How to read real data, plot and fit

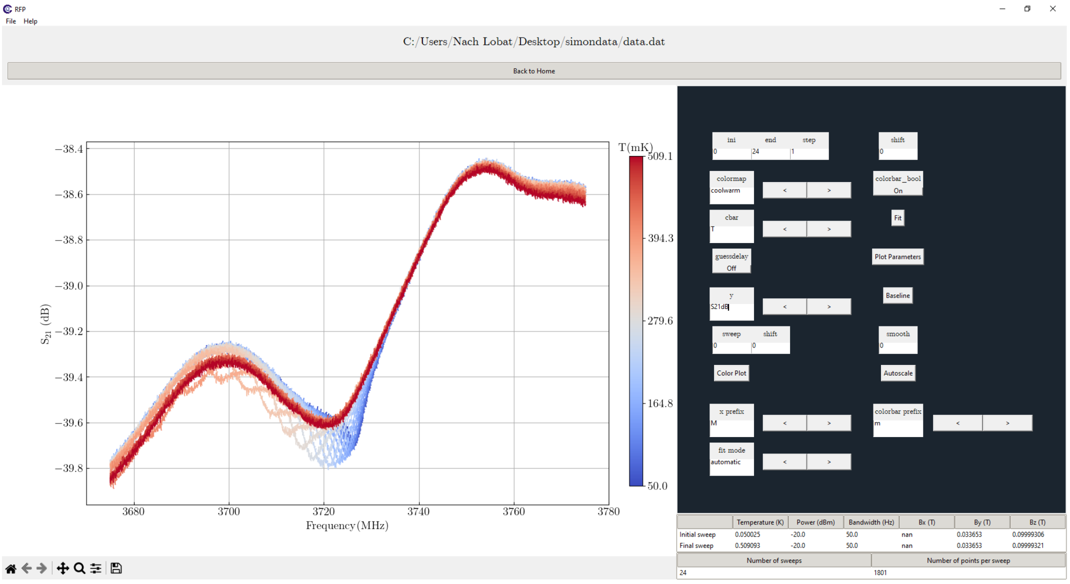
Instructions: It will first ask you to select the folder where the files to plot are, the files should have the following format

- A header with the name of all the parameters in our measurements.
- A complete dataset with all the supported columns should be the following:**# temperature power bandwidth freq Bx By Bz Re_S21 Im_S21 amplitude phase**
- After the header, the data should be in the same order as the header. **The header order is not important**
- All the data should be separated by tabs or spaces, and every sweep should be stacked one after the other.
- The only columns that are necessary are the **frequency** , the **amplitude** , and the **phase** . The other columns are optional.
- For example, for a dataset without Bx magnetic field the format could be:

```
# temperature   power   bandwidth       By      Bz      freq    Re_S21  Im_S21  amplitude       phase
0.050025        -20     50      0.033653        0.09999306      3675000000      -0.005787429322 0.008469726511  -39.77857931    2.170231336
0.050025        -20     50      0.033653        0.09999306      3675055556      -0.00577228832  0.008482358768  -39.77696521    2.168318288
0.050025        -20     50      0.033653        0.09999306      3675111111      -0.005772230999 0.008456827813  -39.79487125    2.169716496
0.050025        -20     50      0.033653        0.09999306      3675166667      -0.005770292262 0.008472179174  -39.78504351    2.168716002
0.050025        -20     50      0.033653        0.09999306      3675222222      -0.005766028865 0.008480375054  -39.78133523    2.167922492
0.050025        -20     50      0.033653        0.09999306      3675277778      -0.005778925255 0.008481270979  -39.77456432    2.168912558
0.050025        -20     50      0.033653        0.09999306      3675333333      -0.005793857048 0.008490710879  -39.76085486    2.169595894
0.050025        -20     50      0.033653        0.09999306      3675388889      -0.005796656751 0.008495190772  -39.75639566    2.169575232
0.050025        -20     50      0.033653        0.09999306      3675444444      -0.00574890799  0.008490336659  -39.78249543    2.165995428
0.050025        -20     50      0.033653        0.09999306      3675500000      -0.005779516886 0.008469899413  -39.78223719    2.169584704
0.050025        -20     50      0.033653        0.09999306      3675555556      -0.005771496017 0.008488298733  -39.77318543    2.167928908
0.050025        -20     50      0.033653        0.09999306      3675611111      -0.005763793605 0.008474528268  -39.78649644    2.168062899
0.050025        -20     50      0.033653        0.09999306      3675666667      -0.005796246276 0.00849447327   -39.75709164    2.169581586
0.050025        -20     50      0.033653        0.09999306      3675722222      -0.005767002803 0.008491204836  -39.77328851    2.167407721
0.050025        -20     50      0.033653        0.09999306      3675777778      -0.005765220151 0.008496072858  -39.77072797    2.166997713
0.050025        -20     50      0.033653        0.09999306      3675833333      -0.005782453396 0.008506834295  -39.7550203     2.167796609
0.050025        -20     50      0.033653        0.09999306      3675888889      -0.005743657015 0.00850503689   -39.77467508    2.164768665
0.050025        -20     50      0.033653        0.09999306      3675944444      -0.005768895803 0.008489221331  -39.77377672    2.167668869
0.050025        -20     50      0.033653        0.09999306      3676000000      -0.005754666273 0.008506068493  -39.76873586    2.165600839
```

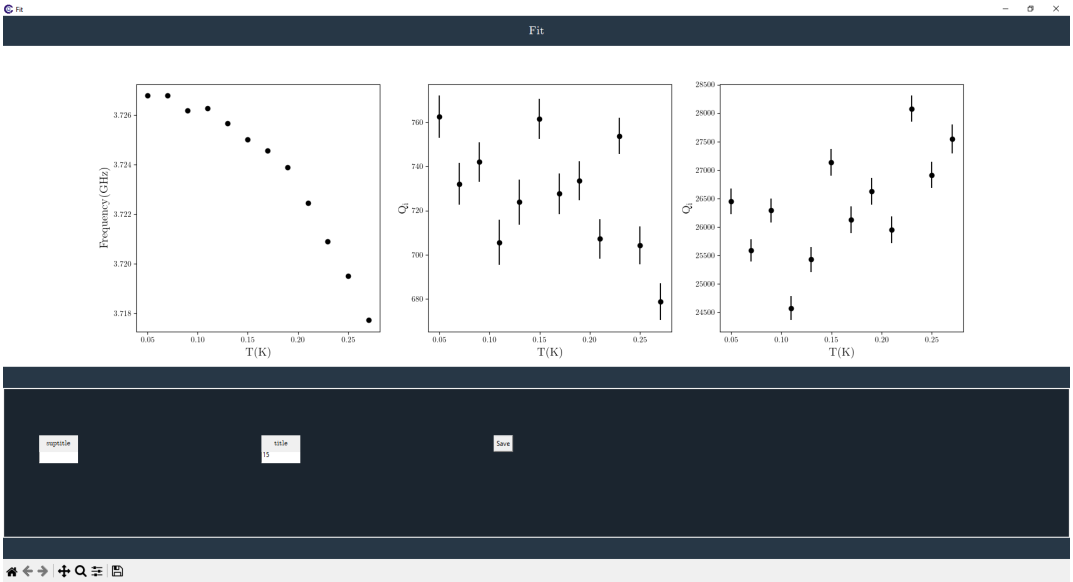
Note: Be sure that your bandwidth column is called **bandwidth** and not **bw** or any other name. Same for **freq**.

Overview:



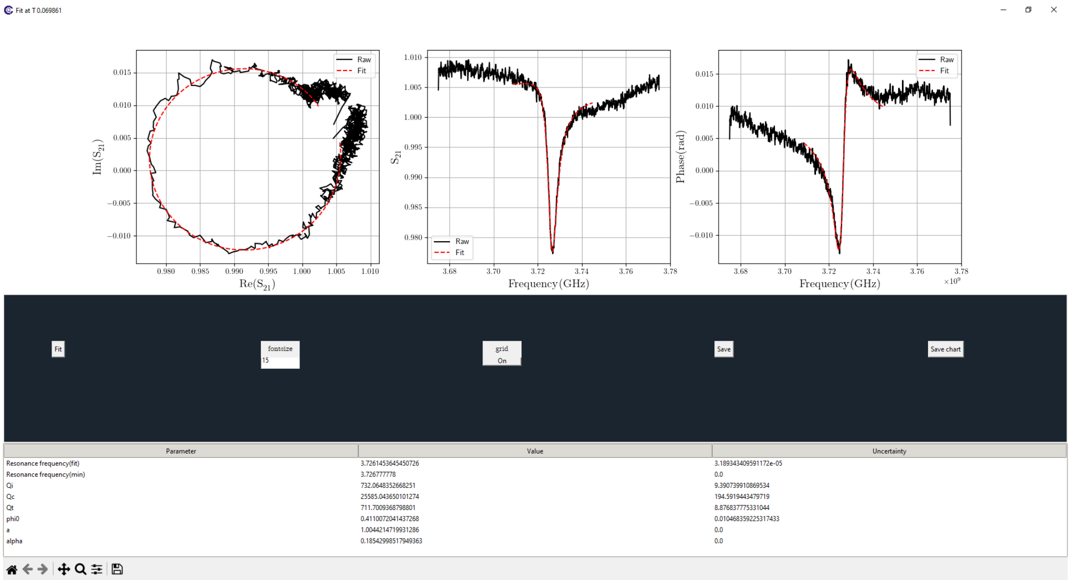
- **Sweep selector:** Show sweeps in the interval [ini,end) spaciated with step.
- **Shift:** Shift the data for a waterfall plot.
- **Colormap selector:** Selects the colormap for the plot.
- **Colorbar switch:** Activates the colorbar.
- **Sweep parameter selector (cbar):** Select the parameter that has been swept. The colorbar will be deactivated if the parameter is not swept or if the parameter selected is not in the datafile.
- **Fit Button:** Fits the data shown in the plot. (See Fit section in this document)
- **Guess delay switch:** Activates the "Guess delay" option during the fitting. It is advisable to leave it OFF.(See Fit section on this document)
- **Plot parameters:** Optional main plot customizable options.
- **Y axis selector:** Select the y axis. Either S21, S21 in DB and Phase.
- **Baseline selector:** Select data file for the baseline. The baseline will be substracted from the data in the plot. Sweep: Select the sweep of the data file as a baseline. Shift: DB shift of the substracted data. Baseline data set should have the same amount of points as the plotted dataset.
- **Smooth:** Window size for data smoothing.
- **Color plot:** Make a color plot of the data. X axis: Frequency. Y axis: Colorbar axis in main plot. Z axis: Y axis in main plot. The colorbar in this plot is interactive.
- **Autoscale:** Autoscale the plot.
- **Prefix selector:** Select prefixes for the x axis and the colorbar.
- **Fit mode:** All in screen: Fits the range in the screen. Automatic: Selects the range automatically. Obtains the full width at half minimun (FWHM) of the resonance. The fitting is performed in the range (min-3*FWHM,min+3*FWHM). Recommended in case baseline is substracted.

Fit: All fitted values are plotted against the sweeping parameter. In the following example, fitted was performed with subtracted baseline and a smooth of 7.



- **Save button:** Saves the fitted data in a .txt file.

In case you want to see how the fitting is performed, you can click on the point in the plot to open the following window:



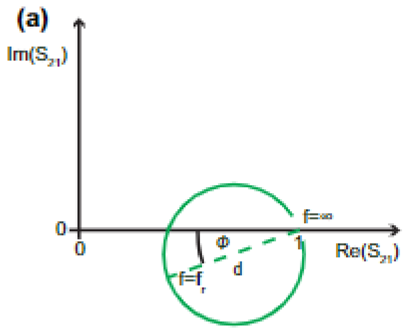
- **Fit button:** Fits the data again, in the range shown in the screen.
- **Save button:** Saves the fitted data in a .txt file.
- **Save chart button:** Saves the chart in a .txt file.

Fitting method:

The fitting function was taken from the following paper [Efficient and robust analysis of complex scattering data under noise in microwave resonators (https://arxiv.org/abs/1410.3365)](https://arxiv.org/abs/1410.3365), takes into account the environment contribution in the S_{21} parameter and the coupling between the resonator and the transmission line. The fitting function is the following:

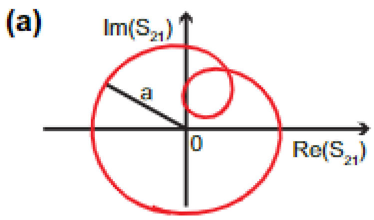
$$S_{21}^{\text{notch}}(f) = ae^{i\alpha}e^{-2\pi i f\tau}\left[1 - \frac{\frac{Q_l}{|Q_e|}e^{i\phi}}{1 + 2iQ_l(f/f_0 - 1)}\right]$$

where a is the amplitude, α is the phase, τ is the delay, f_0 is the resonant frequency, Q_l is the total quality factor ($Q_l^{-1} = Q_i^{-1} + \mathrm{Re}[Q_e{}^{-1}]$), Q_e is the external quality factor. If we focus the term in bracket, and try to plot real and imaginary part we will have a perfect circle of radius $Q_l/|Q_c|$ with the following properties:

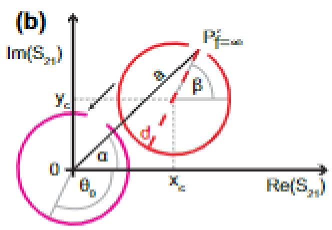


- The circle always intersects the real axis at 1 for $f \to \infty$ independent of the other parameters
- Resonance $f = f_0$ is always located at the opposite side.
- A tilt by φ indicates an impedance mismatch.

If we plot $\mathrm{Re}[S_{21}]$ vs $\mathrm{Im}[S_{21}]$ parameter of some experimental data we will have the following:



where the cable delay τ causes a circular distortion of the ideal resonance circle.



The radius a represents the system's attenuation/gain and the phase α is the phase of the system.

Basing on this, the fitting function is implemented in the code provided in the paper, and roughly speaking, it does the following:

1. Estimate the cable delay by fitting a linear function to the phase signal, which tilts the phase by 2πτ.
2. Perform a non-linear least square fit on the deformed circle-like curve caused by