

HF2PLL Phase-locked Loop

Zurich
Instruments

Connecting an HF2PLL to a Bruker Icon AFM /
Nanoscope V Controller

Technical Note

Keywords: AM-AFM, FM-AFM, AFM control

Release date: February 2012



Introduction

This document reports the successful operation of a Zurich Instruments HF2PLL Phase-locked Loop with a Bruker AFM (Nanoscope V controller). The HF2PLL is an open market instrument supporting higher frequencies, multi-mode measurements, and advanced imaging modes, as for instance the amplitude modulation (AM) and frequency modulation (FM) for surface potential measurements. Moreover, the HF2PLL adds to the Bruker AFM the ability to perform measurements with 2PLLs, hence operate two cantilever modes simultaneously, and to demodulate at up to 6 arbitrary frequencies.

Table 1 summarizes the three AFM measurement modes that are described in this document, used here for force modulation microscopy (FMM), which is based on contact mode topographic feedback.

These modes are sequentially described with focus on the changes to the previous mode are mentioned. For each mode of operation the quantities for imaging are indicated and results of example measurements are presented.

Table 1. FMM measurement modes

Measurement mode	Description
Constant Frequency / Lock-In (AM-AFM)	Constant frequency and constant drive amplitude
Constant Excitation (FM-AFM)	Constant phase and drive amplitude
Constant Amplitude (FM-AFM)	Constant phase and cantilever amplitude

Example Measurements

Example measurements presented in this documents were jointly recorded by Bruker Nano Surfaces Division and Zurich Instruments. The platform under test was a Bruker Dimension Icon AFM controlled by a Nanoscope V AFM controller. However, the described setup can easily be adapted to other Bruker AFM systems. In the presented example measurements a 225 µm long cantilever (3 µm thickness) was used with a nominal resonance frequency of 75 kHz (free space) and a quality factor of 80. Typically a 100 mV (RMS) drive amplitude led to a photo-

diode signal of 145 mV in free space (deflection sensitivity 90–110 nm/V, and spring constant of 2.8 nN/nm). The cantilever dynamics is detected by laser reflection onto a 4 quadrant photodiode (see Figure 2).

Requirements

In order to connect the HF2PLL with the Dimension Icon AFM, a Signal Access Module (break-out box SAM-V provided by Bruker) and 5 BNC cables plus a BNC T-adapter are required. Moreover, the reader should be familiar with the functionality of both the HF2PLL and the AFM. Both instruments are controlled with their original operation software. The HF2PLL can be connected to an independent computer that runs the control software ziServer and ziControl on either a Windows 7, Vista or Linux platform. The Bruker Icon AFM is operated from a Windows XP based computer via the software Nanoscope version 8.15. AFM data can be displayed and analyzed with Bruker's standalone analysis software package Nanoscope Analysis version 1.40.

Constant Frequency and Constant Drive Amplitude (AM-AFM)

Initially a direct comparison of one of the lock-in amplifiers integrated in the Nanoscope V controller and the external HF2PLL can be achieved by connecting

- The vertical photodiode deflection signal (connector labeled Vertical Output on the Signal Access Module) to the Signal Input 1 of the HF2PLL
- The HF2PLL Signal Output 1 to the drive piezo / shaker input (connector DDS1 Input on the Signal Access Module)
- The HF2PLL Auxiliary Outputs 1 and 2 (Aux 1/2) to the Nanoscope V General I/O 1 and 2

See Figure 1 for a schematics of the instrument interconnections. The switches on the Signal Access Module can be set to MIC → CON to only output a Nanoscope V signal for external use without disturbing the internal signal line (e.g. signal connection 1 above), or to EXT → CON to input

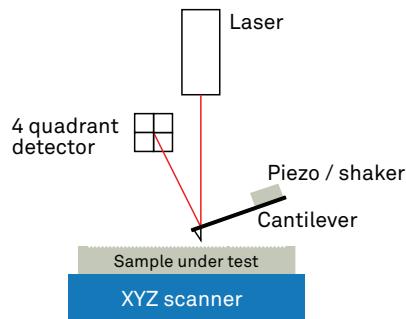


Figure 2. AFM diagram for FMM. A cantilever is brought into contact mode feedback, and additionally modulated by a piezo/shaker. The vertical and lateral cantilever movement is detected by a 4 quadrant photodiode using laser reflection on the cantilever. Depending on the AFM model the relative tip-sample position is changed by a x-y-,z-stage which moves either the cantilever or the sample holder

an external signal into the system and breaking the internal signal line from the Nanoscope V controller.

Recorded and Displayed Quantities

- Vertical cantilever amplitude R: the amplitude reflects the information related to both elastic and inelastic tip-sample-interaction
- Phase Theta between cantilever drive frequency and actual cantilever oscillation: mainly properties related to inelastic tip-sample-interaction (damping).

In addition the horizontal cantilever deflection can be detected in all modes of operation discussed here. The horizontal deflection indicates material properties related to tip-sample-friction.

By changing the switch position on the Signal Access Module to EXT → CON the cantilever drive piezo/shaker is controlled by the HF2PLL and the Vertical Output is applied to the Signal Input 1 for demodulation. The demodulated signals R (amplitude) and Theta (phase) are routed via Auxiliary Outputs 1 and 2 to the analog inputs of the Nanoscope V controller for recording and imaging.

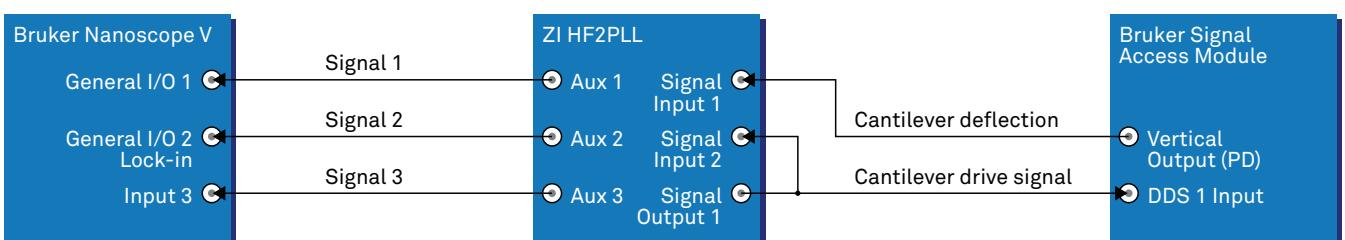


Figure 1. Setup BNC interconnections: a) Nanoscope V with the three inputs for recording of image data, b) HF2PLL with Signal Input 1 and 2, Signal Output 1, and the Auxiliary Outputs 1 to 3, c) Signal Access Module with the Vertical Output (photodiode PD signal) and the DDS 1 input for the piezo / shaker

General Remark

To obtain the best signal to noise ratios, all signal inputs and outputs need to be properly adjusted in terms of offsets and scaling. This is straightforward since both instruments, AFM controller and HF2PLL, provide for scale and offset adjustments on their in- and outputs. By this means signal clipping is avoided and at the same time full bit-resolution for ADC/DAC can be exploited.

Example Measurements

Images were recorded in contact mode with a scan-speed of 1 Hz, a static cantilever deflection of about 14 nm and a scan area of $10 \times 2.5 \mu\text{m}^2$ (512 x 128 pixels). Additionally, the piezo / shaker was driven on a contact resonance (here: ca. 62 kHz, measured at the imaging force in contact with the sample) at fixed frequency and fixed small drive amplitude of 50 mV, resulting in an oscillation amplitude at the given contact force of about 9 mV or 1 nm. Figure 3 shows an example measurement. Besides topographic data in 3a and simultaneously acquired static friction in 3b, panels 3c and 3d show data recorded with the Nanoscope V lock-in (Amplitude and Phase); 3e and 3f display the data recorded on the same sample using the lock-in amplifier of the HF2PLL (Input 1 and Input 2, which correspond to the R and Theta output respectively). All data (except the topographic data in 3a) were scaled to ± 1.5 standard deviations around the histogram maximum to easily compare contrast and noise within the different data sets.

A comparison of results in panels c and d (Nanoscope V lock-in amplifier) with results in panel e and f (HF2PLL) show very similar appearance with respect to resolution, contrast and noise. Minor differences can be expected due to the fact that the 2 measurement sets were taken

subsequently and slight changes of tip and surface conditions might have occurred. It should be noted here, that the data displayed here as Input1 (3e) and Input2 (3f) are both scaled in volt-units. However, using the correct scaling factors a display in nanometers (like 3c) respectively degrees (like 3d) is possible as well.

This measurement shows, that the interconnection of the Nanoscope V controller and the HF2PLL phase locked loop produces comparable low noise and high contrast data as obtained with the internal lock-in amplifiers of the Nanoscope V controller. The connection does not compromise the data acquisition in any way.

Constant Phase and Constant Drive Amplitude (FM-AFM)

In a next experiment, the HF2PLL was used to keep the phase relation between the shaker drive frequency and the measured vertical cantilever excitation constant. Once the working point for the cantilever deflection is set (e.g. 14 nm in this example), the corresponding cantilever frequency and phase settings can be obtained by using the HF2PLL frequency response sweeper.

Parameter settings for the PLL feedback loop are best obtained from the HF2PLL Advisor accessible from the PLL tab in the ziControl software. After switching the phase-lock on, the frequency of oscillator 1 is adjusted such that the phase is held constant. The frequency deviation (dF) can be accessed on Auxiliary Output 3, again, properly adjusted with an offset and scaling. Auxiliary Output 3 is then connected to the Nanoscope V Signal

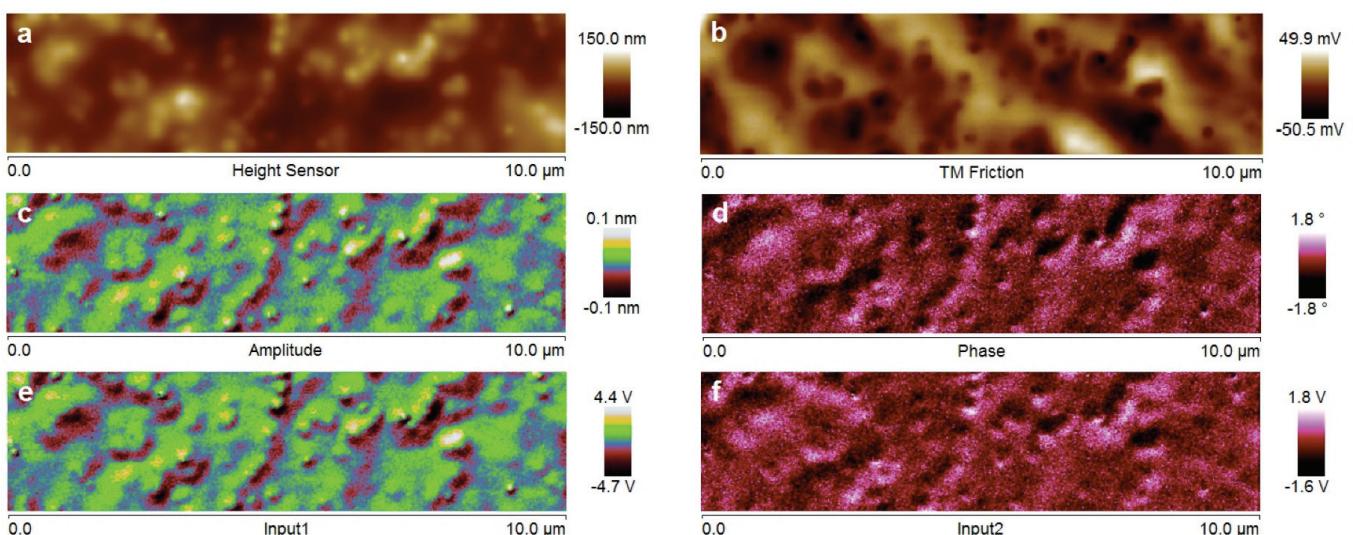


Figure 3. Comparison of Nanoscope V and HF2PLL acquired images with constant frequency and constant excitation on a white paint sample: a) topographic image, b) friction data, c+d) R and Theta measurements with Nanoscope V lock-in amplifier (data sets a-d were taken simultaneously), e+f) R and Theta measurement with HF2PLL lock-in amplifier (data sets e and f were taken simultaneously as well, but subsequently to data sets a-d).

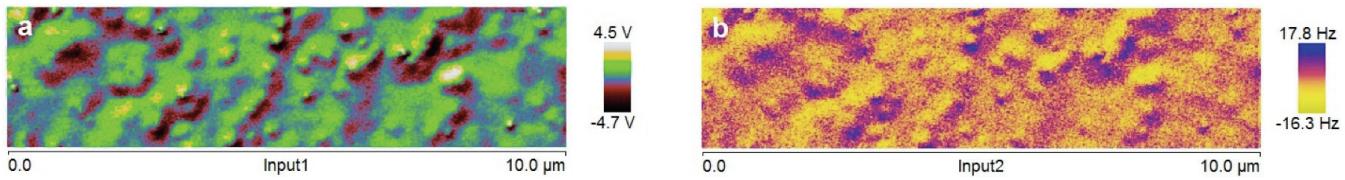


Figure 4. FMM with constant phase and drive amplitude, performed with the HF2PLL, displayed in the Nanoscope software simultaneously to topography and friction (not shown as identical to Figure 3a/b). a) R measurement with HF2PLL, b) dF measurement with HF2PLL (accordingly scaled in Hz)

Input 2 (labeled General I/O Input 2) for recording and imaging.

Recorded and Displayed Quantities

- Vertical cantilever amplitude R
- Differential frequency dF between actual cantilever frequency and the cantilever frequency at set point/start value: material properties related to both elastic and inelastic tip-sample interaction.

Example Measurements

Reference images were recorded with similar parameters on the same sample at the same location as described above, see Figure 4.

The data shows very similar R-data compared to the experiment with constant frequency (Figure 3c/e and Figure 4a). The Q-data from the previous experiment (Figure 3d/f) are now transferred into dF (Figure 4b), which improves contrast and lateral resolution (titania paint particles can clearer be visualized). A significant coupling between topography and mechanical data is present on this rough surface.

Constant Phase and Constant Cantilever Amplitude (FM-AFM and AGC)

Compared to the previous mode of operation, the shaker drive amplitude is now controlled such that the amplitude measured with demodulator 1 is held at a set level. This mode of operation is also termed automatic gain control (AGC). The ziControl needs to be configured in the PID-tab for proper feedback operation by choosing the amplitude of demodulator 1 as input signal of PID 1.

The amplitude set point and the proportional and integral gain need to be set, as well as the output to Signal 1: Amplitude. The settings of center and range are chosen such the cantilever/probe cannot be damaged due to high input amplitudes on the piezo/shaker input. The PID parameters can be obtained by setting the integral gain to zero first while increasing the proportional gain to a value slightly below unstable operation. This can best be observed by using the spectroscope in the ziControl software. After the proportional part is set, the integral gain is increased again as long as a significant reduction of the signal noise in the displayed signal on the spectroscope can be achieved.

Recorded and Displayed Quantities

- Differential cantilever drive amplitude dA: with AGC, the differential amplitude contains the information mainly related to inelastic tip-sample interaction (damping)
- Differential Frequency dF: with AGC, damping effects are largely removed from the frequency information, so that frequency shift resembles here mainly elastic tip-sample interaction

The drive amplitude can be accessed on the auxiliary outputs by using a BNC T-connector and splitting the signal available on Signal Output 1 and feeding it back into the HF2PLL on Signal Input 2 (see Figure 1). By using the same oscillator to demodulate the signal as for Signal Input 1, one obtains the signal amplitude as a result of demodulation. This amplitude can be routed for instance to Auxiliary Output 3, which then connects to the analog signal inputs of the Nanoscope V for imaging and recording.

Example Measurements

Figure 5 displays a $10 \mu\text{m} \times 2.5 \mu\text{m}$ example measurement with constant phase and amplitude.

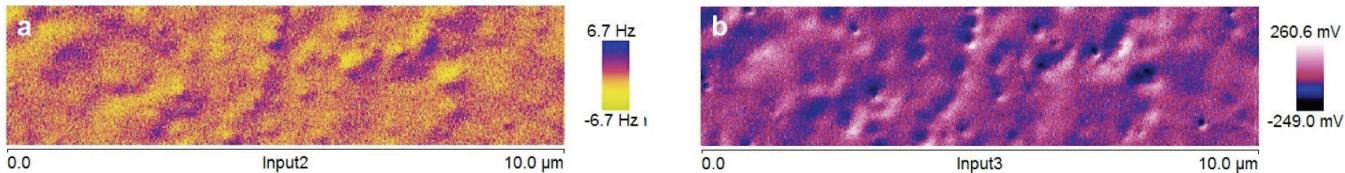


Figure 5. FMM with constant phase and cantilever amplitude, performed with the HF2PLL including the HF2LI-PID option, displayed in the Nanoscope software simultaneously to topography and friction (not shown as identical to Figure 3a/b). a) dF measurement with HF2PLL (accordingly scaled in Hz), b) dA measurement with HF2PLL

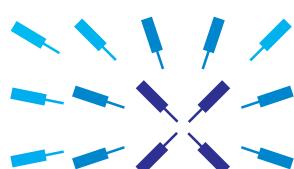
The separation of elastic and inelastic contributions leads to reduced contrast in the dF-image (compare Figure 4b and Figure 5a), but clearer contrast in the dA-image (Figure 5b). dA has similar general appearance as the phase images without frequency tracking, but better lateral resolution (Figure 3d/f). A large part of the cantilever response can be attributed to dissipative effects, as well affected by sample topography.

Note

The HF2LI-PID option is required for this mode of operation.

Conclusion

The Zurich Instruments HF2PLL Phase-locked Loop can be connected and operated together with the Bruker Icon AFM. All interfaces between the instruments are analog and both instruments can independently be controlled with their own graphical user interfaces ensuring straightforward interoperation. Measurements on titania particles have been made in less than 1 day. Two measurement modes are enabled to users of the Icon AFM: constant excitation FM-AFM and constant amplitude FM-AFM.



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About Zurich Instruments

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