1. Introduction

1.1.1. Introduction

The x55 Hyperion interrogator converts high resolution, full spectrum data into precise peak measurements at kHz rates via programmable on-board hardware peak detection. This appendix will illustrate in greater detail the operation of the peak detection algorithm, show the execution of several of the PD presets, and introduce the user to creation and modification of peak detection parameters into new accessible presets.

1.1.2. Applicability

The following algorithmic descriptions and examples apply to all instruments in the x55 Hyperion product family, including the 16 channel/1kHz si255, the 4 channel si155, and the si255 EV option.

1.1.3. Resources

The following screenshots and examples were creating using the si255 Hyperion LabVIEW UI Example, available for download at http://micronoptics.com/support_downloads/ under the si255 Hyperion subheading.

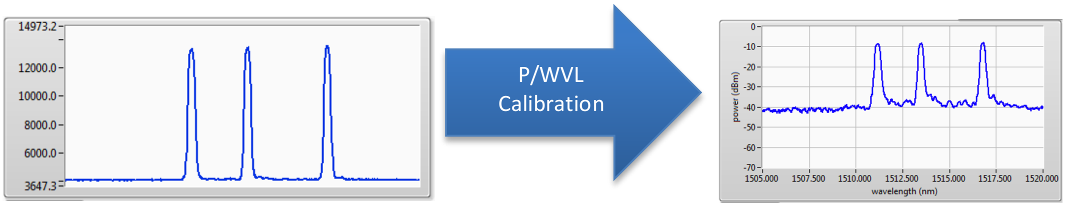
2. Theory of Operation

2.1.1. Data processing paths

The si255 Hyperion interrogator captures and processes full spectrum data at a 1kHz rate. Multiple, parallel data processing paths are followed to yield both power and wavelength calibrated full spectrum data for the user, as well as internally detected peak data at kHz rates.

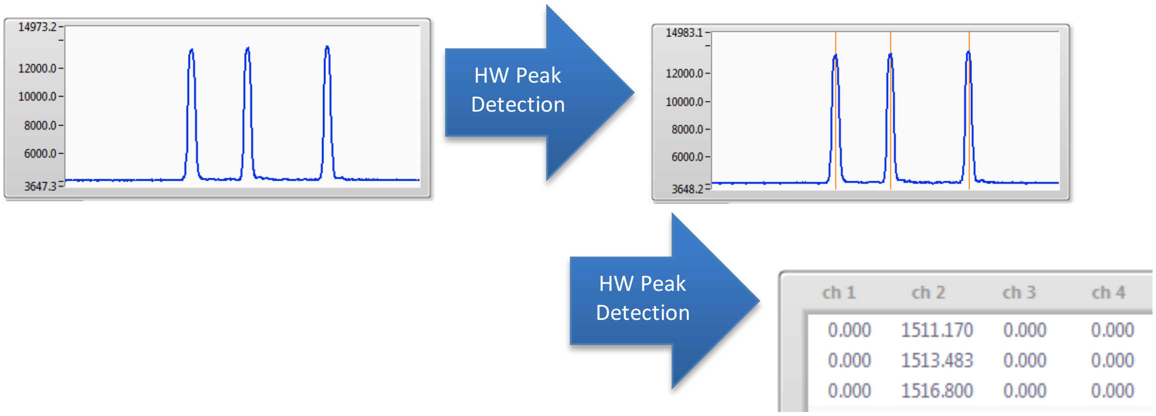
2.1.1.1. Conversion of raw data into calibrated optical spectrum

The source data for both spectral traces and peak detected data are the same. In the images below, it can be seen that raw data is converted from timing a voltage signals into fully calibrated optical spectrum at a rate of 10 Hz.



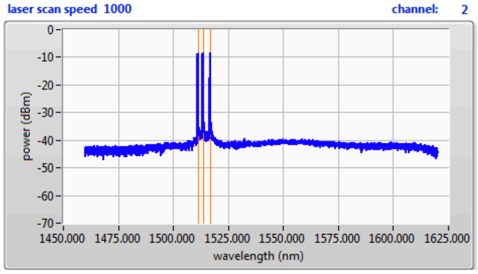
2.1.1.2. Conversion of raw data into high speed peak wavelengths

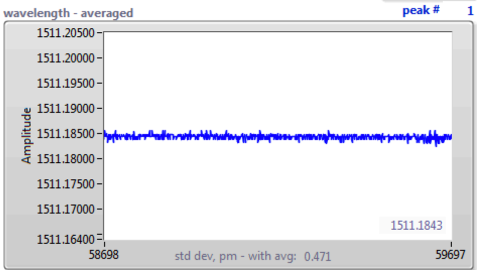
That same source data is simultaneously processed by the internal peak detection algorithms in real time, first with a peak finding algorithm and then with a resultant peak location conversion to wavelength.



ch 1	ch 2	ch 3	ch 4
0.000	1511.170	0.000	0.000
0.000	1513.483	0.000	0.000
0.000	1516.800	0.000	0.000

Both of these processes happen simultaneously and data can be combined to give an instantaneous peak view and detailed high resolution full spectrum view. Like this:



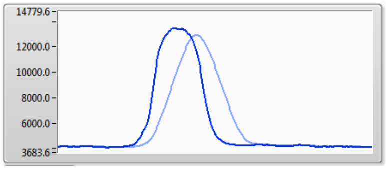


2.1.2. Peak Detection Algorithm (overview, pulled from current user manual or recreated based on current tools)

As described earlier in this user guide, the onboard peak detection algorithm is comprised of a DSP blocks that filter, differentiate, and compare signal values according to a collection of parameters. A grouping of these parameters is stored as a Peak Detection Preset. This section will outline the internal peak detection algorithms in more detail and introduce some of the terms and control parameters associated with that algorithm.

2.1.2.1. Detailed Theory of Operation

The first step in sensor detection is the conversion of light to electricity, which is facilitated by the on-board photodiodes. The current output of the photodiode is converted into a voltage by a high bandwidth transimpedance amplifier, the output of which is converted into a digital signal. That digital representation of the FBG shape is shown as the dark blue Raw signal in the image below.

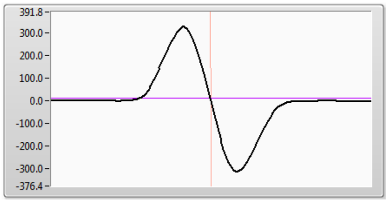


Raw signal (dark blue) and Boxcar filtered signal (light blue)

The first digital signal processing step in the algorithm is to filter out high frequency noise and suppress unwanted spectral side modes from detection. These aims are achieved by use of a **BoxcarFilterLength**. In the algorithm, the BoxCar filter control is in units of pm. As such, a value of 250 corresponds to a 0.250nm "smoothing window".

The effects of this smoothing window are seen in the image above as the Boxcar filtered signal in light blue. Acceptable values range from 1 (no filtering) to 1000 at 1kHz.

Once the signal has been filtered smooth by the Boxcar, it is converted to a differentiated signal by means of a **DifferenceFilterLength** control. Though these are brought out as a separate control from the Boxcar Filter Length, it is recommended that he **DifferenceFilterLength** value be set equal to that of the **BoxcarFilterLength**. The black signal in the following image shows the result of differentiating the Boxcar filtered signal.



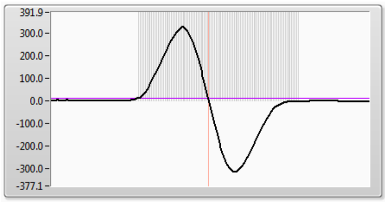
Differentiated signal (black) **threshold** (purple), **zero crossing** (orange)

Once the signal is differentiated, the amplitude of the signal represents the slope of the Boxcar filtered signal. It then follows that the point place at which the differentiated signal crosses zero (i.e. slope of the Boxcar signal is equal to zero) represents the location of the signal peak or null.

It can be seen from the sample image above that the differentiated signal spends most of its time at or near a value of zero. As such, there are many more zero crossing than there are valid signal locations on a trace. To ensure that only valid zero crossings are considered, a **ThresholdLevel** control is introduced into the algorithm. The threshold is represented by the purple horizontal line in the image above.

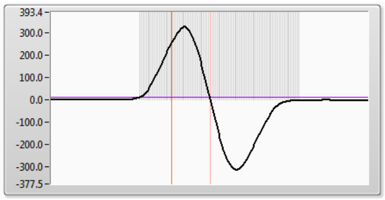
The threshold signal is set such that zero crossing signals will only be considered valid signal peaks if the are generated during a specified window after the differential signal crosses the specified threshold. This makes physical sense, as the differentiated signal will only be non zero in the spectrum amplitude changes rapidly in slope near a spectral peak or null.

The window for zero crossing consideration opens by a positive crossing of the differentiate signal (black) through the threshold value (purple) and is held open for a period of time specified as the NTV period. In the image below, the **NTV period** is depicted by the width of the gray horizontal box.

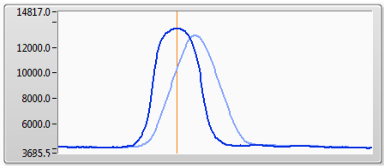


Thus, any negative zero crossing of the **Differentiated Signal** (black) that occurs after a positive crossing through the **ThresholdLevel** level (purple) within the time specified by the **NTV period** (gray) will result in a valid zero crossing detection.

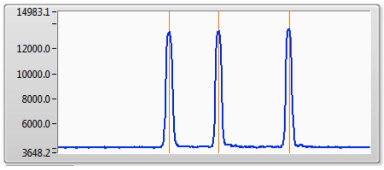
Once the zero crossing is detected, it is corrected for the digital phase delay induced by the **BoxcarFilterLength** and **DifferenceFilterLength** settings. In the following image, the actual **zero crossing signal** is depicted in light orange, and the phase delay corrected peak location is depicted in bright orange.



Having now located a valid zero crossing and corrected for phase delays, the **detected peak** location (orange) is plotted on the same timescale as the original, unfiltered **Raw Signal** (dark blue).



Raw signal (blue), Boxcar averaged signal (light blue), Peak (orange)



This is done on all peaks.

2.1.2.2. definition of terms

BoxcarFilterLength serves as a smoothing window with spectral aperture set in units of pm. As such, a value of 250 corresponds to a 0.250nm “smoothing window” and will serve to filter spectral features with bandwidths at or less than 250 pm.

DifferenceFilterLength should be set to exactly equal that of Boxcar.

Threshold is a % of full scale and scales with Boxcar/DD settings. Valid values are -100 to 0 for nulls, 1 – 100 for peaks. The chosen values are highly dependent on the type of sensor attached and the settings. Default peak values for si255 standard are 10.

NTV period is in units of pm and mostly default to 1000 pm (1 nm). This limits some wider sensor values and should likely be increased to 2000 pm as a standard.

Lockout Period is not used and should be left at 0.

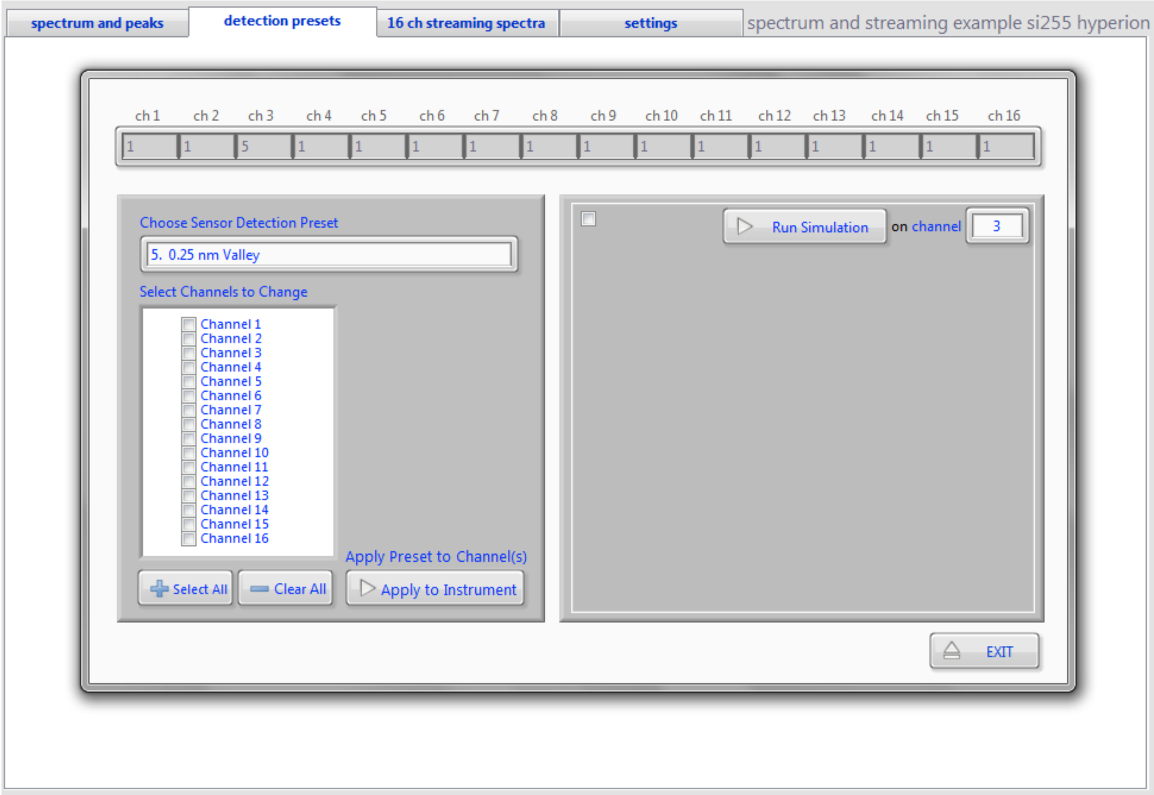
3. Use of Default Peak Detection Profiles

One of the key features of the si255 Hyperion instrument is native peak/null detection support for a number of different optical sensor types. The power of these low-to-no configuration peak finding algorithms is brought forth to the user via the **detection presets** tab of the si255 Hyperion User Example.

Through the use of the **detection presets** tab, the user can select from among a number of peak detection presets and assign that preset to any of the 16 parallel channels. The user can also view the effects of his chosen PD preset on a selected channel through a full peak detection simulation tool. The following images will illustrate how these tools can be used.

The image below shows the contents of the **detection presets** tab. The array on the top conveys the currently set PD preset for each channel. From the image below, it can be noted that all channels 1-16 are currently set to PD preset 1, except for channel 3, which is set to PD preset 5.

The left block of controls facilitates the selection of a PD preset and the assignment to one or more instrument channels.

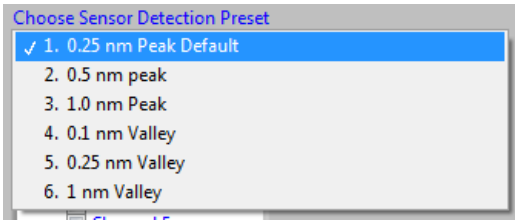


ch 1	ch 2	ch 3	ch 4	ch 5	ch 6	ch 7	ch 8	ch 9	ch 10	ch 11	ch 12	ch 13	ch 14	ch 15	ch 16
1	1	5	1	1	1	1	1	1	1	1	1	1	1	1	1

Choose Sensor Detection Preset: 5. 0.25 nm Valley

on channel 3

The first element of the left block of controls is the **Sensor Detection Preset** selection tool. As seen below, this instrument is equipped with six PD presets – three presets for peaks of various spectral widths and three presets for "null"s of various widths.



These presets have been developed and tested to be compatible with the following types of sensors:

1. 0.25 nm Peak Default

   The PD preset is ideal for common sensor FBGS, ranging in reflectivities from 5% to 100% and bandwidths from 0.1 to 0.3 or 0.4 nm. This preset would be most commonly applied to Draw Tower Gratings, standard strip and recoat FBGs, and any of a number of other common peak signals.

2. 0.5 nm peak

   This preset is ideal for FBGs with broader widths, including strip/recoat FBGs, as well as point-by-point femtosecond laser FBGs. Also, this preset may prove useful when measuring and tracking FBGs with spectral distortions or peak broadening from composite embedment or other sources of transverse strains.

3. 1.0 nm peak

   This preset is ideal for short (1mm) FBGs that may result in wider spectral profiles. This preset may also prove useful in tracking severely distorted FBG peaks, such as those profiles that can result from extremely high strain loads (30 to 50,000 ustrain).

4. 0.1 nm valley

   This preset is ideal for detecting extremely narrow spectral nulls, like those of an atomic spectral absorption cell.

5. 0.25 nm valley

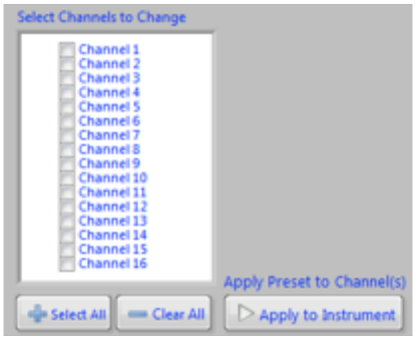
   This preset is optimized for detecting small FSR, high contrast Fabry-Perot sensors, like the Micron Optics os7500 accelerometers used in this section's examples.

6. 1 nm valley

   This preset it optimized for longer FSR and low contrast Fabry-Perot Sensors, as is seen in many extrinsic Fabry-Perot sensors.

Once a peak detection preset is selected, its effect on the received signal can be evaluated prior to assigning the preset to a channel. Visualization of the peak detection algorithm in operation and its related peak results can be seen by clicking on the Run Simulation button on the right-side panel.

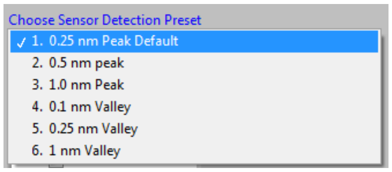
Peak detection presets are applied to individual channels by first choosing the preset from the drop down menu, then selecting the channels to change and clicking on the "Apply to Instrument" Button.



The following sections will explore the inner workings of the standard PD presets by use of the "Run Simulation" feature.

3.1.1. Standard PD profiles FBGS, DTGs, FBGs

This section will demonstrate the execution of the internal peak detection algorithm on a series of standard FBG sensor peaks with varying spectral widths.

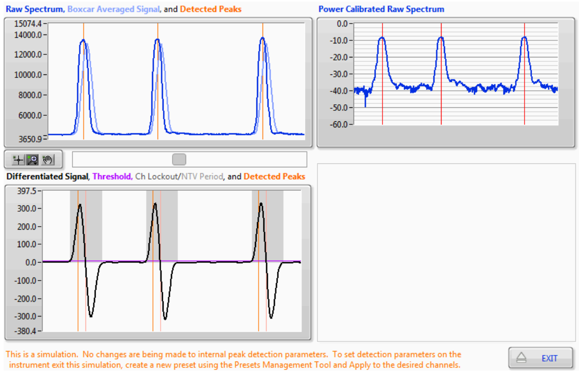


Choose Sensor Detection Preset

- ✓ 1. 0.25 nm Peak Default
- 2. 0.5 nm peak
- 3. 1.0 nm Peak
- 4. 0.1 nm Valley
- 5. 0.25 nm Valley
- 6. 1 nm Valley

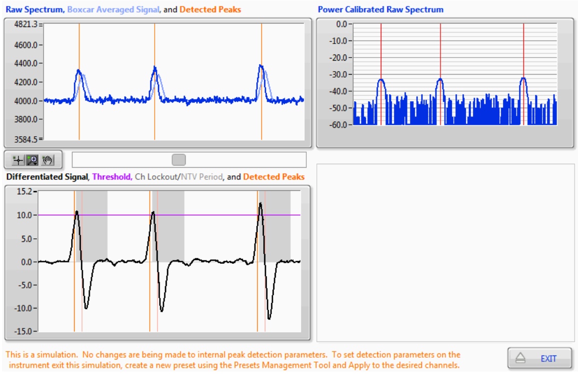
3.1.1.1. 0.25 nm BW FBGs

To detect peaks on standard FBGs of 0.25 nm width, the user would choose the first standard PD profile labeled “0.25 nm Peak Default”. Following the same data processing steps outlined in the previous section, default values for **BoxcarFilterLength**, **DifferenceFilterLength**, and **ThresholdLevel** are applied. Note that the peak detection algorithm is highly amplitude insensitive, yielding stable detections with a single set of parameters over a wide range of sensor insertion losses.



This is a simulation. No changes are being made to internal peak detection parameters. To set detection parameters on the instrument exit this simulation, create a new preset using the Presets Management Tool and Apply to the desired channels.

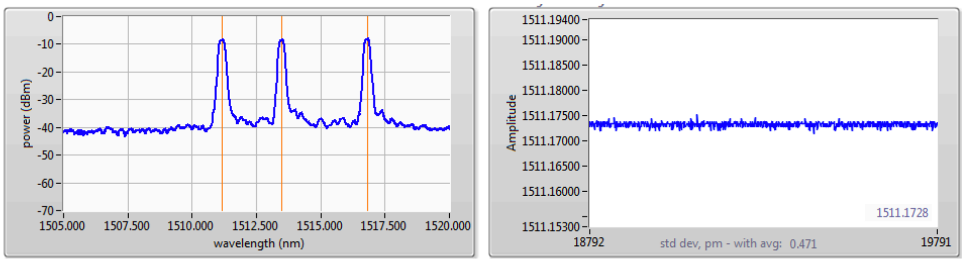
PD results in a low loss state



This is a simulation. No changes are being made to internal peak detection parameters. To set detection parameters on the instrument exit this simulation, create a new preset using the Presets Management Tool and Apply to the desired channels.

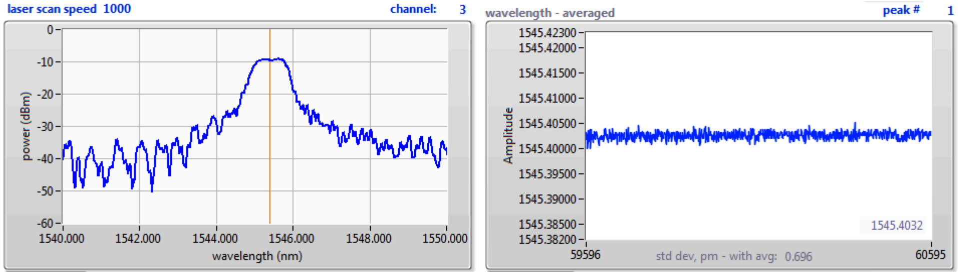
Continued performance in a high loss state

Once peak locations are determined by the real-time algorithm, the results are wavelength calibrated and applied to the following plots.

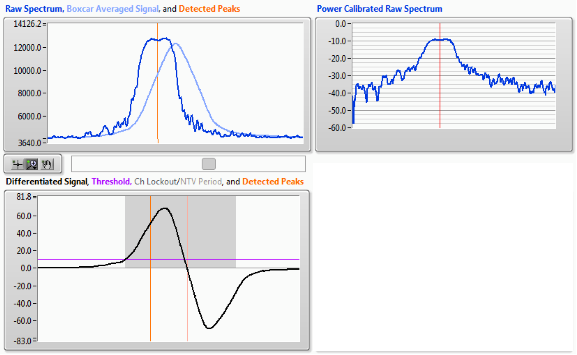


3.1.1.2. 1.0 nm BW FBG

The same algorithm can be applied to FBGs of broader bandwidth, augmenting profile parameters appropriately for the different FBG shape.



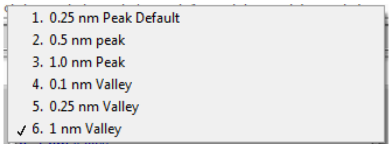
In this case, as the FBG bandwidth is 4x greater than the previous 0.25 nm example, values for **BoxcarFilterLength** and **DifferenceFilterLength** are selected to match the sensor BW of 1.0nm or 1000 pm. The **NTVPeriod** is set to a large enough value to ensure time for a zero crossing to occur after the **ThresholdLevel** crossing and considering the phase shift from the **BoxcarFilterLength** and **DifferenceFilterLength**.



3.1.1.3. Long cavity FP sensors

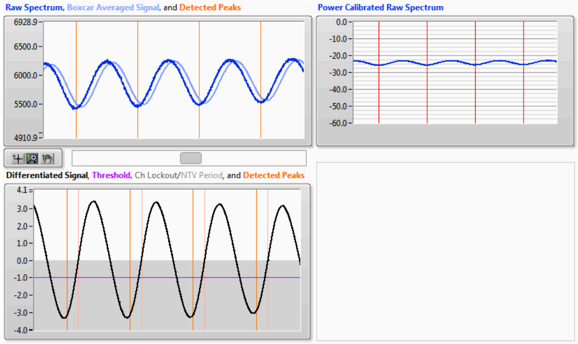
This same algorithm can be successfully applied to other types of optical sensors. This example will demonstrate how the algorithm detects the nulls of a long cavity Fabry-Perot sensor.

In this case, the same algorithm is applied, but with the selection of a different preset. Given the width of the target FP sensor and the desire to monitor the wavelengths of the senor nulls, the PD preset “1 nm Valley” is selected.

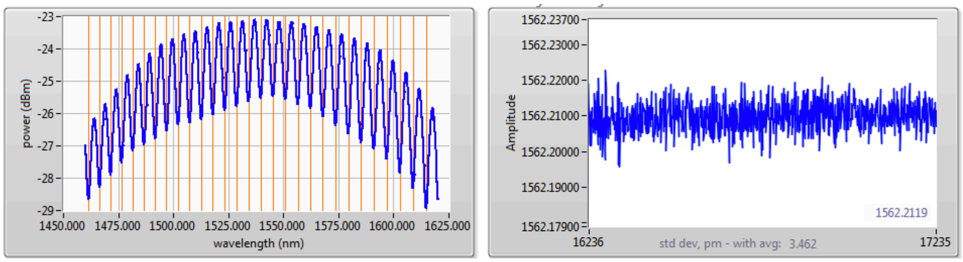


1. 0.25 nm Peak Default
2. 0.5 nm peak
3. 1.0 nm Peak
4. 0.1 nm Valley
5. 0.25 nm Valley
6. ✓ 1 nm Valley

Given the selected profile, the peak detection algorithm applies appropriate values for **BoxcarFilterLength**, **DifferenceFilterLength**, and **ThresholdLevel** to detect the null locations for this relatively broad optical signal.

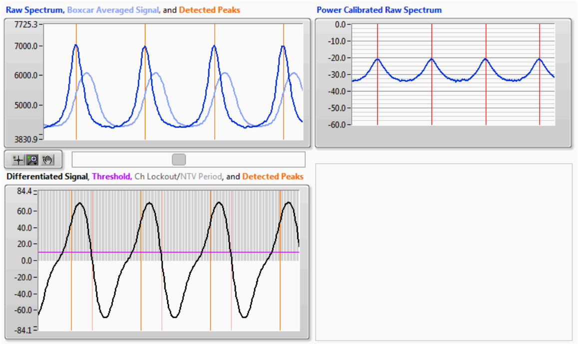


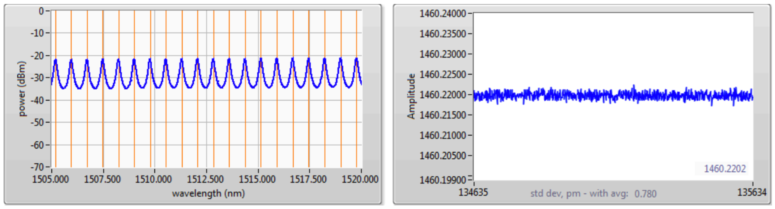
1kHz FP nulls in real time



3.1.1.4. Different FP, same algorithm, different preset

Similarly, should the peak values for a Fabry-Perot sensor wish to be measured, selection of a Peak profile of appropriate width will result in application of suitable parameters to yield highly repeatable measurements.

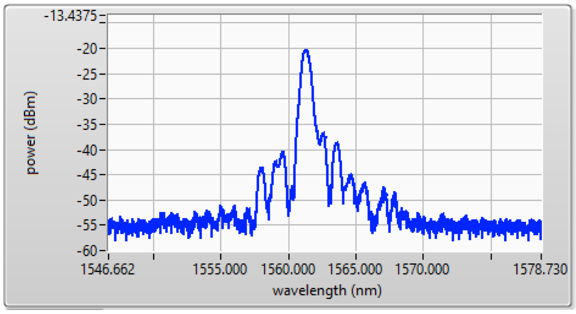




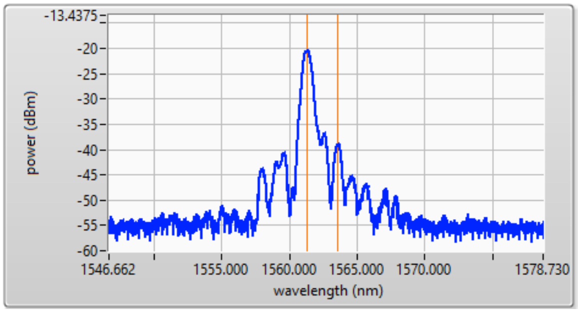
3.1.2. Creating Custom Peak Detection Profiles

Thought the default peak detection presets do cover a wide range of potential measurements scenarios, a user may find certain sensor profiles present detection challenges that are not directly addressed by the standard offerings. This section will demonstrate some of those potential measurement challenges and a method for creating custom PD profiles that can address those challenges.

Consider the following FBG spectrum.



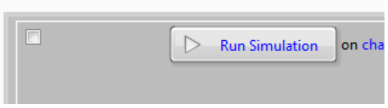
This spectrum has relatively strong and sharp side modes, and if the peak detection parameters are not set to adequately filter or suppress those modes, it may result in detection of unwanted spurious peaks, as is in the following image.



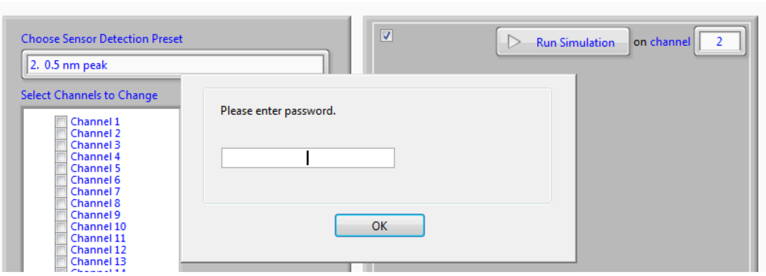
This section will demonstrate how to optimize peak detection parameters for out-or-specification FBGs and/or other custom types of sensor spectra.

3.1.2.1. Activating the Peak Detection Edit Window

The first step towards creating a custom peak detection profile is to enable the password protected Edit Mode. Edit mode can be activated by checking the small Boolean checkbox in the upper left corner of the right-side panel of the Detection Preset management panel.



Click the check box.



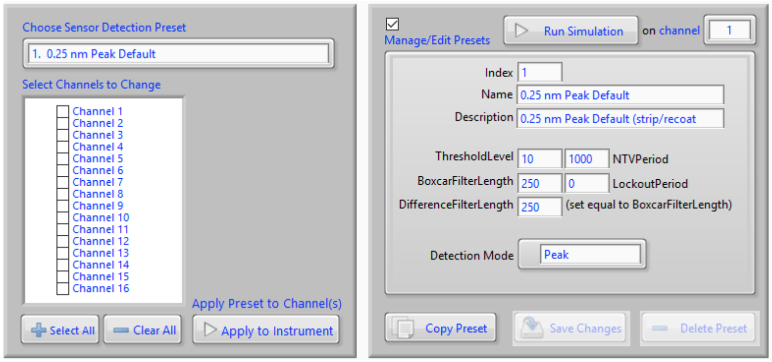
Enter the password (please contact Micron Optics for access)

Once activated, the Manage/Edit Presets window will be visible and reveals all of the detailed settings for the peak detection algorithm.

3.1.2.2. Copying Factory Default Profiles for Editing

The x55 interrogator ships with six standard default peak detection profiles as outlined in an earlier section. These profiles can also be used as starting points for custom PD profiles via a Copy and Edit method.

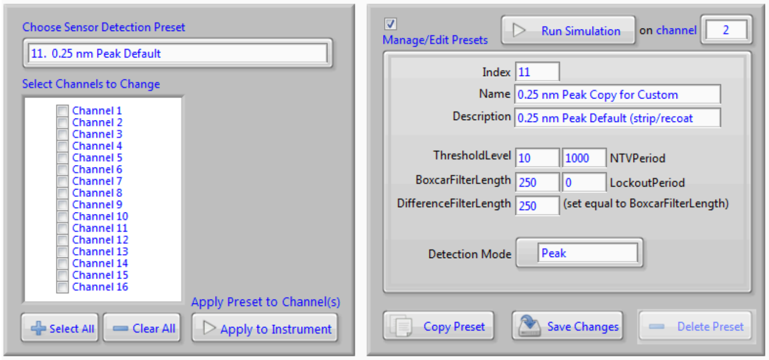
In order to create a custom PD profile that better suppresses this sample FBGs side modes, the first step wil be to select the closest applicable preset, in this case the 0.25 nm Peak Default Preset (Index 1).


Choose Sensor Detection Preset: 1. 0.25 nm Peak Default

☑ Manage/Edit Presets — on channel 1

Index: 1
Name: 0.25 nm Peak Default
Description: 0.25 nm Peak Default (strip/recoat
ThresholdLevel: 10
NTVPeriod: 1000
BoxcarFilterLength: 250
LockoutPeriod: 0
DifferenceFilterLength: 250 (set equal to BoxcarFilterLength)
Detection Mode: Peak

The next step is to press the Copy Preset button, which will create a new profile as Index 11 with the same settings. Note that profile indices 1-10 are reserved for factory presets and that all user create profiles start at index 11.

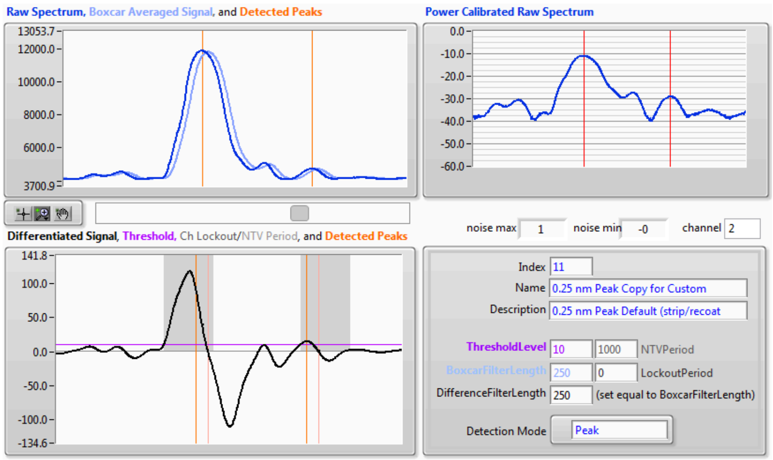

Choose Sensor Detection Preset: 11. 0.25 nm Peak Default

☑ Manage/Edit Presets — on channel 2

Index: 11
Name: 0.25 nm Peak Copy for Custom
Description: 0.25 nm Peak Default (strip/recoat
ThresholdLevel: 10
NTVPeriod: 1000
BoxcarFilterLength: 250
LockoutPeriod: 0
DifferenceFilterLength: 250 (set equal to BoxcarFilterLength)
Detection Mode: Peak

Now with that profile created, it can be edited and then saved by clicking on the Save Changes button.

The best way to implement changes to the PD profile is to do so while observing the effects of those changes in the PD simulation. Simulation is run with the Run Simulation button. Doing so will result in a view like that of the following image.



noise max 1 noise min -0 channel 2

Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 10 1000 NTVPeriod
BoxcarFilterLength 250 0 LockoutPeriod
DifferenceFilterLength 250 (set equal to BoxcarFilterLength)
Detection Mode Peak

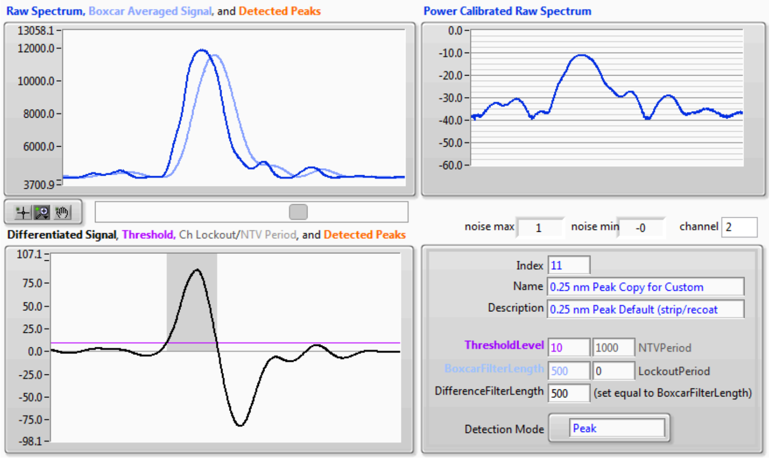
In this simulation view, it can be seen how the combination of **BoxcarFilterLength**, **DifferenceFilterLength**, and **ThresholdLevel** combine to yield the peak detection results.

First, it can be seen that the degree of filtering afforded by the offers a slight, but negligible degree of suppression of the side mode signal (dark blue plot to light blue plot in the upper left image) as a result of the **BoxcarFilterLength = 250** (pm) setting. The output of that filter signal is then sent through the differentiator circuity according to the **DifferenceFilterLength = 250** (pm) setting, resulting in the black trace on the bottom left. That signal is compared to the **ThresholdLevel** , resulting in two zero crossings that meet all of the conditions. As both zero crossings occur within the gray **NTVperiod** condition, both are considered by the PD algorithm to be valid peaks and are output from the algorithm.

To eliminate detection of that side mode, there are several options. The first and most straightforward option would be to increase the value of the **ThresholdLevel**, preventing a crossing of the **ThresholdLevel** by differentiated signal at that wavelength. However, by increasing the threshold, the user would be reducing the dynamic range of the system, as it would also cap the minimum amplitude at which the algorithm could detect a desired FBG peak.

So rather than adjusting the threshold, the recommended course of action would be to increase the values of the of **BoxcarFilterLength** and **DifferenceFilterLength** settings in such a way as to more aggressively filter the sidemode, while still accurately representing the location of the peak. This method will be effective as the width of sidemodes is always less (the frequency content is always greater) than that of the fundamental FBG reflection.

In the images below the setting have been increased from values of 250 (which correspond to a 0.25 nm smoothing window) to values of 300 (which correspond to a 0.300nm smoothing window. The effects of this change are noted below.

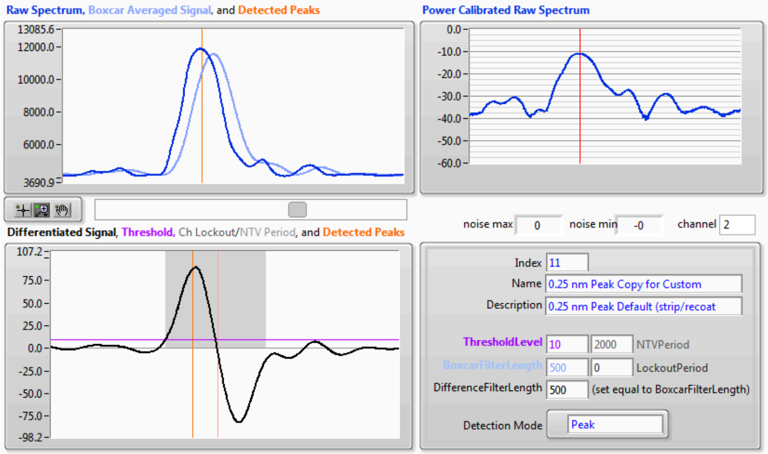


noise max 1 noise min -0 channel 2

Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 10 1000 NTVPeriod
BoxcarFilterLength 500 0 LockoutPeriod
DifferenceFilterLength 500 (set equal to BoxcarFilterLength)
Detection Mode Peak

With larger smoothing function, effects of the side mode are largely mitigated, but the primary sensor shape is also somewhat broadened. This makes sense, as a wider smoothing function will result in a wider output. However, now with the broader signal, the zero crossing does not occur within the specified **NTVperiod** of value 1000 (1nm), so that zero crossing is not considered to be a valid peak by the algorithm.

Mitigation of that issue is straightforward and accomplished by simply increasing the **NTVperiod** from 1000 (1 nm) to an appropriately larger value. Here, a value of 2000 (2 nm) is selected, and the resulting



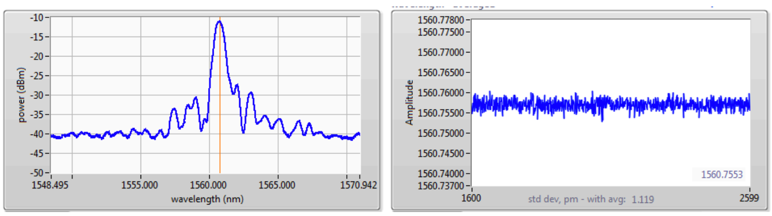
noise max 0 noise min -0 channel 2

Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 10
2000 NTVPeriod
BoxcarFilterLength 500
0 LockoutPeriod
DifferenceFilterLength 500 (set equal to BoxcarFilterLength)
Detection Mode Peak

Note that the increased phase delay from the additional filtering is fully accounted for in the algorithm, resuting in a detected peak that is still exactly in the center of the incoming raw spectrum signal.

With these changes, all is now working well. The user would then **Exit** the simulation, **Save Changes** to incorporate the new settings into the profile and **Apply to Instrument** on the appropriate channel.. Test for stability over loss (top right window as loss guide). Save changes to Preset 11.

With the updated settings, only the desired peak is returned from the PD algorithm.

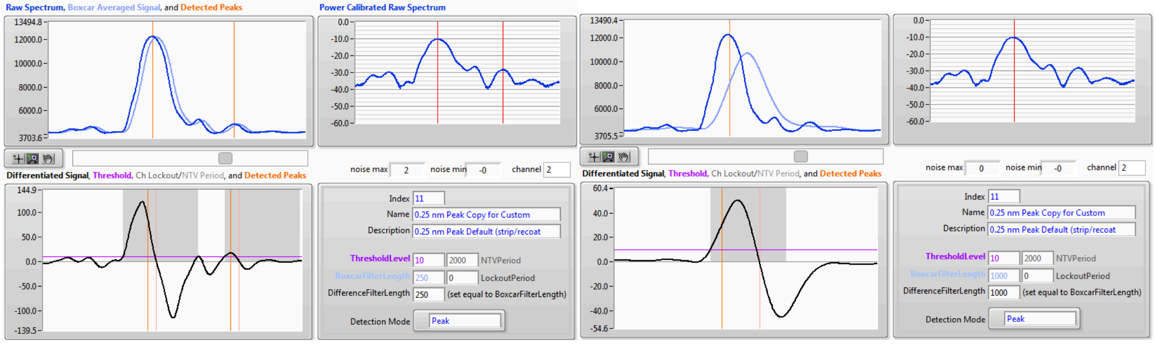


3.1.3. Common Uses for Custom Peak Detection Profiles

The following sections will highlight some common applications for custom peak detection profiles.

3.1.3.1. FBG Smoothing and side-mode suppression

The first reason to use a custom PD profile was introduced in the last section, but shown again here with more aggressive changes. In the image below, it can be seen that adjustment of the **BoxcarFilterLength**, **DifferenceFilterLength**, and **NTVperiod** can dramatically affect the complexity of the features which are considered as potential peaks, thereby greatly increasing the stability of peak detections in certain circumstances.



noise max 2 noise min -0 channel 2

Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 10
NTVPeriod 2000
BoxcarFilterLength 250
LockoutPeriod 0
DifferenceFilterLength 250 (set equal to BoxcarFilterLength)
Detection Mode Peak

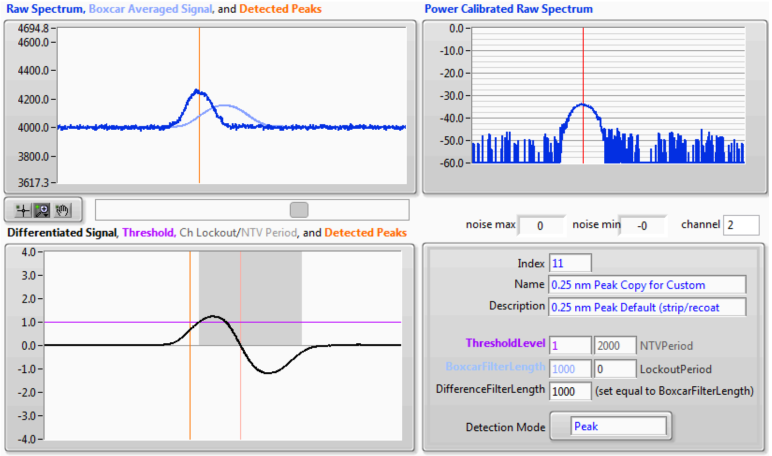
noise max 0 noise min -0 channel 2

Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 10
NTVPeriod 2000
BoxcarFilterLength 1000
LockoutPeriod 0
DifferenceFilterLength 1000 (set equal to BoxcarFilterLength)
Detection Mode Peak

Increasing Boxcar/Difference Filter Lengths from 250 to 1000 pm eliminates all side modes and suppresses noise.

3.1.3.2. FBG loss budget enhancement (especially with si255 EV)

Another use of custom PD profiles is to extend/enhance the total reach of the detection system for installations with maximum loss. By increasing the aggressiveness of the smoothing filters, the overall system noise can be greatly reduced, allowing for a much more aggressive **ThresholdLevel** setting. Here, the total insertion loss that can be accommodated by the system while still achieving robust dynamic internal peak detection has been enhanced by a combination of a 4x increase in the smoothing function and a 10x reduction the threshold.

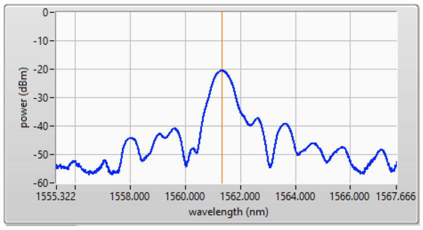


noise max 0 noise min -0 channel 2

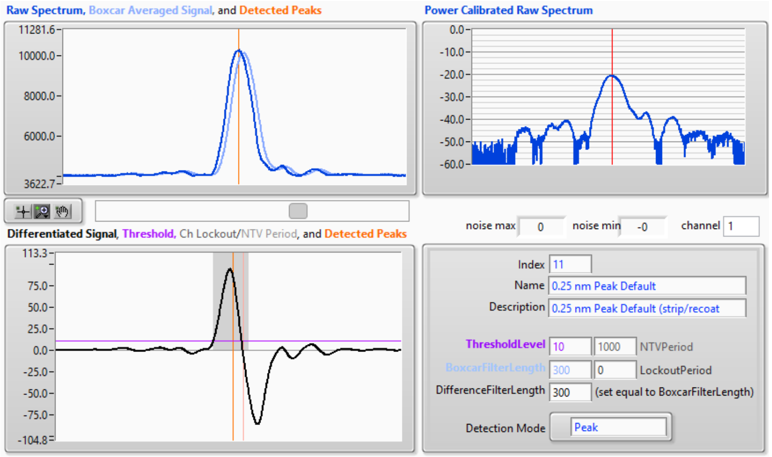
Index 11
Name 0.25 nm Peak Copy for Custom
Description 0.25 nm Peak Default (strip/recoat
ThresholdLevel 1
NTVPeriod 2000
BoxcarFilterLength 1000
LockoutPeriod 0
DifferenceFilterLength 1000 (set equal to BoxcarFilterLength)
Detection Mode Peak

NOTE: these types of adjustments should be made with full consideration of the impact on any other strong sensors on the same channel. Threshold adjustments are most advisable on measurement channels that share some common minimum insertion loss.

The following images illustrate the effects of additional smoothing and threshold adjustment or maximizing loss tolerance.



Sensor at high SNR.



noise max 0 noise min -0 channel 1

Index 11

Name 0.25 nm Peak Default

Description 0.25 nm Peak Default (strip/recoat

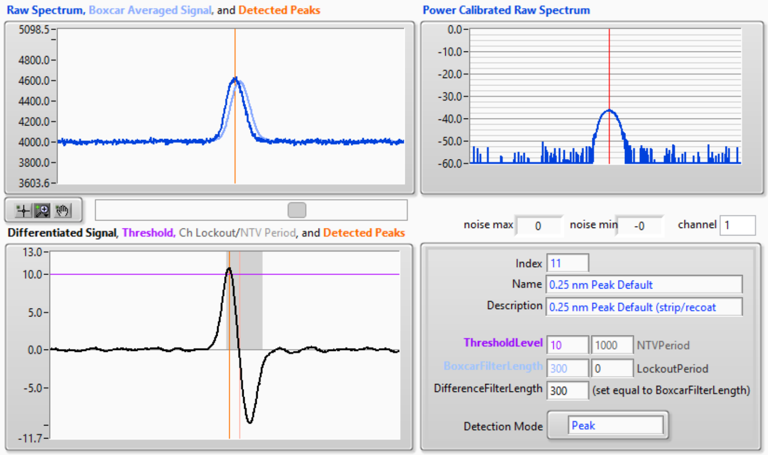
ThresholdLevel 10 1000 NTVPeriod

BoxcarFilterLength 300 0 LockoutPeriod

DifferenceFilterLength 300 (set equal to BoxcarFilterLength)

Detection Mode Peak

Standard detection settings of sensors at high SNR.



noise max 0 noise min -0 channel 1

Index 11

Name 0.25 nm Peak Default

Description 0.25 nm Peak Default (strip/recoat

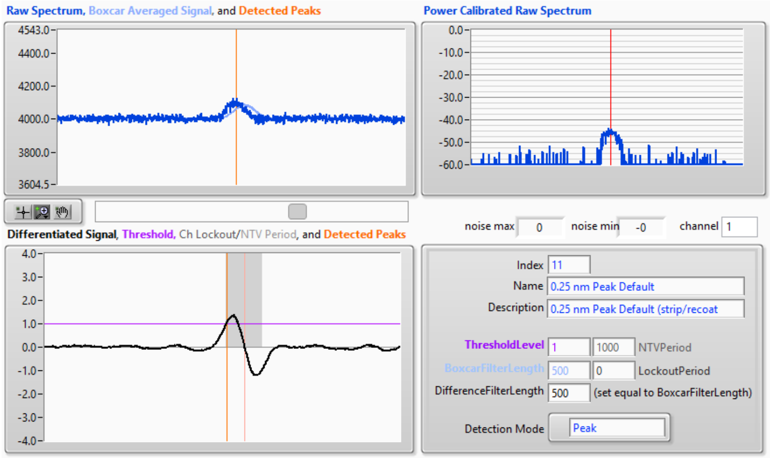
ThresholdLevel 10 1000 NTVPeriod

BoxcarFilterLength 300 0 LockoutPeriod

DifferenceFilterLength 300 (set equal to BoxcarFilterLength)

Detection Mode Peak

Sensor attenuated to minimum detectable signal at standard settings.



noise max 0 noise min -0 channel 1

Index 11

Name 0.25 nm Peak Default

Description 0.25 nm Peak Default (strip/recoat

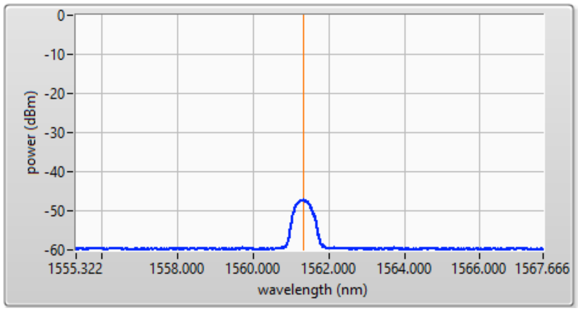
ThresholdLevel 1 1000 NTVPeriod

BoxcarFilterLength 500 0 LockoutPeriod

DifferenceFilterLength 500 (set equal to BoxcarFilterLength)

Detection Mode Peak

Enhancement of smoothing and adjustment of threshold.



Resultant improvement of minimum detectable signal by ~ 10 dB.

With suppressed noise, can lower threshold and track peaks deeper. Note that there will be a tradeoff in repeatability and additional signal averaging may need to be applied. This method best with an si255 EV.

3.1.3.3. Multi-cavity FP sensors

Lastly, custom profiles can be created to contend with a variety of spectral shapes. Below, a custom PD profile has been created and applied to a multiple cavity FP sensor, yielding consistent peak detection results on a rather complex spectrum.

noise max 5
noise min -8
channel 4

Index 17
Name 0.25 nm Valley FP custom
Description 0.25 nm Valley multicavity PF
ThresholdLevel 1
NTVPeriod 10000
BoxcarFilterLength 250
LockoutPeriod 0
DifferenceFilterLength 180 (set equal to BoxcarFilterLength)
Detection Mode Valley