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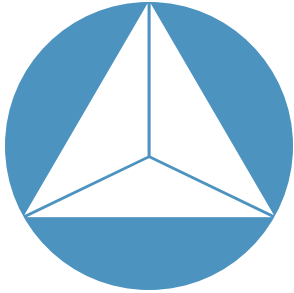
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# RHK Technology

## Application Note:

### Integration of the RHK R9 to an Omicron VT-AFM

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#### Introduction

With the purchase of our Omicron VT-AFM (model XA) in 2007 we decided that we will equip the microscope with the RHK SPM 100 control and the RHK PLLPro2 NC-AFM electronics. In 2015 we upgraded our RHK control system to the new, fully digital R9 due to the fact that in most of our research projects, we need the improved performance of the R9, especially the computer-controlled spectroscopy measurements and frequency modulation techniques.

In the following we will first detail the modifications done to our VT-AFM, then we will describe how we integrated the system to the RHK R9 and finally we will present the performance of the final system by means of a thermal noise analysis and a demonstration of the obtained imaging quality.

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### Modifications to the VT-AFM setup

The STM part of our instrument is unchanged and equipped with the Omicron STM preamplifier. The beam deflection system of our VT-AFM was improved (see figure 1) by using a superluminescent light source with short coherence-length.<sup>2</sup>

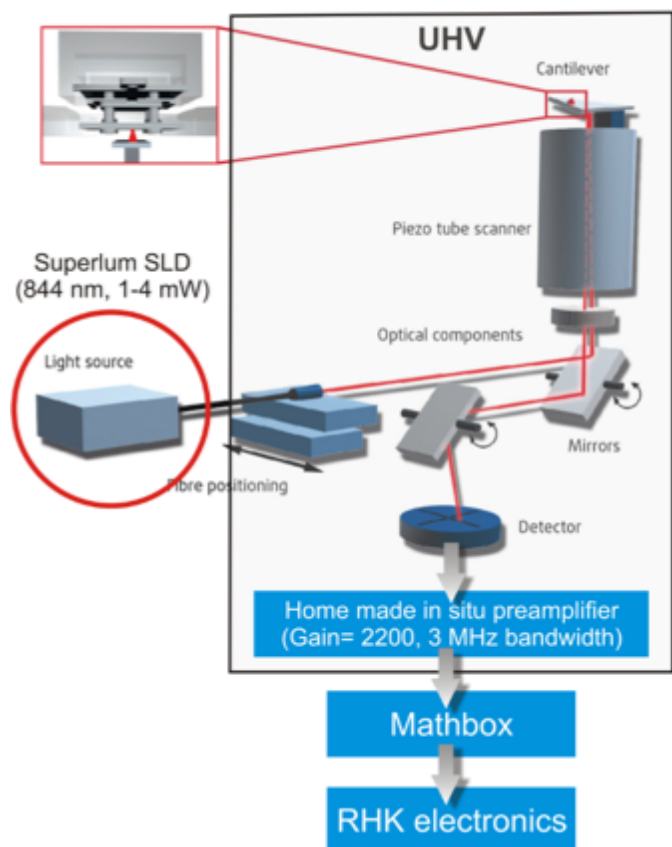


Figure 1 Setup of the VT-AFM including the modification by a new light source and the in situ preamplifier.

The initial ex situ transimpedance amplifier which made the current-to-voltage conversion of the four photocurrents by means of 22 k $\Omega$  resistances ( $I/V=22'000$ , bandwidth approximately 800 kHz) was replaced by two home built amplifiers. The first transimpedance stage being in situ with a voltage-current conversion of  $I/V=2200$  (figure 2), the second (Mathbox in fig.1) adds a variable amplification gain of up to 20, calculates the vertical and lateral deflection signals<sup>3</sup> and does some signal conditioning in order to feed the necessary signals to the RHK R9 (deflection and sum signal, figure 3).

These two amplification stages have a bandwidth of up to 5 MHz in order to profit from the large R9 PLL bandwidth (5 MHz) for the different modulation techniques and multi-frequency applications planned in our Laboratory.



Figure 2 Home built in situ transimpedance preamplifier, current-voltage conversion by 2.2 k $\Omega$  resistances, bandwidth 5 MHz. The chip is a LT1359 (Linear technology) four-operationnal amplifiers circuit.

Print made of TMM10, Rogers Cooperation: <http://www.rogerscorp.com/acs/products/49/TMM-10-Laminates.aspx> Setup of the VT-AFM including the modification by a new light source and the in situ preamplifier.

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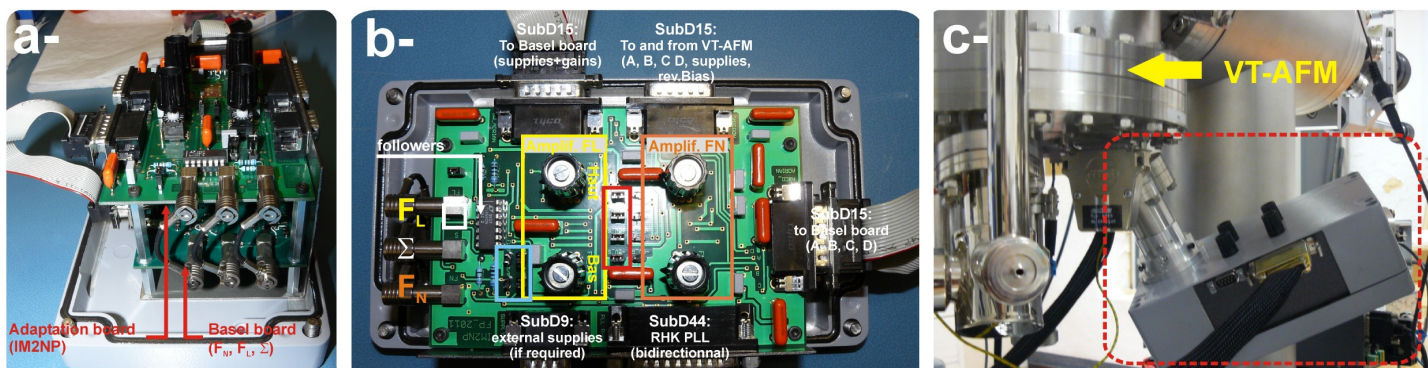


Figure 3 Second stage preamplifier (so-called Mathbox), variable gain of up to 20, calculation of vertical and lateral deflection signals, signal conditioning for the R9 electronics. The box is mounted on the UHV electrical feedthrough of the AFM chamber.

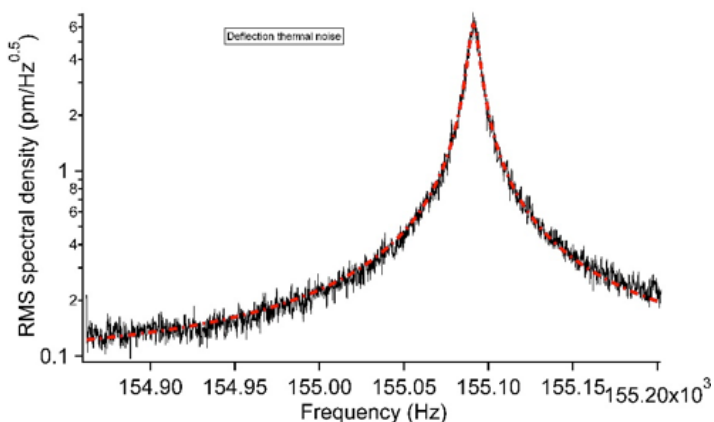
### Noise analysis of the complete system

Thermal noise analysis was performed on the cantilever oscillation signal (the normal force FN output of the R9) by means of an Agilent function generator which served as reference signal to a Stanford lock-in amplifier SR844 (LIA). We calibrate the cantilever oscillation by means of the constant  $\gamma$  method<sup>4</sup> in such a way that the rms value of the power spectrum density (PSD) is calibrated in  $\text{pm}/\sqrt{\text{Hz}}$ . Figure 4 displays such a spectrum (averaging of the LIA R signal and synchronization with the reference signal performed by a LabVIEW program). The noise floor of the complete NC-AFM electronics is evaluated to be  $170 \text{ fm}/\sqrt{\text{Hz}}$  which, for the given bandwidth of 5 MHz, is an excellent value (see also J. Lübke et al.<sup>5</sup>).

### Imaging with the R9 on our VT-AFM

The combination of the VT-AFM with the new RHK R9 electronics allows us to choose the best imaging parameters in order to minimize the noise of our microscope. As Giessibl et al. pointed out<sup>7</sup>, the lowest z-noise is for an amplitude/distance ratio ranging from 1-10. For normal high-resolution imaging at tip-sample distances of a few Ångströms only it is therefore required to measure with amplitudes which normally cannot be obtained by commercial beam-deflection AFMs. In combination with the R9 controller we are able to measure with amplitudes smaller than 1 nm peak-to-peak and we can increase the cantilever resonance frequency up to 5 MHz if necessary (figure 5).

Figure 4 PSD spectrum of the thermal noise of the complete setup. The used cantilever was a reflex-coated PPP-NCL from NanoAnd-More with resonance frequency  $f_0=155 \text{ kHz}$  and  $Q=28'000$ . The fit (continuous black curve) gives a stiffness  $k=27 \text{ N/m}$ , in excellent agreement with the manufacturer's nominal value ( $\sim 30 \text{ N/m}$ ).



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With the integration of the R9 to our VT-AFM we have obtained an increased imaging quality when using relatively small amplitudes of < 5 nm. In such a way, we have been able to get sub-molecular resolution of a monolayer of weakly adsorbed molecules on an ionic crystal surface (see figure 6).

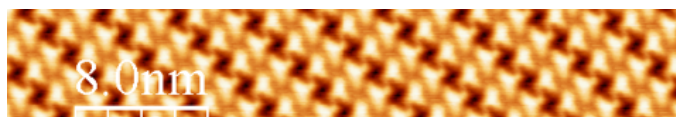


Figure 6 NC-AFM image of 1,3,5-tri(4"-cyano-4,4'-biphenyl) benzene molecules<sup>8</sup> on a single crystal KCl surface. Image was evaluated by WSxM<sup>9</sup> and the mesh-average function.

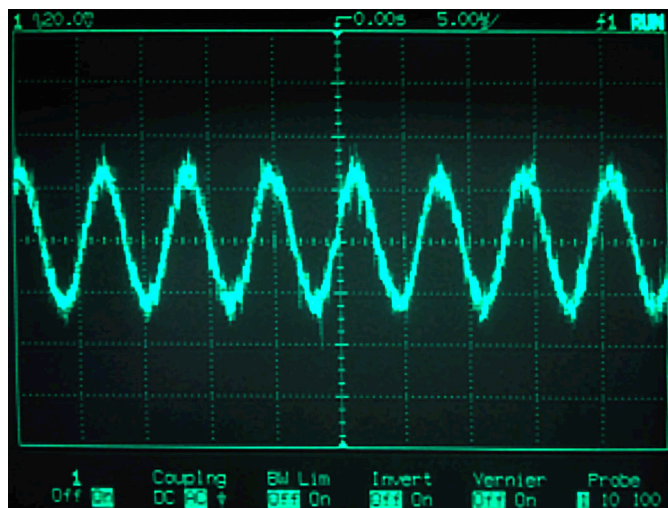


Figure 5 Oscillation signal for a cantilever which oscillates with ~150 kHz at an amplitude of 2 nm peak-to-peak. R9 amplitude set-point is 25 mV; for the used cantilever, the R9 PLL controller works still fine down to 5 mV setpoint (i.e. 4 Å peak-to-peak oscillation amplitude). No low-pass filtering applied (full bandwidth of 5 MHz).

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