Analysis Suite go2signals

Manual

Signal Analyzer

Product Version v25.2

July 4, 2025

PROCITEC®
HOUSE OF SIGNALS

Imprint

PROCITEC GmbH
Rastatter Straße 41
D-75179 Pforzheim
Germany

Phone: +49 7231 15561 0
Fax: +49 7231 15561 11
Email: service@procitec.com
Web: www.procitec.com

CEO:
Dipl.-Kaufmann / M. Sc. Stefan Haase

Registration Court:
HRB 504702 Amtsgericht Mannheim
Tax ID:
DE 203 881 534

Document ID:
PROCITEC-IMA-Signal-Analyzer_E-45ba033524

Subject to technical modifications.

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1. Introduction

This application is dedicated to the manual analysis of recorded signals. It is indented as a toolbox providing commonly used signal processing and visualizations to interactively inspect emissions.

Signal analysis can often be achieved by use of automated systems that can identify emissions, perform a classification of the signal type and estimated or infer parameters of the transmission scheme used to generate them. In cases where automated processing fails or produces insufficiently reliable results, manual analysis can be used to further investigate and analyze. Manual analysis can yield same information as automated system, however, it provides deeper look into the signal to verify and understand automatic results or the lack thereof.

Signal Analyzer is intended as a toolbox to ease the analysis process by providing *′Signal Analyzer Modules′* to analyze and visualize different modulation aspects, e.g. symbol clock. Using the available *Signal Analyzer Modules* the user will be enabled to analyze a variety of signal formats and modulation schemes. The results of *Signal Analyzer* are visualized in plot displays that allow the observation of certain signal properties as a well as getting measurements for parameter estimation. Knowledge and technical background on the topics of signal processing and modulation schemes is recommended to effectively use this application and interpret its results.

Integration in other PROCITEC applications

Signal Analyzer can be used independently of other PROCITEC products by opening signal file to be analyzed. For convenience, it can also be opened directly from other PROCITEC products, pre-configured with the signal input of interest: This includes signal available in the Result Viewer of *go2MONITOR* as well as a snapshot recordings of a live signal.

2. Overview

In this chapter an overview of the application is given. Both, the conceptual workflow and the graphical interface are discussed.

2.1. Start of the application

Signal Analyzer can be started in different ways:

- Select *Signal Analyzer* from the start menu. It can be found in the Windows® program group under "PROCITEC»Analysis Suite xx.y"
- Context menu of a signal file, selecting *Open with*
- Double-click a *Signal Analyzer Project file* (.san)
- Directly from within go2MONITOR. See the go2MONITOR manual for details.

2.2. Basic workflow

The indented usage and typical workflow of the application is comprised of these steps:

1. Load an input signal from file
2. Inspect the sonagram display and select a time/frequency region for analysis.
3. Trigger one or more analysis modules
4. Inspect the results of the analyses - mostly plot displays.
5. Adjust/modify the parameters of the *selection* and/or the analysis. The results are updated automatically.
6. Repeat from step 2 until satisfied

The state of such an analysis can be saved as a *Signal Analyzer Project file*.

2.3. Terminology

Emission

A radio emission on a Radio Frequency (RF) with a bandwidth and time period. Usually, the emitting station transmits a message within a 'short' time period of seconds or minutes. There are also much longer emissions, e.g. broadcast radio stations as on UKW/FM around 100 MHz.

In a communication between two stations, there are multiple (minimum 2) emissions: one for each station.

SNR

Signal to noise ratio. Received signal power primarily depends on the transmitted signal power and the distance of the emission's source to the reception antenna. Especially on HF (High Frequency: 3 - 30 MHz), fading will reduce the SNR. The effects of fading are varying over time - although not always visible in the spectrum or waterfall. Noise sources will also degrade the SNR. Even low-power noise will have huge impact, when located near the reception antenna.

Selection

A *selection* (see 2.4.1) specifies a frequency span (center/bandwidth) and also a time period (from/to) to be analyzed by one or more *analysis modules*.

A *selection* is to be manually defined within the input signal file and should not contain more than one emission. In a (wide-band) recording (signal file), multiple (overlapping) emissions might be present besides noise. Sometimes, especially in case of overlapping, the extents of one single emission is not obvious. Anyway, having multiple/independent emissions in one *selection* will falsify analysis results.

Mixing time regions of noise and signal usually degrades the analysis result. Besides noise, at begin or end of a (burst-)emission, fading and other distortion have similar effects. In case of fading, careful selection of the time-region will be crucial.

This makes it a good idea to "*play*" with the time/frequency-selection - to achieve valid to best analysis (verification) results.

It's also a good idea to compare the results of different time periods - when assuming the same modulation.

Signal Analyzer Module (SAM)

An *analysis module* is a predefined set of signal processing operations and corresponding visualization. This includes simple operations, like an auto-correlation display, as well as various step of demodulation. Examples:

- Time: displays traces of magnitude, phase and instantaneous frequency of a *selection* over time.
- PSK: visualize PSK signal characteristics like center frequency, symbol clock and I/Q-constellation for the modulation order.

As input of these module, the selected region of the input signal is used. In addition, modules can have additional settings; e.g. to display the signal level instead of magnitude in the Time Analysis. They also may react to changes in e.g. cursor positions in result displays of previous runs.

As output, an analysis module generated a result panel, which contains mostly plots. These are arranged in a fixes grid and may be grouped into multiple tabs. Analysis results are automatically updated when any of the inputs change.

2.4. Main window

Figure 1: Signal Analyzer Overview

Aside from statusbar, menus and a toolbar to trigger various actions, the main window (Figure 1) is divided into two parts:

The left part (marked in green) is used to visualize and inspect an input file using a sonagram and spectrum display. It is also used to create and navigate *selections* (see 3.2.3) as input for analysis modules available in the main menu or toolbar.

The right panel (marked in red) shows the results of these analyses, if available, each comprised of multiple signal displays.

2.4.1. Input Sonagram and Spectrum

The upper half shows the sonagram, a (reversed) waterfall, of the input signal, while in the lower half a spectrum view is shown. An detailed explanation of these plots can be found in section 3.2. Different from the result plots explained below, however consistent with other PROCITEC applications, the input sonagram shows frequency on the horizontal axis and time on the vertical axis.

A toolbar (Figure 2) is visible at the top, which provides easy access to plot controls as well as configuration options of the spectra calculation. For details on the control elements see Figure 5.

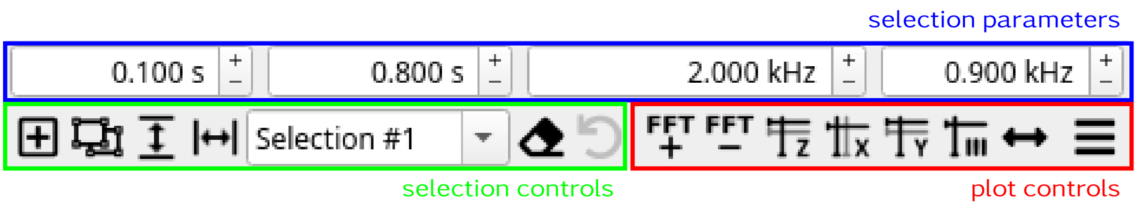


Figure 2: Signal Analyzer input toolbars

The sonagram display is also used to create and modify *selections*. The toolbar contains buttons to add/create, duplicate, rename and delete *selections* as well as undo changes.

Existing *selections* can be modified with the mouse and with the spinboxes in the toolbar. Their parameters are start time offset, duration, center frequency and bandwidth.

Selections are used as input for the the analysis functions available in the main menu. Multiple *selections* may be created, and for each of them multiple analyses may be run.

2.4.2. Result panels

The result of each analysis for each *selection*is shown in a separate panel. By default, these panels come up inside the main window (marked red in in Figure 1) - in docked state - visible as tabs at the bottom. This default can be changed (see section 3.1.3), that new analysis modules start in undocked - or floating mode. Undocked result panels can be placed anywhere on the desktop and allow side-by-side comparison, e.g. from same analysis modules over different *selections*.

In case a analysis module itself has multiple tabs, they are shown at the top of the panel. Each tab has a toolbar for parameters and numeric results. In addition, advanced parameters may be shown on a sidebar. To open the sidebar the settings toolbar button on far right of the toolbar.

Every plot itself has a frame with a title, some plot specific buttons and a "burger" menu ☰. The burger menu ☰ shows additional parameters/options. Plots are placed in a well thought out layout to allow quick perception of the analysis' purpose. Utilization of screen area is a trade-off targeting small mobile and huge stationary screens.

Common plot features include:

- Maximize - to increase readability on small screens
- *Copy as Picture*
- (Harmonic) Cursors for measurement
- Zoom functions

3. User Interface

In this chapter the various parts of the user interface are discussed in detail. The main focus here are the interaction with various plots displays.

3.1. General

3.1.1. Menu and Toolbars

The main menu is located at the very top of the main window, see Figure 1. The main toolbar is located directly below the menu and provides easy access to common main menu entries.

File menu

File and application actions are available in the menu File. From here input and project files can be opened, saved and exported, see 3.1.2. Futhermore, the application settings can be accessed via the Options actions.

Preprocessing menu

The items in the Preprocessing menu are used to process an input signal before the actual analysis. Some modulation techniques need some (analog) preprocessing, before *Signal Analyzer Modules* can be applied - and have a chance to produce useful results.

Analog modulations (AM, FM) are for removing one layer of multiple modulation layers. Crop (DDC) is for reducing the file size, that *Signal Analyzer Modules* can perform faster on the smaller region of interest.

The entries in this menu are *Signal Analyzer Modules* with the primary goal of producing a single output. It is shown in sonagram display and meant to be saved and opened as a input signal file for further analysis.

Analysis menu

The menu Analysis contains all available *Signal Analyzer Modules* which the primary function of signals analysis. Entries here are used to trigger a *Signal Analyzer Module* for the currently active *selection* in the input signal. A full list and description of all *Signal Analyzer Modules* is in section 5.

Future versions include more *Signal Analyzer Modules* for analyzing specific modulation formats as well as modules representing full-fleshed demodulators.

Windows menu

This menu is used to access and set application window options. Options are persistent.

Help menu

The menu item *Manual* opens the product manual (this document).

The documentation of the *Signal Analyzer Modules* is also available inside of the application, from the menu item *Modules Help*. Additionally, individual sections of this documentation can be opened directly from the analysis results using the various Help ("?") buttons. Also, a quick view of the documentation is shown when hovering over result plot titles.

The item *About* opens a dialog showing the software version and build information.

3.1.2. File Handling

Signal files

The following file-formats are supported for signal files:

- WAV: PCM 8/16/24/32 bit integer, PCM 32 bit float (IEEE 754), A-law, μ-law
- Blackbird TCI CAP: 16/32 bit integer, complex/real
- MetadataRaw: 8/16/32 bit integer, 32 bit float (IEEE 754), complex/real, big endian/little endian
- MEDAV DAT/DAZ: 8/16/32 bit integer, 32 bit float (IEEE 754), complex/real
- BLUE (Midas BLUE aka BLUE 1.0 and Platinum BLUE aka BLUE 2.0): 8/16/32 bit integer, 32/64 bit float (IEEE 754), big endian/little endian
- SigMF: 8/16/32 bit integer, 32/64 bit float (IEEE 754), complex/real, big endian/little endian
- SignalHoundIQFile (signal recording from Spike application): 16 bit integer, complex

A signal file can be selected in the open file dialog available in the File menu or main toolbar. Additionally, a list of recently opened files is available in the *Recent files* sub-menu. Also, *Signal Analyzer* may be used in the operation system *Open with..* functionality.

Project files

Signal Analyzer Project files (*.san) are used to save an restore analysis settings. These files can be opened and saved from within the application.

The state of an analysis is stored in these project files:

- relative and absolute path to the corresponding signal file
- selection data
- opened analysis modules (per selection) and the analysis parameters

A project file can be saved in a directory different from the signal file. Also, multiple project files can be saved, referring to one signal file, e.g. for different set of analyses.

Export

Export is a convenience function that is meant for sharing or archiving analysis results.

The File menu item Export is used to select a target filename and triggers the following task:

- Copy the signal file to the target location
- Save the corresponding Analysis Project files (*.san) - alongside the exported signal, omitting the absolute path.

File Info Dialog

This dialog provides an overview about the currently loaded signal and project and information related to the sample format and signal parameters, see Figure 3.

Most fields are for verification only, and therefore read-only. However, depending on signal file-format some meta-data may be missing or incorrect. This dialog allows adjusting these to allow correct interpretation of the data for analysis.

If a signal file with ambiguous sample format is loaded the application may request disambiguating using this dialog. Signal files generated by other PROCITEC applications already contain all meta-data.

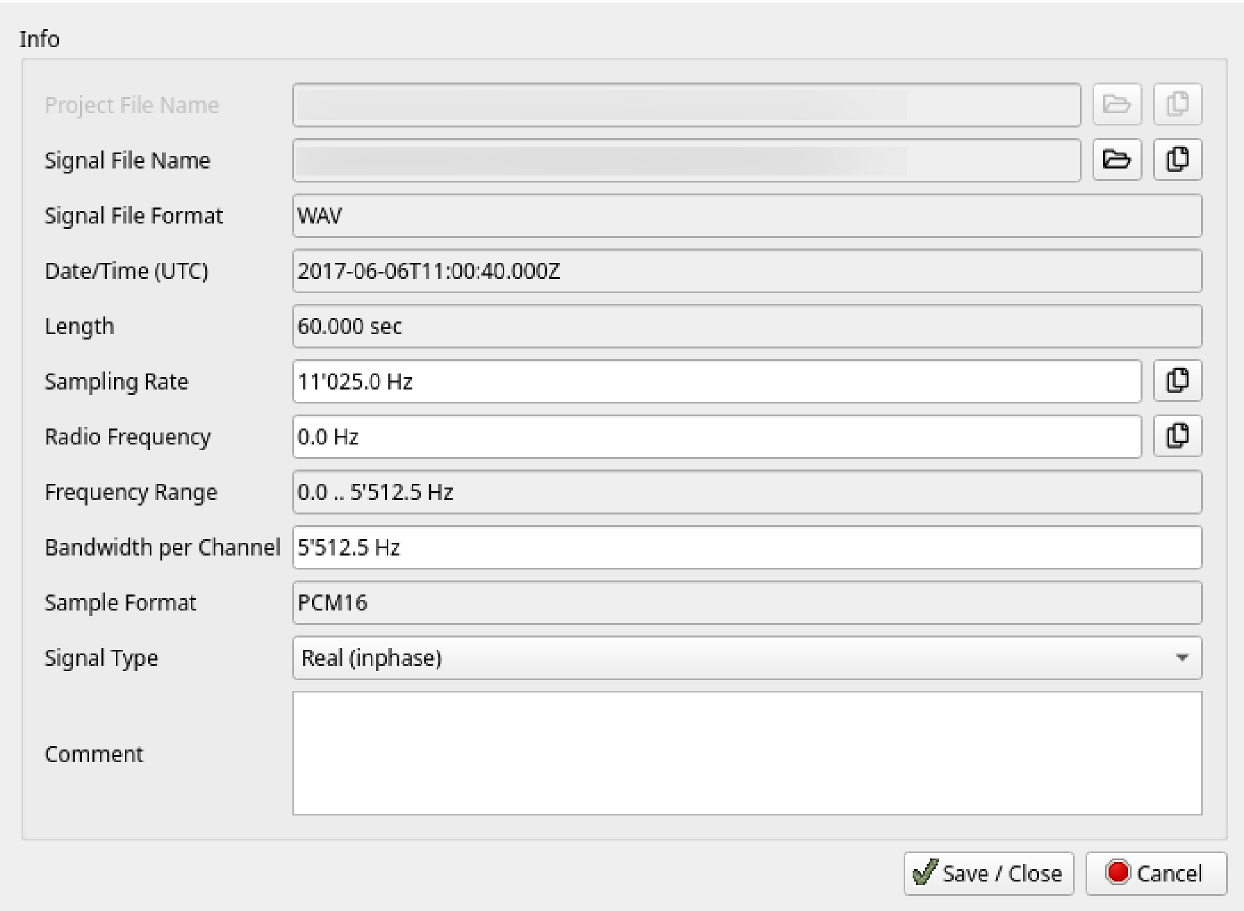


Figure 3: Signal Analyzer file info

3.1.3. Settings Dialog

The following settings allow to change the default behavior and appearanve of the application. Settings are modified using the Settings Dialog from the File menu.

General – Startup

- **Open most recent file on start**

  With this option enabled, the most recent signal or project file is loaded automatically on application start.

- **Number of recent files**

  Number of recently opened project or signal files to keep track of.

General – Projects

- **Open project for signal file**

  When a signal file is opened and a project file with the same name is found next to it, the application can to open the project instead. This can be done automatically, never or after user confirmation (default).

- **Open with saved window layout**

  Restore the last saved window layout for a project when it is loaded.

- **Include main window geometry**

  Also include the main window geometry (position, state and size) when restoring a project window layout.

- **Save current project, when closing the application**

  When enabled and a modified project is closed the changes are saved automatically.

General – Appearance

- **Color scheme**

  General user-interface color scheme for application windows, dialogs and controls:

  – (system default)

  – Light

  – Dark

  Changes to this setting require restarting the application.

  Note, the option "(system default)" depends on availability of a color scheme setting in the operating system. Not not all supported operating systems define a color scheme. Fallback option is "Light".

- **Line/Scatter plot colors**

  Color scheme for all line and scatter plots within the application:

  – Standard

  – Inverse

  – Monochrome

- **Sonagram/Heatmap plot colors**

  Color scheme for sonagram and heatmap plots within the application. Aside from the default "(same as line plots)" the same options as line/scatter plots as available.

Extras – Input sonagram

- **Use relative time**

  Switches the default for timestamps in the Input Sonagram between absolute and relative values. A change becomes effective only after loading a file. The former uses the time of recording, if available, while the later uses times relative to the input signal.

  This setting defines the default for newly opened signal files. It can overwritten per-file using the corresponding item in the burger menu ≡ of the Input Sonagram. That value is also stored in project files.

- **Auto-scale time axis**

  With this option enabled newly opened files will be automatically scaled to bring the entire file in view. A change becomes effective only after loading a file. This behavior is preferable especially for short and medium sized signal files.

  This setting defines the default for newly opened signal files. It can overwritten per-file using the corresponding item in the burger menu ≡ of the Input Sonagram. That value is also stored in project files.

- **Auto-zoom selection of activated modules**

  With this option enabled, activating (clicking) an analysis does automatically activate it's selection and makes sure it is visible.

- **Time-bandwidth auto-selection limit**

  Limits the size of the default selection created if an analysis is started without a selection defined. For the default selection 90% of the currently visualize frequency and time range is used. If the resulting time-bandwidth-product exceeds the value set here, the selection duration will be truncated.

- **Memory limit**

  Default memory limit for input signal selection processing. If exceeded, *Signal Analyzer Modules* will stop reading from input and continue processing with the shortened signal. Some Modules do not require the whole input loaded at once and ignore this limit.

- **Confirm removing selections with associated analyses**

  When enabled (default), removing a selection with associated analyses requires user confirmation to prevent accidental loss of analysis results.

Extras – Analysis result windows

- **Open as floating windows**

  Each *Signal Analyzer Module* has a dedicated result panel - per *selection*. By default, these are stacked on the right-hand side of the main window. Result panels can be un-docked to appear as floating windows. With this option enabled newly created result panels opened as floating windows right away.

- **Clear default analysis layout for ...**

  Default layouts can be saved and restored for each *Signal Analyzer Module*. This option will clear a previously saved layout.

3.1.4. Keyboard Shortcuts

Most program functions are available with keyboard shortcuts:

Shortcut	Function
<Alt> + <F>	Opens "File" menu
<Ctrl> + <O>	Opens load dialog for analysis project or signal file
<Ctrl> + <I>	Shows "File Info & Reconfigure" dialog
<Ctrl> + <S>	Saves analysis projects to file
<Ctrl> + <Shift> + <S>	Opens "Save As.." dialog for analysis project file
<Ctrl> + <G>	Opens Settings Dialog
<Ctrl> + <Shift> + <W>	Closes analysis project
<Ctrl> + <Q>	Quits application
<Alt> + <P>	Opens "Preprocessing" menu
<Alt> + <A>	Opens "Analysis" menu
<Ctrl> + <1>	Show or hide Input Sonagram (toggle function)
<Ctrl> + <0>	Dock all analyses tabbed
<Ctrl> + <Shift> + <C>	Close all analyses
<Alt> + <H>	Opens "Help" menu
<F1>	Open user manual

There are few common plot shortcuts:

Shortcut	Function
<Ctrl> + <W>	Close current *Signal Analyzer Module*
<F6>	AutoRange: Automatic setting of the displayed Y-range to view the total ranges. Additional <Ctrl> also sets the X-range. Not in all plots
<F7>	Show / Hide the analysis parameters (toggle function) - if available
<F12>	Maximize / normalize plot (toggle function)

More shortcuts are listed in the plot specific sections 3.5.2.5, 3.5.5.3 and 3.5.6.7 for Vector/Time-, I/Q- and Sonagram-Plot, respectively. To use the plot-specific keyboard shortcuts, make sure the GUI focus is actually on the plot (indicated in the title bar).

3.2. Input Sonagram

The Input Sonagram is shown on the left-hand side of the main window. It displays the signal data in a sonagram and spectrum plot and has controls to define and modify selections. See Figure 1.

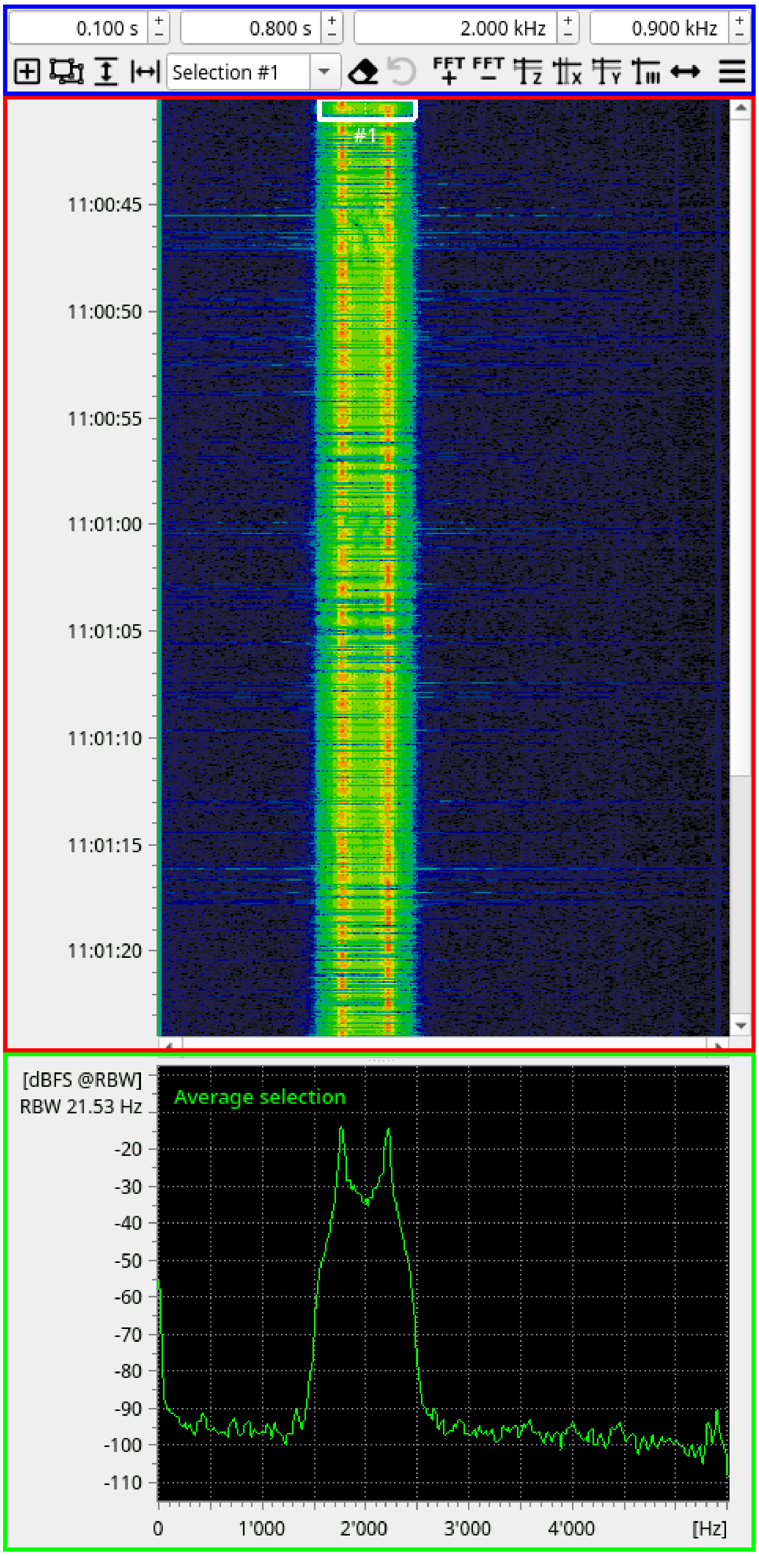


Figure 4: Signal Analyzer input panel

3.2.1. Sonagram

The sonagram plot visualizes a signal in two domains simultaneously: time and frequency. It's a tool to perform time-frequency analysis. It is marked red in in Figure 4.

Showing the energy distribution in colors on a 2-dimensional time/frequency map, the sonagram helps to recognize and select emissions for further analysis. As mentioned in section 2.3 it's crucial to have good *selection* extents for a successful analysis. Most Analysis yield the best results when the selection contains the whole emission along the frequency axis and a continuous section along the time axis.

With zoom, cursors, the spectrum and further functions, the user is supported to make good *selections*. A detailed description of the Spectrum/Sonagram - plot is in section 3.5.6.

3.2.2. Spectrum

The lower pane of Spectrum/Sonagram (marked green in Figure 4) shows an averaged spectrum. It has three averaging modes: By default, the entire visible time-span of the sonagram is used. If at least one selection is defined, the averaged time-span is limited to that of the active selection. If cursors are active the time-span is used instead. The active mode is shown in the upper-left part of the plot.

3.2.3. Selection and controls

The selection and sonagram controls are shown in Figure 5. It shows the blue mark of Figure 4, the input panel.

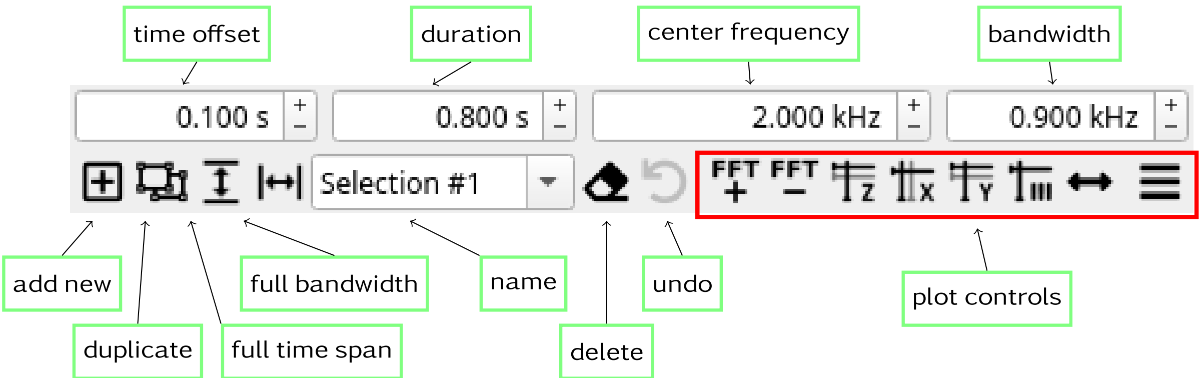


Figure 5: Signal Analyzer input toolbars

These toolbars contain controls for creation, duplication, deletion and (re)naming of *selections*. By default, selections are named by index. A custom name can be set to switching between multiple signal parts of interest. Changes to selections as well as renaming and deletion of selections can be reverted using the *undo* button in the toolbar.

The spinboxes for "time offset", "duration", "center frequency" or "bandwidth" show the numerical values of a selection and allow fine-grained adjustments.

A new selection can be added in various ways:

- Drag an area with the mouse in the waterfall - if there are no previous selections
- Press "Add new selection"-button first, then drag an area with the mouse in the waterfall
- Drag an area with the mouse in the waterfall and keeping the Shift-key pressed before releasing the mouse

- Directly select a preprocessing or analysis function from menu or toolbar. If there's no selection, a new selection - spanning the whole file - will be created automatically.

Dragging a new area without activating modifier (keys) will replace the current selection, if one exists.

Multiple *selections* allow to mark different emissions, or different bursts of one emission in one input signal. Multiple analysis modules can be applied on every single selection, e.g. for comparing different emissions or bursts.

When duplicating a selection, the new one is directly on top of the existing selection: change the new selection's extents or position with the mouse or the spinboxes to separate them.

Press the Ctrl-Key while dragging/moving the outer extents of a selection with the mouse to modify both sides (left/right or top/bottom) symmetrically.

The control elements labeled with "plot control" modify the calculation of the sonagram, e.g. increase/reduce the frequency resolution or provide other functionality, which is described in Section 3.5.6. The right-most button is a burger menu ☰ , which leads to additional controls.

3.3. Result panel

The result panels show the results of *Signal Analyzer Modules*. Usually in form of multiple plot displays layed out in a grid-layout or split across multiple tabs.

By default, the result panels are stacked on the right-hand side of the main window as shown by the red marker in Figure 1. Each panel can be undocked to appear as a separate Window.

Result panel always have a toolbar, the analysis toolbar, at the top. Common items are found on the left and far right: An icon of the corresponding module and a control item showing the execution state. It appears, if warnings or errors were issued during the last update of the results. During execution of the module if appears as a waiting indicator. It may be used to abort execution and e.g. modify the active selection.

The following elements in the analysis toolbar show the main settings and result of the current analysis module, e.g. Figure 6 for the time analysis. These are explained in details as part of the module documentation in chapter 5.

Figure 6: Analysis toolbar of module time

On the far right of the analysis toolbar are again common elements to

- show the Synchronize Parameters panel,
- show the Search Modem panel,
- reset the result panel and its plots to the default state,
- open the module documentation in the integrated help browser and
- toggle the visibility of the extended settings panel.

The latter opens a sidebar on the right with additional options for the analysis, if the module has any. The sidebar controls are again custom to each module, see chapter 5 for details.

3.4. Result Parameter Synchronization

Results obtained in an analysis module, can in turn be used as input to other analyses. This mechanism allows to share and synchronize results for important and common parameters, which are relevant for multiple analyses, like e.g. the modulation type and its order or the symbol rate.

All analysis modules, supporting this mechanism, offer a *Synchronize Parameters* panel, like the one shown in Figure 8. These panels list the suitable parameters for the specific analysis module and provide means to control their synchronization.

For an application global overview, the *Synchronization Overview* window is provided. It offers similar functionality as the *Synchronize Parameters* above, but not limited to a single analyses module. It aggregates all information of the single *Synchronize Parameters* panels.

Besides the panels and the overview, the analysis result parameters itself provide the ability to trigger related actions directly from their context menu.

3.4.1. Sharing parameters

By sharing of parameters, a concrete result value from a specific analysis is transferred to all other analysis instances, which are currently open and accept this parameter. This is a one-shot action, it takes place only once, when explicitly triggered by the user.

Sharing of results can be useful, when a measurement result from one analysis shall quickly be used in another analysis module. It spares manually copying and pasting values from and to widgets.

Buttons for sharing are labeled with the ➦ icon. Parameters can be shared either via their context menu or the *Synchronize Parameters* panel, see section 3.4.3.

Sharing Frequency

The *Frequency* parameter can also be shared between analysis modules, but it has a different effect. The frequency offset is applied to the corresponding input selection. Further, the frequency offset of all depending analyses is set to zero. Note, that frequency can only be shared between analysis instances of the same input selection.

3.4.2. Synchronization of parameters

In addition to sharing, it is also possible to continuously transfer parameter values from an analysis instance, this is denoted as *synchronization*. Effectively, this can be understood as sharing of parameters from a specific analysis (source), which is automatically triggered if the parameter value in the source changes.

Synchronization of parameters allows for example to automatically parametrize the Demodulation module from any analysis module. Further changes in the analysis module will be immediately transferred to the demodulation module, where the new demodulation results can be seen.

Synchronization of result parameters can be controlled via the parameter widgets and their context menu directly. Left clicking the 🔗 button in the analysis toolbar initiates synchronization of all parameters from the present analysis. Further, the *Synchronize Parameters* panel (Section 3.4.3) or the *Synchronization Overview* (Section 3.4.4) provide control over the synchronization.

Synchronized result parameters are indicated by the 🔗 icon or variations of it. See the table below for the possible icons and their meanings.

Icon	Status	
	Unsynchronized	Not synchronized in any analysis.

Icon	Status	
	Source	Synchronized from this analysis.
	Destination	Synchronized from other analysis.
	Destination out-of-sync or missing	Synchronized from another analysis but currently out-of-sync or source doesn't provide this value. Click to re-synchronize from source.

Table 3: Synchronization parameters status icons

As an example, see Figure 7, which shows two currently synchronized result parameters. The left parameter "Variant" is currently synchronized as source, whereas the right parameter "Symbol rate" is synchronized as destination.

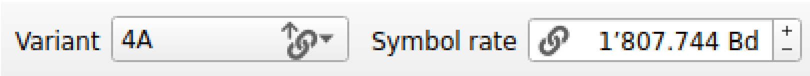


Figure 7: Synchronized parameters in PSK Analysis toolbar

If, in the example above, the parameter "Variant" is changed here, either manually or implicitly e.g. by the estimation process of the analysis, the new value is distributed to all other open analysis instances. Note, that the destination of synchronization is independent of the input selection the analyses belong to.

On the other hand, the parameter "Symbol rate" is synchronized from a different analysis. If it changes there, the present value is updated accordingly.

If such a parameter is changed at a destination analysis instance, it won't have the value from the synchronization source anymore. This conflict is indicated by the icon. It is now possible to re-synchronize this value again, simply by clicking on the button. Note, that if the synchronized value contradicts limits of the destination analysis, it might be impossible to re-synchronize the value. Re-synchronization also takes place, if the parameter is changed in the synchronization source.

3.4.3. Synchronize Parameters panel

The panel can be opened by a right click on the *synchronization* button in the analysis toolbar. Note, that if parameters are currently synchronized from or to the this analysis, the *synchronization* button has a numeric indicator on the icon, stating the number of synchronized parameters.

At the top of the panel all available parameters from the current analysis module are listed. Figure 8 shows the panel for the PSK Analysis, with controls for the parameters *Modulation* and *Symbol rate* which support synchronization here.

The synchronization status of the parameters is indicated by icons on the left, see the table in Section 3.4.2 for a description. Click on the parameter label to initiate synchronization. It is also possible to share a parameter value from here, click on the button. To deactivate synchronization, click on the button. If applicable, there is a button to share the frequency below the other parameters.

Further actions allow to open the *Synchronization Overview* (Section 3.4.4), synchronize all applicable parameters from the present analysis or deactivate synchronization of all parameters from this analysis at once.

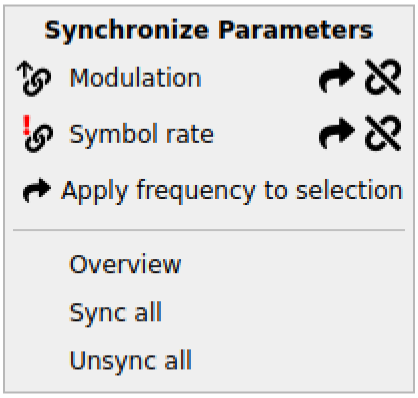


Figure 8: Synchronize parameters panel as in PSK Analysis

3.4.4. Synchronization Overview

The *Synchronization Overview* panel can be opened from any *Synchronize Parameters* panel or by clicking on the synchronization button in the status bar of the application.

Similar to the *Synchronize Parameters* panel it lists all parameters for sharing or synchronization. Here, however, all parameters of all open analyses are included. It also provides similar controls, but from an application global point of view. This means the synchronization source can be explicitly chosen via a combo box. Additionally, the synchronized values are displayed.

Furthermore, this panel can left open and can be docked anywhere in the application or turned into a floating window.

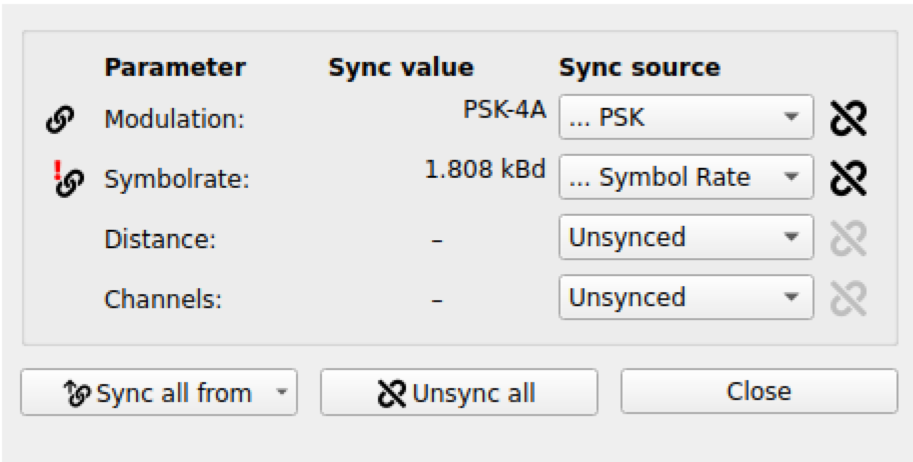


Figure 9: Synchronization overview

3.5. Plot Displays

In this section the various plot displays and their usage are explained. These displays are part of the result panels and are used to visualize a specific property of the the selected signal. This section is dedicated to general usage and control elements of the displays themselves. The motivation and meaning of the results themselves are detailed in following chapters individually.

There a different types of plots, for example generic time plots, histograms and IQ-displays.

3.5.1. Common

All plots share some common controls. A toolbar on the top shows the plot title, usually describing the type of single begin visualized. More information is quickly available by hovering with the mouse pointer over the title shows a pop-up of the corresponding section in the module documentation.

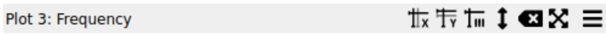


Figure 10: Common toolbar for plots

On the far right are several (often used) control elements. The example in Figure 10 shows:

- (de)activate X-Cursors
- (de)activate Y-Cursors
- (de)activate harmonic cursors and control harmonic cursor settings via right click.
- apply auto-range to set display ranges automatically. additional press of Ctrl-key will include the X axis.
- (un)maximize to enlarge the plot area over other plots, e.g. for better readability
- burger menu ☰ with additional controls

Other plot types my have different or additional controls, e.g. a sonagram provides:

- increase/decrease of applied FFT length to modify the frequency resolution.
- (de)activate Z-Cursors (time)
- burger menu ☰ , contains different controls

3.5.2. Vector/Time-Plot

The time plot shows the signal in the time domain, i.e. it serves as an oscilloscope. As shown in Figure 11, this plot is divided into two parts. In the left part the time evolution of the signal is displayed. The X-Axis of the plot shows the time relative to the start of signal.

Figure 11: Time Plot

In the right part accumulations of signal values are optionally displayed in a histogram. The signal values displayed in the left part are sorted into histograms with equidistant bars and normalized to 100%. If harmonic time cursors are active, the signal values are taken at the positions of the time cursors to build the histogram. The histogram allows aber better perception of the signal values distribution.

The area used for time or histogram plots can be adjusted by a splitter in the middle.

3.5.2.1. Context/Popup menu

Some operations are available in the plot area with the context menu. These are:

- (De)activate X-/Y-cursors and Harmonic
- Zoom in/out: the cursor values are ignored. In case a region is marked (drawn with mouse), it defines the target area for the zoom. Without a marked region, the zoom enlarges the area by factor ½.
- Copy as Picture

3.5.2.2. Parameters

The following parameters are available:

Parameter	Function
Min. time	Definition of the start time.
Time range	Definition of the range of the plot in the time-domain.
Max. (amplitude)	Definition of the maximum displayed signal value (amplitude).
Min. (amplitude)	Definition of the minimum displayed signal value (amplitude).
Autorange	Automatic setting of the displayed range to see the total Y-range of the signal values

3.5.2.3. Cursors

Cursors serve to select, measure or clarify specific values or ranges. They can be activated from plot title bar or the plot context menu. X-Cursors can be used to measure values on the X-Axis, e.g. time or frequencies. Y-Cursors are shown on the Y-Axis to measure i.e. amplitude, phase, frequency.

Harmonic mode shows several cursors at equidistant intervals. The exact number can be set via the context widget, reachable by a right click onto the harmonics button in the plot title bar. In this mode the first cursor will move all other cursors. The intervals are defined by grabbing and moving the second or any following cursor. The Harmonic function can only be applied in combination with X- or Y-cursors, therefore activating it can implicitly activate cursors. It serves to measure repeating intervals.

Each cursor label shows the exact position. For the cursor distance label the tooltip include the inverse value. For each cursor label a floating spinbox is shown on right click. This allows cursor positions to be set using (known) numeric values as well as copying the current value to the clipboard.

3.5.2.4. Markers

Markers serve to measure and visualize values and ranges - quite similar to cursors. But in difference, markers are predefined from an analysis module and usually represent parameter values.

Many markers can be moved, together with their corresponding parameter values, by dragging with mouse. If suitable, the marker jumps to the maximum within some pixels tolerance, when releasing the mouse button. While dragging, the catch-region is visualized, in which the maximum is searched for at release.

Press the <**Ctrl**> key while dragging to deactivate the maximum-search and jump.

3.5.2.5. Keyboard Shortcuts

Important functions are available with mouse wheel and (additional) keyboard shortcuts. To use the keyboard shortcuts, make sure the GUI focus is actually on the display (indicated by the title bar).

Shortcut	Function
Mouse wheel	Scroll in Time
<**Ctrl**> + Mouse wheel	Zoom in/out horizontally: into time at mouse position
<**Shift**> + Mouse wheel	Zoom in/out vertically: into Y-axis at mouse position
<**Ctrl**> + <**Shift**> + Mouse wheel	Zoom in/out horizontally & vertically: into time and Y-axis at mouse position
<**Ctrl**> + Drag marker	Move marker without jumping to the maximum
Drag marker with Mouse	Move marker and jump to the maximum within the tolerance region
<**Ctrl**> + Drag area	Zoom into dragged area
<**+**> or <**-**> <**P**> or <**M**>	Zoom in time. Additional <**Ctrl**> speeds up zoom
<**Shift**> + <**+**> or <**-**> <**Shift**> + <**P**> or <**M**>	Zoom in/out Y-axis. Additional <**Ctrl**> speeds up zoom
<**Alt**> + <**+**> or <**-**>	Zoom in/out time and Y-axis. Additional <**Ctrl**> speeds up zoom
<**Home**>	Move time scrollbar to the start
<**End**>	Move time scrollbar to the end
<**Page Up**>	Move time scrollbar one page towards the start. Additional <**Ctrl**> jumps directly to the start
<**Page Down**>	Move time scrollbar one page towards the end. Additional <**Ctrl**> jumps directly to the end
<**Left Arrow**>	Move time scrollbar towards the start. Additional <**Ctrl**> scrolls one page
<**Right Arrow**>	Move time scrollbar towards the end. Additional <**Ctrl**> scrolls one page
<**Up Arrow**>	Move Y axis up (to higher values). Additional <**Ctrl**> moves faster
<**Down Arrow**>	Move Y axis down (to lower values). Additional <**Ctrl**> moves faster
<**X**>	Activate and deactivate X-cursors (toggle function)
<**Y**>	Activate and deactivate Y-cursors (toggle function)
<**H**>	Activate and deactivate Harmonic cursor mode (toggle function)

3.5.3. Frequency-Plot (spectrum)

This is a vector-plot configured to have frequency as X-axis - not time. Oftentimes the Y-axis is level in dB as shown in Figure 12. However, linear scaling may be more appropriate.

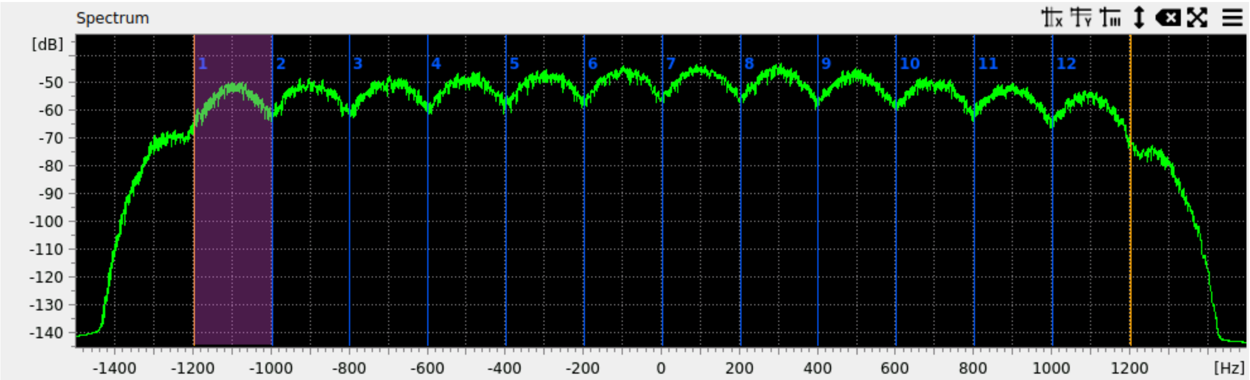


Figure 12: example frequency-plot: averaged spectrum

Usage and operation is the same as with the "Vector/Time-Plot" described in section 3.5.2. This includes parameters, mouse-operation and keyboard-shortcuts. Frequency plots don't have a histogram subplot.

3.5.4. Histogram-Plot

This is a again vector-plot configured to show the distribution of values - by default in bars. Figure 13 shows am exemplary histogram of the difference phase values in the PSK analysis.

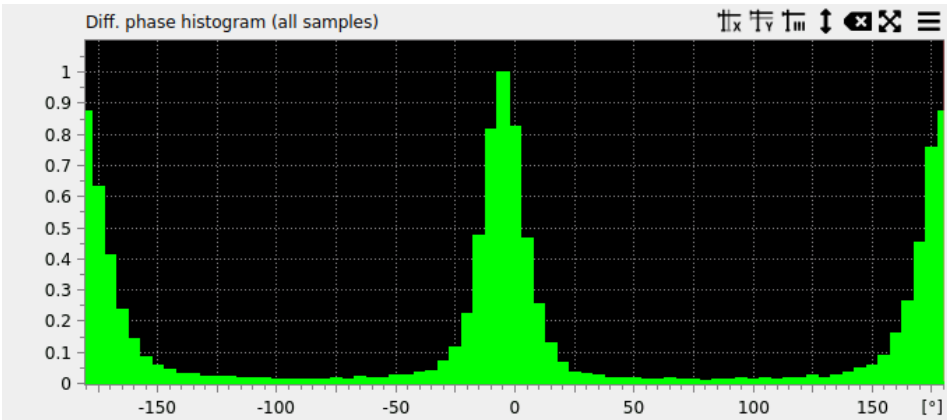


Figure 13: example histogram-plot: A3 spectrum

Usage and operation is the same as with the "Vector/Time-Plot" described in section 3.5.2. This includes parameters, mouse-operation and keyboard-shortcuts.

3.5.5. I/Q-Plot

The I/Q-plot shows the signal in the complex plane of numbers as a real part (in phase) and an imaginary element (quadrature). Several signal sections can be displayed in a superimposed plot.

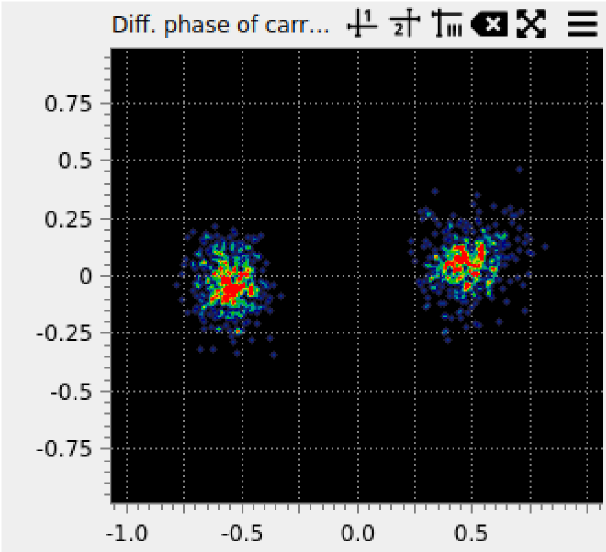


Figure 14: I/Q-plot display

As shown in Figure 14, the real (inphase) part is shown on the X-Axis. The imaginary (quadrature) part is drawn on the Y-Axis. The plot itself uses an overlay-mode. This means, that the more points or lines are drawn at the same area of the plot, the redder this specific area appears.

3.5.5.1. Context/Popup menu

Some operations are available in the plot area with the context menu. These are:

- (De)activate XY-cursor 1/2 and Harmonic
- Zoom in/out: the cursor values are ignored. In case a region is marked (drawn with mouse), it defines the target area for the zoom. Without a marked region, the zoom enlarges the area by factor ½.
- Copy as Picture

3.5.5.2. Parameters

The following plot-specific parameters are available:

Parameter	Function
Min. time	Definition of the start time.
Time range	Definition of the range of the plot in the time-domain.
Range	Extend of the X- and Y-Axis shown
Heatmap max.	Threshold for the upper saturation point
Heatmap min.	Threshold for the lower saturation point
Display mode	Show dots or connect data points with lines

3.5.5.3. Keyboard Shortcuts

Important operations are available with mouse wheel and (additional) keyboard shortcuts. To use the keyboard shortcuts, make sure the GUI focus is actually on the plot (indicated by the title bar).

Shortcut	Function
Mouse wheel	Zoom in/out I/Q. Additional <**Ctrl**> speeds up zoom
<+> or <-> <P> or <M>	Zoom in/out I/Q. Additional <**Ctrl**> speeds up zoom
<X>	Activate and deactivate XY-Cursor 1 (toggle function)
<Y>	Activate and deactivate XY-Cursor 2 (toggle function)
<H>	Activate and deactivate Harmonic cursor mode (toggle function)

3.5.6. Sonagram-Plot

A sonagram plot shows the spectrum of signals over time. One important application is to get an overview of the power distribution. The spectrum/sonagram is a combined display for both, the sequence of the most recent spectra in a waterfall display and an averaged spectrum below.

Figure 15 shows an example of the spectrum/sonagram plot.

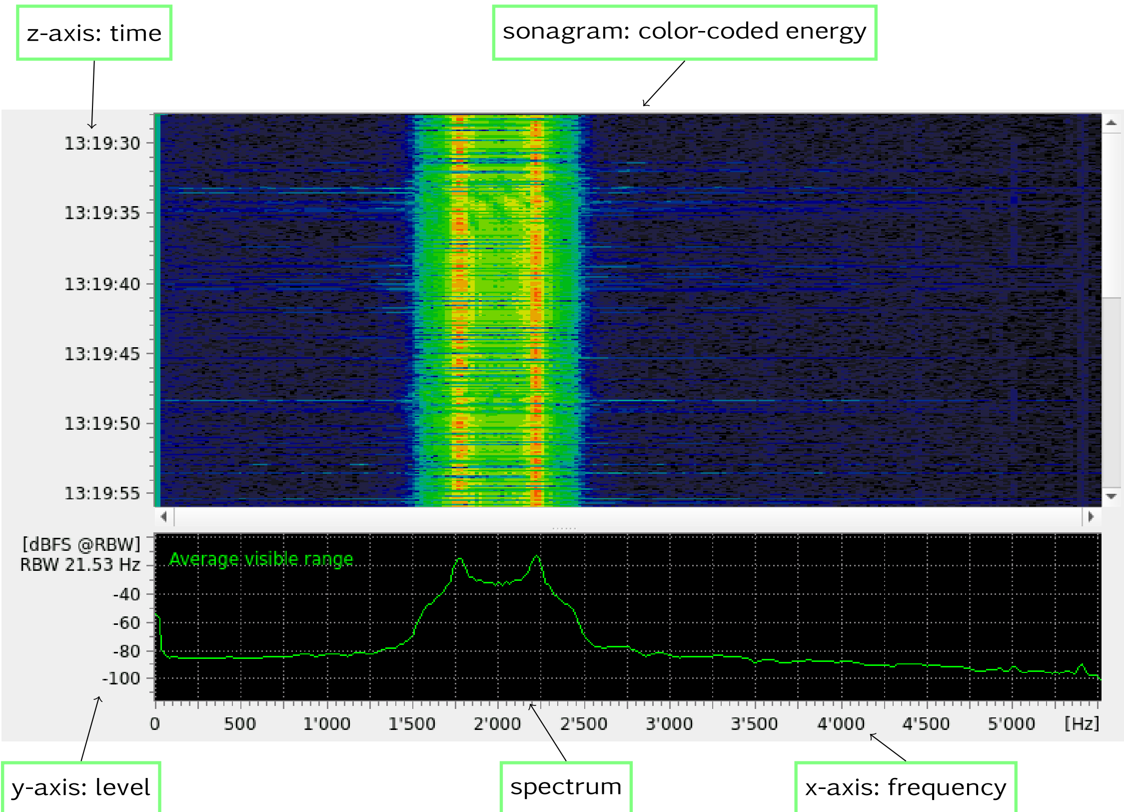


Figure 15: Spectrum/Sonagram

The spectrum/sonagram plot is divided into two panels. Depending on the configuration only one panel might be shown.

The upper panel shows the sonagram (spectrogram). Each horizontal line represents a certain time. The color represents the power on this frequency (from black to blue to green to red). The labels on the time axis (Z-axis) show the recording period of the signal. Changes in the signal level in the course of time can be identified by changes in color.

In the lower panel of this plot the averaged spectrum (FFT) is shown. There are several averaging modes available: If z-cursors are active the time-span between them is used. Else, the averaged time-span is the same as the time-extend of the active selection, if any. Else, the entire visible time-span of the sonagram is used. This is indicated in the upper-left part of the spectrum plot.

X-axis: Frequency 0 corresponds to the center frequency of the input signal, if available.

Y-axis: Shows the logarithmic power, displayed in dBFS. This refers to the level of the signal. 0 dBFS represents full scale and -100 dB is 100 dB below full scale. 0 dBm is for 1 mW, -50 dBm means 50 dB below 1 mW, which equals 10^{-5} mW.

3.5.6.1. Power spectrum

The power spectrum (default) varies the displayed power level depending on the configured FFT length. With the next higher FFT length (factor 2), the spectra resolution is doubled and together with that also the bandwidth of one FFT bin is halved. Thus, also the measured power is halved. With the next smaller FFT length (factor 0.5) the measured power is doubled.

Measuring the power of a modulated signal requires accumulating the power over the signal's bandwidth. See chapter Power spectrum.

The sample rate of a signal and the FFT length define the frequency resolution (also known as bin width, also known as RBW for **r**esolution **b**and**w**idth):

RBW = sample rate / FFT length

The value below the Y-Axis label ([dBFS @ RBW] or [dBm @ RBW]) shows the current resolution bandwidth.

3.5.6.2. Power spectrum density

The unit commonly used for power density is "dB per Hz"; thus normalized to 1 Hz – independent of FFT length. However, the FFT length still defines the frequency resolution.

In a frequency band containing white noise only, the measured power density does not change with the FFT length. In a power spectrum the power level varies for different FFT lengths, which influences the frequency resolution (RBW).

For signals with a bandwidth smaller than the RBW, normalization makes no sense. Especially for unmodulated carriers, the power density cannot get measured, because the power is erroneously distributed over the RBW. A finer frequency resolution has to be applied by increasing the FFT length. Alternatively a power spectrum can be used in order to measure such signals.

To allow direct comparison of the resulting level with other software or other measurement devices, the resolution bandwidth (RBW) can be normalized to a bandwidth of 500 Hz by activating the context menu item "PSD normalization".

3.5.6.3. Power in dBm

The levels are usually displayed without units in dB / dBFS, when no reference level is available with the signal data.

3.5.6.4. Power and SNR measurement

When the X-cursors are active, the upper right corner of the spectrum view shows the total power (total power: signal power S + noise power N), the noise power (N) and the signal to noise ratio SNR (S/N).

These values are calculated for the frequency band spanned by the X-cursors.

The calculation is performed based on the visible spectrum and thus is influenced by various parameters like FFT length, windowing, exp. Averaging and the spectrum plot, e.g. Average value Cur. 1/2. Depending on these parameters, the measured values will vary by some dB. Average value Cur. 1/2 is required for the measurement of short bursts.

The noise level is determined automatically and shown with a horizontal dashed gray line (see Figure 16). The level is calculated from the visible spectrum. It is important to have enough flat noise-only bands in the view. This can be controlled with the parameters Center frequency and Frequency range. The dashed gray line is for verification of the estimated noise level.

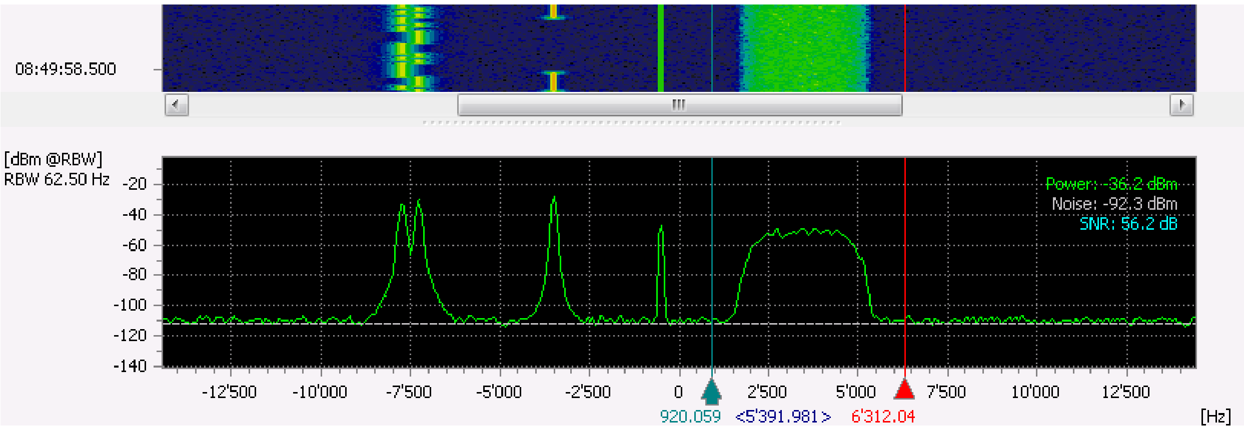


Figure 16: Spectrum/Sonagram with measurement values power, noise and SNR

Selecting the context menu item Sync Noise level with Y-cursor, the Y-cursors are displayed at the currently estimated values for power and noise (red: power, green: noise) (see Figure 17). Modification of the X-cursors leads to a recalculation of the measured values and the Y-cursors also get updated. In case the Y-cursors get modified manually, e.g. for adjusting the noise floor, then the labels in the upper right corner are marked with a star to show that these are not the automatically determined values (see Figure 18).

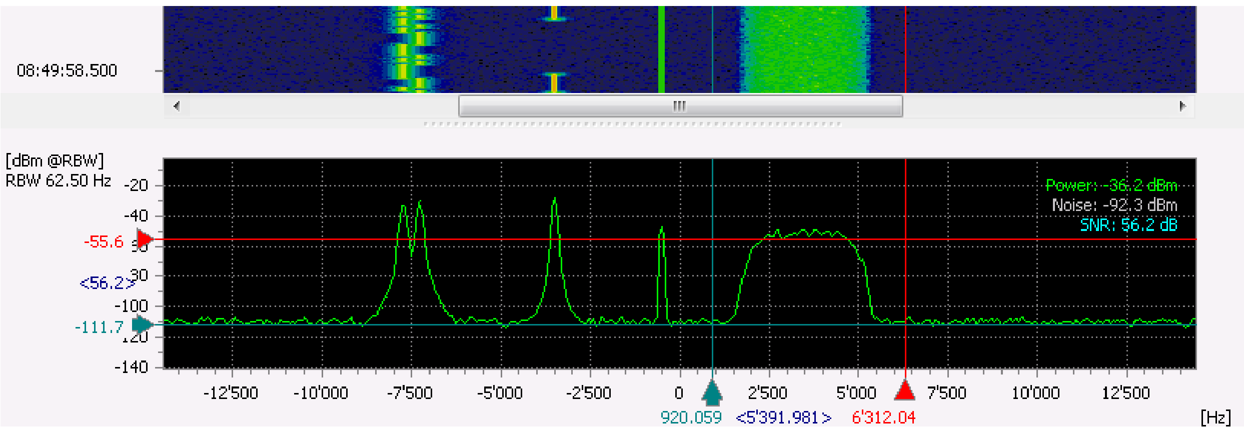


Figure 17: Spectrum/Sonagram with synchronized Y-cursor

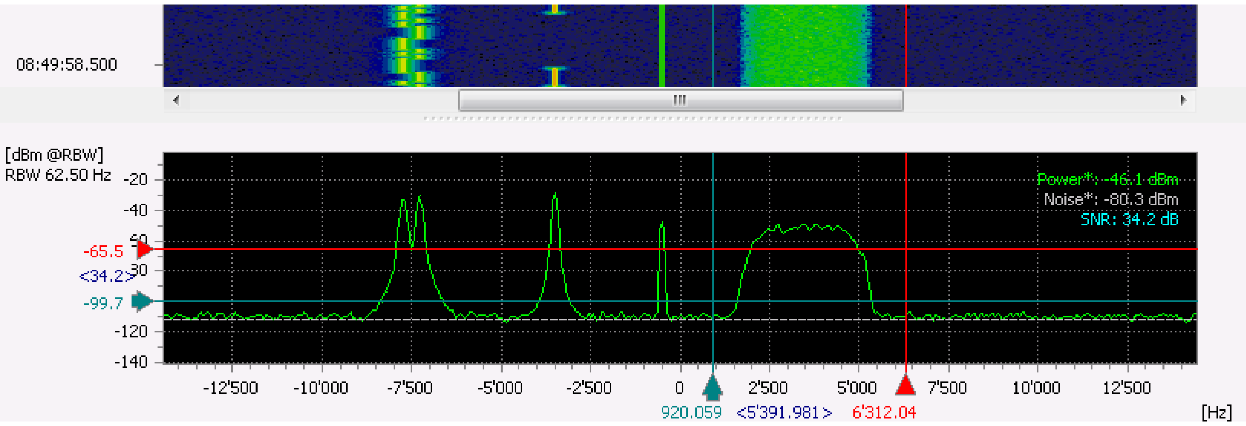


Figure 18: Spectrum/Sonagram with manually positioned Y-cursor

All spectral components between the X-cursors are used for calculation of "power". This also includes regions which obviously contains just noise. Accurate SNR measurements are not possible for signals with smaller bandwidth than the RBW. Pure (unmodulated) carriers don't use bandwidth, thus the SNR can only be specified for a given bandwidth.

The SNR is calculated using following simple formula:

SNR = (Total Power – N) / N = S / N

The value is then displayed in dB.

3.5.6.5. Context/Popup menu

Parameter	Function
Zoom range	Change zoom to include either maximum frequency or time range or both.
Zoom in	Enlarges the visible frequency by factor ½ each time it is activated. If there is a drawn rectangle/area (dragged by mouse) in the plot window, it is zoomed into this section. After zooming, the rectangle/area will disappear - as if clicked any position in the plot window.
Zoom out	Reduced view of the section delimited by the cursors. Repeat this process until the spectrum area displayed is satisfactory.
Immediate mouse zoom	Zoom in by clicking the mouse at the desired position (zoom out using the <**Ctrl**> key).
Sync Noise level with Y-Cursor	The Y-Cursors are displayed at the currently estimated values for power and noise (red: power, green: noise). See chapter Power spectrum.
Power Spectrum Density (PSD)	Switches between power spectrum and power spectrum density (PSD).
Spectrum input	Which time or time range from the sonagram is used for the spectrum display
Show spectrum maximum	Show a peak-hold like graph in the spectrum display

Table 8: Spectrum/Sonagram - Popup Menu

3.5.6.6. Parameters

The parameters of the spectrum/sonagram can be set using the burger menu ≡ in the toolbar or title above.

Parameter	Function
FFT length	Number of values of frequency in which the signal is displayed. To obtain a higher resolution of the displayed frequency range, increase the FFT length.
Lines / second	Number of spectrums that can be calculated and displayed within one second. This parameter serves to set the time resolution for the sonagram, thus also setting the scroll speed.
Show relative time	Use timestamps relative to start of the signal even if absolute timestamps are available.

Table 9: Spectrum/Sonagram - Parameters Tab

3.5.6.7. Keyboard Shortcuts

The following keyboard shortcuts are available in the spectrum/sonagram plot. To use the keyboard shortcuts, make sure the GUI focus is actually on the plot (indicated by the title bar).

Parameter	Function
Mouse Wheel focus on sonagram	Move scrollbar in time direction
Mouse Wheel focus on spectrum	Move scrollbar in frequency direction
<**Left Arrow**>	Move scrollbar to lower frequencies. Additional <**Ctrl**> scrolls one page
<**Right Arrow**>	Move scrollbar to higher frequencies. Additional <**Ctrl**> scrolls one page
<**Up Arrow**>	Move time scrollbar one step towards the start
<**Down Arrow**>	Move time scrollbar one step towards the end
<**Page Up**>	Move time scrollbar one page towards the start. Additional <**Ctrl**> jumps directly to the start
<**Page Down**>	Move time scrollbar one page towards the end. Additional <**Ctrl**> jumps directly to the end
<**Home**>	Move time scrollbar directly to the start
<**End**>	Move time scrollbar directly to the end

Table 10: Spectrum/Sonagram Plot Control, Keyboard Shortcuts: Scroll functions

Parameter	Function
<**Ctrl**> + Mouse Wheel	Zoom in/out in time
<**Ctrl**> + Drag area with Mouse	Zoom into dragged area

Parameter	Function
<Shift> + Mouse Wheel	Zoom in/out in frequency
<Ctrl> + <Shift> + Mouse Wheel	Zoom in/out in time and frequency
<+> / <P>	Zoom in Graphical Zoom enlarges the visible frequency by factor ½ each time it is activated. If there is a drawn rectangle (by mouse) in the plot window, it is zoomed into this section. After zooming, the rectangle, shown as a white dotted line, will disappear - as if clicked any position in the plot window.
<-> / <M>	Zoom out The displayed frequency area is enlarged by factor 2
<Ctrl> + <Up Arrow> / <Down Arrow>	Zoom in/out in time
<Ctrl> + <Shift> + <Up Arrow> / <Down Arrow>	Slow zoom in/out in time
<Ctrl> + <Shift> + <Page Up> / <Page Down>	Fast zoom in/out in time
<Shift> + <Up Arrow> / <Down Arrow>	Zoom in/out in frequency

Table 11: Spectrum/Sonagram Plot Control, Keyboard Shortcuts: Zoom functions

Parameter	Function
	Most Cursor shortcuts are toggle functions
<X>	Activate and deactivate the (X) frequency-cursors
<Y>	Activate and deactivate the (Y) level-cursors
<Z>	Activate and deactivate the (Z) time-cursors
<N>	Switch to normal 2 cursor mode (no toggle function)
<H>	Activate and deactivate Harmonic cursor mode: • all harmonic cursors placed at one side • dragging cursor 1: moves all cursors - keeping distances • dragging cursor >= 2: Cursor 1 stays in place - all other stretch/move
<I>	Activate and deactivate mirrored cursor mode: • harmonic cursors placed on both sides of Cursor 1 • dragging Cursor 1: moves all cursors - keeping distances • dragging Cursor >= 2: Cursor 1 stays in place - all other stretch/move

Parameter	Function
<**S**>	Activate and deactivate centered cursor mode: • harmonic cursors placed on both sides of Cursor 1 • dragging Cursor 1: moves all cursors - keeping distances • dragging Cursor >= 2: cursors at opposite side stay in place - all other stretch/move

Table 12: Spectrum/Sonagram Plot Control, Keyboard Shortcuts: Cursors

Parameter	Function
<**Alt**> + <**Up Arrow**> / <**Down Arrow**>	Increase / decrease FFT length.
<**J**>	Searches the spectrum for the maximum and displays the corresponding X/Y value as a tooltip. With active X-Cursors the search range can be restricted. The values are automatically inserted into the clipboard. The tooltip disappears as soon as the key is released.
<**U**>	Same as <**J**>, but searching for the minimum.
<**L**>	X-Cursor 1 and Y-Cursor 1 are moved to the next maximum of the spectrum curve towards lower frequencies, if X-Cursors are active. If <**Peak-Hold**> is activated, the maxima on the compressed curve are selected.
<**R**>	Same as <**L**>, but towards higher frequencies.

Table 13: Spectrum/Sonagram Plot Control, Keyboard Shortcuts: Minimum/Maximum

3.5.7. Bit Display

The bit display visualizes data produced by a demodulation of a signal.

Data can be selected by holding the left mouse button while dragging the mouse. To select a single element, press and release the left mouse button. The selection is visualized with a blue overlay. Hover the mouse over the selection to display information about it. The selected data can by copied into the clipboard by using the corresponding entry in the selection's context menu or the <**Ctrl**> + <**C**> shortcut.

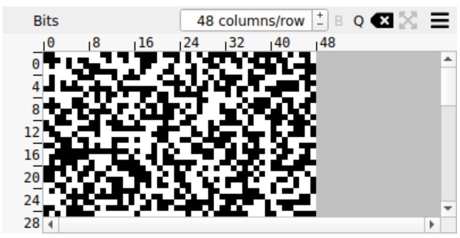


Figure 19: Bit display

3.5.7.1. Options

The following options are available in the toolbar and burger menu of the display:

- Number of columns – bits or symbols depending on display style – per row. This options has no effect when burst view is enabled.
- Burst view (icon **B**): When enabled, each row shows data from a single burst. This option is only available when so-called burst marks are set within the data.
- Show quality (icon **Q**): When enabled, the demodulation quality is color-coded using grey scale (black: good quality, light grey: bad quality). This option is only available when quality information is available withing the data.
- Bit offset: Defines how many bits of the data should be ignored by the display (starting at the first bit).
- Display style: Defines the way data is visualized. The styles □■, −× and ○| display a single bit per element. The first symbol of the style is the representation of bit 0, the second of bit 1. The style "Symbols" displays multiple bits per elements using hexadecimal numbers. The meaning of the symbol values varies between Modules; consult their documentation for details.
- Show burst marks: When enabled, the position of so-called burst marks is visualized with a green overlay. Hove the mouse over a burst mark to display information about it. This option is only available when burst marks are set within the data.

3.5.7.2. Keyboard Shortcuts

Conventional keyboard shortcuts to navigate within a document are supported. Additionally supported shortcut are listed in the table below.

Shortcut	Function
<**Ctrl**> + <**C**>	Copy selected data into the clipboard
<**Ctrl**> + Mouse wheel	Zoom in/out
<**Ctrl**> + <**+**>	Zoom in
<**Ctrl**> + <**-**>	Zoom out
<**Alt**> + <**+**>	Zoom in x-axis
<**Alt**> + <**-**>	Zoom out x-axis
<**Shift**> + <**+**>	Zoom in y-axis
<**Shift**> + <**-**>	Zoom out y-axis
<**Ctrl**> + <**0**>	Reset zoom
<**C**>	Copy bit display as a picture into the clipboard

Table 14: Bit Display - Shortcuts

4. Generic Analysis Modules

These modules provide analysis functionality that is not specialized for certain emission types, e.g. the modulation format.

4.1. Audio

This module provides basic audio playback. The selected signal is played back in a loop. This allows listening to the selected signal and thus, this allows to identify characteristic tone or burst structures.

There is a single plot with a zoomed sonagram showing the used band and the (nominal) **frequency**. The **frequency** marker can be dragged with the mouse. The frequency ranges below and above the used band are shown shaded to visualize the spectral usage at audio-demodulation. An additional (non-movable) marker shows the actual play position.

4.1.1. Parameters

The following parameters can be configured:

- **Modulation**: Digital/CW, USB, LSB, AM, FM
- the nominal **Frequency** of the emission: the probably virtual carrier frequency
- **Bandwidth** of the demodulated audio (not with FM)

The maximum configurable **bandwidth** is limited.

4.1.2. Control

There are basic controls:

The playback can be paused and continued. Playback can be restartet (rewind) from begin.

The volume can be configured.

4.2. Time

This module provides various time domain plots to manually assess basic emission properties, e.g. the modulation type of an emission. This allows examining the selected signals for modulation-specific characteristics and thereby identify the type of modulation. Typical characteristics may be distinct patterns in magnitude or frequency suggesting amplitude-shift keying (ASK) or frequency-shift keying (FSK).

There are three time domain plots displayed, which contain in default configuration, from top to bottom, the instantaneous values for

- *Magnitude*
- *Phase*
- *Frequency*

For each of these plots the type can be changed in the analysis toolbar. Other available plot types are:

- *Amplitude (I+Q)*: Displays the sum of real and imaginary part, i.e. the sum of in-phase and quadrature component of the complex input samples.
- *Real (Inphase)*: Displays the real part, i.e. the in-phase component of the complex input samples.
- *Imag. (Quadrature)*: Displays the imaginary part, i.e. the quadrature component of the complex input samples.
- *Power*: Displays the power, i.e. the squared magnitude, in linear scale.
- *Level*: Displays the power in logarithmic scale.
- *Phase (unwrapped)*: Displays the unwrapped phase. Discontinuous wraps between $\pm\pi$ are removed.
- *Phase Difference*: The phase difference of (non-interpolated) samples is calculated in the distance of the symbol duration (inverse of the extended analysis parameter "Symbol rate"). This parameter does only affect this plot type and by default automatically changes with the bandwidth of the selection - until a manual change is done. The difference phase is calculated without interpolation between samples. Thus, there is practically no effect for high symbol rates. With the extended analysis parameter "Oversampling", the situation can be improved. The "Difference phase" has the advantage - compared to "Phase", that it doesn't need the exact center frequency.

Only the plot types *Phase* and *Phase Difference* have the *Phase multiplier* parameter, which shows the multiplied phase (difference). Phase multiplication corresponds to squaring the quadrature input. This might remove PSK decisions to estimate the channel's phase distortion on the transmitter's carrier. For a useful output with *Phase*, the selection's center frequency has to match the carrier frequency.

For the plot types *Phase*, *Amplitude (I+Q)*, *Real (Inphase)* and *Imag. (Quadrature)* an additional *Phase Shift* can be configured, to avoid phases around ±180°.

All three plots share a common time axis, allowing to analyze different signal characteristics for the same range in time at a glance. This means, that zooming or panning in time domain in a single plot by mouse wheel, the scrollbar or other control elements affects all three plots simultaneously. Furthermore, the time cursors (*X-Cursor*), are also synchronized across all plots.

4.2.1. Magnitude

This display shows a *Magnitude* plot by default, i.e. the absolute value of each complex input sample, of the signal, in linear scale over time. This allows to identify ASK emissions, which typically show distinct levels, as can be seen in Figure 20. Here, one can identify two different levels, which are highlighted by the activated cursors. In the histogram data on the right side the two levels are even better visible. This suggests, that the emission is ASK2 modulated.

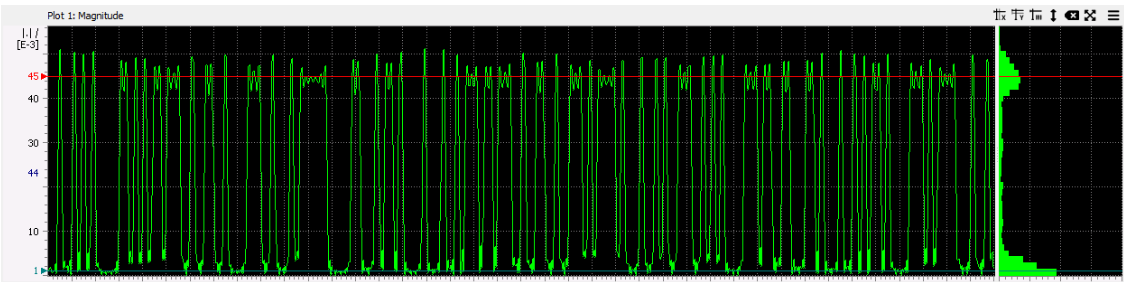


Figure 20: Magnitude plot of a ASK2 emission

4.2.2. Phase

This display shows a *Phase* plot by default. It displays the instantaneous phase values in degrees over time, which are the phase angles of each complex input sample. The phase values are wrapped and displayed in the range of $-180° \ldots +180°$. With this display, it is possible to recognize PSK modulations if the selections center frequency is precisely adjusted to match the carrier frequency. Figure 21 shows the *Phase* plot for a PSK4 modulated emission. There are four distinct phase angles at $\pm180°$, $-90°$, $0°$ and $+90°$ present, which are marked by the cursors. The aggregation of data points around these values is clearly visible in the main plot as well as the histogram.

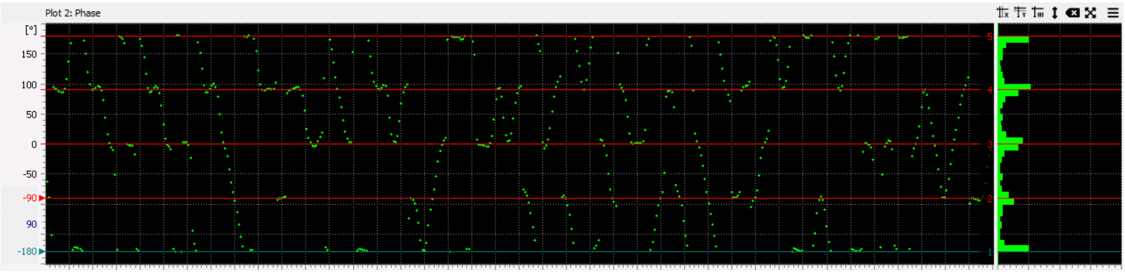


Figure 21: Phase plot of a PSK4 emission

4.2.3. Frequency

This display shows a *Frequency* plot by default. It displays the instantaneous frequency in Hz over time, which is the time derivative of the phase values. An exemplary *Frequency* plot is shown in Figure 22. Four distinct frequencies can be identified, suggesting a FSK4-modulated emission. The exact frequencies can be measured using the cursors.

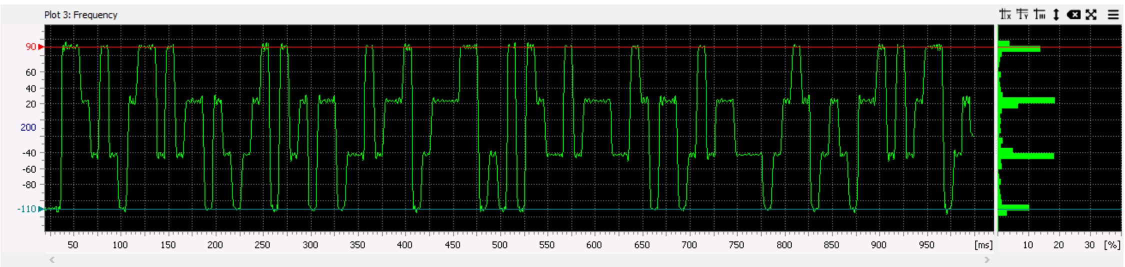


Figure 22: Frequency plot of a FSK4 emission

4.3. Autocorrelation Function (ACF)

This module allows to detect repetitive components, such as regularly sent synchronization sequences. It provides means to measure the ACF peak position - a time duration - between consecutive occurrences.

The module computes an intermediate signal depending on the chosen *Input* in the analysis toolbar. Based on this, an *Autocorrelation* is shown, allowing to recognize dominant peaks immediately.

4.3.1. Autocorrelation

The main result shows an the autocorrelation function of the selected input signal. The module automatically highlights the strongest peak with the smallest time value with a marker. The ACF peak position is displayed directly at the marker as well as in the *Peak position* parameter in the analysis toolbar. The estimate of ACF value is updated upon any changes to the selection or to the parameters of the module.

Move the marker to manually set the ACF peak position, alternatively use the *Peak position* input box in the toolbar. A manually set ACF value disables automatic estimation of its value. Use the estimate button on the left-hand side to re-enable automatic estimation.

Figure 23 shows the autocorrelation of a signal with multiple periodical components, resulting in multiple peaks, differing in their height.

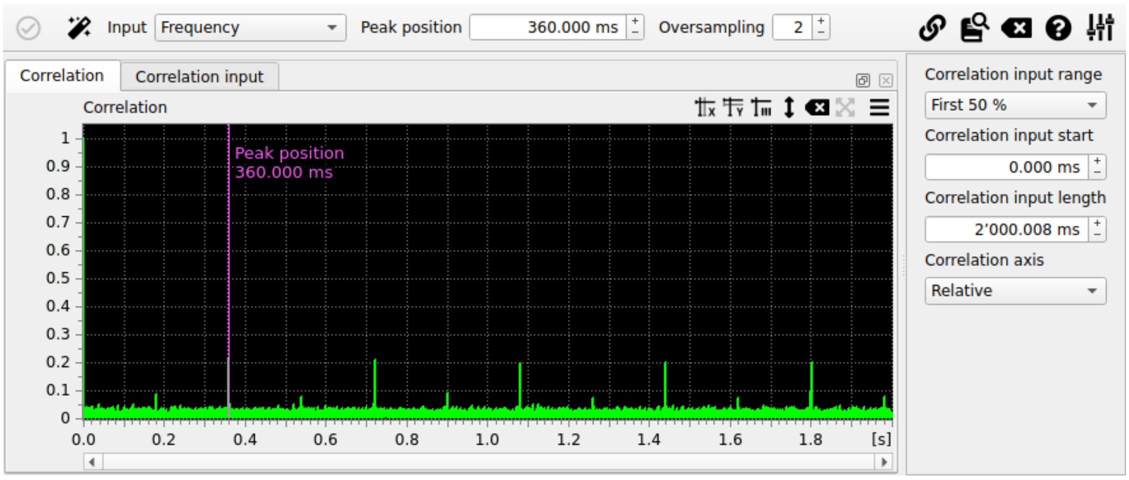


Figure 23: Example of the autocorrelation of a signal with multiple different repetitive components.

4.3.2. Analysis Parameters

The module provides some parameters which influence the calculation of the autocorrelation. These can be found in the analysis toolbar as well as the sidebar.

The parameters determine the correlation input signal and range. In addition, the plot/tab "Correlation input" shows the resulting correlation input signal. It also allows modifying the correlation input start and length using a rectangular marker.

It may be necessary to "play" with these parameters in order to get better results.

Input
: This selects the type of the input signal which is used for the calculation of the autocorrelation. This signal is displayed in the "Correlation input" tab. (Note: For input "Complex baseband" the magnitude of the signal is displayed.)

Oversampling
: Oversampling increases the resolution of the autocorrelation. The default value of 2 is sufficient in most cases.

Correlation input range/start/length
: By default the first 50 % of the selected signal is correlated with the complete selected signal. Only portions with complete overlap are shown (this applies regardless the used "Correlation input range"). Another option is to use the first 25 %. This will increase the range of the autocorrelation (longer periods are detectable) at the expense of increased noise.

: A custom range which is to be correlated with the complete selected signal can be set by modifying "Correlation input start" and "Correlation input length". These parameters can also be modified by markers in the "Correlation input" plot.

Correlation axis
: This parameter modifies the axis of the autocorrelation plot. With "Relative", the axis is relative to "Correlation input start", otherwise the axis is absolute (which is relative to the start of the signal input selection).

4.3.3. Example Project

To further study the *Autocorrelation Analysis* and its functionality, see the example project file "autocorrelation-example.san" and the corresponding signal file. The contained emission shows a periodical component, which appears every 80 ms - after having selected one of *Frequency*, *Weighted frequency* or *Diff. phase* as *Input*.

Note, that every fourth time, there are further repetitive parts, leading to higher peaks in the autocorrelation at multiples of $4 \cdot 80\,\text{ms} = 320\,\text{ms}$.

4.4. Periodicities

This module allows to detect repetitive components, such as regularly sent synchronization sequences. It provides means to measure the time period between consecutive occurrences.

The module computes an intermediate signal depending on the chosen *Metric* in the analysis toolbar. Based on this, an *Autocorrelation* is shown, allowing to recognize dominant periods of repetitive components immediately. Further, in a *Circulation Display*, the intermediate signal is plotted directly, providing the ability to analyse the signal for repetitive components manually.

4.4.1. Autocorrelation

Figure 24 shows the autocorrelation of a signal with multiple periodical components, resulting in multiple peaks, differing strongly in their height. The module automatically highlights the strongest peak with the smallest period length with a marker. The length of the period is displayed directly at the marker as well as in the *Period length* parameter in the analysis toolbar. The estimate of the period length is updated upon any changes to the selection or to the parameters of the module. Move the marker to manually set the period length, alternatively use the *Period length* input box in the toolbar. A manually set period length disables automatic estimation of its value. Use the estimate button on the left-hand side to re-enable automatic estimation.

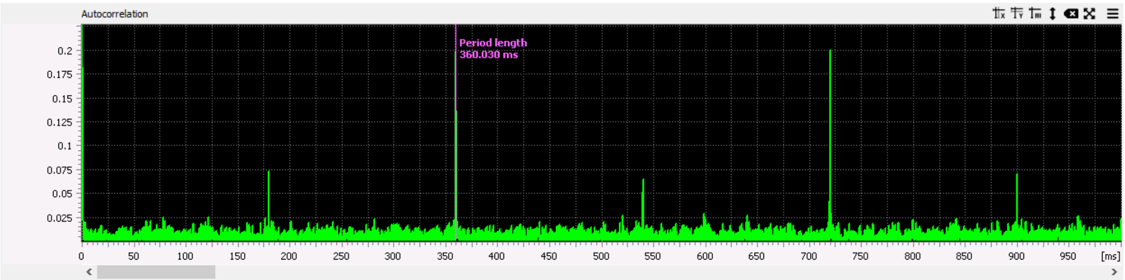


Figure 24: Example of the autocorrelation of a signal with multiple different repetitive components.

4.4.2. Circulation Display

In Figure 25 the circulation display is shown, which draws the intermediate signal, defined by the analysis parameter *Metric*. The signal is drawn line by line, with the line length defined by the parameter *Period length* described above. This display allows to assess the different repetitive components manually. If the *Period length* is approximately equal to an integer multiple of a repetitive component's period, this component will emerge as (nearly) vertical structures in the display. This can be seen in the example in Figure 25, where multiple repetitive components are visible. They appear as vertical structures spanning multiple lines, and thereby stand out against the otherwise unordered background.

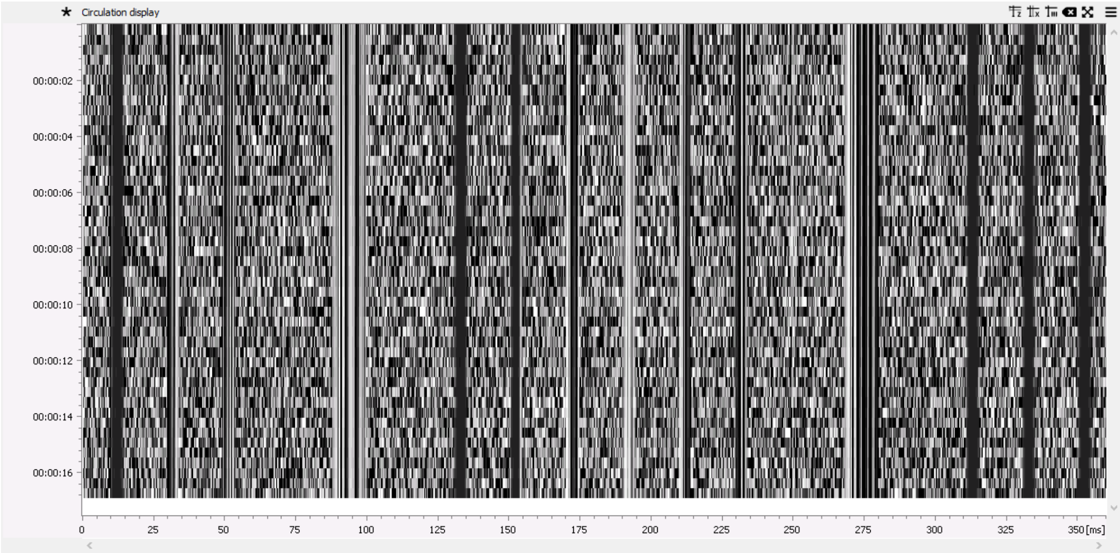


Figure 25: Example of the circulation display

4.4.3. Analysis Parameters

The module provides some parameters which influence the calculation of the autocorrelation and the displayed signal in the circulation display. It may be necessary to "play" with these parameters in order to get better results. The main parameter *Metric* is shown in the analysis toolbar and determines the displayed signal in the circulation display. By default this is also the signal used for the calculation of the autocorrelation.

More options are available in the side bar (use the right-most button in the toolbar or by using the F7 key to open it):

Oversampling
: Oversampling increases the resolution of the autocorrelation. The default value of 2 is sufficient in most cases.

Autocorrelation type
: By default the first 50 % of the selected signal is correlated with the complete selected signal. Only portions with complete overlap are shown. Another option is to use the first 25 %. This will increase the range of the autocorrelation (longer periods are detectable) at the expense of increased noise.

  A third option is to compute the conventional full-length autocorrelation which correlates the complete signal with a copy of itself. The full result is shown. This mode provides the longest range. However, the magnitude of the autocorrelation decreases towards the end because the overlap of the signals decreases. This makes it harder to assess the relevance of peaks occurring towards the end of the autocorrelation.

Autocorrelation input
: This determines the signal used for the calculation of the autocorrelation. By default this signal is determined by the parameter *Metric* in the toolbar. Another option is to use the complex baseband signal.

4.4.4. Example Project

To further study the *Periodicities Analysis* and its functionality, see the example project file "periodicities-example.san" and the corresponding signal file. The contained emission shows a periodical component, which appears every 80 ms.

Note, that every fourth time, there are further repetitive parts, leading to higher peaks in the autocorrelation at multiples of $4 \cdot 80\,\text{ms} = 320\,\text{ms}$.

4.5. Squared Spectrogram

Squaring signals can serve three purposes for phase modulated signals (see *Squared Signal Spectra* in module *PSK Signal Analysis*):

- First, they provide means to estimate the carrier frequency of the emission.
- Second, these plots help to identify the modulation order and version.
- And lastly, the symbol rate can be, at least, verified.

The *PSK Analysis* module assumes an emission, which does not change carrier frequency, modulation order or version.

This module provides a spectrogram for manual analysis of changes in carrier frequency, e.g. in different (burst) emissions.

4.5.1. Mode

Squaring the complex input signal corresponds to multiplication of the complex phase.

Different computation methods are provided, depending on the signal, one or the other might provide better results.

- **Normalized**

  This calculates complex power with exponent, as specified by the parameter "Exponent". Then, the magnitude is normalized to the input signal's level, to keep the mean power.

- **Phase-only**

  Only the phase of the signal is scaled by the value given in the parameter "Exponent". This corresponds to the complex power - after normalizing each sample's magnitude, and multiplying the resulting complex samples with their previous magnitude. This reduces the additional noise of exponentiation.

This might remove PSK decisions - to estimate the channel's phase distortion of the carrier phase.

Keep in mind, that squaring does scale the frequency axis by the value of "Exponent"!

Adjust the spectrogram's *FFT length* and check results with different values for "Exponent".

4.6. Symbol Rate

This module provides various methods for **symbol rate** estimation. Each provides a spectrum over a configurable **metric** based on the selected input signal. This should work for single-carrier signals with linear modulations like *PSK*, *OOK* and *QAM*, but also for some non-linear modulations like *FSK*.

The spectrum will usually show several peaks - depending on the selected **metric**. The position of the maximum (within configurable limits), is visualized with a marker and displayed in the toolbar as **Symbol rate**.

The idea is, that the input signal changes faster at symbol-transitions. The selected **metric** should indicate this with higher values - usually with every symbol. With this property, a dominant peak should be visible in the **spectrum** plot at the frequency of the **symbol rate**.

4.6.1. Metric

Main parameter is **metric** - available in the toolbar.

In the following list with some very subtle differences, "**smoothed**" does refer to the instantaneous frequency, except for the "**Complex distance**": the instantaneous frequency is calculated by using the phase difference over two complex samples. Without **smoothing**, phase difference of adjacent complex samples is used.

"**Weighted**" means multiplied with the magnitude, unless specified otherwise.

- **Complex distance**

  The *I/Q*-distance between adjacent complex samples of the input selection. This should produce acceptable results for most linear modulations like *PSK*, *OOK* and *QAM* - but also for non-linear *CPFSK* modulations, see Figure 26.

- **Complex distance (smoothed)**

  The *I/Q*-distance between complex samples of the input selection - smoothed by using the distance over two complex samples. This should produce acceptable results for most linear modulations like *PSK*, *OOK* and *QAM*.

- **Complex distance (smoothed, squared)**

  The squared *I/Q*-distance between complex samples of the input selection - smoothed by using the distance over two complex samples.

- **Magnitude**

  The magnitude for every complex (*I/Q*) sample. This metric leads to the so-called **A3-method**, usable for *PSK*-modulated signals, where the magnitude drops at symbol changes - especially for *PSK-2A* leading to zero-crossings.

- **Magnitude diff. (abs)**

  The change (difference) of magnitude between the adjacent complex samples. This should produce good results for *OOK*-modulated signals.

- **Magnitude diff. (squared)**

  The squared diffence of magnitude between the adjacent complex samples. This *metric* is quite similar to '*Magnitude (abs of diff)*'.

- **Instantaneous frequency**

  The *instantaneous frequency* is used 'directly' as input for the spectrum.

- **Inst. frequency (abs)**

  The absolute value of the *instantaneous frequency* is used as *metric*. This should work for phase-modulated linear modulations like *PSK*, as the instantaneous frequency is the first derivative of the *phase*.

- **Inst. frequency (squared)**

  The squared value of the *instantaneous frequency* is used as *metric*. This should work for phase-modulated linear modulations like *PSK*, as the instantaneous frequency is the first derivative of the *phase*.

- **Weighted inst. frequency**

  The *instantaneous frequency* is weighted (multiplied) with the magnitude.

- **Weighted inst. frequency (smoothed)**

  The smoothed *instantaneous frequency* is weighted (multiplied) with the magnitude.

- **Power weighted inst. frequency**

  The *instantaneous frequency* is weighted (multiplied) with the squared magnitude, the instantaneous power.

- **Power weighted inst. frequency (smoothed)**

  The smoothed *instantaneous frequency* is weighted (multiplied) with the squared magnitude, the instantaneous power.

- **Inst. frequency diff. (abs)**

  The absolute value of the *instantaneous frequency*-difference. This produces good results for *FSK*-modulated signals, see Figure 27.

- **Inst. frequency diff. (smoothed, abs)**

  The absolute value of the smoothed *instantaneous frequency*-difference.

- **Inst. frequency diff. (squared)**

  The squared value of the *instantaneous frequency*-difference.

- **Inst. frequency diff. (smoothed, squared)**

  The squared value of the smoothed *instantaneous frequency*-difference.

- **Weighted inst. frequency diff. (abs)**

  The absolute value of: the *instantaneous frequency*-difference multiplied with the instantaneous magnitude (weighting).

- **Weighted inst. frequency diff. (smoothed, abs)**

  The absolute value of: the smoothed *instantaneous frequency*-difference multiplied with the instantaneous magnitude (weighting).

- **Weighted inst. frequency diff. (squared)**

  The square value of: the *instantaneous frequency*-difference multiplied with the instantaneous magnitude (weighting).

- **Weighted inst. frequency diff. (smoothed, squared)**

  The square value of: the smoothed *instantaneous frequency*-difference multiplied with the instantaneous magnitude (weighting).

4.6.2. Spectrum of metric

This display shows the spectrum of the selected **metric**.

Shaded and movable markers show the lower and upper limit for the estimation. The resulting **Symbol rate** is also visualized with a movable marker.

4.6.3. Spectrogram of metric

This display shows the spectrogram of the selected **metric**. Visualizing the symbol rate over time, it might allow to detect changes.

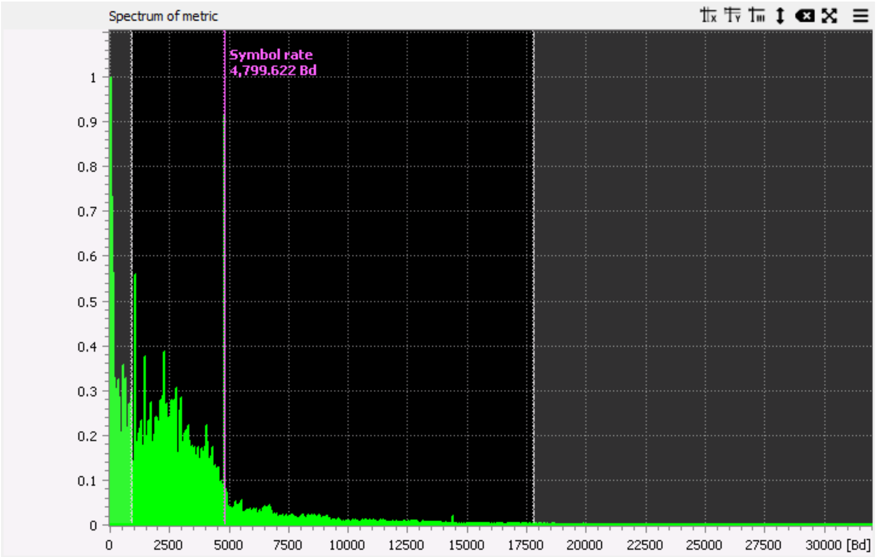


Figure 26: Spectrum for metric '*Complex distance*' on an APCO-25 signal

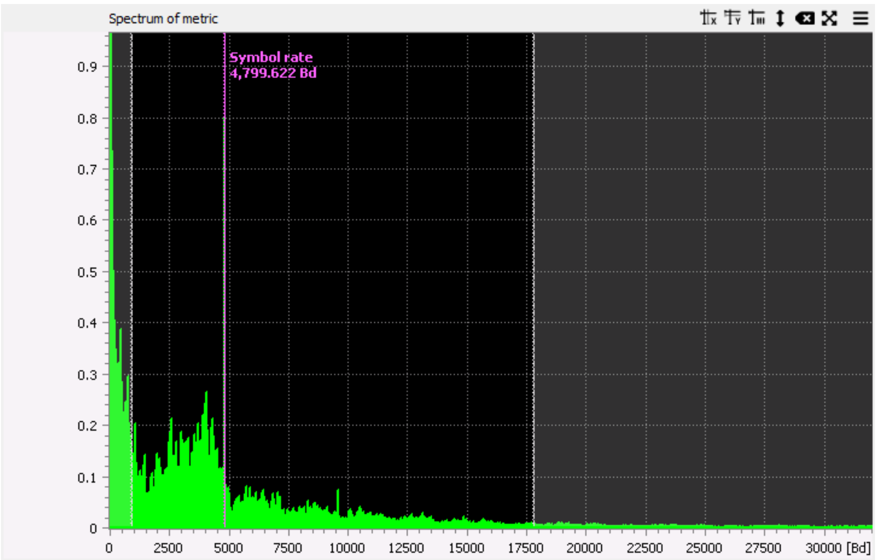


Figure 27: Spectrum for metric '*Inst. Frequency (abs of diff)*' on same APCO-25 signal

4.6.4. Example projects

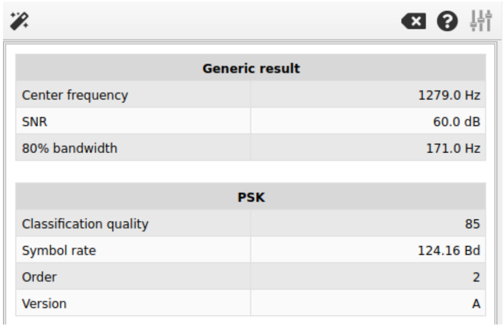
To study the *Symbol Rate* analysis, see the example project files "fsk2-example.san", "fsk4-example.san", "psk4-example.san" or even "multitone-example.san".

Multi-carrier signals usually won't give results, when selecting the whole signal bandwidth. Useful results might be achieved by selecting a single carrier, e.g. of "mc-example.san".

4.7. Classification

This module performs automatic classification of the signal contained within chosen selection. If successful, all relevant signal parameters are displayed in a table. Otherwise only generic parameters are displayed. For an example see Figure 28.

A description of the capabilities and limitations of the classification itself can be found in a separate document. See `PROCITEC-DSC-ClassifierDescription_E.pdf` in the doc folder the installation.



Generic result	
Center frequency	1279.0 Hz
SNR	60.0 dB
80% bandwidth	171.0 Hz

PSK	
Classification quality	85
Symbol rate	124.16 Bd
Order	2
Version	A

Figure 28: Example for successful signal classification

5. Modulation Analysis Modules

These modules provide analysis functionality that is specific to certain modulation formats. Each module aims to provide a comprehensive set of plot and measurements, suitable for interactive analysis of the modulation type and its basic parameters. For most parameters an automatic estimation based on displayed data is performed.

5.1. PSK Signal Analysis

5.1.1. Introduction / Motivation

This module provides tools for manual analysis of PSK-modulated emissions. Various metrics are calculated and plotted to enable users to measure the following modulation parameters:

- carrier frequency f_c
- symbol rate R_s
- Modulation order
- PSK modulation version/variant

See section *I/Q Diagrams and Histogram* for a specification of modulation order and version for PSK signals.

Besides the PSK variants (order and version) supported in this module, there are also other "variants" like (G)MSK and OQPSK. In case of unsatisfying results with this module, also check the FSK analysis (see *FSK Signal Analysis*) for (G)MSK and FSK modulations (with small modulation index), but also the Offset-QPSK analysis (see *Offset-QPSK Signal Analysis*).

5.1.2. Processing

The following list provides a sequence of steps, to exemplarily outline, how an analysis could be carried out.

1. First, estimate the symbol rate using the spectrum of clock-metric[2]. The default metric gives an A3 spectrum.
2. Estimate the carrier frequency f_c using the squared spectra, see section *Squared Signal Spectra*. Its value is expressed relative to the selection center frequency[1] in the analysis parameter "frequency offset". An initial automatically estimated value is calculated. The estimation can be improved by choosing the PSK variant. Adjust the "frequency offset" control element or the selection depending on the estimated value.
3. Find the dominant peaks in the squared signals spectra and use these together with the visible constellations on the I/Q diagrams and the histogram to determine the Modulation order and version.

The signal processing can be further customized by tweaking the (extended) analysis parameters.

[2] spectrum of clock metric of a signal

[1] The *frequency offset* Δf denotes the difference between the carrier frequency f_c and the selections center frequency $f_{selection}$, i.e. $\Delta f = f_c - f_{selection}$.

PSK variant
The assumed variant. This defines the expected peaks and which of the squared signal spectra to use for the estimation of the frequency offset.

Display
Defines the input for the I/Q plots and the Difference-phase histogram. *All samples* and *Symbols* are available. Symbols uses only the samples of the recovered symbol-clock. This cleans the plots, if symbol-clock-recovery works as expected.

Squaring input
Use either magnitude + phase or only phase (discarding amplitude) as input for squaring. Discarding the magnitude may yield better results.

Scaling for power spectra
Optionally enable logarithmic scaling. May help identifying peaks in the squared signal spectra.

Clock metric
This defines the input for the spectrum for the estimation of symbol rate. Available is a selection of metrics of the *Symbol Rate* module, which are useful for PSK modulations (see section *Metric*). The default using *Magnitude* yields an A3 spectrum.

Symbol clock averaging
This defines the number of symbols to "average" to get peaks in such an integrated clock metric signal. For symbol clock recovery, it's important to get a peak for every symbol. It might be beneficial to increase this value for distorted or faded signals.

Phase drift
Optionally enable phase drift compensation, e.g. for fading channels. The carrier frequency's reference phase is determined by squaring: the phase is multiplied by a factor, depending on the selected *PSK variant*. The compensation is applied on the input - affecting squared spectra, if automatic estimation is off and the "frequency offset" is zero, leading to sharper peaks. With automatic estimation, the phase drift compensation is applied after having determined the frequency offset. In this case, the compensation still affects *I/Q Diagrams and Histogram*.

Phase drift averaging
This defines the number of symbols for full compensation of a phase error.

Oversampling
Oversampling increases the resolution in time. The default value of 4 is sufficient in most cases.

Filter type and roll-off
Customize the filter applied to signal. This may yield clearer results in the I/Q displays.

5.1.3. Results

The analysis results are presented on 9 plots, which are discussed in the following sections. Figure 29 shows an overview of the result display. The four plots one the left show the spectra of the one, two, three and four times squared selection signal, for details, see section *Squared Signal Spectra*. Below those, the left plot at the bottom shows a zoomed squared spectrum, which should allow reading the frequency offset; see section *Zoom: N'th power spectrum of phase*. The clock-metric spectrum, which is discussed in section *Clock-metric Spectrum*, is displayed on the right side at the top. At the bottom, on the right side, there are two I/Q diagrams with the diff.-phase histogram above, all three being explained in section *I/Q Diagrams and Histogram*.

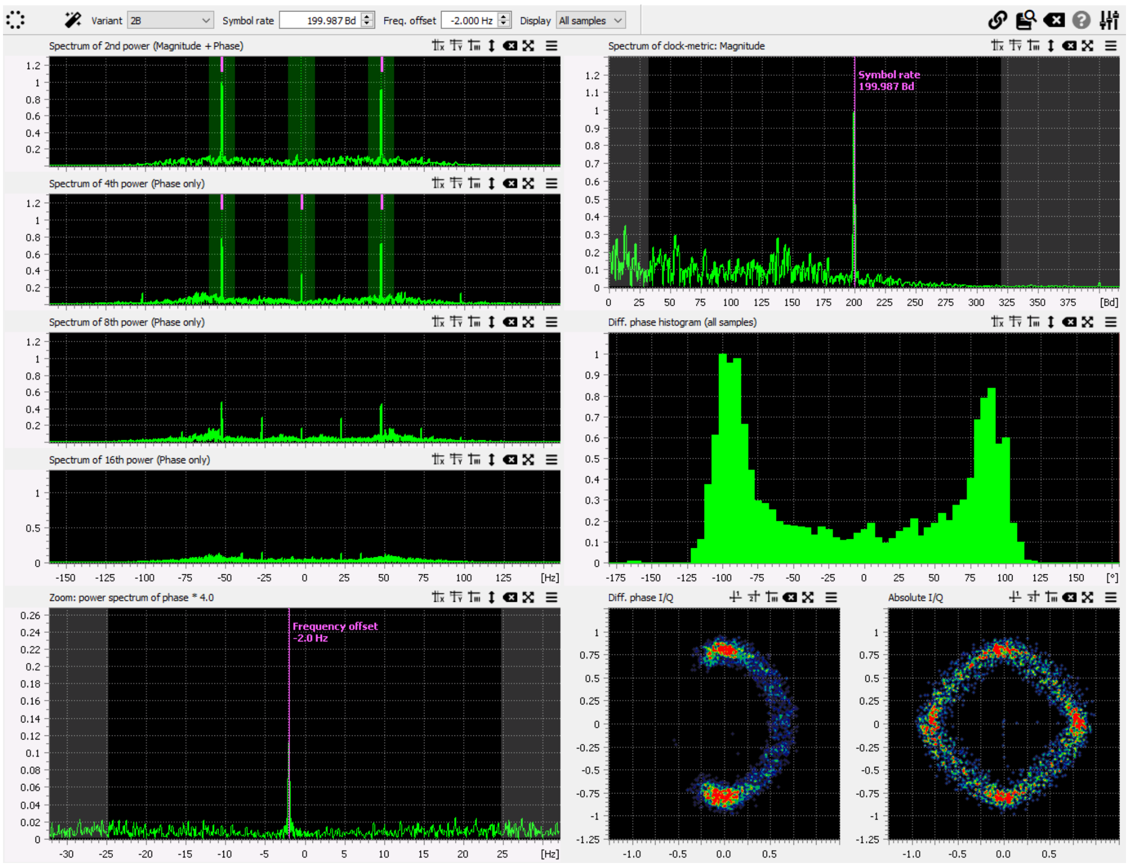


Figure 29: PSK analysis result display overview.

5.1.3.1. Squared Signal Spectra

Spectra of squared signals can serve three purposes: First, they provide means to estimate the carrier frequency of the emission. Second, these plots help to identify the modulation variant: order and version. And lastly, the symbol rate R_s can be, at least, verified.

Depending on the underlying order and version, the necessary number of different spectra and their degree of exponentiation varies. Figure 30 provides a reference, what combination of peaks can be expected on which exponentiation degree for different PSK modulation types. Note, that additional peaks will occur if the emissions data contains periodicities. And the higher the squaring factor, the better signal to noise ratio must be provided to see results. For signals with higher modulation order, up from 8, the peaks might not show up. In these cases it might help to switch the parameter “Squaring input” to “Phase”. In addition, linear parameter “Scaling” might help readability. Logarithmic scale might help with small / suppressed peaks.

Expected peaks and their positions depend on the PSK variant, the frequency offset and the symbol rate. These positions are visualized with a small vertical line at the top of some plots. For assistence, up to 6 areas are automatically searched for peaks and compared with the expectance for the selected PSK variant. These areas are highlighted: green, if actual spectrum matches the expectation - or red. But, be aware, that this comparison is error prone and might indicate wrong results.

The centered peaks allow the aforementioned estimation of the carrier frequency, whereas the outer peaks indicate the PSK order, version and also the symbol rate R_s. Reading the precise symbol rate might be difficult, but it's easy to verify the value, the *Clock-metric Spectrum* delivered.

As an example Figure 31 shows the spectra of an one and a two times squared signal (2nd and 4th power). Here, the center frequency offset can be estimated with the center peak on the second plot. Use zoom and cursor functionality of the displays for precise measurement.

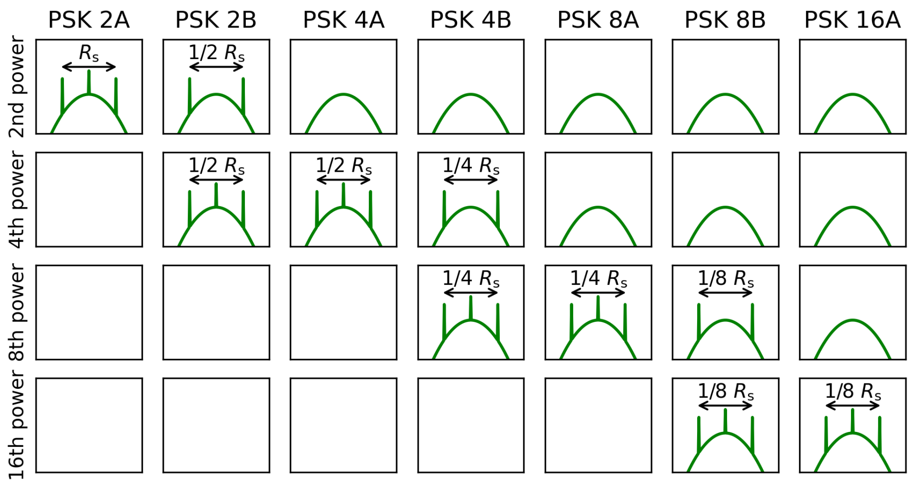


Figure 30: Expected peaks in squared signals spectra for different PSK modulation types and squaring degrees.

Further, one can clearly recognize two peaks in the upper (2nd power) and three peaks in the lower (4th power) spectrum. With the help of Figure 30, this pattern is found as being characteristic for a PSK-2B modulated emission. Additionally, we find in the reference, that the outer peaks in both spectra should be separated by half the symbol rate. Again one can use zoom and cursor functionality for a precise measurement. Here we find the peaks roughly separated by $100\,\mathrm{Hz}$, meaning that the symbol rate R_s can be estimated to around $200\,\mathrm{Bd}$.

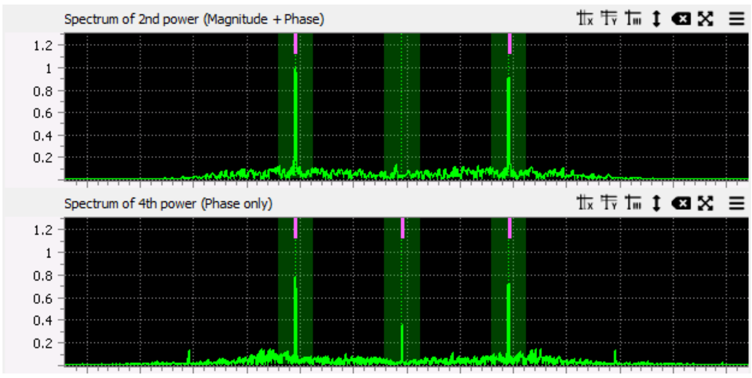


Figure 31: Spectra for one and two times squared signal (2nd and 4th power).

5.1.3.2. Zoom: N'th power spectrum of phase

This plot indicates the frequency offset. Different from the squared spectra, the squaring input is always *Phase* and the extents are limited depending on the selected *Variant*. Depending on modulation order and signal, the analysis-parameter *Variant* has to be adjusted to see a clear peak. Frequencies outside the actual estimation limits are displayed shaded. To get potential good peaks considered in the estimation process, the selected frequency band needs to be moved.

To center the squared spectra, the selection parameters can be changed. Alternatively, move/drag the frequency marker and apply the frequency offset to the selection by selecting the corresponding action from the context menu of frequency offset control widget in the toolbar.

Figure 32 shows an example of this plot. A dominant peak can be observed at $-2.0\,\mathrm{Hz}$. Having the expected peaks of squared spectra in mind (Figure 30), this suggests a PSK-2B modulated emission.

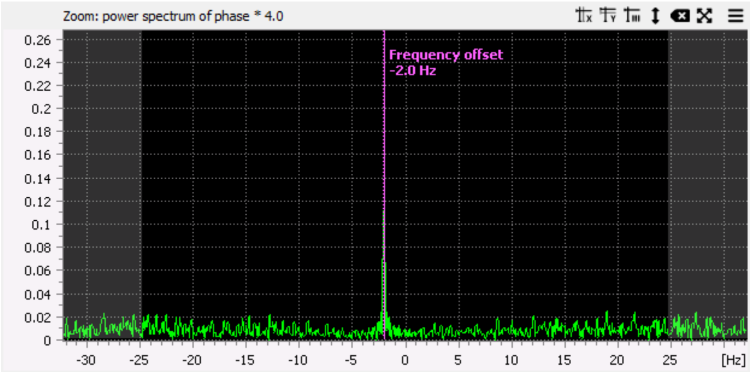


Figure 32: Zoomed: 4th power spectrum of phase.

5.1.3.3. Clock-metric spectrum

For this plot the parametrized clock metric of the selected signal is computed and its spectrum is displayed. This *Clock-metric Spectrum* is called *A3 Spectrum* for the default metric *Magnitude*. It typically shows a distinct peak at a value equal to the symbol rate R_s. The outer peaks of *Squared Signal Spectra* should be used for verification.

Since the metrics of the selected signal are real valued, only the positive frequencies of the spectrum are shown. The limits for the frequency range depend on the selection bandwidth, which should be larger than the expected symbol rate. The symbol rate regions, which are not considered at the estimation, are displayed with shading.

A significant peak above the considered estimation range (approximately at twice the bandwidth) might indicate an Offset-QPSK modulation (see *Offset-QPSK Signal Analysis*).

Figure 33 shows an example of this plot. A dominant peak can be observed at $200\,\mathrm{Hz}$, which can be measured exactly, using zoom and cursor functionality. This suggests a PSK modulated emission using a symbol rate R_s of $200\,\mathrm{Bd}$.

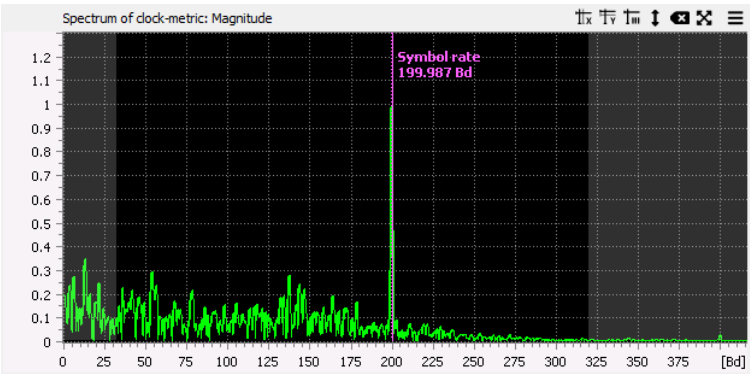


Figure 33: Clock-metric spectrum for symbol rate estimation.

5.1.3.4. I/Q Diagrams and Histogram

Displaying the complex signal of the selection in an I/Q diagram can reveal information about the Modulation order as well as the PSK version. For PSK with modulation order M there are M symbols, which are positioned on a circle in the complex plane such that their phase angles are equally spaced. This constellation of symbols is directly used for version *A*, whereas for version *B* an additional constellation is used, alternating with the original one. The second constellation is created by rotating the first constellation by the half of the phase difference between to adjacent symbols, i.e. by $\frac{360°}{2M} = \frac{\pi}{M}$, around the origin of the complex plane.

For the right *Absolute* I/Q diagram, the complex samples of the selection are plotted directly. Therefore, for PSK version *A*, M distinct points, whereas for version *B*, $2M$ distinct points can be expected. The latter is based on the fact, that the aforementioned two different constellations of version *B* appear superimposed.

The left plot is a *Differential* I/Q diagram, where so called differential samples are displayed. The computation of the differential samples is as following:

- The symbol distance d in samples is calculated from the estimated symbol rate R_s: $d = \frac{1}{R_s} = T$.
- Differential values are computed by multiplying each sample with the complex conjugate of the sample, d samples ago. The phase of the resulting difference values contains the differential symbol information.

The *Differential* I/Q diagram can be used to distinguish PSK version *A* and *B* modulated emissions. For a version *B* modulated emission, M distinct points can be expected in the *Differential* I/Q diagram.

Above the I/Q diagrams, a histogram of the phase values of the differential symbols (or samples) is displayed. In contrast to the I/Q diagrams that may be affected by distorted magnitudes, the histogram allows a better estimation of the number of distinct phase angles.

Note, that the I/Q diagrams may also show distinct phases even if the emission is not PSK-modulated, but uses QAM or ASKnPSKn.

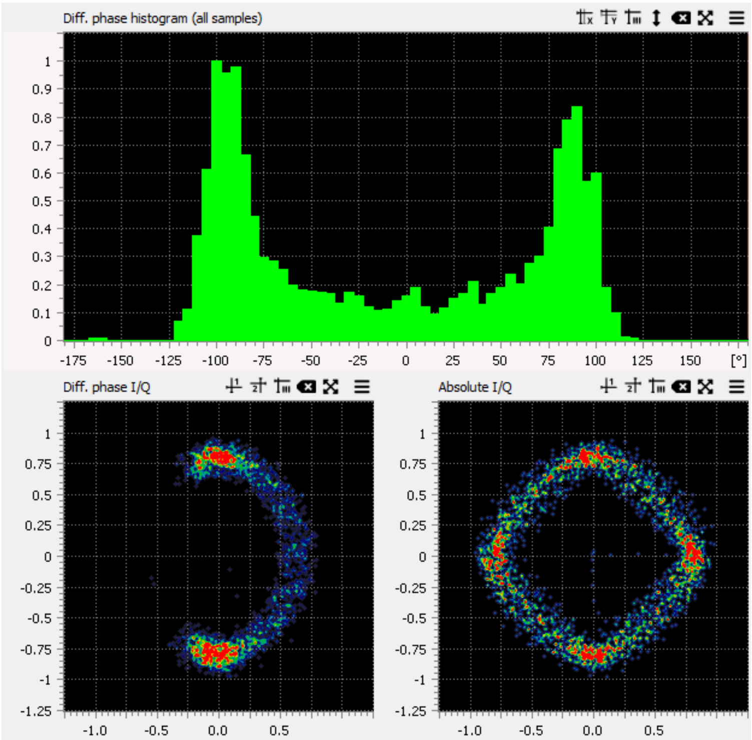


Figure 34: Differential phase histogram (top), differential (bottom left) and absolute (bottom right) I/Q diagrams.

5.1.4. Example project

To further study the *PSK Analysis* module and its functionality, see the example project file "psk4-example.san". The signal contains multiple bursts, each one modulated with PSK-4A and a symbol rate of 200 Bd.

5.2. Offset-QPSK Signal Analysis

5.2.1. Introduction / Motivation

This module provides tools for manual analysis of Offset-QPSK (OQPSK) modulated emissions, similar to the PSK-analysis (see module *PSK Signal Analysis*). OQPSK is a special case of QPSK (aka PSK-4A), where the Q-branch is shifted (offset) by half a symbol duration relative to the I-branch - before transmission. The offset reduces the variation of the envelope - compared to a usual QPSK waveform. Moreover the transitions through zero are completely removed. The power spectrum of OQPSK is same as for a usual QPSK.

Initially modulating 2 bits in one symbol, the offset'ed signal modulates 1 bit per half symbol duration, alternating I- and Q-branch per bit.

Metrics are calculated and plotted to enable users to measure the following modulation parameters:

- carrier frequency f_c
- symbol rate R_s

5.2.2. Processing

The following list provides a sequence of steps, to exemplarily outline, how an analysis could be carried out.

1. First, estimate the symbol rate using the spectrum of clock-metric[2].
2. Estimate the carrier frequency f_c using the squared spectra, see section *Squared Signal Spectra*. Its value is expressed relative to the selection center frequency[1] in the analysis parameter "frequency offset". An initial automatically estimated value is calculated. Adjust the "frequency offset" control element or the selection depending on the estimated value.
3. Find the dominant peaks in the squared signals spectra and use these together with the visible constellations on the I/Q diagrams to verify an OQPSK modulation.

The signal processing can be further customized by tweaking the (extended) analysis parameters.

Display
: Defines the input for the I/Q plots and the Difference-phase histogram. *All samples* and *Symbols* are available. Symbols uses only the samples of the recovered symbol-clock. This cleans the plots, if symbol-clock-recovery works as expected.

Symbol clock averaging
: This defines the number of symbols to "average" to get peaks in such an integrated clock metric signal. For symbol clock recovery, it's important to get a peak for every symbol. It might be beneficial to increase this value for distorted or faded signals.

Phase drift
: Optionally enable phase drift compensation, e.g. for fading channels. The carrier frequency's reference phase is determined by squaring: the phase is multiplied by a factor of 4. The compensation is applied on the input - affecting squared spectra, if automatic estimation is off and the "frequency offset" is zero, leading to sharper peaks. With automatic estimation, the phase drift compensation is applied after having determined the frequency offset. In this case, the compensation still affects *I/Q Diagrams* and *Diff. phase histogram*.

Phase drift averaging
: This defines the number of symbols for full compensation of a phase error.

---

[2] spectrum of clock metric of a signal

[1] The *frequency offset* Δf denotes the difference between the carrier frequency f_c and the selections center frequency $f_{selection}$, i.e. $\Delta f = f_c - f_{selection}$.

Oversampling
: Oversampling increases the resolution in time. The default value of 6 is sufficient in most cases.

Filter type and roll-off
: Customize the filter applied to signal. This may yield clearer results in the I/Q displays.

5.2.3. Results

The analysis results are presented on 9 plots, which are discussed in the following sections. Figure 35 shows an overview of the result display. The two plots on the top / left show the spectra of the one and two times squared selection signal. For details, see section *Squared Signal Spectra*. Directly below these, the left plot shows a zoomed squared spectrum, which should allow reading the frequency offset. In the top right corner, the clock-metric spectrum is shown. It is discussed in section *Clock-metric Spectrum*. At the bottom of the left side, the diff.-phase histogram is shown. At right side below the clock-metric, four I/Q diagrams plotted. These are explained in section *I/Q Diagrams*.

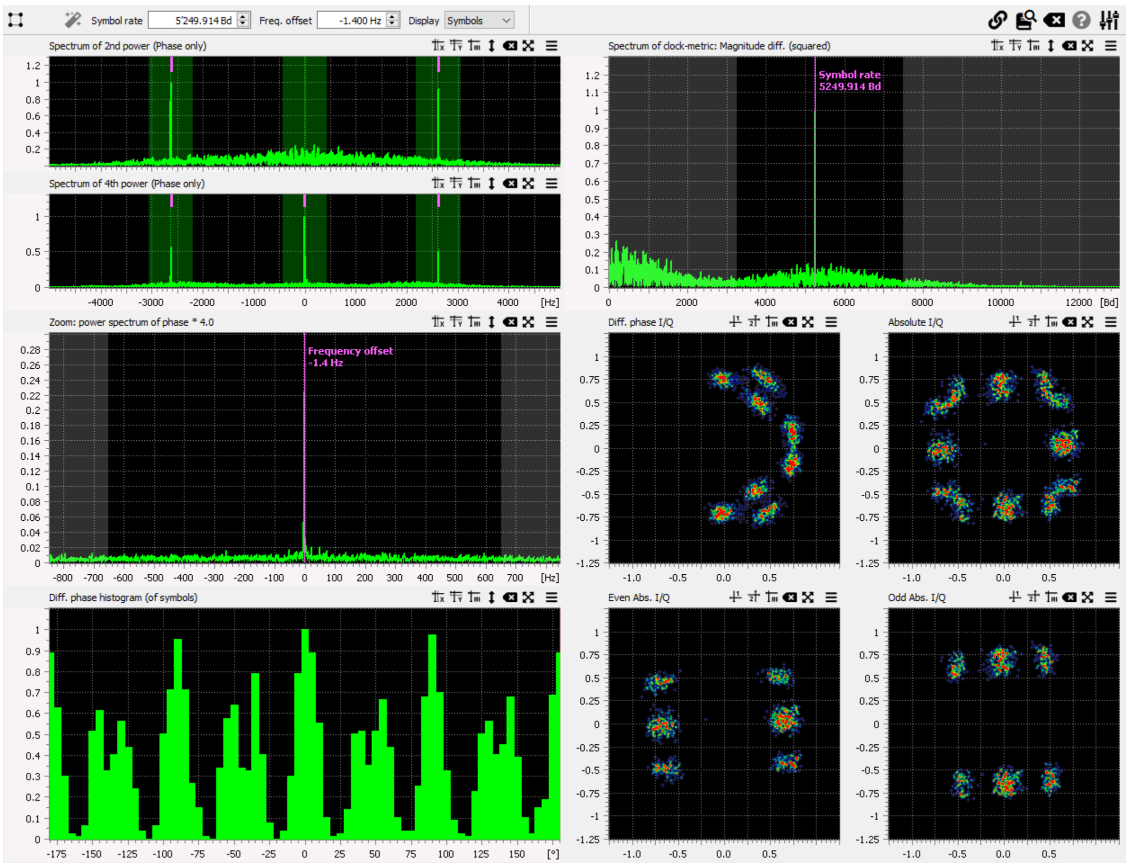


Figure 35: OQPSK analysis result display overview.

5.2.3.1. Squared Signal Spectra

Spectra of squared signals can serve three purposes: First, they provide means to estimate the carrier frequency of the emission. Second, these plots help to identify a PSK modulation variant: order and version. OQPSK is similar to *PSK-2B*, when it comes to the expected peak positions. And lastly, the symbol rate R_s can be, at least, verified.

Note, that additional peaks will occur if the emissions data contains periodicities.

Expected peaks and their positions depend on the PSK variant, the frequency offset and the symbol rate. These positions are visualized with a small vertical line at the top of some plots. For assistence, 6 areas are automatically searched for peaks and compared with the expectance for an OQPSK modulation. These areas are highlighted: green, if actual spectrum matches the expectation - or red. But, be aware, that this comparison is error prone and might indicate wrong results.

Figure 36 provides a reference, what peaks can be expected on which exponentiation degree for an Offset-QPSK modulation. See also and compare against the PSK modulation references in Figure 30 of module *PSK Signal Analysis*.

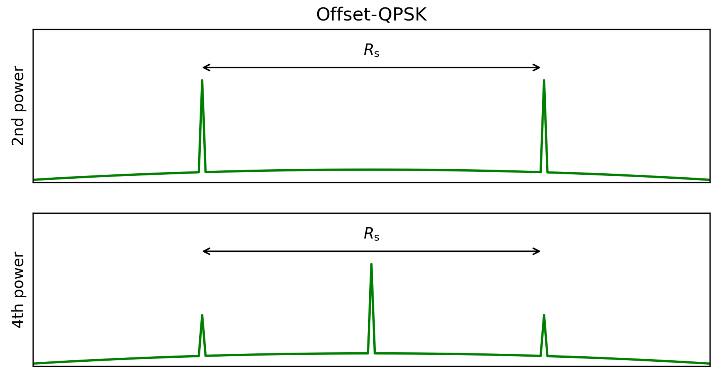


Figure 36: Expected peaks in squared signals spectra for Offset-QPSK.

The centered peak in the 4th power spectrum allows the aforementioned estimation of the carrier frequency, whereas the outer peaks indicate the symbol rate R_s. Reading the precise symbol rate might be difficult, but it's easy to verify the value, the *Clock-metric Spectrum* delivered.

Further, one can clearly recognize two peaks in the upper (2nd power) and three peaks in the lower (4th power) spectrum. This pattern is found as being characteristic for an OQPSK modulated emission.

As an example Figure 37 shows the spectra of an one and a two times squared signal (2nd and 4th power). Use zoom and cursor functionality of the displays for precise measurement.

Again one can use zoom and cursor functionality for a precise measurement. Here we find the peaks roughly separated by $5250\,\mathrm{Hz}$, meaning that the symbol rate R_s can be estimated to $\sim 5250\,\mathrm{Bd}$.

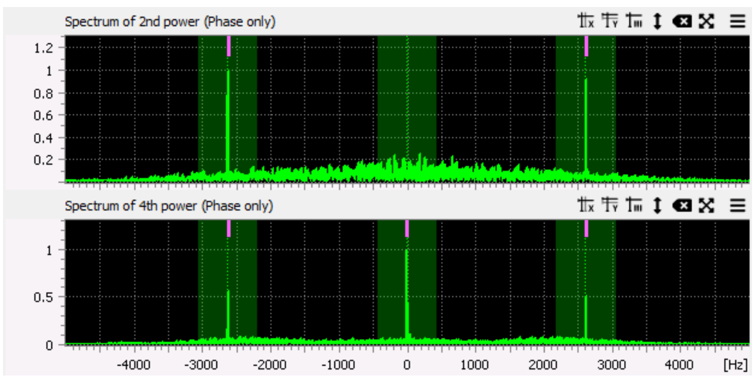


Figure 37: Spectra for one and two times squared (2nd and 4th power) OQPSK-signal.

5.2.3.2. Zoom: 4th power spectrum of phase

This plot indicates the frequency offset. A clear peak should be visible for an Offset-QPSK modulated signal. Frequencies outside the actual estimation limits are displayed shaded. To get potential good peaks considered in the estimation process, the selected frequency band needs to be moved.

To center the squared spectra, the selection parameters can be changed. Alternatively, move/drag the frequency marker and apply the frequency offset to the selection by selecting the corresponding action from the context menu of frequency offset control widget in the toolbar.

Figure 38 shows an example of this plot with a dominant peak.

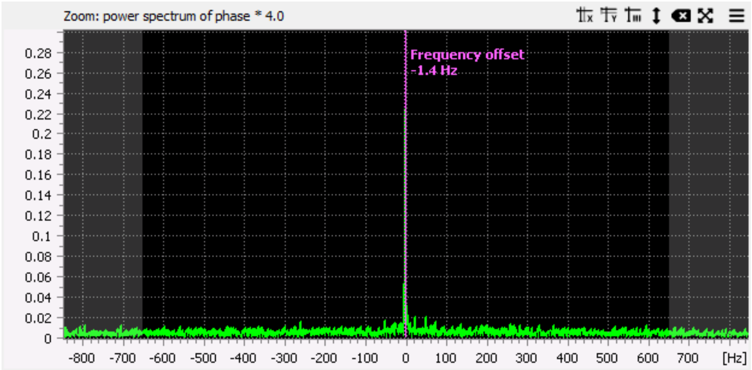


Figure 38: Zoomed: 4th power spectrum of phase.

5.2.3.3. Clock-metric spectrum

For this plot the parametrized clock metric of the selected signal is computed and its spectrum is displayed. OQPSK uses a special metric: *Magnitude (squared diff)*. It typically shows a distinct peak at a value equal to the symbol rate R_s. Internally, the peak is at a frequency, twice the symbol rate, which is caused by the offset by half a symbol duration, producing up to 2 transitions in one symbol duration. The outer peaks of *Squared Signal Spectra* should be used for verification.

Since the metric of the selected signal is real valued, only the positive frequencies of the spectrum are shown. The limits for the frequency range depend on the selection bandwidth, which should be larger than the expected symbol rate. The symbol rate regions, which are not considered at the estimation, are displayed with shading. Caused by the offset, the estimation range differs from usual PSK.

Figure 39 shows an example of this plot. A dominant peak can be observed at $\sim 5250\,\mathrm{Bd}$, which can be measured exactly, using zoom and cursor functionality. This suggests an OQPSK modulated emission using a symbol rate R_s of $5250\,\mathrm{Bd}$ - or $10500\,\mathrm{bps}$ with 2 bits per symbol.

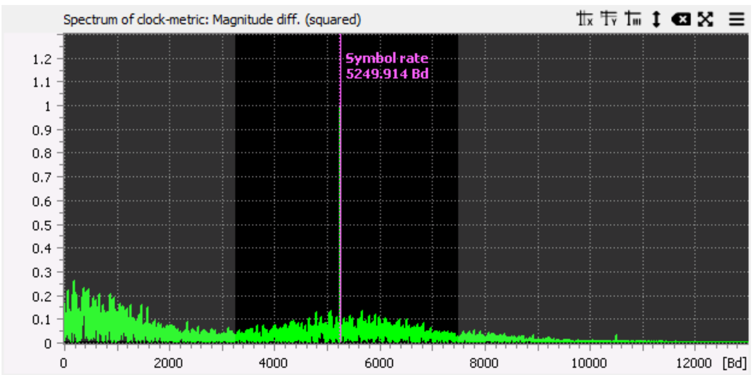


Figure 39: Clock-metric spectrum for symbol rate estimation.

5.2.3.4. I/Q Diagrams

Displaying the complex signal of the selection in an I/Q diagram can reveal information about the Modulation order as well as the PSK version. For usual PSK with modulation order M there are M symbols, which are positioned on a circle in the complex plane such that their phase angles are equally spaced.

This constellation of symbols is directly used for version *A*, whereas for version *B* an additional constellation is used, alternating with the original one. The second constellation is created by rotating the first constellation by the half of the phase difference between to adjacent symbols, i.e. by $\frac{360°}{2M} = \frac{\pi}{M}$, around the origin of the complex plane.

All I/Q diagrams use a modified symbol duration of $\frac{1}{2 \cdot R_s} = \frac{T}{2}$. In effect the Absolute I/Q plot shows twice as many symbols - as would be expected from the symbol rate R_s.

The *Differential* I/Q diagram shows so called differential samples. The computation of differential samples is as following:

- The symbol distance d in samples is calculated from the estimated symbol rate R_s: $d = \frac{1}{2 \cdot R_s} = \frac{T}{2}$.
- Differential values are computed by multiplying each sample with the complex conjugate of the sample, d samples ago. The phase of the resulting difference values contains the differential symbol information.

When displaying symbols (default), the absolute I/Q plot (upper right) should show 8 points arranged on a square in case of a successful symbol clock recovery (Figure 40).

The Diff. phase I/Q plot shows a bunch of points between ±90° through 0° (Figure 40). The number of points varies depending on the signal quality. The points might coalesce to 3 points for *all samples* (see Figure 41).

Switching *Display* to *All samples*, 3 points (at ±90° and 0°) will be shown in the differential plot. This differential plot is characteristic for OQPSK. The absolute I/Q plot will show (phase rotated) 4 points and the transitions on the square (see Figure 41).

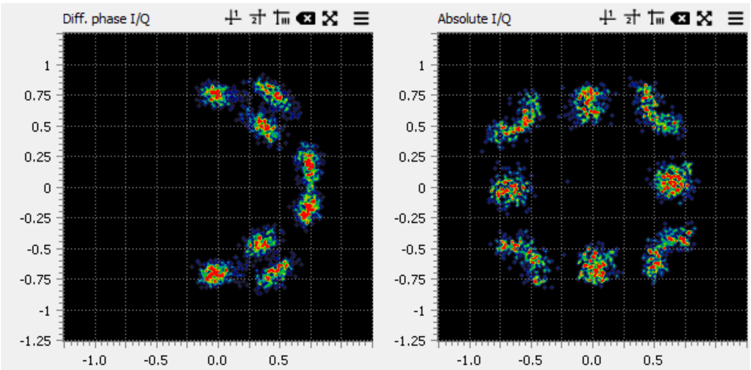


Figure 40: Differential (left) and absolute (right) I/Q diagram, displaying symbols.

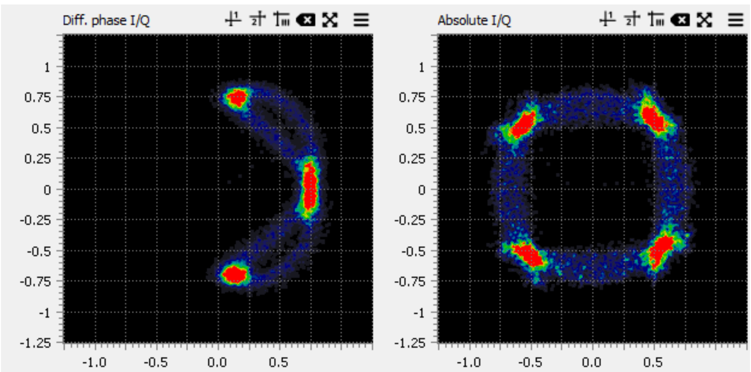


Figure 41: Differential (left) and absolute (right) I/Q diagram, displaying all samples.

With successful symbol clock recovery when displaying symbols, the even and odd absolute symbol positions are very characteristic for OQPSK (Figure 42). Each I/Q plot will show 6 points. Odd and even symbols are rotated by 90° to each other: imagine deciding a single bit on the (phase-rotated) I-plane (e.g. even) followed by deciding on the Q-plane (e.g. odd) alternately. With 2 bits, the initial QPSK symbol state/value is gathered.

Displaying all samples without clock recovery, these even/odd symbol plots are not available.

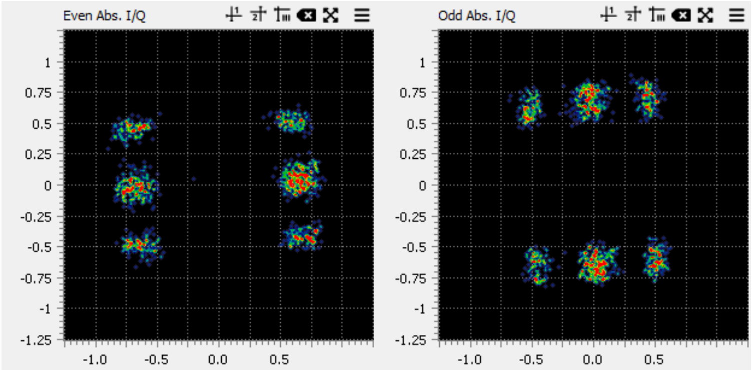


Figure 42: Absolute even (left) and odd (right) symbols

5.2.3.5. Diff. phase histogram

On the left bottom, a histogram of the phase values of the differential symbols (or samples) is displayed. In contrast to the I/Q diagrams that may be affected by distorted magnitudes, the histogram allows a better estimation of the number of distinct phase angles.

This plot depends on the *Display* parameter, showing all samples (Figure 44) or just the symbols (Figure 43).

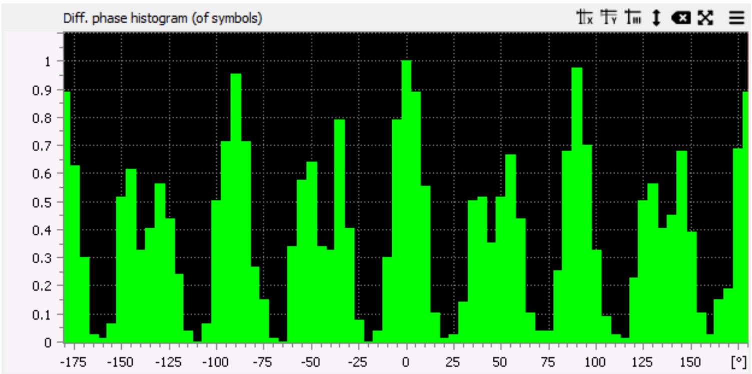


Figure 43: Differential phase histogram - on symbols

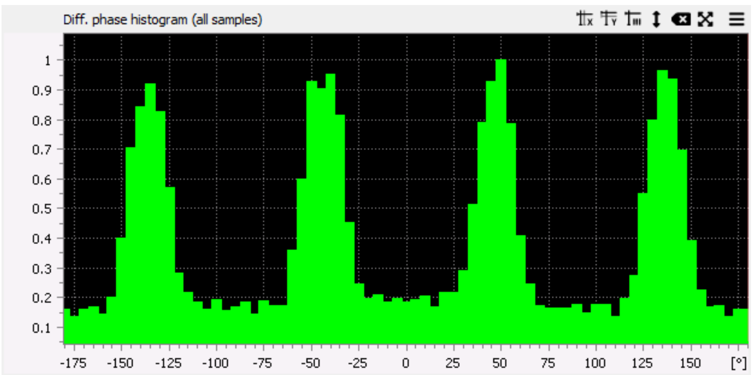


Figure 44: Differential phase histogram - on all samples

5.2.4. Example project

To further study the *OQPSK Analysis* module and its functionality, see the example project file "oqpsk-example.san". The signal contains multiple bursts, each one modulated with Offset-QPSK and a symbol rate of 5250 Bd.

5.3. QAM Signal Analysis

5.3.1. Introduction / Motivation

This module provides tools for manual analysis of Quadrature-Amplitude-Modulation (QAM) emissions. QAM is a generalization of PSK with many possible different I/Q constellations. The power spectrum of QAM is same as for a usual PSK.

Metrics are calculated and plotted to enable users to measure the following modulation parameters:

- carrier frequency f_c
- symbol rate R_s
- I/Q constellation

5.3.2. Processing

The following list provides a sequence of steps, to exemplarily outline, how an analysis could be carried out.

1. First, estimate the symbol rate using the spectrum of clock-metric[2].
2. Estimate the carrier frequency f_c utilizing the entropy, see section *I/Q entropy*. Its value is expressed relative to the selection center frequency[1] in the analysis parameter "frequency offset". An initial automatically estimated value is calculated. Adjust the "frequency offset" control element or the selection depending on the estimated value.
3. Find the dominant peak in the entropy and use this together with the visible constellations on the I/Q diagrams to verify a QAM modulation. On distorted signals, especially with a high modulation order, an equalizer will be necessary.

The signal processing can be further customized by tweaking the (extended) analysis parameters.

Display
: Defines the input for the Raw I/Q plot. *All samples* and *Symbols* are available. Symbols uses only the samples of the recovered symbol-clock. This usually cleans the plot, if symbol-clock-recovery works as expected.

Constellation
: Defines the QAM constellation for the blind equalizer. A bunch a constellations is available - besides the entries *Equalizer Off* (default) and *Auto*. *Auto* does automatically test all constellations and sets the one with the best metrics. As there are many more constellations 'in the wild', the selected one might not be the correct one.

Active
: Temporarily switch off calculations: frequency offset estimation, mixing and equalization. Allow to change multiple parameters, where each change would need some calculation time, before re-activating the calculations.

[2] spectrum of clock metric of a signal

[1] The *frequency offset* Δf denotes the difference between the carrier frequency f_c and the selections center frequency $f_{selection}$, i.e. $\Delta f = f_c - f_{selection}$.

Clock metric
: This defines the input for the spectrum for the estimation of symbol rate. Available is a selection of metrics of the *Symbol Rate* module, which are useful for QAMs (see section *Metric*). Using *Magnitude* yields an A3 spectrum.

Clock averaging
: This defines the number of symbols to "average" to get peaks in such an integrated clock metric signal. For symbol clock recovery, it's important to get a peak for every symbol. It might be beneficial to increase this value for distorted or faded signals.

Frequency search span
: The calculation of entropy for all possible frequencies has to be performed very fine granular and consumes a lot of CPU/computation time. Entropy is calculated within this *frequency search span*. The necessary frequency granularity/step is computed internally - depending on the selection's duration.

Entropy segment size
: Number of (estimated) symbols per segment, on which a 2D-histogram and entropy calculation is performed. A bigger size does increase the number of test frequencies and increases the computation time.

Max entropy segments
: Max number of segments, on which entropy is calculated and summed up.

Equalizer filter length (taps)
: Defines the number of equalizer taps - for solving/adapting the equalization filter.

Equalized I/Q
: Defines what to show in the Figure 48 plot.

Oversampling
: Oversampling increases the resolution in time. The default value of 6 is sufficient in most cases.

Filter type and roll-off
: Customize the filter applied to signal. This may yield clearer results in the I/Q displays.

5.3.3. Results

The analysis results are presented on 5 plots, which are discussed in the following sections. Figure 45 shows an overview of the result display. In the top right corner, the clock-metric spectrum is shown. It is discussed in section *Clock-metric Spectrum*. Top left corner shows the I/Q entropy plot, which should allow reading the frequency offset. For details, see section *I/Q entropy*. The plot at center left shows the Raw I/Q signal. At it's right, the equalized I/Q symbols are shown - for a given constellation. At the bottom, the symbol quality - after equalization - is shown.

5.3.3.1. Clock-metric spectrum

For this plot the parametrized clock metric of the selected signal is computed and its spectrum is displayed. QAM uses the metric *Complex distance* by default. *Magnitude* might produce better results. It typically shows a distinct peak at a value equal to the symbol rate R_s.

Since the metric of the selected signal is real valued, only the positive frequencies of the spectrum are shown. The limits for the frequency range depend on the selection bandwidth, which should be larger than the expected symbol rate. The symbol rate regions, which are not considered at the estimation, are displayed with shading.

Figure 46 shows an example of this plot. A dominant peak can be observed at $\sim 600\,\mathrm{Bd}$, which can be measured exactly, using zoom and cursor functionality. This suggests an QAM emission using a symbol rate R_s of $600\,\mathrm{Bd}$.

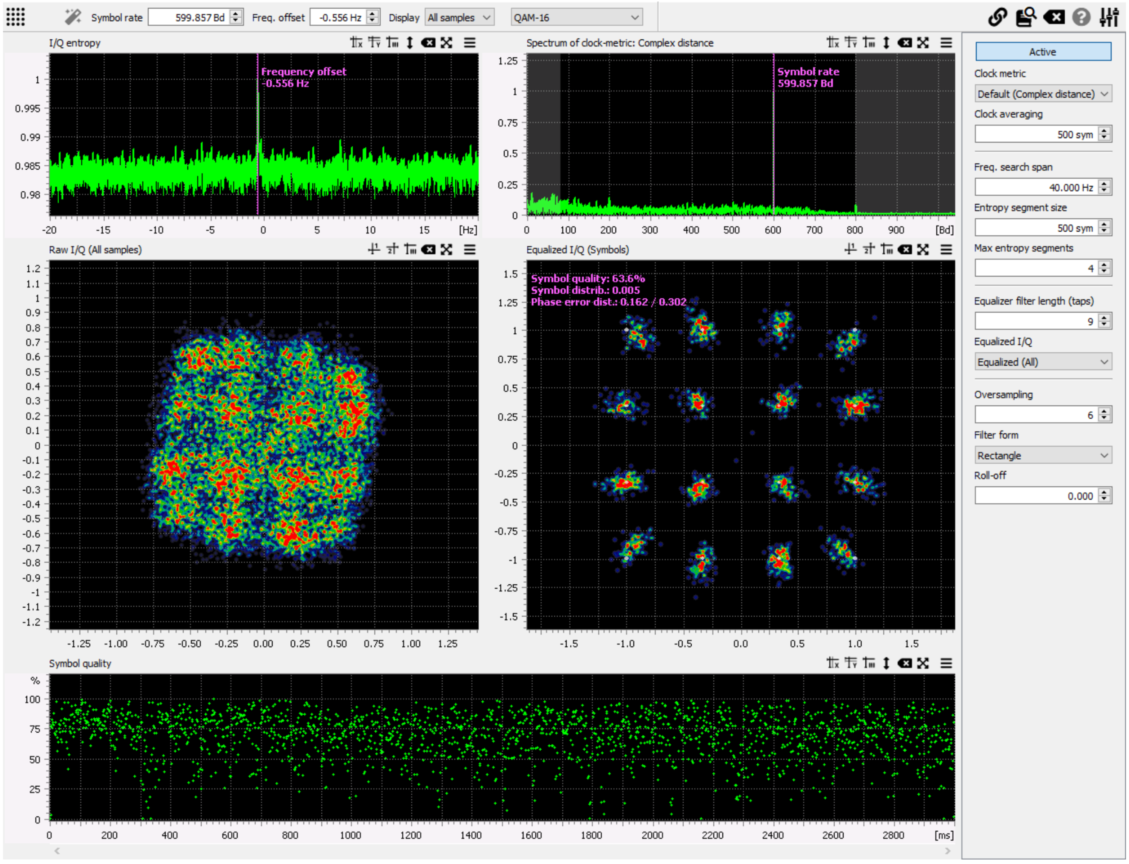


Figure 45: QAM analysis result display overview.

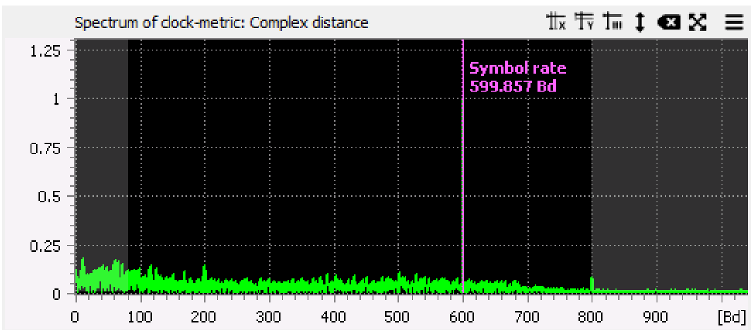


Figure 46: Clock-metric spectrum for symbol rate estimation.

5.3.3.2. I/Q entropy

The frequency offset is determined for a linear modulation with an unknown constellation. To achieve this, every possible frequency is mixed on zero and multiple (*Max entropy segments*, default: 4) 2D-histograms (dimensions I and Q) are calculated and summed. I/Q heatmap plots are also based on such 2D-histograms - mapping number of occurrences to color values. On top of these 2D-histograms, the (complemented) entropy is calculated for each frequency: smeared traces lower the objective value. Fewer non-zero I/Q points/bars in the 2D-histogram result in higher objective values. A peak could identify the correct frequency offset.

Symbol rate R_s and clock is not utilized when calculating the I/Q entropy.

Reading the precise symbol rate might be difficult, but it's easy to verify the value, the *Clock-metric Spectrum* delivered.

5.3.3.3. I/Q Diagrams

Displaying the complex signal of the selection in an I/Q diagram can reveal information about the QAM constellation as well as its modulation order.

When displaying *All samples* (default), the raw I/Q plot (left, Figure 47) could already indicate the constellation. This requires the correct frequency offset, a successful symbol clock recovery (Figure 47) and little channel distortion (fading).

Having selected a QAM constellation, a blind equalizer is applied on the mixed signal. The resulting equalized symbols are plotted (Figure 48). A good plot might indicate the right constellation - but verify the symbol quality (Figure 50) and the other metrics displayed in the top left corner:

- (average) symbol quality in percent
- symbol distribution: metric showing how uniform all symbols (constellation points) are distributed
- phase error distribution: average / max metric of, how uniform the phase errors are per symbol (constellation points)

The normalized Kullback-Leibler divergence is utilized as a metric for uniform distribution. 0 ist optimum.

Also check the parameter *Equalized I/Q*, that all symbols (constellation points) are used.

Switch *Equalized I/Q* to 'Decision' to see the decided constellation points together with all possible reference points, see Figure 49 plot. The size and transparency of the drawn circles at a constellation point depends on the number of decisions. A tooltip with some info is shown on mouseover of a constellation point.

The Diff. phase I/Q plot isn't shown, cause usually useless on complex constellations.

5.3.3.4. Symbol Quality

Having selected a QAM constellation, a blind equalizer is applied on the mixed signal. The resulting symbol error (distance from mixed I/Q to decided I/Q constellation point) is transformed into a quality in percent.

5.3.4. Example project

To further study the *QAM Analysis* module and its functionality, see the example project file "qam16-example.san". The signal contains a QAM-16 modulated emission with a symbol rate of 2400 Bd.

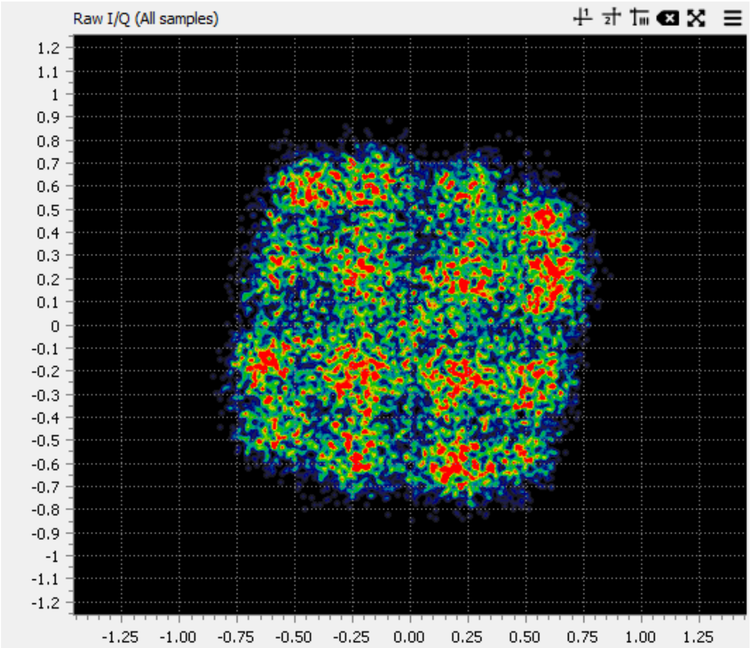


Figure 47: I/Q diagram of raw mixed signal (All samples or Symbols)

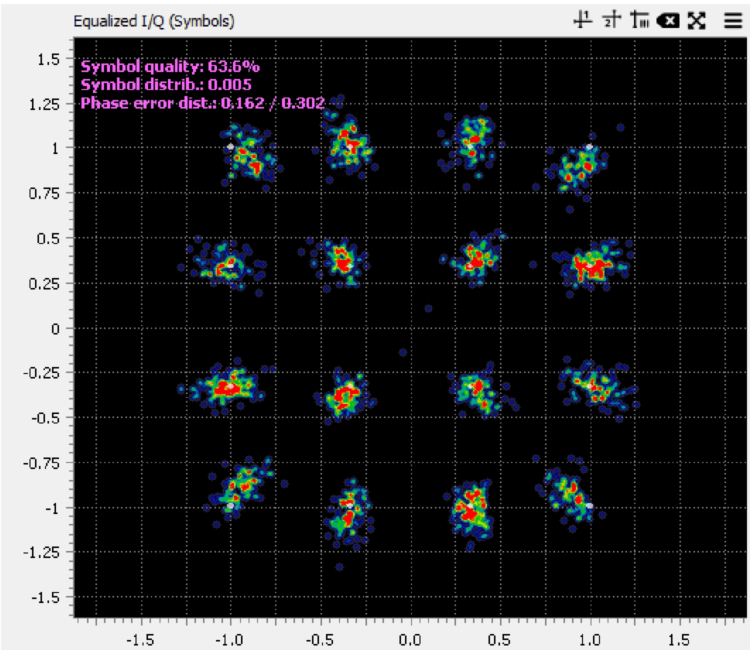


Figure 48: I/Q diagram of equalized signal (always Symbols)

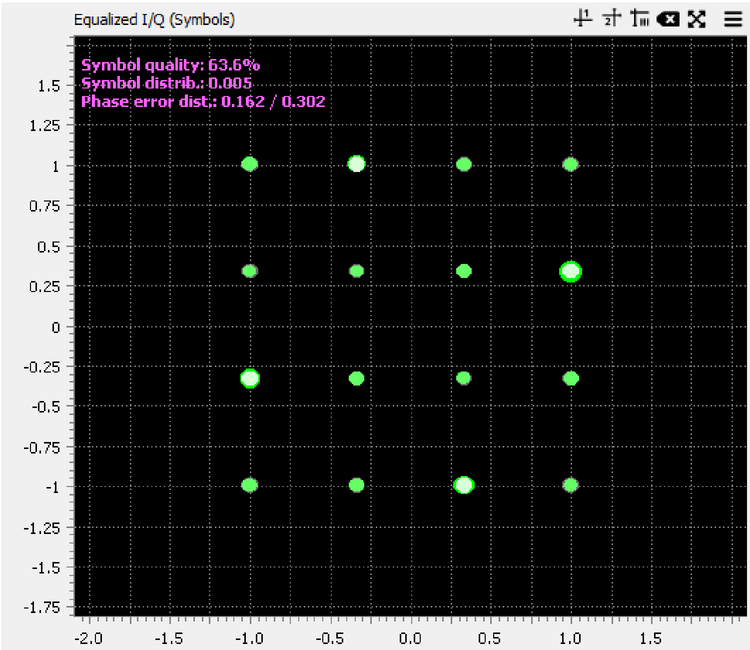


Figure 49: I/Q diagram of decided (and reference) symbols

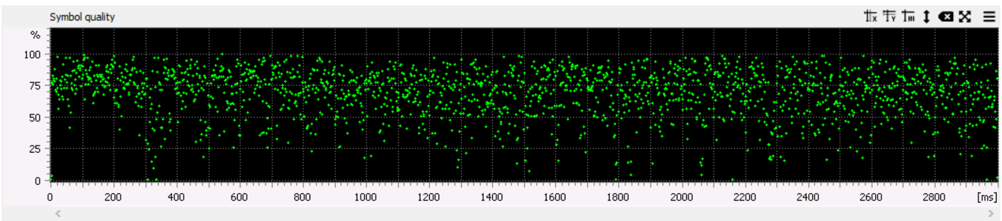


Figure 50: Quality over symbols

5.4. FSK Signal Analysis

5.4.1. Introduction / Motivation

This module provides a tool for manual analysis of emissions using frequency shift keying (FSK) and the special case of minimum shift keying (MSK). Various metrics are calculated and displayed as plots, enabling the user to determine the parameters of the modulation. These are

- symbol rate R_s,
- modulation order N, the number of tones,
- frequency offset[1] or frequency center f_c,
- shift f_S, the frequency distance of neighbor tones, and
- coarse instantaneous frequency filter settings.

5.4.2. Processing

The following list provides a sequence of steps, to exemplarily outline, how an analysis could be carried out.

1. Estimate the *symbol rate* R_s on the basis of the *Spectrum of clock-metric*. Trying different 'Clock metric' settings may reduce the noise and give a better readability, depending on signal and modulation, some metrics. In addition, the 'Inst. frequency filter' (also in the side panel) might improve (but also worsen) readability of the number of tones in the *Power weighted frequency histogram*. Note, asynchronous symbol durations, e.g. 1.5 stop bits or random stop bits, will distort the peak. In this case manual measurement of the symbol durations is required, e.g. using periodic cursors.
2. Find and count the dominant peaks in the *Welch Spectrum* and/or the *Power weighted frequency histogram*. Iteratively adjust/improve the selection's *frequency center*, bandwidth and also start and duration - until dominant peaks can be recognized. The 'Inst. frequency filter' might improve (but also worsen) readability of the number of tones. This option offers the parameter 'Bandwidth factor'. This optional filter smoothens the instantaneous frequency and is useful for distinct tones, where modulation index is greater than one, e.g. MFSK (multitone) modulations. Switching the *Display* control to 'Symbols' in the analysis toolbar, the *Power weighted frequency histogram* might get improved. Note, for signals with a small *modulation index*[2], there are no dominant peaks in the *Welch Spectrum*.
3. Set the *Mode* using the control in the analysis toolbar: 'MSK' for 2 tones at *modulation index* 0.5, FSK-N for general 2 or 4 tones. *MSK* mode does synchronize *symbol rate* and *shift* to the *modulation index* 0.5. Changing the *modulation order* updates the estimations for *frequency offset, shift* f_S and *symbol rate*. The modulation order is not estimated. Default setting is 'FSK-2', which might get switched to 'MSK', if the estimated modulation index is around 0.5.
4. Adjust the controls *frequency offset* and *shift* to match the dominant peaks. Be aware, that changing the *shift* does also update the *symbol rate* in 'MSK' mode - but *symbol rate* usually gives the better readability. A first estimation is provided automatically for each *modulation order*. The estimation results may need manual correction. Adjust the *frequency offset* control element or the selection depending on the estimated value. Note, the visible/measured *shift* might be smaller, due to the applied filters.
5. Cross check *Diff. phase I/Q Diagram* for constant envelope. The 'Envelope constness' is also shown as measured value in left upper corner of the *Power weighted frequency histogram*. Values below 100% indicate an amplitude modulated signal, e.g. PSK. Ideal continuous phase signals should be at ~100%.

[1] The *frequency offset* Δf denotes the difference between the carrier frequency f_c and the selections center frequency $f_{selection}$, i.e. $\Delta f = f_c - f_{selection}$.

[2] The *modulation index* is the quotient of neighbor tone distance f_S to the *symbol rate*: $\frac{f_S}{R_s}$

6. Cross check the peaks in the *Squared Signal Spectrum* for MSK with modulation index ~0.5.
7. Cross check *Eye Diagram of frequency* for readable eyes at clock positions. Having 'All Samples' in the *Display* control, the clock recovery algorithm is inactive - resulting in time shifted eyes.

For emissions with a very low or high *modulation index* the outlined analysis has limited applicability. A successful analysis can be expected for a *modulation index* between roughly 0.2 and 20. A fixed *symbol rate* (synchronous clock) is beneficial for the correct estimation of the *symbol rate*. Filtered symbols, e.g. Gaussian pulse shaped, are also disadvantageous.

The signal processing can be further customized by tweaking the (extended) analysis parameters.

Display
: Setting 'Symbols', this option activates a clock recovery algorithm, which is controlled with the parameters *Clock metric* and *Clock averaging*. 'All Samples' deactivates the clock recovery. In result, the *Power weighted frequency histogram* will be cleaned to the samples at the recovered clock positions.

Clock metric
: Different metrics can be approached. This defines the input for the spectrum for the estimation of symbol rate and is also input for the clock recovery algorithm. The *Spectrum of clock-metric* will get updated to regard the chosen metric. Available is a selection of metrics of the *Symbol Rate* module, which are useful for FSK modulations (see section *Metric*).

Clock averaging
: Available with the enabled clock recovery (*Display*), it defines the number of symbols to "average", cause the metric itself will not show peaks without symbol changes. This enables small deviations of the clock positions, e.g. to compensate for drifts of a fading signal.

First clock pos
: Available with disabled clock recovery (*Display*). This option simply shifts the traces of the *Eye Diagram of frequency*.

Number of frequency points
: This changes the frequency resolution of the histogram in *Power weighted frequency histogram*.

Oversampling (channel)
: Increases the resolution in time.

Inst. frequency filter
: Activates a smoothing filter on the instantaneous frequency, which is used for *Power weighted frequency histogram* and *Eye Diagram of frequency*. This optional filter smoothens the instantaneous frequency and is useful for distinct tones, where modulation index is greater than one, e.g. MFSK (multitone) modulations.

Bandwidth factor
: Bandwidth factor is relative to the parametrized *symbol rate*. It defines the amount of smoothing applied on the instantaneous frequency.

First trace
: Defines the first trace/clock to be shown in the *Eye Diagram of frequency*.

Max num traces
: This limits the number of shown traces in the *Eye Diagram of frequency*. A value of zero shows all available traces within the selection signal.

Trace step
: This defines the number of symbols (or clocks) between to consecutive shown traces. This allows to skip every 2nd clock, e.g. to verify, that the *symbol rate* isn't at a doubled value.

5.4.3. Results

The analysis results are presented on four plots in the general tab. Additional three plots are available in the additional 'MSK' tab. These are discussed in the following sections. Figure Figure 51 shows an overview of the result display and figure Figure 52 shows the MSK tab.

General tab: The upper plot shows the *Welch Spectrum* of the selection signal. Underneath is the closely related *Power weighted frequency histogram*. Following is the *Weighted instantaneous frequency* and the *Spectrum of clock-metric* for *symbol rate* estimation.

MSK tab: The left upper corner shows the *Diff. phase I/Q Diagram*. The right upper corner show the power spectrum similar to PSK. At the bottom, the *Eye Diagram of frequency* is shown.

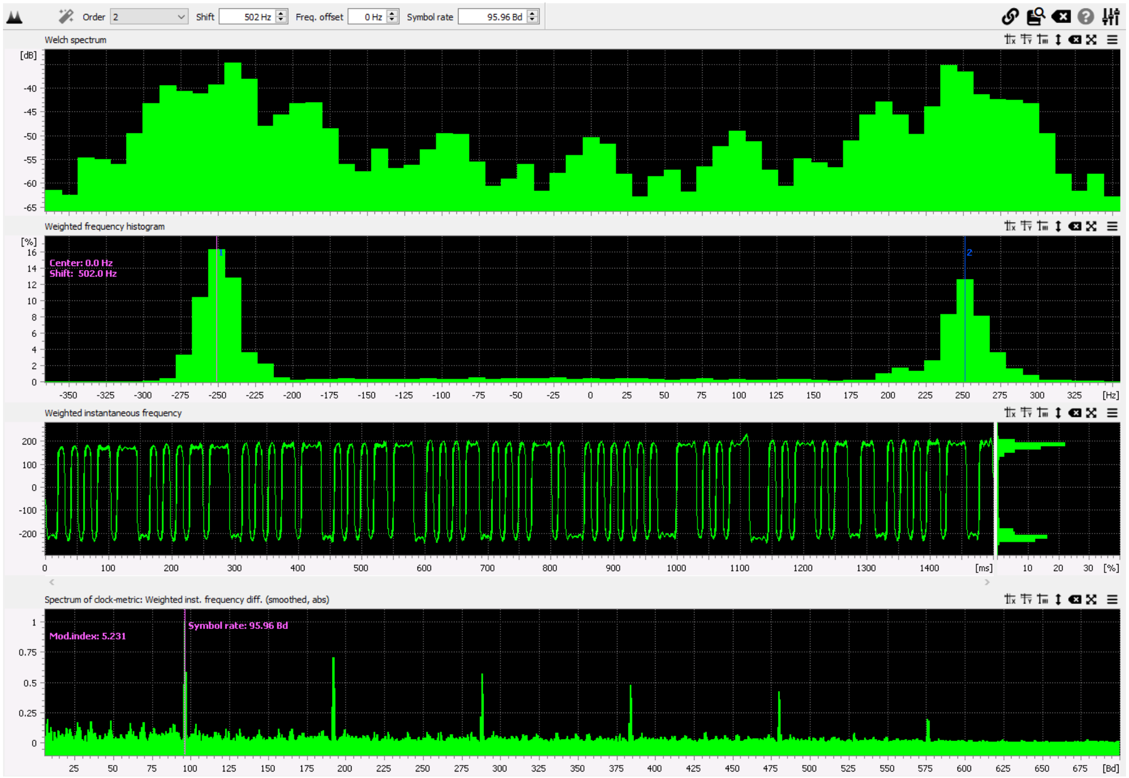


Figure 51: FSK analysis result display overview (FSK-2).

Envelope constness

An indication of the envelope constness is shown in the *Power weighted frequency histogram*, as the magnitude isn't available in this analysis - except when looking at the *Diff. phase I/Q Diagram* with inactive clock recovery. Continous-phase FSK (CP-FSK) emissions have constant envelope (magnitude). For PSK and QAM signals the magnitude varies with the symbols; usually the magnitude is (implicitly) smaller at symbol transitions.

This measure calculates the magnitudes at (possible) clock positions, half a symbol away and calculates a statistic value. With inactivate clock recovery algorithm (*Display* control set to 'All Samples'), the measure is calculated for a bunch of start sample offsets assuming a constant symbol distance from the symbol rate R_s and the minimum is taken. That explains a (slightly) different result as with activated clock recovery.

For given clock positions (from the recovery algorithm or a fixed start offset), the mean of the normalized absolute magnitude differences at these clock positions and half a symbol duration away is calculated and converted into %.

$$\text{envelope constness} = 100 \times \max\left\{0\,,\,1 - \text{mean}\left\{\frac{\left||s(k\cdot T)| - |s(k\cdot T + \frac{T}{2})|\right|}{|s(k\cdot T)|}\right\}\right\}$$

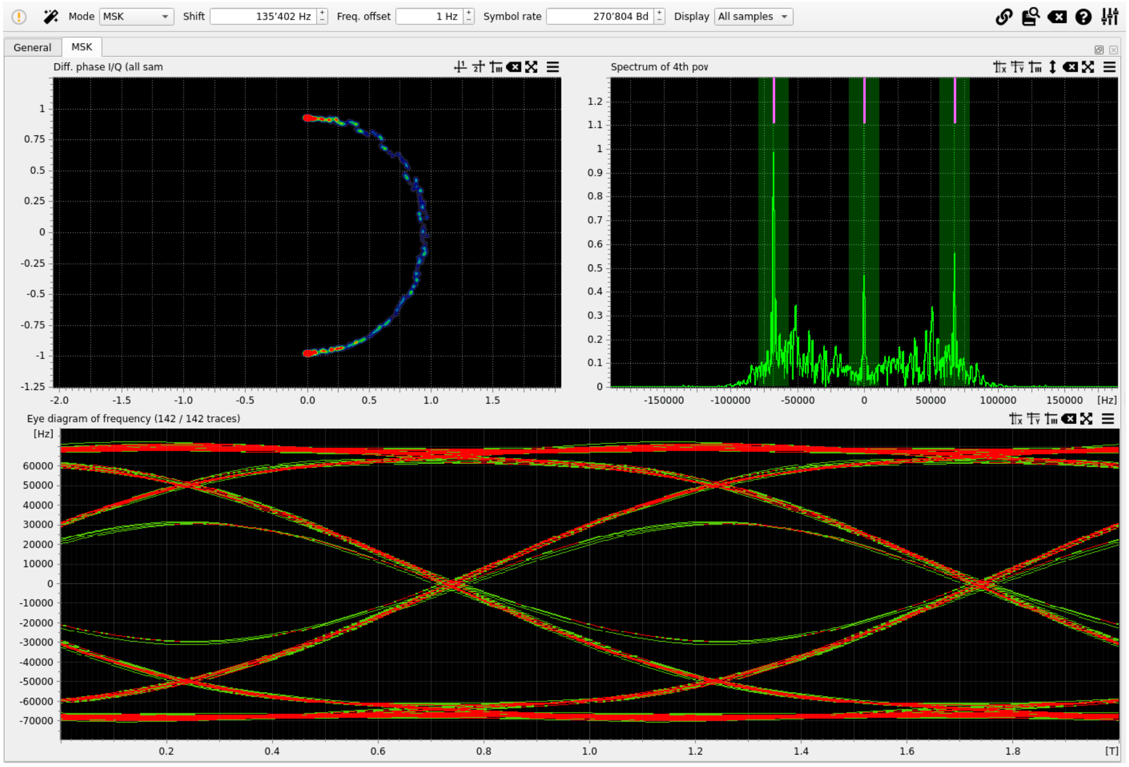


Figure 52: FSK analysis result display for MSK.

This measure differs from a well known standard deviation of the magnitude, which won't consider clock positions and fading.

5.4.3.1. Welch Spectrum

The *welch spectrum* is computed by averaging multiple spectra over the selection. It is quite similar to the spectrum of the input sonagram - but zoomed in.

For FSK signals with *modulation index* $\frac{f_S}{R_s} \gg 1$ distinct frequency tones are visible with dominant peaks. Smaller *modulation indices* do not present distinct dominant peaks. The analysis parameter *Num. Freq. Points* can be used to modify the frequency resolution, if required.

An example of *welch spectrum* is shown in Figure 53.

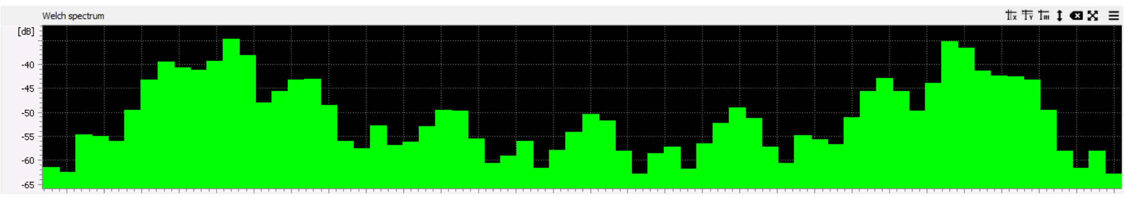


Figure 53: Welch spectrum

5.4.3.2. Power weighted frequency histogram

This plot shows a histogram built from the (smoothed) instantaneous frequency weighted with the instantaneous power.

Purpose of this plot is visualize the distribution of the symbol values. The dominant peaks may differ from the ones in the *welch spectrum*. With (Gaussian) filtered values of an emission, the values of the instantaneous frequency will be dampened.

Markers visualize the initially estimated or (later) user modified frequency tones. The estimated values may be modified with the *Shift* or *Frequency offset* controls in the toolbar - or simply by dragging the markers with the mouse. In MSK mode, *Shift* and *Symbol rate* are synchronized.

Figure 54 shows an example of this plot.

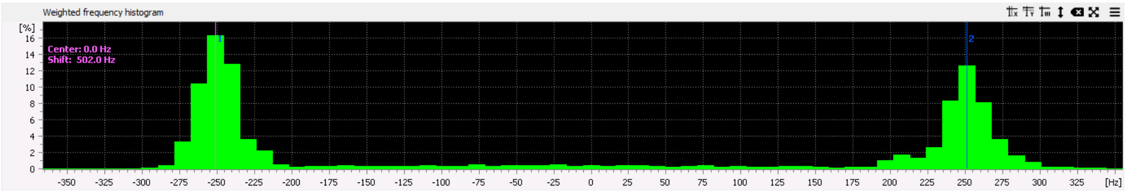


Figure 54: Power weighted frequency histogram

5.4.3.3. Weighted instantaneous frequency

This plot shows a time trace of the instantaneous frequency - smoothed and weighted with the instantaneous magnitude.

Purpose of this plot is to measure the symbol values and durations but also visualize fading effects and allow the recognition of burst/emission pauses. Weighting is key to visualize fading or emission/burst pauses. Note, weighted values do not show the frequency in the Hz-unit on the y-axis.

Symbol duration(s) and the related *symbol rate* R_s might be verified or measured utilizing this plot's *Harmonic cursors*.

For an example see Figure 55

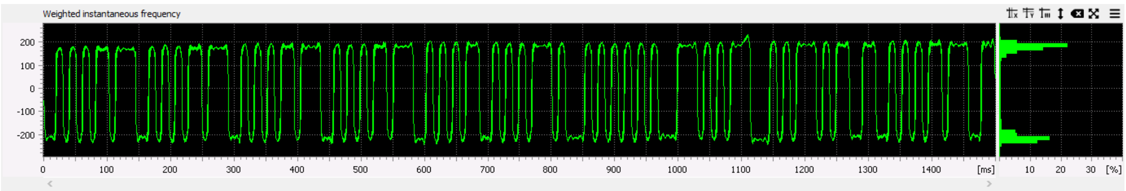


Figure 55: Weighted instantaneous frequency

5.4.3.4. Spectrum of clock-metric

For this plot the metric is computed (usually some differential). By default, the metric is the differential of the instantaneous frequency computed and weighted with the instantaneous power. The spectrum of the resulting signal is displayed. It is similar to the so called *A3 Spectrum*: it also exhibits a distinct peak at a value equal to the *symbol rate* R_s. Goal is to get a distinct peak at a value equal to the *symbol rate* R_s.

The frequency range depends on the selection bandwidth, which should be larger than the expected *symbol rate* - especially for small *modulation index*. Note, that the values in a small range from $0\,\mathrm{Hz}$ are suppressed, since this region contains misleading data.

Figure 56 shows an example of this plot. A dominant peak can be observed at $96\,\mathrm{Bd}$, which can be measured, using zoom and cursor or marker functionality. This suggests an FSK modulated emission with a *symbol rate* R_s of $96.0\,\mathrm{Bd}$. Also, a synchronous emission with fixed symbol duration: no fractional start/stop bits. With asynchronous emissions, having start/stop-bit with fractional symbol durations, the peak is often split in two peaks around the searched *symbol rate*. For these asynchronous emissions, sometimes a good peak is at a multiple of the searched *symbol rate* R_s.

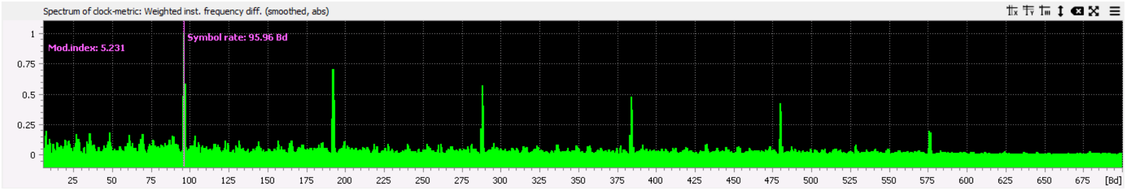


Figure 56: Spectrum of clock-metric for *symbol rate* estimation.

5.4.3.5. Diff. phase I/Q Diagram

Displaying the complex signal of the selection in an I/Q diagram can reveal information about the Modulation and the envelope constness.

The plot is a *Differential* I/Q diagram, where so called differential samples are displayed. The computation of the differential samples is as following:

- The symbol distance d in samples is calculated from the estimated symbol rate R_s: $d = \frac{1}{R_s} = T$.
- Differential values are computed by multiplying each sample with the complex conjugate of the sample, d samples ago. The phase of the resulting difference values contains the differential symbol information.

The *Differential* I/Q diagram, as in Figure 57, can be used to distinguish constant envelope CP-FSK emissions (including (G)MSK) from other non-constant envelope modulations as PSK, OQPSK or QAM.

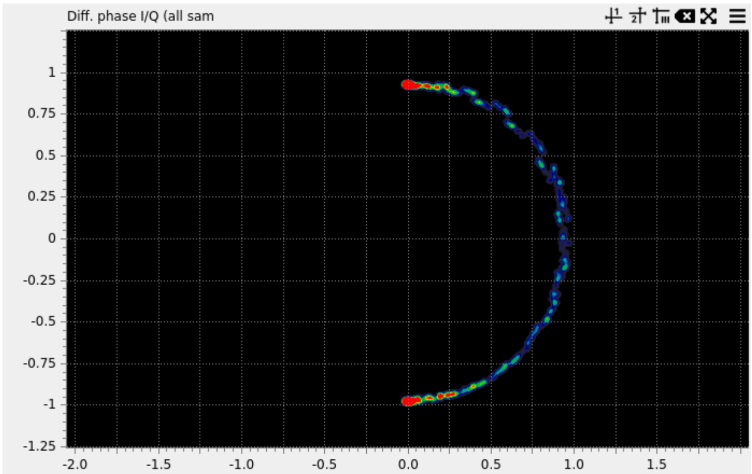


Figure 57: Differential phase I/Q diagram.

5.4.3.6. Squared Signal Spectrum

Squaring signals can serve three purposes for phase modulated signals (see *Squared Signal Spectra* in module *PSK Signal Analysis*):

- First, they provide means to estimate the carrier frequency of the emission.
- Second, these plots help to identify the (PSK) modulation variant: order and version. MSK (but also OQPSK) is similar to PSK-2B, when it comes to the expected peak positions. With (Gaussian) filtering of an MSK emission, a GMSK modulation, the center peak is dampened or completely removed.
- And lastly, the symbol rate R_s can be, at least, verified. Reading the precise symbol rate might be difficult, but it's easy to verify the value, the *Spectrum of clock-metric* delivered.

Note, that additional peaks will occur if the emissions data contains periodicities.

Expected peaks and their positions depend on the PSK or MSK variant, the frequency offset, the symbol rate and the filtering. These positions are visualized with a small vertical line at the top of some plots. For assistence, 3 areas are automatically searched for peaks and compared with the expectance for an MSK modulation. These areas are highlighted: green, if actual spectrum matches the expectation - or red. The *Shift* value is not considered or used for the positions as this plot serves for validating a specific *MSK* modulation. But, be aware, that this comparison is error prone and might indicate wrong results.

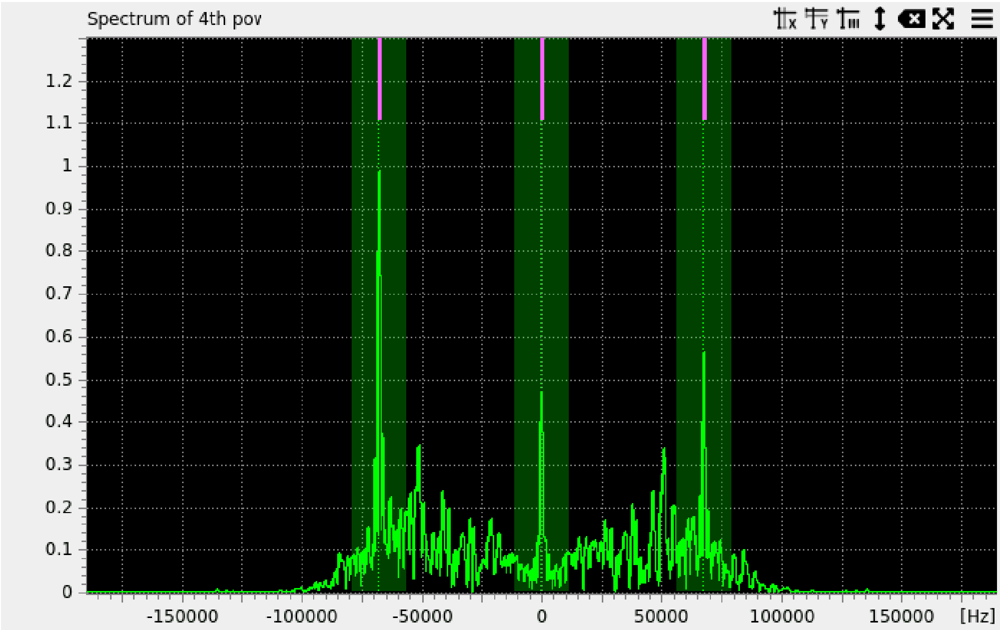


Figure 58: Spectrum of 4th power.

5.4.3.7. Eye Diagram of frequency

The plot is an *Eye* diagram, where (filtered) instantaneous frequency is displayed - synchronized with the (manual or regenerated) clock: For every symbol clock, one trace is shown and overlayed with the other clocks/traces. In Figure 59, the clock position isn't synchronized with the clock recovery algorithm: the ideal clock position should be at $0.25 \cdot T$. Switching the *Display* control to 'Symbols' synchronizes the frequency with the clock and moves the eye to the center.

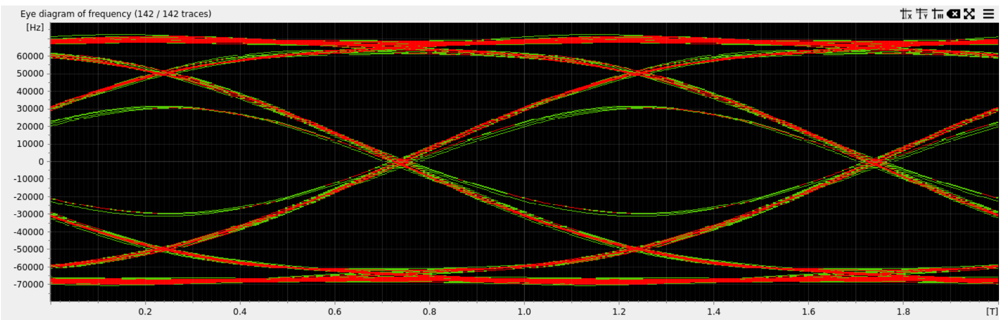


Figure 59: Eye diagram of frequency.

5.4.4. Example projects

To further study the *FSK Analysis* and its functionality, see the example project files "fsk2-example.san" and "fsk4-example.san" with the corresponding signal files. For studying MSK, see the example project file "fsk-msk-example.san" with the corresponding GSM signal.

5.5. Multi-carrier PSK/QAM Signal Analysis

5.5.1. Introduction / Motivation

This module provides plots and measurements for the analysis of multi-carrier PSK/QAM signals. Carrier distance, symbol rate and the constellation used for symbol representation can be determined.

The following assumptions apply for a signal that is being analyzed:

- Carriers are equidistant in frequency.
- Symbol rate on all carriers is the same.
- Analyzed signal is coherent, i.e. is contain only a single burst or a continuous emission.
- There is enough signal available for processing, i.e. at least a few hundred symbols are recommended. The automatic estimation of parameters uses statistical properties of the signal. The analysis performs best on strong (high SNR), undistorted signal. Idle or repeating symbol sequences may lead to confusing analysis results.

5.5.2. Processing

The following parameters can be measured using the analysis:

- Carrier distance Δf
- Carrier count N
- Symbol rate R_s
- Carrier frequency f_c, i.e. center of the first (leftmost) carrier, relative to input selection
- Used constellation on each modulated carrier

Parameters as shown in the analysis toolbar present automatically estimated values after the initial execution. Afterwards these values can be manually modified. Each parameter is coupled to a cursor position in the plots described below. The controls allow, beside adjusting measured values, also the choice of displayed carrier (by its index). Using the estimate button on the left-hand side triggers the automatic estimation discarding all manual changes. This button is only enabled after parameters have been modified by the operator.

The analysis itself is comprised of the following steps:

1. Estimate carrier distance using peaks in the autocorrelation
2. Use the carrier distance on averaged spectrum to find carrier frequencies and the number of carriers
3. Extract a single modulated carrier using carrier distance as a filter bandwidth and one of carrier frequencies as DDC center
4. Single carrier: spectrum of signals magnitude (A3 spectrum) delivers symbol rate estimation
5. Single carrier: estimated symbol rate allows an approximation of differential constellation for an I/Q plot

Each step followed and verified using the plotted results as presented in Figure 60.

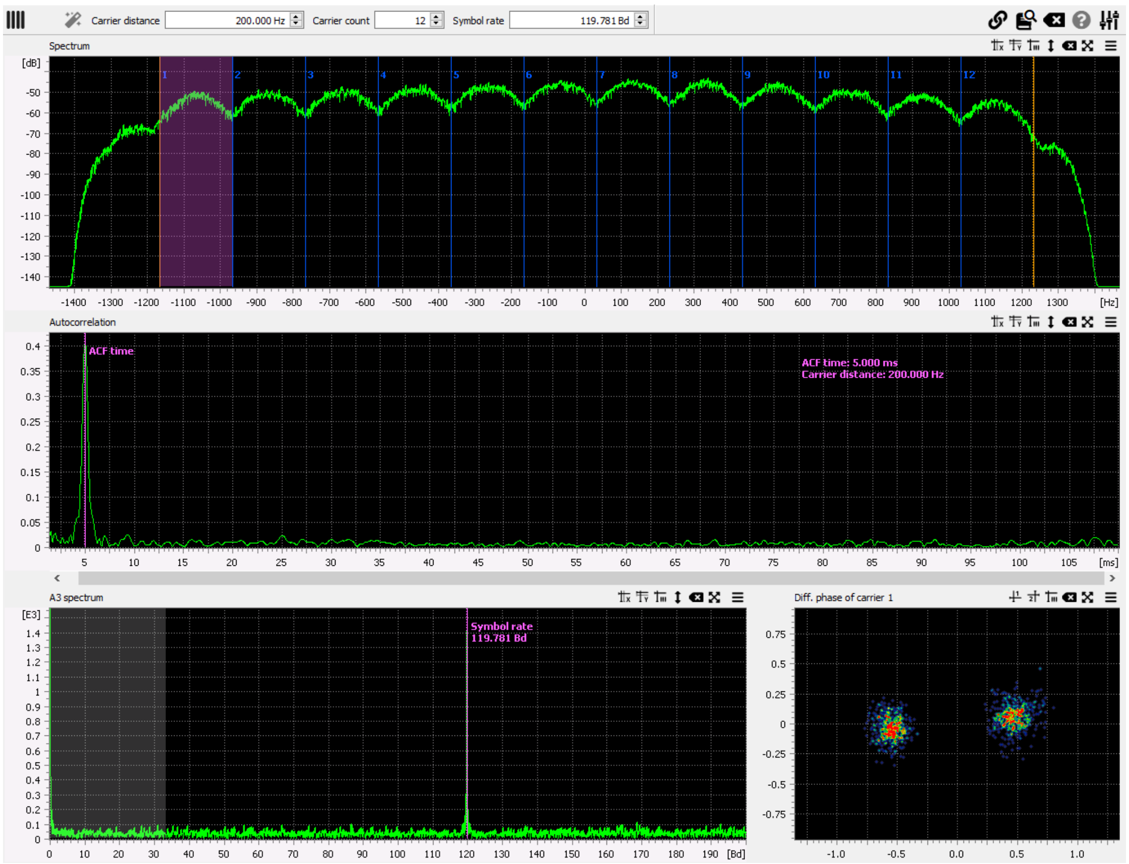


Figure 60: Multi-carrier analysis view of an example 12 carrier PSK2 signal

5.5.3. Results

The analysis results are presented on four plots, siehe Figure 60.

The initial execution of the analysis uses parameter estimation to determine required values automatically. Some assumptions about the minimum number of carriers and the minimum carrier distance apply. These boundary values may be changed in the extended analysis parameters[1].

Averaged spectrum and autocorrelation plots are augmented with visible cursors placed at positions corresponding to determined values. Once estimated, values can be changed by moving cursor positions. Manual change of cursor positions or of values in the toolbar above the plot trigger recomputation and thus change contents of dependent plots.

5.5.3.1. Averaged Spectrum

This plot allows an estimation of the carrier frequencies. It is usually much easier to measure frequencies between carriers instead of their center frequencies. This is because the spectrum contains distinctive minima between two carriers (cf. Figure 61); therefore markers are placed between carriers by default. The analysis parameter[1] *Carrier marker position* changed to place the markers on the center of carriers instead (cf. Figure 62). This can be useful if an unmodulated (pilot) carrier is visible in the spectrum or symbol sequences build visible maximum at the carrier frequency.

The second marker from the left (the first blue one) is repeated for all carriers in equal distance (harmonic marker). All markers are numbered from 1 onwards, so that the number of modulated carriers can be picked directly from the display. These numbers can be used for selection of the carrier frequency corresponding to the carrier to be shown in *A3 spectrum* and differential I/Q plot.

[1] analysis parameter side bar can be activated from analysis toolbar or with **F7** key

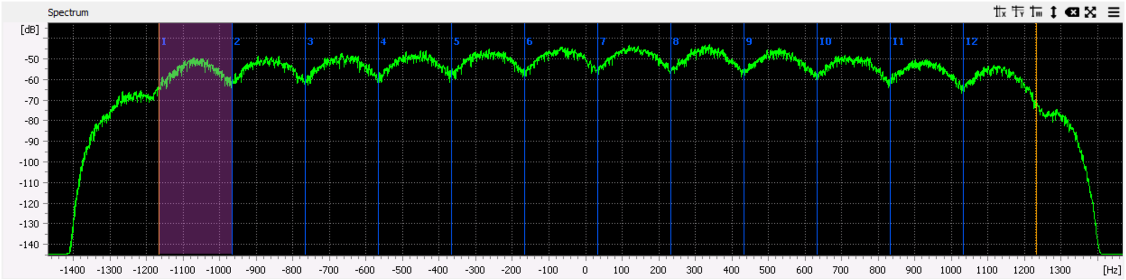


Figure 61: Averaged spectrum with cursors placed between carriers.

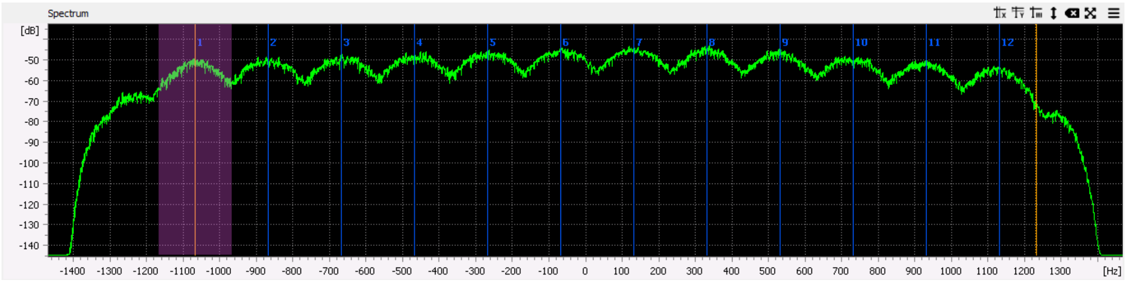


Figure 62: Averaged spectrum with markers placed on carrier frequencies.

The rightmost marker (analysis parameter[Page 68, 1] *Last carrier frequency*) is positioned on the upper signal band edge. It represents the upper limit for carrier frequencies and is used to determine the number of carriers. The value is limited so that the last carrier is contained entirely within the input bandwidth.

The single carrier signal presented on the two following plots can be specified by placing the leftmost marker at any, usually the leftmost, carrier (carrier center) and providing the carrier number in *Selected carrier* parameter field in the extended analysis toolbar. The carrier number can be read from the cursor number, see Figure 60.

5.5.3.2. Autocorrelation

For multi-carrier PSK/QAM-modulated signals the magnitude of the autocorrelation has a local maximum at delay offset equal to the inverted carrier distance.

The marker in this plot represents the current estimate or chosen value. Interaction with the marker changes the assumed carrier distance Δf and filter bandwidth for extraction of data shown in single carrier plots.

The unit and scaling of horizontal axis can be changed using the extended analysis parameters[Page 68, 1]. The following settings are defined:

Time t
: The "natural" unit for the independent variable of an autocorrelation plot

Carrier distance $\Delta f = 1/t$
: This inverts the "natural" unit and therefore this plot significantly differs from a plot with one of the other units:

  - The graph is reversed: What used to be at the right side (high time or carrier count) is now at the left side (low carrier distance) and vice versa.
  - Equidistant peaks with time or carrier count axis turn into non-equidistant peaks.
  - Peaks with the same width but different positions become peaks with different widths.

The autocorrelation method of carrier distance estimation may lead to confusing and incorrect results if there are idle or repeating symbol sequences in the analyzed signal selection. It is therefore necessary in such problematic cases to analyze the signal at different time positions in order to make sure the measurement corresponds to the carrier distance and is not a result of periodic symbol sequences at multiple time offsets correlating with itself. The more coherent and undistorted signal (symbols and carriers) is available, the better the statistics of the signal can be utilized for parameter estimation. Beware, that too long signal selections may counterproductive due to changes in signal propagation.

5.5.3.3. A3 Spectrum (single carrier)

Once carrier distance and carrier frequency has been estimated a single carrier signal is extracted. The Spectrum of the magnitude (A3) reveals the value of symbol rate R_s. A peak at the position of the symbol rate can develop only if the signal indeed only contain a single carrier. That means the carrier bandwidth (carrier distance) and carrier center (carrier frequency) have to be reasonably correct.

The marker represents the symbol rate R_s. Interaction modifies symbol rate used for the constellation shown in I/Q diagram. Note, the symbol rate should be smaller than carrier distance ($R_s < \Delta f$).

The region around 0 Bd is excluded when searching the maximum, to suppress noise. This region and also symbol rates > carrier distance are marked gray. The dimension of the excluded region around 0 Bd can be modified with the analysis parameter *Min. carrier distance / symbol rate*, the minimum ratio from carrier distance to the symbol rate. With this parameter, the minimum symbol rate is defined relative to the estimated carrier distance.

5.5.3.4. I/Q Diagram (single carrier)

The last step in the analysis shows the differential I/Q constellation used in the selected single carrier carrier. The quality of the constellation shown depends on the proper selection of the frequency range for the signal and symbol rate estimation. The correct choice of carrier distance Δf (equal to carrier bandwidth) and carrier frequency f_{c_1} minimizes inter carrier interference (ICI). The symbol rate defines the distance between symbols $T_s = 1/R_s$.

As the proper pulse shape (i.e. for a matched filter) is not known the resulting I/Q diagram may show a distorted view of the actual constellation.

5.5.4. Example project

To further study this module and its functionality, see the example project file "mc-example.san". The signal contains 12 PSK2-modulated carriers with a symbol rate of 120 Bd at a spacing of 200 Hz.

5.6. OFDM Analysis and Demodulation

5.6.1. Introduction / Motivation

Orthogonal Frequency Division Multiplexing (OFDM) signals are a special case of multicarrier PSK/QAM modulation. This modulation method transmits complex symbols (I/Q values) on multiple carriers. The modulation and demodulation is usually implemented by application of the Inverse Discrete Fourier Transform (IDFT) respectively the Discrete Fourier Transform (DFT).

The analysis performs automatic estimation of basic modulation parameters of an OFDM signal. These parameters can be verified and, when required, adjusted by the user. Further parameters can be overridden which enables manually controlled demodulation. Demodulation results and intermediate control signals are presented on multiple displays.

The following assumptions and restrictions apply:

- The analysed signal is an OFDM or a multicarrier PSK/QAM signal.
- Optimal results can be expected only for OFDM signals employing a cyclic prefix (CP-OFDM). Note: In this document the term OFDM generally denotes CP-OFDM.
- There is enough signal available for processing, at least a few hundred symbols are recommended: The automatic estimation of parameters uses statistical properties of the signal.
- The analysis performs best on strong (high SNR) and undistorted signals.
- Repeating symbol sequences (e.g. idle sequences and pilots) may lead to confusing analysis results.

The following parameters can be measured using the analysis results:

- Carrier distance $\Delta f = \frac{1}{T_u}$ (in Hz)
- Symbol rate $R_s = \frac{1}{T_s}$ (in Bd)
  - Cyclic prefix (guard interval) length $T_g = T_s - T_u$
  - T_g to T_u ratio: $\frac{T_g}{T_u} = \frac{T_s - T_u}{T_u}$
- Frequency f_0 of carrier zero, as defined by DFT
- Number of modulated carriers
- Constellation used on each modulated carrier
- Secondary parameters for manually controlled demodulation:
  - Sampling position
  - Sampling rate error

5.6.2. Results

The OFDM analysis performs automatic estimation of carrier distance and symbol rate and thereby their inverse values $T_u = \frac{1}{\Delta f}$ respectively $T_s = \frac{1}{R_s}$. With these basic parameters known, the signal is demodulated in order to acquire further estimates such as the carrier frequency of carrier zero, the first symbol position and number of modulated carriers. The results of initial estimation and demodulation are presented on multiple displays grouped in a few tabs.

5.6.2.1. Estimation Results

Parameters required for OFDM demodulation are determined automatically. The estimation of the carrier distance Δf $(1/T_u)$ is made assuming a minimum and a maximum value. By default, sensible limits based on real-world signals are chosen depending on the selection bandwidth. The limits can be modified in the advanced analysis parameters. Numeric values of the estimation of T_u, T_s and f_0 are presented in a table on the *Estimation result* tab page as shown on Figure 63. The relatively large number of significant digits for measured values presented in the table is not exaggerated. In case of manually controlled demodulation – where control loops are switched off – even tiny adjustments to these numbers affect the demodulation, which is visible on plotted results.

The carrier distance $(\Delta f = \frac{1}{T_u})$ is determined by finding the position of the significant maximum in the magnitude of the autocorrelation function (ACF) of the baseband signal. The validity of the estimated value can be verified using the ACF plot placed below the result table as shown on Figure 64. A marker in the ACF plot shows the chosen value for T_u. The estimation of the symbol rate is more complex: It is based on a running autocorrelation of the baseband signal at fixed delays of T_u. The magnitude of this signal is used for clock recovery and is presented as *Clock recovery signal* (tab *Synchronisation*) in Figure 65. The magnitude of the autocorrelation of the clock recovery signal has its first nontrivial local maximum at T_s.

Estimation result	
Carrier distance	62.47958 Hz
Symbol rate	50.00333 Bd
Tu duration	16.005229 ms
Ts duration	19.998668 ms
Tg to Tu ratio	0.250
Modulated carriers	from -12 to 11 (24 in total)
Detected constellation	PSK-4

Figure 63: Result table of estimated basic OFDM parameters

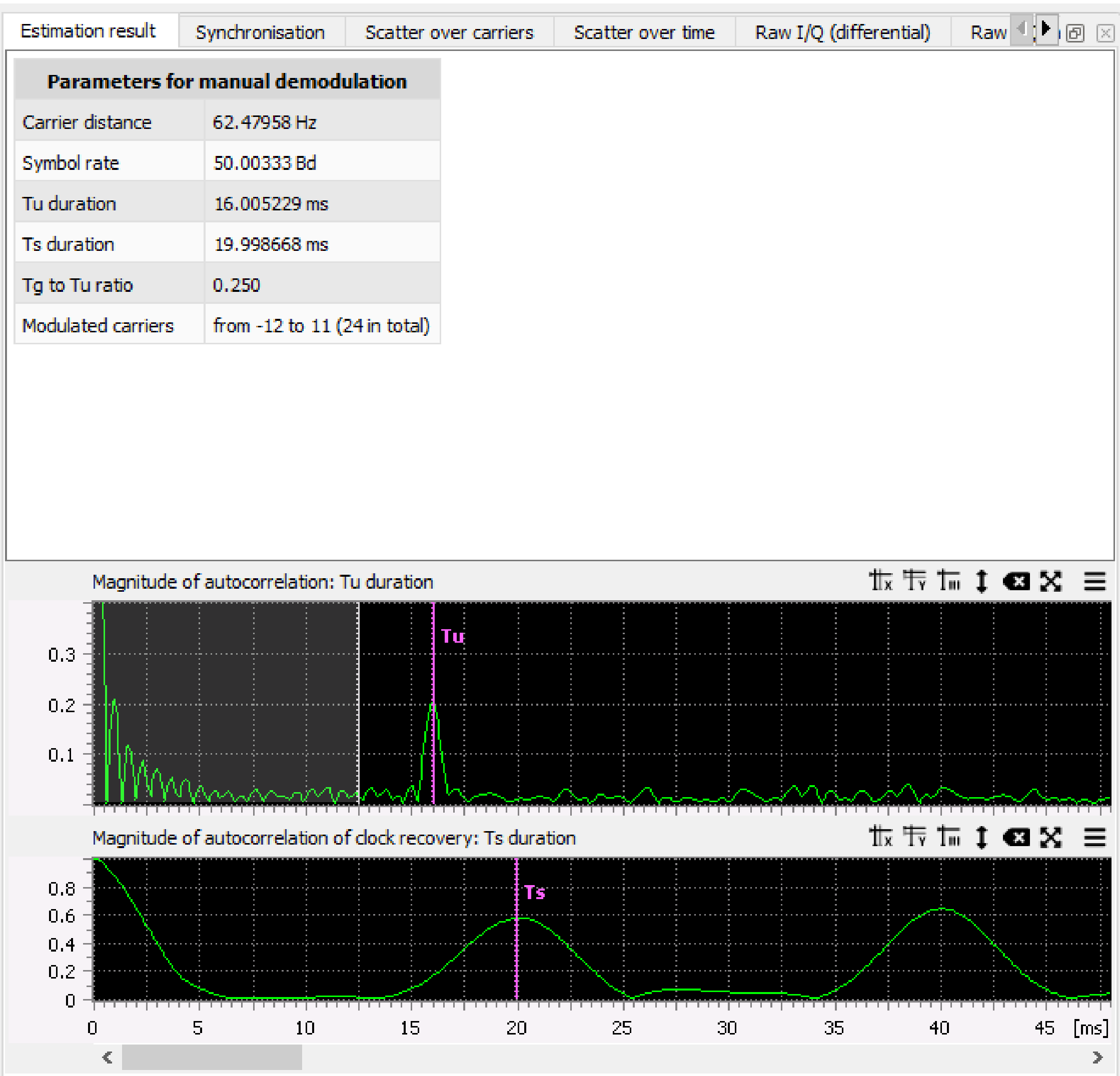


Figure 64: Results of estimation of basic OFDM parameters.

The estimation of the frequency f_0 is determined with the assumption that modulated carriers are placed symmetrically around baseband. That is, counting carriers from the leftmost to the rightmost one, the carriers take numbers $k \in \left\{-\left\lfloor \frac{K}{2} \right\rfloor, \dots, 0, \dots, \left\lfloor \frac{K-1}{2} \right\rfloor\right\}$, where K is the number of modulated carriers. For example: For an even value of $K = 4$ one gets $k \in \{-2, -1, 0, 1\}$, for an odd value of $K = 5$ one gets $k \in \{-2, -1, 0, 1, 2\}$. With this definition, f_0 is the frequency of the carrier with carrier number $k = 0$. The frequency is estimated up to the range $\pm\frac{\Delta f}{2}$ using the phase of the clock recovery signal at symbol sampling positions. The integer offset is then determined based on the number of modulated carriers K and the symmetry assumption. The incorrect choice of the carrier zero results in misrepresentation of constellations.

To be noted is that the estimations mentioned above are independent of constellations or pilots used on modulated carriers. It means also, that e.g. f_0 cannot be as precisely determined as it can be measured once pilot carriers, pilot symbols or constellation knowledge are combined into the computation.

The sampling rate error is determined from the mismatch of estimated symbol sampling positions and parametrized values of symbol rate and sampling rate of the input signal. This value should be close to zero, but can be as high as ± 500 ppm for recordings done with consumer grade sampling equipment (i.e. a PC sound card).

The first symbol position is the time offset from the start of the signal selection to the symbol sampling position of the first symbol. This value can be used for manual demodulation with disabled clock recovery control loop.

The automatic estimation of signal parameters also provides a hint for possible differential PSK constellation. It is computed under the assumption that the majority of the carriers is modulated with the same PSK constellation and that the automatically determined value for f_0 is correct.

The DFT length N is chosen based on the number of modulated carriers K such that it is a power of 2 with $K < N = 2^n$. This allows for an efficient computation of the DFT using the FFT algorithm. The choice of a specific N implicitly defines the sample rate $f_{s,OFDM} = N/T_u$ the signal is resampled to before demodulation is performed.

5.6.2.2. Synchronisation

Time and frequency synchronisation are the most crucial steps in the demodulation of an OFDM Signal. Therefore the second tab page *Synchronisation*, shown in Figure 65, displays the results of clock recovery and blind frequency control loop processing.

The clock recovery is based on the cyclic prefix (guard interval) of length T_g within the symbol duration $T_s = T_u + T_g$. The running autocorrelation at a delay of T_u reveals the sampling positions. The *Clock recovery signal* is the result of the running autocorrelation. If the magnitude of this signal exhibits local maxima at a constant interval of T_s, then the analyzed signal is most probably an OFDM or at least a multicarrier PSK/QAM signal. The *Averaged clock recovery signal* is constructed from the signal above by averaging about 20 symbols. A signal with good quality should exhibit triangles spaced at T_s with base width of $2 \cdot T_g$ in this plot. This smoothed signal is used to estimate the sampling positions. The *Sampling positions* plot marks the start of symbols (which start with the cyclic prefix of length T_g).

If the estimated symbol start position is not stable, e.g. due to changing propagation conditions or sampling frequency errors, it is moved by one sample forwards or backwards (at $f_{s,OFDM}$). These corrections are shown on the subplot *Corrections of sampling positions* as ± 1 samples. A stable signal with good quality should contain no or only a few corrections. Frequent corrections of the sampling position indicate one or multiple of the following issues:

- T_u and/or T_s incorrect
- The signal has too low SNR
- The signal is significantly distorted by fading (multipath propagation)
- Sampling frequency error
- The signal is not an OFDM or multicarrier signal

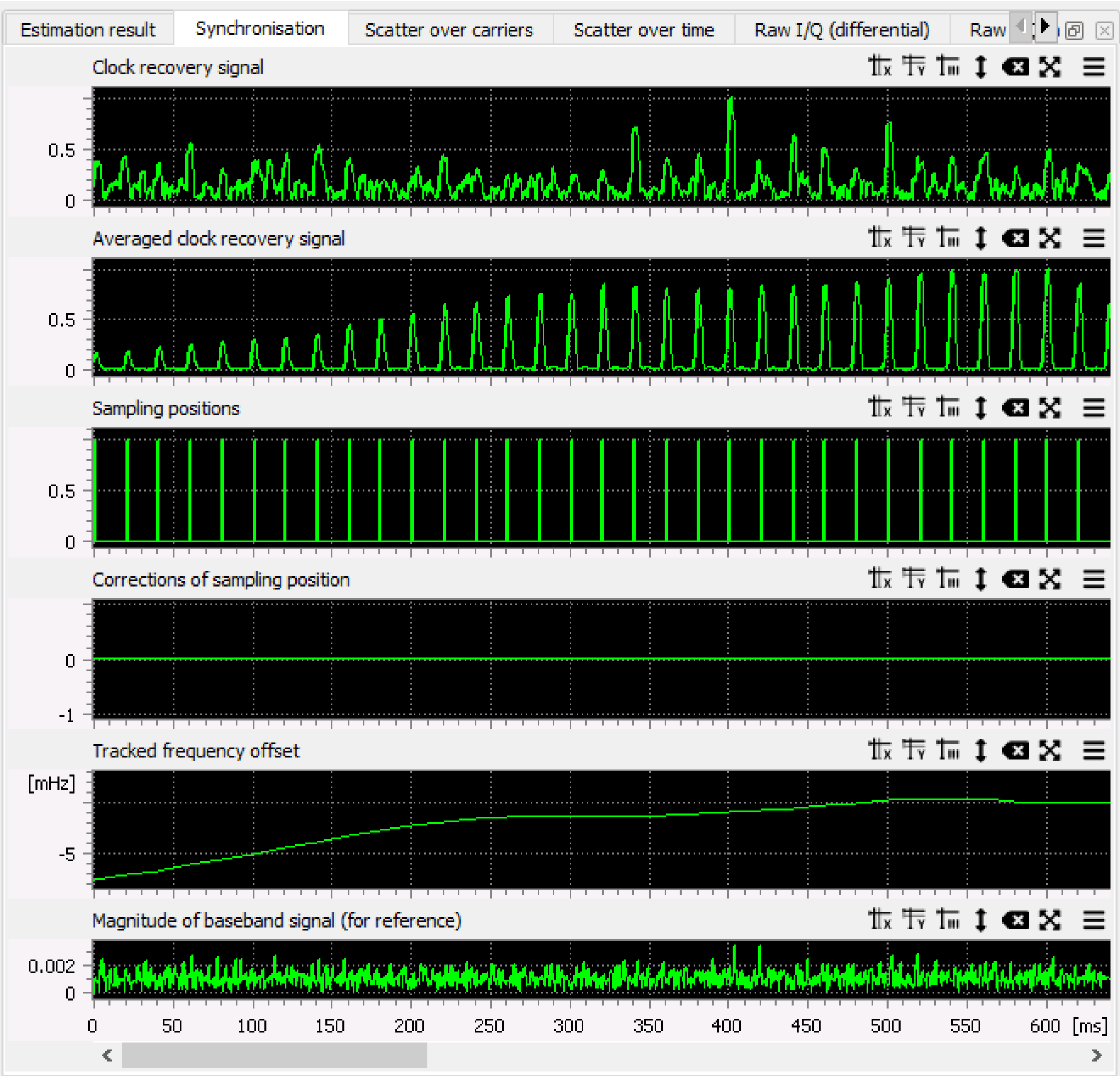


Figure 65: Verification of clock recovery.

Below the clock recovery plots is the output of the frequency offset tracking (i.e. f_0 tracking).

At the very bottom the magnitude of the baseband signal is plotted. It serves as a reference and can be very useful in assessment of potential reasons for clock/frequency recovery failures.

5.6.2.3. Scatter Diagrams

The scatter diagrams show demodulated signal components over time and frequency and allow visual assessment of signal quality and distortions that could be corrected using manual override of some analysis parameters.

For the purpose of OFDM demodulation and analysis there are $3 \cdot 2 \cdot 2$ relevant plots. This number stems from the combination of possible signal components (transformations), the unit of the horizontal axis and the used input signal:

- Differential phase, absolute phase, magnitude
- Unit of the horizontal axis: carrier number (i.e. frequency) or symbol number (i.e. time)
- Raw or soft symbols

There are two tabs: The tab *Scatter over carriers* uses the carrier number as unit of the horizontal axis, the tab *Scatter over time* uses the symbol number as unit of the horizontal axis. See Figure 66 respectively Figure 67 for an example of the scatter plots. The plots within each tabs are placed in a grid as described in the table below.

Table 15: Arrangement of scatter plots in the tabs *Scatter over carriers* and *Scatter over time*

differential phase (raw)	absolute phase (raw)	magnitude (raw)
differential phase (soft)	absolute phase (soft)	magnitude (soft)

The top row shows the phase and magnitude of *raw* I/Q values directly after OFDM demodulation (i.e. after application of the DFT). The bottom row shows *soft symbols*, which are the raw I/Q samples after application of magnitude, phase and frequency correction control loops. The bottom row with *soft symbols* is only populated with data if a constellation has been set in the analysis parameters.

The first column shows the differential phase (the phase difference to the preceding symbol in time on the same carrier), the second column the absolute phase and the third column the magnitude. The phase is shown in range $[-\pi, \pi)$ radians (that is $[-180, 180)$ degrees), the magnitude as a linear value.

The horizontal axis is the carrier number (frequency) in the tab *Scatter over carriers* respectively the symbol number (time) in the tab *Scatter of timer*.

The scatter diagrams allow the selection of a subset of symbols and carriers to be included in the plots, e.g. every second carrier in every fourth symbol. By default, *Scatter over carriers* includes all carriers from all symbols. *Scatter over time*, however, includes only the modulated carriers from all symbols.

5.6.2.4. I/Q Diagrams

Multicarrier I/Q diagrams display the constellations (I/Q values) of a selected subset of symbols and carriers (by default all). The tabs *Raw I/Q (differential)* and *Raw I/Q (absolute)* are always visible. The tab *Soft symbols I/Q (differential)* is only populated if a constellation has been set in the analysis parameters and if the analysis parameter *Use differential decision* is unchecked. The tab *Soft symbols I/Q* is only populated if a constellation has been set in the analysis parameters.

The I/Q value of differential symbols is determined by a division of a symbol by the symbol on the same carrier in the previous OFDM symbol. The number of differential symbols in time direction is smaller than the number of absolute symbols by one. The I/Q diagrams of all carriers are scaled to the same range in order to make them comparable. This way unmodulated carriers should exhibit a small dot or circular cloud in

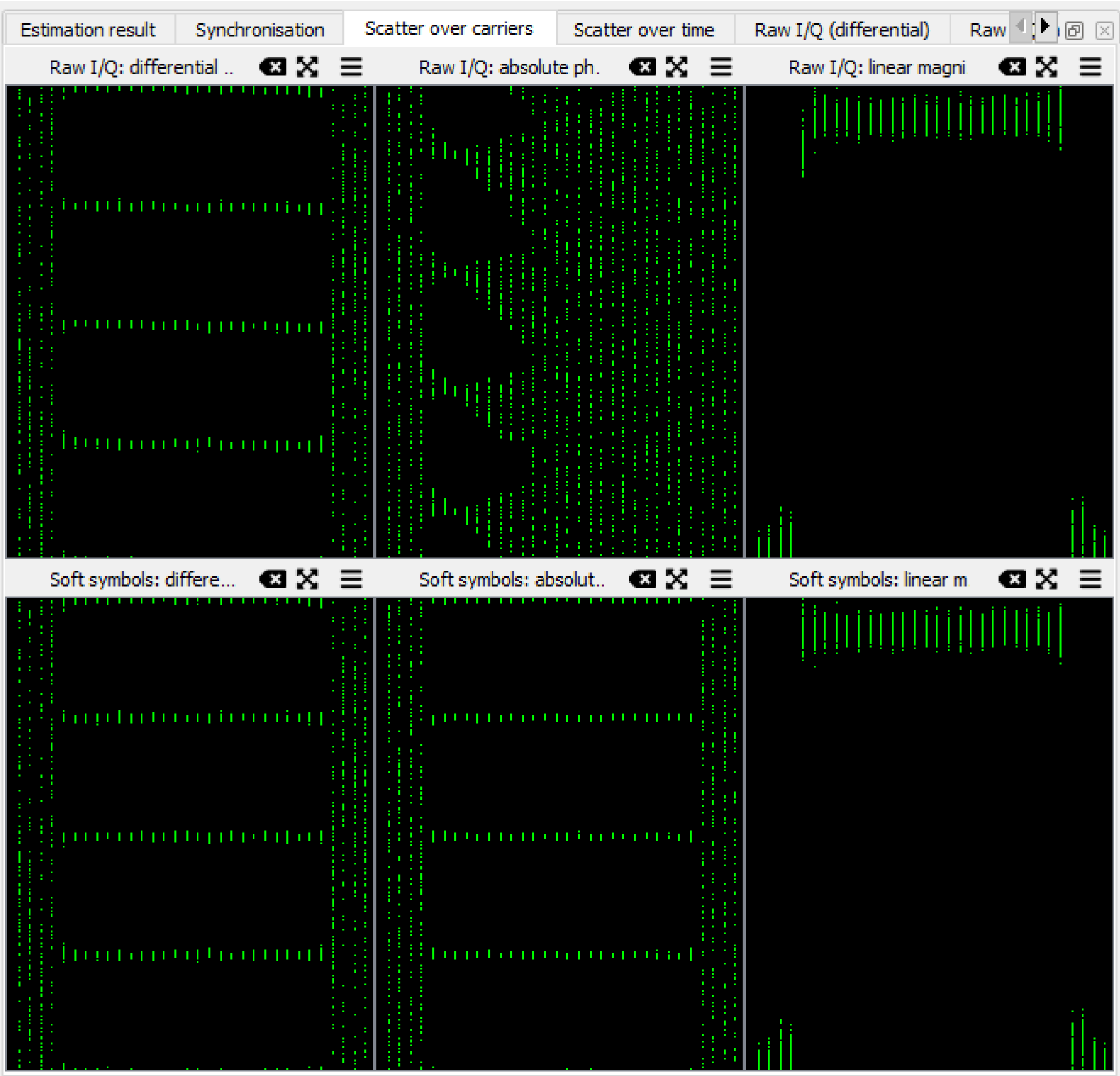


Figure 66: Example output of scatter diagrams over carrier number (i.e. frequency)

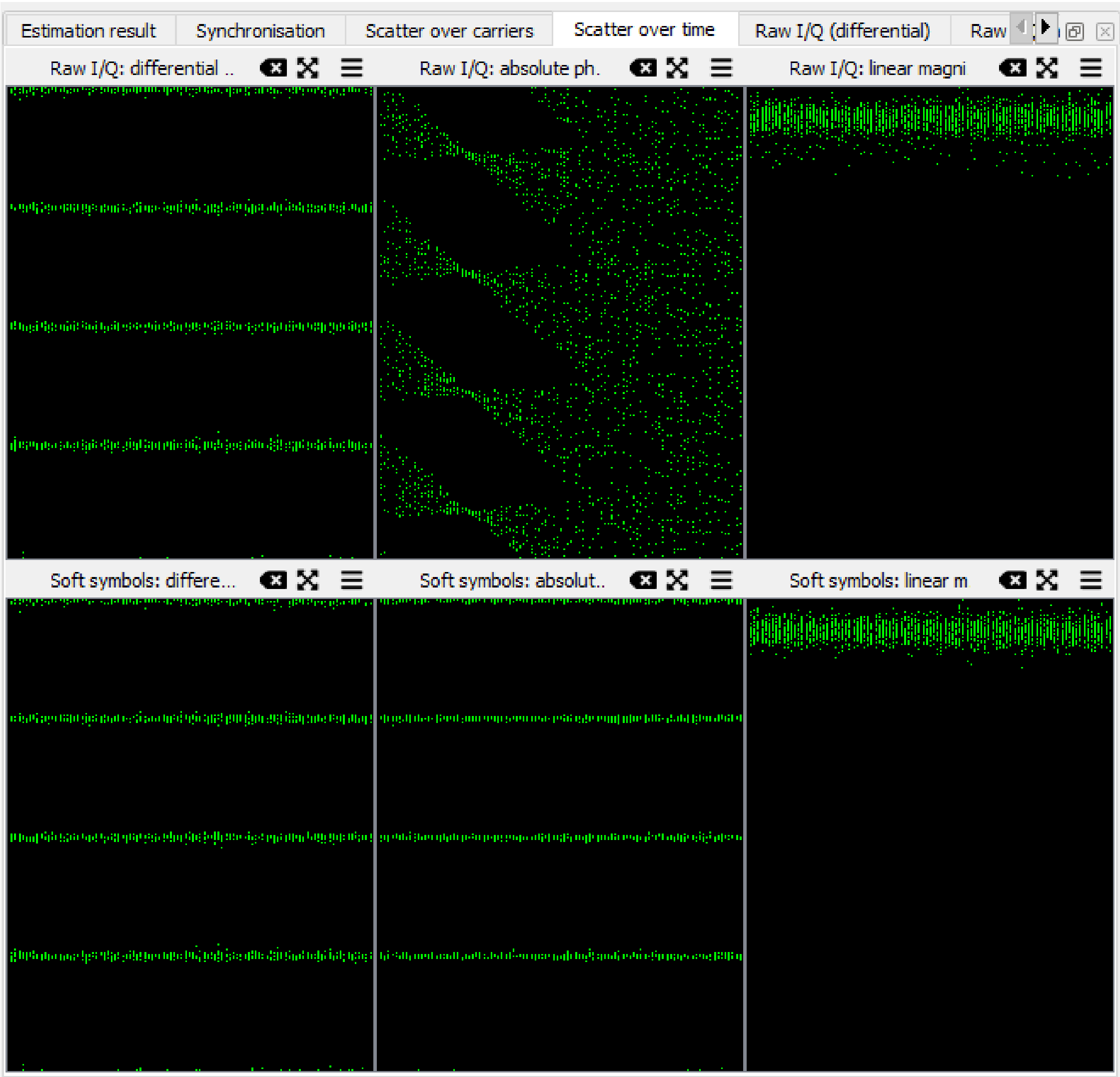


Figure 67: Example output of scatter diagrams over symbol number (i.e. time)

the middle in the absolute plots respectively a random cloud of points filling most of the rectangular box in the differential plots.

Scatter and I/Q diagrams of differential raw symbols are usually the best way to determine the signal quality and further analysis steps.

Absolute raw symbols are useful to

- manually correct the centre frequency f_0,
- diagnose issues introduced by a sample rate error or failing symbol clock recovery
- and to diagnose inaccurate T_u and T_s measurements.

Multicarrier I/Q displays can display a selected subset of symbols and carriers (as in the scatter diagrams). Initially, the displayed range of values (zoom of constellations plots) is determined automatically. It can be changed by pressing the <**Ctrl**> key and using the mouse wheel. To zoom the displayed area (overall zoom), use the mouse wheel without pressing any keyboard modifiers.

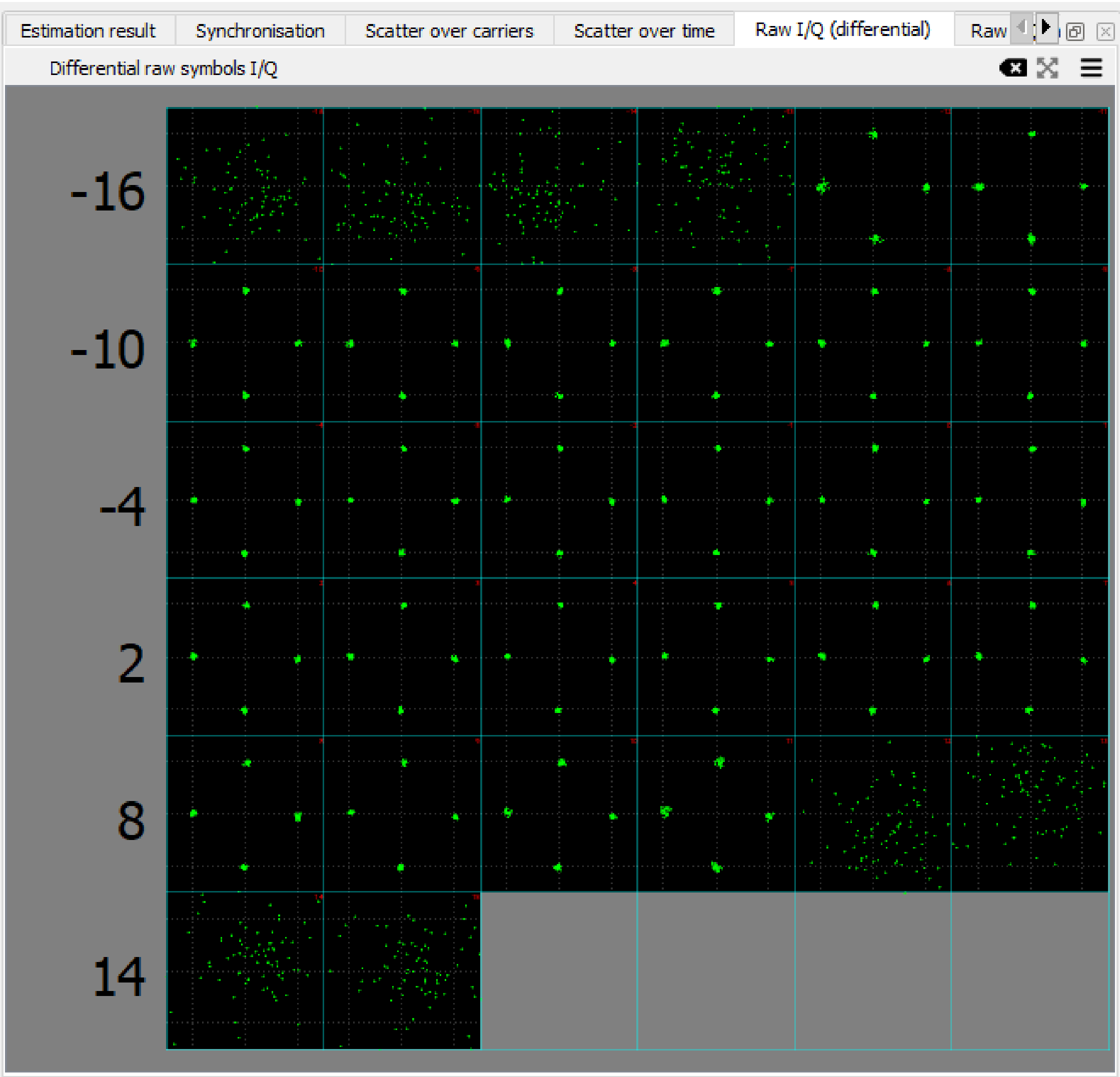


Figure 68: Example output of a multicarrier I/Q diagram of raw differential symbols

5.6.2.5. Bit Display

The bit display visualizes the data bits contained within the demodulated signal. This display is only populated with data if a constellation has been set in the analysis parameters. The symbol to bit mapping for

PSK modulations is the binary representation of the symbol number, counted in counterclockwise direction starting at the real axis.

Figure 69: Bit display

5.6.3. Manual parametrisation

Basic OFDM signal parameters – carrier distance, symbol rate and center frequency – are estimated automatically. These and further parameters can be modified, enabling a fully manually controlled demodulation. All demodulation parameters are described in the tables below.

In manual mode, the *Estimation result* tab displays the manually selected parameters used for demodulation (see Figure 70).

Table 16: Analysis parameter for OFDM demodulation (toolbar)

Parameters for manual demodulation	
Carrier distance	62.50000 Hz
Symbol rate	50.00000 Bd
Tu duration	16.000000 ms
Ts duration	20.000000 ms
Tg to Tu ratio	0.250
Modulated carriers	from -12 to 11 (24 in total)

Figure 70: Table displaying parameters used for demodulation

Parameter	Function
<**Carrier distance**>	Specifies symbol rate value default: automatically estimated value
<**Symbol rate**>	Specfies symbol rate value. default: automatically estimated value
<**Frequency for 0th carrier**>	Specifies frequency of the carrier number 0 default: automatically estimated value

Table 17: Analysis parameter for OFDM demodulation (side panel)

Parameter	Function
<**Disable automatic frequency control**>	Enables/disables use of automatic frequency control loop. default: off (automatic frequency control is enabled
<**Disable clock recovery**>	Enables/disables use of the clock recovery control loop. Uses *First symbol position* and parametrized symbol rate for determination of sampling positions. default: off (automatic clock recovery and its control loop enabled)
<**Disable automatic sampling rate correction**>	Enables/disables automatic measurement and correction of sampling rate. Uses specified *Sampling rate error* for correction. default: off (estimation and correction is enabled)
<**First symbol position**>	Specifies position of the first symbol, see <**Disable clock recovery**> default: automatically estimated value
<**Sampling rate error**>	Specifies sampling rate error, see <**Disable automatic sampling rate correction**> default: automatically estimated value
<**Leftmost modulated carrier**>	Allows manual specification of the carrier range (lower limit, inclusive) of modulated channels. default: automatically estimated value
<**Rightmost modulated carrier**>	Allows manual specification of the carrier range (upper limit, inclusive) of modulated channels. default: automatically estimated value
<**Multicarrier PSK correction**>	Enables phase adjustment required for correct demodulation of multicarrier PSK signals. The phase correction is equivalent to rotation introduced by sampling position offset of T_g. default: off
<**Decision directed PLL**>	Specifies PSK constellation to be used for decision directed control loops and symbol decision, including symbol to bit mapping. • OFF • PSK-2 • PSK-4 • PSK-8 • PSK-16 • QAM-4 • QAM-16 Plots with *soft symbols* and bit display are not available when *OFF*. default: OFF
<**Use differential decision**>	Enable/disable the use of differential decision for computation of *soft symbols* and symbol to bit mapping. With this option turned on *soft symbols* are the differential soft symbols. Bits are then mapped from those diff. soft symbols. default: off (differential decision is not used)

Table 18: Actions

Button	Function
Estimate (magic wand)	Triggers automatic estimation of signal parameters.
<**Export modem description**> (side panel)	Export a template of modem description as required by go2DECODE (*.ver file).
<**Export demodulator parameters (XML)**> (side panel)	Export demodulator description as required by go2DECODE. An alternative to <**Export modem description**>

5.6.4. Multicarrier PSK/QAM vs. OFDM

Multicarrier signals not created with the application of IDFT, or its mathematical equivalent, produce slightly different results than conventional OFDM. There are two aspects to consider:

- Pulse forming: Usage of IDFT implies $\mathrm{sinc}(x) := \frac{\sin(\pi x)}{\pi x}$ as filter curve for the modulated carriers. Any other method of signal generation will result in a different pulse forming and requires a filtering method different from DFT at the receiver.
- Phase rotation at sampling position: There is usually a phase offset in all carriers equivalent to the offset in symbol sampling position by T_g. The *Multicarrier PSK correction* checkbox enables the necessary phase adjustment.

5.6.5. Multicarrier plots

The *OFDM Analysis and Demodulation* provides some specialized plot types which have been introduced in *Scatter Diagrams*, *I/Q Diagrams* and *Bit Display*. The parameters of these plots and the navigation within them is described hereafter.

5.6.5.1. Multicarrier Scatter

A scatter plot, as the name suggests, displays data using points scattered on a two-dimensional plane. This allows visual assessment of the distribution of the data.

5.6.5.1.1. Parameters Settings

Table 19: Parameter settings of multicarrier scatter plot

Parameter	Function
<**Carriers**>	Specifies which carriers are to be displayed, defined by first carrier, last carrier (excluding) and step size
<**Symbols**>	Specifies which symbols are to be displayed, defined by first symbol, last symbol (excluding) and step size

5.6.5.2. Multicarrier IQ

The multicarrier IQ plot consists of multiple conventional I/Q diagrams, with each I/Q diagram displaying data from a single subcarrier.

5.6.5.2.1. Parameters Settings

Table 20: Parameter settings of multicarrier I/Q plot

Parameter	Function
<**Carriers**>	Specifies which carriers are to be displayed, defined by first carrier, last carrier (excluding) and step size
<**Symbols**>	Specifies which symbols are to be displayed, defined by first symbol, last symbol (excluding) and step size
<**Range**>	Specifies the displayed range in a single I/Q display. The value defines bounding box coordinates for the rectangle of a single I/Q plot.

5.6.5.2.2. Navigation

The multicarrier I/Q plot supports standard keyboard navigation within a document. Panning of the plot is possible by moving the mouse while the left mouse button is pressed. The zoom of the plot can be adapted with <**+**> and <**-**> keys or by using the <**Mouse Wheel**>.

Direct navigation to the I/Q subplot of a specific carrier is possible by typing the number and pressing <**Enter**>. Example: The sequence of keys: <**4**>, <**5**>, <**Enter**> centers the display at carrier 45, the sequence <**-**>, <**2**>, <**0**>, <**Enter**> centers the display at carrier -20.

Table 21: Keyboard/mouse navigation for multicarrier I/Q plot

Shortcut	Function
<**Arrows**>	Pan the display (plot must be zoomed in)
<**Home**>	Move to the left edge
<**End**>	Move to the right edge
<**Ctrl**> + <**Home**>	Move to the top edge
<**Ctrl**> + <**End**>	Move to the bottom edge
<**PageUp**>	Move one screen towards top edge
<**PageDown**>	Move one screen towards bottom edge
<**+**> or <**P**>	Zoom in the entire display
<**-**> or <**M**>	Zoom out the entire display
<**Ctrl**> + <**+**> or <**P**>	Zoom in range of each I/Q subplot
<**Ctrl**> + <**-**> or <**M**>	Zoom out range if each I/Q subplot
<**Mouse Wheel**>	Zoom in/out the entire display
<**Ctrl**> +<**Mouse Wheel**>	Zoom in/out range of each I/Q subplot
<**A**>	Autorange I/Q subplots
<**F**>	Fit entire display to screen
<**C**>	Copy as Picture to clipboard
<**F10**>	Show context menu
<**Menu**>	Show context menu

5.7. MFSK (multitone) Signal Analysis

5.7.1. Introduction / Motivation

This module provides a tool for manual analysis of emissions using frequency shift keying (FSK) with multiple tones (4 or more). Various metrics are calculated and displayed as plots, enabling the user to determine the parameters of the modulation. These are

- symbol rate R_s,
- the number of tones N (4 or more), and
- the tone distance f_d between the equidistant tones.

In contrast to the FSK analysis, more than 4 tones can be determined and measured.

5.7.2. Processing

The following list provides a sequence of steps, to exemplarily outline, how an analysis could be carried out.

1. Check/Verify the existence of a dominant peak in the *Differential F3 Spectrum* with the default *Symbol rate metric Instantaneous frequency*.
2. In case, there's no plausible dominant peak, switch the symbol rate metric to *DFT maxima* and iteratively adjust the frequency *resolution* of the discrete fourier transform (DFT) until a dominant peak gets visible in the *Differential F3 Spectrum*. Increasing the *DFT Overlap* will help, to get a higher maximum baudrate in the *Differential F3 Spectrum* plot.
3. Set the *Symbol rate* R_s manually to the assumed peak, in case the automatic estimation failed. Altering the *Symbol rate* will also prevent further automatic changes by estimations.
4. For the tone analysis, the *DFT Overlap* might be reduced to cover a longer time range, which is displayed in the *Spectrogram* plot, in case you get the warning "Signal selection too big".
5. Iteratively adjust the frequency *resolution*, until equidistant dominant peaks get visible in the *Distribution of frequency maxima* plot. With some luck, the *Tone distance* and the number of tones (*# Tones*) were estimated correctly - together with the frequencies of the outer tones.
6. Adjust/fix the outer tone frequencies - if necessary. This will update the *# Tones* plot, showing a metric of the possible number of tones.
7. Adjust/fix the number of tones - until markers match peaks in the *Distribution of frequency maxima* plot.

For emissions with non-equidistant tones or multiple tones at a time, the outlined analysis has limited applicability.

For emissions with a big bandwidth or high number of tones or simply a low *signal to noise ratio* (SNR), it will be necessary to set *Symbol rate metric* to *DFT maxima* and test with several frequency resolutions.

A fixed *symbol rate* is beneficial for the correct estimation of the *symbol rate*. Some multitone modems change the symbol rate. Thus, a selection should only contain one single symbolrate.

The signal processing can be further customized by tweaking the extended analysis parameters.

DFT Overlap
: Defines the percentage, how much time one *discrete fourier transform* (DFT) should overlap with it's predecessor. It can be interpreted as a sort of *oversampling*.

Frequency interpolation
: Defines the interpolation factor for the *discrete fourier transform* (DFT) calculation. Some interpolation shows finer frequency bins, which should allow distinguishing the tone frequencies.

Symbol rate metric
: Optionally switch the input of the *Differential F3 Spectrum*, used for estimating the symbol rate.

Auto Symbol rate
: Re-estimates the symbol rate, by setting the symbol rate to the maximum peak of the *Differential F3 Spectrum*.

Outer tone distance
: Shows the product of *Tone distance* and (*# Tones* - 1), without having to use a calculator. This is the distance between first and last tones' center frequency.

First tone
: The frequency of the first (or lowest) tone, which is also visible with the leftmost marker in the *Distribution of frequency maxima* plot.

5.7.3. Results

The analysis results are presented on four plots, which are discussed in the following sections. Figure Figure 71 shows an overview of the result display. The upper plot shows the *Spectrogram* of the selection signal. Underneath is the closely related *Distribution of frequency maxima*. Following is the *# Tones* and the *Differential F3 Spectrum* for *symbol rate* estimation.

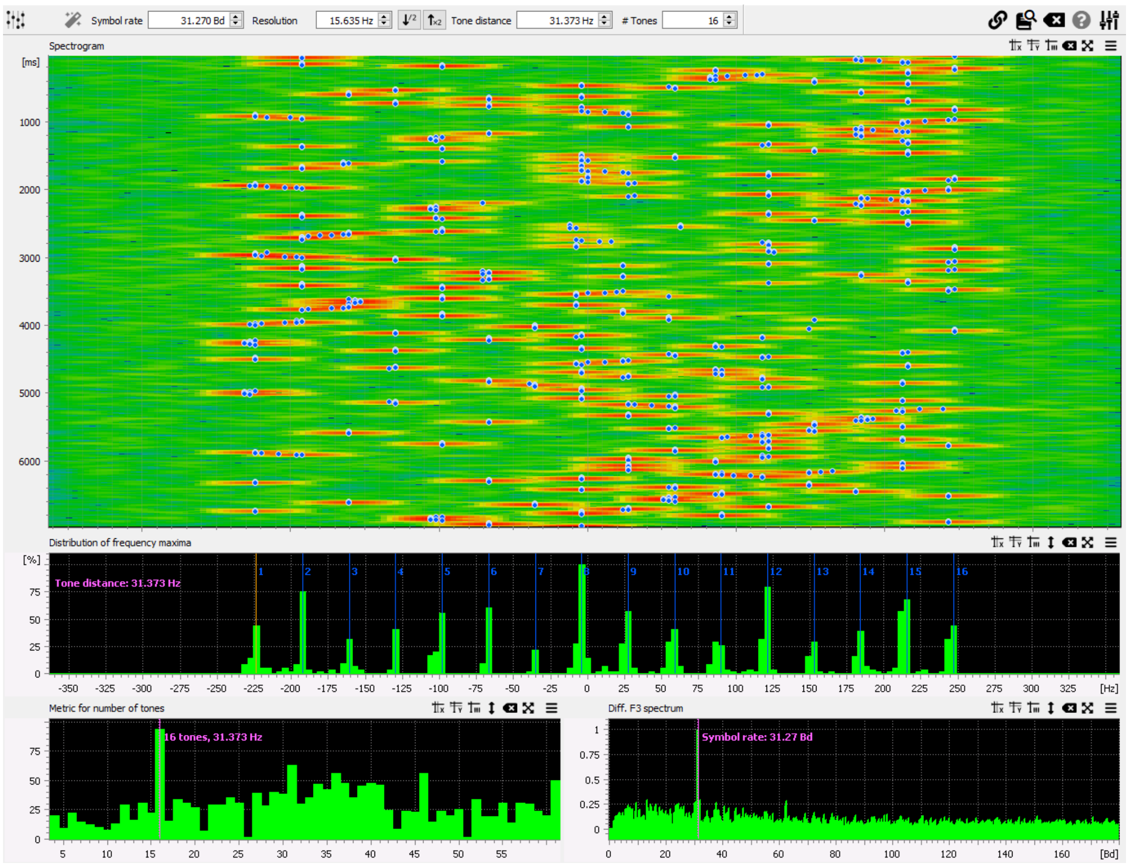


Figure 71: MFSK analysis result display overview (Contestia with 16 tones).

5.7.3.1. Spectrogram

The *spectrogram* is computed with multiple overlapping *discrete fourier transforms* (DFTs) over the selection. It is quite similar to the input sonagram - but the frequency resolution can be adjusted in finer steps. In addition, the resolution is parametrized - not the *fast fourier transform* (FFT) length. One more difference: the overlap is parametrized in percent - not in terms of *lines per second*.

Markers visualize the maximum frequency positions per DFT.

An example of *spectrogram* is shown in Figure 72.

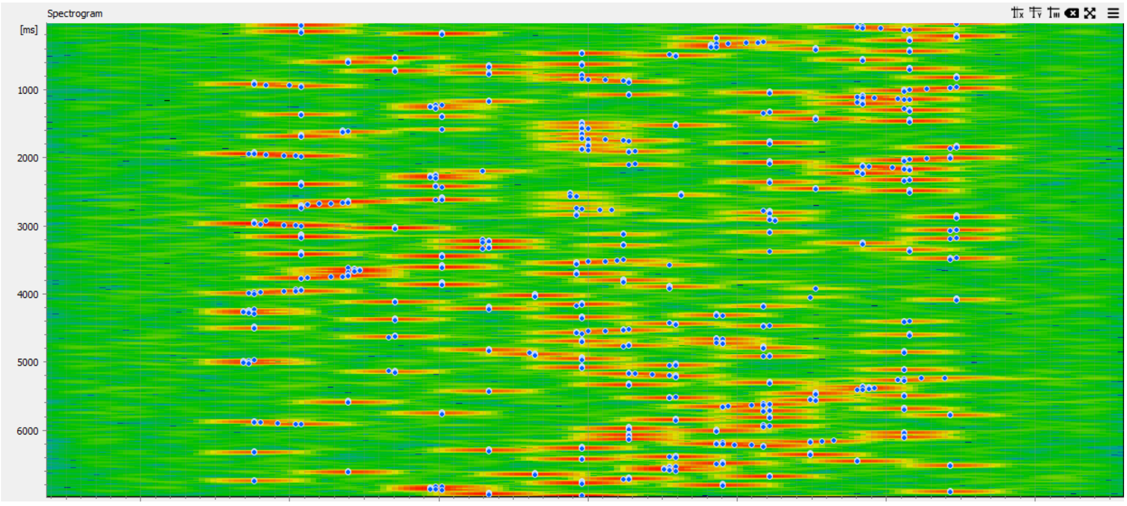


Figure 72: Spectrogram

5.7.3.2. Distribution of frequency maxima

This plot shows a histogram built from the maximum frequency positions of the DFTs, which are visualized in the *Spectrogram* .

Purpose of this plot is visualize the distribution of the symbol values. The dominant peaks may differ from the ones in an *averaged spectrum*.

Markers visualize the initially estimated or (later) user modified frequency tones. The estimated values may be modified with the *Tone distance*, *# Tones* or *First tone* controls in the toolbar - or simply by dragging the markers with the mouse.

Figure 73 shows an example of this plot.

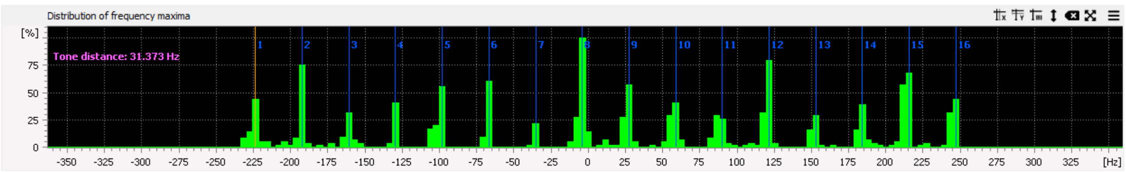


Figure 73: Distribution of frequency maxima - after doubling the DFT length once

5.7.3.3. # Tones

This plot shows a metric for the possible number of tones (horizontal axis). The metric depends on the frequencies of the outer (leftmost and rightmost) tones and the *Distribution of frequency maxima*.

Purpose of this plot is to see good candidates for the *# Tones*.

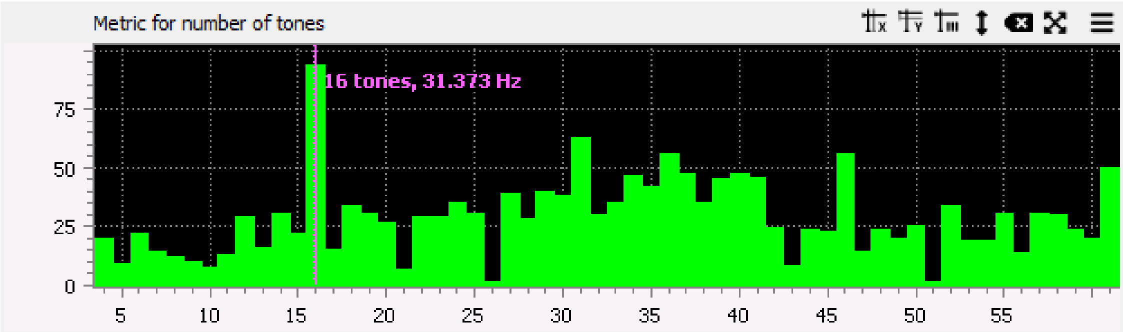


Figure 74: Metric for Number of Tones

5.7.3.4. Differential F3 Spectrum

For this plot the differential of the instantaneous frequency computed and weighted with the instantaneous power - when using the *Instantaneous frequency* metric. Having set the *DFT maxima* metric, the differential of the frequency maxima positions (of the calculated DFTs) is computed. For later one, the *DFT overlap* limits the time resolution.

The spectrum of the resulting signal is displayed. It is similar to the so called *A3 Spectrum*: it also exhibits a distinct peak at a value equal to the *symbol rate* R_s.

The frequency range depends on the selection bandwidth and *DFT Overlap*, which should be much larger than the expected *symbol rate*. With the *DFT maxima* metric, the frequency resolution also has a significant impact, that multiple resolutions should get tested. Usually, a good peak is observable, when the frequency resolution is smaller than the expected symbol rate. Note, that the values in a small range from $0\,\mathrm{Hz}$ are suppressed, since this region contains misleading data.

Figure 75 shows an example of this plot. A dominant peak can be observed at $31.25\,\mathrm{Bd}$, which can be measured, using zoom and cursor or marker functionality. This suggests a modulated emission with a *symbol rate* R_s of $31.25\,\mathrm{Bd}$.

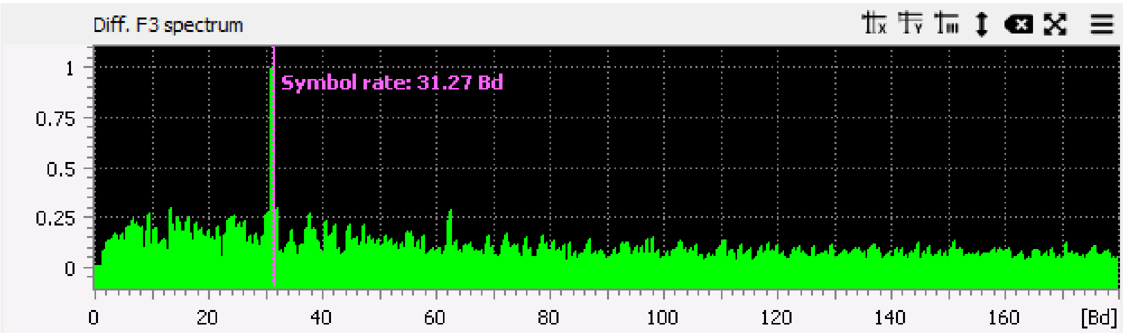


Figure 75: Diff. F3 spectrum for *symbol rate* estimation.

5.7.4. Example project

To further study the *MFSK Analysis* and its functionality, see the example project file "multitone-example.san" with the corresponding signal file. Figure 71 shows the corresponding results: 16 tones, 31.25 Bd and 31.25 Hz tone distance in a bandwidth of nearly 500 Hz.

5.8. Demodulation

5.8.1. Introduction / Motivation

This module provides demodulation functionality for several modulation types. Purpose of this module is to visualize demodulation quality to enable the user to verify and tune demodulation parameters.

Graphical eye pattern diagram and I/Q-plot provide a very good perception of the demodulation quality. The demodulator output is provided in a bit/symbol display to allow cursory examination of the data. In-depth bit analysis and decoding can performed in other Procitec products after exporting this data from here.

There are some very sophisticated parameters available for the Automatic-Production-Channel (APC) in the modem editor - but unused in Signal Analyzer.

5.8.2. Demodulation parameters

The signal selection configures first important parameters, with the selection's offset, duration, bandwidth and especially the center frequency.

All demodulator parameters are part of a modem description from the Automatic-Production-Channel (APC). Amongst these are:

- demodulation family
- modulation order
- symbol rate

These are shown in the toolbar of an analysis. More/additional parameters follow in the sidebar:

- channel count
- channel distance

but also some demodulator specific parameters:

- PSK version: A or B (=pi/2 or pi/4)
- FSK shift

All of these and the advanced parameters are available in a separate dialog, the modem editor (see below). These include:

- burst and filter settings
- symbol table
- differential decider (or coherent) for PSK
- tolerance ranges for symbol rate and shift

5.8.3. Modem editor

This dialog shows all parameters that effect the demodulation processing of this module. Parameters are grouped into sections on the left, which can also be used for navigation.

The fundamental parameter modem family can be found on the upper left-hand side. Its value affects the availability of other parameters.

In general, a modem description has many additional parameters that effect processing in the APC. The checkbox on the lower left-hand side can be used to also show and edit these parameters. For a list of all available parameters and their meaning see the separate document `PROCITEC-DSC-ModemParameters_E.pdf` in the `doc` folder the installation.

Parameters can also be imported from and exported to modem description files. This way the demodulation process of existing modems can be examined for specific signals. Note, exporting a newly created modem description from here requires further configuration in e.g. the Modem Lab application. Only there, can the other steps of APC processing be evaluated.

5.8.4. Processing

The following list provides a sequence of steps, to exemplarily outline, how a demodulation could be carried out.

1. Parametrize the demodulator:
   a) manual with analysis results of other modules, e.g. PSK
   b) with parameters from a modem of the *Signal Information Database* (use "apply to Demodulation"-option)
   c) import (a subset of) parameters from a modem description file
2. Regard the demodulation quality
3. Depending on expected or desired quality results, further tuning of parameters might be necessary. Don't forget the selection parameters.
4. Finally export a modem description or the produced symbols (bits).

5.8.5. Results

For a well parametrized FSK-2 signal, Figure 76 , shows an exemplary demodulation output overview.

Some of the following output plots can show specific or combined channel data selectable via combobox 'Plot channel(s)'

5.8.5.1. Output Table

On successful demodulation (see Figure 76), a brief tabular summary of demodulation results are shown containing at least the average of:

- *Detection quality*
- *Symbol quality*
- *Symbol rate*
- *Clock quality*
- *Frequency offset*

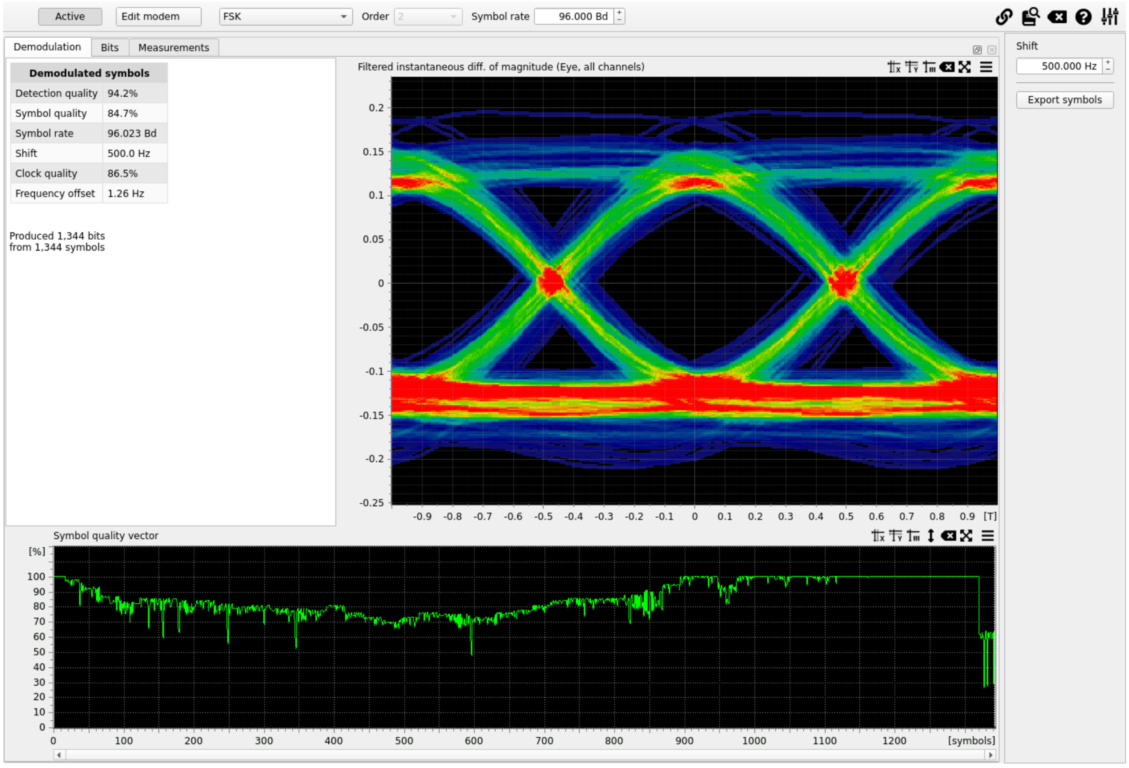


Figure 76: Demodulation output overview (FSK-2).

The *Detection quality* summarizes all measured values, including symbol quality, clock, rate, shift, burst, .. Below that table additional information are shown. If the demodulation is processed improperly, one may find warnings and additional user instructions in the table´s space.

5.8.5.2. Symbol quality vector

The symbol qualities in percent are shown over the demodulated symbols. See bottom of Figure 76. Symbols from same time but different carriers/channels are shown interleaved on the symbol-axis.

In case of burst, the pauses between two bursts are not visible, but the burst starts are visualized with markers.

Additional movable markers define, which symbols (time) are shown in the eye pattern or I/Q-diagram. By default, all symbols are plotted.

5.8.5.3. Eye pattern or I/Q-diagram

Depending on the choosen demodulation type an eye pattern or I/Q diagram shows the decision quality in a visually appealing way. This plot is shown at top-right of Figure 76.

The eye-pattern diagram shows the decision signal over time - overlayed per symbol (tick). Unfortunately, this plot gets hard to read for higher modulation orders. In addition, it´s not possible to show multiple decision dimensions like phase and amplitude for PSK/QAM modulations.

In contrast, the I/Q-plot can show the two dimensions (I and Q) per decision/symbol - but it can´t show the trace at non-decision times. See and compare figures Figure 77 and Figure 78

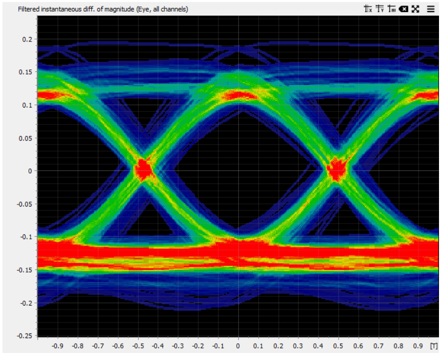


Figure 77: Eye pattern diagram for FSK-2

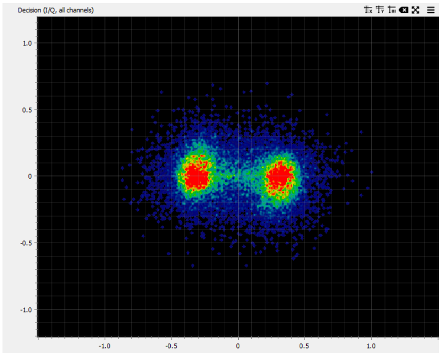


Figure 78: I/Q plot for 12-channel DPSK-2A

5.8.5.4. Bit display

Produced symbols and bits are shown in this display. The produced symbols can be exported for further analysis.

5.8.5.5. Measurement plots

Demodulation is processed in blocks of samples. This defines the granularity of several measurements:

- symbol rate and it's quality
- shift (for FSK)
- frequency offset

These measurements are plotted over the symbol axis, see figure Figure 79

5.8.6. Example projects

To further study the *Demodulation* module and its functionality, see the example project files "demodulation-fsk-2.san" and "demodulation-12-psk-2.san".

First one contains a single channel FSK-2 at 96 Bd and 500 Hz Shift. Second one contains a 12 channel PSK-2 at 120 Bd and a channel distance of 200 Hz.

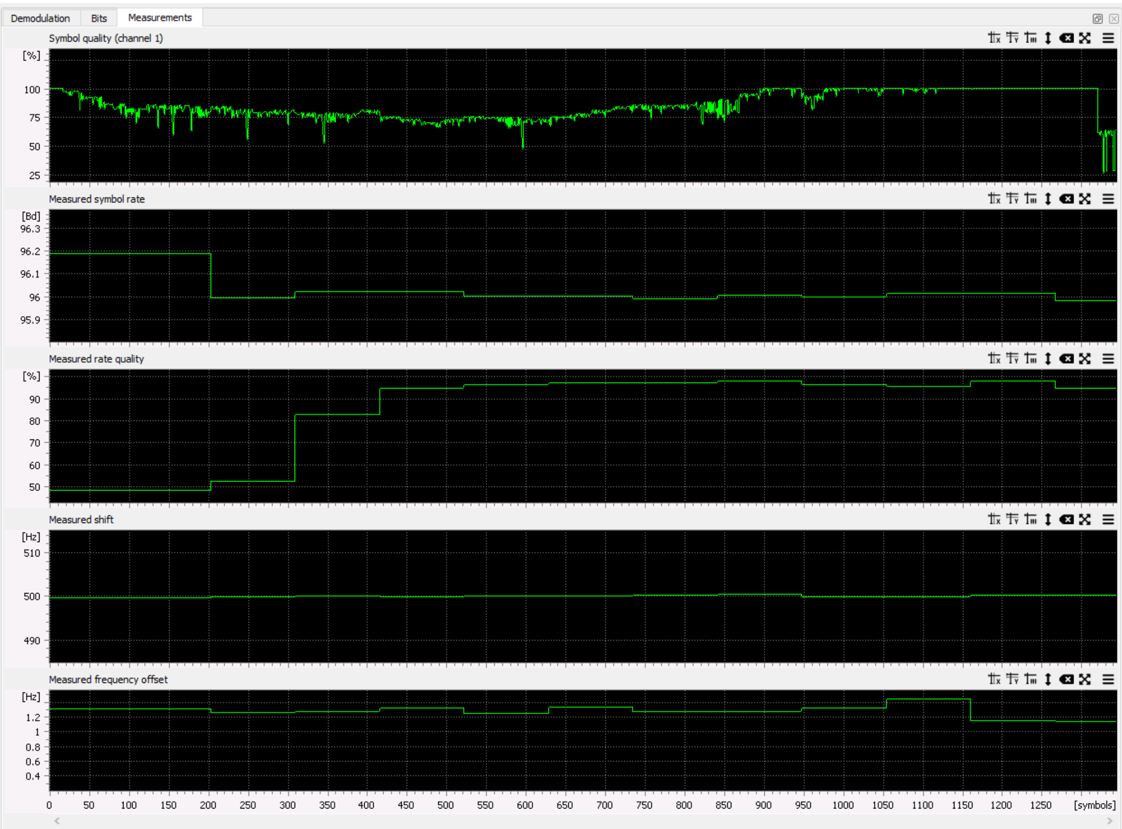


Figure 79: Measured result traces over time (for FSK-2)

6. Pre-processing Modules

These modules allow pre-processing of the signal selection, usually to remove some form of outer modulation. In contrast to other Analysis Modules the main result is another signal which can be opened in a new application instance for further analysis.

6.1. Crop

This module can be used to "crop" the selected time-frequency region from the input file. This operation involves filtering and down-sampling. Is is also know as *Digital Down Conversion* (*DDC*).

The spectrum of the cropped signal can be optionally mirrored. The center of the selection is used as the mirror axis. This can be used to turn a *lower sideband (LSB)* signal into an *upper sideband (USB)* one (and vice versa).

For further analysis, the "Open Signal" button in the analysis toolbar may be used to open a new instance of the application with this signal preloaded. The cropped signal can also be export using the "Export" action in the Burger Menu of the sonagram plot.

6.2. Frequency Demodulation

This module performs a frequency demodulation of the down-converted (see module *Crop*) signal selection. An additional *DC Filter* can be adjusted or switched off. The resulting signal is displayed in a sonagram/spectrum plot.

In case of a bursted input signal, the output can be squelched (silenced) at sections with low strength. The *Squelch* parameter allows to select two squelch variants.

The plot "Input band level" show the resulting squelch metric. With activated squelch an additional *Threshold* parameter can be configured - or adjusted dragging the marker in the plot "Input band level". With the extended analysis parameter "LP cutoff", the visualized squelch metric's smoothing can be controlled.

For further analysis, the "Open Signal" button in the analysis toolbar may be used to open a new instance of the application with this signal preloaded. The demodulated signal can also be export using the "Export" action in the Burger Menu of the sonagram plot.

6.3. Amplitude Demodulation

This module takes the amplitude of the down-converted (see module *Crop*) signal selection. An additional *DC Filter* can be adjusted or switched off. The resulting signal is displayed in a sonagram/spectrum plot.

For further analysis, the "Open Signal" button in the analysis toolbar may be used to open a new instance of the application with this signal preloaded. The demodulated signal can also be export using the "Export" action in the Burger Menu of the sonagram plot.

6.4. Linear Chirp Demodulation

This module performs a linear chirp demodulation of the signal selection - a down-mixing process. Afterwards, the dechirped signal is down-converted (see module *Crop*).

The resulting dechirped signal is displayed in a sonagram plot.

6.4.1. Parameters

The following parameters can be configured:

- **Mode**: Linear Up or Down
- **Duration** defines the period, which the chirp takes from the start frequency to reach the stop frequency
- **Offset** defines the next or nearest start of the chirp. Alternative: modifying selection's start time. This parameter is for syncing the chirp to the signal.

The selection's center and bandwidth implicitly defines the chirps' start and stop frequency. Center and bandwidth need to be parametrized precisely.

Following additional parameters can be configured:

- **Metric defines, what to display in the additional time plot, below the sonagram.**
  Magnitude, *Frequency*, *Phase* and several scaled phases are available. Scaled phase metrics result from multiplying the signal phase by a factor which is equivalent to exponentiation.
- **Output Bandwidth** in percent for an additional low-pass filter on the dechirped output

6.4.2. Time plot

A time plot of the dechirped signal is plotted below the sonagram. This plot and the *metric* parameter should help for proper parametrization - before opening or exporting the dechirped result.

6.4.3. Processing

These steps exemplarily outline how an analysis could be carried out:

1. Set the appropriate selection with center, bandwidth and time - as precise as possible
2. Find the chirp duration, e.g. zooming in the input-sonagram an utilizing harmonic time cursors. The analysis modules Time, Autocorrelation and Periodicity can also be useful here.
3. The mode (up or down) by examining the sonagram plot of a single chirp.
4. Iteratively adjust/improve the selection's *frequency center* and *bandwidth*. These parameters need to be set very precisely.
5. The selection's start or the *offset* parameter can be set, to sync the chirp carrier frequency. With correct settings - in case of a narrow PSK signal, the narrow PSK should occur frequency centered around 0 Hz.

For further analysis, the "Open Signal" button in the analysis toolbar may be used to open a new instance of the application with this signal preloaded. The demodulated signal can also be export using the "Export" action in the Burger Menu of the sonagram plot.

7. Signal Information Database

The *Signal Analyzer* offers an integrated signal information database (SigInfoDB). This is a knowledge base which contains signal information for a large number of known signals and their signal information descriptions. In connection with the *Signal Analyzer* and its analysis capabilities, this provides the ability to automatically compare the analysis results of an unknown signal recording with the signal information descriptions within the database. This database search enables a fast matching of signal recordings to known signal information.

Signal information typically refer to modems, which are used to generate this signals. Therefore, the term *modem* will be used in the following to denote a group of signal parameters and must not be confused with the modem as a device or a demodulator. The signal information, i.e. modem, contains various parameters like modulation, symbolrate, modem name, but also background information like typical users of this type of modem, see Section 7.1 for a full description.

Besides the pre-installed database, the *SigInfoDB* provides the ability to extend the database by user-defined modems. This can be useful for newly discovered signals which don't match to any modem in the database or also if a signal of a known modem is found, of which one or more parameters might deviate from the existing database entries. The *SigInfoDB* further allows to add comments for all modems.

All this is provided by a separate window, the SigInfoDB-*Viewer*, which can be used to browse, edit and add new modems to the database.

The next Section 7.1 provides the aforementioned description of all signal parameters, which occur in the database and specifies their meaning. After that, the user interface of the SigInfoDB-*Viewer* is outlined in Section 7.2.

The last two sections explain the main two workflows on how to use the *SigInfoDB* together with the *Signal Analyzer Modules*. This is first, how to search modems from analysis results (Section 7.3) and second, how to apply values from a specific modem in the database to an open analysis (Section 7.4).

7.1. Signal Parameters

The following table lists all *SigInfoDB* Parameters, together with a detailed description of their meaning. Note, that some parameters are not used or have a different meaning, depending on the modulation value.

Parameter	Description
Modem	Modem name For alternative names, the parameter *Alias* is used.
Band	Typically used radio band, like *HF*, *VHF*, *UHF*, etc.
Mode	Typically used transmission mode, like *USB*, *LSB*, *AM*, etc.
Modulation	Modulation type, like *PSK*, *FSK*, *MC-PSK*, *MFSK*, *OFDM*, etc. Note, the specific pattern for some modulation types, which contains more information on the specific modulation, like e.g. modulation order. This conventions should always be followed to allow a flawless search of modems via the filters, see Section 7.2.1 for details.

Parameter	Description
Channels	Relevant for Multitone, MC and OFDM modulations. Number of tones or carriers.
Constellation	Specifies constellations used on subcarriers for modulations with multiple carriers like *MC* or *OFDM*.
Symbolrate	The symbol rate also known as Baud rate.
Distance	Relevant for FSK, Multitone, MC and OFDM modulations. Always the distance between two adjacent frequencies, tones or carriers.
Bandwidth	The bandwidth refers usually to the visually perceptible width of a signal in a sonagram display.
ACF-Peaks	Period of repetitive components in signals of this modem. Appears as peak in an autocorrelation of such signals. The value usually refers to either the first major peak or the strongest peak in the autocorrelation. Sometimes also referred to as "Periodicity".
User	Typical users of this modem.
Alias	Alternative names for this modem, see also the parameter *Modem*.
Notes	Arbitrary notes on this modem like further information, which might help identifying signals for this specific modem using the *Signal Analyzer*.

Table 22: Signal information parameters description

7.2. User Interface

The SigInfoDB-*Viewer* can be opened using the button in the *Signal Analyzer* toolbar. The table in the center displays the database entries and offers some filter functionality, described below. A toolbar above the table provides the main control elements. Optionally, at the right of the table, a sidebar can be displayed, which contains the *Detail-View*.

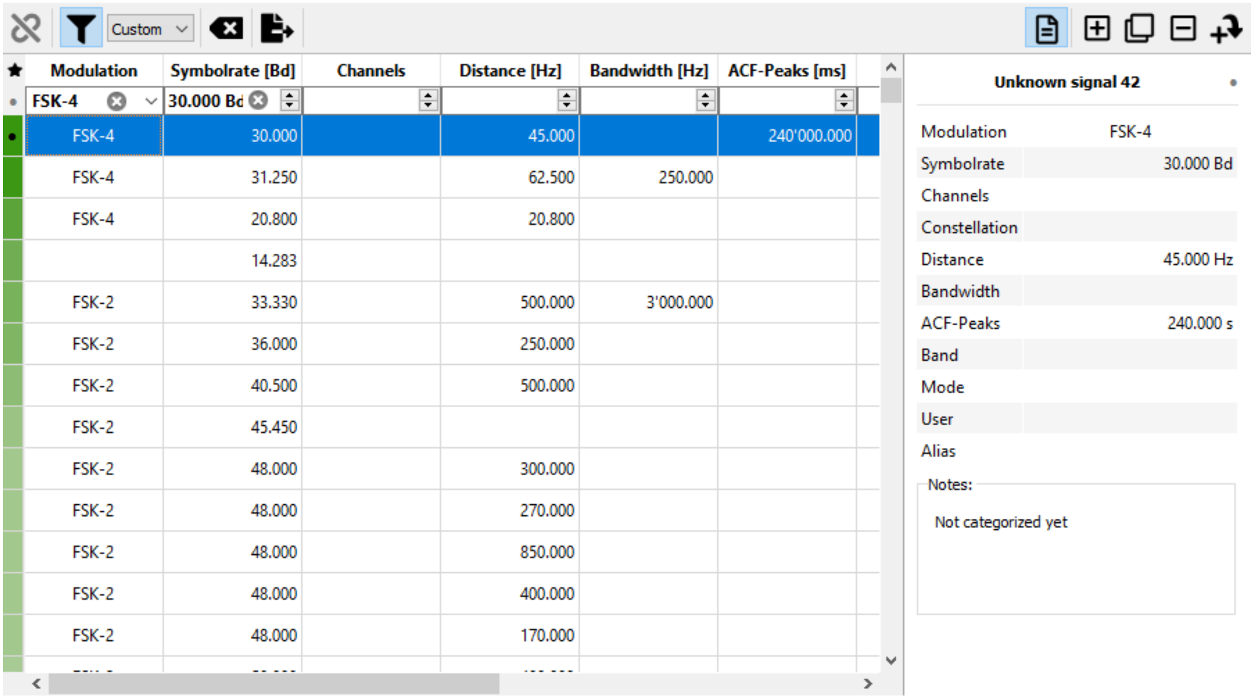


Figure 80: SigInfoDB-*Viewer* with visible *Detail-View*

7.2.1. Table

The table contains all database entries as rows, each entry corresponds to a modem with specific signal information.

The table is for displaying information only, for editing, use the *Detail-View*, see also Section 7.2.3.

Note, that cells might contain multiline content, or simply very long text, which isn't displayed completely. In this case, one have to use the *Detail-View*, to see the full content.

Right clicking at a tables row opens a context menu which offers functionality introduced later in Section 7.4.

Header

At the top, the table header describes the columns. A detailed description of the columns has been given in Section 7.1.

The header further allows to resize the column widths by click'n'drag at a line between two columns. You can also sort the table by a column by clicking on a column in the header. A little arrow symbol above a headers column title depicts the currently sorted column as well as the sorting order, ascending (^) or descending (v).

The leftmost column displays the so called *score*, which is explained in the following Paragraph. Sorting according to the score is indicated with a star symbol ★. Only descending sorting is possible.

By right click on the header, a context menu enables the hiding of specific columns.

Scoring and Filters

Right below the header, a row of control elements, called *filters*, allow to search modems in the table. This means, one can search for database entries, which match best to a given set of parameters. This is called *scoring*.

Scoring allows to quickly find known modems. If, for example, analyzing an unknown signal results in modulation value "FSK-4" and a symbolrate of 30 Bd, simply type these values into the corresponding filters and the table will automatically show the best matches at the top. See Figure 80, where those values are used as filters.

The deviation of the entries' values to the filter values is determined for each database entry, this is called the *score*. The score is visually displayed by the color of the leftmost column. The darker the green is, the higher is the score, which means the better matches this entry to the filter values.

The leftmost element ● in the filter row allows to select which kind of database entries are displayed: pre-installed, user-defined or both. Simply click on the circle icon ● to switch to the next selection or use the context menu via a right click on the icon to set directly the desired value.

Some columns contain only textual information, like for example the *Modem* column. The score depends on a text based matching between the filter value and a database entries' value. A special case are the filters for the *Modem* and *Alias* column. Searching in one of those columns includes also the other column.

Other columns like *Modulation* also contain textual information, but usually have a certain pattern. Therefore those filter elements offer a drop down menu with some predefined standard values. For searching, choose either one of those or simply type in some arbitrary value. The scoring for those kind of parameters can go beyond a simple text based matching. For example, a *Modulation* filter value "PSK-4" matches much better to a database entry value "PSK-2" than to "OFDM". This is, because the base modulation matches for the first case. Therefore, for the *Modulation* filter, those base modulations like "PSK", "FSK", etc. are listed separately at the beginning of the drop down menu.

The last type are columns with numerical values like *Channels* or *Symbolrate*. Here, the closer the filter value is to the value of the database entry, the better the score.

Most of the filters offer a clear button ⊗. It appears if a filter is set with some value and allows to clear this specific filter by clicking on it. Simply removing all characters or digits from the filter field also clears it. To clear all filters at once, click on the clear button in the toolbar ⌫. Note, that closing the SigInfoDB-*Viewer* also clears all filters.

7.2.2. Toolbar

The leftmost button indicates the current pairing state and allows to unpair all analyses. This is explained in Section 7.3.

The preset button and combo box [All] provides the ability to hide a set of columns, which might be irrelevant in certain situations. When working only with signals of a specific modulation type, for example *PSK*, one can use the given *PSK* preset, to hide all columns which are usually irrelevant for this modulation. Changing the preset in the combo box will only show the relevant columns, keeping the table compact. Further, the preset button becomes activated, indicating, that currently a preset is set. To make all columns visible again, either switch the combo box to *All* or deactivate the preset button. Note, that the last set preset is saved. This means, that if no preset is set, clicking on the preset button reactivates the last set preset. Hiding or displaying of single columns via the context menu of the tables header sets the combo box to the *Custom* preset.

Likewise to the last set preset, the visible columns associated with the *Custom* preset are saved, meaning that you can always restore your previously set preferred configuration of visible columns, by switching the combo box to *Custom*.

The clear button ⌫ removes all filters values as described before in the paragraph **Scoring and Filters**.

To export database content use the export button. Note, only entries matching the current filter and only visible columns are exported. Supported file-formats are XSLX and CSV.

On the right side of the toolbar, one can show or hide the *Detail-View* using the corresponding button. For further information on the *Detail-View*, see Section 7.2.3.

To create a new, duplicate an existing or delete an existing database entry, use the create, duplicate or delete button, respectively. Note, that deleting is only possible for user-defined entries, not for pre-installed ones. Furthermore, using the create from filter button a new entry populated with the current filter is created.

7.2.3. *Detail-View*

The *Detail-View* allows to see all parameters and their values of a modem, independent of any set preset or visible columns. Further it can be used to edit the modem and thereby modify the database content, if editable. It always displays the content of the currently selected modem in the table.

At the top, the *Modem* name is displayed. Right of it appears a circle ●, like at the filter for user-defined modems, if the currently displayed content belongs to a user-defined modem and is therefore editable.

Below the *Modem* name is a table like list with the main signal information parameters. If the currently displayed modem is editable, simply double click into the right column of this table at a certain row, to edit this value. An appropriate control widget appears, letting you type in a new or modify an existing value.

For pre-installed modems, which cannot be edited, there might be displayed some additional generic notes below the table of values.

At the bottom of the *Detail-View*, a field *Notes*, provides space for arbitrary notes of the user. This is irrespective of whether or not the current visible modem is a user-defined or a pre-installed database entry.

7.3. Search Modem from Analysis

The integration of the *SigInfoDB* into the *Signal Analyzer* allows to easily use analysis results and search modems in the database matching those analysed results. Most of the analysis modules support this feature, which is indicated by appearance of the search button in the analysis toolbar.

By clicking on the search button, all applicable analysis results are automatically inserted in the filters of the SigInfoDB-*Viewer*, which is also displayed. Further, the preset might be changed, to display only columns relevant for the current type of analysis. Be aware, that this action clears all previously set values of the filters.

A right click on the search button opens a popup dialog offering additional functionalities. This dialog is examplarily shown in Figure 81 for the case of the PSK analysis module.

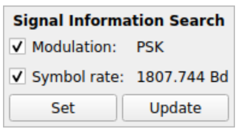


Figure 81: Search dialog opened from the PSK analysis module

It lists all the parameters and corresponding values which are used for the filters, when triggering the search as described before. Further it allows to prevent single parameters to be used in the search by unchecking the corresponding check box, before triggering the search. By the two buttons *Set* and *Update* at the bottom, one can trigger the search with only the selected parameters. The *Set* button triggers a search like outlined above, which means, it clears all previously set values in the filters. Contrarily, the

Update button triggers the search, but without clearing the filters previously. On *Update*, only the clashing parameters are overwritten, all other parameters are left as they were before.

Pairing

After a search, the filters which are set with an analysis parameter become *paired*. This means that if the corresponding analysis parameter changes, the values at the filters update accordingly.

Which filters are *paired* can be noticed by the colored filter elements, as can be seen in Figure 82. Here, the *SigInfoDB* is paired with two different analysis modules. The filters *Modulation* and *Symbolrate* are paired to one analysis, whereas the *ACF-Peaks* filter is paired to another analysis. This indicates the different color, each paired analysis is referred to with a different color. Further, tooltips on each paired filter state the name of the paired analysis. Also note, that if a paired filter value is modified manually the pairing of this parameter is removed.

Figure 82: Filters with paired parameters from two different *Signal Analyzer Modules*

If any filter is paired, the *pairing* button becomes is activated. This provides the ability to unpair all currently paired filters, by deactivating the button. Doing so will keep the current values in the filters. Be aware, that closing the SigInfoDB-*Viewer* will also unpair all filters.

7.4. Apply *SigInfoDB* Modem to Analysis

If a signal is difficult to analyze using the *Signal Analyzer Modules* or if one has an assumption for the signals modem, the *SigInfoDB* allows to crosscheck this assumption.

To do so, it is necessary to have a suitable analysis open for the signal in question. By right clicking onto the assumed modem in the table, a list of all currently open and supported analyses appear, as displayed in Figure 83. Click on the one corresponding to the signal in question. This will apply all applicable values from the modem to this analysis.

Note, there are some limitations on which and how parameters get applied to *Signal Analyzer Modules*. E.g. the applicability of parameters like *Symbolrate*, *Shift*, *Channels* and *Distance* is constrained by the bandwidth of the selection. Furthermore, not all *Signal Analyzer Modules* support all available fields listed in Section 7.1. Check each value to make sure it is applied as excepted!

You can then assess, if the signal information values from the chosen modem match to the signal in question.

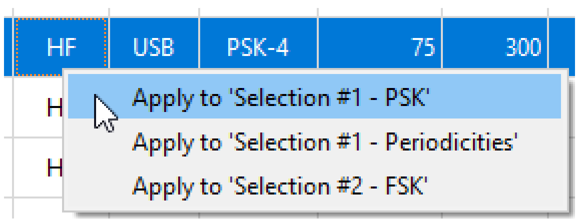


Figure 83: Context menu of the SigInfoDB-*Viewer* with multiple analyses, to apply the selected modem parameters

A. Glossary

ASK
Amplitude-Shift Keying

CP-OFDM
Cyclic Prefix Orthogonal Frequency Division Multiplex

DDC
Digital Down Converter: is equivalent to mixing a given frequency to base band (0 Hz) and applying a low pass filter and optional downsampling (i.e. reduction of the sampling rate)

DFT
Discrete Fourier Transform

FFT
Fast Fourier Transform, special case of DFT

FSK
Frequency Shift Keying

I/Q
In-phase/Quadrature, values or signals that can be placed on a complex plane with real and imaginary component values as coordinates, complex numbers

ICI
Inter-carrier Interference, additive distortion of the signal caused by signal leaking from neighbouring carriers

ISI
Inter-symbol Interference, additive distortion of the signal caused by signal leaking from neighbouring symbols

IDFT
Inverse Discrete Fourier Transform

IFFT
Inverse Fast Fourier Transform, special algorighm for IDFT

LSB-0
Least Significant Bit first, ordering of bits in a symbol number representation

MSB-0
Most Significant Bit first, ordering of bits in a symbol number representation

OFDM
Orthogonal Frequency Division Multiplex

PSK
Phase Shift Keying

ppm
parts per million (10^-6)

QAM
Quadrature Amplitude Modulation

SNR
Signal to Noise ratio, usually expressed in decibel (dB)

symbol rate

signaling rate, number of symbols transmitted per second, $R_s = \frac{1}{T_s}[Bd]$, where T_s is symbol duration in seconds

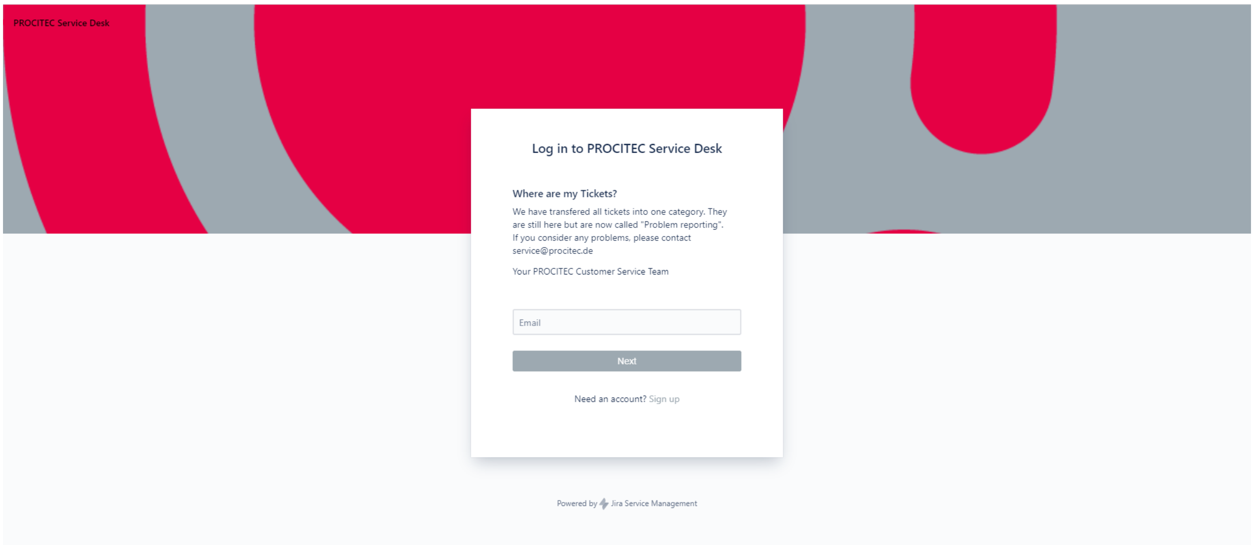
B. Support

Requests and suggestions?

All requests or suggestions regarding our go2signals product-range are very much appreciated; we would be delighted to hear from you.

Any questions? We are happy to assist you!

If you have any further questions, please do not hesitate to contact our Support Team for rapid assistance – just raise a service request at: **http://servicedesk.procitec.com**.



PROCITEC GmbH
Rastatter Straße 41
D-75179 Pforzheim
Phone: +49 7231 15561 0
Web: www.procitec.com
Email: service@procitec.com