

Tutorial 4

Spectral Analysis

The **Spectral Analysis** class contains two subclasses of methods: a) Power Spectral Density (PSD) analysis with the Welch algorithm (**PSD-Welch** analysis) and b) the analysis of the evolution of the PSD in time – the **Spectrogram** analysis. When the user opens the Spectral Analysis module by clicking on the corresponding button of the *left hand side menu* a new window opens as shown by Figure 1 below.

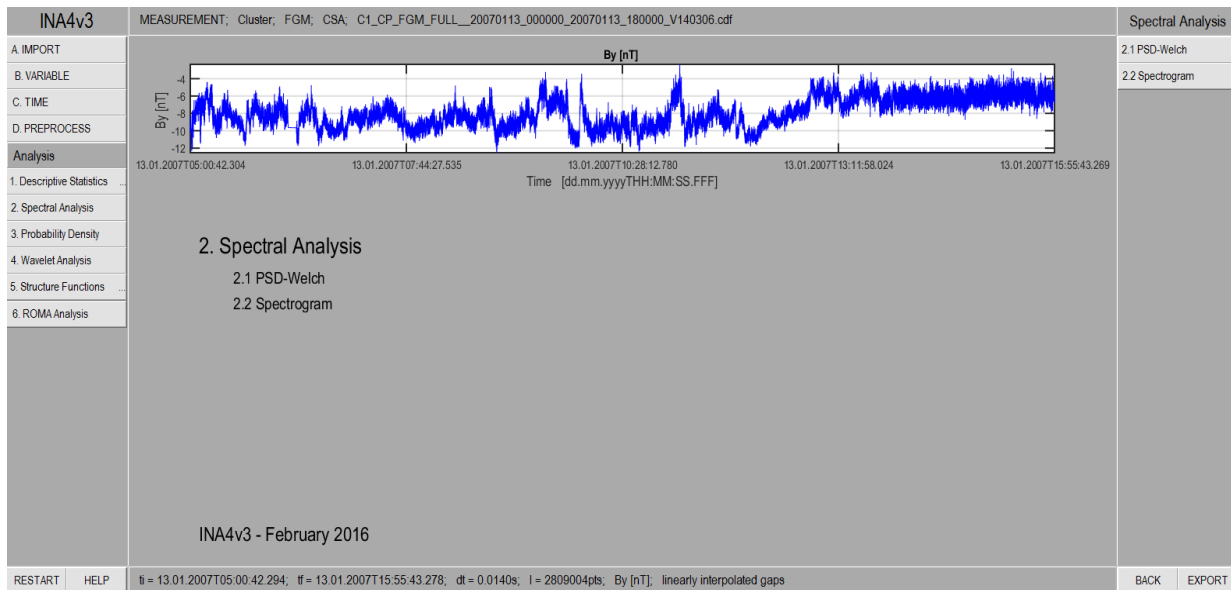


Figure 1. Illustration of the start window of the Spectral Analysis module. The upper plot shows the time series to be analyzed. The two buttons at the right are links to the two main parts of the spectral analysis module: the Power Spectral Density (PSD) with the Welch algorithm and respectively the windowed spectral analysis or spectrogram.

a) PSD-Welch

This functionality is devoted to computing the Power Spectral Density (PSD) of the selected variable using the Welch algorithm. A screenshot from the PSD-Welch panel is depicted in Figure 2. The user controls the analysis and can modify a list of options organized in five categories: i) parameters, ii) “logmean”, iii) “frequency zoom”, iv) display parameters and v) slope analysis. There are four adjustable display parameters (linx, liny, logx and logy), that control the representation of y and x axis (logarithmic or linear representations).

The Welch algorithm is widely used in the community, for a reference in the field the user may check an ESA document available online at:

http://www.rssd.esa.int/SP/LISAPATHFINDER/docs/Data_Analysis/PSD_Recipe.pdf

The Welch approach is based on splinting the signal in N possibly overlapping sub-segments of data of length L each. The PSD is computed with a standard periodogram routine for each segment and the resulting PSDs for all segments are averaged to produce the final PSD result assigned to the analyzed time series. Prior to computing the PSD one applies a window in order to reduce the lobe effects.

The user can modify the default analysis parameters for the PSD-Welch method by choosing a different window type (the parameter *win*), a different individual segment length (the parameter *sgm* modifies the length L) and/or a different overlap between adjacent segments (the parameter *ovr*). INA offers 16 different types of windows. The parameters *sgm* and *ovr* can be adjusted either by setting them as a percent of the total length of the time series or as a fixed number of data points.

The logmean functionality is introduced as a tool to decrease the variance of the spectrum. The *Logmean* function available in the right hand side panel of the spectral analysis window helps to divide the frequency interval into equally logarithmically spaced bins; it also averages the power values inside each bin. The user can adjust the frequency bin width with the *sgl* parameter and the overlap percent between adjacent bins with the *ovl* parameter. The method is especially useful for “noisy” PSDs, for which peaks and spectral breaks may be hidden by the noise.

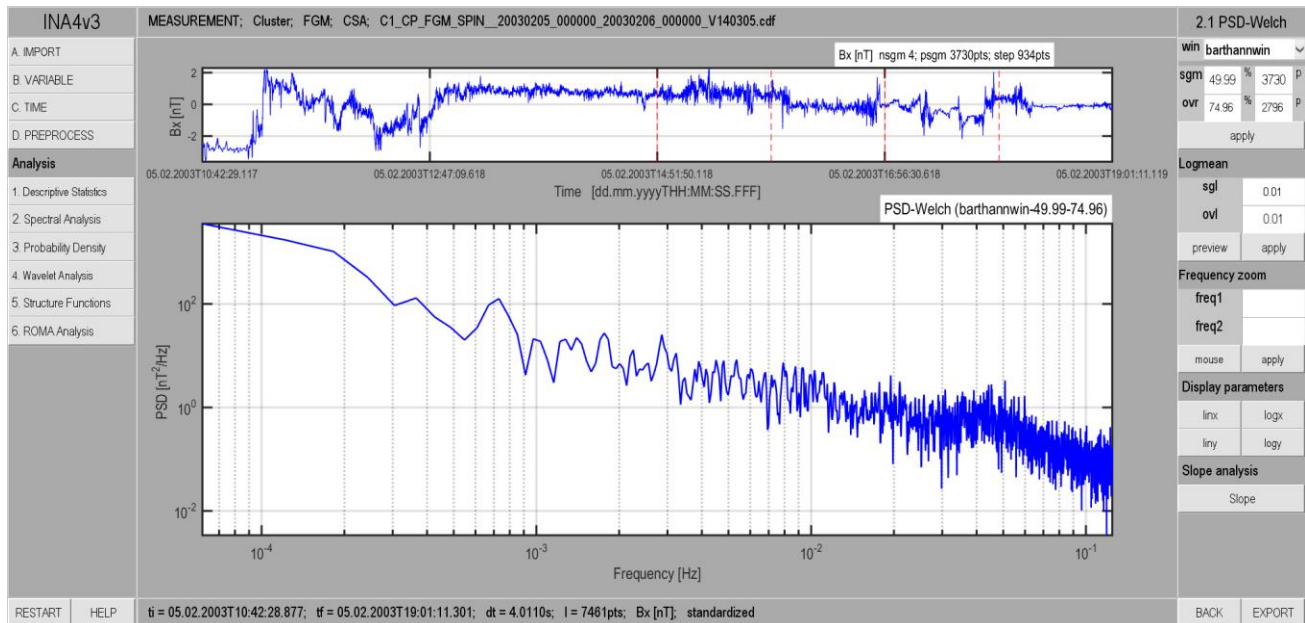


Figure2. Illustration of the **Spectral Analysis** layer: the **PSD-Welch** method. The window opens when the user clicks the **2.1 PSD-Welch** button in the right of the main **Spectral Analysis** window. The upper plot shows the time series to be analyzed, the central plot shows the corresponding PSD estimated with the Welch algorithm. The panel at the right hand side of the figure controls the output: the first group of parameters controls the windowing function (the **win** parameter), the length of the individual Welch segments (the parameter **sgm**, to be given either in percentage or in number of data points). The selected window function and the Welch parameters are indicated in the captions attached to the upper and central pots. The **frequency zoom** function allows the user to select a given frequency

range, either with the mouse or by specifically specifying the start/end frequencies. The buttons grouped under **Display parameters** control can switch between linear and logarithmic representations of the PSD.

If the user wishes to take a more detailed look on some particular range of frequencies of the PSD, the *Frequency Zoom* function of the right hand side panel can be used to extract and display specific parts of the spectrum. The user may select the end/start frequencies with the cursor or manually by using the editable text fields located in the right hand side control panel.

The slope analysis function contains 3 drop-down menus:

- i) **fitmet**: the user can choose one of the three implemented fit methods: 1) linfit (simple linear regression), 2) LMfit (Levenberg Marquardt fit algorithm) and 3) rLMfit (robust Levenberg Marquardt fit algorithm) (<http://www.mathworks.com/help/curvefit/fitoptions.html>);
- ii) **interval**: the user can choose to fit simultaneously one, two, or three frequency intervals of the PSD;
- iii) **method**: the user can choose how the frequency range for slope computation is defined: using the “mouse” or by typing the explicit values of the start/end frequencies for fit.

The *Apply* button computes the fit and overplots it on the PSD plot; it also displays on the plot the computed value of the slope together with the frequency domain for which the slope was computed. A screenshot of the slope analysis module is displayed in Figure 3.

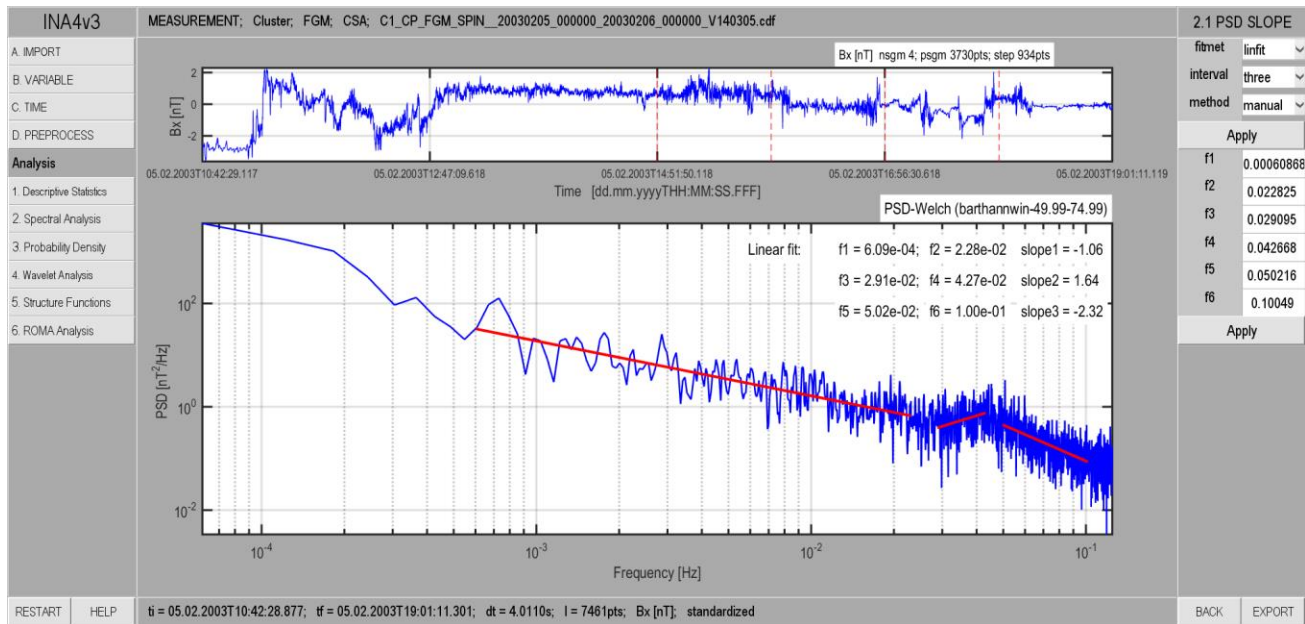


Figure3. Illustration of the spectral slope analysis. This window is opened after clicking on the **Slope** button of the PSD-WELCH window illustrated in Figure 2. The user can choose between three fitting methods from the **fitmet** dropdown; the user can specify from the **interval** dropdown up to three different frequency intervals of the PSD for which the spectral slope is computed simultaneously; the user can choose from the **method** dropdown to specify the frequency range for fit by selection with the mouse or by typing the explicit values of the start/end frequencies. The example shown here illustrates the latter possibility for a fit computed for three different frequency ranges.

b) Spectrogram

In addition to computing one PSD spectrum for a selected time interval using the Welch algorithm, INA also offers the possibility to compute a series of PSD spectra and display their evolution in time on a spectrogram. The spectrogram is a three dimensional plot (time, frequency, PSD) where the third dimension (corresponding to PSD values) is color coded. An example is shown in figure 4. The right hand side menu looks similar to the one displayed for the PSD-WELCH module but the actions are different. First, the user can choose the type of windowing applied prior to the Fourier analysis. The default type is the modified Bartlett-Hann window that is labeled as “barthannwin” in the uppermost dropdown menu of the right panel. It is also possible to choose the number of individual PSD spectra to be computed for the spectrogram by modifying the *sgm* parameter that defines the length of the window for which one PSD is computed. The total number of spectra is obtained then by dividing the total length of the time series to the length of the window. The user can specify *sgm* either as a percentage of the total length or as a total number of points. The user can also specify the *ovr* value that sets the degree of overlapping between two consecutive windows.

Larger percent of overlap results in larger segmentation of the time-series, and, consequently, the visualization of finer details in the temporal evolution of the spectral properties of the time-series. The segment length and overlap degree can be used to increase either the frequency resolution (by setting the *sgm* and *ovr* parameters to values above ~ 85%) or the time resolution of the spectrogram (by setting the *sgm* and *ovr* parameters to values below ~ 15%).

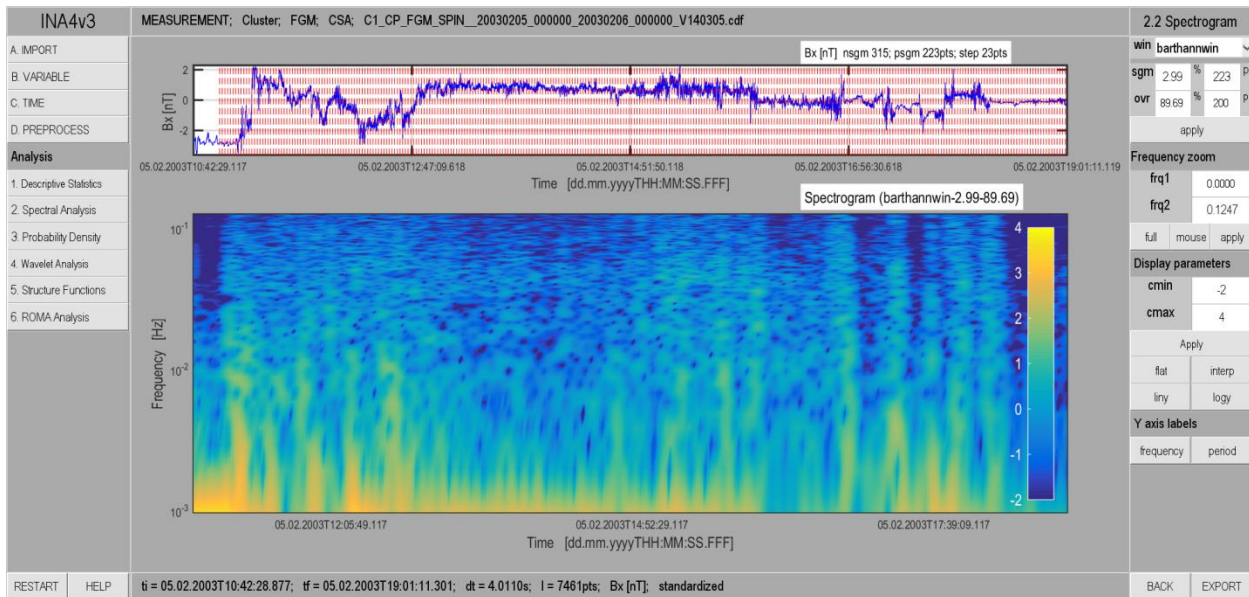


Figure 4. Illustration of the Spectrogram analysis window. The upper panel shows the analyzed signal, the limits of the windows for which the individual PSDs are computed are marked with dashed red lines. The main plot displays the spectrogram, the values of each PSD are color coded as described by the color table displayed at the right. The panel at the right displays the controlling parameters that are described in the text above.

Like in the PSD-Welch part, the spectrogram can also be zoomed in a certain frequency range by setting its limits with the mouse or with the manual filling of the input fields labeled as `frq1` and `frq2`. After zooming, the original spectrogram can be restored by clicking on the “full” button located in the Frequency zoom part of the right panel.

The spectrogram window allows for setting of several adjustable display parameters. The user can set the limits of the color axis (**`cmin`** and **`cmax`**) thus modifying the range of the displayed spectrogram. It is also possible to control the shading of the spectrogram plot by switching between **`flat`** (for which the color coded coefficients appear in distinct parcels whose dimensions directly represent the time-frequency resolution of the spectrogram) and **`interp`** (for which the color coded coefficients in adjacent parcels are linearly interpolated). The `flat` option interprets the spectral coefficients in domains whose dimensions represent the frequency and temporal resolution of the spectrogram, while the `interp` option adjusts the sharp variations of the coefficients among the domain edges. The scale of the vertical axis can be switched between logarithmic and linear by pushing the buttons labeled respectively by “`liny`” and “`logy`”. Finally, the labels of the ticks in the vertical axis can also be changed from frequency (Hz) to period (s) units and vice versa by using the “frequency” and “period” buttons.