Infrared Thermometers
A wide variety of infrared thermometers is available in order to accommodate for the different emissive properties of various materials to be measured under varying measurement conditions.
Infrared thermometers do not measure temperature. Instead, they measure infrared energy. Because infrared energy is emitted by an object as a function of temperature and emissivity, all infrared thermometers calculate a temperature value based upon an assumption concerning the emissivity character of the measured material.

Every infrared thermometer may be categorized into one of three sensor types - brightness, ratio, and multi-variant. See figure 1. Each different type plays an important role for various industrial applications, and each makes different assumptions about the measurement conditions.

Brightness Sensors (Single-Wavelength or One-Color Sensors)

Assumption: Emissivity is reasonably constant and known.

Brightness sensors measure the amplitude of infrared energy collected over a specific wavelength span. These sensors provide an average temperature reading (moderately weighted towards the hotter temperature), and are affected by changes in emissivity, dirty optics, and other optical obstructions. Stray infrared energy from background sources will affect the sensor reading if the energy is significant. Sensitivity to emissivity variation, optical obstructions, temperature gradient and background energy varies with wavelength. Wavelength selection can significantly impact the ability to view through certain intervening media, such as steam or combustion gasses. Similarly, wavelength selection can significantly impact the ability to measure transparent, reflective or crystalline materials such as glass, plastic films, flames, thin coatings, silicon and germanium.

Ratio Sensors (Dual-Wavelength or Two-Color Sensors)

Assumption: The ratio of emissivity values at wavelengths A & B is reasonably constant and known (greybody materials).

Ratio sensors measure the ratio of energy collected at two adjacent wavelengths. The ratio value is not affected by so called “grey” obstructions (those that obstruct both wavelengths equally). As such, these sensors are able to correct for emissivity variations, and to view through smoke, dust, and most other optical obstructions, including dirty lenses. This sensor tends to provide a very heavily weighted average towards the hottest temperature viewed. Compared to a brightness sensor, stray infrared energy from a hotter background will affect the sensor reading more, and from a cooler background, significantly less. Wavelength selection and wavelength separation influence the measurement range, the weighting towards the hottest temperature, the sensitivity to e-slope variation (a variation in the ratio of emissivity values at wavelengths at the measured wavelengths), the signal dilution capability, and the sensitivity to some types of intervening media such as plasma, water, steam and combustion byproducts.

Multi-Variant Sensors (Multi-Wavelength Sensors)

Assumption: The effective target emissivity (or other emissivity-related parameter such as e-slope) is related to some measurable parameter (such as measured reflectivity, signal strength or signal dilution) with a strong one-to-one correlation.

A multi-variant sensor measures infrared energy at two or more wavelengths, and calculates the target temperature based upon an application-specific algorithm. This algorithm is based upon a one-to-one correlation between a corrective emissivity adjustment (or some other emissivity-related parameter, such as e-slope) and a meaningful measured parameter. Multi-wavelength algorithms vary from simple second-order corrections to complex multi-variant iterative programs, and may include additional application information, such as background temperature. The complexity of the sensor and the temperature algorithm varies according to the application requirements. These sensors are used for materials and applications where traditional brightness or ratio sensors are ineffective.

Optimization for Accuracy

Regardless of the infrared technology incorporated, these devices do not measure temperature directly; instead, they infer a temperature value based upon the infrared energy emitted by the target of interest, which is measured and converted into an electrical signal by an internal infrared detector. The infrared thermometer calculates a temperature value by correlating the measured infrared energy to a calibrated temperature value. The resultant temperature measurement is accurate so long as the measurement assumptions inherent in the sensor design accurately represent the application conditions encountered by the sensor when placed in use. When application conditions exist that are not accounted for by the sensor design, then an error will result.

Each of these sensor technologies has its own inherent strengths and weaknesses; however, within each type of infrared thermometer, sensor performance may be optimized and sensitivity to interference may be reduced through thoughtful sensor design.

Sensor wavelength is perhaps the most important optimization consideration. As is clearly apparent from the following page, infrared thermometers filtered at relatively short wavelengths are considerably more sensitive to changes in temperature than are sensors filtered at longer wavelengths. The top figure shows the infrared energy variation with temperature to be much greater at the shorter wavelengths than it is at the longer. Indeed, when viewed at the scale depicted in the figure, the infrared energy emitted at the longer wavelengths barely seems to change with a change in temperature.

The sensitivity of brightness sensors to emissivity variation and optical obstruction is shown in the middle figure, where the error associated with a 10% reduction of infrared energy is shown. This figure clearly shows that measurement errors are significantly smaller when using a short wavelength brightness sensor, particularly when measuring at a relatively low temperature. Indeed, the improved accuracy of a short-wavelength sensor is somewhat understated by the theoretical values depicted here. This is because the emissivity value of a reflective material is almost always significantly higher at shorter wavelengths than it is at longer wavelengths (lower figure), making any given absolute change in emissivity a smaller percentage change. For example, a change in emissivity from 0.30 to 0.31 is about a three percent change. On the other hand, a change from 0.10 to 0.11 is about a ten percent change. Particularly for low emissivity materials, the short-wavelength sensor is typically 4 to 16 times more accurate due to the combination of the inherent lower sensitivity and smaller percentage variation.

Recent advances in short-wavelength sensor technology allow short-wavelength sensors to rival the broad temperature spans historically available only when using a long-wavelength sensor. Many mill applications requiring a broad temperature span, such as refractory preheating and reheat furnace entry measurements, have historically used long-wavelength sensors to provide the necessary temperature span. These measurements proved problematic due to a high sensitivity to dirty optics and emissivity variation. Now these applications may take advantage of short-wavelength technology to dramatically improve measurement accuracy.

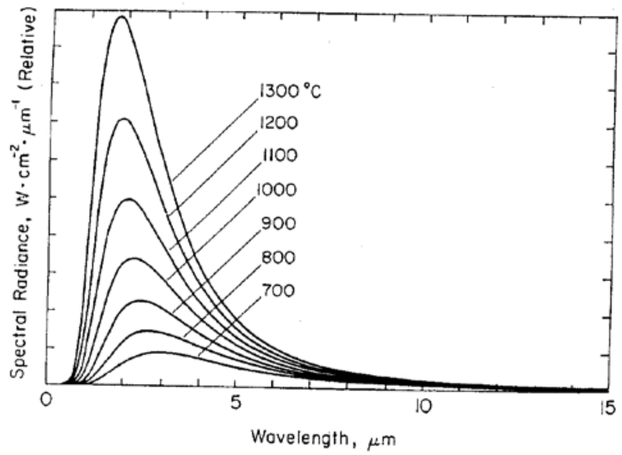
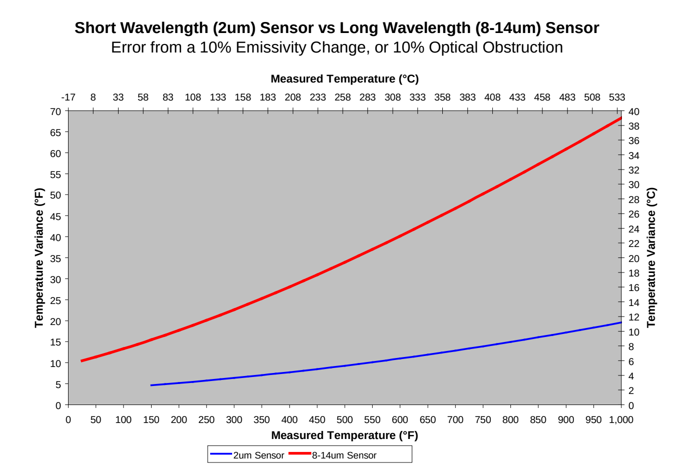
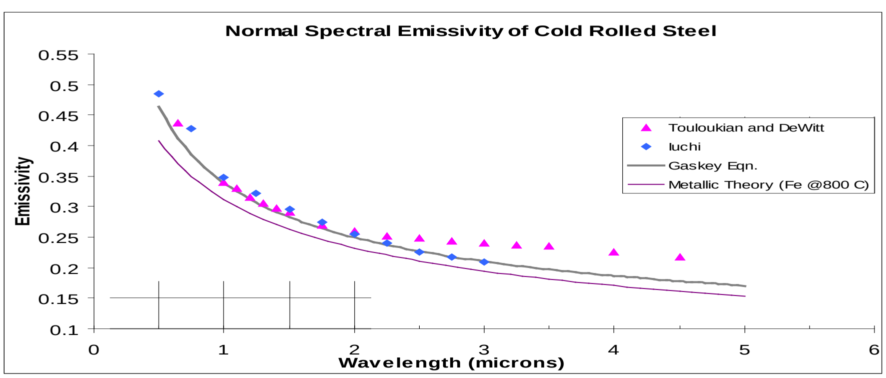


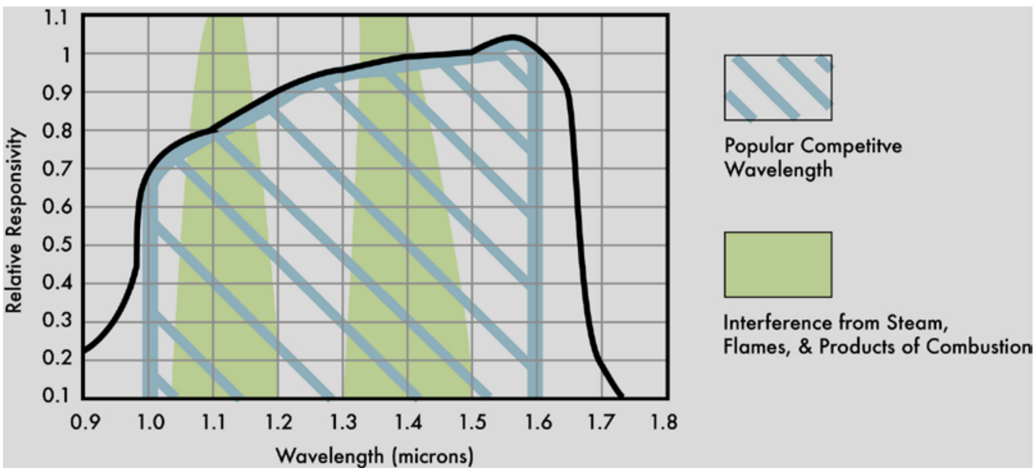
Figure 2 = Infrared Energy vs Temperature vs Wavelength Curve

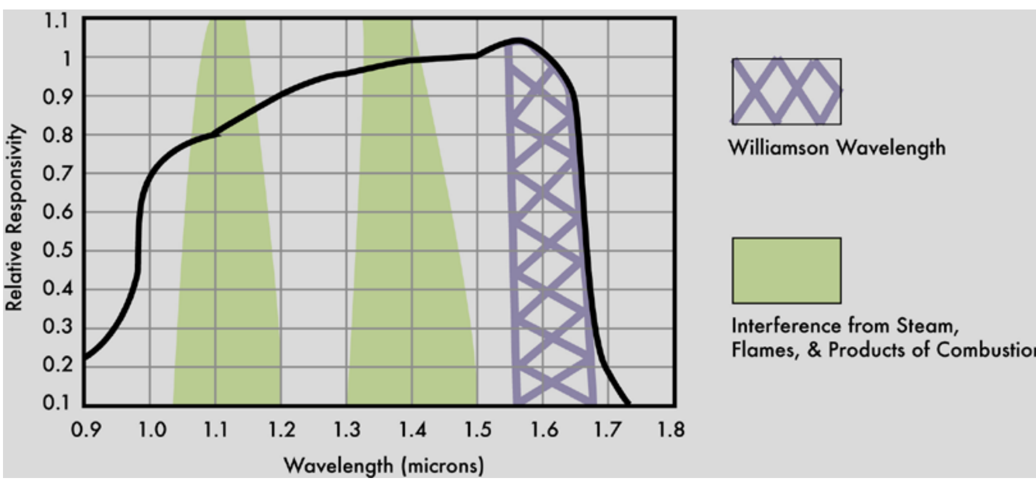




Atmospheric Transmission Issues

The fact that a short wavelength sensor is more accurate when confronted with optical obstruction and emissivity variation is generally known and understood by experienced infrared thermometer users, but the importance of wavelength selection does not end with this fundamental rule. General purpose short-wavelength sensors filtered over a waveband of 0.7 to 1.1 microns, 1.0 to 1.7 microns, or 2.0-2.8 microns are commonly available and routinely employed by industrial users. As illustrated below, these popular wavebands are selected by most sensor manufacturers because they correspond to the range of highest responsively for the semiconductor detectors used to convert the infrared energy into an electrical signal. Unfortunately, none of these general purpose wavebands is appropriate whenever steam, flames, products of combustion or a relatively long viewing path is encountered.





Just as fog prevents humans from seeing clearly through moisture-laden air, sensors filtered over these common wavebands can not clearly see through these common interference sources. The result is a measurement error whenever they are encountered. Appropriate wavelength selection is critical for accurate measurement whenever steam, flames, water vapor, carbon dioxide, combustion byproducts, or long sight paths are encountered.

The following figure demonstrates that optimal wavelength bands exist throughout the infrared spectrum where water vapor, carbon dioxide, and carbon monoxide gasses are highly transparent.

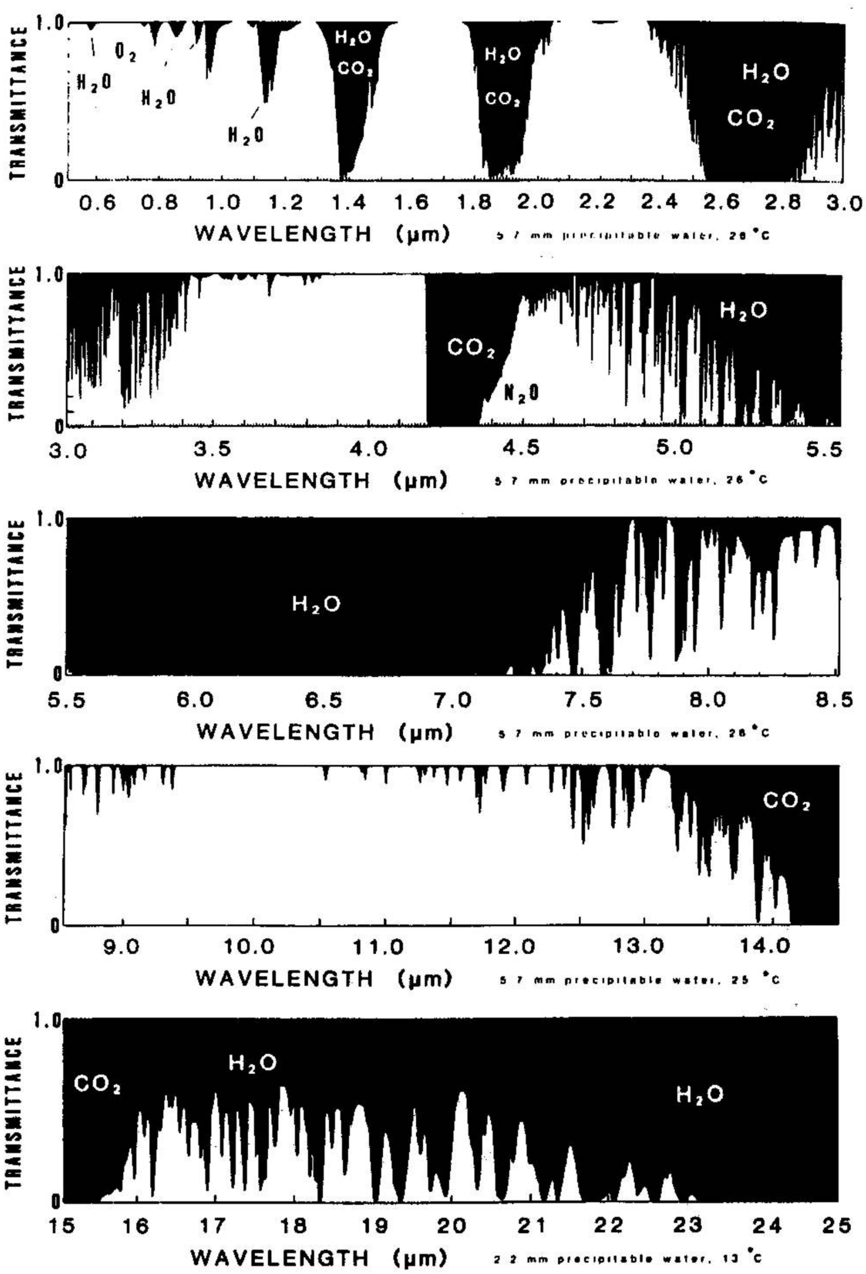
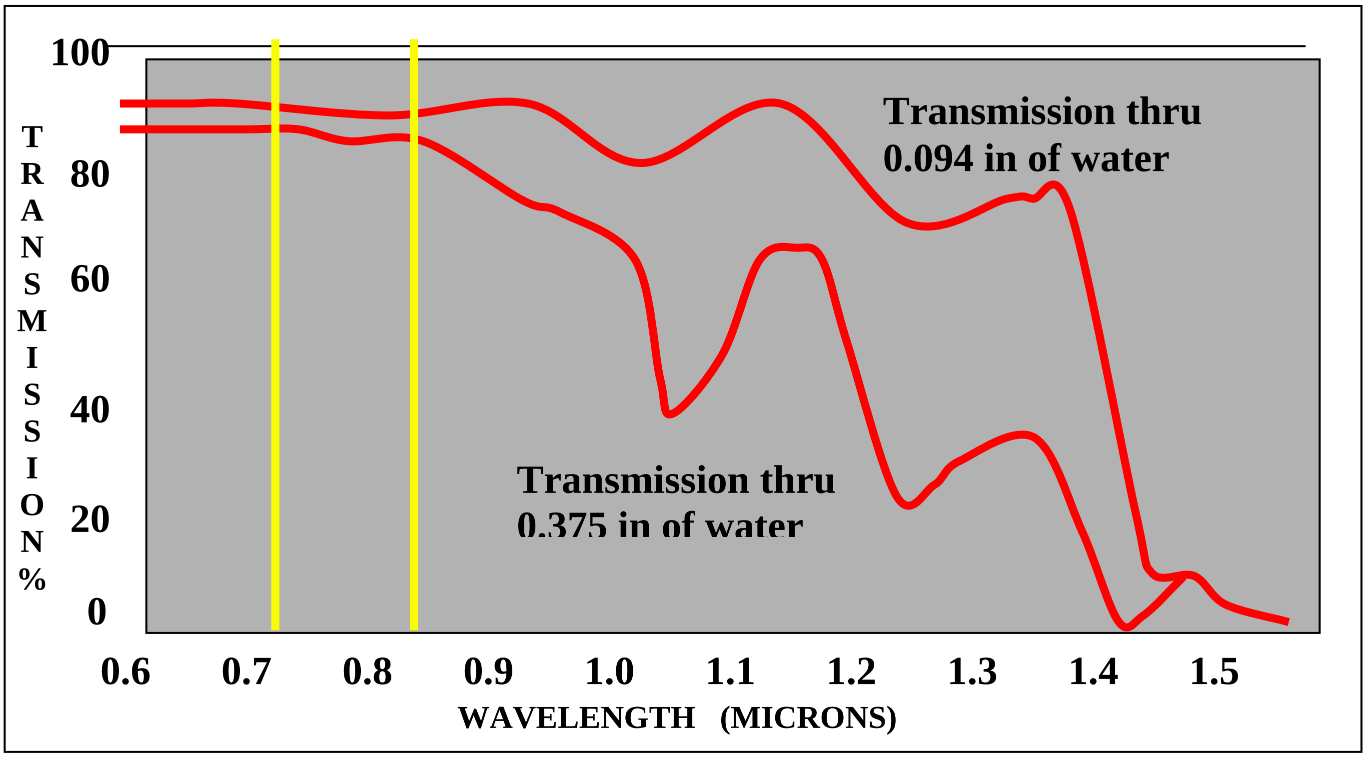


Figure 4.20 Atmospheric transmittance at sea level over a 0.3 km path. Atmospheric absorption and emission is a major factor in the selection of the wavelength and bandwidth for use in radiation thermometry. Absorption varies with gas concentration and optical pathlength. Adapted from H.W. Yates and J.H. Taylor, Infrared Transmission of the Atmosphere. [8]

Optimal Wavelength Selection for Ratio Sensors

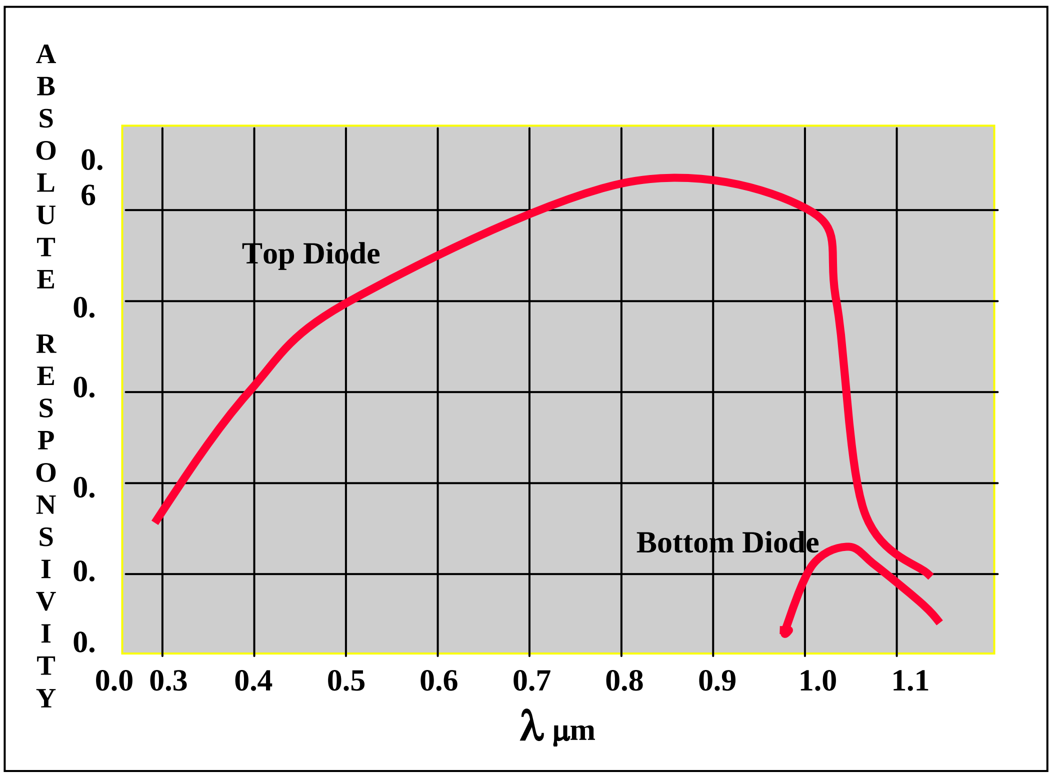
The selection of a sensor filtered within a wavelength region of high optical transmission is essential for brightness, ratio, and multi-variant sensors alike whenever water, steam, flames or products of combustion are encountered. For example, below is the optical transmission of infrared energy through two different thickness of water. A ratio sensor can tolerate an optical obstruction without error so long as both wavelengths are obstructed equally. Two wavebands selected at wavelengths in the 0.7 and 0.8 micron range will view through the water without interference, sensors filtered at 0.8 and 0.9 microns will indicate only minimal interference, and sensors filtered at 0.7 and 1.1 micron will indicate a relatively large interference. This is because the water absorbs much more infrared energy at wavelengths beyond one micron than at wavelengths shorter than one micron.

Water transmission showing selected Williamson ratio wavelengths.



Additional wavelength considerations exist when selecting the most appropriate ratio sensor. Like the legs of a table, a ratio sensor is unstable when the wavelength pairs are too close together. Most ratio sensors use a bi-level two-element detector to separate the measured wavelength into two wavebands. The responsivity curve for one such detector is shown in figure 8. The top element is opaque at and sensitive to shorter wavelengths, and is translucent at longer wavelengths; thereby allowing some infrared energy at the longer waveband to pass through to the lower detector element.   The lower detector element is sensitive to infrared energy at this longer wavelength range. This relatively straightforward approach effectively separates the infrared energy into two wavebands, as is required for a ratio sensor, but the resultant wavelength bands overlap each other with absolutely no wavelength separation, leaving it relatively unstable to potential optical obstructions and spectral emissivity (e-slope) variation.

Typical two-color detector responsivity curve.

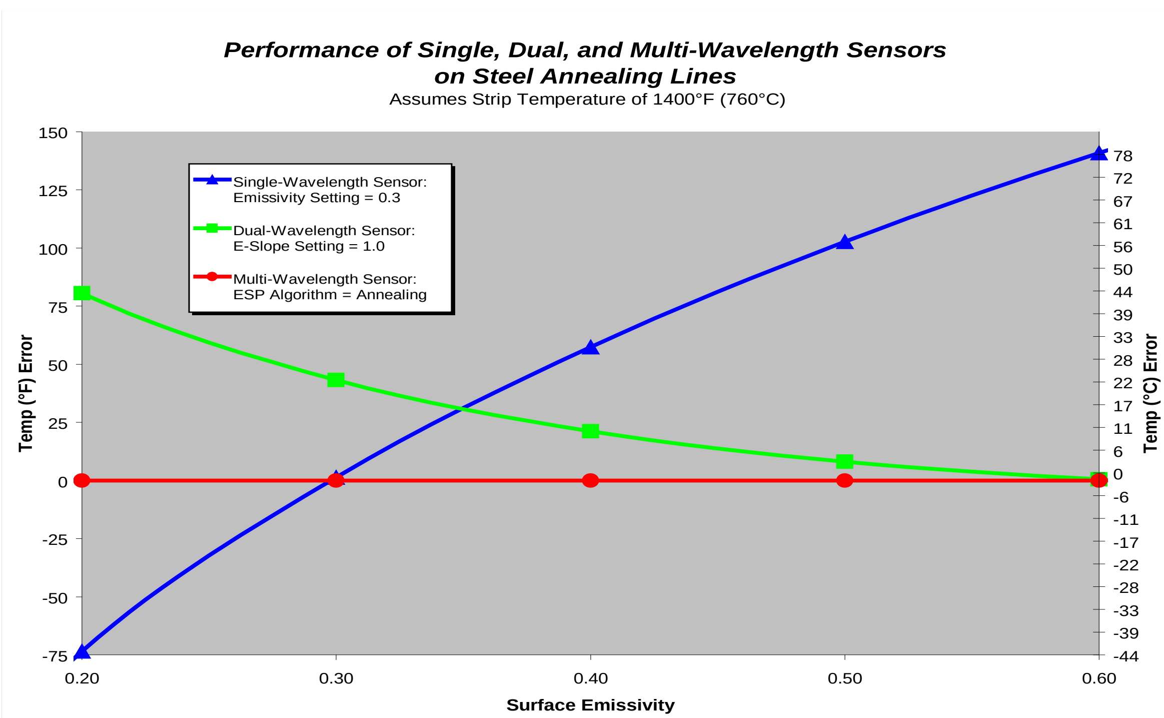


For ratio sensors, robust sensor performance demands the selection of wavelengths able to view through common interference sources without interference and the need for separation between wavelengths. A ratio sensor designed with these issues in mind is able to tolerate water, steam, and combustion byproducts, is as much as 20 times less sensitive to temperature gradients (scale formation, for example), and can tolerate 20 to 60 times more optical obstruction (dirty optics, for example) as compared to traditional, general-purpose ratio sensors with overlapping wavebands. Such powerful and robust ratio sensors may be used with confidence where other sensors are not able to produce acceptable results. Clearly, the operating wavelength is a critical design criterion when selecting an infrared thermometer of any type for applications involving interference sources.

Multi-Variant Infrared Thermometers

While significant advancements have been made in both brightness and ratio sensor technology, perhaps the most significant recent development is the coming-of-age of the multi-variant infrared thermometer. Long considered problematic and difficult to work with, these sophisticated temperature sensors have matured over the past several years to become highly accurate, reliable and easy to use, and they have gained wide-spread acceptance for specific applications within several industries. Each multi-variant infrared thermometer is specifically designed to account for the unique emissivity character associated with a particular problematic measurement, material, or application.

The following figure compares the multi-variant infrared thermometer with the brightness and ratio models for the measurement of steel strip temperature. The y-axis indicates temperature error, while the x-axis indicates the steel strip emissivity. Note that a brightness sensor is only accurate when the strip emissivity value is equal to the emissivity parameter setting of the sensor, in this case 0.3. If the strip emissivity is lower than the emissivity setting, then the brightness sensor will read too low. If the strip emissivity is higher than the emissivity setting, then the brightness sensor will read too high. On line temperature data for a brightness sensor is also shown as a reference. Also note that the ratio sensor will measure the correct temperature value so long as the strip emissivity value is higher than about 0.6, but will read a value that is too high for lower emissivity values. When using a ratio sensor at emissivity values above 0.6. the strip is sufficiently coarse at the microscopic level so that the emissivity is equal at both measured wavelengths. However, as the strip emissivity drops below the 0.6 value, the strip becomes smoother at the microscopic level, and the emissivity starts to differ at the two measured wavelengths. The lower is the strip emissivity, then the greater is the difference in emissivity values at the two measured wavelengths, and the greater is the error indicated by the ratio sensor. A multi-variant infrared thermometer is able to characterize this emissivity variation across the measured wavelengths and to make the appropriate compensation.



Other Infrared Thermometer Technologies

Infrared thermometers come in a variety of different types. Williamson manufactures only spot sensors – meaning that our sensors view a specific optical area or spot. Other types of sensors include line scanners, thermal imaging cameras, flame detectors, hot metal detectors, and laser-based devices. Each of these sensor types will be briefly described below.

Line Scanners

Line scanners are essentially brightness spot pyrometers equipped with a rotating mirror that allows them to view along a line. By linking the temperature reading with the position of the rotating mirror a thermal picture may be obtained. Each successive swipe along the line will measure the temperature of a new segment of a moving measured target. Software programs are used to assemble each successive swipe into a two-dimensional picture. This type of device is very popular for measuring moving strips or webs, or for measuring rotating equipment such as rotary kiln shells.

It is important to recognize that the line scanner is, at its heart, a single-wavelength infrared thermometer. The wavelength of operation is usually very broad, and so interference from water vapor, steam, flames and products of combustion can be an issue. As with any single-wavelength infrared thermometer, the sensitivity to emissivity variation and optical obstruction will be minimized by selecting the shortest practical wavelength. Line scanners are available at short and long-wavelengths, and also with specific-purpose wavelengths, such as for the measurement of thin film plastics. Because of the need for a fast response time, the measured wavebands are typically significantly wider than for traditional spot sensors.

Note: Williamson does not manufacture line scanners.

Thermal Imaging Cameras

A thermal imaging camera is similar to a brightness infrared thermometer; however, instead of a single detector element, there is an array of multiple detector elements. Detector arrays range from as few as 16 detector elements to thousands of detector elements. Each detector element represents a separate single-wavelength sensor. These temperature readings are typically displayed graphically on a television screen, with different colors representing different temperatures. A discreet temperature value may be made by averaging the temperature reading within a designated area. Some models allow the operator to specify dozens of areas from which to measure an average temperature value. In most cases, custom software packages may be used to generate application specific algorithms using temperature data at the pixel level.

Like the line scanner, the thermal imaging camera is a single-wavelength device. Because the individual detector elements are very small, these devices generally collect infrared energy from a wide wavelength band; however, many models allow for the use of external filters that will reduce distance sensitivity while viewing through long sight paths, for example. Thermal imaging sensors are not available at short wavelengths except for measurements at extremely high temperatures.

Note: Williamson does not manufacture thermal imaging cameras.

Flame Detectors
Traditional flame detectors operate in the UV spectrum. This is because flames typically emit energy at these very short wavelengths, but hot furnace walls do not. The most advanced flame detectors look for a fluttering signal, as will be produced by a flame. Some fuels, however, do not emit UV energy. CO gas, for example does not emit energy in the UV spectrum. An IR-based sensor filtered at 4.75 microns must be used to sense a CO flame, because this is the only significant wavelength at which this gas will emit energy.

Note: Williamson manufactures specialty flame detectors for CO gas and flare stacks, but does not manufacture flame detectors for traditional burner applications.

Hot Metal Detector
A hot metal detector is a specialized spot infrared thermometer designed to quickly alarm the presence of a hot object. It does this by sensing infrared energy emitted by the object. Not usually intended for use as a temperature measurement device, these sensors generally view a large area and use unfiltered infrared detectors, and therefore lose sensitivity when viewing through steam and water. Williamson manufactures a hot metal detector with a narrow waveband specifically designed to view through water and steam. In addition, traditional hot metal detectors are not sensitive enough to differentiate between a hot low-emissivity metal and a warm high-emissivity background.

Note: Williamson manufactures hot metal detectors, including specialty hot metal detectors designed for low-emissivity materials such as aluminum, and for viewing through optical obstructions such as steam, severe dust and water spray.

Laser-Based Systems
There are two laser-based temperature measurement systems of note. One uses a laser to excite a phosphorescent coating. The coating may be applied directly to the measured target, or it may be applied to the tip of a fiber optic cable. The rate of phosphorescent decay is proportional to the temperature of the coating. This approach works well whenever the measured target may be coated, and the fiber-optic type with the coated end-tip is popular as a replacement for a thermocouple for applications where metal wires are not appropriate (Chemical Vapor Deposition, for example). Another type of sensor uses a laser to measure the percent of emitted energy that is reflected off the measured target. In this way an emissivity value may be determined. At

first glance this approach seems reasonable; however, this laser system measures only the secular component of the reflection and ignores the diffuse component. This technique works well for optically diffuse surfaces (high emissivity), but does not work so well for optically smooth surfaces (low emissivity). Because other technologies exist for the measurement of high-emissivity materials (ratio infrared thermometers, for example) this technology has not gained popularity in the metals industry. This technology has proven popular for the measurement of reformer tube temperatures in the petrochemical industry.

Note: Williamson uses lasers only as pointing devices to aid in sensor alignment. Williamson does not manufacture laser-based temperature measurement systems.