Principles of Noncontact Temperature Measurement

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Contents

Introduction

This manual was written for people who are unfamiliar with noncontact infrared temperature measurement. A conscious attempt has been made to present the subject matter as briefly and simply as possible. Readers who wish to gain more in-depth knowledge can follow the suggestions for further reading in the bibliography. This manual focuses on the practical operations of noncontact temperature measurement devices and IR thermometry, and answers important questions that may arise. If you plan to use a noncontact temperature measurement device and require further advice, send us the completed questionnaire (in the appendix) prior to use.

Section 1 The Advantages of Using IR Thermometers

Temperature is the most frequently measured physical quantity, second only to time. Temperature plays an important role as an indicator of the condition of a product or piece of machinery, both in manufacturing and in quality control. Accurate temperature monitoring improves product quality and increases productivity. Downtimes are decreased, since the manufacturing processes can proceed without interruption and under optimal conditions.

Infrared technology is not a new phenomenon—it has been utilized successfully in industrial and research settings for decades—but new innovations have reduced costs, increased reliability, and resulted in noncontact infrared sensors offering smaller units of measurement. All of these factors have led infrared technology to become an area of interest for new kinds of applications and users.

What are the advantages offered by noncontact temperature measurement?

1. It is fast (in the ms range)—time is saved, allowing for more measurements and accumulation of data (determination of temperature field).
2. It facilitates measurement of moving targets (conveyor processes).
3. Measurements can be taken of hazardous or physically inaccessible objects (high-voltage parts, great measurement distance).
4. Measurements of high temperatures (greater than 1300°C) present no problems. In similar cases, contact thermometers cannot be used, or have a limited life.

5. There is no interference—no energy is lost from the target. For example, in the case of a poor heat conductor such as plastic or wood, measurements are extremely accurate with no distortion of measured values, as compared to measurements with contact thermometers.
6. There is no risk of contamination and no mechanical effect on the surface of the object; thus wear-free. Lacquered surfaces, for example, are not scratched and soft surfaces can also be measured.

Having enumerated the advantages, there remains the question of what to keep in mind when using an IR thermometer:

1. The target must be optically (infrared-optically) visible to the IR thermometer. High levels of dust or smoke make measurement less accurate. Concrete obstacles, such as a closed metallic reaction vessel, allow for only topical measurement—the inside of the container cannot be measured.
2. The optics of the sensor must be protected from dust and condensing liquids. (Manufacturers supply the necessary equipment for this.)
3. Normally, only surface temperatures can be measured, with the differing emissivities of different material surfaces taken into account.

Summary: The main advantages of noncontact IR thermometry are speed, lack of interference, and the ability to measure in high temperature ranges to 3000°C. Keep in mind that only the surface temperature can be measured.

Section 2 The Infrared Measuring System

An IR thermometer can be compared to the human eye. The lens of the eye represents the optics through which the radiation (flow of photons) from the object reaches the photosensitive layer (retina) via the atmosphere. This is converted into a signal that is sent to the brain. Fig. 1 shows an infrared measuring system process flow.

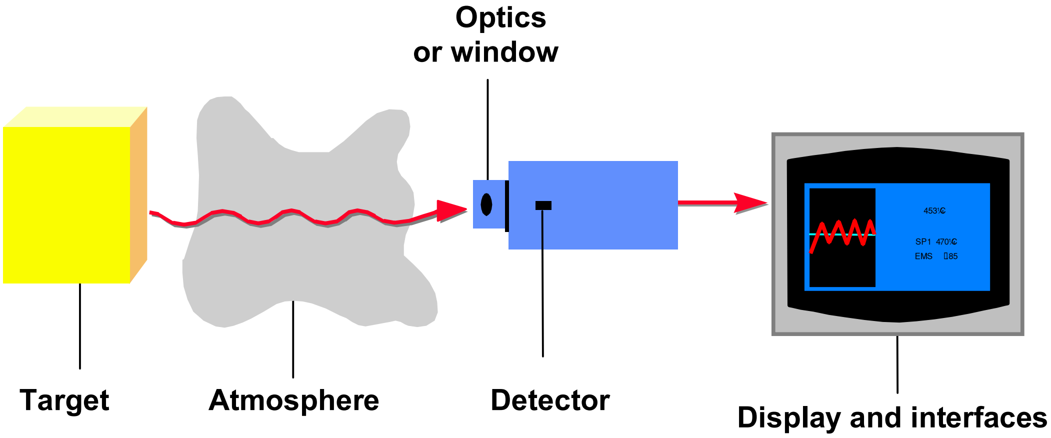


Fig. 1: Infrared measuring system

2.1 The Target

Every form of matter with a temperature (T) above absolute zero emits infrared radiation according to its temperature. This is called characteristic radiation. The cause of this is the internal mechanical movement of molecules. The intensity of this movement depends on the temperature of the object. Since the molecule movement represents charge displacement, electromagnetic radiation (photon particles) is emitted. These photons move at the speed of light and behave according to the known optical principles. They can be deflected, focused with a lens, or reflected from reflective surfaces. The spectrum of this radiation ranges from 0.7 to 1000 µm wavelength. For this reason, this radiation cannot normally be seen with the naked eye. This area lies within the red area of visible light and has therefore been called "infra"-red after the Latin. (See Fig. 2)

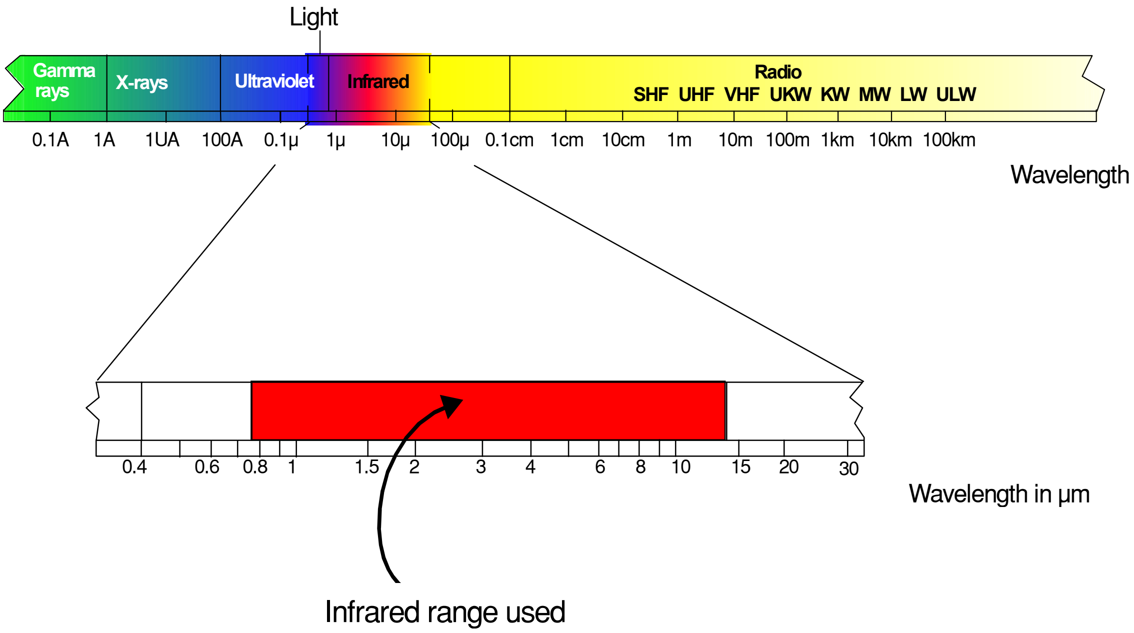


Fig. 2: The electromagnetic spectrum, with range from around 0.7 to 14 µm useful for measuring purposes

Fig. 3 shows the typical radiation of a body at different temperatures. As indicated, bodies at high temperatures still emit a small amount of visible radiation. This is why everyone can see objects at very high temperatures (above 600°C) glowing somewhere from red to white. Experienced steelworkers can even estimate temperature quite accurately from the color. The classic disappearing filament pyrometer was used in the steel and iron industries from 1930 on. The invisible part of the spectrum, however, contains up to 100,000 times more energy. Infrared measuring technology builds on this. It can likewise be seen in Fig. 3 that the radiation maximum move toward ever-shorter wavelengths as the target temperature rises, and that the curves of a body do not overlap at different temperatures. The radiant energy in the entire wavelength range (area beneath each curve) increases to the power of 4 of the temperature. These relationships were recognized by Stefan and Boltzmann in 1879 and illustrate that an unambiguous temperature can be measured from the radiation signal. [1, 3, 4, 5]

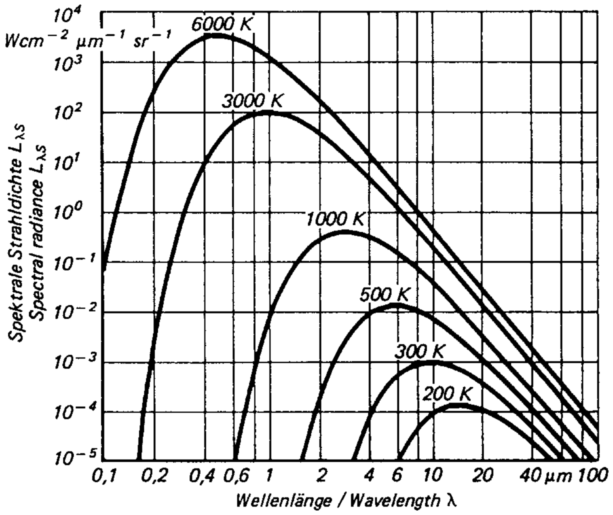


Fig. 3: Radiation characteristics of a blackbody in relation to its temperature. [3]

Looking at Fig. 3, then, the goal should be to set up the IR thermometer for the widest range possible in order to gain the most energy (corresponding to the area below a curve) or signal from the target. There are, however, some instances in which this is not always advantageous. For instance, in Fig. 3, the intensity of radiation increases at 2 µm—much more when the temperature increases than at 10 µm. The greater the radiance difference per temperature difference, the more accurately the IR thermometer works. In accordance with the displacement of the radiation maximum to smaller wavelengths with increasing temperature (Wien's Displacement Law), the wavelength range behaves in accordance with the measuring temperature range of the pyrometer. At low temperatures, an IR thermometer working at 2 µm would stop at temperatures below 600°C, seeing little to nothing since there is too little radiation energy. A further reason for having devices for different wavelength ranges is the emissivity pattern of some materials known as non-gray bodies (glass, metals, and plastic films). Fig. 3 shows the ideal—the so-called "blackbody". Many bodies, however, emit less radiation at the same temperature. The relation between the real emissive power and that of a blackbody is known as emissivity ε (epsilon) and can be a maximum of 1 (body corresponds to the ideal blackbody) and a minimum of 0. Bodies with emissivity less than 1 are called gray bodies. Bodies where emissivity is also dependent on temperature and wavelength are called non-gray bodies.

Furthermore, the sum of emission is composed of absorption (A), reflection (R) and transmission (T) and is equal to one. (See Equation 1 and Fig. 4)

$$\mathbf{A + R + T = 1} \qquad \textbf{(1)}$$

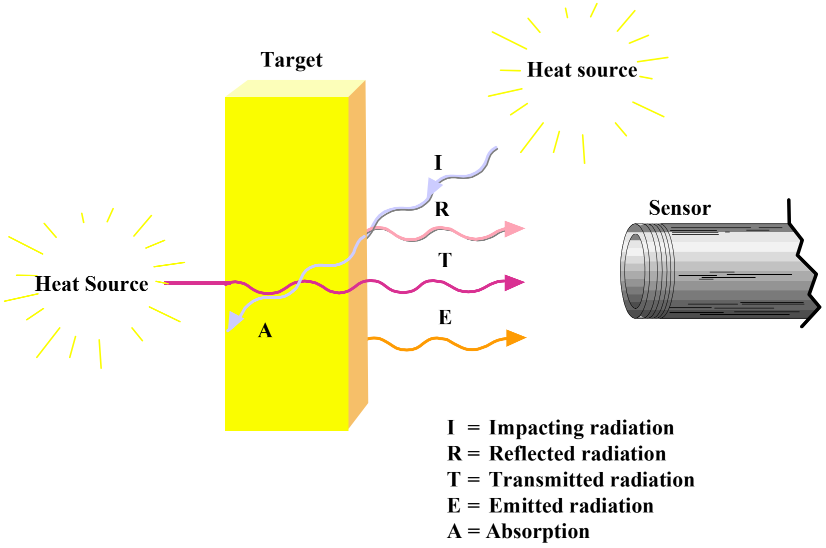


Fig. 4: In addition to the radiation emitted from the target, the sensor also receives reflected radiation and can also let radiation through.

Solid bodies have no transmission in the infrared range (T = 0). In accordance with Kirchhof's Law, it is assumed that all the radiation absorbed by a body, and which has led to an increase in temperature, is then also emitted by this body. The result, then, for absorption and emission is:

A ⇔ E = 1 - R

The ideal blackbody also has no reflectance (R = 0), so that E = 1.

Many non-metallic materials such as wood, plastic, rubber, organic materials, rock, or concrete have surfaces that reflect very little, and therefore have high emissivities between 0.8 and 0.95. By contrast, metals—especially those with polished or shiny surfaces—have emissivities at around 0.1. IR thermometers compensate for this by offering variable options for setting the emissivity factor. (See also Fig. 5)

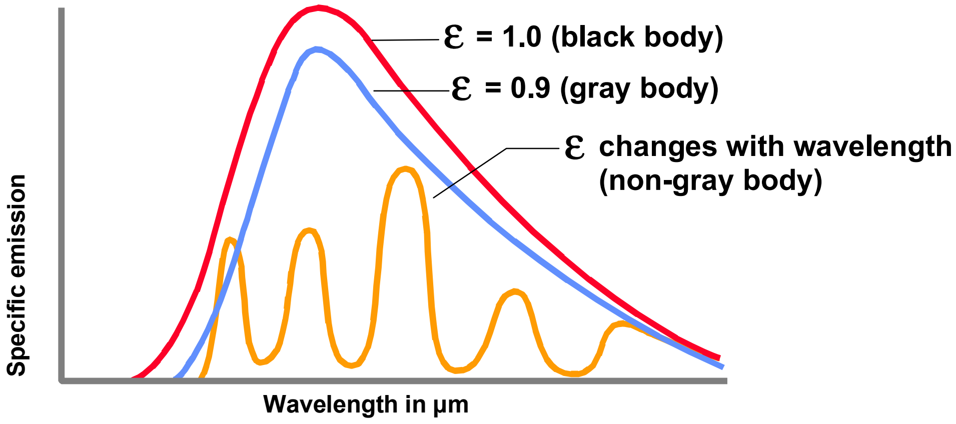


Fig. 5: Specific emission at different emissivities

2.1.1 Determining Emissivity

There are various methods for determining the emissivity of an object. First, you can find the emissivity of many frequently used materials in a table. Emissivity tables also help you find the right wavelength range for a given material, and, so, the right measuring device. Particularly in the case of metals, the values in such tables should only be used for orientation purposes since the condition of the surface (e.g. polished, oxidized or scaled) can influence emissivity more than the various materials themselves. It is possible to determine the emissivity of a particular material yourself using different methods. To do so, you need a pyrometer with emissivity setting capability.

1. Heat up a sample of the material to a known temperature that you can determine very accurately using a contact thermometer (e.g. thermocouple). Then measure the target temperature with the IR thermometer. Change the emissivity until the temperature corresponds to that of the contact thermometer. Now keep this emissivity for all future measurements of targets on this material.

2. At a relatively low temperature (up to 260°C), attach a special plastic sticker with known emissivity to the target. Use the infrared measuring device to determine the temperature of the sticker and the corresponding emissivity. Then measure the surface temperature of the target without the sticker and re-set the emissivity until the correct temperature value is shown. Now, use the emissivity determined by this method for all measurements on targets of this material.

3. Create a blackbody using a sample body from the material to be measured. Bore a hole into the object. The depth of the borehole should be at least five times its diameter. The diameter must correspond to the size of the spot to be measured with your measuring device. If the emissivity of the inner walls is greater than 0.5, the emissivity of the cavity body is now around 1, and the temperature measured in the hole is the correct temperature of the target[4]. If you now direct the IR thermometer to the surface of the target, change the emissivity until the temperature display corresponds with the value given previously from the blackbody. The emissivity found by this method can be used for all measurements on the same material.

4. If the target can be coated, coat it with a matte black paint ("3-M Black" from the Minnesota Mining Company or "Senotherm" from Weilburger Lackfabrik[2], either which have an emissivity of around 0.95). Measure the temperature of this blackbody and set the emissivity as described previously.

2.1.2 Measuring Metals

The emissivity of a metal depends on wavelength and temperature. Since metals often reflect, they tend to have a low emissivity which can produce differing and unreliable results. In such a case it is important to select an instrument which measures the infrared radiation at a particular wavelength and within a particular temperature range at which the metals have the highest possible emissivity. With many metals, the measurement error becomes greater with the wavelength, meaning that the shortest wavelength possible for the measurement should be used. (See Fig. 6)

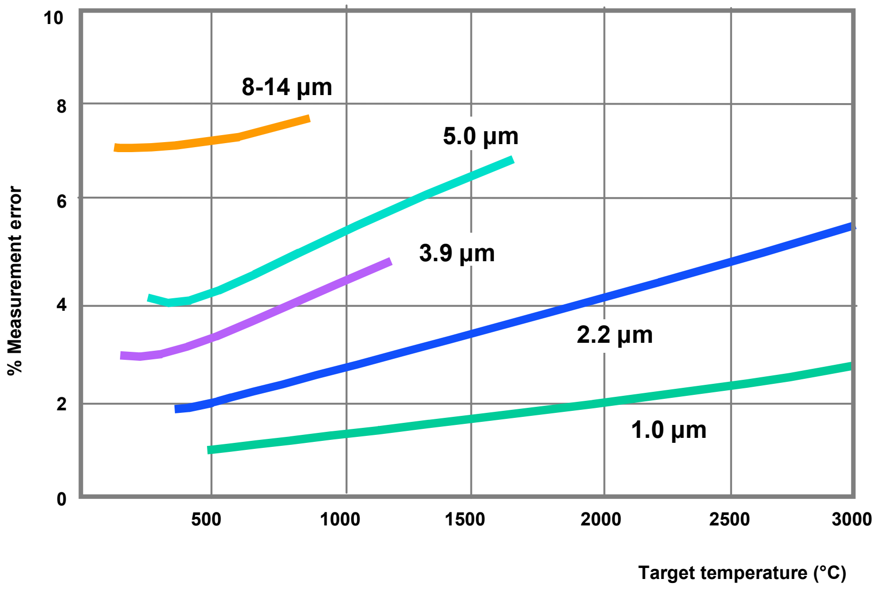


Fig. 6: Measurement error in the case of 10% error in setting emissivity dependent on wavelength and target temperature.

The optimal wavelength for high temperatures in the case of metals is, at around 0.8 to 1.0 µm, at the limit to the visible range. Wavelengths of 1.6, 2.2, and 3.9 µm are also possible. Good results can be achieved using ratio pyrometers in cases (e.g. heating processes) where measurement is to take place across a relatively wide temperature range and the emissivity changes with the temperature. (See Section 3)

2.1.3 Measuring Plastics

The transmittance of a plastic varies with the wavelength and is proportional to its thickness. Thin materials are more transmissive than thick plastics. In order to achieve optimal temperature measurement it is important to select a wavelength at which transmittance is nearly zero. Some plastics (polyethylene, polypropylene, nylon, and polystyrol) are not transmissive at 3.43 µm; others (polyester, polyurethane, Teflon FEP, and polyamide) at 7.9 µm. With thicker (> 0.4 mm), strongly-colored films, you should choose a wavelength between 8 and 14 µm. If you are still uncertain, send a sample of the plastic to the manufacturer of the infrared device to determine the optimal spectral bandwidth for measurement. Almost all plastic films have reflectance between 5 and 10%.

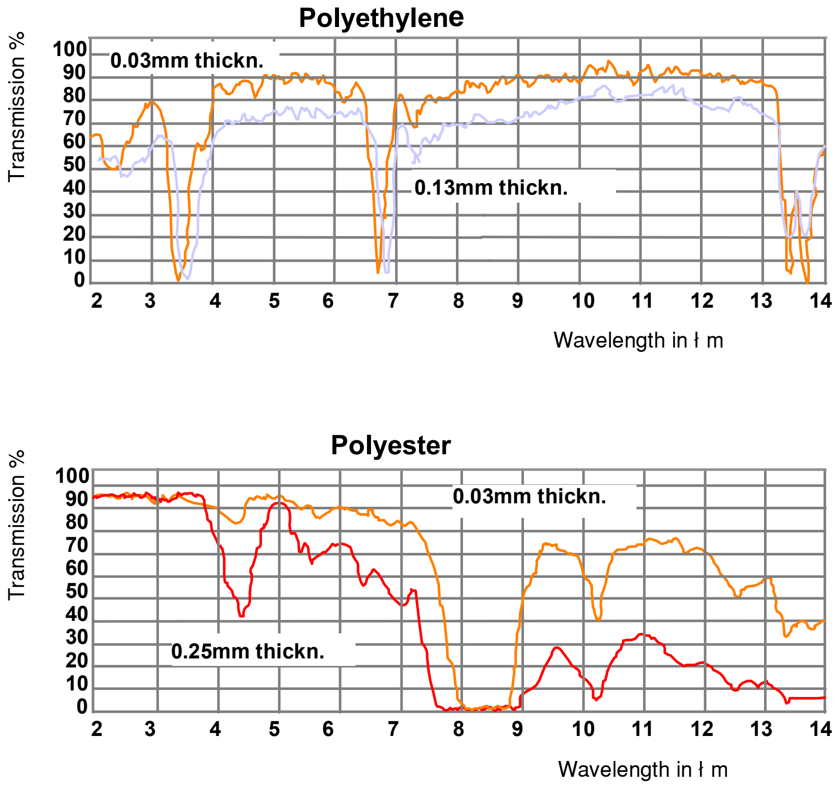


Fig. 7: Spectral transmittance of plastic films. Irregardless of thickness, polyethylene is almost intransmissive at 3.43 µm and polyester is completely intransmissive at 7.9 µm.

2.1.4 Measuring Glass

When measuring the temperature of glass with an infrared thermometer, both reflectance and transmittance must be considered. By carefully selecting the wavelength, it is possible to measure temperature of both the surface and at a depth. When taking measurements below the surface, a sensor for 1.0, 2.2, or 3.9 µm wavelength should be used. We recommend you use a sensor for 5 µm for surface temperatures. At low temperatures, 8–14 µm should be used with the emissivity set to 0.85, to compensate for reflectance. Since glass is a poor conductor of heat, and can change surface temperature rapidly, a measuring device with a short response time is recommended.

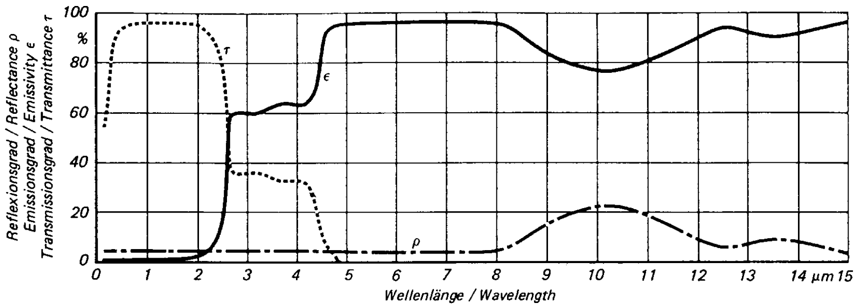


Fig. 8: Spectral transmittance of glass.[3]

Summary: Every body emits infrared radiation. This radiation is only visible to the naked eye at temperatures above 600°C (e.g. glowing-hot iron). The wavelength range is from 0.7 µm to 1000 µm. Blackbodies absorb and emit 100% of the radiation that corresponds to their characteristic temperature. All other bodies are placed in relation to this when evaluating their radiation emission. This is called emissivity.

2.2 Ambient Conditions

Another reason for setting up an IR thermometer for a particular spectral range only (spectral radiation pyrometer), is the transmission behavior of the transmission path, usually the ambient air. Certain components of the atmosphere, such as vapor and carbon dioxide, absorb infrared radiation at particular wavelengths which result in transmission loss.

If absorption media is not taken into account, it can lead to a temperature displayed below that of the actual target temperature. Fortunately, there are "windows" in the infrared spectrum which do not contain these absorption bands. In Fig. 8 the transmission curve of a 1 m long air distance is represented. Typical measuring windows are 1.1–1.7 µm, 2–2.5 µm, 3–5 µm and 8–14 µm. Since the manufacturers have already furnished infrared measuring devices with atmospheric correction filters, the user is spared such worries.

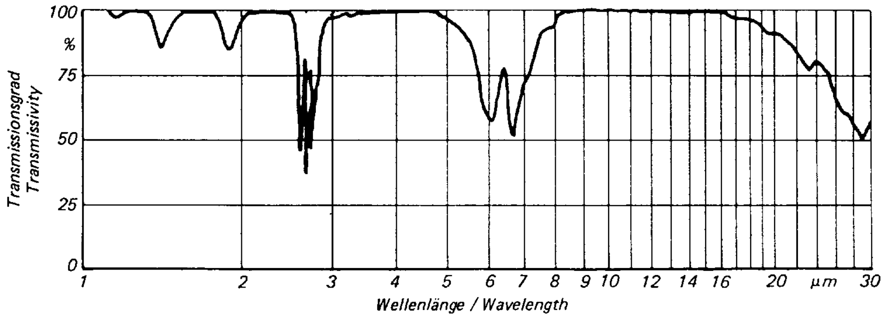


Fig. 9: Transmittance of a 1 m long air distance at 32°C and relative 75% humidity.[3]

Thermal radiation in the environment surrounding the target should likewise be taken into account. The higher temperatures of the furnace walls could lead to errors in temperature measurement on metal pieces in an industrial furnace. The possible effect of the ambient temperature has been taken into consideration by many infrared measuring devices, with compensation built in. The other possibility is a too-high temperature being displayed for the target. A correctly set emissivity, along with automatic ambient temperature compensation from a second temperature sensor ensures extremely accurate results.

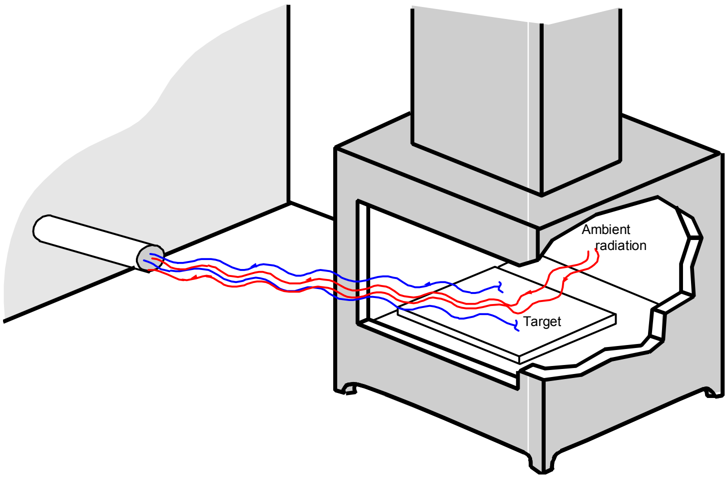


Fig. 10: Ambient temperature compensation is important where targets are cooler than the surrounding environment.

Dust, smoke, and suspended matter in the atmosphere can result in contamination of the optics and, therefore, in false measured values. In order to prevent deposition of suspended matter, optional air-blowing attachments are offered. These are usually screw-on pipe connections with a compressed air supply. The air ensures overpressure in front of the optics, thus keeping contaminating particles at bay. If a great amount of dust or smoke is created during the measurement procedure and affect the result, then ratio pyrometers should be used. (See Section 3)

IR sensors are electronic devices and can only work within certain operating temperature ranges. Some sensors allow an upper limit of 85°C. Above the permitted operating temperature, air or water-cooling accessories must be used and there must be special connection cables for the application of high temperature. When using water-cooling it is often useful to use it in conjunction with the air-blowing attachment to prevent formation of condensation on the optics.

Summary:

Factors	**Solution**
◆ **Ambient radiation Is hotter than target**	◆ **Sensor with ambient radiation compensation** ◆ **Shielding of target background**
◆ **Dust, vapor, particles in the atmosphere**	◆ **Air-blowing unit for lens** ◆ **Ratio pyrometer**
◆ **High operating temp.**	◆ **Thermally insulated assembly** ◆ **Water or air-cooling** ◆ **Air-blowing unit for lens** ◆ **Heat shield**

2.3 Optics and Window

The optical system of an infrared thermometer picks up the infrared energy emitted from a circular measurement spot and focuses it on a detector. The target must completely fill this spot, otherwise the IR thermometer will "see" other temperature radiation from the background making the measured value inaccurate. (See Fig. 11)

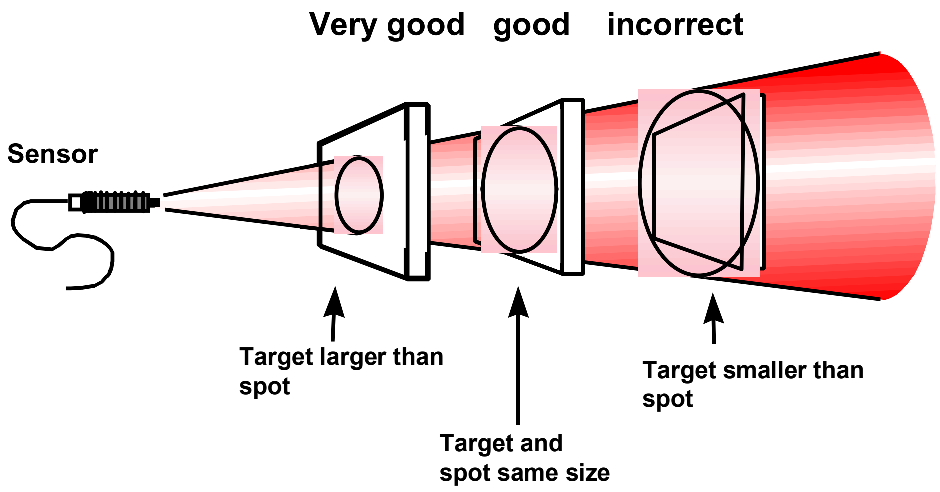


Fig. 11: The target must completely fill the spot to be measured, otherwise the measured value will be incorrect (exception: ratio pyrometer). (See Section 3)

The optical resolution is defined as the relationship between the distance of the measuring device from the target, and the diameter of the spot (D:S). The greater this value, the better the optical resolution of the measuring device, and the smaller the target can be at a given distance. (See Fig. 12)

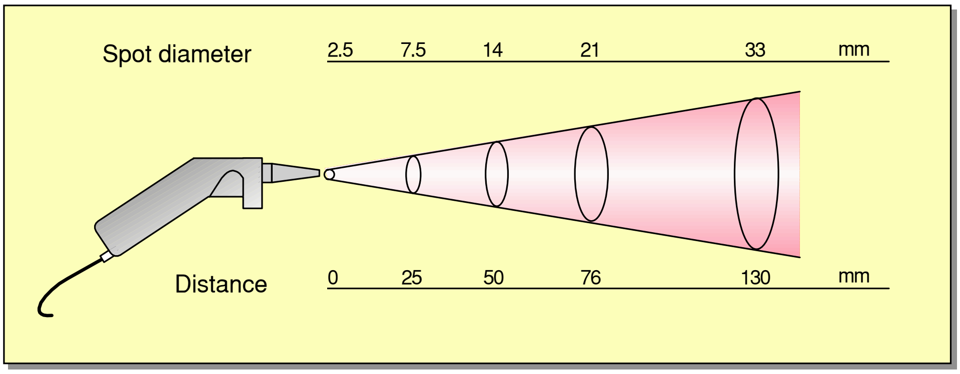


Fig. 12: Optical diagram of an infrared sensor. At a distance of 130 mm the spot measured is 33 mm, giving a ratio of around 4:1.

The optics themselves can be mirror optics or lens optics. Lenses can only be used for particular wavelength ranges due to their material wavelength ranges. They are, however the preferred solution for reasons of design. Fig. 13 shows some typical lenses and window materials for IR thermometers, along with their wavelength ranges.[3]

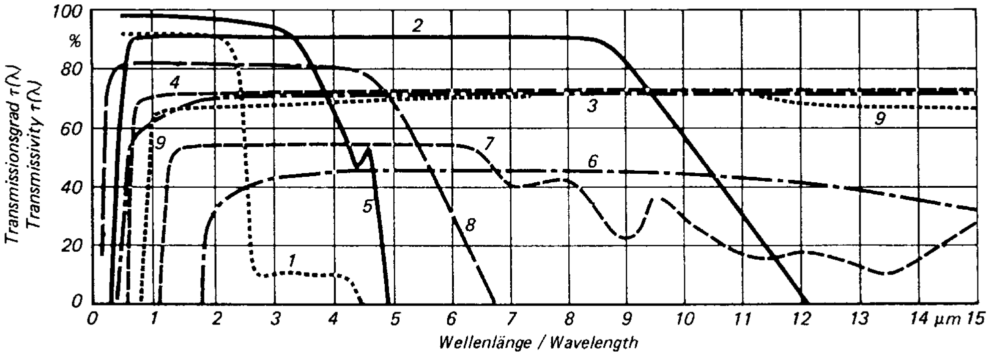


Fig. 13: Transmittance of typical IR materials (1 mm thick)

1- Optical glass	6- Germanium
2- Calcium fluoride (CaF)	7- Silicon
3- Zinc selenide (ZnSe)	8- Lithium fluoride
4- KRS-5	9- Chalcogenide glass IG-2
5- Quartz glass	

For measurement in a closed reaction vessel, furnace, or vacuum chamber, it is usually necessary to measure through a suitable measuring window. When selecting a material for the window, keep in mind that the transmission values of the window are tuned to the spectral sensitivity of the sensor. At high temperatures, the material most often used is quartz glass. At low temperatures (in the range 8–14 µm), it is necessary to use a special IR-transmissive material such as germanium, Amtir, or zinc selenide. When choosing the window, consider the spectral sensitivity parameters, diameter of the window, temperature requirements, maximum window pressure difference, and ambient conditions as well as the possibility of keeping the window free from contamination on both sides. It is also important to have transparency in the visible range in order to be able to align the device better with the target (e.g. in a vacuum container).

Table 1 gives an overview of various window materials.

Table 1

Window material /properties	Sapphire Al_2O_3	Fused silica SiO_2	CaF_2	BaF_2	AMTIR	ZnS	ZnSe	KRS5
Recommended IR wavelength range in µm	1–4	1–2.5	2–8	2–8	3–14	2–14	2–14	1–14
Maximum window temp in °C	1800	900	600	500	300	250	250	---
Transmission in visible range	yes	yes	yes	yes	no	yes	yes	yes
Resistance to damp, acids, ammonia compounds	very good	very good	poor	poor	good	good	good	good
Suitable for UHV	yes	yes	yes	yes	---	yes	yes	yes

The transmittance of the window greatly depends upon its thickness. For a window with a diameter of 25 mm, (which should be able to withstand the pressure difference of one atmosphere), a thickness of 1.7 mm is adequate.

Windows with an antireflecting layer exhibit much higher transmittance (up to 95%). If the manufacturer states the transmittance for the corresponding wavelength range, the transmission loss can be corrected along with the emissivity setting. For example, an Amtir window with 68% transmittance is used to measure a target with emissivity of 0.9. Then 0.9 is multiplied by 0.68, resulting in 0.61. This is the emissivity value to be set on the measuring device.

Pyrometers are often fitted with an aligning telescope or with lasers that are either built-in or screwed in front of the device. The laser beam enables the user to aim at the measuring spot even more quickly and precisely, which benefits applications of the IR-measuring device considerably. In particular, it is very useful to sight on the measuring spot with a laser for the measurement of moving objects and in poor light conditions.

One can distinguish between the following laser sighting setups:

1. Laser beam with an offset from the optical axis
This is the simplest model, especially for devices with low optical resolution (for big measuring objects). The laser spot aims approximately at the centre of the measuring object, but there is a noticeable error at close range.

2. Coaxial laser beam
This laser beam comes out of the centre of the optics and remains along the optical axis. The centre of the measuring spot is precisely marked at any measuring distance.

3. Double/Twin laser
Twin laser with two aiming points can be used to show the diameter of the measuring spot over a long distance. With this, the user does not need to guess the size of the diameter or calculate it beforehand. Furthermore it prevents the user from making mistakes during the measurement.

4. Circular laser sighting with offset
This device is the simplest solution to show not only the location of the measuring area but also the size and outer form of it. The measuring surface is within the laser circle from a certain minimum distance onwards. The manufacturer calculates the laser circle to be larger

than the real measuring spot in order to reduce the parallax error. Consequently, the user has to ensure that the laser circle as a whole is filled by the subject to have a correct measurement. But this prevents the user from making full use of the geometrical resolution stated for this device (compare red area with laser sighting circle [interrupted line] in fig. 14).

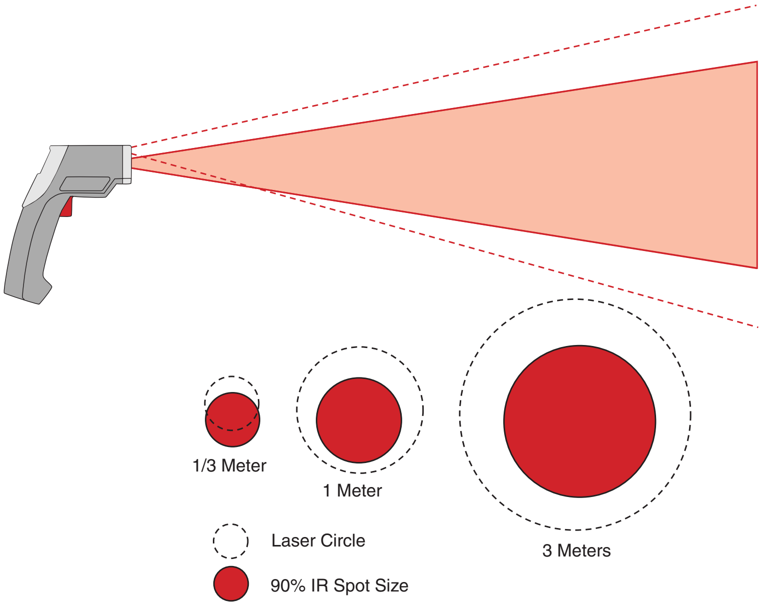


Fig. 14: The circular laser sighting with offset has a circular marking that is larger than the actual measuring spot – which is then situated inside the laser circle from a certain measuring distance outwards.

5. Precision 3-point coaxial laser sighting (True Dimension)

A laser beam is divided up to project three bright laser points in a row that enable the user to clearly mark the dimensions of the measurement spot from all distances and measurement angles. The middle laser point always shows the centre of the target, while the two outside laser points mark the diameter of the measurement spot.

In addition, the position of the outer points can be used to indicate the distance to the smallest spot size possible. When the outer points align e.g. vertically or horizontal the distance to the smallest spot size is indicated (See Figure 15).

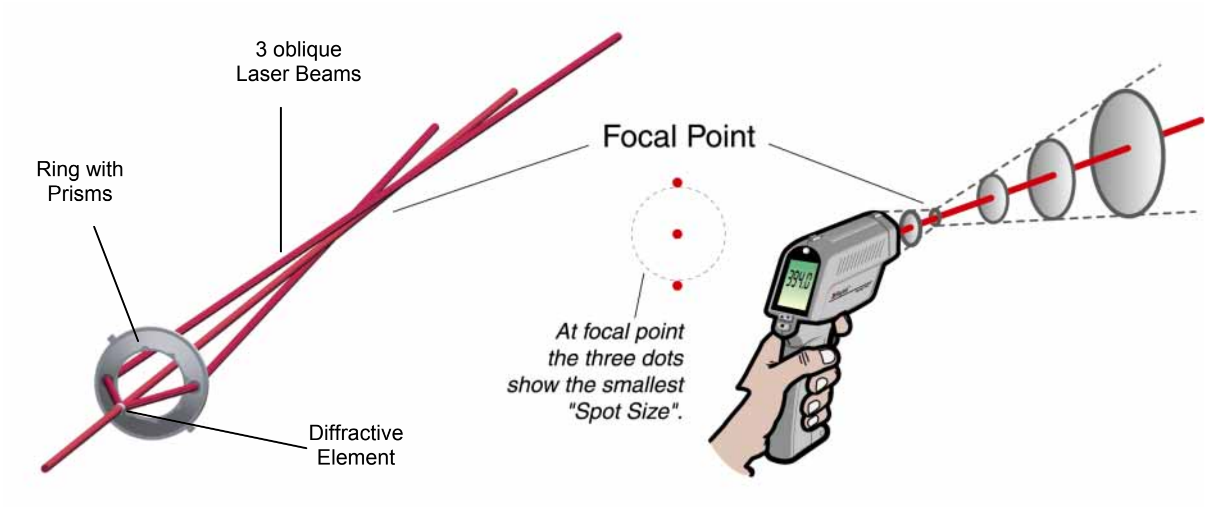


Fig. 15: The precision 3-point coaxial laser sighting helps to avoid measuring mistakes. The user is able to use the specification of the infrared optics to their full extent.

The use of the laser measuring spot proves to be an effective visual help in guiding the infrared measuring device precisely to the measuring object.

The application of an aligning telescope together with laser sighting is very useful for the determination of the measuring area when optically aimed at bright objects (at high temperatures) or to make measurements in strong daylight or at long distances.

Fig. 16: Devices with laser sighting allow a precise spot measurement even of small objects.

Summary: Just as with a camera, the performance of the optics (e.g. telephoto lens), determines what size target can be viewed or measured. The distance ratio (distance from object : diameter of spot) characterizes the performance of the optics in an IR measuring device. The projected spot must be completely filled for an exact measurement of the target to result. For easier alignment, the optics are equipped with a through-the-lens sighting device, or with laser pointers. If protective windows between the measuring device and the target are necessary, the right window material must be chosen. In this case, wavelength range and operating conditions play a significant role.

2.4 Detectors

The detector forms the core of the IR thermometer. It converts the infrared radiation received into electrical signals, which are then emitted as temperature values by the electronic system. In addition to reducing the cost of IR thermometers, the most recent developments in processor technology have meant increases in system stability, reliability, resolution, and speed.

Infrared detectors fall into 2 main groups: quantum detectors and thermal detectors. Quantum detectors (photodiodes) interact directly with the impacting photons, resulting in electron pairs and therefore an electrical signal. Thermal detectors change their temperature depending upon the impacting radiation. The temperature change creates—similar to a thermocouple—a voltage. Thermal detectors are much slower than quantum detectors due to the self-heating required. (Here, much slower means ms in relation to ns or µs of the latter detectors.) Quantum detectors are always used for imaging systems and line scanners.

2.5 Display and Interfaces

The interfaces and types of measured value displays available are important to the user. Some devices, especially hand-held ones, have a directly accessible display and control panel combination which can be considered the primary output of the measuring device. Analog or digital outputs control the additional displays in the measuring station or can be used for regulating purposes. It is also possible to connect data loggers, printers, and computers directly.

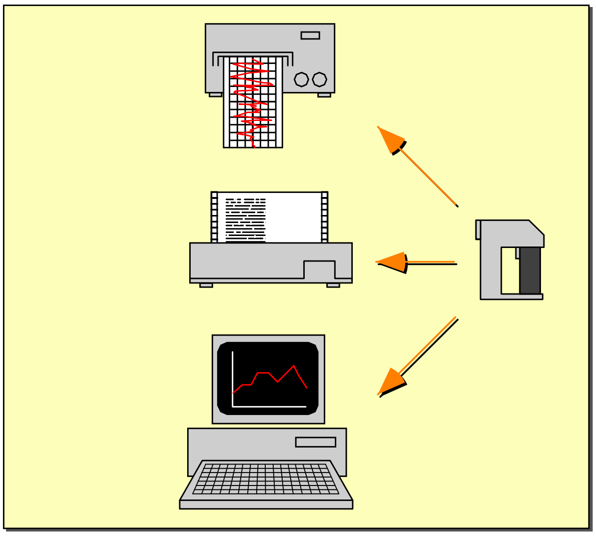


Fig. 17: The data outputs of the IR thermometer can be connected directly to the data logger or printer. Customer-specific graphics and tables can be created using PC software.

Industrial field bus systems are becoming ever more significant and afford the user greater flexibility. For example, the user can set the sensors from a control station without having to interrupt the manufacturing process. It is also possible to change parameters when different products are running on the same production line. Without such remote setting options, any change to the sensor parameters—emissivity, measuring range, or limit values—would have to be made manually at the sensor itself. Since the sensors are often mounted at difficult-to-access points, the intelligent sensor ensures continuous monitoring and control of the process with minimal input from personnel. If a malfunction occurs—ambient temperature too high, interrupted supply, component failure—an error message will appear automatically.

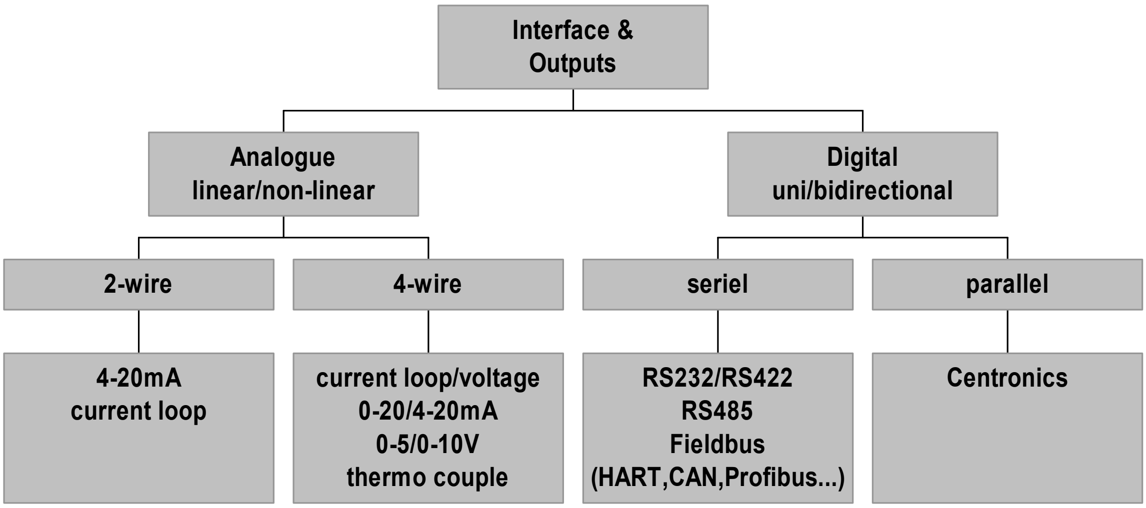


Fig. 18: Examples of interfaces in current infrared measuring devices (except Centronics).

The addressability of pyrometers facilitates operation of a number devices (usually up to 32) on one network (multi-drop operation), resulting in lower installation costs. With the multiplicity of bus protocols and types of field bus now available, there are different converters (gateways) on the market which perform the task of converting (translating) device-specific commands into the appropriate protocol (e.g. Profibus PA). The RS485 is the most-used hardware platform in this respect.

A further advantage of the pyrometer with a digital interface is that it allows field calibration using calibration software available from the device manufacturer.

Section 3 Special Pyrometers

3.1 Fiber-optic Pyrometers

Pyrometers with fiber optics are used for applications involving strong electrical or magnetic interference fields. This makes it possible to place the sensitive electronic system outside the danger zone. Typical of these applications are induction heating and induction welding. Since the fiber optics themselves contain no electronic components, the operating temperature can be raised significantly without the need for cooling. The standard temperature for use is 200°C, with the highest possible temperature up to 300°C. Installation and continuous operating costs per measuring point are low since no water cooling is required.

With modern devices, it is possible to replace the fiber-optic cable and optics without recalibration. Simply input a multi-digit factory calibration number. Fiber-optics are available for wavelengths of 1µm and 1.6 µm. Targets from 250°C can be measured with these.

Fig. 19: Modern digital fiber-optic pyrometer

3.2 Ratio Pyrometers

Special pyrometers (also called two-color or dual wavelength pyrometers) have two optical and electrical measuring channels identical in structure. Both wavelength ranges are placed as close as possible to each other and set very narrow-banded, so that the effect of material-specific peculiarities (reflectance, emissivity) from the target is near-identical to both wavelengths. By means of a mathematical calculation of ratio, certain influences on measurement can be eliminated. The following procedures have proved successful:

1. Splitting the measured radiation using two filters which revolve in front of a radiation detector (filter wheel). Measurement in both channels thus takes place alternately which, in the case of fast-moving targets, can result in errors in ratio calculation (channel 1 sees a different point on the target than channel 2).

2. Splitting of the measured radiation using beam splitters and two radiation detectors fitted with filters.
3. The measured radiation reaches—without the beam-splitter—a double detector (sandwich design) fitted with filters. Here, the front detector represents the filter for the second detector behind it.

Using the pyrometer equations[5] for channel 1 with wavelength λ_1 and channel 2 with λ_2 The result for the measured temperature T_{meas} is :

$$1/T_{meas} = 1/T_{target} + (\lambda_1 \lambda_2)/(c_2 (\lambda_2 - \lambda_1)) \ln(\varepsilon_2/\varepsilon_1)$$

If the emissivity in both channels is the same, then the term after the plus sign becomes zero and the measured temperature corresponds to the target temperature T_{target}. (c_2 : second radiation constant in µm·K).

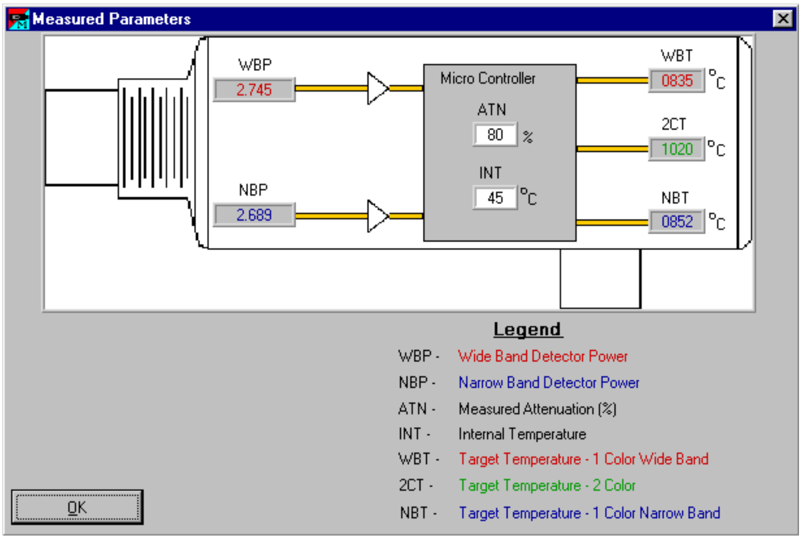
The same can be applied to the target surface A, which as A_2 and A_1 is of course identical in the case of both channels, meaning that here too the term after the plus sign is dispensed with.

$$1/T_{meas} = 1/T_{target} + (\lambda_1 \lambda_2)/(c_2 (\lambda_2 - \lambda_1)) \ln(A_2/A_1)$$

Thus, the measurement is independent of the size of the target. Moreover, the object radiation being sent to the pyrometer becomes reduced proportionally, not only when there is a smaller measuring surface, but also when the pyrometer "gets to see" the target for a shorter time span. By this means, targets that are in the line of sight for a shorter period than the response time of the pyrometer can also be measured.

Changing transmittance characteristics in the measurement path are eliminated in the same way. The devices can be used where there is dust or smoke present, or any other interfering factor that reduces radiation from the target. Modern devices can apply this effect (attenuation) to their own optics, and send out an alarm signal at the appropriate level of contamination (e.g. air purge failure with the air-blowing attachment).

In some applications where the nature of the technology means a certain particle density around the target, a ratio pyrometer with attenuation factor read-out can provide additional information. Fig. 20 shows the information given by a ratio pyrometer using PC software. In addition to the temperature calculated from the ratio, the measured temperatures from both individual channels are given. Moreover, attenuation that is calculated by comparing the two is displayed in percent.



WBP 2.745

NBP 2.689

ATN 80 %

INT 45 °C

WBT 0835 °C

2CT 1020 °C

NBT 0852 °C

Legend

WBP -	Wide Band Detector Power
NBP -	Narrow Band Detector Power
ATN -	Measured Attenuation (%)
INT -	Internal Temperature
WBT -	Target Temperature - 1 Color Wide Band
2CT -	Target Temperature - 2 Color
NBT -	Target Temperature - 1 Color Narrow Band

Fig. 20: Measuring data issued by PC software of a ratio pyrometer, e.g. target temperature in measuring channel 1 (WBT), target temperature in measuring channel 2 (NBT), and the target temperature calculated from the ratio (2CT). The measured attenuation is also displayed in percent (ATN) along with further information.

Summary : Ratio pyrometers can measure temperature when:

1. **The target is smaller than the spot or is constantly changing in size (background cooler than target).**
2. **The target moves through the spot within the response time.**
3. **The line of sight to the target is restricted (dust or other particles, vapor or smoke).**
4. **Emissivity changes during measurement.**
5. **The attenuation factor provides additional information about the technological process or can be used as an alarm in the case of overcontamination of lenses or windows.**

Table 2

The following materials with an oxidized surface behave as gray bodies and can be measured with a slope (relative emissivity) of 1.00:	
Iron	**Steel**
Cobalt	**Stainless steel**
Nickel	

Table 3

The following materials with a smooth, non-oxidized surface are non-gray bodies and are measured with a slope or relative emissivity of 1.06.	
Iron	**Steel**
Cast iron	**Stainless steel**
Cobalt	**Tantalum**
Nickel	**Rhodium**
Tungsten	**Platinum**
Molybdenum	

Section 4 Bibliography and Further Reading

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Date:

Request from:

Name:

Phone:

Department:

Company:

Street name or mail box:

Post code:

City:

Surface/material description:

Measurement distance (min/max):

Spot size or size of the object:

Maximum possible response time:

Estimated ambient temperature at sensor location:

What Temperature changes per minute can be expected:

Output/Interface:

Application drawing:

Raytek Corporation

Raytek designs, manufactures and markets a complete line of infrared temperature measurement instruments for industrial, maintenance and quality control applications. Raytek infrared temperature sensors are used worldwide in a broad range of applications where temperature plays an important role to ensure quality – whether in service trades, or in metal, glass and cement plants.

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