Unit 5

Thermal Imaging Systems

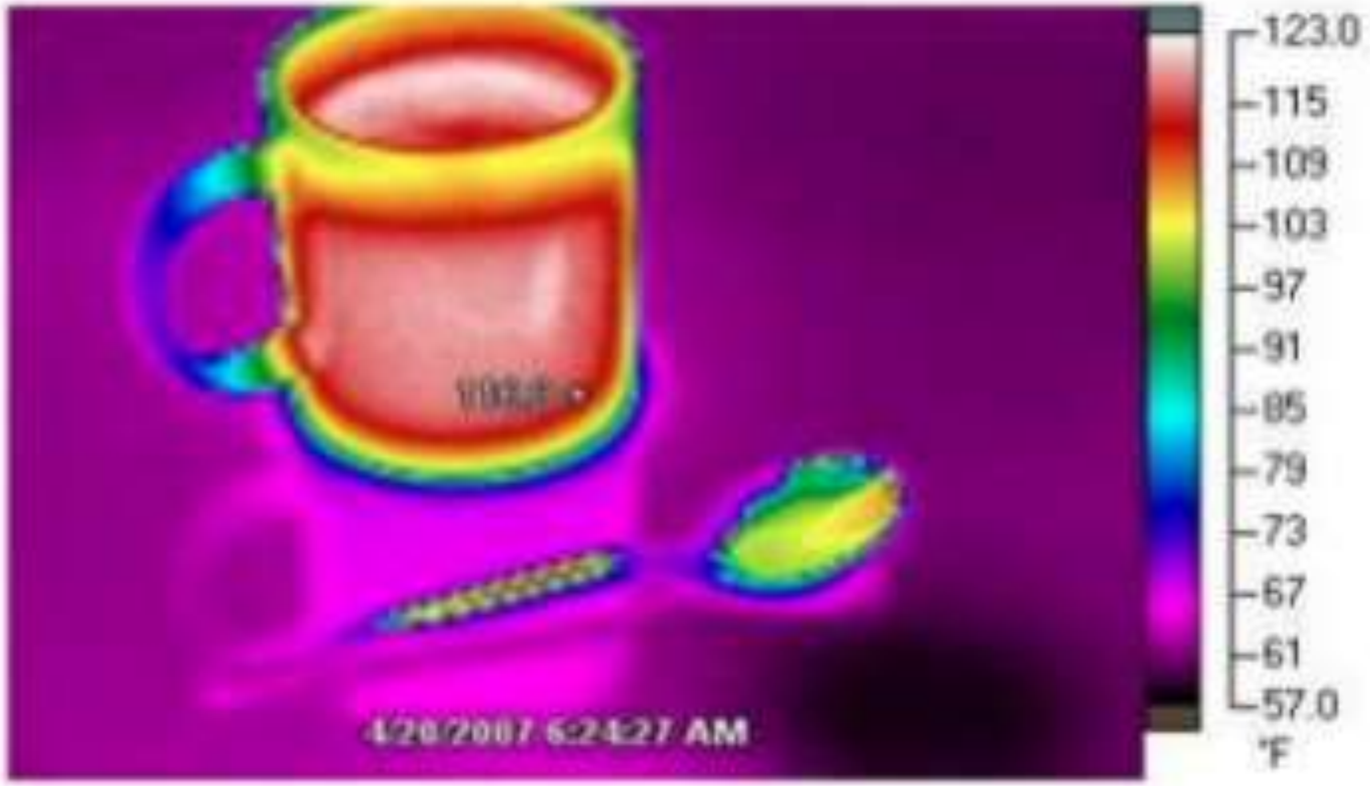
- Medical thermography
- Physics of thermography
- Infrared detectors
- Thermographic equipment
- Quantitative medical thermography
- Pyroelectric vidicon based thermographic camera
- Thermal camera based on IR array sensor

THERMAL IMAGING

- It is the technique of using the heat given off by an object to produce an image of it .
- Works in environments without any ambient light and can penetrate obscurants such as smoke, fog and haze.
- Normally grey scale in nature: black objects are cold, white objects are hot and the depth of grey indicates variations between the two.
- Some thermal cameras, however, add color to images to help users identify objects at different temperatures

- An image generated from a Thermal Imaging Camera. Note the persons skin (as a heat source) is shown as 'white hot' whilst the sky (which is cold) is shown as black.

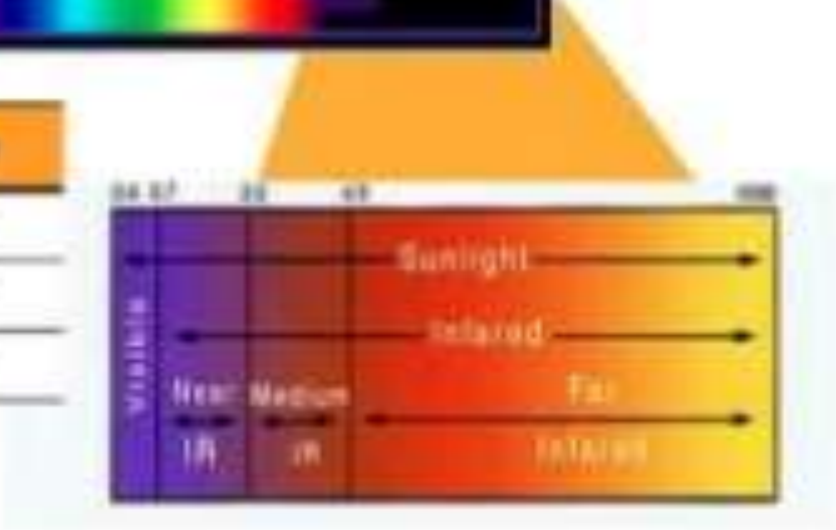
- Cup Filled With Hot Water



THERMAL IMAGING CAMERA (TIC)

- A thermal imaging camera records the intensity of radiation in the infrared part of the electromagnetic spectrum and converts it to a visible image.

IR Band	Wavelength Range
IR-A	700nm - 1400nm
IR-B	1400nm - 3000nm
IR-C	3000nm - 1 mm



COMPONENTS OF THERMAL IMAGING CAMERA

- An optic system
  - ✓ Lens
- Detector
  - ✓ Cooled Detector
  - ✓ Uncooled Detector
- Amplifier
- Signal processing
- Display
  - ✓ Standard Video Monitor

Uncooled vs Cooled Thermal Comparison (640 x 480)

Uncooled

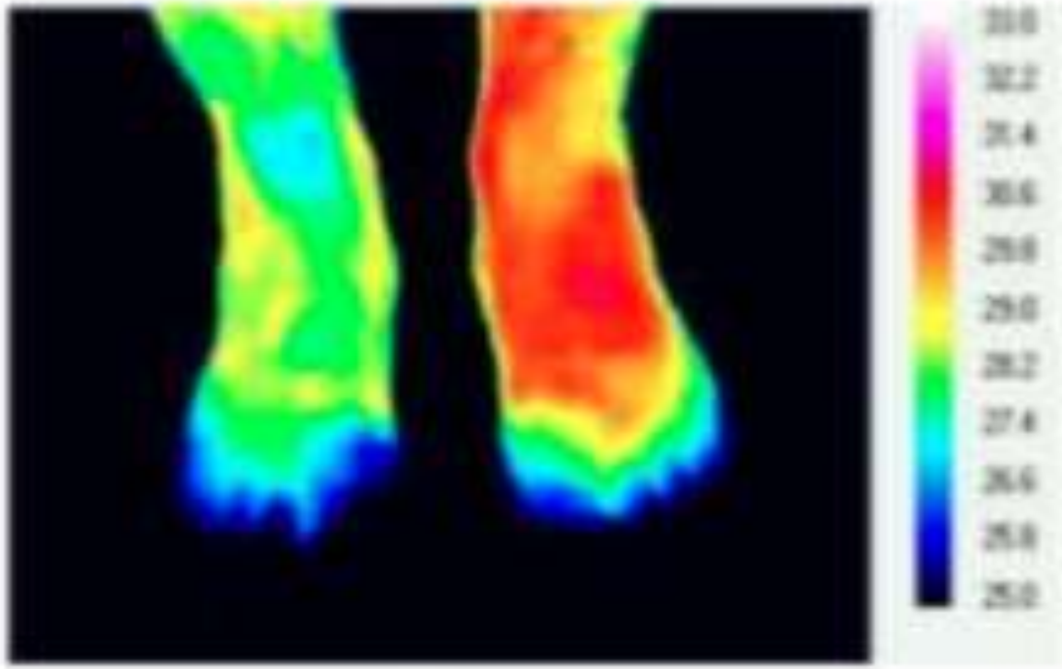
Cooled

THERMAL IMAGING APPLICATIONS

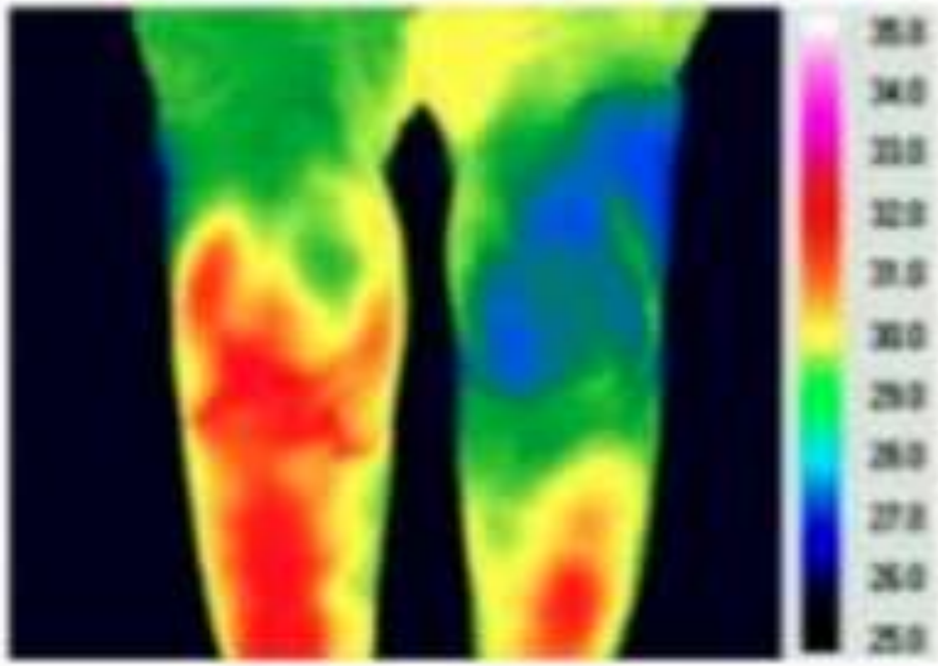
- INDUSTRIAL APPLICATIONS
- MEDICINE APPLICATIONS
- SECURITY APPLICATIONS
- BUILDING CONSTRUCTIONS
- NIGHT VISION

INFLAMMATORY ARTHRITIS

- (A) Chronic inflammation of the forefoot following a sports injury
- (B) rheumatoid arthritis of one knee (left of the image)



(A)

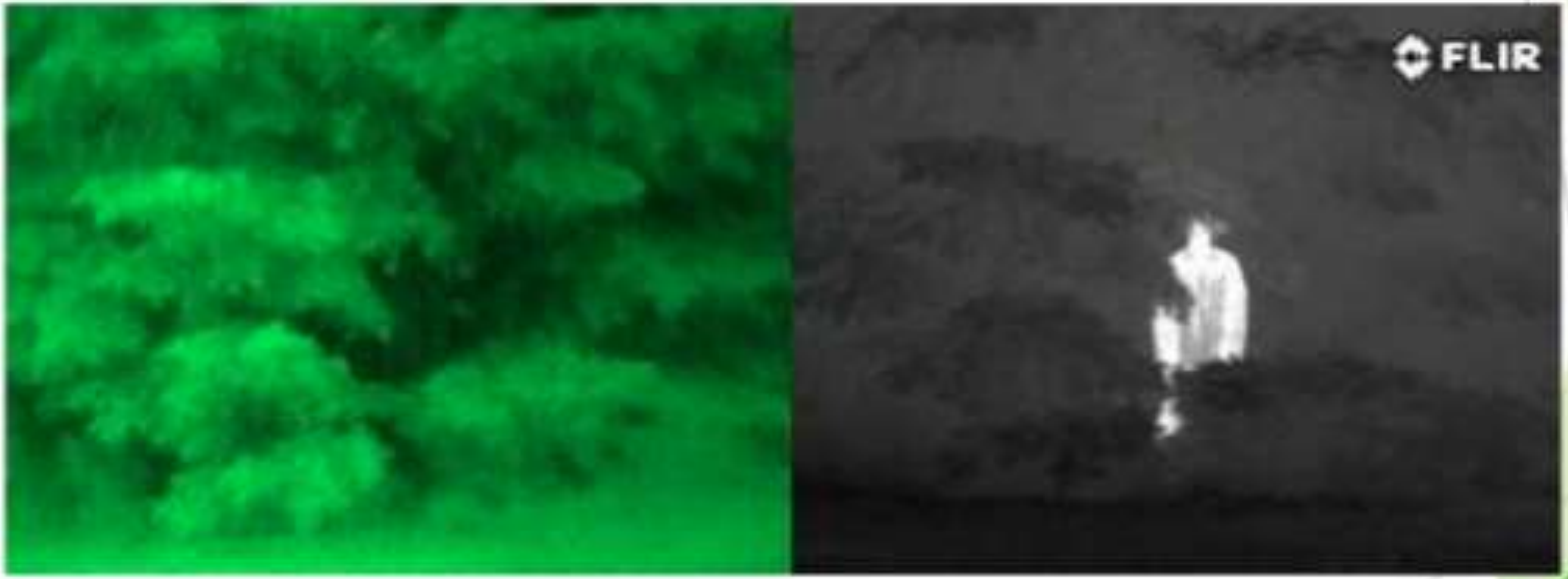


(B)

FEVER SCREENING

- Shows the detection of SARS and Swine flue among passengers using Thermal Imaging Technology

THERMAL IMAGING IN NIGHT VISION



OTHER APPLICATIONS

- Evaluation of Solar Panels
- Thermal mapping
- Archaeological kite aerial thermography
- Veterinary Thermal Imaging
- Food and Agriculture
- Research
- Weather Forecasting
- Nondestructive testing
- Defense
- Chemical imaging
- Volcanology

Medical thermography

- The medical thermograph is a sensitive infrared camera which presents a video image of the temperature distribution over the surface of the skin
- This image enables temperature differences to be seen instantaneously, providing fairly good evidence of any abnormality. However, thermography still cannot be considered as a diagnostic technique comparable to radiography
- Radiography provides essential information on anatomical structures and abnormalities while thermography indicates metabolic process and circulation changes, so the two techniques are complementary

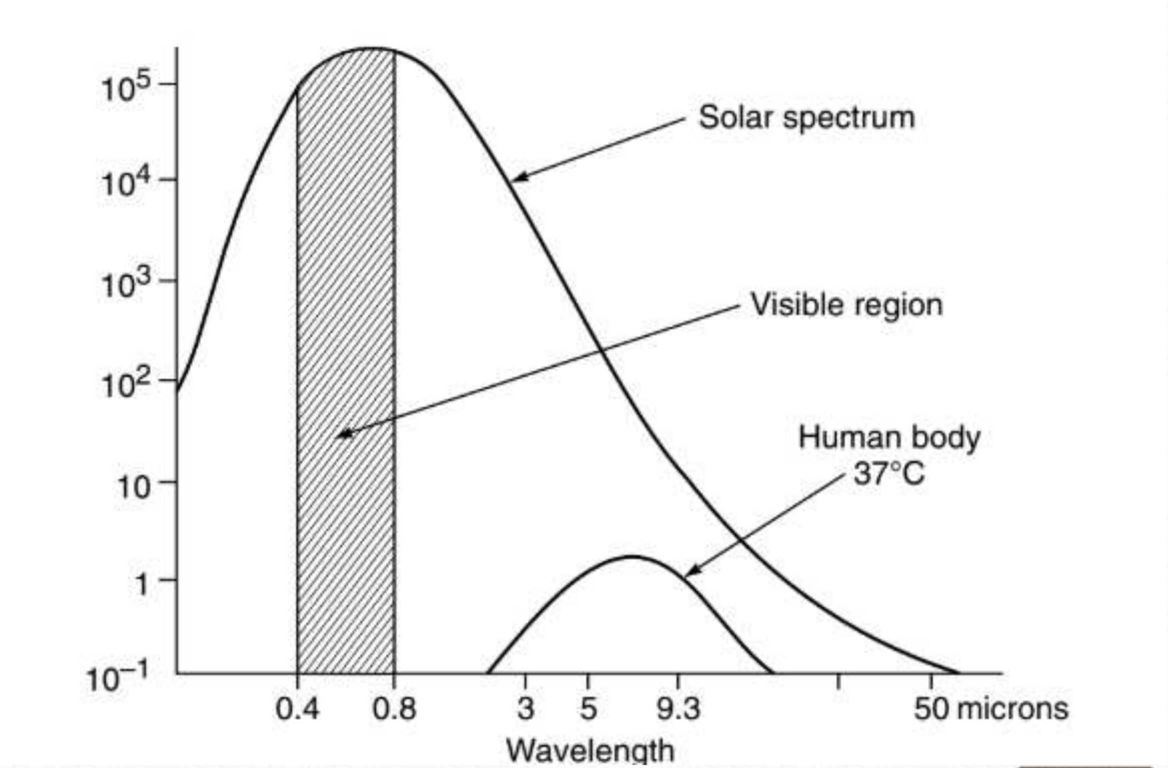
Medical thermography

- The human body absorbs infrared radiation almost without reflection, and at the same time, emits part of its own thermal energy in the form of infrared radiation
- The intensity of this radiant energy corresponds to the temperature of the radiant surface
- It is, therefore, possible to measure the varying intensity of radiation at a certain distance from the body and thus determine the surface temperature

Medical thermography

- Thermography is the science of visualizing these patterns and determining any deviations from the normal brought about by pathological changes
- Thermography often facilitates detection of pathological changes before any other method of investigation, and in some circumstances, is the only diagnostic aid available

Medical thermography



- Spectral distribution of infrared emission from human skin.
- The emission peaks at around 9 microns regardless of pigmentation

Advantages

- Thermography has a number of distinct advantages over other imaging systems.
- It is completely non-invasive, there is no contact between the patient and system as with ultrasonography
- There is no radiation hazard as with X-rays.
- Thermography is a real-time system.

Application

- The examination of the female breast as a reliable aid for diagnosing breast cancer is probably the best known application of thermography.
- The mammary glands were the first organs that thermography was clinically applied to
- It is assumed that since cancer tissue metabolizes more actively than other tissues and thus has a higher temperature, the heat produced is conveyed to the skin surface resulting in a higher temperature in the skin directly over the malignancy than in other regions.

Applications

- Assessment and monitoring of inflammatory joint diseases,
- Diagnosing deep vein thrombosis and the problem of peripheral circulation.
- Also in many fields of medicine from general surgery to ophthalmology.

Physics of Thermography

- Infrared rays are radiated spontaneously by all objects having a temperature above absolute zero.
- The total energy 'W' emitted by the object and its temperature are related by the Stefan Boltzman formula,

$$W = \sigma \in T^4$$

where W = radiant flux density and is expressed in W/cm^2

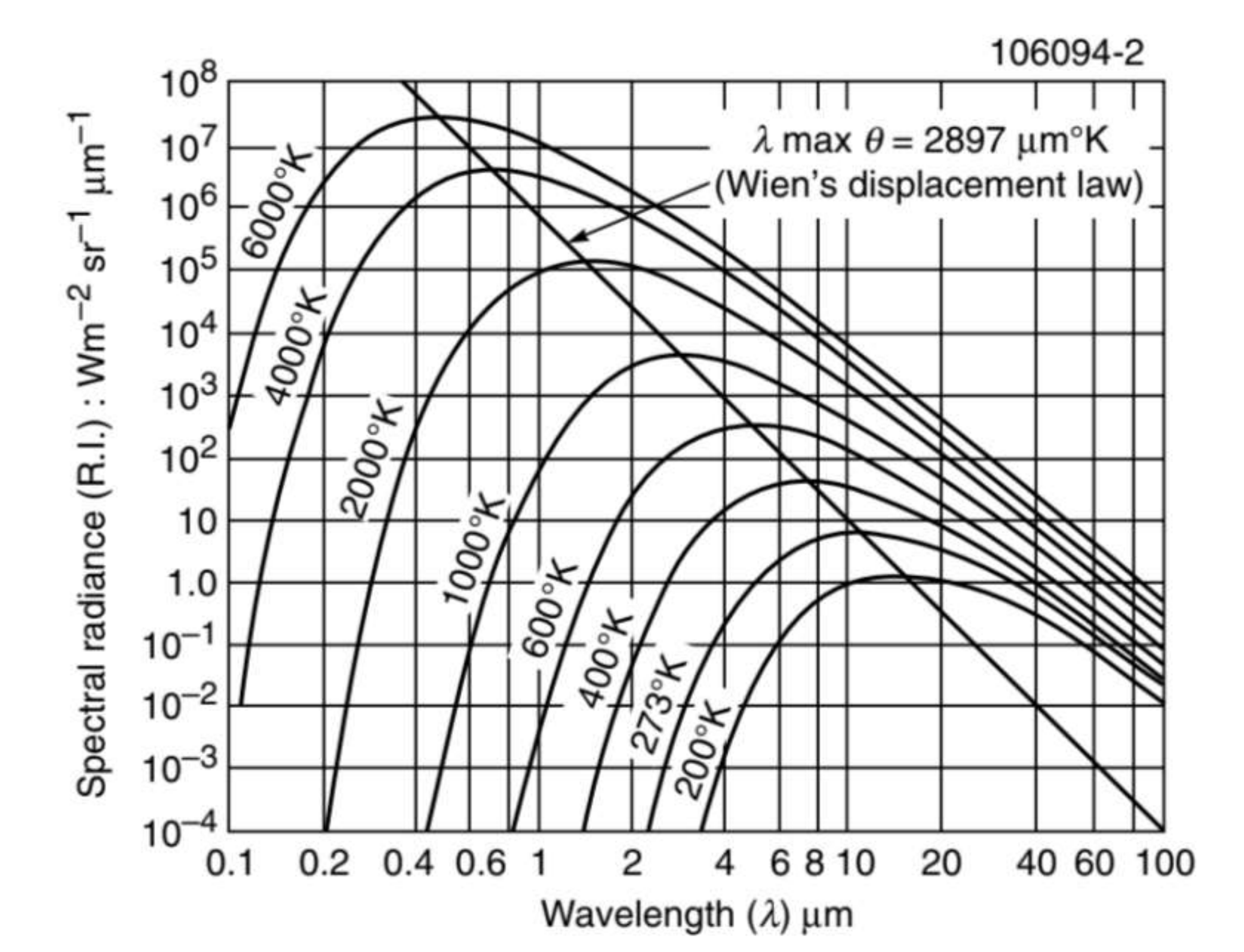
$\in$ = Emissivity factor

σ = Stefan-Boltzman constant = $5.67 \times 10^{-12}\ W/(cm^2 \times K^4)$

T = Absolute temperature

Shows that the amount of infrared energy emitted varies with temperature of the object.

Black body spectral radiance



- The wavelength of the energy peak and the absolute temperature is given by the Wien formula,

$$\lambda_{max} = \frac{2897\,(\mu m)}{T(K)}$$

The human body has a temperature of 37°C (310 K), therefore,

$$\lambda_{max}(\text{human body}) \approx 10\,\mu m$$

Physical factors

- There are several physical factors which affect the amount of infrared radiation from the human body.

 Emissivity, Reflectivity and Transmittance or Absorption.

Emissivity: An object which absorbs all radiation incident upon it, at all wavelengths; is called a black body. A black body is only an idealized case and, therefore, all objects encountered in practice can be termed gray bodies. We thus define the term emissivity as representing the ratio of the radiant energy emitted per unit area by an object to the radiant energy emitted per unit area of the black body at the same temperature.

Emissivity

$$\in = \frac{W_o}{W_b}$$

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

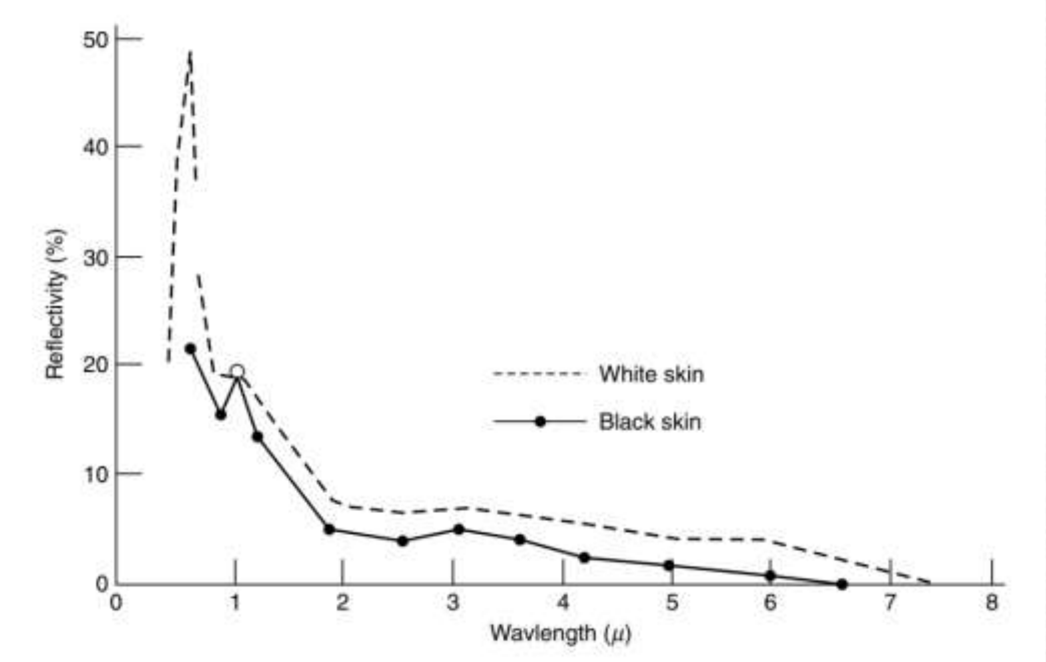
- The value of € for human skin at ambient temperature is virtually unity within the limit of infrared wavelengths of 3-16 micrometer.
- If a body has an emissivity that is less than one, and constant whatever the wavelength, it is called a gray body.
- A change in emissivity causes an error in temperature measurement, calculated that 1% of € is equivalent to approximately 0.3°C ΔT.
- In the infrared region, the spectral radiant emissivity of most solids decreases as the wavelength increases.

Reflection

- Spectral reflectivity λis defined as the ratio of reflected power to the incident power at a given wavelength. So,

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

where $\in_\lambda$ is the spectral emissivity, then $\in_\lambda = 1 - \rho_\lambda$.



Spectral distribution of the reflectivity of human skin

- If emissivity decreases, there is a corresponding increase in the reflection coefficient
- Shows that the reflectivity of human skin between the range 2 and 6 μm is 0.02–0.05

Transmittance and Absorption

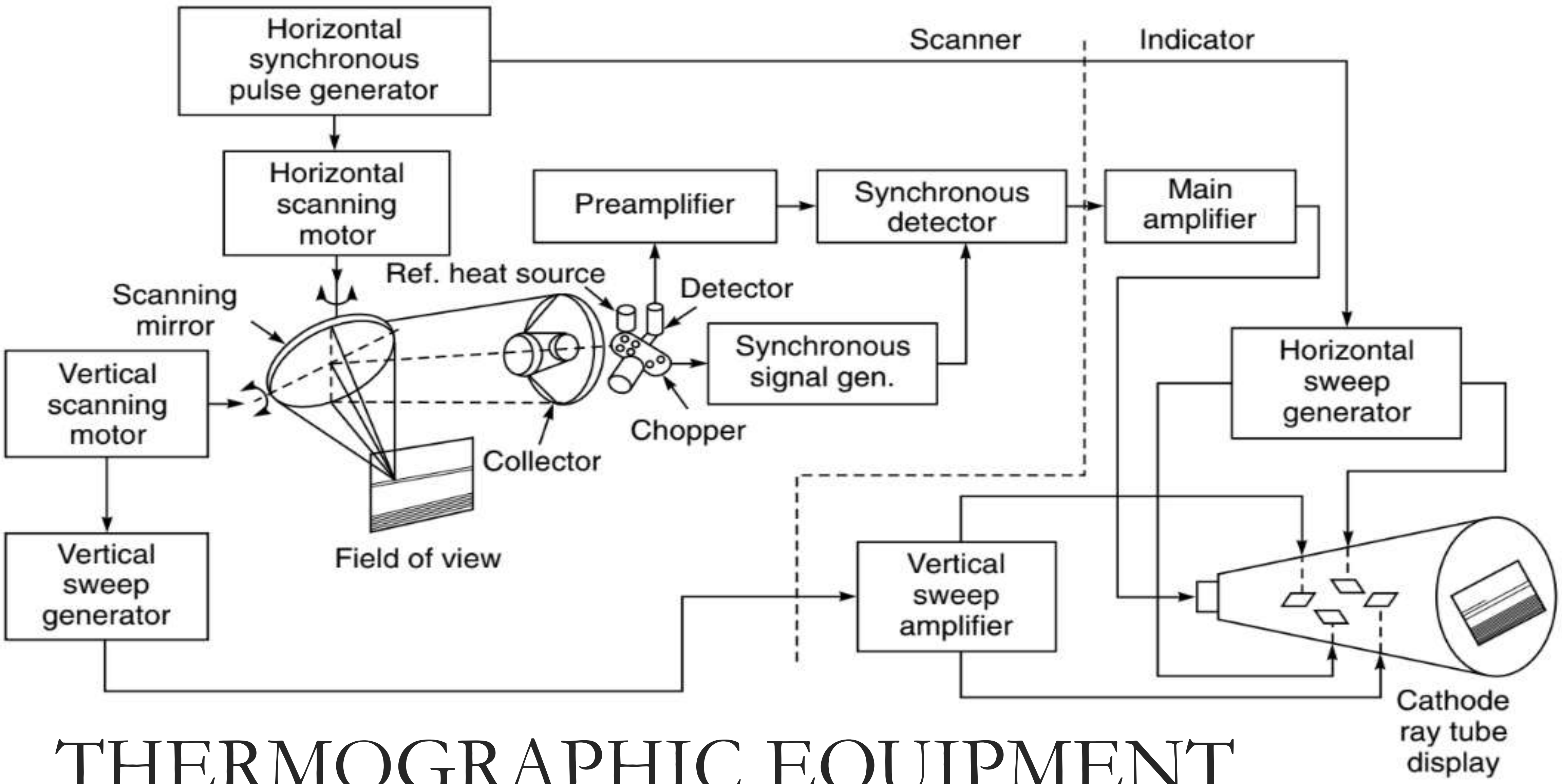
- When a semi-transparent body is placed between the surface of any radiation-emitting body and a detector, it is necessary to consider the change in emissivity related to its transmittance, reflectivity and emissivity.
- The presence of tape, paste or ointments have influence on thermograms.
- Hardy (1939) studied the spectral absorption of infrared radiance through human skin and found that the human skin is almost opaque at the wavelengths encountered in thermography.
- The background radiation of infrared rays is also found to influence the thermograms.
- When the infrared radiation from the background and that of the body are equal or nearly equal, it is difficult to distinguish the body from the background.

Infrared Detectors

- Infrared detectors are used to convert infrared energy into electrical signals.
- There are two types of detectors: thermal detectors and photo-detectors
- Thermal detectors include thermocouples and thermistor bolometers. They feature constant sensitivity over a long wavelength region. However, they are characterized by long-time constant, and thus show a slow response
- The wavelength at which the human body has maximum response is 9–10 μm
- . Therefore, the detector should ideally have a constant spectral sensitivity in the μm infrared range
- The spectral response of the photo-detectors is highly limited. Most of the infrared cameras use indium antimonide (InSb) (indium antimonide) detector which detects infrared rays in the range 2–6 μm
- Only 2.4% of the energy emitted by the human body falls within the region detected by InSb detectors. But they are highly sensitive and are capable of detecting small temperature variations as compared to a thermistor
- Another detector making use of an alloy of cadmium, mercury and telluride (CMT) and cooled with liquid nitrogen, has a peak response at 10–12 μm

THERMOGRAPHIC EQUIPMENT

- Thermographic cameras incorporate scanning systems which enable the infrared radiation emitted from the surface of the skin within the field of view to be focused on to an infrared detector
- Most systems have a wide range of absolute temperature sensitivity ranging from 1 to 50°C.
- The gray scale is generally adjusted to represent a much narrower range of temperature, depending on the area to be examined
- A full scale (black to white) temperature difference of between 5 to l0°C is usually adequate
- For breast examinations, the absolute temperature range may be 25 to 35°C, for the legs 23 to 33°C and for the forehead 31 to 36°C
- With the gray-scale spanning a temperature range of 50 C, it is possible to resolve temperature variations of 0.5°C on the skin
- Most of the clinical changes in temperature are of the order of 1°C or more
- It is not necessary to use the system on a more sensitive mode, even though some systems can theoretically resolve 0.1°C.



THERMOGRAPHIC EQUIPMENT

THERMOGRAPHIC EQUIPMENT

- The equipment used in thermography basically consists of two units:
  - a special infrared camera that scans the object,
  - a display unit for displaying the thermal picture on the screen
- The camera is generally mounted on a tripod that is fitted on wheels

THERMOGRAPHIC EQUIPMENT

- The camera unit contains an optical system which scans the field of view at a very high speed and focuses the infrared radiation on a detector that converts the radiation signal into an electrical signal
- The signal from the camera is amplified and processed before being used to modulate the intensity of the beam in the picture tube
- The beam sweeps across the tube face in a pattern corresponding to the scanning pattern of the camera
- The picture on the screen can be adjusted for contrast (temperature range) and brightness (temperature level) by means of controls on the display unit

THERMOGRAPHIC EQUIPMENT

- The thermal and spatial resolution of a thermographic system is determined by the optical parameters, detector performance, preamplifier's noise, the signal processing system, the picture presentation and evaluation systems
- A figure of merit for the thermographic imaging system is the noise equivalent temperature difference (NETD). This is usually called minimum temperature resolution, i.e., the temperature differential between two adjacent elements in the scene that will give a signal equal to the system noise. Thus, the smaller the NETD, the better the sensitivity
- InSb detector is one order of magnitude more sensitive than cadmium, mercury and telluride (CMT)

Quantitative medical thermography

- For comparing the results of successive thermographic examinations, it is essential that the results are standardized and quantified.
- In the earlier thermographic equipment, the thermograph was recorded on a photographic film from which it was possible to quantify it by densitometry. Work with this system was limited by the long scanning time.
- A practical solution to this problem is the use of ‘isotherms’. Differences between the various gray tones are determined accurately by means of a thermal band or isotherm. This is visualized by calibrating the electronic circuitry inside the camera, so that a particular gray level (i.e., temperature) is depicted as bright white on the screen.
- Thus, the isotherm is built up from white areas each indicating the selected temperature. These isotherms can be shifted to any temperature level and will register temperature differences as small as 0.2°C which are read from a scale on the monitor screen.

Quantitative medical thermography

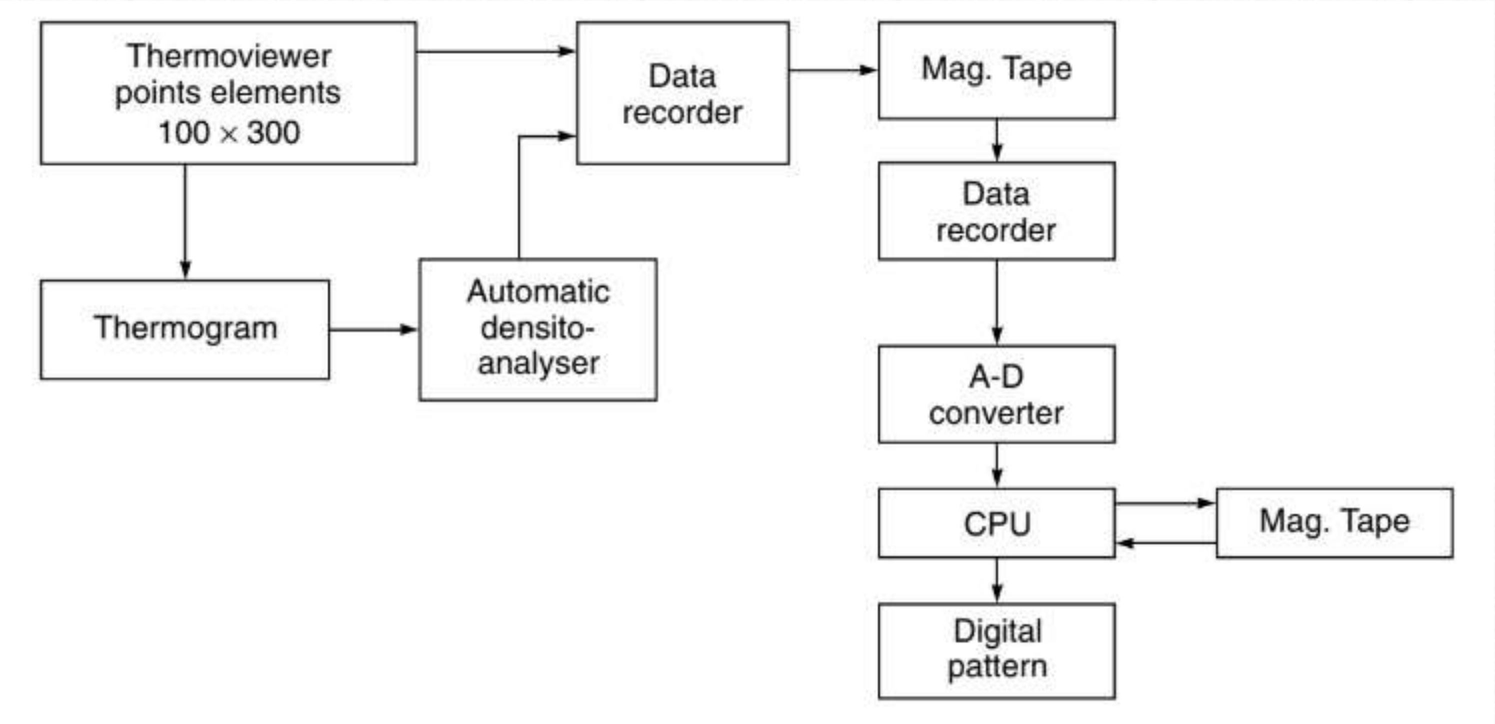
- In the modern thermographic equipment, temperature measurement is improved by providing two simultaneous isotherm functions.
- One isotherm could be located on an external temperature reference and the other on a point of interest. The unknown temperature is determined by difference.
- A convenient method of quantitative recording is the superimposition of a range of isotherms in a 7, 8 or 10 colour coded sequence between 26 and 34°C, representing the temperature range from the normal to the grossly inflamed, yellow usually represents the maximum temperature and blue the minimum.

Analog analysis

There are many possibilities of analog analysis of the gray tone image including the following:

- isotherm function
- level analysis
- sample area selector
- thermal profile analysis

Digitization of Thermogram

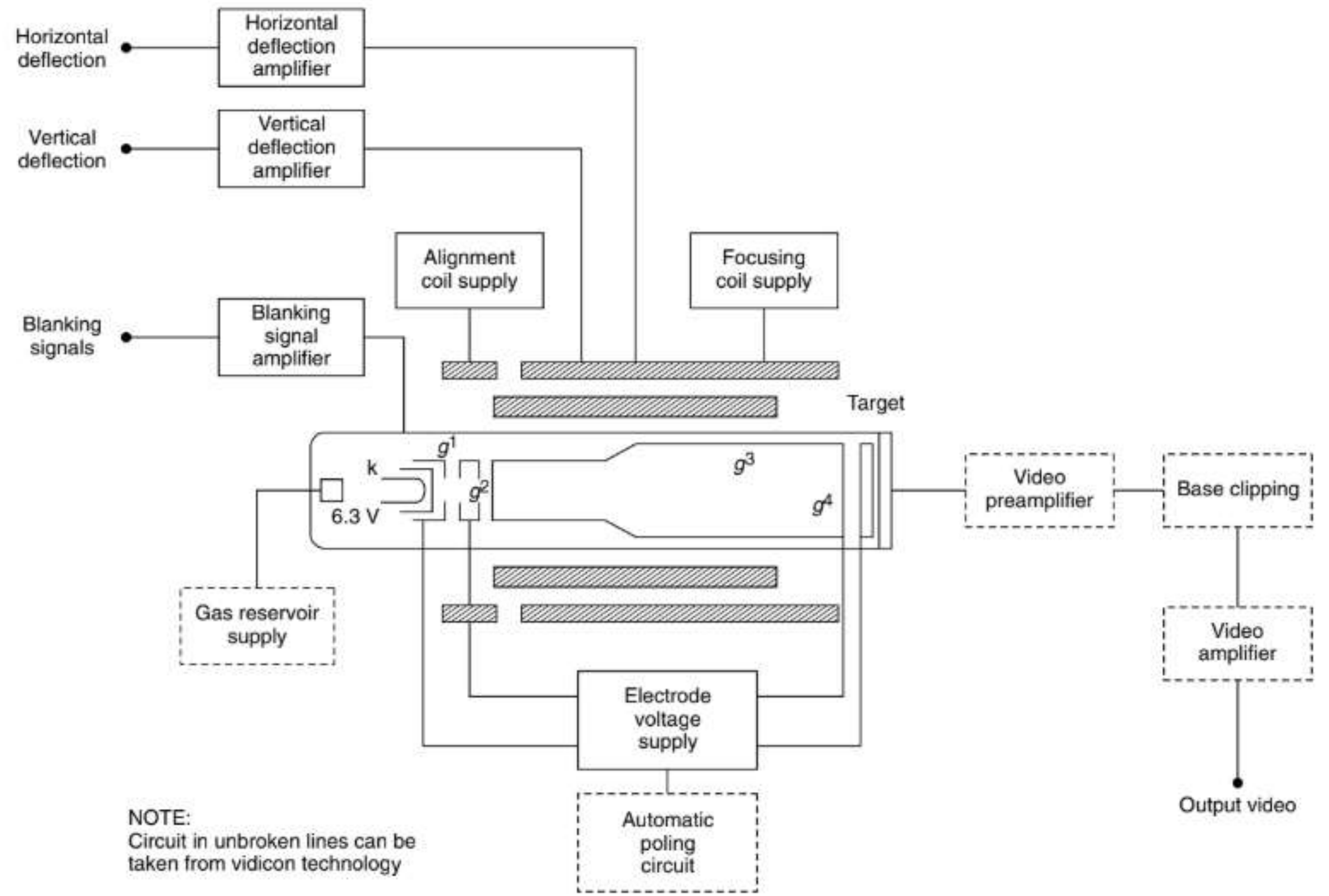


Digitization of Thermogram

- Analog outputs from the camera are converted into digital thermo-profiles by the A-D converter of a computer
- The control processing unit of the computer converts digital values into true temperature values based on the calibration data stored in the memory or magnetic tape
- Thermographic patterns can be scanned and converted into analog electrical signals by a scanning densitometer and are converted into digital form
- For a precise analysis of surface temperatures, the thermogram digitization and computers are useful in the automatic analysis of thermograms

Pyroelectric vidicon camera

- The pyroelectric vidicon is a thermal imaging tube. This tube resembles the standard vidicon, the main difference being that the material used for the target is sensitive to infrared instead of visible light.
- It is a compact, sensitive and reliable device and can thus find convenient application in medical thermography.



Block diagram of camera electronics used with Pyricon

Pyroelectric vidicon camera

- The pyroelectric vidicon basically consists of:

  (i) a glass envelope; fitted with a germanium faceplate, matching the 8 to 14 mm atmospheric window

  (ii) a pyroelectric target mounted on a metal backing plate that also acts as the video output electrode

  (iii) an electron gun and beam shaping electrodes like those of a standard vidicon,

  (iv) a gas reservoir heated by a tungsten filament.

- The tube is surrounded by focusing and deflection coils that are identical to those used with a standard vidicon.

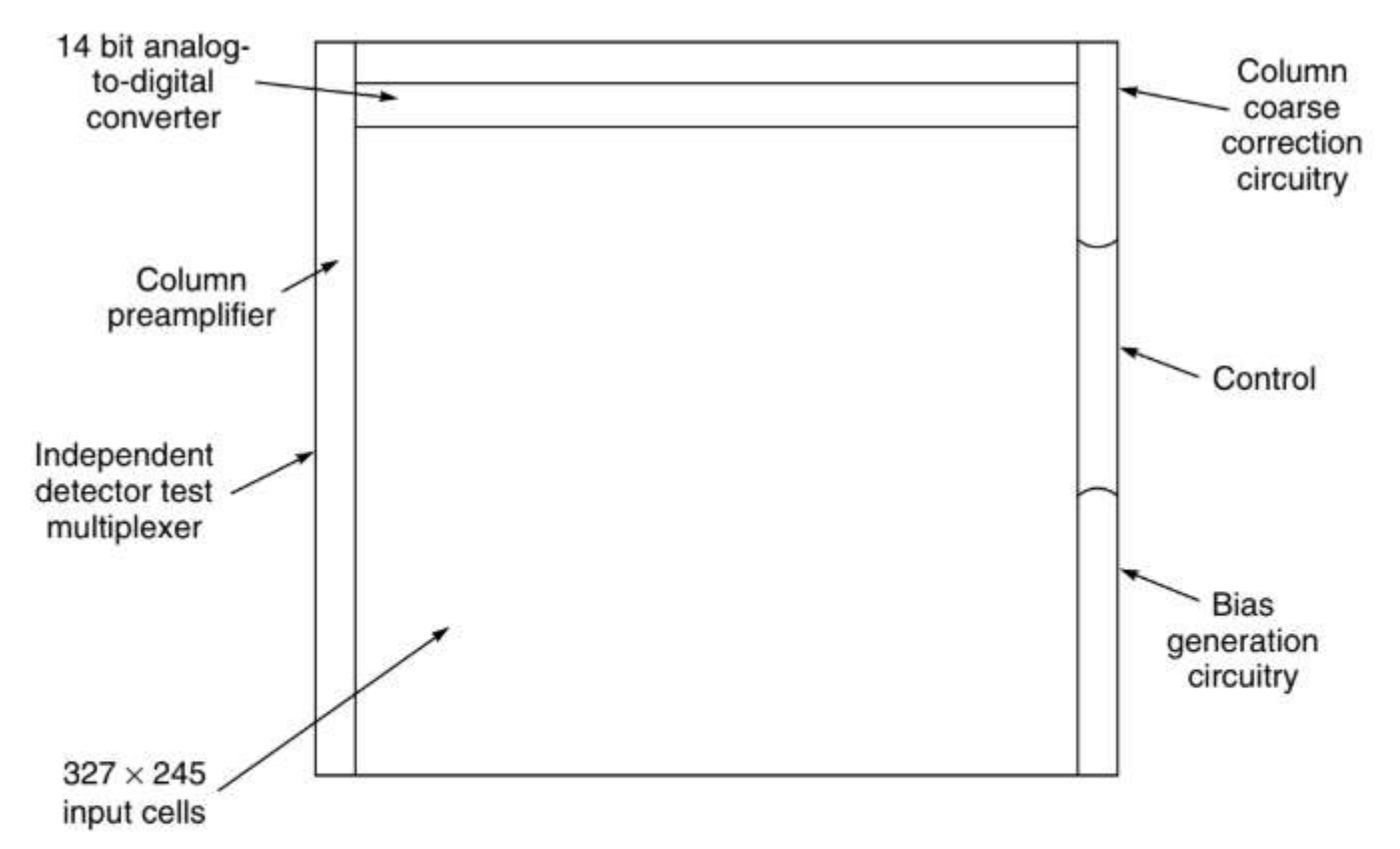
Pyroelectric vidicon camera

- Incoming thermal radiation is focused by an infrared transmitting lens through the infrared transmitting face plate of the tube onto the target.
- The target is a triglycine-sulphate (TGS) pyro-electric target which has a high sensitivity in the 8 to 14 mm range of the spectrum.
- Electrical changes are produced only when the temperature of the pyroelectric material changes.
- The maximum useful pyroelectric effect is obtained with a target temperature of about 35°C. It must never exceed 40°C, the curie point of TGS.
- Pyricon is the name given to pyroelectric vidicon (PEV) manufactured by Thomson CSF.

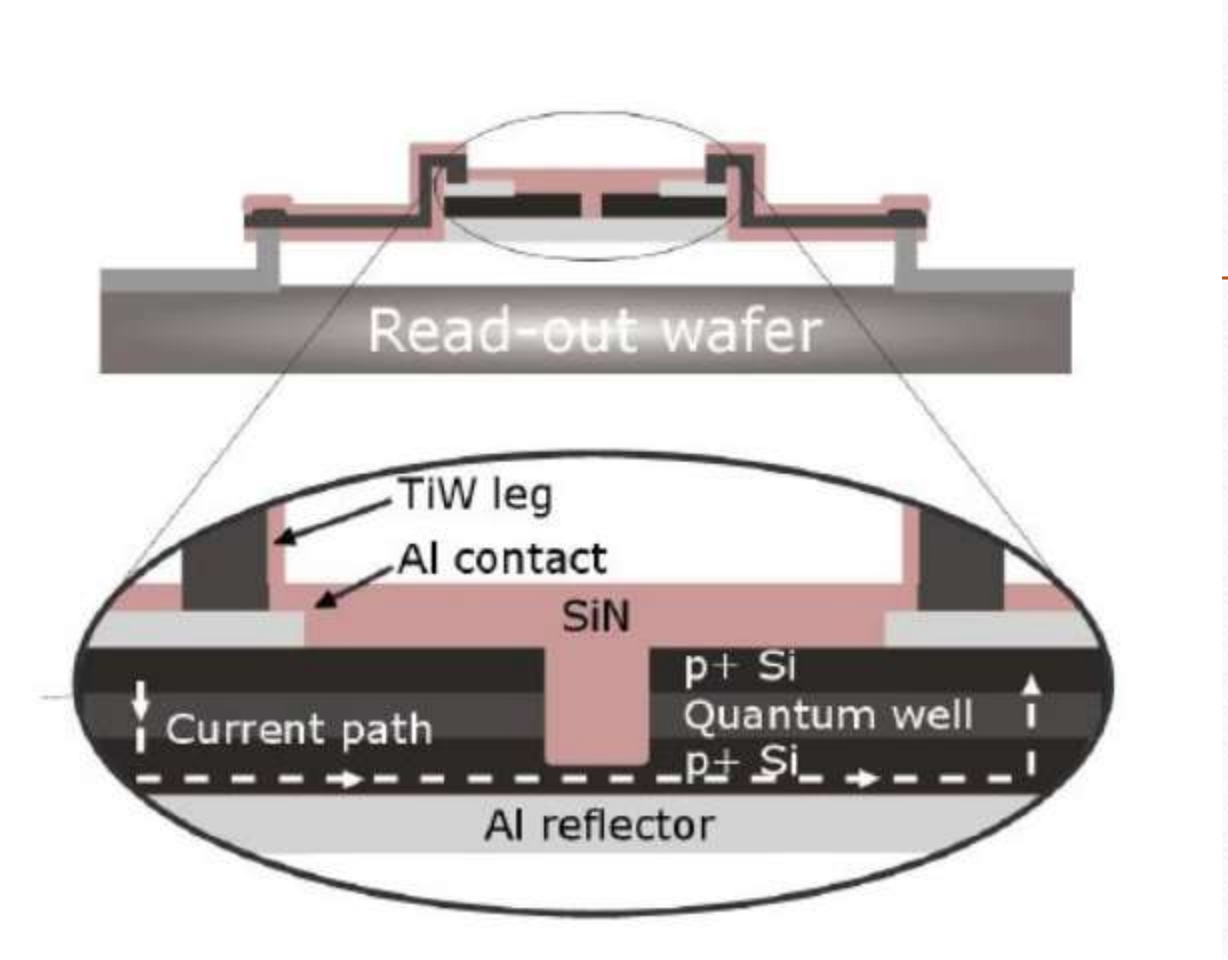
Thermal camera based on IR array sensor

- Sensors make use of micro-bolometer technology which involves a silicon micro-machined sensor that uses wafer-level silicon processing to fabricate a thermal sensor.
- A bolometer is a thermal detector heated by incident radiation, resulting in temperature rise that is sensed as a change in the element resistance.
- The 327 x 245 micro-bolometer focal plane array (FPA) has micro-machined bolometer elements on a 46.25 mm pitch.
- Each micro-bolometer detector consists of a silicon nitride micro-bridge that lies above a CMOS silicon substrate and is supported by two silicon nitride legs.
- A vanadium oxide film which has an approximately 2% temperature coefficient of resistance at ambient temperatures is deposited on the bridge to form the bolometer resistor.
- Each of the microbolometer detectors is connected to an underlying unit cell in the silicon CMOS readout integrated circuit substrate via two holes in the passivation layer on the top of the integrated circuit.

Layout of an integrated circuit used as a micro-bolometer focal plane



- The IR absorption in the 8–12 mm range is 80%
- Video output is in NTSC or PAL format



Cross section of a bolometer

GOOD LUCK