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# **pyfda Documentation**

***Release v0.9.0b2***

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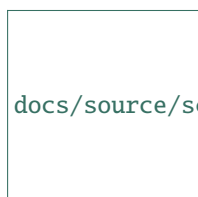
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## 1.1 Python Filter Design Analysis Tool

**pyfda** is a tool written in Python / Qt for analyzing and designing discrete time filters with a user-friendly GUI. Fixpoint filter implementations (for some filter types) can be simulated and tested for overflow and quantization behaviour in the time and frequency domain.



`docs/source/screenshots/pyfda_screenshot.png`

## 1.2 License

pyfda source code is distributed under a permissive MIT license, binaries / bundles come with a GPLv3 license due to bundled components with stricter licenses.

## 1.3 Installing, running and uninstalling pyfda

For details, see `INSTALLATION.md`.

### 1.3.1 Binaries

Binaries can be downloaded under [Releases](#) for versioned releases and for a latest release, automatically created for each push to the main branch.

Self-extracting archives for **64 bit Windows**, **OS X** and **Ubuntu Linux** are created with ``pyInstaller`` [<https://www.pyinstaller.org/>](https://www.pyinstaller.org/)``_`. The archives self-extract to a temporary directory that is automatically deleted when pyfda is terminated (except when it crashes), they don't modify the system except for two ASCII configuration files and a log file. No additional software / libraries need to be installed, there is no interaction with existing python installations and you can simply overwrite or delete the executables when updating. After downloading the Linux archive, you need to make it executable (`chmod 775 pyfda_linux`).

Binaries for **Linux** are created as Flatpaks as well (**currently defunct**) which can also be downloaded from ``Flathub`` [\(<https://flathub.org/apps/details/com.github.chipmuenk.pyfda>`\\_](https://flathub.org/apps/details/com.github.chipmuenk.pyfda). Many Linux distros have built-in flatpak support, for others it's easy to install with e.g. `sudo apt install flatpak`. For details check the [Flatpak](#) home page.

### 1.3.2 pip

**Python 3.8** and above is supported, there is only one version of pyfda for all operating systems at [PyPI](#). As pyfda is a pure Python project (no compilation required), you can install pyfda the usual way, required libraries are downloaded automatically if missing:

```
> pip install pyfda
```

Upgrade:

```
> pip install pyfda -U
```

Uninstall:

```
> pip uninstall pyfda
```

### Starting pyfda

A pip installation creates a start script `pyfdax` in `&lt;python>/Scripts` which should be in your path. So, simply start pyfda using

```
> pyfdax
```

The following libraries are required and installed automatically by pip when missing.

- ``PyQt`` [\(<https://www.riverbankcomputing.com/software/pyqt/>`\\_](https://www.riverbankcomputing.com/software/pyqt/) and ``Qt5`` [\(<https://qt.io/>`\\_](https://qt.io/)
- ``numpy`` [\(<https://numpy.org/>`\\_](https://numpy.org/)
- ``numexpr`` [\(<https://github.com/pydata/numexpr>`\\_](https://github.com/pydata/numexpr)
- ``scipy`` [\(<https://scipy.org/>`\\_](https://scipy.org/): 1.2.0 or higher
- ``matplotlib`` [\(<https://matplotlib.org/>`\\_](https://matplotlib.org/): 3.1 or higher
- ``Markdown`` [\(<https://github.com/Python-Markdown/markdown>`\\_](https://github.com/Python-Markdown/markdown)

Optional libraries:

- ``mplcursors`` [\(<https://mplcursors.readthedocs.io/>`\\_](https://mplcursors.readthedocs.io/) for annotating cursors
- ``docutils`` [\(<https://docutils.sourceforge.io/>`\\_](https://docutils.sourceforge.io/) for rich text in documentation
- `xlwt` and / or `XlsxWriter` for exporting filter coefficients as `*.xls(x)` files

### 1.3.3 conda

If you're working with Anaconda's packet manager conda, there is a recipe for pyfda on conda-forge since July 2023:

```
> conda install --channel=conda-forge pyfda
```

You should install pyfda into a new environment to avoid unwanted interaction with other installations.

### 1.3.4 git

If you want to contribute to pyfda (great idea!), fork the latest version from <https://github.com/chipmuenk/pyfda.git> and create a local copy using

```
> git clone https://github.com/<your_username>pyfda
```

This command creates a new folder pyfda at your current directory level and copies the complete pyfda project into it. This [Github tutorial](#) provides a good starting point for working with git repos.

pyfda can then be installed (i.e. creating local config files and the pyfdax starter script) from local files using

```
> pip install -e <YOUR_PATH_TO_PYFDA_setup.py>
```

Now you can edit the code and test it. If you're happy with it, push it to your repo and create a Pull Request so that the code can be reviewed and merged into the chipmuenk/pyfda repo.

## 1.4 Building pyfda

For details on how to publish pyfda to PyPI, how to create pyInstaller and Flatpak bundles, see [BUILDING.md](#).

## 1.5 Customization

The location of the following two configuration files (copied to user space) can be checked via the tab Files -> About:

- Logging verbosity can be controlled via the file `pyfda_log.conf`
- Widgets and filters can be enabled / disabled via the file `pyfda.conf`. You can also define one or more user directories containing your own widgets and / or filters.

Layout and some default paths can be customized using the file `pyfda/pyfda_rc.py`, at the moment you have to edit that file at its original location.

## 1.6 Features

### 1.6.1 Filter design

- **Design methods:** Equiripple, Firwin, Moving Average, Bessel, Butterworth, Elliptic, Chebyshev 1 and 2 (from `scipy.signal` and custom methods)
- **Second-Order Sections** are used in the filter design when available for more robust filter design and analysis
- **Fine-tune** manually the filter order and corner frequencies calculated by minimum order algorithms
- **Compare filter designs** for a given set of specifications and different design methods
- **Filter coefficients and poles / zeroes** can be displayed, edited and quantized in various formats

- **Fixpoint filters** based on the integrated `Fixed()` class or on the [Amaranth](#) hardware description language.

### 1.6.2 User Interface

- enhanced Matplotlib NavigationToolbar (nicer icons, additional functions)
- tooltips for all UI widgets and help files
- specify frequencies as absolute values or normalized to sampling or Nyquist frequency
- specify ripple and attenuations in dB, as voltage or as power ratios
- enter values as expressions like `exp(-pi/4 * 1j)` using [numexpr](#) syntax

### 1.6.3 Graphical Analyses

- Magnitude response (lin / power / log) with optional display of specification bands, phase and an inset plot
- Phase response (wrapped / unwrapped) and group delay
- Pole / Zero plot
- Transient response (impulse, step and various stimulus signals) in the time and frequency domain. Define your own stimuli like `abs(sin(2*pi*n*f1))` using [numexpr](#) syntax and the UI.
- 3D-Plots ( $H(f)$ , mesh, surface, contour) with optional pole / zero display

### 1.6.4 Import / Export

- Filter designs in JSON, pickled and in numpy's NPZ-format
- Coefficients and poles/zeros as comma-separated values (CSV), in CMSIS format in numpy's NPY- and NPZ-formats, in Excel (R), as a Matlab (R) workspace or in FPGA vendor specific formats like Xilinx (R) COE-format
- Transient stimuli ( $y[n]$  tab) as wav and csv files

## 1.7 Target group

- **Educators and students:** Provide an easy-to-use FOSS tool for demonstrating DSP stuff and interactive filter design that also works with the limited resolution of a beamer.
- **Fixpoint filter designer:** Recursive fixpoint filter design has become a niche for experts. Convenient design and simulation support (round-off noise, stability under different quantization options and topologies) could attract more designers to these filters that are easier on hardware resources and much more suitable especially for uCs and low-budget FPGAs.

## 1.8 Release History

For details, see [CHANGELOG.md](#).



## 1.9 Planned features (help wanted)

- Dark mode
- Use [Amaranth](#) to simulate fixpoint filters and export them in HDL format
- Graphical modification of poles / zeros
- Document filter designs in PDF / HTML format
- Design, analysis and export of filters as second-order sections, display and edit them in the P/Z widget
- Multiplier-free filter designs (CIC, GCIC, LDI,  $\Sigma\Delta$ , ...) for fixpoint filters with a low number of multipliers (or none at all)
- Analysis of different fixpoint filter topologies (direct form, cascaded form, parallel form, ...) concerning overflow and quantization noise



## 2.1 UI Overview

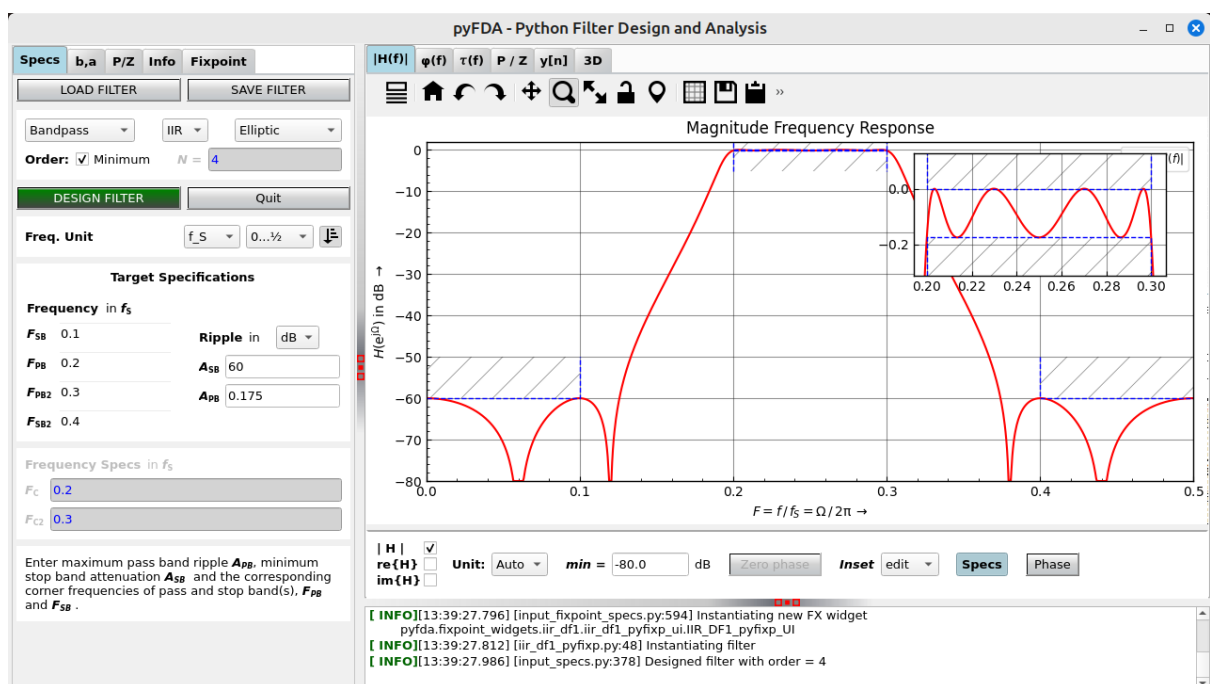


Fig. 2.1: Screenshot of pyfda

Fig. 2.1 shows the main pyfda screen with three subwindows that can be resized with the handles (red dots).

The tabs on the left-hand side access widgets to enter and view various specification and parameters for the filter / system to be designed resp. analyzed.

### Subwindow for Input Widgets

#### 2.1.1 Input Specs

##### Introduction

Fig. 2.2 shows a typical view of the **Specs** tab.

“Load” and “Save” ... well, loads and saves complete filter designs. Coefficients and poles / zeros can be imported and exported in the “b,a” resp. the “P/Z” tab.

For the actual filter design, you can specify the kind of filter to be designed and its specifications in the frequency domain:

- **Response type** (low pass, band pass, ...)
- **Filter type** (IIR for a recursive filter with infinite impulse response or FIR for a non-recursive filter with finite impulse response)
- **Filter class** (elliptic, ...) allowing you to select the filter design algorithm

The screenshot shows the 'Specs' tab of the pyfda interface. It includes buttons for 'LOAD FILTER' and 'SAVE FILTER'. The 'Response type' is set to 'Lowpass', 'Filter type' to 'FIR', and 'Filter class' to 'Equiripple'. 'Grid Density' is 16. Under 'Order', the 'Minimum' checkbox is unchecked and 'N' is 5. The 'DESIGN FILTER' button is highlighted in yellow. Below, 'Freq. Unit' is 'MHz' and the range is '0...1/2'. The sampling frequency 'fs' is 13. The 'Target Specifications' section shows 'Frequency in MHz' with 'fPB' at 1.3 and 'fSB' at 7 (highlighted in red), and 'Ripple in dB' with 'APB' at 0.347 and 'ASB' at 60. A 'Weight Specifications' section is partially visible at the bottom.

Fig. 2.2: Screenshot of specs input window

Not all combinations of design algorithms and response types are available - you won't be offered unavailable combinations and some fields may be greyed out.

A nice description of the design of FIR filters (also with pyfda) can be found at [Designing Generic FIR Filters with pyFDA and NumPy] (<https://tomverbeure.github.io/2020/10/11/Designing-Generic-FIR-Filters-with-pyFDA-and-Numpy.html>)

## Order

The **order** of the filter, i.e. the number of poles / zeros / delays is either specified manually or the minimum order can be estimated for many filter algorithms to fulfill a set of given specifications.

## Frequency Unit

In DSP, specifications and frequencies are expressed in different ways:

$$F = \frac{f}{f_S} \text{ or } \Omega = \frac{2\pi f}{f_S} = 2\pi F$$

In pyfda, you can enter parameters as absolute frequency  $f$ , as normalized frequency  $F$  w.r.t. to the *Sampling Frequency*  $f_S$  or to the *Nyquist Frequency*  $f_{Ny} = f_S/2$  (Fig. 2.3):

The screenshot shows the 'Specs' tab of the pyfda GUI. It includes buttons for 'LOAD FILTER' and 'SAVE FILTER'. The filter type is set to 'Bandpass', 'FIR', and 'Equiripple'. The 'Grid Density' is 16. The 'Order' is set to 'Minimum' with  $N = 5$ . There are 'DESIGN FILTER' and 'Quit' buttons. The 'Freq. Unit' is set to  $f_s$ . The 'Target Specifications' section shows normalized frequencies:  $F_{SB} = 0.1$ ,  $F_{PB} = 0.2$ ,  $F_{PB2} = 0.3$ , and  $F_{SB2} = 0.4$ . The 'Ripple' is set to 'dB' with values  $A_{SB} = 60$ ,  $A_{PB} = 0.347$ , and  $A_{SB2} = 80$ . The 'Weight Specifications' section has a 'Reset' button.

Fig. 2.3: Displaying normalized frequencies

## Amplitude Unit

Amplitude specification can be entered as V, dB or W; they are converted automatically. Conversion depends on the filter type (IIR vs. FIR) and whether pass or stop band are specified. For details see the conversion functions `pyfda.libs.pyfda_lib.unit2lin()` and `pyfda.libs.pyfda_lib.lin2unit()`.

## Background Info

### Sampling Frequency

One of the most important parameters in a digital signal processing system is the **sampling frequency**  $f_s$ , defining the clock frequency with which the registers (flip-flops) in the system are updated. In a simple DSP system, the clock frequency of ADC, digital filter and DAC might be identical:

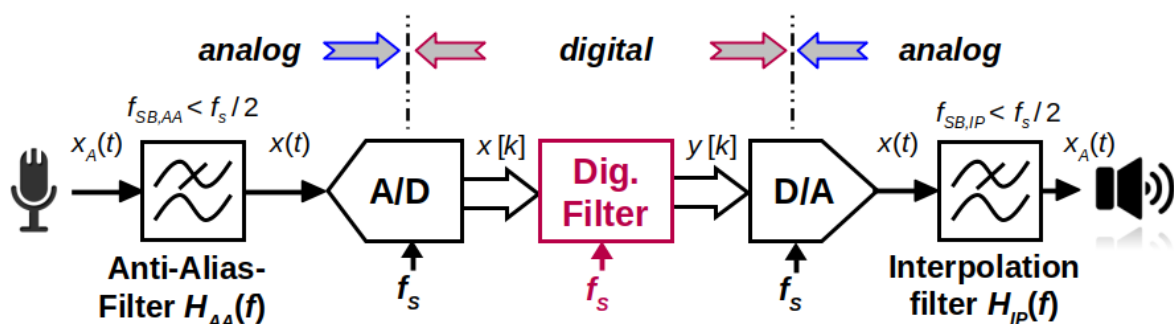


Fig. 2.4: A simple signal processing system

Sometimes it makes sense to change the sampling frequency in the processing system e.g. to reduce the sampling rate of an oversampling ADC or to increase the clocking frequency of a DAC to ease and improve reconstruction of the analog signal.

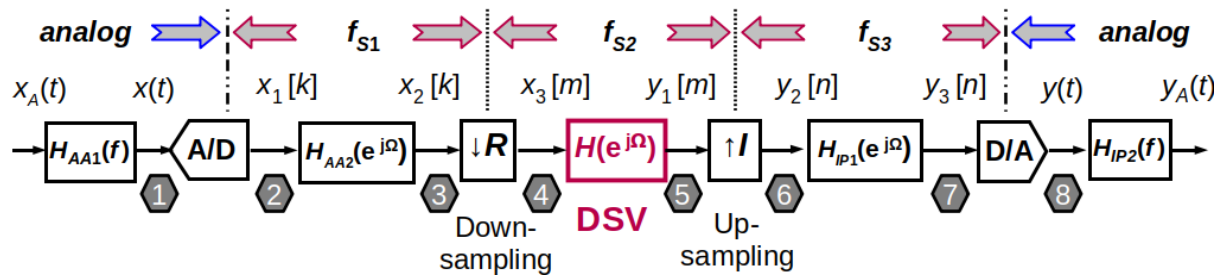


Fig. 2.5: A signal processing system with multiple sampling frequencies

### Aliasing and Nyquist Frequency

When the sampling frequency is too low, significant information is lost in the process and the signal cannot be reconstructed without errors (forth image in Fig. 2.6) [Smith99]. This effect is called *aliasing*.

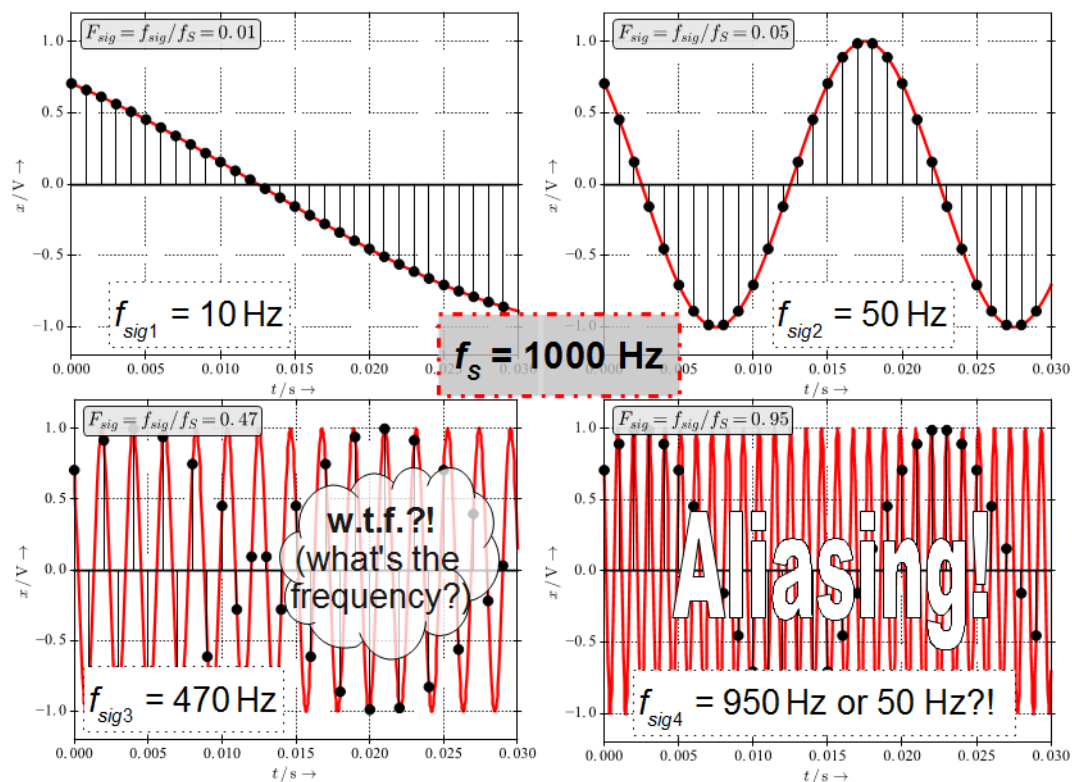


Fig. 2.6: Sampling with  $f_s = 1000$  Hz of sinusoids with 4 different frequencies

When sampling with  $f_s$ , the maximum signal bandwidth  $B$  that can be represented and reconstructed without errors is given by  $B < f_s/2 = f_{Ny}$ . This is also called the *Nyquist frequency* or *bandwidth*  $f_{Ny}$ . Some filter design tools and algorithms normalize frequencies w.r.t. to  $f_{Ny}$  instead of  $f_s$ .

## Half-Band Filters

Explanation of half-band filters and how to design them with pyfda can be found at [Half-Band Filters, a Workhorse of Decimation Filters] (<https://tomverbeure.github.io/2020/12/15/Half-Band-Filters-A-Workhorse-of-Decimation-Filters.html#designing-a-half-band-fir-filter-with-pyfda>)

## Development

More info on this widget can be found under *input\_specs*.

### 2.1.2 Input Coeffs

Fig. 2.7 shows a typical view of the **b,a** tab where you can view and edit the filter coefficients. Coefficient values are updated every time you design a new filter or update the poles / zeros.

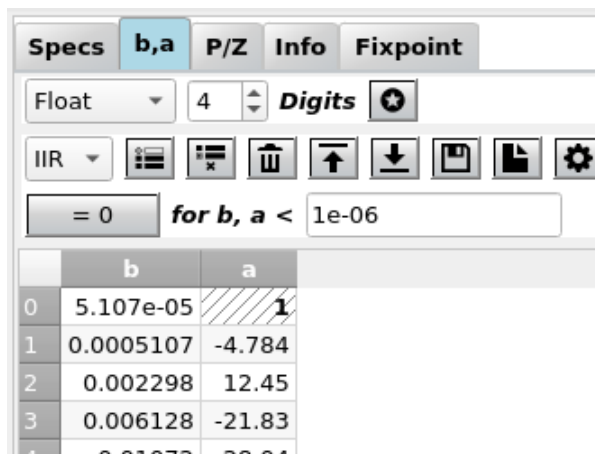


Fig. 2.7: Screenshot of the coefficients tab for floating point coefficients

In the top row, the display of the coefficients can be disabled as a coefficient update can be time consuming for high order filters ( $N > 100$ ).

## Quantization format

By default, coefficients are displayed in float quantization format, the format returned by the filter design algorithm, with a selectable number of decimal places. Internally, full precision is always used.

However, many hardware platforms with limited computing resources like uCs can only perform fix-point arithmetics. Here, scaling and wordlength have a strong influence on the obtainable accuracy.

It is important to understand that the quantization format only influences the *display* of the coefficients, the frequency response etc. is only updated when the quantize icon (the staircase) is clicked. Only when you do a *fixpoint simulation* or generate Verilog code from the fixpoint tab, the selected word format is used for the coefficients.

## Fixpoint

When the format is set to fractional or integer, the fixpoint options are displayed as in Fig. 2.8. Here, the format *Binary* has been set.

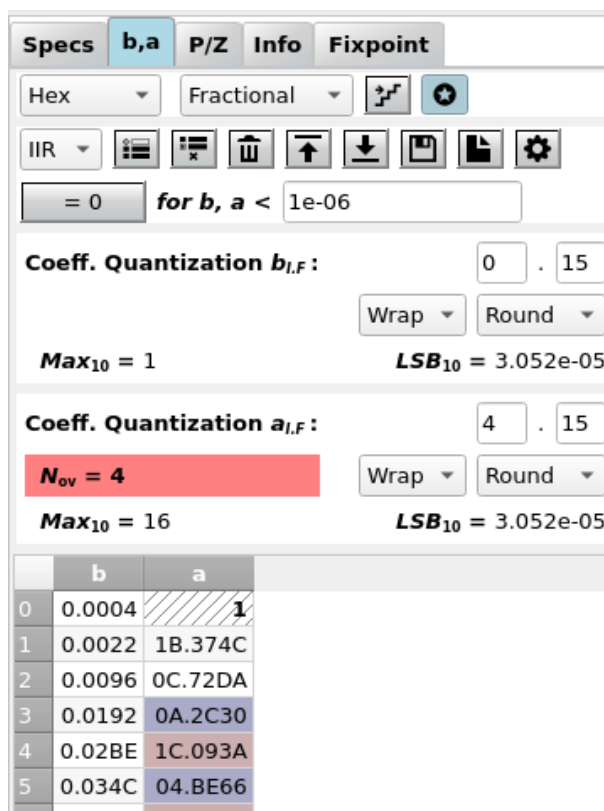


Fig. 2.8: Screenshot of the coefficients tab for fixpoint formats (binary display)

## Fixpoint Formats

Any other format (Binary, Hex, Decimal, CSD) is a fixpoint format with a fixed number of binary places which activates further display options. These formats (except for CSD) are based on the integer value i.e. by simply interpreting the bits as an integer value  $INT$  with the MSB as the sign bit.

The scale between floating (“Real World Value”,  $RWV$ ) and fixpoint format is determined by partitioning the word length  $W$  into integer and fractional places  $WI$  and  $WF$  with total word length  $W = WI + WF + 1$  where the “+ 1” accounts for the sign bit.

Three kinds of partitioning can be selected in a combo box:

- **The integer format has no fractional bits,  $WF = 0$  and**  
 $W = WI + 1$ . This is the format used by amaranth as well,  $RWV = INT$
- **The normalized fractional format has no integer bits,  $WI = 0$  and**  
 $W = WF + 1$ .
- **The general fractional format has an arbitrary number of fractional**  
 and integer bits,  $W = WI + WF + 1$ .

In any case, scaling is determined by the number of fractional bits:

$$RWV = INT \cdot 2^{-WF}$$

In addition to setting the position of the binary point you can select the behaviour for:



- **Quantization: The very high precision of the floating point format** needs to be reduced for the fixpoint representation. Here you can select between `floor` (truncate the LSBs), `round` (classical rounding) and `fix` (always round to the next smallest magnitude value)
- **Saturation: When the floating point number is outside the range of** the fixpoint format, either two's complement overflow occurs (`wrap`) or the value is clipped to the maximum resp. minimum ("saturation", `sat`)

More info on fixpoint arithmetics can be found under [Fixpoint Arithmetics](#).

## Development

More info on this widget can be found under [input\\_coeffs](#).

### 2.1.3 Input P/Z

Fig. 2.9 shows a typical view of the **P/Z** tab where you can view and edit the filter poles and zeros. Pole / zero values are updated every time you design a new filter. After editing poles or zeros by hand, the changes have to be applied via the (highlighted) button "Apply P/Z to filter".

In real-valued systems (i.e. systems with a real-valued impulse response and real-valued coefficients) poles and zeros are real-valued or come in conjugate complex pairs. This means they have the same real part and positive / negative imaginary part, e.g.  $p_1 = 0.5 + 0.5j$  and  $p_2 = 0.5 - 0.5j$  or  $z_1 = 1\angle + 0.25\pi$  and  $z_2 = 1\angle - 0.25\pi$ . Otherwise, you end up with a complex-valued system with complex-valued coefficients which is not what you want in most cases.

#### Cartesian format

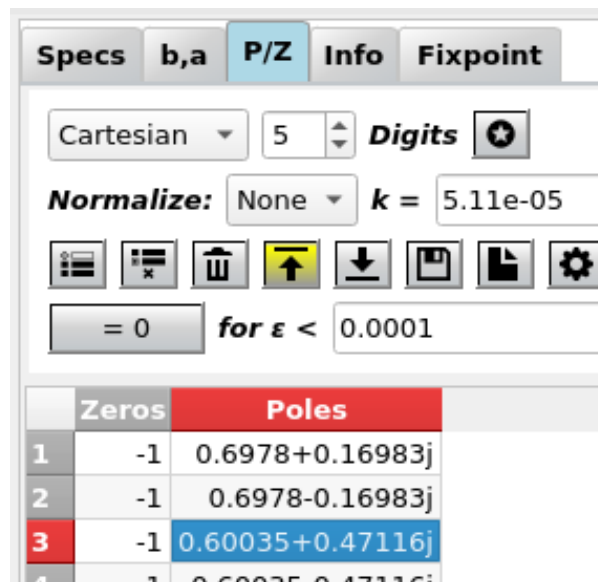


Fig. 2.9: Screenshot of the pole/zero tab in cartesian format

Poles and zeros are displayed and can be edited in cartesian format ( $x$  and  $y$ ) by default as shown in Fig. 2.9.

## Polar format

	Zeros	Poles
1	-1	0.71817 $\angle$ 13.679°
2	-1	0.71817 $\angle$ -13.679°
3	-1	0.76316 $\angle$ 38.125°
4	-1	0.76316 $\angle$ -38.125°
5	1	0.00003 $\angle$ 55.130°

Fig. 2.10: Screenshot of the pole/zero tab in polar format with activated “Format” button

Alternatively, poles and zeros can be displayed and edited in polar format (radius and angle) as shown in Fig. 2.10. Especially for zeros which often are placed on the unit circle ( $r = 1$ ) this format may be more suitable.

During editing, use the ‘>’ character to separate radius and phase. The phase can be displayed and entered in the following formats:

- **Degrees** with a range of  $\pm -180 \dots +180$ , terminate the phase with an ‘o’ or ‘°’ to indicate degrees.
- **Rad** with a range of  $\pm -\pi \dots +\pi$ , simply enter the value or terminate the phase with an ‘r’ or with ‘rad’ to indicate rads.
- Multiples of **pi** with a range of  $\pm -1 \dots +1$ , terminate the phase with a ‘p’ or ‘pi’ to specify multiples of pi.

When entering poles or zeros, the format is chosen automatically, depending on which special characters (like ‘<’, ‘o’, ‘r’ or ‘pi’) have been found in the text field.

You can “misuse” this feature as a converter between different number formats:

- ‘3<0.7854’ or ‘3<0.7854r’ or ‘3<0.7854rad’
- ‘3<0.25p’ or ‘3<0.25pi’
- ‘3<45°’ or ‘3<45o’
- 2.12132+2.12132j

all represent the same value. You can omit the radius if  $r = 1$ , simply enter ‘<45°’ instead of ‘1<45°’.

Use the corresponding icons to enter a new row or delete one. The trash can deletes the whole table.

## Saving and Loading

Poles and zeros can be saved in various file formats (CSV, MAT, NPZ, NPY). CSV file format options (row or column, delimiter, ...) are selected in the CSV pop-up menu (the ‘cog’ icon). Independent of the table display format, coefficients are saved with full precision in complex (cartesian) number format when the format button (the “star”) is deactivated.

When the format button *is* activated, values are saved *exactly as displayed*. This means, cells may be saved with reduced number of digits and in polar number format, containing special characters like ‘<’.

## Development

More info on this widget can be found under [input\\_pz](#).

### 2.1.4 Input Info

The **Info** tab (Fig. 2.11) displays infos on the current filter design and design algorithm.

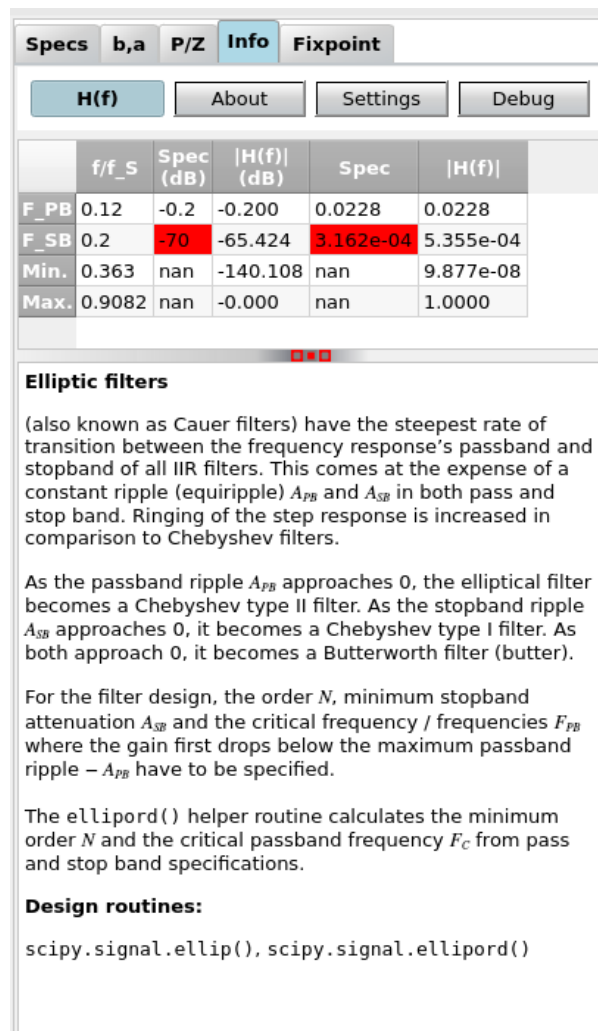


Fig. 2.11: Screenshot of the info tab

The buttons in the top row select which information is displayed:

The **H(f)** button activates the display of specifications in the frequency domain and how well they are met. Failed specifications are highlighted in red.

The **About** button opens a pop-up window with general infos about the software, licensing and module versions (Fig. 2.12).



Fig. 2.12: Screenshot of the “About” pop-up window

The **Debug** button enables some debugging options:

- **Doc\$:** Show docstring info from the corresponding python (usually scipy) module.
- **RTF:** Use Rich Text Format for documentation.
- **FiltDict:** Display the dictionary containing all current settings of the software. This dictionary is saved and restored when saving / loading a filter.
- **FiltTree:** Display the hierarchical tree with all filter widgets that have been detected during the start of the software

## Development

More info on this widget can be found under [input\\_info](#).

### 2.1.5 Fixpoint Specs

#### Overview

The **Fixpoint** tab (Fig. 2.13) provides options for generating and simulating discrete-time filters that can be implemented in hardware. Hardware implementations for discrete-time filters usually imply fixpoint arithmetics but this could change in the future as floating point arithmetics can be implemented on FPGAs using dedicated floating point units (FPUs).

Order and the coefficients have been calculated by a filter design algorithm from the `pyfda.filter_widgets` package to meet target filter specifications (usually in the frequency domain).

In this tab, a fixpoint implementation can be selected in the upper left corner (fixpoint filter implementations are available only for a few filter design algorithms at the moment, most notably IIR filters are missing).

The fixpoint format of input word  $Q_X$  and output word  $Q_Y$  can be adjusted for all fixpoint filters, pressing the “lock” button makes the format of input and output word identical. Depending on the fixpoint filter, other formats (coefficients, accumulator) can be set as well.

In general, **Overflow** combo boxes determine overflow behaviour (Two’s complement wrap around or saturation), **Quantization** combo boxes select quantization behaviour between rounding, truncation (“floor”) or round-towards-zero (“fix”). These methods may not all be implemented for each fixpoint filter. Truncation is easiest to implement but has an average bias of  $-1/2$  LSB, in contrast, rounding has no bias but requires an additional adder. Only rounding-towards-zero guarantees that the magnitude of the rounded number is not larger than the input, thus preventing limit cycles in recursive filters.

See also [Yates\_2020] and [Lyons]

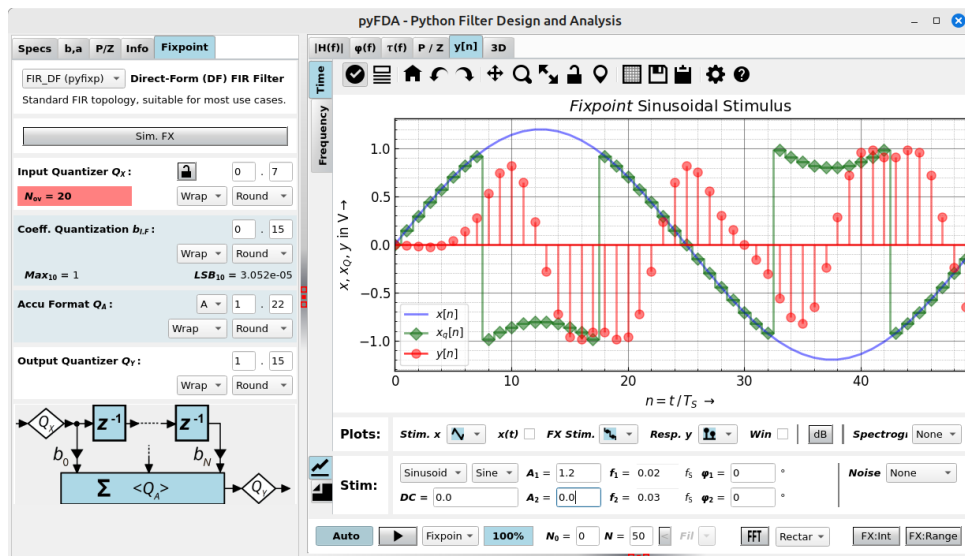


Fig. 2.13: Fixpoint parameter entry widget (overflow = wrap)

Typical simulation results are shown in Fig. 2.14 (time domain) and Fig. 2.15 (frequency domain).

Fixpoint filters are inherently non-linear due to quantization and saturation effects, that’s why frequency characteristics can only be derived by running a transient simulation and calculating the Fourier response afterwards:

The following shows an example of a coefficient in Q2.4 and Q0.3 format using wrap-around and truncation. It’s easy to see that for simple wrap-around logic, the sign of the result may change.

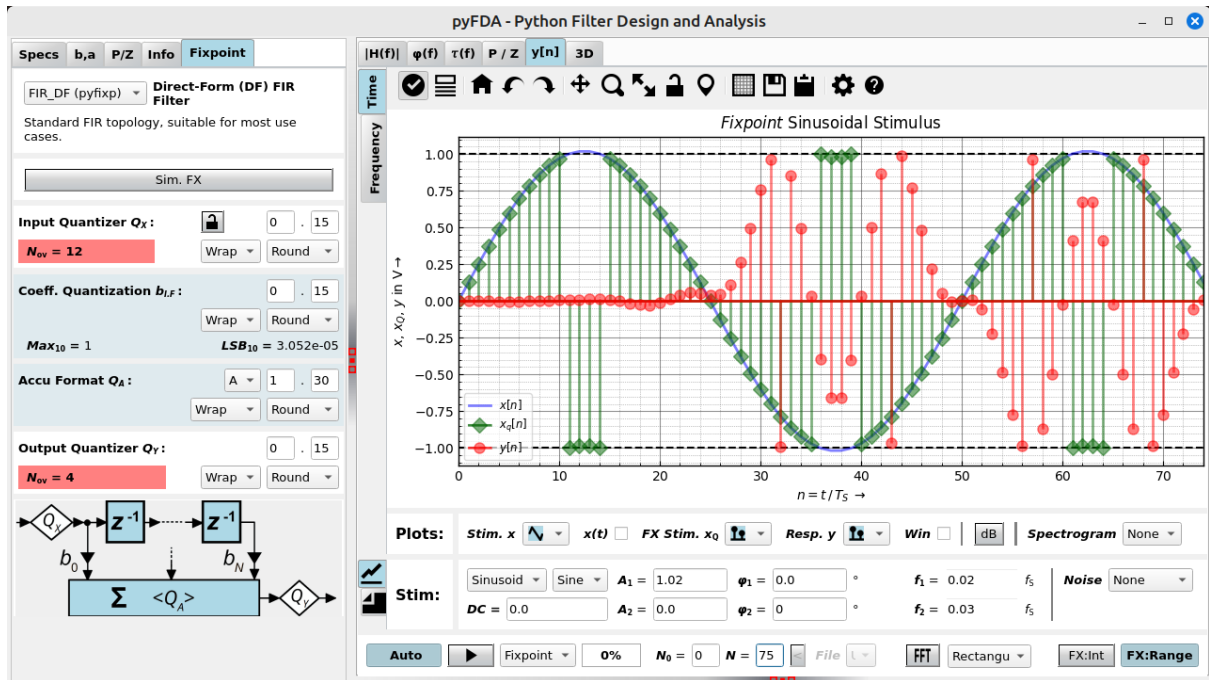


Fig. 2.14: Fixpoint simulation results (time domain)

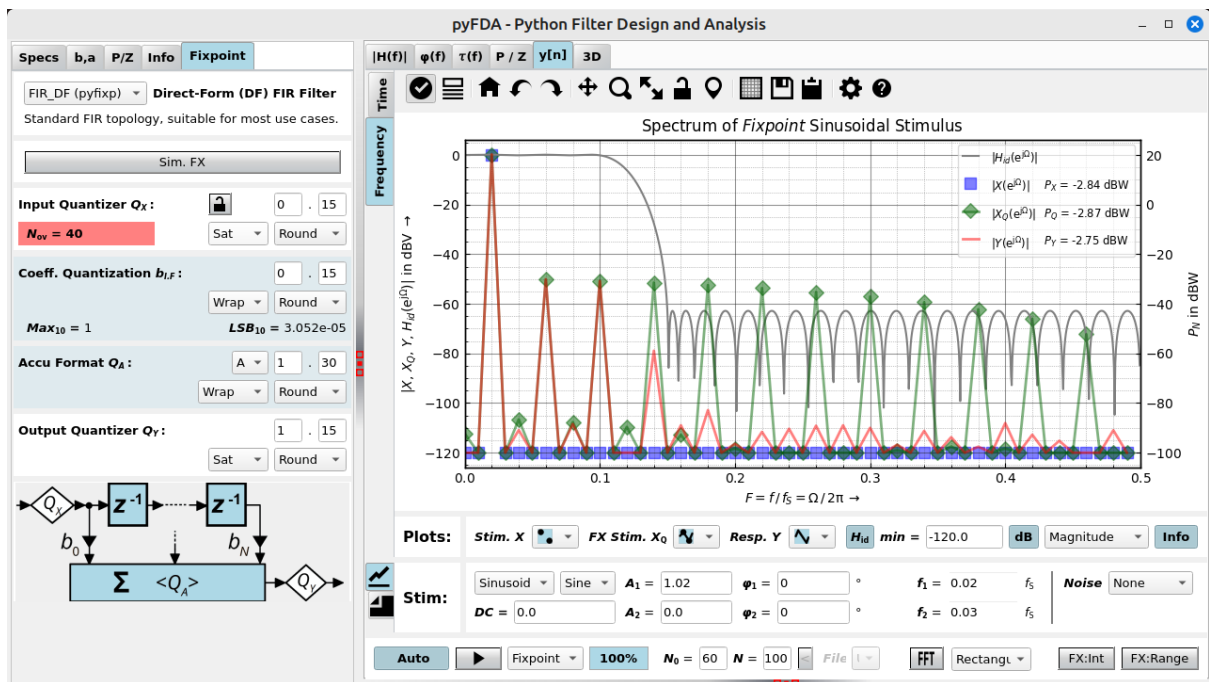


Fig. 2.15: Fixpoint simulation results (frequency domain)

S	WI1	WI0	.	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	1	0	.	1	0	1	1	=	43 (INT) <b>or</b> 43/16 = 2 + 11/16
→ (RWV)									
	S	.	WF0	WF1	WF2			:	WI = 0, WF = 3, W = 4
	0	.	1	0	1			=	5 (INT) <b>or</b> 5/8 (RWV)

## Summation

Before adding two fixpoint numbers with a different number of integer and/or fractional bits, integer and fractional word lengths need to be equalized:

- the fractional parts are padded with zeros
- the integer parts need to be sign extended, i.e. with zeros for positive numbers and with ones for negative numbers
- adding numbers can require additional integer places due to word growth

For this reason, the position of the binary point needs to be

S	WI1	WI0	.	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	1	0	.	1	0	1	1	=	43 (INT) <b>or</b> 43/16 = 2 + 11/16
→ (RWV)									
+									
S	WI1	WI0	.	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	0	0	.	1	0	1	0	=	10 (INT) <b>or</b> 10/16 (RWV)
=====									
S	WI1	WI0	.	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	1	1	.	0	1	0	1	=	53 (INT) <b>or</b> 53/16 = 3 + 5/16 (RWV)

More info on fixpoint numbers and arithmetics can be found under *Fixpoint Arithmetics*.

## Configuration

The configuration file `pyfda.conf` lists the fixpoint classes to be used, e.g. DF1 and DF2. `pyfda.libs.tree_builder.Tree_Builder` parses this file and writes all fixpoint modules into the list `fb.fixpoint_widgets_list`. The input widget `pyfda.input_widgets.input_fixpoint_specs.Input_Fixpoint_Specs` constructs a combo box from this list with references to all successfully imported fixpoint modules. The currently selected fixpoint widget (e.g. DF1) is imported from `pyfda.fixpoint_widgets` together with the referenced image.

## Development

More info on this widget can be found under `input_widgets.input_fixpoint_specs`.

The subwidgets on the right-hand side allow for graphical analyses of the system.

## 2.1.6 Subwindow for Plotting Widgets

### Plot $H(f)$

Fig. 2.16 shows a typical view of the  $|H(f)|$  tab for plotting the magnitude frequency response.

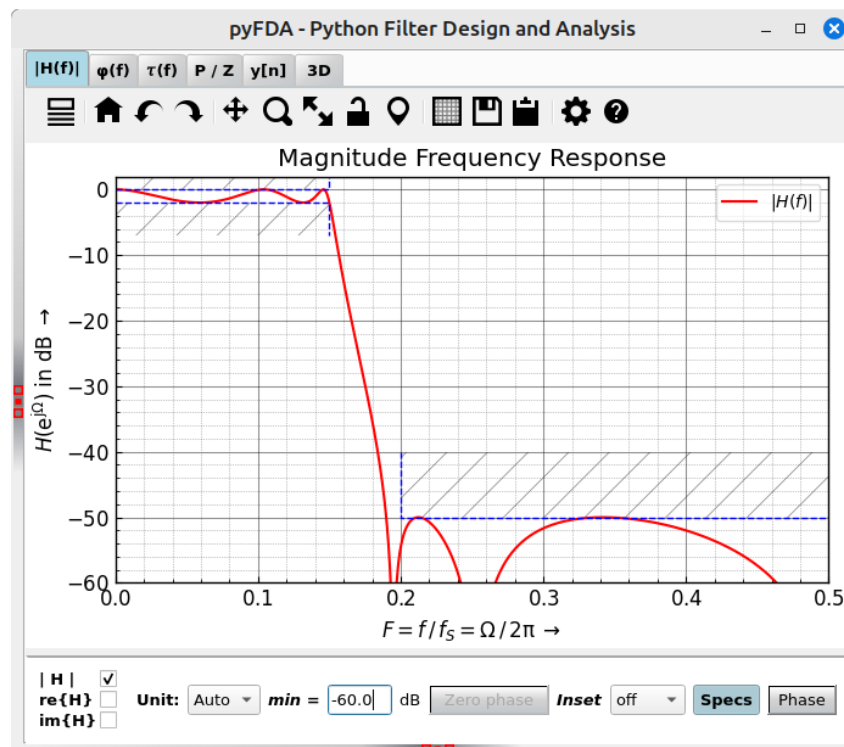


Fig. 2.16: Screenshot of the  $|H(f)|$  tab

You can plot magnitude, real or imaginary part in V (linear), W (squared) or dB (log. scale).

**Zero phase** removes the linear phase as calculated from the filter order. There is no check whether the design actually is linear phase, that's why results may be nonsensical. When the unit is dB or W, this option makes no sense and is not available. It also makes no sense when the magnitude of  $H(f)$  is plotted, but it might be interesting to look at the resulting phase.

Depending on the **Inset** combo box, a small inset plot of the frequency response is displayed, changes of zoom, unit etc. only have an influence on the main plot ("fixed") or the inset plot ("edit"). This way, you can e.g. zoom into pass band and stop band in the same plot. The handling still has some rough edges.

**Show specs** displays the specifications; the display makes little sense when  $\text{re}(H)$  or  $\text{im}(H)$  is plotted.

**Phase** overlays a plot of the phase, the unit can be set in the phase tab.

### Development

More info on this widget can be found under [plot\\_hf](#).



## Plot $\Phi(f)$

Fig. 2.17 shows a typical view of the  $\varphi(f)$  tab for plotting the phase response of an elliptical filter (IIR).

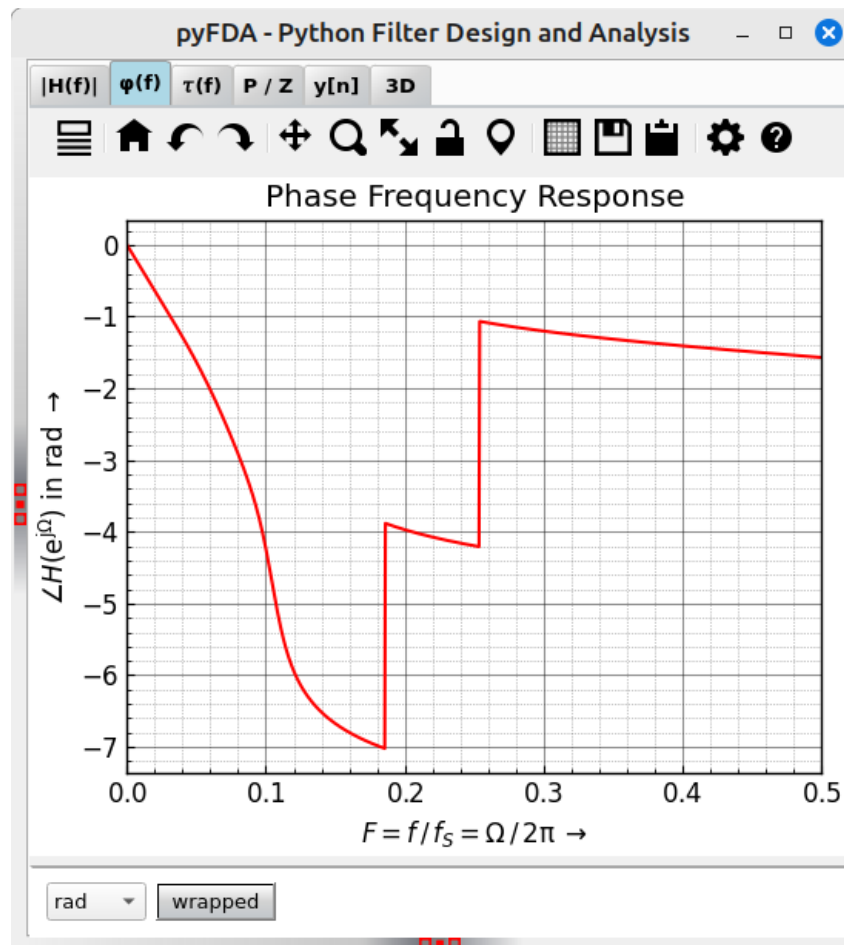


Fig. 2.17: Screenshot of the  $\varphi(f)$  tab

You can select the unit for the phase and whether the phase will be wrapped between  $-\pi \dots \pi$  or not.

## Development

More info on this widget can be found under [plot\\_phi](#).

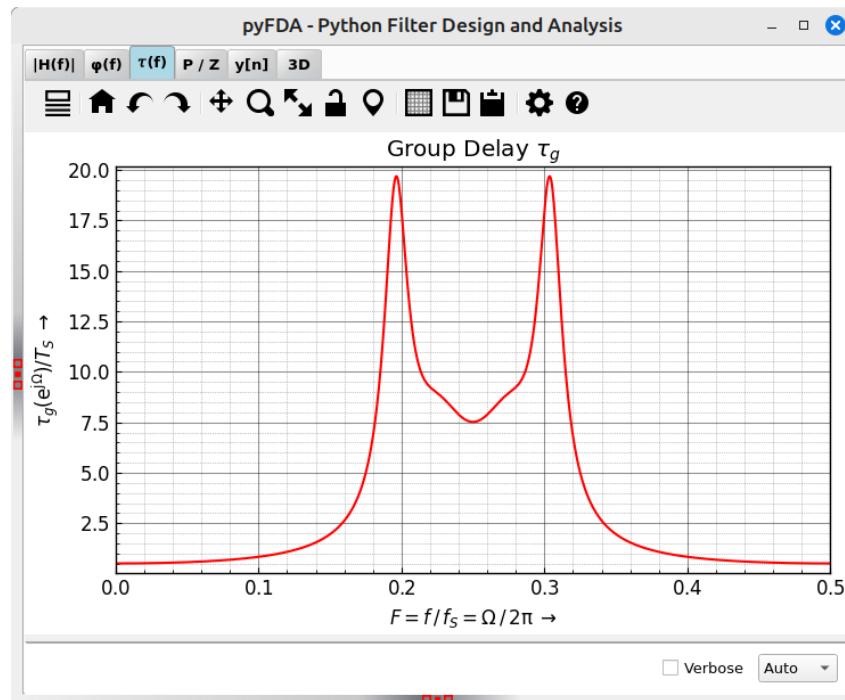
## Plot $\tau(f)$

Fig. 2.18 shows a typical view of the  $\tau(f)$  tab for plotting the group delay, here, an elliptical filter (IIR) is shown.

There are no user servicable parts on this tab.

The algorithm for calculating the group delay is explained in detail in [pyfda.libs.pyfda\\_sig\\_lib.group\\_delay\(\)](#).

Show `group_delay()`

Fig. 2.18: Screenshot of the  $\tau(f)$  tab

## Development

More info on this widget can be found under [plot\\_tau\\_g](#).

## Plot P/Z

Fig. 2.19 shows a typical view of the **P/Z** tab for plotting poles and zeros, here, an elliptical filter (IIR) is shown.

Optionally, the magnitude frequency response can be plotted around the unit circle to show the influence of poles and zeros (Fig. 2.20).

## Development

More info on this widget can be found under [plot\\_pz](#).

## Plot y[n]

Fig. 2.21 shows a typical view of the **y[n]** tab for plotting the transient response and its Fourier transformation, here, for a Chebychev filter (IIR).

This tab is split into several subwindows:

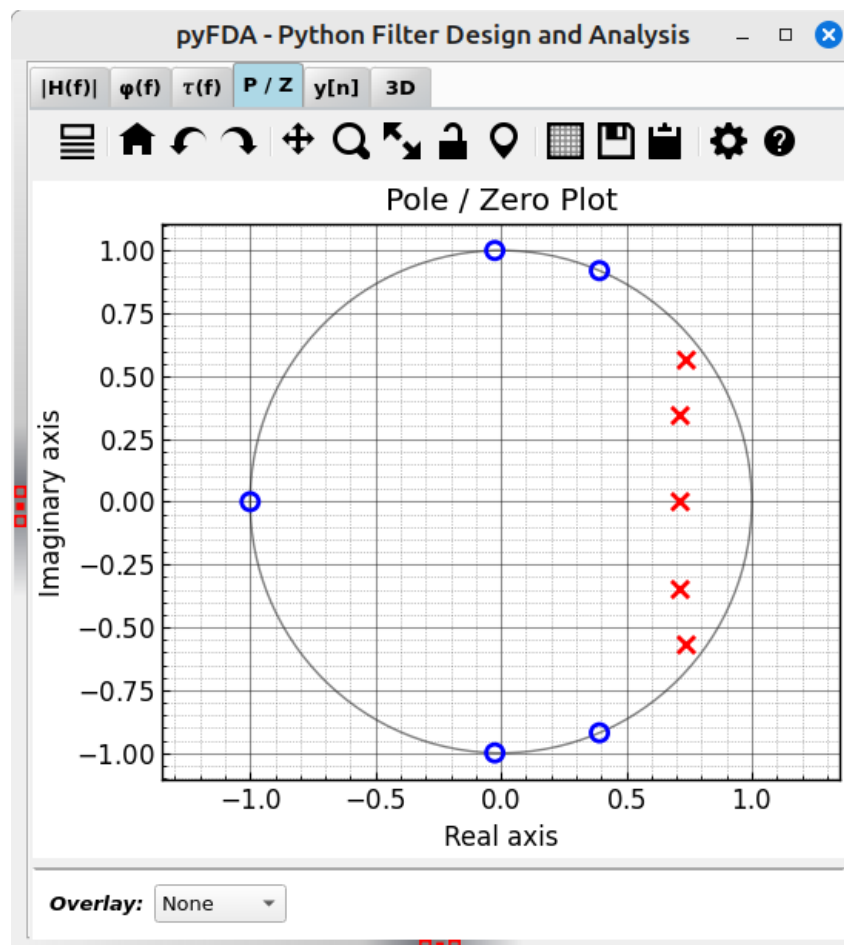
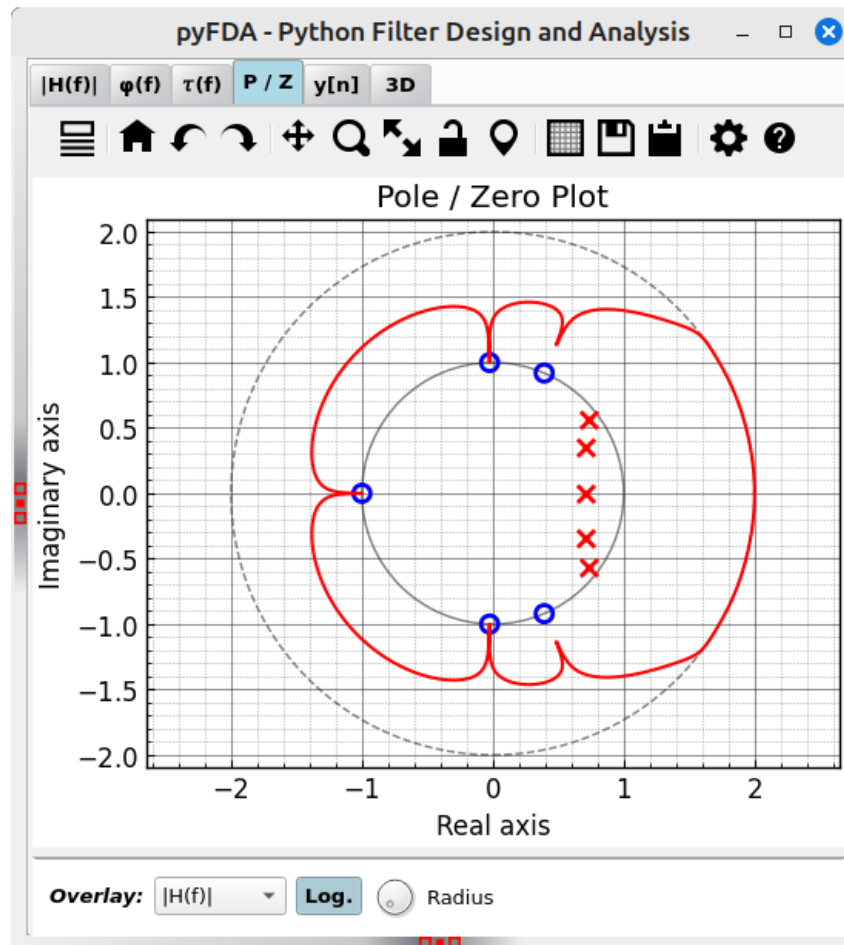
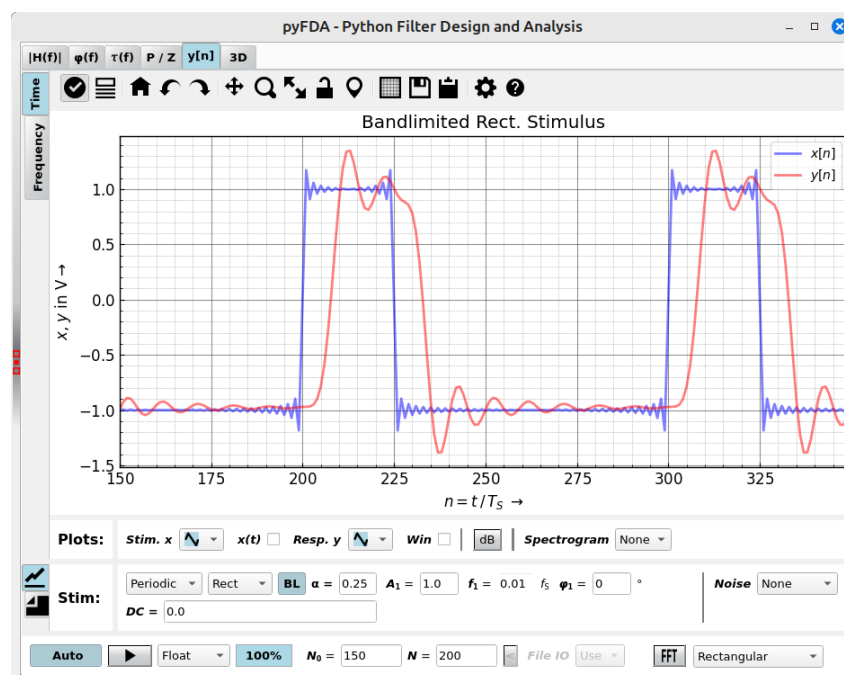


Fig. 2.19: Screenshot of the P/Z tab

Fig. 2.20: Screenshot of the P/Z tab with overlaid  $H(f)$  plotFig. 2.21: Screenshot of the  $y[n]$  tab (time domain)

## Time / Frequency (main plotting area)

These vertical tabs select between the time (transient) and frequency (spectral) domain. Signals are calculated in the time domain and then transformed using Fourier transform.

### Time

### Frequency

The Fourier transform of the transient signal can be viewed in the vertical tab “Frequency” (Fig. 2.22). This is especially important for fixpoint simulations where the frequency response cannot be calculated analytically.

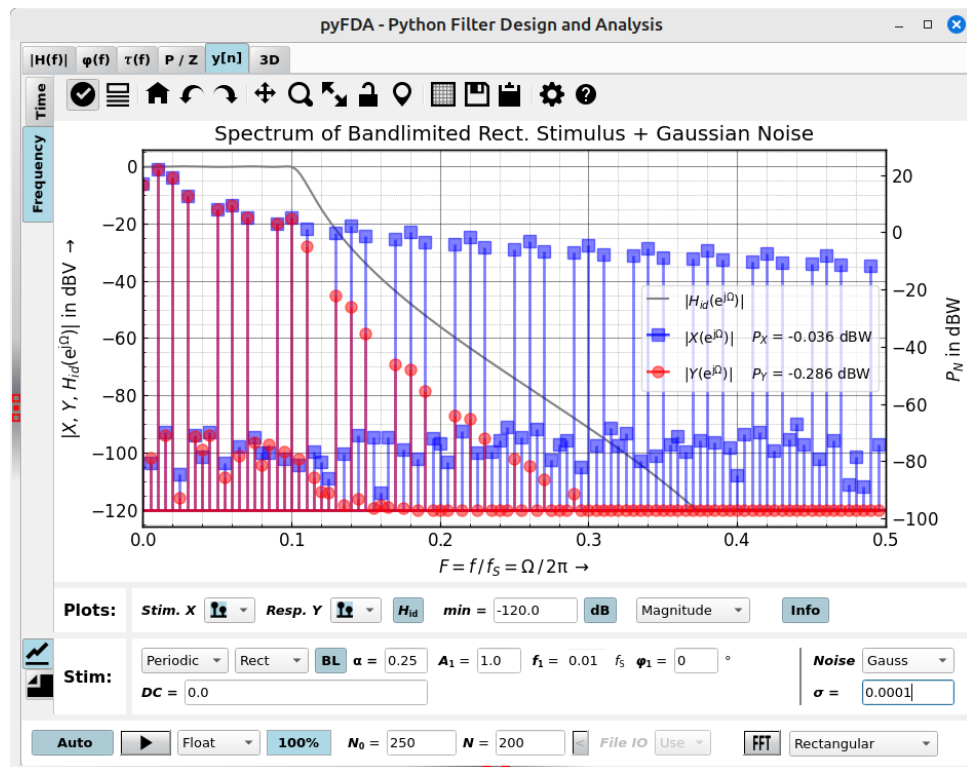


Fig. 2.22: Screenshot of the y[n] tab (frequency domain)

For an transform of periodic signals without leakage effect, (“smeared” spectral lines) take care that:

- The filter has settled sufficiently. Select a suitable value of **N0**.
- Choose the number of data points **N** in such a way that an integer number of periods is displayed (and transformed).
- The FFT window is set to rectangular. Other windows work as well but they distribute spectral lines over several bins. When it is not possible to capture an integer number of periods, use another window as the rectangular window has the worst leakage effect.

## Plots

What will be plotted and how.

## Stim.

Select the stimulus, its frequency, DC-content, noise ... When the BL checkbox is checked, the signal is bandlimited to the Nyquist frequency. Some signals have strong harmonic content which produces aliasing. This can be seen best in the frequency domain (e.g. for a sawtooth signal with  $f = 0.15$ ).

DC and Different sorts of noise can be added.

## Run

Usually, plots are updated as soon as an option has been changed. This can be disabled with the **Auto** checkbox for cases where the simulation takes a long time (e.g. for some fixpoint simulations).

## Development

More info on this widget can be found under [plot\\_impz](#).

## Plot 3D

[Fig. 2.23](#) shows a typical view of the **3D** tab for 3D visualizations of the magnitude frequency response and poles / zeros. [Fig. 2.23](#) is a surface plot which looks nice but takes the longest time to compute.

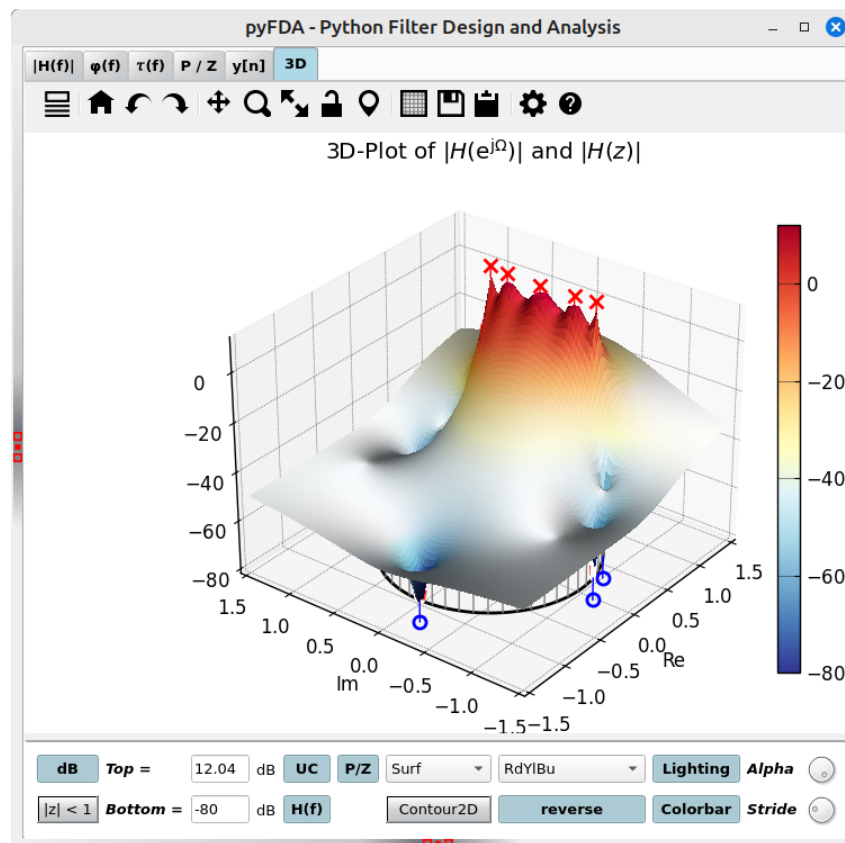


Fig. 2.23: Screenshot of the 3D tab (surface plot)

You can plot 3D visualizations of  $|H(z)|$  as well as  $|H(e^{j\omega})|$  along the unit circle (UC).

For faster visualizations, start with a mesh plot (Fig. 2.24) or a contour plot and switch to a surface plot when you are pleased with scale and view.

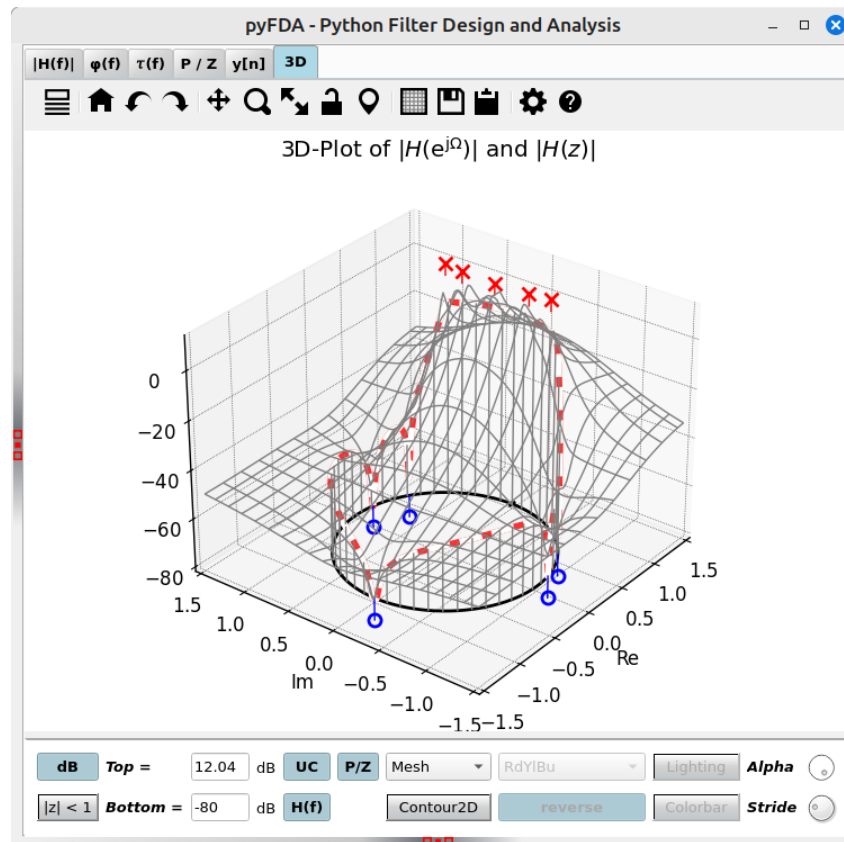


Fig. 2.24: Screenshot of the 3D tab (mesh plot)

## Development

More info on this widget can be found under [plot\\_3d](#).

Some documentation treats general filter design and fixpoint arithmetics stuff.

## General Documentation

### Fixpoint Arithmetics

#### Overview

In contrast to floating point numbers, **fixpoint** numbers have a fixed scaling, requiring more care to avoid over- or underflows. The same binary word can represent an integer (Fig. 2.25) or a fractional (Fig. 2.26) number, signed or unsigned. The position of the binary point and whether the MSB represents the sign bit or not, it is all in the designer's head ...

The fixpoint format of input word  $Q_X$  and output word  $Q_Y$  can be adjusted for all fixpoint filters, pressing the “lock” button makes the format of input and output word identical. Depending on the fixpoint filter, other formats (coefficients, accumulator) can be set as well.

In general, **Ovfl.** combo boxes determine overflow behaviour (Two's complement wrap around or saturation), **Quant.** combo boxes select quantization behaviour between rounding, truncation (“floor”) or round-towards-zero (“fix”). These methods may not all be implemented for each fixpoint filter. Truncation is easiest to

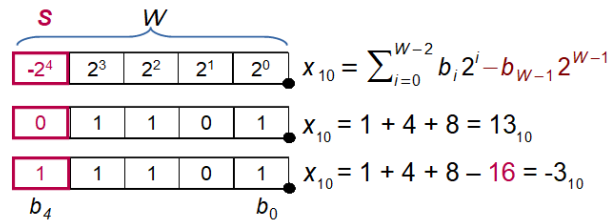


Fig. 2.25: Signed integer number in two's-complement format

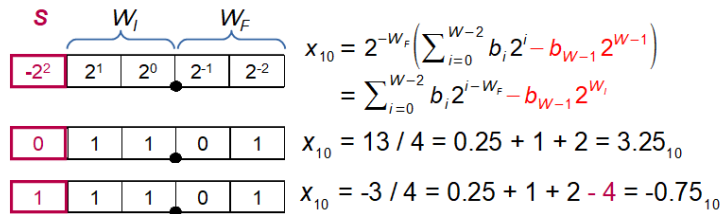


Fig. 2.26: Signed fractional number in two's-complement format

implement but has an average bias of -1/2 LSB, in contrast, rounding has no bias but requires an additional adder. Only rounding-towards-zero guarantees that the magnitude of the rounded number is not larger than the input, thus preventing limit cycles in recursive filters.

Typical simulation results are shown in Fig. 2.27, where first the input signal exceeds the numeric range and then the output signal. The overflow behaviour is set to 'wrap', resulting in two's-complement wrap around with changes in the sign.

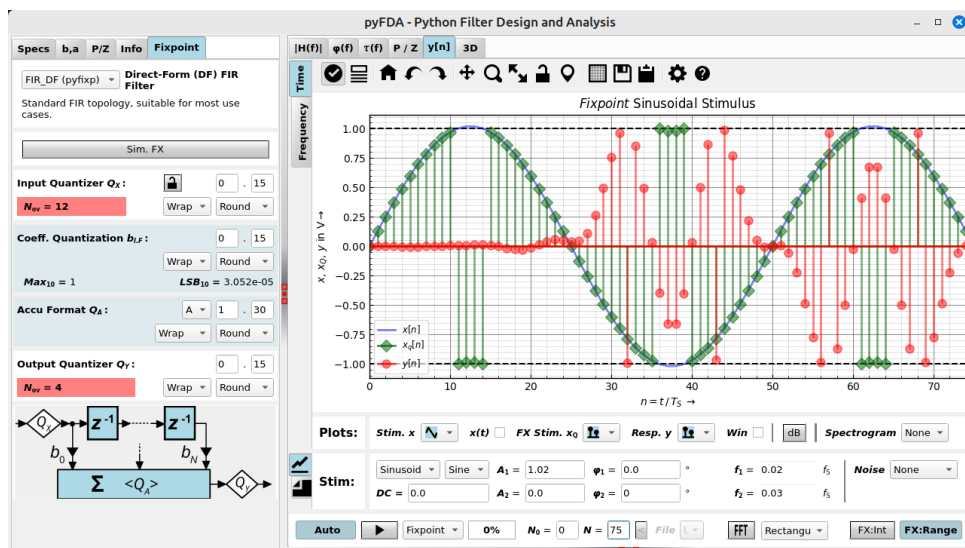


Fig. 2.27: Fixpoint filter response with overflows



## Sign extension

When increasing the number of integer bits, numbers need to be sign extended, i.e. the new leading bits need to be filled with the sign bit (Fig. 2.28). Extending the number of fractional bits just requires zero padding.

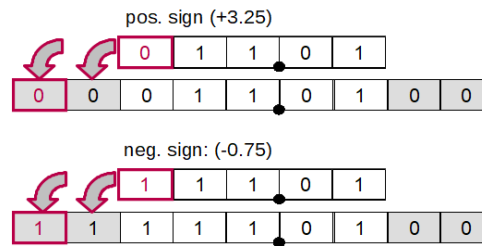


Fig. 2.28: Sign extension of integer and fractional numbers

## Overflow behaviour

After summation or when reducing the number of integer bits, the result may not fit in the numeric range.

Discarding one or more leading bits to obtain the desired wordlength is easy but may produce wrap-arounds. The resulting sign changes can introduce instability and limit-cycle oscillations to the system (Fig. 2.29, left-hand side).

Saturation (Fig. 2.29, right-hand side) is much more benign but requires a little more effort: Before adding two numbers, both need to be sign extended by one bit to enable overflow detection. As shown in Fig. 2.29, when the two leading bits (sign and carry) are 01 or 10, the result exceeds the numeric range and needs to be replaced by the maximum resp. minimum representable value. When reducing the number of integer bits, similar checks need to be performed to test for overflows.

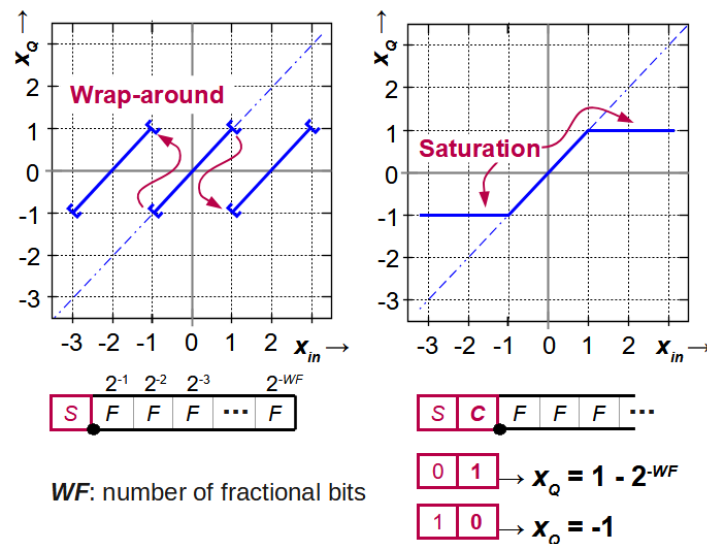


Fig. 2.29: Overflow behaviour with wrap-around or saturation

## Truncation and rounding

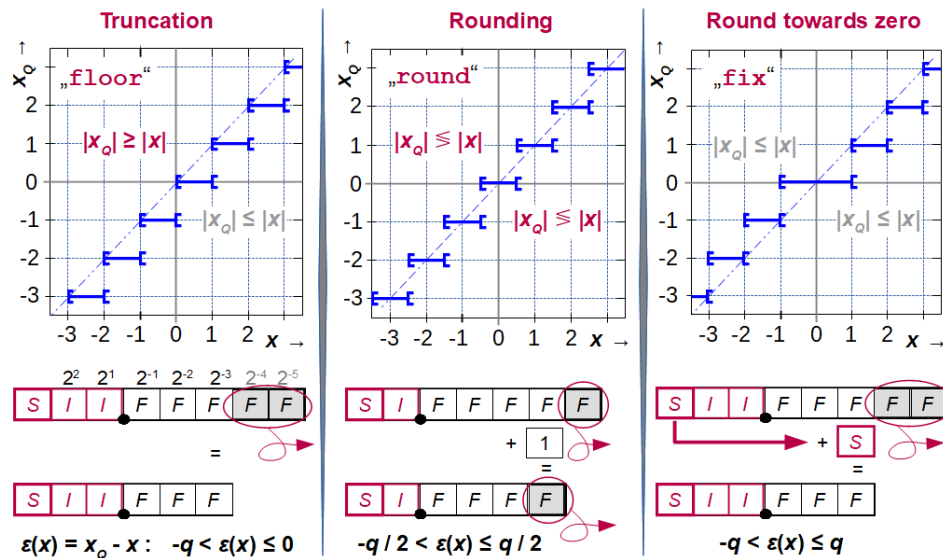


Fig. 2.30: Reducing fractional word length using truncation, rounding and round-towards-zero

The following shows an example of a positive number in Q2.4 that is converted to Q1.3 format using truncation. It's easy to see that for simple wrap-around logic, the sign of the result may change.

S	WI1	WI0	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	1	0	1	0	1	1	=	43 (QINT) or 43/16 = 2 + 11/16 (QFRAC)
v								
S	WI0	WF0	WF1	WF2				
1	0	1	0	1				
→ bit)								
: WI = 1, WF = 3, W = 5								
= -32 + 21 = -11 (subtract $-2^{\hat{W}}$ for sign_								
= -16 + 5 = -11 (sign bit as $-2^{(W-1)}$ )								
or -2 + 5/8 = -11 / 8								

## Summation

Before adding two fixpoint numbers with a different number of integer and/or fractional bits, integer and fractional word lengths need to be equalized:

- the fractional parts are padded with zeros
- the integer parts need to be sign extended, i.e. with zeros for positive numbers and with ones for negative numbers
- adding numbers can require additional integer places due to word growth

For this reason, the position of the binary point needs to be respected when summing fixpoint numbers.

S	WI1	WI0	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	1	0	1	0	1	1	=	43 (INT) or 43/16 = 2 + 11/16 (RWV)
+								
S	WI1	WI0	WF0	WF1	WF2	WF3	:	WI = 2, WF = 4, W = 7
0	0	0	1	0	1	0	=	10 (INT) or 10/16 (RWV)

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```

      =
S | WI1 | WI0 . WF0 | WF1 | WF2 | WF3 : WI = 2, WF = 4, W = 7
0 | 1   | 1   . 0   | 1   | 0   | 1   = 53 (INT) or 53/16 = 3 + 5/16 (RWV)

```

## Products

### 2.1.7 Logger Subwindow

The logging window in the lower part of the plotting window can be resized or completely closed. Its content can be selected, copied or cleared with a right mouse button context menu.

## 2.2 Customization

You can customize pyfda behaviour in some configuration files:

### 2.2.1 pyfda.conf

A copy of pyfda/pyfda.conf is created in <USER\_HOME>/pyfda/pyfda.conf where it can be edited by the user to choose which widgets and filters will be included. Fixpoint widgets can be assigned to filter designs and one or more user directories can be defined if you want to develop and integrate your own widgets (it's not so hard!):

```

# This file configures filters and plotting routines for pyFDA
# -----
# - Encoding should be either UTF-8 without BOM or standard ASCII
# - All lines starting with # or ; are regarded as comments,
#   inline comments are not allowed
# - [Section] starts a new section
# - Options and values are separated by a ":" or "=" (e.g. dir1 : /home),
#   values are optional
# - Values are "sanitized" by removing [], ' and "
# - Values are split at commas, semicolons or CRs into a list of values
# - Values starting with a { are converted to a dict
# - "Interpolation" i.e. referencing values within the config file via e.g. ${dir1}
#   or ${Common:user_dir1} can be used

#####
[Common]
#####
# Stop pyfda when the parsed conf file has a lower version than required

version = 4

#-----
# Define variables than can be referenced in other sections by preceding the
# section name, e.g. fir_df1 = ${Common:FIR} is resolved to
# fir_df1 = [Equiripple, Firwin, Manual, MA]
#-----

#
IIR = [Bessel, Butter, Cheby1, Cheby2, Ellip]

```

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```

FIR = [Equiripple, Firwin, Manual, MA]

#-----
# Add paths for special tools (optional):
#-----
# yosys = "D:\Programme\yosys-win32-mxebin-0.9\yosys.exe"

#-----
# Add user directory(s) to sys.path (optional):
#-----
#
# Specify relative or absolute path(s) to one or more user directories. These
# directories are searched for the following subdirectories which must be named
# like the corresponding pyfda directories:
#
# input_widgets      # widgets for specifying filter parameters
# plot_widgets       # widgets for plotting filter properties
# filter_widgets     # widgets for controlling filter design algorithms
# fixpoint_widgets   # widgets for specifying fixpoint filters
#
# These subdirectories need to contain an (usually empty)
# __init__.py file to be recognized as python modules.
#
# When a specified directory cannot be found, only a warning is issued.
#-----
# Uncomment and specify your user directory (optional):
#
#user_dirs = "D:\Daten\design\python\git\pyfda\pyfda\widget_templates",
#            "/home/muenker/Daten/design/python/user_pyfda"

#####
# The following sections define which classes will be imported by specifying
# the module names (= file names without .py suffix). The actual class names are
# obtained from a module level attribute "classes" in each module which can be a:
#
# - String, e.g. classes = "MyClassName"
# - List, e.g.   classes = ["MyClassName1", "MyClassName2"]
# - Dict, e.g.   classes = {"MyClassName1": "DisplayName1", "MyClassName2":
#   ↳ "DisplayName2"}
#
# When no display name is given, the class name is used for tab labels, combo boxes,
# ↳ etc.
#
# Modules are searched in all directories defined in sys.path and the user dir(s)
# and their subdirectories containing __init__.py files (subpackages) with the
# names listed above ("input_widgets" etc.)
#
# In addition to specifying only the module name, options can be passed as key-
# value combinations. Unknown options just raise a warning.

#####
[Input Widgets]
#####
# Try to import from the following input widget modules (files) from sys.path

```

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```

# and subdirectories / subpackages named "input_widgets".

input_specs
input_coeffs
input_pz
input_info
input_fixpoint_specs

#####
[Plot Widgets]
#####
# Try to import from the following plot widget modules (files) from sys.path
# and subdirectories / subpackages named "plot_widgets".

plot_hf : {'opt1':'aaa', 'opt2':'bbb'}
plot_phi
plot_tau_g
plot_pz
plot_impz
plot_3d
# myplot # this could be the name of your user module

#####
[Filter Widgets]
#####
# The specified filter design modules (files) are searched for in sys.path
# and in subdirectories / subpackages named "filter_widgets".
#
# The optional 'fix' argument defines one or more fixpoint implementations for
# the filter design. Unknown fixpoint implementations only raise a warning.
# In the "Fixpoint Widgets" section, fixpoint implementation can be assigned
# to filter designs as well.

# --- IIR ---
# super_filter : {'fix':['iir_cascade', 'iir_df1']}
# bessell : {'fix':['iir_cascade', 'iir_df1']}
bessell
butter
# cheby1 : "yet another option"
cheby1
# cheby2 : {'fix':'iir_special'}
cheby2
ellip
# ellip_zero # too specialized for general usage

# --- FIR ---
equiripple
firwin
ma
# delay # still buggy
# savitzky_golay # not implemented yet

# --- Manual (both FIR and IIR) ---
manual

```

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```
#####
[Fixpoint Widgets]
#####
# Try to import from the following fixpoint widget modules (files) from sys.path
# and subdirectories / subpackages named "fixpoint_widgets".
#
# Value is a filter design or a list of filter designs for which the fixpoint
# widget can be used.

fir_df.fir_df_pyfixp_ui = ${Common:FIR}
iir_df1.iir_df1_pyfixp_ui = ${Common:IIR}
# fir_df.fir_df_amaranth_ui = ${Common:FIR}
# fx_delay = ['Equiripple', 'Delay'] # need to fix fx_delay and Delay modules
```

## 2.2.2 pyfda\_log.conf

A copy of pyfda/pyfda\_log.conf is created in <USER\_HOME>/pyfda/pyfda\_log.conf where it can be edited to control logging behaviour:

```
[loggers]
# List of loggers:
# - root logger has to be present
# - section name is "logger_" + name specified in the keys below. The logger
#   name is derived automatically in the files-to-be-logged from their
#   __name__ attribute (i.e. the file name without suffix)
# When a file doesn't exist (e.g. no_existo.py)
#
keys=root, pyfdax, pyfda_class, filter_factory, filterbroker,
    pyfda_lib, pyfda_sig_lib, pyfda_fix_lib, pyfda_qt_lib, pyfda_io_lib,
    pyfda_fft_windows_lib, tree_builder, csv_option_box,
    amplitude_specs, freq_specs, freq_units, input_coeffs, input_coeffs_ui,
    input_fixpoint_specs, input_info, input_pz, input_pz_ui, input_specs,
    input_tab_widgets, select_filter, target_specs,
    bessel, equiripple, firwin,
    fir_df_pyfixp, fir_df_pyfixp_ui, iir_df1_pyfixp, iir_df1_pyfixp_ui,
    mpl_widget, plot_3d, plot_fft_win, plot_hf, plot_impz, plot_impz_ui,
    plot_phi, plot_pz, plot_tab_widgets, plot_tau_g,
    plot_tran_stim, plot_tran_stim_ui, tran_io, tran_io_ui,
    no_existo

[handlers]
# List of handlers
keys=consoleHandler,fileHandler,QHandler

[formatters]
# List of formatters
keys=simpleFormatter,noDateFormatter,ezFormatter

# =====
[logger_root]
level=NOTSET
handlers=consoleHandler, QHandler

[logger_pyfdax]
level=INFO
```

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```

handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.pyfdax
propagate=0

[logger_pyfda_class]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.pyfda_class
propagate=0

[logger_filter_factory]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.filter_factory
propagate=0

[logger_filterbroker]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.filterbroker
propagate=0

#----- libs -----
[logger_pyfda_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.pyfda_lib
propagate=0

[logger_pyfda_sig_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.pyfda_sig_lib
propagate=0

[logger_pyfda_fix_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.pyfda_fix_lib
propagate=0

[logger_pyfda_qt_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.pyfda_qt_lib
propagate=0

[logger_pyfda_io_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.pyfda_io_lib
propagate=0

[logger_pyfda_fft_windows_lib]
level=INFO
handlers=fileHandler,consoleHandler, QHandler

```

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```

qualname=pyfda.libs.pyfda_fft_windows_lib
propagate=0

[logger_tree_builder]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.tree_builder
propagate=0

[logger_csv_option_box]
level=INFO
handlers=fileHandler,consoleHandler, QHandler
qualname=pyfda.libs.csv_option_box
propagate=0

#----- input_widgets -----
[logger_amplitude_specs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.amplitude_specs
propagate=0

[logger_freq_specs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.freq_specs
propagate=0

[logger_freq_units]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.freq_units
propagate=0

[logger_input_coeffs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_coeffs
propagate=0

[logger_input_coeffs_ui]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_coeffs
propagate=0

[logger_input_fixpoint_specs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_fixpoint_specs
propagate=0

[logger_input_info]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_info

```

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```

propagate=0

[logger_input_pz]
level=WARNING
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_pz
propagate=0

[logger_input_pz_ui]
level=WARNING
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_pz_ui
propagate=0

[logger_input_specs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_specs
propagate=0

[logger_input_tab_widgets]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.input_tab_widgets
propagate=0

[logger_select_filter]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.select_filter
propagate=0

[logger_target_specs]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.input_widgets.target_specs
propagate=0

#----- filter_widgets -----
[logger_bessel]
level=INFO
handlers=fileHandler, consoleHandler,QHandler
qualname=pyfda.filter_widgets.bessel
propagate=0

[logger_equiripple]
level=INFO
handlers=fileHandler, consoleHandler,QHandler
qualname=pyfda.filter_widgets.equiripple
propagate=0

[logger_firwin]
level=INFO
handlers=fileHandler, consoleHandler,QHandler
qualname=pyfda.filter_widgets.firwin
propagate=0

```

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```

#----- fixpoint_widgets -----
[logger_fir_df_pyfixp]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.fixpoint_widgets.fir_df.fir_df_pyfixp
propagate=0

[logger_fir_df_pyfixp_ui]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.fixpoint_widgets.fir_df.fir_df_pyfixp_ui
propagate=0

[logger_iir_df1_pyfixp]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.fixpoint_widgets.iir_df1.iir_df1_pyfixp
propagate=0

[logger_iir_df1_pyfixp_ui]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.fixpoint_widgets.iir_df1.iir_df1_pyfixp_ui
propagate=0
#----- plot_widgets -----
[logger_mpl_widget]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.mpl_widget
propagate=0

[logger_plot_3d]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_3d
propagate=0

[logger_plot_fft_win]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.logger_plot_fft_win
propagate=0

[logger_plot_hf]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_hf
propagate=0

[logger_plot_impz]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_impz
propagate=0

[logger_plot_impz_ui]

```

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```

level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_impz_ui
propagate=0

[logger_plot_phi]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_phi
propagate=0

[logger_plot_pz]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_pz
propagate=0

[logger_plot_tab_widgets]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_tab_widgets
propagate=0

[logger_plot_tau_g]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.plot_tau_g
propagate=0

[logger_plot_tran_stim]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.tran.plot_tran_stim
propagate=0

[logger_plot_tran_stim_ui]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.tran.plot_tran_stim_ui
propagate=0

[logger_tran_io]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.tran.tran_io
propagate=0

[logger_tran_io_ui]
level=INFO
handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.tran.tran_io_ui
propagate=0

#----- Test Case, file doesn't exist -----
[logger_no_existo]
level=INFO

```

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```

handlers=fileHandler,consoleHandler,QHandler
qualname=pyfda.plot_widgets.no_existo
propagate=0
#-----

# specify how to log to:  text console / logging file / GUI logging window
#
# For each handler, define the class (implementation), formatting (see next section)
# and the minimum logging level (defined by the higher of global and individual level,
# e.g. level=INFO prevents all DEBUG level messages).
#---- Console
[handler_consoleHandler]
class=StreamHandler
level=INFO
formatter=noDateFormatter
args=(sys.stdout,)
#---- File
[handler_fileHandler]
class=DynFileHandler # FileHandler is default
level=INFO
formatter=simpleFormatter
args=('pyfda.log', 'w', 'utf-8') # overwrites log file
#args=('pyfda.log','a', 'utf-8') # appends to log file
#---- GUI
[handler_QHandler]
class=QEditHandler
level=INFO
formatter=ezFormatter
args=()

#-----

[formatter_simpleFormatter]
format=[%(asctime)s.%(msecs).03d] [%(levelname)7s] [%(name)s:%(lineno)s] %(message)s
# for linebreaks simply make one!
datefmt=%Y-%m-%d %H:%M:%S

[formatter_noDateFormatter]
format=[%(levelname)7s] [%(name)s:%(lineno)s] %(message)s

[formatter_ezFormatter]
format=[%(levelname)7s] [%(asctime)s.%(msecs).03d] [%(filename)s:%(lineno)d]
→%(message)s
datefmt=%H:%M:%S

```

### 2.2.3 pyfda\_rc.py

Layout and some parameters can be customized with the file `pyfda/pyfda_rc.py` (within the install directory right now, no user copy).

## DEVELOPMENT

This part of the documentation describes the features of pyFDA that are relevant for developers.

### 3.1 Software Organization

The software is organized as shown in the following figure

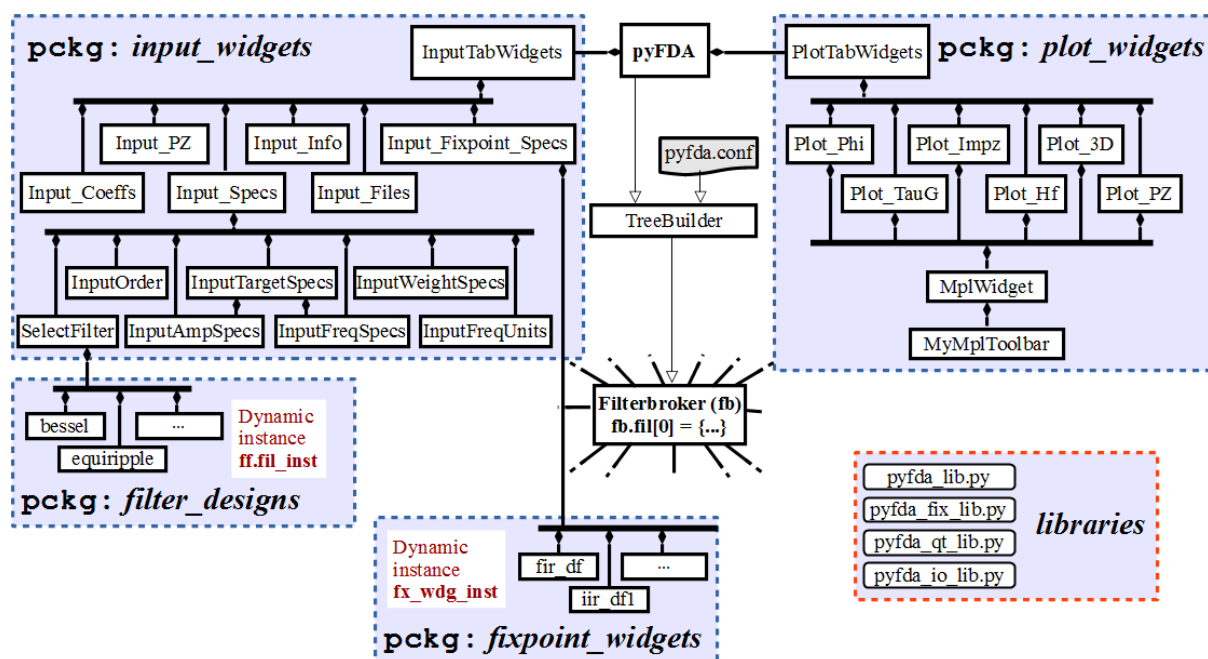


Fig. 3.1: pyfda Organization

#### Communication:

The modules communicate via Qt's signal-slot mechanism (see: *Signalling: What's up?*).

#### Data Persistence:

Common data is stored in dicts that can be accessed globally (see: *Persistence: Where's the data?*).

#### Customization:

The software can be customized a.o. via the file **conf.py** (see: *Customization*).

## 3.2 Signalling: What's up?

The figure above shows the general pyfda hierarchy. When parameters or settings are changed in a widget, a Qt signal is emitted that can be processed by other widgets with a `sig_rx` slot for receiving information. The dict `dict_sig` is attached to the signal as a “payload”, providing information about the sender and the type of event. `sig_rx` is connected to the `process_sig_rx()` method that processes the dict.

Many Qt signals can be connected to one Qt slot and one signal to many slots, so signals of input and plot widgets are collected in `pyfda.input_widgets.input_tab_widgets` and `pyfda.plot_widgets.plot_tab_widgets` respectively and connected collectively.

When a redraw / calculations can take a long time, it makes sense to perform these operations only when the widget is visible and store the need for a redraw in a flag.

```
class MyWidget(QWidget):
    sig_resize = pyqtSignal()    # emit a local signal upon resize
    sig_rx = pyqtSignal(object)  # incoming signal
    sig_tx = pyqtSignal(object)  # outgoing signal
    from pyfda.libs.pyfda_qt_lib import emit

    def __init__(self, parent):
        super(MyWidget, self).__init__(parent)
        self.data_changed = True # initialize flags
        self.view_changed = True
        self.filt_changed = True
        self.sig_rx.connect(self.process_sig_rx)
        # usually done in method ``_construct_UI()``

    def process_sig_rx(self, dict_sig=None):
        """
        Process signals coming in via subwidgets and sig_rx
        """
        if dict_sig['id'] == id(self):
            logger.warning("Stopped infinite loop:\n{0}".format(pprint_log(dict_sig)))
            return
        if self.isVisible():
            if 'data_changed' in dict_sig or self.data_changed:
                self.recalculate_some_data() # this may take time ...
                self.data_changed = False
            if 'view_changed' in dict_sig and dict_sig['view_changed'] == 'new_limits'\
            or self.view_changed:
                self._update_my_plot()      # ... while this just updates the display
                self.view_changed = False
            if 'filt_changed' in dict_sig or self.filt_changed:
                self.update_wdg_UI()        # new filter needs new UI options
                self.filt_changed = False
        else:
            if 'data_changed' in dict_sig or 'view_changed' in dict_sig:
                self.data_changed = True
                self.view_changed = True
            if 'filt_changed' in dict_sig:
                self.filt_changed = True
```

Data can be transmitted via the global `sig_tx` signal (referenced by the imported `emit()` method):

```
dict_sig = {'fx_sim': 'update_data', 'fx_results': some_new_data}
self.emit(dict_sig)
```

The following dictionary keys are generally used, individual ones can be created as needed.

**‘id’**

Python `id(self)` reference to the sending widget instance, needed a.o. to prevent infinite loops which may occur when the rx event is connected to the tx signal. **Automatically added by** ```emit()`` if not in ``dict_sig```.

**‘class’**

Class name of the sending widget, usually given as `self.__class__.__name__`. This can be used for debugging purposes. **Automatically added by** ```emit()`` if not in ``dict_sig```.

**‘ttl’**

Optional, defines the “time-to-live”. The integer value given at definition is decreased every time `emit()` is called. When zero is reached, the signal is terminated.

**‘filt\_changed’**

A different filter type (response type, algorithm, ...) has been selected or loaded, requiring an update of the UI in some widgets.

**‘data\_changed’**

A filter has been designed and the actual data (e.g. coefficients) has changed, you can add the (short) name or a data description as the dict value. When this key is sent, most widgets have to be updated.

**‘specs\_changed’**

Filter specifications have changed - this will influence only a few widgets like the *plot\_hf* widget that plots the filter specifications as an overlay or the *input\_info* widget that compares filter performance to filter specifications.

**‘view\_changed’**

When e.g. the range of the frequency axis is changed from  $0 \dots f_S/2$  to  $-f_S/2 \dots f_S/2$ , this information can be propagated with the ‘view\_changed’ key.

**‘ui\_local\_changed’**

Propagate a change of the UI to the containing widget but not to other widgets, examples are:  
- ‘ui\_local\_changed’: `self.sender().objectName()` to propagate the name of the emitting subwidget

**‘ui\_global\_changed’**

Propagate a change of the UI to other widgets, examples are:

- ‘ui\_global\_changed’: ‘csv’ for a change of CSV import / export options
- ‘ui\_global\_changed’: ‘resize’ when the parent window has been resized
- ‘ui\_global\_changed’: ‘tab’ when a different tab has been selected

**‘fx\_sim’**

Signal the phase / status of a fixpoint simulation (‘finished’, ‘error’)

### 3.3 Persistence: Where’s the data?

At startup, a dictionary is constructed with information about the filter classes and their methods. The central dictionary `fb.dict` is initialized.

## 3.4 Main Routines

### 3.4.1 `pyfda.libs.pyfda_dirs`

Handle directories in an OS-independent way, create logging directory etc. Upon import, all the variables are set. This is imported first by `pyfdax`, logger cannot be used yet. Hence, messages are printed to the console.

`pyfda.libs.pyfda_dirs.CONF_FILE = 'pyfda.conf'`

name for general configuration file

`pyfda.libs.pyfda_dirs.HOME_DIR = '/home/docs'`

Home dir and user name

`pyfda.libs.pyfda_dirs.LOG_CONF_FILE = 'pyfda_log.conf'`

name for logging configuration file

`pyfda.libs.pyfda_dirs.LOG_DIR_FILE = '/tmp/.pyfda/pyfda_20240423-191007.log'`

Name of the log file, can be changed in `pyfdax.py`

`pyfda.libs.pyfda_dirs.TEMP_DIR = '/tmp'`

Temp directory for constructing logging dir

`pyfda.libs.pyfda_dirs.USER_DIRS = []`

Placeholder for user widgets directory list, set by `treebuilder`

`pyfda.libs.pyfda_dirs.USER_NAME = ''`

Home dir and user name

`pyfda.libs.pyfda_dirs.copy_conf_files(force_copy=False, logger=None)`

If they don't exist, create `pyfda.conf` und `pyfda_log.conf` from template files. in the user directory where they can be edited by the user without admin rights. If they exist and `force_copy=True`, make a backup of the old files and then overwrite them.

#### Parameters

- **force\_copy** (*bool*) – When True, make a backup and overwrite existing config files.
- **logger** (*logger instance*) – Write info and error messages to *logger* when it exists, otherwise use `print()`. When called during the initial phase, loggers have not been created yet and `print()` has to be used.

#### Return type

None.

`pyfda.libs.pyfda_dirs.env(name)`

Get value for environment variable *name* from the OS.

#### Parameters

**name** (*str*) – environment variable

#### Returns

value of environment variable

#### Return type

*str*

`pyfda.libs.pyfda_dirs.get_conf_dir()`

Return the user's configuration directory

`pyfda.libs.pyfda_dirs.get_home_dir()`

Return the user's home directory and name



`pyfda.libs.pyfda_dirs.get_log_dir()`

Try different OS-dependent locations for creating log files and return the first suitable directory name. Only called once at startup.

see <https://stackoverflow.com/questions/847850/cross-platform-way-of-getting-temp-directory-in-python>

`pyfda.libs.pyfda_dirs.get_yosys_dir()`

Try to find YOSYS path and version from environment variable or path:

`pyfda.libs.pyfda_dirs.last_file_dir = '/home/docs'`

Place holder for file type selected (e.g. “csv”) in last file dialog

`pyfda.libs.pyfda_dirs.last_file_name = ''`

Place holder for storing the directory location of the last file

`pyfda.libs.pyfda_dirs.last_file_type = ''`

Global handle to pop-up window for CSV options - this window must be closed before opening another pop-up window! Otherwise, the second window becomes unaccessible (?) and pyfda becomes unresponsive.

`pyfda.libs.pyfda_dirs.update_conf_files(logger)`

Copy templates to user config and logging config files, making backups of the old versions.

`pyfda.libs.pyfda_dirs.valid(path)`

Check whether path exists and is valid

### 3.4.2 pyfda.libs.tree\_builder

Create the tree dictionaries containing information about filters, filter implementations, widgets etc. in hierarchical form

**exception** `pyfda.libs.tree_builder.ParseError`

**class** `pyfda.libs.tree_builder.Tree_Builder`

Read the config file and construct dictionary trees with

- all filter combinations
- valid combinations of filter widgets and fixpoint implementations

**build\_class\_dict**(*section*, *subpackage*=“”)

- Try to dynamically import the modules (= files) parsed in *section* reading their module level attribute *classes* listing the classes contained in the module.

When *classes* is a dictionary, e.g. {“Cheby”: “Chebyshev I”} where the key is the class name in the module and the value the corresponding display name (used for the combo box).

- When *classes* is a string or a list, use the string resp. the list items for both class and display name.
- Try to import the filter classes

#### Parameters

- **section** (*str*) – Name of the section in the configuration file to be parsed by `self.parse_conf_section`.
- **subpackage** (*str*) – Name of the subpackage containing the module to be imported. Module names are prepended successively with [`‘pyfda.’` + *subpackage* + `‘.’`, `‘sub-package’` + `‘.’`]

#### Returns

- **classes\_dict** (*dict*)
- A dictionary with the *classes* as keys; values are dicts which define

- the options (like display name, module path, fixpoint implementations etc).
  - Each entry has the form e.g.
  - {<class name> ({'name':<display name>, 'mod':<full module name>}) e.g.)
  - .. code-block:: python –
- ```
{'Cheby1':{'name':'Chebyshev 1',
  'mod':'pyfda.filter_design.cheby1', 'fix': 'IIR_cascade', 'opt': ["option1", "option2"]}}
```

**build\_fil\_tree**(fc, rt\_dict, fil\_tree=None)

Read attributes (ft, rt, rt:fo) from filter class fc) Attributes are stored in the design method classes in the format (example from `common.py`)

```
self.ft = 'IIR'
self.rt_dict = {
    'LP': {'man':{'fo':      ('a','N'),
                        'msg':      ('a', r"<br /><b>Note:</b> Read this!"),
                        'fspecs': ('a','F_C'),
                        'tspecs': ('u', {'freq':('u','F_PB','F_SB'),
   'amp':('u','A_PB','A_SB')})},
          },
    'min':{'fo':      ('d','N'),
          'fspecs': ('d','F_C'),
          'tspecs': ('a', {'freq':('a','F_PB','F_SB'),
                           'amp':('a','A_PB','A_SB')})},
          },
    'HP': {'man':{'fo':      ('a','N'),
                        'fspecs': ('a','F_C'),
                        'tspecs': ('u', {'freq':('u','F_SB','F_PB'),
   'amp':('u','A_SB','A_PB')})},
          },
    'min':{'fo':      ('d','N'),
          'fspecs': ('d','F_C'),
          'tspecs': ('a', {'freq':('a','F_SB','F_PB'),
                           'amp':('a','A_SB','A_PB')})},
          },
    }
}
```

Build a dictionary of all filter combinations with the following hierarchy:

response types -> filter types -> filter classes -> filter order rt (e.g. 'LP') ft (e.g. 'IIR') fc (e.g. 'cheby1') fo ('min' or 'man')

All attributes found for fc are arranged in a dict, e.g. for `cheby1.LPman` and `cheby1.LPmin`, listing the parameters to be displayed and whether they are active, unused, disabled or invisible for each subwidget:

```
'LP':{
'IIR':{
  'Cheby1':{
    'man':{'fo':      ('a','N'),
              'msg':      ('a', r"<br /><b>Note:</b> Read this!"),
              'fspecs': ('a','F_C'),
              'tspecs': ('u', {'freq':('u','F_PB','F_SB'),
                               'amp':('u','A_PB','A_SB')})},
          },
    },
  }
```

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```

        'min': {'fo':      ('d', 'N'),
                'fspecs': ('d', 'F_C'),
                'tspecs': ('a', {'freq': ('a', 'F_PB', 'F_SB'),
                                     'amp': ('a', 'A_PB', 'A_SB')})
              }
    }
}
}, ...

```

Finally, the whole structure is frozen recursively to avoid inadvertently changing the filter tree.

For a full example, see the default filter tree `fb.fil_tree` defined in `filterbroker.py`.

#### Parameters

None

#### Returns

filter tree

#### Return type

dict

### `init_filters()`

Run at startup to populate global dictionaries and lists:

- Read attributes (*ft*, *rt*, *fo*) from all valid filter classes (*fc*) in the global dict `fb.filter_classes` and store them in the filter tree dict `fil_tree` with the hierarchy

**rt-ft-fc-fo-subwidget:params** .

#### Parameters

None

#### Returns

- `fb.fil_tree` :

#### Return type

None, but populates the following global attributes

### `parse_conf_file()`

Parse the configuration file `pyfda.conf` (specified in `dirs.USER_CONF_DIR_FILE`). This is run only once at instantiation.

This is performed using `build_class_dict()` which calls `parse_conf_section()`:

- Try to find and import the modules specified in the corresponding sections
- Extract and import the classes defined in each module and give back an `OrderedDict` with the successfully imported classes and their options (like fully qualified module names, display name, associated fixpoint widgets etc.).
- Information for each section is stored in globally accessible `OrderedDicts` like `fb.filter_classes`.

The following sections are analyzed:

#### [Commons]

Try to find user directories; if they exist add them to `dirs.USER_DIRS` and `sys.path`

For the other sections, `OrderedDicts` are returned with the class names as keys and dictionaries with options as values.

#### [Input Widgets]

Store (user) input widgets in `fb.input_classes`

**[Plot Widgets]**

Store (user) plot widgets in *fb.plot\_classes*

**[Filter Widgets]**

Store (user) filter widgets in *fb.filter\_classes*

**[Fixpoint Widgets]**

Store (user) fixpoint widgets in *fb.fixpoint\_classes*

**Parameters**

None

**Return type**

None, but *self.conf* contains the parsed configuration file.

**parse\_conf\_section(section)**

Parse section in config file *conf* and return an OrderedDict with the elements {key:<OPTION>} where *key* and <OPTION> have been read from the config file. <OPTION> has been sanitized and converted to a list or a dict.

**Parameters**

**section** (*str*) – name of the section to be parsed

**Returns**

**section\_conf\_dict** – Ordered dict with the keys of the config files and corresponding values

**Return type**

dict

`pyfda.libs.tree_builder.merge_dicts_hierarchically(d1, d2, path=None, mode='keep1')`

Merge the hierarchical dictionaries *d1* and *d2*. The dict *d1* is modified in place and returned

**Parameters**

- **d1** (*dict*) – hierarchical dictionary 1
- **d2** (*dict*) – hierarchical dictionary 2
- **mode** (*str*) – Select the behaviour when the same key is present in both dictionaries:
  - **'keep1'**  
keep the entry from *d1* (default)
  - **'keep2'**  
keep the entry from *d2*
  - **'add1'**  
merge the entries, putting the values from *d2* first (important for lists)
  - **'add2'**  
merge the entries, putting the values from *d1* first ( “ )
- **path** (*str*) – internal parameter for keeping track of hierarchy during recursive calls, it should not be set by the user

**Returns**

**d1** – a reference to the first dictionary, merged-in-place.

**Return type**

dict

### Example

```
>>> merge_dicts_hierarchically(fil_tree, fil_tree_add, mode='add1')
```

### Notes

If you don't want to modify d1 in place, call the function using:

```
>>> new_dict = merge_dicts_hierarchically(dict(d1), d2)
```

If you need to merge more than two dicts use:

```
>>> from functools import reduce # only for py3
>>> reduce(merge, [d1, d2, d3...]) # add / merge all other dicts into d1
```

Taken with some modifications from:

<http://stackoverflow.com/questions/7204805/dictionaries-of-dictionaries-merge>

## 3.4.3 pyfda.filter\_factory

Dynamic parameters and settings are exchanged via the dictionaries in this file. Importing `filterbroker.py` runs the module once, defining all module variables which have a global scope like class variables and can be imported like

```
>>> import filter_factory as ff
>>> myfil = ff.fil_factory
```

### class pyfda.filter\_factory.FilterFactory

This class implements a filter factory that (re)creates the globally accessible filter instance `fil_inst` from module path and class name, passed as strings.

#### call\_fil\_method(method, fil\_dict, fc=None)

Instantiate the filter design class passed as string `fc` with the globally accessible handle `fil_inst`. If `fc = None`, use the previously instantiated filter design class.

Next, call the design method passed as string `method` of the instantiated filter design class.

#### Parameters

- **method** (*string*) – The name of the design method to be called (e.g. 'LPmin')
- **fil\_dict** (*dictionary*) – A dictionary with all the filter specs that is passed to the actual filter design routine. This is usually a copy of `fb.fil[0]` The results of the filter design routine are written back to the same dict.
- **fc** (*string (optional, default: None)*) – The name of the filter design class to be instantiated. When nothing is specified, the last filter selection is used.

#### Returns

**err\_code** –

one of the following error codes:

- 1  
filter design operation has been cancelled by user
- 0  
filter design method exists and is callable

- 16  
passed method name is not a string
- 17  
filter design method does not exist in class
- 18  
filter design error containing “order is too high”
- 19  
filter design error containing “failure to converge”
- 99  
unknown error

**Return type**

`int`

**Examples**

```
>>> call_fil_method("LPmin", fil[0], fc="cheby1")
```

The example first creates an instance of the filter class ‘cheby1’ and then performs the actual filter design by calling the method ‘LPmin’, passing the global filter dictionary `fil[0]` as the parameter.

**create\_fil\_inst(*fc*, *mod=None*)**

Create an instance of the filter design class passed as a string `fc` from the module found in `fb.filter_classes[fc]`. This dictionary has been collected by `tree_builder.py`.

The instance can afterwards be globally referenced as `fil_inst`.

**Parameters**

- **fc** (*str*) – The name of the filter design class to be instantiated (e.g. ‘cheby1’ or ‘equiripple’)
- **mod** (*str* (*optional*, *default = None*)) – Fully qualified name of the filter module. When not specified, it is read from the global dict `fb.filter_classes[fc]['mod']`

**Returns**

**err\_code** –

one of the following error codes:

- 1  
filter design class was instantiated successfully
- 0  
filter instance exists, no re-instantiation necessary
- 1  
filter module not found by FilterTreeBuilder
- 2  
filter module found by FilterTreeBuilder but could not be imported
- 3  
filter class could not be instantiated
- 4  
unknown error during instantiation

**Return type**

`int`

## Examples

```
>>> create_fil_instance('cheby1')
>>> fil_inst.LPmin(fil[0])
```

The example first creates an instance of the filter class 'cheby1' and then performs the actual filter design by calling the method 'LPmin', passing the global filter dictionary `fil[0]` as the parameter.

```
pyfda.filter_factory.fil_factory = <pyfda.filter_factory.FilterFactory object>
```

Class instance of FilterFactory that can be accessed in other modules

```
pyfda.filter_factory.fil_inst = None
```

Instance of current filter design class (e.g. "cheby1"), globally accessible

```
>>> import filter_factory as ff
>>> ff.fil_factory.create_fil_instance('cheby1') # create instance of dynamic_
↪ class
>>> ff.fil_inst.LPmin(fil[0]) # design a filter
```

### 3.4.4 pyfda.filterbroker

Dynamic parameters and settings are exchanged via the dictionaries in this file. Importing `filterbroker.py` runs the module once, defining all module variables which have a global scope like class variables and can be imported like

```
>>> import filterbroker as fb
>>> myfil = fb.fil[0]
```

The entries in this file are only used as initial / default entries and to demonstrate the structure of the global dicts and lists. These initial values are also handy for module-level testing where some useful settings of the variables is required.

## Notes

Alternative approaches for data persistence could be the packages *shelve* or *pickleshare* More info on data persistence and storing / accessing global variables:

- <http://stackoverflow.com/questions/13034496/using-global-variables-between-files-in-python>
- <http://stackoverflow.com/questions/1977362/how-to-create-module-wide-variables-in-python>
- [http://pymotw.com/2/articles/data\\_persistence.html](http://pymotw.com/2/articles/data_persistence.html)
- <http://stackoverflow.com/questions/9058305/getting-attributes-of-a-class>
- <http://stackoverflow.com/questions/2447353/getattr-on-a-module>

```
pyfda.filterbroker.base_dir = ''
```

Project base directory

```
pyfda.filterbroker.clipboard = None
```

Handle to central clipboard instance

```
pyfda.filterbroker.filter_classes = {'Bessel': {'mod':
'pyfda.filter_widgets.bessel', 'name': 'Bessel'}, 'Butter': {'mod':
'pyfda.filter_widgets.butter', 'name': 'Butterworth'}, 'Cheby1': {'mod':
'pyfda.filter_widgets.cheby1', 'name': 'Chebyshev 1'}, 'Cheby2': {'mod':
'pyfda.filter_widgets.cheby2', 'name': 'Chebyshev 2'}, 'Ellip': {'mod':
'pyfda.filter_widgets.ellip', 'name': 'Elliptic'}, 'EllipZeroPhz': {'mod':
'pyfda.filter_widgets.ellip_zero', 'name': 'EllipZeroPhz'}, 'Equiripple': {'mod':
'pyfda.filter_widgets.equiripple', 'name': 'Equiripple'}, 'Firwin': {'mod':
'pyfda.filter_widgets.firwin', 'name': 'Windowed FIR'}, 'MA': {'mod':
'pyfda.filter_widgets.ma', 'name': 'Moving Average'}, 'Manual_FIR': {'mod':
'pyfda.filter_widgets.manual', 'name': 'Manual'}, 'Manual_IIR': {'mod':
'pyfda.filter_widgets.manual', 'name': 'Manual'}}
```

The keys of this dictionary are the names of all found filter classes, the values are the name to be displayed e.g. in the comboboxes and the fully qualified name of the module containing the class.

`pyfda.filterbroker.redo()`

Store current filter to undo memory *fil\_undo*

`pyfda.filterbroker.undo()`

Restore current filter from undo memory *fil\_undo*

## 3.5 Libraries

pyfda contains the following libraries:

- *pyfda\_lib*: General functions
- *pyfda\_sig\_lib*: Functions related to signal processing
- *pyfda\_qt\_lib*: Functions related to Qt
- *pyfda\_io\_lib*: Functions related to file I/O
- *pyfda\_fix\_lib*: Fixpoint classes and functions

### 3.5.1 pyfda\_lib

Library with various general functions and variables needed by the pyfda routines

`pyfda.libs.pyfda_lib.H_mag(num, den, z, H_max, H_min=None, log=False, div_by_0='ignore')`

Calculate  $|H(z)|$  at the complex frequency(ies)  $z$  (scalar or array-like). The function  $H(z)$  is given in polynomial form with numerator and denominator. When `log == True`,  $20 \log_{10}(|H(z)|)$  is returned.

The result is clipped at  $H_{\min}$ ,  $H_{\max}$ ; clipping can be disabled by passing `None` as the argument.

#### Parameters

- **num** (*float* or *array-like*) – The numerator polynome of  $H(z)$ .
- **den** (*float* or *array-like*) – The denominator polynome of  $H(z)$ .
- **z** (*float* or *array-like*) – The complex frequency(ies) where  $H(z)$  is to be evaluated
- **H\_max** (*float*) – The maximum value to which the result is clipped
- **H\_min** (*float*, *optional*) – The minimum value to which the result is clipped (default: `None`)
- **log** (*boolean*, *optional*) – When true, return  $20 * \log_{10}(|H(z)|)$ . The clipping limits have to be given as dB in this case.



- **div\_by\_0** (*string*, *optional*) – What to do when division by zero occurs during calculation (default: ‘ignore’). As the denominator of  $H(z)$  becomes 0 at each pole, warnings are suppressed by default. This parameter is passed to `numpy.seterr()`, hence other valid options are ‘warn’, ‘raise’ and ‘print’.

**Returns**

**H\_mag** – The magnitude  $|H(z)|$  for each value of  $z$ .

**Return type**

`float` or `ndarray`

`pyfda.libs.pyfda_lib.calc_Hcomplex(fil_dict, worN, wholeF, fs=6.283185307179586)`

A wrapper around `signal.freqz()` for calculating the complex frequency response  $H(f)$  for antiCausal systems as well. The filter coefficients are extracted from the filter dictionary.

**Parameters**

- **fil\_dict** (*dict*) – dictionary with filter data (coefficients etc.)
- **worN** (*{None, int or array-like}*) – number of points or frequencies where the frequency response is calculated
- **wholeF** (*bool*) – when True, calculate frequency response from  $0 \dots f_S$ , otherwise calculate between  $0 \dots f_S/2$
- **fs** (*float*) – sampling frequency, used for calculation of the frequency vector. The default is  $2\pi$

**Returns**

- **w** (*ndarray*) – The frequencies at which  $h$  was computed, in the same units as  $fs$ . By default,  $w$  is normalized to the range  $[0, \pi)$  (radians/sample).
- **h** (*ndarray*) – The frequency response, as complex numbers.

**Examples**

`pyfda.libs.pyfda_lib.ceil_even(x) → int`

Return the smallest even integer not less than  $x$ .  $x$  can be integer or float.

`pyfda.libs.pyfda_lib.ceil_odd(x) → int`

Return the smallest odd integer not less than  $x$ .  $x$  can be integer or float.

`pyfda.libs.pyfda_lib.clean_ascii(arg)`

Remove non-ASCII-characters (outside range  $0 \dots x7F$ ) from *arg* when it is a *str*. Otherwise, return *arg* unchanged.

**Parameters**

**arg** (*str*) – This is a unicode string under Python 3

**Returns**

**arg** – Input string, cleaned from non-ASCII characters when *arg* is a string

or

Unchanged parameter *arg* when not a string

**Return type**

`str`

`pyfda.libs.pyfda_lib.cmp_version(mod, version)`

Compare version number of installed module *mod* against string *version* and return 1, 0 or -1 if the installed version is greater, equal or less than the number in *version*. If *mod* is not installed, return -2.

**Parameters**

- **mod** (*str*) – name of the module to be compared
- **version** (*str*) – version number in the form e.g. “0.1.6”

#### Returns

**result** –

one of the following error codes:

- 2**  
module is not installed
- 1**  
version of installed module is lower than the specified version
- 0**  
version of installed module is equal to specified version
- 1**  
version of installed module is higher than specified version

#### Return type

*int*

`pyfda.libs.pyfda_lib.cmplx_sort(p)`

sort roots based on magnitude.

`pyfda.libs.pyfda_lib.cround(x, n_dig=0)`

Round complex number to *n\_dig* digits. If *n\_dig* == 0, don't round at all, just convert complex numbers with an imaginary part very close to zero to real.

`pyfda.libs.pyfda_lib.dB(lin: float, power: bool = False) → float`

Calculate dB from linear value. If *power* = True, calculate 10 log ..., else calculate 20 log ...

`pyfda.libs.pyfda_lib.expand_lim(ax, eps_x: float, eps_y: float = None) → None`

Expand the xlim and ylim-values of passed axis by *eps*

#### Parameters

- **ax** (*axes object*)
- **eps\_x** (*float*) – factor by which x-axis limits are expanded
- **eps\_y** (*float*) – factor by which y-axis limits are expanded. If *eps\_y* is None, *eps\_x* is used for *eps\_y* as well.

#### Return type

None

`pyfda.libs.pyfda_lib.fil_convert(fil_dict: dict, format_in) → None`

Convert between poles / zeros / gain, filter coefficients (polynomes) and second-order sections and store all formats not generated by the filter design routine in the passed dictionary *fil\_dict*.

#### Parameters

- **fil\_dict** (*dict*) – filter dictionary containing a.o. all formats to be read and written.
- **format\_in** (*string or set of strings*) – format(s) generated by the filter design routine. Must be one of
  - 'sos'**  
a list of second order sections - all other formats can easily be derived from this format
  - 'zpk'**  
[z,p,k] where z is the array of zeros, p the array of poles and k is a scalar with the gain - the polynomial form can be derived from this format quite accurately

**'ba'**

[b, a] where b and a are the polynomial coefficients - finding the roots of the a and b polynomes may fail for higher orders

**Returns**

- *None*
- *Exceptions*
- *-----*
- *ValueError for Nan / Inf elements or other unsuitable parameters*

pyfda.libs.pyfda\_lib.**fil\_save**(fil\_dict: *dict*, arg, format\_in: *str*, sender: *str*, convert: *bool* = *True*) → *None*

Save filter design arg given in the format specified as format\_in in the dictionary fil\_dict. The format can be either poles / zeros / gain, filter coefficients (polynomes) or second-order sections.

Convert the filter design to the other formats if convert is True.

**Parameters**

- **fil\_dict** (*dict*) – The dictionary where the filter design is saved to.
- **arg** (*various formats*) – The actual filter design
- **format\_in** (*string*) – Specifies how the filter design in 'arg' is passed:

**'ba'**

Coefficient form: Filter coefficients in FIR format (b, one dimensional) are automatically converted to IIR format (b, a).

**'zpk'**

Zero / pole / gain format: When only zeroes are specified, poles and gain are added automatically.

**'sos'**

Second-order sections

- **sender** (*string*) – The name of the method that calculated the filter. This name is stored in fil\_dict together with format\_in.
- **convert** (*boolean*) – When convert = True, convert arg to the other formats.

**Return type**

*None*

pyfda.libs.pyfda\_lib.**floor\_even**(x) → *int*

Return the largest even integer not larger than x. x can be integer or float.

pyfda.libs.pyfda\_lib.**floor\_odd**(x) → *int*

Return the largest odd integer not larger than x. x can be integer or float.

pyfda.libs.pyfda\_lib.**format\_ticks**(ax, xy: *str*, scale: *float* = 1.0, format: *str* = '%.1f') → *None*

Reformat numbers at x or y - axis. The scale can be changed to display e.g. MHz instead of Hz. The number format can be changed as well.

**Parameters**

- **ax** (*axes object*)
- **xy** (*string, either 'x', 'y' or 'xy'*) – select corresponding axis (axes) for reformatting
- **scale** (*float* (default: 1.)) – rescaling factor for the axes
- **format** (*string* (default: '%.1f')) – define C-style number formats

**Return type**  
None

### Examples

Scale all numbers of x-Axis by 1000, e.g. for displaying ms instead of s.

```
>>> format_ticks('x', 1000.)
```

Two decimal places for numbers on x- and y-axis

```
>>> format_ticks('xy', 1., format = "%.2f")
```

`pyfda.libs.pyfda_lib.lin2unit(lin_value: float, filt_type: str, amp_label: str, unit: str = 'dB') → float`

Convert linear amplitude specification to dB or W, depending on filter type ('FIR' or 'IIR') and whether the specifications belong to passband or stopband. This is determined by checking whether `amp_label` contains the strings 'PB' or 'SB' :

- **Passband:**

$$\text{IIR: } A_{dB} = -20 \log_{10}(1 - \text{lin\_value})$$

$$\text{FIR: } A_{dB} = 20 \log_{10} \frac{1 + \text{lin\_value}}{1 - \text{lin\_value}}$$

- **Stopband:**

$$A_{dB} = -20 \log_{10}(\text{lin\_value})$$

Returns the result as a float.

`pyfda.libs.pyfda_lib.mod_version(mod=None)`

Return the version of the module 'mod'. If the module is not found, return None. When no module is specified, return a string with all modules and their versions sorted alphabetically.

`pyfda.libs.pyfda_lib.qstr(text)`

Convert text (QVariant, QString, string) or numeric object to plain string.

In Python 3, python Qt objects are automatically converted to QVariant when stored as "data" (itemData) e.g. in a QComboBox and converted back when retrieving to QString. In Python 2, QVariant is returned when itemData is retrieved. This is first converted from the QVariant container format to a QString, next to a "normal" non-unicode string.

**Parameters**

**text** (QVariant, QString, string or numeric data type that can be converted) – to string

**Return type**

The current *text* data as a unicode (utf8) string

`pyfda.libs.pyfda_lib.round_even(x) → int`

Return the nearest even integer from x. x can be integer or float.

`pyfda.libs.pyfda_lib.round_odd(x) → int`

Return the nearest odd integer from x. x can be integer or float.

`pyfda.libs.pyfda_lib.safe_eval(expr, alt_expr=0, return_type: str = 'float', sign: str = None)`

Try ... except wrapper around `numexpr` to catch various errors When evaluation fails or returns *None*, try evaluating *alt\_expr*. When this also fails, return 0 to avoid errors further downstream.

**Parameters**

- **expr** (*str* or *scalar*) – Expression to be evaluated, is cast to a string
- **alt\_expr** (*str* or *scalar*) – Expression to be evaluated when evaluation of first string fails, is cast to a string.
- **return\_type** (*str*) – Type of returned variable ['float' (default) / 'cmplx' / 'int' / '' or 'auto']
- **sign** (*str*) –  
**enforce positive / negative sign of result** ['pos', 'poszero' / None (default) 'negzero' / 'neg']

**Returns**

the evaluated result or 0 when both arguments fail

**Return type**

float (default) / complex / int

Function attribute *err* contains number of errors that have occurred during evaluation (0 / 1 / 2)

`pyfda.libs.pyfda_lib.set_dict_defaults(d: dict, default_dict: dict) → None`

Add the key:value pairs of *default\_dict* to dictionary *d* in-place for all missing keys.

`pyfda.libs.pyfda_lib.sos2zpk(sos)`

Taken from `scipy/signal/filter_design.py` - edit to eliminate first order section

Return zeros, poles, and gain of a series of second-order sections

**Parameters**

**sos** (*array\_like*) – Array of second-order filter coefficients, must have shape (*n\_sections*, 6). See *sosfilt* for the SOS filter format specification.

**Returns**

- **z** (*ndarray*) – Zeros of the transfer function.
- **p** (*ndarray*) – Poles of the transfer function.
- **k** (*float*) – System gain.

**Notes**

Added in version 0.16.0.

`pyfda.libs.pyfda_lib.to_html(text: str, frmt: str = None) → str`

**Convert text to HTML format:**

- pretty-print logger messages
- convert “n” to “<br />”
- convert “<” and “>” to “&lt;” and “&gt;”
- format strings with italic and / or bold HTML tags, depending on parameter *frmt*. When *frmt=None*, put the returned string between <span> tags to enforce HTML rendering downstream
- replace ‘\_’ by HTML subscript tags. Numbers 0 ... 9 are never set to italic format

**Parameters**

- **text** (*str*) – Text to be converted
- **frmt** (*str*) – define text style
  - ‘b’ : bold text
  - ‘i’ : italic text

- ‘bi’ or ‘ib’ : bold and italic text

**Returns**

HTML - formatted text

**Return type**

str

**Examples**

```
>>> to_html("F_SB", frmt='bi')
"<b><i>F<sub>SB</sub></i></b>"
>>> to_html("F_1", frmt='i')
"<i>F</i><sub>1</sub>"
```

```
pyfda.libs.pyfda_lib.unique_roots(p, tol: float = 0.001, magsort: bool = False, rtype: str = 'min', rdist:
                                str = 'euclidian')
```

Determine unique roots and their multiplicities from a list of roots.

**Parameters**

- **p** (*array\_like*) – The list of roots.
- **tol** (*float*, *default tol = 1e-3*) – The tolerance for two roots to be considered equal. Default is 1e-3.
- **magsort** (*Boolean*, *default = False*) – When magsort = True, use the root magnitude as a sorting criterium (as in the version used in numpy < 1.8.2). This yields false results for roots with similar magnitudes (e.g. on the unit circle) but is significantly faster for a large number of roots (factor 20 for 500 double roots.)
- **rtype** (*{'max', 'min', 'avg'}, optional*) – How to determine the returned root if multiple roots are within *tol* of each other. - ‘max’ or ‘maximum’: pick the maximum of those roots (magnitude?). - ‘min’ or ‘minimum’: pick the minimum of those roots (magnitude?). - ‘avg’ or ‘mean’: take the average of those roots. - ‘median’: take the median of those roots
- **dist** (*{'manhattan', 'euclid'}, optional*) – How to measure the distance between roots: ‘euclid’ is the euclidian distance. ‘manhattan’ is less common, giving the sum of the differences of real and imaginary parts.

**Returns**

- **pout** (*list*) – The list of unique roots, sorted from low to high (only for real roots).
- **mult** (*list*) – The multiplicity of each root.

**Notes**

This utility function is not specific to roots but can be used for any sequence of values for which uniqueness and multiplicity has to be determined. For a more general routine, see *numpy.unique*.

## Examples

```
>>> vals = [0, 1.3, 1.31, 2.8, 1.25, 2.2, 10.3]
>>> uniq, mult = unique_roots(vals, tol=2e-2, rtype='avg')
```

Check which roots have multiplicity larger than 1:

```
>>> uniq[mult > 1]
array([ 1.305])
```

Find multiples of complex roots on the unit circle: `>>> vals = np.roots(1,2,3,2,1) uniq, mult = unique_roots(vals, rtype='avg')`

`pyfda.libs.pyfda_lib.unit2lin(unit_value: float, filt_type: str, amp_label: str, unit: str = 'dB') → float`

Convert amplitude specification in dB or W to linear specs:

- **Passband:**

$$\text{IIR: } A_{PB,lin} = 1 - 10^{-unit\_value/20}$$

$$\text{FIR: } A_{PB,lin} = \frac{10^{unit\_value/20} - 1}{10^{unit\_value/20} + 1}$$

- **Stopband:**

$$A_{SB,lin} = -10^{-unit\_value/20}$$

Returns the result as a float.

## 3.5.2 pyfda\_sig\_lib

Library with various signal processing related functions

`pyfda.libs.pyfda_sig_lib.angle_zero(X, n_eps=1000.0, mode='auto', wrapped='auto')`

Calculate angle of argument X when `abs(X) > n_eps * machine resolution`. Otherwise, zero is returned.

`pyfda.libs.pyfda_sig_lib.div_safe(num, den, n_eps: float = 1.0, i_scale: float = 1.0, verbose: bool = False)`

Perform elementwise array division after treating singularities, meaning:

- check whether denominator (*den*) coefficients approach zero
- check whether numerator (*num*) or denominator coefficients are non-finite, i.e. one of *nan*, *inf* or *ninf*.

At each singularity, replace denominator coefficient by 1 and numerator coefficient by 0

### Parameters

- **num** (*array\_like*) – numerator coefficients
- **den** (*array\_like*) – denominator coefficients
- **n\_eps** (*float*) – `n_eps * machine resolution` is the limit for the denominator below which the ratio is set to zero. The machine resolution in numpy is given by `np.spacing(1)`, the distance to the nearest number which is equivalent to matlab's "eps".
- **i\_scale** (*float*) – The scale for the index *i* for *num*, *den* for printing the index of the singularities.
- **verbose** (*bool*, *optional*) – whether to print The default is False.

### Returns

**ratio** – The ratio of num and den (zero at singularities)

**Return type**

array\_like

```
pyfda.libs.pyfda_sig_lib.group_delay(b, a=1, nfft=512, whole=False, analog=False, verbose=True,
                                     fs=6.283185307179586, sos=False, alg='scipy', n_eps=100)
```

Calculate group delay of a discrete time filter, specified by numerator coefficients  $b$  and denominator coefficients  $a$  of the system function  $H(z)$ .

When only  $b$  is given, the group delay of the transversal (FIR) filter specified by  $b$  is calculated.

**Parameters**

- **b** (*array\_like*) – Numerator coefficients (transversal part of filter)
- **a** (*array\_like (optional, default = 1 for FIR-filter)*) – Denominator coefficients (recursive part of filter)
- **whole** (*boolean (optional, default : False)*) – Only when True calculate group delay around the complete unit circle ( $0 \dots 2\pi$ )
- **verbose** (*boolean (optional, default : True)*) – Print warnings about frequency points with undefined group delay (amplitude = 0) and the time used for calculating the group delay
- **nfft** (*integer (optional, default: 512)*) – Number of FFT-points
- **fs** (*float (optional, default: fs = 2\*pi)*) – Sampling frequency.
- **alg** (*str (default: "scipy")*) –

**The algorithm for calculating the group delay:**

- “scipy” The algorithm used by scipy’s `grpdelay`,
- “jos”: The original J.O.Smith algorithm; same as in “scipy” except that the frequency response is calculated with the FFT instead of `polyval`
- “diff”: Group delay is calculated by differentiating the phase
- “Shpakh”: Group delay is calculated from second-order sections
- **n\_eps** (*integer (optional, default : 100)*) – Minimum value in the calculation of intermediate values before `tau_g` is set to zero.

**Returns**

- **tau\_g** (*ndarray*) – group delay
- **w** (*ndarray*) – angular frequency points where group delay was computed

**Notes**

The following explanations follow [JOS].

**Definition and direct calculation (‘diff’)**

The group delay  $\tau_g(\omega)$  of discrete time (DT) and continuous time (CT) systems is the rate of change of phase with respect to angular frequency. In the following, derivative is always meant w.r.t.  $\omega$ :

$$\tau_g(\omega) = -\frac{\partial}{\partial \omega} \angle H(\omega) = -\frac{\partial \phi(\omega)}{\partial \omega} = -\phi'(\omega)$$

With numpy / scipy, the group delay can be calculated directly with

```
w, H = sig.freqz(b, a, worN=nfft, whole=whole)
tau_g = -np.diff(np.unwrap(np.angle(H)))/np.diff(w)
```



The derivative can create numerical problems for e.g. phase jumps at zeros of frequency response or when the complex frequency response becomes very small e.g. in the stop band.

This can be avoided by calculating the group delay from the derivative of the *logarithmic* frequency response in polar form (amplitude response and phase):

$$\begin{aligned}\ln(H(\omega)) &= \ln(H_A(\omega)e^{j\phi(\omega)}) = \ln(H_A(\omega)) + j\phi(\omega) \\ \Rightarrow \frac{\partial}{\partial\omega} \ln(H(\omega)) &= \frac{H'_A(\omega)}{H_A(\omega)} + j\phi'(\omega)\end{aligned}$$

where  $H_A(\omega)$  is the amplitude response.  $H_A(\omega)$  and its derivative  $H'_A(\omega)$  are real-valued, therefore, the group delay can be calculated by separating real and imaginary components (and discarding the real part):

$$\Re\left\{\frac{\partial}{\partial\omega} \ln(H(\omega))\right\} = \frac{H'_A(\omega)}{H_A(\omega)} \quad \Im\left\{\frac{\partial}{\partial\omega} \ln(H(\omega))\right\} = \phi'(\omega) \quad (3.1)$$

and hence

$$\tau_g(\omega) = -\phi'(\omega) = -\Im\left\{\frac{\partial}{\partial\omega} \ln(H(\omega))\right\} = -\Im\left\{\frac{H'(\omega)}{H(\omega)}\right\}$$

Note: The last term contains the complex response  $H(\omega)$ , not the amplitude response  $H_A(\omega)$ !

In the following, it will be shown that the derivative of birational functions (like DT and CT filters) can be calculated very efficiently and from this the group delay.

#### J.O. Smith's basic algorithm for FIR filters ('scipy')

An efficient form of calculating the group delay of FIR filters based on the derivative of the logarithmic frequency response has been described in [JOS] and [Lyons08] for discrete time systems.

A FIR filter is defined via its polyome  $H(z) = \sum_k b_k z^{-k}$  and has the following derivative:

$$\frac{\partial}{\partial\omega} H(z = e^{j\omega T}) = \frac{\partial}{\partial\omega} \sum_{k=0}^N b_k e^{-jk\omega T} = -jT \sum_{k=0}^N k b_k e^{-jk\omega T} = -jT H_R(e^{j\omega T})$$

where  $H_R$  is the "ramped" polynome, i.e. polynome  $H$  multiplied with a ramp  $k$ , yielding

$$\tau_g(e^{j\omega T}) = -\Im\left\{\frac{H'(e^{j\omega T})}{H(e^{j\omega T})}\right\} = -\Im\left\{-jT \frac{H_R(e^{j\omega T})}{H(e^{j\omega T})}\right\} = T \Re\left\{\frac{H_R(e^{j\omega T})}{H(e^{j\omega T})}\right\}$$

scipy's `grpdelay` directly calculates the complex frequency response  $H(e^{j\omega T})$  and its ramped function at the frequency points using the `polyval` function.

When zeros of the frequency response are on or near the data points of the DFT, this algorithm runs into numerical problems. Hence, it is necessary to check whether the magnitude of the denominator is less than e.g. 100 times the machine eps. In this case,  $\tau_g$  is set to zero.

#### J.O. Smith's basic algorithm for IIR filters ('scipy')

IIR filters are defined by

$$H(z) = \frac{B(z)}{A(z)} = \frac{\sum b_k z^k}{\sum a_k z^k},$$

their group delay can be calculated numerically via the logarithmic frequency response as well.

The derivative of  $H(z)$  w.r.t.  $\omega$  is calculated using the quotient rule and by replacing the derivatives of numerator and denominator polynomes with their ramp functions:

$$\begin{aligned}\frac{H'(e^{j\omega T})}{H(e^{j\omega T})} &= \frac{(B(e^{j\omega T})/A(e^{j\omega T}))'}{B(e^{j\omega T})/A(e^{j\omega T})} = \frac{B'(e^{j\omega T})A(e^{j\omega T}) - A'(e^{j\omega T})B(e^{j\omega T})}{A(e^{j\omega T})B(e^{j\omega T})} \\ &= \frac{B'(e^{j\omega T})}{B(e^{j\omega T})} - \frac{A'(e^{j\omega T})}{A(e^{j\omega T})} = -jT \left( \frac{B_R(e^{j\omega T})}{B(e^{j\omega T})} - \frac{A_R(e^{j\omega T})}{A(e^{j\omega T})} \right) \quad (3.2)\end{aligned}$$

This result is substituted once more into the log. derivative from above:

$$\begin{aligned}\tau_g(e^{j\omega T}) &= -\Im \left\{ \frac{H'(e^{j\omega T})}{H(e^{j\omega T})} \right\} = -\Im \left\{ -jT \left( \frac{B_R(e^{j\omega T})}{B(e^{j\omega T})} - \frac{A_R(e^{j\omega T})}{A(e^{j\omega T})} \right) \right\} \\ &= T\Re \left\{ \frac{B_R(e^{j\omega T})}{B(e^{j\omega T})} - \frac{A_R(e^{j\omega T})}{A(e^{j\omega T})} \right\}\end{aligned}\quad (3.4)$$

If the denominator of the computation becomes too small, the group delay is set to zero. (The group delay approaches infinity when there are poles or zeros very close to the unit circle in the  $z$  plane.)

### J.O. Smith's algorithm for CT filters

The same process can be applied for CT systems as well: The derivative of a CT polynome  $P(s)$  w.r.t.  $\omega$  is calculated by:

$$\frac{\partial}{\partial \omega} P(s = j\omega) = \frac{\partial}{\partial \omega} \sum_{k=0}^N c_k (j\omega)^k = j \sum_{k=0}^{N-1} (k+1) c_{k+1} (j\omega)^k = j P_R(s = j\omega)$$

where  $P_R$  is the “ramped” polynome, i.e. its  $k$  th coefficient is multiplied by the ramp  $k+1$ , yielding the same form as for DT systems (but the ramped polynome has to be calculated differently).

$$\tau_g(\omega) = -\Im \left\{ \frac{H'(\omega)}{H(\omega)} \right\} = -\Im \left\{ j \frac{H_R(\omega)}{H(\omega)} \right\} = -\Re \left\{ \frac{H_R(\omega)}{H(\omega)} \right\}$$

### J.O. Smith's improved algorithm for IIR filters (‘jos’)

J.O. Smith gives the following speed and accuracy optimizations for the basic algorithm:

- convert the filter to a FIR filter with identical phase and group delay (but with different magnitude response)
- use FFT instead of polyval to calculate the frequency response

The group delay of an IIR filter  $H(z) = B(z)/A(z)$  can also be calculated from an equivalent FIR filter  $C(z)$  with the same phase response (and hence group delay) as the original filter. This filter is obtained by the following steps:

- The zeros of  $A(z)$  are the poles of  $1/A(z)$ , its phase response is  $\angle A(z) = -\angle 1/A(z)$ .
- Transforming  $z \rightarrow 1/z$  mirrors the zeros at the unit circle, correcting the negative phase response. This can be performed numerically by “flipping” the order of the coefficients and multiplying by  $z^{-N}$  where  $N$  is the order of  $A(z)$ . This operation also conjugates the coefficients (?) which mirrors the zeros at the real axis. This effect has to be compensated, yielding the polynome  $\tilde{A}(z)$ . It is the “flip-conjugate” or “Hermitian conjugate” of  $A(z)$ .

Frequently (e.g. in the scipy and until recently in the Matlab implementation) the conjugate operation is omitted which gives wrong results for complex coefficients.

- Finally,  $C(z) = B(z)\tilde{A}(z)$ :

$$C(z) = B(z) [z^{-N} A^*(1/z)] = B(z) \tilde{A}(z)$$

where

$$\begin{aligned}\tilde{A}(z) &= z^{-N} A^*(1/z) = a_N^* + a_{N-1}^* z^{-1} + \dots + a_1^* z^{-(N-1)} + z^{-N} \\ \Rightarrow \tilde{A}(e^{j\omega T}) &= e^{-jN\omega T} A^*(e^{-j\omega T}) \\ \Rightarrow \angle \tilde{A}(e^{j\omega T}) &= -\angle A(e^{j\omega T}) - N\pi\end{aligned}\quad (3.6)$$

In Python, the coefficients of  $C(z)$  are calculated efficiently by convolving the coefficients of  $B(z)$  and  $\tilde{A}(z)$ :

```
c = np.convolve(b, np.conj(a[::-1]))
```

where  $b$  and  $a$  are the coefficient vectors of the original numerator and denominator polynomials. The actual group delay is then calculated from the equivalent FIR filter as described above.

Calculating the frequency response with the `np.polyval(p,z)` function at the  $NFFT$  frequency points along the unit circle,  $z = \exp(-j\omega)$ , seems to be numerically less robust than using the FFT for the same task, it is also much slower.

This measure fixes already most of the problems described for narrowband IIR filters in scipy issues [Scipy\_9310] and [Scipy\_1175]. In my experience, these problems occur for all narrowband IIR response types.

### Shpak algorithm for IIR filters

The algorithm described above is numerically efficient but not robust for narrowband IIR filters. Especially for filters defined by second-order sections, it is recommended to calculate the group delay using the D. J. Shpak's algorithm.

Code is available at [Endolith\_5828333] (GPL licensed) or at [SPA] (MIT licensed).

This algorithm sums the group delays of the individual sections which is much more robust as only second-order functions are involved. However, converting  $(b,a)$  coefficients to SOS coefficients introduces inaccuracies.

## Examples

```
>>> b = [1,2,3] # Coefficients of  $H(z) = 1 + 2z^2 + 3z^3$ 
>>> tau_g, td = pyfda_lib.grpdelay(b)
```

```
pyfda.libs.pyfda_sig_lib.group_delayz(b, a, w, plot=None, fs=6.283185307179586)
```

Compute the group delay of digital filter.

### Parameters

- **b** (*array\_like*) – Numerator of a linear filter.
- **a** (*array\_like*) – Denominator of a linear filter.
- **w** (*array\_like*) – Frequencies in the same units as *fs*.
- **plot** (*callable*) – A callable that takes two arguments. If given, the return parameters *w* and *gd* are passed to plot.
- **fs** (*float, optional*) – The angular sampling frequency of the digital system.

### Returns

- **w** (*ndarray*) – The frequencies at which *gd* was computed, in the same units as *fs*.
- **gd** (*ndarray*) – The group delay in seconds.

```
pyfda.libs.pyfda_sig_lib.impz(b, a=1, FS=1, N=0, step=False)
```

Calculate impulse response of a discrete time filter, specified by numerator coefficients *b* and denominator coefficients *a* of the system function  $H(z)$ .

When only *b* is given, the impulse response of the transversal (FIR) filter specified by *b* is calculated.

### Parameters

- **b** (*array\_like*) – Numerator coefficients (transversal part of filter)
- **a** (*array\_like (optional, default = 1 for FIR-filter)*) – Denominator coefficients (recursive part of filter)
- **FS** (*float (optional, default: FS = 1)*) – Sampling frequency.
- **N** (*float (optional)*) – Number of calculated points. Default:  $N = \text{len}(b)$  for FIR filters,  $N = 100$  for IIR filters

- **step** (*bool* (*optional*, *default False*)) – return the step response instead of the impulse response

#### Returns

- **hn** (*ndarray*) – impulse or step response with length *N* (see above)
- **td** (*ndarray*) – contains the time steps with same length as *hn*

#### Examples

```
>>> b = [1,2,3] # Coefficients of  $H(z) = 1 + 2z^2 + 3z^3$ 
>>> h, n = dsp_lib.impz(b)
```

`pyfda.libs.pyfda_sig_lib.quadfilt_group_delayz(b, w, fs=6.283185307179586)`

Compute group delay of 2nd-order digital filter.

#### Parameters

- **b** (*array\_like*) – Coefficients of a 2nd-order digital filter.
- **w** (*array\_like*) – Frequencies in the same units as *fs*.
- **fs** (*float*, *optional*) – The sampling frequency of the digital system.

#### Returns

- **w** (*ndarray*) – The frequencies at which *gd* was computed.
- **gd** (*ndarray*) – The group delay in seconds.

`pyfda.libs.pyfda_sig_lib.sos_group_delayz(sos, w, plot=None, fs=6.283185307179586)`

Compute group delay of digital filter in SOS format.

#### Parameters

- **sos** (*array\_like*) – Array of second-order filter coefficients, must have shape (*n\_sections*, 6). Each row corresponds to a second-order section, with the first three columns providing the numerator coefficients and the last three providing the denominator coefficients.
- **w** (*array\_like*) – Frequencies in the same units as *fs*.
- **plot** (*callable*, *optional*) – A callable that takes two arguments. If given, the return parameters *w* and *gd* are passed to plot.
- **fs** (*float*, *optional*) – The sampling frequency of the digital system.

#### Returns

- **w** (*ndarray*) – The frequencies at which *gd* was computed.
- **gd** (*ndarray*) – The group delay in seconds.

`pyfda.libs.pyfda_sig_lib.validate_sos(sos)`

Helper to validate a SOS input

Copied from `scipy.signal._filter_design._validate_sos()`

`pyfda.libs.pyfda_sig_lib.zeros_with_val(N: int, val: float = 1.0, pos: int = 0)`

Create a 1D array of *N* zeros where the element at position *pos* has the value *val*.

#### Parameters

- **N** (*int*) – number of elements
- **val** (*scalar*) – value to be inserted at position *pos* (default: 1)
- **pos** (*int*) – Position of *val* to be inserted (default: 0)

**Returns**

**arr** – Array with zeros except for element at position *pos*

**Return type**

np.ndarray

`pyfda.libs.pyfda_sig_lib.zorp_group_delayz(zorp, w, fs=1)`

Compute group delay of digital filter with a single zero/pole.

**Parameters**

- **zorp** (*complex*) – Zero or pole of a 1st-order linear filter
- **w** (*array\_like*) – Frequencies in the same units as *fs*.
- **fs** (*float, optional*) – The sampling frequency of the digital system.

**Returns**

- **w** (*ndarray*) – The frequencies at which *gd* was computed.
- **gd** (*ndarray*) – The group delay in seconds.

`pyfda.libs.pyfda_sig_lib.zpk2array(zpk)`

Test whether  $Z = \text{zpk}[0]$  and  $P = \text{zpk}[1]$  have the same length, if not, equalize the lengths by adding zeros.

Test whether  $\text{gain} = \text{zpk}[2]$  is a scalar or a vector and whether it (or the first element of the vector) is  $\neq 0$ . If the gain is 0, set  $\text{gain} = 1$ .

Finally, convert the gain into an vector with the same length as  $P$  and  $Z$  and return the the three vectors as one array.

**Parameters**

**zpk** (*list, tuple or ndarray*) – Zeros, poles and gain of the system

**Return type**

zpk as an array or an error string

`pyfda.libs.pyfda_sig_lib.zpk_group_delay(z, p, k, w, plot=None, fs=6.283185307179586)`

Compute group delay of digital filter in zpk format.

**Parameters**

- **z** (*array\_like*) – Zeroes of a linear filter
- **p** (*array\_like*) – Poles of a linear filter
- **k** (*scalar*) – Gain of a linear filter
- **w** (*array\_like*) – Frequencies in the same units as *fs*.
- **plot** (*callable, optional*) – A callable that takes two arguments. If given, the return parameters *w* and *gd* are passed to plot.
- **fs** (*float, optional*) – The sampling frequency of the digital system.

**Returns**

- **w** (*ndarray*) – The frequencies at which *gd* was computed.
- **gd** (*ndarray*) – The group delay in seconds.

### 3.5.3 pyfda\_qt\_lib

Library with various helper functions for Qt widgets

**class** `pyfda.libs.pyfda_qt_lib.EventTypes`

<https://stackoverflow.com/questions/62196835/how-to-get-string-name-for-qevent-in-pyqt5> Events in Qt5:  
<https://doc.qt.io/qt-5/qevent.html>

Stores a string name for each event type.

With PySide2 `str()` on the event type gives a nice string name, but with PyQt5 it does not. So this method works with both systems.

Example usage (simultaneous initialization and method call / translation) > `event_str = EventTypes().as_string(QEvent.UpdateRequest)` > `assert event_str == "UpdateRequest"`

Example usage, separate initialization and method call > `event_types = EventTypes()` > `event_str = event_types.as_string(event.type())`

**as\_string**(*event: Type*) → *str*

Return the string name for this event.

**class** `pyfda.libs.pyfda_qt_lib.PushButton`(*txt: str = "", icon: QIcon = None, N\_x: int = 8, checkable: bool = True, checked: bool = False, objectName=""*)

Create a QPushButton with a width fitting the label with bold font as well

#### Parameters

- **txt** (*str*) – Text for button (optional)
- **icon** (*QIcon*) – Icon for button. Either *txt* or *icon* must be defined.
- **N\_x** (*int*) – Width in number of “x”
- **checkable** (*bool*) – Whether button is checkable
- **checked** (*bool*) – Whether initial state is checked

**minimumSizeHint**(*self*) → *QSize*

**sizeHint**(*self*) → *QSize*

**class** `pyfda.libs.pyfda_qt_lib.QHLine`(*width=1*)

Create a thin horizontal line utilizing the HLine property of QFrames Usage:

> `myline = QHLine()` > `mylayout.addWidget(myline)`

**class** `pyfda.libs.pyfda_qt_lib.QLabelVert`(*text, orientation='west', forceWidth=True*)

Create a vertical label

Adapted from [https://pyqtgraph.readthedocs.io/en/latest/\\_modules/pyqtgraph/widgets/VerticalLabel.html](https://pyqtgraph.readthedocs.io/en/latest/_modules/pyqtgraph/widgets/VerticalLabel.html)

<https://stackoverflow.com/questions/34080798/pyqt-draw-a-vertical-label>

check <https://stackoverflow.com/questions/29892203/draw-rich-text-with-qpainter>

**minimumSizeHint**(*self*) → *QSize*

**paintEvent**(*self, a0: QPaintEvent | None*)

**sizeHint**(*self*) → *QSize*

**class** `pyfda.libs.pyfda_qt_lib.QVLine`(*width=2*)

Create a thin vertical line utilizing the HLine property of QFrames Usage:

> `myline = QVLine()` > `mylayout.addWidget(myline)`

**class pyfda.libs.pyfda\_qt\_lib.RotatedButton**

Create a rotated QPushButton

Taken from

<https://forum.qt.io/topic/9279/moved-how-to-rotate-qpushbutton-63/7>

**minimumSizeHint**(*self*) → QSize

**paintEvent**(*self*, *a0*: QPaintEvent | None)

**sizeHint**(*self*) → QSize

**pyfda.libs.pyfda\_qt\_lib.emit**(*self*, *dict\_sig*: dict = {}, *sig\_name*: str = 'sig\_tx') → None

Emit a signal *self*.<*sig\_name*> (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit*().

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

**pyfda.libs.pyfda\_qt\_lib.popup\_warning**(*self*, *param1*: int = 0, *param2*: str = "", *message*: str = "") → bool

Pop-up a warning box and require a user prompt. When *message* == "", warn of very large filter orders, otherwise display the passed message

**pyfda.libs.pyfda\_qt\_lib.qcmb\_box\_add\_item**(*cmb\_box*, *item\_list*, *data*=True, *fireSignals*=False, *caseSensitive*=False)

Add an entry in combobox with text / data / tooltip from *item\_list*. When the item is already in combobox (searching for data or text item, depending *data*), do nothing. Signals are blocked during the update of the combobox unless *fireSignals* is set *True*. By default, the search is case insensitive, this can be changed by passing *caseSensitive*=False.

**Parameters**

- **item\_list** (*list*) – List with ["new\_data", "new\_text", "new\_tooltip"] to be added.
- **data** (*bool* (default: False)) – Whether the string refers to the data or text fields of the combo box
- **fireSignals** (*bool* (default: False)) – When True, fire a signal if the index is changed (useful for GUI testing)
- **caseInsensitive** (*bool* (default: False)) – When true, perform case sensitive search.

**Returns**

- The index of the found item with string / data. When not found in the
- combo box, return index -1.

**pyfda.libs.pyfda\_qt\_lib.qcmb\_box\_add\_items**(*cmb\_box*: QComboBox, *items\_list*: list) → None

Add items to combo box *cmb\_box* with text, data and tooltip from the list *items\_list*.

Text and tooltip are prepared for translation via *self.tr*()

**Parameters**

- **cmb\_box** (*instance of QComboBox*) – Combobox to be populated
- **items\_list** (*list*) –

**List of combobox entries, in the format**

(“data 1st item”, “text 1st item”, “tooltip for 1st item” # [optional]), (“data 2nd item”, “text 2nd item”, “tooltip for 2nd item”)]

**Return type**

None

```
pyfda.libs.pyfda_qt_lib.qcmb_box_del_item(cmb_box: QComboBox, string: str, data: bool = False,
   fireSignals: bool = False, caseSensitive: bool = False)
   → int
```

Try to find the entry in combobox corresponding to *string* in a text field (*data* = *False*) or in a data field (*data*=*True*) and delete the item. When *string* is not found, do nothing. Signals are blocked during the update of the combobox unless *fireSignals* is set *True*. By default, the search is case insensitive, this can be changed by passing *caseSensitive*=*False*.

**Parameters**

- **string** (*str*) – The label in the text or data field to be deleted.
- **data** (*bool* (default: *False*)) – Whether the string refers to the data or text fields of the combo box
- **fireSignals** (*bool* (default: *False*)) – When *True*, fire a signal if the index is changed (useful for GUI testing)
- **caseInsensitive** (*bool* (default: *False*)) – When *true*, perform case sensitive search.

**Returns**

- *The index of the item with string / data. When not found in the combo box,*
- *return index -1.*

```
pyfda.libs.pyfda_qt_lib.qcmb_box_populate(cmb_box: QComboBox, items_list: list, item_init: str) →
   int
```

Clear and populate combo box *cmb\_box* with text, data and tooltip from the list *items\_list* with initial selection of *init\_item* (data).

Text and tooltip are prepared for translation via *self.tr()*

**Parameters**

- **cmb\_box** (*instance of QComboBox*) – Combobox to be populated
- **items\_list** (*list*) – List of combobox entries, in the format [“Tooltip for Combobox”, (“data 1st item”, “text 1st item”, “tooltip for 1st item”), (“data 2nd item”, “text 2nd item”, “tooltip for 2nd item”)]

Tooltips are optional.

- **item\_init** (*str*) – data for initial setting of combobox. When data is not found, set combobox to first item.

**Returns**

**ret** – Index of *item\_init* in combobox. If index == -1, *item\_init* was not in *items\_list*

**Return type**

int

```
pyfda.libs.pyfda_qt_lib.qget_cmb_box(cmb_box: QComboBox, data: bool = True) → str
```

Get current itemData or Text of comboBox and convert it to string.

In Python 3, python Qt objects are automatically converted to QVariant when stored as “data” e.g. in a QComboBox and converted back when retrieving. In Python 2, QVariant is returned when itemData is retrieved. This is first converted from the QVariant container format to a QString, next to a “normal” non-unicode string.



Returns:

The current text or data of combobox as a string

`pyfda.libs.pyfda_qt_lib.qget_selected(table, select_all=False, reverse=True)`

Get selected cells in `table` and return a dictionary with the following keys:

‘idx’: indices of selected cells as an unsorted list of tuples

‘sel’: list of lists of selected cells per column, by default sorted in reverse

‘cur’: current cell selection as a tuple

#### Parameters

- **select\_all** (*bool*) – select all table items and create a list when True
- **reverse** (*bool*) – return selected fields upside down when True

`pyfda.libs.pyfda_qt_lib.qset_cmb_box(cmb_box: QComboBox, string: str, data: bool = False, fireSignals: bool = False, caseSensitive: bool = False) → int`

Set combobox to the index corresponding to *string* in a text field (*data* = *False*) or in a data field (*data*=*True*). When *string* is not found in the combobox entries, select the first entry. Signals are blocked during the update of the combobox unless *fireSignals* is set *True*. By default, the search is case insensitive, this can be changed by passing *caseSensitive=False*.

#### Parameters

- **string** (*str*) – The label in the text or data field to be selected. When the string is not found, select the first entry of the combo box.
- **data** (*bool* (default: *False*)) – Whether the string refers to the data or text fields of the combo box
- **fireSignals** (*bool* (default: *False*)) – When True, fire a signal if the index is changed (useful for GUI testing)
- **caseSensitive** (*bool* (default: *False*)) – When true, perform case sensitive search.

#### Returns

- *The index of the string. When the string was not found in the combo box,*
- *select first entry of combo box and return index -1.*

`pyfda.libs.pyfda_qt_lib.qstyle_widget(widget, state)`

Apply the “state” defined in `pyfda_rc.py` to the widget, e.g.: Color the >> DESIGN FILTER << button according to the filter design state.

This requires setting the property, “unpolishing” and “polishing” the widget and finally forcing an update.

- ‘normal’ : default, no color styling
- ‘ok’: green, filter has been designed, everything ok
- ‘changed’: yellow, filter specs have been changed
- ‘running’: orange, simulation is running
- ‘error’ : red, an error has occurred during filter design
- ‘failed’ : pink, filter fails to meet target specs (not used yet)
- ‘u’ or ‘unused’ : grey text color
- ‘d’ or ‘disabled’: background color darkgrey
- ‘a’ or ‘active’ : no special style defined

```
pyfda.libs.pyfda_qt_lib.qtext_height(text: str = 'X', font=None) → int
```

Calculate size of *text* in points`.

The actual size of the string is calculated using fontMetrics and the default or the passed font

**Parameters**

**test** (*str*) – string to calculate the height for (default: “X”)

**Returns**

**lineSpacing** – The height of the text (line spacing) in points

**Return type**

int

**Notes**

This is based on <https://stackoverflow.com/questions/27433165/how-to-reimplement-sizehint-for-bold-text-in-a-delegate-qt> and

<https://stackoverflow.com/questions/47285303/how-can-i-limit-text-box-width-of-qlinedit-to-display-at-most-four-characters/47307180#47307180>

<https://stackoverflow.com/questions/56282199/fit-qtextedit-size-to-text-size-pyqt5>

```
pyfda.libs.pyfda_qt_lib.qtext_width(text: str = '', N_x: int = 17, bold: bool = True, font=None) → int
```

Calculate width of *text* in points`. When *text* = ``, calculate the width of number *N\_x* of characters ‘x’.

The actual width of the string is calculated by creating a QTextDocument with the passed text and retrieving its *idealWidth()*

**Parameters**

- **test** (*str*) – string to calculate the width for
- **N\_x** (*int*) – When *text* == ``, calculate the width from *N\_x* \* *width*(‘x’)
- **bold** (*bool* (default: *True*)) – When *True*, determine width based on bold font

**Returns**

**width** – The width of the text in points

**Return type**

int

**Notes**

This is based on <https://stackoverflow.com/questions/27433165/how-to-reimplement-sizehint-for-bold-text-in-a-delegate-qt> and

<https://stackoverflow.com/questions/47285303/how-can-i-limit-text-box-width-of-qlinedit-to-display-at-most-four-characters/47307180#47307180>

```
pyfda.libs.pyfda_qt_lib.qwindow_stay_on_top(win: QDialog, top: bool) → None
```

Set flags for a window such that it stays on top (True) or not

On Windows 7 the new window stays on top anyway. Additionally setting *WindowStaysOnTopHint* blocks the message window when trying to close pyfda.

On Windows 10 and Linux, *WindowStaysOnTopHint* needs to be set.

### 3.5.4 pyfda\_io\_lib

Library with classes and functions for file and text IO

**class** `pyfda.libs.pyfda_io_lib.NumpyEncoder`(*\*, skipkeys=False, ensure\_ascii=True, check\_circular=True, allow\_nan=True, sort\_keys=False, indent=None, separators=None, default=None*)

Special json encoder for numpy and other non-supported types, building upon <https://stackoverflow.com/questions/26646362/numpy-array-is-not-json-serializable>

**default**(*obj*)

Implement this method in a subclass such that it returns a serializable object for *o*, or calls the base implementation (to raise a `TypeError`).

For example, to support arbitrary iterators, you could implement default like this:

```
def default(self, o):
    try:
        iterable = iter(o)
    except TypeError:
        pass
    else:
        return list(iterable)
    # Let the base class default method raise the TypeError
    return JSONEncoder.default(self, o)
```

`pyfda.libs.pyfda_io_lib.coe_header`(*title: str*) → *str*

Generate a file header (comment) for various FPGA FIR coefficient export formats with information on the filter type, corner frequencies, ripple etc

#### Parameters

**title** (*str*) – A string that is written in the top of the comment section of the exported file.

#### Returns

**header** – The string with all the gathered information

#### Return type

*str*

`pyfda.libs.pyfda_io_lib.create_file_filters`(*file\_types: tuple, file\_filters: str = ""*)

Create a string with file filters for `QFileDialog` object from *file\_types*, a tuple of file extensions and the global *file\_filters\_dict*.

When the file extension stored after last `QFileDialog` operation is in the tuple of file types, return this file extension for e.g. preselecting the file type in `QFileDialog`.

#### Parameters

- **file\_types** (*tuple of str*) – list of file extensions which are used to create a file filter.
- **file\_filters** (*str*) – String with file filters for `QFileDialog` object with the form “Comma / Tab Separated Values (\*.csv);; Audio (\*.wav \*.mp3)”. By default, this string is empty, but it can be used to add file filters not contained in the global *file\_filters\_dict*.

#### Returns

- **file\_filters** (*str*) – String containing file filters for a `QFileDialog` object
- **last\_file\_filter** (*str*) – Single file filter to setup the default file extension in `QFileDialog`

`pyfda.libs.pyfda_io_lib.csv2array(f: TextIO)`

Convert comma-separated values from file or text to numpy array, taking into account the settings of the CSV dict.

#### Parameters

- **f** (*TextIO*) – handle to file or file-like object, e.g.
- **open(file\_name** (>>> *f* =)
- **or** ('r') #)
- **io.StringIO(text)** (>>> *f* =)

#### Returns

- **data\_arr** (*ndarray*) – numpy array of str with table data from file or *None* when import was unsuccessful
- *Read data as it is, splitting each row into the column items when*
  - – *CSV\_dict['orientation'] == cols* or
  - – *CSV\_dict['orientation'] == auto* and *cols <= rows*
- *Transpose data when*
  - – *CSV\_dict['orientation'] == rows* or
  - – *CSV\_dict['orientation'] == auto* and *cols > rows*
- *np.shape(data)* returns rows, columns
- While opening a file, the *newline* parameter can be used to
- *control how universal newlines works (it only applies to text mode).*
- It can be *None*, *''*, *'n'*, *'r'*, and *'rn'*. It works as follows
- - **Input** (If *newline == None*, universal newlines mode is enabled. Lines in) – the input can end in *'n'*, *'r'*, or *'rn'*, and these are translated into *'n'* before being returned to the caller. If it is *''*, universal newline mode is enabled, but line endings are returned to the caller untranslated. If it has any of the other legal values, input lines are only terminated by the given string, and the line ending is returned to the caller untranslated.
- - *On output, if newline is None, any 'n' characters written are translated* – to the system default line separator, *os.linesep*. If *newline* is *''*, no translation takes place. If *newline* is any of the other legal values, any *'n'* characters written are translated to the given string.
- **Example** (*convert from Windows-style line endings to Linux:*)
- .. *code-block:: python* – `fileContents = open(filename,"r").read() f = open(filename,"w", newline="n") f.write(fileContents) f.close()`
- **https** (*//pythonconquerstheuniverse.wordpress.com/2011/05/08/newline-conversion-in-python-3/*)

`pyfda.libs.pyfda_io_lib.data2array(parent: object, fkey: str, title: str = 'Import', as_str: bool = False)`

Copy tabular data from clipboard or file to a numpy array

#### Parameters

- **parent** (*object*) – parent instance with a *QFileDialog* attribute.
- **fkey** (*str*) – Key for accessing data in *.npz* file or *Matlab workspace* (.mat)
- **title** (*str*) – title string for the file dialog box
- **as\_str** (*bool*) – When True, return *ndarray* in raw str format, otherwise convert to float or complex

**Returns**

table data

**Return type**ndarray of `str` or `None`

The following keys from the global dict `params['CSV']` are evaluated:

**‘delimiter’**

str (default: &lt;tab&gt;), character for separating columns

**‘lineterminator’**

str (default: As used by the operating system), character for terminating rows. By default, the character is selected depending on the operating system:

- Windows: Carriage return + line feed
- MacOS : Carriage return
- \*nix : Line feed

**‘orientation’**

str (one of ‘auto’, ‘horiz’, ‘vert’) determining with which orientation the table is read.

**‘header’**

str (‘auto’, ‘on’, ‘off’). When `header==‘on’`, treat first row as a header that will be discarded.

**‘clipboard’**

bool (default: True). When `clipboard == True`, copy data from clipboard, else use a file

Parameters that are ‘auto’, will be guessed by `csv.Sniffer()`.

`pyfda.libs.pyfda_io_lib.export_coe_TI(f: TextIO) → None`

Save FIR filter coefficients in TI coefficient format Coefficient have to be specified by an identifier ‘b0 ... b191’ followed by the coefficient in normalized fractional format, e.g.

b0 .053647 b1 -.27485 b2 .16497 ...

\*\* not implemented yet \*\*

`pyfda.libs.pyfda_io_lib.export_coe_cmsis(f: TextIO) → None`

Get coefficients in SOS format and delete 4th column containing the ‘1.0’ of the recursive parts.

See [https://www.keil.com/pack/doc/CMSIS/DSP/html/group\\_\\_BiquadCascadeDF1.html](https://www.keil.com/pack/doc/CMSIS/DSP/html/group__BiquadCascadeDF1.html) <https://dsp.stackexchange.com/questions/79021/iir-design-scipy-cmsis-dsp-coefficient-format> <https://github.com/docPhil99/DSP/blob/master/MatlabSOS2CMSIS.m>

# TODO: check `scipy.signal.zpk2sos` for details concerning sos paring

`pyfda.libs.pyfda_io_lib.export_coe_microsemi(f: TextIO) → bool`

Save FIR filter coefficients in Microsemi coefficient format as file ‘\*.txt’. Coefficients have to be in integer format, the last line has to be empty. For (anti)symmetric filter only one half of the coefficients must be specified?

`pyfda.libs.pyfda_io_lib.export_coe_vhdl_package(f: TextIO) → bool`

Save FIR filter coefficients as a VHDL package ‘\*.vhd’, specifying the number base and the quantized coefficients (decimal or hex integer).

`pyfda.libs.pyfda_io_lib.export_coe_xilinx(f: TextIO) → bool`

Save FIR filter coefficients in Xilinx coefficient format as file ‘\*.coe’, specifying the number base and the quantized coefficients (decimal or hex integer).

Returns error status (False if the file was saved successfully)

```
pyfda.libs.pyfda_io_lib.export_fil_data(parent: object, data: str, fkey: str = "", title: str = 'Export',
   file_types: Tuple[str, ...] = ('csv', 'mat', 'npz', 'npz'))
```

Export filter coefficients or pole/zero data in various formats, file name and type are selected via the ui.

#### Parameters

- **parent** (handle to calling instance for creating file dialog instance)
- **data** (*str*) – formatted as CSV data, i.e. rows of elements separated by ‘delimiter’, terminated by ‘lineterminator’. Some data formats
- **fkey** (*str*) – Key for accessing data in \*.npz or Matlab workspace (\*.mat) file. When fkey == ‘ba’, exporting to FPGA coefficients format is enabled.
- **title** (*str*) – title string for the file dialog box (e.g. “filter coefficients”)
- **file\_types** (*tuple of strings*) – file extension (e.g. (csv) or list of file extensions (e.g. (csv, txt) which are used to create a file filter.

```
pyfda.libs.pyfda_io_lib.extract_file_ext(file_type: str, return_list: bool = False) → str
```

Extract list with file extension(s), e.g. ‘.vhd’ from type description ‘VHDL (\*.vhd)’ returned by QFileDialog. Depending on the OS, this may be the full file type description or just the extension like ‘(\*.vhd)’.

When *file\_type* contains no ‘(’, the passed string is returned unchanged.

For an explanation of the RegEx, see the docstring for *prune\_file\_ext*.

#### Parameters

- **file\_type** (*str*)
- **return\_list** (*bool* (default = False)) – When True, return a list with file extensions (possibly empty or with only one element), when False (default) only return the first element (a string)

#### Returns

The file extension between ( ... ), e.g. ‘csv’ or the list of file extension or the unchanged input argument *file\_type* when no ‘(’ was contained.

#### Return type

*str* or *list of str*

```
pyfda.libs.pyfda_io_lib.load_data_np(file_name: str, file_type: str, fkey: str = "", as_str: bool = False)
→ ndarray
```

Import data from a file and convert it to a numpy array.

#### Parameters

- **file\_name** (*str*) – Full path and name of the file to be imported
- **file\_type** (*str*) – File type, currently supported are ‘csv’, ‘mat’, ‘npz’, ‘npz’, ‘txt’, ‘wav’.
- **fkey** (*str*) – Key for accessing data in .npz or Matlab workspace (.mat) files with multiple entries.
- **as\_str** (*bool*) – When False (default), try to convert results to ndarray of float or complex. Otherwise, return an ndarray of str.

#### Returns

Data from the file (ndarray) or None (error)

#### Return type

ndarray of float / complex / int or *str*

```
pyfda.libs.pyfda_io_lib.load_filter(self) → int
```

Load filter from zipped binary numpy array or (c)pickled object to filter dictionary

`pyfda.libs.pyfda_io_lib.prune_file_ext(file_type: str) → str`

Prune file extension, e.g. ‘Text file’ from ‘Text file (\*.txt)’ returned by QFileDialog file type description.

Pruning is achieved with the following regular expression:

```
return = re.sub('\([^\\)]+\)', '', file_type)
```

#### Parameters

**file\_type** (*str*)

#### Returns

The pruned file description

#### Return type

*str*

### Notes

Syntax of python regex: `re.sub(pattern, replacement, string)`

This returns the string obtained by replacing the leftmost non-overlapping occurrences of **pattern** in **string** by **replacement**.

- ‘.’ means any character
- ‘+’ means one or more
- ‘[a]’ means except for ‘a’
- ‘([a])+’ : match ‘(’, gobble up all characters except ‘)’ till ‘)’
- ‘(’ must be escaped as ‘\('

`pyfda.libs.pyfda_io_lib.qtable2csv(table: object, data: ndarray, zpk=False, formatted: bool = False) → str`

Transform QTableWidget data to CSV formatted text

#### Parameters

- **table** (*object*) – Instance of QTableWidget
- **data** (*object*) – Instance of the numpy variable shadowing table data
- **zpk** (*bool*) – when True, append the gain (*data[2]*) to the table
- **formatted** (*bool*) – When True, copy data as formatted in the table, otherwise copy from the model (“shadow”).

The following keys from the global dict `dict params['CSV']` are evaluated:

#### ‘delimiter’

str (default: “,”), character for separating columns

#### ‘lineterminator’

str (default: As used by the operating system), character for terminating rows. By default, the character is selected depending on the operating system:

- Windows: Carriage return + line feed
- MacOS : Carriage return
- \*nix : Line feed

#### ‘orientation’

str (one of ‘auto’, ‘horiz’, ‘vert’) determining with which orientation the table is written. ‘vert’ means a line break after each entry or pair of entries which usually is not what you want. ‘auto’ doesn’t make much sense when writing, ‘horiz’ is used in this case.

**‘header’**

str (default: ‘auto’). When header=‘on’, write the first row with ‘b, a’.

**‘clipboard’**

bool (default: True), when clipboard == True, copy data to clipboard, else use a file.

**Returns**

Nothing, text is exported to clipboard or to file via `export_fil_data`

**Return type**

None

`pyfda.libs.pyfda_io_lib.read_csv_info_old(filename)`

DON’T USE ANYMORE! Get infos about the size of a csv file without actually loading the whole file into memory.

See <https://stackoverflow.com/questions/64744161/best-way-to-find-out-number-of-rows-in-csv-without-loading-the-full-th>

`pyfda.libs.pyfda_io_lib.read_wav_info(file)`

Get infos about the following properties of a wav file without actually loading the whole file into memory. This is achieved by reading the header.

`pyfda.libs.pyfda_io_lib.save_data_np(file_name: str, file_type: str, data: ndarray, f_S: int = 1, fmt: str = ‘%f’) → int`

Save numpy ndarray data to a file in wav or csv format

**Parameters**

- **file\_name** (*str*) – Full path and name of the file to be imported
- **file\_type** (*str*) – File type, currently supported are ‘csv’ or ‘wav’
- **data** (*np.ndarray*) – Data to be saved to a file. The data dtype (uint8, int16, int32, float32) determines the bits-per-sample and PCM/float of the WAV file
- **f\_S** (*int* (*optional*)) – Sampling frequency (only used for WAV file format), only integer sampling frequencies are supported by the WAV format.
- **fmt** (*str* (*optional*)) – Optional, default ‘%f’. Format string, only used for exporting data in CSV format. Other options are e.g. ‘%1.2f’ for reduced number of digits, ‘%d’ for integer format or ‘%s’ for strings.

**Return type**

0 for success, -1 for file cancel or error

`pyfda.libs.pyfda_io_lib.save_filter(self)`

Save filter as JSON formatted textfile, zipped binary numpy array or pickle object

`pyfda.libs.pyfda_io_lib.select_file(parent: object, title: str = “”, mode: str = ‘r’, file_types: Tuple[str, ...] = (‘csv’, ‘txt’)) → Tuple[str, str]`

Select a file from a file dialog box for either reading or writing and return the selected file name and type.

**Parameters**

- **title** (*str*) – title string for the file dialog box (e.g. “Filter Coefficients”),
- **mode** (*str*) – file access mode, must be either “r” or “w” for read / write access
- **file\_types** (*tuple of str*) – supported file types, e.g. (‘txt’, ‘npy’, ‘mat’) which need to be keys of `file_filters_dict`

**Returns**

- **file\_name** (*str*) – Fully qualified name of selected file. *None* when operation has been cancelled.
- **file\_type** (*str*) – File type, e.g. ‘wav’. *None* when operation has been cancelled.



```
pyfda.libs.pyfda_io_lib.write_wav_frame(parent, file_name, data: array, f_S=1, title: str = 'Export')
```

Export a frame of data in wav format

#### Parameters

- **parent** (handle to calling instance for creating file dialog instance)
- **data** (*np.array*) – data to be exported
- **title** (*str*) – title string for the file dialog box (e.g. “audio data”)

### 3.5.5 pyfda\_fix\_lib

Fixpoint library for converting numpy scalars and arrays to quantized numpy values and formatting reals in various formats

```
class pyfda.libs.pyfda_fix_lib.Fixed(q_dict)
```

Implement binary quantization of signed scalar or array-like objects in the form WI.WF where WI and WF are the wordlength of integer resp. fractional part; total wordlength is  $W = WI + WF + 1$  due to the sign bit.

#### Examples

Define a dictionary with the format options and pass it to the constructor:

```
>>> q_dict = {'WI':1, 'WF':14, 'ovfl':'sat', 'quant':'round'}
>>> myQ = Fixed(q_dict) # instantiate fixpoint quantizer
>>> WI = myQ.q_dict['WI'] # access quantizer parameters
>>> myQ.set_qdict({'WF': 13, 'WI': 2}) # update quantizer parameters
```

#### Parameters

- **q\_dict** (*dict*) – define quantization options with the following keys
- **'WI'** (\*)
- **'WF'** (\*)
- **'quant'** (\*) –
  - ‘floor’: (default) largest integer  $I$  such that  $I \leq x$  (= binary truncation)
  - ‘round’: (binary) rounding
  - ‘fix’: round to nearest integer towards zero (‘Betragsschneiden’)
  - ‘ceil’: smallest integer  $I$ , such that  $I \geq x$
  - ‘rint’: round towards nearest int
  - ‘none’: no quantization
- **'ovfl'** (\*) –
  - ‘wrap’: do a two’s complement wrap-around
  - ‘sat’: saturate at minimum / maximum value
  - ‘none’: no overflow; the integer word length is ignored
- **N\_over** (\*) – total number of overflows (should be considered as read-only except for when an external quantizer is used)
- **Additionally**
- **the** (the following keys from global dict *fb.fil[0]* define)

- **numbers** (number base and quantization/overflow behaviour for *fixpoint*)
- `'fx_sim'` (\*)
- `'fx_base'` (\*) –
  - 'dec' : decimal (base = 10)
  - 'bin' : binary (base = 2)
  - 'hex' : hexadecimal (base = 16)
  - 'oct' : octal (base = 8)
  - 'csd' : canonically signed digit (base = "3")
- `'qfrmt'` (\*) –
  - 'qint' : fixpoint integer format
  - 'qfrac' : fractional fixpoint format

**q\_dict**

A reference to the quantization dictionary passed during construction (see above). This dictionary is updated here and can be accessed from outside.

**Type**

dict

**LSB**

value of LSB (smallest quantization step),  $self.LSB = 2^{** -q\_dict['WF']}$

**Type**

float

**MSB**

value of most significant bit (MSB),  $self.MSB = 2^{** (q\_dict['WI'] - 1)}$

**Type**

float

**MIN**

most negative representable value,  $self.MIN = -2 * self.MSB$

**Type**

float

**MAX**

largest representable value,  $self.MAX = 2 * self.MSB - self.LSB$

**Type**

float

**N**

total number of simulation data points

**Type**

integer

**N\_over\_neg**

number of negative overflows (commented out)

**Type**

integer

**N\_over\_pos**

number of positive overflows (commented out)

**Type**

integer

**ovr\_flag**

overflow flag, meaning:

0 : no overflow

+1: positive overflow

-1: negative overflow

has occurred during last fixpoint conversion.

**Type**

integer or integer array (same shape as input argument)

**places**

number of places required for printing in the selected 'fx\_base' format. For binary formats, this is the same as the wordlength. Calculated from the numeric base 'fx\_base' and the total word length WI + WF + 1.

**Type**

integer

Overflow flags and counters are set in ``self.fixp()`` and reset in ``self.reset_N()``

**Example**

class *Fixed()* can be used like the Matlab *quantizer()* object / function from the fixpoint toolbox, see (Matlab) 'help round' and 'help quantizer/round' e.g.

**MATLAB**

```
>>> q_dsp = quantizer('fixed', 'round', [16 15], 'wrap');
>>> yq = quantize(q_dsp, y)
```

**PYTHON** >>> q\_dsp = {'WI':0, 'WF': 15, 'quant': 'round', 'ovfl': 'wrap'} >>> my\_q = Fixed(q\_dsp) >>> yq = my\_q.fixp(y)

**fixp**(y, in\_frmt: *str* = 'qfrac', out\_frmt: *str* = 'qfrac')

Return a quantized copy *yq* for *y* (scalar or array-like) with the same shape as *y*. The returned data is always in float format, use *float2frmt()* to obtain different number formats.

This is used a.o. by the following methods / classes:

- *frmt2float()*: always returns a float with RWV
- *float2frmt()*: starts with RWV, passes on the scaling argument
- *input\_coeffs*: uses both methods above when quantizing coefficients

Saturation / two's complement wrapping happens outside the range +/- MSB, requantization (round, floor, fix, ...) is applied on the ratio  $y / LSB$ .

**Fractional number format WI.WF** (*fb.fil[0][`qfrmt'] = 'qfrac'*):  $LSB = 2^{** -WF}$

- Multiply float input by  $1 / self.LSB = 2^{**WF}$ , obtaining integer scale
- Quantize
- Scale back by multiplying with *self.LSB* to restore fractional point

- Find pos. and neg. overflows and replace them by wrapped or saturated values

**Integer number format**  $W = 1 + WI + WF$  (`fb.fil[0]['qfrmt'] = 'qint'`):  $LSB = 1$

- Multiply float input by  $2^{WF}$  to obtain integer scale
- Quantize and treat overflows in integer scale

#### Parameters

- **y** (*scalar or array-like object of float*) – input value (floating point format) to be quantized
- **in\_frmt** (*str*) – Determine the scaling *before* quantizing / saturation ‘*qfrac*’ (default): fractional float input, y is multiplied by  $2^{WF}$  *before* quantizing / saturating.

For all other settings, y is transformed unscaled.

- **out\_frmt** (*str*) – Determine the scaling *after* quantizing / saturation ‘*qfrac*’ (default): fractional fixpoint output format, y is divided by  $2^{WF}$  *after* quantizing / saturating.

For all other settings, y is transformed unscaled.

#### Returns

**yq** – with the same shape as y, in the range  $-2^{self.MSB} \dots 2^{self.MSB} - self.LSB$

#### Return type

float scalar or ndarray

### Examples

```
>>> q_obj_a = {'WI':1, 'WF':6, 'ovfl':'sat', 'quant':'round'}
>>> myQa = Fixed(q_obj_a) # instantiate fixed-point object myQa
>>> myQa.resetN() # reset overflow counter
>>> a = np.arange(0,5, 0.05) # create input signal
```

```
>>> aq = myQa.fixp(a) # quantize input signal
>>> plt.plot(a, aq) # plot quantized vs. original signal
>>> print(myQa.q_dict('N_over'), "overflows!") # print number of overflows
```

```
>>> # Convert output to same format as input:
>>> b = np.arange(200, dtype = np.int16)
>>> btype = np.result_type(b)
>>> # MSB = 2**7, LSB = 2**(-2):
>>> q_obj_b = {'WI':7, 'WF':2, 'ovfl':'wrap', 'quant':'round'}
>>> myQb = Fixed(q_obj_b) # instantiate fixed-point object myQb
>>> bq = myQb.fixp(b)
>>> bq = bq.astype(btype) # restore original variable type
```

**float2frmt**(y) → str

Convert an array or single value of float / complex / string to a quantized representation in one of the formats float / int / bin / hex / csd.

Called a.o. by `itemDelegate.displayText()` for on-the-fly number conversion. Returns fixpoint representation for y (scalar or array-like) with numeric format `self.frmt` and a total wordlength of  $W = self.q\_dict['WI'] + self.q\_dict['WF'] + 1$  bits. The result has the same shape as y.

The float is always quantized / saturated using `self.fixp()` before it is converted to different fixpoint number bases.

**Parameters**

**y** (*scalar or array-like*) – y has to be an integer, float or complex decimal number

**Returns**

The numeric format is set in `fb.fil[0]['fx_base']`. It has the same shape as y. For all formats except *float* a fixpoint representation with a total number of  $W = W_I + W_F + 1$  binary digits is returned.

**Return type**

`str`, `float` or an ndarray of `float` or string

**frmt2float(y)**

Return floating point representation for fixpoint y (scalar or array) given in format `fb.fil[0]['fx_base']`.

When input format is float, return unchanged.

Else:

- Remove illegal characters and leading '0's
- Count number of fractional places `frc_places` and remove radix point
- Calculate decimal, fractional representation `y_dec` of string, using the base and the number of fractional places
- Calculate two's complement for *W* bits (only for negative bin and hex numbers)
- Calculate fixpoint float representation `y_float = fixp(y_dec, out_frmt='qfrmt')`, dividing the result by  $2^{**WF}$ .

**Parameters**

**y** (*scalar or string or array of scalars or strings in number format float or*) – `fb.fil[0]['fx_base']` ('dec', 'hex', 'oct', 'bin' or 'csd')

**Returns**

- Quantized floating point (`dtype=np.float64`) representation of input string
- of same shape as y.

**frmt2float\_scalar(y: str) → float**

Convert a string in 'dec', 'bin', 'oct', 'hex', 'csd' numeric format to float.

- format is taken from the global `fb.fil[0]['fx_base']`
- maximum wordlength is determined from the local quantization dict keys `self.q_dict['WI']` and `self.q_dict['WF']`
- negative numbers can be represented by a '-' sign or in two's complement
- represented numbers may be fractional and / or complex.
- the result is divided by  $2^{**WF}$  for `fb.fil[0]['qfrmt'] == 'qint'` in `fixp()`

**Parameters**

**y** (*str*) – A string formatted as a decimal, binary, octal, hex or csd number representation. The number string may contain a '.' or ',' to represent fractal numbers. When the string contains a 'j' it is tried to split the string into real and imaginary part.

**Returns**

The float / complex representation of the string

**Return type**

`float` or `complex`

**requant( $x_i$ ,  $QI$ )**

Change word length of input signal  $x_i$  with fractional and integer widths defined by ‘ $QI$ ’ to the word format defined by  $self.q\_dict$  using the quantization and saturation methods specified by  $self.q\_dict[‘quant’]$  and  $self.q\_dict[‘ovfl’]$ .

**Input and output word are aligned at their binary points.**

**Parameters**

- **self** (`Fixed()` *object*) –  $self.q\_dict()$  is the quantizer dict that specifies the output word format and the requantizing / saturation methods to be used.
- **$x_i$**  (*int*, *float* or *complex scalar* or *array-like*) – signal to be requantized with quantization format defined in quantizer  $QI$
- **$QI$**  (*quantizer*) – Quantizer for input word, only the keys ‘ $WI$ ’ and ‘ $WF$ ’ for integer and fractional wordlength are evaluated.  $QI.q\_dict[‘WI’] = 2$  and  $QI.q\_dict[‘WF’] = 13$  e.g. define Q-Format ‘2.13’ with 2 integer, 13 fractional bits and 1 implied sign bit = 16 bits total.

**Returns**

$y$  – requantized output data with same shape as input data, quantized as specified in  $self.q\_dict$ .

**Return type**

any

**Example**

The following shows an example of rescaling an input word from Q2.4 to Q0.3 using wrap-around and truncation. It’s easy to see that for simple wrap-around logic, the sign of the result may change.

|   |   |     |   |     |   |     |  |     |   |                        |  |     |   |                               |
|---|---|-----|---|-----|---|-----|--|-----|---|------------------------|--|-----|---|-------------------------------|
| S |   | WI1 |   | WI0 | * | WF0 |  | WF1 |   | WF2                    |  | WF3 | : | WI = 2, WF = 4, W = 7         |
| 0 |   | 1   |   | 0   | * | 1   |  | 0   |   | 1                      |  | 1   | = | 43 (dec) or 43/16 = 2 + 11/16 |
|   |   |     |   |     |   |     |  |     |   |                        |  |     |   | → (float)                     |
| * |   |     |   |     |   |     |  |     |   |                        |  |     |   |                               |
|   |   | S   | * | WF0 |   | WF1 |  | WF2 | : | WI = 0, WF = 3, W = 4  |  |     |   |                               |
| 0 | * | 1   |   | 0   |   | 1   |  |     | = | 7 (dec) or 7/8 (float) |  |     |   |                               |

When the input is integer format, the fractional value is calculated as an intermediate representation by multiplying the integer value by  $2^{**(-WF)}$ . Integer and fractional part are truncated / extended to the output quantization specifications.

Changes in the number of integer bits  $dWI$  and fractional bits  $dWF$  are handled separately.

When operating on bit level in hardware, the following operations are used:

**Fractional Bits**

- For reducing the number of fractional bits by  $dWF$ , simply right-shift the integer number by  $dWF$ . For rounding, add ‘1’ to the bit below the truncation point before right-shifting.
- Extend the number of fractional bits by left-shifting the integer by  $dWF$ , LSB’s are filled with zeros.

**Integer Bits**

- For reducing the number of integer bits by  $dWI$ , simply right-shift the integer by  $dWI$ .
- The number of fractional bits is SIGN-EXTENDED by filling up the left-most bits with the sign bit.

**resetN()**

Reset counters and overflow-flag of Fixed object

**set\_qdict**(*d*: *dict*) → *None*

Update the instance quantization dict *self.q\_dict* from passed dict *d*:

- Sanitize *WI* and *WF*
- Calculate attributes *MSB*, *LSB*, *MIN* and *MAX*
- Calculate number of places needed for printing from *qfmt*, *fx\_base* and *W* and store it as attribute *self.places*

Check the docstring of class *Fixed()* for details on quantization

**verify\_q\_dict\_keys**(*q\_dict*: *dict*) → *None*

Check against *self.q\_dict\_default* dictionary whether all keys in the passed *q\_dict* dictionary are valid.

Unknown keys throw an error message.

`pyfda.libs.pyfda_fix_lib.bin2hex(bin_str: str, WI=0) → str`

Convert number *bin\_str* in binary format to hex formatted string. *bin\_str* is prepended / appended with zeros until the number of bits before and after the radix point (position given by *WI*) is a multiple of 4.

`pyfda.libs.pyfda_fix_lib.bin2oct(bin_str: str, WI=0) → str`

Convert number *bin\_str* in binary format to octal formatted string. *bin\_str* is prepended / appended with zeros until the number of bits before and after the radix point (position given by *WI*) is a multiple of 3.

`pyfda.libs.pyfda_fix_lib.csd2dec(csd_str)`

Convert the CSD string *csd\_str* to a decimal, *csd\_str* may contain '+' or '-', indicating whether the current bit is meant to positive or negative. All other characters are simply ignored (= replaced by zero).

*csd\_str* has to be an integer CSD number.

#### Parameters

**csd\_str** (*string*) – A string with the CSD value to be converted, consisting of '+', '-', '.' and '0' characters.

#### Return type

decimal (integer) value of the CSD string

### Examples

$+00- = +2^3 - 2^0 = +7$

$-0+0 = -2^3 + 2^1 = -6$

`pyfda.libs.pyfda_fix_lib.dec2csd(dec_val, WF=0)`

Convert the argument *dec\_val* to a string in CSD Format.

#### Parameters

- **dec\_val** (*scalar (integer or real)*) – decimal value to be converted to CSD format
- **WF** (*integer*) – number of fractional places. Default is *WF* = 0 (integer number)

#### Returns

- *string* – containing the CSD value
- **Original author** (*Harnesser*)
- **https** ([//sourceforge.net/projects/pycsd/](https://sourceforge.net/projects/pycsd/))
- **License** (*GPL2*)

`pyfda.libs.pyfda_fix_lib.dec2hex(val, nbits, WF=0)`

— currently not used, no unit test —

Return *val* in hex format with a wordlength of *nbits* in two's complement format. The built-in hex function returns args < 0 as negative values. When *val* >= 2\*\**nbits*, it is “wrapped” around to the range 0 ... 2\*\**nbits*-1

#### Parameters

- **val** (*integer*) – The value to be converted in decimal integer format.
- **nbits** (*integer*) – The wordlength

#### Return type

A string in two's complement hex format

`pyfda.libs.pyfda_fix_lib.qstr(text)`

carefully replace `qstr()` function - only needed for Py2 compatibility

`pyfda.libs.pyfda_fix_lib.quant_coeffs(coeffs: iterable, Q, recursive: bool = False, out_frmt: str = "")`  
→ ndarray

Quantize the coefficients, scale and convert them to a list of integers, using the quantization settings of *Fixed()* instance *Q* and global setting *fb.fil[0][‘qfrmt’]* (‘qfrac’ or ‘qint’) and *fb.fil[0][‘fx\_sim’]* (*True* or *False*)

#### Parameters

- **coeffs** (*iterable*) – An iterable of coefficients to be quantized
- **Q** (*object*) – Instance of *Fixed* object containing quantization dict *q\_dict*
- **recursive** (*bool*) – When *False* (default), process all coefficients. When *True*, The first coefficient is ignored (must be 1)
- **out\_frmt** (*str*) – Output quantization format (“qint” or “qfrac”). When nothing is specified, use the global setting from *fb.fil[0][‘qfrmt’]*.

#### Returns

- A numpy array of integer coefficients, quantized and scaled with the
- settings of the quantization object dict.

## 3.6 Package input\_widgets

This package contains the widgets for entering / selecting parameters for the filter design.

### 3.6.1 input\_tab\_widgets

Tabbed container for all input widgets

**class** `pyfda.input_widgets.input_tab_widgets.InputTabWidgets`(*parent=None, object-Name='input\_tab\_widgets\_inst'*)

Create a tabbed widget for all input subwidgets in the list *fb.input\_widgets\_list*. This list is compiled at startup in *pyfda.libs.tree\_builder.TreeBuilder*.

**emit**(*dict\_sig: dict = {}, sig\_name: str = 'sig\_tx'*) → *None*

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys ‘*id*’ and ‘*class*’ with *id* resp. class name of the calling instance if not contained in the dict
- If key ‘*tvl*’ is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.



- If the sender has passed an `objectName`, add it with the key “sender\_name” to the dict.

**log\_rx**(*dict\_sig=None*)

Enable *self.sig\_rx.connect(self.log\_rx)* above for debugging.

### 3.6.2 input\_specs

Widget stacking all subwidgets for filter specification and design. The actual filter design is started here as well.

**class** `pyfda.input_widgets.input_specs.Input_Specs`(*parent=None, objectName='input\_specs\_inst'*)

Build widget for entering all filter specs

**emit**(*dict\_sig: dict = {}, sig\_name: str = 'sig\_tx'*) → `None`

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt’s *emit()*.

- Add the keys ‘id’ and ‘class’ with id resp. class name of the calling instance if not contained in the dict
- If key ‘ttl’ is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an `objectName`, add it with the key “sender\_name” to the dict.

**load\_dict**()

Reload info text from global dict *fb.fil[0]* and reset ‘DESIGN’ button

**process\_sig\_rx**(*dict\_sig, propagate=False*)

Process signals coming in via subwidgets and *sig\_rx*

All signals terminate here unless the flag *propagate=True*.

The sender name of signals coming in from local subwidgets is changed to its parent widget (*input\_specs*) to prevent infinite loops.

**process\_sig\_rx\_local**(*dict\_sig=None*)

Signals coming in from local subwidgets need to be propagated, so set *propagate=True* and proceed with processing in *process\_sig\_rx*.

**quit\_program**()

When <QUIT> button is pressed, send ‘quit\_program’

**start\_design\_filt**()

Start the actual filter design process:

- store the entries of all input widgets in the global filter dict.
- call the design method, passing the whole dictionary as the argument: let the design method pick the needed specs
- update the input widgets in case weights, corner frequencies etc. have been changed by the filter design method
- the plots are updated via signal-slot connection

**update\_UI**(*dict\_sig={}*) → `None`

*update\_UI* is called every time the filter design method or order (min / man) has been changed as this usually requires a different set of frequency and amplitude specs.

At this time, the actual filter object instance has been created from the name of the design method (e.g. ‘cheby1’) in *select\_filter.py*. Its handle has been stored in *fb.fil\_inst*.

*fb.fil[0]* (currently selected filter) is read, then general information for the selected filter type and order (min/man) is gathered from the filter tree [*fb.fil\_tree*], i.e. which parameters are needed, which widgets are visible and which message shall be displayed.

Then, the UIs of all subwidgets are updated using their “update\_UI” method.

**update\_info()**

Update the info field of the filter selection

```
pyfda.input_widgets.input_specs.classes = {'Input_Specs': 'Specs'}  
display name
```

**Type**

Dict containing class name

### 3.6.3 select\_filter

Subwidget for selecting the filter, consisting of combo boxes for: - Response Type (LP, HP, Hilbert, ...) - Filter Type (IIR, FIR, CIC ...) - Filter Class (Butterworth, ...)

```
class pyfda.input_widgets.select_filter.SelectFilter(parent=None,  
  objectName='select_filter_inst')
```

Construct and read combo boxes for selecting the filter, consisting of the following hierarchy:

1. Response Type rt (LP, HP, Hilbert, ...)
2. Filter Type ft (IIR, FIR, CIC ...)
3. Filter Class (Butterworth, ...)

Every time a combo box is changed manually, the filter tree for the selected response resp. filter type is read and the combo box(es) further down in the hierarchy are populated according to the available combinations.

sig\_tx({'filt\_changed'}) is emitted and propagated to input\_filter\_specs.py where it triggers the recreation of all subwidgets.

```
emit(dict_sig: dict = {}, sig_name: str = 'sig_tx') → None
```

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

**load\_dict()**

Reload comboboxes from filter dictionary to update changed settings after loading a filter design from disk. *load\_dict* uses the automatism of *\_set\_response\_type* etc. of checking whether the previously selected filter design method is also available for the new combination.

```
load_filter_order(enb_signal=False)
```

Called by *set\_design\_method* or from *InputSpecs* (with *enb\_signal = False*),  
load filter order setting from *fb.fil[0]* and update widgets

```
process_sig_rx(dict_sig)
```

Process signals coming in via *sig\_rx*

All signals terminate here.

The sender name of signals coming in from local subwidgets is changed to its parent widget to prevent infinite loops.

### 3.6.4 input\_coefs

Widget for displaying and modifying filter coefficients

**class** pyfda.input\_widgets.input\_coefs.**Input\_Coeffs**(parent=None)

Create widget with a (sort of) model-view architecture for viewing / editing / entering data contained in *self.ba* which is a list of two numpy arrays:

- *self.ba[0]* contains the numerator coefficients (“b”)
- *self.ba[1]* contains the denominator coefficients (“a”)

The lists don’t necessarily have the same length but they are always defined. For FIR filters, *self.ba[1][0] = 1*, all other elements are zero.

The length of both lists can be equalized with *self.\_equalize\_ba\_length()*.

Views / formats are handled by the ItemDelegate() class.

**clear\_table()**

Clear *self.ba*: Initialize coeff for a poles and a zero @ origin, *a = b = [1; 0]*.

Refresh QTableWidgetItem

**dict2ui()**

- update the UI from the dictionary
- Update the fixpoint quant. object
- Update the quantized coefficient view and the overflow counter
- Refresh the table

Triggered by:

- *process\_sig\_rx(): self.fx\_specs\_changed == True or dict\_sig[‘fx\_sim’] == ‘specs\_changed’*
- *self.qfmt2dict()*
- *self.fx\_base2dict()*

**emit**(dict\_sig: dict = {}, sig\_name: str = ‘sig\_tx’) → None

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt’s *emit()*.

- Add the keys ‘id’ and ‘class’ with id resp. class name of the calling instance if not contained in the dict
- If key ‘ttl’ is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key “sender\_name” to the dict.

**export\_table()**

Export data from coefficient table *self.tblCoeff* to clipboard / file in CSV format.

**fx\_base2dict()**

Read out the UI settings of *self.ui.cmb\_fx\_base* (triggering this method) which specifies the fx number base (dec, bin, ...) for display and store it in *fb.fil[0][‘fx\_base’]*.

Refresh the table and update quantization widgets. Don’t emit a signal because this only influences the view not the data itself.

**load\_dict()**

- Copy filter dict array *fb.fil[0][‘ba’]* to the coefficient list *self.ba*
- Set quantization UI from dict, update quantized coeff. display / overflow counter

- Update the display via *self.refresh\_table()*.

The filter dict is a “normal” 2D-numpy float array for the *b* and *a* coefficients while the coefficient list *self.ba* is a list of two float ndarrays to allow for different lengths of *b* and *a* subarrays while adding / deleting items.

#### **process\_sig\_rx(dict\_sig=None)**

Process signals coming from sig\_rx

#### **qfrmt2dict()**

Read out the UI settings of *self.ui.cmb\_qfrmt* (triggering this method) and store it under the ‘qfrmt’ key if it is a fixpoint format. Set the *fb.fil[0][‘fx\_sim’]* flag accordingly.

Refresh the table and update quantization widgets, finally emit a signal {‘fx\_sim’: ‘specs\_changed’}.

#### **quant\_coeffs\_save()**

Triggered by pushing “Quantize button”:

- Store selected / all quantized coefficients in *self.ba*
- Refresh table (for the case that anything weird happens during quantization)
- Reset Overflow flags *self.ba\_q[2]* and *self.ba\_q[3]*
- Save quantized *self.ba* to filter dict (in *\_save\_dict()*). This emits {‘data\_changed’: ‘input\_coeffs’}

#### **quant\_coeffs\_view()**

This method only creates a view on the quantized coefficients and stores it in *self.ba\_q*, the actual coefficients in *self.ba* remain unchanged!

- Reset overflow counters
- Quantize filter coefficients *self.ba* with quantizer objects *self.Q[0]* and *self.Q[1]* for *b* and *a* coefficients respectively and store them in the array *self.ba\_q*. Depending on the number base (float, dec, hex, ...) the result can be of type float or string.
- Store pos. / neg. overflows in the 3rd and 4th column of *self.ba\_q* as 0 or +/- 1.

#### **refresh\_table()**

Update *self.ba\_q* from *self.ba* (list with 2 one-dimensional numpy arrays), i.e. requantize displayed values (not *self.ba*) and overflow counters.

Refresh the table from it. Data is displayed via *ItemDelegate.displayText()* in the number format set by *fb.fil[0][‘fx\_base’]*.

- *self.ba[0]* -> *b* coefficients
- *self.ba[1]* -> *a* coefficients

The table dimensions are set according to the filter type set in *fb.fil[0][‘ft’]* which is either ‘FIR’ or ‘IIR’ and by the number of rows in *self.ba*.

Called at the end of nearly every method.

#### **class pyfda.input\_widgets.input\_coeffs.ItemDelegate(parent)**

The following methods are subclassed to replace display and editor of the QTableWidgetItem.

- *displayText()* displays the data stored in the table in various number formats
- *createEditor()* creates a line edit instance for editing table entries
- *setEditorData()* pass data with full precision and in selected format to editor
- *setModelData()* pass edited data back to model (*self.ba*)

Editing the table triggers *setModelData()* but does not emit a signal outside this class, only the *ui.btnSave* button is highlighted. When it is pressed, a signal with ‘data\_changed’: ‘input\_coeffs’ is produced in class *Input\_Coeffs*. Additionally, a signal is emitted with ‘fx\_sim’: ‘specs\_changed’

**createEditor**(*parent, options, index*)

Need to set editor explicitly, otherwise QDoubleSpinBox instance is created when space is not sufficient?! editor: instance of e.g. QLineEdit (default) index: instance of QModelIndex options: instance of QStyleOptionViewItemV4

**displayText**(*text, locale*) → *str*

Display *text* with selected fixpoint base and number of places

text: string / QVariant from QTableWidgetItem to be rendered locale: locale for the text

**The instance parameter *Q[c].ovr\_flag* is set to +1 or -1 for**  
positive / negative overflows, else it is 0.

**initStyleOption**(*option, index*)

Initialize *option* with the values using the *index* index. When the item (0,1) is processed, it is styled especially. All other items are passed to the original *initStyleOption()* which then calls *displayText()*. Afterwards, check whether an fixpoint overflow has occurred and color item background accordingly.

**setEditorData**(*editor, index*)

Pass the data to be edited to the editor: - retrieve data with full accuracy from *self.ba* (in float format) - quantize data according to settings in fixpoint object - represent it in the selected format (int, hex, ...)

editor: instance of e.g. QLineEdit index: instance of QModelIndex

**setModelData**(*editor, model, index*) → *None*

When editing has finished, read the updated data from the editor (= QTableWidgetItem), and store it in *self.ba* as float / complex for *fb.fil[0][‘fx\_sim’]* == *False*.

For all other formats, convert data back to floating point format via *frmt2float()* and store it in *self.ba* as float / complex. Next, use *float2frmt()* to quantize data and store it in *parent.ba\_q*. Finally, refresh the table item to display it in the selected format via *\_refresh\_table\_item()*.

editor: instance of e.g. QLineEdit model: instance of QAbstractTableModel index: instance of QModelIndex

**text**(*item*) → *str*

Return item text as string transformed by *self.displayText()*

This is used a.o. by *pyfda\_io\_lib.qtable2csv()* and *libs.pyfda\_fix\_lib* to read out a table in text mode, e.g. *text = table.itemDelegate().text(item)*

```
pyfda.input_widgets.input_coeffs.classes = {'Input_Coeffs': 'b,a'}
```

display name

**Type**

Dict containing class name

### 3.6.5 input\_pz

Widget for displaying and modifying filter Poles and Zeros

```
class pyfda.input_widgets.input_pz.Input_PZ(parent=None)
```

Create the window for entering exporting / importing and saving / loading data

**cmplx2frmt**(*text, places=-1*)

Convert number “text” (real or complex or string) to the format defined by *cmbPZFrmt*.

**Returns**

string

**emit**(dict\_sig: dict = {}, sig\_name: str = 'sig\_tx') → None

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

**eventFilter**(source, event)

Filter all events generated by the QLineEdit widgets. Source and type of all events generated by monitored objects are passed to this eventFilter, evaluated and passed on to the next hierarchy level.

- When a QLineEdit widget gains input focus (*QEvent.FocusIn*), display the stored value from filter dict with full precision
- When a key is pressed inside the text field, set the *spec\_edited* flag to True.
- When a QLineEdit widget loses input focus (*QEvent.FocusOut*), store current value in linear format with full precision (only if *spec\_edited == True*) and display the stored value in selected format

**export\_table**()

Export data from coefficient table *self.tblCoeff* to clipboard in CSV format or to file using a selected format

**frmt2cmplx**(string: str, default: float = 0.0) → complex

Convert string to real or complex, try to find out the format (cartesian, polar with various angle formats)

**load\_dict**()

Load all entries from filter dict *fb.fil[0]['zpk']* into the Zero/Pole/Gain list *self.zpk* and update the display via *self.\_refresh\_table()*. The explicit *np.array( ... )* statement enforces a deep copy of *fb.fil[0]*, otherwise the filter dict would be modified inadvertently. *dtype=object* needs to be specified to create a numpy array from the nested lists with differing lengths without creating the deprecation warning

"Creating an ndarray from ragged nested sequences (which is a list-or-tuple of lists-or-tuples-or ndarrays with different lengths or shapes) is deprecated."

The filter dict *fb.fil[0]['zpk']* is a list of numpy float ndarrays for z / p / k values *self.zpk* is an array of float ndarrays with different lengths of z / p / k subarrays to allow adding / deleting items.

Format is: [array[zeros, ...], array[poles, ...], k]

**process\_sig\_rx**(dict\_sig=None)

Process signals coming from sig\_rx

**class** pyfda.input\_widgets.input\_pz.ItemDelegate(parent)

The following methods are subclassed to replace display and editor of the QTableWidgetItem.

- *displayText()* displays the data stored in the table in various number formats
- *createEditor()* creates a line edit instance for editing table entries
- *setEditorData()* pass data with full precision and in selected format to editor
- *setModelData()* pass edited data back to model (*self.zpk*)

**createEditor**(parent, options, index)

Need to set editor explicitly, otherwise QDoubleSpinBox instance is created when space is not sufficient?! editor: instance of e.g. QLineEdit (default) index: instance of QModelIndex options: instance of QStyleOptionViewItemV4

**displayText(text, locale)**

Display *text* with selected format (cartesian / polar) and number of places

text: string / QVariant from QTableWidgetItem to be rendered locale: locale for the text

**initStyleOption(option, index)**

Initialize *option* with the values using the *index* index. All items are passed to the original *initStyleOption()* which then calls *displayText()*.

Afterwards, check whether a pole (`index.column() == 1`) is outside the UC and color item background accordingly (not implemented yet).

**setEditorData(editor, index)**

Pass the data to be edited to the editor: - retrieve data with full accuracy (*places=-1*) from *zpk* (in float format) - represent it in the selected format (Cartesian, polar, ...)

editor: instance of e.g. QLineEdit index: instance of QModelIndex

**setModelData(editor, model, index)**

When editor has finished, read the updated data from the editor, convert it to complex format and store it in both the model (= QTableWidgetItem) and in *zpk*. Finally, refresh the table item to display it in the selected format (via *to be defined*) and normalize the gain.

editor: instance of e.g. QLineEdit model: instance of QAbstractTableModel index: instance of QModelIndex

**text(item)**

Return item text as string transformed by `self.displayText()`

```
pyfda.input_widgets.input_pz.classes = {'Input_PZ': 'P/Z'}
```

display name

**Type**

Dict containing class name

### 3.6.6 input\_info

Widget for displaying infos about filter and filter design method and debugging infos

```
class pyfda.input_widgets.input_info.Input_Info(parent=None)
```

Create widget for displaying infos about filter specs and filter design method

```
emit(dict_sig: dict = {}, sig_name: str = 'sig_tx') → None
```

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys '*id*' and '*class*' with id resp. class name of the calling instance if not contained in the dict
- If key '*ttl*' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an *objectName*, add it with the key "*sender\_name*" to the dict.

**load\_dict()**

update docs and filter performance

**process\_sig\_rx(dict\_sig=None)**

Process signals coming from *sig\_rx*

```
pyfda.input_widgets.input_info.classes = {'Input_Info': 'Info'}
```

display name

**Type**

Dict containing class name

### 3.6.7 input\_fixpoint\_specs

The configuration file *libs.pyfda\_template.conf* lists which fixpoint classes (e.g. FIR\_DF and IIR\_DF1) can be used with which filter design algorithm. *libs.tree\_builder* parses this file and writes all fixpoint modules into the list *fb.fixpoint\_widgets\_list*. The input widget *pyfda.input\_widgets.input\_fixpoint\_specs* constructs a combo box from this list with references to all successfully imported fixpoint modules. The currently selected fixpoint widget (e.g. *FIR\_DF*) is imported from *Package fixpoint\_widgets* together with the referenced picture.

Each fixpoint module / class contains a widget that is constructed using helper classes from *fixpoint\_widgets.fixpoint\_helpers.py*. The widgets allow entering fixpoint specifications like word lengths and formats for input, output and internal structures (like an accumulator) for each class. It also contains a reference to a picture showing the filter topology.

Details of the mechanism and the module are described in *input\_widgets.input\_fixpoint\_specs*.

## 3.7 Package plot\_widgets

Package providing widgets for plotting various time and frequency dependent filter properties

### 3.7.1 plot\_tab\_widgets

Create a tabbed widget for all plot subwidgets in the list *fb.plot\_widgets\_list*. This list is compiled at startup in *pyfda.tree\_builder.Tree\_Builder*, it is kept as a module variable in *pyfda.filterbroker*.

```
class pyfda.plot_widgets.plot_tab_widgets.PlotTabWidgets(parent=None,  
   objectName='plot_tab_widgets_inst')
```

```
emit(dict_sig: dict = {}, sig_name: str = 'sig_tx') → None
```

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

```
eventFilter(source, event)
```

Filter all events generated by the QTabWidget. Source and type of all events generated by monitored objects are passed to this eventFilter, evaluated and passed on to the next hierarchy level.

This filter stops and restarts a one-shot timer for every resize event. When the timer generates a timeout after 500 ms, *current\_tab\_redraw()* is called by the timer.

```
log_rx(dict_sig=None)
```

Enable *self.sig\_rx.connect(self.log\_rx)* above for debugging.

### 3.7.2 plot\_hf

The *Plot\_Hf* class constructs the widget to plot the magnitude frequency response  $|H(f)|$  of the filter either in linear or logarithmic scale. Optionally, the magnitude specifications and the phase can be overlaid.

```
class pyfda.plot_widgets.plot_hf.Plot_Hf
```

Widget for plotting  $|H(f)|$ , frequency specs and the phase

```
align_y_axes(ax1, ax2)
```

Sets tick marks of twinx axes to line up with total number of ax1 tick marks



**calc\_hf()**

(Re-)Calculate the complex frequency response  $H_{\text{cmplx}}(W)$  (complex) for  $W = 0 \dots 2\pi$ :

**draw()**

Re-calculate  $|H(f)|$  and draw the figure

**draw\_inset()**

Construct / destruct second axes for an inset second plot

**draw\_phase(ax)**

Draw phase on second y-axis in the axes system passed as the argument

**init\_axes()**

Initialize and clear the axes (this is run only once)

**plot\_spec\_limits(ax)**

Plot the specifications limits ( $F_{\text{SB}}$ ,  $A_{\text{SB}}$ , ...) as hatched areas with borders.

**process\_sig\_rx(dict\_sig=None)**

Process signals coming from the navigation toolbar and from sig\_rx

**redraw()**

Redraw the canvas when e.g. the canvas size has changed

**update\_view()**

Draw the figure with new limits, scale etc without recalculating  $H(f)$

```
pyfda.plot_widgets.plot_hf.classes = {'Plot_Hf': '|H(f)|'}
```

display name

**Type**

Dict containing class name

### 3.7.3 plot\_phi

Widget for plotting phase frequency response  $\phi(f)$

```
class pyfda.plot_widgets.plot_phi.Plot_Phi
```

**calc\_resp()**

(Re-)Calculate the complex frequency response  $H(f)$

**draw()**

Main entry point: Re-calculate  $|H(f)|$  and draw the figure

```
emit(dict_sig: dict = {}, sig_name: str = 'sig_tx') → None
```

Emit a signal *self*.<sig\_name> (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

**init\_axes()**

Initialize and clear the axes - this is only called once

**process\_sig\_rx(dict\_sig=None)**

Process signals coming from the navigation toolbar and from sig\_rx

**redraw()**

Redraw the canvas when e.g. the canvas size has changed

**unit\_changed()**

Unit for phase display has been changed, emit a 'view\_changed' signal and continue with drawing.

**update\_view()**Draw the figure with new limits, scale etc without recalculating  $H(f)$ `pyfda.plot_widgets.plot_phi.classes = {'Plot_Phi': '(f)'}`

display name

**Type**

Dict containing class name

### 3.7.4 plot\_tau\_g

Widget for plotting the group delay

**class** `pyfda.plot_widgets.plot_tau_g.Plot_tau_g`

Widget for plotting the group delay

**calc\_tau\_g()**(Re-)Calculate the complex frequency response  $H(f)$ **init\_axes()**Initialize the axes and set some stuff that is not cleared by `ax.clear()` later on.**process\_sig\_rx**(*dict\_sig=None*)Process signals coming from the navigation toolbar and from `sig_rx`**redraw()**

Redraw the canvas when e.g. the canvas size has changed

**update\_view()**Draw the figure with new limits, scale etc without recalculating  $H(f)$ 

### 3.7.5 plot\_pz

Widget for plotting poles and zeros

**class** `pyfda.plot_widgets.plot_pz.Plot_PZ`**draw\_Hf**(*r=2, Hf\_visible=True*)

Draw the magnitude frequency response around the UC

**draw\_pz()**

(re)draw P/Z plot

**init\_axes()**

Initialize and clear the axes (this is only run once)

**process\_sig\_rx**(*dict\_sig: dict = None*) → `None`Process signals coming from the navigation toolbar and from `sig_rx`**redraw()**

Redraw the canvas when e.g. the canvas size has changed

**update\_view()**Draw the figure with new limits, scale etc without recalculating  $H(f)$  – not yet implemented, just use `draw()` for the moment

```
zplane(b=None, a=1, z=None, p=None, k=1, pn_eps=0.001, analog=False, plt_ax=None,
        plt_poles=True, style='equal', anaCircleRad=0, lw=2, mps=10, mzs=10, mpc='r', mzc='b',
        plabel="", zlabel="")
```

Plot the poles and zeros in the complex z-plane either from the coefficients ( $b$ ,  $a$ ) of a discrete transfer function  $H(z)$  (zpk = False) or directly from the zeros and poles (z,p) (zpk = True).

When only  $b$  is given, an FIR filter with all poles at the origin is assumed.

#### Parameters

- **b** (*array\_like*) – Numerator coefficients (transversal part of filter) When  $b$  is not None, poles and zeros are determined from the coefficients  $b$  and  $a$
- **a** (*array\_like (optional, default = 1 for FIR-filter)*) – Denominator coefficients (recursive part of filter)
- **z** (*array\_like, default = None*) – Zeros When  $b$  is None, poles and zeros are taken directly from  $z$  and  $p$
- **p** (*array\_like, default = None*) – Poles
- **analog** (*boolean (default: False)*) – When True, create a P/Z plot suitable for the s-plane, i.e. suppress the unit circle (unless  $\text{anaCircleRad} > 0$ ) and scale the plot for a good display of all poles and zeros.
- **pn\_eps** (*float (default : 1e-2)*) – Tolerance for separating close poles or zeros
- **plt\_ax** (*handle to axes for plotting (default: None)*) – When no axes is specified, the current axes is determined via `plt.gca()`
- **plt\_poles** (*Boolean (default : True)*) – Plot poles. This can be used to suppress poles for FIR systems where all poles are at the origin.
- **style** (*string (default: 'scaled')*) – Style of the plot, for `style == 'scaled'` make scale of x- and y- axis equal, `style == 'equal'` forces x- and y-axes to be equal. This is passed as an argument to the matplotlib `ax.axis(style)`
- **mps** (*integer (default: 10)*) – Size for pole marker
- **mzs** (*integer (default: 10)*) – Size for zero marker
- **mpc** (*char (default: 'r')*) – Pole marker colour
- **mzc** (*char (default: 'b')*) – Zero marker colour
- **lw** (*integer (default: 2)*) – Linewidth for unit circle
- **plabel** (*string (default: "")*) – This string is passed to the plot command for poles and zeros and can be displayed by `legend()`
- **zlabel** (*string (default: "")*) – This string is passed to the plot command for poles and zeros and can be displayed by `legend()`

#### Returns

**z, p, k**

#### Return type

ndarray

## Notes

`pyfda.plot_widgets.plot_pz.classes = {'Plot_PZ': 'P / Z'}`

display name

### Type

Dict containing class name

## 3.7.6 plot\_impz

Widget for plotting impulse and general transient responses

**class** `pyfda.plot_widgets.plot_impz.Plot_Impz(objectName='plot_impz_inst')`

Construct a widget for plotting impulse and general transient responses

**calc\_auto**(*autorun*: *bool* = *None*) → *None*

Triggered when checkbox “Autorun” is clicked or specs have been edited, requiring a recalculation.

When Autorun has been pushed (*but\_auto\_run.isChecked()* == *True*) and calculation is required, automatically run *impz\_init()*.

**calc\_fft**()

(Re-)calculate FFTs of stimulus *self.X*, quantized stimulus *self.X\_q* and response *self.Y* using the window function from *self.ui.win\_dict['win']*.

**draw**(*arg*=*None*)

(Re-)draw the figure without recalculation. When triggered by a signal- slot connection from a button, combobox etc., *arg* is a boolean or an integer representing the state of the widget. In this case, *needs\_redraw* is set to *True*.

**draw\_data**(*plt\_style*: *str*, *ax*: *object*, *x*: *ndarray*, *y*: *ndarray*, *bottom*: *float* = 0, *label*: *str* = "", *plt\_fmt*: *dict* = {}, *mkr\_fmt*: *dict* = {}, \*\**args*)

Plot *x*, *y* data (numpy arrays with equal length) in a plot style defined by *plt\_style*.

### Parameters

- **plt\_style** (*str*) – one of “line”, “stem”, “steps”, “dots”
- **ax** (*matplotlib axis*) – Handle to the axis where signal is to be plotted
- **x** (*array-like*) – x-axis: time or frequency data
- **y** (*array-like*) – y-data
- **bottom** (*float*) – Bottom line y-coordinate for stem plot. The default is 0.
- **label** (*str*) – Plot label
- **plt\_fmt** (*dict*) – Line styles (color, linewidth etc.) for plotting (default: *None*).
- **mkr\_fmt** (*dict*) – Marker styles
- **args** (*dict*) – additional keys and values. As they might not be compatible with every plot style, they have to be added individually

### Returns

**handle** – This provides a handle to the properties of line and marker (optionally) which are displayed by legend

### Return type

A *lines.Line2D()* objects or tuple with two of them

**draw\_freq**()

(Re-)draw the frequency domain mplwidget

**draw\_time**(*N\_start=0, N\_end=0*)

(Re-)draw the time domain mplwidget

**emit**(*dict\_sig: dict = {}, sig\_name: str = 'sig\_tx'*) → *None*

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an objectName, add it with the key "sender\_name" to the dict.

**file\_io**() → *None*

Check status of file\_io widget:

- if no file is loaded, do nothing and return 0, disable *cmb\_file\_io* and the option to transfer the number of samples to N
- **else map the file data to *self.stim\_wdg.x\_file* to make it accessible**  
from the stimulus widget. If *cmb\_file\_io == 'use'*, disable the widget to modify stimuli

**impz**()

Calculate floating point / fixpoint response and redraw it

Triggered by:

- *self.impz\_init()* (floating point)
- **Fixpoint widget, requesting "start\_fx\_response\_calculation"**  
via *process\_rx\_signal()* (fixpoint filter)

**impz\_finish**()

Do some housekeeping, resetting and drawing when *self.impz()* has finished:

- Calculate step error if selected
- Check for complex stimulus or response
- Calculate simulation time
- Draw the signals
- Reset Run Icon to normal state, reset *needs\_calc* flag
- Update File IO save combo boxes

**impz\_init**(*arg=None*) → *None*

Initialize transient simulation.

#### Parameters

**arg** (*bool* or *None*)

#### Return type

*None*

Triggered by:

- *\_construct\_UI()* during initialization
- Pressing "Run" button, passing button state as a bool
- *self.ui.cmb\_sim\_select* when changing between fixpoint and float mode
- *self.calc\_auto()* when activating "Autorun"
- Autorun (when something relevant in the UI has been updated)
- signal {'fx\_sim' : 'specs\_changed'}

The following tasks are performed:

- Enable energy scaling for impulse stimuli when requirements are met
- check for and enable fixpoint settings
- resize stimulus widget
- when triggered by *but\_run* or when *Auto* is pressed and *self.needs\_calc == True*, continue with calculating stimulus / response
- When in fixpoint mode, initialize quantized stimulus *x\_q* and input quantizer and emit *{'fx\_sim': 'init'}*

**process\_sig\_rx(dict\_sig=None)**

Process signals coming from - the navigation toolbars (time and freq.) - local widgets (*impz\_ui*) and - *plot\_tab\_widgets()* (global signals)

**process\_sig\_rx\_f(dict\_sig=None)**

Special treatment for signals coming from *FREQ* plot navigation toolbar

**process\_sig\_rx\_t(dict\_sig=None)**

Special treatment for signals coming from *TIME* plot navigation toolbar

**redraw()**

Redraw the currently visible canvas (but not the plot!) when e.g. the canvas size has changed

**resize\_stim\_tab\_widget()**

Resize active tab of stimulus Tab widget to fit the height of the contained widget. This is triggered by: - initialization in *\_construct\_UI()* - changed tab in the stimulus tab widget (signal-slot) - an 'ui-changed' - signal (*process\_signal\_rx()*)

**set\_N\_to\_file\_len()** → *None*

Check status of *file\_io* widget: - if no file is loaded, do nothing. This shouldn't happen (check to be sure ...) - else set *N\_end = len(file\_data)* in the UI

**set\_ui\_level(ui\_level)**

Sync time and frequency subwidget and set their ui display level

**toggle\_fx\_settings(arg=None)**

*arg* can be the following arguments, triggered by:

- *arg None*: from *\_\_init\_\_()*, *impz\_init()* or *process\_sig\_rx()* when *{dict\_sig['fx\_sim'] == 'specs\_changed'}* was received. Read the state of *fb.fil[0]['fx\_sim']* and update combobox correspondingly
- *arg int 0 or 1* from *self.ui.cmb\_sim\_select* when index was changed (signal-slot-connection), update *fb.fil[0]['fx\_sim']* correspondingly, fire signal *{'fx\_sim': 'specs\_changed'}* and start simulation
- *arg "fixpoint" or "float"* from a direct call with (not used currently), update ui and combobox *self.ui.cmb\_sim\_select* correspondingly

When fixpoint simulation is selected, all corresponding widgets are made visible and *fb.fil[0]['fx\_sim']* is set to *True*.

If *fb.fil[0]['fx\_sim']* has been changed since last time, *self.needs\_calc* is set to *True* and the run button is set to 'changed'.

**toggle\_stim\_options()**

Toggle visibility of stimulus options, depending on the state of the "Stimuli" button

**zoom\_home()**

Zoom to home settings

```
pyfda.plot_widgets.plot_impz.classes = {'Plot_Impz': 'y[n] / Y(f)'}
```

display name

**Type**

Dict containing class name

### 3.7.7 plot\_3d

Widget for plotting  $|H(z)|$  in 3D

**class** pyfda.plot\_widgets.plot\_3d.Plot\_3D

Class for various 3D-plots: - lin / log line plot of  $H(f)$  - lin / log surf plot of  $H(z)$  - optional display of poles / zeros

**draw()**

Main drawing entry point: perform the actual plot

**draw\_3d()**

Draw various 3D plots

**init\_axes()**

Initialize and clear the axes to get rid of colorbar The azimuth / elevation / distance settings of the camera are restored after clearing the axes. See <http://stackoverflow.com/questions/4575588/matplotlib-3d-plot-with-pyqt4-in-qtabwidget-mplwidget>

**process\_sig\_rx(dict\_sig=None)**

Process signals coming from the navigation toolbar and from sig\_rx

**redraw()**

Redraw the canvas when e.g. the canvas size has changed

```
pyfda.plot_widgets.plot_3d.classes = {'Plot_3D': '3D'}
```

display name

**Type**

Dict containing class name

## 3.8 Package filter\_widgets

Package providing various algorithms for FIR and IIR filter design.

### 3.8.1 pyfda.filter\_widgets.bessel

Design Bessel filters (LP, HP, BP, BS) with fixed or minimum order, return the filter design in zeros, poles, gain (zpk) format

This class is re-instantiated dynamically every time the filter design method is selected, reinitializing instance attributes.

**API version info:**

**1.0**

initial working release

**1.1**

- copy A\_PB -> A\_PB2 and A\_SB -> ``A\_SB2 for BS / BP designs
- mark private methods as private

**1.2**

new API using `fil_save` (enable SOS features)

**1.3**

new public methods `destruct_UI` and `construct_UI` (no longer called by `__init__`)

**1.4**

- module attribute `filter_classes` contains class name and combo box name instead of class attribute `name`
- `FRMT` is now a class attribute

**2.0**

Specify the parameters for each subwidget as tuples in a dict where the first element controls whether the widget is visible and / or enabled. This dict is now called `self.rt_dict`. When present, the dict `self.rt_dict_add` is read and merged with the first one.

**2.1**

Remove empty methods `construct_UI` and `destruct_UI` and attributes `self.wdg` and `self.hdl`

**2.2**

Rename `filter_classes` -> `classes`, remove Py2 compatibility

**class** `pyfda.filter_widgets.bessel.Bessel`

Design Bessel filters (LP, HP, BP, BS) with fixed or minimum order, return the filter design in zeros, poles, gain (zpk) format

**ft**

filter type

**info**

filter variants

`pyfda.filter_widgets.bessel.classes = {'Bessel': 'Bessel'}`

display name

**Type**

Dict containing class name

## 3.9 Package `fixpoint_widgets`

This package contains widgets and fixpoint descriptions for simulating filter designs with fixpoint arithmetics and for converting filter designs to Verilog using the `migen` library. These Verilog netlists can be synthesized e.g. on an FPGA.

Hardware implementations for discrete-time filters usually imply fixpoint arithmetics but this could change in the future as floating point arithmetics can be implemented on FPGAs using dedicated floating point units (FPUs).

Filter topologies are defined in the corresponding classes and can be implemented in hardware. The filter topologies use the order and the coefficients that have been determined by a filter design algorithm from the `pyfda.filter_widgets` package for a target filter specification (usually in the frequency domain). Filter coefficients are quantized according to the settings in the fixpoint widget.

Each fixpoint module / class contains a widget that is constructed using helper classes from `fixpoint_widgets`. `fixpoint_helpers`. The widgets allow entering fixpoint specifications like word lengths and formats for input, output and internal structures (like an accumulator) for each class. It also contains a reference to a picture showing the filter topology.

The configuration file `pyfda.conf` lists which fixpoint classes (e.g. `FIR_DF` and `IIR_DF1`) can be used with which filter design algorithm. `tree_builder` parses this file and writes all fixpoint modules into the list `fb.fixpoint_widgets_list`.



The widgets are selected and instantiated in the widget `input_widgets.input_fixpoint_specs`.

The input widget `pyfda.input_widgets.input_fixpoint_specs` constructs a combo box from this list with references to all successfully imported fixpoint modules. The currently selected fixpoint widget (e.g. `FIR_DF`) is imported from `Package fixpoint_widgets` together with the referenced picture.

First, a filter widget is instantiated as `self.fx_filt_ui` (after the previous one has been destroyed).

Next, `fx_filt_ui.construct_fixp_filter()` constructs an instance `fixp_filter` of a fixpoint filter class (of e.g. `pyfda.fixpoint_widgets.fir_df`).

The widget's methods

- `response = fx_filt_ui.fx_filt.run_sim(stimulus)`
- `fx_filt_ui.fx_filt.to_verilog()`

are used for bit-true simulations and for generating Verilog code for the filter.

### 3.9.1 input\_widgets.input\_fixpoint\_specs

A fixpoint filter for a given filter design is selected in this widget. Widget for simulating fixpoint filters and generating Verilog Code

**class** `pyfda.input_widgets.input_fixpoint_specs.Input_Fixpoint_Specs`(*parent=None, object-Name='input\_fixpoint\_spec\_inst'*)

Create the widget that holds the dynamically loaded fixpoint filter UI

**dict2ui()**

Called during `__init__()` and from `process_sig_rx()`.

Update UI from `fb.fil[0]['fx_sim']`, `fb.fil[0]['qfrmt']` and the fx filter dict `fb.fil[0]['fxq']`. This affects the visibility and the fx settings of input, output and dyn. filter widget via their `dict2ui()` methods. The setting of the `self.cmb_qfrmt` combobox influencing float / fixpoint number format is updated as well.

**embed\_fixp\_img**(*img\_file: str*) → QPixmap

Embed *img\_file* in png format as *self.img\_fixp*

**Parameters**

**img\_file** (*str*) – path and file name to image file

**Returns**

**self.img\_fixp** – pixmap containing the passed *img\_file*

**Return type**

QPixmap object

**emit**(*dict\_sig: dict = {}*, *sig\_name: str = 'sig\_tx'*) → *None*

Emit a signal *self.<sig\_name>* (defined as a class attribute) with a dict *dict\_sig* using Qt's *emit()*.

- Add the keys 'id' and 'class' with id resp. class name of the calling instance if not contained in the dict
- If key 'ttl' is in the dict and its value is less than one, terminate the signal. Otherwise, reduce the value by one.
- If the sender has passed an *objectName*, add it with the key "sender\_name" to the dict.

**exportHDL()**

Synthesize HDL description of filter

**fx\_filt\_init()**

Wrapper around *self.fx\_filt\_ui.init\_filter()* to catch errors. Initialize fix-point filter, reset registers and overflow counters

TODO: - Update the *fxqc\_dict* containing all quantization information

**Returns**

**error** – 0 for successful fx widget construction, -1 for error

**Return type**

`int`

**fx\_sim\_calc\_response**(*dict\_sig*) → `None`

- Read fixpoint stimulus from *dict\_sig* in integer format
- Pass it to the fixpoint filter which calculates the fixpoint response
- Store the result in *fb.fx\_results* and return. In case of an error, *fb.fx\_results* == `None`

**Return type**

`None`

**load\_fx\_filter**() → `None`

A new filter has been loaded, create fixpoint filter from scratch.

(Re-)Read list of available fixpoint filters for a given filter class every time a new filter has been designed or loaded.

Then try to import the fixpoint designs in the list and populate the fixpoint implementation combo box *self.cmb\_fx\_wdg* with successful imports.

**process\_sig\_rx**(*dict\_sig*: *dict* = `None`) → `None`

Process signals coming in via *sig\_rx* from other widgets.

Trigger fx simulation:

1. *fx\_sim*: 'init': Start fixpoint simulation by sending '*fx\_sim*': 'start\_fx\_response\_calculation'
2. Store fixpoint response in *fb.fx\_result* and return to initiating routine

**process\_sig\_rx\_local**(*dict\_sig*: *dict* = `None`) → `None`

Process signals coming in from input and output quantizer subwidget and emit {'fx\_sim': 'specs\_changed'} in the end.

**qfrmt2ui**()

Triggered by a change of index of the combo box *self.cmb\_qfrmt*.

- Update UI (fixpoint format, visibility of fixpoint widgets) from combobox *self.cmb\_qfrmt* to *fb.fil[0]['fx\_sim']* and *fb.fil[0]['qfrmt']*.
- Update fixpoint widget settings via *self.dict2ui*()
- Emit {'fx\_sim': 'specs\_changed'}.

**resize\_img**() → `None`

Triggered when *self* (the widget) is selected or resized. The method resizes the image inside `QLabel` to completely fill the label while keeping the aspect ratio.

The parent *InputTabWidget* defines the available width (minus some offset due to margins etc.), unfortunately *self.width()* cannot be used as a measure as it expands with the parent but doesn't shrink.

```
pyfda.input_widgets.input_fixpoint_specs.classes = {'Input_Fixpoint_Specs':  
'Fixpoint'}
```

display name

**Type**

Dict with class name

### 3.9.2 `pyfda.fixpoint_widgets.fir_df`



**LITERATURE**

**References**



## API DOCUMENTATION

### 5.1 pyfda – Main package





## INDICES AND TABLES

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