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Measurement Specification for Distributed Temperature Sensing

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1 Introduction

This document was written by and on the initiative of the SEAFOM Measurement Specifications Working Group. It is targeted specifically for “Distributed Temperature Sensing” (DTS). It is intended to be used as a guide to enable the characterization of performance of any DTS as defined by the measurement parameters and via the use of a standardized set of measurement practices contained: including test setups, procedures, and calculation methods. It is not intended to actually define any specific acceptance criteria for any given application, neither to limit the ability for any user to use any brand of DTS with any desired fiber and cable that is compatible with such system. The temperature controlling devices and the reference measurement equipment that are required to support these setups and procedures do not require any particular class of performance; however their performance parameters will limit the quality of the determination of the various fiber measurement parameters.

1.1 Objective

The objective of this document is to describe a harmonized set of DTS performance testing procedures. The testing procedures are valid for any brand or model of a DTS system. This document does not pose any requirements on the actual DTS system performance.

1.2 Scope

The scope of this document is to specify the measurement procedure for obtaining the following DTS performance parameters:

- Calibration Error
- Spatial Resolution
- Temperature Repeatability
- Spatial Temperature Resolution
- Environmental Temperature Stability
- Warm-up time

In addition to the group of measurement specifications, a list of supporting parameters has been defined to support the definition of the measurement specifications and their associated test procedures.

These supporting parameters are listed below:

- Temperature Sample Point
- Temperature Trace
- Temperature Measurement
- Distance Range
- Fiber Distance
- Total Fiber Length
- Measurement Time
- Sampling Interval
- Hot spot
- Start-up Time
- Point Defect
- Temperature Disturbance Width
- Temperature Offset

The definitions of these supporting parameters are provided for information purposes and shall be included with the sets of measurement specifications. A general test setup has been created with
which all specifications can be gathered through a set of tests. The specific tests are described within the section for each measurement parameter. This general test setup is depicted and described in Appendix A along with a list of general information that must be documented based upon the specific DTS instrument and test setup used to measure these parameters per this standard.

The Measurement Parameter Performance Table provided in Appendix B should be used to record the measured parameter values for a given DTS instrument and chosen optical test setup configuration.

Additional non-required measurement parameters and methods (Point Defect Effect and Optical Budget - Alternative 1 and Optical Budget - Alternative 2) are found in Appendices C, D AND E respectively. These sections are provided as guides to these optional measurements.

Appendix F suggests an additional test setup and procedure to directly measure Spatial Resolution instead of evaluating the response to multiple width hot spots described in Section 3.2.

Appendix G describes the test setup and procedure to measure calibration error for high temperatures.
2 Supporting Parameters Definitions

2.1 Temperature Sample Point:

2.1.1 Definition:

A “temperature sample point” is a measured temperature value associated with a single point at a known distance along a fiber. The measured value represents the temperature along a section of fiber which includes the point.

2.2 Temperature Trace:

2.2.1 Definition:

A “temperature trace” is a set of temperature sample points, at equally spaced distances, distributed along a single optical fiber. All the sample points are associated with a common time of measurement, often called the trace timestamp. The measured values represent the temperature during a period which includes the timestamp.

All the sample points in a “temperature trace” are measured values produced by the DTS, and not interpolated or smoothed values produced by subsequent processing outside the instrument.

2.3 Temperature Measurement:

2.3.1 Definition:

A “temperature measurement” is the operation of producing a new measured temperature value for every temperature sample point in a temperature trace.

2.4 Distance Range

2.4.1 Definition:

The “distance range” is the maximum distance from the instrument for which the manufacturer will measure and guarantee a measurable standard of performance. For the specified “distance range”, all of the other key measurement specifications shall be stated.

2.4.2 Usage:

Specified in distance units (e.g. 6km)

2.4.3 Comments:

This supporting parameter is closely related to the “optical budget” of the unit. In test cases used to prove or verify the reported specifications, the total fiber length shall be equal to or greater than the specified “distance range” (equal to or greater than twice the “distance range” in the double-ended configuration).

2.5 Fiber Distance

2.5.1 Definition:

The “fiber distance” is the optical distance from the connector on the unit to the desired temperature sample point along the fiber that is the furthest from the instrument for the particular test. In Appendices A & B, it is quantified as “Z”km and is often chosen to be the same as the distance range for purposes of comparing the measurement results with quoted specifications.

2.5.2 Usage:

Specified in distance units (e.g. 6 km).
2.5.3 Comments:

This parameter is used to report the distance from the instrument at which all parameters are measured. In the case of a double-ended test setup, no measurements shall be reported at a “fiber distance” beyond one half of the total fiber length.

2.6 Total Fiber Length

2.6.1 Definition:

The “total fiber length” is the maximum optical distance from the connector on the unit to the final end of the optical path. This end shall either be a purposefully cut or terminated end of the fiber physically far from the unit (in a single-ended configuration), or the end of a loop consisting of a connector that is connected to the same instrument (in a double-ended configuration).

2.6.2 Usage:

Specified in distance units (e.g. 12km).

2.6.3 Comments:

This parameter is either equal or greater than to the distance range if performance is specified in a single-ended configuration, or twice the distance range in the double-ended case.

2.7 Measurement Time

2.7.1 Definition:

The “measurement time” is the period between successive independent temperature measurements, when making continuous measurements on a single fiber. Equivalently, it is the time interval between successive temperature trace timestamps, under these conditions.

2.7.2 Usage:

Specified in time units (e.g. 8sec, 3.5min, or 1.2hrs).

2.7.3 Comments:

This parameter is sometimes referred to as “acquisition time”, but the processing time for the measurement must be included to be accurate. This value is selectable by the user typically in some limited fashion. Multiple independent temperature measurements may be averaged together to provide the desired measurement time.

2.8 Sampling Interval

2.8.1 Definition:

The “sampling interval” is the difference in fiber distance between consecutive temperature sample points in a single temperature trace.

2.8.2 Usage:

Specified in distance units (e.g. 0.5m).

2.8.3 Comments:

The “sampling interval” may be a user-specified parameter.
Each temperature measurement produces a temperature trace containing a full set of temperature sample points, updated at the specified trace timestamp, along the entire length of the fiber.

![Temperature trace diagram]

Figure 1 Example of a temperature trace with temperature sampling points

2.9 Hot spot

2.9.1 Definition:

The “hot spot” is a length of fiber which has been increased in temperature by an easily measurable temperature change of at least 20°C as confirmed by the reference temperature devices in the two thermal chambers. The “hot spot” has both a “height” (a ΔT of 20°C) and a width which is measured as the actual fiber length over which the temperature rise occurs.

2.9.2 Usage:

Specified in distance units (e.g. 1.5m).

2.9.3 Comments:

This parameter is used to assist the measurement of spatial resolution by providing a means to create and measure a known temperature event and then to confirm whether the DTS unit can “resolve” the associated temperature change within the specified tolerance (in this case ±2°C).

2.10 Start-up time

2.10.1 Definition:

The “start-up time” is the duration of time from the initial powering on the instrument until the first temperature measurement is permitted.

2.10.2 Usage:

A value of time(s) measured to the nearest 30 seconds corresponding to instrument starting temperatures of maximum, minimum, and nominal (20°C).
2.10.3 Comments:

This value is determined by the DTS system provider to insure safe operation of the instrument without risk of damage. It shall be specified for the maximum, minimum and nominal instrument operating temperatures. As a minimum, the worst case of these three values shall be specified.

2.11 Point Defect

2.11.1 Definition:

A “point defect" is a deviation of the optical fiber from its nominal optical and mechanical properties occurring at a single fiber distance, or over a range of fiber distances substantially less than the DTS spatial resolution.

2.11.2 Comments:

The definition of a point defect encompasses a wide range of situations, which may produce similar effects on the temperature trace. Examples include:

- A point loss, such as a bad fiber splice
- A back reflection, such as may arise from a fiber connector
- A localized region of high loss, such as a bend or kink in the fiber
- A physical discontinuity in the fiber, such as a splice between two fibers of different core diameters

The effect of a point defect on the temperature trace is determined according to the measurement procedure given below.

2.12 Temperature Disturbance Width

2.12.1 Definition:

The “temperature disturbance width” is the width of the zone on the temperature trace, where the presence of a point defect causes the error on the temperature sample points to lie outside the expected limits for the temperature repeatability of the undisturbed parts of the trace.

2.12.2 Comments:

Different types of point defect may produce different temperature disturbance widths. The width may be zero, if the defect produces no significant disturbance.

Temperature points more than three standard deviations away from the mean are considered to lie outside the expected limits for the temperature repeatability.

2.13 Temperature Offset

2.13.1 Definition:

The “temperature offset" is the difference between the average values of the temperature sample points in two zones on the temperature trace, one each side of a point defect, where the actual fiber temperatures are the same.

2.13.2 Comments:

The temperature offset may be positive, negative or zero.

The lengths and positions of the two zones are shown in Figure 17 in Appendix C.
3 Definitions and Procedures for Measurement Specifications:

3.1 Calibration Error

3.1.1 Definition:

The maximum difference between a running average of the measured temperature and the reference temperature for all data points over the full operating temperature range of the controlled fiber and all acquisition times, after system calibration.

3.1.2 Usage:

Single value (worst case) specified in temperature units (e.g. ±0.8°C).

3.1.3 Test Procedures and Conditions:

1. Use a standard SEAFOM “General Test Set-up” as shown in Appendix A.
2. Make the total fiber length (Z) equal to or greater than the distance range quoted for the specific DTS unit to be tested (twice the distance range in the double-ended configuration).
3. Place the DTS unit in a chamber and stabilize it at 20°C.
4. Calibrate the DTS units over a fiber temperature range from 0°C to 150°C.
5. Stabilize temperature of controlled fiber length(s) at each of the three stated temperatures (0°C, 75°C, and 150°C).
6. Collect 20 temperature traces at each of the three required measurement times (30 sec or fastest possible, 10 min., and 1 hour) for each fiber temperature. (same data sets can be used for the performance evaluations of spatial resolution, spatial temperature resolution, and temperature repeatability).

3.1.4 Parameter Calculation Method:

1. Calculate the calibration error as a function of fiber length by taking the difference between a centered and uniformly weighted running average of 51 temperature sample points from the actual fiber temperature (as measured by an independent calibrated reference sensor) over the entire distance range at each fiber temperature, and each averaging time. The largest value of the difference at any point for each acquisition time – fiber temperature set will be reported as the calibration error.
2. Compute the average of all 20 temperature traces for each temperature sampling point over the entire fiber distance.
3. Calculate the smoothed average by computing a centered and uniformly weighted running average over 51 of the averaged DTS readings.
4. Compute the average error for each sampling point by subtracting the smoothed average from the actual fiber temperature (as measured by a independent calibrated reference sensor) over the entire fiber distance.

5. Calculate the absolute average error by taking the absolute value of each average error for each temperature sampling point.
6. The calibration error for that set of test conditions is the maximum value of all absolute average error values that correspond to measurements collected from fiber that was clearly inside the stabilization chamber (no end or lead in fiber values are used for computation).

7. Repeat calculation steps 1 – 6 for all other sets of test conditions (a total of 6 conditions exist for each measurement time).

8. Record all 18 measured values for the calibration error in the Measurement Parameter Performance Sheet.

Note: A “High Temperature Calibration” test setup is described in Appendix G.
3.2 Spatial Resolution

3.2.1 Definition:

The smallest length of temperature effected fiber for which a DTS system can measure the reference temperature of this Hot Spot fiber condition.

3.2.2 Usage:

Single value (worst case) specified in distance units (e.g. 1.2 m).

3.2.3 Test Procedures and Conditions:

1. Use the standard SEAFOM “General Test Set-up”.
2. The “Hot Spot” fiber segment lengths shall be equal to the following:
   a. The “A” length shall be less than the claimed DTS unit spatial resolution, such that no single temperature point will show the “Hot Spot” reference temperature.
   b. The “B” length shall be equal to the claimed spatial resolution for the DTS unit being tested, such that one data point shows a temperature value increase within 10% of the temperature step difference to the segment reference temperature.
   c. The “C” length shall be greater than 4 times the claimed spatial resolution for the DTS unit being tested.
3. The sampling interval must be less than or equal to one-half the claimed spatial resolution.
4. “Hot Spots” will be 20°C hotter than surrounding fiber temperature. Collect performance data set as specified in calibration error.
5. Collect performance data set as specified in calibration error.

3.2.4 Parameter Calculation Method:

1. Spatial resolution is equal to the “B” fiber segment length, and is validated with this test by at least one data point in the “B” segment fiber calculating a temperature equal to 90% or greater of the “Hot Spot” reference temperature increase (18 °C above surrounding fiber) above the surrounding fiber temperature.
2. The “A” fiber segment must validate that no data points show the hot spot reference temperature.
3. The “C” fiber hot spot segment must show all data points past the spatial resolution length equal to the hot spot reference temperature, within the expected spatial temperature resolution.

![Spatial Resolution illustration](image)

Figure 5 Spatial Resolution illustration

Note: An additional test setup and procedure for the direct measurement of Spatial Resolution is described in Appendix F.
3.3 Temperature Repeatability

3.3.1 Definition:

The temperature repeatability is the random variation in calculated temperature between successive temperature traces, at a given fiber distance. It is determined from twice the standard deviation of corresponding temperature sample points in each temperature trace, with the fiber held at constant temperature.

3.3.2 Usage:

A table of values selected from calculated values for each measurement time and at two specified in distances (100m and Z-100m) for all fiber temperatures; specified in temperature units (e.g. ± 0.24°C).

3.3.3 Test Procedures and Conditions:

1. Use the standard SEAFOM “General Test Set-up”.
2. Collect performance data set as specified in calibration error:
3. Collect 20 consecutive traces with a quoted spatial resolution over the fiber length Z after the fiber temperature is stabilized:
   a. for each measurement time (30s, 10min, 1 hr) and
   b. for all fiber temperatures (0°C, 75°C and 150°C).
4. The performance data set comprises 9 data subsets for above specified pairs of measurement time and fiber temperature.
5. Each subset is used to evaluate the values of temperature repeatability over length. The results are to be plotted and the values for the distances at 100m and Z-100m are to be stated in the “Measurement Parameter Performance Table”.

3.3.4 Parameter Calculation Method:

1. Collect 20 consecutive traces for each data subset.
   E.g. Traces for 10min measurement time at a fiber temperature of 75°C:

![Figure 6 Temperature Repeatability calculation step 1.](image)

2. Calculate the temperature repeatability for each spatial data point over time (20 consecutive traces) by taking twice the standard deviation of temperature for each single data point. Plot above calculated twice the standard deviation values vs. distance.
   E.g. Twice the Standard Deviation of the traces shown in Figure 6.
3. Create a 51 point equally center weighted moving average curve $S_i$ to use to select the reported distance based temperature repeatability values for each measurement time at each fiber temperature.

4. Report the distance based temperature repeatability for two fiber distances, 100 m, and at (Z-100m). Report in the Measurement Performance table.

Figure 8 represents temperature repeatability as a function of fiber distance.
5. Repeat this procedure at each measurement time for each "Fiber Temperature".

Formulas:

Standard Deviation:

\[ s_X := \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \]

Moving average applied on twice the Standard Deviation:

\[ S_i := \frac{1}{51} \sum_{x = i - 25}^{i + 25} 2 \times S_X \]

3.4 Spatial Temperature Resolution

3.4.1 Definition:

The spatial temperature resolution is the random variation in calculated temperature with fiber distance, in a single temperature trace. It is determined from twice the standard deviation of adjacent temperature sample points, with the fiber held at constant temperature.

3.4.2 Usage:

A table of values selected from the calculated values for each measurement time and at two specified distances (100m and Z-100m) for all fiber temperatures; specified in temperature units (e.g. ±0.24°C).

3.4.3 Test Procedures and Conditions:

1. Use the standard SEAFOM “General Test Set-up”.
2. Collect 20 consecutive traces of temperature data over fiber length Z set as specified in calibration error after the fiber temperature is being stabilized:
   - for each measurement time (30 s, 10 min., 1 hr)
   - for all fiber temperatures (0°C, 75°C, 150°C)

3.4.4 Parameter Calculation Method:

1. Calculate twice the standard deviation over 51 points (centered and uniformly weighted) of collected temperature \( T_j(i) \) for each data point of a single temperature trace.

   \( T_j(i) \): collected temperature data at \( i \)-th fiber distance of \( j \)-th trace.

   \( S_j(d) \): the Standard deviation over 51 points at \( d \)-th fiber distance of \( j \)-th trace;
Figure 9 Spatial Temperature Resolution: 20 traces collected over time $T_j(i)$

$$S_j(d) = \sqrt{\frac{n \sum_{i=d-25}^{d+25} (T_j(i))^2 - \left( \sum_{i=d-25}^{d+25} T_j(i) \right)^2}{n(n-1)}}$$

$d = 100$ m to $Z-100$m: temperature sampling point
$n = 51$: Number of data points for calculation

2. Calculate the spatial temperature resolution $A(d)$ by averaging $2 \times S_j(d)$ for 20 traces collected over time at $d$-th fiber distance.

$$A(d) = \frac{2 \times \sum_{j=1}^{20} S_j(d)}{20}$$

3. Report the distance based spatial temperature resolution $A(d)$ for two fiber distances $d = 100$ m (or as close as measurable) and the distance range - 100m ($Z-100m$) for each measurement time at each fiber temperature. Report in the Measurement Parameter Performance table.
Figure 10 Spatial Temperature Resolution: 51 point running standard deviations $S_j(d)$

Figure 11 Spatial Temperature Resolution: 20 trace average. A(d) over time of 2 x $S_j(d)$
3.5 Environmental Temperature Stability

3.5.1 Definition:

The variation in the measured fiber temperature for measurements taken across the entire instrument operating temperature range. This includes the following three aspects:

Worst Case Environmental Temperature Effect: The maximum variation in the measured fiber temperature at different distances during a complete environmental temperature cycle.

High/Low Environmental Temperature Effect: The difference in the measured fiber temperature at each of the extremes (Cold and Hot) of the instrument temperature operating range.

Environmental Temperature Repeatability: The difference in the measured fiber temperature at a set instrument temperature before and after temperature cycling.

3.5.2 Usage:

A table of values for each of the definitions.

3.5.3 Test Procedures and Conditions:

1. Use the standard SEAFOM “General Test Set-up”.

2. Fiber to be held at constant temperature of 75°C for entire environmental test.

3. Instrument to be contained within a chamber and cycled through the environmental temperature cycle described in the table below.

The example given below is for a specified instrument operating temperature range of 0°C to 40°C. If an instrument has a wider operating temperature range, then the temperature cycle shall still follow the same outline of 3 hour hold periods, 20°C/hr ramp periods, and hold temperatures of the minimum, maximum and mid points of the instrument operating temperature range.

<table>
<thead>
<tr>
<th>Step Time (hrs)</th>
<th>Total Time (hrs)</th>
<th>Temp (deg C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
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<td>13</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>20</td>
</tr>
</tbody>
</table>

Figure 12 Example of environmental temperature cycle.

4. Collect temperature traces throughout the environmental cycle using a measurement time of 10 minutes.

3.5.4 Parameter Calculation Method:

1. Calculate a 101 point moving average (centered and uniformly weighted) of the temperature sample points from every collected temperature trace.

2. Determine the peak to peak variation in moving average temperatures at each distance point of the temperature stabilized fiber across all temperature traces taken during the environmental temperature cycle.
3. The **Worst Case Environmental Temperature Effect** will be quoted as the worst case peak to peak (maximum – minimum) value calculated in the previous step.

4. Average the 101 point moving averages temperatures for each temperature sample point calculated above (step 1), for the last 6 temperature traces taken during each hold period i.e. average the last hour of measurements taken at the hold temperatures of middle, minimum, maximum and middle again of the instrument operating range.

5. Calculate the difference between these values collected at the maximum operating temperature and the initial middle operating temperature and take the maximum difference for any temperature sample point as the **High Environmental Temperature Effect**.

6. Calculate the difference between the values in step 4, collected at the minimum operating temperature and the initial middle operating temperature and take the maximum difference for any temperature sample point as the **Low Environmental Temperature Effect**.

7. Calculate the difference between the values in step 4, collected at the initial middle operating temperature and the final middle operating temperature, and take the maximum difference for any temperature sample point as the **Environmental Temperature Repeatability**.

The following figure gives a better understanding of the calculations required.

![Environmental Temperature Stability parameter calculation method](image)
3.6 Warm-up Time

3.6.1 Definition:

The duration of time starting from the initiation of the first temperature measurement until the unit complies with the stated values of the main measurement specifications.

3.6.2 Usage:

A value of time(s) measured to the nearest 30 seconds corresponding to instrument operating temperatures of maximum (hot), minimum (cold), and nominal (20°C). All measurements shall be collected and recorded for the fiber distance of Z-100 meters only.

3.6.3 Comment:

If a warm-up time of less than 10 minutes is possible and desired, then a shorter measurement time than 30 seconds may be used. In this case, the main measurement specifications used as thresholds in this specification must also be generated and reported in the same way with the same shorter measurement time.

3.6.4 Test Procedures and Conditions:

1. Use the standard SEAFOM “General Test Set-up”. All main measurement specifications shall have been previously determined.
2. Fiber is to be held at a constant temperature of 75°C for the entire environmental test. The instrument is to be contained within a chamber set to the nominal operating temperature (20°C). The instrument shall be powered off completely, and must be allowed to stabilize within the chamber for at least 3 hours.
3. After the 3 hour soak, power on the instrument normally, but do not initiate a temperature measurement.
4. Allow the unit to wait the specified start-up time then begin the first temperature measurement with the measurement time set to 30 seconds and start a timer.
5. Continue collecting temperature traces at the 30 second measurement time.
6. Calculate the calibration error, the spatial temperature resolution, and the temperature repeatability using the same methods as described in the elsewhere within this document for each measurement specification with the following exceptions: For all three of these measurement specifications, the distance at which they shall be measured and recorded is Z-100 meters only. For calibration error, no averaging over time shall be performed – the value is calculated from each individual trace. For spatial temperature resolution, a running average of the last 20 temperature traces collected over time shall be used. For temperature repeatability, a running standard deviation of the last 20 temperature traces collected over time shall be used.
7. Once the measured values of all three main measurement specifications meet or exceed the claimed values for those parameters at a 30 second measurement time, then the timer is stopped and the time duration is recorded.
8. Record the time duration as the warm-up time for the nominal instrument temperature (20°C).
9. Repeat steps 2 through 7 except set the initial temperature of the chamber that contains the instrument to the minimum operating temperature. Do not allow the instrument to cool at a rate greater than 20°C / hour. Record the time duration as the warm-up time for the minimum instrument operating temperature.
10. Repeat steps 2. through 7. except set the initial temperature of the chamber that contains the instrument to the maximum operating temperature. Do not allow the instrument to cool at a rate greater than 20°C / hour. Record the time duration as the warm-up time for the maximum instrument operating temperature.

3.6.5 Parameter Calculation Method:

1. Use the calculation methods described for the main measurement parameters with the exceptions as described in step 2. listed above in the test procedures.

2. Refer to the charts below showing the hypothetical results from such tests for the case where the instrument started at the minimum operating temperature, and note that the reported value is determined as the longest time for any of the three main specification parameters to reach its specified value.

3. Note that each point in the graphs below represents a 10 minute (20 point over time) running average or 2 x running standard deviation, depending on the measurement specification. The X-axis begins at 10 minutes as this is the minimum time required to gather 20 temperature traces at a 30 second measurement time.

4. In the hypothetical example below, the spatial temperature resolution meets the specification at 13.0 minutes (all points starting at 13.0 minutes are below the specification value of 0.5°C).

5. In the hypothetical example below, the temperature repeatability meets the specification at 15.0 minutes (all points starting at 15.0 minutes are below the specification value of 0.8°C).

6. In the hypothetical example below, the calibration error meets the specification at 18.0 minutes (all points starting at 18.0 minutes are below the specification value of 1.0°C).

7. Since the longest time to meet all three measurement specifications is 18.0 minutes, then this is the reported value for the warm-up time for the minimum operating temperature.
Figure 14 Example illustrating the calculation of the warm-up time.
Appendices

Appendix A

A.1 General Test Setups

The General test setups depicted below aim to provide a common base for determining the measurement specifications while at the same time minimizing complexity, cost, reconfiguration requirements, and test execution time. The lengths of the fiber coils in the chambers at the end of the setup are selected based upon the expected spatial resolution for the system. The longer length of fiber in the center chamber is chosen to make the total fiber length match the distance range of the particular DTS model being tested. The use of 1km lengths, located before and after a long length “W” of fiber (which makes up the total fiber length “Z”), provides a test setup capable of accommodating various instruments with different distance ranges from as short as 2km to as long as is required. However, the use of a length of fiber outside the central chamber is optional – all fiber may be contained within the chamber if desired as single or multiple coils. The total fiber length “Z” is equal to the total length of fiber from the instrument connector up to the start of the spatial resolution fiber section, and is roughly equal to “W” plus 2km. Fusion splices are used to minimize additional optical losses and unwanted back-reflections.

It must be noted that the General Test Setup provides a schematic diagram only. The real implementation may differ in certain respects such as replacing any of the fiber containing chambers with liquid filled calibration baths or replacing the double chamber with an alternative implementation that provides a large and sharp enough temperature difference between the coils (at least 20°C occurring over no longer than 50% of the rated spatial resolution).

A.1.1 Test Setup Requirements

It is required that the uncertainty of the reference temperature measurement is at least a factor 5 smaller than the calibration error that is being assessed. Such reference temperature sensors are not shown in the setup diagrams but are required to be present and properly calibrated within each temperature chamber and/or bath.

Setting requirements on the homogeneity or stability of the chambers or the sharpness of the realized temperature step is not necessary. Failure to realize these test setup qualities at a sufficient level will only produce measurement data that is more conservative (worse performance).

A.2 General required documented information:

- The completion date of all testing
- The name of the organization executing the testing
- The test setup configuration (single-ended or double-ended as shown below)
- The operating mode of the instrument (either single-ended or double-ended)
- The measurement time used for initial calibration (prior to calibration error measurement)
- The wavelength(s) of the launched signals (operating wavelength(s))
- The wavelength used to measure the loss to end of the fiber distance (Zkm)
- The distance range of the DTS instrument
- The sampling interval used for all measurements
- The spatial resolution setting used for all measurements
- The measurement time used during system calibration
- The lengths of fiber coils “A”, “B”, and “C” and spool(s) “W”
- The nominal temperature “Y” in °C of the cooler side of the double-chamber
- The hot and cold operating temperature limits (°C) of the DTS instrument

General Test setup: single-ended configuration

General Test setup: double-ended configuration

The general required information for the tested DTS unit and the associated test setup shall be recorded along with the calculated measurement specifications in a table as provided in Appendix B. For both configurations shown above, “Z” is equal to W + 2km.
Appendix B: Measurement Parameter Performance Table

Test Completion Date: ___________ Testing Organization: __________________________

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>30 sec</th>
<th>10 min</th>
<th>1 hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber Distance</td>
<td>m</td>
<td>100</td>
<td>(Z - 100)</td>
<td>100</td>
</tr>
<tr>
<td>Fiber Temperature</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Calibration Error</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Temperature Repeatability</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Spatial Temperature Resolution</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Spatial Resolution</td>
<td>m</td>
<td>0</td>
<td>100</td>
<td>(Z - 100)</td>
</tr>
<tr>
<td>Warm-up Time - nominal</td>
<td>sec</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Warm-up Time - cold</td>
<td>sec</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Warm-up Time - hot</td>
<td>sec</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Worst Case Env. Temp. Effect</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Low Environmental Temp. Effect</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>High Environmental Temp. Effect</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Environmental Temp. Repeatability</td>
<td>°C</td>
<td>0</td>
<td>75</td>
<td>150</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test Setup Configuration:</th>
<th>Single-ended</th>
<th>Double-ended</th>
<th>Calibration measurement time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating mode</td>
<td>Single-ended</td>
<td>Double-ended</td>
<td>Wavelength(s) of launched signal(s) (nm)</td>
</tr>
<tr>
<td>DTS Make &amp; Model</td>
<td>DTS serial number</td>
<td>A coil length (m)</td>
<td></td>
</tr>
<tr>
<td>Fiber Make</td>
<td>Fiber Model</td>
<td>B coil length (m)</td>
<td></td>
</tr>
<tr>
<td>Distance Range (km)</td>
<td>Sampling Interval (m)</td>
<td>C coil length (m)</td>
<td></td>
</tr>
<tr>
<td>Fiber Distance “Z” (km)</td>
<td>Optical loss at Z (dB)</td>
<td>W spool length (m)</td>
<td></td>
</tr>
<tr>
<td>Spatial resolution setting (m)</td>
<td>Wavelength of loss measurement (nm)</td>
<td>Y temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>Higest instrument operating temp. (°C)</td>
<td>Lowest instrument operating temp.(°C)</td>
<td>Start-up Time (min)</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** Although this table is intended to record the measured parameter values, a similar table may be used to provide a set of quoted specifications for the same measurement parameters.

**Requirement:** All different fiber makes and models used in any of the coils within the configurations must be individually identified. If a shorter measurement time has been used to specify warm-up time, then the calibration error, spatial temperature resolution, and temperature repeatability must also be reported on a separate page.

**Guidance:** For actual installations optical loss in the path can be traded against fiber distance using the reported loss figure. For multi channel systems the measurements should be performed on the least favorable channels by design.
Appendix C

C.1 Point Defect Effects

C.1.1 Definition:

*Note:* This procedure allows the effect of a specific *point defect* on the measurement performance of a DTS (and associated fiber) to be measured in a controlled way. For example, the *point defect* might be a wet-mate connector with its own particular levels of loss, back reflection, and other properties. Because of the difficulty of creating a test *point defect* which is both representative of real-world defects, and reproducible between test setups, it is recommended that the parameters measured by the following procedure be used only to compare the effects of the same *point defect* on different instruments.

For these reasons, the response to a *point defect* is not a recommended DTS specification item. This test does not make use of the SEAFOM General Test setup described in Appendix A.

C.1.2 Point Defect

The effect of a *point defect* on the measurement performance of a DTS is characterized by the following parameters:

- The *temperature disturbance width* caused by the *point defect*. The zone of temperature disturbance is defined as that length of the temperature trace where the error on the indicated temperature is outside the expected bounds for the performance of the DTS under test, on undisturbed fiber.
- The temperature offset caused by the point defect. The offset is the difference between the average indicated temperatures along two lengths of the temperature trace immediately each side of the zone of temperature disturbance.
- The calibration error increase caused by the point defect. The point defect may cause an increase in calibration error, measured over a specified fiber length each side of, but excluding the zone of temperature disturbance.

This procedure applies to any type of *point defect*.

C.1.3 Test Procedures and Conditions:

1. The *point defect* to be tested must be fusion-spliced between two equal lengths of fiber, each of which must be a minimum of 1km long. The two fibers must be loose wound or wrapped on collapsible spools, and the *point defect* and both fiber lengths must be placed in a temperature-controlled chamber. The fiber type and length, a description of the *point defect*, and any available measurements such as its forward and return losses, must be recorded. For a DTS operating in double-ended mode, both fiber ends are connected to the DTS, so the *point defect* is at the center of the loop.
2. Configure the DTS as for normal operation with an undisturbed fiber, including calibration of the fiber, if this is standard for normal operation. The DTS must be configured to provide a full temperature measurement for all temperature sample points including those at the location of the *point defect*. The spatial resolution used must be stated.
3. Stabilize the test fiber, including the *point defect*, at a temperature of 75°C.
4. Collect 20 consecutive temperature traces at measurement times of 30s and 10min. The following steps (5 to 10) must be repeated for each measurement time.
5. Calculate the average temperature along a 51-point section of each averaged trace, 25m each side of the (nominal) location of the *point defect* (these are the points highlighted in red below: the nominal location of the *point defect* is shown in cyan). The two average temperatures are shown in blue and green. The sampling interval in this example is 0.5m.
6. Repeat the calculation of the two average temperatures for the entire set of 20 traces, and form the grand average of each. Report the difference between the two grand averages, the temperature offset. One temperature offset must be calculated for each measurement time.

7. Calculate the standard deviation of the 51 points in each of the two sections. Repeat the calculation for the entire set of 20 traces, and take the average of the 20 results to obtain the temperature standard deviation σ of each section.

8. For each trace, use the two measured temperature standard deviations to obtain error bounds at ±3σ about the two average temperatures each side of the nominal location of the point defect (these are shown as dashed lines).

9. Calculate the fiber distance of the first sample point within ±25m of the nominal defect location to lie outside the left (green) error bounds, and the fiber distance of the last sample point within ±25m of the nominal defect location to lie outside the right (blue) error bounds. Repeat the calculation for the entire set of 20 traces, and calculate the median of the 20 results to obtain the temperature disturbance width. One temperature disturbance width must be calculated for each measurement time.

10. Use the parameter calculation method from section 5 of this document to calculate the calibration error for the test fiber, excluding the 25m each side of the nominal location of the point defect. One calibration error must be calculated for each measurement time.

11. The test results shall be reported including the following information:

   1. The type of point defect introduced and its location; also measurements of loss, back-reflection, or other parameters, if available,
   2. The averaging time and spatial resolution used,
   3. The measured temperature disturbance width,
   4. The measured temperature offset,
   5. The measured calibration error.

If an appropriate baseline exists (i.e. a measurement of calibration error using the same length and type of fiber as in the point defect test) the baseline calibration uncertainty shall also be reported. It is recommended that the baseline calibration error is always reported.
Appendix D

D.1 Optical Budget test - Alternative 1

D.1.1 Definition:

The “optical budget” corresponds to the total cumulated optical loss (one way loss) tolerated by the system without affecting the DTS measurement performance more than a given factor at a given fiber distance, spatial resolution and measurement time.

D.1.2 Usage:

The “optical budget” is given as a one-way optical loss measured in decibels (dB).

D.1.3 Comments:

- The total cumulative loss can be the fiber attenuation, point defect losses introduced by components such as connectors, splices, kink in the fiber, attenuators, etc.
- The optical budget as evaluated with this procedure corresponds to the average fiber attenuation/losses over the different wavelengths used by the system.
- The optical budget may depend on other measurement parameters, such as measurement time, spatial resolution and fiber distance; these parameters shall be mentioned together with the reported optical budget.
- The optical budget may be evaluated by measuring the temperature repeatability and/or spatial temperature resolution for a given spatial resolution and given measurement time.
- The optical budget is estimated taking into account the “maximum acceptable temperature repeatability” set by the application requirements, e.g. a DTS can accommodate 3dB of total loss at a fiber distance of 5km, a measurement time of 10 minutes, and at a spatial resolution of 1.7 meters while maintaining a 0.5°C temperature repeatability which corresponds to the maximum acceptable temperature repeatability for the application.
- The optical budget shall NOT include the loss of the fiber connector at the wall of the instrument enclosure itself. However, it is cautioned that this loss be minimized and verified (if possible) to be within the normal loss levels of such connectors (typically < 0.5dB).

The system “optical budget” is determined according to the measurement procedure given below.

D.1.4 Definitions and Procedures for Measurement Specifications:

The “optical budget” for a given spatial resolution and measurement time is measured by evaluating the effect of additional loss introduced in the optical system on the temperature repeatability and/or spatial temperature resolution. The additional loss (typically created by a variable optical attenuator) is then added to the total cumulative loss measured at the same Z-100 meter fiber distance to compute the “optical budget”. In the hereafter test procedure, the optical budget is evaluated with respect to the temperature repeatability performance, as an example. The same procedure can be used to evaluate the optical budget for spatial temperature resolution.

D.1.5 Test Procedures and Conditions:

The temperature repeatability is measured using the SEAFOM “General Test Setsups” Fig. 15 (Single-ended) or Fig. 16 (Double-ended) while the additional loss is introduced by means of a variable optical attenuator (VOA). The VOA is placed outside the 2 temperature chambers where the DTS and 1km fiber spools are placed. It is connected to the DTS output fiber and to the first 1km fiber spool. The spatial resolution test section is optional for this test.

The 1 km fiber spools are maintained at a 75°C temperature. The additional attenuation is gradually increased and both the temperature repeatability and spatial temperature resolution are measured.
until the temperature repeatability is until the “maximum acceptable Temperature Repeatability” is exceeded at distance Z-100m.

The “optical budget” reported value shall correspond to the VOA attenuation plus the cumulated fiber & point defect losses over the distance Z-100 (measured at the system operating wavelength). The “optical budget” shall be evaluated for a given spatial resolution and for a 10min. acquisition time.

The detailed procedure is as follows:

1. Use the standard SEAFOM “General Test Set-up” but with the modifications as shown above in Figure A. Preferably by fusion splicing, insert a VOA (variable optical attenuator) into the fiber path between the chamber containing the instrument and the chamber contain the long length of fiber. All main measurement specifications shall have been previously determined per the procedures described in this document.
2. Insure that the variable optical attenuator is set to its minimum value: this should ideally result in an insertion loss of less than 1.0 dB at the operating wavelengths of the instrument.
3. Fiber is to be held at a constant temperature of 75°C for the entire test. The instrument is to be contained within a chamber set to the nominal operating temperature (20°C). Allow sufficient time for the instrument to stabilize within the chamber (normally 3hrs).
4. Collect 20 temperature traces at a 10 minutes measurement time.
5. Calculate the temperature repeatability and spatial temperature resolution using the same methods as described in the main body of MSP018 for both measurements.
6. Compare the obtained temperature repeatability with the “maximum acceptable Temperature Repeatability”.
7. Change the VOA setting in order to increase the attenuation by steps of about 0.5dB.
8. Repeat steps 4 through 7 until the calculated temperature repeatability is larger than the “maximum acceptable Temperature Repeatability” at a fiber distance of Z-100 meters.
9. Disconnect the test fiber and measure the VOA attenuation preferably using a cut-back method.
10. Report the “optical budget” values as the sum of the VOA attenuation, all point defect / connector losses (excluding that at the instrument) plus the fiber loss over the distance Z-100 (measured at the system operating wavelength). Also report the considered “maximum acceptable temperature repeatability”.

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Appendix E

E.1 Optical Budget test - Alternative 2

E.1.1 Definition:
The Optical Budget test provides an informational plot of Spatial Temperature Resolution vs loss at a specified spatial resolution and various averaging times.

E.1.2 Usage:
A single graph with plots of Spatial Temperature Resolution vs Loss for various measurement times.

E.1.3 Test Procedures and Conditions

1. Use the standard SEAFOM "General Test Set-up", including the VOA. The length W can be any desired length
   i. The fiber length, W, may also be placed in the fiber spool oven to maintain a constant temperature over the whole measurement length
2. Set the fiber spool oven to 75 °C
3. Set the instrument oven to 20 °C
4. Set the VOA to the minimum loss setting
5. Measure the distributed loss of the test set-up at the pump wavelength of the instrument (using OTDR or return signals of the instrument)
6. Collect a single trace with a quoted spatial resolution over the fiber length Z after the fiber temperature is stabilized for each of the following measurement times:
   a. 30 seconds per trace
   b. 10 minutes per trace
   c. 1 hr per trace
7. Increase the loss of the VOA
8. Repeat steps 5, 6 and 7 until the instrument reports errors or bad data
9. Create a chart of Spatial Temperature Resolution vs loss according to the Parameter Calculation Method, with plots for each measurement time

E.1.4 Parameter Calculation Method

Calculate twice the standard deviation ($2 \times S(d)$, below) over 51 points (centered and uniformly weighted) of collected temperature for each data point of each temperature trace

$$ S(d) = \sqrt{\frac{n \sum_{i=d-25}^{d+25} (T(i))^2 - \left( \sum_{i=d-25}^{d+25} T(i) \right)^2}{n(n-1)}} $$

$S(d) = $ Standard deviation

$T(i) = $ Temperature data

d = 100m to Z-100m: temperature sampling point

n = 51: Number of data points for calculation

1. Establish the loss at the location of each data point of each temperature trace from the OTDR (or instrument return signal loss) trace at each VOA setting
2. Plot the Resolution vs Loss for all VOA settings for a single measurement time on the same graph (see Figure 18)
3. Add an exponential function trendline through the entire data set for the single measurement time
4. Repeat steps 3 and 4 for all measurement times
5. Plot the trendlines for all measurement times on a single graph (see Figure 19)
Appendix F

F.1 Spatial Resolution (additional test method)

F.1.1 Definition:

The smallest length of temperature effected fiber for which a DTS system can measure the reference temperature of this Hot Spot fiber condition.

F.1.2 Usage:

Single value specified in distance units (e.g. 1.2 m).

F.1.3 Comments:

The described test method has been proposed to the SEAFOM MSP-01 working group as an alternative to the original spatial resolution test described in chapter 3.2. As the spatial resolution is dependent upon the total fiber length (dispersion) and the fiber type (bandwidth), the original spatial resolution test in chapter 3.2 requires a different test setup with different A, B (and C) length for each fiber configuration to do the correct “binning”. The main advantage of the proposed alternative test procedure is the direct measurement of the spatial resolution for any fiber type and any fiber length with just one single test setup. A comparison of the spatial resolution values derived from both test methods showed excellent congruence.

F 1.4 Test Procedures and Conditions:

1. Use the simplified SEAFOM “General Test Set-up”.
2. The “Spatial Reference Temperature Step” fiber segment lengths shall be equal to the following:
   a. The “A” length is uncritical but shall be greater than at least 5 times the maximum claimed spatial resolution for the DTS unit being tested, e.g. 100 meters and will be at least 20°C hotter than surrounding “C” fiber temperature.
   b. The “C” length is uncritical but shall be greater than at least 5 times the maximum claimed spatial resolution for the DTS unit being tested, e.g. 100 meters.
3. The sampling interval must be less than or equal to one-half the claimed spatial resolution.

F 1.5 Parameter Calculation Method:

1. Spatial resolution is determined by measuring the maximum spatial distance the DTS needs to follow an abrupt spatial change of the reference temperature, measured between 10% and 90% of a positive change or 90% to 10% for a negative change in reference temperature.
2. Compute the average temperature over 2.5 times the estimated spatial resolution before and after the temperature step to get the 0% and 100% temperatures. Compute the 10% and 90% temperatures. Ignore preshoot / overshoot region.
3. Compute the difference of the spatial locations at 10% and 90% for the positive temperature step and the difference of the spatial locations at 90% and 10% for the negative temperature step using an appropriate interpolation method (e.g. cubic spline or least squares fit of an appropriate response function). A linear interpolation method is not sufficient for the calculations.
   (1) The interpolation method must be reported as part of the test results.
   (2) The error margin must be reported.
4. Convert the measured 10/90% value to Spatial Resolution by multiplication with 1.31
5. Convert the measured 90/10% value to Spatial Resolution by multiplication with 1.31
6. Record the larger of the 2 values as spatial resolution in the Measurement Parameter Performance Sheet.
F.2 Simplified General Test Setups

The alternative test setups depicted below aim to provide a common base for determining the measurement specifications while at the same time minimizing complexity, cost, reconfiguration requirements, and test execution time. The lengths of the fiber coils in the chambers at the end of the setup are selected to be large compared to the expected spatial resolution for the system (e.g., 100 m each). The longer length of fiber in the center chamber is chosen to make the total fiber length match the distance range of the particular DTS model being tested. The use of 1km lengths, located before and after a long length “W” of fiber (which makes up the total fiber length “Z”), provides a test setup capable of accommodating various instruments with different distance ranges from as short as 2km to as long as is required. However, the use of a length of fiber outside the central chamber is optional – all fiber may be contained within the chamber if desired as single or multiple coils. The total fiber length “Z” is equal to the total length of fiber from the instrument connector up to the start of the spatial resolution fiber section, and is roughly equal to “W” plus 2km. Fusion splices are used to minimize additional optical losses and unwanted back-reflections.

It must be noted that the Simplified General Test Setup provides a schematic diagram only. The real implementation may differ in certain respects such as replacing any of the fiber containing chambers with liquid filled calibration baths or replacing the double chamber with an alternative implementation that provides a large and sharp enough temperature difference between the coils (at least 20°C occurring over at least 5 times of the maximum rated spatial resolution).

Test Setup Requirements

It is required that the uncertainty of the reference temperature measurement is at least a factor 5 smaller than the calibration error that is being assessed. Such reference temperature sensors are not shown in the setup diagrams but are required to be present and properly calibrated within each temperature chamber and/or bath.

Setting requirements on the homogeneity or stability of the chambers or the sharpness of the realized temperature step is not necessary. Failure to realize these test setup qualities at a sufficient level will only produce measurement data that is more conservative (worse performance).
General required documented information:

- The completion date of all testing
- The name of the organization executing the testing
- The test setup configuration (single-ended or double-ended as shown below)
- The operating mode of the instrument (either single-ended or double-ended)
- The measurement time used for initial calibration (prior to calibration error measurement)
- The wavelength(s) of the launched signals (operating wavelength(s))
- The make and model number and serial number of the DTS instrument
- The make, model, and length of the fiber in the test setup (inside the temperature chamber(s))
- The optical loss (one-way in dB) of the optical setup to the end of the fiber distance (Zkm)
- The wavelength used to measure the loss to end of the fiber distance (Zkm)
- The distance range of the DTS instrument
- The sampling interval used for all measurements
- The spatial resolution setting used for all measurements
- The measurement time used during system calibration
- The lengths of fiber coils “A” and “C” and spool(s) “W”
- The nominal temperature “Y” in °C of the temperature step chamber
- The hot and cold operating temperature limits (°C) of the DTS instrument

General Test setup: single-ended configuration

![Diagram of single-ended configuration]

Figure 21  Simplified General Test Setup: Single-ended
Figure 22. Simplified General Test Setup: Double-ended

The general required information for the tested DTS unit and the associated test setup shall be recorded along with the calculated measurement specifications in a table as provided in Appendix B.
Appendix G

G.1 High temperature calibration test setup

G.1.1 Definition:

High temperature calibration is required to achieve proper temperature accuracy in high temperature applications. We have chosen a setup with short (100m) lengths for proving the accuracy at 20, 75 and 250°C at the beginning and the end of a fiber length corresponding to the distance range of the DTS.

20°C and 75°C are standard calibration temperatures also used for lower temperature applications. The highest temperature at which the DTS has been calibrated shall be reported and documented if it is different or below the customer's highest required operating temperature. In case the highest calibrated temperature point is below the requirement (i.e. 250°C calibration point for 300°C), vendors must demonstrate, either empirically or statistically, that the system's capability meets the specification for the maximum operating temperature.

We use a sampling interval of 1 m and calculate the moving average over 51 sampling points. For each short length of fiber, we evaluate the sampling point right in the middle. We calculate the maximum deviation of the moving average at this point over 20 measurements. This is the maximum temperature accuracy at this temperature and position. All the results are listed in a table and compared with the specification.

| Channel 1 start | 1.2°C | ... | ... |
| Channel 1 end | 1.5°C | ... | ... |
| Specification | X°C | ... | ... |
| Result | passed | ... | ... |

Note 1: From the vendor's perspective, there is concern regarding the high cost that would be involved with working with more than 3 calibration temperatures (i.e. more than three ovens) in order to conduct the test at: 20°C, 75°C, 150°C and 300°C.

Note 2: From the operator's perspective, there is concern that the test must be physically carried out above the vendor specified limit (assumed to be 250°C) in order to achieve a full high temperature calibration test at a temperature (for example) at 300°C.

Note 3: The "High Temperature" used (point 3) must be reported during the calibration test if it is different/below the customer's required High Temperature target.

Note 4: Any statistical methodology that is used to calculate the high temperature capability beyond the physical testing point must be recorded as part of the test.

Note 5: Fiber used in the 250°C chamber must be suitable for operation at this temperature, under the conditions and duration of the test. It is recommended that this fiber be monitored for potential degradation (for example by measuring & recording the attenuation of the fiber after each test) and replaced when necessary.
G.1.2 Test setup diagram:

Description:

Figure 23  General Test Setup - High temperature calibration