15 Minute Break

Components of a Temperature Sensor

- **The Optics** collect & focus the emitted energy onto a detector. Types of lenses include glass, quartz, achromat, germanium, and zinc.
- **The Filters** optimize the operation of the sensor to selected energy wavelengths.
- **The Detector** converts the infrared energy signal into an electrical signal. Common detectors include Ge, Si, InGaAs, Thermopile, PbS, PbSe, InAs.

Williamson

Temperature Range

Sensor Type

Optics

Wavelength

Williamson

Infrared Thermometers

- **Brightness**

  (a.k.a. Single-Wavelength or One-Color)

- **Ratio**

  (a.k.a. Dual-Wavelength of Two-Color)

- **Multi-Variant**

  (a.k.a. Multi-Wavelength or Other)

Williamson

Three Sensor Types

Brightness Sensor
ε = constant

Dual-wavelength sensor
e-slope = $\varepsilon_1/\varepsilon_2 - 1$ = constant

Multi-wavelength Sensor (Williamson)
e-slope = $f(\varepsilon_2)$

e-slope function is material specific

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Brightness Sensors

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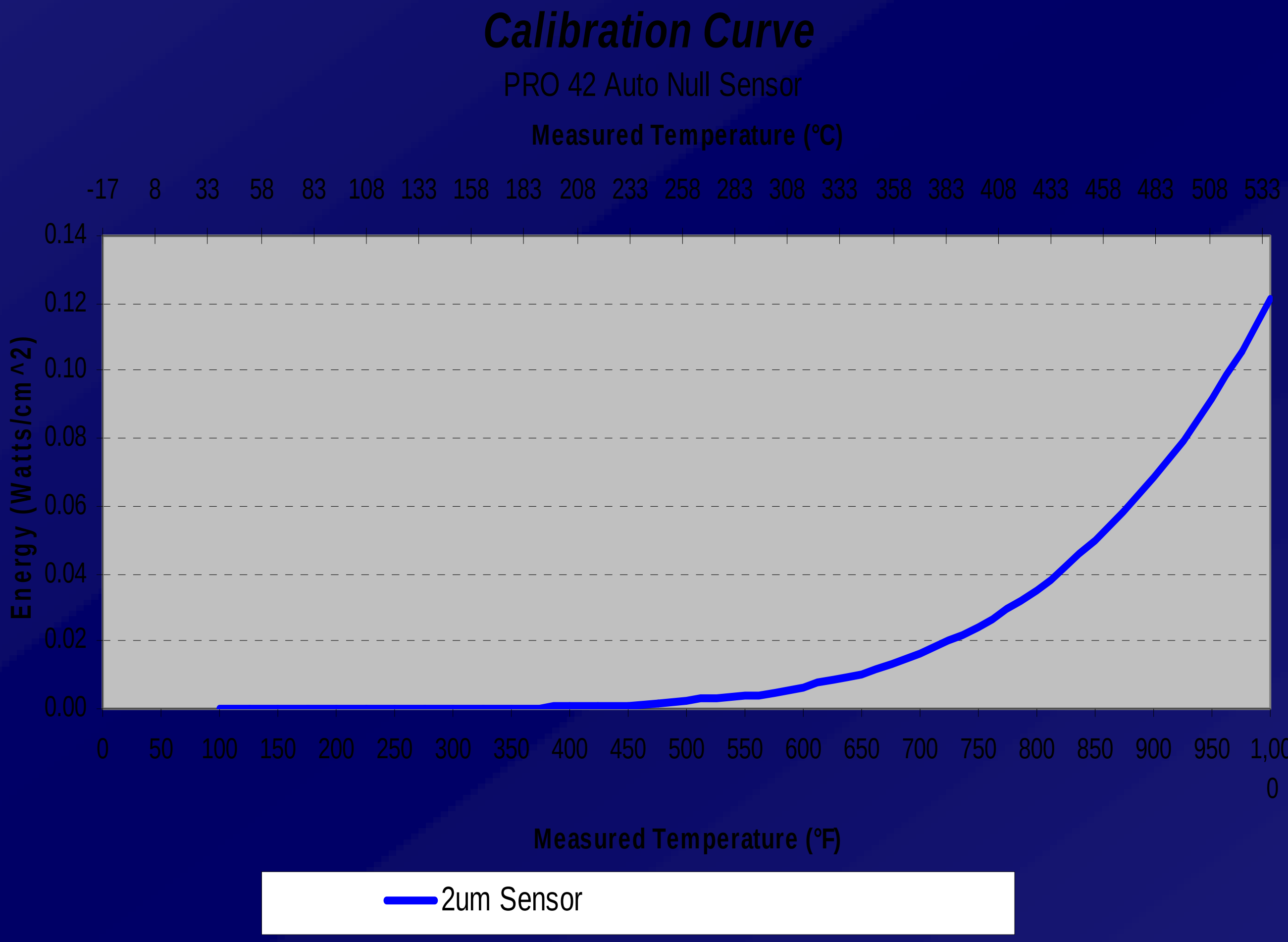
Infrared Energy vs. Temperature



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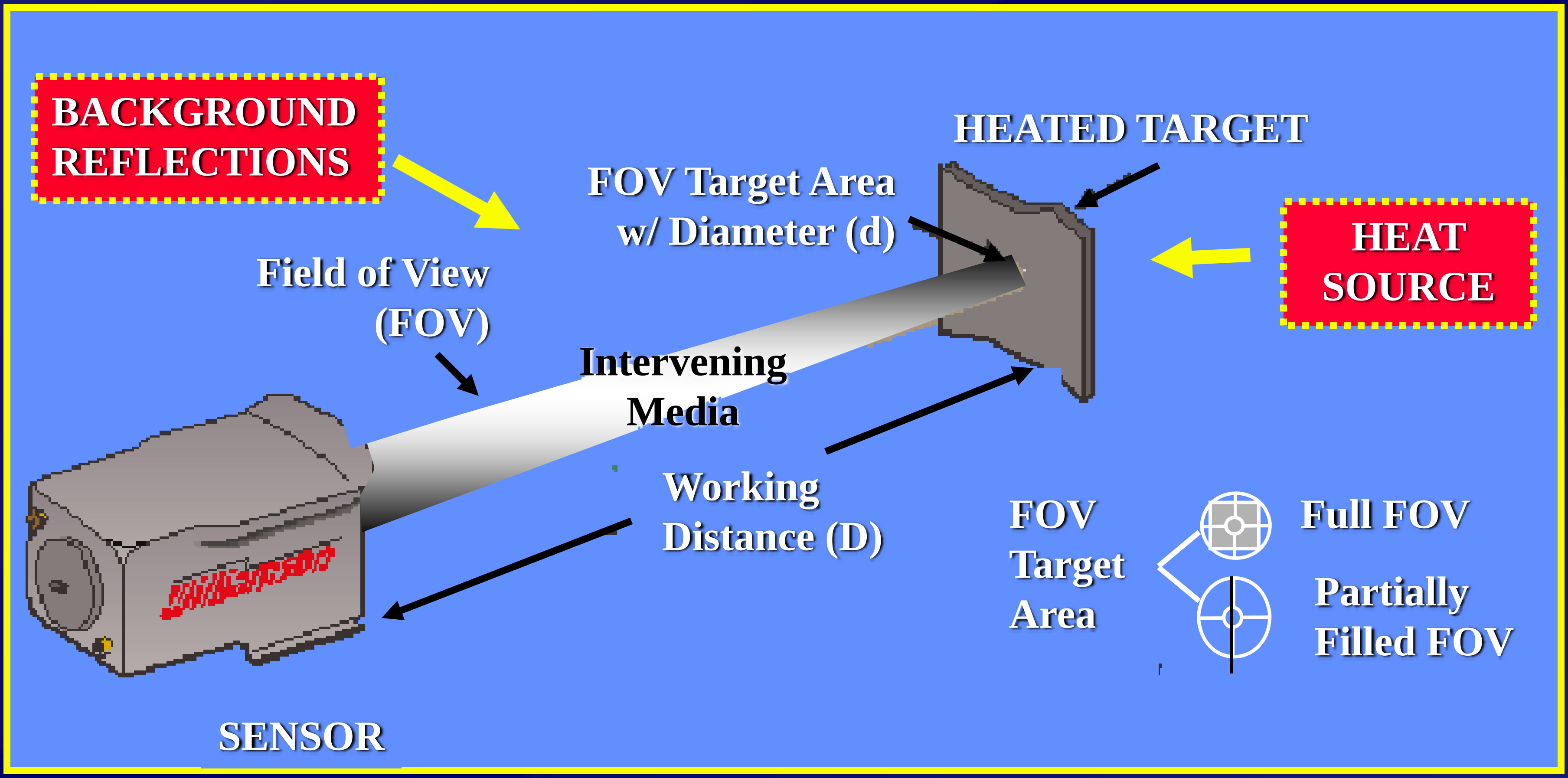
Temperature Application Issues



ΔT (System) = ΔT (Emissivity) + ΔT (Transmission) + ΔT (Background) + ΔT (Instrument) + ΔT (Alignment)

Williamson

Brightness Sensors

- Tend to measure an average temperature value
- Are affected by changes in emissivity, optical obstruction & stray background energy
- **Wavelength Matters!**

Williamson

Why Wavelength Matters

- **Shorter Wavelengths** are less sensitive to emissivity variation and optical obstruction.
- **Shorter wavelength** readings are more highly weighted towards the hottest temperature viewed & **longer wavelengths** are less sensitive to hot reflections.
- For low-emissivity materials, the emissivity is higher at a **shorter wavelength**, further reducing errors.
- Wavelength selection is critical for viewing through **steam, flames and products of combustion,** for avoiding **IR heater** interference, and for measuring coated products.

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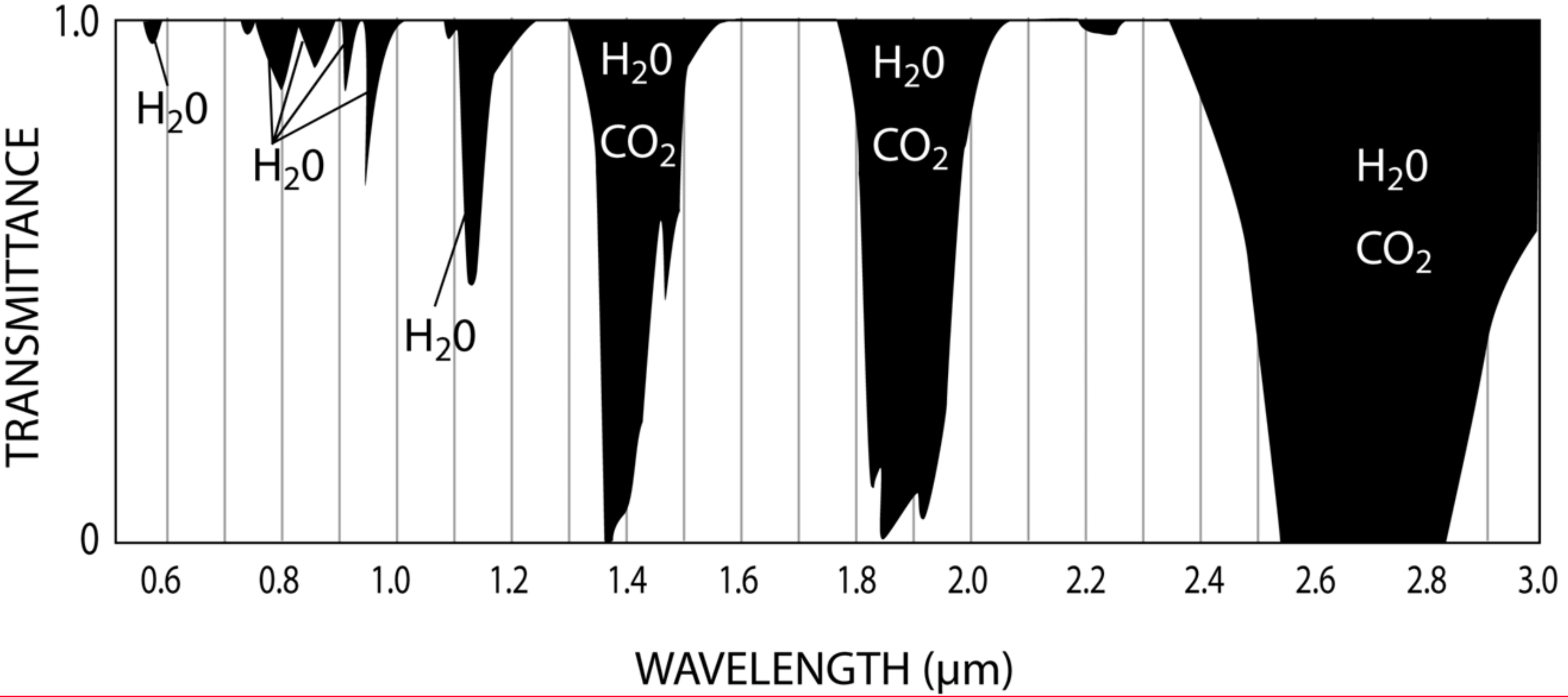
Atmospheric Absorption



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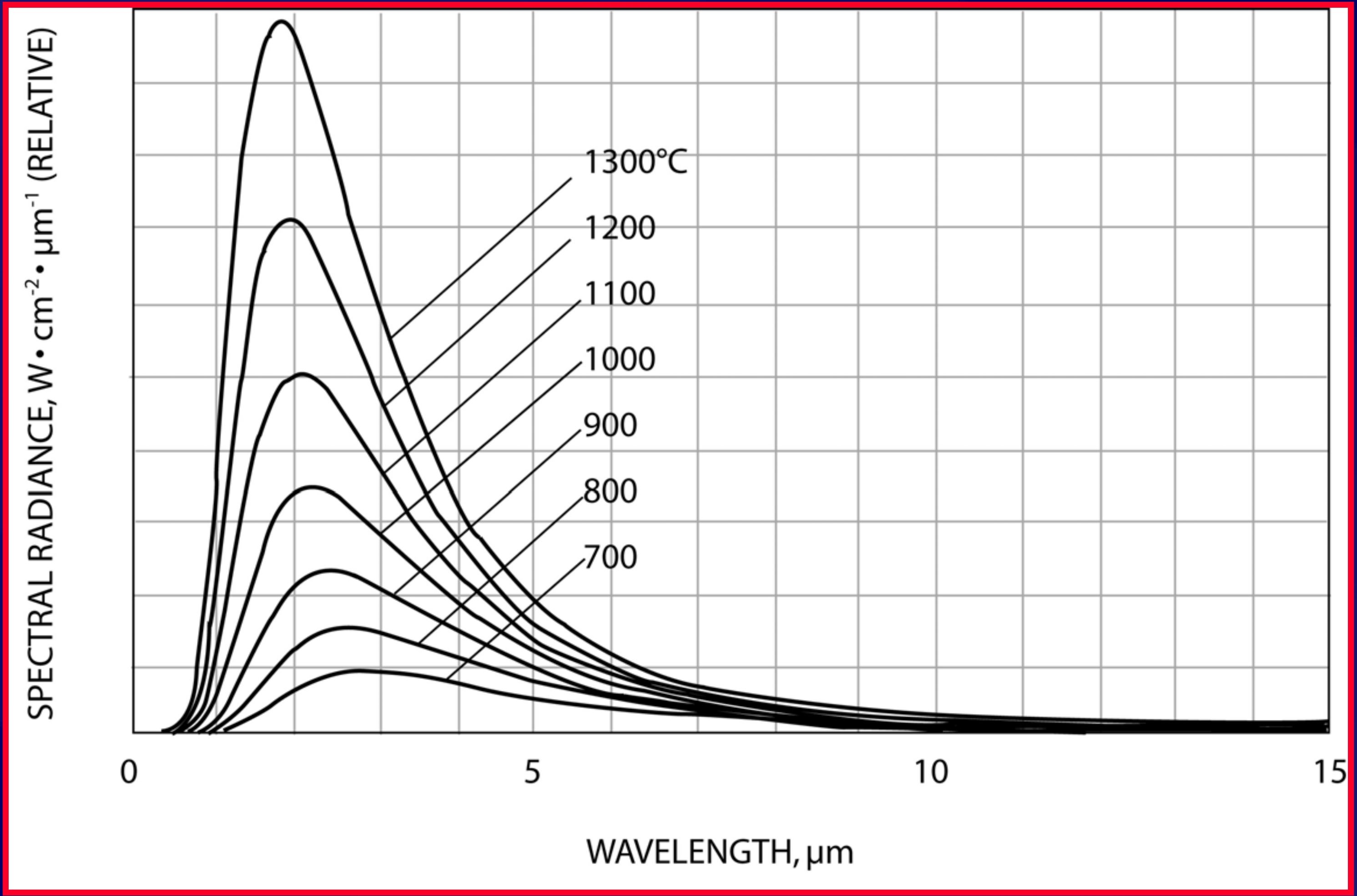
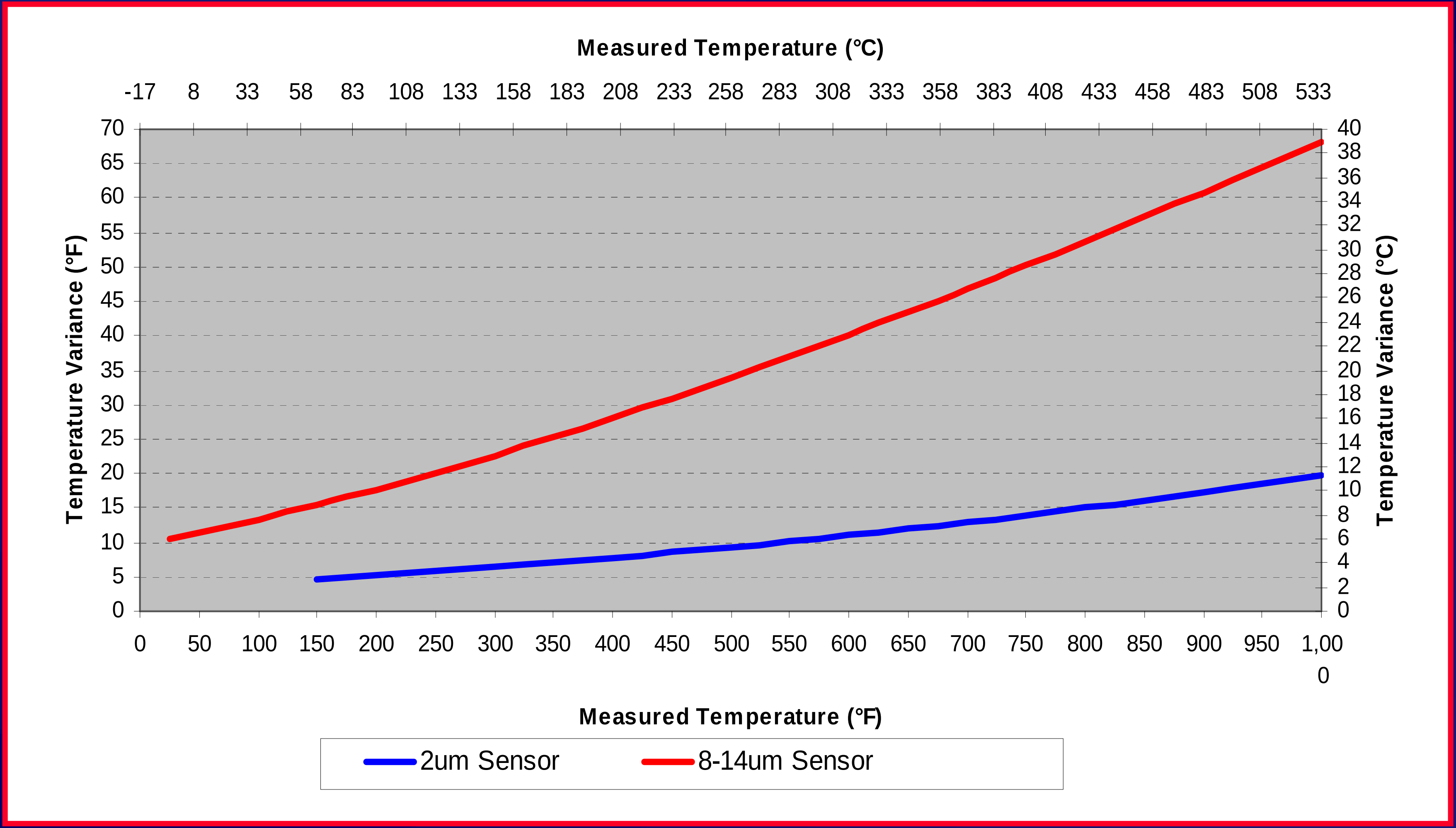
Infrared Energy vs Wavelength



Short Wavelength (2um) vs. Long Wavelength (8-14um) Sensor
Error from 10% Emissivity Change, or 10% Optical Obstruction



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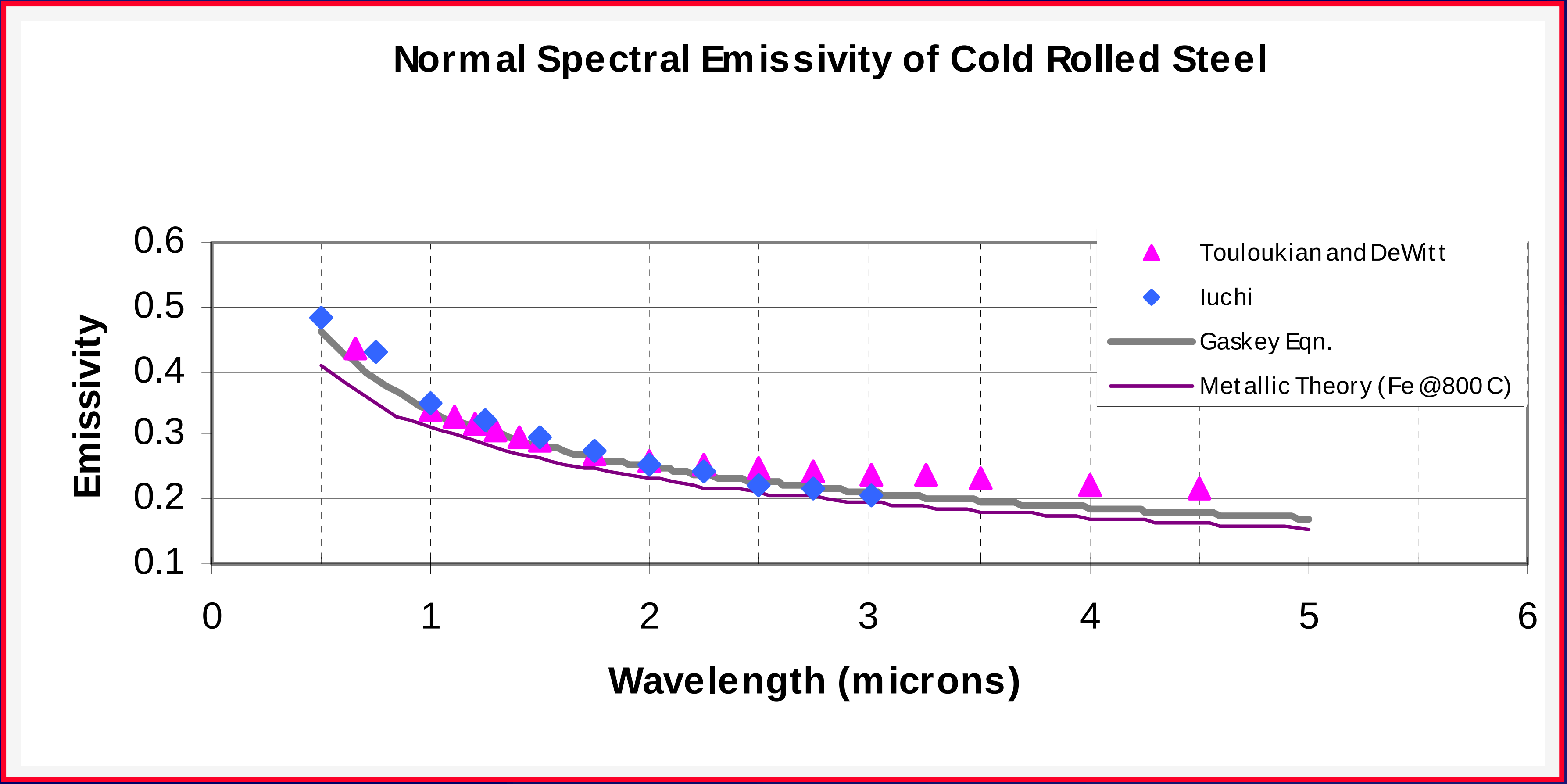
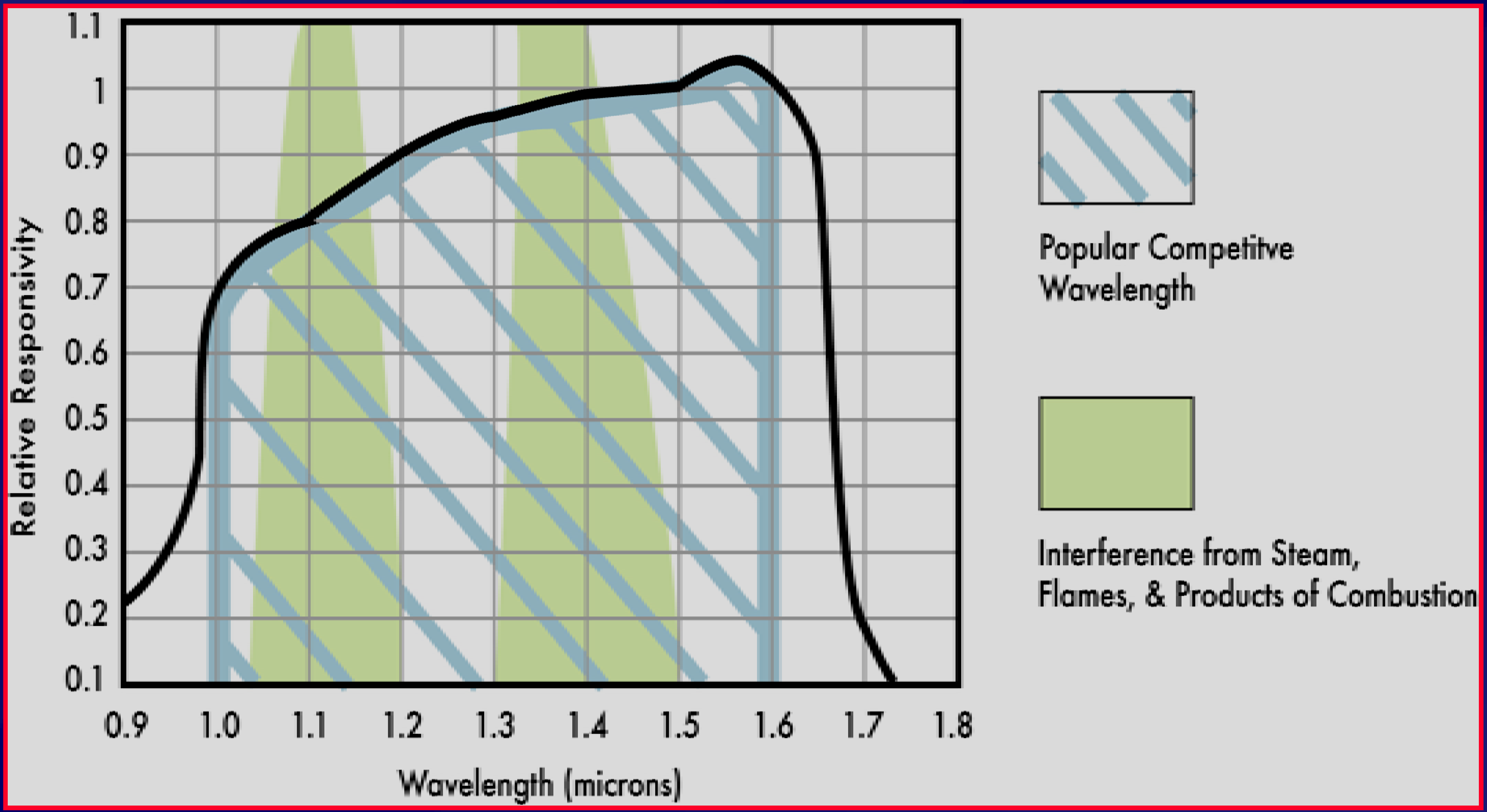
Emissivity vs. Wavelength



Traditional Operating Wavelength Showing Interference from Steam & Products of Combustion



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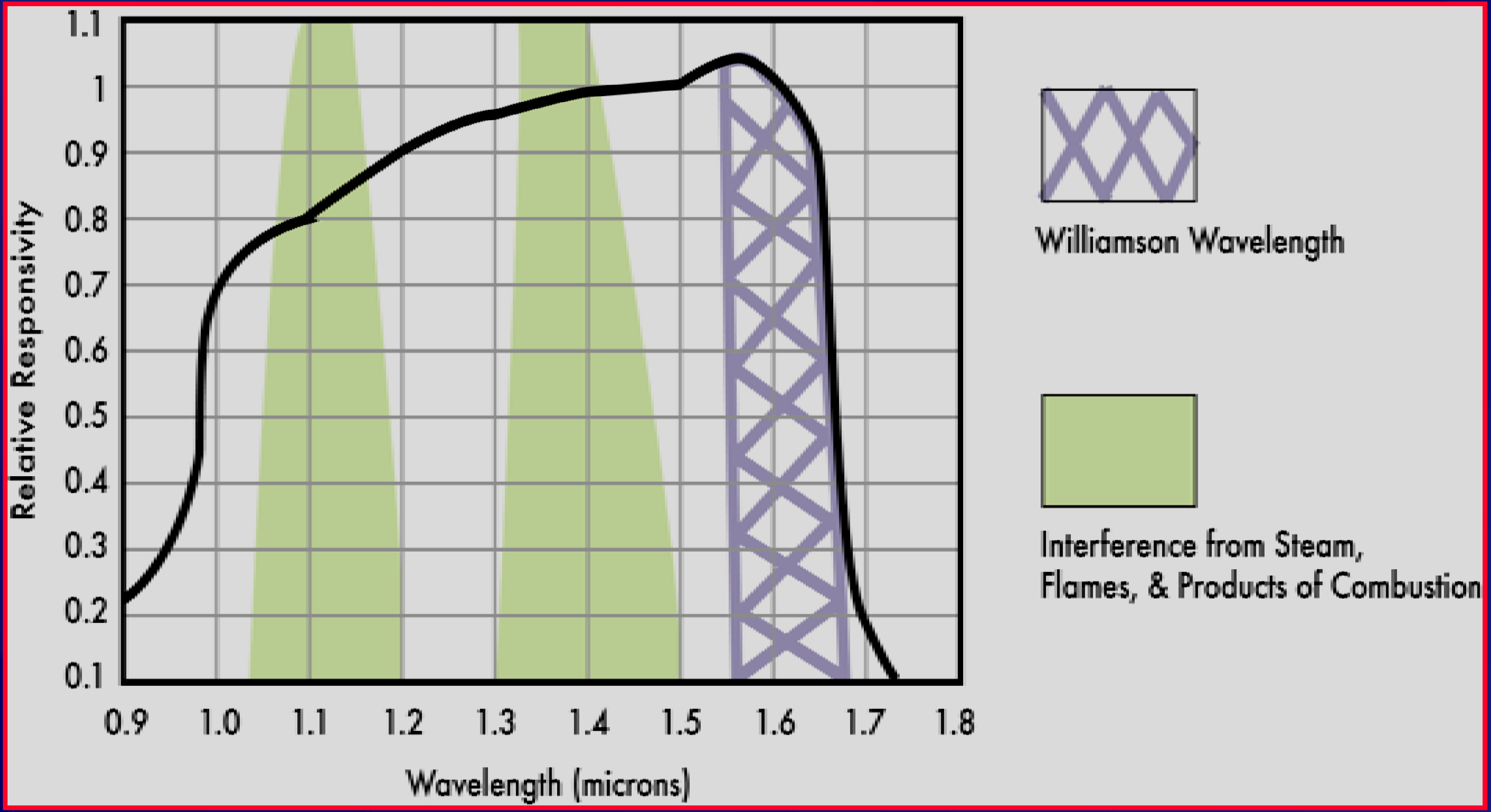
Wavelength Selection to View Through Steam and Products of Combustion



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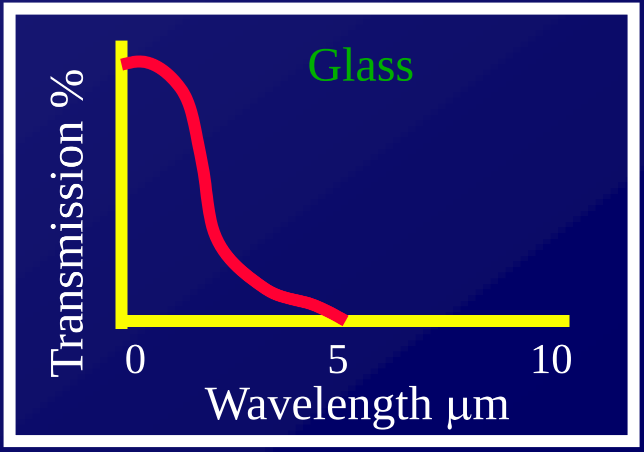
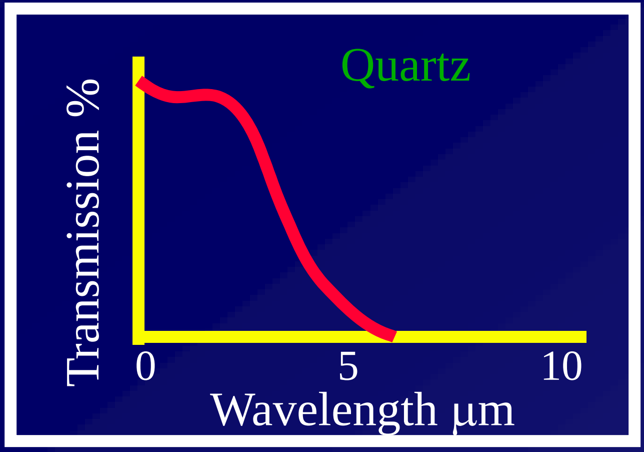
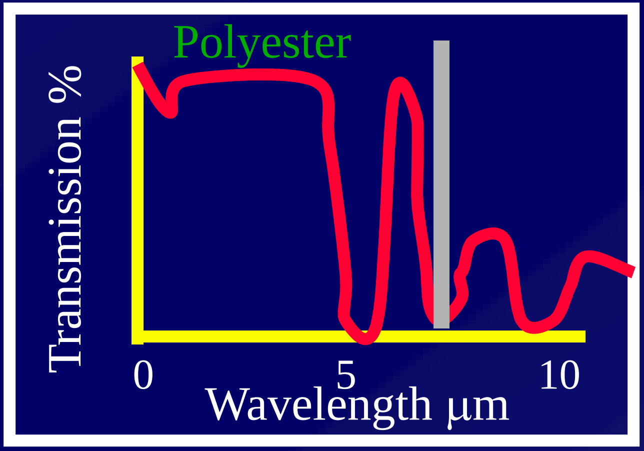
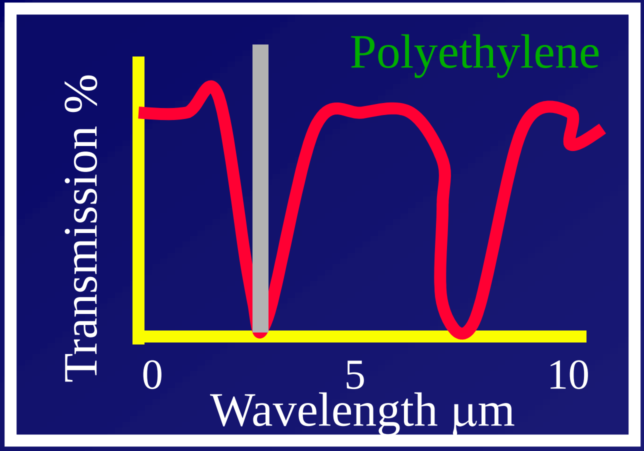
Transmission Characteristics (Selective Emitters)









Brightness Wavelength Selection

- Use the **shortest practical wavelength** for most applications to minimize sensitivity to emissivity variance & optical obstruction.
- Use a specific wavelength to eliminate or minimize **transmission or reflection issues** (i.e. coatings, flames, products of combustion, water vapor, steam, water spray, plastics, glass, crystalline materials).

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Compensation for Emissivity

- Single-wavelength sensors require a **constant emissivity**
- Select the **shortest possible wavelength** (1-2um) to minimize errors due to changes in emissivity
- An emissivity adjustment compensates for **different emissivity values**
- Many applications require **repeatability**, not **absolute accuracy**

Williamson

Brightness Sensor Summary

- Short wavelengths minimize errors due to emissivity variation, optical obstruction & misalignment.
- Wavelength may be optimized to view through steam, flames & products of combustion.
- Wavelength may be optimized to view flames or gasses.

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The Advantage of Auto Null

- The Auto Null Sensors provide greater **accuracy** & **repeatability** for low emissivity applications at temperatures as low as 100°F / 35°C
  - A **Short wavelength** of 2µm minimizes sensitivity to emissivity variation.
  - The **Patented Design** provides automatic calibration 20 times / second to eliminate noise & drift common for this type of sensor
- Used to measure low temperature metals.
- Views through steam & common windows.

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Sample Brightness Sensor Wavelength-Critical Applications

- Coke Conveyor Protection
- CO Flame Monitor
- Ladle / Refractory Preheat
- Reheat Furnace Heating Zones
- Dual-Phase Steel Quench
- Low-Temperature Strip or Bar (Cold Mill, Coating Lines)
- Heat Treat Furnaces
- Hot Metal Detector

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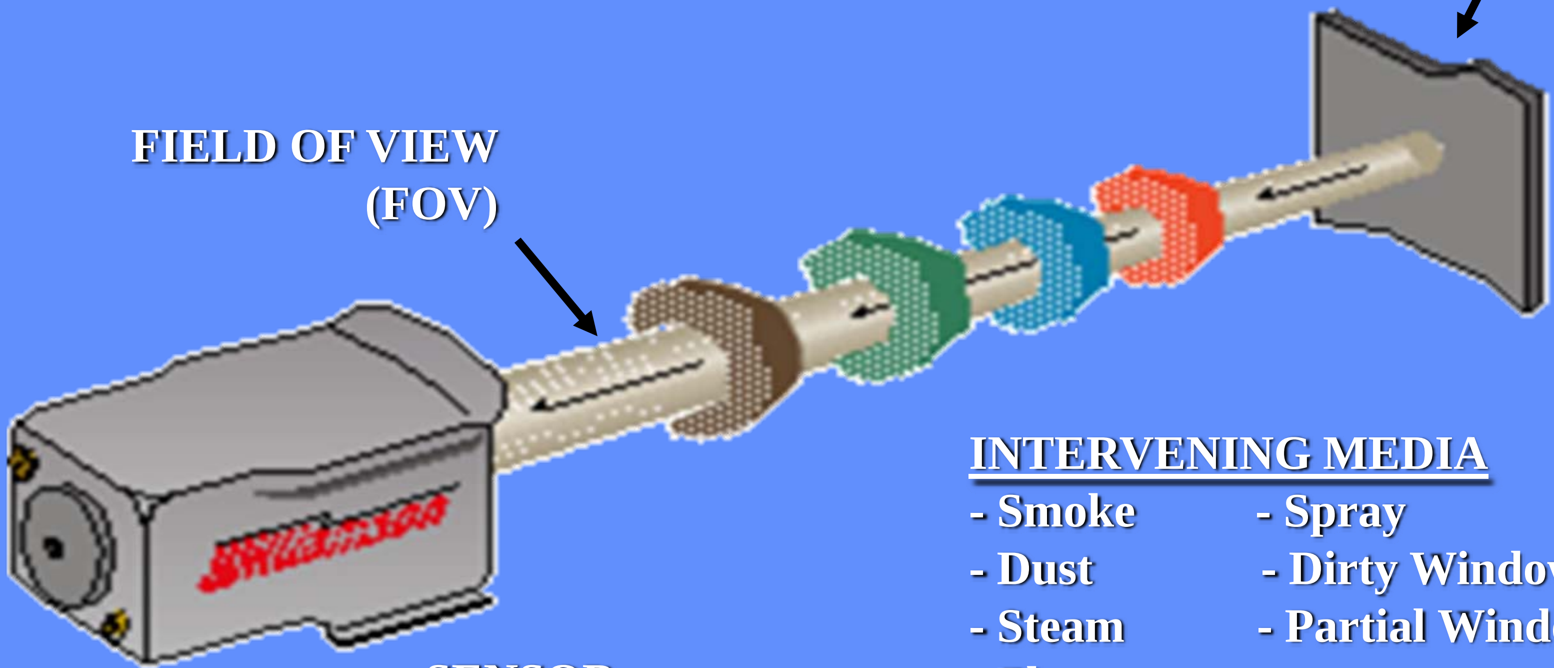
Ratio Sensors

Compensates for Signal Dilution from Intervening Media



INTERVENING MEDIA

- Smoke
- Dust
- Steam
- Plasma
- Spray
- Dirty Windows
- Partial Windows

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Ratio Sensors

- Compensate for emissivity variation, and tend to measure the hottest temperature viewed.
- Are affected by changes in e-slope, wavelength-selective optical obstruction and excessively hot background reflections.
- **Wavelength Matters!**

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Definition of e-slope offset

For a dual-wavelength pyrometer operating at wavelengths λ_1 and λ_2

$$eslope = \left(\frac{\varepsilon_{\lambda_1}}{\varepsilon_{\lambda_2}}\right) - 1$$

Error due to Emissivity Variation – Ratio Sensor

$$\frac{\Delta T}{T} \approx \frac{\Lambda T}{C_2} \frac{\Delta r}{r}$$

$$\Lambda = \frac{\lambda_1 \cdot \lambda_2}{(\lambda_2 - \lambda_1)}$$

$$r = \frac{\varepsilon_1}{\varepsilon_2}$$

Why Wavelength Matters

- Both measured wavelengths must be equally influenced by any optical obstruction or emissivity variation.
- Greater wavelength separation reduces sensitivity to e-slope variation and reduces sensitivity to warm interferences (scale / temperature gradients).
- Wavelength affects low temperature performance (available as low as 95 C/200 F).

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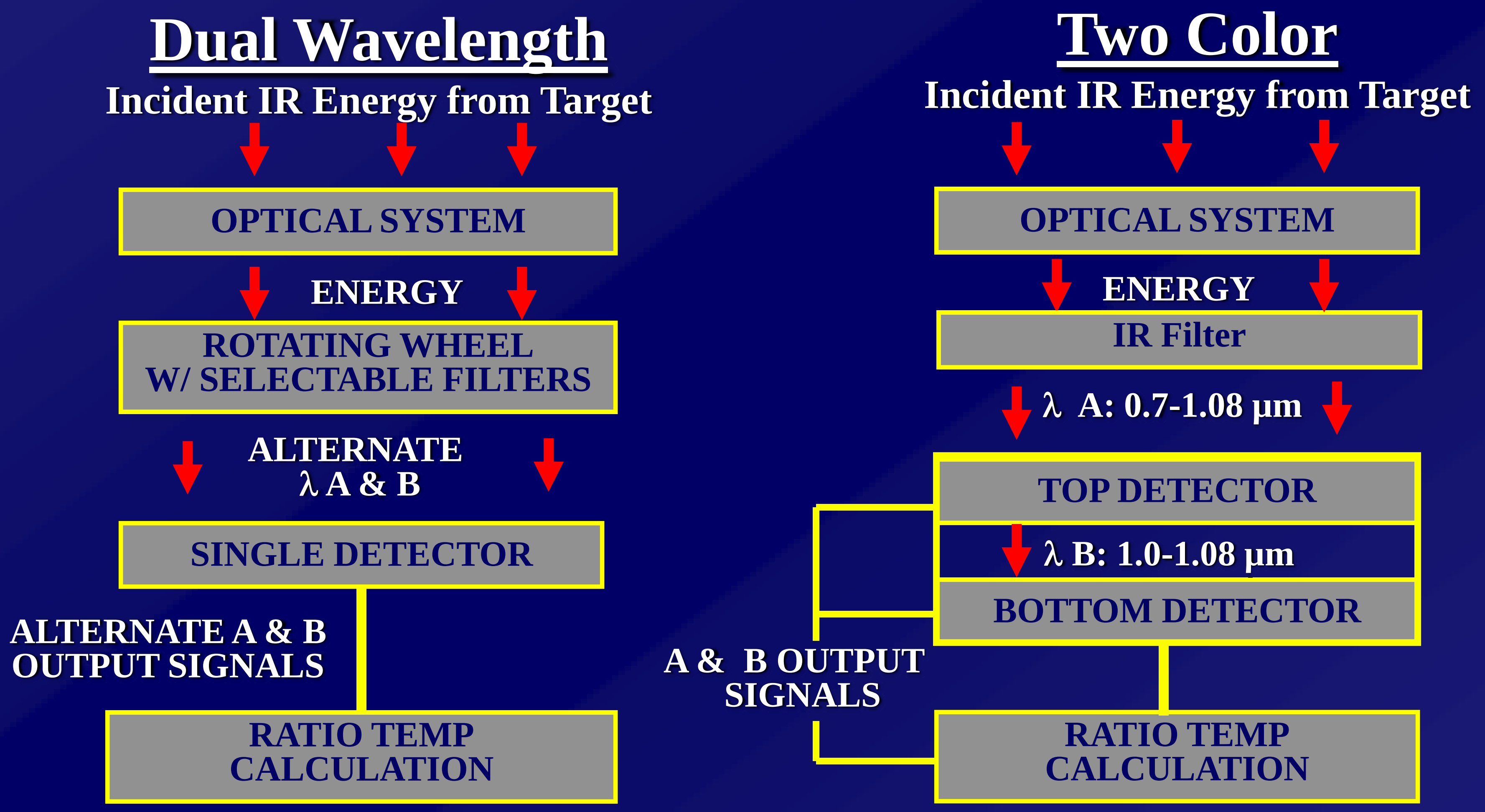
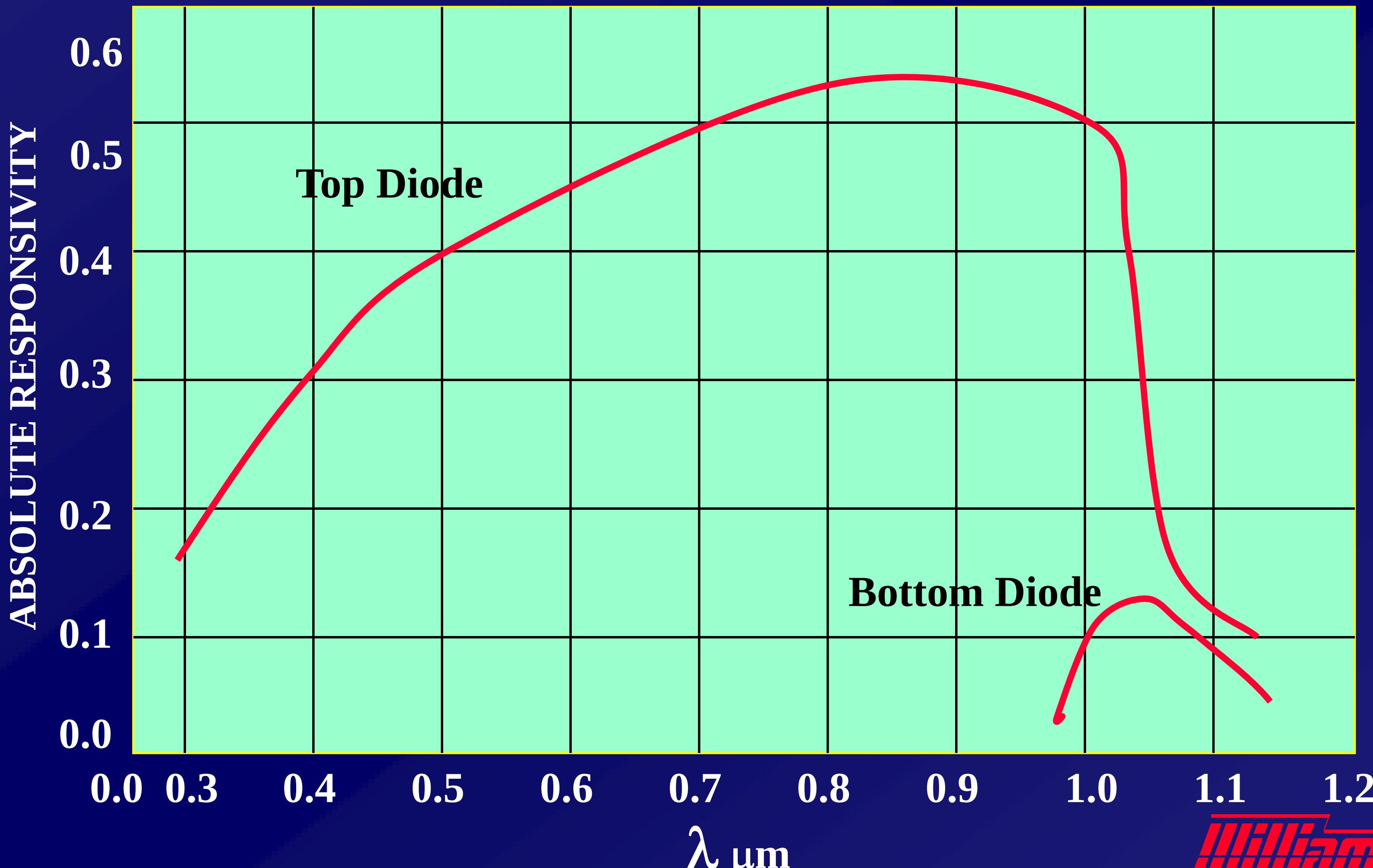
Two Ratio Designs



Traditional "Two-Color" Wavelengths



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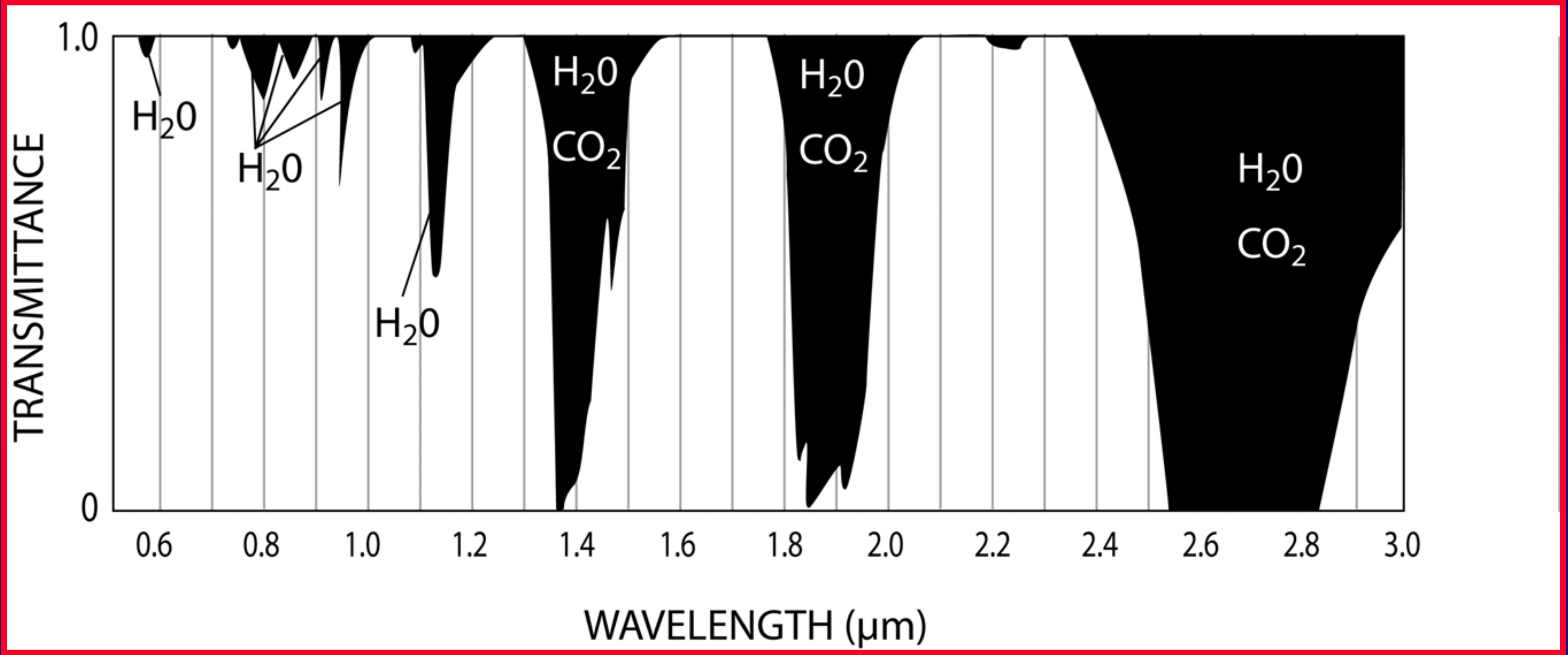
Viewing Through Steam & Products of Combustion



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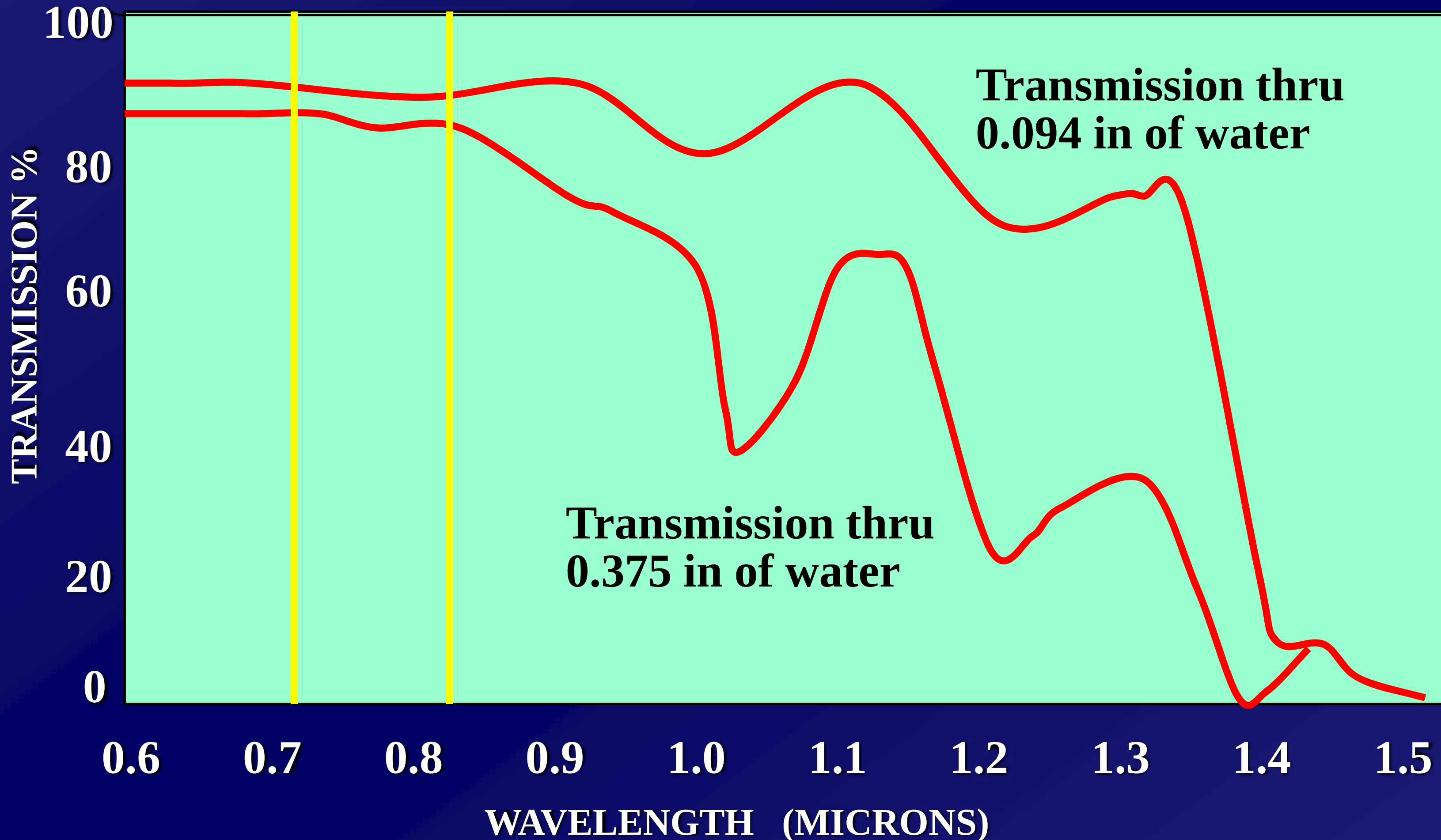
Infrared Transmission Through Water



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Signal Dilution

- A measure of infrared energy compared to the amount of energy required to make a reading. 50:1 means that the sensor is collecting 50 times the energy required to make a reading.
- Typical application factors that dilute the energy signal level are
  - Misalignment, low emissivity, dirty optics, water spray, dust, scale, small targets.

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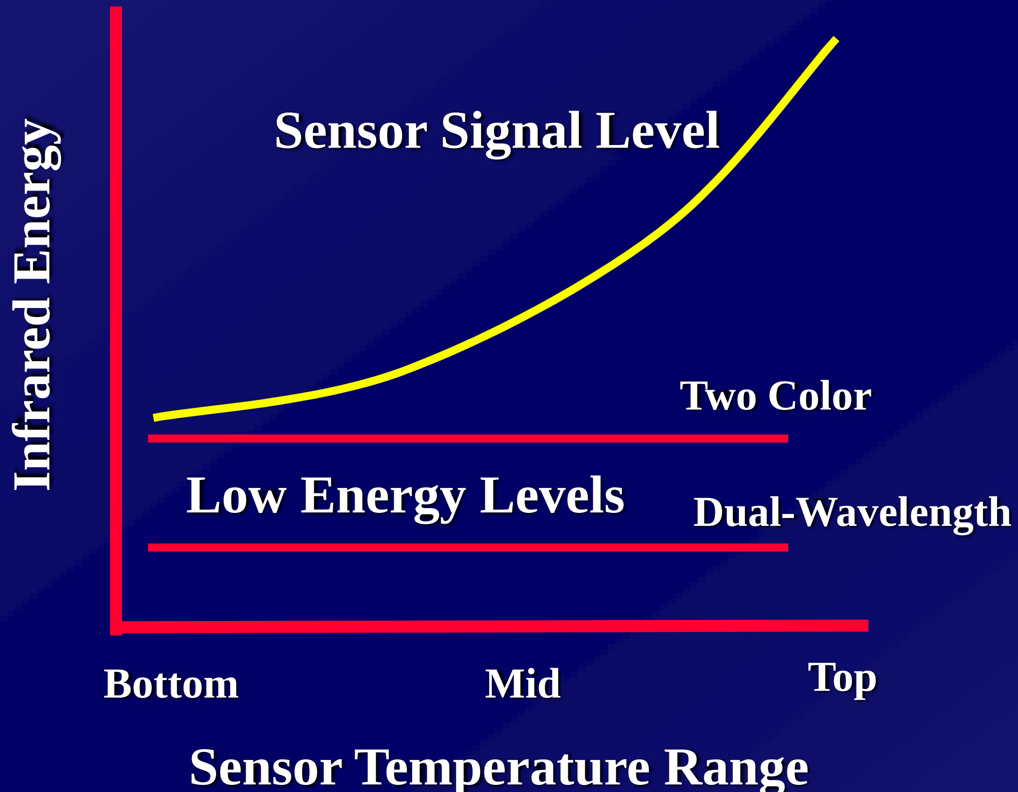
Signal Dilution Capability

SIGNAL DILUTION = SENSOR SIGNAL / LOW ENERGY LIMIT



SAMPLE SIGNAL DILUTION FACTOR VALUES		
Segment of Temperature Range	**Dual Wavelength**	**Typical Two Color**
Bottom End	5:1	1:1 or 2:1
Mid Range	500:1 1500:1	20:1
Top End	2000:1 6000:1	20:1 100:1

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Dual-Wavelength Features

- Automatic Emissivity Compensation
- Compensates for scale & oxide formation
- Views thru dust, dirty optics, & water Spray
- Measures highly weighted average towards the hottest temperature viewed
  - Accurate measurements with a partial FOV
  - Effective for small & moving targets like wires & molten pours
- Measures the Target Emissivity & Signal Dilution
- Includes advanced ESP Filters for Signal Dilution and Signal Strength

Williamson

Ratio Sensor Summary

- Wavelength separation optimizes stability and the ability to tolerate scale & other temperature gradients.
- Ability to tolerate optical obstruction is measured by Signal Dilution.
- Selective wavelengths tolerate water, steam, flames & products of combustion.

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Dual Wavelength Temperature Applications

- Difficult to measure applications in demanding industrial environments
- Applications where single wavelength sensors can not meet requirements
  - surfaces with low or varying emissivity
  - View thru obstructions or intervening media
  - Compensate for dirty optics, & oxide or scale formation
  - Measure small or wandering targets that do not fill the sensors field of view (FOV)

Williamson

Sample Ratio Sensor Wavelength-Critical Applications

- Coke Guide
- Sintered Briquette
- Molten Iron Stream / Vacuum Melter
- Caster Containment Zone
- HSM Re-Heat Furnace Soaking Zone
- Hot Mill (Scale, Water & Steam)
- Weld Temperature
- Heat Treat Furnaces

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Multi-Variant Sensors

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Multi-Variant Sensors

- Are used whenever traditional sensors are not appropriate.
- Use multiple wavelengths to characterize the emissive nature of the measurement.
- Multi-Variant algorithms are developed for each application type (usually the same from one plant to the next) to address specific emissivity or interference issues.

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Multi-Wavelength Infrared Thermometers

- Designed for difficult materials and challenging applications.
- Used where single- & dual-wavelength sensors can’t meet requirements
- Common measurements include Aluminum, Brass, Copper, Zinc, Galvanneal, Stainless Steel, Electrical Steel, High Strength Steel, Cold Rolled Steel, Magnesium, Chrome, etc… .

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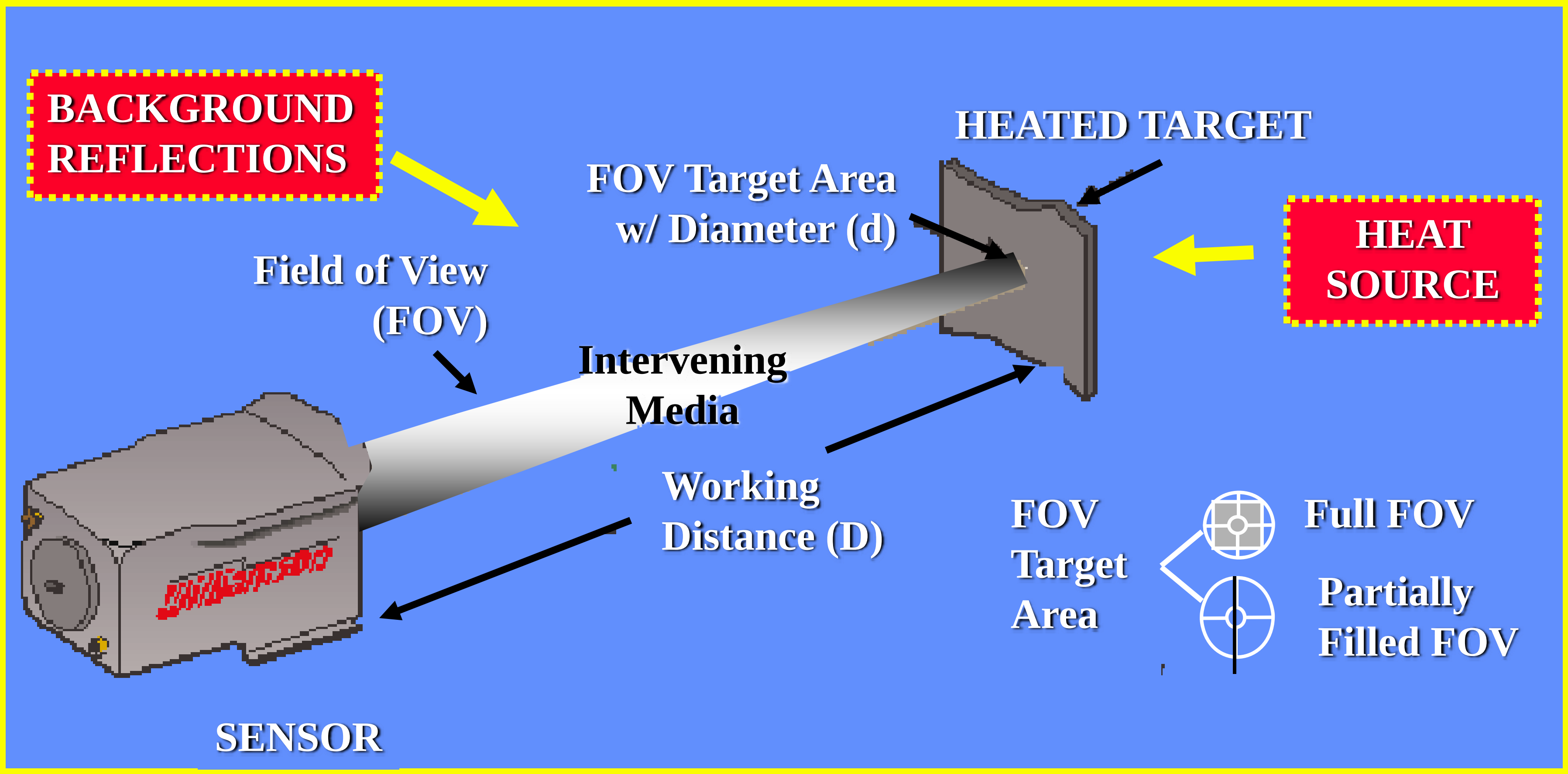
Temperature Application Issues



ΔT (System) = ΔT (Emissivity) + ΔT (Transmission) + ΔT (Background) + ΔT (Instrument) + ΔT (Alignment)

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Multi-Wavelength Design

- ESP technology to accurately compensate for complex application issues
  - ESPs are computer based empirical algorithms that are application specific
  - The ESPs are application specific, factory programmed, and menu selectable
  - Eliminate field calibration requirements

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Multi-wavelength Sensor

Brightness Sensor

ε = constant

Dual-wavelength sensor

e-slope = $\varepsilon_1/\varepsilon_2 - 1$ = constant

Multi-wavelength Sensor (Williamson)

e-slope = f(ε_2)

e-slope function is material specific

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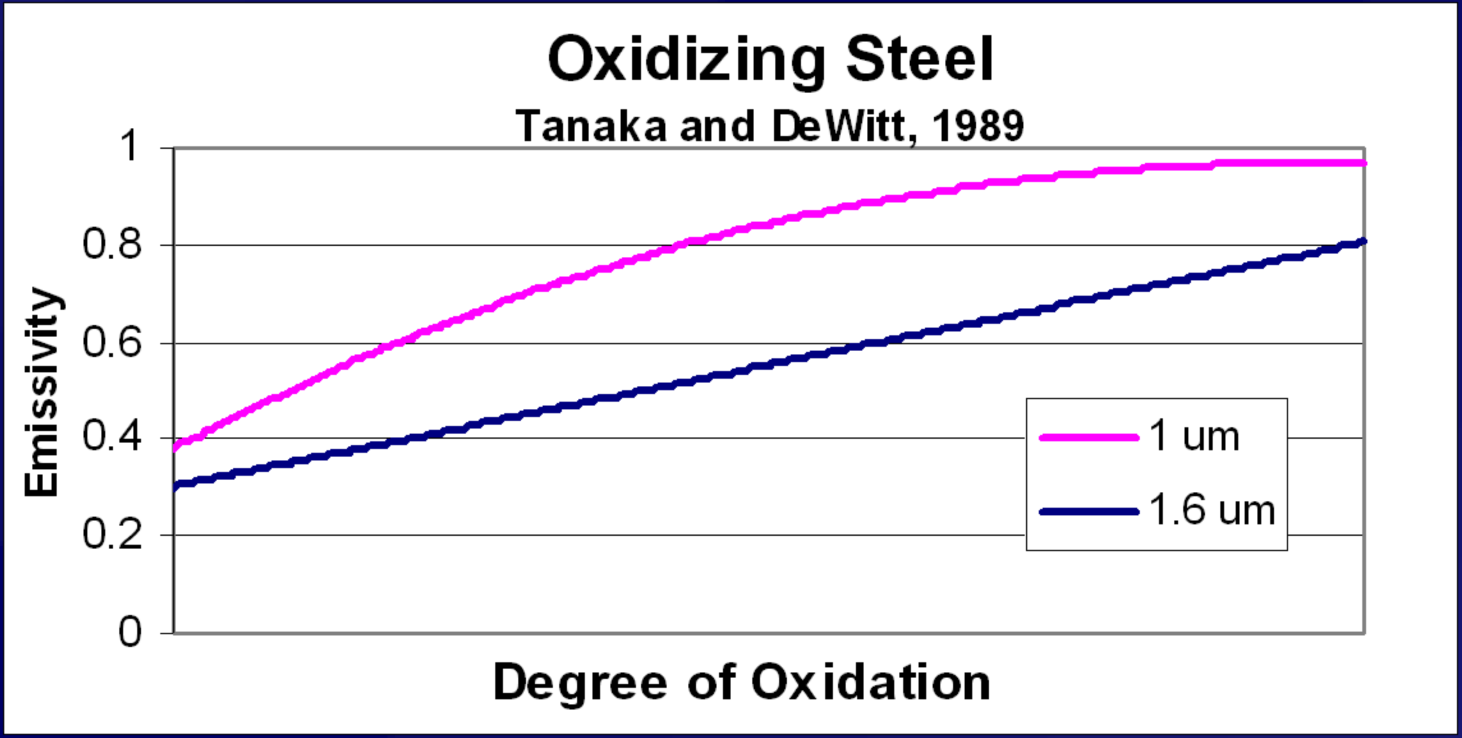
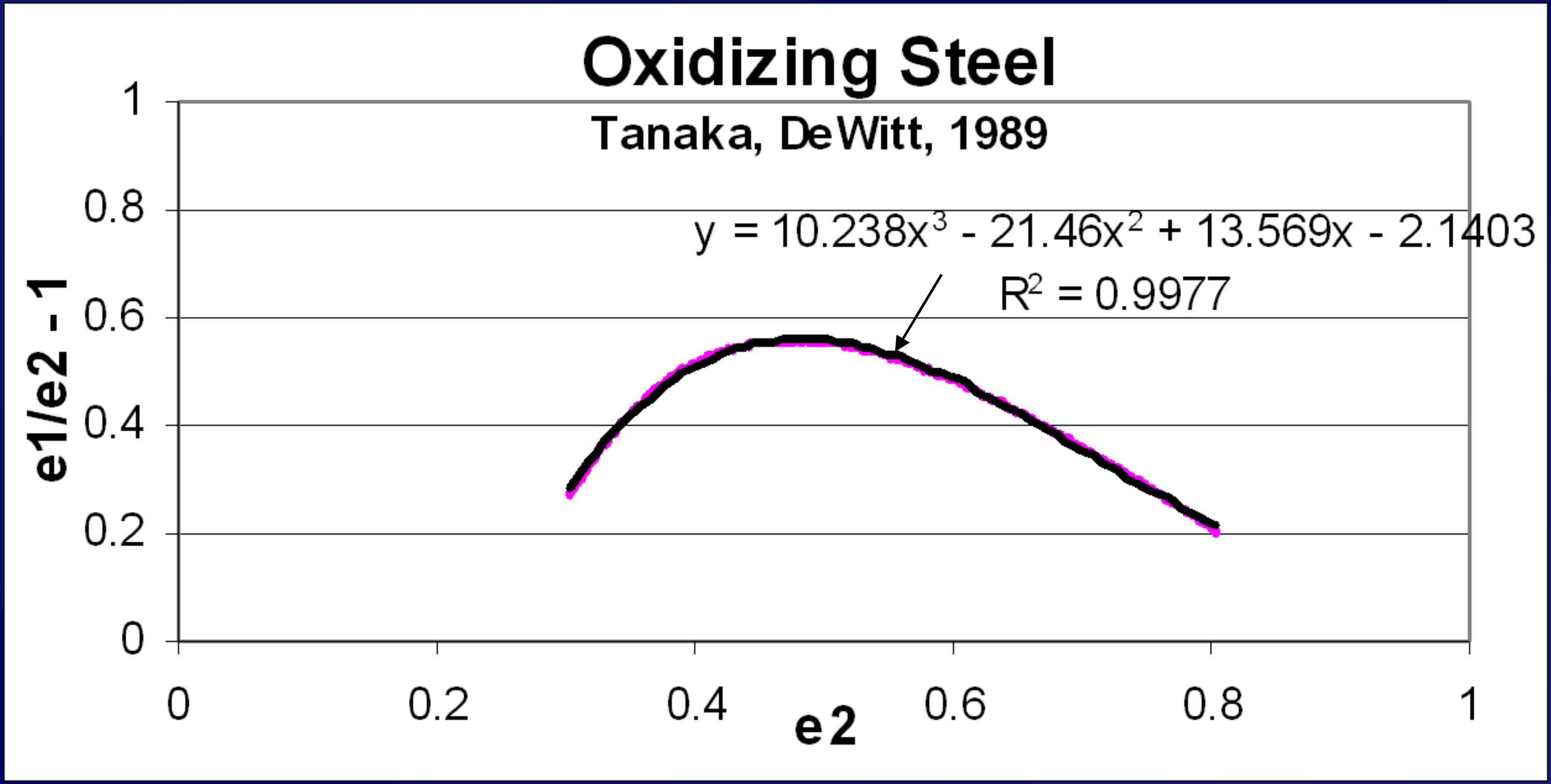
e-slope Function Example: Oxidizing Steel



e-slope Function Example: Oxidizing Steel



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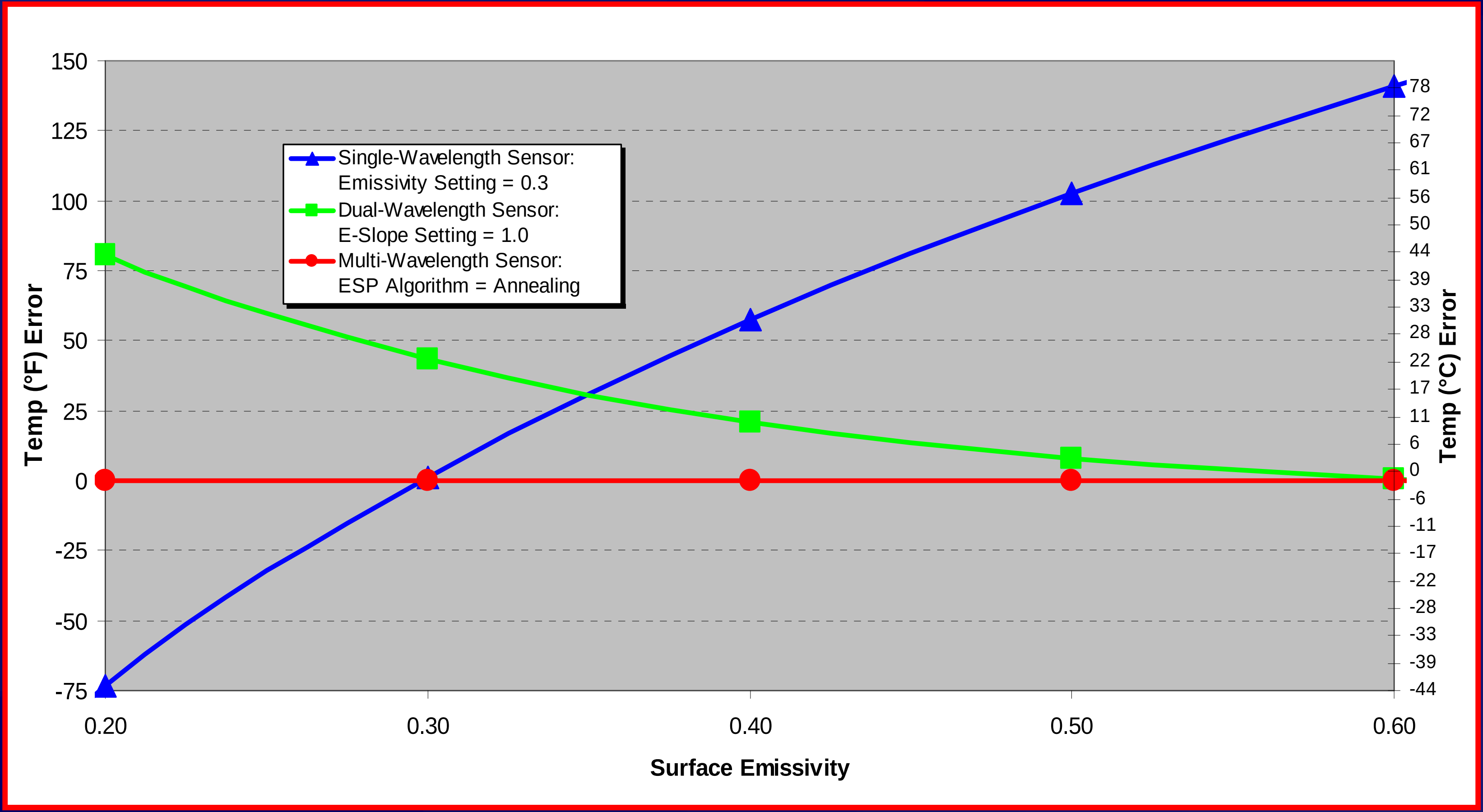
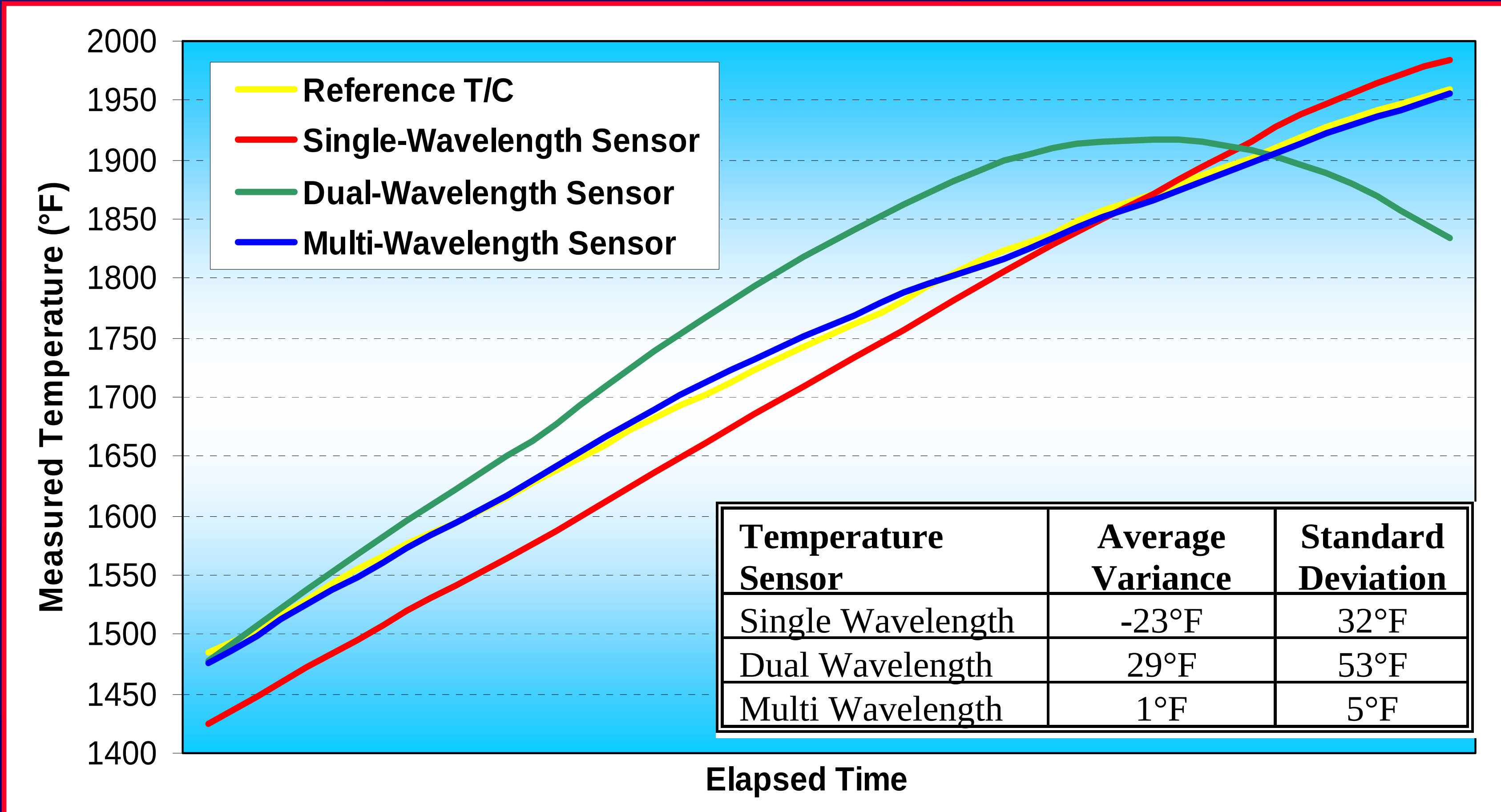
Performance of Single, Dual, and Multi-Wavelength Sensors on Steel Annealing Lines

Assumes Strip Temperature of 1400°F (760°C)



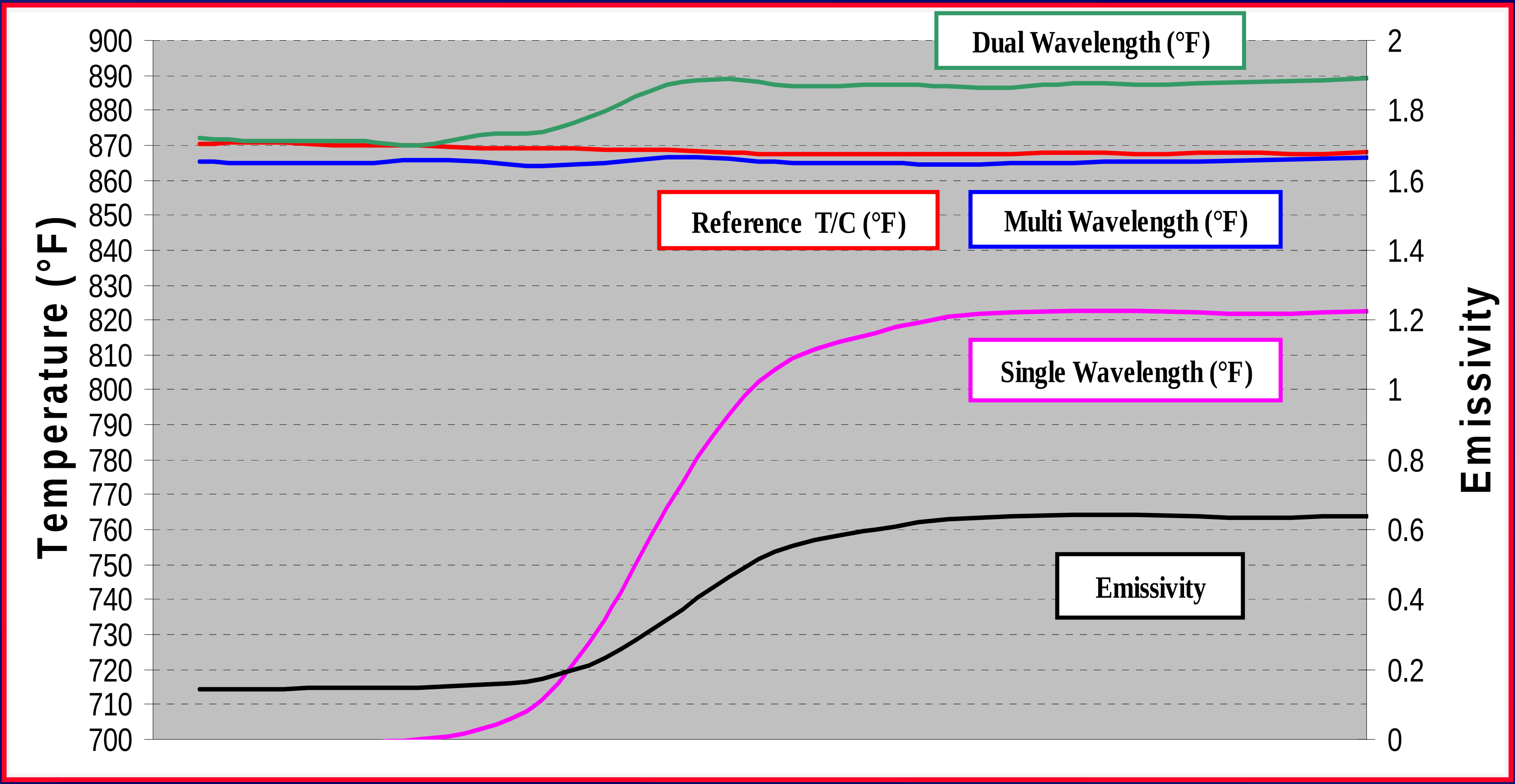
Stainless Steel Measurements



Temperature Sensor	Average Variance	Standard Deviation
Single Wavelength	-23°F	32°F
Dual Wavelength	29°F	53°F
Multi Wavelength	1°F	5°F

ESP can compensate for Changes in Emissivity from 0.4 to 0.9

Performance of Single, Dual, and Multi-Wavelength Sensors on Galvanneal Measurements



TEST PROFILE		TEST RESULTS		
Sample Material:	Galvanneal	**Sensor**	**Avg. Var.**	**Std. Dev.**
Sensor Model:	Steel	Single Wavelength	-50°F	36°F
Temperature Range:	110-10	Dual Wavelength	21°F	6°F
Change in Emissivity:	700 to 2100°F	Multi Wavelength	-1°F	2°F
	0.1 to 0.7			

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Sample Multi-Variant Sensor Applications

Annealing Furnace

Mild, Stainless, High Strength and High Temperature Alloys

Hot-Dip Lines

Galvanize, Galvalume and Galvanneal

Tube Mills

Cold Rolled Alloys

Sample Multi-Wavelength Applications

- Steel Annealing Lines
- Cold Rolled Steel Strip
- Nonferrous and High Alloy Metals
  - preheating, forming, heat treating
- Nonferrous coating lines
- Glass Mold Measurements
- Many applications where single- and dual-wavelength sensors won’t work

Williamson

Alignment Issues

Defining the Sensor FOV

Spot Size (d) @ Working Distance (D)

$$d = D/F$$

- d = Focal Diameter
- D = Focal Distance
- F = Optical Resolution Factor

(Formula applies to English and metric units of measurement)

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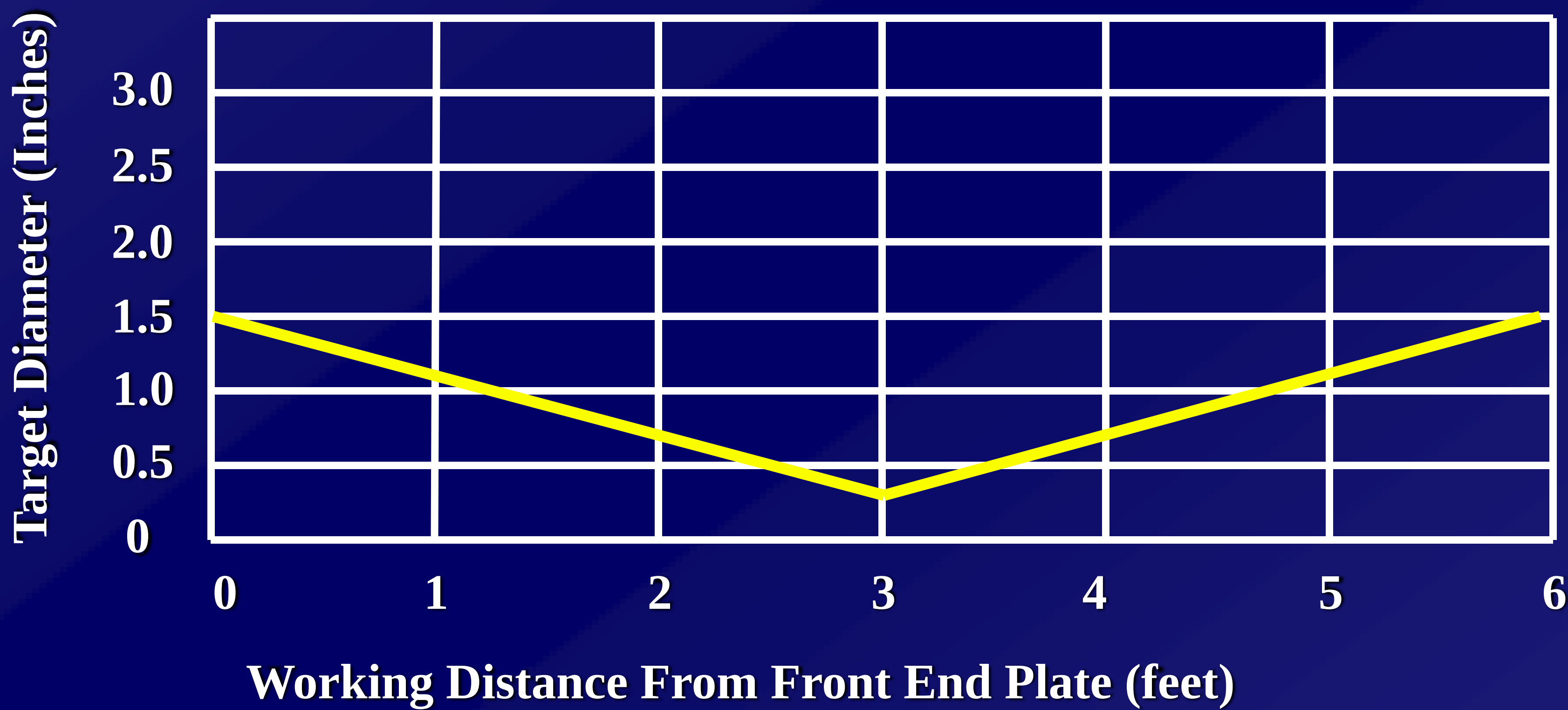
Typical Sensor FOV Diagram

FOV36in/100 : 0.36in at 36inches



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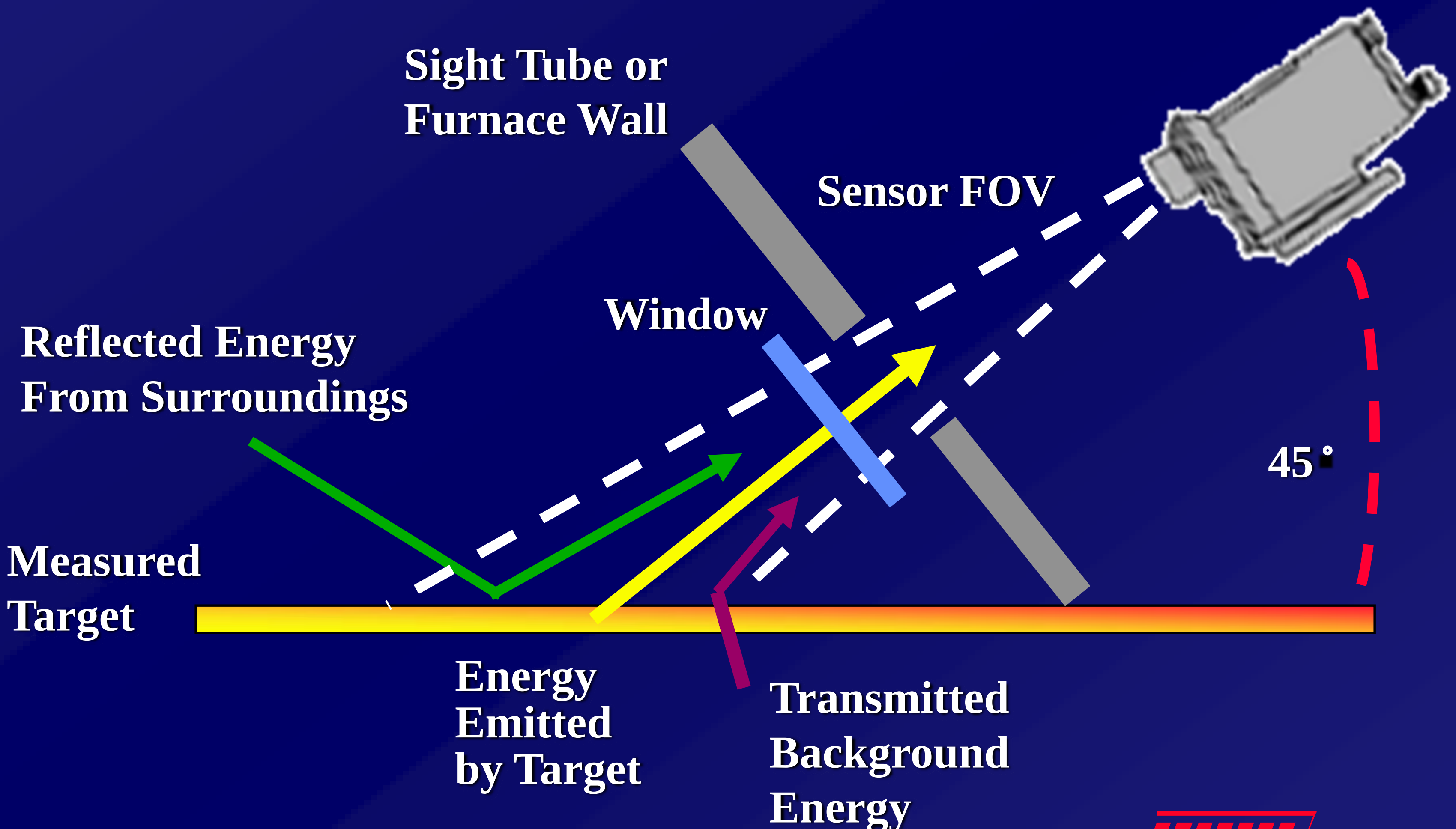
Alignment Guidelines



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Alignment Guidelines

- FOV must clear sight tubes & obstacles
- Windows must be transparent at the sensor operating wavelength
- Position & align to eliminate interference from background & reflected energy
- Rule of thumb for angle of incidence from normal : generally up to 60°, rough surfaces up to 85 °

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Fiber Optic Systems

- Provide access to tight spaces
- Some operate in strong magnetic fields.
- Survive hostile environments.

- Glass / Quartz
- Small diameter, non-conductive mono-filament
- Standard mono-coil multi-strand
- Stainless Steel Braid
- ArmorGuard
- Rigid Light Guides

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PRO 90
With ArmorGuard

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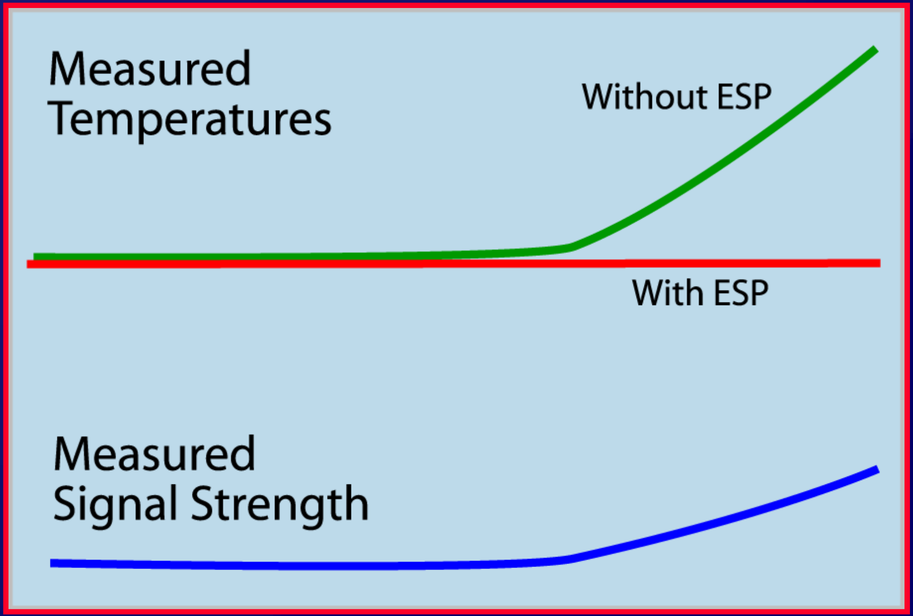
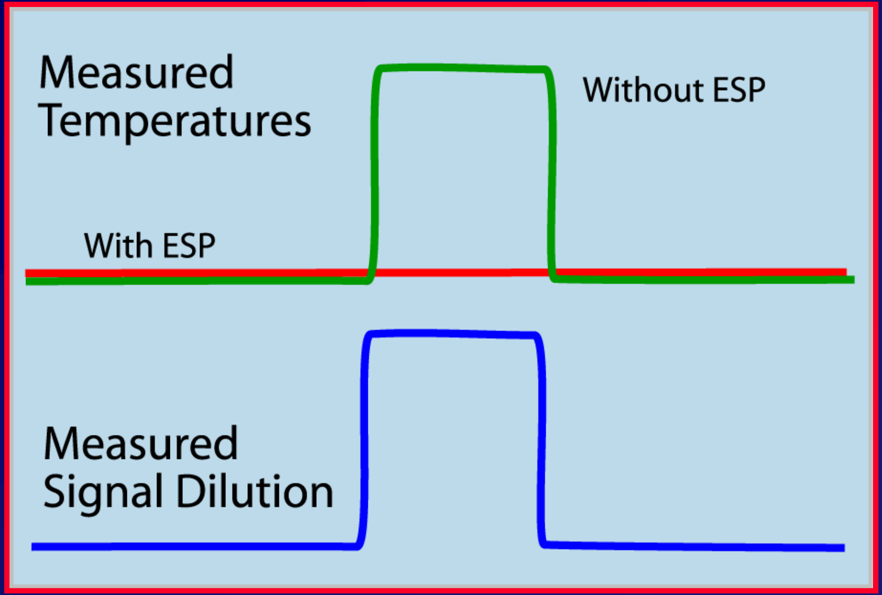
Advanced Signal Conditioning: ESP Filtering





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Williamson's Advanced Infrared Technologies

- Brightness Technology
  - Auto Null Technology for Low-Temperature, Short-Wavelength, Single-Wavelength Measurements.
  - Low or Varying Emissivity at Low Temperatures (below 400-600 F / 200-300 C)
  - Low Temperature Measurement through Windows.
  - Narrow band wavelengths to avoid common interference sources or to measure selective emitters.
- Dual-Wavelength Technology
  - Compensates for varying emissivity, optical obstructions, temperature gradients, and misalignment.
  - Unique wavelength selection to view through water and steam and for low-temperature measurement.
  - Advanced Signal Conditioning with Unique ESP Technology
- Multi-Wavelength Technology
  - Used for Non-Greybody Measurements.
  - Advanced Signal Conditioning with Unique ESP Technology

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Other Infrared Technologies

- Line Scanners
- Thermal Imaging Cameras
- Flame Detectors
- Hot Metal Detectors
- Two-Component Background Compensation System
- Laser Reflection Multi-Variant Type

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