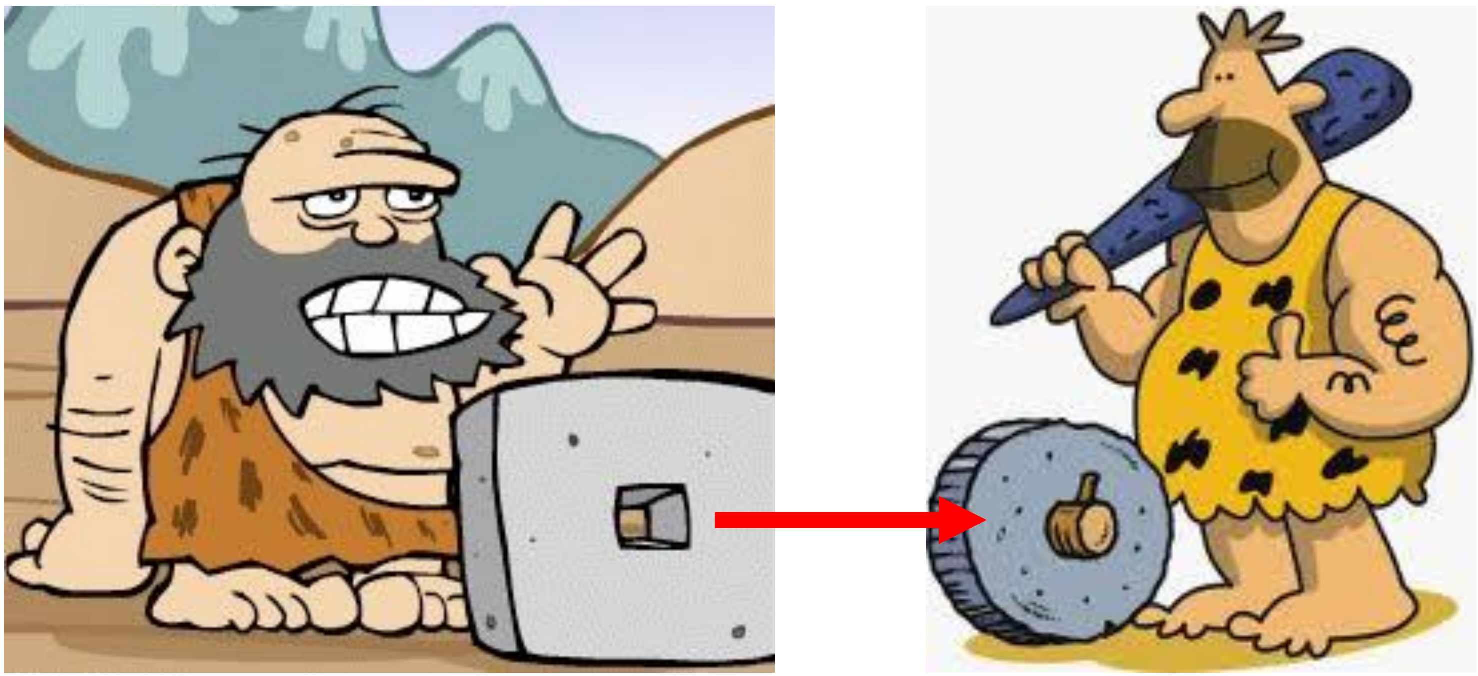
Algorithmic control

of stochastic cooling systems

21 September 2017 | Nikolay Shurkhno, Rolf Stassen, FZ Jülich

Experience

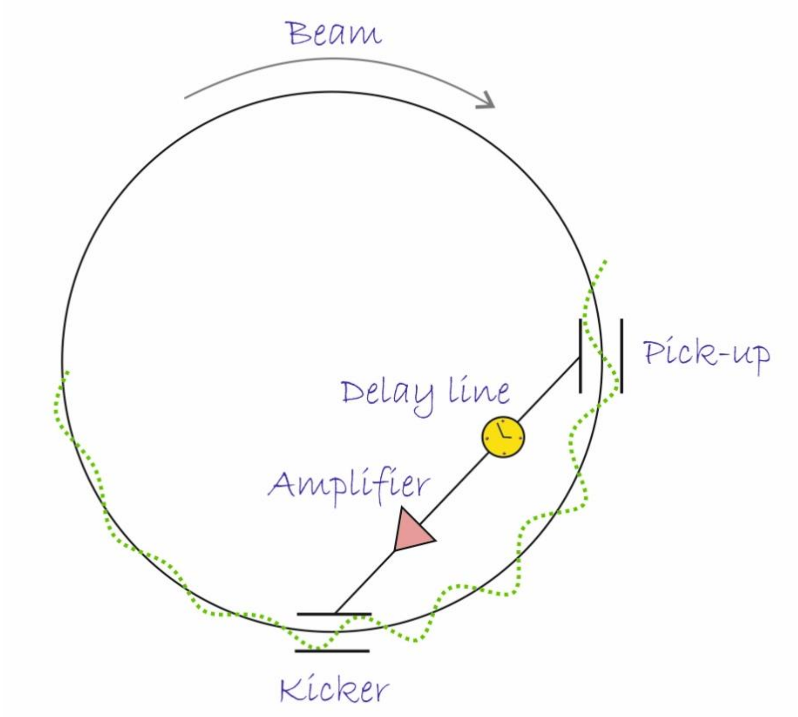


Stochastic cooling system adjustment

We adjust **frequency response** of a microwave SC system S_{21}:

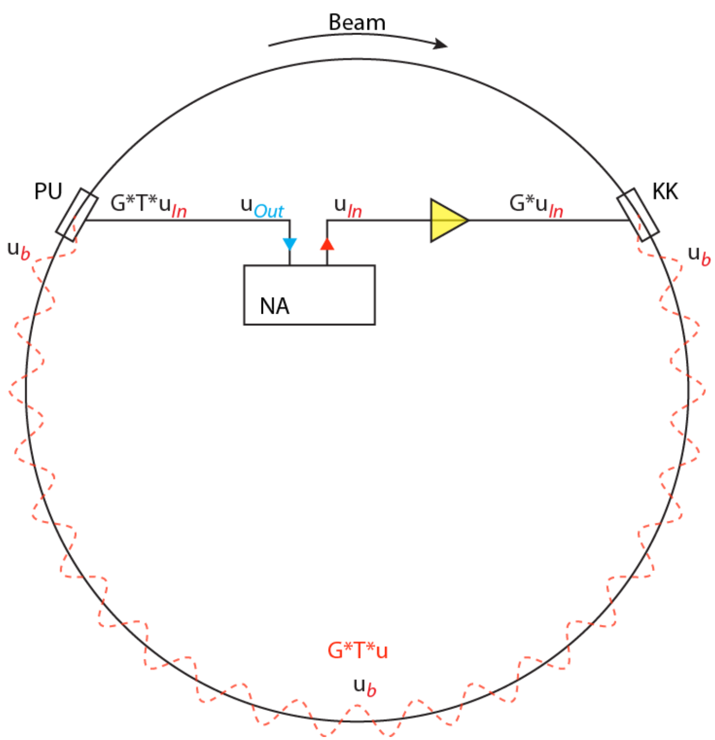
- $abs(S_{21})$ - *gain*
- $arg(S_{21})$ – *delay*
- *+ opt. notch-filter*

But for noisy data in wide bandwidth..



1. **How to measure?**
2. **How to adjust then?**

Open-loop measurements: idea



$$S_{OL} = \frac{u_{out}}{u_{in}} = HTF \cdot BTF$$

BTF could be restored with additional measurements:

$$\tilde{T}_n^{\perp} = \frac{1}{2\omega_\beta} \int \frac{\Psi(E)}{\omega_n(E) - \omega} dE$$

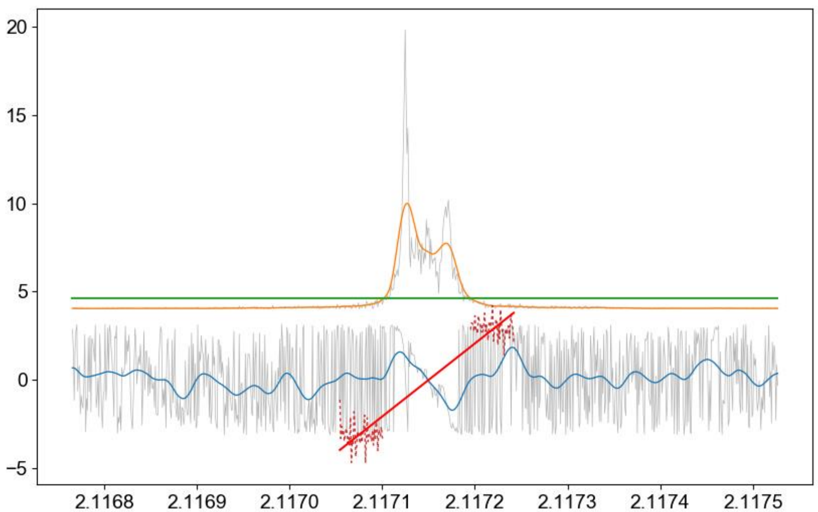
$$\tilde{T}_n^{\Sigma} = j \frac{e^2 f_0^2}{nk} \int \frac{\partial \Psi / \partial E}{E - \bar{E}} dE$$

Open-loop measurements: techniques

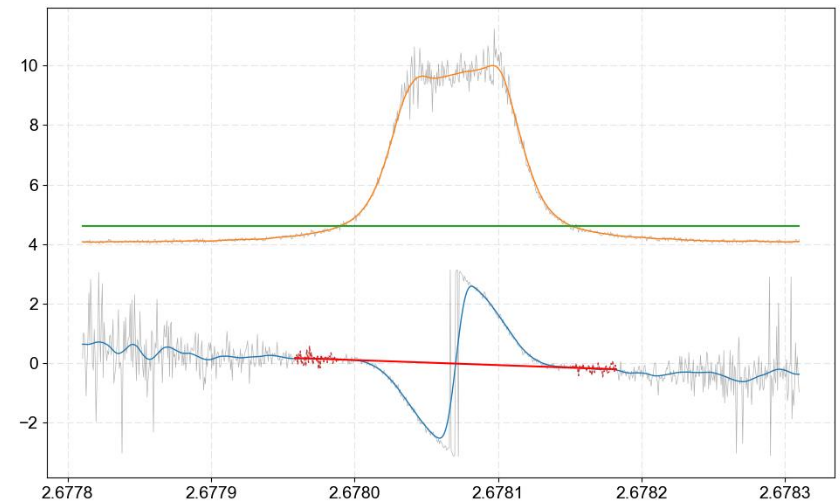
- Single sweep
  - Manually set Network analyzer points to harmonics
  - Very fast (**~ *sec***), especially for small number of points, but may produce inaccurate phase

- Harmonic sweep
  - Measure harmonics individually and calculate
  - More time-consuming (**~ *sec-min*** – *depend on number of points*), but precise and doesn't require manual setting for points of NA (not every device has this option)

Longitudinal harmonic sweep: trick



Phase “as is”

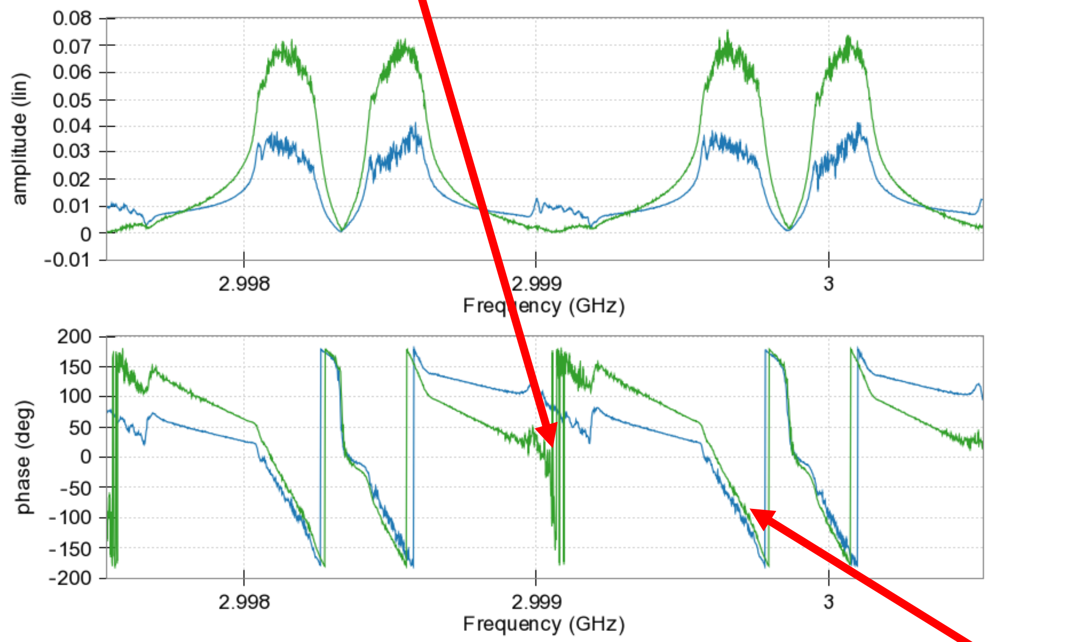


Corrected phase

$$dt_{opt} = minimize(\arg(S(dt)))$$

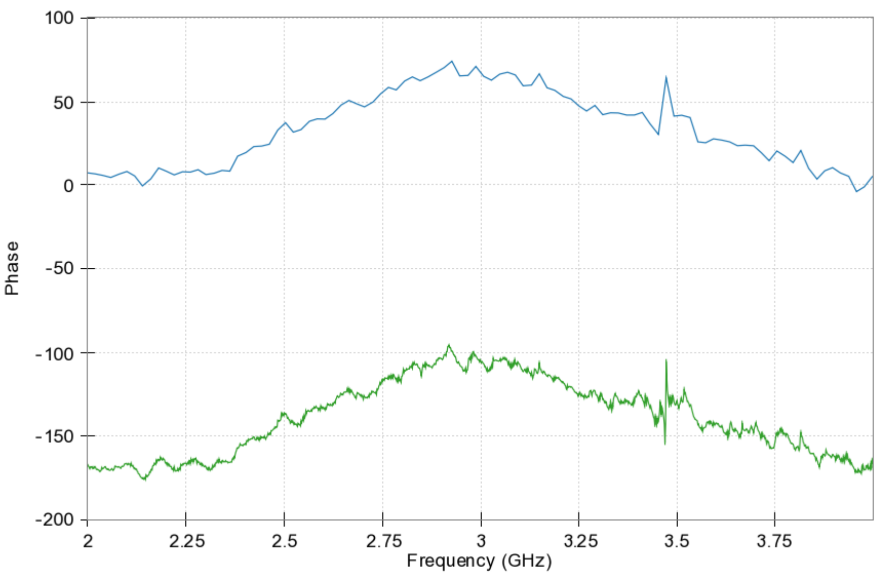
Transverse harmonic sweep: problem

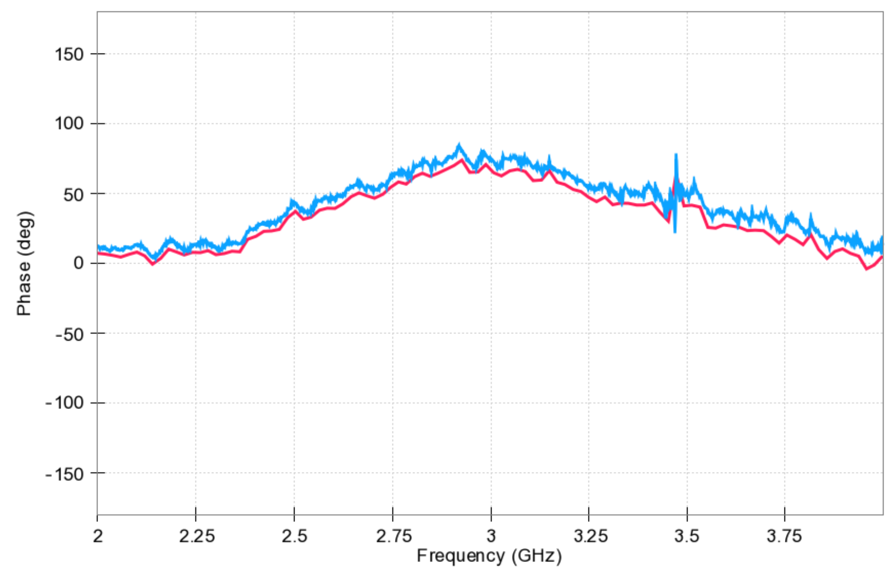
It’s easy to measure **center frequency** for longitudinal cooling



But for transverse cooling one need to know exact **fractional tune**, which could be unknown..

Single sweep vs. harmonic sweep

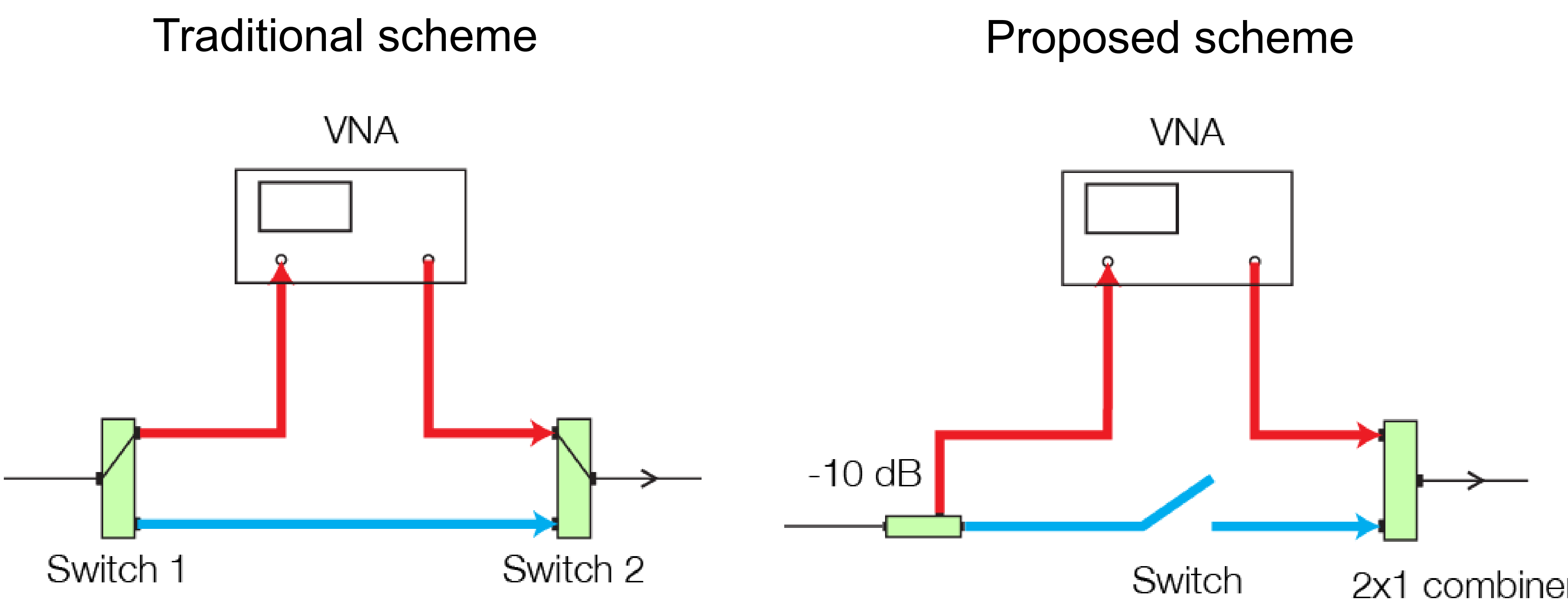




Green – single sweep ph.
Blue – harmonic sweep ph.

Blue – single sweep ph. + 180°
Red – harmonic sweep ph.

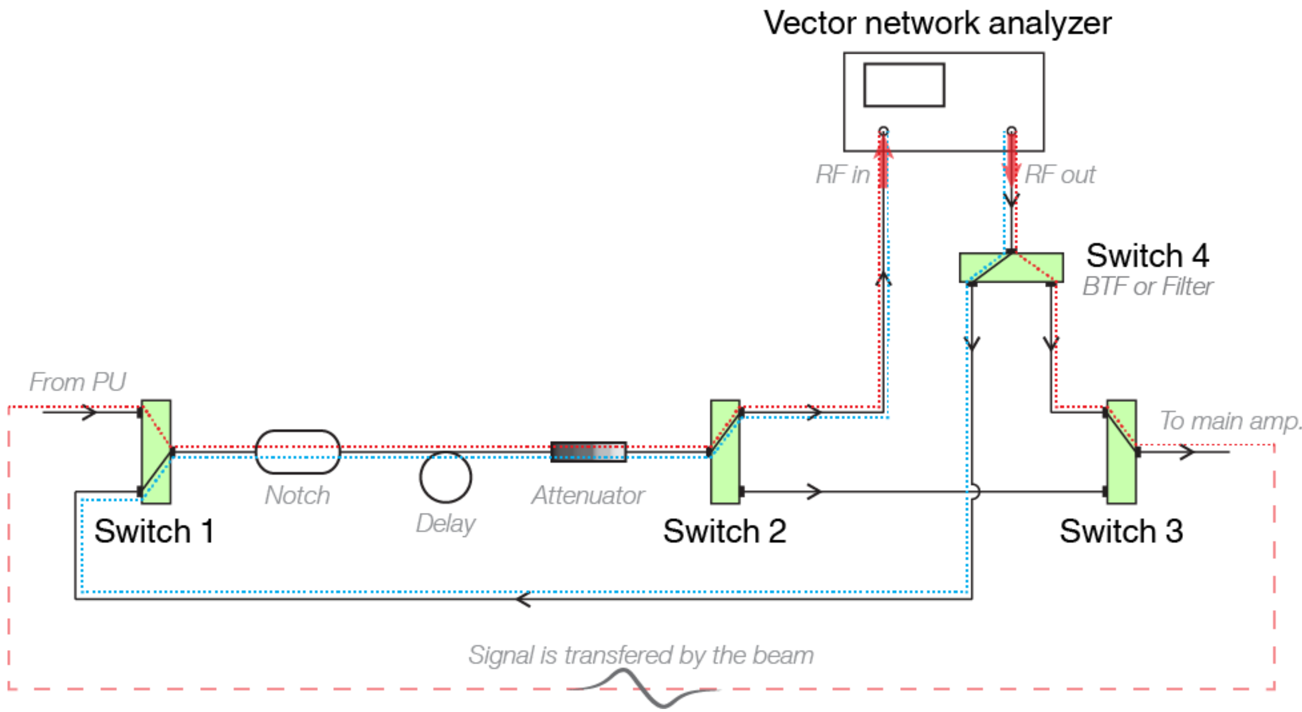
Setup for open-loop measurements



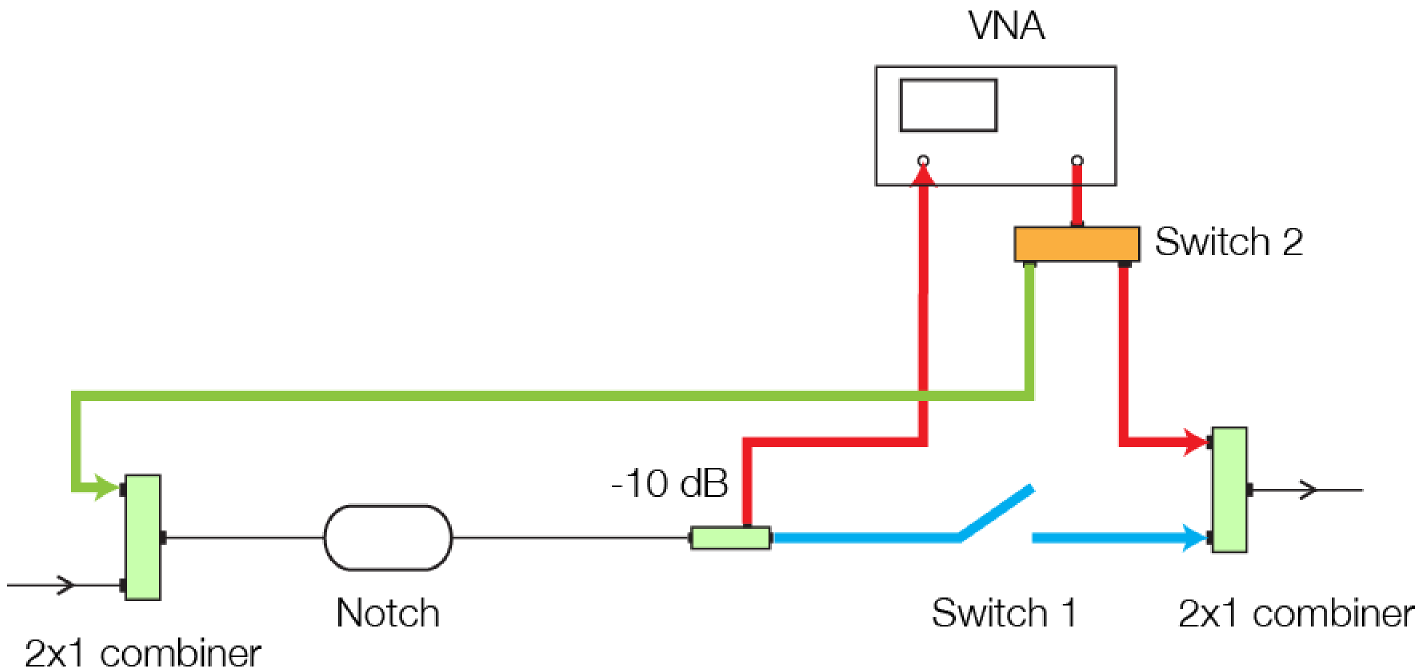
Maintenance stops for adjustment

Parallel adjustment

Setup for open-loop measurements incl. notch-filter



Setup for open-loop measurements incl. notch-filter



Filter and system adjustments is done on the run

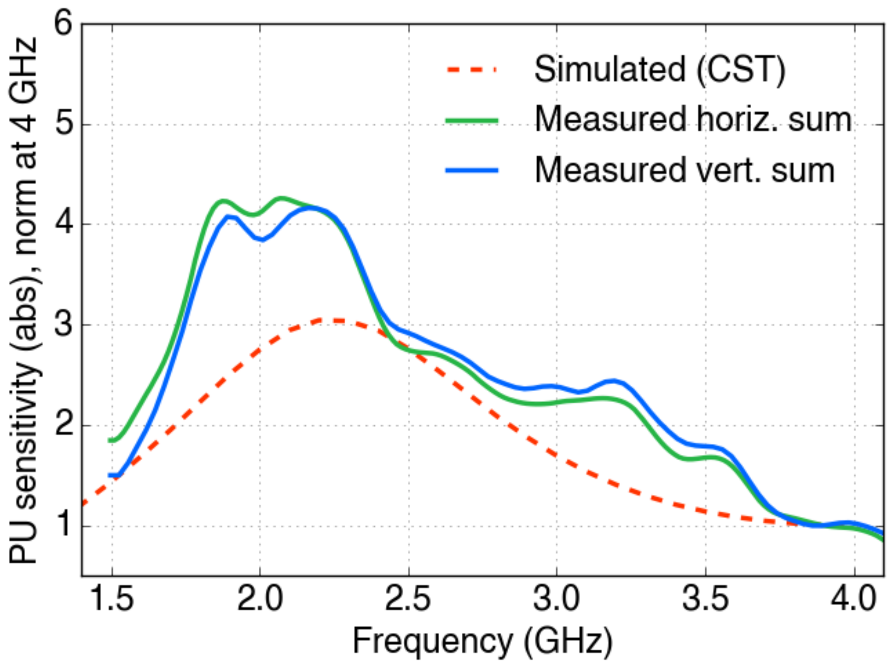
Off-topic: PU/K amplitude behavior

Signal from spectrum analyzer: $S(f)$

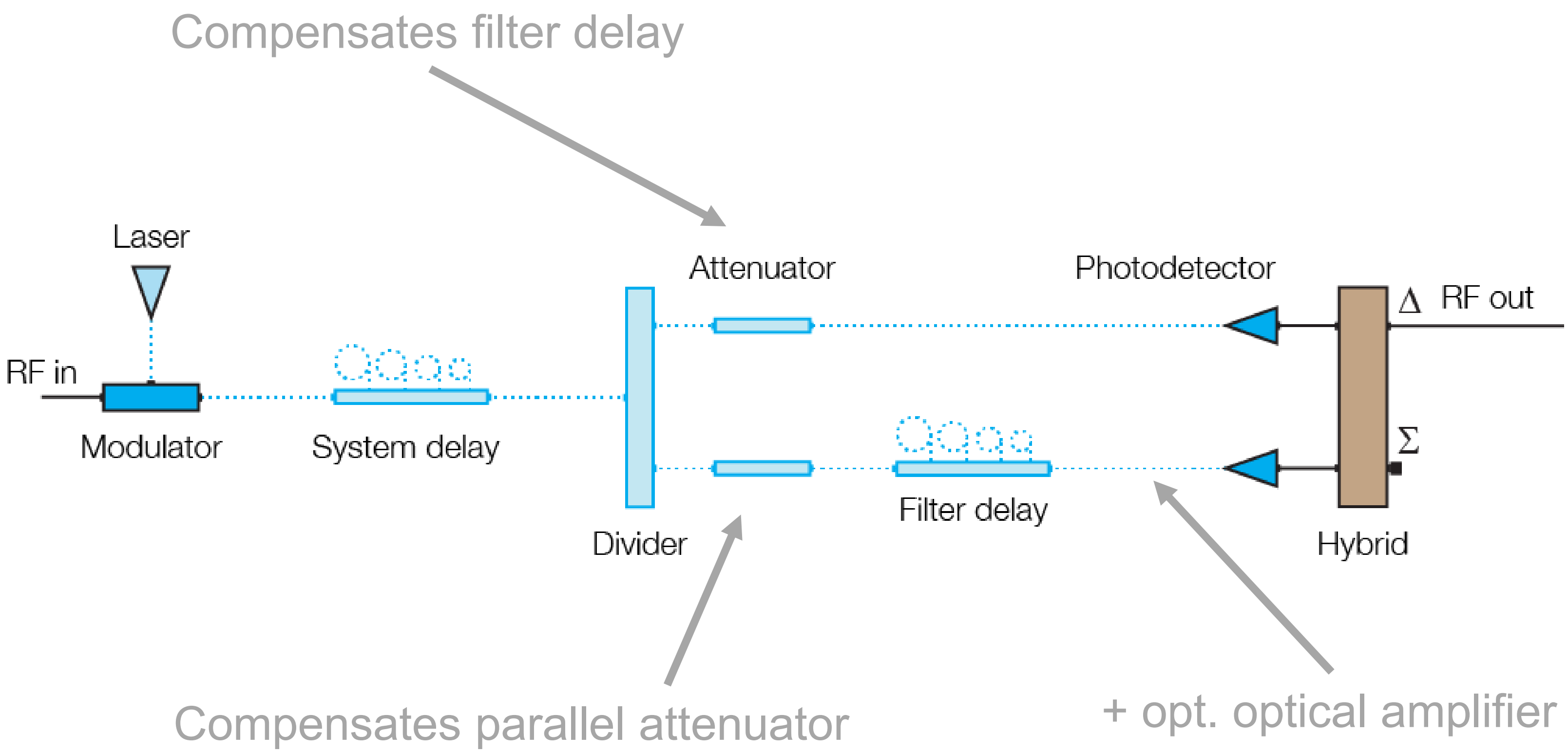
$$S(f) \sim \Psi \sim \frac{1}{\mathrm{n}}$$

So

$$|T_{PU}| \sim S(f) \cdot n$$

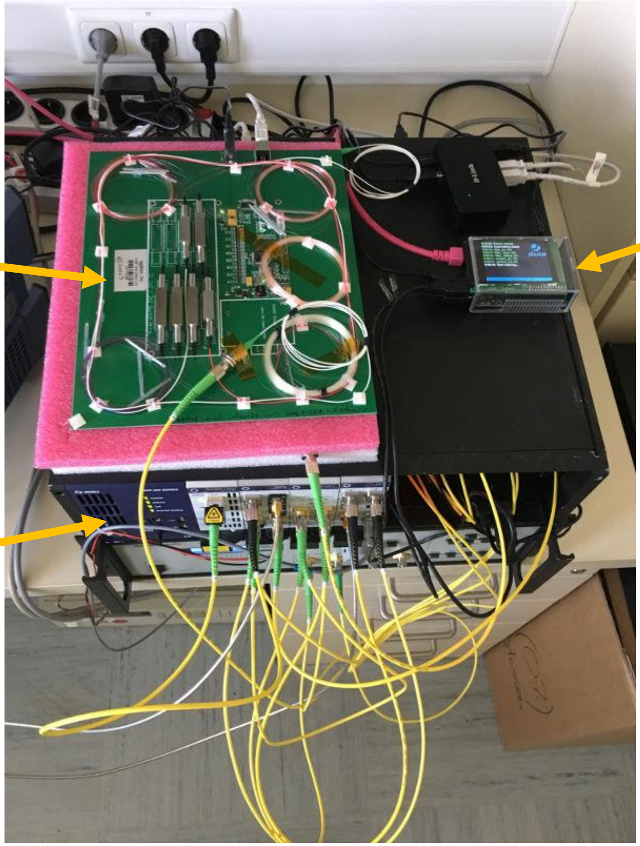


Optical notch-filter layout



Notch-filter

Delays
0-15.5ns / dt=0.5ns
0-496ns / dt=16ns



RPi control

JDSU crate
Laser, modulator,
attenuators,
0-0.5ns delay, etc.

JÜLICH
FORSCHUNGSZENTRUM

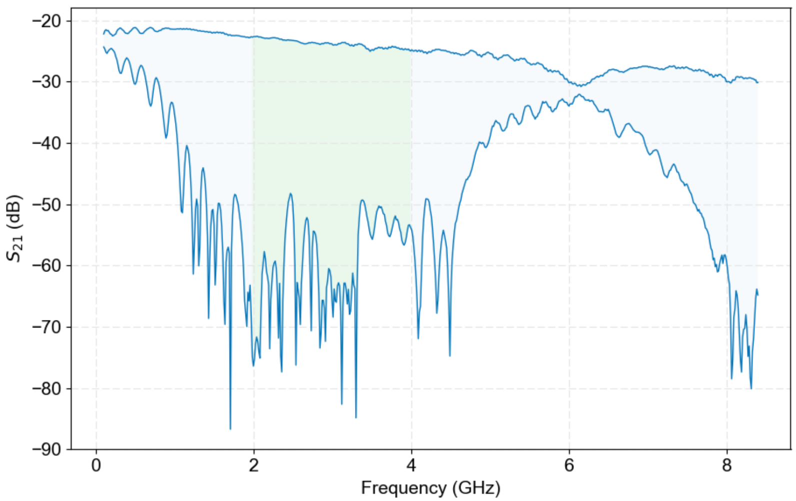
Notch-filter adjustment

Parameters to adjust: <u>notch frequency</u> and <u>depths</u>

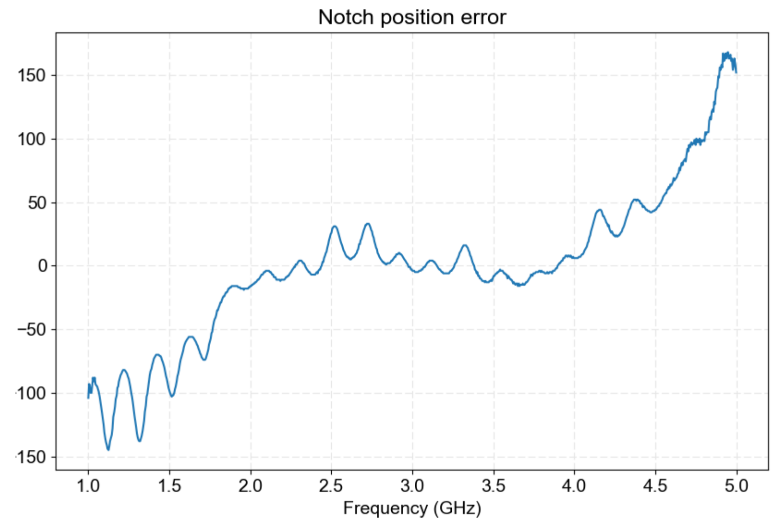
1. Harmonic per harmonic **~ 1-3 min**
    1. Measure average frequency and correct it
    2. Measure average depths and correct it
    3. Repeat it

2. Measurement of delay and power difference of both legs **~ 1-5 sec**

Notch-filter characteristics



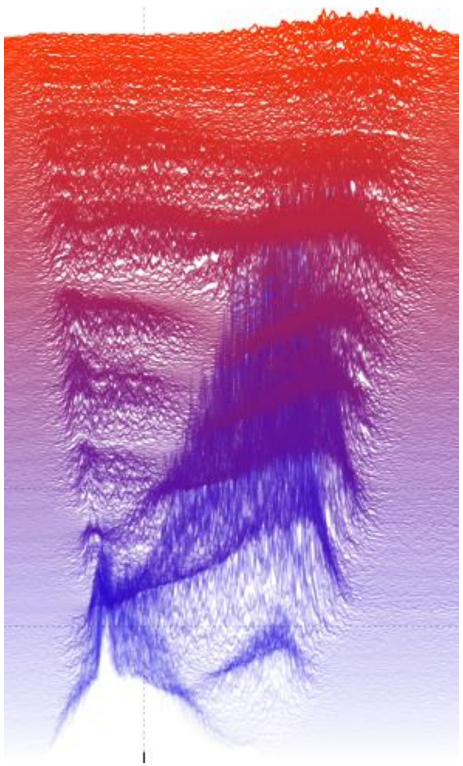
Notch-filter amplitude response



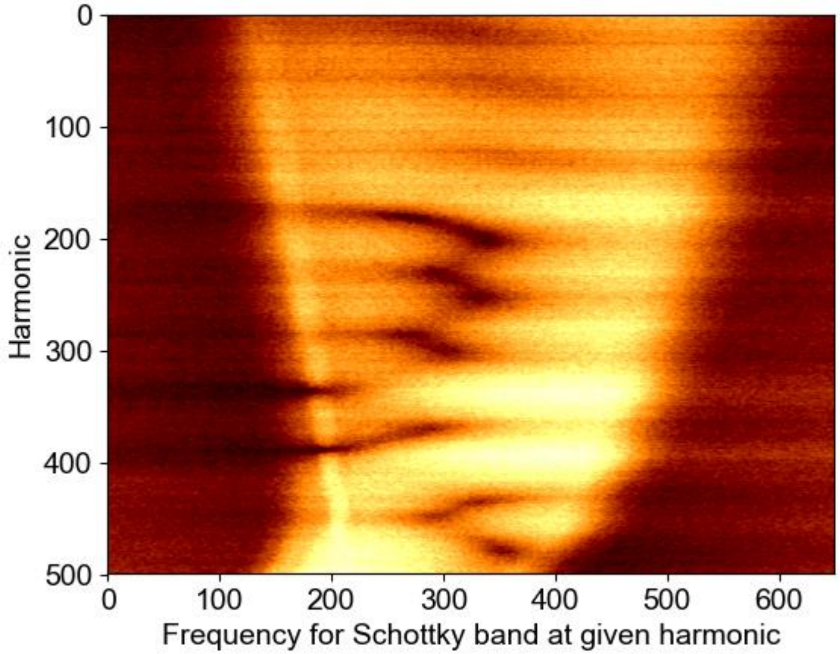
Measured notches' position errors (difference between expected and measured notch)

Is this dangerous?

Notch-filter dispersion vs. small spreads



Waterfall plot of filtered longitudinal Schottky noise



Small dispersion is not a problem!

How to adjust?

Since freq. response is non-linear, so:

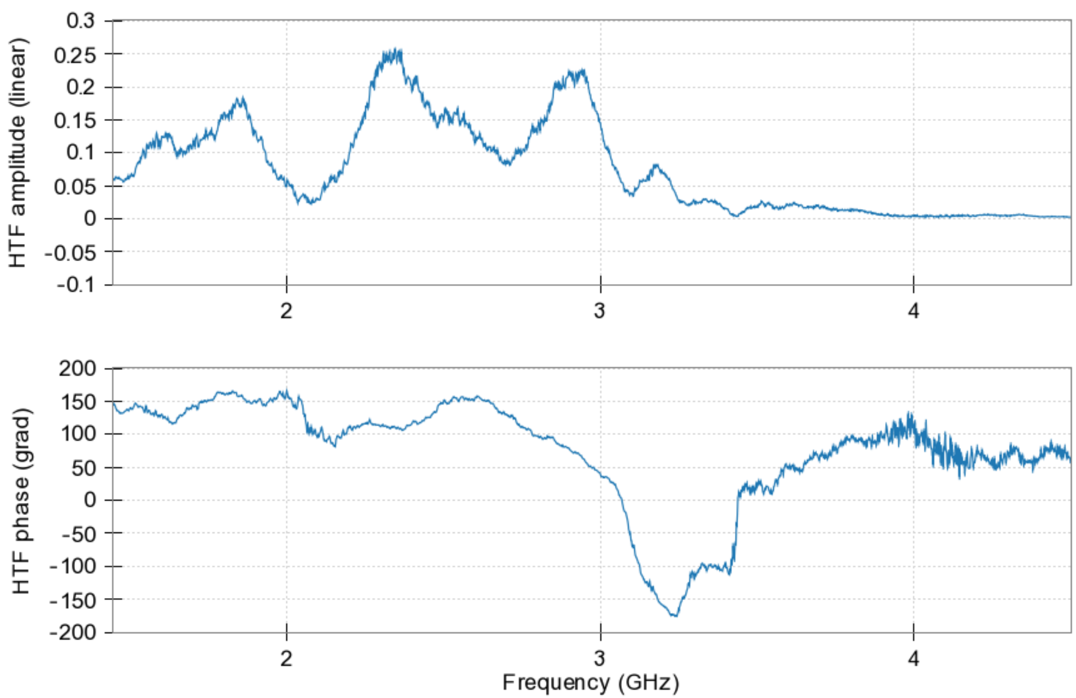
- Optimum gain – NO
- Flat phase – NOT ALWAYS

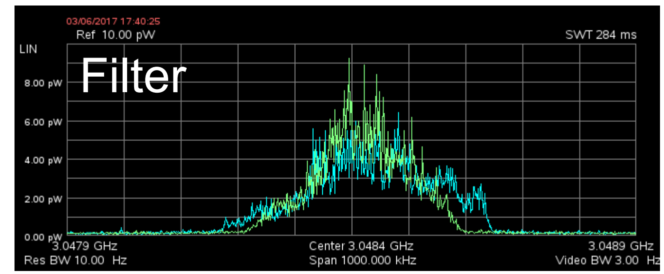
- **Cooling rate vs. equilibrium ($t = \infty$ or $t = t_{lim}$)**

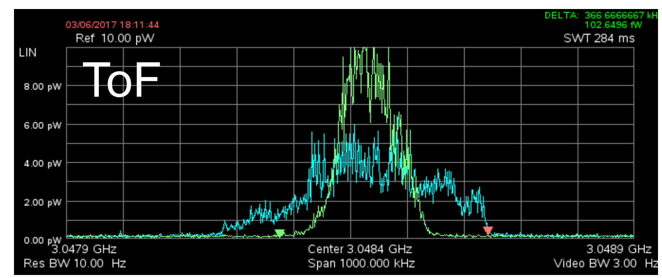
We need simulation!

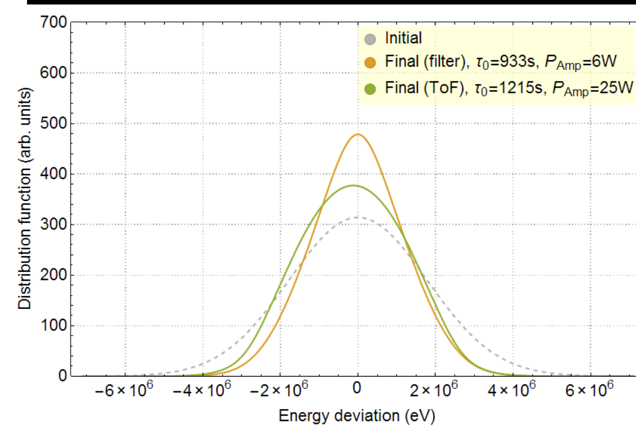
The need of simulation

HTF of system with inversed kicker:

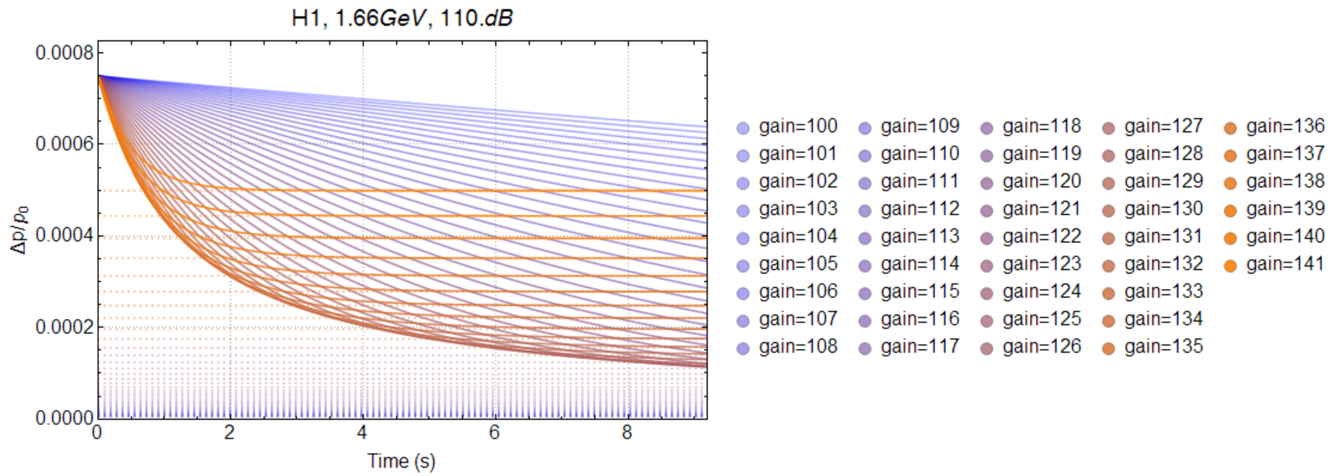


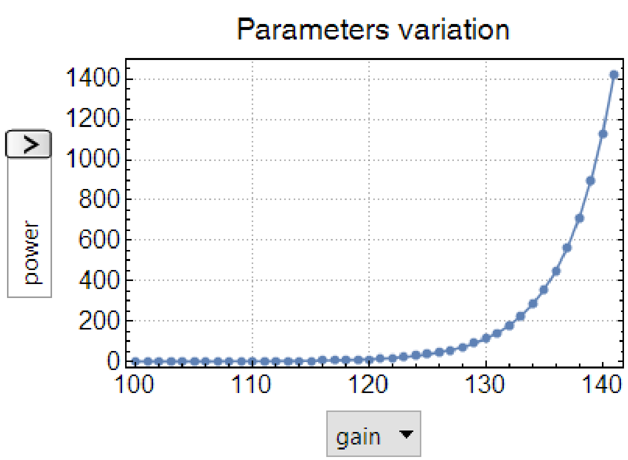


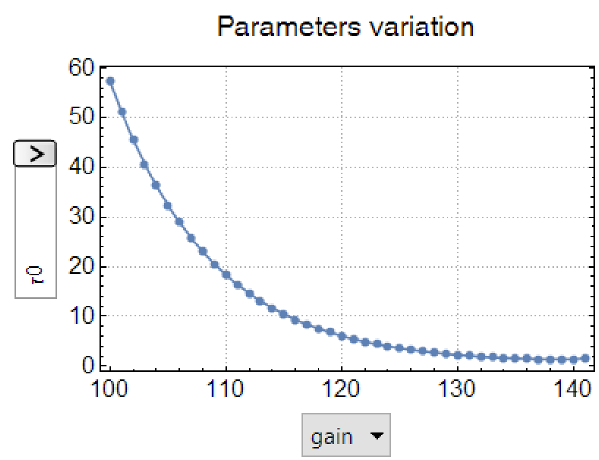




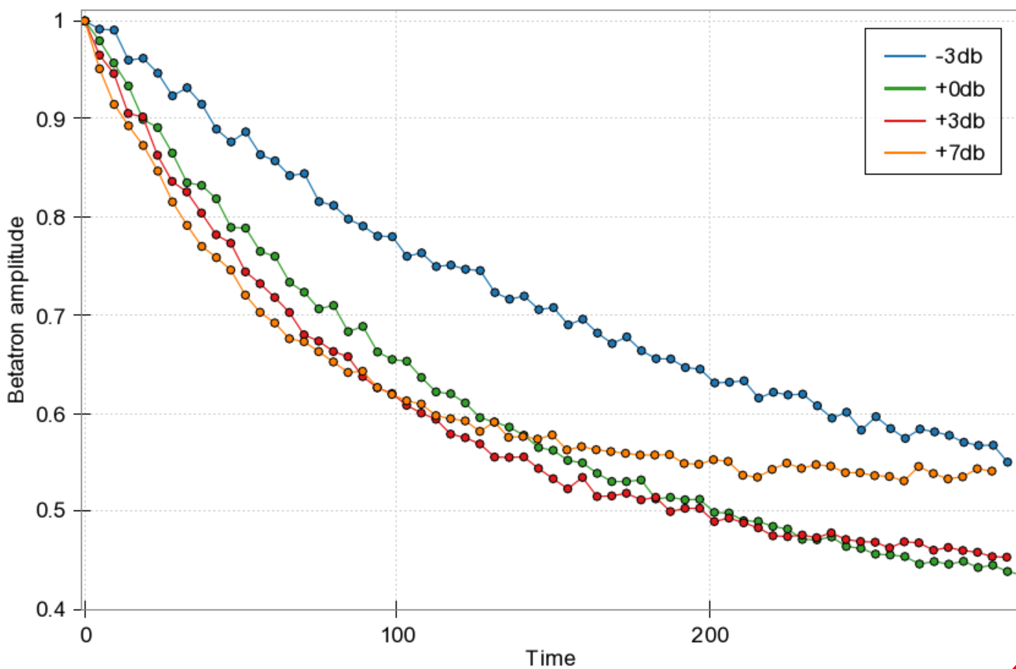
Initial cooling rate vs. equilibrium



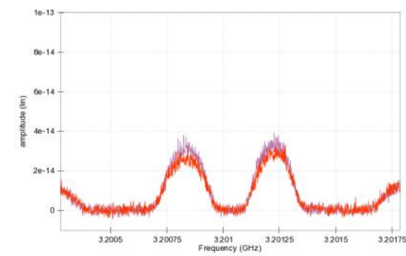




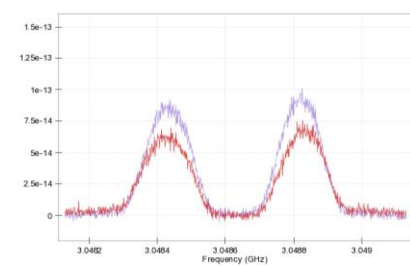
Initial cooling rate vs. equilibrium



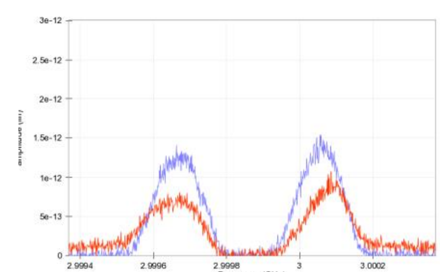
Open/closed-loop meas.
for gain adjustment:



0 *dB*



3 *dB*



7 *dB*

Gain adjustment by comparison of open/closed-loop is time-consuming and not that precise

Simulation

System gain is optimized for:

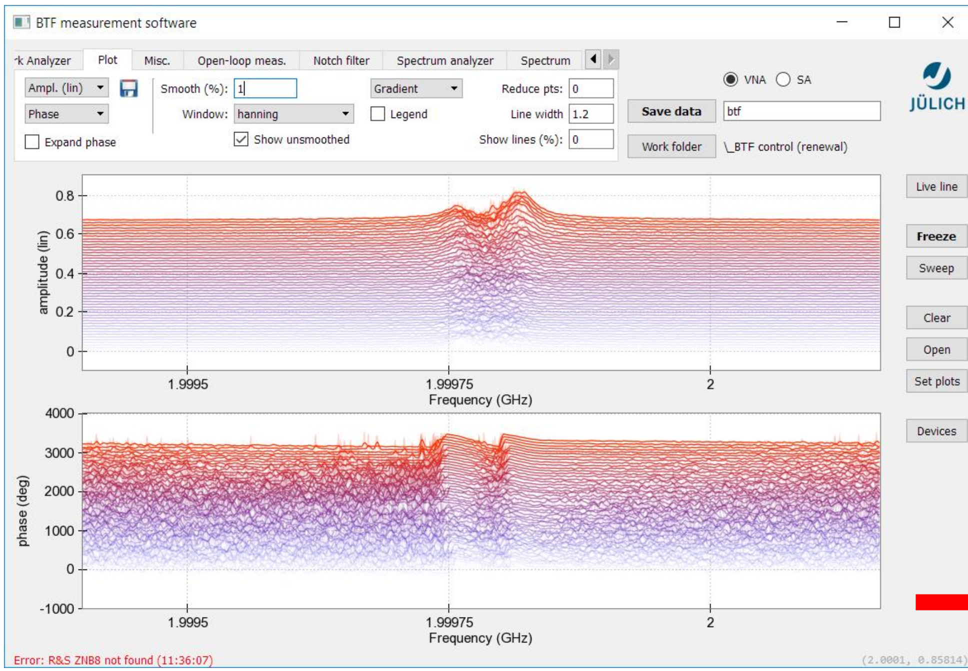
1. Initial cooling rate ($t = 0$): $\frac{1}{\tau_0} = -\frac{F}{x_{rms}} - \frac{D}{x_{rms}^2}$ (see TUP06)

2. Final distribution:

$$t = \infty \qquad \frac{\partial \Psi}{\partial t} = -\frac{\partial}{\partial x}\left(F\Psi_\infty - D\frac{\partial \Psi_\infty}{\partial x}\right) = 0$$

$t = t_{\text{lim}}$ Fokker-Planck or equations for rms-values

Universal software for automatic control and adjustment of SC systems



A lot of different algorithms in a handy, though a bit messy interface

Open-source *"one-button solution"*

Thank you for your attention!