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EXACTUS®
Optical temperature measurement tools

Technical Note: Temperature Resolution

Section 1 - Introduction:
In the field of temperature measurement, the term 'resolution' is commonly defined as the ability to detect a change in temperature. The BASF Exactus Optical Thermometer has the capability to resolve variations in temperature of 0.01°C or smaller.

How small of a variation can be measured, will depend on a number of factors such as:

- Wavelength of the light used to measure temperature
- Range of temperatures the instrument was designed to measure
- Type of optics attached to the instrument
- Operating temperature of the instrument
- Measurement rate, in readings per second, the user selects

A minimum and maximum temperature an instrument can measure is set at the factory, usually based on:

- Minimum Temperature: The temperature where a change of 1.0°C can easily be measured using a measurement rate of one reading per second.
- Maximum Temperature: The temperature at which the electronics is approaching saturation.

Instruments can be configured to measure both below the minimum temperature and above the maximum temperature although some loss of performance may occur. The table below provides the minimum and maximum temperatures for our standard instruments.

The type of optics and the measurement wavelength will define the temperature range and the temperatures at which certain improvements in resolution and measurement speed occur. The following section contains a series of tables that provide temperature, resolution, and measurement speed data for each of the primary optic types. Following the tables is a section on the effect of the probe temperature on resolution and a list of suggestions for improving the resolution in your application.

Section 2 - Resolution tables:
Note the optics type, measurement wavelength, and temperature range in the upper left hand corner of each table. Find a measurement resolution on the left hand side and follow it across to a column for the desired measurement rate, there you will find the temperature at which you would expect to achieve the desired performance.

Temperature range table				
	900nm Measurement Wavelength		**1600nm Measurement Wavelength**	
	Min. Temp.	**Max. Temp.**	**Min. Temp.***	**Max. Temp.**
Pyrometer Low Range	275°C	2150°C	65°C	975°C
Pyrometer High Range	325°C	2600°C	135°C	2400°C
Lightpipe 2mm	220°C	1300°C	35°C	625°C
Lightpipe 3mm	215°C	1250°C	30°C	670°C
Lightpipe 4mm	210°C	1200°C	25°C	575°C

*Instrument temperature must be below target temperature.

Pyrometer Low Range 900 nm (275 – 2150°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	275°C	325°C	390°C	470°C
0.10°C Resolution	325°C	390°C	470°C	570°C
0.01°C Resolution	390°C	470°C	570°C	710°C

Pyrometer High Range 900nm (325 – 2600°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	325°C	385°C	465°C	565°C
0.10°C Resolution	385°C	465°C	565°C	700°C
0.01°C Resolution	465°C	560°C	695°C	890°C

Pyrometer Low Range 1600nm (65 - 975°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	65°C	80°C	108°C	148°C
0.10°C Resolution	102°C	125°C	154°C	201°C
0.01°C Resolution	146°C	175°C	215°C	275°C

Pyrometer High Range 1600nm (135 – 2400°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	135°C	160°C	198°C	255°C
0.10°C Resolution	188°C	225°C	270°C	350°C
0.01°C Resolution	258°C	308°C	370°C	485°C

Lightpipe 2mm / 900nm (220 – 1300°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	220°C	260°C	310°C	372°C
0.10°C Resolution	262°C	310°C	370°C	448°C
0.01°C Resolution	312°C	370°C	442°C	545°C

Lightpipe 3mm / 900nm (215 - 1250°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	215°C	253°C	302°C	362°C
0.10°C Resolution	255°C	300°C	360°C	435°C
0.01°C Resolution	304°C	360°C	430°C	525°C

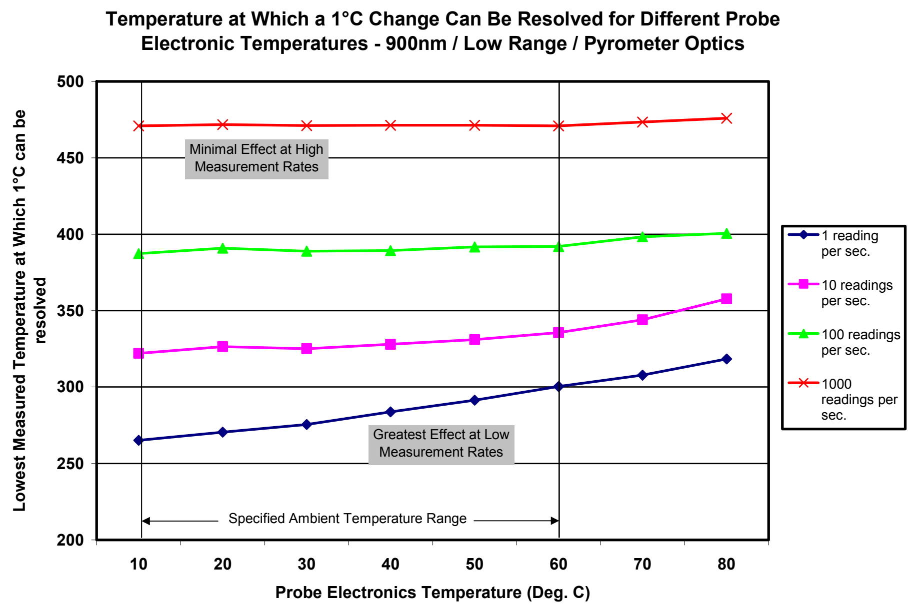
Lightpipe 4mm / 900nm (210 - 1200°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	210°C	248°C	295°C	355°C
0.10°C Resolution	250°C	295°C	350°C	425°C
0.01°C Resolution	297°C	350°C	422°C	510°C

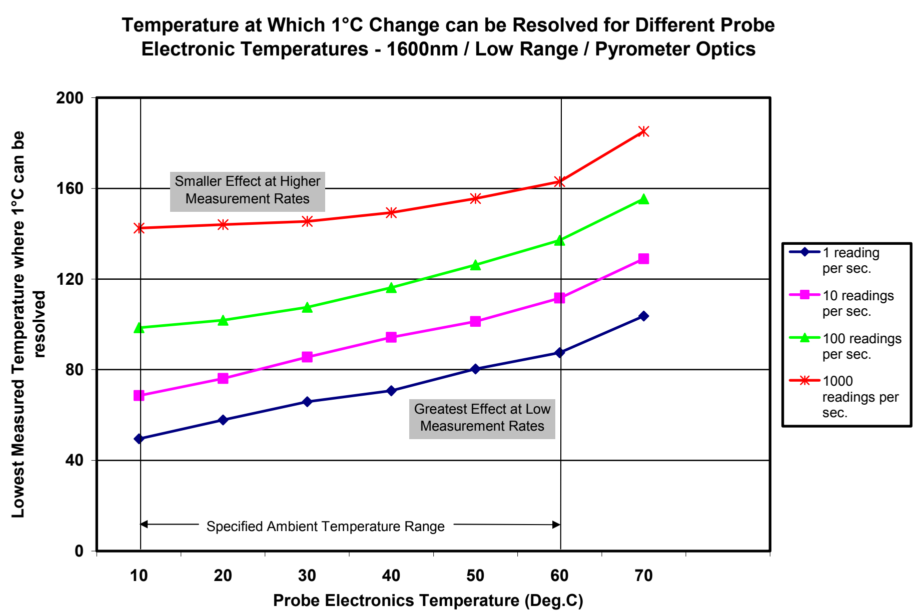
Lightpipe 2mm / 1600nm (35 - 625°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	35°C	44°C	60°C	90°C
0.10°C Resolution	55°C	75°C	93°C	130°C
0.01°C Resolution	90°C	111°C	138°C	181°C

Lightpipe 3mm / 1600nm (30 - 590°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.00°C Resolution	30°C	40°C	56°C	85°C
0.10°C Resolution	52°C	70°C	91°C	124°C
0.01°C Resolution	85°C	108°C	130°C	175°C

Lightpipe 4mm / 1600nm (25 - 575°C)				
Readings per second	**1**	**10**	**100**	**1000**
1.0°C Resolution	25°C	36°C	54°C	82°C
0.10°C Resolution	50°C	68°C	88°C	120°C
0.01°C Resolution	82°C	101°C	126°C	150°C

Section 3 - Ambient temperature effects:
All of the preceding data is based on an ambient probe temperature of 30°C. The internal electronics of an Exactus temperature probe will reach a temperature of approximately 30°C when running in a mildly warm room for an extended period. The measurement resolution will improve for cooler probe temperatures and degrade somewhat for warmer probe temperatures. As the following two graphs exhibit, the effect is more pronounced at lower measurement rates and smaller at higher measurement rates. For details on a particular probe configuration, please contact a factory applications engineer.





Section 4 - Optimizing measurement resolution:
If the target temperature is in the upper two thirds of the measurement range, the resolution will be 0.01°C or better. If the temperature is in the lower third, or the process naturally varies, several techniques can be used to optimize the measurement resolution:

Measurement averaging:
The Exactus probe can be configured so that each reading is based on a user selectable number of previous readings. For example, if the measurement rate is set at 100 readings per second, and the Averaging Buffer Depth is set to 10, than each of the 100 readings will be based on the average of the measurements taken over the previous one tenth (0.10) second.

The Averaging Buffer Depth may also be programmed so the number of points averaged changes as the process temperature changes. For example, if the probe measurement rate is set for 10 readings per second, the user can program the Averaging Buffer to use no averaging above 500°C, average 3 readings between 375 and 500°C, average 6 readings between 325 and 375°C, and average 10 readings for any temperature below 325°C.

Low temperature signal averaging:
There is also a feature, found on the 'Advanced' tab of the probe configuration menu, called ‘Low Temperature Signal Averaging’. Selecting the 'Low Temperature Signal Averaging' feature will instruct the probe to automatically optimize the amount of averaging (up to 1 second of averaging time), in the generation of each reading. As the temperature increases, the amount of averaging will decrease until the probe has sufficient light so that averaging is no longer required.

Cooling the electronics:
Reducing the temperature of the probe electronics will generally improve the measurement resolution (see graphs on previous page). BASF’s TemperaSure™ data acquisition software will record the probe operating temperature along with the temperature measurement data; please see the Exactus Optical Thermometer User Manual for details. The recommended minimum temperature for the probe electronics is 10°C (50°F).

Increasing available light:
The reason resolution degrades at the low end of a measurement range is due to the lack of light at the lower temperatures. If the measurement requirements allow for optics that will gather more light from the target, the measurement resolution will improve at lower temperatures. Some of the methods for gaining light include larger spot size pyrometers, larger diameter lightpipes, or possibly custom optics engineered for your process. Please consult a BASF Exactus applications engineer for assistance.

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