

Zurich
Instruments

Suivie de résonance: méthodes à fréquences multiples

Romain Stomp

Application Scientist, Zurich Instruments AG

Sommaire

1. Un peu de traitement du signal pour le SPM

- Détection synchrone pour le champs proche
- Génération et acquisition d'image à n fréquences

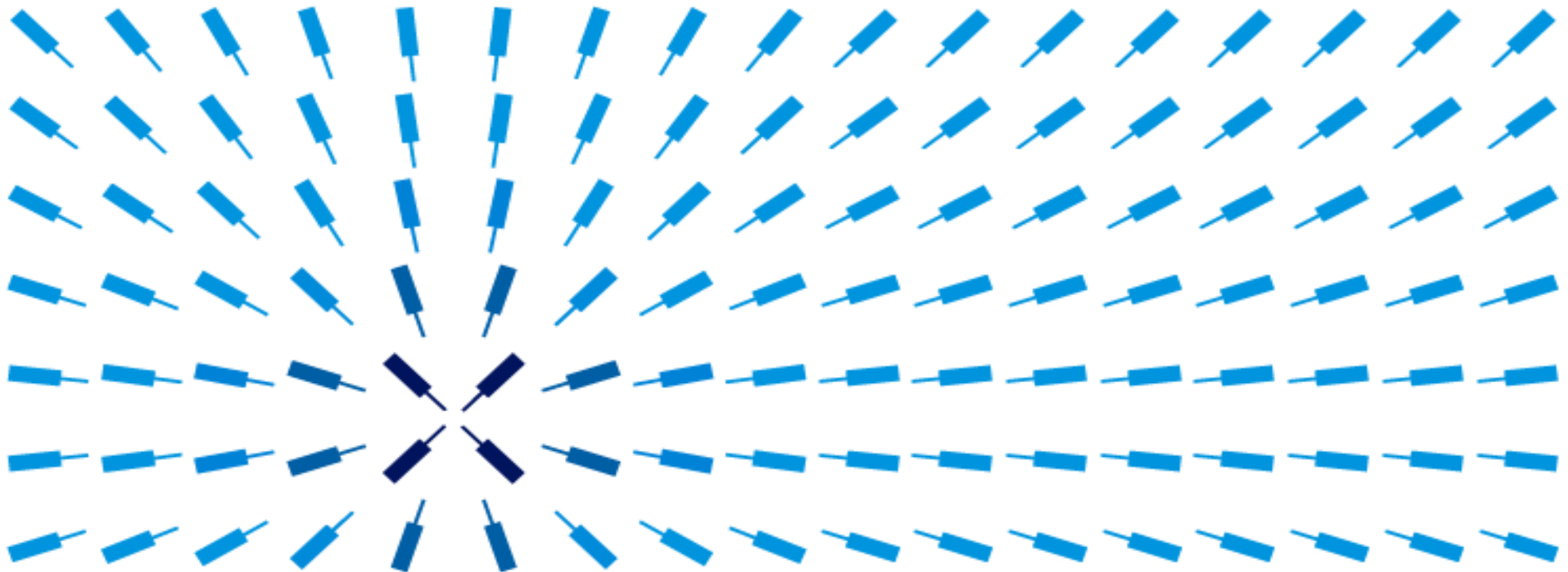
2. Méthode 'Dual Frequency Resonance Tracking' (DFRT)

- Principe
- Exemple

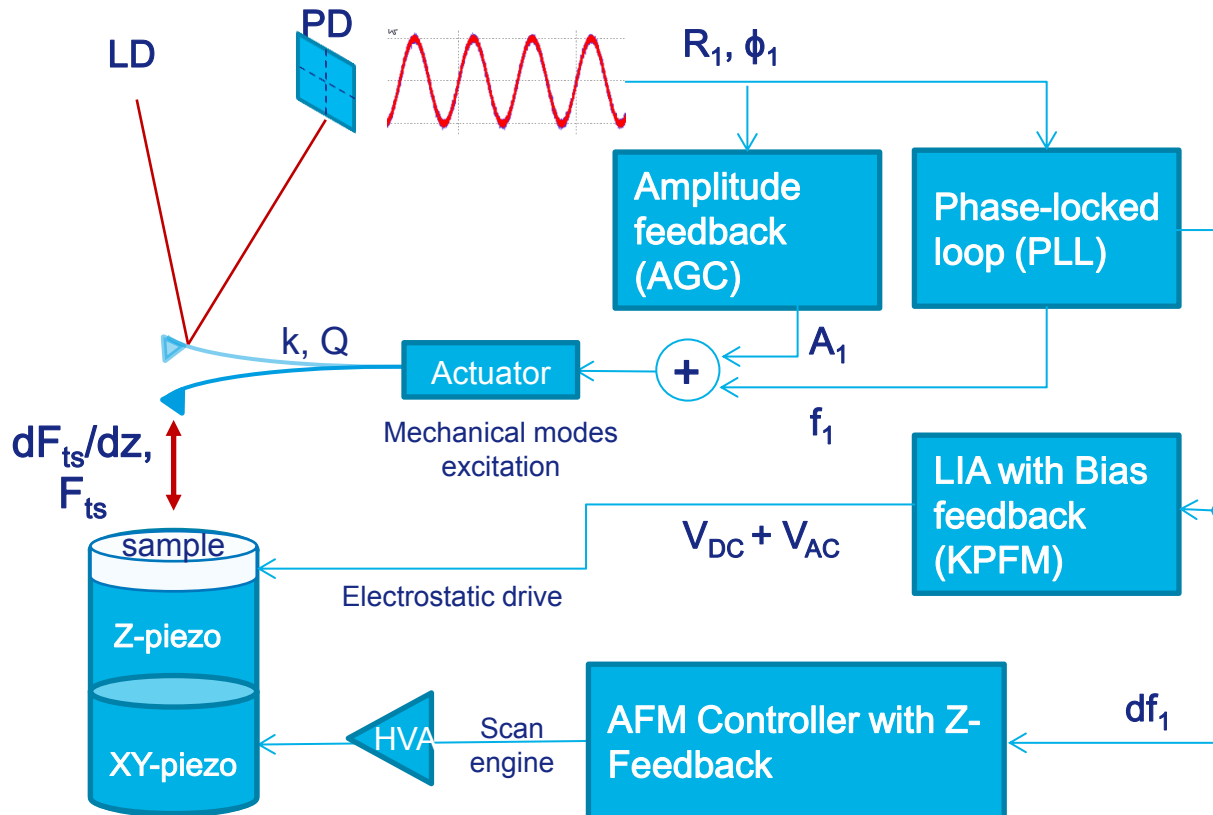
3. Suivie de résonance de contact à 1 ou 2 PLL

- Variation sur le même thème
- La DFRT appliquée au KPFM

1. Un peu de traitement du signal pour le SPM



Multifrequency & multiple feedback loops in SPM



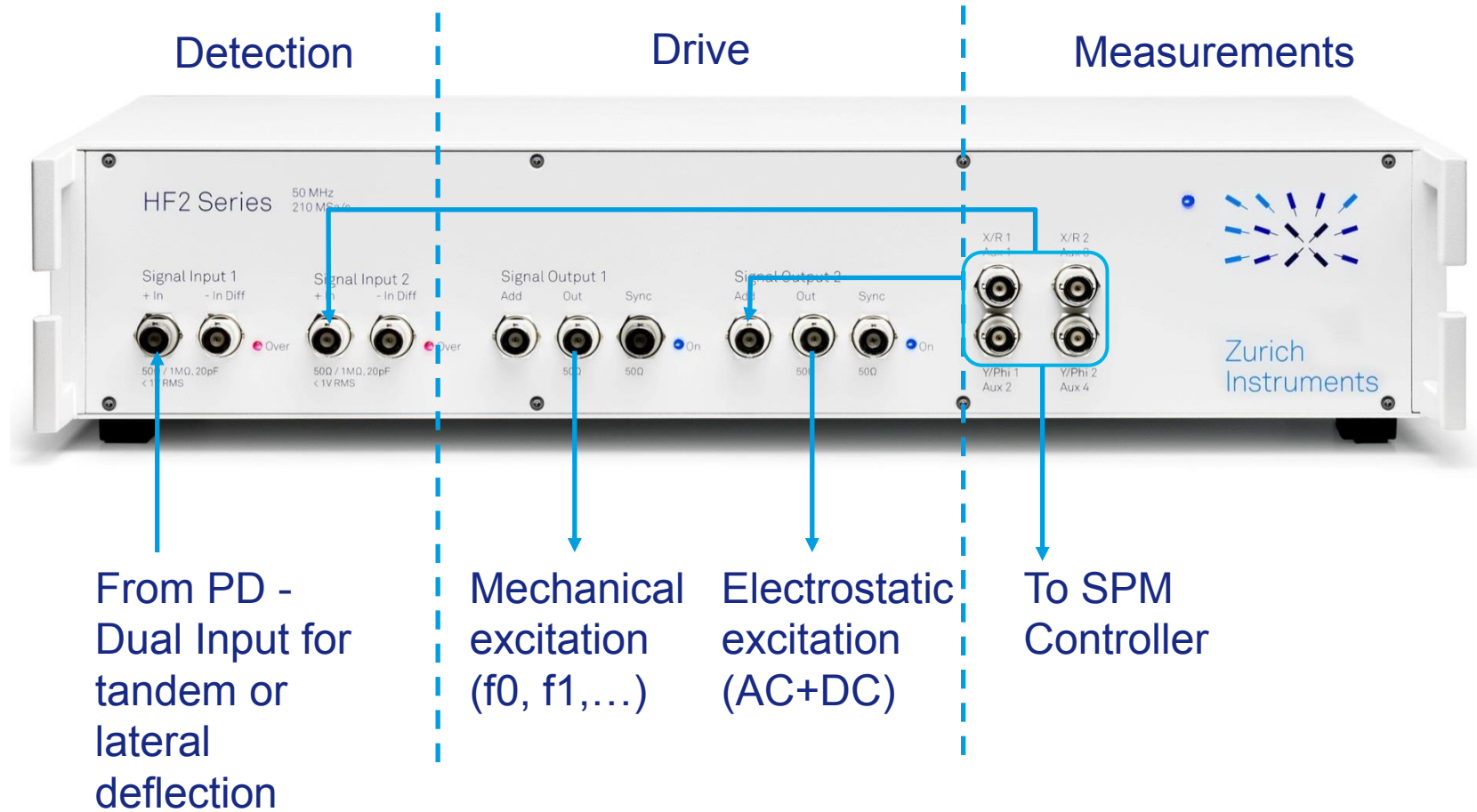
Most common AFM modes:

- Contact Modes (DC deflection)
- Tapping Modes (AC Modulation & Amplitude demodulation)
- Non-Contact Modes (FM-AFM, measure dissipation or drive and conservative forces or freq shift)

Many variations:



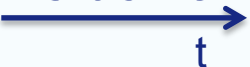
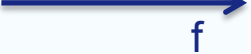
- Electrostatic modes (EFM, KPFM, SSRM, ...)
- Magnetic modes (MFM, MRFM)
- Resonance Contact modes (PFM, DFRT, ...) for nanomechanics
- Spectroscopic modes (Force volume)

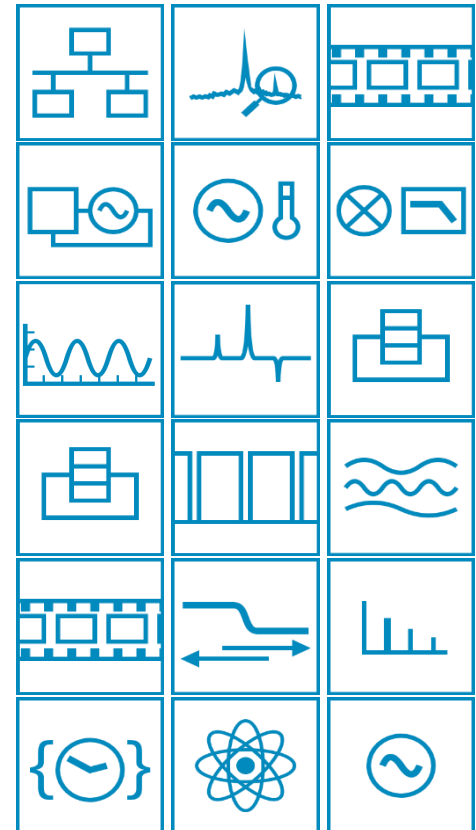
HF2LI – Multiple detection and excitation



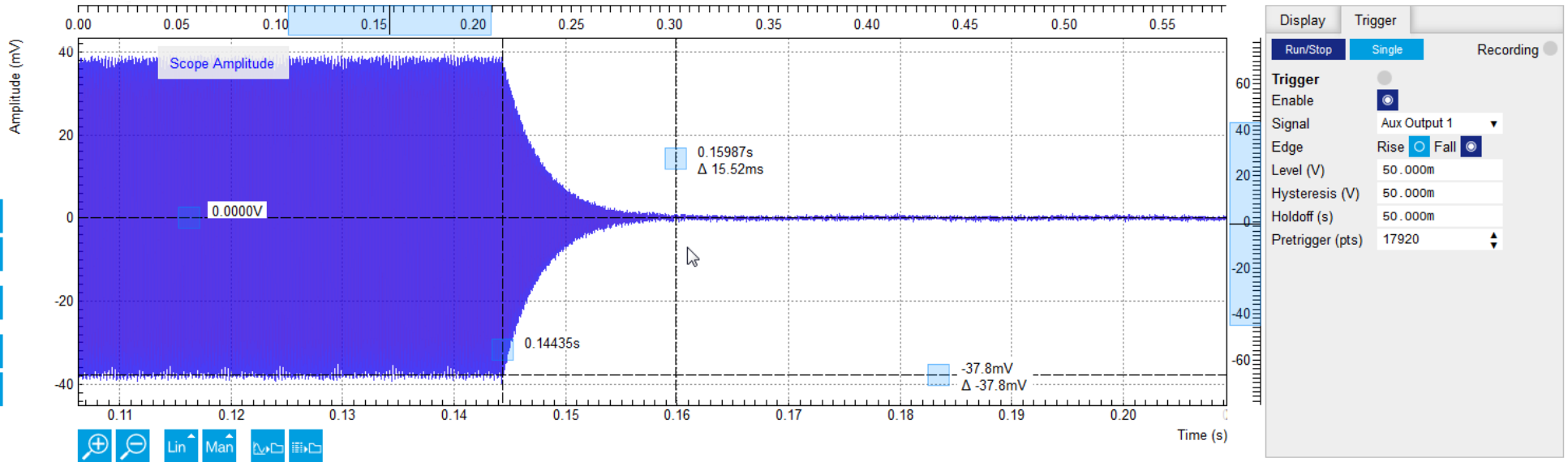
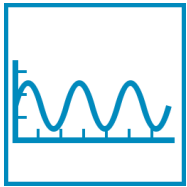
Complete dynamic signal generations & detections

Time and Frequency Domain Analysis

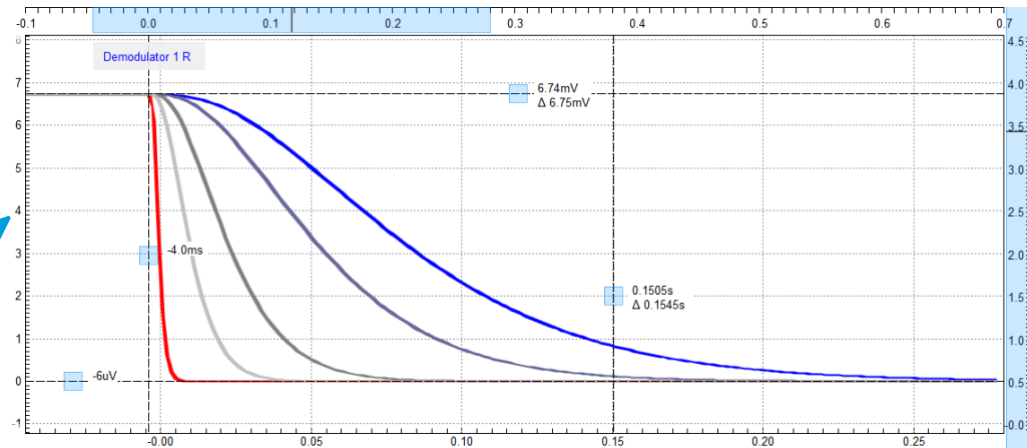
All digital Solution	Digitized samples 	Demodulated signal after down conversion 
Time domain 	Oscilloscope Digitizer Function Generator	Multiple Demods Numerical and Plotter Tools Software Trigger
Frequency domain 	Raw FFT Analyzer Frequency Tracking	Frequency Response Analyzer (FRA) Zoom FFT

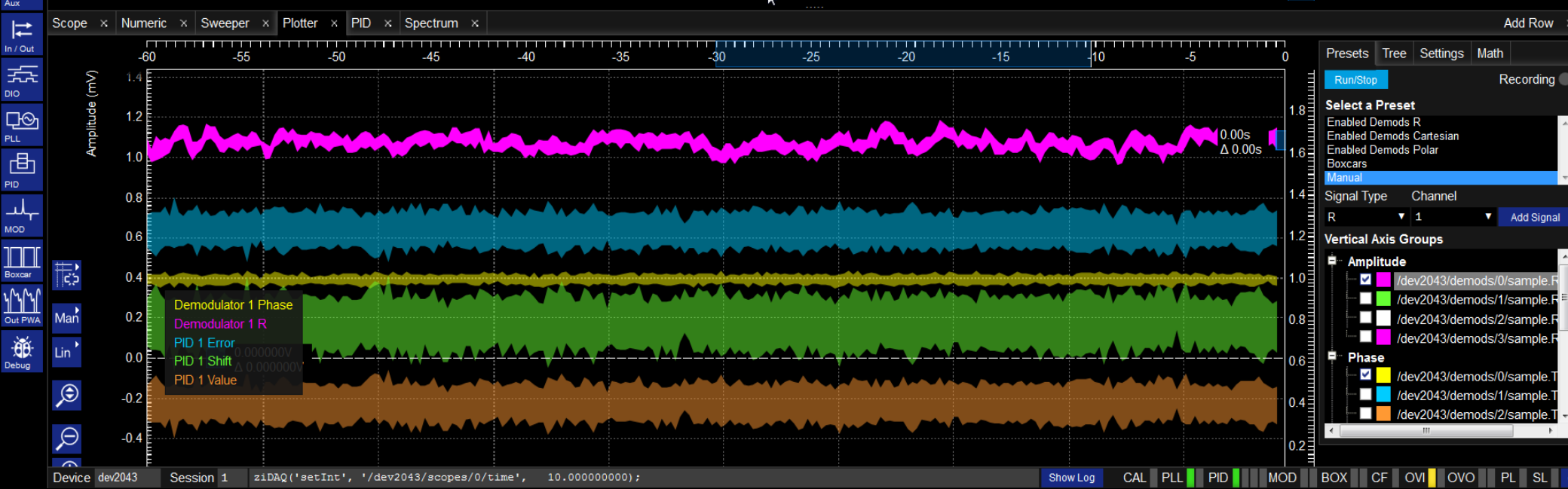
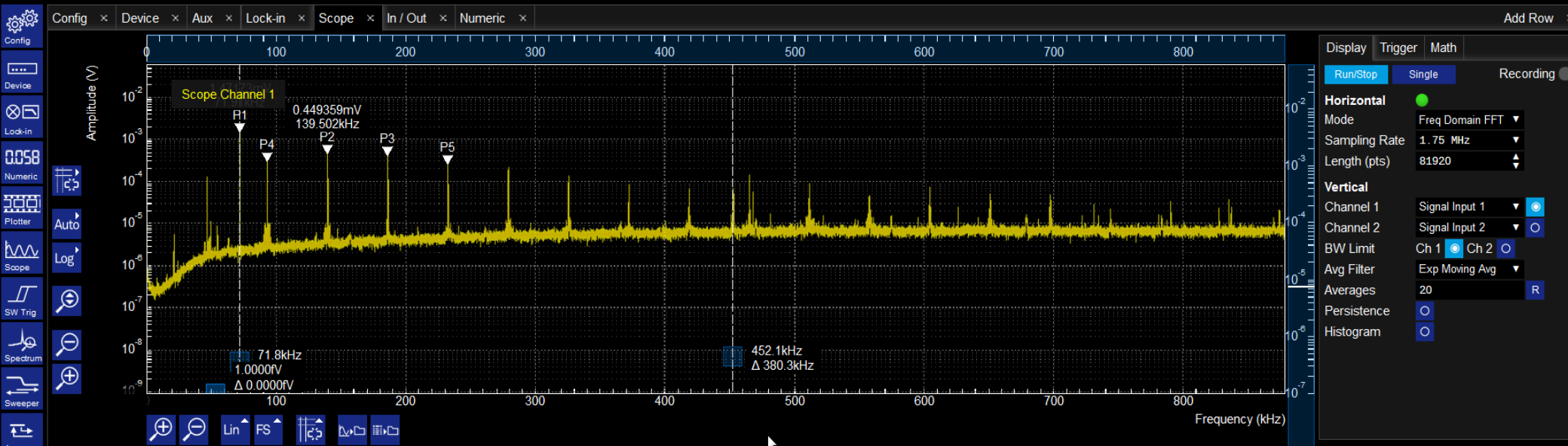


LabOne example: Oscilloscope and Trigger

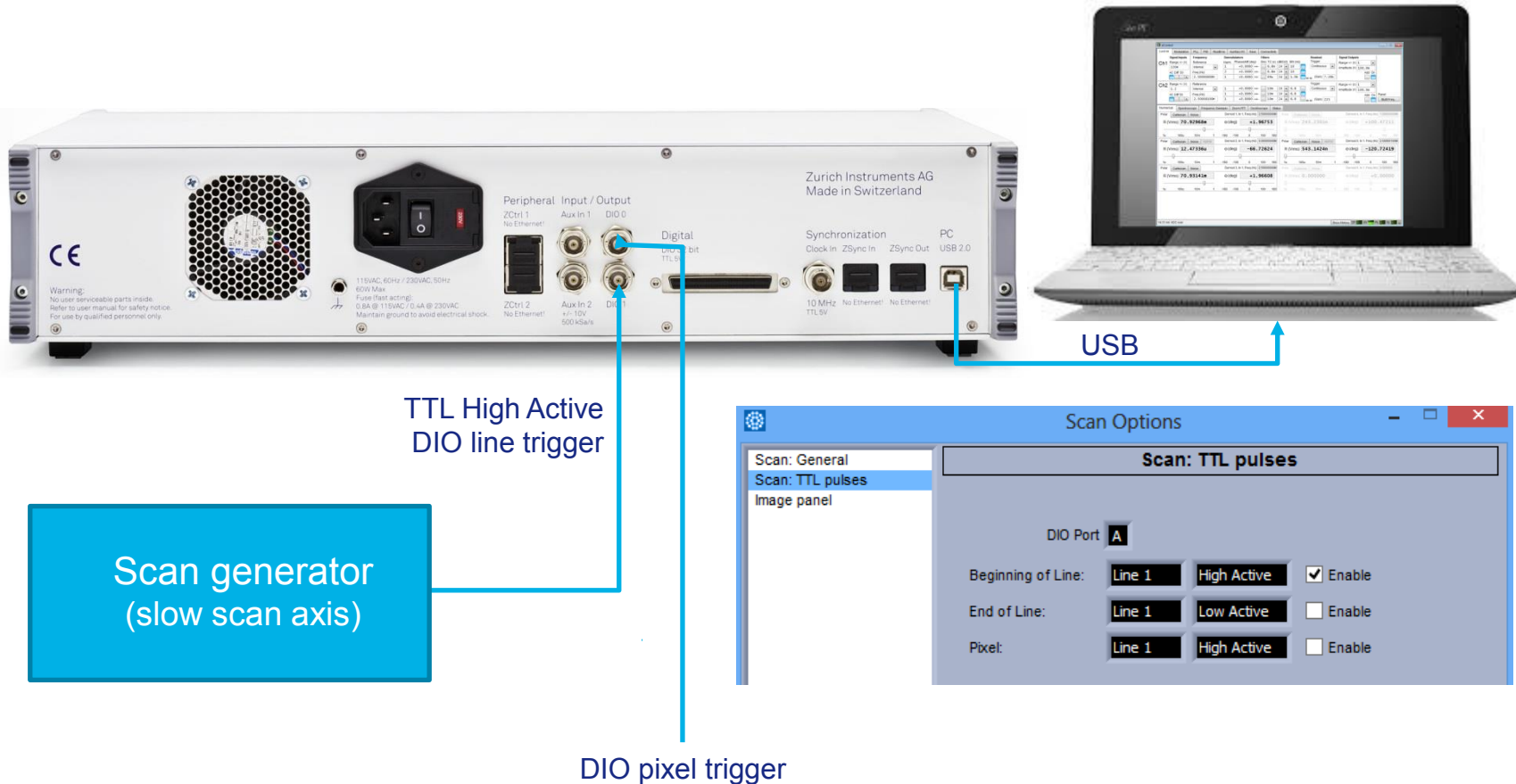


- 65kSa scope memory (extendable to 20MSa)
- trigger on any internal or external signal
- ring-down of transient phenomena





HF2LI – Back panel and data synchronization



All reference inputs and scan engine synchronization
Save more SPM image than # of Aux Out available!

HF2LI – Back panel and data synchronization



Demodulators

Reference Mode	Frequencies Osc	Harm	Demod	Freq (Hz)	Phase (deg)	Input Signal	Low-Pass Filters Order	TC	Sinc	Data Transfer En Rate (Sa/s)	Trigger	Trig Mode
1 Demod	1	1		996.63814003k	0.000	Sig In 1	8	3.300u	○	107.1k	Trigger In 1	Rise
2 ExtRef	1	1		997.25824099k	0.000	Aux In 1	4	12.45u	○			

Trigger Settings

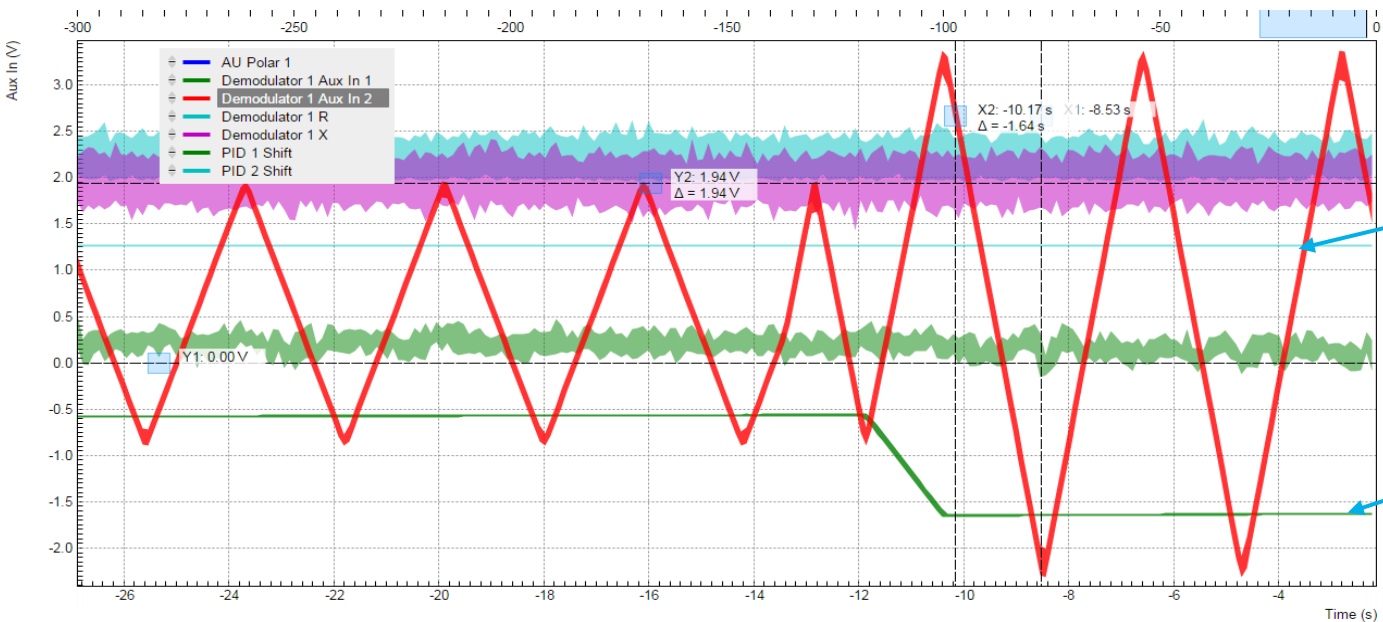
Trigger Signal	Demod 1 Trig In 2
Trigger Type	HW Trigger
Trigger Edge	Positive
Count	10

Horizontal

Hold Off Time (s)	100.000m
Hold Off Count	0
Delay (s)	0.000
Duration (s)	110.000m

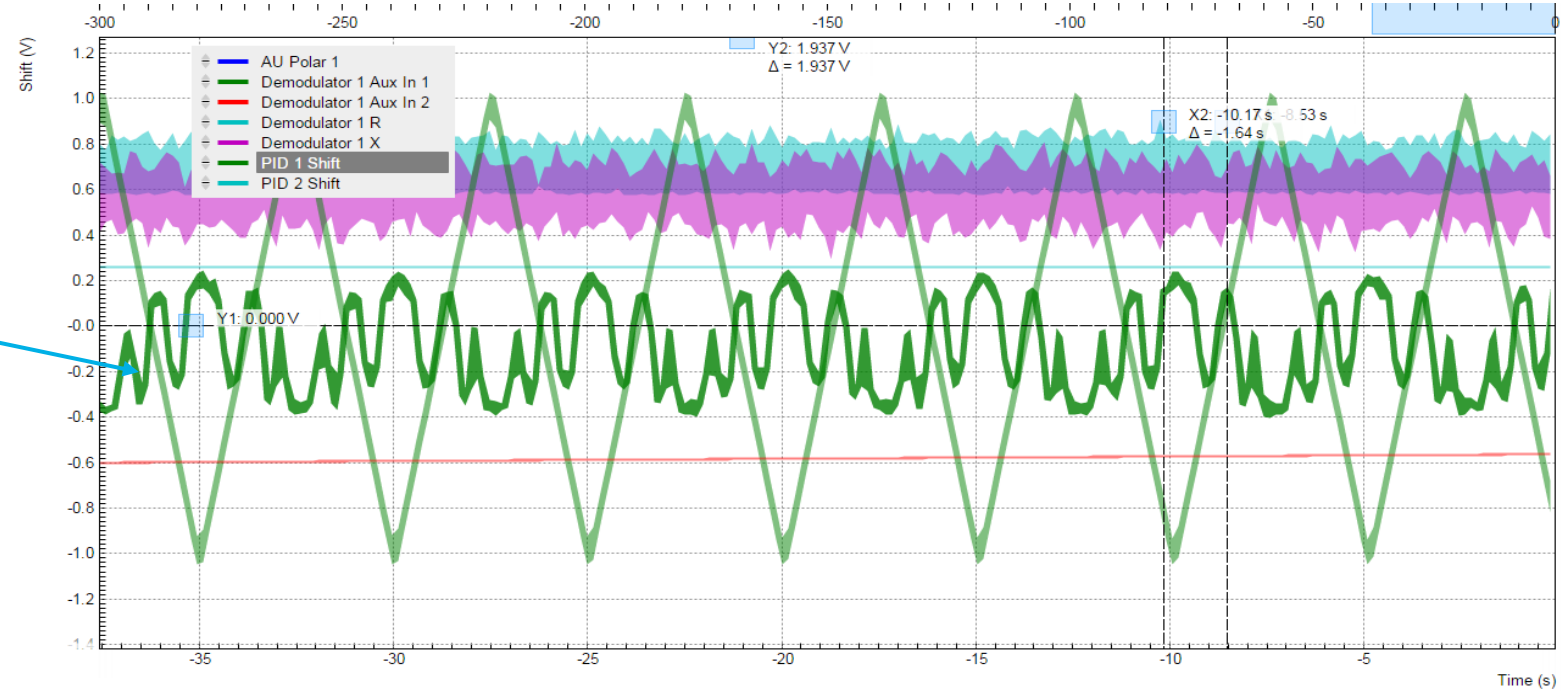
Software (SW) Trigger: data capture of all internal signals upon any trigger conditions

Scan synchronisation for mapping applications



X fast scan axis
Aux In1

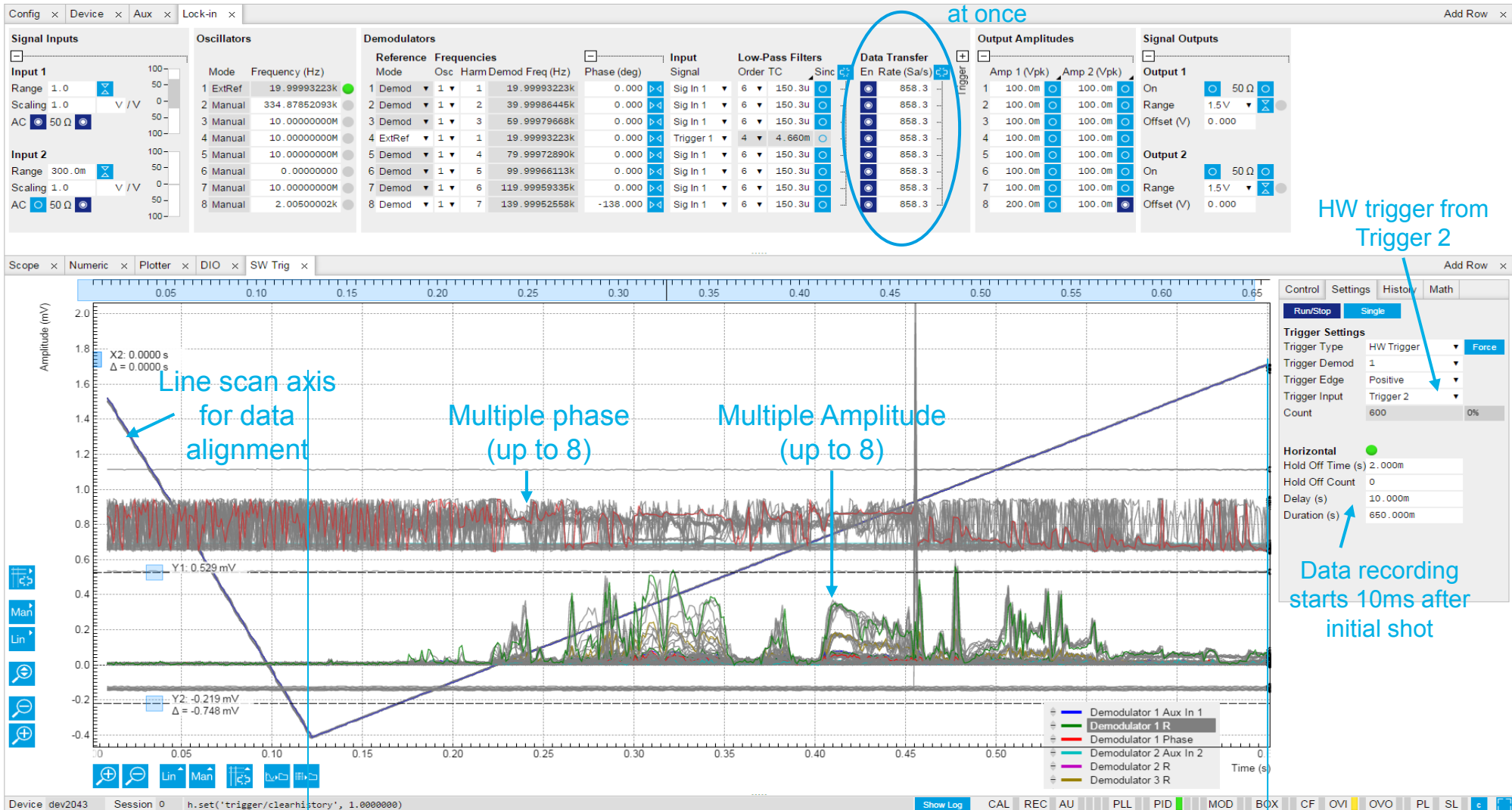
Y slow scan axis
Aux In2



Line scan

Mapping applications: Multichannel SW trigger

Save all 8 demodulators
at once



HW trigger from
Trigger 2

Line scan axis
for data
alignment

Multiple phase
(up to 8)

Multiple Amplitude
(up to 8)

Data recording
starts 10ms after
initial shot

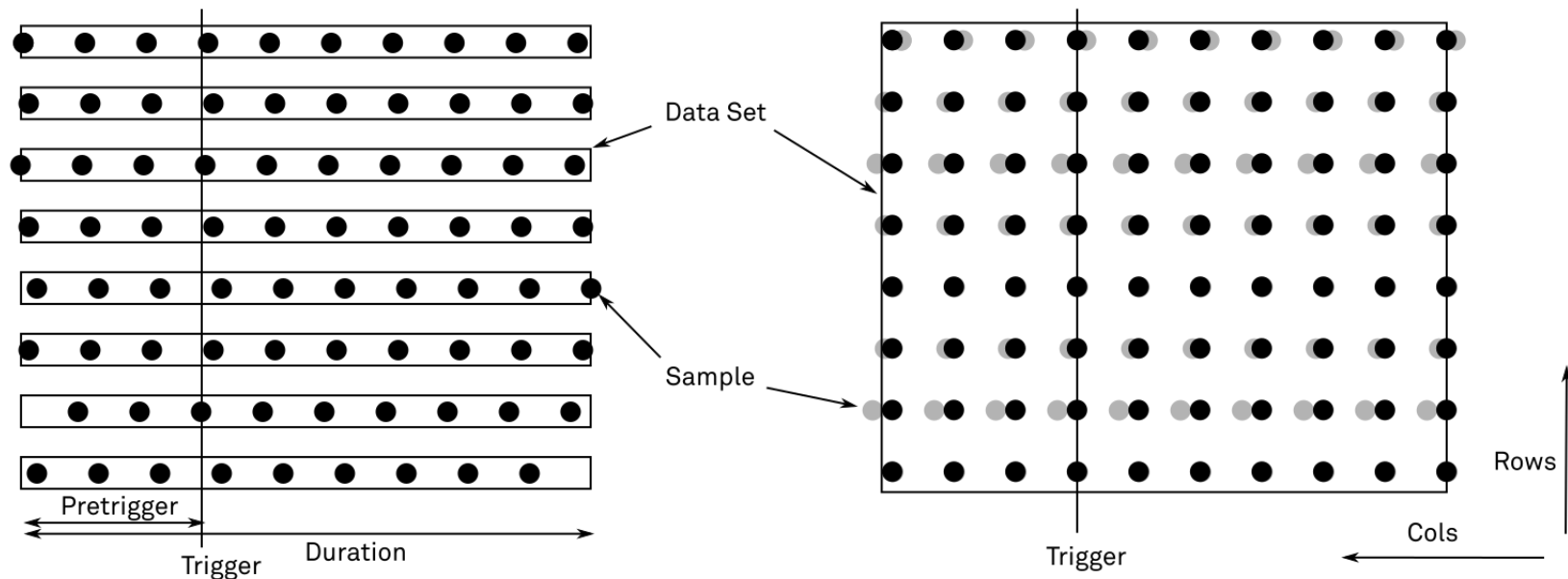
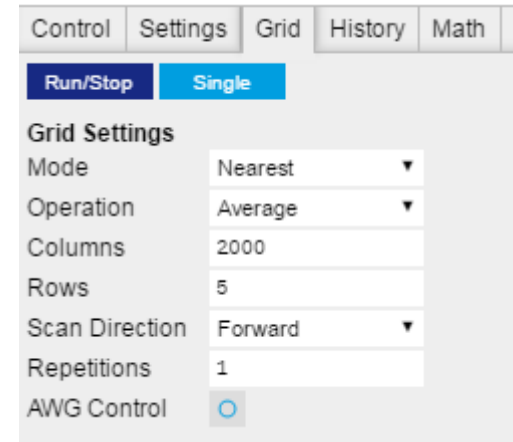
(bwd trace)

One triggered scan line
(superposed fwd traces)

Mapping applications: image reconstruction

Grid alignment:

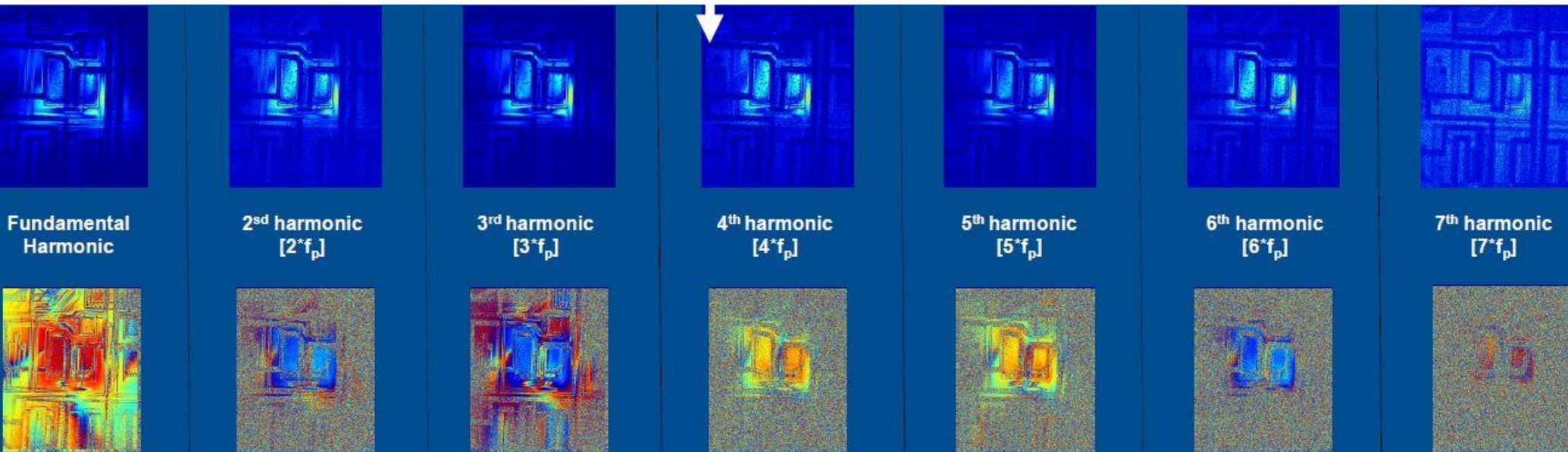
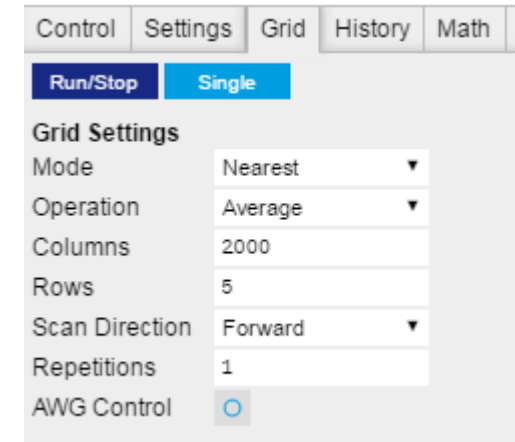
1. DIO trigger for line (and pixel trigger)
2. Data alignment on a user-defined grid
3. Matrix data file saved with number of rows and columns



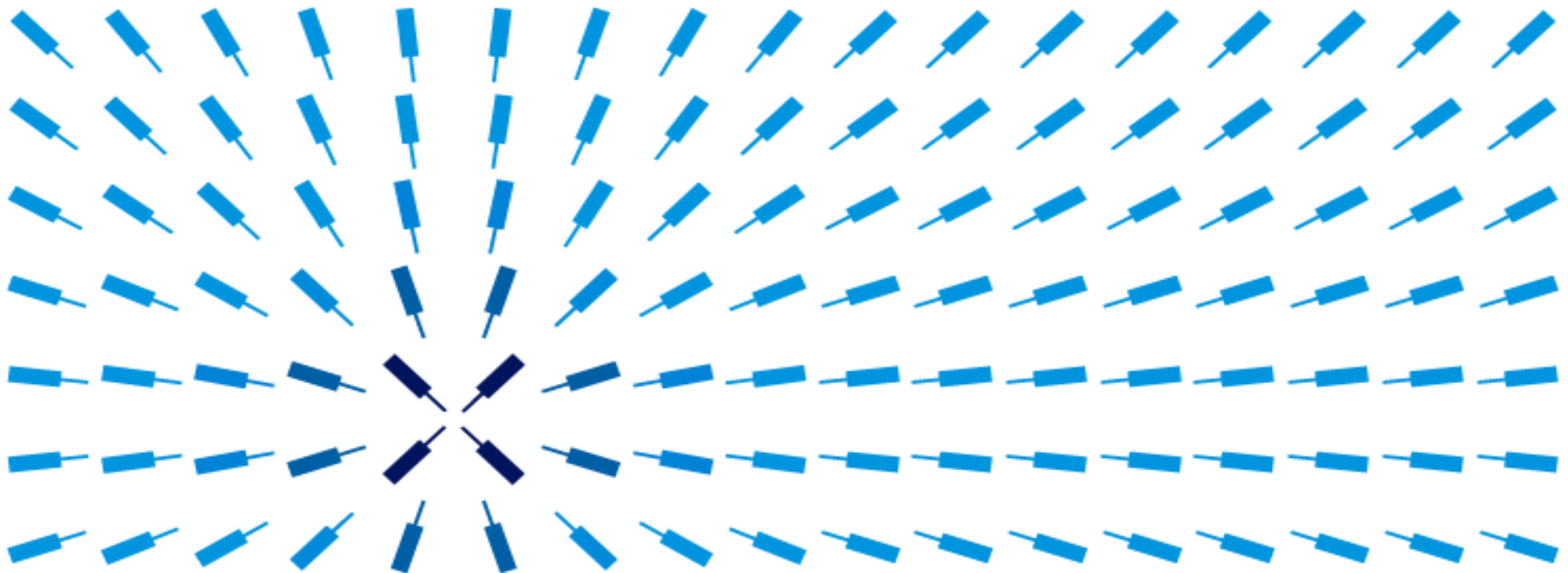
Mapping applications: image reconstruction

Grid alignment:

1. DIO trigger for line (and pixel trigger)
2. Data alignment on a user-defined grid
3. Matrix data file saved with number of rows and columns

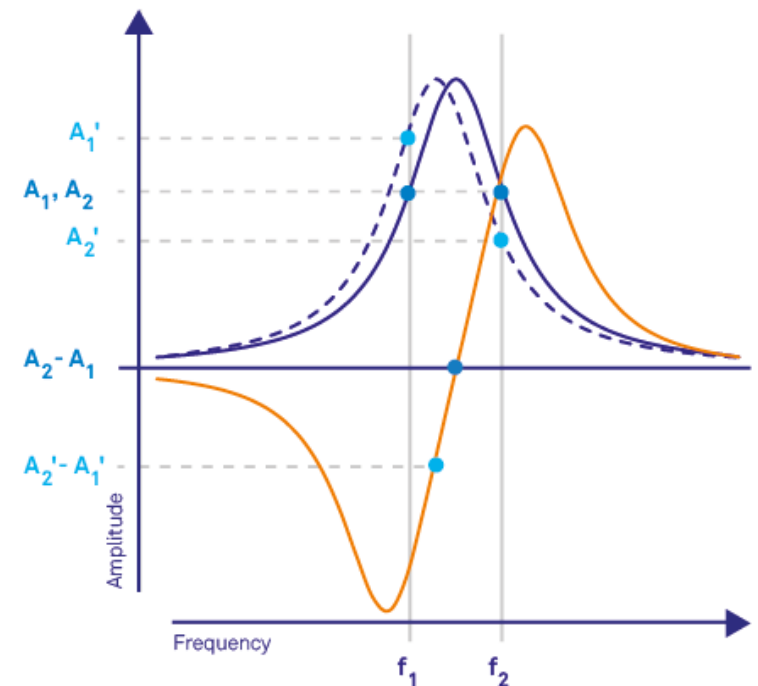
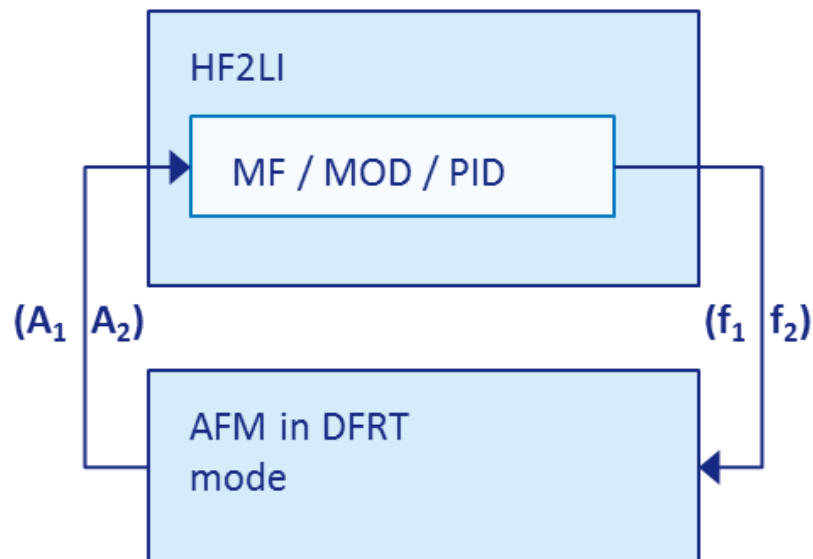


2. Méthode 'Dual Frequency Resonance Tracking' (DFRT)

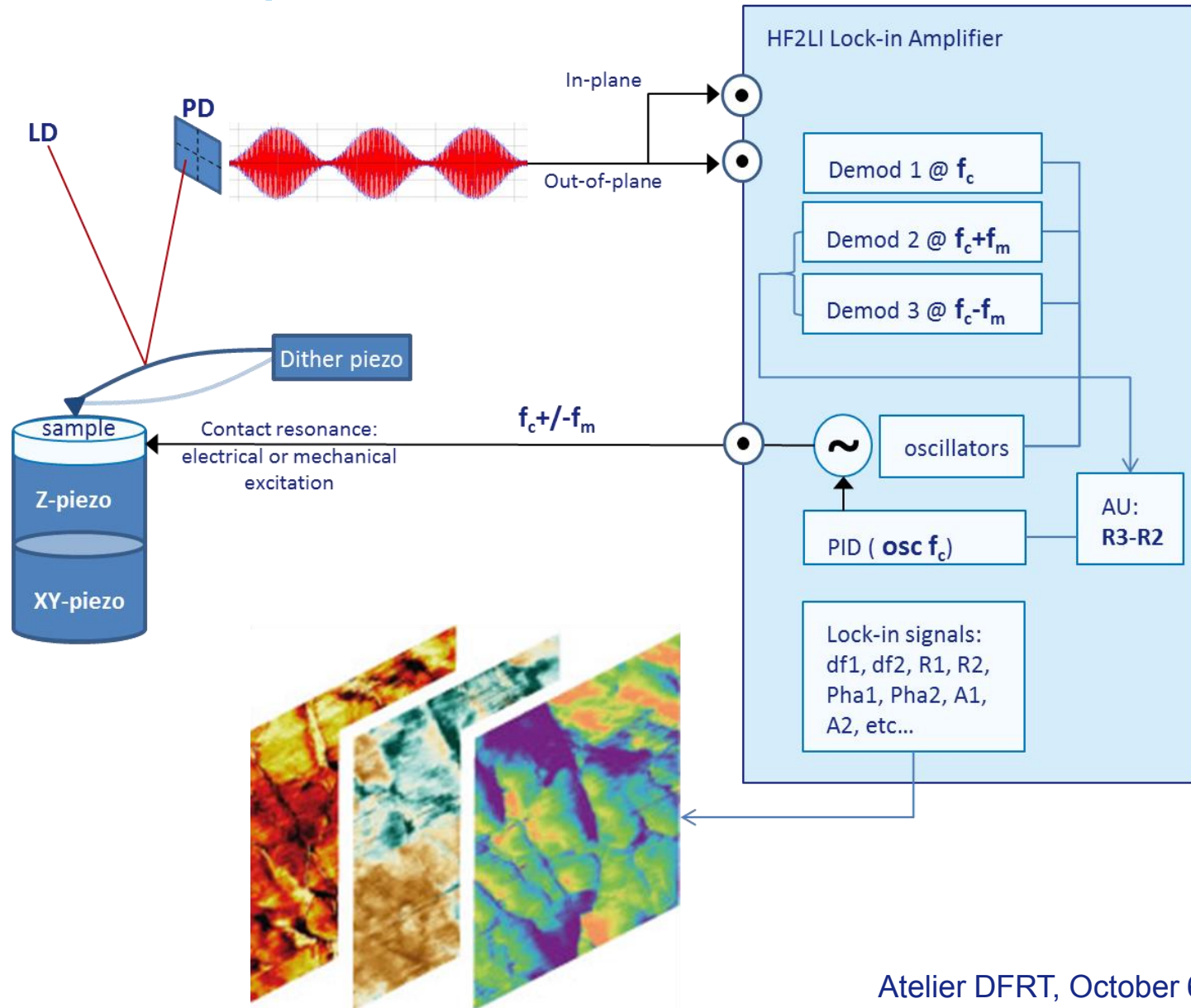


Dual Frequency Resonance Tracking (DFRT)

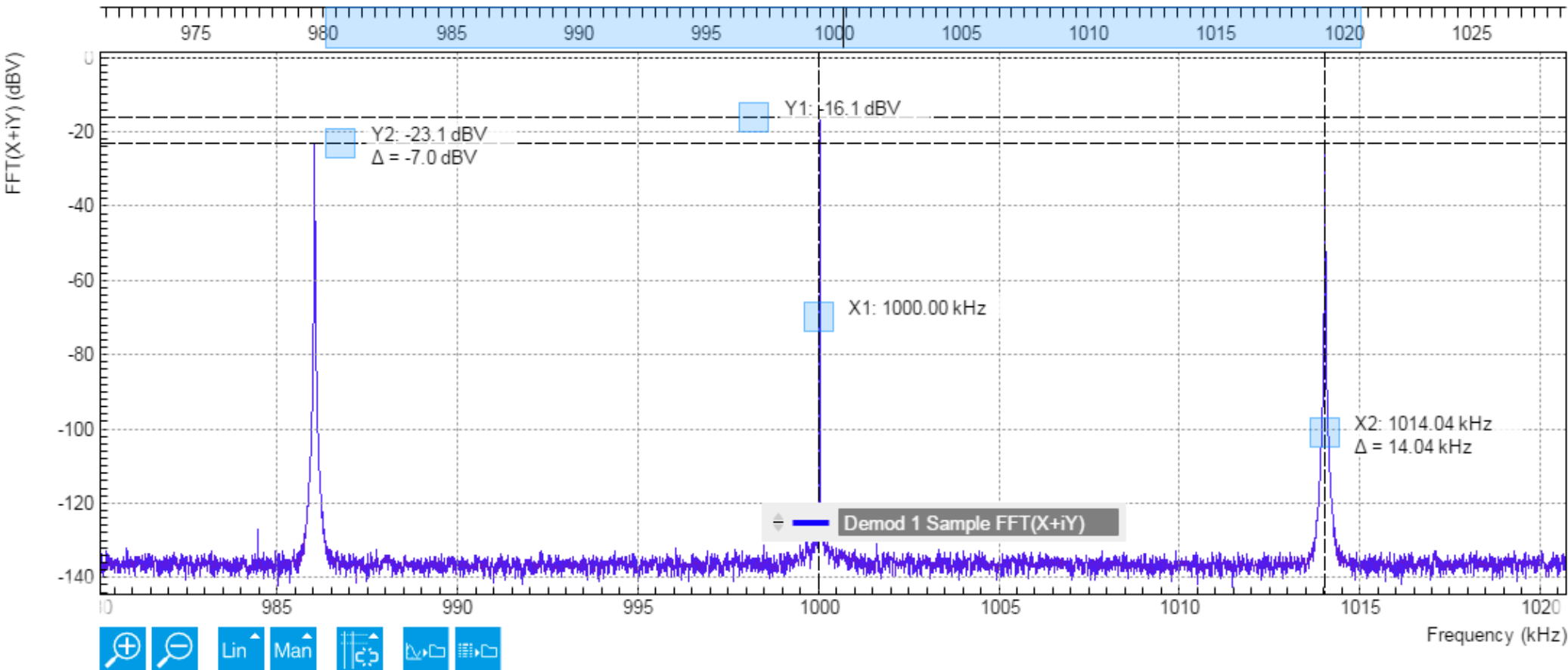
1. Bimodal excitation @ $f_c \pm f_m$ (just around the resonance)
2. Both sides of the resonance amplitude are measured simultaneously.
3. The difference of amplitude exhibits a linear dependence with a set-point of 0 at resonance.



How it works in practice



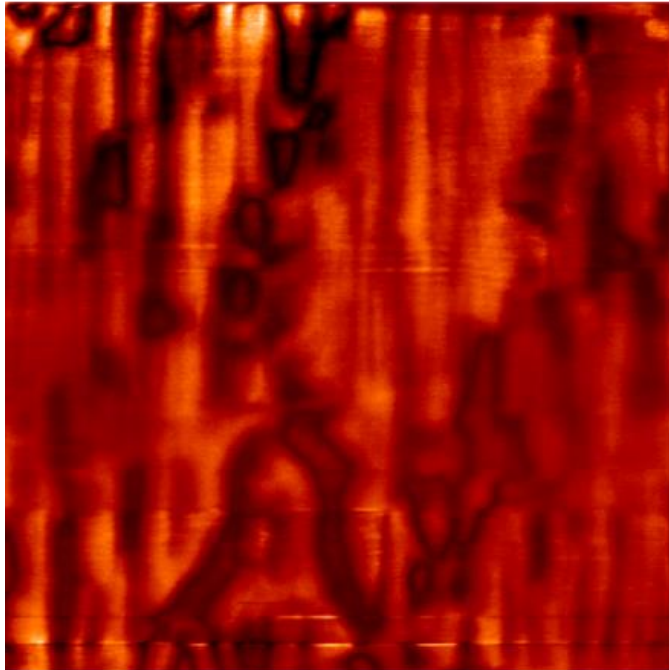
AM Modulation: frequency domain



Amplitude Modulation can be with or without carrier suppression

How it looks like

Contact Resonance PFM image of 100nm BFO layer, 2x2um scan size



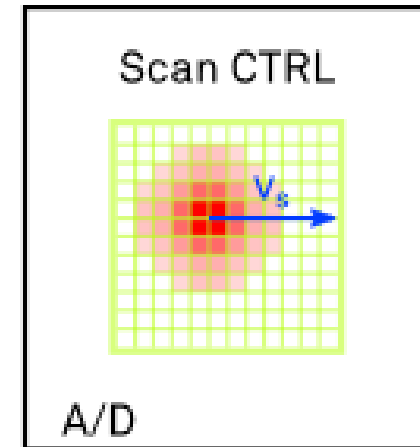
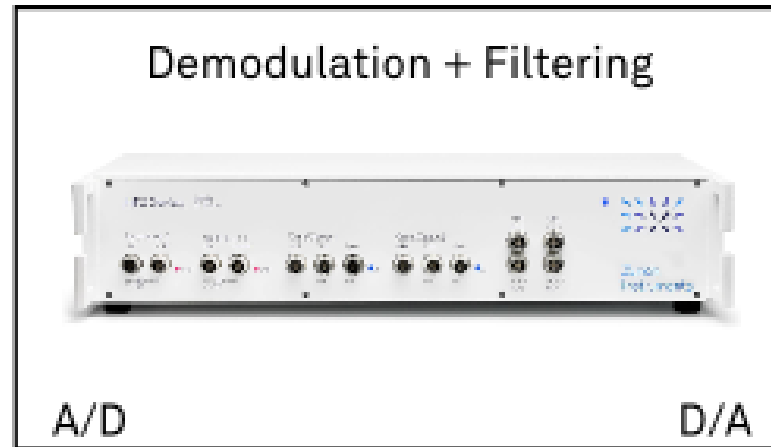
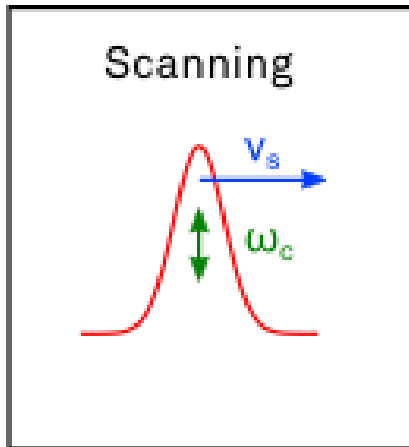
Piezoresponse Amplitude



Piezoresponse Phase

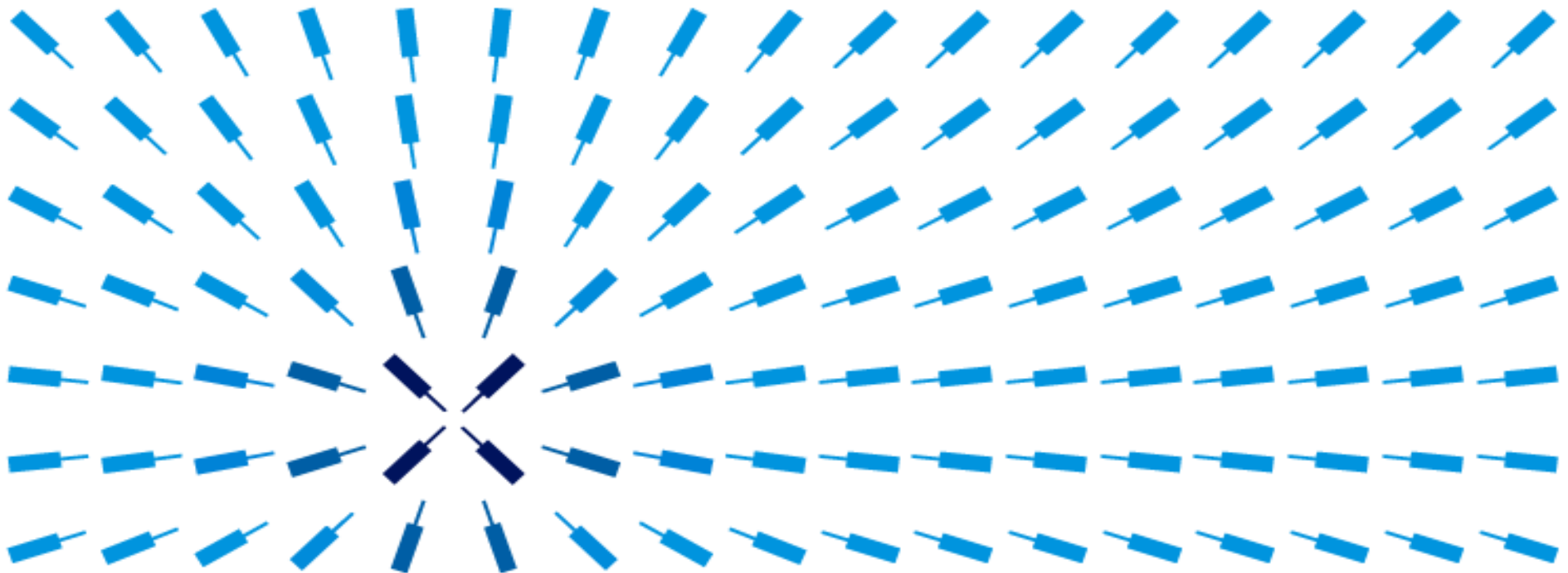
Image Courtesy of Igor Stolichtnov and Enrico Colla, Ceramic Lab, EPF Lausanne, Switzerland

Speed versus Resolution

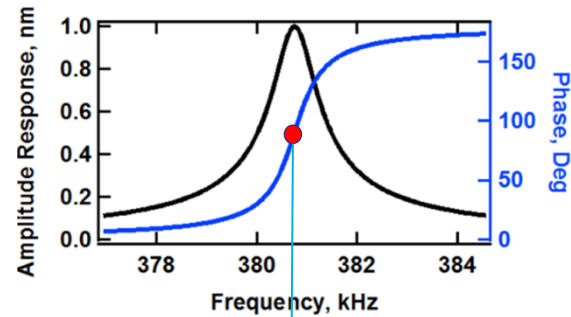


- **Pixel Dwell Time:** the less time per pixel, the faster the image
- Modulation always introduce some 'blurring' effect: challenge is to make it (and detect it) as small as possible with appropriate **filter settings**
- The higher the drive modulation, the more 'disturbing' side effect it produces

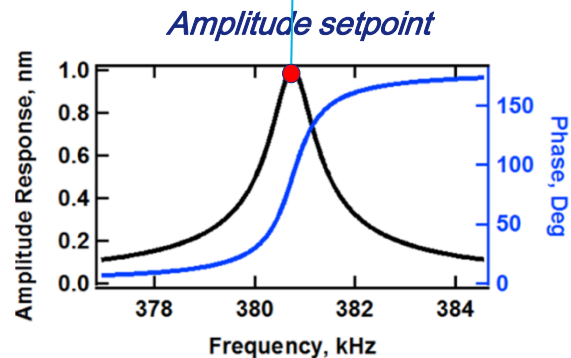
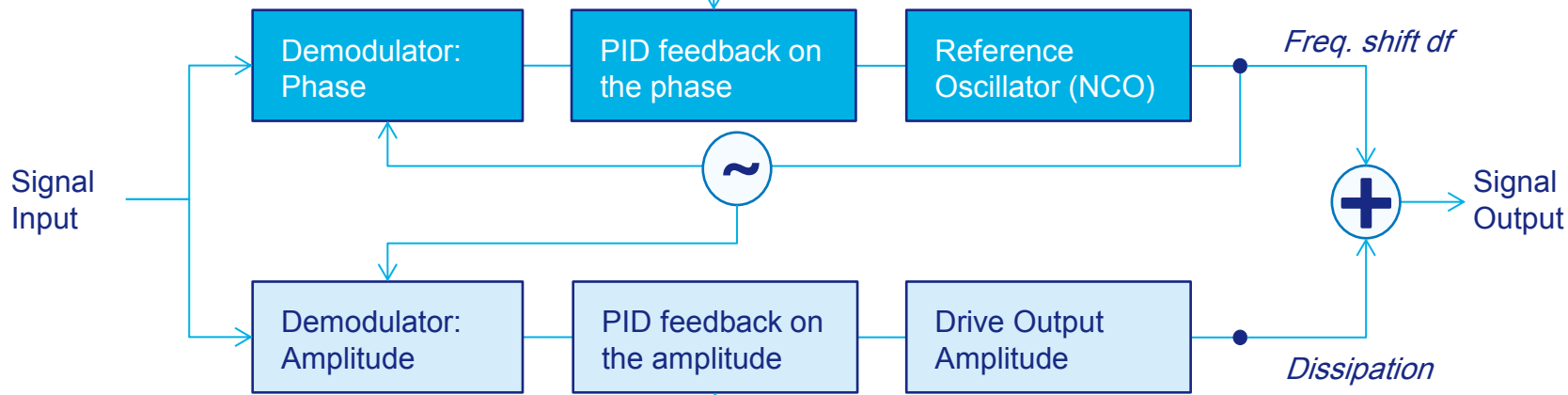
3. Suivie de résonance de contact à 1 ou 2 PLL



NC-AFM: Phase & Amplitude feedback loops



Phase setpoint

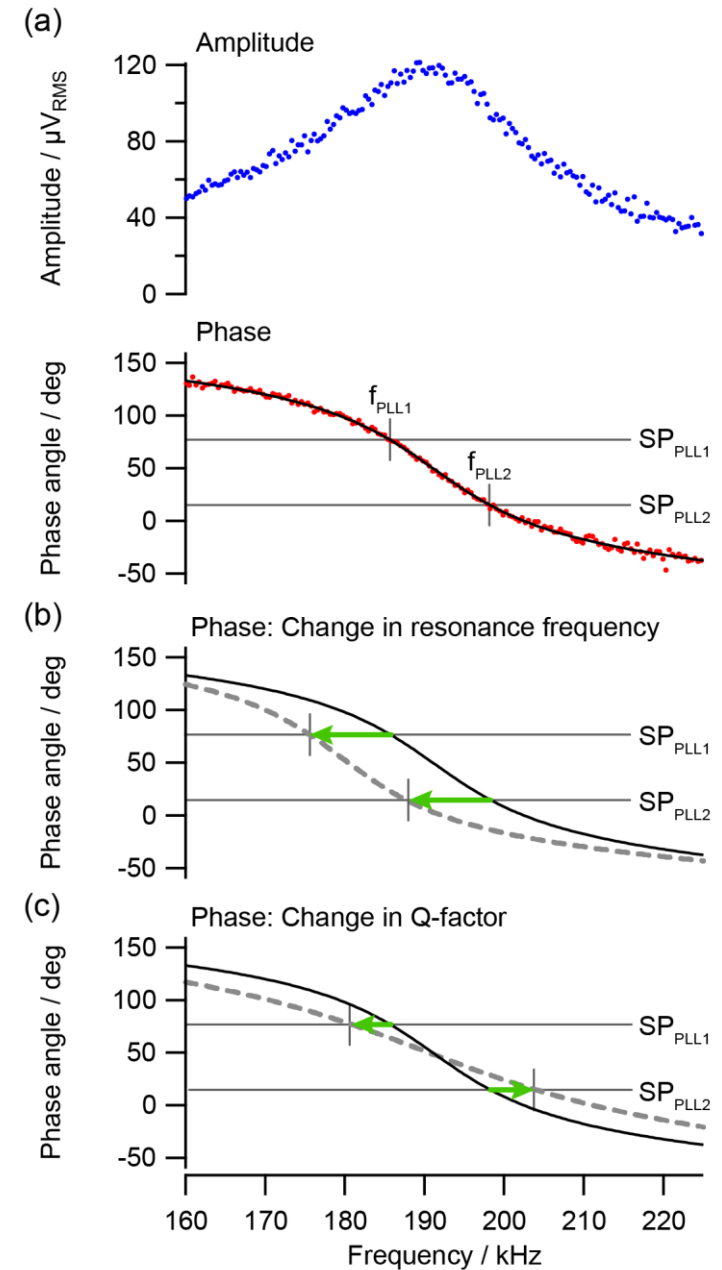


Amplitude setpoint

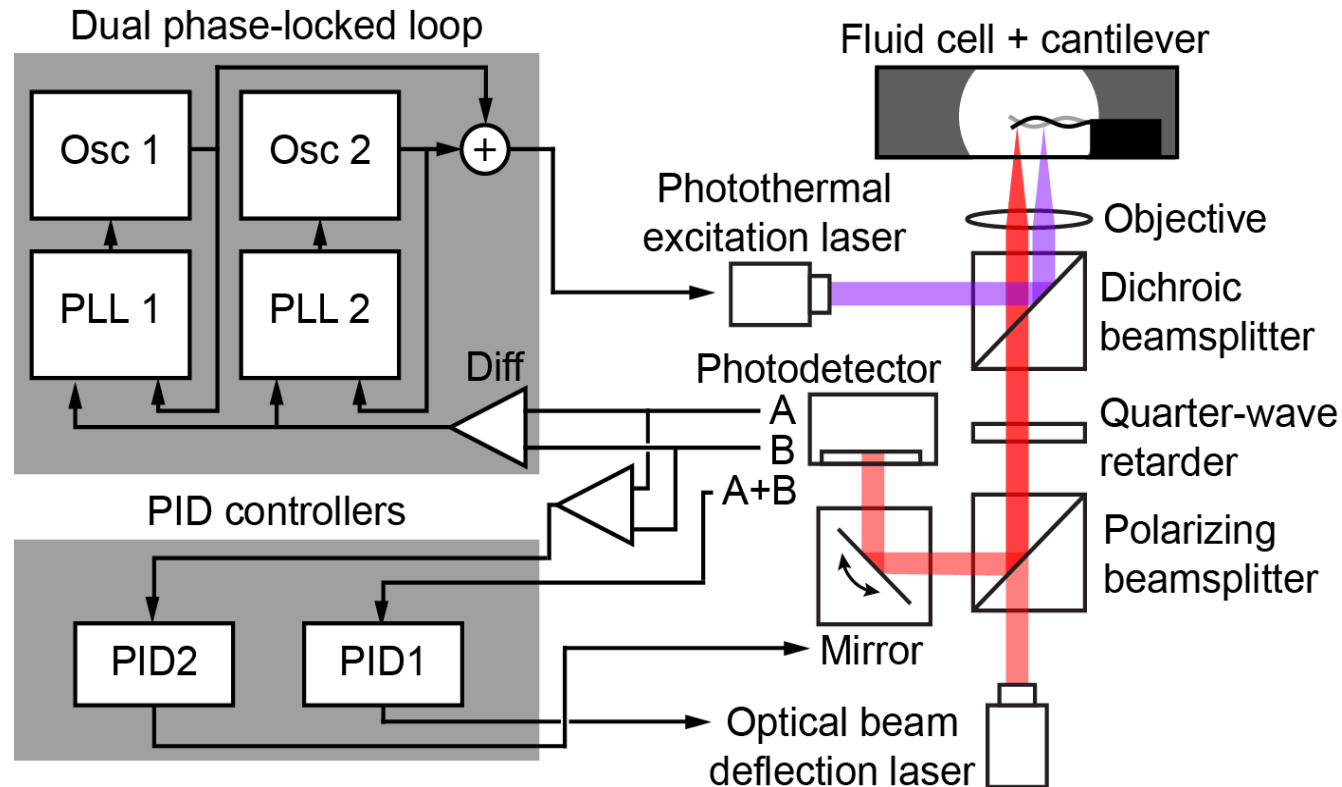
- Phase sensitive: the higher the Q , the better
- Quantitative : separation between conservative and dissipative interaction

Phase-Locked Loops

- DFRT doesn't provide info on Q factor (dissipation)
- Single PLL does not perform well with low Q
- Dual PLL operation for quantitative feedback even with low Q



Dual Phase-Locked Loop

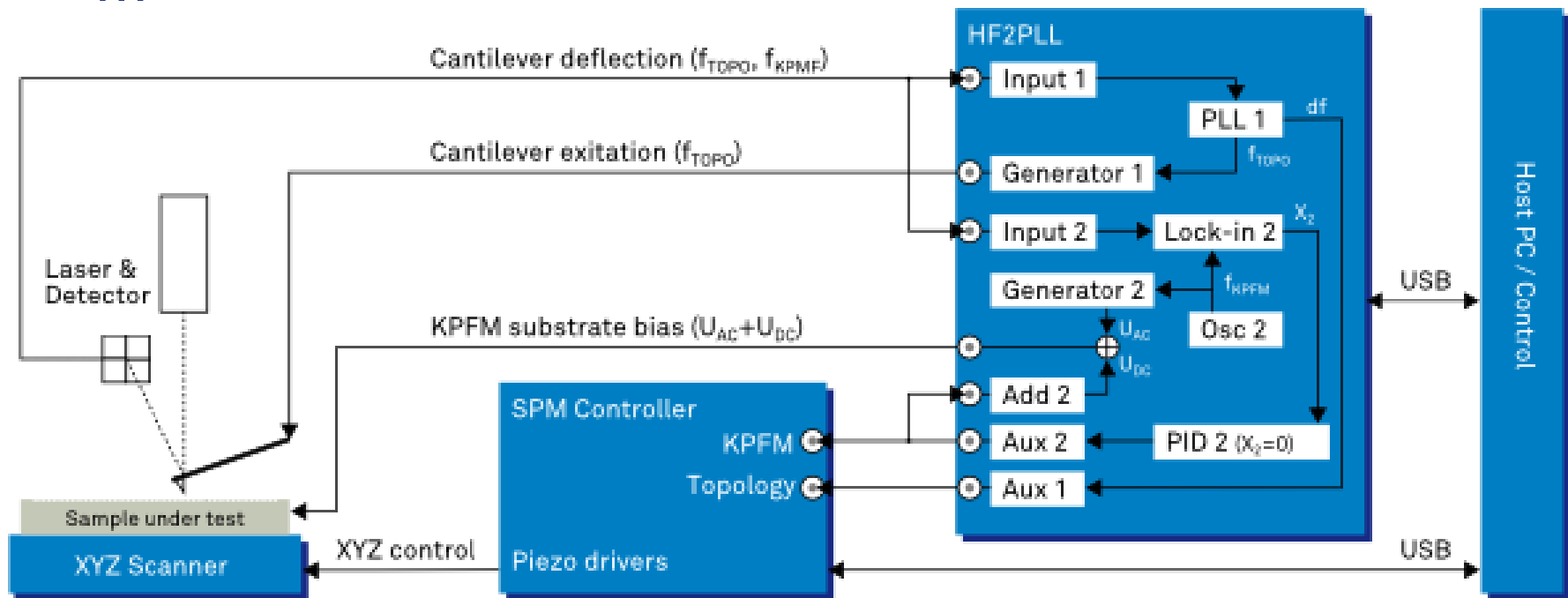


$$f_R \square \frac{f_{PLL1} + f_{PLL2}}{2}$$

$$Q \square \frac{f_R f_{PLL1}}{f_R^2 - f_{PLL1}^2} \tan \left(\frac{SP_{PLL1} - SP_{PLL2}}{2} \right)$$

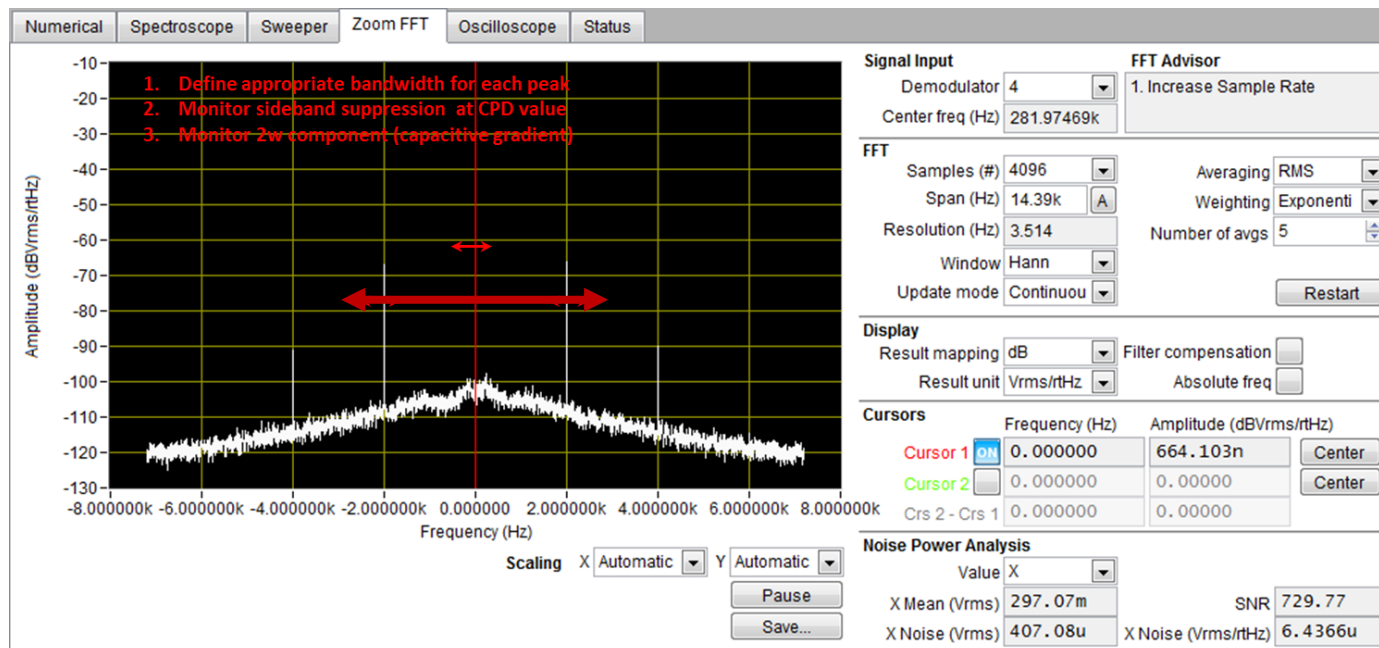
Kelvin Probe Microscopy: chose your mode

- Single-pass vs Mutli-pass
- AM-KPFM vs FM-KPFM
- Tandem vs Direct Sideband
- ...



FM-KPFM: why using direct sideband detection ?

1. Faster bias modulation possible (independent of PLL BW)
2. Optimization of PLL settings for better resolution (narrow band) regardless of AC modulation
3. Potential increase of SNR for the Kelvin feedback since both sidebands are measured and added



FM-KPFM: benefit of using many demodulators

MOD1 takes first 3 demod. X(2) & X(3) will be max with the right phaseshift

All 6 demodulated signals on Input 1

Demodulators		Filters		Readout		Signal Output Amplitudes				
Osc	Frequency (Hz)	Harm	Phaseshift (deg)	Input (dB/Oct)	BW (Hz)	Sinc	Trigger	(Sa/s)	Output 1 (V)	Output 2 (V)
1	77.2288759k	1	+70.0000	1	48	500	Cont.	7.20k	0.000	0.000
2	1.00000000k	1	+114.4629	1	48	1.10	Cont.	7.20k	0.000	0.000
2	1.00000000k	1	+114.0000	1	48	1.10	Cont.	7.20k	0.000	0.000
1	77.2288759k	1	+0.0000	1	48	1.00k	Cont.	7.20k	5.000m	0.000
2	1.00000000k	2	+0.0000	1	48	100	Cont.	899	0.000	500.0m
3	2.00000000k	2	+0.0000	1	48	100	Cont.	899	0.000	2.000
1	77.2288759k	Signal In 1 (auto)		Locked		BW NEP			62.50m	2.000
2	1.00000000k	Internal							0.000	1.000

MOD2 can be used to measure second harmonic simultaneously (capacitive gradient of the force)

Mechanical excitation on Output 1 (PLL and AGC locked)

Electrostatic excitation on Output 2 AC+DC added (demodulated in MOD1)

FM-KPFM: example on Graphene flakes

Image of Graphene flakes on Cu (111) in FM-KPFM mode

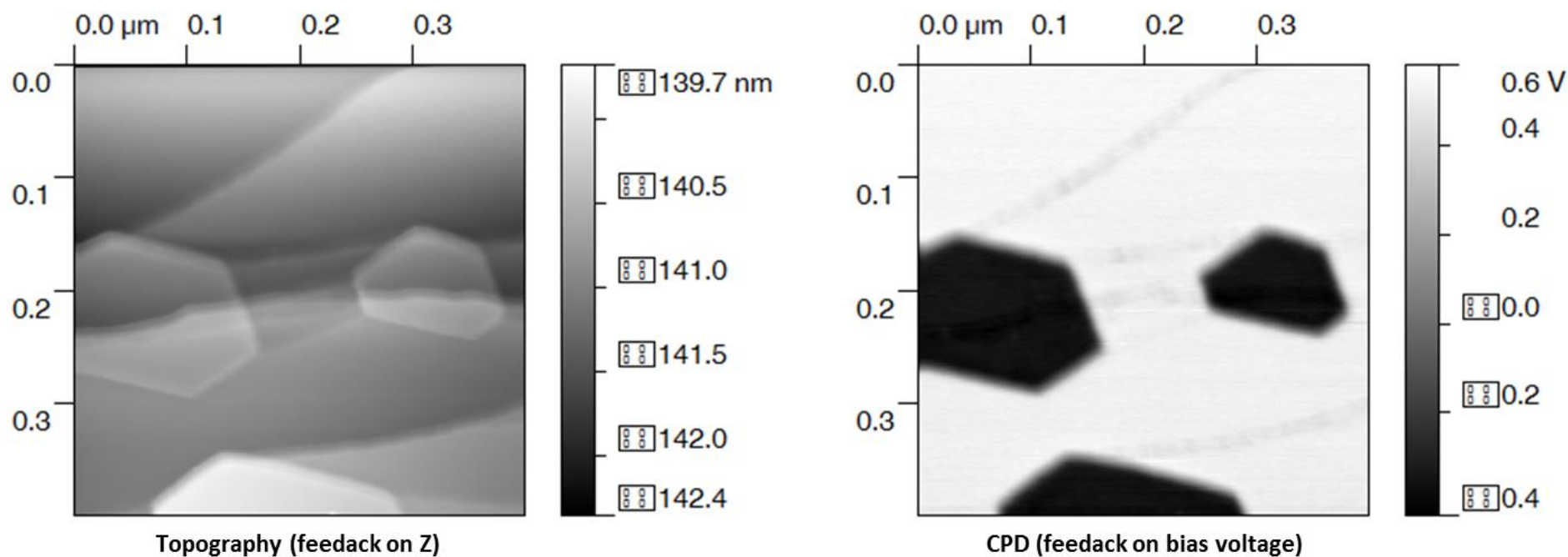


Image courtesy of Thilo Glatzel and Ernst Meyer, Universität Basel, Switzerland

Why phase adjustment is important for KPFM ?

Config x Device x Aux x Lock-in x DIO x Add Row x

All

Signal Inputs

1 Input 1
Range 300.0m
Scaling 1.0 V/V
AC 50 Ω

2 Input 2
Range 10.0m
Scaling 1.0 V/V
AC 50 Ω

Oscillators

Mode	Frequency (Hz)
1 PID	937.41002152k
2 Manual	190.00000293
3 Manual	150.10000000k
4 Manual	10.00000000M
5 Manual	10.00000000M
6 Manual	10.00000000M
7 Manual	10.00000000M
8 Manual	10.00000000M

Demodulators

Reference	Frequencies	Phase (deg)	Input	Low-Pass Filters	Data Transfer				
Mode	Osc	Harm	Demod	Freq (Hz)	Order	BW 3 dB	Sinc	En	Rate (Sa/s)
1 Mod	1	1	937.40933982k	0.000	Sig In 1	4	193.1	3.433k	
2 Mod	2	1	937.59961713k	0.000	Sig In 1	4	100.3	1.717k	
3 Mod	2	1	937.21961713k	0.000	Sig In 1	4	100.3	858.3	
4 Manual	1	1	937.40962606k	115.164	Sig In 1	8	33.39	1.717k	
5 Demod	2	3	570.00000879	0.000	Sig In 1	4	11.14	1.717k	
6 Demod	2	1	190.00000293	0.000	Sig In 2	3	100.1	1.717k	
7 Demod	2	1	190.00000293	0.000	Sig In 2	3	100.1	1.717k	
8 Demod	3	1	150.10000000k	0.000	Sig In 2	3	100.1	6.866k	

Output Amplitudes

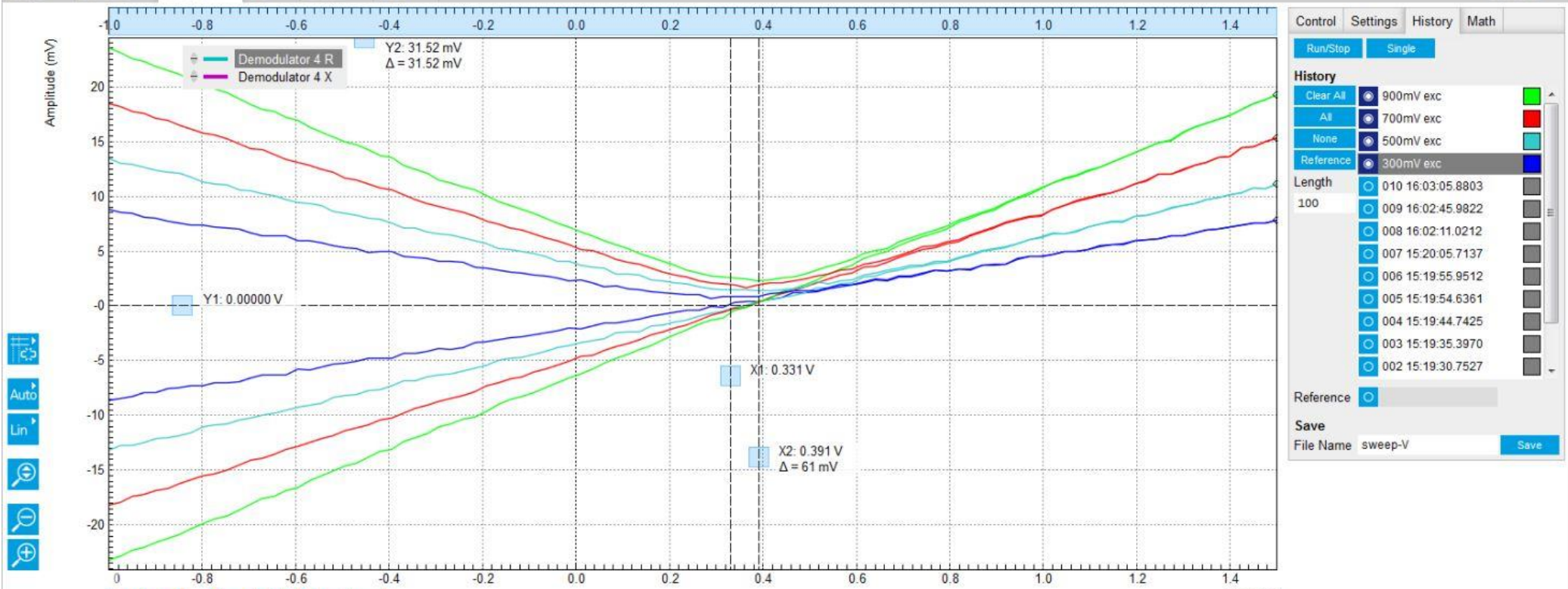
Amp 1 (Vpk)	Amp 2 (Vpk)
1 900.0m	1.000m
2 0.000	249.5u
3 0.000	249.5u
4 100.0m	100.0m
5 100.0m	100.0m
6 300.0m	100.0m
7 100.0m	100.0m
8 100.0m	150.0m

Signal Outputs

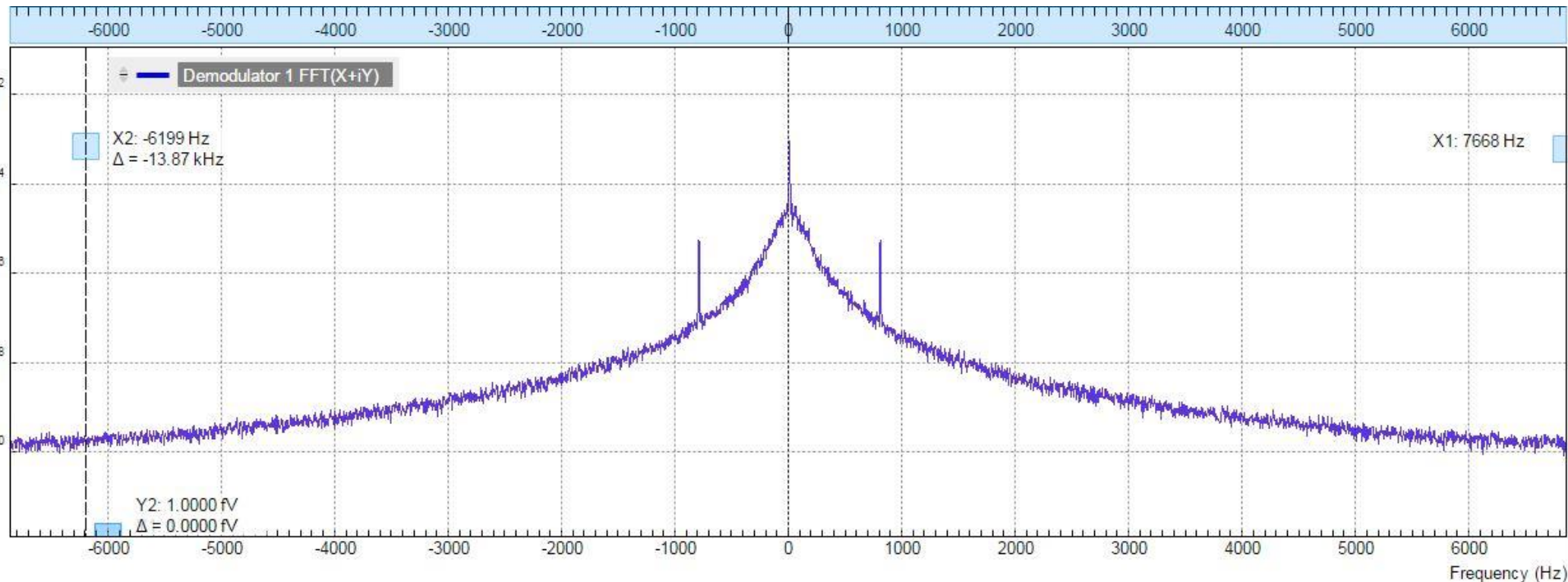
Output 1
On 50 Ω
Range 1.5V
Offset (V) 0.000

Output 2
On 50 Ω
Range 150 mV
Offset (V) 0.000

Scope x Numeric x Sweeper x PID x Plotter x MOD x Add Row x



Combining DFRT & KPFM method ?



Second eigenmode for bias modulation with mechanical frequency tracking

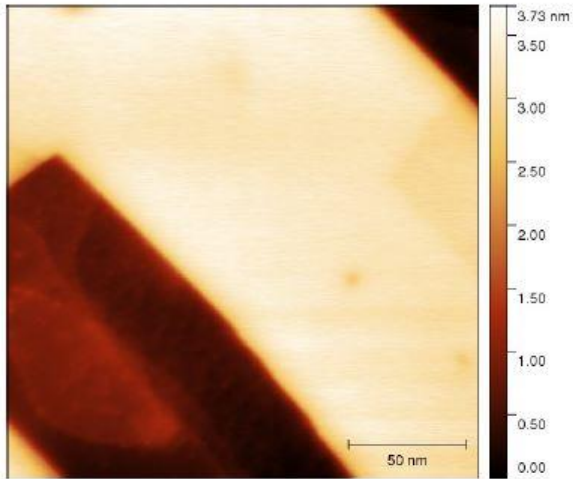
1. Carrier is electrostatically driven
2. Sidebands are mechanical modulated

More KPFM imaging...

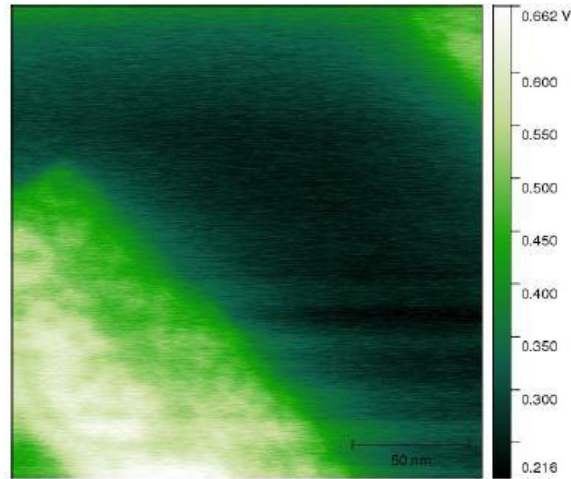
Cu(111) on KBr - 300mV V_{ac} @ second eigenmode (f2)

AM-KPFM

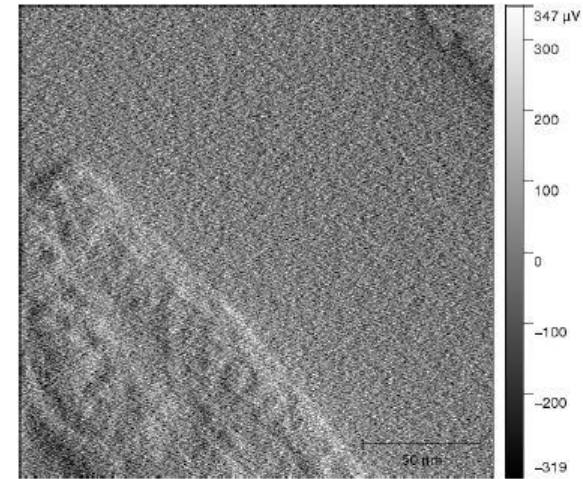
Topo



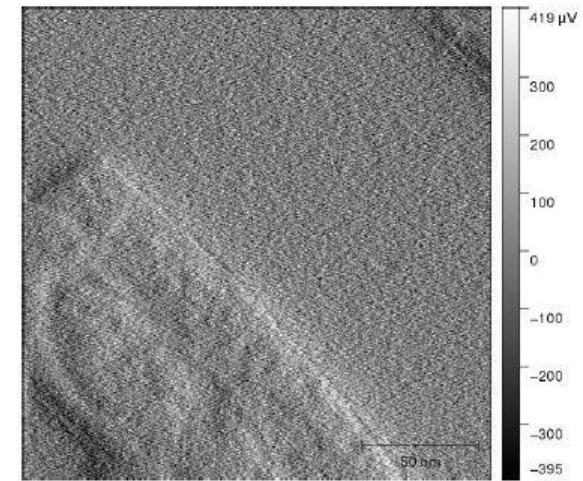
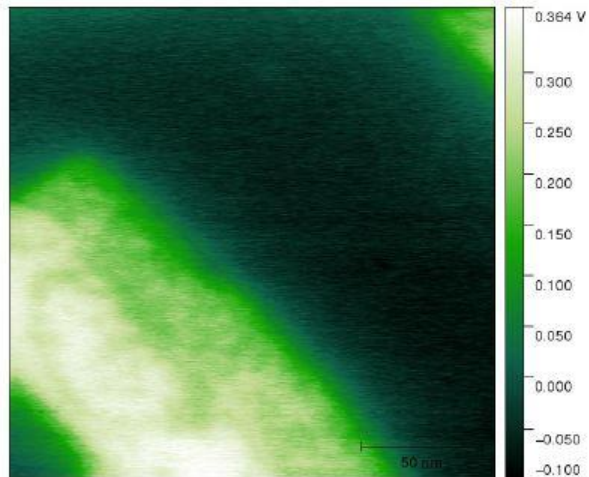
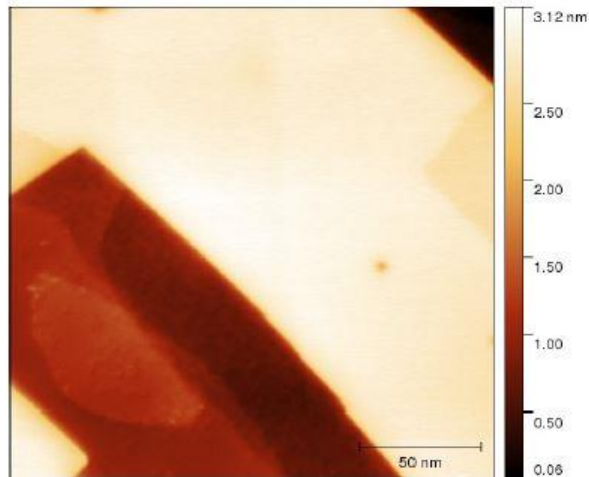
CPD



Lock-In X

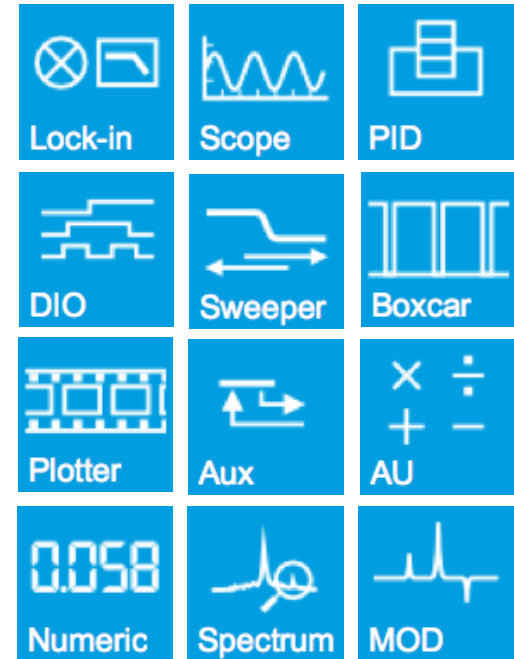


DFRT-AM-KPFM

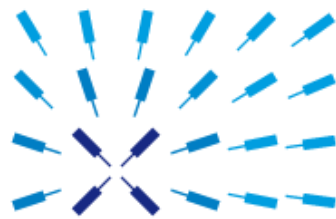


Conclusion: The Benefit of Digital

- Zurich Instruments integrates in one box
 - Lock-in (6/8 demodulators)
 - Dual signal generator
 - Oscilloscope / Digitizer
 - FFT / Spectrum Analyzer
 - Boxcar Integrator
 - Frequency Sweeper
 - PLL / PID Controller
- Most SPM modes available with Basic HF2LI Lock-in configuration and upgradable later with options (PLL, PID, MOD,...).
- Increase Demodulation Speed and reduce pixel dwell time



More resources on ZI website & ZI blogs !



Most Recent

< Older

Search

Search for:

 Search

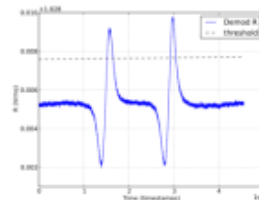
Synchronisation of HF2LI/UHFLI with External Scan Engines for Image Acquisition

on 10.09.2014 at 23:50 by Romain Stomp on Blog of Romain Stomp

Since a lock-in amplifier is most of all used for synchronous measurements, it comes at no surprise that many HF2 or UHF users want to synchronize saved demodulated sample with their scan generator either for mapping, scanning or imaging in [...]

Loading data saved from the LabOne UI in Python

on 05.08.2014 at 17:07 by Daniel on Blog of Daniel Wright



The LabOne User Interface can continuously save instrument data such as demodulator samples to hard disk as binary data in MAT (Matlab®) files or as plain text in CSV (comma separated value) files. Using MAT files, demodulator data can be recorded at full [...]

Basic vector network analyzer (VNA) measurements using the UHFLI

on 03.07.2014 at 15:43 by dragan on Blog of Dragan Lesic

Introduction This article describes how to measure reflection and transmission coefficients using a Zurich Instruments UHFLI Lock-in Amplifier and a directional coupler. Network analysis is a commonly performed in RF measurement. A network analyzer is an instrument that measures the network [...]

Processing Data in Different Applications with LabOne Net

Categories

- Applications (14)
 - Electrical Impedance Spectroscopy (2)
 - SPM / AFM (9)
- Downloads (2)
- LabOne (12)
 - LabVIEW API (2)
 - Python API (2)
 - ziControl (5)
- LabOne Net Link (1)
- LabVIEW API (1)
- MATLAB (13)
 - Plot2mif (1)
 - Plot2svg (10)
 - Tutorial (8)
- Matlab API (1)
- Measurements (21)
 - 10 MHz Clock Reference (1)
 - Impedance Measurement (7)
 - Lock-in Amplifier (7)
 - Modulation (5)
- Microfluidics (1)
- PID Controllers (4)
- PID Controllers (1)
- PLL (4)
- Python API (1)
- Python API (1)
- Theory (2)
- Tips & Tricks (20)
- UHFLI (4)
- Uncategorized (1)
- Visual Basic (1)