

HYPERION DISTANCE COMPENSATION

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1. Overview

This document explains the concept of “distance compensation”, which is a mechanism that allows us to achieve more accurate absolute temperature/strain measurements of sensors. When only a relative measurement is needed, then distance compensation isn’t required. But if a single FBG is used (instead of using a temperature compensating grating in addition to your other sensor), then this technique will provide much more accurate results.

2. Basic Theory

The finite speed of light causes a perceived wavelength shift in swept wavelength FBG interrogators such as those from Micron Optics. The interrogator is comprised of a tunable, narrow wavelength source, and a broadband detector. Because there is no wavelength discrimination on the detector, we have to assume that any light hitting the detector at a certain time is at the same wavelength as the light being emitted by the laser at that time.

The amount of perceived wavelength shift can be roughly approximated by looking at the amount of time that the light needs to travel to/from your sensor, and multiplying by the span of wavelength that the swept laser covers in that time.

$$= \frac{2 \times L \times n}{c} \times \frac{\Delta \lambda \times S}{D}$$

Where:

- L length of fiber between instrument and sensor
- n index of refraction of the fiber optic cable
- c speed of light in a vacuum
- $\Delta \lambda$ wavelength range of the instrument in nm (typically 80 or 160 for MOI instruments)
- D duty cycle of the laser drive
- S slew rate of the laser

The first part of the equation tells you the amount of time that it takes a photon to leave the interrogator, reflect off the FBG, and return to the detector. This time is then multiplied by how quickly the instrument sweeps across the spectrum (nm/s), resulting in the perceived wavelength shift due to the speed of light through the fiber.

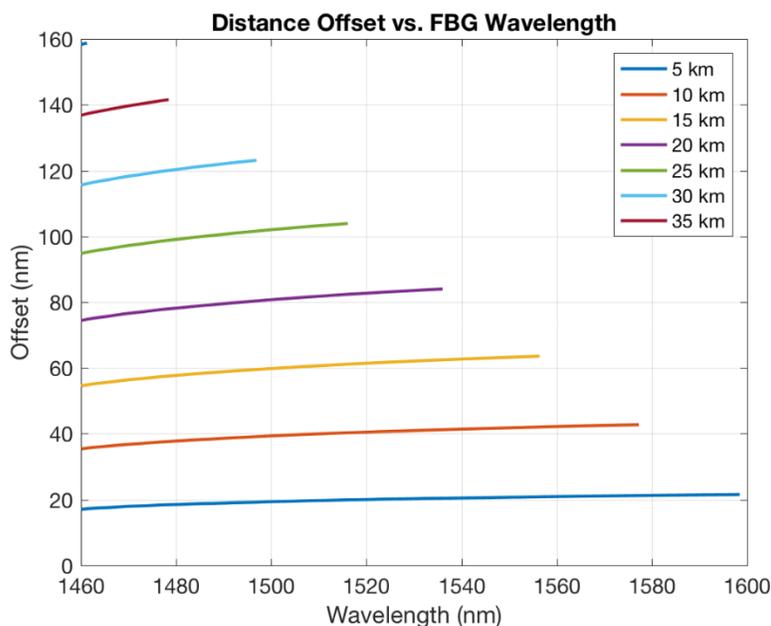
This is a first order approximation, though, as the instrument’s wavelength scan rate is not precisely linear. The result is that the wavelength offset is larger at longer wavelengths than short wavelengths.

3. Example Plots

The following figures gives some typical shifts from the various instruments manufactured by MOI. You'll notice that:

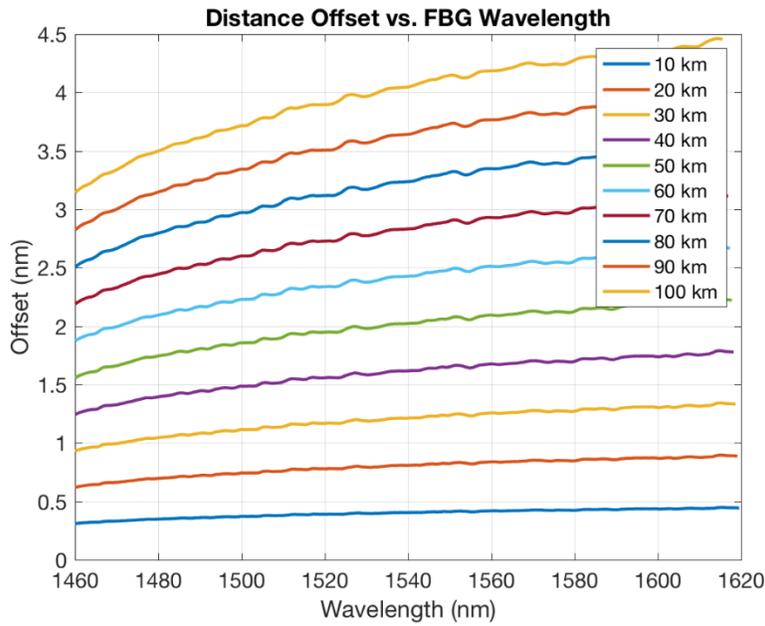
- a) Sensors which are located farther away from the interrogator experience greater perceived shifts in wavelength, since it takes the light longer to reach the sensor and then return to the instrument.
- b) Faster instruments (higher scan rates) lead to greater perceived shifts, since the laser will have scanned further in the time it takes for the reflection to reach the instrument.
- c) Instruments with wider spectral widths result in greater shift because the laser scans faster (nm/s) in order to cover the additional spectral width within the scan time.

Spectral Width: 160nm Scanning Rate: 1kHz



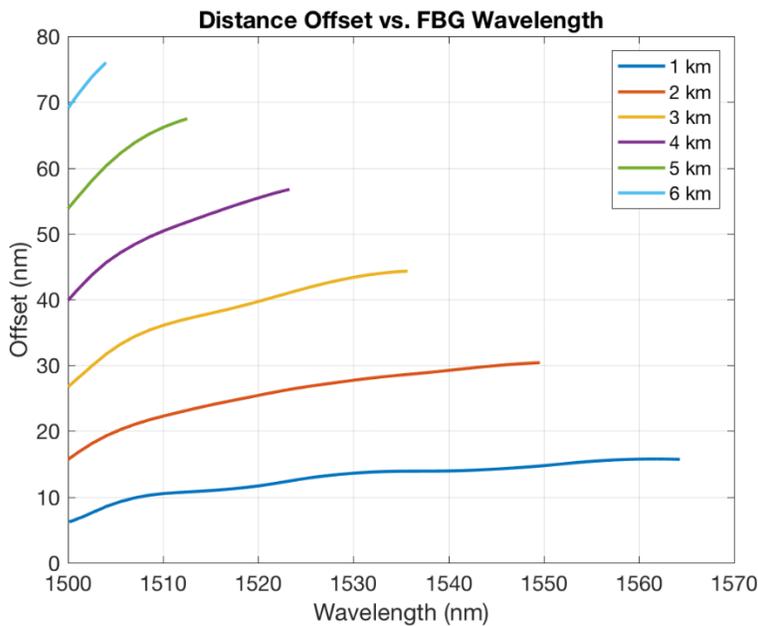
Note that the usable wavelength range of a 1 kHz instrument is significantly affected as you get to distances over 15 km. By 35 km you are left with < 20 nm of usable wavelength range.

Spectral Width: 160nm Scanning Rate: 10 Hz



At the slow scan rate of 10 Hz, you maintain the full wavelength range even out to 100 km.

Spectral Width: 80nm Scanning Rate: 5 kHz



The 5 kHz instruments scan so quickly that fiber lengths must be kept relatively short.

4. Limitations

Micron's firmware can be setup to compensate for errors noted above. We call this "Distance Compensation". Distance can have a dramatic and confusing effect on the data, but customers can mitigate the issues by following a few best practices.

1. FBGs on the array should be arranged so that the sensor with the shortest wavelength is placed closest to the instrument, and all subsequent sensors are at longer wavelengths. This ensures that light reflected from an FBG does not return at the same time as light from another FBG returns after a delay.
2. Using the typical tables of wavelength offset (or maximum distance as a function of real wavelength) for the instrument configuration, ensure the maximum distance is not exceeded. The instruments only collect data within a specific window. It is possible for reflected light from a sensor to arrive after the scan is complete and therefore not be detected.
3. Avoid changing the scanning speed of the instrument. Since proper distance compensation requires knowledge of an instrument's scanning speed, a change in scanning speed will require that the offsets be updated.

5. Compensations Instructions

Users setup compensation by defining boundaries on each channel, and all sensors within a boundary are compensated by a specified amount. The base command used to set these boundaries is `#setpeakoffsets`. See section 8 for further details.

Distance compensation was enabled in HYPERION firmware version 12.8.1. Please be sure that you're using this version, or a newer one. Firmware is available for download on the Sensing Products Support page at www.micronoptics.com. The simplest way to install firmware is to use the free ENLIGHT utility, also available on our website. On the Settings tab you'll find a section labeled Firmware Upgrade.

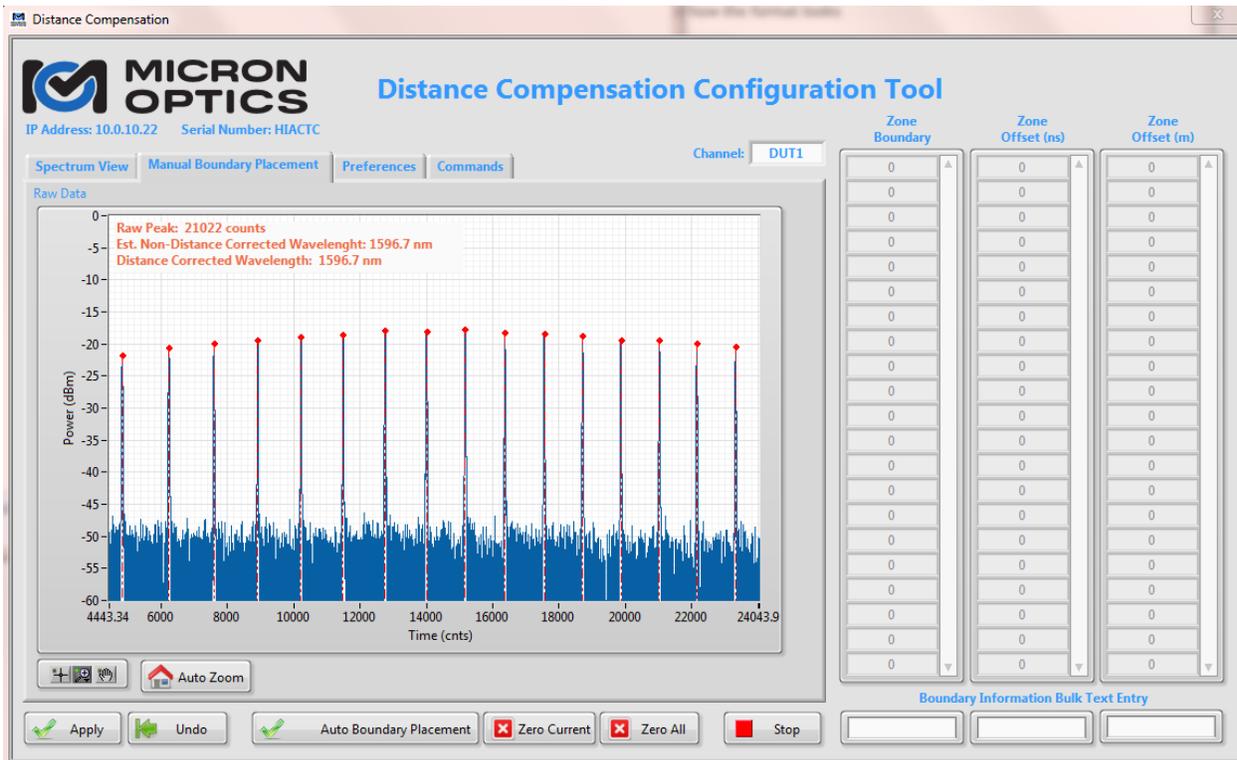
The amount of compensation is specified in nanoseconds. For example, a sensor 1km away will have ~9740ns offset ($\Delta T = 2 * \text{distance} / \text{SpeedOfLight} * \text{IndexOfRefraction}$, for fiber with an Index of Refraction of 1.4682). The boundaries are specified as the right boundary edge.

Boundary Definitions

When inputting offset boundaries, the count numbers entered indicate the *end* of a bin. So if I entered boundaries at 2,000 and 3,000 counts, then there would be two bins:

- The first bin goes from 0 to 2,000 counts
- The second bin goes from 2001 to 3,000 counts
- After 3,000 counts, no compensation is applied

6.2. Manual Boundary Placement Tab



Channel: This control (top right of plot) selects channel on your instrument is being viewed/edited. Each channel must have different offsets, depending on the sensor array which is attached.

Apply: This button must be pressed in order to apply changes made to the compensation zones.

Undo: This button removes changes made to the compensation settings in the application, by reading the current settings from the instrument.

Auto Boundary Placement: This button will place a boundary half-way between peaks. No offsets applied, but the locations (in counts) are marked. Users then need to set the offset (using either the ns or m offset boxes).

Zero Current: This button will zero-out (clear) all distance compensation from this channel.

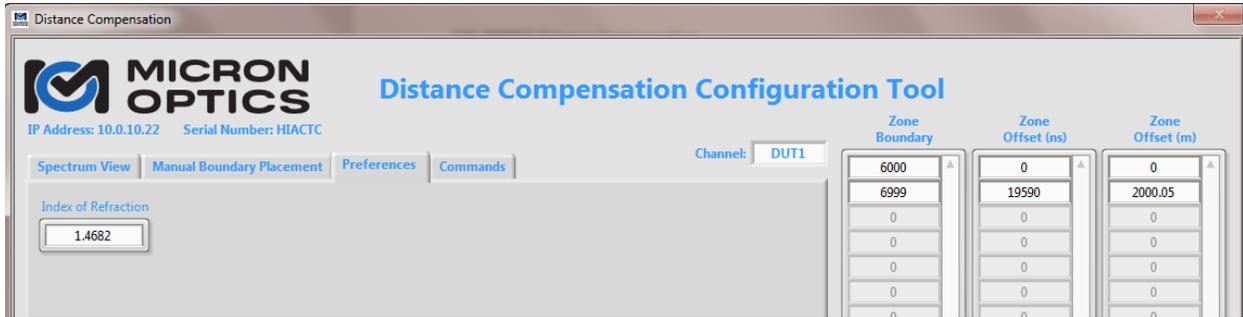
Zero All: This button will zero-out (clear) all distance compensation from *all channels*.

Stop: This button will stop the Windows application from running.

If the distance to the sensor is well known, you may simply enter that distance into the **Zone Offset (m)** field, in units of meters. The tool will use the index of refraction (set on the **Preferences** tab) to calculate the offset in time (ns). Or if you have an OTDR that reports the time of flight, you can enter that in the **Zone Offset (ns)** field.

Controls just under the plots allow users to zoom in/out of the plots. The **Auto Zoom** button will return the zoom to show the full bandwidth if that becomes helpful.

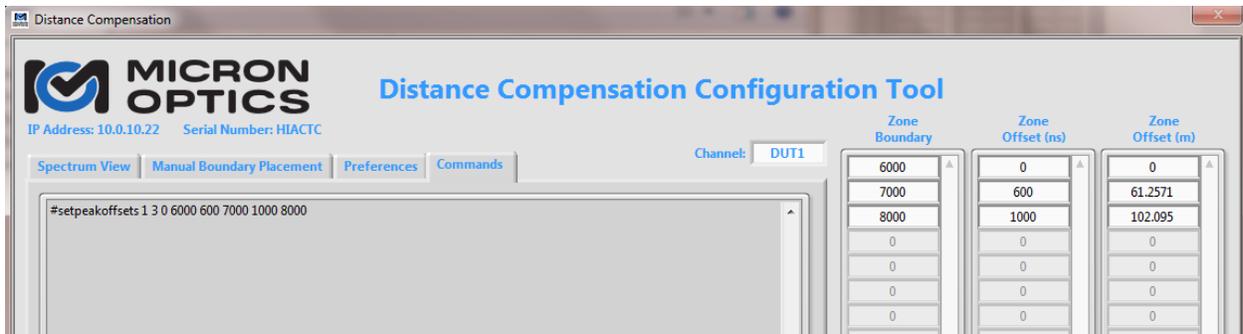
6.3. Preferences Tab



The only item to be entered on the **Preferences** tab is the **Index of Refraction** of your fiber. To achieve the most accurate compensation, please enter the index of the fiber in your sensor.

Standard SMF-28 fiber has an index of 1.4782 at 1550 nm, so this is the program default.

6.4. Commands Tab



This window allows users to see the commands issued to the instrument when applying boundaries from within the configuration tool. The window is for display only; not for input. It may be useful if users are developing their own software and are having difficulty generating the proper command syntax.

6.5. Example Case

Let us imagine a system with 3 sensors occurring as 5000 counts, 10000 counts, and 15000 counts and 1km, 2km, and 3km respectively.



The distance compensation could be defined as follows:

- 1) Determine appropriate boundaries for the distance compensation. Bisecting the times that the FBGs are detected is easiest, so the boundaries could be:
 - a) All peaks from time 0 to 7,500 counts are offset by 1km (or 9795ns)
 - b) All peaks from time 7,500 to 12,500 are offset by 19,590 ns (2km).
 - c) All peaks from time 12,500 to 20,000 are offset by 29,384 ns (3km).
- 2) Issue the following command: `#setpeakoffsets 1 3 9759 7500 19590 12500 29384 20000`

In the example above, we could have taken the bisecting wavelength and converted that to a count value and used that value in the `#setpeakoffsets` command. However, keep in mind that the two commands above are only accurate for the current instrument at the current scan speed at the current time of day. There will be small (most likely negligible) differences from box to box and day to day. These commands are not meant for absolute accuracy and should be sufficient when FBGs are spaced out appropriately.

7. Fine Adjustments

In order to achieve the most accurate distance compensation, users may want to:

- Using an OTDR, you can determine a very precise measurement of the distance of a sensor. You can then use this distance to set the compensation in the Windows tool.
- To obtain highly accurate temperature measurements, measure the temperature with another sensor (such as a handheld digital thermometer) which is co-located with the fiber sensor. You can then adjust the offset in nm until ENLIGHT properly reflects the “real” temperature measured by the other thermometer. This will set the proper delay, which will give you accurate readings from the fiber sensor going forward.

8. Firmware Requirements

Distance compensation was enabled in HYPERION firmware version 12.8.1. Please be sure that you're using this version, or a newer one. Firmware is available for download on the Sensing Products Support page at www.micronoptics.com. The simplest way to install firmware is to use the free ENLIGHT utility, also available on our website. Users should save the firmware file to the firmware folder that is created by ENLIGHT:

```
\Documents\Micron Optics\ENLIGHT\Firmware
```

9. API Commands

To accommodate distance compensation changes via the HYPERION API (instead of using the Windows tool), we have added the following commands.

Set Peak Offsets

Synopsis

This command sets the peak offsets (in nanometers) for the specified channel and wavelengths.

Usage

```
#setpeakoffsets <Channel Number> <Offset Definitions>
```

Description

This command creates an offset that helps the instrument correct the perceived wavelength of sensors which are located far enough away from the instrument that the propagation delay of light in the fiber creates a problem.

The first parameter is the instrument channel number. The second is the number of correction count/delay pairs to be specified. The remainder of the data specifies the location and magnitude of the offsets. Each zone is defined by the count in the scan and the offset in nanoseconds to apply. Any DUT peak that falls within the zone will be adjusted by the time offset before it is converted to a wavelength value.

Examples

Command:

```
#setpeakoffsets 1 4 1234 5000 2345 7000 3456 10000 4567  
19999
```

Response:

```
The peak offsets for Channel 1 have been updated.
```

Get Peak Offsets

Synopsis

Gets a list of current offsets for a specific channel.

Usage

```
#getpeakoffsets <Channel Number>
```

Description

This command gets the distance related time of flight peak offsets (in ns) for the specified channel. The first two bytes are an UInt16 with the number of pairs. This is followed by each time/boundary offset as UInt32 then UInt16.

Examples

Command:

```
#getpeakoffsets 1
```

Response:

```
4 peak offsets: (1234, 5000) (2345, 7000) (3456, 10000)  
(4567, 19999)
```

Response Content:

Clear Peak Offsets

Synopsis

Clears all peak offsets for the specified channel.

Usage

```
#clearpeakoffsets <Channel Number>
```

Examples

Command:

```
#clearpeakoffsets 1
```

Response:

```
Peak offsets for channel 1 have been cleared.
```

Response Content:

Clear All Peak Offsets

Synopsis

Clears all peak offsets defined in the instrument, for all channels.

Usage

```
#clearallpeakoffsets
```

Examples

Command:

```
#clearallpeakoffsets
```

Response:

```
Peak offsets for all channels have been cleared.
```

Response Content:

Convert Count To Wavelength

Synopsis

This command returns the wavelength (in units of nm) that corresponds to the specified count. The data bytes are a DBL.

Usage

```
#convertcounttowavelength
```

Examples

Command:

```
#convertcounttowavelength 10000
```

Response:

```
The wavelength (in nm) corresponding to the count is  
1524.6412
```

Response Content:

```
1 DBL
```

Convert Wavelength To Count

Synopsis

Get the count (for the current speed) value that corresponds to the specified wavelength (in nanometers) and offset (in nanoseconds).

Usage

```
# convertwavelengthtount <Wavelength> <Offset>
```

Description

Wavelength is a u16

Offset is given as a u16

Examples

Command:

```
#convertwavelengthtount 1550 29000
```

Response:

```
The count corresponding to the wavelength is 13659.0759
```

Response Content:

```
1 DBL
```

Shift Wavelength By Offset

Synopsis

This command provides the result of shifting a wavelength by a number of counts.

Usage

```
#shiftwavelengthbyoffset <Wavelength> <Offset>
```

Description

The number of counts come as the result of the time of flight of the photons.

Wavelength is in units of nm, given as a DBL.

Offset is in units of counts, given as a U16.

Examples

Command:

```
#shiftwavelengthbyoffset 1550.202 29000
```

Response:

```
The shifted wavelength is 1554.1927
```

Response Content:

```
1 DBL
```