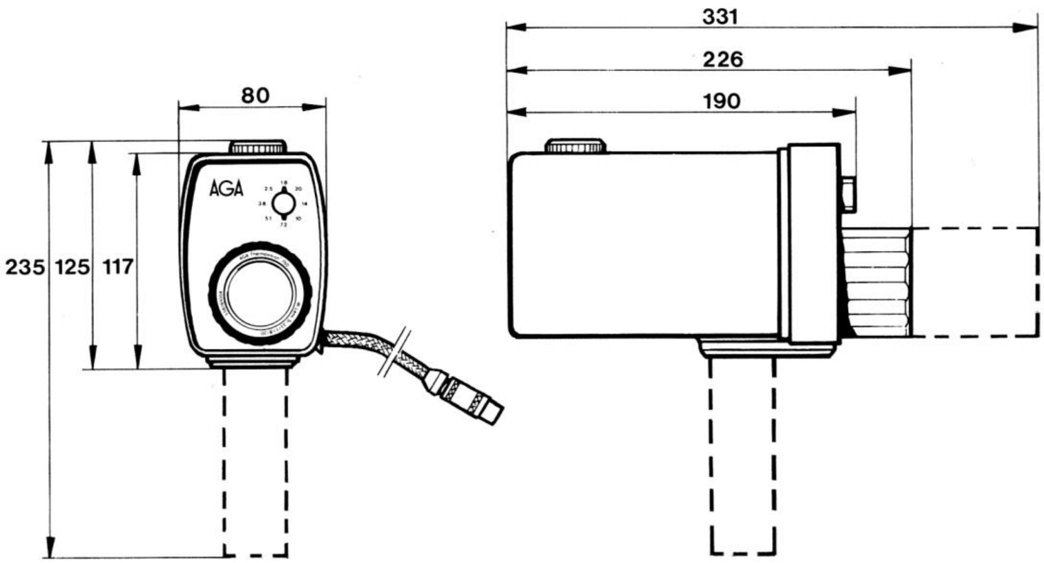
Thermal picture display

Thermal picture size:	50×45 mm, framed by temperature measurement scale and range digit-display
Picture-field frequency:	25 per second



Field of view (in metres):										
7° lens:	b	0.10	0.22	0.34	0.47	0.59	0.71	0.95	1.2	2.4
	h	0.09	0.20	0.31	0.41	0.53	0.63	0.85	1.1	2.1
20° lens:	b	0.33	0.68	1.0	1.4	1.7	2.1	2.8	3.6	7.0
	h	0.29	0.61	0.92	1.2	1.5	1.9	2.5	3.2	6.2

Depth of field (in metres):										
7° lens:	+	0.06	0.22	0.40	0.75	1.2	1.7	3.3	5.5	35
	—	0.03	0.17	0.35	0.60	0.9	1.2	2.0	2.8	9
20° lens:	+	0.5	1.5	4.6	24	∞	∞	∞	∞	∞
	—	0.3	0.8	1.4	2.1	3	4	5	7	17



Camera unit dimensions (mm).

Scanning-line frequency:	2500 per second
Lines per frame:	280 (1:4 interlaced)
Resolving power:	100 picture-elements per line
Pictures modes:	
NORMAL:	Darker = cooler, lighter = warmer
INVERTED:	Darker = warmer, lighter = cooler
BLACK:	For isotherms only, with gray tones suppressed
GRAY SCALE:	Gray-tone wedge presentation, for adjusting BRIGHTNESS and CONTRAST
Photo-recording:	Manual or automatic, timed 4-field-interlaced or single-field (moving object) exposure
Isotherm function:	Width (2—30 %) and level continuously adjustable within temperature spanned by thermal picture

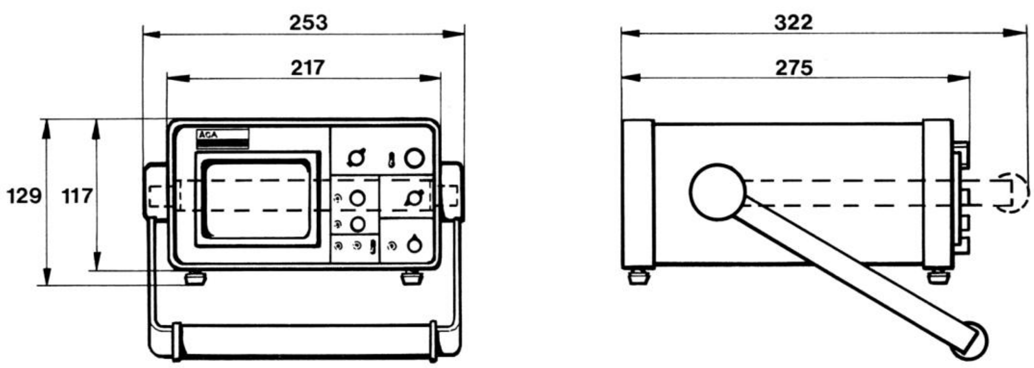
Temperature measurement

Range:	Objects from —20 to +900°C (without filter) in 8 camera f/stops and 9 display range-selections, increased to 2000°C by inserting filter inside camera unit
Minimum detectable temperature difference:	0.2°C at 30°C object temperature
Picture temperature level control:	Automatic (average picture level), or manually adjusted (for precise temperature measurements)

Dimensions

See illustration

Weight: 4.5 kg



Display unit dimensions (mm).

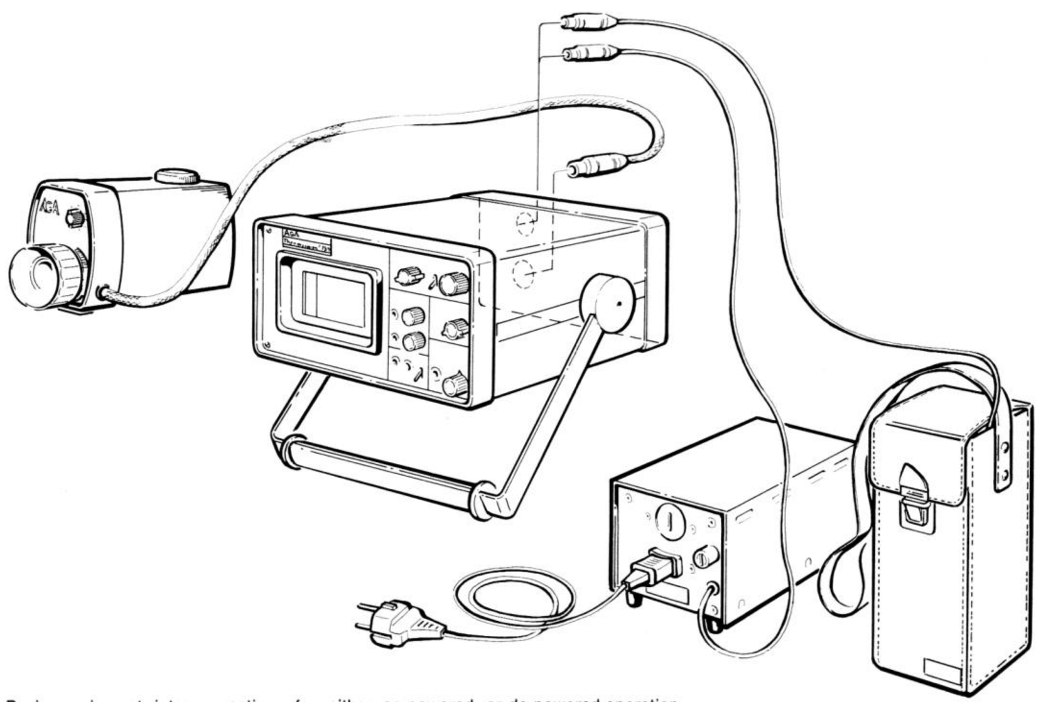
SECTION 2
Operating instructions

GENERAL

The AGA Thermovision 750 equipment is an advanced-technology instrument system, designed for easy operation in the field. Before attempting to use the equipment, please read this section carefully to understand its operation and capabilities. Read especially FIRST-TIME OPERATION, before connecting the equipment to the power-line or battery pack for the first time.

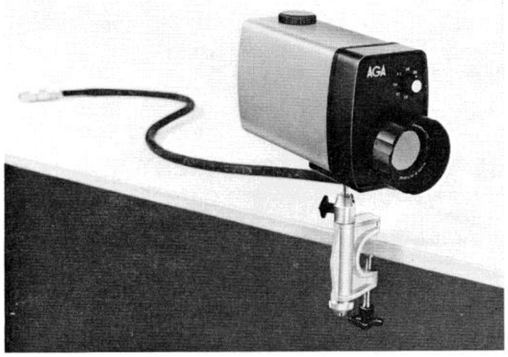
SETTING UP THE EQUIPMENT

The four main operational units of the Thermovision 750 equipment are designed to be interconnected as shown in the illustration, for either ac-powered or battery-powered operation. Methods of mounting the camera and display units vary with each type of thermal-viewing application. The different available mounting possibilities are described under appropriate headings.



Basic equipment interconnections for either ac-powered or dc-powered operation.

For fixed-site operation, the camera unit mounts on the pan/tilt head with the tripod.



Use a photographer's clamping swivel-mount for holding the camera unit stationary, where the tripod may be inconvenient.

The carrying harness enables the operator to observe the thermal-picture display while standing or walking with the equipment.

The cable attached to the camera unit provides a camera-to-display distance of 1.1 m, adequate for ordinary viewing purposes. For increased camera-to-display distances, an extension cable 10 m long is available, As many as three of these extension cables may be connected together without degrading the quality of the thermal picture display.

NOTE: All cable connectors are of the push-to-connect, pull-to-release type—do not turn.

Alternatively, if the cable of the power supply/charger is removed from the back of the display unit and plugged into the top of the battery pack, the power supply can be used to recharge the battery. In addition, a special 2-way cable adapter can be had which enables two battery packs to be recharged from the one power supply unit.

METHODS OF MOUNTING THE CAMERA UNIT

The Thermovision 750 camera unit has a pair of threaded mounting holes in the base (standard UNC $^3/_8$-inch and $^1/_4$-inch) which accept most existing photographic mounting accessories: tripods, clamping swivel-mounts or panorama heads. **When not actually hand-holding the camera unit, it is advised always to secure it to a mount of this type**—both to protect it from being dropped accidentally, and to avoid losing liquid nitrogen coolant from the camera's Dewar flask.

Camera handgrip

For applications where the camera unit is hand-held, a simple AGA-designed handgrip is provided which screws into the front $^3/_8$-inch mounting hole in the camera base. An identical hole is also located in the bottom of the handgrip to enable mounting the camera unit temporarily, without first having to remove the handgrip.

Camera tripod and pan/tilt head

A lightweight tripod and a pan/tilt head are highly recommended for mounting the camera unit in a stationary position. AGA supplies an adjustable tripod which is ideal for the purpose.

Camera (clamping) swivel-mount

Often there is little space to carry a tripod, or else to set one up, where the Thermovision 750 camera unit can be taken. In such cases the only means of mounting the camera unit is to adapt one of various clamping swivel-mounts which are available to photographers.

METHODS OF MOUNTING THE DISPLAY UNIT

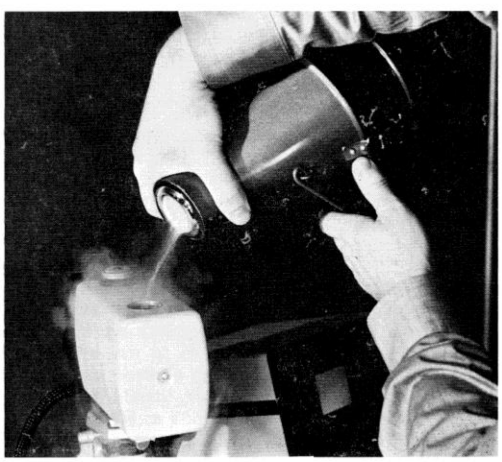
The Thermovision 750 display unit is designed to be mounted in different ways according to the application. It has a universal carrying handle which can be rotated completely around the case to permit different mounting possibilities, and locked in any required position. The handle positions are changed by pressing-in on the side attachment discs and rotating, releasing the side discs to spring out again and lock the handle in its new position.

Display carrying harness

A special two-piece harness is available for carry-around portable Thermovision 750 applications—used to support the display unit in a convenient viewing position in front of the body while standing or walking with the equipment. A straight viewing hood is also available, which slides down in front of the display screen to shade it from the light. The hood contains a magnifying lens, to improve

The tripod-platform provides an integrated IR-camera/display setup for fixed-site viewing.

AC line-voltage switch on the rear of the power supply/charger unit.



Be careful not to allow the liquid nitrogen (—196°C) to come in contact with your eyes or skin when filling the camera dewar.

the visibility of details in the thermal picture when viewed from the distance imposed by the carrying harness. A soft-rubber, angled eyepiece completes the portable display setup.

Display tripod-platform

For viewing objects from a fixed location, a special tripod-platform is available for mounting the display together with the IR-camera on a single tripod. When mounted on the platform, the display can be tilted up or down to present the screen at the best viewing angle, and then locked in that position.

Directing the camera unit with the aid of the panorama head is independent of the display tilting angle. The tripod platform mounting setup permits panning both the camera and display units in unison, providing an integrated IR-camera/display which is ideal for single operators to use in fixed locations.

FIRST-TIME OPERATION

Before connecting the Thermovision 750 equipment to the ac power-line for the first time, be sure that the voltage selector of the power supply unit is set to the correct line voltage.

Operating temperatures

Thermovision 750 is designed to be operated where the ambient air temperature is between —15 and +55°C. The system requires approximately 5 minutes for rated temperature measurement accuracies in the AUTO level control mode, and 30 minutes in the MANUAL mode—after filling the detector dewar with liquid nitrogen and power is applied.

Filling with liquid nitrogen

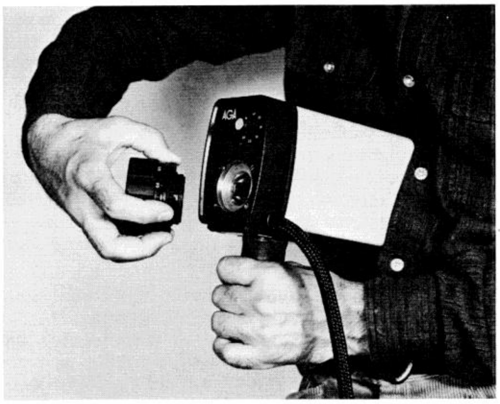
The sensitive detector element in the camera unit is cooled by liquid nitrogen (LN2), at —196°C, to obtain optimum camera response to infrared radiation. The camera will not be damaged if operated without coolant, but no thermal picture will result.

SAFETY FIRST: Although liquid nitrogen is not particularly hazardous, some safety precautions must be observed, i.e.

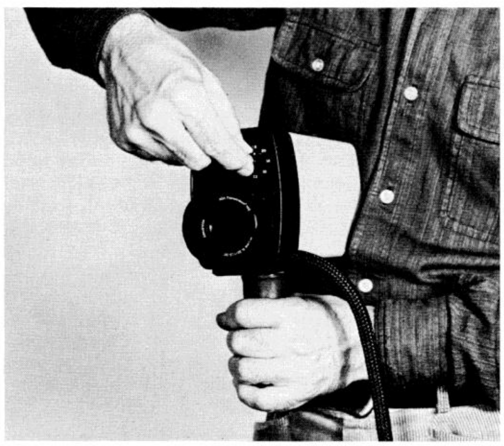
- **Never store the liquid, even briefly, in a tightly stoppered container.** LN2 and similar cryogenic liquids are always stored in Dewar (thermos-type) flasks or the equivalent, with loosely-fitting covers which allow the gas to boil away without building up dangerous pressures.
- **Never come into direct contact with liquid nitrogen.** Serious frostbite injury (similar to a burn) can result if the liquid is allowed to splash into the eyes or onto the skin.
- **Never leave the filler cap off the camera case.** Screw it on again immediately after filling liquid nitrogen to avoid the risk of spilling the liquid outside the case—especially advisable when hand-holding the camera unit.

Use the following procedure for filling the camera dewar with LN 2:

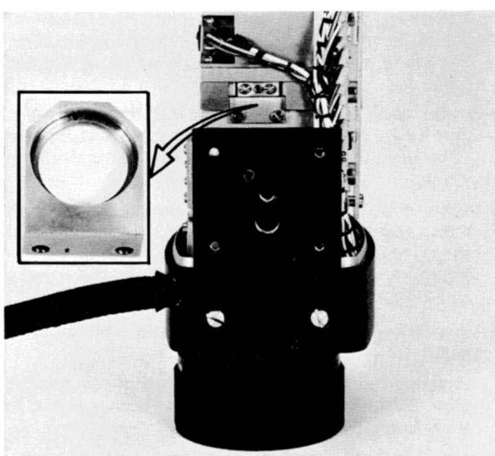
1. Unscrew the filler cap from the top of the camera case. (Make it habit to place the cap in your pocket to avoid losing it.)
2. Check that the dewar is dry. If there is any condensed water in the bottom, wipe it dry. (Cotton wool on the end of a thin stick is ideal for the purpose.)



Grip the knurled lens-ring nearest the camera front when removing or mounting lenses on the camera unit.



Selecting the temperature-range aperture setting on the front of the camera unit.



The filter holder is exchanged by first removing the camera case and then unscrewing its two mounting screws.

3. Pour in the liquid nitrogen from a storage container, slowly at first until boiling of the liquid stops. Then fill the dewar to the top.
4. Screw on the filler cap again securely.

Useful tip: When atmospheric humidity is high, ice may form in the bottom of the dewar if the coolant is allowed to boil completely away. To avoid unnecessary delay between fillings, while waiting for the ice to melt and removing the water, always try to keep the dewar at least partly filled with coolant while the camera unit is in use.

Exchanging the camera front lenses

The lenses and extension rings of the camera unit are screwed on and off like ordinary photographic camera lenses. The only precautions are;

- Always remove or mount front lenses by gripping knurled ring nearest camera front.
- Always keep lenses protected in their cases, or with covers on, when not in use. Screw threaded dust cover over lens opening to protect scanner optics.
- Shelter the camera unit from blowing dust or sand when exchanging lenses and rings.
- Avoid touching the IR-optical surfaces of the lenses and camera with the fingers. (To clean any smudges from the IR optics, use only alcohol and clean cotton wool).
- Brush away any sand or grit from the mounting threads of the lenses and rings, and **lubricate very lightly** with lens grease, if necessary, to prevent damage to the threads.

Selecting the camera apertures

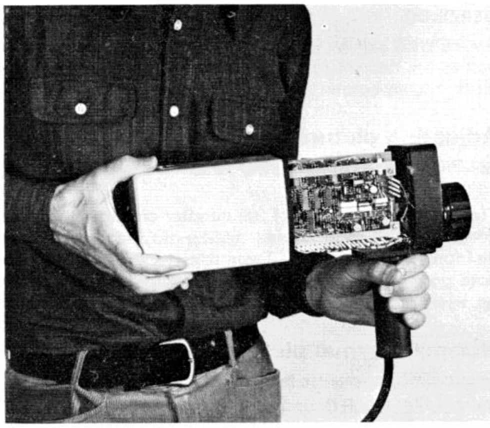
The camera unit is provided with 8 selectable temperature-range apertures, or f/numbers, which are set by the knob on the camera-front. Setting "1.8" (= f/1.8 aperture) provides the range of lowest temperature viewing. Setting "20" (= f/20) provides the range of highest temperature viewing. With the addition of an IR-attenuation filter in the camera the temperature within each of the 8 aperature temperature ranges increases by the amount of attenuation specified for the type of filter used.

When choosing the optimum aperture f-number setting for a given object or temperature range, refer to the set of TYPICAL CALIBRATION CHARTS in section 4. (If an IR filter is used in the camera unit, a special set of calibration curves is required for each filter type.)

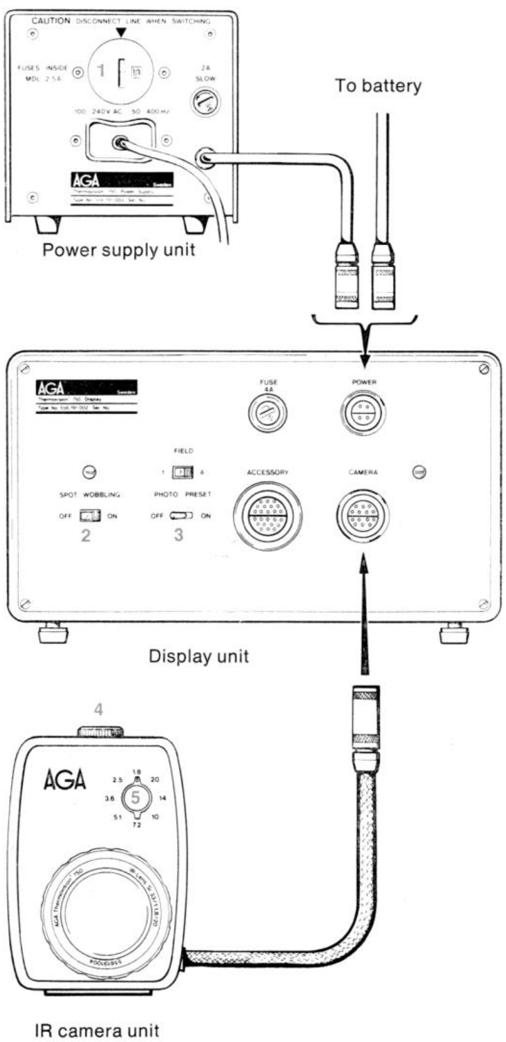
Inserting the camera filters

The camera unit has a special receptacle in the bottom (inside the case) for inserting IR filters in the optical path, used to modify the scanned IR-radiation which reaches the camera detector. Various types of filters are sometimes necessary, to extend the range of the detector when viewing higher-temperature objects, or to permit the temperature patterns to be observed in materials otherwise difficult or impossible to detect. The camera unit is delivered with an empty filter holder already inserted, useful for mounting commercially available disc-type filters having diameters up to 18 mm and 4 mm thick. AGA Infrared Systems AB, in addition, can supply special-purpose IR filters to order. Standard IR filters (complete with holders) are available as standard Thermovision 750 acessories.

Use the following procedure when inserting filters in the camera unit:



When sliding the cover onto the camera unit, be careful not to damage any of the electronic components of the printed circuit board.



NOTE: Same precautions apply as when exchanging the camera lenses.

1. Disconnect the camera unit from the display.
2. Unscrew and remove the coolant filler cap, then carefully **pour out any remaining liquid nitrogen** from the camera dewar.
3. Remove the single screw at the back of the camera unit, which secures the cover to the camera front, and carefully draw the cover back and away from the camera body.
4. Invert the camera body, and remove the two screws from the bottom filter holder. Now lift out the filter holder from the receptacle.
5. Select the holder containing the desired filter and insert it in the receptacle, replacing the two screws.
6. Fit the cover back over the camera body, and then draw it up tight against the camera front with the back mounting screw.
7. Refill the camera dewar with liquid nitrogen, and screw on the filler cap securely again.

ROUTINE OPERATING PROCEDURE

Connecting the equipment

The equipment can be powered either from the power supply unit, the portable battery pack, or (via an auxiliary cable) from any other suitable 12-volt dc source. CAUTION! Before connecting power supply unit, be sure voltage selector **1** is set to correct line voltage. Connect units as shown in figure.

Filling with liquid nitrogen

Unscrew filler cap **4** on IR camera unit. Turn camera upside-down to remove any condensed water from the detector dewar. Carefully pour liquid nitrogen into dewar until full. Screw on filler cap again securely.

Mounting the camera lens

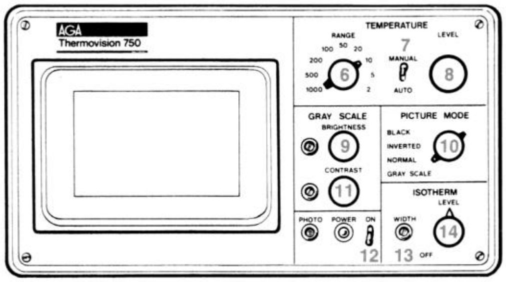
Screw lens onto camera. Adjust lens ring to approximate distance of object. Avoid touching the lens surfaces. (When cleaning lens surfaces, use cotton wool dipped in alcohol or ether, wiping gently once only with each new piece of cotton.)

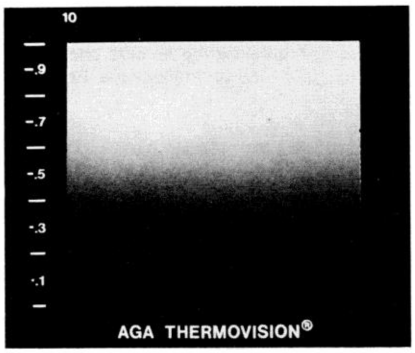
Selecting camera aperture

For object temperatures below 200°C set aperture knob **5** to "1.8". For higher temperatures, select proper aperture from calibration curves in Section 3.

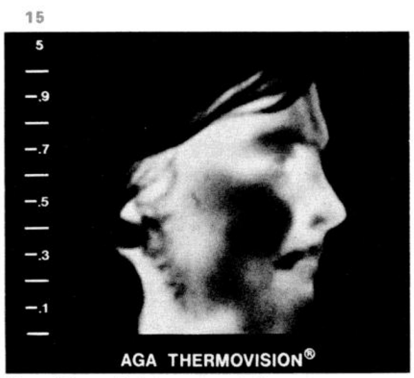
Setting the display unit

Set SPOT WOBBLING switch **2** to "ON" and PHOTO PRESET switch **3** to "OFF" (both on rear of display unit).

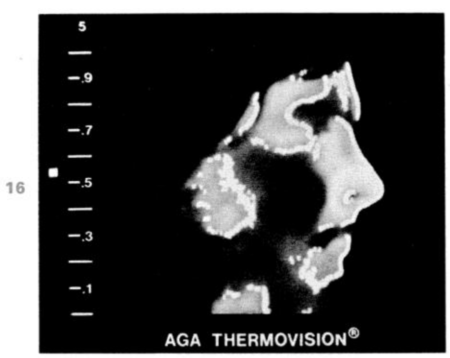




Correctly adjusted gray scale



Normal thermal picture presentation



Normal presentation with isotherm contours

Starting

Set POWER switch **12** to "ON". Red lamp beside switch comes on, camera motors start and, after about 10 seconds, display screen lights up.

Adjusting picture gray scale

Set PICTURE MODE selector **10** to "GRAY SCALE" and adjust as follows:

Turn CONTRAST knob **11** full counter-clockwise. Adjust BRIGHTNESS knob **9** until middle-gray tone is evenly distributed over screen. Then adjust CONTRAST knob until gray scale appears black at bottom, gray halfway up, white at top.

Normal thermal picture

Automatic temperature level control

Set MANUAL/AUTO switch **7** to "AUTO" and PICTURE MODE switch **10** to "NORMAL" (warmer details appear lighter in picture, cooler details darker). Set TEMPERATURE RANGE selector **6** (e.g. position "10" gives a temperature span in picture of 10°C at room temperature). Chosen range appears on screen above picture, **15.** Start with a high setting and reduce to desired value. Refocus camera to obtain sharpest possible image.

Manual temperature level control

For manual adjustment of picture temperature levels, set MANUAL/AUTO switch **7** to "MANUAL". Adjust TEMPERATURE LEVEL multiturn knob **8** until desired gray tones are obtained.

Inverted presentation

For a thermal picture in which warmer details show up darker and cooler details lighter, set PICTURE MODE selector **10** to "INVERTED".

Isotherm function

To utilize the isotherm function (which brightens up all details having the same temperature in picture) turn ISOTHERM LEVEL knob **14** clockwise from the "OFF" position.

Adjusting the isotherm level

The position of an isotherm within the picture temperature range is adjusted with ISOTHERM LEVEL knob **14.** Position is indicated by a marker **16** on vertical scale of display screen, the 10 divisions of which span the selected temperature range.

Adjusting the isotherm width

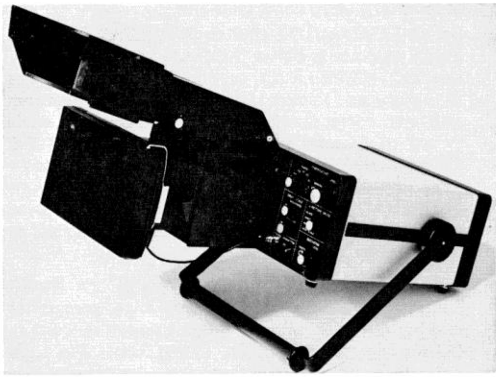
The width of the isotherm marker **16** can be varied by adjusting ISOTHERM WIDTH screwdriver control **13.** A commonly used width is 1 scale division.

Black picture

For isotherm-only presentation (with gray tones in picture suppressed) set PICTURE MODE selector **10** to "BLACK".

PHOTO-RECORDING ATTACHMENT WITH POLAROID CAMERA BACK

This photo-recording attachment is designed for making thermograms from the Thermovision 750 display screen, on Polaroid Land Type 87 or Type 107 film (depending on type of camera back supplied).



Display unit with photo-recording attachment mounted.

Step-by-step photographing instructions

Mount attachment

1. Mount photo-recording attachment on display unit: Mate grooves and slide down in front of display screen.

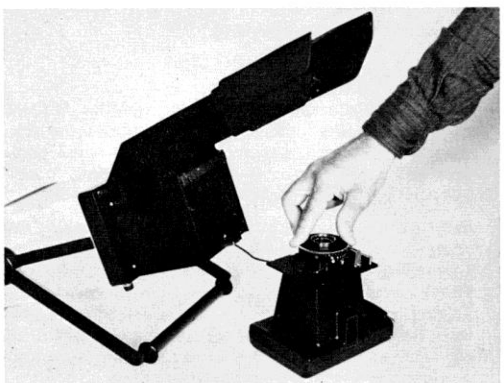
Load film

2. Load film in camera back: Open back, place film pack inside, close back, pull out black paper protective sheet.

Set shutter-speed and f/stop

3. Remove camera from photo-recording attachment. First press in sides of bottom latch while lifting up on camera back, then carefully lower and pull out camera.
4. Set camera shutter-speed dial to "1" (front ring).
5. Set camera f/stop index to "8". On rear of display unit: Set SPOT WOBBLING switch to "ON", FIELD switch to "4". Four interlaced picture fields will then be automatically exposed (4/25 sec).

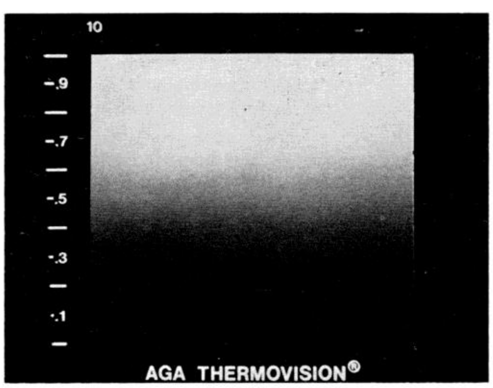
   For moving objects, or when IR camera is handheld, set f/stop index to "5,6", FIELD switch to "1". One picture field will then be automatically exposed (1/25 sec).
6. Replace camera in photo-recording attachment: First tilt camera upwards while engaging two slots with guide pins and front plate in groove at top of opening. Then swing camera down carefully while pressing firmly against back until sides of bottom latch snap open outside mounting plate.
7. Plug in synchronization cable connector to PHOTO receptacle (push-to-lock connector, do not turn).



The camera body removed to adjust shutter speed and f/stop settings.

Make gray-scale test exposure

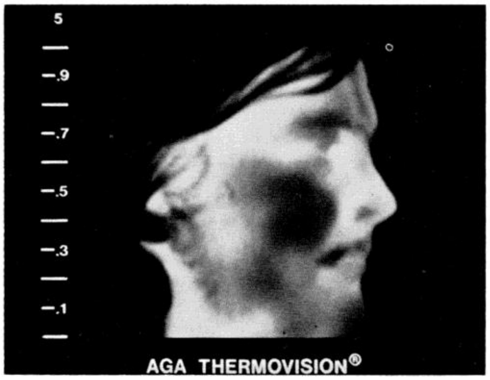
8. Set PICTURE MODE selector to "GRAY SCALE".
9. Make gray-scale test exposure: Close viewing door. Depress shutter control all the way down and then release it.
10. Develop film: Pull out white tab, then slowly and steadily draw emerging yellow tab clear out to obtain developing film.
11. Let develop at least 30 seconds in ambient temperatures 21—35°C (70—95°F), then quickly separate print from paper negative — starting at end near yellow tab. (Avoid contact with development chemicals. Fold negative, moist side in, and dispose in litter container).



Thermogram showing an optimum gray-scale reproduction as the result of having correct photo-preset brightness and contrast settings.

Adjust gray tones

12. Compare gray tones in print with display: If not satisfactory, set rear PHOTO PRESET switch to "ON", make fine adjustments to BRIGHTNESS and CONTRAST screwdriver controls, and repeat test exposure. When finished, return PHOTO PRESET switch to its normal "OFF" position.



Example of a correctly exposed thermogram, with properly adjusted brightness and contrast.

Adjust thermal picture using isotherm

13. Set MANUAL/AUTO switch to "MANUAL", PICTURE MODE selector to either "NORMAL" or "INVERTED". Use ISOTHERM LEVEL control to determine areas of highest and lowest temperatures to be recorded, and read corresponding marker positions on scale to left of thermal picture. Adjust TEMPERATURE LEVEL control so that these positions fall symmetrically above and below ".5" on the scale. Choose TEMPERATURE RANGE selector setting which gives greatest spread between highest and lowest marker positions on scale.

14. If necessary, adjust BRIGHTNESS and CONTRAST controls to obtain optimal picture on screen for viewing (settings will not affect thermogram print). Do not use TEMPERATURE LEVEL control to compensate for different ambient light conditions.

Make thermogram exposure

15. Depress shutter control all the way down and then release it.

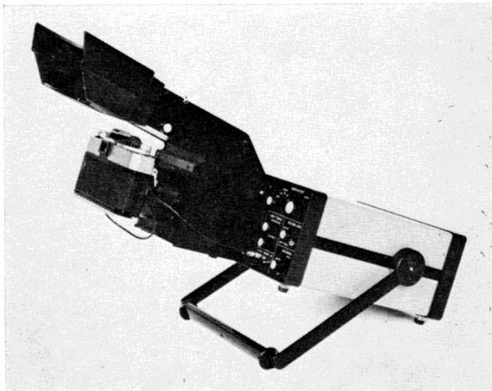
16. Develop film according to steps 10 and 11, and compare print with display: If still not satisfied, adjust with screwdriver controls according to step 12, and repeat thermogram exposure.

Film developing tips

- Develop the film longer in cooler weather. Underdevelopment produces gray, low-contrast thermogram prints. Overdevelopment gives too much contrast. Lengthen or shorten development time to obtain optimum image contrast.
- Pictures made on Type 107 film should be coated as soon as it is convenient to do so — within two hours, if possible. Uncoated pictures may begin to fade and streak. Avoid touching the face of uncoated prints. To coat print: Lay it face up on a clean smooth surface, hold one edge and coat entire print with 6—8 overlapping strokes of the coater, making sure that corners and borders are covered.
- Before loading each film pack, check that developer spreader mechanism in camera back is clean. Dirt or chemical residue in spreader rollers or film exit door can cause stoppages which may ruin an entire film pack.

Cleaning the Polaroid camera back

1. Open the cover of the camera back, grasp both loops of the developer spreader and lift the entire assembly out of the cover.
2. Turn over the spreader assembly and lift up on the lever which locks open the spreader blades.
3. Hold the spreader under running water to rinse away any dirt or chemical residue from the blades and mechanism, shake and let dry. Alternatively, clean the spreader blades, etc. with a piece of damp cloth or paper towel—being careful not to leave any paper bits in the mechanism.
4. Check also for dirt, torn-paper bits, etc. in the film-exit door and slit located on the short side of the back cover. Clean if necessary, using a damp cloth.
5. Finally, replace the spreader in the cover again: Release the blade locking-lever to close the blades, turn over the spreader assembly and position it with the blades against the inside of the black exit door and snap both loops back down into place.



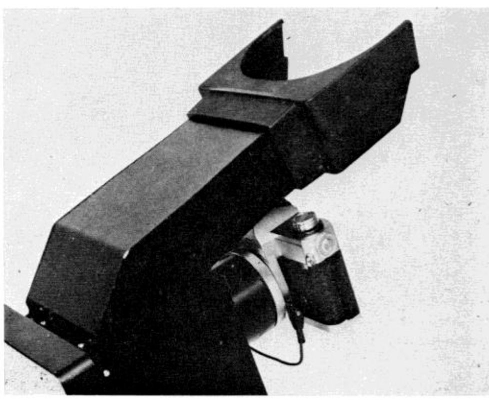


PHOTO-RECORDING ATTACHMENT WITH 35-MM CAMERA BACK

This photo-recording attachment is designed for making thermograms from the Thermovision 750 display screen on 35-mm film.

Step-by-step photographing instructions

Mount attachment

1. Mount photo-recording attachment on display unit.
2. Mount camera back on attachment.
3. Connect both camera cables: one to PHOTO receptacle on display unit, the other one to flash contact on camera back.

Set camera

4. Set camera shutter-speed dial to "1". No aperture or film speed setting is required.

Check function

5. Start system by setting POWER switch to "ON".
6. On rear of display unit: Set FIELD switch to "4", SPOT WOBBLING switch to "OFF", and PHOTO PRESET to "ON".
7. On front of display unit: Set PICTURE MODE selector to "GRAY SCALE" and adjust BRIGHTNESS and CONTRAST screw driver controls to obtain a clear gray scale.
8. Open camera back and cock shutter by means of film advance lever.
9. Press shutter release button and at the same time look through the camera housing (not through the viewer.) If everything is OK one should see a brief flicker just before the shutter curtain closes when going up.

Make final settings

10. Set FIELD switch to "1" and SPOT WOBBLING switch to "ON" (for moving objects), or "4" and "OFF" respectively (for non-moving objects.)
11. Set CONTRAST screwdriver control to suit film type used. The values given in the table below may be used as a guide for first-time setting; make your own notations to obtain best results. ($^1/_4$, $^1/_2$ and $^3/_4$ indicates how much the control is turned clockwise from its zero position.)

Film type	Setting
Black/white 125 ASA (22 DIN)	$^1/_2$
Black/white 400 ASA (27 DIN)	$^1/_4$
Kodak Ektachrome 160 ASA (23 DIN)	$^3/_4$
Kodacolor 80 ASA (20 DIN)	$^3/_4$

Colour film usually makes better thermograms, and is normally used for transparencies.

12. Pressing face against rubber eyepiece, adjust BRIGHTNESS screwdriver control until scanning lines just become invisible below .2 on the isotherm scale.
13. Reset PHOTO PRESET to "OFF". All the knob-operated controls on the front can now be operated in the usual way.

Expose

14. Close the light hatch, expose, and advance the film one frame.

SECTION 3
Temperature measurements

FUNCTIONS OF THE DISPLAY CONTROLS

Basically, three separate functions are provided by the display controls when measuring temperatures, i.e.

- TEMPERATURE RANGE and LEVEL—Different temperature ranges spanned by the thermal picture can be selected, and the absolute temperature level of the picture adjusted by the operator.
- ISOTHERM WIDTH and LEVEL—Temperatures are measured in the picture by superimposing brightened-up isotherm contours on the thermal images of objects. The isotherm contours identify areas of equal temperature (i.e. equal tones of gray) in the picture. The isotherm level and width adjustment are indicated by the length and position of the vertical marker which moves up and down the left-hand picture scale as the controls are adjusted. The ten divisions of the scale represent fractions between 0—1 of temperatures spanned within the picture. The absolute temperature level of the picture moves up or down within the total observable temperature range of the instrument under control of the TEMPERATURE LEVEL knob.
- GRAY SCALE BRIGHTNESS and CONTRAST—These characteristics of the picture can be adjusted to suit different ambient-light viewing conditions. When photographing the thermal picture, the special duplicate screwdriver controls are used to match picture brightness and contrast to the type of film in the photo-recording attachment. The preset adjustments are then activated automatically during the instant of shutter opening to expose the film properly, regardless of the actual viewed brightness and contrast control settings. The temperature measurements are not affected by these controls, only the visual qualities of the picture.

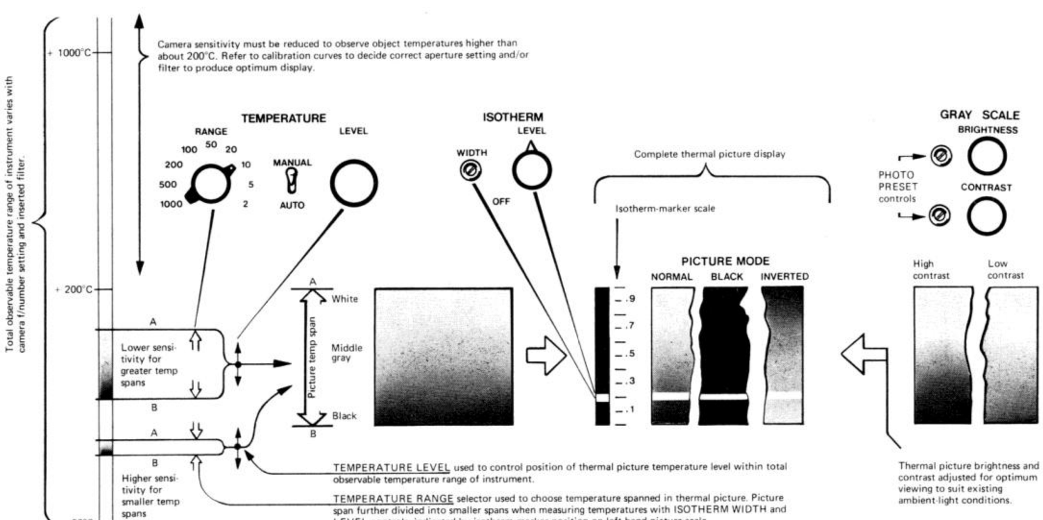
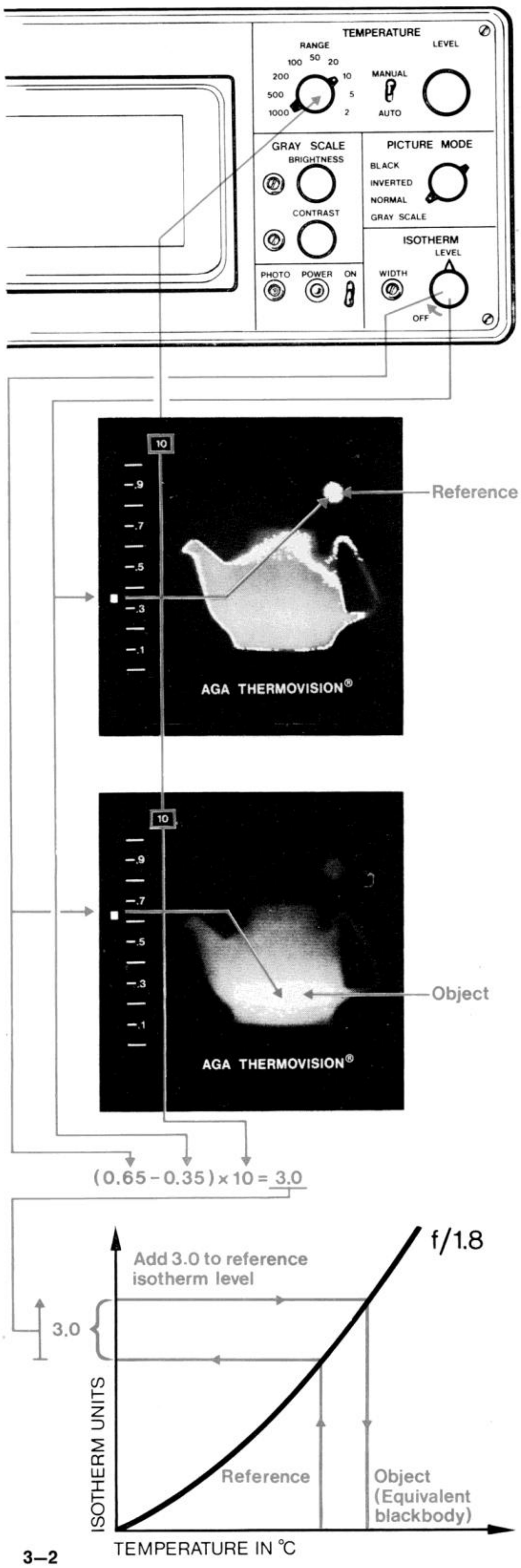


Diagram illustrating the relationship between the three separate display control functions: TEMPERATURE RANGE/LEVEL. ISOTHERM WIDTH/LEVEL and GRAY SCALE BR:GHTNESS/ CONTRAST.



TEMPERATURE MEASUREMENT PROCEDURE

When making precise temperature measurements, a known-temperature source is always used as a reference in the thermal picture. The reference temperature level should not lie too far from the apparent temperature of the object of interest in the picture.

First, the BRIGHTNESS and CONTRAST controls are adjusted in the GRAY SCALE picture mode. **These controls do not affect the temperature measurement—only the visual appearance of the picture.**

The TEMPERATURE RANGE and LEVEL controls are then adjusted to obtain images of all objects of interest in the picture. If the sensitivity of the IR-camera unit is too great at the f/1.8 setting to include the object images in the picture, the optimum f/number setting is chosen with the help of the calibration curves.

The picture adjustments are made easier if the ISOTHERM function is used at the same time to brighten-up object details for identification. The BLACK and INVERTED modes are also helpful for identifying details of objects in the picture.

When an optimum thermal picture has been obtained which contains images of all details to be measured (including a known-temperature source for reference) the temperature measurements can begin. **Do not make any changes in the TEMPERATURE RANGE and LEVEL control settings during the step-by-step measurement procedure:**

The following procedure assumes that the object is a blackbody radiator:

1. Brighten up reference source in picture with isotherm contour. Note resulting marker position on vertical scale.
2. Now brighten up object area of interest with isotherm contour and note the new marker position.
3. Subtract lower from higher marker position and multiply difference by TEMPERATURE RANGE setting.
4. Next, using correct f/number calibration curve, locate temperature of reference source on TEMPERATURE axis, proceed straight up to curve, then over to ISOTHERM UNITS axis. Read off reference isotherm level.
5. Add or subtract difference found in Step 3: add if marker position for object (Step 2) is higher than for reference (Step 1), subtract if lower. Result is object isotherm level.
6. Finally, using calibration curve again, locate object isotherm level on ISOTHERM UNITS axis, proceed straight over to curve, then down to TEMPERATURE axis and read off temperature level of object area.

NOTE: The calibration curves are plotted for blackbody simulation objects and references having emissivities in excess of 0.98. (Ideal blackbody = 1.) To obtain accurate results for objects with emissivities less than around 0.95, use the formulas or the computer program given further on in this section.

TEMPERATURE MEASUREMENT CALCULATIONS

The problem of measuring true temperature when objects differ significantly from the blackbody ideal involves calculation. Most objects are essentially opaque in the infrared, so the IR-property which influences the temperature measurements in most cases is the emissivity of objects.

In the general case, a number of different parameters are involved in the temperature and emissivity determinations which are related to each other by two basic formulas.

These parameters are:

- T_o = object temperature
- ε_o = object emissivity
- T_r = reference temperature
- ε_r = reference emissivity
- T_a = ambient temperature ($\varepsilon_o \simeq 1$)
- $\triangle i_{or}$ = image isotherm difference (i_o—i_r) observed between the thermal images of the object and reference temperatures
- I_o = absolute isotherm level for the object temperature T_o read from the calibration charts
- I_r = absolute isotherm level for the reference temperature, T_r read from the calibration charts
- I_a = absolute isotherm level for the ambient temperature T_a read from the calibration charts

NOTE: The image isotherm levels i_o and i_r are obtained by multiplying the isotherm marker positions for the object and reference temperatures, respectively, by the RANGE setting of the display. The sign of $\triangle i_{or}$ is (+) if the isotherm marker position for the object temperature is higher on the scale at the left of the thermal picture than the marker position for the reference temperature, and (—) if the marker position for the reference temperature is highest on the scale. (This is true for the image isotherm regardless of the true relation of the two temperatures.)

When both object and temperature reference emissivities can vary:

Basic formula for determining isotherm value I_o for true temperature of object when object emissivity ε_o reference temperature T_r and reference emissivity ε_r are known:

$$I_o = \frac{\triangle i_{or}}{\varepsilon_o} + \frac{\varepsilon_r}{\varepsilon_o} I_r + \left(1 - \frac{\varepsilon_r}{\varepsilon_o}\right) I_a \qquad (1a)$$

Basic formula for determining object emissivity ε_o when object temperature T_o reference temperature T_r and reference emisivity ε_r are known:

$$\varepsilon_o = \frac{\triangle i_{or} + \varepsilon_r (I_r - I_a)}{I_o - I_a} \qquad (2a)$$

When the reference temperature source is a blackbody simulator ($\varepsilon_r \simeq 1$):

Formula for determining I_o when ε_o and T_r are known:

$$I_o = \frac{\triangle i_{or}}{\varepsilon_o} + \frac{I_r}{\varepsilon_o} + \left(1 - \frac{1}{\varepsilon_o}\right) I_a \qquad (1b)$$

Formula for determining ε_o when T_o and T_r are known:

$$\varepsilon_o = \frac{\triangle i_{or} + I_r - I_a}{I_o - I_a} \qquad (2b)$$

When the reference is the unfocused background temperature ($T_r = T_a, \varepsilon_r \simeq 1$):

Formula for determining I_o when ε_o is known:

$$I_o = \frac{\triangle i_{oa}}{\varepsilon_o} + I_a \qquad (1c)$$

NOTE: $\triangle i_{oa} = i_o - i_a$, difference between image isotherm values for object and ambient temperatures.

Formula for determining ε_o when T_o is known:

$$\varepsilon_o = \frac{\triangle i_{or}}{I_o - I_a} \qquad (2c)$$

When the difference in temperature between points on the same object is measured ($\varepsilon_r = \varepsilon_o$):

Formula for determining I_o when ε_o and T_r are known:

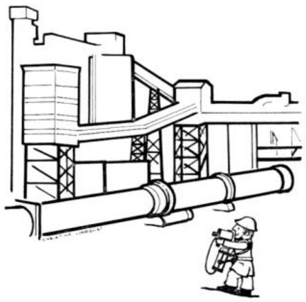
$$I_o = \frac{\triangle i_{or}}{\varepsilon_o} + I_r \qquad (1d)$$

Formula for determining ε_o when T_o and T_r are known:

$$\varepsilon_o = \frac{\triangle i_{or}}{I_o - I_r} \qquad (2d)$$

SOME WORKED EXAMPLES

The following worked examples are selected to demonstrate the use of the above-derived formulas together with the thermal picture display scales and the calibration charts in determining temperatures and emissivities of objects with Thermovision in a variety of industrial situations.



1. Emissivity when the reference temperature source is a blackbody simulator, in the case of an industrial kiln

It is required to determine the emissivity of the oxidized steel shell of a large industrial drying kiln, for use later in determining the shell temperature remotely while the kiln is rotating.

For the purpose of the emissivity determination the shell temperature is held at 100°C. A temperature reference source is available with $\varepsilon \simeq 1$, which can be set to the temperature of the shell. The temperature of the surroundings is 20°C. The given parameters are, thus:

$\varepsilon_o = ?$ $T_o = 100°C$
$\varepsilon_r \simeq 1$ $T_r = 100°C$
$\varepsilon_a \simeq 1$ $T_a = 20°C$

From the camera-aperture f/1.8 calibration curve we read the following absolute isotherm levels for the known temperatures:

$I_o = 191$ isotherm units
$I_r = 191$ isotherm units
$I_a = 21$ isotherm units

With RANGE set at 50, we adjust the LEVEL control to brighten up the thermal image of the reference source with the isotherm marker set at .9 on the scale at the left side of the thermal picture. We find the isotherm marker position which brightens up the thermal image of the shell is, then, .24 on the scale. Calculating the image isotherm levels, we get:

$i_o = 0.24 \cdot 50 = 12$
$i_r = 0.90 \cdot 50 = 45$

From this we calculate the difference between the two image isotherms levels:

$\triangle i_{or} = 12 - 45 = -33$

Since $\varepsilon_r \simeq 1$, Formula (2b) can be used. Thus, we have:

$$\varepsilon_o = \frac{-33 + 191 - 21}{191 - 21} = \frac{137}{170} = 0.81$$

2. Temperature when the reference temperature source is a blackbody simulator, in the case of the kiln described in the first example

We can now monitor the shell temperature of the kiln in EXAMPLE 1 while it is rotating. Since we have an adjustable temperature source, we are able to use a higher sensitivity setting by making the two isotherm marker positions coincide. Choosing RANGE 10, we find that the thermal image of the oxidized steel shell of the kiln brightens up when the isotherm marker position is .7 on the scale. Adjusting the reference temperature to brighten up its image at the same isotherm marker position, we find we have a temperature setting of 84°C. The image isotherm difference is, now:

$\triangle i_{or} = (0.7 - 0.7) \cdot 10 = 0$

Since there are no other changes in the conditions, the given parameters are:

$\varepsilon_o = 0.81$ $T_o = ?$ $I_o = ?$
$\varepsilon_a \simeq 1$ $T_r = 84°C$ $I_r = 133$
$\varepsilon_r \simeq 1$ $T_a = 20°C$ $I_a = 21$

Since $\varepsilon_r \simeq 1$, we can use Formula (1b). Substituting the above parameters into the formula, we get:

$$I_o = \frac{0}{0.81} + \frac{133}{0.81} + \left(1 - \frac{1}{0.81}\right) \cdot 21 = 0 + 164 + 21 - 26 = 159$$

With this value for the absolute isotherm level, we read the temperature of the shell:

$T_o = 92°C$

3. Temperature when both object and temperature reference emissivities can vary, in the case of a high voltage transformer

A temperature measurement is required on one of the porcelain high voltage insulators of a large oil-cooled transformer while the substation in which it is situated remains in operation. The glazed insulator surface has a known low emissivity value of 0.15. The painted side of the transformer itself provides a convenient reference temperature source — with emissivity 0.94 — at the 100°C temperature of the circulating oil used to cool it. The temperature of the surrouding air is 12°C.

The given parameters are thus:

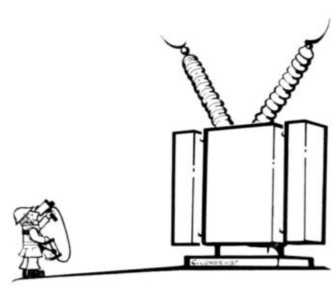
$\varepsilon_o = 0.15$ $T_o = ?$ $I_o = ?$
$\varepsilon_r = 0.94$ $T_r = 100°C$ $I_r = 191$
$\varepsilon_a \simeq 1$ $T_a = 12°C$ $I_a = 16$

With RANGE set at 100, we adjust the LEVEL control to brighten up the thermal image of the transformer with the isotherm marker set at .9 on the bottom scale. At the same setting, the image of the insulator brightens up with the marker set at .44 on the scale. From these two marker positions we calculate the image isotherm levels:

$i_o = 0.44 \cdot 100 = 44$
$i_r = 0.90 \cdot 100 = 90$

From this we get the image isotherm difference:

$\triangle i_{or} = 44 - 90 = -46$

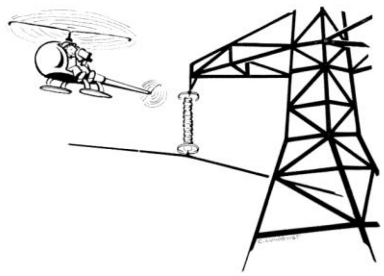


Since both ε_o and ε_r are less than 1, Formula (1a) is used. Substituting the parameters into the formula, we get:

$$I_o = \frac{-46}{0.15} + \frac{0.94}{0.15} \cdot 191 + \left(1 - \frac{0.94}{0.15}\right) \cdot 16 = 806$$

Using this value for the absolute isotherm level, we read the temperature of the insulator:

$T_o = 180°C$



4. Reference = unfocused background temperature, during helicopter power transmission line patrol

When the Thermovision equipment is being carried in a helicopter, ambient air temperature is the only convenient reference temperature source available to enable measurement of detected overheating joints and fittings while on power transmission line patrols.

Assume while flying a patrol parallel to a high line that the air temperature is 10° — monitored continously by means of a thermometer probe which projects into the airstream of the helicopter. The transmission line fittings consist of heavily oxidized copper components with a known emissivity of $\varepsilon = 0.78$, determined experimentally before starting the patrol flight.

Using RANGE 20, the isotherm marker is set at .1 on the thermal picture left-hand scale, and the LEVEL control is adjusted to brighten up the background of the picture with the image isotherm. The image isotherm level for the ambient air temperature is thus:

$i_a = 0.10 \cdot 20 = 2$ units

Keeping these control settings, a hot spot is detected at an angle tower anchor clamp location. Adjusting the isotherm control, the clamp is seen to brighten up with the marker position .85 on the picture scale. The image isotherm level for the clamp is thus:

$i_o = 0.85 \cdot 20 = 17$ units

What is the temperature of the overheating clamp?
Since $T_r = T_a$ and $\varepsilon_a \simeq 1$, Formula (1c) can be used. The parameters are:

$T_o = ?$
$\varepsilon_o = 0.78$
$I_a = 16$ units
$\triangle i_{oa} = i_o - i_a = 17 - 2 = 15$ units

Substituting the parameters into the formula, we have:

$$I_o = \frac{15}{0.78} + 16 = 19 + 16 = 35 \text{ units}$$

Since this is within the direct-readout range of the f/1.8 calibration curve, we get approximately the same value for the temperature of the clamp, i.e.

$T_o = 35°C$

5. The difference in temperature between two points on the same object are measured during an aerial thermal pollution survey of a river

The Thermovision equipment is carried by an airplane above a river to investigate the extent of thermal pollution caused by a new central heating plant which discharges into it.

The water temperature upstream of the point of efflux is 14°C, measured by a thermometer in the water and the data radioed to the aircraft. The value of the emissivity for the water is taken to be 0.96.

At RANGE 10, the isotherm marker is set at .1 on the thermal picture left-hand scale. The LEVEL control is adjusted to brighten up the image of the river, giving an image isotherm level of:

$i_r = 0.10 \cdot 10 = 1$ unit

Maintaining the same control settings, the central heating plant is overflown and the image of the river at the point of discharge brightens with the isotherm marker at position .9 on the thermal picture left scale. Half a kilometre downstream of the plant, the image of the river brightens up at marker position .3 on the scale. The image isotherm levels for these two observation are thus:

$i_o = 0.90 \cdot 10 = 9$ units, for the discharge point
$i_o = 0.30 \cdot 10 = 3$ units, for the downstream point

What are the temperatures of the river at these two points? Since $\varepsilon_r = \varepsilon_o$, Formula (1d) can be used, and the parameters are:

$T_o = ?$
$\varepsilon_o = 0.96$
$T_r = 14°C$
$I_r = 17$ units
$\triangle i_{or} = i_o - i_r = 9 - 1 = 8$ units (point of discharge)
$\triangle i_{or} = 3 - 1 = 2$ units (downstream point)

Substituting into the formula, we get for the discharge point:

$$I_o = \frac{8}{0.96} + 17 = 8.33 + 17 \simeq 25 \text{ units}$$

From this we read on the calibration chart that the temperature of the river at the point of discharge is:

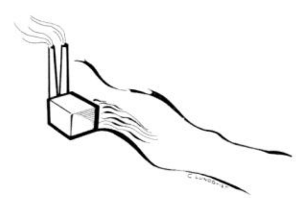
$T_o = 25°C$

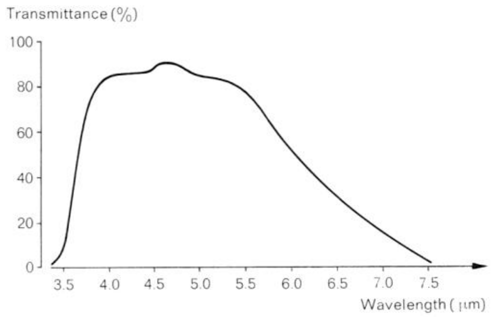
In the second instance, we have:

$$I_o = \frac{2}{0.96} + 17 = 2.08 + 17 \simeq 19 \text{ units}$$

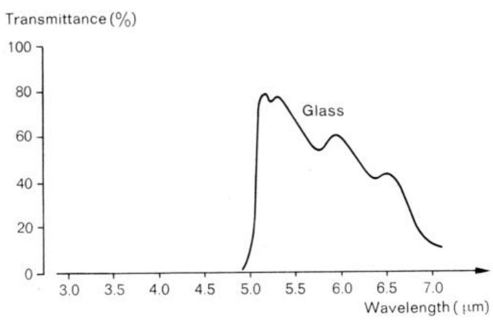
With this level for the absolute isotherm level of the water at the half-kilometer downstream point on the river, we get:

$T_o = 17°C$





Spectral filter characteristic for suppressing reflections resulting from solar radiation.



Spectral filter characteristics for glass measurements.

INFRARED FILTERS

A number of specific applications for AGA Thermovision require special filters to be inserted in the optical path of the IR camera in order to obtain the proper conditions for thermal image observation and temperature measurement.

Some IR filters having specific spectral properties are described below.

On special request, AGA's infrared optics technicians can also supply filters solving other Thermovision observation problems — for instance, filters for performing selective absorption studies of carbon dioxide (CO_2) and water vapor (H_2O) constituents of exhaust gases.

For sunlight

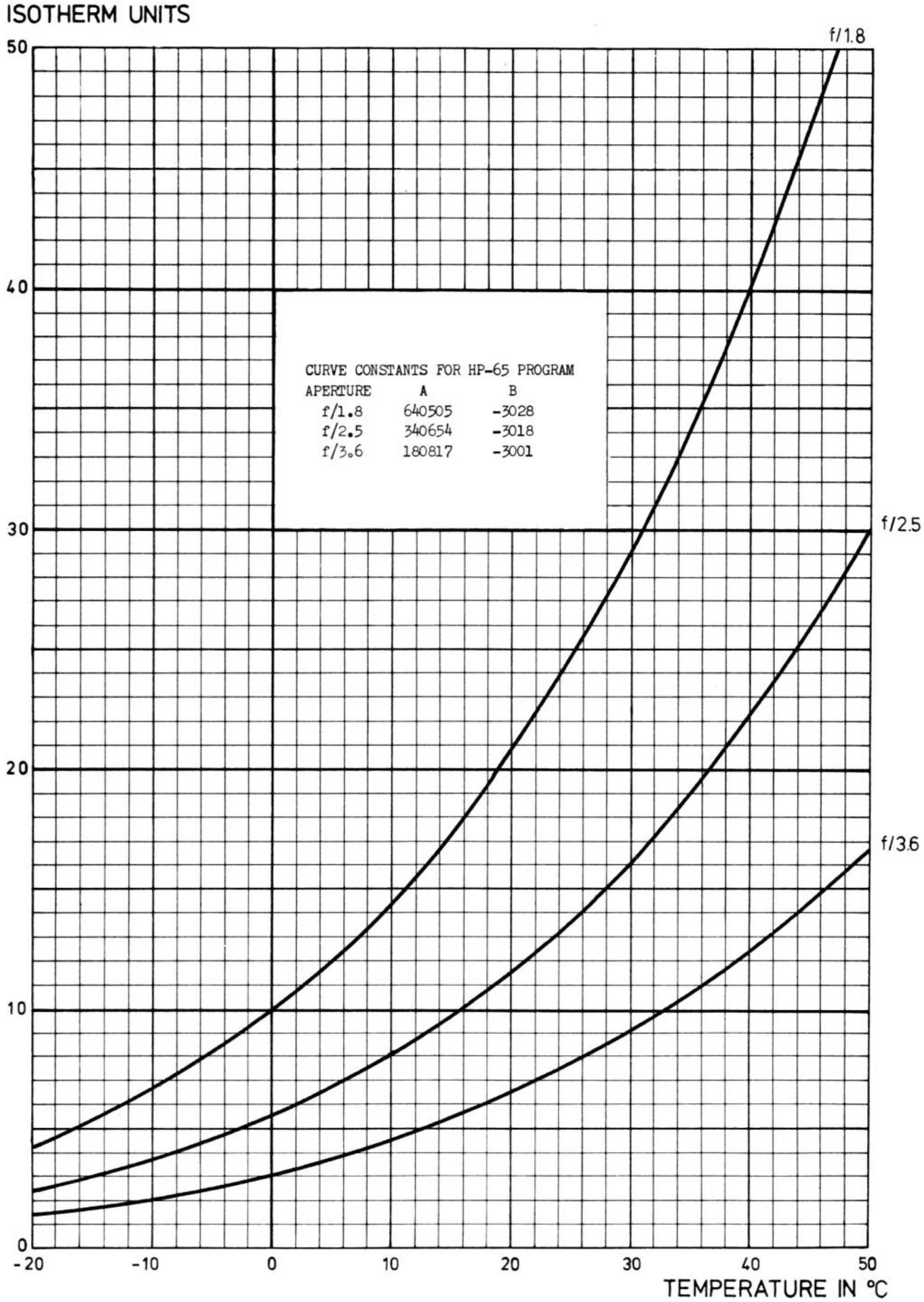
A long wavelength-pass filter, having a cut-on wavelength of 3.5 μm is also available. This filter is designated 'Anti-solar reflection filter' designed for outdoor Thermovision applications where reflected radiation from the sun may disturb remote temperature measurements. The filter transmits only radiation having wavelengths longer than 3.5 μm, and thus renders negligible the influence of reflected high-intensity, short wavelength radiation from the sun with respect to thermal radiation from objects at ambient temperatures.

For glass

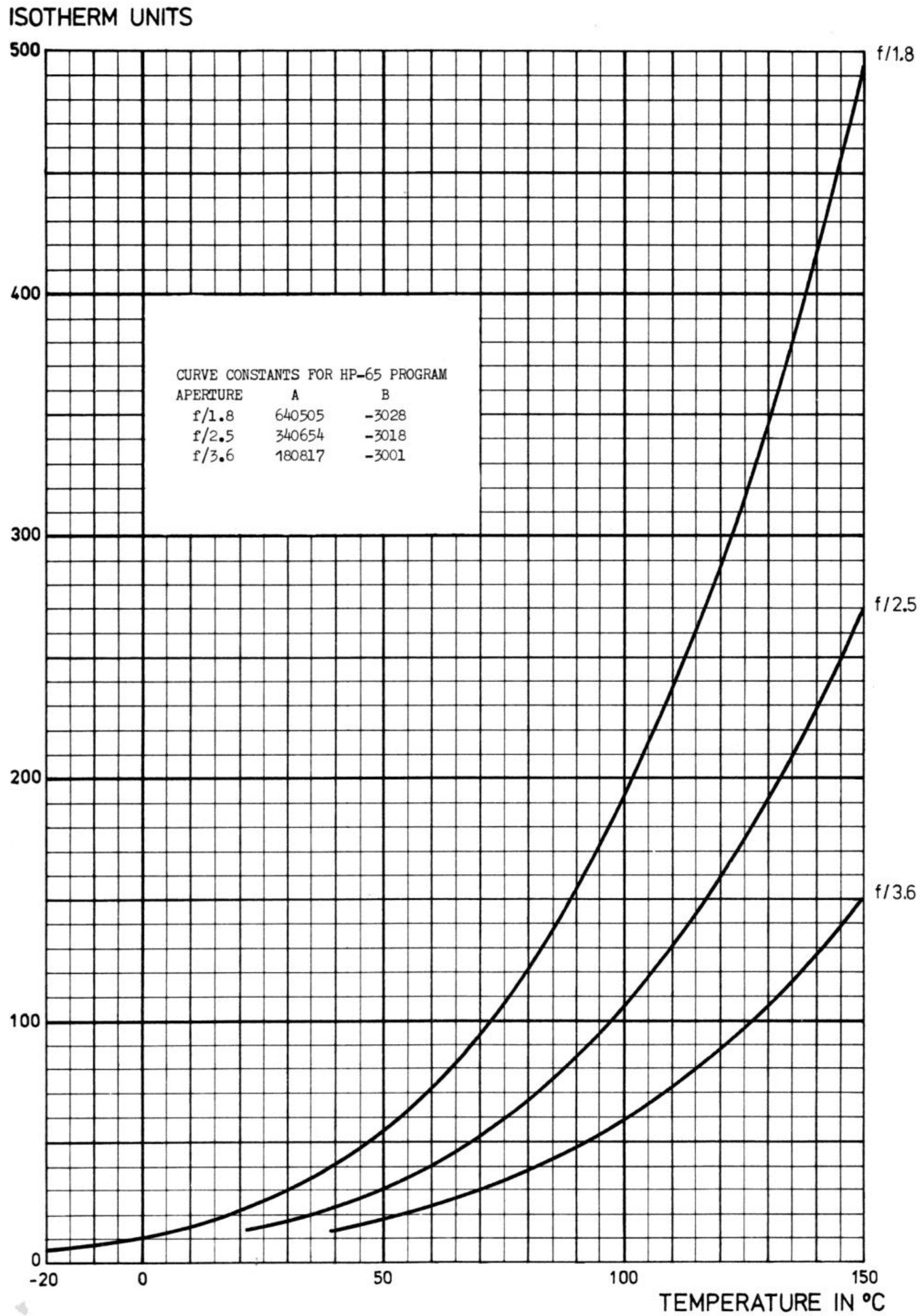
Transmission through glass is high for infrared radiation of wavelengths less than 3 μm, dropping off rapidly with increasing wavelength so as to be completely opaque for wavelengths greater than about 4.5 μm.

A long wavelength-pass filter has been developed for glass, designated 'Glass measurements filter'. This filter transmits only radiation above 4.8 μm cut-on wavelength.

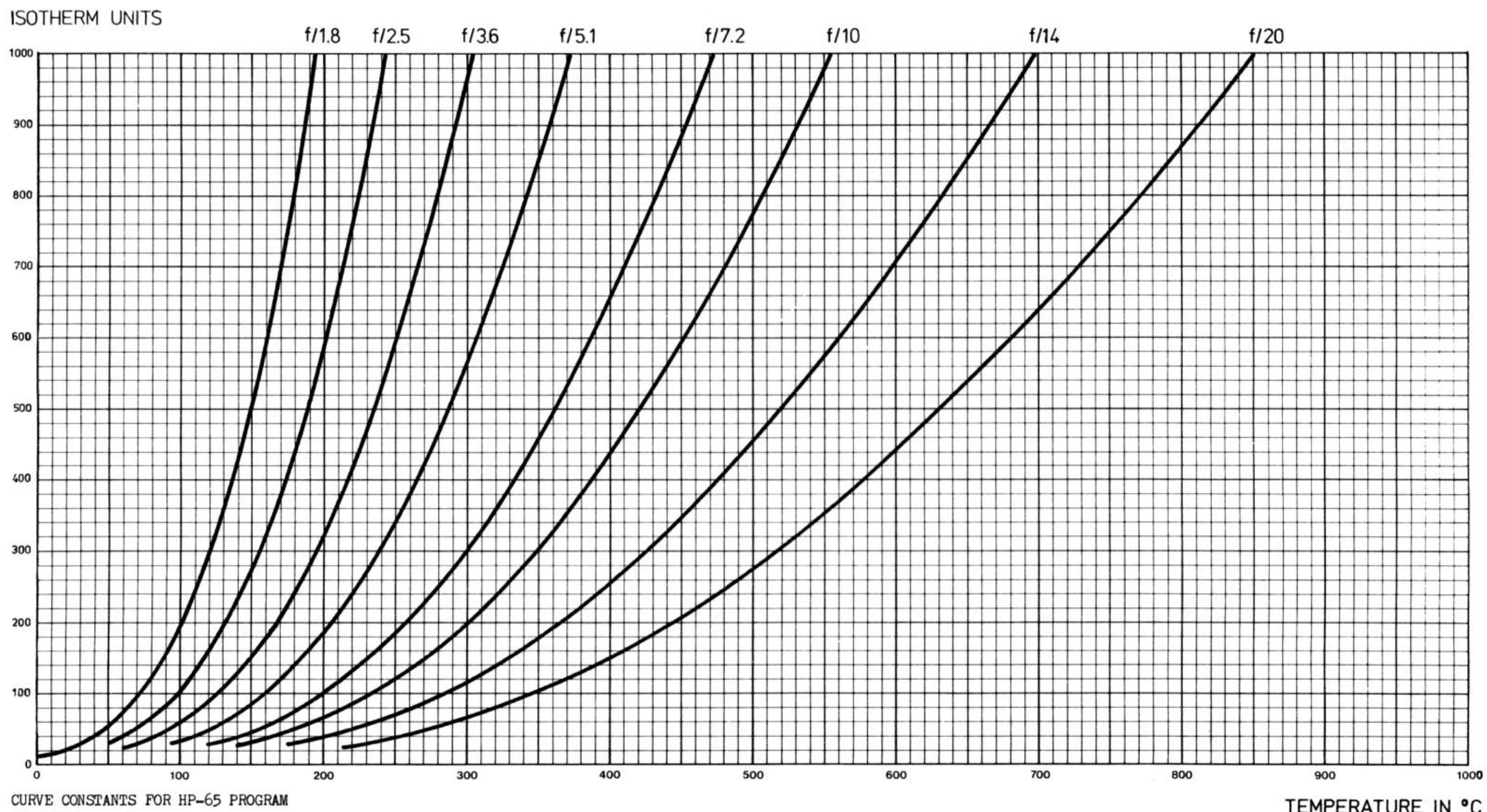
NOTE: The cut-on or cut-of wavelength λ_c is the wavelength at which the transmittance of the filter falls to 10 % of its peak transmittance.



AGA LIDINGÖ—SWEDEN	AGA THERMOVISION® 750 Typical calibration curves (-20° to +50°)	Drawn by: EIKK / A-BJ	Date: 75-12-01
		556 | 106 | 630	



AGA LIDINGÖ–SWEDEN	AGA THERMOVISION® 750 Typical calibration curves (-20° to +150°)	Drawn by: EIKK / A-BJ	Date: 75-12-01
		556 | 106 | 631	



CURVE CONSTANTS FOR HP-65 PROGRAM

APERTURE	A	B
f/1.8	640505	-3028
f/2.5	340654	-3018
f/3.6	180817	-3001
f/5.1	103882	-3001
f/7.2	54663	-2987
f/10	38355	-3022
f/14	22038	-3008
f/20	16788	-3179

AGA LIDINGÖ–SWEDEN

AGA THERMOVISION® 750

Typical calibration curves (0° to 1000°)

Drawn by: EIKK/A-BJ | Date 75-12-01

556 106 632

TEMPERATURE MEASUREMENT ACCURACY

Greatest possible temperature measurement accuracy is obtained with the help of reference measurements, i.e. with a temperature reference source located close to the object of interest.

To obtain the temperature difference between various points on the object, the appropriate temperature level of the object must be known.

Parameters which influence measurement accuracy

The following parameters must be considered, whether a reference is used or not:

- Overall accuracy of IR-camera system
- Emissivity of object surface
- Size of object.

When using a temperature reference the following must also be considered:

- Accuracy of temperature reference source
- Temperature difference between object and reference (accuracy increases as difference decreases)
- Size of reference source compared with size of object.

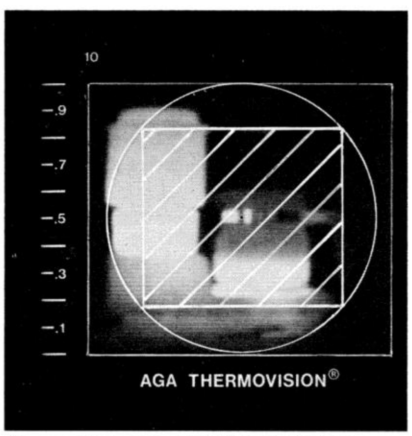
In addition, atmospheric attenuation is a very important factor when temperature measurements are performed with no reference source, or with a reference source which is some distance from the object.

Accuracy of the IR-camera system

The so-called typical calibration curves included in the manual are valid for IR-cameras without filter. The system can also be delivered individually calibrated on special order. When filters are delivered with the equipment, the system is calibrated individually for each filter as well.

During calibration, the output signal levels (i.e. isotherm units) are measured as the difference between a variable temperature reference source and a fixed source derived from the temperature of boiling nitrogen (−196°C).

The IR-camera system must be recalibrated at least once a year to ensure that specified accuracy is maintained.



Accuracy figures are valid within shaded area.

The accuracy of a typical calibration curve is ±5 % at an object temperature below 200°C, ±12 % above 200°C.

The corresponding accuracy of an individually calibrated instrument curve is ± 4 % and ±6 % respectively.

> NOTE: The above specified accuracies are improved when the reference temperature is near the object temperature. For example, if the reference temperature is 10 % higher or 15 % lower than the object temperature, the above accuracy percentages are approximately halved. However, a curve accuracy will never be better than ±2°C.

The above accuracy figures are valid for the following conditions:

- Object distance = 1 m
- Temperature measurements are made with the largest possible camera aperture (smallest f/number)
- IR image is located within shaded area of display screen (see figure), and has a minimum height and width of 2.5 mm.

Emissivity

The calibration curves are strictly valid only for objects with surface IR emissivities near the blackbody ideal of 1. Ordinarily, object materials and surface treatments exhibit emissivities ranging from 0.1–0.95, approximately. A highly polished (mirror) surface falls below 0.1, while an oxidized or painted surface has greatly increased emissivity. Oil-based paint, regardless of colour in the visible spectrum, has an emissivity over 0.9 in the infrared. Human skin exhibits an emissivity of 0.98, which is made use of in medical thermography for direct body-temperature readings.

See also Section 4 of the manual.

Object size

For accurate temperature measurements, the IR image of the object must have a minimum height and width of 2.5 mm. Small objects or details which are around the system's 'instantaneous field' (but not so small that they can not be seen in the picture) will appear to have lower than actual temperatures.

See specific instruction on compensation for small objects (Section 6).

Atmospheric attenuation

Atmospheric attenuation within the 1.2–6.0 μm IR spectral band depends upon the following atmospheric parameters:

- Air temperature
- Air pressure
- Relative humidity (H_2O)
- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Dinitrogen oxide (N_2O)
- Ozone (O_3)
- Methane (CH_4)
- Aerosol visibility (particles).

In normal conditions, CO, N_2O, O_3 and CH_4 can be neglected.

The effect of atmospheric attenuation is, of course, that the infrared radiation which reaches the IR camera diminishes when the distance of the object is increased. This is shown in the following example:

Assume that the air temperature is 15°C, air pressure 101.3 kPa, relative humidity 50 %, and object temperature 90°C. If the object distance is increased from 5 m to 50 m, the transmission is decreased from 92 % to 74 % (see chart). This means that the infrared radiation is attenuated by a factor of $\frac{92-74}{92} \approx 0.2$ or 20 %.

For specific questions you may have concerning atmospheric attenuation, please feel free to contact us for further information.

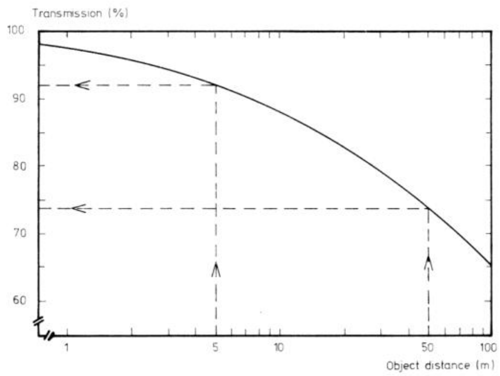


Chart of atmospheric attenuation vs distance.

USING A CALCULATOR FOR DIRECT TEMPERATURE READOUT

Each AGA Thermovision system is delivered with a set of programmed magnetic cards which can be used with the Hewlett-Packard HP-67/97 calculators to provide direct temperature readout of objects presented on the display screen.

Each set consists of one program card and one or more data cards. The program card holds the formulas used in the calculations, and the data card the characteristics for a specific combination of IR camera, lens, filter, etc.

The program allows the emissivity of an object to be calculated and also contains a method for compensating the influence from atmospheric attenuation when measuring over longer distances.

HP-67/69 operating instructions

1. Set W/PRGM/RUN switch to "RUN".
2. Set power switch to "ON".
3. Insert program card (both sides).
4. Insert appropriate data card (both sides).
5. Initialize calculations by keying aperture number (f/) and pressing keys A and E. Reference emissivity (ε_r) and distance to object (d_o) are now automatically initialized to 1.0, and ambient temperature (T_a) to 20°C. These values may be changed later if necessary.
6. Key in reference temperature (T_r) and press keys A and B.
7. Key in reference emissivity (ε_r) (if not equal to 1.0) and press key B.
8. Key in ambient temperature (T_a) (if not equal to 20°C) and press keys A and C.
9. Key in distance from camera to object (d_o) (if not equal to 1.0 metre) and press key C.
10. Key in object emissivity (ε_o) and press key D or, to calculate the emissivity, key in object temperature (T_o) and press keys A and D.
11. Key in image isotherm difference ($\triangle i_{or}$) and press key E.

The above parameters 6–11 may be entered in arbitrary order.

12. Compute object temperature (T_o) by pressing keys A and D. To compute object emissivity (ε_o) press key D.

    NOTE: Do not key in any number on keybord when performing step 12. To correct, repeat step 12.

Parameters in step 6–11 remain set until changed. To calculate a new T_o or ε_o, change parameters and repeat step 12. Calculated values are stored for future use.

To convert a temperature to corresponding isotherm value, press keys f, GSB and 0.

To convert an isotherm value to the corresponding temperature, press keys f, GSB and 1.

NOTE 1: If the unfocused ambient temperature background is used as reference temperature, omit step 6 and enter $\varepsilon_r = 0$ in step 7.

NOTE 2: To ensure right atmospheric correction, the temperature reference and the object must be at the same distance from the camera.

13. To print out all parameters on HP-97 printer, press keys f and a. The parameters will be printed in the order $T_r - \varepsilon_r - T_a - d_o - T_o - \varepsilon_o -$ f/ $- \triangle i_{or}$. On HP-67 the parameters will be displayed successively with flashing decimal point.

SECTION 4
Theory of infrared radiation

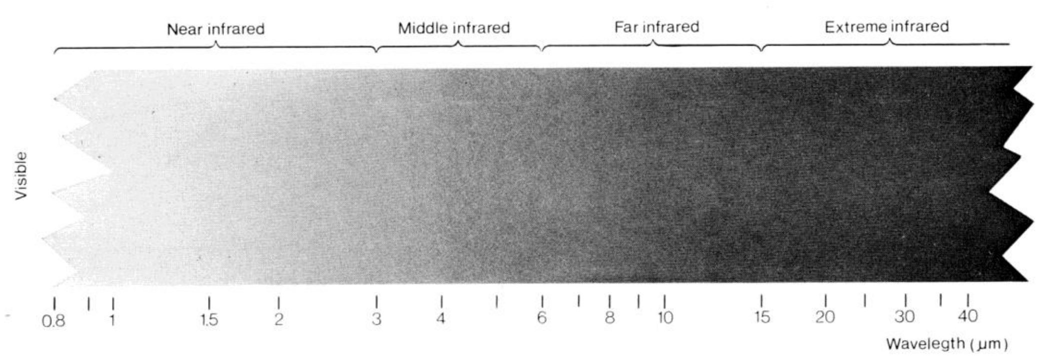
THE INFRARED SPECTRUM

The electromagnetic spectrum is divided more-or-less arbitrarily into a number of wavelength regions, called 'bands', distinguished by the methods utilized to produce and detect the radiation. There is no fundamental difference between radiation in the different bands of the electromagnetic spectrum, however; they are all governed by the same laws and the only differences are those due to the differences in wavelength.

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 commonly further subdivided into four lesser bands, the boundaries of which are also arbitrarily choosen. 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—1000 μm). Although the wavelengths are given in μm (micrometers), other units are often still utilized to measure wavelength in this spectral region, viz. microns (μ), nanometers (nm), and Ångströms (Å). The relationship between the different wavelength measures is

$$10000\ \text{Å} = 1000\ \text{nm} = 1\ \mu = 1\ \mu\text{m}.$$



The infrared spectrum

BLACKBODY RADIATION

A blackbody is defined as an object which absorbs all radiation that impinges upon it at any wavelength. The apparent misnomer "black" relating to an object emitting radiation is explained by Kirchhoff's Law, which states that a body capable of absorbing all radiation at any wavelength is equally capable in the emission of radiation.

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.

By providing such an isothermal cavity with a suitable heater it becomes what is termed a 'cavity radiator'. Such a cavity heated to a uniform temperature generates blackbody radiation, the characteristics of which are Planckian, i.e. determined solely by the temperature of the cavity.

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

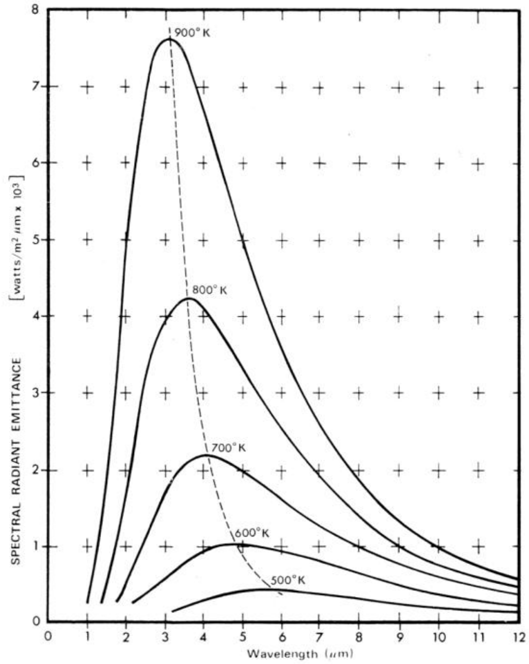
(1) Planck's Law. Max Planck was able to describe the spectral distribution of the radiation from a blackbody by means of the following formula:

$$W\lambda_b = \frac{2\pi hc^2}{\lambda^5 (e^{hc/\lambda kT} - 1)} \times 10^{-6} \text{ [watts/m}^2\ \mu\text{m]}$$

where

$W\lambda_b$ = the blackbody spectral radiant emittance within a spectral interval 1 μm wide at wavelength λ.
c = the velocity of light = 3×10^8 m/sec.
h = Planck's constant = 6.6×10^{-34} joule sec.
k = Boltzmann's constant = 1.4×10^{-23} joule/°K.
T = the absolute temperature (°K) of the blackbody.
λ = wavelength [m].

Note: The factor 10^{-6} is used since spectral emittance in the curves is expressed in watts/m² μm. If the factor is excluded, the dimension will be watts/m² m.



Blackbody spectral radiant emittance according to Planck's law, plotted for various temperatures.

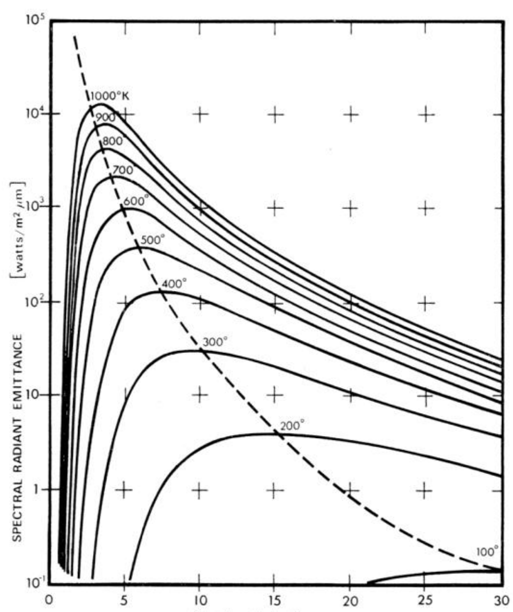
The significance of the 1 μm spectral interval in the value of $W\lambda_b$ is that the instrument used for measuring spectral emittance characteristics (i.e. the 'spectroradiometer') must utilize a narrow band of radiation in order to register a reading. Thus, a value for spectral radiant emittance is meaningless unless the spectral interval is also specified.

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 $\lambda = 0$, 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 the maximum occurs.

(2) Wien's Displacement Law. By differentiating Planck's formula with respect to λ, and finding the maximum, we have

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

This is Wien's formula, 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 (3000/°K). Thus, a very hot star such as Sirius (11000°K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occuring within the invisible ultraviolet spectrum,



Planckian curves plotted on semi-log scales, from 100° to 1000°K. The dotted line represents the locus of maximum radiant emittance at each temperature as described by Wien's displacement law.

at wavelength .27 μm. The sun (approx. 6,000°K) emits yellow light, peaking at about .5 μm in the middle of the visible light spectrum. At room-ambient 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.

(3) The Stefan-Boltzmann Law. By integrating Planck's formula from $\lambda = 0$ to $\lambda = \infty$, we obtain the total radiant emittance (W_b) of a blackbody:

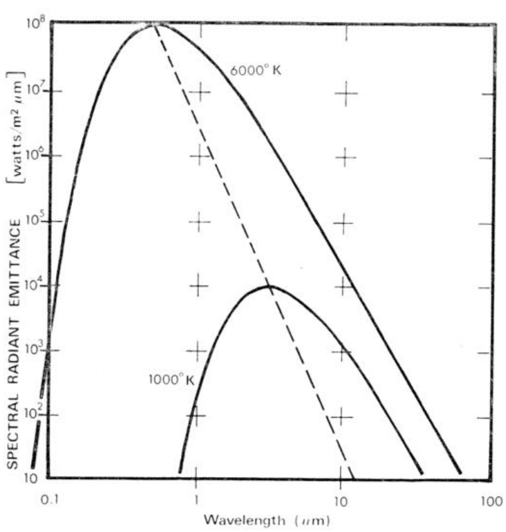
$$W_b = \sigma T^4 \qquad \text{[watts/m}^2\text{]}$$

where

σ = the Stefan-Boltzmann constant
$= 5.7 \times 10^{-8}$ watts/m² °K⁴.

This is the Stefan-Boltzmann formula, 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 under the Planck curve for a particular temperature. It can be shown that the radiant emittance in the interval $\lambda = 0$ to λ_{max} is only 25 per cent of the total, which represents about the amount of the sun's radiation which lies inside the visible light spectrum.

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 (say) 2 m², we obtain one kilowatt! This great power loss could not be sustained if it were not for the compensating absorption of radiation from surrouding surfaces, at room temperatures which do not vary too drastically from the temperature of the body—or, of course, the addition of clothing.



Planckian curves plotted on log-log scales. The curves for the different temperatures are identical, changing only their position with temperature by sliding up and down the Wien displacement locus—which becomes a straight line in this representation.

PHOTON EMISSION

The energy emitted by a thermal radiator is not transferred as a continuous flow, as Max Planck proved. The radiation occurs as discrete energy "jumps", or quanta—called 'photons'. The energy of a photon (Q) is given by

$$Q = \frac{hc}{\lambda} \qquad \text{[joule]}$$

from which it is seen that photon energy is inversely proportional to the wavelength of the radiation.

The three radiation laws given earlier, which describe the radiation of a blackbody, were all concerned with the energy of the radiation. **They can, however, be modified to deal with the number of photons (N_b) rather than the energy. This is of interest where photon detectors rather than energy detectors are utilized, as in the case of AGA Thermovision.**

By dividing Planck's formula by hc/λ, the energy of one photon, we obtain

$$N\lambda_b = \frac{\lambda}{hc} W\lambda_b = \frac{2\pi c}{\lambda^4 (e^{hc/\lambda kT} - 1)} \times 10^{-6} \text{[photons/sec m}^2\,\mu\text{m]}$$

where

$N\lambda_b$ = the spectral photon emittance for a blackbody within a spectral interval 1 μm wide at wavelength λ.

The family of curves for the spectral photon emittance resembles the former spectral radiant emittance curves, but has a less abrupt maximum; and the peaks are shifted toward the long-wavelength side.

The Wien formula for calculating the wavelength of peak photon emission for a given absolute temperature becomes

$$\lambda'_{max} = \frac{3663}{T} \qquad [\mu\text{m}]$$

The wavelength at which the maximum occurs is about 25 per cent greater for photon emission than for energy emission. Thus, for T = 300°K, we get $\lambda'_{max} = 12.2$ μm instead of the value 9.7 μm obtained if the energy emission is considered.

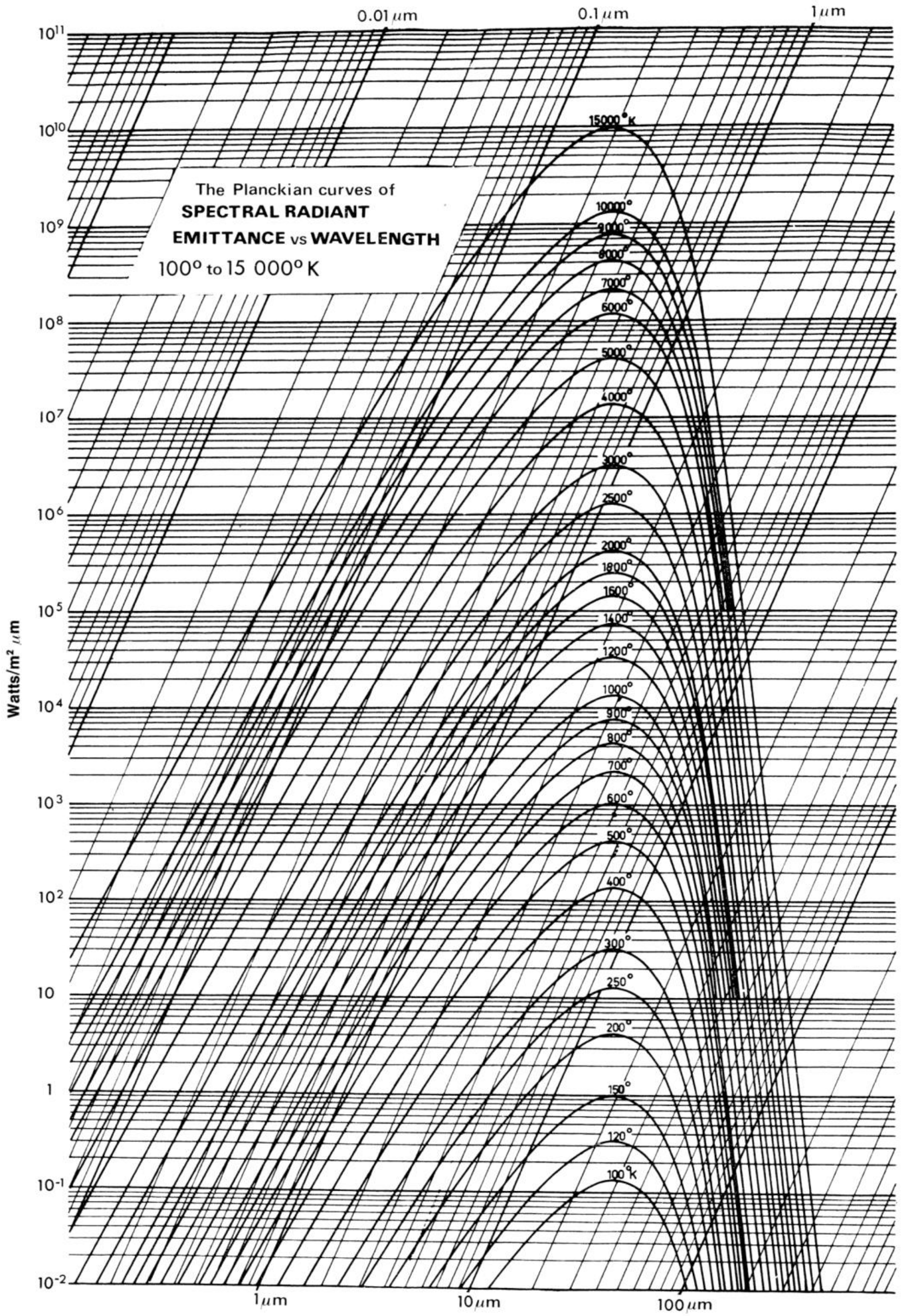
The Stefan-Boltzmann formula, written to express the total number of photons emitted from a blackbody at a specific temperature, becomes

$$N_b = \frac{0.37 \sigma T^3}{k} \qquad \text{[photons/sec m}^2\text{]}$$

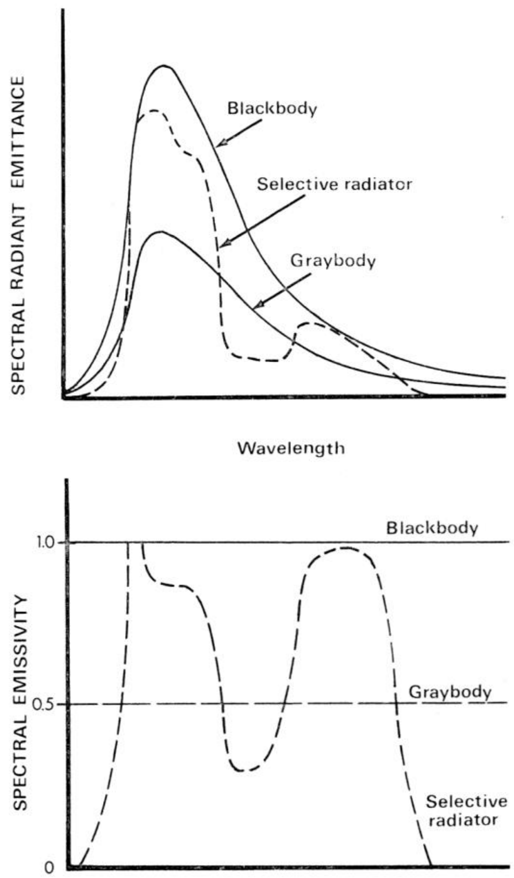
This alternative form of the Stefan-Boltzmann formula states that the total photon emission of a blackbody is proportional only to the third power of its absolute temperature.

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, white paint appears perfectly "white" in the visible light spectrum, but becomes distinctly "gray" at about 2 μm, and beyond 3 μm it is almost "black".



An interesting and very useful diagram of the Planckian curves is obtained by inclining the vertical lines of the log-log representation so that the peaks of maximum spectral radiant emittance are aligned vertically. The entire range of temperatures from 100° to 15000°K can thus be shown most conveniently, with good separation between the curves even in the long-wavelength direction.



Spectral radiant emittance and spectral emissivity of three types of radiators.

There are three processes which can occur which 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 fractions must always add up to the whole at any wavelength, so we have the relation

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

For opaque materials $\tau\lambda = 0$, and the relation simplifies to

$$\alpha_\lambda + \varrho_\lambda = 1$$

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 a 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:

(1) A blackbody, for which $\varepsilon_\lambda = \varepsilon = 1$.

(2) A graybody, for which $\varepsilon_\lambda = \varepsilon$ = constant less than 1.

(3) A selective radiator, for which ε_λ 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 $\alpha_\lambda + \delta_\lambda = 1$):

$$\varepsilon_\lambda + \varrho_\lambda = 1$$

For highly polished materials ε_λ approaches zero, so that for a perfect reflecting material (= a perfect mirror) we have

$$\varrho_\lambda = 1$$

Taking into account ε for a graybody radiator, the Stefan-Boltzmann formula becomes

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

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

TYPICAL VALUES OF EMISSIVITY

The values for ε obtained by using Thermovision are, in effect, the average of ε_λ occuring over the middle-infrared wavelength interval utilized by the Thermovision detector. If ε_λ varies with the wavelength, ε (the average value) will be dependent on the object temperature.

Unoxidized metals represent an extreme case of almost perfect opacity and high spectral reflectivity, which does not vary greatly with wavelength. Consequently, the emissivity of metals is low—only slowly increasing with temperature. For nonmetals, emissivity tends to be high, and decreases with temperature.

Typical emissivities for a variety of common materials are listed in the table below. **The values are meant to be used only as a guide, however, because they depend upon the spectral response of the instrument used to obtain them.** For this reason, AGA Thermovision measurements may result in emissivities which vary somewhat from these, so varification is recommended in each case.

Table of emissivities (total normal) for various common materials.

Metals and their Oxides	Temperature (°C)	Emissivity (ε)
Aluminium:		
polished sheet	100	0.05
anodized sheet, chromic acid process	100	0.55
Brass:		
highly polished	100	0.03
oxidized	100	0.61
Copper:		
polished	100	0.05
heavily ozidized	20	0.78
Gold: highly polished	100	0.02
Iron:		
cast, polished	40	0.21
cast, oxidized	100	0.64
sheet, heavily rusted	20	0.69
Magnesium: polished	20	0.07
Nickel:		
electroplated, polished	20	0.05
oxidized	200	0.37
Silver: polished	100	0.03
Stainless Steel (type 18—8):		
buffed	20	0.16
oxidized	60	0.85
Steel:		
polished	100	0.07
oxidized at 800°C	200	0.79
Tin: commercial tin-plated sheet iron	100	0.07
Other materials:		
Brick: common red	20	0.93
Carbon:		
candle soot	20	0.95
graphite, filed surface	20	0.98
Concrete:	20	0.92
Glass: polished plate	20	0.94
Lacquer:		
white	100	0.92
matte black	100	0.97
Oil, lubricating (thin film on nickel base):		
nickel base alone	20	0.05
film thickness 0.025 mm	20	0.27
0.051 mm	20	0.46
0.125 mm	20	0.72
thick coating	20	0.82
Paint, oil: average of 16 colours	100	0.94
Paper: white bond	20	0.93
Plaster: rough coat	20	0.91
Sand	20	0.90
Skin, human	32	0.98
Soil:		
dry	20	0.92
saturated with water	20	0.95
Water:		
distilled	20	0.96
ice, smooth	—10	0.96
frost, crystals	—10	0.98
snow	—10	0.85
Wood: planed oak	20	0.90

OBJECT THERMAL EQUILIBRIUM

Kirchhoff's law can be written as the ratio between the spectral absorptance and spectral emissivity of a body, i.e.

$$\alpha_\lambda/\varepsilon_\lambda = 1$$

In this form Kirchhoff's law may be said to state that at a given temperature a body absorbs most strongly radiation of that wavelength which it emits. However, in actual situations it is more likely for α and ε not to be equal for a surface, due to the temperature differences between radiating sources—thus accounting for the often surprising temperatures we notice in our environment.

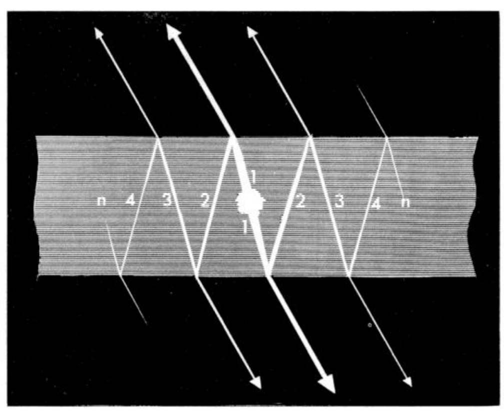
For example, take automobiles or aircraft parked out in the sunlight. The only means which energy absorbed from the sun can be transferred away is through radiation. Thus, for thermal control of such objects it is important to know the spectral absorptance for solar (5700°K) radiation α_s and the spectral emissivity for earth-ambient (300°K) radiation ε_a. Space technology has shown that the equilibrium temperature of a body depends only on the value of α_s/ε_a. High values of α_s/ε_a result in a "hot" vehicle, while low values result in a "cool" one. In the table below, a comparison of the values of α_s/ε_a for polished aluminium and for white titanium dioxide paint (TiO_2) shows why many aircraft are painted to reduce their internal temperatures while being parked out in the hot sun.

Table of solar absorptance α_s and earth-ambient (300°K) emissivity ε_a for spacecraft materials.

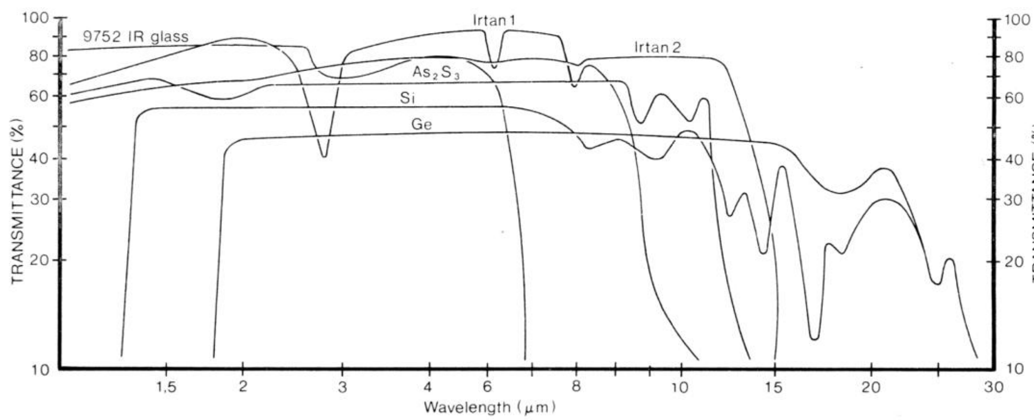
Material	α_s	ε_a	α_s/ε_a
Aluminium:			
polished and degreased	0.387	0.027	14.35
foil, dull side, crinkled and smoothed	0.223	0.030	7.43
foil, shiny side	0.192	0.036	5.33
sandblasted	0.42	0.21	2.00
oxide, flame sprayed, 0.025 mm thick	0.422	0.765	0.55
anodized	0.15	0.77	0.19
Fiberglass:	0.85	0.75	1.13
Gold: plated on stainless steel, polished	0.301	0.028	10.77
Magnesium: polished	0.30	0.07	4.3
Paints:			
Aquadag, 4 coats on copper	0.782	0.490	1.60
aluminium	0.54	0.45	1.2
Microbond, 4 coats on magnesium	0.936	0.844	1.11
TiO_2, gray	0.87	0.87	1.00
TiO_2, white	0.19	0.94	0.20
Rokide A	0.15	0.77	0.20
Stainless steel (type 18—8): sandblasted	0.78	0.44	1.77

IR-SEMITRANSPARENT MATERIALS

Consider now a nonmetallic, semitransparent body—for simplicity, 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 opposite surface, through which it mostly escapes; part of it is reflected back again. Although the progressive reflections become weaker and weaker, they must all be added up



Spectral characteristics of semitransparent materials—radiation emitted by a volume element of a semitransparent (i.e partially absorbing) plastic plate.



The spectral transmittance of some preferred IR-optical materials, thickness 2 mm

when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semitransparent plate is obtained as

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

This formula represents a generalization of Kirchhoff's law, which reduces when the plate becomes opaque ($\tau_\lambda = 0$) to the simple form

$$\varepsilon_\lambda = 1-\varrho_\lambda$$

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

IR-OPTICAL MATERIALS

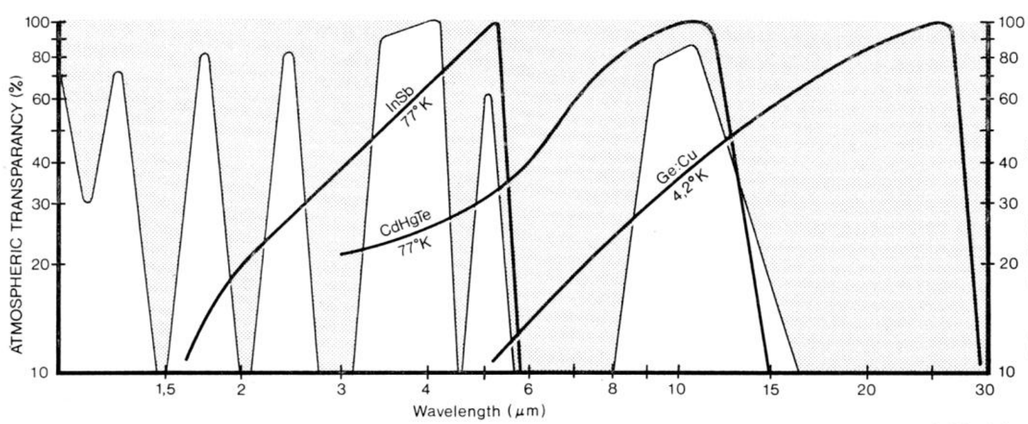
There are also very useful materials which are transparent to the infrared. These are not necessary transparent in the visible region of the spectrum, of course. For instance, while silicon and germanium are opaque in the visible wavelengths they are transparent in parts of the infrared spectrum. Some infrared transmitting materials and their IR-refractive indexes (n) are listed in the table below, together with their transmission cutoff wavelengths.

Material	n (at $\lambda = 2$ μm)	λ_{cutoff} (approx.)
Germanium (Ge)	4.0	50
Silicon (Si)	3.4	40
Arsenic trisulfide glass (As_2S_3)	2.4	12
Irtran 2 (ZnS)	2.2	14
Sapphire (Al_2O_3)	1.8	7
Irtran 1 (MgF_2)	1.3	8

A high value of n is advantageous in lens design, but on the other hand it is a fact that materials with high refractive indexes have rather low transmittances. The relation between transmittance and refractive index for non-absorbing materials can be shown to be

$$\tau = \frac{2n}{n^2+1}$$

For germanium ($n = 4$), τ becomes 0.47. Each germanium element in an IR-camera lens system should thus reduce the transmittance by a factor of 2. These high reflective losses can be eliminated, however, by anti-reflection coatings which can raise the transmittance to as high as 95—97 per cent for a given wavelength interval. The wavelength interval is determined by the thickness of the coating. With multilayer coatings, the transmission interval can be increased over a wide wavelength band.



Atmospheric transmission of infrared radiation over one sea mile, and relative detectivity of IR materials: Indium antimode (InSb) is the rugged, stable detector material used in the standard Thermovision 750 camera to cover the middle infrared wavelengths.

Vista Explodida da Unidade de Câmera com Part Numbers

Extraída do Manual de Manutenção do AGA Thermovision 750