AGEMA

Thermovision® 870.

Operating Manual

New Publ. No. 1 557 631 — Rev. A (2002-11-08)

WARRANTY

All AGEMA Infrared Systems instruments are warranted against defective materials and workmanship for one year. Complete components included in a system, but not manufactured by AGEMA Infrared Systems, carries the warranty of that particular supplier. Any questions with respect to the warranty should be directed to your local representative.

We reserve the right to change prices and specifications without notice. Contact your local representative for the most up to date information.

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TRADEMARKS

Thermovision® is a registered trademark of AGEMA Infrared Systems AB. CP/M is an operating system registered by Digital Research.

WARNING:

This equipment generates, uses, and can radiate radio frequency energy and if not installed and used in accordance with the instructions manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J or Part 15 of FCC Rules, which are designed to provide reason-able protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference. This warning is only applicable to TIC-8000 and DISCON equipment used with Thermovision® 870.

This warning is a requirement by the US authority FCC (Federal Communication Committee).

AGEMA Pub. No. 556 804 Ed. 2

AGEMA Infrared Systems Sales Organization

All AGEMA's products are sold through the world wide AGEMA sales organisation of subsidiaries and specially trained representatives. The sales organisation is shown below.

Each subsidiary are experts in their field. They can provide factory authorized service, to AGEMA's known high standards, so that defects are quickly repaired and the system is soon back in operation. Specialized training in all aspects of thermal analysis, R & D, PMC, CM, medical etc. is also given.

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ALPHABETICAL INDEX

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SECTION 1

Introduction

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1.1 PRESENTATION OF THERMOVISION® 800 SYSTEM

Thermovision® is the registered trade name of the world's first real-time infrared imaging system. In 1965 the first model was introduced and Thermovision® 800 series represents the fifth generation of the infrared scanning systems produced by AGEMA Infrared Systems AB. Thermovision® 870 also represents the state of the art with a thermoelectrically cooled detector element and an optional advanced computer analysis program.

Thermoelectrical cooling offers many advantages to an infrared scanner. Operate the switch and soon the image will be visible on the screen. This is of great value when used in the field, and for daily use in the laboratory. One big advantage is not to have to handle liquid nitrogen used for cooling the detector.

Thermovision® 870 is a mobile-cart supported or stationary system, designed for quality imaging including highly accurate measuring and image analysis capabilities.

Before continuing with details relating to the Thermovision® 870 system to be used, this section of the manual gives the system specification and overall configuration.

Fig. 1.1 A Thermovision® 870 System Set-up

1.2 SPECIFICATION

Scanner	**Shortwave**
Infrared detector	SPRITE, thermoelectrically cooled MCT.
Spectral response	SWB version with broadband anti-reflective coating 2-5 microns.
Temperature measurement range	−20° to 500°C (extended to 1500°C with filter)
Field frequency	25Hz
Line frequency	2500Hz
Lines per frame	280 (interlace 4:1)
Resolution elements/line	100 at 50% modulation
Apertures	Three, externally selectable
Infrared filters	Two optional, externally selectable
Sensitivity NETD	0.1°C at 30°C object temperature
Accuracy	±2% or ±2°C
System operating temperature –	−15°C to +50°C
Storage –	−40°C to +55°C
Dimensions (without lens)	92 x 150 x 205 mm (W x H x L)
Weight (without lens)	2.5kg
Length of detachable cable	1.5 m
Lenses	7°, 12°, 20°, 40°, 2.5° field of view, and microscope lens
Scanner mount	Photographic standard UNC ¼" and ⅜" threaded mounting holes
Part number	192 984

Control units

There are two types of control available for use with a Thermovision® 870 system.

CU 800 V	–	For mobile/stationary thermal colour video systems
CU 800 C	–	For use with a Thermal Image Computer – TIC8000 system

		CU 800 V	CU 800 C
Picture modes	– Live/Playback	√	√
	– Normal/Inverted	√	√
	– Colour and B/W	√	
	– Image freeze	√	
Thermal range	8 calibrated ranges:- 2, 5, 10, 20, 50, 100, 200, 500	√	√
Thermal level	Five turn graduated control	√	√
Isotherm	Two – Green/Red	√	
	– On TIC-8000		√
Focus	Remote control	√	√
Video output *NTSC only	– B/W - Composite video CCIR or EIA (RS 170)	√	
	– Colour – Analogue RGB/S NTSC or PAL	√	
	– Composite video NTSC or PAL	√	√*
System video recording for measurement on playback	Recording/Playback of Video, Range, Level, Aperture, Filter, Date, Time and text	√	√ (video only)
Accessory	Computer interface for TIC-8000	√	√
Data	For TRC and TIC-8000	√	√
Power Requirements			
– Battery operation	12V, 35 Watt, NiCd battery Operation time 2 hours (standard battery), including 5" RGB monitor	√	
– Stationary operation	100V/120V/220V/240V AC ±10% 50-60Hz from separate power supply	√ √	√
Dimension W x H x D(mm)	270 x 115 x 460	√	√
Weight (kg)		5.7	4.7
Part Numbers	CU 800 V – 193 115 CU 800 C – 193 110		

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Accessories

Video Recording	Electronic interface to Video Tape Recorder Retains measurement capability DC level clamping Composite video and sync
Signal levels	Composite video 0.7V p-p negative sync
Computer Output	
Accessory Connector	For Temperature Readout Computer (TRC). For Thermal Image Computer (TIC-8000)

Thermovision® 800 is in every respect a measuring instrument equipped with built-in references for a stable baseline and the possibility to measure absolute temperatures directly or with reference to a known source.

Direct read-out of temperature in real-time is carried out using isotherms (1 and 2) with the aid of the portable computer (TRC) and spot, profiles or isotherms using the desk top computer (TIC-8000). Figure 1.2 shows the overall Thermovision® 800 system connected for all options.

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Section 1 – Introduction

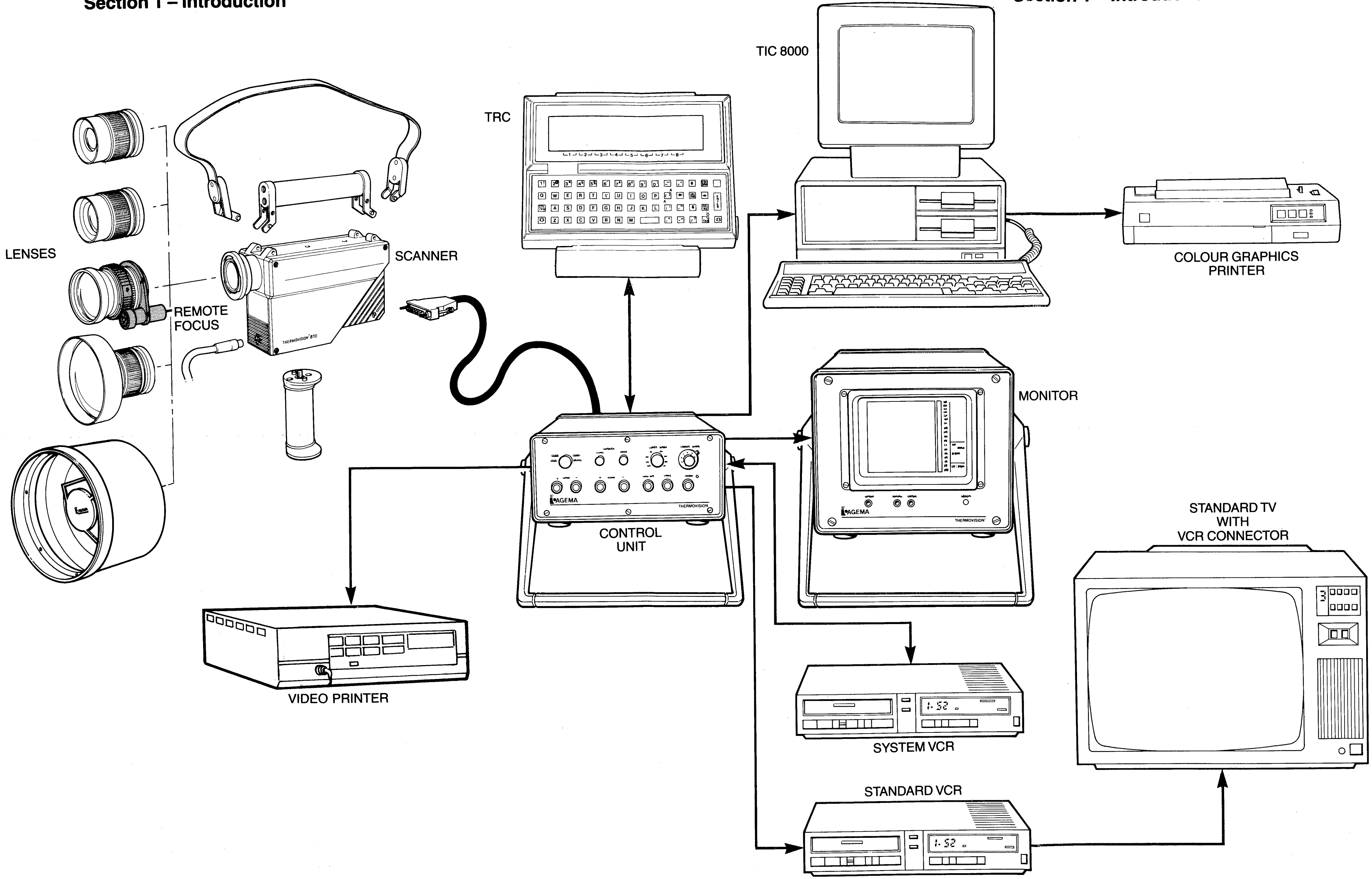

Fig. 1.2 Thermovision® 870 Overall Configuration

1.3 THE COMPANY BEHIND THE PRODUCT

AGEMA Infrared Systems AB, the producer of Thermovision® 800, is the world leader in the civil use of infrared thermography since the introduction of the first Thermovision® in the mid-sixties. Several thousand systems have been installed in almost every country of the world. A vast experience of IR technology has been collected by AGEMA over the years and this has been the base for the design of the Thermovision® 800 system. AGEMA expertise is thermal measurement but our know-how spans a wider field including electronics, optics, precision engineering and electro-optics.

AGEMA headquarters and production facilities are housed in a modern purpose designed building at Danderyd, 15 km north of Stockholm. Here almost 150 people are involved in the design and development, manufacturing and marketing of thermography equipment. Thermovision®, Thermoprofile® and Thermopoint® are all trade names of AGEMA products.

Thermovision® 800 uses a unique optical scanning system which requires highly sophisticated production technology. The tolerances relating to deviations in optical surface measurements are extremely small. AGEMA therefore have invested in a diamond turning machine, this is one of the first installed in Europe. Using such a machine optical surfaces can be manufactured in metal and germanium with far more accuracy than when using conventional techniques. Thanks to this investment AGEMA retains full control of a very important part of the scanner production.

The sales, installation and servicing of AGEMA products are carried out through a worldwide organisation of AGEMA subsidiaries and specially-trained representatives. These people are experts in their field and can provide specialised training in various aspects of thermal image analysis and provide factory-authorised service. Fast repair and to return the system to operation is the goal of the AGEMA organisation.

For names and addresses of our subsidiaries please turn to the back of the title page of this manual.

Fig. 1.3 AGEMA Headquarters

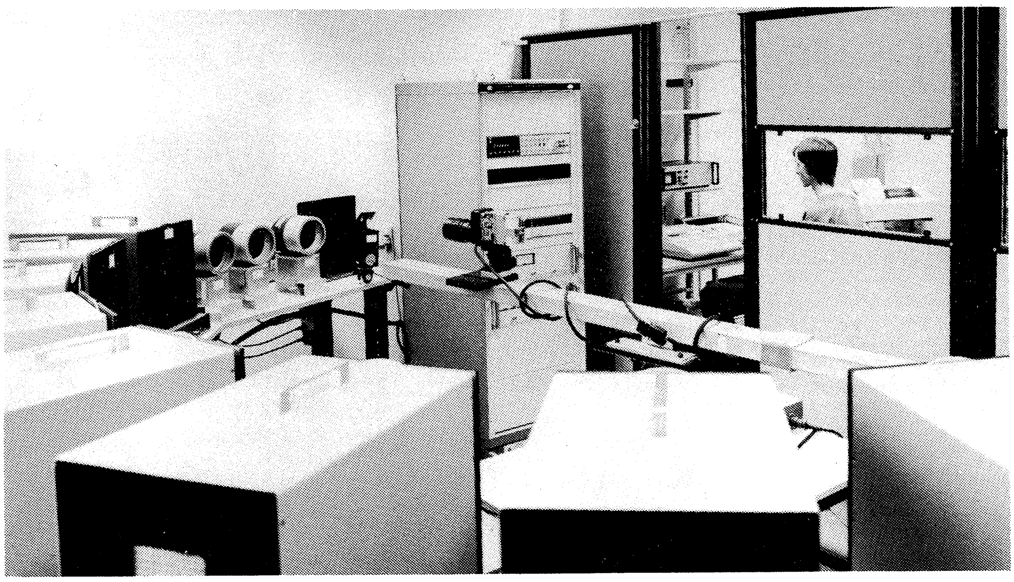

Fig. 1.4 AGEMA Calibration Department

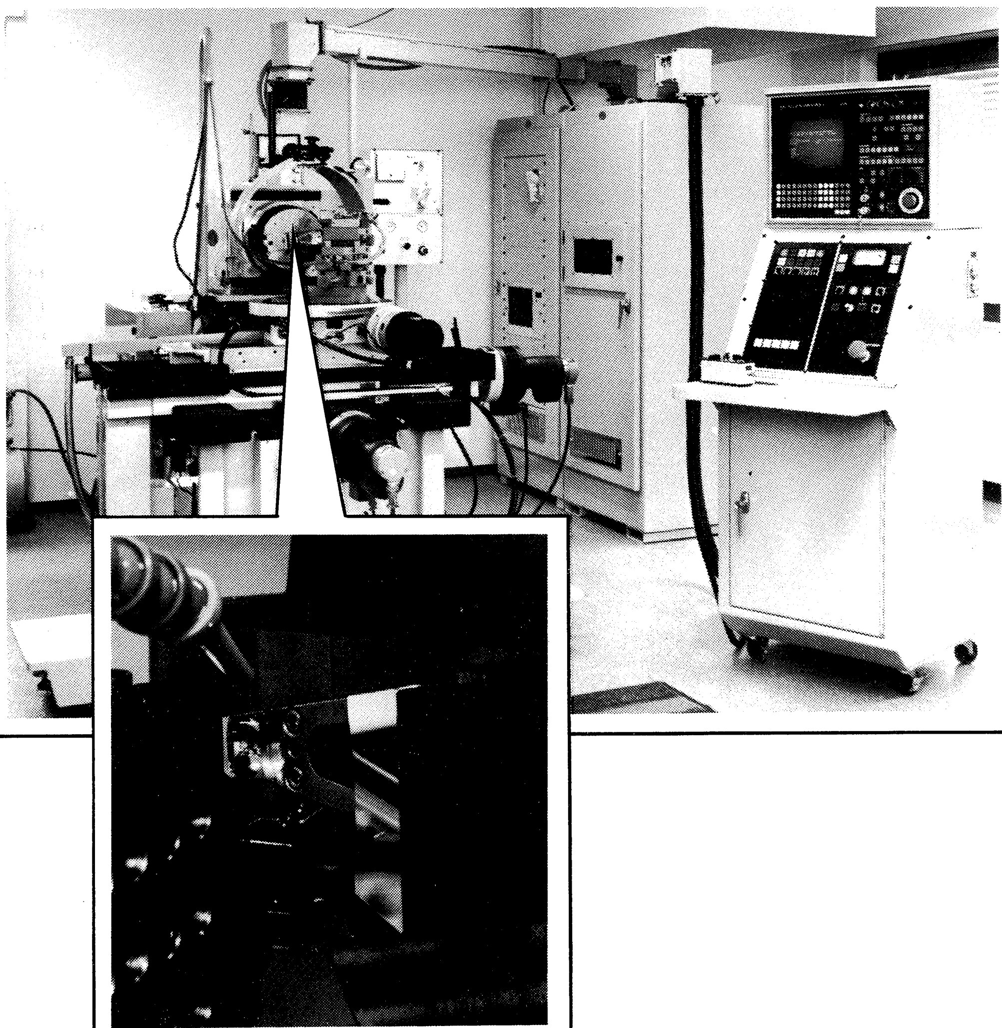

Fig. 1.5 Diamond turning machine installed at AGEMA

SECTION 2

Unpacking, Inspection and First Time Operation

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2.1 INTRODUCTION

A standard Thermovision® 800 system normally comprises a scanner, control unit, monitor, power supply and an operating manual in a carrying case. A number of optional accessories will possibly be included in another carrying case; recording camera, carrying straps, handles, lenses etc.

This section details the unpacking, setting-up and first time operation of the equipment in its standard configuration.

The system, depending on the configuration, is supplied in one or two carrying cases, the typical contents of which are shown in Fig. 2.1.

2.2 UNPACKING AND INSPECTION

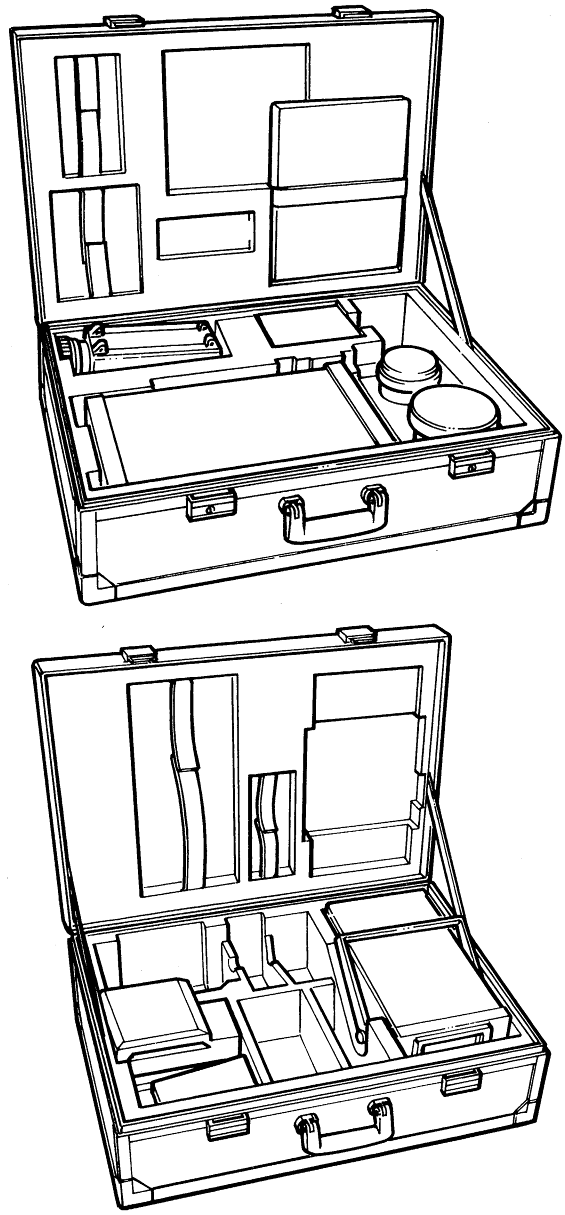

Fig. 2.1 Carrying Cases

Section 2 – Unpacking, Inspection and First Time Operation

On receipt of your Thermovision® 800 system remove each component from the carrying case, inspect each item and check them against the delivery note. Any damaged items must be reported to the local representative immediately.

Scanner

Remove the lens cover after turning the locking ring clockwise as seen from the front until the two dots are aligned (note this is a bayonet fitting), (Fig. 2.2) and ensure the fixed front lens is not scratched. Operate the FILTER and APERTURE controls located on the rear of the scanner and ensure that they operate freely. Set both controls to 0.

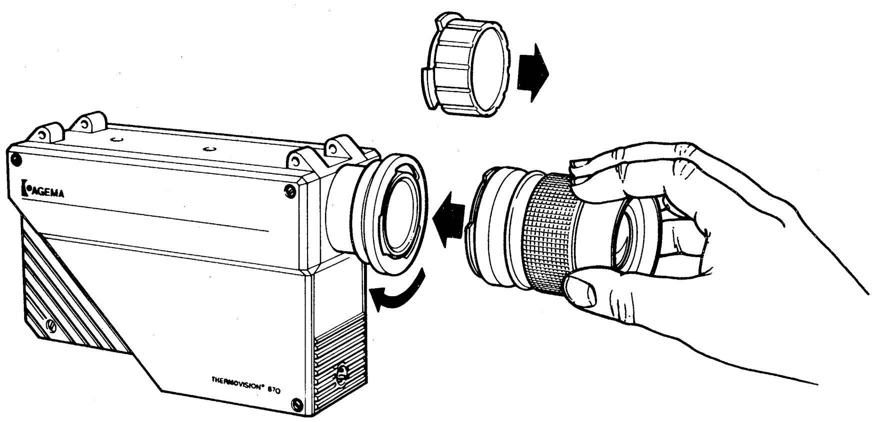

Fig. 2.2 Removing the Lens Cover and Fitting the Lens

Check that the other lenses included are in good condition (Fig. 2.3). If the equipment is to be tested in operation, fit an interchangeable lens in place of the scanner lens cover. Push the lens carefully against the bayonet fitting aligning the two dots. Turn the dot on the locking ring of the scanner anti-clockwise. The lens is now securely locked.

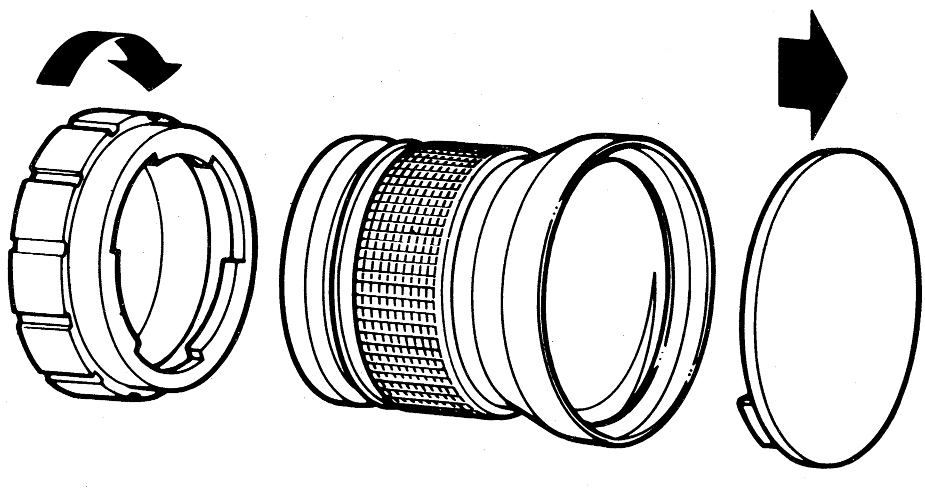

Fig. 2.3 Checking the Lenses

Control Unit

Check that the switches and controls operate correctly (Fig. 2.4).

Carry out an inspection of all remaining items and ensure that they are undamaged.

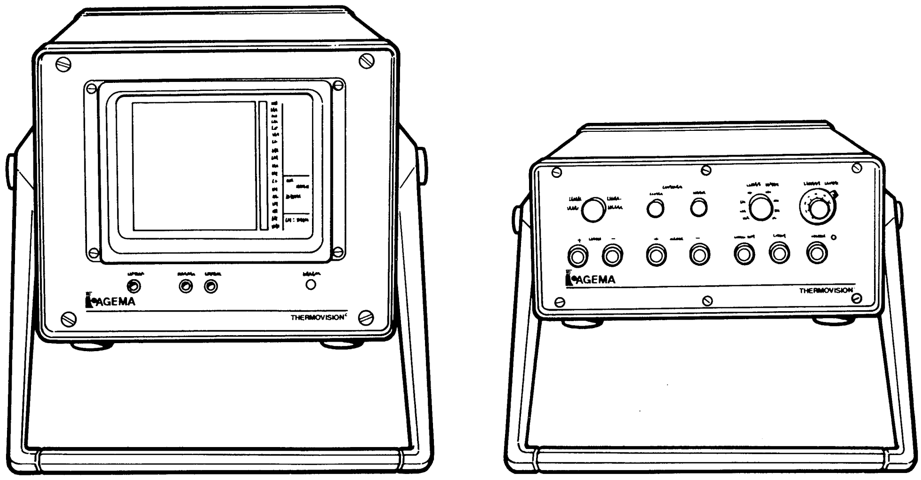

Fig. 2.4 Thermovision® Control Unit 800V

2.3 ASSEMBLY

Thermovision® 800 is designed to be used in one of three methods: Mobile, Stationary or Workstation. In the mobile configuration a transport cart provides a combination of a stable platform for the equipment while retaining portability of the system. In the stationary mode the scanner is often mounted on a tripod and the control unit, monitor, computers etc., on a table top. The workstation mode allows a complete system to be mounted on a single mobile platform. The three methods of installation are described in Fig's 2.5, 2.6 and 2.7.

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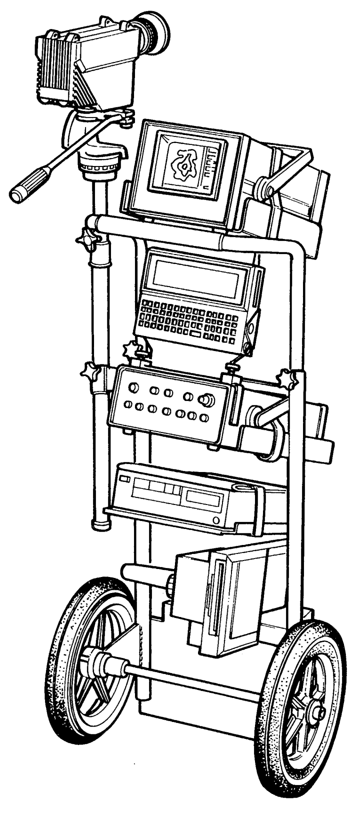

Fig. 2.5 Mobile System

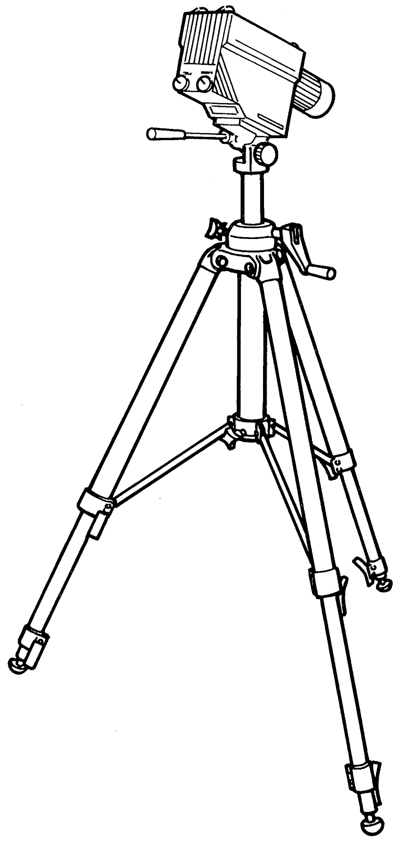

Fig. 2.6 Stationary System

(a) **Mobile System.** The transport cart (optional) is a lightweight two wheeled cart designed for easy transportation of the Thermovision® 800 system. It has the advantage of providing a mobile yet stable base so that the Thermovision® 800 system can be operated either on the cart or alternatively, the scanner may be removed from the cart and operated separately using a fixed tripod. The transport cart has a position to mount the Control Unit and Monitor and compartments are fitted to enable the operator to transport Polaroid films, recording camera, battery power packs and video equipment. The cart has a telescopic handle that may be retracted to enable the complete equipment and cart to be easily transported. Figure 2.5 shows the transport cart with the equipment fully installed.

(b) **Stationary System** is designed for static installation with scanner mounted on a fixed tripod and other equipment placed on a work bench. It can be combined with the desk computer, colour monitor or colour graphics printer and provides the complete facility requirements for scientific analysis of thermograms (Fig. 2.6).

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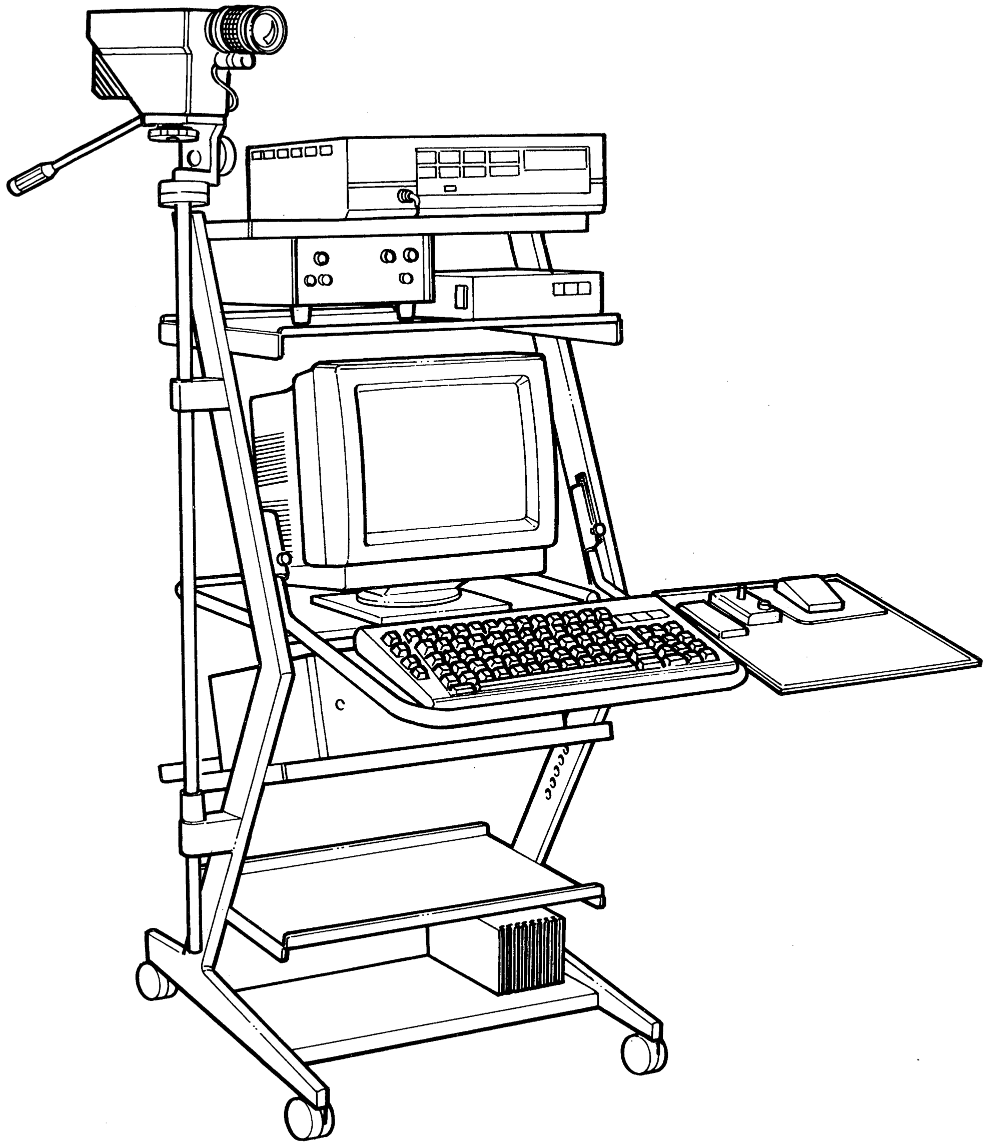

Fig. 2.7 Mobile Workstation

(c) **Mobile Workstation.** The precision of Thermovision® makes it suitable for laboratory based Research and Development work. In such an environment it is useful to have the equipment installed on a trolley so that it can be moved around the laboratory if necessary. The scanner can either be mounted on a separate tripod or attached to a support on the trolley with the rest of the equipment.
A trolley comprising various optional trays and an adjustable monitor shelf can be optionally provided for this type of installation.

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2.4 INTERCONNECTIONS

The scanner is connected to the Control Unit via a single interconnecting cable. The cable terminates in a plug which is connected to the SCANNER socket at the rear of the Control Unit. This plug is fixed in position by retaining clips. The plug on the scanner is secured by two screws located beneath the unit.

NOTE: When removing the interconnecting cable it is essential that the Control Unit retaining clips are unclipped and the plug removed in the normal manner. **NEVER try to remove the plug from the socket while the clips are still in the retaining position or the cable, equipment or both will be damaged.**

When an RGB monitor is used, to obtain good quality images, the four BNC sockets (R, G, B and S) on the control Unit are connected to the corresponding BNC sockets (R, G, B and S) on the monitor. The AGEMA 5" RGB monitor is provided with power via the MONITOR socket on the rear panel of the Control Unit, which is connected to the power input socket on the monitor (see Fig. 2.8).

The portable Temperature Readout Computer (TRC) is connected to the DATA socket on the rear of the display unit. Interconnection for the system is shown in Fig. 2.8.

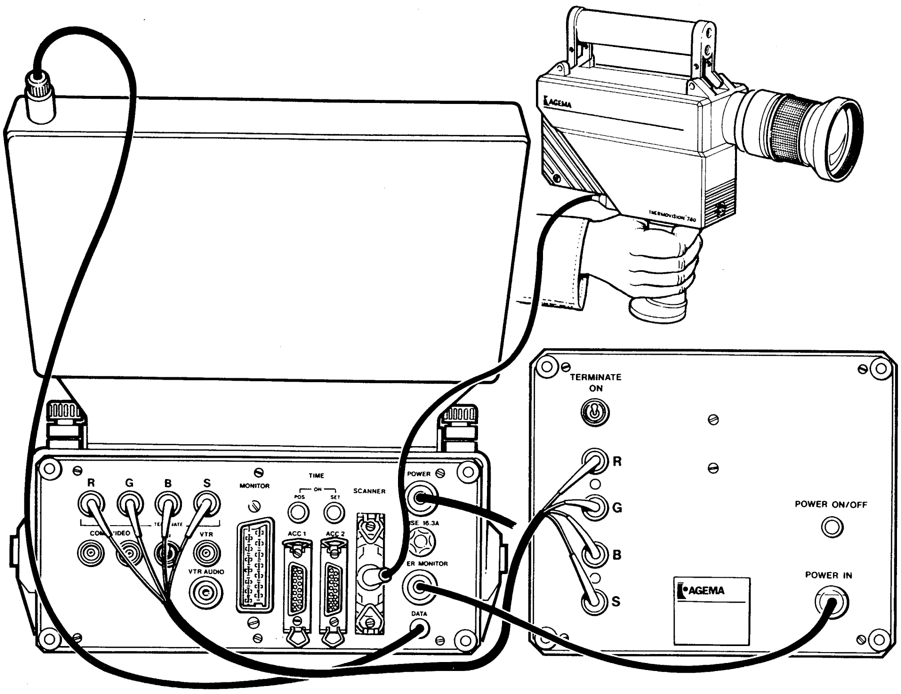

Fig. 2.8 Thermovision® 800 Interconnections

2.5 POWER SUPPLIES

The Thermovision® 800 power requirement is $\pm$15V dc for the Control Unit and Scanner and +5V dc for the Computer. The system may be powered from the ac/dc power converter (supplied) or via a battery (optional). Two types of nickel cadmium (NiCd) rechargeable battery packs are available:

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(a) Heavy duty type in leather case (7.0 Ah with minimum two hours continuous operation)

(b) Lighter version (4.5 Ah with 1.2 hours continuous operation)

Power Connections. The Battery Packs or the Power Supply/Charger Unit are connected as shown in Fig. 2.9.

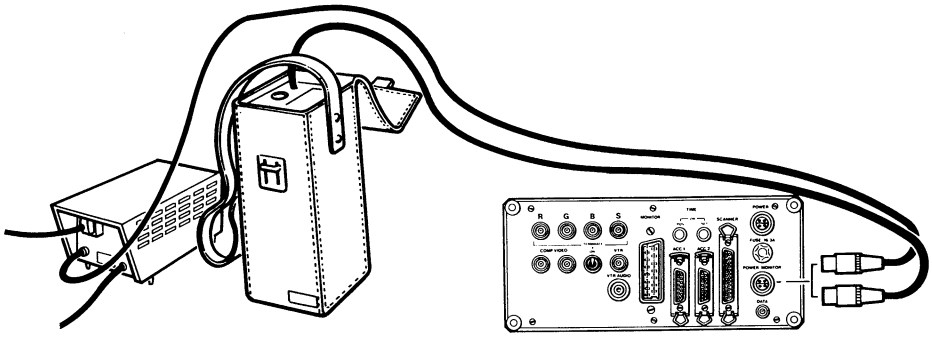

Fig. 2.9 Standard Battery Pack and Charger Unit

Power from the mains. The power supply/charger unit can operate on 100-240V ±10% ac. There are two ±15V outlets, one for the Thermovision® 800 Control Unit using a fixed cable and one connector for charging or an accessory.

Before connecting the power supply/charger unit to the ac supply, check that the equipment is set to the correct voltage. If necessary the voltage selection can be changed as follows:

Voltage Selection

CAUTION: Before carrying out any of the following operations, disconnect the unit from the ac supply.

1. Open the cover next to the mains input using the blade of a small screwdriver or similar.
2. Remove the fuse block assembly and remove the voltage selector card from the housing.
3. Orientate the card so that the desired voltage is read at the bottom of the card.
4. Insert the card with the printed side facing the connector and the bottom edge where the desired voltage is read, fed to the socket first.
5. Replace the fuse block and the cover.
6. Ensure that the indicator pin shows the desired voltage.
7. Switch ON and test the power supply.

Fuse Change

1. Open the cover next to the mains input using the blade of a small screwdriver or similar. The fuses can be selected to suit either the European or American standards of fuse. To change a fuse continue as follows:
2. To remove the fuse block loosen the cross head screw by two turns, remove the fuse block by sliding the block upwards away from the cross head screw.

   Note: Two European fuses are required although a dummy fuse may be fitted to the lower holder.
3. Remove and discard the blown fuse and insert a new fuse into the holder.
4. Replace the fuse block and tighten the cross head screw.

   Note: On the inside of the units is a thermal strip switch. If this switch has actuated, the cover of the power supply should be removed and the switch reset.
5. Replace the fuse block and the cover.
6. Ensure that the indicator pin shows the desired voltage.
7. Switch ON and test the power supply.

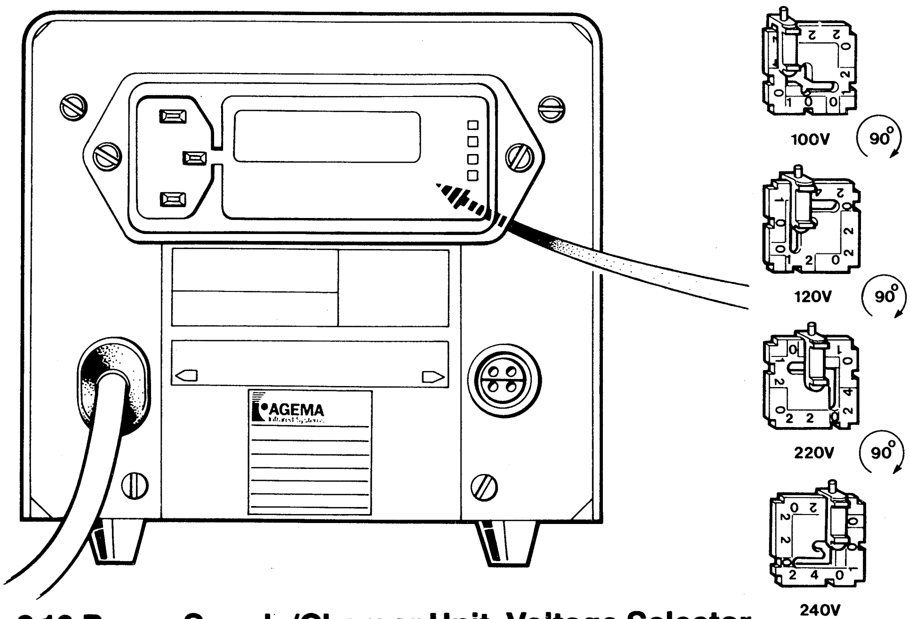

Fig. 2.10 Power Supply/Charger Unit, Voltage Selector

Battery Charging

Heavy duty version. The ac Power Supply/Charger Unit is also used to recharge this type of battery. Two batteries may be recharged at the same time using cable part no. 192 844. The time taken to charge the batteries from fully discharged to fully charged is approximately eighteen hours. The Power Supply/Charger Unit can be used to power the Thermovision® 800 or used to charge the batteries, but not both.

Recharging Instructions

1. Connect the cable from the power supply to the battery.
2. Connect the power supply to the ac supply. The LED lamp on the battery will be illuminated.
3. The battery should be charged between 16 and 20 hours (see Note (1)).
4. Batteries should not be charged in temperatures above +30°C (+86°F) or below +10°C (+50°F).

Lighter version. This battery is provided with a separate charger unit, which plugs directly into the ac supply. The charging time is 14 to 18 hours for a fully discharged battery.

NOTE: (1) Even though, using NiCd batteries, there is no danger of overcharging the batteries, using the correct charger unit, the batteries should be removed from the battery charger when not in use (i.e. the batteries are fully charged).

(2) Modern NiCd batteries should not develop a 'memory' even if they are discharged only by a small portion of the total capacity and then recharged. However, it is recommended that the batteries are recycled three or four times a year, i.e. fully discharged and then recharged (provided the normal use does not discharge the batteries regularly).

(3) NiCd batteries are the most practical power sources for portable instruments. They can be charged and discharged many times, have good capacity, work at lower temperatures, can be charged at lower temperatures and can be left unattended. However, **never** continue to draw current when the voltage is below 1V per cell = 10 volt. Try to make it a habit to recharge the batteries at regular intervals.

(4) Full capacity from new NiCd batteries is only obtained after two or three full discharge and recharge cycles.

Notes 1-4 apply equally for both versions of battery.

2.6 FIRST TIME OPERATION

After checking and assembling the equipment, using the following detailed step-by-step operating text, it should be possible to operate Thermovision® 800. It is recommended that first time operation should be carried out using the Power Supply/Charger Unit. Ensure that you familiarise yourself with the location and function of all switches and controls prior to switching on the ac supply.

(a) Ensure that the scanner and monitor are correctly connected to the Control Unit, that the ac setting on the Power Supply/Charger Unit is correctly set for the supply being used, the unit is connected to the mains, the lens cover is removed and that APERTURE and FILTER controls are set to 0.

(b) Switch on both the Control Unit and Monitor.

(c) Check that the power indicator LED's are illuminated.

(d) Ensure that the scanner motor starts and (within 20 seconds), the scale illumination is lit and the raster appears on the monitor screen.

(e) Set the PICTURE MODE selector to 'LIVE-NORMAL'.

(f) Set the THERMAL RANGE switch to 10.

(g) Point the scanner at a test object, e.g. a person's face. (Fig. 2.11).

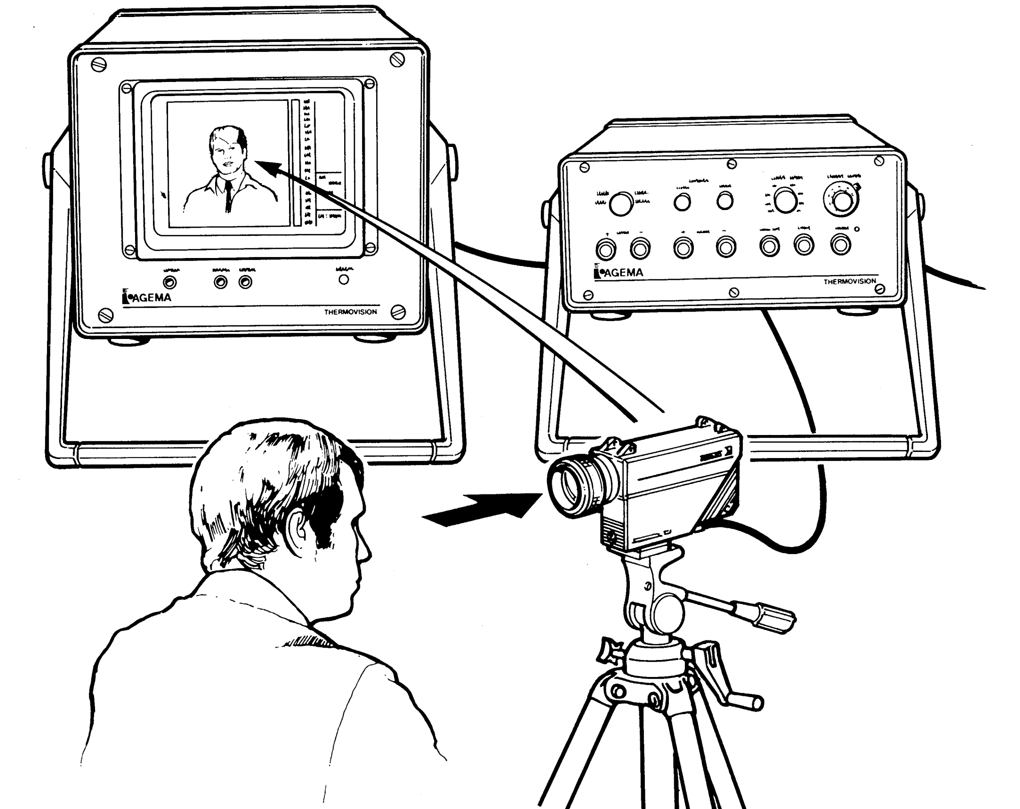

Fig. 2.11 First Time Operation

(h) Adjust the THERMAL LEVEL control until the thermal image of the object being viewed appears on the screen (Fig. 2.12).

(i) Set the COLOR B/W switch to B/W to obtain a gray tone image.

(j) Adjust the lens focus manually for the sharpest image.

(k) Adjust the monitor trimmers, using the long narrow screwdriver supplied in the tool kit, to obtain a stable image and optimum brightness.

Isotherm Adjustment

To test the remaining functions proceed as follows (Fig. 2.12).

(a) Rotate the ISOTHERM LEVEL controls from the OFF position until the Isotherm markers are on the Isotherm scale (right-hand side of the screen).

(b) Adjust the ISOTHERM WIDTH to obtain the desired Isotherm marker width.

(c) Adjust the ISOTHERM LEVEL controls to find the lowest and highest object temperatures, this is indicated by saturated red (1) and green (2) being displayed as the temperature levels are monitored. If the differ-

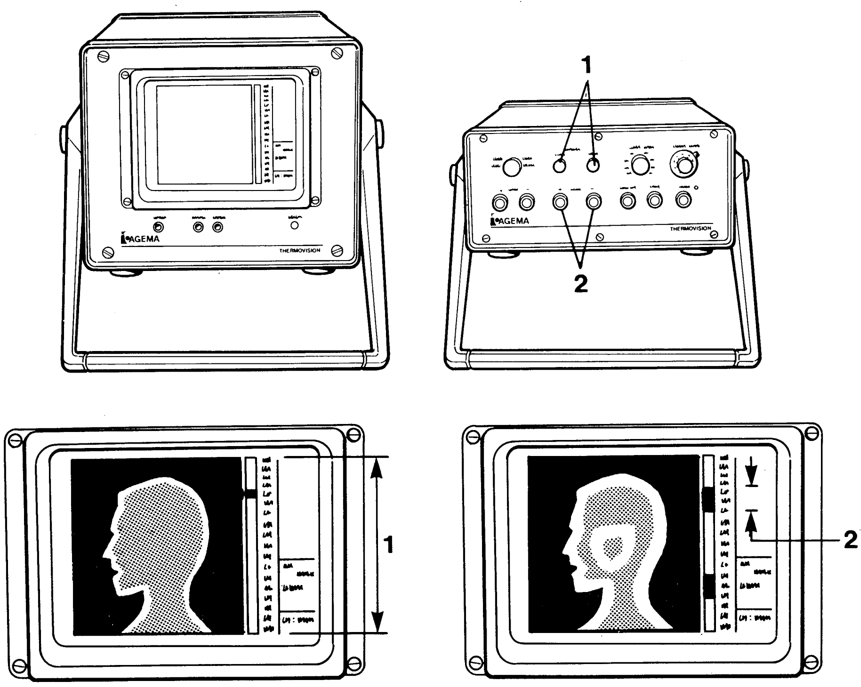

Fig. 2.12 Adjustment of the Isotherm Controls

ences exceed both the low and high end of the isotherm scale, readjust the THERMAL RANGE until both the lowest and highest object temperatures can be displayed.

(d) Adjust the THERMAL LEVEL to centre the two levels equally either side of the 0 position on the Isotherm scale.

(e) Adjust the THERMAL RANGE switch to the position which produces the greatest spread between the two temperature levels within the limits of the RANGE selected.

(f) Set the PICTURE MODE switch to INVERTED. Check that white indicates cooler and black indicates hotter temperatures.

(g) Set the COLOR B/W switch to COLOR. Check that the temperature levels are represented in colour (see scale on monitor), and the isotherm markers have become light (1) and dark (2).

Testing and Check List

The preceding first time operation instructions give the basic details for the operator to obtain a picture using the Thermovision® 800 system. If the system is not working satisfactorily, it can be due to an incorrect position of a control or switch. Listed below are some of the most obvious points to check prior to contacting the service representative. It should also be noted that this section deals with the operation of the standard system and details of thermal measurements can be found in Section 8.

The check list below is written using a person's face as the object being viewed. If higher or lower temperatures are used as a test object the THERMAL LEVEL and RANGE will have to be changed accordingly.

Section 2 – Unpacking, Inspection and First Time Operation

Check that the item or controls are set as follows:

Scanner

(a) Lens cap removed

(b) Filter set to 0

(c) Aperture set to 0

(d) Motor running (with Control Unit POWER switch on)

(e) Focus correctly set

(f) Interconnecting cable correctly terminated

Control Unit (Front Panel)

(a) THERMAL RANGE set to 10

(b) THERMAL LEVEL set to 30

(c) PICTURE MODE set to LIVE and NORMAL

(d) ISOTHERM LEVEL controls fully counter-clockwise

(e) POWER LED illuminated

Control Unit (Rear Panel)

(a) Monitor power and R, G, B and S cables control

(b) Scanner correctly connected

(c) Power Supply/Charger Unit connected, properly adjusted and connected to the ac supply

(d) No other accessories connected

With the controls set in the correct position a picture should be obtained with the minimum of adjustment. If a picture is not available recheck the system or contact your AGEMA service representative.

Figs 2.13 and 2.14 show a photograph of a normal heating radiator and a thermogram showing the temperature gradient and the invisible internal structure.

Section 3 describes in more detail the major units used in the standard system such as the Scanner with Lenses, Filters and the Control Unit.

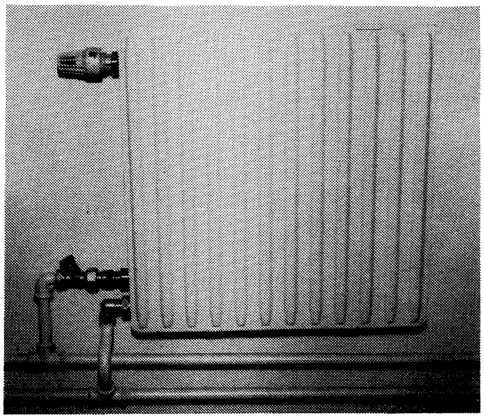

Fig. 2.13 Normal Heating Radiator

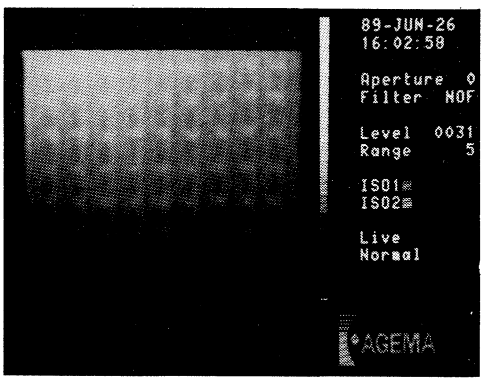

Fig. 2.14 Thermogram of Normal Heating Radiator

SECTION 3

Detailed Description

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3.1 THE SCANNER UNIT

Basic Description

The infrared scanner unit converts electromagnetic thermal energy radiated from an object into electronic video signals. These signals are amplified and transmitted via an interconnecting cable to the Control Unit where the signals are further amplified and the resultant image is displayed on a monitor.

The scanner unit comprises the following:

(a) Fixed lens (ocular).

(b) Electro-optical scanning mechanism.

(c) Infrared detector.

(d) Video interface.

(e) Control electronics and microprocessor for data output.

Electro-magnetic energy radiating from the object being scanned is focused by an infrared lens into a mirror. The mirror is oscillated by a dc motor. The optical output from the oscillating mirror is focused by three fixed mirrors onto a horizontal mirror polygon which rotates at 15000rpm. Both the oscillating mirror and the horizontal mirror polygon are controlled by the microprocessor. The microprocessor provides horizontal and vertical trigger pulses to the Control Unit trigger circuits (Fig. 3.2 shows a simplified block diagram).

The oscillating mirror and horizontal motors are synchronised in such a way that four fields produce one interlaced frame (Fig. 3.3) each having 100 horizontal scanning lines. Of these, 70 are used as active imaging lines per field, or 280 per frame. With a scanning rate of 25 fields per second, 25/4 completely interlaced picture frames per second are thus produced.

The reflected beam from the horizontal mirror polygon is passed through a set of relay optics containing a selectable aperture unit and a filter unit and finally focussed onto a point detector (see Fig. 3.1).

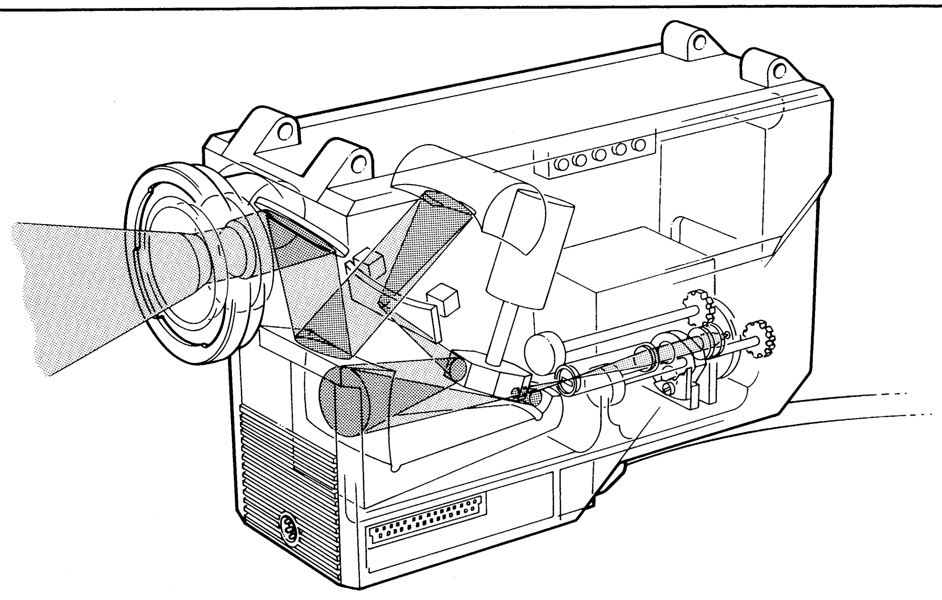

Fig. 3.1 Cutaway View of Thermovision® Scanner

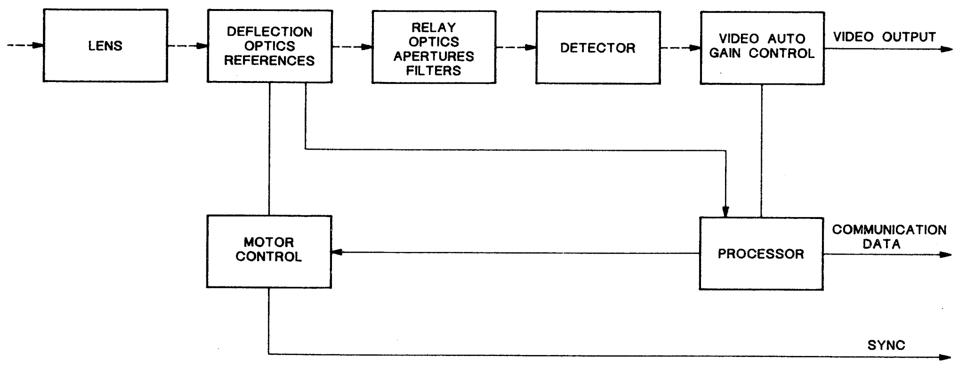

Fig. 3.2 Thermovision® Scanner Simplified Block Diagram

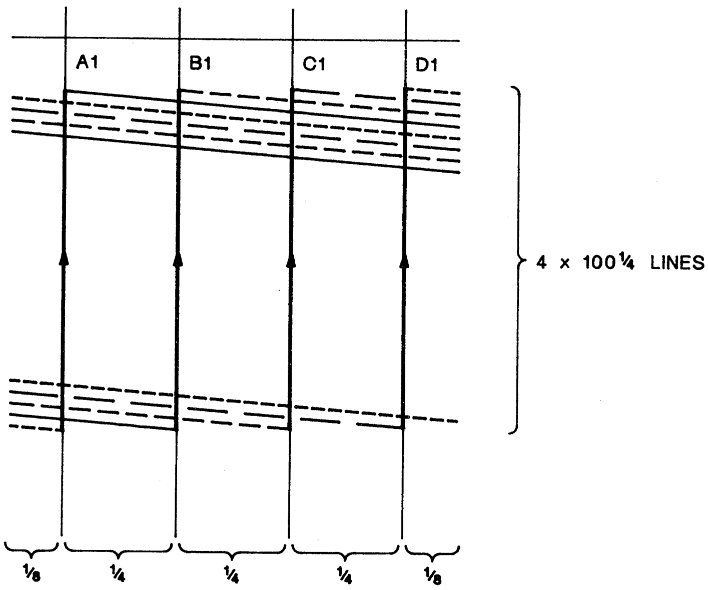

Fig. 3.3 Single Interlaced Frame

Detector

The detector is entitled SPRITE – **S**ignal **PR**ocessing **I**n **T**he **E**lement. Essentially the detector is a strip of infrared sensitive material (mercury cadmium telluride) mounted on a sapphire substrate.

If a small region of the detector chip is exposed to infrared radiation, excess current carriers are generated in that region. The excess current carriers 'drift' towards the readout region matched at the same velocity as the image which is scanned along the strip. Therefore, the excess carriers are fed along the strip together with the infrared image, resulting in all the carriers

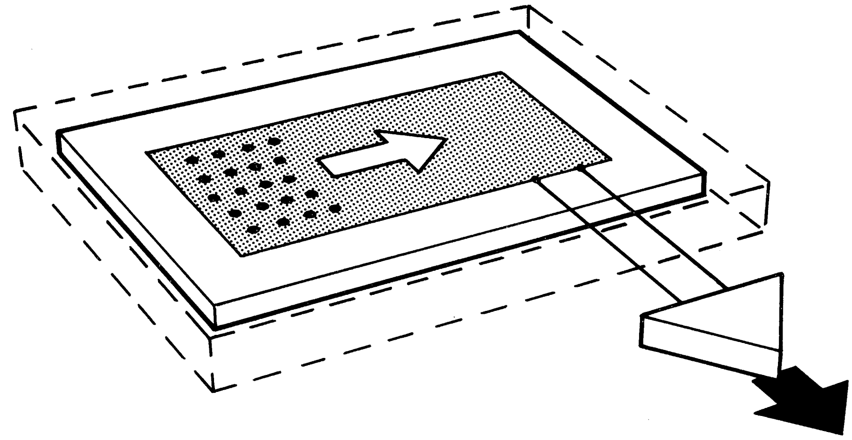

Fig. 3.4 Internal Integration Function

arriving at the readout region at the same time. The result is an improvement in signal/noise ratio obtained by an internal integration function from the detector itself (Fig. 3.4).

The SPRITE detector operates at a temperature of −70°C. This is achieved using a 3-stage thermoelectric cooler (Peltier element) incorporated into the encapsulators. This single element SPRITE detector is sensitive to radiation between 2 and 5 μm (Fig. 3.5).

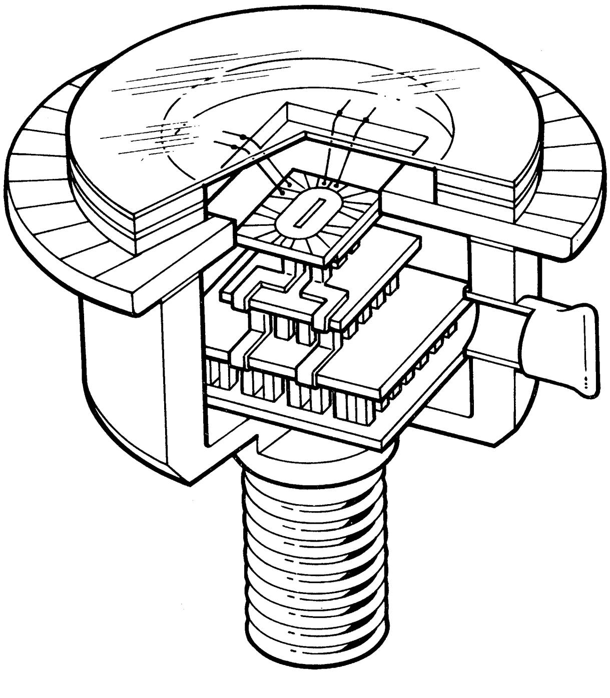

Fig. 3.5 Thermoelectric Cooler and SPRITE Detector

Interchangeable Lenses

CAUTION: When exchanging lenses particular care should be taken to avoid touching the surface coating of the lens. All lenses are anti-reflective coated and care must be taken when they are cleaned. Only cotton wool soaked in ethyl alcohol should be used to clean the lens. The lens should be wiped once with the solution then the cotton wool should be discarded. It should be noted that the lens has a bayonet fitting.

Lenses are fitted to the scanner unit in the same manner as photographic lenses with bayonet fittings (see Fig. 2.2). When fitting or exchanging lenses the following points should be noted:

(a) Always fit or remove a lens by gripping the ring nearest the scanner unit.

(b) When fitting or exchanging lenses protect the scanner fixed lens from ingress of foreign matter.

(c) Avoid touching the surface of the lens or the scanner optics.

(d) Clean any dirt or grit from the lens mounting area.

NOTE: Once fitted, lenses should only be removed from the scanner when being exchanged. Therefore the scanner should best be returned to the transport case complete with lens attached if possible.

Types of Lenses

The scanner unit of Thermovision® 800 can be fitted with any one of five different standard lenses with fields of view varying from 2.5° to 40° (Fig. 3.6). Table 3.1 lists typical values for the lenses that can be used.

Table 3.1 Lens Specification

Lens	Min Focus	Focal dist	Geo Res*
2.5°	20 ~~12~~m	308mm	0.43 mrad
7°	1.2m	110mm	1.2 mrad
12°	0.8m	65mm	2.1 mrad
20°	0.5m	38mm	3.5 mrad
40°	0.3m	19mm	7.0 mrad

*Geometrical resolution measured as slit response at 50% contrast.

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The lenses can be interchanged and focussed in the same way as normal photographic lenses are changed and focussed.

The fixed lens can be used for macro work from an object distance of approx. 20mm. An area of 13 x 13mm will be shown enlarged to the full screen size of the Monitor.

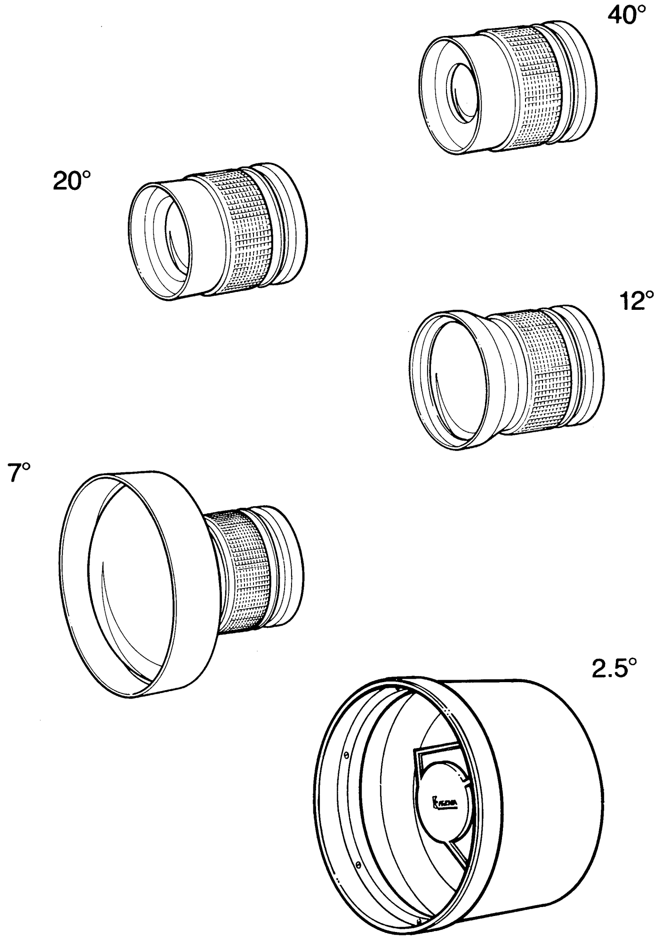

Fig. 3.6 Thermovision® 800 Lenses

Object Field Data

The table 3.2 and Fig. 3.7 give the dimensions of the scanned field surrounding the object at a set distance d, and using the four different lenses. The tables also detail the depth of focus within which a sharp picture of the object may be obtained.

Table 3.2 Scanned field (w) and depth of focus (+) set at various distances (d)

Lens	d	12	100	500
2.5° × 2.5°	w	0.49	4.3	21.7

Lens	d	0.3	0.5	0.8	1.2	2	3	5	10
7° × 7°	w				0.13	0.22	0.34	0.59	1.2
	+				0.04	0.12	0.30	1.2	4.6
	–				0.04	0.11	0.25	0.7	2.4
12° × 12°	w			0.13	0.23	0.42	0.65	1.1	2.1
	+			0.05	0.13	0.41	0.83	4.2	∞
	–			0.04	0.10	0.29	0.62	1.6	4.7
20° × 20°	w		0.13	0.22	0.37	0.68	1.0	1.7	3.5
	+		0.05	0.16	0.45	1.9	12.1	∞	∞
	–		0.04	0.11	0.25	0.6	1.3	2.8	7.1
40° × 40°	w	0.17	0.34	0.59	0.82	1.6	2.4	4.0	8.2
	+	0.05	0.29	1.9	∞	∞	∞	∞	∞
	–	0.03	0.12	0.3	0.6	1.3	2.2	4.1	9.0

NOTE: All measurements are in metres.

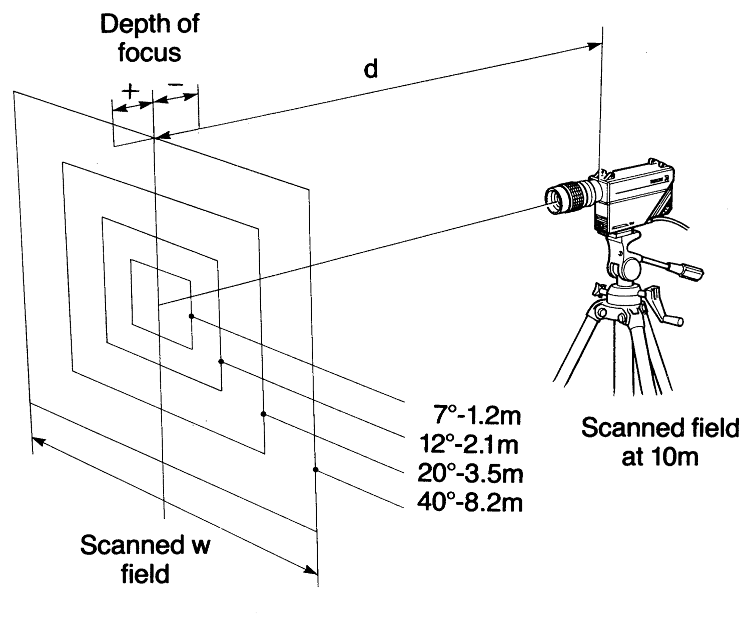

Fig. 3.7 Dimensions of Scanned Surfaces with Various Lenses

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Remote Focus

This option comprises an electric drive motor fitted to the scanner lens. Using the FOCUS (+/-) buttons on the Control Unit it is possible to focus the scanner from a remote site.

The motor shown in Fig. 3.8 is fitted beneath the lens and is powered via the connector located on the front of the scanner. To mount the motor first remove the motor cover, this is secured by two screws. The motor drive unit is mounted onto the lens using two screws. The drive cog must be mounted with the drive wheel in contact with the gear on the focusing ring. Replace the cover and connect the lead.

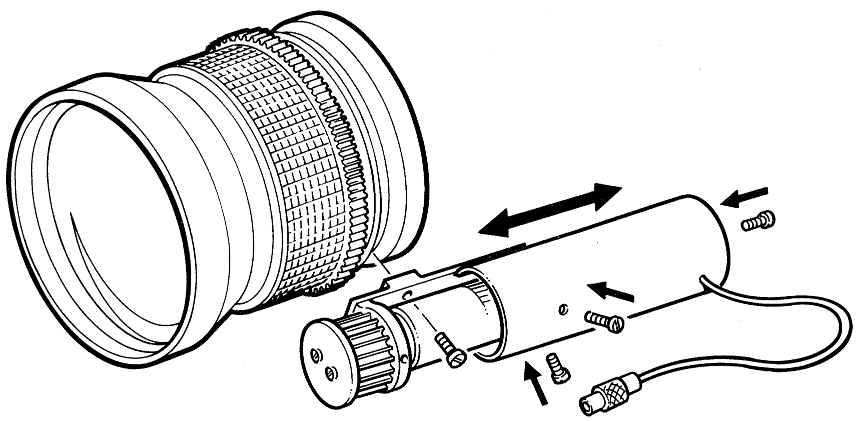

Fig. 3.8 Remote Focusing Attachment

Optical Coatings

Thermovision® 800 uses a broadband coating (Fig. 3.9) which increases the relative response of the scanner in the 2.0 to 4μm region of the spectrum. This is an advantage where spectral filtering may be required, e.g. target signature, petrochemical and laser applications.

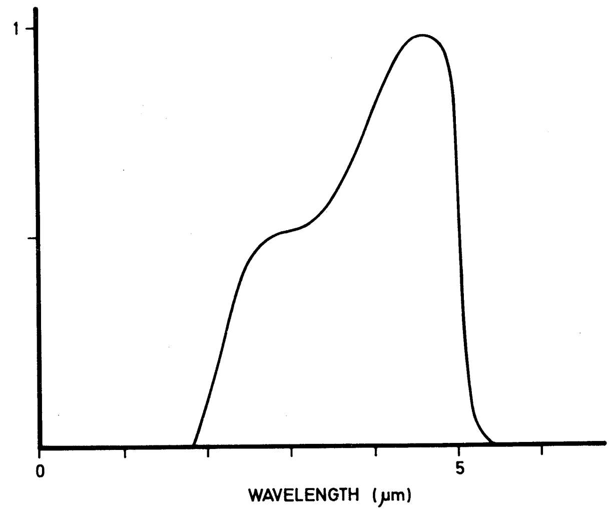

Fig. 3.9 Broadband Coating Response

Aperture Selection

Fitted at the back of the scanner assembly is an aperture turret which has positions for three apertures (Fig. 3.10). These are marked 0, 1 and 2, which correspond to 5.8, 2.4 and 1.0mm diameter. The apertures are selected so that the object temperatures covering the range −20°C to +500°C can be measured without the use of filters. The smaller the aperture (2) selected the higher the temperatures that can be viewed. The apertures are also selected to ensure a 20% overlap between temperature ranges. For the purpose of setting up the standard system for the first time set the aperture to the most sensitive setting (0).

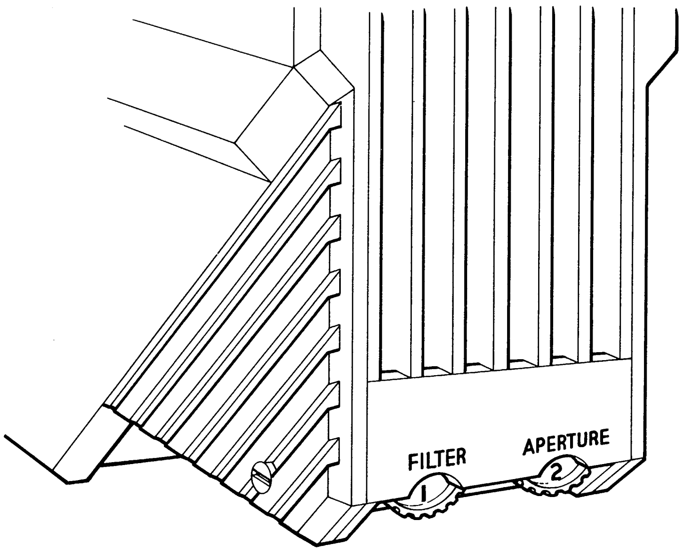

Fig. 3.10 Aperture and Filter Controls

Filter Selection

The filters are fitted to a filter turret housed within the scanner unit. A maximum of two filters may be fitted into a revolving holder controlled at the rear of the scanner.

Note: The operator can change a filter in position 2 as described below. The filter in position 1 is always fitted at the factory.

To remove or install a filter. Remove the left hand side cover (as viewed from the back) of the scanner. Remove the pcb to expose the filter area (Fig. 3.11) then proceed as follows:

(a) Rotate the filter turret until the first position (2) is clear of the mounting. This is indicated by CH on the filter selection control.

(b) Fit the new filter into the mounting, lock the filter with the locking ring

(c) Rotate the mounting unit to its original position

(d) Replace the pcb, check that the connections are replaced, tighten the screws and replace the scanner cover.

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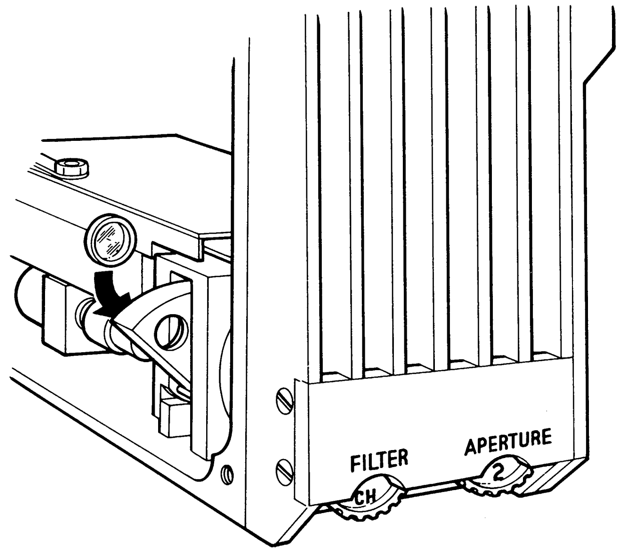

Fig. 3.11 Position for Filter Changing

Assuming that the scanner has been delivered with two calibrated filters to be used in position 2, the micro-processor must be informed as to which filter is installed. This is carried out using a switchbank mounted on the processor PCB (Fig. 3.12). Switches 1 to 3 (4 is used for calibration) can be set to give the information to the micro computer (ON = 1; OFF = 0):
Therefore after changing a filter, use a small screwdriver to reset the switches to the combination contained in the calibration data sheet. The PROM in the scanner will feed to the TRC or TIC the correct constants (R.B.F) to be used in the calculations.
If a filter is to be added to an instrument already delivered, the scanner and lens or lenses must be returned to AGEMA for calibration and the insertion of a new PROM.
NOTE 1: When ordering new filters please state which filter is to be placed into position 1 (fixed) and which to be placed into position 2 (changeable by the operator). A maximum of six different filters can be handled by the CATS software.
NOTE 2: If a change is made in the positioning of the switches in the switchbank always ensure that switch 4 (calibration) is set to OFF.

FROM CALIBRATION DATA SHEET

SWITCH	3	2	1
FILTER	X	X	X
POS./ SER 2 / 45			
SWITCH	0	0	1

NOTE: THE POSITION OF THE SWITCH ON THE SHEET AND ON THE BOARD ARE REVERSED

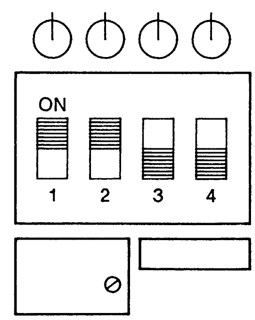

Fig. 3.12 Example of Switchbank setting for a Filter in Position 2

Table 3.3 lists a number of standard filters and their uses, however this is not a complete list and many other filters may be used dependent on the application of the job in hand.

Table 3.3 Filters

Filter	Description	Colour Code
Flame or High Temperature "FLM"	Used when measuring hot objects through the flames e.g. as used in a furnace or as a high temperature damping filter for objects between 500°C and 1500°C.	Black/Green
Atmospheric "ATM"	Used when measuring objects hotter than 200 to 300°C from a distance.	Black/Brown
Carbon Dioxide "COS"	Used when measuring energy in the CO_2 absorption band. Combines energy in the blue and red spike regions.	Black/Red
Sun Reflex "SRX"	Used for suppressing reflected short wave radiation below 3.4 μm, e.g. from the sun received at a peak of 1.7 μm.	Brown/Blue

The curves for the filters are shown in Fig. 3.13. The colour code is shown by dots on the filters (Fig. 3.14).

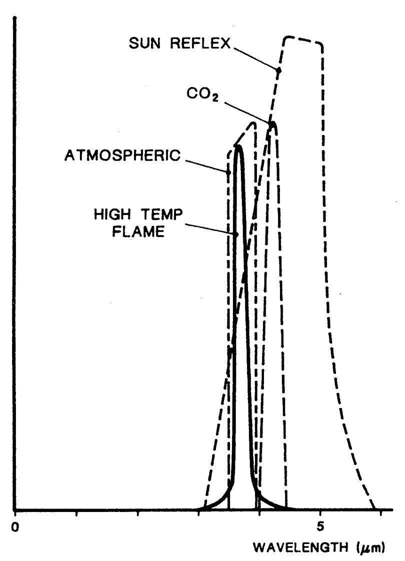

Fig. 3.13 Filter Curves

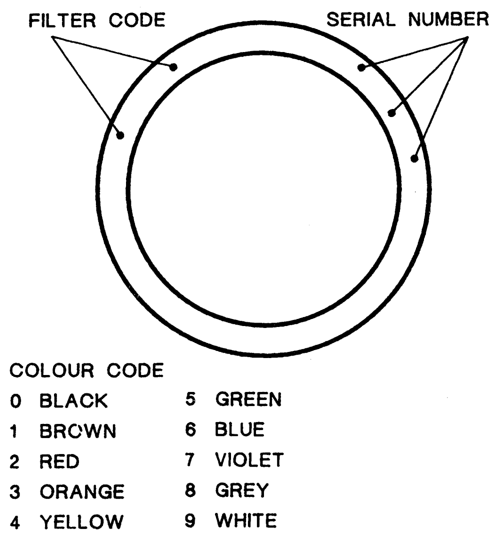

Fig. 3.14 Filter Colour Code and Serial Numbers

3.2 THE CONTROL UNITS

Introduction

The Control Unit houses all of the operational controls of the Thermovision® 800 scanner. There are two standard types available:

CU 800 V (video) is used together with; a RGB monitor for display of image and data; a Temperature Read-out Computer (TRC) for calculation of correct temperature values; storing test data and writing comments. A system or a standard video recorder (VCR) can be connected to record images.

CU 800 C (computer) is used as an interface between the scanner unit and the computer system TIC-8000. The CU 800 C is used to optimise the image signal from the scanner, to obtain a good image on the computer monitor. The scanner can be remotely focused by the control unit, and image presentation can be selected between real time or VCR play-back.

DU 800 is a combined control unit and monitor and is designated as a Display Unit. This version can be ordered if a man carried system is required. The DU 800 is described in Appendix A.

Control Unit CU 800 V
Controls and Indicators

The front of the CU 800 V unit is shown in fig. 3.15 and the functions of the controls are as described in table 3.4.

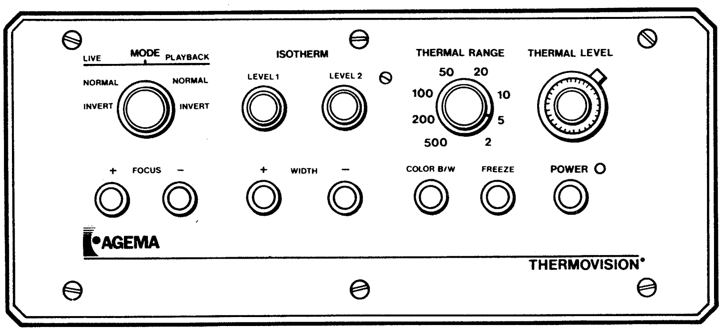

Fig. 3.15 Control Unit CU 800 V – Front View

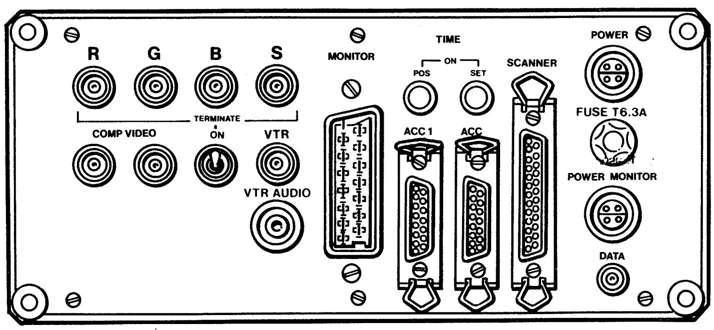

Fig. 3.16 Control Unit CU 800 V – Rear View

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Table 3.4 Control Unit CU 800 V-Front Panel Controls and Indicators.

Description	Function
POWER	Applies power to the system from the power supply. The green indicator (when lit) indicates that power is available
THERMAL RANGE	An eight position switch, which selects the thermal range of the image display. The switch is calibrated between 2 and 500 isotherm units.
THERMAL LEVEL	Adjusts the thermal level of the image display.
MODE	Selects the type of image to be displayed, LIVE/NORMAL-INVERT or PLAYBACK/ NORMAL-INVERT.
FOCUS (+/−)	These two pushbuttons are used to operate the (optional) focus motor attached to the lens.
ISOTHERM LEVEL 1	Switches on the isotherm 1 function and adjusts it for identification of discrete thermal levels on the object. In position COLOR the ISO 1 isotherms are coloured light gray and in position B/W coloured red.
ISOTHERM LEVEL 2	Similar to ISOTHERM LEVEL 1. ISO 2 isotherms are coloured dark gray in position COLOR and green in position B/W
ISOTHERM WIDTH(+/−)	These two push buttons set the width (in steps) of the isotherm markers displayed on the vertical scale on the screen
COLOUR B/W	With this control the image can be presented in colour or gray tone.
FREEZE	Freezes the image displayed when the push-button is pressed. The first time the button is pressed the image is frozen in Frame mode. Press the button again to freeze the image in Field mode. The third press of the button returns the image to live.

Table 3.5 Control Unit CU 800 V – Rear Panel Controls and Connectors

Description	Function
R, G, B, S	Red, Green, Blue and Sync output sockets (BNC).
TERMINATE	This switch should be set to the off position, except when no accessory is connected when it should be set to the ON position to terminate the sockets
COMP VIDEO	Two parallel output sockets (BNC) for connecting composite (TV) video signals to standard VCR or TV/monitor (NTSC or PAL version must be specified when ordering CU 800 V).
VTR	In/output socket (BNC) for system Thermovision® (modified) VCR.
VTR AUDIO	In/output socket used for transferring of LEVEL, RANGE, TIME/DATE, aperture and filter settings during recording.
MONITOR	Standard European SCART output connector for TV-set, monitor or VCR (parallel with RGB/S and COMP VIDEO).
TIME	These two pushbuttons (POS/SET) are used for setting the correct date and time.
ACC 1 and 2	Two parallel accessory sockets used to connect TIC-8000 or other accessories.
SCANNER	This socket is used to connect the scanner to the control unit.
POWER	This plug is used to connect the power supply to the unit (11-15 V DC).
FUSE 6.3 A	This holder contains a 6.3 amp slow-blow fuse (20 mm length).
POWER MONITOR	This output socket supplies power for the 5" RGB monitor (12 V DC).
DATA	This socket should be connected to the TRC or TIC-8000 for transferring data.

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Interconnections

Fig. 3.17 shows a simplified interconnection diagram of a Thermovision® 800 system, incorporating a CU 800 V Control Unit. A more detailed description of the interconnection is given in Section 4 (Recording) and Section 5 (Computers). Also see Section 2 (Unpacking,Inspection and First Time Operation).

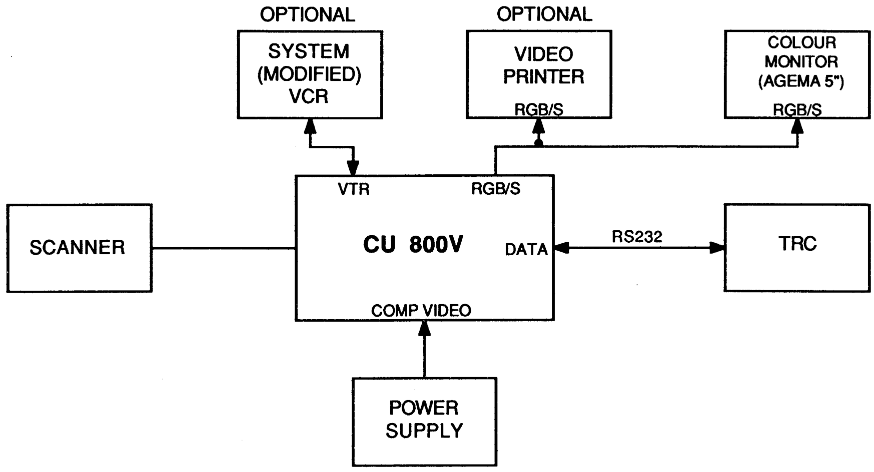

Fig. 3.17 CU 800 V Standard System Interconnections (with Optional Accessories)

Level Adjustments

Check the settings of he CU 800 V controls before carrying out any measurements. Adjustment must always be carried out.

- when changing the cable length between the Scanner and Control Unit
- whenever the minimum dc offset is important, i.e. for Direct measurement in general and in particular combination with low object temperatures.

The check procedures are performed as follows:

(a) On the Scanner set the APERTURE control to position 2 and the FILTER control to the position marked with a dot.

(b) Set RANGE to 500 and LEVEL to 0.

(c) Adjust ISO LEVEL 1 (or 2) control until the image is filled with an isotherm. The isotherm marker now indicates the true 0 point of the scale. This point should not differ by more than 0.02 from the indicated 0 marker on the scale. If the difference is outside this level, alignment should be carried out as described in the maintenance manual.

(d) Set RANGE to 2.

(e) Check that the image is filled with an isotherm. If not adjust LEVEL ADJ.

The level adjust trimmer is located behind the front panel. It is possible to gain access to the trimmer, by removing a screw, located between the ISO LEVEL 2 and RANGE controls.

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Date & Time Adjustments

To set the date and time correctly, use the TIME control on the rear panel of the CU 800 V. Simultaneously press POS and SET, a cursor will appear at the first figure of the year. Press SET to increment the digit by one, and repeat until the correct digit is displayed. Move to the next digit by pressing POS. When the last digit has been set and POS is then pressed the cursor disappears and the clock begins to operate. If the back-up battery becomes disharged, the clock will not operate, then reset the digits by simultaneously pressing POS, SET and + and - (ISOTHERM WIDTH).

Changing the Battery

The back-up battery (for the clock) should operate for 12 to 18 months. When is becomes discharged it must be exchanged. However changing the battery requires the CU 800 V to be dismantled, therefore it is recommended to send the unit to your local AGEMA representative so that the battery can be changed. The recommended replacement battery is the VARTA CR 2032 Li 3.0V, AGEMA part no. 905 590, (or alternatively the lower capacity VARTA CR 2016).

If it is not possible to return the unit to your local representative then the procedure below should be followed to replace the battery.

(a) Remove the TRC holder.

(b) Remove the top and bottom covers of the unit.

(c) Remove the front panel of the unit and the cable connector.

(d) Remove the rear panel and the four cable connectors.

(e) Remove the PCB cassette from the unit frame.

(f) Unscrew and swing aside the two brackets clamping the PCB.

(g) Disconnect the two narrow cable connectors. The battery is located on the PCB in the middle position.

(h) Remove the middle PCB and replace the battery.

(i) Reassemble the unit carrying out steps (a)-(g) in the reverse order.

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Control Unit CU 800 C
Control and Indicators

The front of the CU 800 C unit is shown in Fig. 3.18 and the functions of the controls are described in Table 3.6.

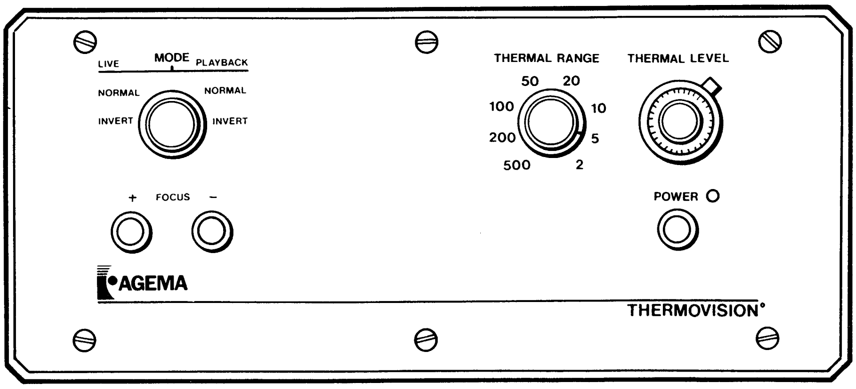

Fig. 3.18 Control Unit CU 800 C – Front View

Table 3.6 Control Unit CU 800 C-Front Panel Controls and Indicators.

Description	Function
POWER	This button applies power to the system from the power supply. The green indicator (when lit) indicates that power is available.
THERMAL RANGE	An eight position switch, which selects the thermal range of the image display. The switch is calibrated between 2 and 500 isotherm units.
THERMAL LEVEL	This control adjusts the zero thermal level (as seen on the vertical temperature scale) of the display image.
MODE	This switch selects the type of image to be displayed, LIVE/NORMAL-INVERT or PLAYBACK/NORMAL-INVERT.
FOCUS (+/–)	These two pushbuttons are used to operate the (optional) focus motor attached to the lens.

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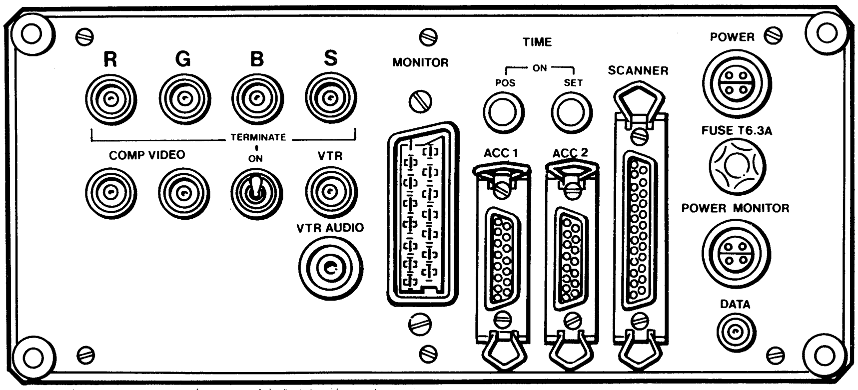

Fig. 3.19 Control Unit CU 800 C – Rear View

Table 3.7 Control Unit CU 800 C-Rear Panel Controls and Connectors

Description	Function
R, G, B, S	Red, Green, Blue and Sync input sockets (BNC). NTSC version only.
TERMINATE	This switch should be set to the off position, except when no accessory is connected, when it should be set to the ON position to terminate the sockets.
COMP VIDEO	Two parallel output sockets (BNC) for connecting composite video signals to standard VCR (NTSC version only).
VTR	Input/output socket (BNC) for Thermovision® system VCR.
VTR AUDIO	Socket not used in this version.
MONITOR	Not normally used in this version.
ACC 1 and 2	Accessory sockets used to connect TIC-8000 (these sockets are in parallel).
SCANNER	This socket is used to connect the scanner to the control unit.
POWER	This plug is used to connect the power supply to the unit (11-15 V DC).

Table 3.7 (continued)

Table 3.7 (continued)

Description	Function
FUSE 6.3 A	This holder contains a 6.3 amps slow blow fuse (20mm length).
POWER MONITOR	This output plug is not normally used for this version.
DATA	This socket should be connected to the computer for transferring scanner data.

Interconnections

Fig. 3.20 shows a simplified interconnection diagram of a Thermovision® 800 system incorporating a CU 800 C control unit. A more detailed description of the interconnections is given in Section 5 (computers) Section 2 (standard system).

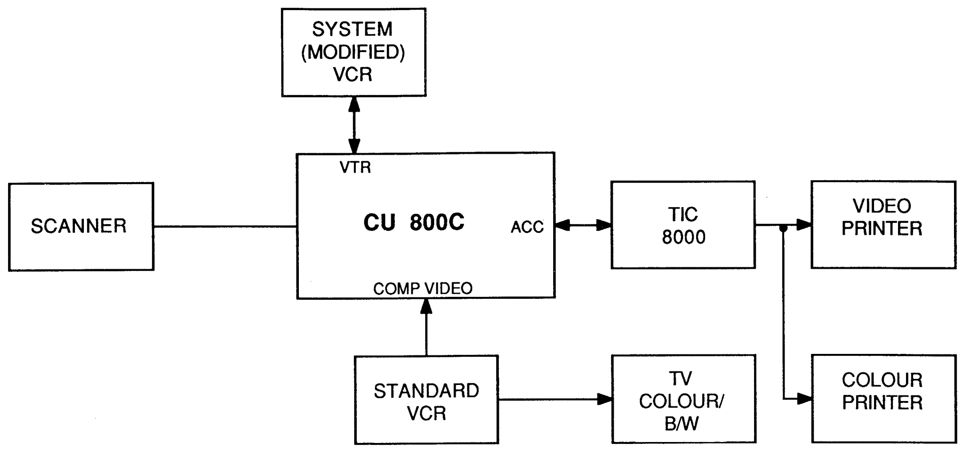

Fig. 3.20 CU 800 C Interconnections

Monitor

The AGEMA 5" RGB monitor is the standard monitor available for use with the CU 800 V control unit. Fig. 3.21 shows the unit, while Table 3.8 describes the functions of the controls.

The monitor power cable is connected to the POWER MONITOR socket on the CU 800 V.

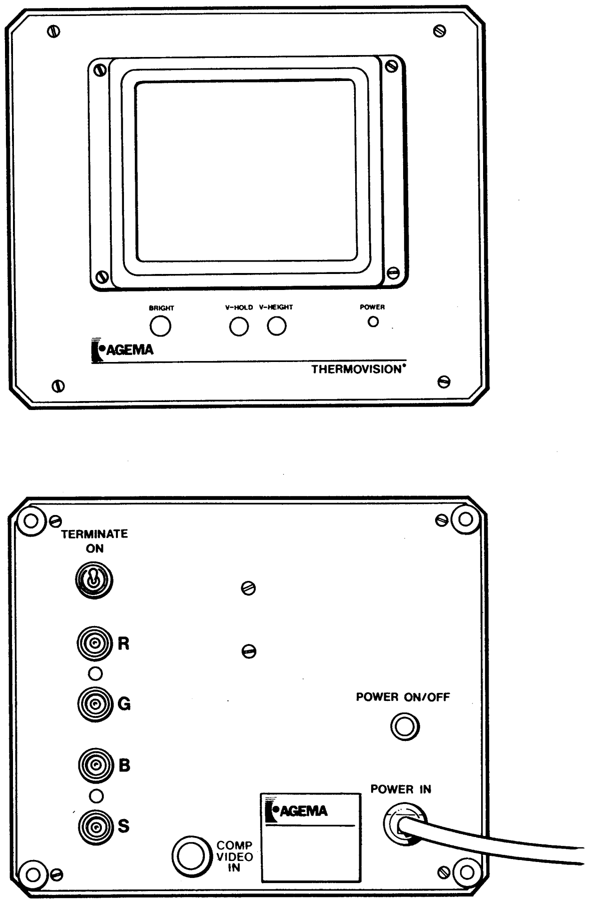

Fig. 3.21 AGEMA 5" Monitor

Table 3.8 AGEMA 5" RGB Monitor – Front Panel Controls and Indicators

Description	Function
BRIGHT	Image brightness adjustment.
V-HOLD	Adjust to prevent vertical movement of the image.
V-HEIGHT	Vertical image height adjustment.
POWER	Lit when the monitor is switched on, green LED.

Table 3.9 AGEMA 5" RGB Monitor – Rear Panel Switches and Connectors

Description	Function
TERMINATE	Normally set to the ON position, unless another accessory is connected
COMP VIDEO IN	Input socket (BNC) for composite video, e.g. playback from a standard VCR, or image control
R, G, B, S	Red, Green, Blue and Sync input sockets (BNC)
POWER ON/OFF	Push button when pressed applies power, from the Control Unit, to the monitor.

When the system is started a message is displayed in the image area for several seconds, detailing the control unit type and program version. An image will then appear together with a parameter menu.

Monitor Specification

CRT	High resolution 5 inch
Input	–Analogue RGB/S, NTSC or PAL –Composite, NTSC or PAL
Power	11-15V from CU 800 V
Dimension	240x170x375 (WxHxD)mm
Weight	5.8kg
Part No.	193 142 (NTSC)/193 143 (PAL)

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APPENDIX A

Display Unit

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Appendix A – Display Unit

A.1 INTRODUCTION

The Display Unit houses all the operational controls for the Thermovision® 800 system. Each control and its function are shown in Fig. A.1 and A.2 and described in Tables A.1 and A.2 for the front and rear panels of the Display Unit respectively.

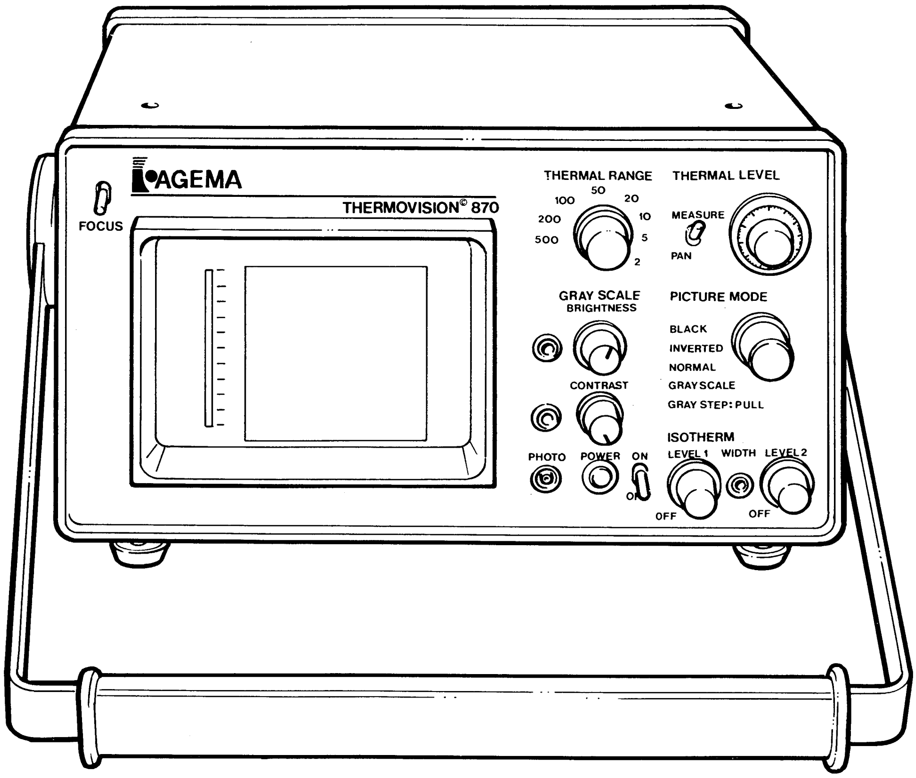

Fig. A.1 Display Unit – Front View

Table A.1 Display Unit Front Panel Controls and Indicators

Description	Function
ON/OFF	This two position switch applies power to the system. The switch controls both battery power pack or power supply/ charger unit as appropriate.
POWER (LED)	This indicator shows that power is available to the Display Unit.
PHOTO	This connection socket is used in conjunction with the photo recording equipment.
GRAY SCALE BRIGHTNESS (MANUAL)	This control increases or decreases the display brightness.

Table A.1 (continued)

Description	Function
BRIGHTNESS (PRESET CONTROL)	This screwdriver adjusted control sets the brightness on the display when photo recording equipment is plugged into the PHOTO socket and activated, or when the photo preset control is set to ON.
GRAY SCALE CONTRAST (MANUAL)	This control increases or decreases the display contrast.
CONTRAST (PRESET CONTROL)	This screwdriver adjusted control sets the contrast on the display when photo recording equipment is plugged into the PHOTO socket and activated, or when the photo preset control is set to ON.
THERMAL RANGE	This eight position switch selects the thermal range of the object being viewed. The switch is calibrated between 2 and 500 isotherm units.
MEASURE/PAN	This two position switch when set to PAN causes an image determined by the object mean temperature to be displayed. In the MEASURE mode the temperature level is adjusted by the THERMAL LEVEL control and is used during thermal measurement only.
THERMAL LEVEL	This control adjusts the zero thermal level (as seen on the vertical scale) of the thermal image (see Section 8).
PICTURE MODE	This switch selects the type of image to be displayed.
GRAY SCALE	This position causes a continuous gray scale to be displayed on the screen.
NORMAL	This position selects a normal thermal image display, where the hotter object temperatures appear as white and the cooler as black.
INVERTED	This position is used to invert the display representation, i.e. warm = black, cool = white.
BLACK	This position causes only isotherm levels to be displayed while suppressing the gray tone image (used in conjunction with the ISOTHERM LEVEL and WIDTH controls).

Table A.1 (continued)

Table A.1 (continued)

Description	Function
GRAY STEP (pull)	This push-pull switch changes the continuous gray tone image on the display screen to a five step gray tone image.
ISOTHERM LEVEL (1)	This control is used to turn one of the two isotherm functions ON and to adjust for identification of discrete thermal levels on the object (shown as saturated white).
ISOTHERM LEVEL (2)	See Isotherm Level (1).
ISOTHERM WIDTH	This control sets the width of the 2 isotherm markers, displayed on the vertical scale.
REMOTE FOCUS	A two-way switch for operating an optional focus motor which can be attached to the lenses.

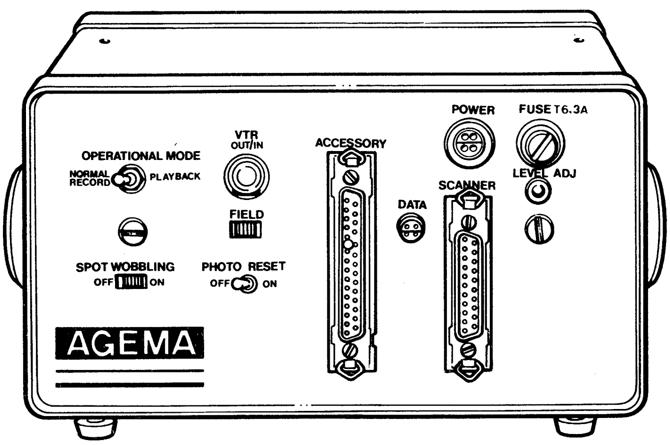

Fig. A.2 Thermovision® Display Unit – Rear View

Table A.2 Display Unit – Rear Panel Connectors and Switches

Description	Function
SPOT WOBBLING	This switch selects whether SPOT WOBBLING will be added to the display image.
OPERATIONAL MODE	This switch selects which image source is displayed (live or video).
NORMAL/RECORD	This position selects normal live images for display or recording.
PLAYBACK	This position is selected to replay images previously recorded on a VTR.
FIELD 1-4	This switch selects either 1 or 4 fields that will be recorded onto a film (the 4 position is generally recommended).
ACCESSORY CONNECTOR	The accessory socket is used to connect accessories to the Display Unit, e.g. TIC-8000.
VIDEO	This socket output is connected directly to a VTR.
POWER	This plug is used to connect power supplies to the system.
FUSE 6.3A	A holder containing a 6.3 amp slow blow fuse (20mm)
DATA	This socket output is connected directly to the TRC.
SCANNER.	This socket is used to connect the Scanner Unit to the Display Unit.
LEVEL ADJUST	This control adjusts the THERMAL LEVEL during system calibration.
PHOTO PRESET	This switch when set to ON enables the operator to set up the preset contrast and brightness controls on the front panel.

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Level Adjustments

NOTE: This check or adjustment should always be carried out;

- When changing cable length between the Scanner and Display Unit.
- Whenever Minimum dc offset is of importance, i.e. for Direct measurement in general and in combination with low object temperatures in particular.

To carry out the check proceed as follows;

(a) Set the APERTURE to 2.

(b) Set the FILTER to the position marked with a dot.

(c) Set the THERMAL LEVEL control to 0 and the THERMAL RANGE to 500.

(d) Set the PICTURE MODE control to BLACK.

(e) Adjust the ISOTHERM LEVEL control until the screen becomes white. The isotherm marker now indicates the true 0 point of the scale. This point should not differ by more than 0.02 from the indicated 0 marker on the scale. If the difference is outside this level, alignment should be carried out as described in the maintenance manual.

(f) With the isotherm marker set to the true 0 point and the THERMAL LEVEL set to 0, set the THERMAL RANGE to 2.

(g) Check that the display screen is filled with an isotherm. Adjust the LEVEL ADJ Trimmer control if required.

Gray-step function

When using the gray-step function, the video image is quantised into five intervals as shown in Fig. A.3. All thermal amplitudes outside the scale, i.e. amplitudes below and above ±0.5, are displayed as black.

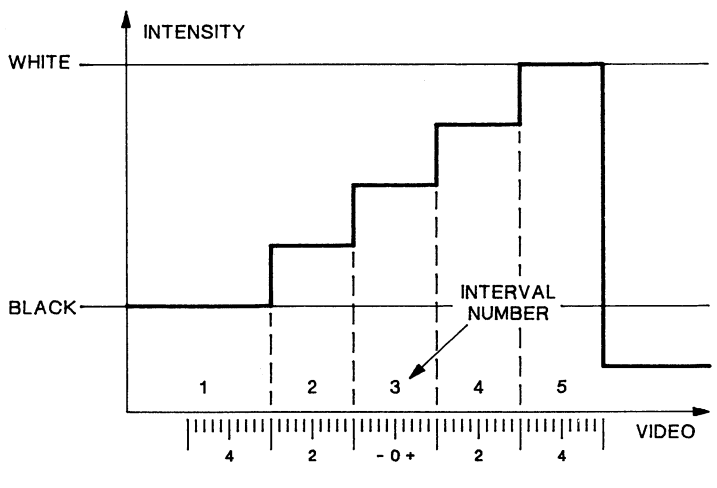

Fig. A.3 Signal Relationship Using the Gray-step Function

Appendix A – Display Unit

Display Unit – Specification

Thermal image size	50 x 50 mm framed by temperature measurement scale and range digit display
Thermal range	8 calibrated ranges from 2 to 500 (IU)
Thermal level	5-turn graduated control
Picture modes	Normal, inverted, black, gray scale, gray step
Isotherm function	Width (2 to 30%) and two levels continuously adjustable within selected thermal range
Power	Power supply/battery charger unit for 100 to 240V, 50/60Hz, 35VA or separate battery for 8 to 15V DC, 20W
Dimensions	W x H x D: 235 x 129 x 322mm
Weight	4.5 kg
Part No.	192 905

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A.2 PHOTO RECORDING

A photo recording attachment is designed to be used with the Thermovision® system. The attachment employs the use of specially adapted Polaroid or 35mm film cameras. These cameras are connected via the photo attachment to the display unit. It should be emphasised that the system should be correctly set up for thermal measurement prior to the commencement of photo recording. Figure A.4 shows how the Polaroid and 35mm cameras are fitted to the attachment. This unit is optional and can be purchased separately.

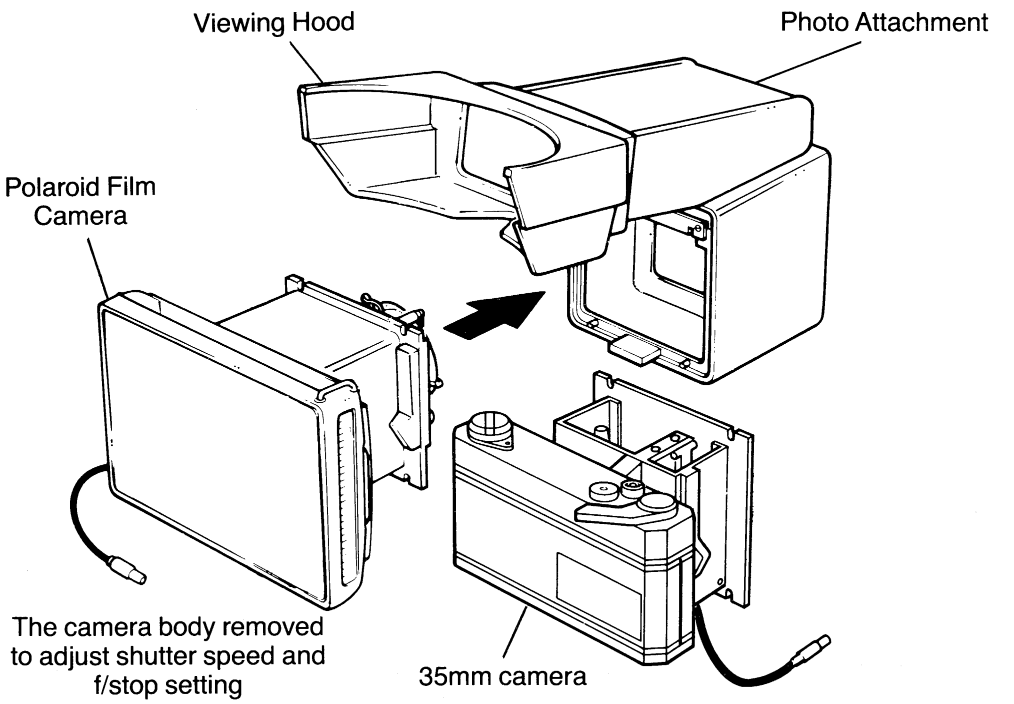

Fig. A.4 Photo Recording Attachment (Polaroid and 35mm)

POLAROID FILM CAMERA

Installing the Attachment to the Display Unit

The photo recording attachment is mounted to the display unit by locating the 'rails' at either side of the attachment into location grooves fitted on either side of the display screen.

Setting the Shutter Speed and Aperture

Prior to inserting the camera into the attachment the shutter speed should be set to 1 second and the aperture to f/8 (Fig. A.5).

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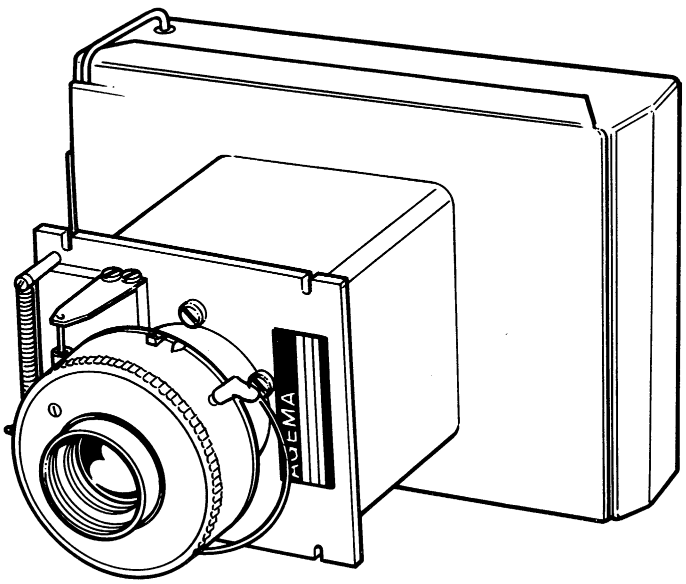

Fig. A.5 Polaroid Camera

Fitting the Camera to the Attachment

The camera is fitted to the attachment by tilting the camera so that the lens is pointing down and then engaging the two guide pins into the slots on the recording attachment. The camera should then be tilted down and by pressing at the back of the camera the lower latch will snap into place. The synchronisation cable is connected to the PHOTO socket on the display unit.

NOTE: This connection is a push-to-lock connection and the cable should not be turned. If the sync cable is not used the exposure time should be reset to 0.25 second at f/11.

Loading the Film

Loading instructions are contained in the film pack for Polaroid Land type 339 Autofilm (or equivalent).

Preset Display Unit Controls

On rear of display unit: set SPOT WOBBLING switch to "ON", PHOTO PRESET to "ON" and FIELD switch to "4" (to "1" in case of moving objects). On front of display unit: set PICTURE MODE selector to "GRAY STEP" and adjust BRIGHTNESS and CONTRAST preset screwdriver controls to obtain a clean (stepped) gray scale picture. Low brightness and contrast settings give correct thermogram exposures (Fig. A.6).

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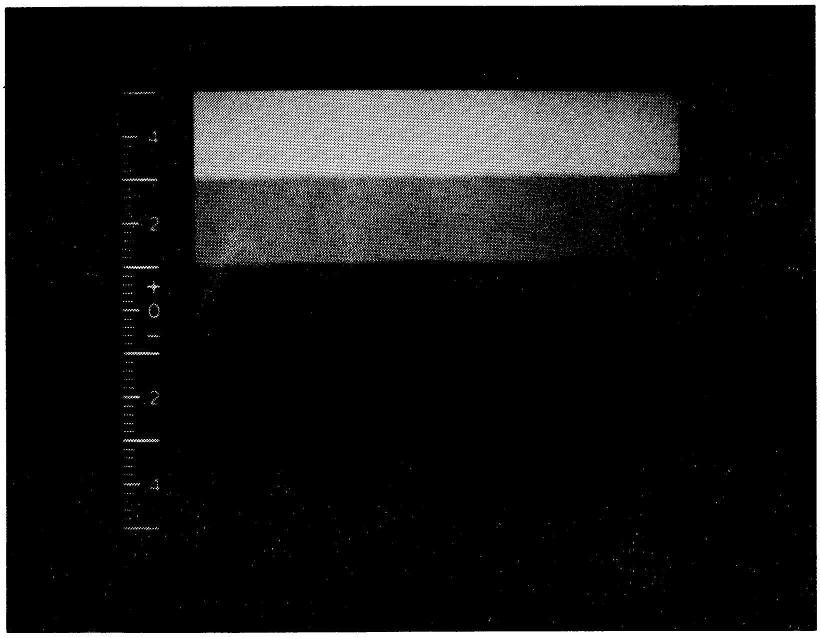

Fig. A.6 Gray Scale Picture

Gray Scale Test Exposure

To make a test exposure proceed as follows:

(a) Ensure the Thermovision® system is set up as described in Section 2.

(b) Set the PICTURE MODE switch to GRAY SCALE.

(c) View the display screen through the viewing hood of the attachment.

(d) Close the viewing door.

(e) Depress the shutter fully and release.

(f) To develop the Polaroid picture proceed as follows:-

- (i) Grip the centre of the WHITE TAB of the film and carefully pull it all the way out of the camera.
- (ii) Carefully grip the YELLOW TAB and pull it straight and at a constant speed all the way out of the camera.

NOTE: This action must be continuous. Start timing the development of the film from the time the photograph is clear of the camera.

(g) Allow 45 seconds for the film to develop at room temperature, i.e. greater than 21 °C.

WARNING: THE CHEMICALS USED FOR THE FILM DEVELOPMENT CAN CAUSE SKIN IRRITATION. THEREFORE CARE SHOULD BE TAKEN TO AVOID CONTACT WITH THE CHEMICALS ON FILM SEPARATION.

(h) Separate the print from the film starting at the yellow tab.

(j) Compare the gray tone print with the display (Fig. A.7). If necessary fine adjustments to the CONTRAST and BRIGHTNESS preset controls may be required. A small screwdriver included in the tool kit is required to carry out this operation. Clockwise rotation causes an increase of brightness or contrast. Counter-clockwise rotation causes a decrease of brightness or contrast. If adjustment is required a further test print should be carried out.

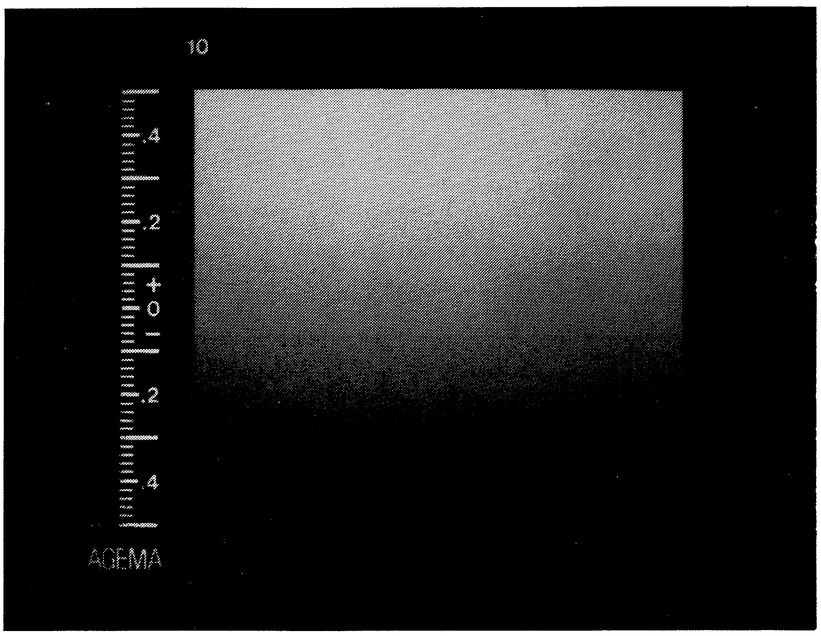

Fig. A.7 Gray Scale Sample Picture

NOTE: The PHOTO PRESET switch should be set to 'ON' to allow adjustments of the preset controls. When a satisfactory print is obtained the switch should be set to 'OFF'. In this position the BRIGHTNESS and CONTRAST manual controls can be adjusted for optimum viewed image without affecting the preset controls.

Thermogram Recording

Set PICTURE MODE selector to either NORMAL or INVERTED as required. Use ISOTHERM LEVEL controls to determine area of highest and lowest temperatures to be recorded and proceed as detailed in the Gray Scale Test Exposure.

Optimum Exposure Tips

The best balanced exposures are achieved by avoiding the use of saturated white as the highest temperature level in the NORMAL mode of operation. One method is to set one isotherm marker to +0.3 by adjustment of the ISOTHERM LEVEL 1 control and to adjust the THERMAL LEVEL control until the isotherm just brightens the highest thermal area. All details are then rendered in varying tones of gray and only the isotherm as saturated white. Subsequent exposures can be changed by slight adjustment of the BRIGHTNESS and CONTRAST screwdriver controls without affecting the THERMAL LEVEL setting.

Film Developing Tips

Develop the film longer in cooler conditions (i.e. below 19°C). Underdevelopment results in gray, low-contrast thermogram prints. Over-development results in too much contrast.

Before loading the film pack, check that development spreader mechanism in camera back is clean. Dirt or chemical residue in spreader rolls or film exit door can cause stoppages which may ruin an entire film pack.

Cleaning the Polaroid Film Camera

Instructions for care and cleaning of the Polaroid camera are detailed on the inside of the camera back.

35mm CAMERA

Fitting the Camera and the Attachment

The 35mm camera is fitted to the attachment in the same way as previously described for the Polaroid film camera. The photo attachment is located into the grooves fitted to each side of the display unit.

Setting the Shutter Speed and Aperture

Prior to inserting the camera into the attachment the shutter speed should be set to 1 sec. The aperture setting is dependent on the film speed. Try using 5.6 or 8 by making test exposures.

Loading the Film

The 35mm film is loaded in the normal way (see camera instruction manual).

Preset Display Unit Controls

At the rear of the display unit set SPOT WOBBLING switch to OFF, PHOTO PRESET to ON and FIELD to 4. On the front of display unit set PICTURE MODE to GRAY SCALE.

Gray Scale Adjustment

Set CONTRAST screwdriver control to suit film type being used. The values given in Table A.3 may be used as a guide for initial settings. These adjustments are only a guide and more accurate settings will be obtained as experience is gained. If reflections or several TEMPERATURE RANGE figures are shown, the picture is over-exposed and the CONTRAST setting needs to be reduced.

Holding the face tight against the rubber eyepiece, adjust BRIGHTNESS screwdriver control until the scanning lines just become invisible at the bottom of the gray scale. Reset SPOT WOBBLING to ON, and PHOTO PRESET to OFF. All the control knobs on the front can now be operated in the usual way.

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Thermogram Recording

Set PICTURE MODE selector to either NORMAL or INVERTED as required. Close the viewing door, press exposure button, and advance the film one frame. The thermograms will be exposed in the preset gray tones, irrespective of how the manual control knobs are operated. For Optimum Exposure Tips refer to Polaroid Recording.

Table A.3 Contrast Setting

Film Type	CONTRAST (Screwdriver) Control
Black/White 125 ASA (22 DIN)	1/4 – 1/2 turn clockwise from fully counter-clockwise.
Black/White 400 ASA (27 DIN)	1/8 – 1/4 turn clockwise from fully counter-clockwise.
Kodak Ektachrome 160 ASA (23 DIN)	3/4 turn clockwise from fully counter-clockwise.
Kodacolor II 100 ASA (21 DIN)	3/4 turn clockwise from fully counter-clockwise.
Kodacolor 400 ASA (27 DIN)	1/4 turn clockwise from fully counter-clockwise.

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A.3 VIDEO RECORDING

A system (modified) cassette recorder (VCR) can be used with Thermovision® because the Display Unit has a built-in adapter circuit to which a modified recorder can be connected.

The PICTURE MODE switch and the ISOTHERM LEVEL controls can be utilised during play-back to enable the image to be analysed on the Thermovision® Display Unit.

The video signal for recording is extracted from the video chain after the THERMAL LEVEL and THERMAL RANGE, termed 'B' or system video. On playback the gray level of the image is restored by clamping circuits. It is recommended that a log book is maintained during recording and the settings of the THERMAL RANGE and LEVEL controls noted so that accurate analysis can be carried out when playing back the video recording. If this is not carried out the analysis, when using the isotherm levels, can give erroneous results.

The accuracy of the measurement is directly dependent on the quality of the VCR being used. During all recordings only the highest quality tape should be used and the VCR recorder heads should be kept clean as described in the handbook associated with the VCR.

Setting Up

Prior to carrying out a video tape recording the equipment should be set up as described in Section 2. Detailed operation of the VCR is explained in the Operating Manual accompanying the VCR being used.

Connect the VCR, using the special cable supplied, to the VCR OUT/IN socket on the rear panel of the Display Unit and to the CAMERA input of the VTR (Fig. A.8). Load the cassette into the recorder in accordance with the instructions and the equipment is ready for use.

Record

To record an image after setting up the equipment the OPERATIONAL MODE switch on the rear panel of the Display Unit should be set to NORMAL/RECORD.

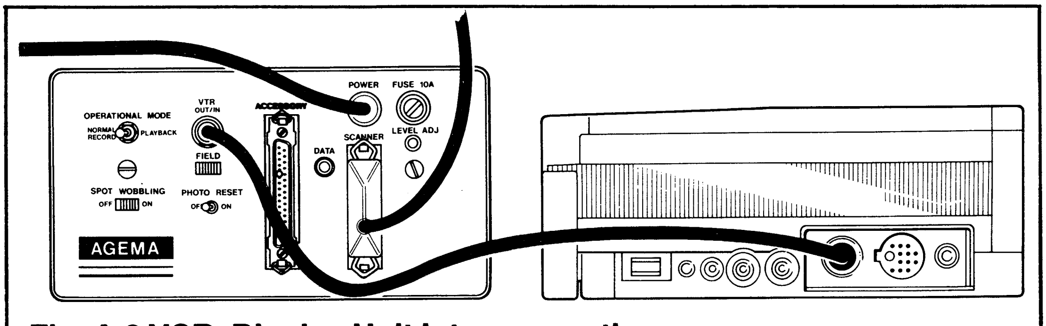

Fig. A.8 VCR, Display Unit Interconnection

Playback

To playback recorded tapes, the OPERATIONAL MODE switch should be set to PLAYBACK. Set RANGE and LEVEL control to the setting which where noted previously (see above).

In playback mode it is not necessary to have the scanner connected to the display.

Connecting Accessories

Figure A.9 details the interconnection of the Display Unit to VCR and TIC-8000.

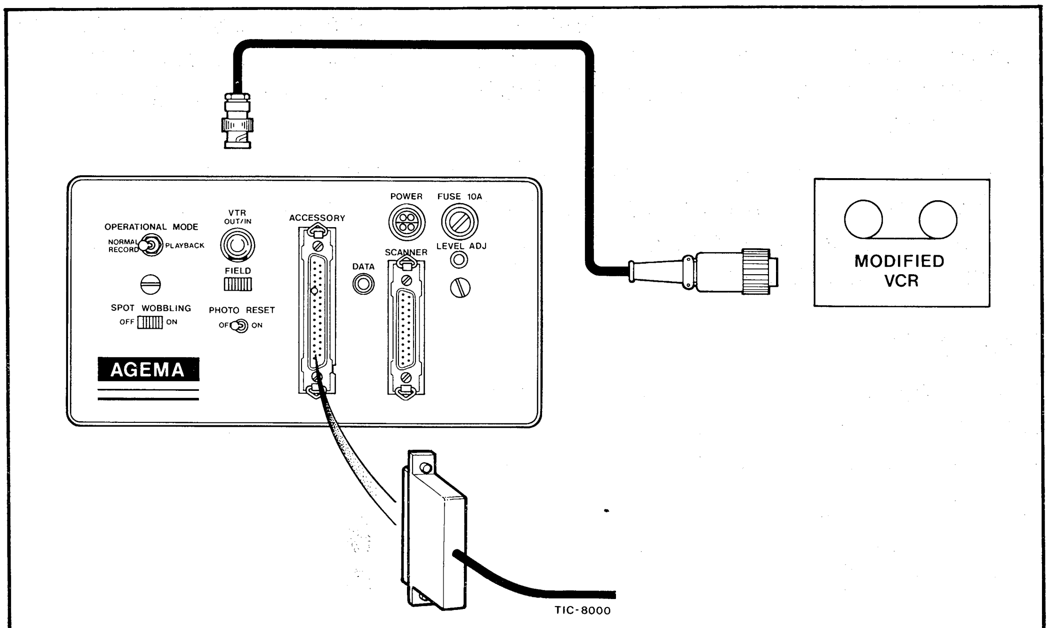

Fig. A.9 Accessory Interconnections

The following VCR function should **not** be used when the VCR is connected to Thermovision®.

- PAUSE
- SLOW MOTION

SECTION 4

Recording

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4.1 VIDEO PRINTER

A video printer can be used to obtain good quality hard-copies from the image display. The best results are gained from a RGB video printer connected in series with a RGB monitor.

A recommended video printer is the Hitachi VY-100 A. This printer incorporates loops for RGB/S which enables it to be connected in series with the AGEMA 5" monitor. Section 4.3 details the interconnections for connecting a video printer to Thermovision®. The composite video output from the control unit (CU 800 V) can be used, but this could mean that the quality of the image hard-copy may be slightly reduced.

If the TRC is connected to the control unit it can be used to insert text onto the image which can then be printed on the hard-copy (See below inserting Data from the TRC)

Before recording images with the video printer, ensure that it is properly adjusted. Point the scanner at a test object (see Section 2.6 'FIRST TIME OPERATION') and print out a hard copy of the image. Adjust the video printer, as given by the manufacturers instructions, as necessary after checking the test print.

4.2 VIDEO TAPE RECORDING

Introduction

There are two methods of video recording when operating with Thermovision® 800. Either with a modified system VCR (Video Cassette Recorder) connected to the CU 800 V (VTR output), or by using a standard VCR connected to the CU 800 V (COMP VIDEO output).

In the former method the image MODE switch and the ISOTHERM controls can be utilised during play-back to enable the image to be analysed on the Thermovision® 800 Monitor.

With the latter method the image can only be played back on a standard monitor in the same form it was recorded.

However, it is possible to operate both techniques independently and to transfer images recorded on a system VCR to a standard VCR.

Video Recording with a System VCR

When a system VCR is connected to the Thermovision® 800 Control Unit the video signal for recording is extracted from the video chain after the THERMAL LEVEL and THERMAL RANGE, this is termed 'B' or system video. On playback the gray level of the image is restored by clamping circuits. During recording the THERMAL RANGE and LEVEL settings, date time and inserted comment are stored via the TRC. Accurate analysis can be carried out when playing back the video recording. If the RANGE and LEVEL settings are not returned to their original levels during analysis, when using the isotherm levels, then erroneous results can be produced.

The accuracy of the measurement is directly dependent on the quality of the VCR being used. During all recordings only the highest quality tape should be used and the VCR recorder heads should be kept clean as described in the handbook associated with the VCR.

System VCR Operation

Use the supplied cable to connect the system VCR to the VTR socket and VTR AUDIO sockets on the rear panel of the CU 800 V. Read the instructions supplied with the VCR and load a video cassette into the recorder.

Recording of images takes place automatically when the VCR is started and the MODE selector is set to the LIVE position.

Playback of images takes place automatically when the MODE selector is set to the PLAYBACK position (NORMAL or INVERT). If data is also to be played back, disconnect the plug from VTR AUDIO and connect to AUDIO OUT on the VCR using the cable supplied (with two phono plugs). The cable can be left plugged into AUDIO OUT during recording.

Standard VCR Operation

A standard VCR can be connected to the VIDEO COMP socket. The cable used depends upon the type of recorder. Load a video cassette and record as described for the system VCR.

Playback of images is carried out using standard TV equipment as the monitor conncted to the recorder (VIDEO OUT).

Notes

1. If a standard VCR is to be used for recording then the CU 800 V must be set to the correct format (i.e. EIA or CCIR). A VCR or TV set operating to a different format to the CU 800 V (i.e. NTSC or PAL) cannot be used. Therefore the appropriate type of CU 800 V must be specified when ordering.
2. In playback mode it is not necessary to leave the Scanner connected to the CU 800 V.
3. The following VCR functions cannot be used, when the VCR is connected to Thermovision®.
   - PAUSE (use FREEZE)
   - SLOW MOTION (viewing when running)

Using the TRC to Insert and Record Comments.

Section 5 of this manual, describes how to use the TRC to enter parameters, and temperature calulation. However the TRC can be used to enter comments onto the image, which can then be recorded.

Connect the TRC as shown in Section 2. Switch on the TRC and set the parameters as necessary to obtain a satisfactory image.

Comments can be inserted as follows:

- When the results of the two isotherms are displayed on the TRC screen, press the TAB and DEL/BS keys. This enters any comments into the CU 800 V, which will then be inserted onto the image. The comments can consist of two lines of 31 characters each and a change of line can be made by pressing [^]. All editing is confirmed by pressing ENTER. Text can be erased by using the SPACE key.
- The comments can be recorded as and played back on a system VCR as described above. The text can also be changed during playback, but not when the image is frozen.

4.3 INTERCONNECTIONS

Figure 4.1 and 4.2 detail the interconnections for the recording accessories of the Thermovision® 800 System.

Two versions of connecting the recording accessories are shown. Note that the Hitachi Video Printer VY-100A has a loop-through connector for RGB/S, so that the monitor can be connected in series.

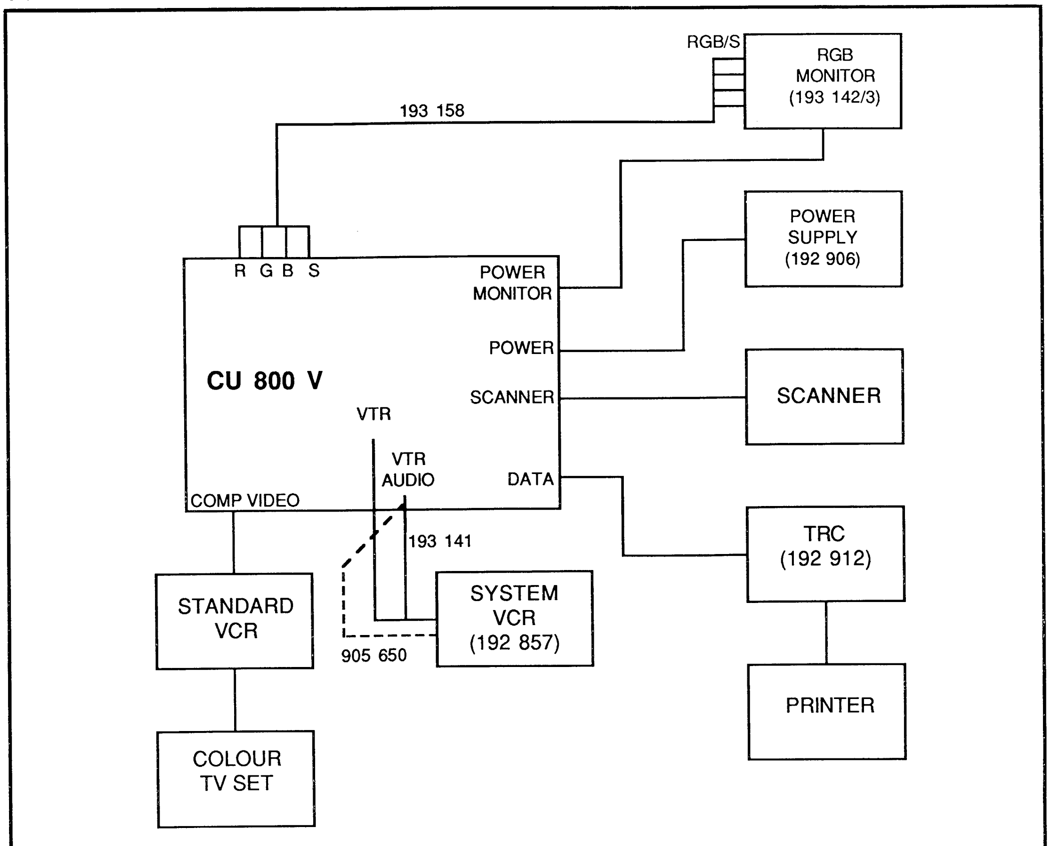

Fig. 4.1 Recording Accessories Interconnections

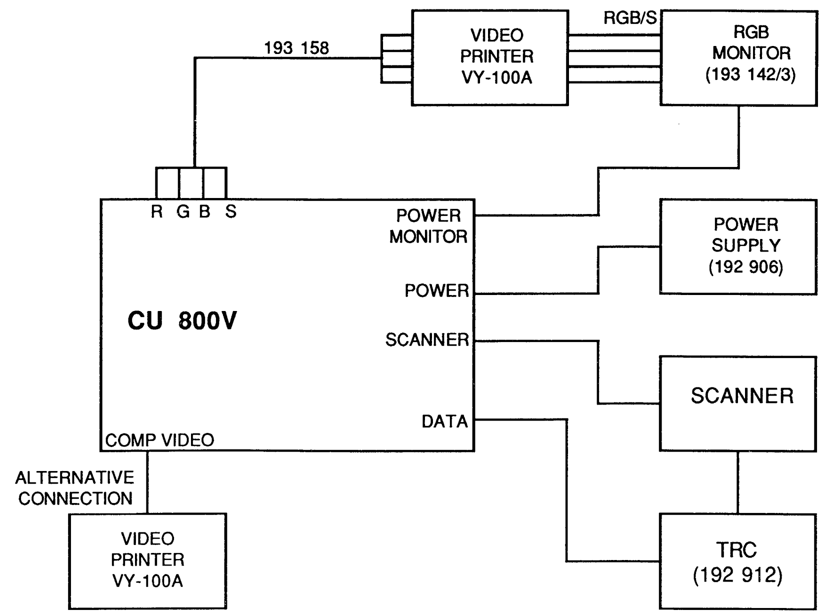

Fig. 4.2 Recording Interconnections with the Alternative Video Prints

4.4 PHOTOGRAPHIC

Images from Thermovision® 800 can also be recorded photographically. For this purpose a standard hood for a 5" RGB monitor is available with a built-in Polaroid camera (see Fig. 4.3)

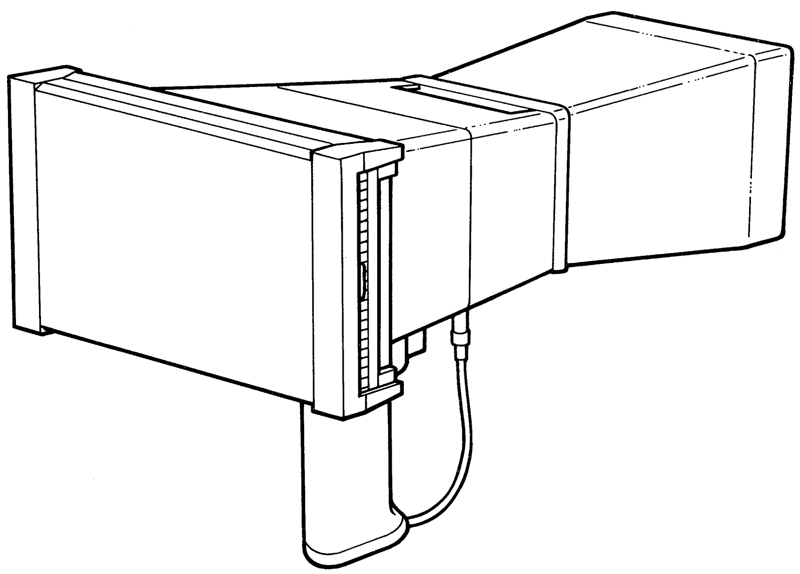

Fig. 4.3 Polaroid Camera using Standard Hood

Loading the Film

Loading instructions are contained in the film pack.

CRT Photography

The Polaroid Type 667 is recommended for Photographing grey scale displays, while Polaroid Types 669 or 668 are recommended for colour displays.

When photographing video displays, set the PICTURE MODE switch for the desired image (NORMAL or INVERT). Then adjust the brightness or controls as required. The exposure time must be 1 sec. (at f/ 5, 6 to 8) colour, or ¼ sec. (at f/22) for B/W. When first using the film, make test exposures to determine the optimum camera and monitor settings.

Test Exposure

To make a test exposure proceed as follows:

a) Switch on the system point the scanner at a suitable object.

b) Adjust the monitor display brightness so that a satisfactory image can be seen. Set the MODE switch to LIVE either INVERT or NORMAL.

c) Hold the hood assembly firmly against the monitor screen. Ensure that the hood is square with the monitor screen.

d) Depress the shutter trigger fully and release.

e) To develop the Polaroid film proceed as follows:

   - Grip the centre of the WHITE tab of the film and carefully pull it all of the way out of the camera.
   - Carefully grip the YELLOW tab and pull it straight, at a constant speed, all of the way out of the camera.
   - Start timing the development of the film from the time the film is clear of the camera.
   - Allow 45 seconds for the film to develop at room temperature, i.e. greater than 21°C.

   WARNING: THE CHEMICALS USED FOR FILM DEVELOPMENT CAN CAUSE SKIN IRRITATION. THEREFORE CARE SHOULD BE TAKEN TO AVOID CONTACT WITH THE CHEMICALS WHEN SEPARATING THE FILM.

   - Separate the print from the film, start at the YELLOW tab.

f) Compare the print with the display. Adjust the monitor's brightness and contrast (or colour) controls so that all of the 10 temperature levels can be discerned. Check the Polaroid camera is properly focused.

Image Recording

When taking a photograph of the displayed image, select FREEZE. Avoid using saturated white as the highest temperature level. Adjust the THERMAL LEVEL control so that saturated white is not displayed.

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SECTION 5

Computers

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Section 5 – Computers

5.1 INTRODUCTION

Thermographic images contain much information which is not always perceptable to the human eye. By using a computerised image processing system it is possible to simplify the information. By image reduction or by subtracting one image from another it is possible to enhance the differences. Computer aided analysis also includes calculations, statistical analysis and presentation, storage and retrieval of information. Using a computer, results are obtained quicker and usually with more accuracy, as external parameters, i.e. emissivity, ambient temperature, distance etc. are easily included in any calculations.

There are two methods used for computer analysis of images that can be provided with Thermovision® 800; TIC-8000 and TRC.

5.2 THERMAL IMAGE COMPUTER SYSTEM TIC-8000

The Thermal Image Computer System (Fig. 5.1) operates in conjunction with a PC. AGEMA has developed the interface and software (CATS and MEDS) which enables image analysis in colours to be carried out on-line and in real time, using Thermovision®. This system can include a colour graphics printer and other hard copy facilities if required. There is a separate operating manual available for TIC-8000.

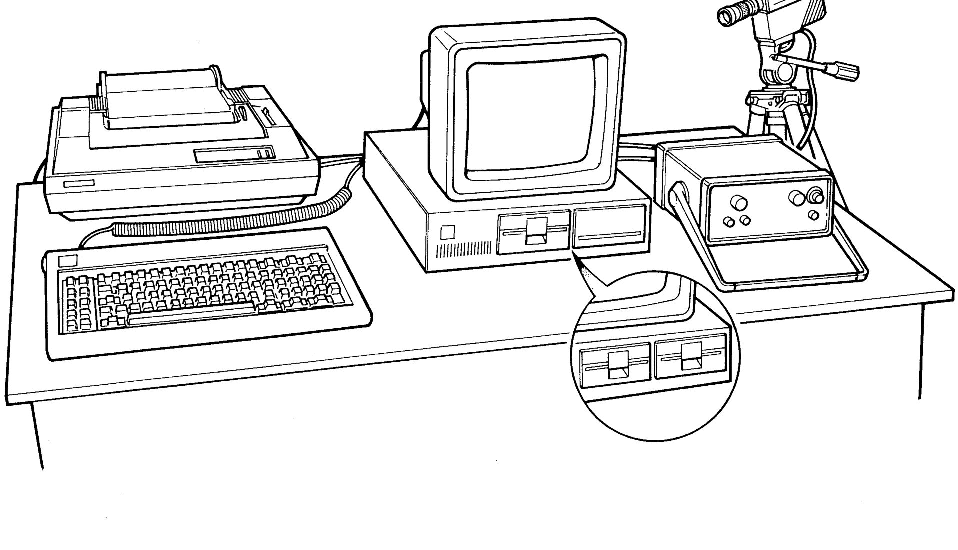

Fig. 5.1 Thermal Image Computer System

5.3 INTERCONNECTIONS

Figures 5.2 and 5.3 detail the interconnections for the TIC-8000 accessories with Control Unit 800.

Two versions of connecting the recording accessories are shown. Note the Hitachi Video Printer VY-100A has a loop-through connector for RGB/S, so that the monitor can be connected in series. Table 5.1 is a cable selection guide.

Table 5.1 Cables

Connection	RGB Monitor	
	Hitachi CM1216 AE	NEC JC1401 P3E
Cable A ACC – TIC interface	193 133	193 133
Cable B – Graphic board TIC interface RGB monitor	193 006	193 083
Cable C DATA-Multifunction board	193 015	193 015
HITACHI VY-100A Video Printer	198 158 (1m) Alternatively 192 148 (2m)	193 006 and 700 065 (193 083 can be excluded if VY-100A is added).

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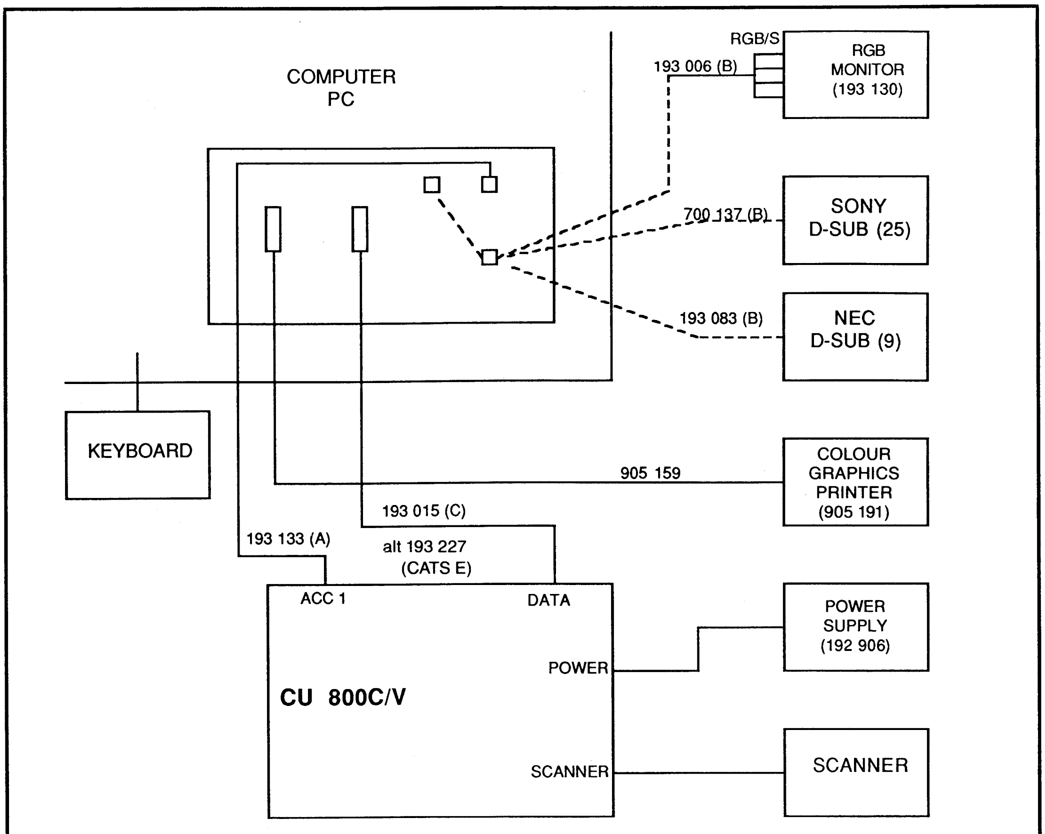

Fig. 5.2 Computer Accessories Interconnections

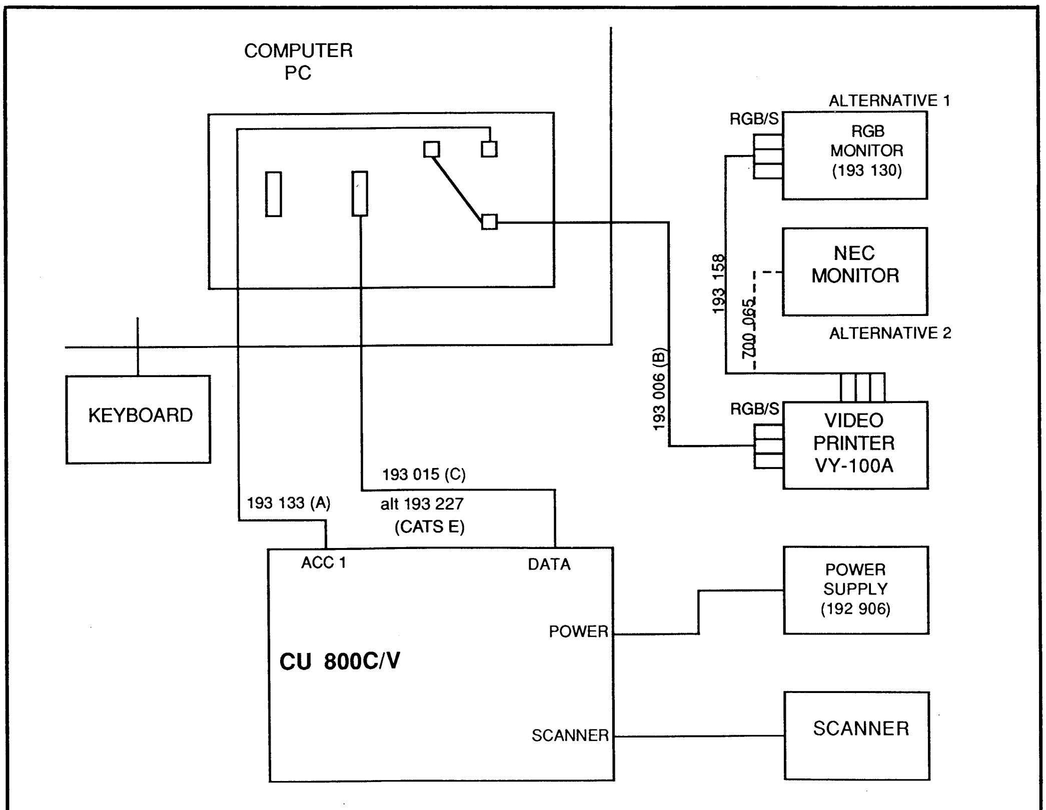

Fig. 5.3 Alternative Computer Accessories Interconnections

5.4 TEMPERATURE READOUT COMPUTER TRC

The version described in this section uses a HUNTER portable computer, manufactured by HUSKY and loaded with a special software program developed so that Thermovision® 800 can be operated on line with the computer. This ensures that it is possible to display immediately on the computer screen both the temperatures or emissivities which correspond to the two isotherm settings on the Control Unit. Before the result is calculated, the operator enters the relevant parameters.

THERMAL RANGE and LEVEL settings are transferred automatically from the Thermovision® 800 Control Unit to the computer and from the Thermovision® scanner the aperture, filter positions etc are also transferred. Fig. 5.4 shows a TRC mounted onto the Control Unit.

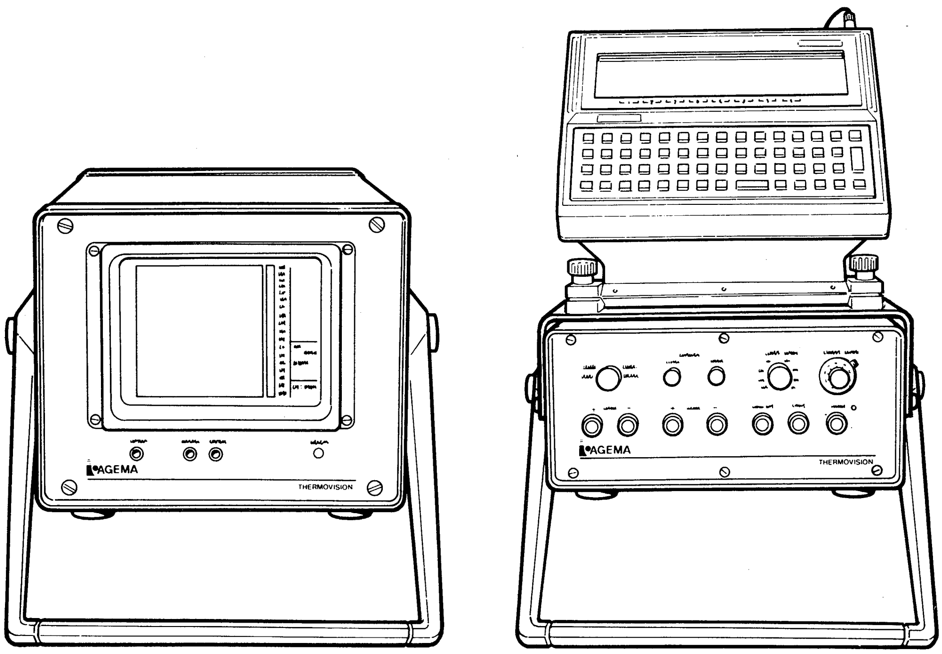

Fig. 5.4 TRC Mounted onto the Control Unit

Installation

The TRC is mounted onto the Control Unit of Thermovision® 800, as follows. The angled bracket is secured to the Control Unit by four self-locking devices, which are positioned in grooves along both sides of the unit. Check how the self-locking devices are locked, and therefore from which side the bracket securing screw should be inserted. Position the self-locking devices close to the front of the Control Unit, and place the angled bracket over the Control Unit. Secure the bracket with the bracket securing screw using an Allen key. Position the tiltable support holder on top of the bracket and secure it using the four screws. Then place the TRC onto the support holder and secure it with the two large locking screws on the sides of the TRC. A coin can be used for tightening the screws. The cable is connected between the IN/OUT socket on top of the TRC and the DATA connector on the rear of the Control Unit. The sockets are marked with red dots and these should be aligned with red dots on the plugs.

Daily Operation

The Thermovision® 800 and TRC combination should be prepared for use and operated as detailed in the following paragraphs.

(a) Set the Thermovision® 800 Control Unit to ON. The interfacing microcomputer built into Thermovision® 800 will start up automatically and will be ready to transfer information to the TRC on demand.

(b) Press the red PWR (power) button on the TRC. This action will restart the TRC from where it was previously switched off, if it was left in INPUT mode. In any other mode the menu/parameter list shown in Fig. 5.5 will be displayed, including the main menu (MENU) at the bottom of the display. If any of the displayed parameters (except the scanner type and serial number) need to be altered before the measurement result is automatically calculated, refer to sub para (e). Aper and Filt are default values, which refer to play back from the System VCR. Enter the values used during the recording as new default values and they will be shown in the RESULT display.

Fig. 5.5 TRC Main Menu Readout

(c) The desired MEASURING mode ① can be selected from items 1 to 5 in the MENU by pressing the CTL/FN key together with the selection number, from 1 to 5 on the TRC keyboard. Press BRK (Break) to perform the measurement and display the result in the chosen mode.

Press CTL/FN together with key 8 to display the UTILITY menu ④ this is described in sub para (j) and (k).

1. **DirT** (Direct Temperature) measures two isotherm temperatures, ISO 1 and ISO 2.
2. **DirE** (Direct Emissivity) measures two emissivities for ISO 1 and ISO 2.
3. **RelT** (Relative Temperature) measures the temperature of ISO 1, using ISO 2 as a reference.
4. **RelE** (Relative Emissivity) measures the emissivity if ISO 1, using ISO 2 as a reference.
5. **Diff** (Differential temperature) measures the difference between the temperatures of ISO 1 and ISO 2.

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(d) Temperature values can be displayed in degrees Celsius or Fahrenheit. (See page 5.10).

(e) If parameters (but not the scanner type and serial number) are to be changed, use the arrow keys to position the cursor ② over the figure to be altered, type in the new value and confirm this by pressing ENTER. The cursor can be moved horizontally within the input fields with the ← and → keys. To move to a new input field use either the ↑ and ↓ keys, or ENTER (for downward movements).

Note: When the display includes a cursor, **ENTER** is normally used for terminating the input, or for moving to the next field. BRK is the general command for **exiting** from the current display.

(f) On this display the TAB (tabulate) key can be used to switch ISO 2 on and off ③

(g) When the necessary parameter changes have been made, the MEASURING mode selected in sub para c is entered by pressing the BRK key. A typical example of the resulting display is shown in fig. 5.6.

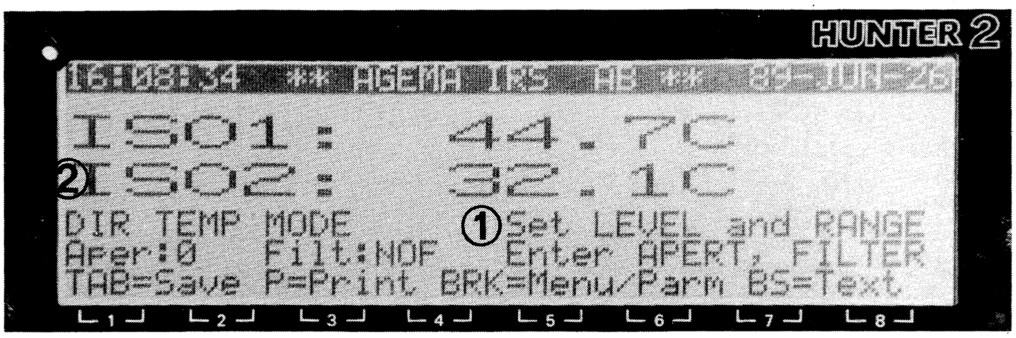

Fig. 5.6 Result Display

① Will be displayed if the image is being played back from the System VCR and the default values for Aperture and Filter will be displayed and used.
② Will not be displayed if ISO 2 was switched off at sub para (f) above.

Any changes to the input parameters, such as LEVEL, RANGE, isotherm levels, Aperture and Filter position will cause either ISO 1 and ISO 2 results to be displayed.

(h) The MEASURING mode menu comprises the following:

1. **TAB = Save**

Press TAB to save the displayed values in the memory. An identifying name (of up to 5 characters) and notes (up to 33 characters of additional information) can be entered for the package of parameters and data which is to be stored. Automatic consecutive numbers are assigned to stored data. If the storage memory is full, the warning message and prompt explained in sub para (h) 4 will be displayed.

Use ENTER to terminate the input and save the measured data; the program will then return to the MEASURING mode.

2. **P = Print**

Press P to print the displayed data immediately, without saving it in memory. No name will be requested or number allocated, however a Note message up to a maximum of 33 characters can be added to the data. The printout will begin when ENTER is pressed, and the program will then return to the MEASURING mode.

3. **BRK = Menu/Parm**

Press BRK to exit and return to the MENU. BRK is pressed to:

- select another MEASURING mode
- change parameters
- enter the Utility menu

4. **Storage Memory Full**

Overwrite? (Y/N) [N]

This message will be displayed if no more space is available in the memory. If the existing material in the memory cannot be erased and replaced by the displayed data, press ENTER (equivalent to N, the default reply). The program will return to the MEASURING mode.

If the displayed data needs to be saved, press Y to display the memory contents, a total of 96 numbers and names (data records) on four "pages". 24 data records can be viewed at one time; use the ↑ and ↓ keys to display the other pages.

Space can be cleared in the memory by selectively deleting separate numbers of records, e.g. record numbers 5 and 17 (type in 5,17 then press ENTER); or by deleting a complete group, e.g. records 22-35 inclusive (type in 22-35 ENTER); or even by deleting the complete memory contents (press A = ALL then press ENTER). In each case the deletion will be followed by an automatic return to the MEASURING mode.

Overwrite? (Y/N) [N] will also be displayed if the name listed in sub para (h) 1 is occupied. Y will overwrite the earlier package of parameters and data. N will automatically return the program to the MEASURING mode.

Note: Delete records as soon as they are no longer needed. Unwanted records stored in the memory slow down the program and can cause the **Storage Memory Full** message to appear.

(j) Stored records can also be deleted via the UTILITY program. This is entered from the MEASURING mode by pressing first BRK to display the MENU, the CTL and 8 together to select option 8, UTILITY.

(k) The Utility menu displayed at the bottom of the screen offers six options, selected by pressing CTL together with the appropriate number key from 1 to 6.

1. **Prnt** (Print) causes one or more selected stored records containing parameters, data and notes to be printed out (providing a printer has been connected via the TRC serial data connector). The desired record or records are selected from the complete list of record numbers displayed on the screen by typing in the appropriate number or numbers followed by ENTER. The record numbers are defined in the same way as described in the deletion procedure, in sub para (h) 4.

2. **Dspl** (Display) causes all the stored record numbers and names to be displayed as a list on the screen, so that specific records can be found and displayed under their assigned record numbers.

3. **Ctrl** (Control) is used to check incoming data from the display unit.

4. **Cnst** (Constant) is used for checking and entering calibrating data.

5. **Clck** (Clock) is used to set the time and date.

6. **Dstr** (Delete storage) is used for deleting stored data.

BRK is used to reselect the MENU.

If option (k) 2 or (k) 6 is selected for deleting, the following procedures apply:

2. **Dspl** (Display) This menu choice can be used to determine which data records will be deleted from the memory to leave space for new data. The first 24 record numbers and names will be displayed; use the ↑ or ↓ keys to display records contained on the other "pages". If it is required to display all data which has been stored under a specific record number type in that number. The number will be displayed at the cursor position as it is typed in. Check that it is correct and then press ENTER.

The following may be displayed:

NOT FOUND which means that no data block exists in the memory under this number.
or
WRONG NUMBER which means that the entered number is outside the range 1 to 96.

Press BRK to return to the Dspl function, and if required press BRK once more to return to the UTILITY menu.

6. **Dstr** (Delete Storage) This option is used for deleting records. First type in the number of the record or records to be deleted. This number will be displayed at the cursor position as it is typed in. Check that it is correct and then press ENTER.
Note:- more than one record may be deleted at one time:

type A to delete all records and thus empty the memory
type n,n,n to delete individual records
type n-n to delete a group of records

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Storage space made available by deleting unwanted records can now be used for storing new records.

Entering the Program and Inserting Scanner Parameters

When the TRC is operated for the first time, or when restarting from CP/M, the scanner type and serial number will be loaded into the program from the scanner.

(a) After the scanner type and serial number have been loaded, the program will search for a calibration table. If the table is found, the program will enter the menu/parameter and if no table is found, the following prompt will appear:

Create calibration table? (Y/N) [N]

The default answer is [N] (no), and if this is selected by pressing ENTER the existing calibration files are displayed and by pressing any key the program will load the scanner type and serial number again.

Press Y (yes) if new scanner parameters are to be loaded or entered, then the program will proceed to Cnst in UTILITY.

If there is no contact between the computer and the scanner, there will be a timeout after approximately 5 seconds then it will be possible to enter the scanner type and serial number via the keyboard.

(b) If a new scanner type for which no calibration file exists, the display will prompt with:

Load calibration table? (Y/N) [N]

Normally the answer is yes [Y], and if this is selected, the calibration tables will be loaded from the scanner. The program will return to MENU after loading is completed. When loading, ". . . ." is displayed on the screen. When completed an acoustic signal will be heard. Press N if the calibration data is to be entered via the keyboard, the display will prompt with:

Lens
Filter
Serial numbers
Cal dist

The default lens and filter values are 20 degrees and NOF respectively. Then enter R, B and F constants for each aperture. If ↓ or TAB is pressed, the following prompt appears:

Changing Alpha/Beta? (Y/N) [N] The normal reply is N, however, if Y is pressed the Alpha/Beta values will be displayed and if N is pressed the following prompt appears:

Continue? (Y/N) [N] If Y is pressed the program will return to lens and filter input and if N is pressed the program will return to UTILITY menu.

Note If a non-standard filter is being used, Alpha/Beta for that filter has to be entered.

Press TAB to store the R, B and F constants or Alpha/Beta values as appropriate.

Two scanners and lens/filter combinations with their corresponding constants can normally be stored (depending on the total of filters, lenses etc. that are stored).

The UTILITY is normally used for the first time operation in the following functions:

(c) **Cnst** (Constant) When CTL is pressed together with 4, this option can be used to check, enter or correct calibration data, constants etc. The following will appear:

Scanner type, Serial No and Prompt D (identification of PROM). All three values are transferred from the scanner. Press ENTER to continue.

(d) **Clck** (Clock) When CTL is pressed together with 5, the clock time and date can be set. These consist of day, month, year, hour, minute and second, and are set by moving the cursor with the ←and → keys, and increasing the displayed value with ↑ or decreasing it with ↓ until the required value is shown. ENTER must then be pressed to confirm the value.

Time is set to the nearest minute, but it can be set to a precise second by setting the minutes figure one minute ahead and then pressing ENTER at the exact synchronization time. The program then returns to the UTILITY menu.

(e) In the MENU display, a choice of temperature values displayed in degrees Celsius or Fahrenheit can be made.

Press CTL together with 6 for Celsius and CTL and 7 for Fahrenheit.

Additional TRC Information

The HUSKY HUNTER computer can be used on its own as a quite powerful and very rugged portable computer which can be programmed in Basic. In this case the original operating manual should be used. However, if you do exit the special Thermovision® program which has been loaded into the computer, to enter CP/M and Basic, ensure that you **do not** also erase the Thermovision® program. If by accident you do erase the program, or for any other reason have difficulty with it, return the TRC to the AGEMA sales organisation.

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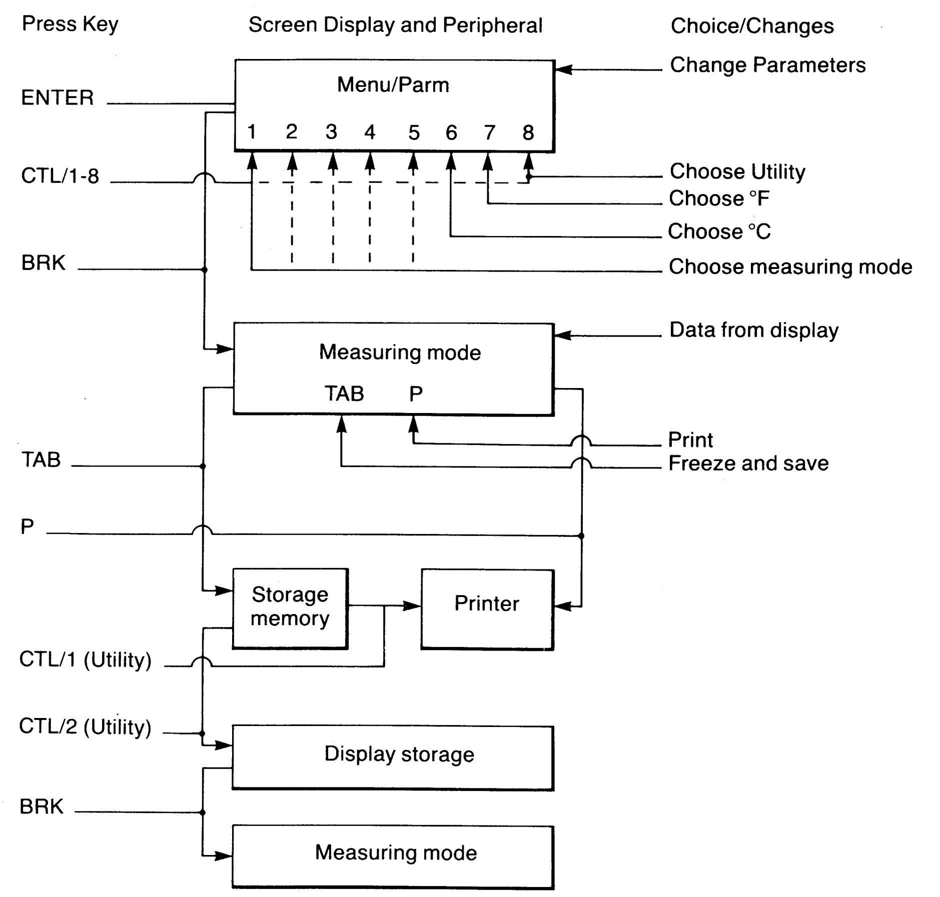

Fig. 5.7 TRC Flow Chart

(a) TRC Program Flow Chart and Summarized Operating Procedure.

Brief operating procedure

1. Switch on Thermovision®
2. Select MENU/parameters display
3. Select and change parameters as necessary – ENTER
4. Measure – BRK
5. Save measured data – TAB
6. Add notes then print – P
7. Save record under assigned name – ENTER
8. Print from storage – CTL/1 in Utility
9. Return to measuring mode – BRK

(b) List of Abbreviations

Although many abbreviations are self-explanatory, or have been interpreted previously, the following is a complete list which may be used as a glossary.

Keyboard Abbreviations

CTL/FN	Used with a specific numerical key to select a menu function
ENTER	Used to terminate an input sequence of letters and/or numbers and to enter the value into the program
ESC/BRK	BRK is used to exit from one part of the program and enter another, e.g. to move from the measuring display to the results display. ESC (shifted ESC/BRK key) is not used within the Thermovision® program
PWR	TRC power on/off
TAB	Assigned to implement the SAVE function in the MEASURING mode

Display Abbreviations

Time is displayed in hours, minutes and seconds. The clock runs continuously, even when the TRC is switched off.

The date is expressed as the month (shortened to three letters), day and year (last two figures).

8xxxxxxxxxx	Thermovision® scanner type 8xx, waveband (SWB/LWB) and serial number
Amb tmp	Reflecting ambient temperature surrounding the object which is to be measured
Aper	Selected scanner aperture position
Atm tmp	Atmospheric temperature
C	Degree Celsius
Cal dist	Calibration distance (Scanner to object)
Clck	Time and date clock
Cnst	Constants and calibration data
Const	Constants of R, B and F
Ctrl	Check that incoming data is correct
Diff	Differential temperature measuring mode
DirE	Direct emissivity mode
DirT	Direct temperature measuring mode
Dspl	Display saved parameters
Dstr	Delete items from memory storage
F	Degree Fahrenheit
Filt:NOF	Filter selected; no filter in this case

ISO	Isotherm as set on the Thermovision® 800 Control Unit
Lens:20	Scanner lens with 20° field of view
m	Distance in metres
Menu/Parm	Display containing main MENU and measuring parameters
Obj dst	Distance between the object and the scanner
Obj ems	Emissivity at the surface of the object
P	Printout of displayed data
Pbflag	Play-back flag (shown = 1 on UTILITY Ctrl screen when VTR is in operation)
Prnt	Printout of saved parameters
Promid	Identification number of PROM in the scanner
RelE	Relative emissivity measuring mode
RelT	Relative temperature measuring mode
Ser-no	Serial number of lens and filter
TAB	Assigned to save displayed values into the memory
Util	UTILITY menu for saving, checking, printing etc.

(c) Error Messages

The following messages may be shown on the top line of the display screen:

ONLY NUMERICS ALLOWED	Wrong input, only numeric values.
WRONG EMISSIVITY	Wrong input, should be in the range 0.01-1.00.
WRONG APERTURE	Incorrect input, should be one of the, following: 0, 1 ,2
WRONG LENS	Incorrect input, should be one of the following: 7, 12, 20, 40
WRONG FILTER	Incorrect input
WRONG LENS/FILTER	Incorrect lens/filter combination
DISTANCE TOO LONG	Distance between scanner and object too long
WRONG CAL CONSTANT	Incorrect R, B or F constants
YOU MUST ENTER DATA	Data is missing in one or more input fields
OTHER CALC ERROR	Other calculation error
ISO VALUE < = 0	Calculated isotherm value less than zero
AMB TMP = OBJ TEMP	Ambient temperature is equal to object temperature

WRONG NUMBER	Entered number for stored data is not within range 1 to 96
NOT FOUND	Data block does not exist
TOO MANY FILTERS	When trying to enter more than nine filters
WRONG SCANNER	If the scanner type and serial number from the scanner do not correspond with the scanner type in the computer

(d) Default Values

The Thermovision® program contains the following default values. These values are inserted in the program sequence automatically if ENTER is pressed at the appropriate time.

On the MENU/PARM display screen the following are default values: Amb tmp: 20°C, Obj dst: 1 m, Obj ems: 1, Lens: 20°, Aper 0; Filt: NOF.

In MEASURING Mode – If the storage memory is full, the default for Overwriting is N in order to avoid overwriting by mistake.

In UTILITY mode, when entering/checking the calibrating data, the R, B and F constants are default set to 0 for a new scanner. For NOF and standard filters the Alpha and Beta values are default.

In UTILITY mode, when entering the CP/M operating system, the default value to the 'Enter CP/M? (Y/N): prompt is N.

(e) Power Supply

The TRC is delivered with four 1.5 V dry batteries installed and one extra set of rechargeable 1.24 V NiCd batteries.

Note:

1. The TRC should use dry batteries if it is to be stored for long periods of time, as they have a longer lifetime than rechargeable cells. If this is not carried out, the program may be lost.

   As an extra security there is a second back-up battery built into the HUNTER, which is recharged by the exchangeable set.

2. For regular use of the TRC, it is advised to use the set of rechargeable batteries (after giving them an appropriate charge) and **not** dry batteries. There is a risk for overcharging if the Control Unit is left switched ON but the computer switched OFF.

3. The Thermovision® 800 Control Unit, when switched on, will charge the TRC both during operation and when the TRC is switched off. During normal operation the TRC will get a charge but not enough to keep the rechargeable batteries charged (typical holdtime will be 7 hours). If the batteries are low, switch off the TRC and leave the Thermovision® display unit on (with the scanner disconnected). **NEVER use this method of charging if standard dry cells are installed in the HUNTER, as they can leak or explode.** The Thermovision® display charges at a rate of 50 mA, but the HUNTER consumes about 100 mA when in operation. Thus there is no risk of overcharging **as long as** the HUNTER is switched on.
4. If the batteries are low, it is recommended that you connect a 50 mA charger to the TRC when it is out of use for approx. 14 hours.

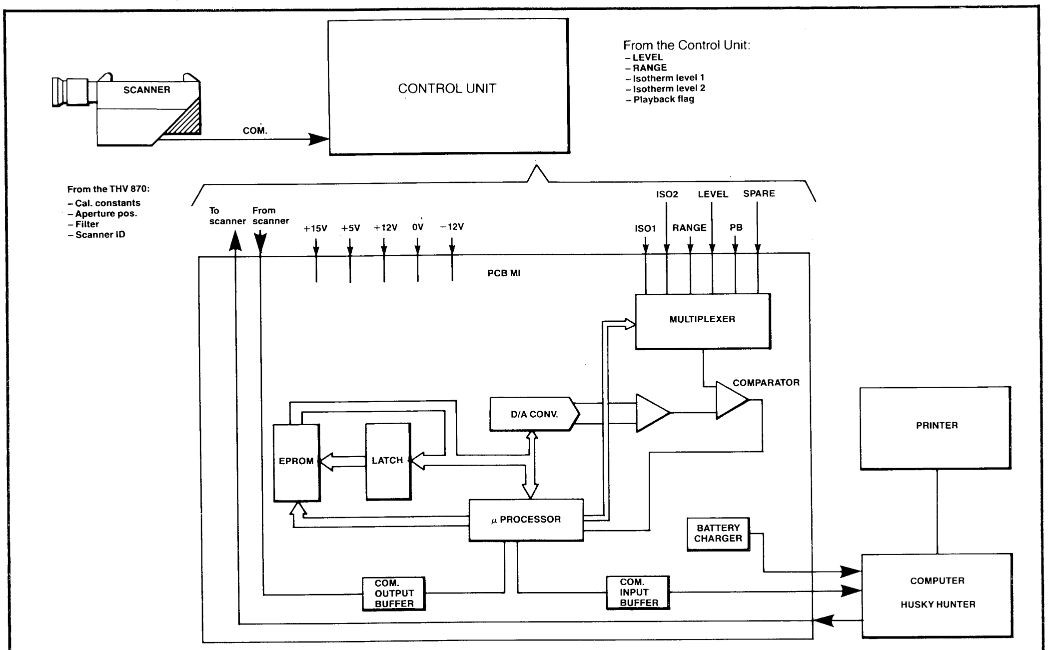

Fig. 5.8 Interface Block Diagram

(f) Technical Specification

The general specification for the computer can be found in Section 9.1 of the HUNTER Operating Manual.

The TRC capacity is 144 kbyte of which 80 kbyte is RAM (held on disk) and 40 kbyte is ROM.

The TRC software is written in Microsoft BASIC which has been compiled for faster operation.

The program can be transferred between two HUNTERs. See HUNTER Operating Manual, Section 3.

The contrast on the screen can be changed by pressing CTL ↑ and ↓.

If the computer gets no data from the Thermovision® 800 Control Unit, it will give an acoustic alarm. If after 5 minutes, the computer still has not received any data, it will switch itself off. This will occur in any case if the Thermovision® Display Unit is not switched on.

In the left, lower corner of the screen there is a blue moisture indicator.

If this turns pink, return the HUNTER to the AGEMA sales organisation. See also Section 8.4 in HUNTER Operating Manual.

(g) TRC Thermovision® program exit and re-entry routines

To exit from the Thermovision® program to CP/M, select the UTILITY menu and then press CTL together with 7. The following message will appear.

If you want to enter CP/M make sure that you do not erase the TRCH800. COM file. Please consult the Hunter manual.

Enter CP/M? (Y/N)   N

Press Y and ENTER to obtain the CP/M menu. The Display screen shown in Section 3.1 of the HUNTER Operating Manual will be shown.

When you want to re-enter the TRC program type TRCH800 and press ENTER.

(h) Printer Interface and Recommendation

Printout is normally possible with standard serial printers using the RS 232/V24 port at a baud rate of 4800.

Specification TRC

Parameter input	Settings of measurement parameters: Emissivity, ambient temperature, atmosphere temperature object distance correction.
Measurement modes	On-line temperature calculations of two isotherms simultaneously: – direct temperature measurement – temperature difference of two isotherms – relative temperature measurement – emissivity calculations – simultaneous reading of correct temperature from two objects with different emissivity – Celsius of Fahrenheit
Information storage capacity	96 complete measurements with comments
Key-board	Complete alphanumeric key-board with text editor for comments
Printer output	RS 232/V24, baud rate 4800
Dimension	216x156x32 (WxHxD) mm
Weight	1.15kg
System ambient temp. – Operation	 – 15°C to + 55°C
– Storage	–40°C to + 70°C
Part No.	192 912

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SECTION 6

Trouble Shooting

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Section 6 – Trouble Shooting

Introduction

The following guide lists operational faults that may occur when using the Thermovision® system. It is assumed that the equipment is connected to the correct ac supply and that the POWER is set to ON.

The guide is divided into three sections which deal with symptoms arising during switch-on, whilst running, and if a Display Unit is used. It does not include faults that may occur in accessories. In such cases please contact the representative or refer to any relevant separate information sheets.

6.1 FAULTS DURING SWITCH-ON

Symptom	Possible Causes	Actions
POWER lamp on the Control Unit does not light and polygon drive motor is not heard to start.	Battery flat.	Change battery pack or use Power Supply/ Charger Unit.
	Power Supply connection at rear of Control Unit not correctly terminated.	Remove and refit connector correctly.
	Battery fuse at rear of Control Unit blown.	Replace fuse (6.3A).
POWER lamp lights but polygon drive motor is not heard to start.	Problems in the Control Unit or scanner unit circuits.	Contact representative.
POWER lamp lights, polygon drive motor is heard to start, the monitor screen lights up but there is no image and the THERMAL LEVEL control is not effective.	Problems in the Control Unit or scanner circuits.	Contact representative.
	FREEZE mode selected.	Set the FREEZE switch to off
POWER lamp lights, polygon motor is heard to start, monitor screen does not light up.	Fault in the monitor	Contact representative
	THERMAL LEVEL set too low.	Turn THERMAL LEVEL control clockwise.
	PICTURE MODE switch set incorrectly.	Set PICTURE MODE switch to NORMAL or INVERT as required.

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6.2 FAULTS OCCURING WHILST EQUIPMENT IS RUNNING

Symptom	Possible Causes	Actions
Image on the monitor screen has insufficient contrast between objects of significantly different temperatures.	THERMAL RANGE switch setting too high (low sensitivity) for the object temperature.	Reduce THERMAL RANGE switch to achieve best image.
	Moisture or condensation on front of lens.	Allow time for lens to warm up. Large amounts of moisture may be removed with soft lint-free cloth, or lens tissue.
White lines appear at bottom of monitor screen and gradually move upwards.	Battery gradually being discharged.	Change battery pack or use Power Supply/ Charger Unit.
	External electro-magnetic field influencing cathode ray tube of the monitor.	Move or shield Control Unit against electro-magnetic field.
	Incorrect mains voltage setting on Power Supply/Charger Unit.	Check mains supply voltage and set Power Supply/Charger Unit accordingly.

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6.3 APPENDIX – DISPLAY UNIT

6.3.1 Faults During Switch-On

Symptom	Possible Causes	Actions
POWER lamp does not light and polygon drive motor is not heard to start.	Battery flat.	Change battery pack or use Power Supply/ Charger Unit.
	Power Supply connection at rear of Display Unit not correctly terminated.	Remove and refit connector correctly.
	Battery fuse at rear of Display Unit blown.	Replace fuse (T6.3A).
Image appears on screen but THERMAL LEVEL control is not effective.	MEASURE/PAN switch set to PAN.	Set MEASURE/PAN switch to MEASURE.
POWER lamp lights but polygon drive motor is not heard to start.	Problems in the Display Unit or scanner unit circuits.	Contact representative.
POWER lamp lights, polygon drive motor is heard to start, screen lights up but there is no image and the THERMAL LEVEL control is not effective.	Problems in the Display Unit or scanner circuits.	Contact representative.
POWER lamp lights, polygon motor is heard to start, screen does not light up.	BRIGHTNESS and/or CONTRAST controls incorrectly set.	Adjust BRIGHTNESS and CONTRAST controls as described in Section 2.
	THERMAL LEVEL Set too low	Turn THERMAL LEVEL Control clockwise.
	PICTURE MODE switch set incorrectly.	Set PICTURE MODE switch to NORMAL or INVERTED as required.
	MEASURE/PAN switch Set to PAN.	Set MEASURE/PAN switch to MEASURE.

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6.3.2 Faults Occurring Whilst Equipment is Running

Symptom	Possible Causes	Actions
Image on screen has insufficient contrast between objects of significantly different temperatures.	MEASURE/PAN switch set to PAN.	Set MEASURE/PAN switch to MEASURE
	BRIGHTNESS and/or CONTRAST controls.	Adjust BRIGHTNESS and CONTRAST controls as necessary.
	THERMAL RANGE switch setting too high (low sensitivity) for the object temperature.	Reduce THERMAL RANGE switch to achieve best image.
	Moisture or Condensation on front of lens.	Allow time for lens to warm up. Large amounts of moisture may be removed with soft lint-free cloth, or lens tissue.
White lines appear at bottom of screen and gradually move upwards.	Batteries gradually being discharged.	Change battery pack or use Power Supply/ Charger Unit.
	External electro-magnetic field influencing cathode ray tube of Display Unit.	Move or shield Display Unit against electro-magnetic field.
	Incorrect mains voltage setting on Power Supply/Charger Unit.	Check mains supply voltage and set Power Supply/Charger Unit accordingly.

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6.3.3 Photographic Faults

Symptom	Possible Causes	Actions
Photograph shows flare on letters and isotherm scale numbers.	MEASURE/PAN switch set to PAN.	Set MEASURE/PAN switch to MEASURE.
	THERMAL LEVEL is set too high.	Turn THERMAL LEVEL control counter-clockwise.
	PHOTO connector at front of Display Unit not correctly engaged in socket.	Remove and ensure the connector is correctly positioned.
	PHOTO BRIGHTNESS and/or CONTRAST controls incorrectly set.	Adjust PHOTO BRIGHTNESS and CONTRAST screw-driver controls as described in Section 2(manual) and Section 3 (preset).
	Polaroid film camera lens set to incorrect f stop.	Adjust Polaroid film camera aperture to f/8.
Photograph has lines or looks grainy.	SPOTWOBBLING switch set to OFF.	Set SPOTWOBBLING switch to ON.
	Polaroid film camera lens set to incorrect f stop.	Adjust Polaroid film camera aperture to f/8.

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SECTION 7

High Temperature Measurement

Section 7 – High Temperature Measurement

If Thermovision® 800 is used in areas of high environmental temperatures or on-line measurement of furnace tubes, the following special design accessories are available.

Scanner Heat Shield

The purpose of this accessory is to protect the scanner and the operator's hand from excessive temperatures when viewing furnaces. The shield is mounted onto the scanner when using any of the 7° to 40° lenses. The scanner must never be exposed to furnace openings for periods in excess of 10 minutes. After exposure to furnace temperatures remove the heat shield and allow the scanner to cool at ambient temperature for approximately ten minutes. It is advisable when not making actual measurements that the scanner is pointed away from the inspection hole. Fig. 7.1 illustrates the heat shield.

Temperature Reference Probe

The probe together with a thermocouple temperature meter establishes a reference temperature inside the furnace for use when analysing surface temperature of the tubes, the probe and meter are shown in Fig. 7.2. The probe is constructed with a grounded hot thermocouple function which is mounted in the centre of a piece of the furnace tube mounted at the end of the probe. Unless otherwise specified, ASTM HK 40 tube is supplied. The thermocouple is of the 'K' type, this is valid for the complete wire test set in order to avoid inaccuracies during measurement.

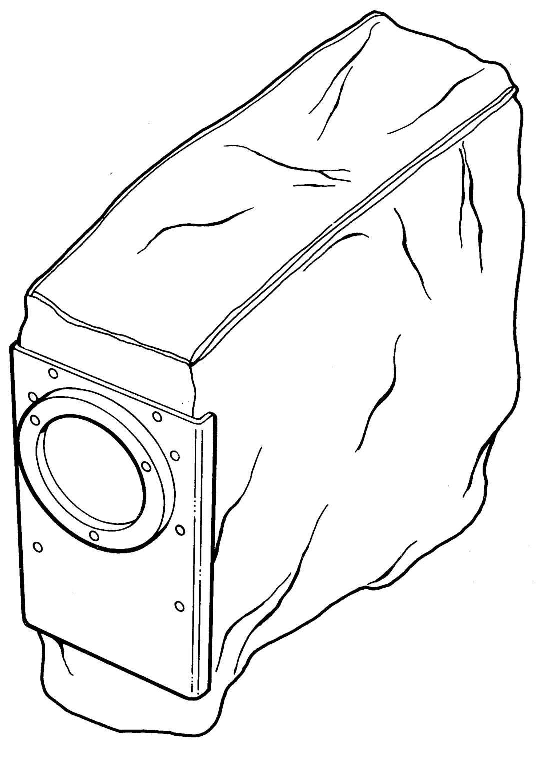

Fig. 7.1 Heat Shield

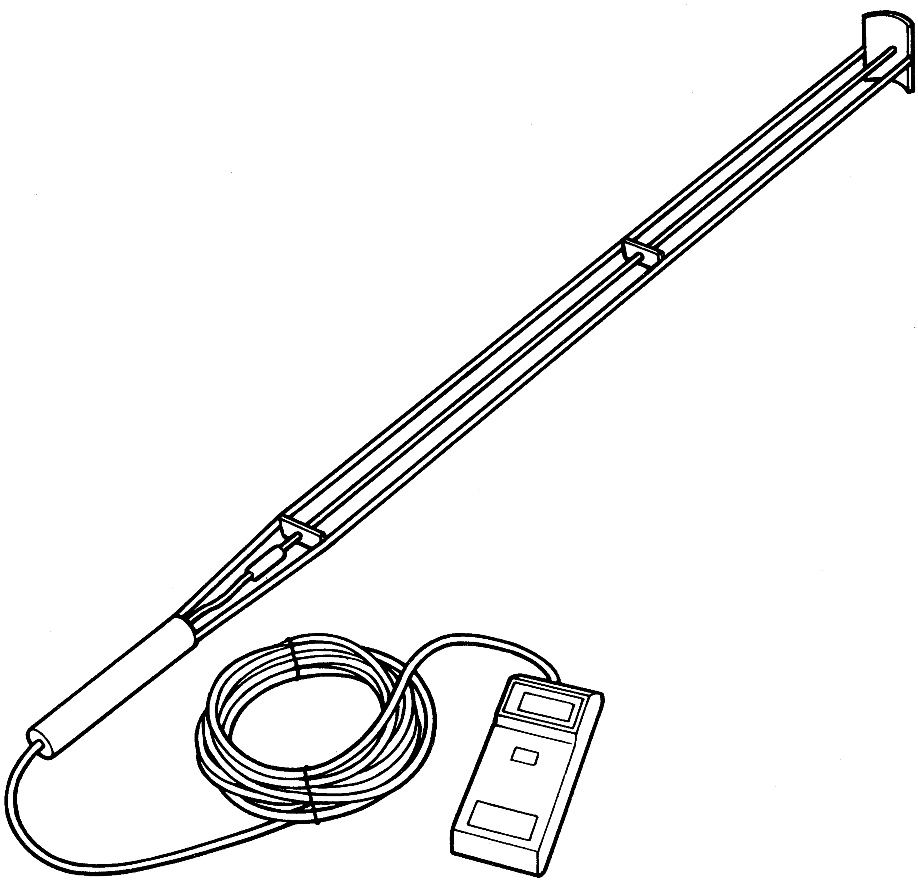

Fig. 7.2 Temperature Reference Probe and Meter

Temperature Meter Specifications

Thermocouple Type 'K' NiCr/NiAl Chromel Alumel

Range:	Maximum +1400°C.
Accuracy Range:	0.2% of reading within ± 1 digit. Better than 1% of the reading outside the specified range.
Resolution:	1°
Display:	LED – digital

The above specification is detailed for the portable battery operated instrument supplied by the factory. Other instruments with equivalent data can be used.

Flame Filter

Details of the Flame Filter are available for furnace application. The filter can be fitted as described in Section 2. If the heat shield and filters are added the scanner will require recalibration. Details can be obtained from your local representative.

SECTION 8

Thermal Measurement Techniques

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8.1 INTRODUCTION

The Thermovision® 800 infrared scanner measures infrared radiation within a certain spectral range. Since the received radiation has a non-linear relationship to the object temperature, can be affected by atmospheric damping and includes reflected radiation from object surroundings, calibration and correction procedures have to be applied.

This section describes some standard procedures of how to translate the instrument's numerical output into object temperature.

The instruments numerical measure of the received and detected infrared radiation is called **Thermal Value.** It is traditionally measured in Isotherm Units (IU), which is a practical arbitrary unit of measurement. The relationship between thermal value and received photon radiation is linear (proportional). However, the relationship between thermal value and object temperature is non-linear. The latter relationship is the calibration function which can be given as an algorithm for the computer or a graphical curve for manual calculation.

This function represents the basic means for translating measured thermal value into object temperature. The calibration function is obtained by plotting the instruments thermal value against the object temperature when viewing an accurate blackbody radiator. The calibration function can be used directly when measuring the temperature of an object that can be considered black (i.e. the object surface emissivity $\epsilon_0 \approx 1$) and positioned close to the scanner (i.e. the transmission factor $\tau_0 \approx 1$). If, however, $\epsilon_0 < 1$ and/or the atmospheric damping must be considered, corrections have to be carried out before applying the calibration function.

The measured thermal value can be translated to object temperature using different methods and depending on the kind of computing means that is available. Ideally a TRC or a TIC-8000 should be used. See section 5. Even without any computing assistance the output can be translated directly into temperature using a typical calibration curve. A certain loss in accuracy should be anticipated when using the graphical method.

The same measurement formulae (derived in Appendices 1 and 2 of this section) for translation of thermal values to temperature shall be used in all cases. However, the operator need not bother with the fomulae himself when using on-line computers. This is written into the software. The operator has only to feed in parameter values such as emissivity, ambient and atmosphere temperature and object distance.

Users operating Thermovision® 800 equipped with a computer on line (which converts the output from the scanner into object temperature), will find the measuring procedure, using TRC, detailed in Section 5. Measuring procedure when using TIC-8000 is contained in a separate manual.

The graphical method is described below under BASIC THERMAL MEASUREMENT.

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8.2 CALIBRATION FUNCTION

The amount of infrared radiation emitted by an ideal blackbody increases non-linearily with increasing temperature. It is therefore necessary to know the actual relation between blackbody object temperature and instrument read-out (the calibration function) to enable the conversion of measured thermal value to object temperature.

The calibration function is accurately described by the mathematical model:

$$I = \frac{R}{\exp\left(\frac{B}{T}\right) - F}$$

Where

I = Thermal value corresponding to temperature T (IU).

T = Absolute temperature (K).

R = Response factor.

B = Spectral factor.

F = Shape factor.

During calibration the radiation from a number of blackbody sources at different temperatures are measured with the system. The results are fed into a computer which using a least square method fits the model to the measured values and computes R, B and F.

Each combination of scanner, lens, filter and aperture has its own set of calibration constants R, B and F.

The system can be furnished with individual calibration curves and an example of calibration curves and data for a scanner with and without filter are reproduced at the end of this section in Figs. 8.6, 8.7 and Table 8.3.

Check before measurement

NOTE: Regardless of the calculation method used the following check and/ or adjustments should always be carried out;

- when changing cable length between the Scanner and Control Unit
- whenever minimum dc offset is of importance, i.e. for Direct measurement in general and in combination with low object temperatures in particular

To carry out the check see Section 3, CU 800|V and Appendix-Display Unit.

Object size

The following should be taken into consideration relating to object size. The detector subtends a certain solid angle in the object space. If the object does not cover this angle the detector will receive radiation from the object background. This will tend to lower the temperature difference indicated between the object and background. It is therefore recommended that the size of the image area, where temperature is to be measured, should not be less than approximately 5% of the height of the monitor screen.

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8.3 BASIC THERMAL MEASUREMENTS

The purpose of this paragraph is to give a general knowledge of the isotherm function (to which the TRC is connected), about controls involved in measurements, about the graphical methods and the two basic measurement principles: Direct and Relative measurement:

(a) **Direct measurement** utilising the instruments high stability (accomplished using two built-in temperature references and a temperature compensation system) that permits temperature measurement without the use of an external temperature reference.

(b) **Relative measurement** using an external reference with known temperature and emissivity factor.

The first method is generally easier to perform but absolute accuracy is not guaranteed at low object temperatures (<30°C). The second method is generally recommended whenever the highest possible accuracy is required, provided that a suitable and accurate reference is available. The reference temperature should ideally be as close to the object temperature as possible or lower.

Relative measurement is also suitable when the purpose of the measurement is to evaluate temperature differences (variations) over an object surface rather than the actual temperature values.

NOTE 1: Symbols used in this paragraph are listed and explained in Appendices 1 and 2 of this section.

NOTE 2: In order to simplify the following description, initially all objects have been considered black and the atmospheric damping has been neglected. Correction techniques where due consideration has been given to objects other than black, or when atmospheric damping is a factor of measurement, are described later under "General thermal measurement".

Direct Measurement

When making temperature measurements of subjects without the use of a known reference or a TRC. The following step by step measurement procedure can be used for CU 800.

(a) Adjust the THERMAL RANGE and LEVEL controls to obtain a satisfactory thermal picture. Note the setting of the THERMAL LEVEL control knob, "L" (see figure 8.1). **Full scale equals 500 isotherm units.**

(b) Adjust the ISOTHERM LEVEL 1 control to bright up the point of interest on the object in view. Multiply the marker reading by the THERMAL RANGE setting to obtain the relative thermal value "i" in isotherm units.

Under the assumed simplified conditions, having $\epsilon_0 = 1$ and $\tau_0 = 1$, the calibration curve can be used directly for translating the measured thermal value I'_0 to temperature.

(c) Mark the I'_0 value on the calibration chart vertical axis and read the corresponding object temperature on the horizontal axis. See figure 8.1.

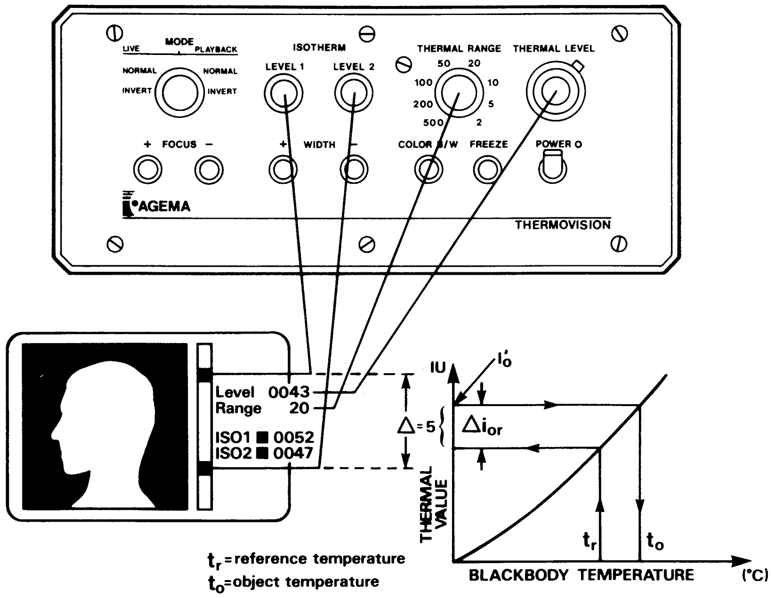

Fig. 8.1 Direct Temperature Measurement Procedure

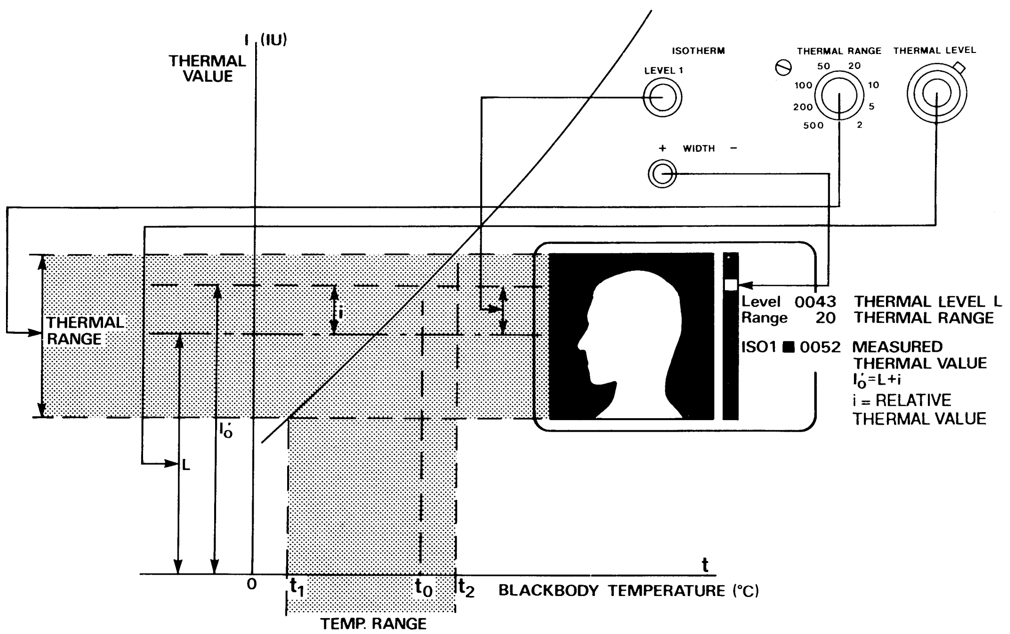

Fig. 8.2 Relative Temperature Measurement Procedure

Relative Measurement

In this type of measurement, the thermal difference between the object and a reference surface is measured. Knowing the temperature of the reference, the object temperature can then be calculated.

A variety of references could be used depending on the actual requirements of accuracy and other measurement conditions.

The ideal reference has a temperature close to the object temperature. It has the same emissivity as the object and is situated near the object.

If a certain spot of the object has a temperature which is known exactly this area should preferably be used as the reference, particularly since it is likely to have the same emissivity factor as the rest of the object, which makes it an "ideal" reference, (see above).

The actual choice of reference has often to be a compromise between the ideal reference and what can be practically achieved. The AGEMA Temperature Reference is recommended whenever applicable.

When making relative measurements the THERMAL LEVEL and RANGE controls must be set such that both the object and the reference isotherms are displayed. It should be possible to indicate both the reference and the object with isotherms without changing the THERMAL LEVEL and RANGE settings. This could be achieved as follows:

(a) Switch on an isotherm (e.g. LEVEL 1) and place the isotherm marker at approximately 1/4 from the top of the isotherm scale (see Fig. 8.2).

(b) Adjust THERMAL LEVEL until the warmest of the two areas of interest (object area or reference area) is just brightened up by the isotherm. For ease of operation this is often carried out with the MODE switch set to INVERT.

(c) Adjust the second isotherm (LEVEL 2) to indicate the coldest of the two areas of interest. If this cannot be achieved, increase the THERMAL RANGE one step at a time and repeat (a) and (b) and (c) again until both colder and warmer areas are covered by the same selected range.

NOTE: For overall accuracy maintain the THERMAL RANGE setting at its lowest level consistent with displaying both the reference and object area isotherms.

Without re-adjusting THERMAL RANGE or LEVEL proceed as follows:

(d) Carefully adjust the two isotherm controls to indicate the object area to be measured and the reference area respectively. This is shown by the areas being displayed as red and green on a gray tone image.

(e) Read the difference between ISO 1 and 2.

This results in a thermal difference value $\triangle i_{or}$ that can be applied directly to the calibration curve since we have postulated $\epsilon_o = \epsilon_r = 1$ and $\tau_o = 1$. Proceed as follows:

(f) Mark the reference temperature on the calibration chart. Read via the curve the corresponding thermal value I_r. Add the thermal difference value $\triangle i_{or}$ obtained in (e) to I_r. This gives the blackbody thermal value I_o of the object, which is then converted to temperature t_o by means of the curve.

NOTE: If the reference should have higher temperature than the object, the thermal difference $\Delta i_{or} = i_o - i_r$ becomes negative and should consequently be subtracted from the reference thermal value I_r.

8.4 GENERAL THERMAL MEASUREMENT

In the Basic Thermal Measurement detail it was assumed that the ideal conditions existed, i.e. the object is a blackbody and no other factors would influence the measurement.

In general thermal measurement situations, where several factors influence the measurements, the true object temperature has to be derived by calculation.

An expression is set up to include the radiation that reaches the scanner from the object. From this expression the unknown quantity is extracted (e.g. object temperature or object emissivity see Appendix 1 in this section). The resulting measurement formulae (2) – (5), as detailed in Appendix 1, together with the calibration function are used as algorithms in the software of TRC and TIC-8000.

The operator has only to feed in parameter values such as emissivity, ambient and atmosphere temperature and object distance.

The parameters detailed in the following paragraphs are related to object, surroundings and atmosphere, these have to be given by the operator:

Emissivity

Actual objects are seldom "black". The emissivity factor must therefore often be taken into account in infrared temperature measurements as detailed in the measurement formulae. Individual object emissivity can be measured or can be found in tables.

Ordinarily, object materials and surface treatments exhibit emissivities ranging from approximately 0.1 to 0.95. A highly polished (mirror) surface falls below 0.1, while an oxidised 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 close to 1 which is used in medical thermography for direct body-temperature readings.

Surroundings

The reflectivity factor ρ of an opaque, non-defined surface can be written $\rho = 1 - \epsilon$.

A low emissivity factor indicates therefore that not only the emission from the object is lower than from a blackbody of the same temperature, it also indicates that undesired radiation from the surroundings is reflected into the scanner. The measurement formulae is therefore corrected for reflected radiation. The correction is based on the temperature of the surroundings, t_{amb}, which has to be estimated by the operator.

It is important that the object surroundings have a homogeneous (ambient) temperature and do not include hot areas so positioned that their radiation can be reflected by the object. Sometimes an efficient ambient temperature has to be estimated to take into account radiation sources that cannot be

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removed or shielded.

The Atmosphere

Certain constituents of the atmosphere absorb infrared radiation in the spectral bands being used. The most important gases are water vapour (H_2O) and carbon dioxide (CO_2). This absorption will attenuate the infrared radiation from the object to the instrument.

An algorithm is used to calculate the transmission factor. This depends on the object to scanner distance, which the operator has to insert. This detailed calculation is described in Appendix 2.

The atmospheric self emission is also taken into account. This is established by the operator inserting the actual air temperature of the measurement path. Normally this correction is often insignificant, however, in some cases (e.g. hot combustion flames) the self-emission of atmospheric gases is very high and has to be taken into consideration.

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APPENDIX 1: DERIVATION OF MEASUREMENTS FORMULAE

In general a number of different parameters are involved in temperature determinations using radiometric methods. Here are listed all symbols used in the following description. They are divided into three groups of which the last is used only for formula derivation.

Radiation Source and Atmosphere Related Parameters

t_o	=	object temperature (°C)
t_a	=	temperature of object surroundings (ambient) (°C)
t_r	=	reference temperature (°C)
t_{atm}	=	atmosphere temperature (°C)
ϵ	=	emissivity factor, $0 \leqslant \epsilon \leqslant 1$ ($\epsilon = 1$ for a "blackbody")
ϵ_o	=	object emissivity
ϵ_r	=	emissivity of reference surface
ϵ_a	=	emissivity of object surroundings (ϵ_a is considered ≈ 1)
τ_o	=	atmospheric correction factor for the atmosphere between scanner and object, i.e. atmospheric transmission corrected for systems spectral response
τ_r	=	as above for the atmosphere between scanner and reference
d_o	=	distance scanner to object (m)
d_r	=	as above to reference (m)
I	=	calibrated thermal value. Refers to the instruments calibration function (graphical curve or calculator program) which describes the relation between object blackbody temperature and instrument numerical output on short distance. $I=f(t)$ (IU)
I_o	=	calibrated thermal value for $t=t_o$ (IU)
I_a	=	calibrated thermal value for $t=t_a$ (IU)
I_r	=	calibrated thermal value for $t=t_r$ (IU)
I_{atm}	=	calibrated thermal value for $t=t_{atm}$ (IU)

Instrument Reading Parameters

I'_o	=	measured object thermal value. Instrument reading of radiation received from the object surface via the atmosphere (IU)
I'_r	=	as above for the reference (IU)

The instrument reading consists of two terms: $I' = L + i$,
where

L	=	THERMAL LEVEL setting of the instrument (IU)
L_o	=	as above at object measurement (IU)
L_r	=	as above at reference measurement (IU)
i	=	measured relative thermal value = isotherm scale reading x THERMAL RANGE setting (IU)

i_o = as above referring to object measurement (IU)

i_r = as above referring to reference measurement (IU)

$\triangle i_{or}$ = as above referring to the difference between object and reference measurement (IU)
$\triangle i_{or} = i_o - i_r$

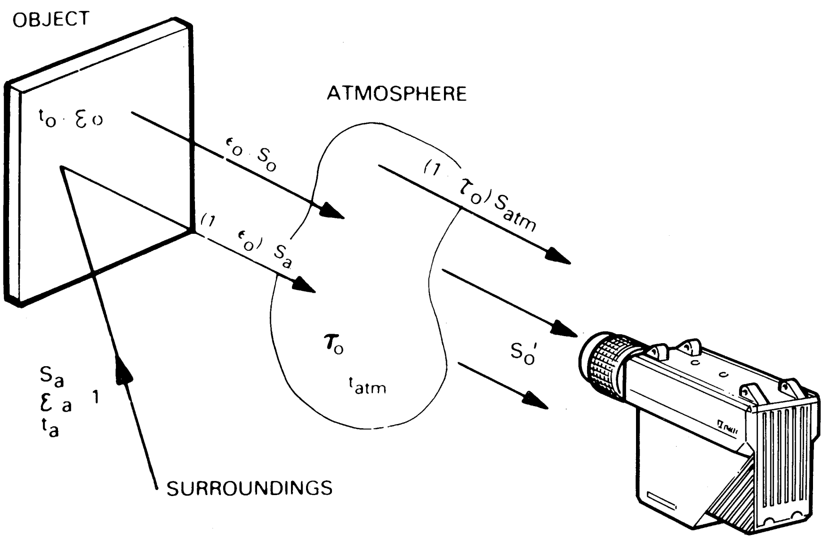

Fig. 8.3 Radiation Conditions in the General Measurement Situation

Radiation Notations

S = received and detected radiation from a blackbody of temperature t, at short distance (Photons/sec)

S_o = as above when $t=t_o$ (Photons/sec)

S_a = as above when $t=t_a$ (Photons/sec)

S_{atm} = as above when $t=t_{atm}$ (Photons/sec)

S'_o = radiation received via the atmosphere from the object surface (Photons/sec)

Figure 8.3 illustrates schematically the radiation conditions in the general measurement situation. Note that the reflection factor of the object surface is $1 - \epsilon_o$ for an opaque object, and that the emission factor of the atmosphere is $(1 - \tau_o)$. With the support of this figure the received radiation can be written.

$$S'_o = \tau_o \cdot \epsilon_o \cdot S_o + \tau_o (1 - \epsilon_o) S_a + (1 - \tau_o) S_{atm}$$

object radiation	reflected radiation	atmosphere radiation

This radiation relationship can be converted into a thermal value relationship by utilising the fact that Thermovision® 800 has a linear photon counting detector.

We can therefore write the thermal value

$$I = C \times S$$

where C is an empirical instrument factor.

Replacing S'_o, S_o, S_a and S_{atm} by $\frac{I'_o}{C}, \frac{I_o}{C}, \frac{I_a}{C}$ and $\frac{I_{atm}}{C}$ respectively results in

$$I'_o = \tau_o \epsilon_o I_o + \tau_o (1-\epsilon_o) I_a + (1-\tau_o) I_{atm} \quad (1)$$

This is the general measurement formula describing how the measured thermal value I'_o relates to the three radiation sources: object, surroundings and atmosphere, together with their associated parameters emissivity and transmission. The object is considered opaque (i.e. no transmitted radiation through the object) and all the relevant surrounding surfaces are assumued to have the same (ambient) temperature t_a (from that assumption follows automatically $\epsilon_a = 1$).

The radiation terms are expressed as blackbody thermal values determined by the calibration function at respective source temperature.

This formula is a suitable starting point for derivation of special measurement formulae adapted to special measurement situations.

For **direct measurements** (without reference) the formula can be rewritten, using the relation $I'_o = L_o + i_o$. Solve for I_o:

$$I_o = \frac{L_o + i_o}{\tau_o \epsilon_o} - \frac{1-\epsilon_o}{\epsilon_o} I_a - \frac{1-\tau_o}{\tau_o \epsilon_o} I_{atm} \quad (2)$$

In case the object temperature is known but the object emissivity unknown, the latter can be calculated, Solve for ϵ_o:

$$\epsilon_o = \frac{L_o + i_o - \tau_o I_a - (1-\tau_o) I_{atm}}{\tau_o (I_o - I_a)} \quad (3)$$

For **relative measurements** with a known temperature reference, corresponding formulae are derived as follows:

$$I'_o = \tau_o \epsilon_o I_o + \tau_o (1-\epsilon_o) I_{ao} + (1-\tau_o) I_{atm}$$

$$I'_r = \tau_r \epsilon_r I_r + \tau_r (1-\epsilon_r) I_{ar} + (1-\tau_r) I_{atm}$$

where I_{ao} and I_{ar} refer to the surroundings of object and reference respectively.

$$I_o' - I_r' = L_o + i_o - L_r - i_r = L_o - L_r + \Delta i_{or}$$

As previously described under relative measurements, the THERMAL LEVEL should be kept constant when using this method. Thus $L_o = L_r$ and from that follows:

$$I_o' - I_r' = \Delta i_{or}$$

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In a practical measurement situation, we assume that object and reference are placed close together. Hence $\tau_r = \tau_o$ and $I_{ao} = I_{ar} = I_a$. With these assumptions we get

$$I_o = \frac{\Delta i_{or}}{\tau_o \epsilon_o} + \frac{\epsilon_r}{\epsilon_o} I_r + (1 - \frac{\epsilon_r}{\epsilon_o}) I_a \qquad (4)$$

Solve for ϵ_o:

$$\epsilon_o = \frac{\Delta i_{or} + \tau_o \epsilon_r (I_r - I_a)}{\tau_o (I_o - I_a)} \qquad (5)$$

The above derivated formulae can be a great deal simplified under special conditions. For instance if all ϵ and τ are close to unity we get

$$I_o \approx I_o' \text{ and } I_o \approx \Delta i_{or} + I_r$$

for direct and relative measurement respectively, i.e. as assumed in the first part of this section. The formula for relative measurement will be reduced and thereby the overall accuracy improved, if $\epsilon_o = \epsilon_r$ and $\tau_o = \tau_r$.

This requirement is met if for example the reference surface is a part of the object surface itself where the temperature is known. The formula is then reduced to

$$I_o = \frac{\Delta i_{or}}{\tau_o \; \epsilon_o} + I_r$$

APPENDIX 2: ATMOSPHERIC INFLUENCE ON INFRARED TEMPERATURE MEASUREMENTS

To correct for the atmospheric influence the correction factor τ must be known. τ depends on a number of parameters. The most important parameters are listed below together with the actual values for what is defined as "standard atmosphere". (See Table 8.1).

Table 8.1 Parameters Influencing the Atmospheric Correction Factor

Parameter	Standard atmosphere
Scanner type (SWB)	
Distance Scanner Object	
Air temperature	15°C
Air pressure	1 atm = 1013 mb
Relative humidity (H_2O)	50%
Carbon dioxide (CO_2)	300 ppm
Carbon monoxide (CO)	1 ppm
Dinitrogen oxide (N_2O)	0.3 ppm
Ozone (O_3)	0.355 ppm
Methane (CH_4)	2 ppm
Aerosol visibility (particles)	10 km

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

The atmospheric correction factor versus object distance can be measured. This is, however, a quite tedious procedure. It can also be calculated by using the following simple formula:

$$\tau = \exp\left[-\alpha\left(\sqrt{d_o} - \sqrt{d_{cal}}\right) - \beta\left(d_o - d_{cal}\right)\right]$$

where

τ is the correction factor

α, β are the attenuation coefficients or "atmospheric constants"

d_o is the distance from the scanner to the object in meters

d_{cal} is the distance from the scanner to the reference source at calibration

NOTE: The formula above should not be used if the calculation results in τ -values below approx. 0.6.

The atmospheric constants α and β have been computed for best fit of the algorithm above to a computed τ versus distance function. The well recognized LOWTRAN atmospheric model is used for this computation, which has been carried out by AGEMA for all spectra defined by the Thermovision® 800 scanner plus standard filters in standard atmosphere. All these α- and β-values are contained in the TRC and TIC-8000 software. They are listed in Table 8.2.

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Table 8.2 Atmospheric Constants for Standard Filters

Filter	α	β
NOF (no filter)	0.03330	0.00049
GLS (glass)	0.02147	0.00277
ATM (atmosphere)	0.00080	0.00019
COS (CO_2 – SW)	0.21351	0.02056
SRX (sun reflex)	0.02502	0.00205
PEN (polyethylene)	0.00301	0.00062
FLM (flame/high temperature)	0.00017	0.00013

Fig. 8.4 is a plot of τ versus measurement distance for Thermovision® 800 without filter and with two or the standard filters.

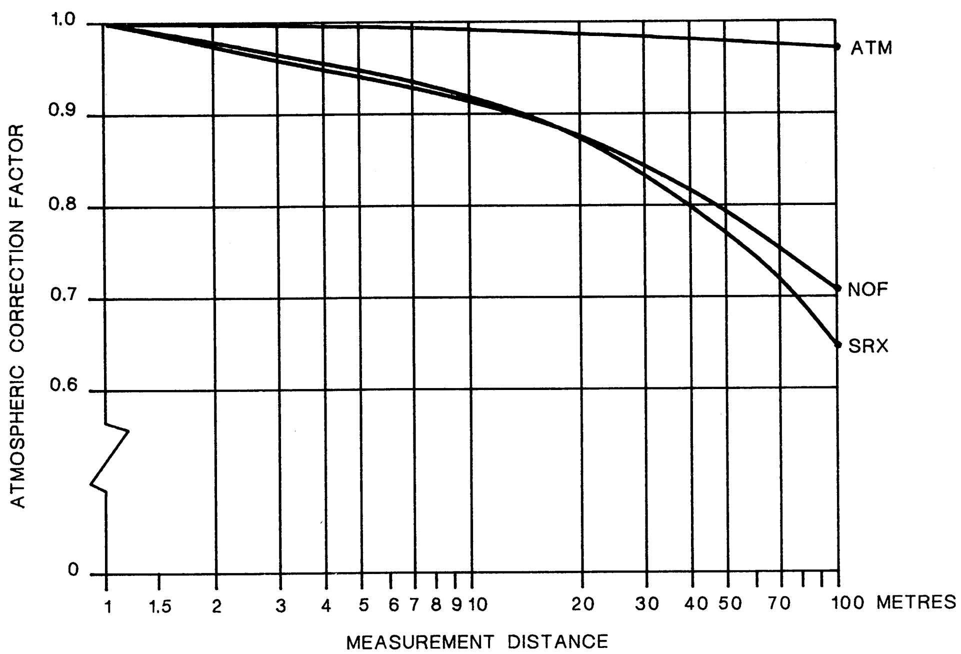

Fig. 8.4 The Atmospheric Correction Factor for Standard Atmospheric

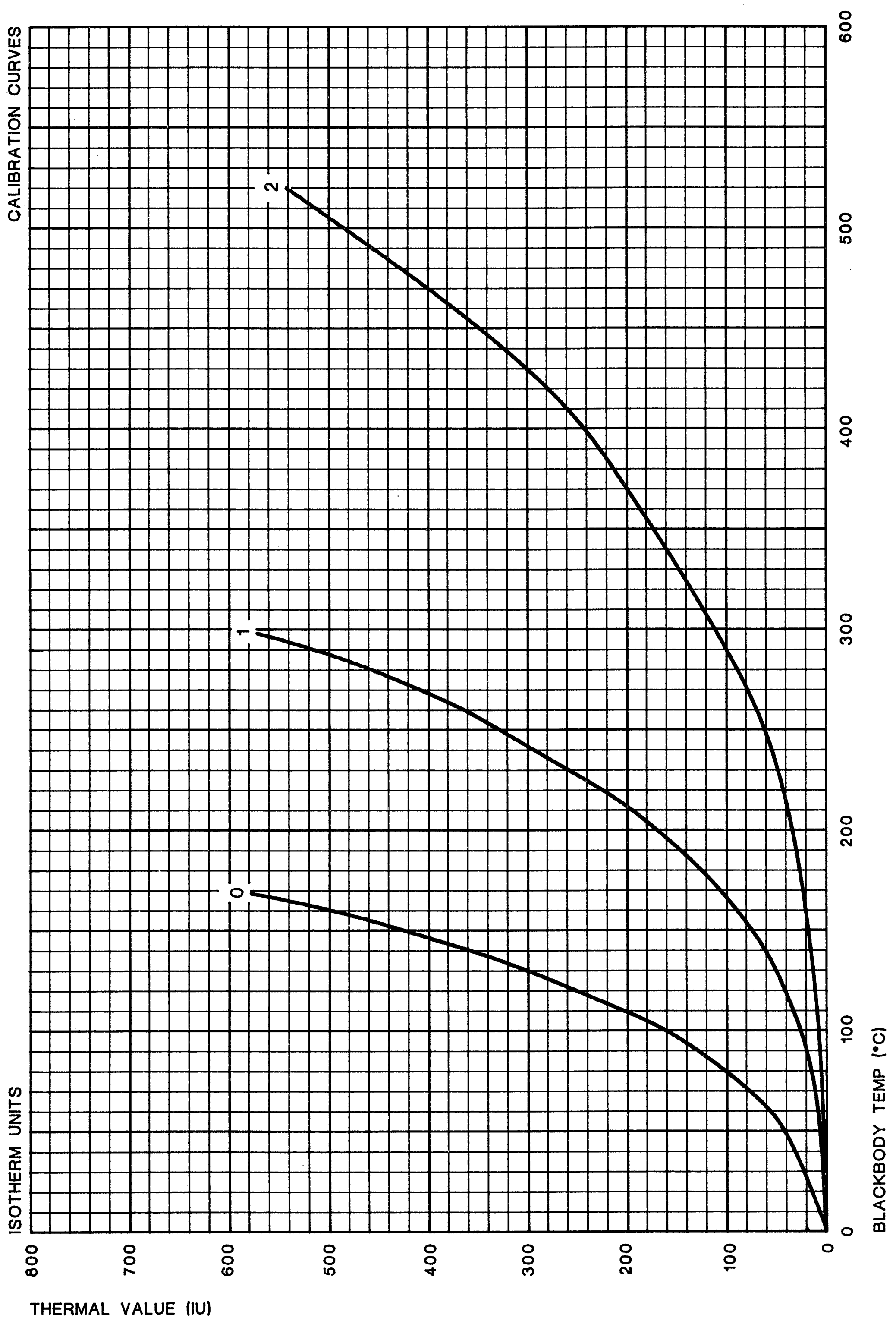

Fig. 8.5 Example of Calibration Curves

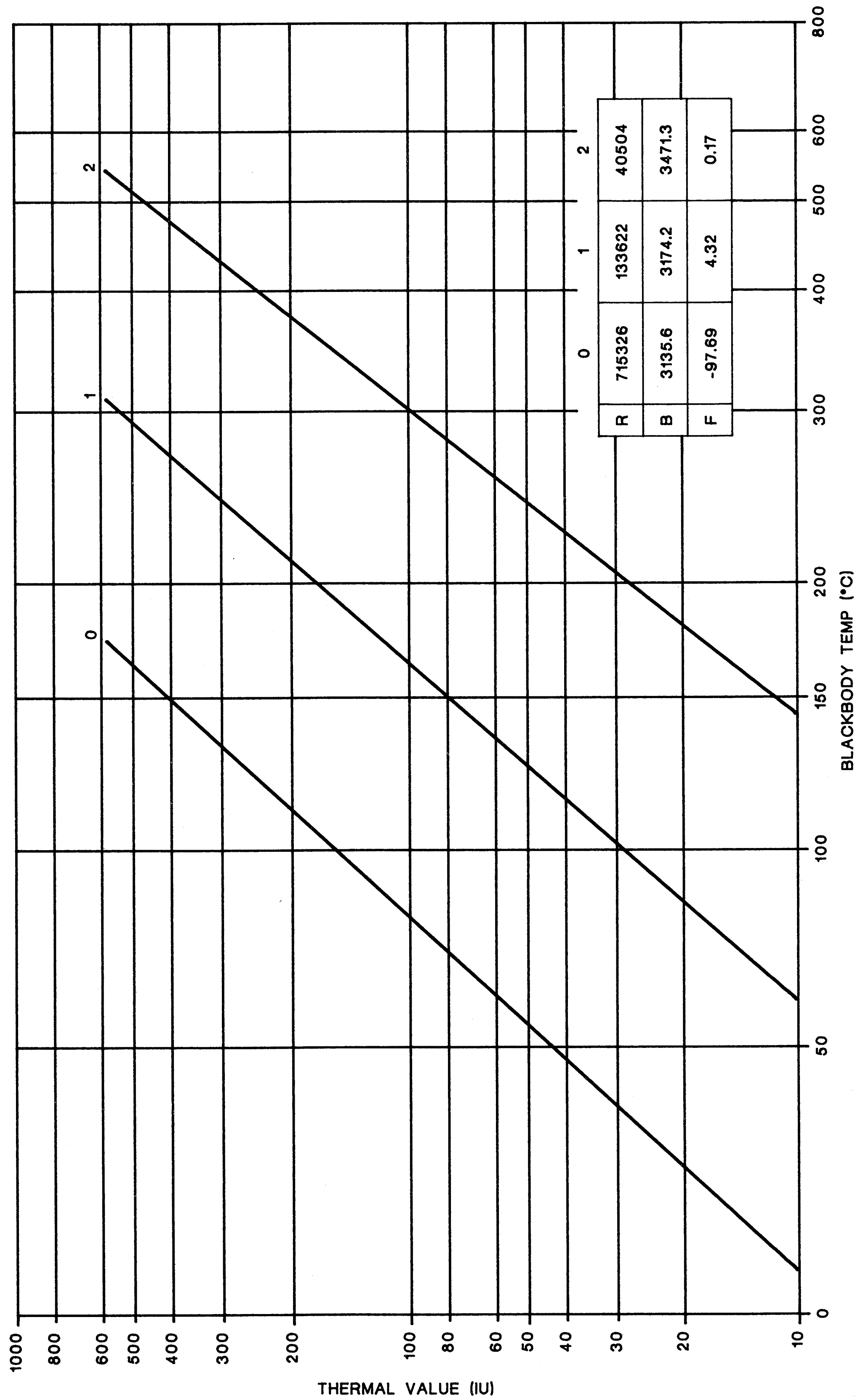

Fig. 8.6 Example of Calibration Curves

							Operator	J.E
							Temperature	30C
							Humidity	30%
Scanner type 8xx			Version xWB		Ser xxxx		Detector M	xxx
					Aprt 0	Aprt 1	Aprt 2	
Lens	40	Filter	NOF	R:	703100	97920	42290	
Ser	13	Pos/Ser	0/	B:	3098.0	3044.0	3403.0	
Dcal	0.5m	Switch	–––	F:	–348.00	–7.80	–1.00	
Lens	40	Filter	ATM	R:	132900	54780	10860	
Ser	13	Pos/Ser	1/10	B:	3349.0	3662.0	3713.0	
Dcal	0.5m	Switch	–––	F:	–10.60	–19.40	–2.80	
Lens	40	Filter	GLS	R:	70670	15160	2942	
Ser	13	Pos/Ser	2/32	B:	2782.0	2882.0	2925.0	
Dcal	0.5m	Switch	000*	F:	–19.10	–4.80	–0.40	
Lens	40	Filter	SRX	R:	515100	94030	26770	
Ser	13	Pos/Ser	2/30	B:	3045.0	3075.0	3272.0	
Dcal	0.5m	Switch	001*	F:	–59.50	–16.40	–6.60	
Lens	7	Filter	NOF	R:	514700	110800	41950	
Ser	0	Pos/Ser	0/	B:	3011.0	3088.0	3407.0	
Dcal	1.7m	Switch	–––	F:	7.70	–15.00	–0.80	
Lens	7	Filter	ATM	R:	149300	53060	14140	
Ser	0	Pos/Ser	1/10	B:	3385.0	3643.0	3852.0	
Dcal	1.7m	Switch	–––	F:	–26.10	–13.30	–9.50	
Lens	7	Filter	GLS	R:	61660	15300	2860	
Ser	0	Pos/Ser	2/32	B:	2737.0	2890.0	2916.0	
Dcal	1.7m	Switch	000*	F:	–11.70	–5.50	–0.20	
Lens	7	Filter	SRX	R:	505900	99140	26370	
Ser	0	Pos/Ser	2/30	B:	3044.0	3095.0	3278.0	
Dcal	1.7m	Switch	001*	F:	–23.60	–21.70	–7.30	

––– = Undefined settings in position 1
* = Position 2 switch settings defined

SECTION 9

Introduction to and Theory of Thermography

New Publ. No. 1 557 631 — Rev. A (2002-11-08)

Section 9 – Introduction to and Theory of Thermography

9.1 INTRODUCTION

The subject of infrared radiation and the related technique of thermography are still new to many who are in a position to make use of Thermovision®. In this section the theory behind thermography will be given and the basic outline of the history and the men who invented the technique will be explored.

Theory of Infrared Radiation

This part of the section will deal with the development of the theory of infrared radiation and present the laws of Planck, Wien and Stefan-Boltzmann. The spectral dependence on emissivity, reflection and transmission is described. Different types of detectors are also described at the end of this section.

9.2 ORIGINS OF MODERN RADIATION THEORY

One of the major problems facing physicists during the second half of the nineteenth century was to explain the energy distribution in the spectrum of a thermal radiation. Common experience had shown that objects seem to absorb more or less heat depending on how "dark" or "light" their surface colouration appears to be. Gustav Kirchhoff sought to eliminate this sort of arbitrariness from theoretical considerations by proposing the term 'blackbody' to describe an object which absorbs all incident radiation energy. In 1860 he introduced his famous law that states, in effect, that a good thermal absorber is also a good radiator. As a consequence of Kirchhoff's Law, then, the blackbody provides the standard of comparison for radiation sources: it is the ultimate thermal radiator with which we can compare any other thermal radiation source.

In 1879, Josef Stefan concluded from experimental measurements that the total amount of energy radiated by a blackbody is proportional to the fourth power of its absolute temperature, a conclusion which was also reached via theoretical thermodynamic relationships by Ludwig Boltzmann in 1884. This important formula has since come to be known as the Stefan-Boltzmann law.

In the meantime, the physicist Clark Maxwell had predicted the theoretical existence of electromagnetic waves (in 1865) and proposed their identity with light waves. Heinrich Hertz, confirming Maxwell's prediction, produced electromagnetic waves in his laboratory in Germany in 1887, and showed that they propagate with the same velocity as light waves.

During the last decade of the nineteenth century it became increasingly easy to recognise the basic unity of the different kinds of radiation in the electromagnetic spectrum, but the basic laws of infrared radiation still eluded attempts to derive from them its thermal origin. Many attempts were made to derive the radiation law behind the distribution of radiant energy in the blackbody spectrum, but even before the end of the century it was becoming clear that it would never be possible to derive a generally valid law from electromagnetic theory alone. Wilhelm Wien and Lord Rayleigh were among the last to make the attempt by basing their entire arguments on classical physics, but their results tended to disagree with the experimental results – at opposite ends of the spectrum. For instance, Rayleigh's expression fitted the data at long wavelengths but unfortunately predicted that the energy increases without limit as the wavelength decreases toward zero, causing it to be known as “the ultraviolet catastrophe”.

It was the German physicist, Max Planck, who finally recognised that it was necessary to depart from the classical approach. He was forced to the conclusion that the proper distribution of energy among the elementary oscillators comprising the blackbody radiator can be obtained only if one abandons the concept that the energy is continuously divisible. The postulate of discontinuous, quantised exchange of radiant energy, which he introduced, appeared to him to be the only alternative leading to a correct theory that would be in agreement with experimental evidence. In 1900 he finally produced a derivation of the law of radiation, which bears his name, which precisely describes the spectral distribution of the radiation from a blackbody.

The assumptions behind the Planck’s Law were radical ones, and Planck himself resisted accepting them for many years. The concepts, when they finally gained acceptance, resulted in the formal discipline of ‘quantum mechanics’ and today the mechanics of classical physics are regarded as merely the special case of quantum mechanics that is successful in the realm of engineering, but is inadequate to describe processes at the atomic level.

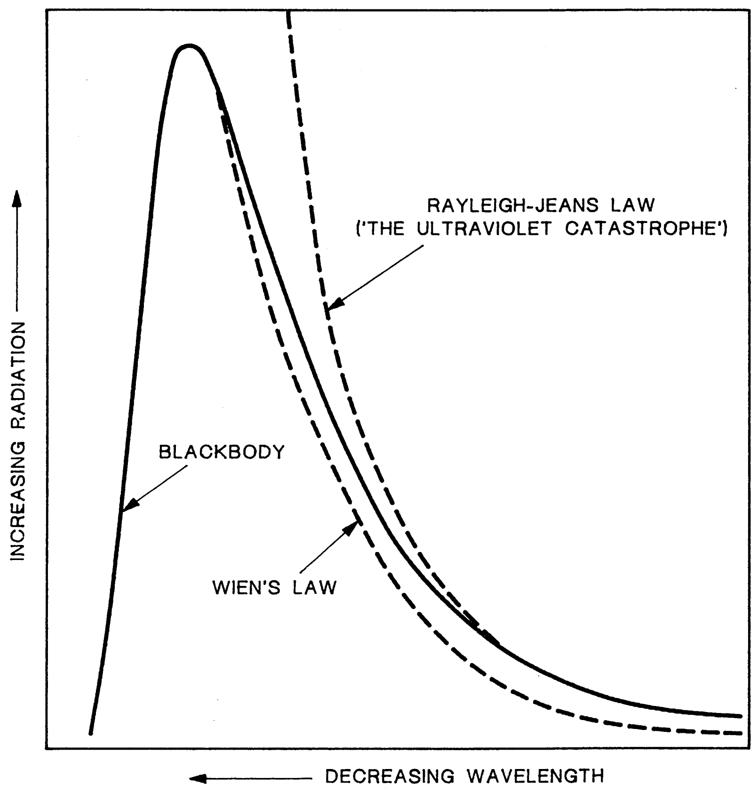

Fig. 9.1 Discrepancy between observed blackbody radiation spectral characteristics and those calculated from classical theory at the end of the 1800’s

9.3 THE INFRARED SPECTRUM

The electromagnetic spectrum is divided more-or-less arbitrarily into a number of wavelength regions, called 'bands', distinguished by the methods utilised 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 millimetre range.

The infrared band is commonly further sub-divided into four lesser bands, the boundaries of which are also arbitrarily chosen. They include: the 'near infrared' (0.75 – 3μm), and the 'middle infrared' (3 – 6μm), the 'far infrared' (6 – 15μm) and the 'extreme infrared' (15 – 100μm). Although the wavelengths are given in μm (micrometres), other units are often still utilised to measure wavelength in this spectral region, viz. microns (μ), nanometres (nm), and Ångströms (Å). The relationship between the different wavelength measurements is

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

Some confusion has existed in the past concerning the term 'infrared photography', as contrasted with thermography. The distinction is one of wavelength – conventional 'infrared film' photographic emulsions are sensitive to wavelengths no longer than 1.2μm. For this reason, astronomers call the wavelength-span 0.75 – 1.2μm the 'photographic infrared spectrum'. Beyond the 2μm wavelength lies the so-called 'thermal infrared'. Infrared photography exploits the differences in the absorptive and emissive properties of surfaces. It depends upon the reflection of very short infrared wavelengths generated by outside sources such as the sun, or lamps, which are much hotter than the object.

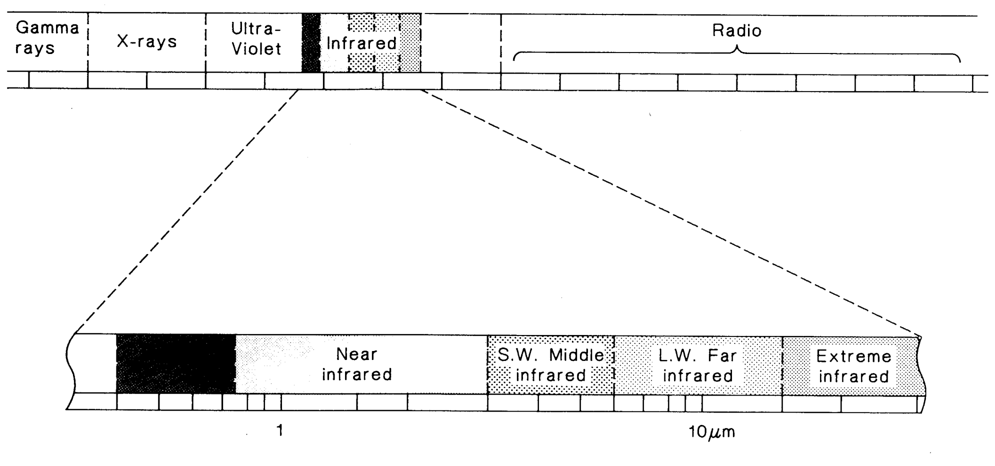

Fig. 9.2 The Electromagnetic Spectrum

9.4 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.

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

By providing such an isothermal cavity with a suitable heater it becomes what is termed a 'cavity radiator'. 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. Such cavity radiators are commonly utilised as sources of radiation in temperature reference standards in the laboratory for calibrating thermographic instruments, such as Thermovision® 870 for example.

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

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

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 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/m$^2\mu$m. If the factor is excluded, the dimension will be Watts/m^{2}m.

NOTE: Instruments used for measuring spectral emittance characteristics (i.e. the 'spectroradiometer') must utilise 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.

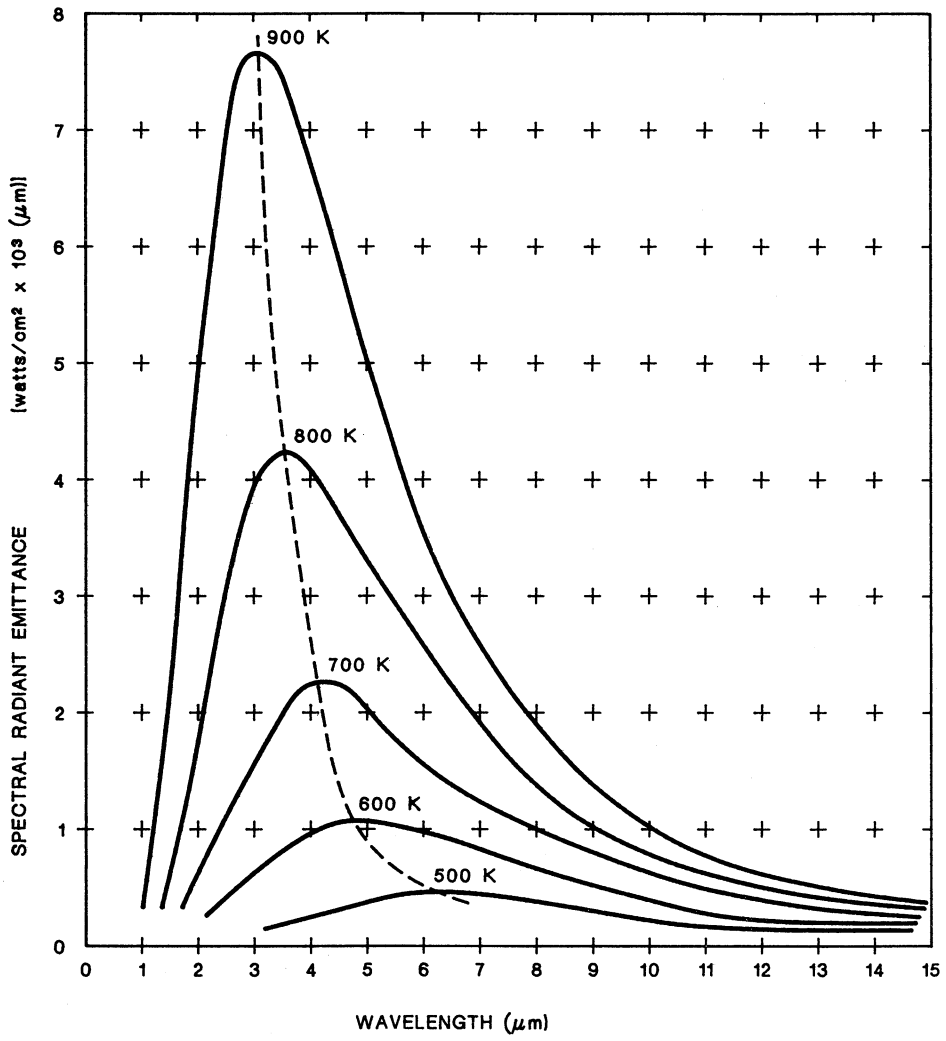

Fig. 9.3 Blackbody spectral radiant emittance according to Planck's law, plotted for various temperatures

Wien's Displacement Law.

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

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

This is Wien's formula, which expresses mathematically the common observation that colours vary from red to orange or yellow as the temperature of a thermal radiator increases. The wavelength of the colour is the same as the wavelength calculated for $\lambda_{max.}$ A good approximation of the value of λ max for a given blackbody temperature is obtained by applying the rule-of-thumb (3000K). Thus, a very hot star such as Sirius (11,000K), emitting bluish-white light, radiates with the peak of spectral radiant emittance occurring within the invisible ultraviolet spectrum, at wavelength 0.27μm. The sun (approx. 6,000K) emits yellow light, peaking at about 0.5μm in the middle of the visible light spectrum. At room temperature (300K) the peak of radiant emittance lies at 9.7μm, in the far infrared, while at the temperature of liquid nitrogen (77K) the maximum of the almost insignificant amount of radiant emittance occurs at 38μm, in the extreme infrared wavelengths.

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:

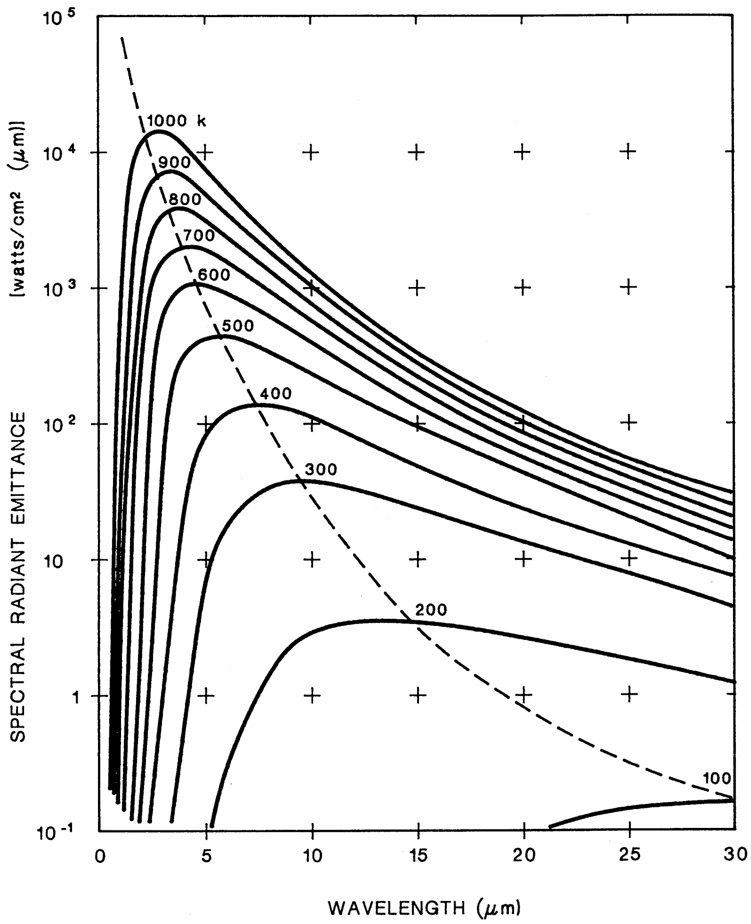

Fig. 9.4 Planckian curves plotted on semi-log scales from 100 to 1000K. The dotted line represents the locus of maximum radiant emmittance at each temperature is described by Wien's displacement law

$W_b = \sigma T^4$ [Watts/m^2]

where

σ = the Stefan-Boltzmann constant = 5.7×10^{-8} Watts/m^2.

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 percent 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 300K and an external surface area of (say) 2m^2, we obtain 1 kilowatt. This great power loss could not be sustained if it were not for the compensating absorption of radiation from surrounding surfaces, at room temperatures which do not vary too drastically from the temperature of the body – or, of course, the addition of clothing.

9.5 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

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

from which it is seen that photon energy is inverseley 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 a number of photons (N_b) rather than the energy. This is of interest where photon detectors rather than energy detectors are utilised, as in the case of 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 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 Wíen formula for calculating the wavelength of peak photon emission for a given absolute temperature becomes

$$\lambda_{max} = \frac{3663}{T} \ [\mu m]$$

The wavelength at which the maximum occurs is about 25 percent greater for photon emission than for energy emission. Thus, for T = 300K, we get $\lambda_{max} = 12.2\mu m$ instead of the value $9.7\mu m$ 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

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

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.

9.6 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 behaviour in certain spectral intervals. For example, white paint appears perfectly “white” in the visible light spectrum, but becomes distinctly “gray” at about $2\mu m$, and beyond $3\mu m$ it is almost “black”.

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 factors must always add up to the whole at any wavelength, so we have the relation

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

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

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

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

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

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

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

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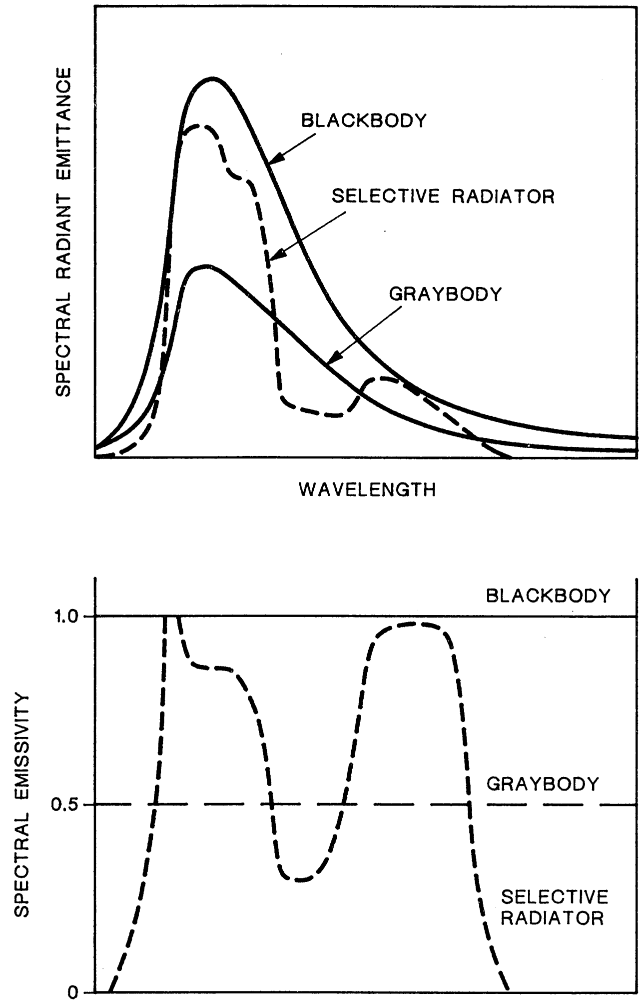

Fig. 9.5 & 9.6 Spectral radiant emittance and spectral emissivity of three types of radiators

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

(a) A blackbody, for which $\epsilon_\lambda = \epsilon = 1$.

(b) A graybody, for which $\epsilon_\lambda = \epsilon =$ constant less than 1.

(c) 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 to any specified temperature and wavelength. That is: $\epsilon_\lambda = \alpha_\lambda$. From this we obtain, for an opaque material (since $\alpha_\lambda + \rho_{\simeq} = 1$):

$$\epsilon_\lambda + \rho_\lambda = 1$$

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

$$\rho_\lambda = 1$$

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

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

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.

9.7 TYPICAL VALUES OF EMISSIVITY

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

Unoxidised 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 increasing with temperature. For non-metals, emissivity tends to be high, and decreases with temperature.

Typical emissivities for a variety of common materials at various wavelengths are listed 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, Thermovision® measurement may result in emissivities which vary somewhat from these, so verification is recommended in each case.

Table 9.1 Emissivities (total normal) of various common materials

Metals and their oxides	μm	Temperature (°C)	Emissivity (ϵ)
Aluminium:			
foil	3	28	0.09
foil	10	28	0.04
weathered	SW	17	0.83-0.94
Copper:			
polished	3	20	0.03
polished	10	20	0.02
heavily oxidized	SW	20	0.78
Iron:			
cast, oxidized	SW	100	0.64
sheet, heavily rusted	SW	20	0.91-0.96
Nickel:	SW	20	0.05
electroplated polished			
Stainless Steel (type 18-8):			
polished	SW	20	0.16
oxidized	SW	60	0.85
Steel:			
polished	SW	100	0.07
oxidized at 800°C	SW	200	0.79

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Other Materials	μm	Temperature (°C)	Emissivity (÷)
Brick, common red	SW	20	0.93
Carbon candle soot	SW	20	0.95
Concrete, dry	5	35	0.95
Glass, chemical ware	5	35	0.97
Oil:			
lubricating	SW	17	0.87
film thickness 0.03mm	SW	20	0.27
film thickness 0.13mm	SW	20	0.72
thick coating	SW	20	0.82
Paint:			
black flat,	SW	17	0.94
Krylon black flat	10	50	0.96
Paper:			
white	SW	20	0.68
white	LW	20	0.95
Plaster:	LW	20	0.86-0.90
Rubber, black	5	35	0.97
Skin, human	SW	32	0.98
Soil:			
dry	SW	20	0.92
saturated with water	SW	20	0.95
Water:			
distilled	SW	20	0.96
frost crystals	SW	−10	0.98
snow	SW	−10	0.85
Wood panelling, light finish	5	35	0.87

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Table 9.2 Solar absorptance α_s and earth-ambient (300K) 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, 0.025mm thick	0.422	0.765	0.55
anodized	0.15	0.77	0.19
Fibreglass	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

9.8 INFRARED SEMI-TRANSPARENT MATERIALS

Consider now a non-metallic, semi-transparent 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 when the total emittance of the plate is sought. When the resulting geometrical series is summed, the effective emissivity of a semi-transparent plate is obtained as

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

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

$$\epsilon_\lambda = 1 - \rho_\lambda$$

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

9.9 INFRARED OPTICAL MATERIALS

There are also very useful materials which are transparent to the infrared. These are not necessarily 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 below (see Table 9.3), together with their transmission cut-off wavelengths:

Table 9.3 IR-Optical materials

Material	n(at$\lambda = 2\mu$m)	λ cut-off (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

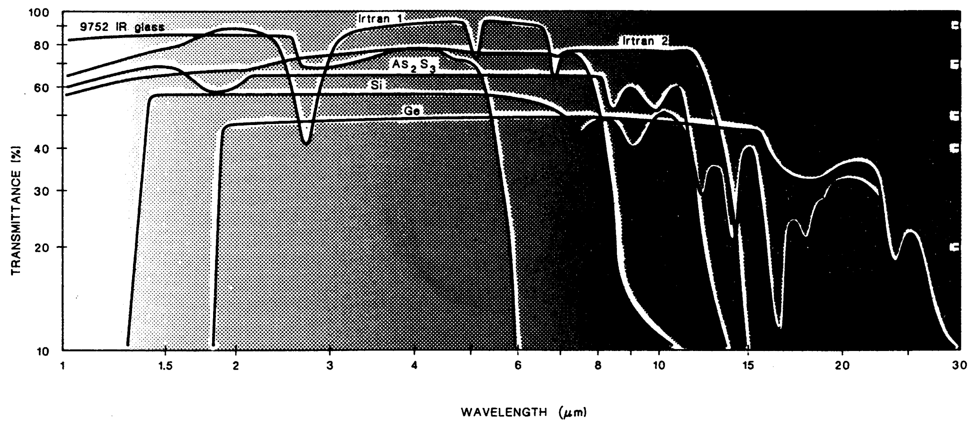

Fig. 9.7 The Spectral transmittance of some preferred infrared optical materials, thickness 2mm

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-scanner lens system should thus reduce the transmittance by a factory of 2. These high reflective losses can be eliminated, however, by anti-reflection coatings which can raise the transmittance to as high as 95-99 percent for

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a given wavelength interval. The wavelength interval is determined by the thickness of the coating. With multi-layer coatings, the transmission interval can be increased over a wide wavelength band.

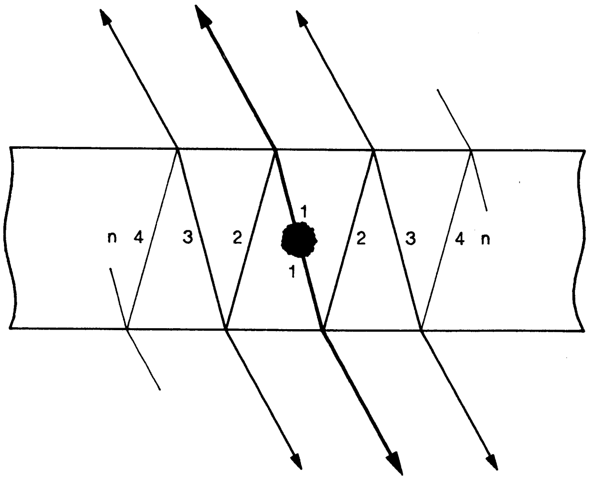

Fig. 9.8 Special characteristics of semi-transparent materials – radiation emitted by a volume element of a semi-transparent plastic plate.

9.10 IR DETECTORS

We have no difficulty detecting infrared energy when standing in front of an open fire or lying on the beach in the sun. But to produce an infrared picture at normal temperatures of the objects around us, we are dealing with such exceedingly small radiant powers that one of the principal problems in infrared technology has been the search for adequate IR detectors.

An infrared detector is a converter that absorbs IR energy and converts it to a signal, usually an electrical voltage or current. There are two principle types: thermal detectors and photon detectors. Thermal detectors have been conceived on the notion of the temperature rise produced in an absorbing receiver, such as in the pneumatic (Golay) cell, the thermocouple, the bolometer, and the new pyroelectric (capacitor) detector. The most important thermal detector today is the thermistor bolometer, which utilises the change in resistance of a semiconductor film when it is heated by the radiation. Typical of thermal detectors is the "flat" spectral response. If they have been properly blackened, the output signal remains practically constant over a very wide range of wavelengths. The main drawback with most thermal detectors is the comparatively slow response to radiation variations, due to thermal processes involved. The pyroelectric thermal detector, however, has relatively fast response – owing to its use of the ferroelectric effect of certain crystals.

There are also a variety of different kinds of photon (or 'quantum') detectors. They show distinctly different spectral responses between types – characterised by a sharp cut-off in the long-wavelength range. All photon detectors are composed of semiconductor material, in which the release or transfer of charge carriers (e.g. electrons) is directly associated with photon absorption. The energy of the photon is inversely proportional to the wavelength

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associated with it and the disappearance of photoelectric activity at wavelength longer than the 'cut-off' wavelength (λc) indicates the energy of the photons to be insufficient to set electrons free. That is, the photons must exceed the so-called 'forbidden energy gap' (Eg) in the semiconductor material. This cut-off wavelength is:

$$\lambda c = \frac{hc}{Eg} \ [m]$$

where Eg is expressed in Joules.

In general, the width of the forbidden energy gap is increased by cooling, so that the cut-off wavelength is decreased when the detector is cooled.

Two principal types of photon detector are of particular interest today: the 'photoconductive' and the 'photovoltaic' detectors. In a photoconductive detector the gap energy is determined by the nature of the material itself, and the effect of photon absorption is to "free" the electrons and thereby increase the detector's conductivity.

In photovoltaic detectors the gap energy is also determined by the material, but the radiation-generated charge carriers are swept away by the electric field in a p-n junction, thereby directly producing a voltage rather than a change in conductivity.

High-speed scanning of necessity requires a detector with a very short response time. The advantage of photon detectors is that they are more sensitive, and have a much shorter response time than thermal detectors but they have also a limited spectral-response, and require cooling for optimum sensitivity – generally to the temperature of liquid nitrogen (77K). However, the SPRITE detector produces excellent results at a working temperature of 203K.

In the case of an ideal thermal detector which has a perfectly flat spectral response curve, it is sufficient to state a single value of detectivity (D*). However, the situation is more complicated with photon detectors, whose spectral response is not flat, and typically drops off to zero at the long-wavelength cut-off point. The D* is, then, wavelength dependent and consequently bears the usual subscript, $D^* \lambda$ $D^* \lambda_{max}$ is noted at the peak of the spectral response curve.

The ultimate limit on detectivity is set by the 'radiation noise' signal which is generated in a detector, resulting from the statistical fluctuation of the radiation received and re-emitted by the detector itself. The noise signal is characterised by its random fluctuations in amplitude, frequency and phase. The result due to noise on the Thermovision® display is the familiar TV "snow" on the picture screen. A detector where this noise sets the limit of detectivity is said to be 'background limited'.

9.11 INFRARED SCANNERS

It is possible to obtain an infrared picture using infrared sensitive film loaded into a regular camera. Contrary to the passive technique used with an infrared scanning head the film uses active methods previously described.

The film emulsion is only sensitive between 0.7μm and 1.2μm in the electromagnetic spectrum. This technique is very useful for airborne inspections of forests agriculture areas. In medicine it will show arteries and veins (darker) in a picture, however it does not give any information regarding temperature distribution over a surface. This is carried out in the longer wavelengths usually above the 2μm to 12μm band and using a measuring function for temperature evaluation.

It is not possible to, with passive techniques, obtain a single frame shot using a camera. As a solution the surface has to be scanned and the temperature identified and measured point by point (horizontal scan) and along a number of lines (vertical scan). The infrared image is built up like a TV picture. Therefore it is easy to understand that an infrared element must be extremely sensitive together with a short response time if a thermographic image is to be presented in real time, i.e. 20-25 fields per second. To be sensitive not only to higher temperatures but also to both ambient and lower temperatures and to eliminate electrical noise, the detector is normally cooled by liquid nitrogen.

Today very satisfactory results can be obtained without the necessity of super-cooling. With the development of more sophisticated detectors and the advantage obtained using Peltier elements, detectable voltages corresponding to the heat radiated by an object can be measured.