Locking Status

MightyLaser meeting

2011 – 19th of January

Ronic Chiche

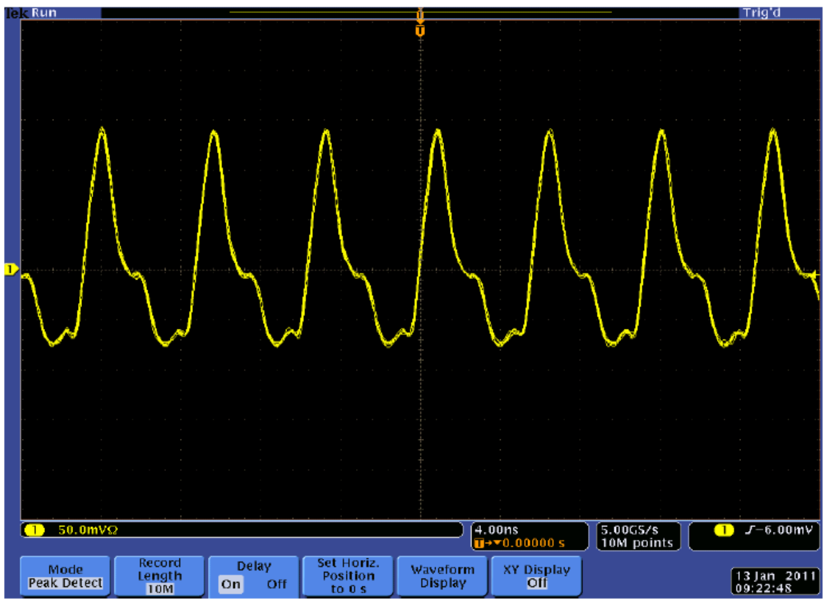
Plan

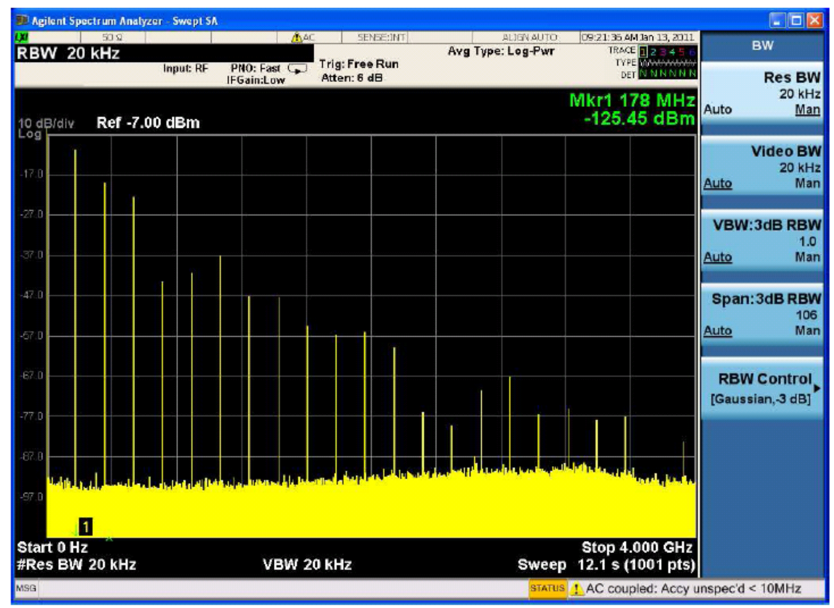
- Measurements at OneFive
- Data on the present locking
- Next step for the locking

Measurements at OneFive
Laser signal

- Repetition rate at reset : 178 499 234 Hz

  ATF Frequency at 2011/01/12 : 178 498 622 Hz (- 600 Hz)
- The internal PHD output is unfiltered :





Measurements at OneFive Actuators

Peltier :

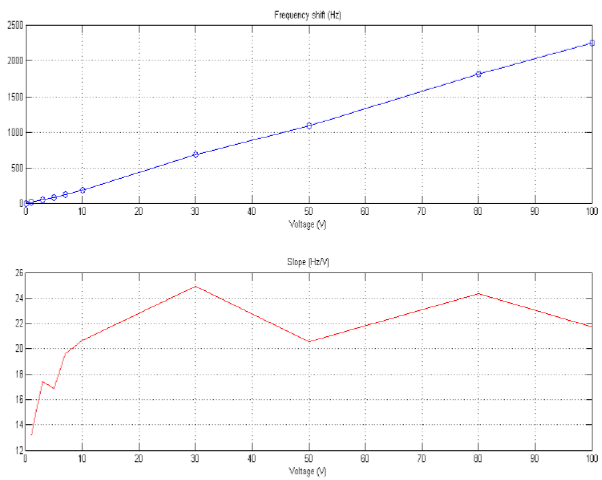
- 1 external step ⬄ internal counter = 5 steps (accessible by RS232 : set / read)
- Stable repetition rate range : Frep = 178 494 850 - 178 503 800 Hz

I stopped the measurements at roughly +/- 4kHz around 178.499 MHz (new central rep. rate)
But the maximum range should be wider.

- Slope : ~ 105 Hz / external step

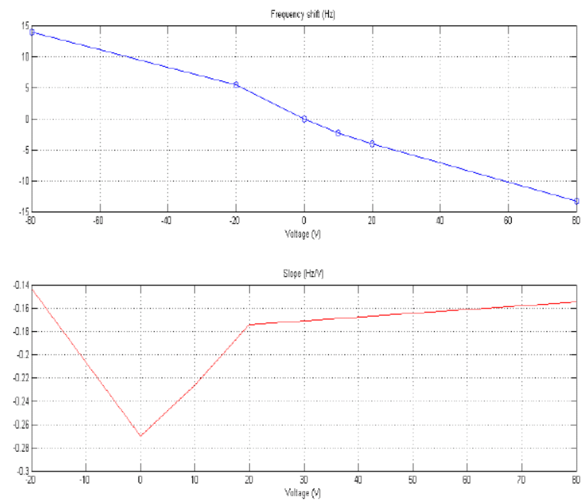
PZT coarse : unipolar

- 13Hz/V < slope < 24 Hz/V



PZT fine : bipolar

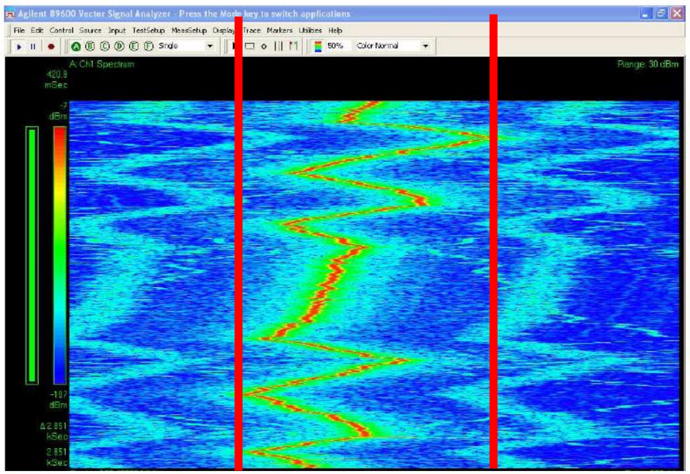
- slope ~ -0.2 Hz/V



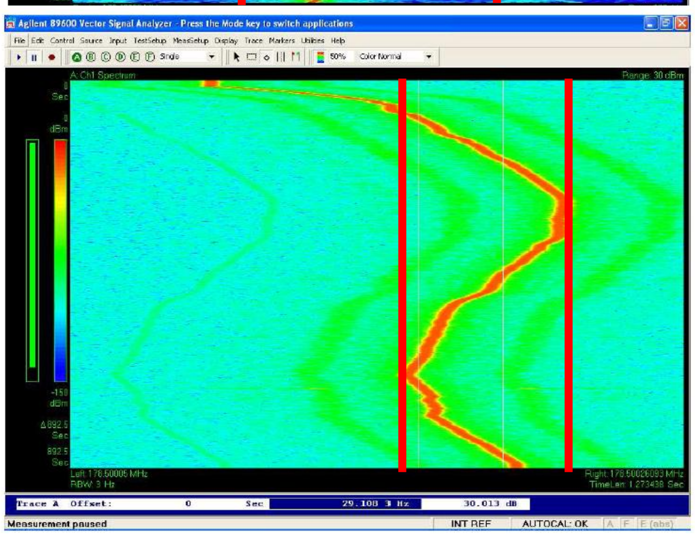
PZT Measurements are difficult due to natural fluctuations of the laser rep. rate

Measurements at OneFive Stability

Long term stability :



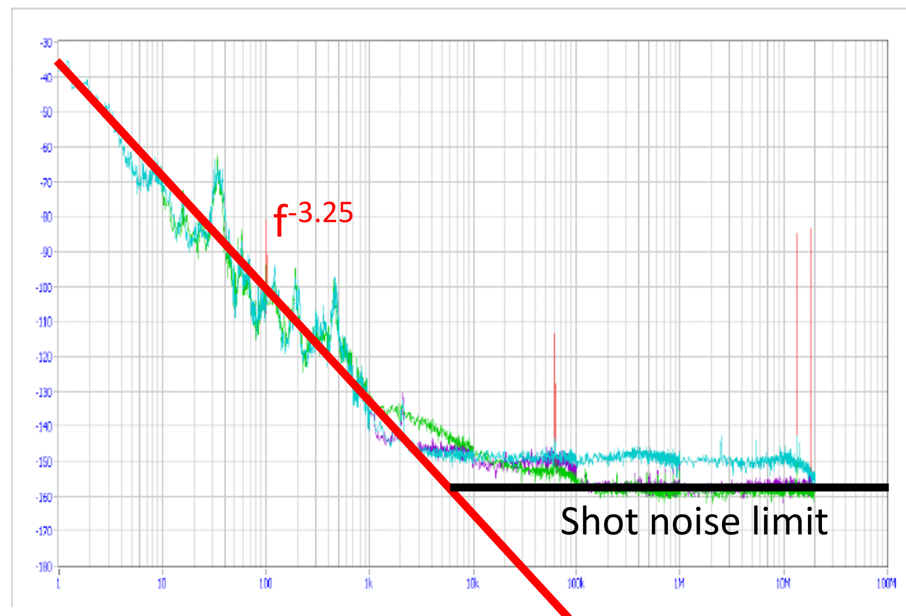
$\Delta t = 3/4h$
$\Delta f = 42$ Hz



Step response
$\Delta t = 1/4h$
$\Delta f = 60$ Hz

Short term stability

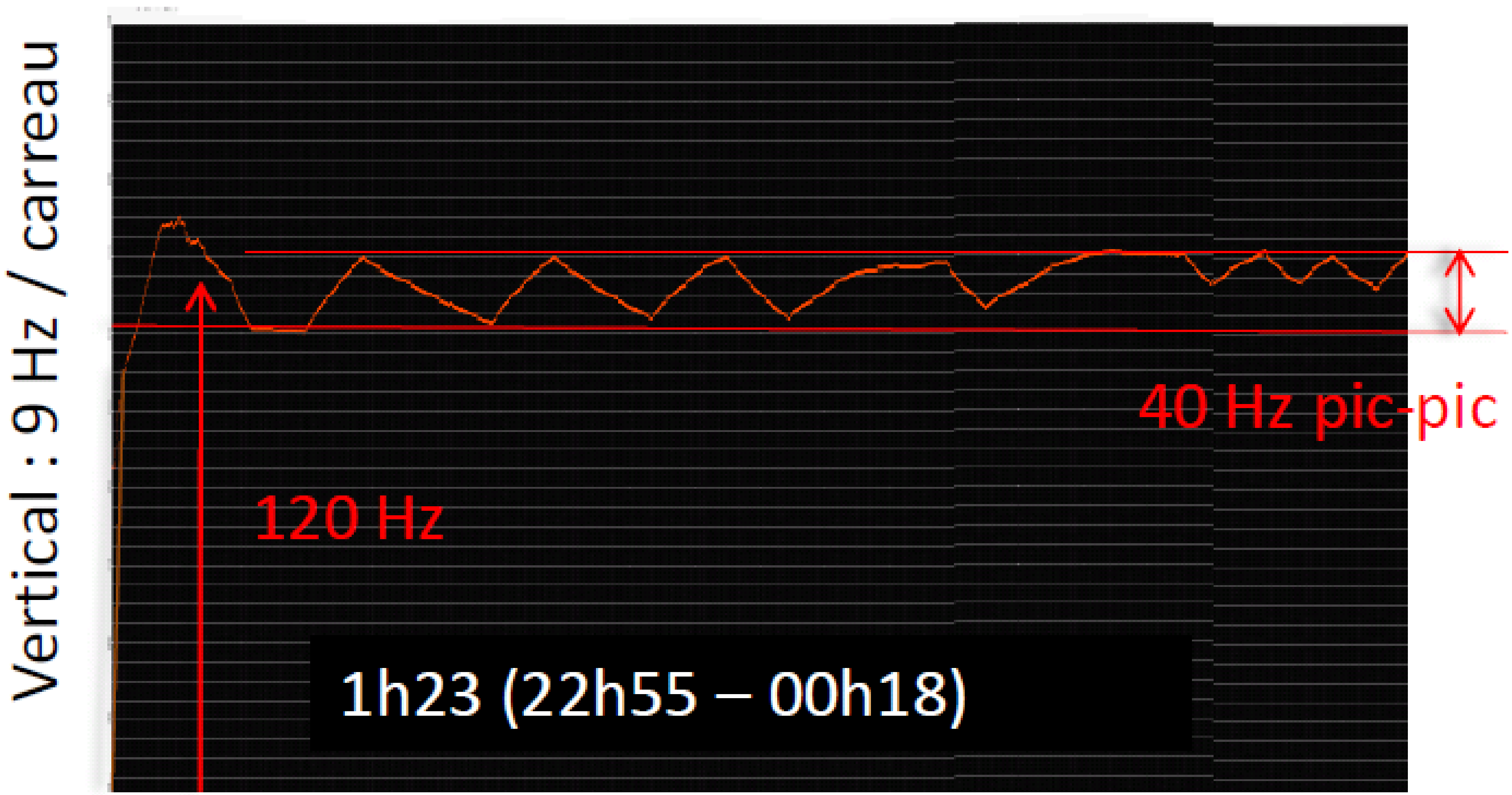
Phase noise :



$$\mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}}$$

Measurements at OneFive
Rep. Rate stability comparison

Dynamique : Peltier 120 Hz / step



Plan

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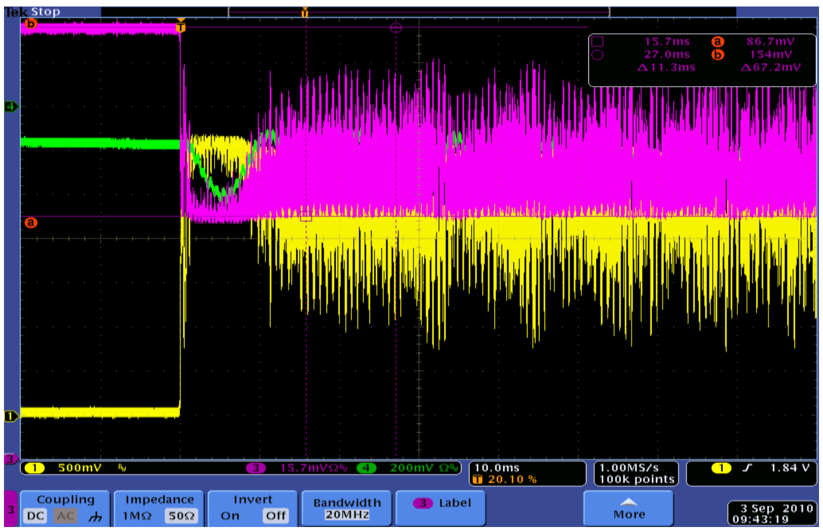
- Data on the present locking
- Next step for the locking

Present Locking
2 situations at 2010/09/03

Locking on fondamental

Frep ~ Fcav => Fopt



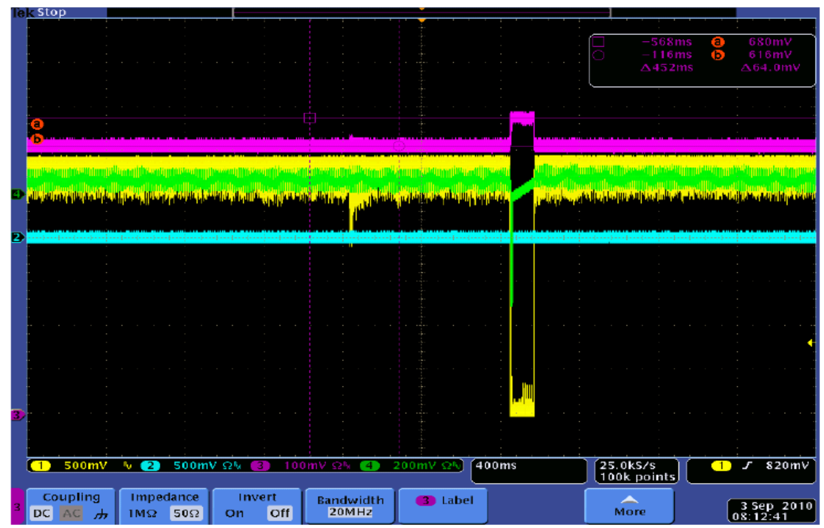
Good coupling ~ 50%

But not stable

$$\mathbb{F}=3000 \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} < \frac{\lambda}{2L\mathbb{F}} \sim \frac{1}{3}\frac{\lambda}{2L\mathbb{F}} \sim 3\;10^{-11}$$

Locking on the 1st harmonic

Fopt+/-Frep



Stable

But weak coupling ~ 10%

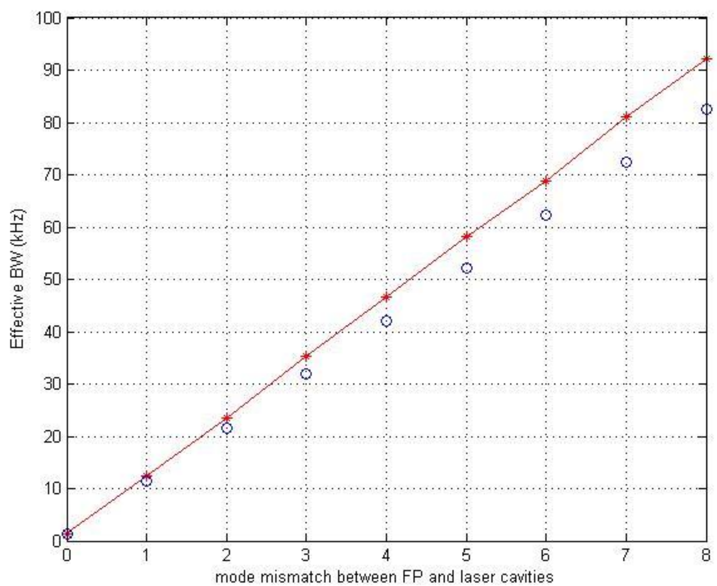
=> Effective finesse depends on several parameters

Present locking
Effect of frequency detuning

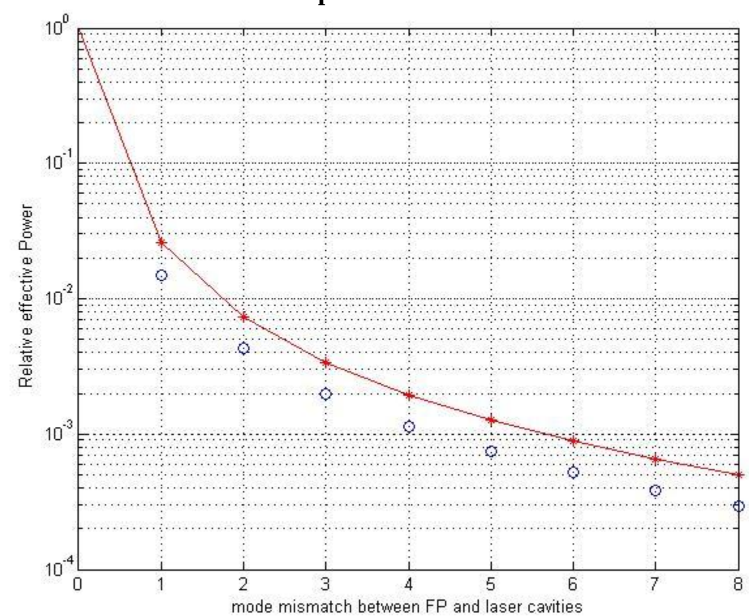
$$TF\left\{\frac{\Delta\nu_{PDH}}{\Delta\omega_q}\right\}\upsilon_n \simeq -\frac{\kappa_{PDH}P}{\pi\delta\upsilon}\frac{1}{\left(\frac{\delta\upsilon}{2}+\frac{\left(\overline{\Delta q}-\frac{\Delta\Phi_{CEO}}{2\pi}\right)}{\pi^2\tau\bar{q}}\right)\left(\frac{\delta\upsilon}{2}+\frac{\left(\overline{\Delta q}-\frac{\Delta\Phi_{CEO}}{2\pi}\right)}{\pi^2\tau\bar{q}}+i\upsilon_n\right)}$$

Example with PLIC MIRA laser

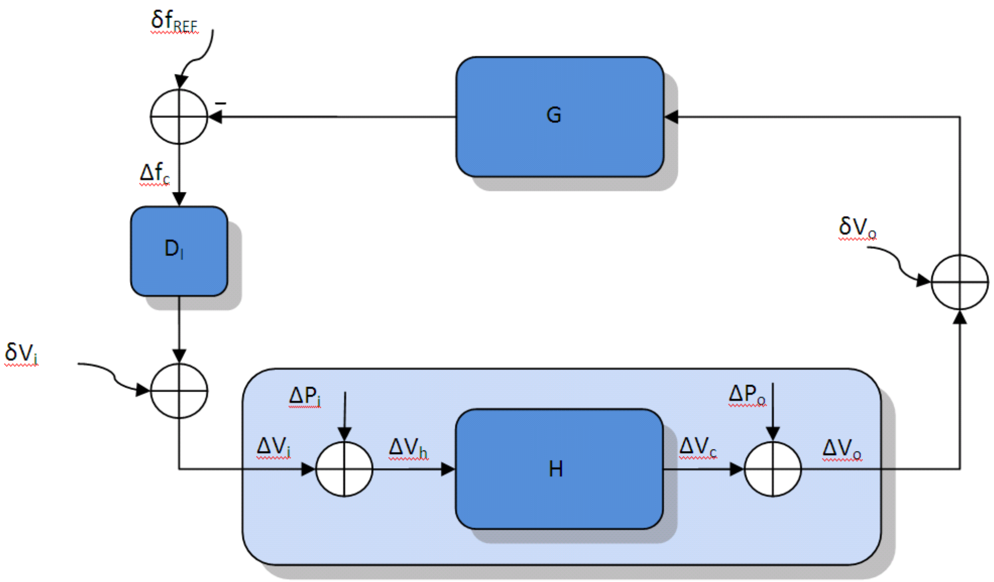
Increasing of the Fabry-Perot PDH signal bandwidth
Function of frequency mismatching between laser and Fabry-Perot cavity
Expressed in numbers of FSR

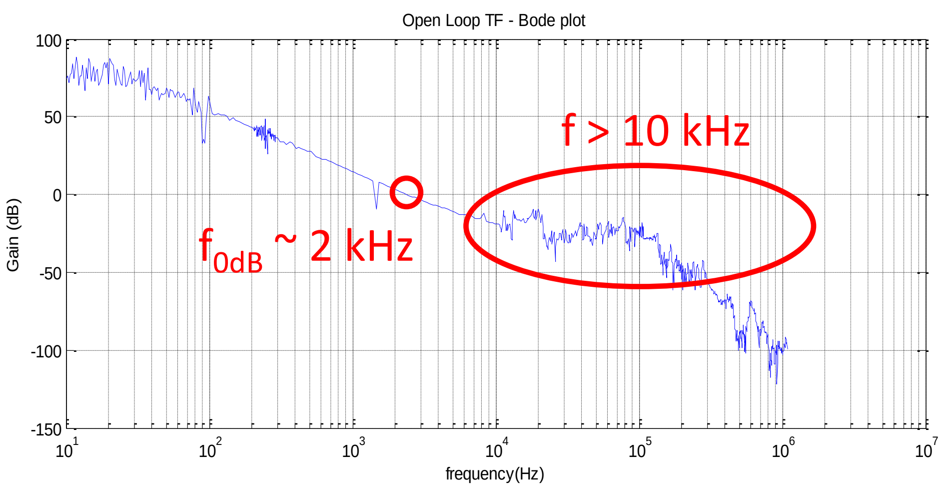


Power loss
Function of frequency mismatching between laser and Fabry-Perot cavity
Expressed in numbers of FSR

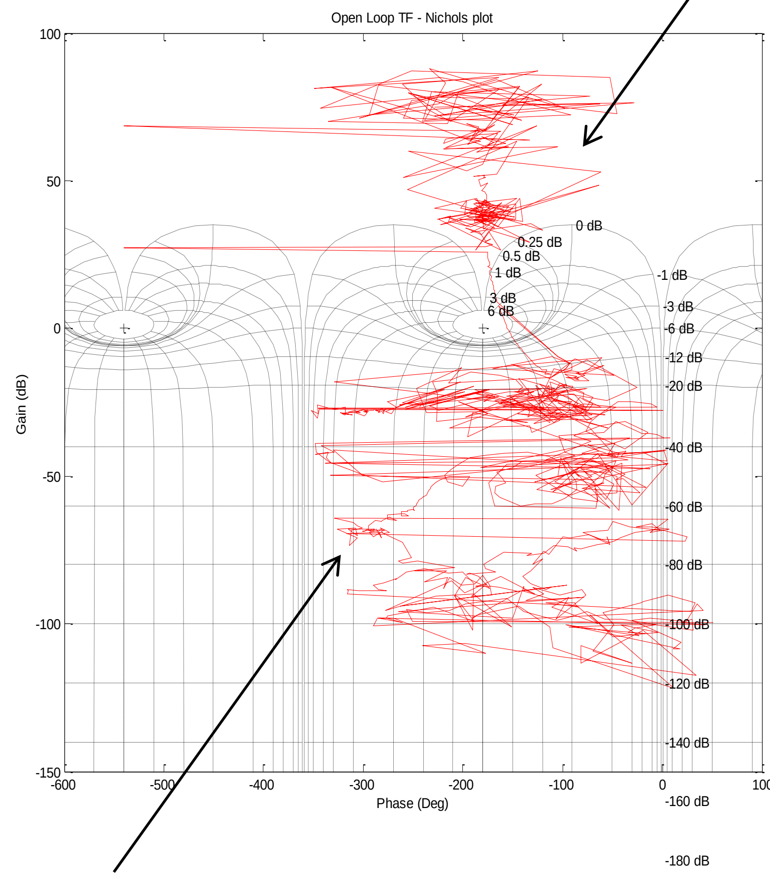


Present locking Identification





Estimation problem



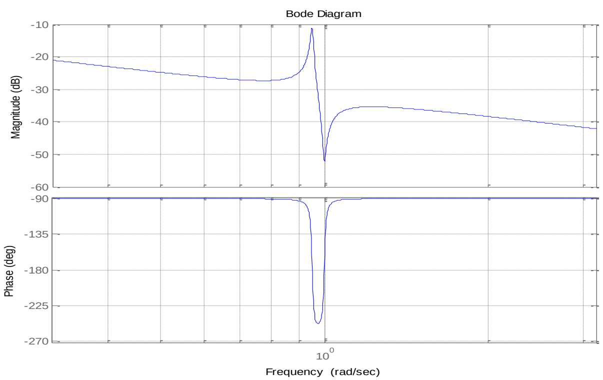
Coarse PZT resonances

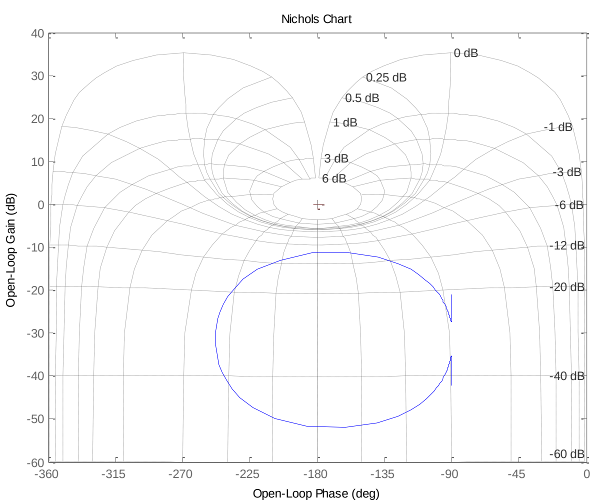
Present locking

Pole-Zero identification

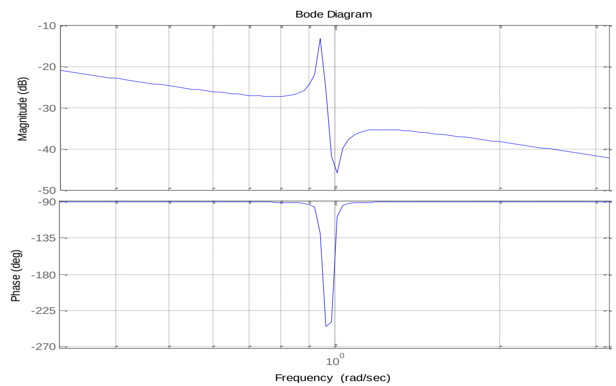
Resolution effect with Bode and Nichols plots

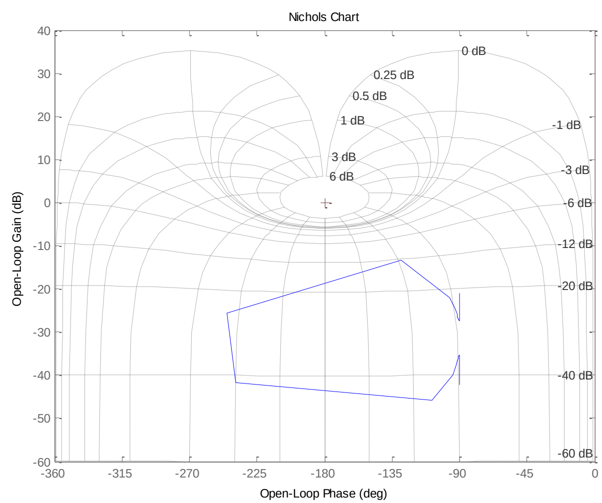
Resonance Q=100
1000 pts /decade



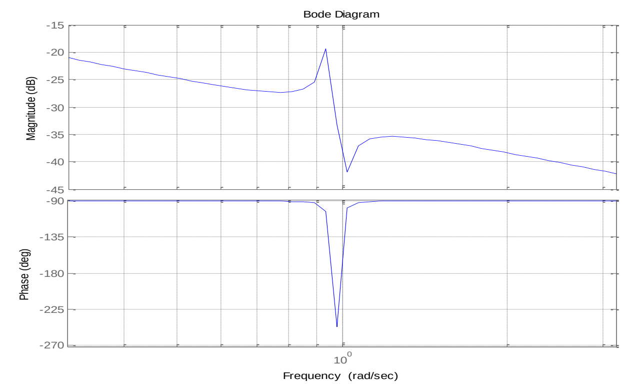


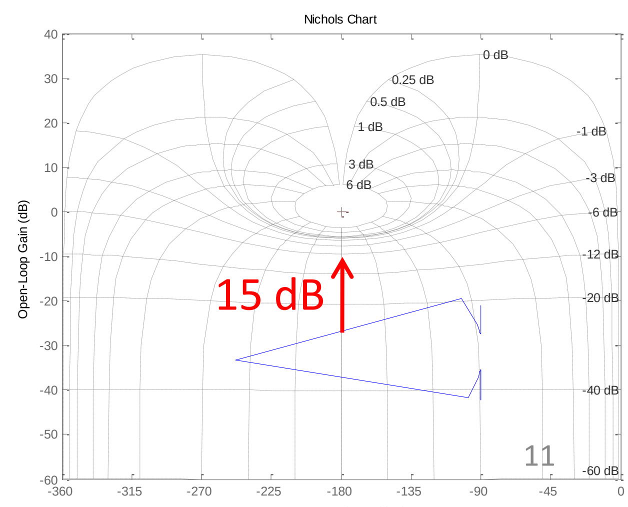
Resonance Q=100
100 pts /decade



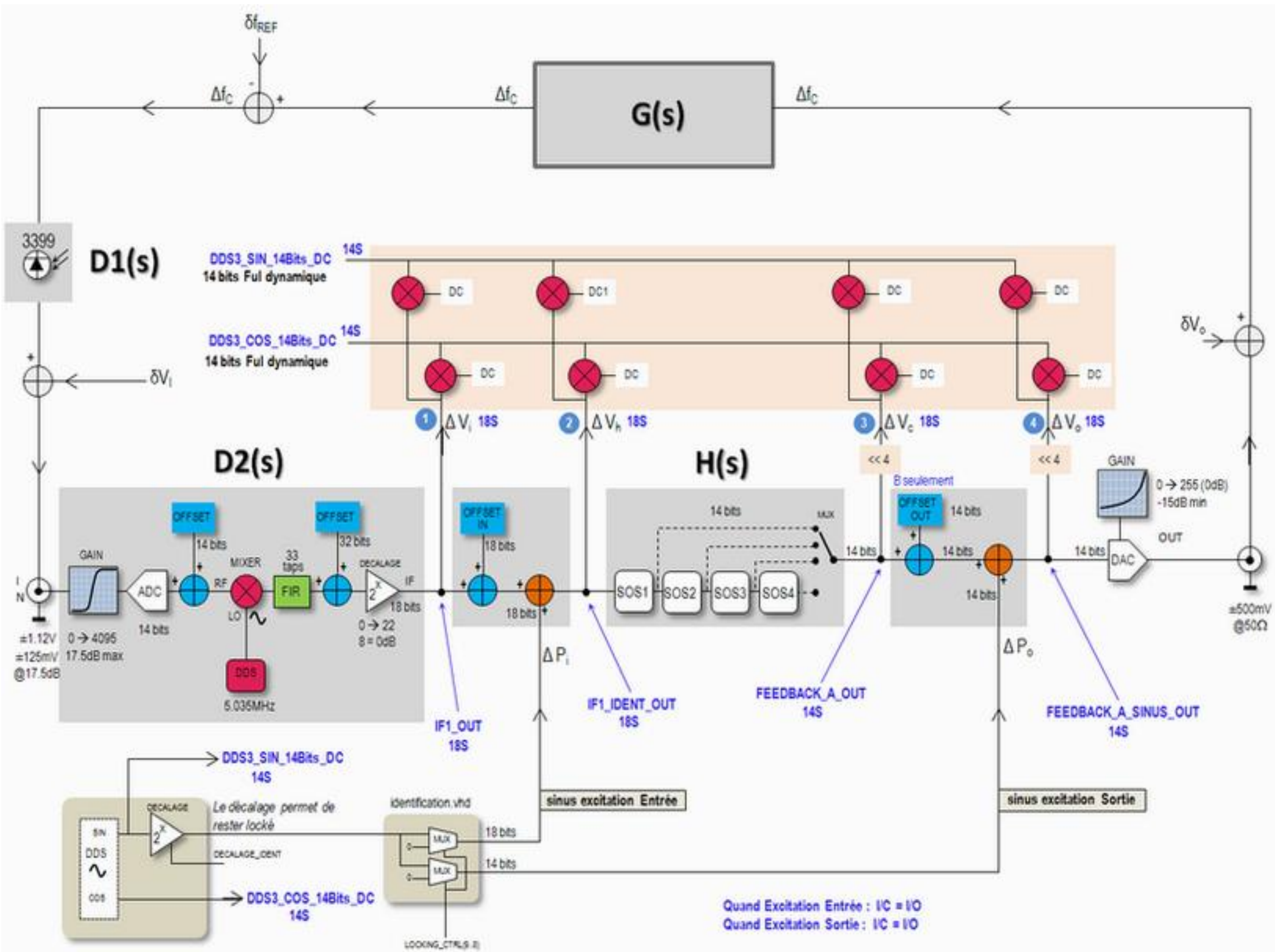


Resonance Q=100
50 pts /decade



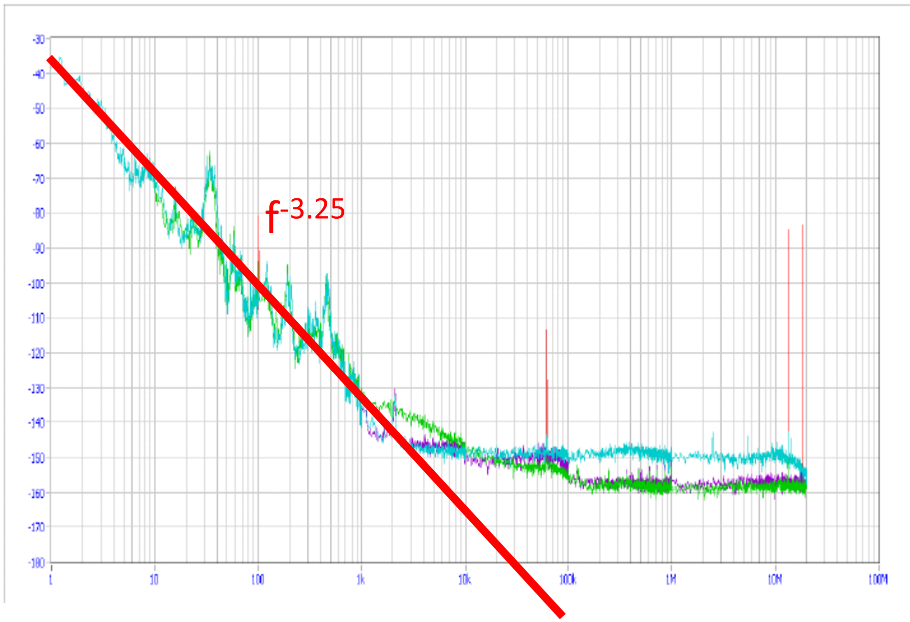


Present locking
Identification inside the FPGA



Present locking
Estimation de la stabilité relative

L(f)=Phase noise power spectral density / 2



$$\frac{\Delta F_{REP}}{F_{REP}} = \sqrt{\int_0^{+\infty} \frac{f^2}{F_{REP}^{\ 2}} 2\mathbb{L}(f)\,df} \sim 3\,10^{-11}$$

$$\mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}}$$

Present feedback : 2 filters P-I in 1/f

f_{0dB} = 2 kHz

$$f < f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}} \left| \frac{f^2}{f_{0dB}^{\ 2}} \right|^2 \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 3\ 10^{-11}$$

$$f > f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}} \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 11\ 10^{-11}$$

And do not forget :

- Between the 2 zones, the system is less stable and we can have a bump of noise power.
- Actuation noise (electronics noise transmitted to the laser via the PZT)
- Spikes not taken into account in this model
- No data @ f>2kHz

$$\frac{\Delta F_{REP}}{F_{REP}} > 10^{-10}\ !!!$$

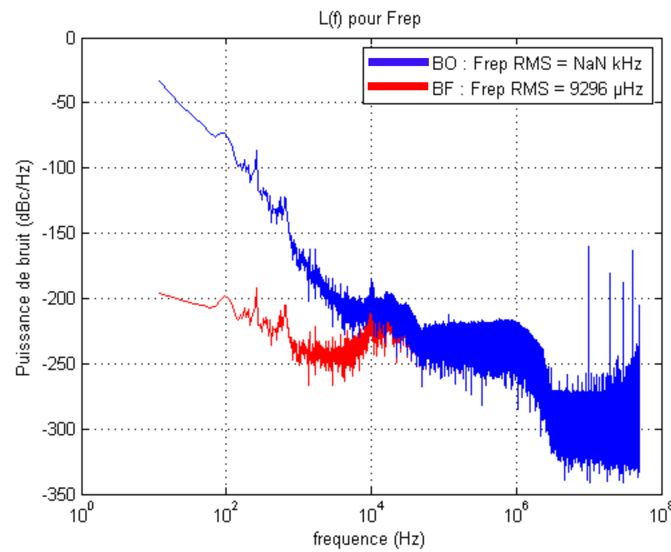
Plan

- Measurements at OneFive
- Data on the present locking
- Next step for the locking

Next step for the locking
Which ways for noise reduction ?

- We need to know the noise shape
  - ⇒ Identification in closed loop
  - ⇒ Scope acquisition => FFT
  - ⇒ RF spectrum analyzer measurements
  - ⇒ Need a calibration
- Reduce the electronic noise
- Change the shape of the coarse PZT channel
  - ⇒ Increase gain
  - ⇒ Increase stability
- Increase the loop bandwidth
  - ⇒ Using the fine PZT channel
  - ⇒ We need a PZT test bench with Michelson interferometer for good characterization

Measurement example with the MIRA laser
Scope acquisition + FFT



Possible calibration :
- Using the open loop phase noise
- Using a calibrated modulation

Next step for the locking
Actuation noise

$$\delta F_{OPT} = \frac{c}{\lambda L}\left[\frac{\Delta L}{\Delta V}\right]_{PZT} \delta V < \frac{F_{REP}}{\mathbb{F}} \Leftrightarrow \delta V < \frac{\lambda}{\mathbb{F}}\left[\frac{\Delta L}{\Delta V}\right]_{PZT}^{-1}$$

The electronics boards have been used @ LAL :

$$\lambda = 800\,nm$$

$$\mathbb{F} = 30000$$

$$\left[\frac{\Delta L}{\Delta V}\right]_{PZT} = 61\,nm / V$$

30x less sensitive →

@ KEK :

$$\lambda = 1032\,nm$$

$$\mathbb{F} = 3000$$

$$\left[\frac{\Delta L}{\Delta V}\right]_{PZT} = 23\,nm / V$$

We need to check the installation… but should not be the faulty element
(CHECK THE NEED OF A LOW-PASS FILTER ON “GAIN 10” CHANNEL)
We can check this assumption easily with the PDH signal in closed loop

Next step for the locking
Filters transformation

Present feedback : 2 filters P-I in 1/f

f_{0dB} = 2 kHz

$$f < f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}} \left| \frac{f^2}{f_{0dB}{}^2} \right|^2 \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 3\;\;10^{-11}$$

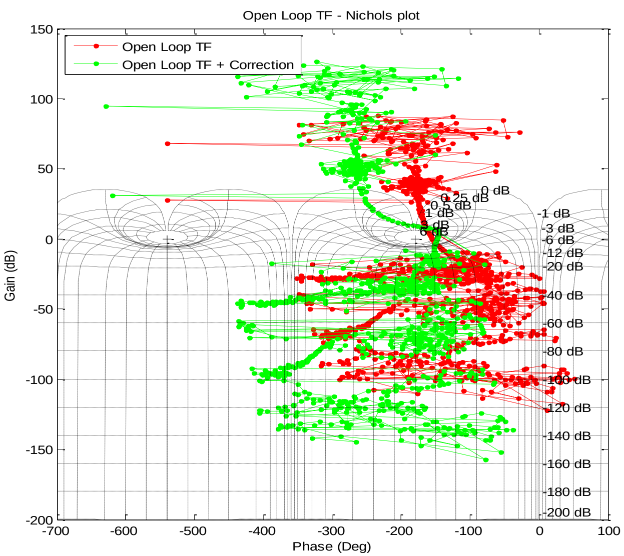
$$f > f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^{3.25}} \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 11\;\;10^{-11}$$

The noise is not coming from the frequency band which is locked

⇒ A priori, no need to increase the gain

⇒ We need to increase the bandwidth

That means to increase the gain outside of the present locking bandwidth



Example :

Gain increased and + stability improvement

Can be checked after laser installation

Next step for the locking
Fine PZT channel

- Dynamic range :

$$\Delta F_{OPT} < 10\frac{F_{REP}}{\mathbb{F}}$$

$$\frac{\Delta F_{REP}}{F_{REP}} = \frac{\Delta F_{OPT}}{F_{OPT}} \Rightarrow \Delta F_{REP} < 10\frac{\lambda}{L}\frac{F_{REP}}{\mathbb{F}} \sim 0.4\,Hz$$

Fine PZT sensitivity measurement :
0.2 Hz/V x +/- 1V => No problem

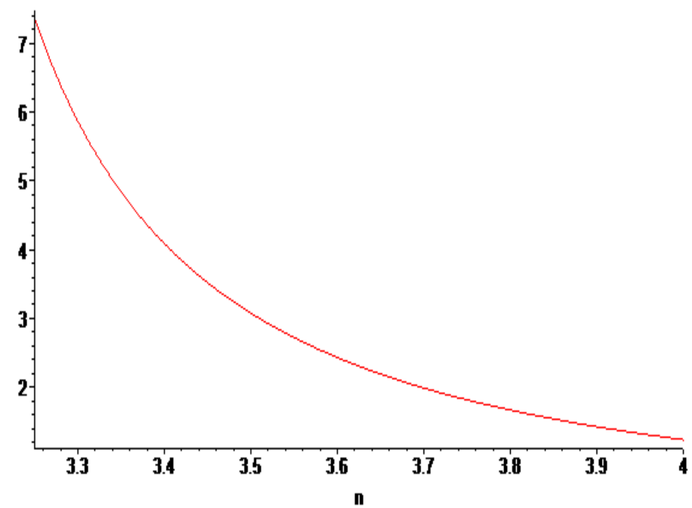
- Bande passante :

$$\frac{\Delta F_{REP}}{F_{REP}} \sim 3\,10^{-11} \Rightarrow \Delta F_{REP} = \sqrt{\int_{f_{0dB}}^{+\infty} f^2\, 2\mathbb{L}(f)\,df} \sim 6\,mHz$$

$$\mathbb{L}(f) = \frac{a}{f^n} \Rightarrow \Delta F_{REP} = \sqrt{\frac{2a}{n-3\;\; f_{0dB}{}^{n-3}}}$$

$$\Rightarrow f_{0dB} = \exp\left(-\frac{\ln\;(n-3)\Delta F_{REP}{}^{2}\; - \ln\; 2a}{n-3}\right)$$

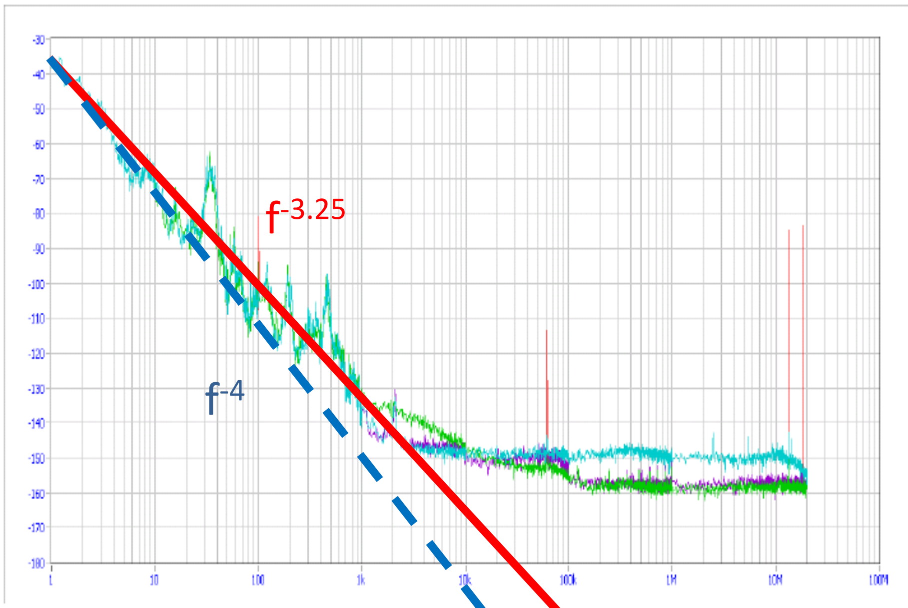
$Log_{10}(f_{0dB})$



The needed bandwidth will STRONGLY depend on the real phase noise shape
It could be estimated in closed loop to confirm the measurement in open loop (with PNA)

Next step for the locking
"n=4" hypothesis

L(f) = Phase noise power spectral density /2



f_{0dB} = 2 kHz

$$f < f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^4}\left|\frac{f^2}{f_{0dB}{}^2}\right|^2 \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 1.8\ 10^{-12}$$

$$f > f_{0dB} \Rightarrow \mathbb{L}(f) = \frac{3\,10^{-4}}{f^4} \quad \Rightarrow \frac{\Delta F_{REP}}{F_{REP}} = 3\ 10^{-12}$$

$\Rightarrow$ Is it realistic ?
Could be if the excess of noise is coming from bumps or resonances

We can check this open loop measurement by a measurement in closed loop

Conclusion
Working program

1) We need to know the phase noise shape
   - ⇒ Identification in open/closed loop => In progress
   - ⇒ Scope acquisition / RF spectrum analyzer => can be done quickly
2) Reduce the electronic noise (if necessary)
   - ⇒ Measurements during the laser installation process is possible
   - ⇒ Identification in closed loop => Technical run
3) Change the filters on the coarse PZT channel
   - ⇒ In progress
   - ⇒ But should not be very effective
4) Increase the bandwidth of the fine PZT channel
   - ⇒ 2 channels working together is already working in simulation
   - ⇒ We need to know precisely the PZT transfer function
     - ⇒ Identification in closed loop => Technical run
     - ⇒ OneFive agreed a priori : Start of a PZT test bench