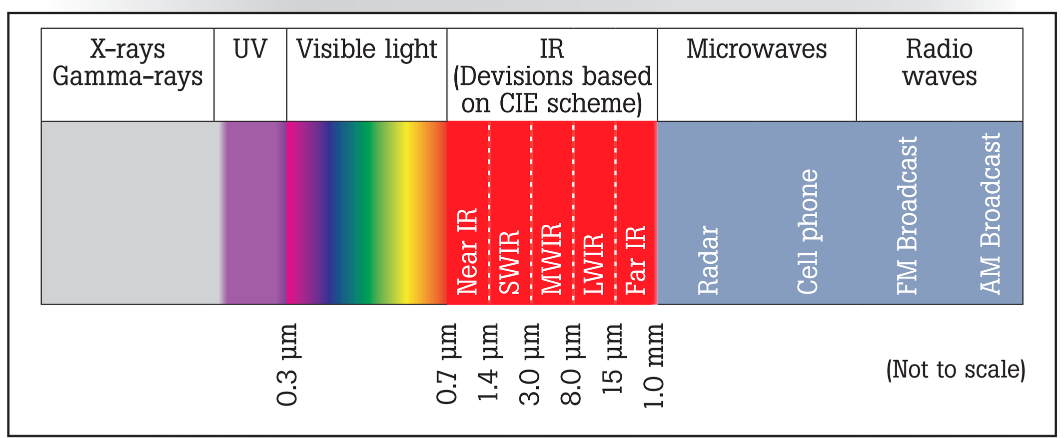
Quick reference to infrared thermometer calibration

FLUKE Calibration

Infrared theory

IR and the electro-magnetic spectrum



Blackbody theory

Planck's Law

Describes the amount of spectral radiance emitted by a perfect blackbody at a given temperature, wavelength and solid angle.

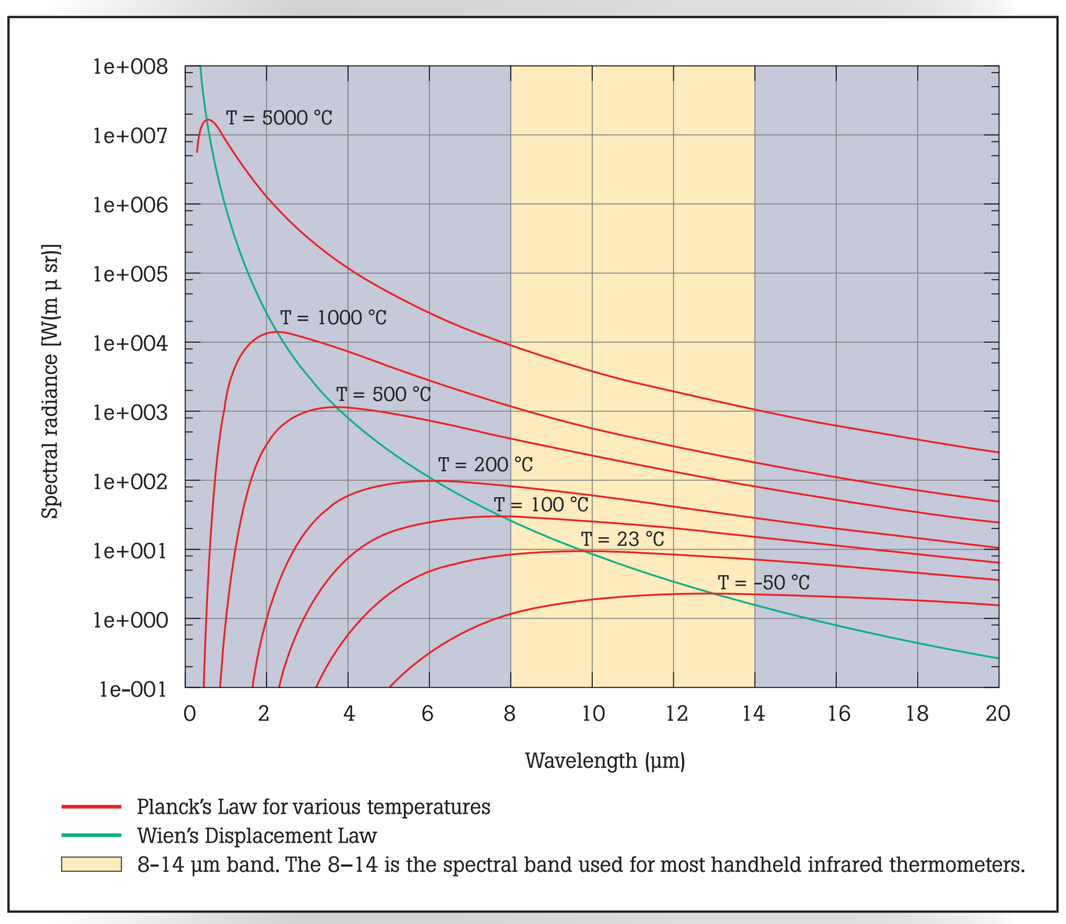
$$L(\lambda,T) = \frac{c_{1L}}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]}$$

Wien's Displacement Law

Shows the peak wavelength for a given temperature (as predicted by Planck's Law).

$$\lambda_{PEAK}T = c_3$$

Planck's Law and Wien's Displacement Law



Stefan-Blotzmann Law

Shows the total irradiance in the entire electro-magnetic spectrum.

$$M = \sigma T^4 = \pi\int_0^\infty \frac{c_{1L}}{\lambda^5\left[\exp\left(\frac{c_2}{\lambda T}\right)-1\right]}d\lambda$$

Physical constants

Name	Symbol	Value
First radiation constant for spectral radiance	c_{1L}	1.191 042 759 e^8 W µm^{4}m^{-2}sr^{-1}
Second radiation constant	c_2	1.438 7752 e^4 µm K
Wien Wavelength Displacement Law constant (Third radiation constant)	c_3	2.897 7685 e^3 µm K
Stefan-Boltzmann constant	σ	5.670 400 e^{-8} Wm^{-2} K^{-4}

Sakuma Hattori Equation (Planckian Form)

The Sakuma-Hattori Equation is used to approximate Planck's Law for instruments with non-finite bandwidth. It can be used for a determination of temperature from radiance, or it can be used for determination of uncertainty using generalized constants.

$$S = \frac{C}{\exp\left(\frac{c_2}{AT+B}\right)-1}$$

$$T = \frac{c_2}{A\ln\left(\frac{C}{S}\right)+1} - \frac{B}{A}$$

Generalized constants for 8–14 µm Band:

A = 9.364 µm
B = 178.4 µm K
C = 1.000 (unitless)

$$\frac{\partial S}{\partial T} = [S(T)]^2\frac{Ac_2}{C(AT+B)^2}\exp\left(\frac{c_2}{AT+B}\right)$$

Use Kelvins

When doing calculations with any of the equations above, be sure do the calculations using kelvins, not degrees Celsius.

Kirchhof's Law and Emissivity

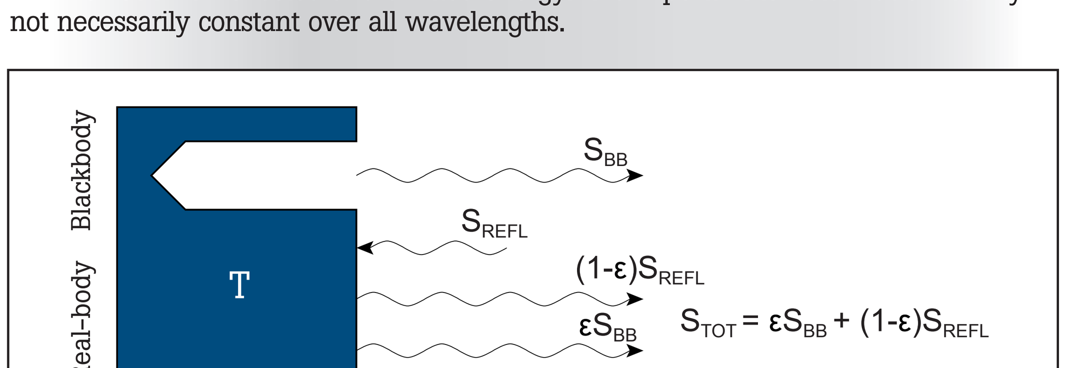
For energy incident on a surface, the ratios of the energy reflected, transmitted and emitted sum to unity. When a surface is opaque, the emitted and reflected energy sum to unity. The emissivity is the ratio a surface of temperature (T) emits when compared to a perfect blackbody of the same temperature.

$$1 = \varepsilon + \rho + \tau$$

For opaque surfaces:

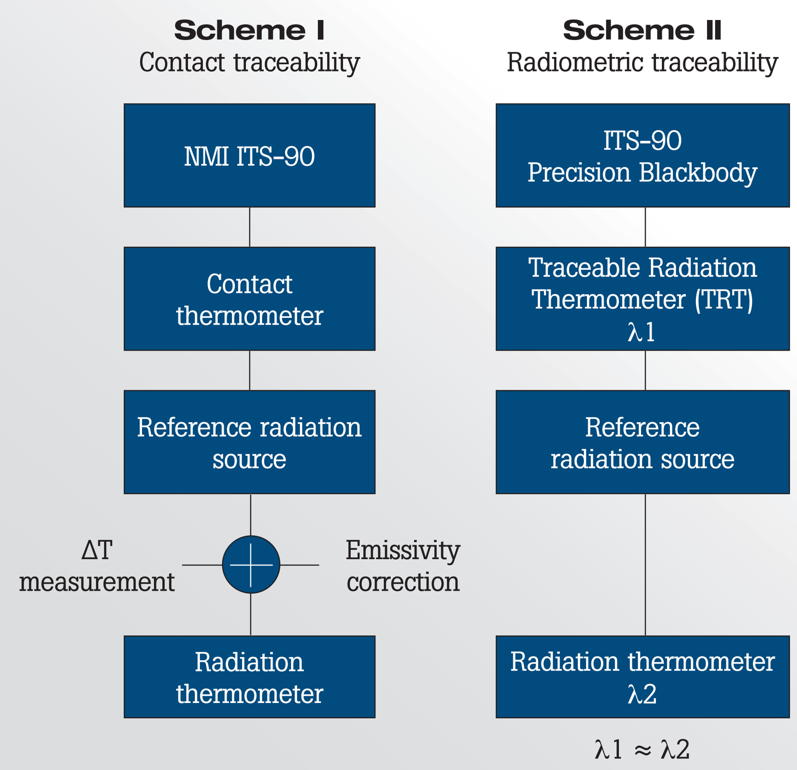
$$\tau = 0 \longrightarrow 1 = \varepsilon + \rho$$

Every object has an emissivity less than unity. The energy exiting an opaque surface is a combination of reflected and emitted energy. It is important to note that emissivity is not necessarily constant over all wavelengths.



Calibration

Calibration schemes



Uncertainty budget structure

Blackbody

- Calibration temperature (VTBB)
- Impurities (FPBB)
- Plateau identification (FPBB)
- Blackbody emissivity, isothermal
- Blackbody emissivity, non-isothermal (VTBB)
- Reflected ambient radiation
- Cavity bottom heat exchange
- Convection (VTBB)
- Cavity bottom uniformity (VTBB)
- Ambient conditions (VTBB)
- VTBB: Variable Blackbody scheme only
- FPBB: Fixed Point Blackbody scheme only

Radiation thermometer

- Size-of-source effect
- Non-linearity
- Reference temperature
- Ambient temperature
- Atmospheric absorption
- Gain ratios
- Noise

Use

- Interpolation error
- Drift
- Unknown temperature

(based on BIPM CCT-WG5 on Radiation Thermometry, Uncertainty Budgets for Calibration of Radiation Thermometers below the Silver Point)

Measurement equation

Generalized measurement equation

The true temperature of the surface being measured.

$$S(T_{MEAS}) = S(T_{SURF})$$

Account for the effects of uncertainty in reflected temperature.

$$+\frac{(1-\varepsilon_{IRT})}{\varepsilon_{IRT}}[S(T_{REFL}) - S(T_{DET})]$$

Account for the effects of uncertainty in emissivity.

$$+\frac{(\varepsilon_{SURF}-\varepsilon_{IRT})}{\varepsilon_{IRT}}[S(T_{SURF}) - S(T_{REFL})]$$

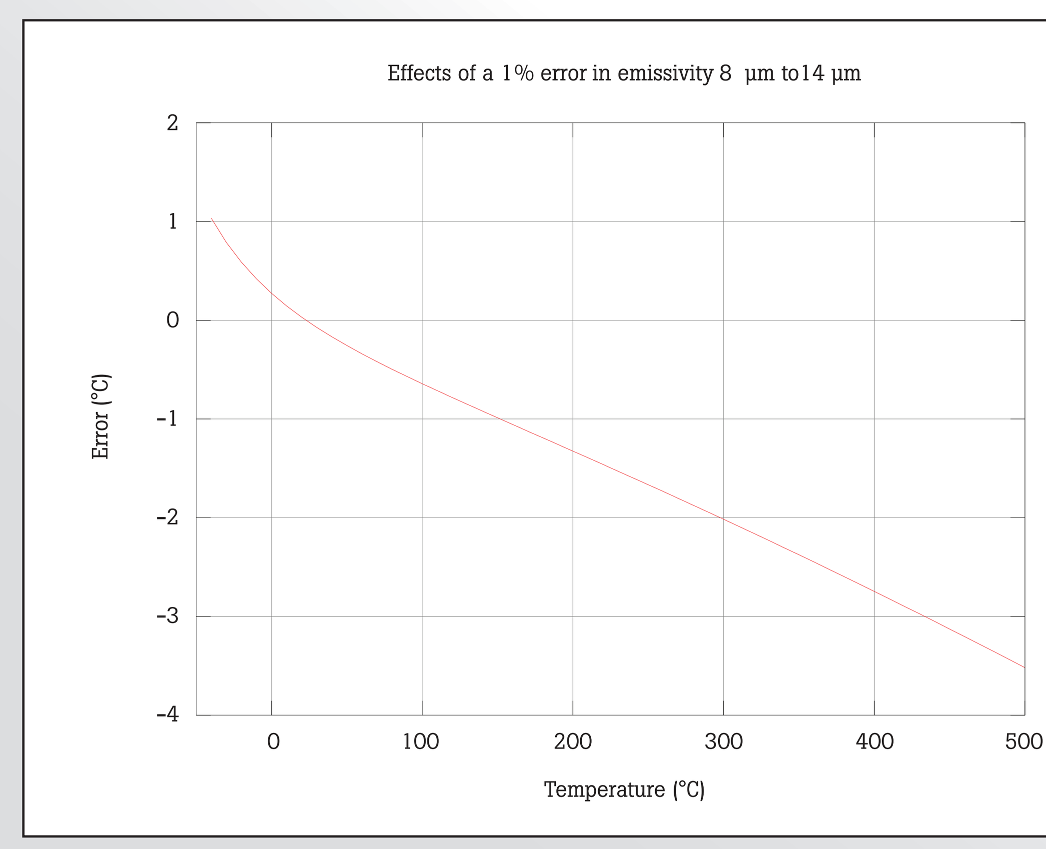
To calculate the error based on any of these elements, simply perform the following calculation: $\text{error} = S(T_{MEAS}) - S(T_{SURF})$

Effects of emissivity uncertainty

To calculate the effects of emissivity uncertainty, ASTM E2758 provides the equation to the right. Any S(T) involves a calculation using the Sakuma-Hattori Equation.

$$\text{error} = \frac{(\varepsilon_{SURF}-\varepsilon_{IRT})}{\varepsilon_{IRT}}[S(T_{SURF}) - S(T_{REFL})]$$

For the various spectral bands, the following graph shows the results error based on the following conditions.



Effects of reflected temperature

$$\text{error} = \frac{(1-\varepsilon_{IRT})}{\varepsilon_{IRT}}[S(T_{REFL}) - S(T_{DET})]$$

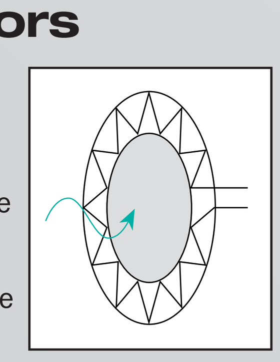
Infrared thermometers

What is an infrared thermometer?

Infrared thermometers are a subset of radiation thermometers. These devices measure infrared radiation and display a temperature based on the radiation measured by the infrared thermometer and the emissivity setting of the infrared thermometer. The term infrared thermometer generally refers to handheld devices with a thermopile detector. Some other names used for infrared thermometers are IR guns, point and shoot thermometers, spot pyrometers, laser thermometers.

Thermopile detectors

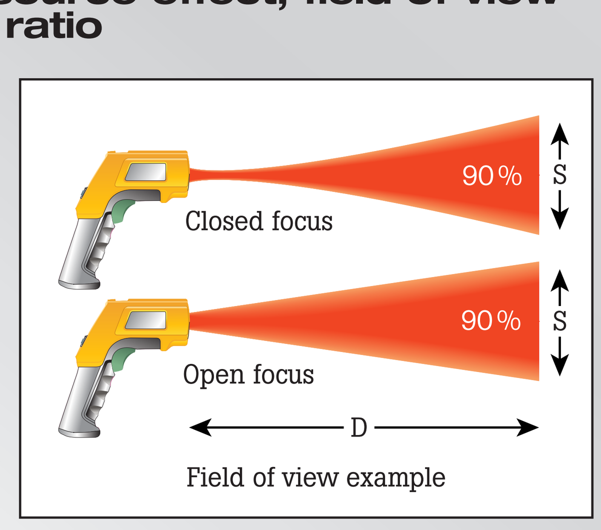
Essentially, a thermopile is a number of thermocouple junctions joined in series. The radiation strikes a drum-like disk, causing it to heat. A ring forms a surface for the reference temperature. The voltage of the thermopile is measured and a temperature is assigned to that voltage, similar to what is done with thermocouple measurement.



Infrared thermometer optics

Size-of-source effect, field of view and D:S ratio

Size-of-source, field-of-view and distance to size ratio refer to optical characteristics of the IR thermometer. In the case of field of view and distance to size ratio, both specifications refer to a diameter, a measuring distance and a percentage of energy within the diameter. This means that even though a radiation thermometer has a given source diameter, there is still some measurement coming from outside that diameter. This is called scatter.



In the example to the right, a radiation thermometer's field of view has been measured at various diameters at a fixed measuring distance. In this example, the radiation thermometer measured 90% of the target's energy within a diameter of 19 mm. If the measuring distance is 400 mm, then the field of view would be specified as: 19 mm diameter (90%), measuring distance: 400 mm. Source: IEC/TS 62492-1

Classification of instruments

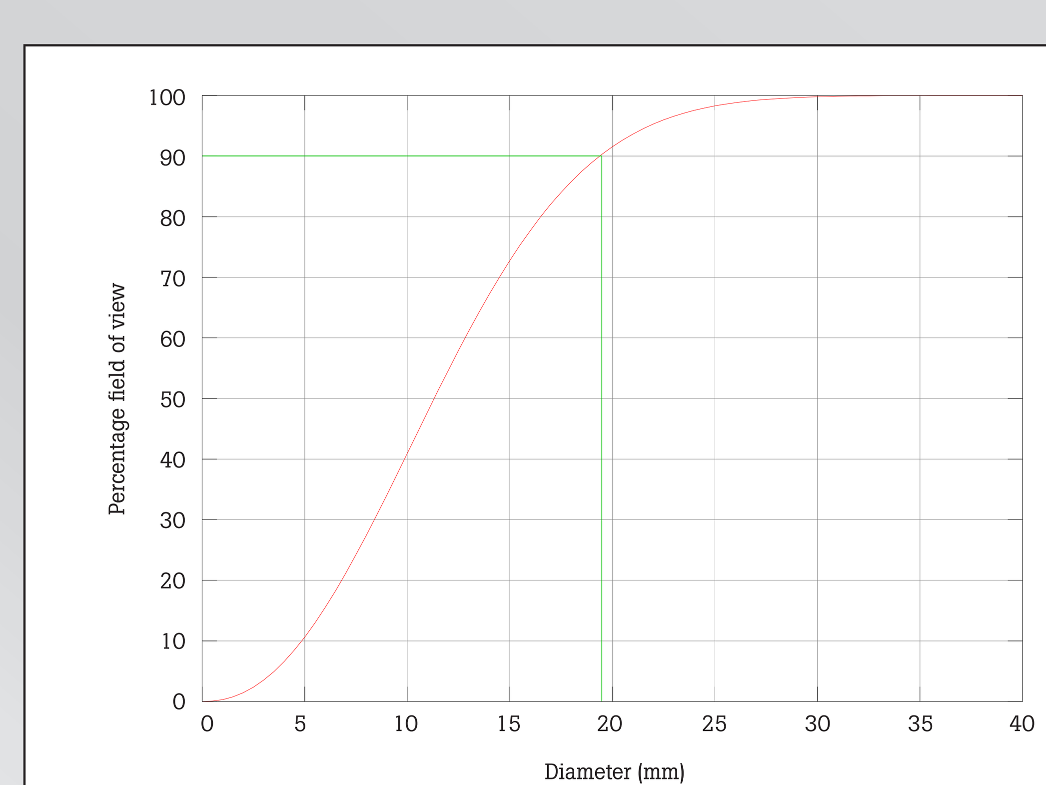
Point measurement: Radiation thermometers

1D Measurement: Line scanners

2D Measurement: Thermal imagers

Infrared thermometer models

Model	Measuring range	D:S
Fluke 561	-40 °C to 550 °C (-40 °F to 1022 °F)	12:1
Fluke 566	-40 °C to 650 °C (-40 °F to 1202 °F)	30:1
Fluke 568	-40 °C to 800 °C (-40 °F to 1472 °F)	50:1
Fluke 572	-30 °C to 900 °C (-40 °F to 1652 °F)	50:1 or 60:1
Fluke 574	-30 °C to 900 °C (-40 °F to 1652 °F)	50:1 or 60:1



The Fluke Calibration 4180 and 4181 Precision Infrared Calibrators

- Radiometric calibration to account for emissivity
- Large enough target to reproduce calibration geometry
- Thermometer emissivity setting compensation

www.flukecal.com/4180series

©2011 Fluke Corporation. 9/2011 4100366A G-EN