Lecture: P1_Wk3_L6

The AFM as a System

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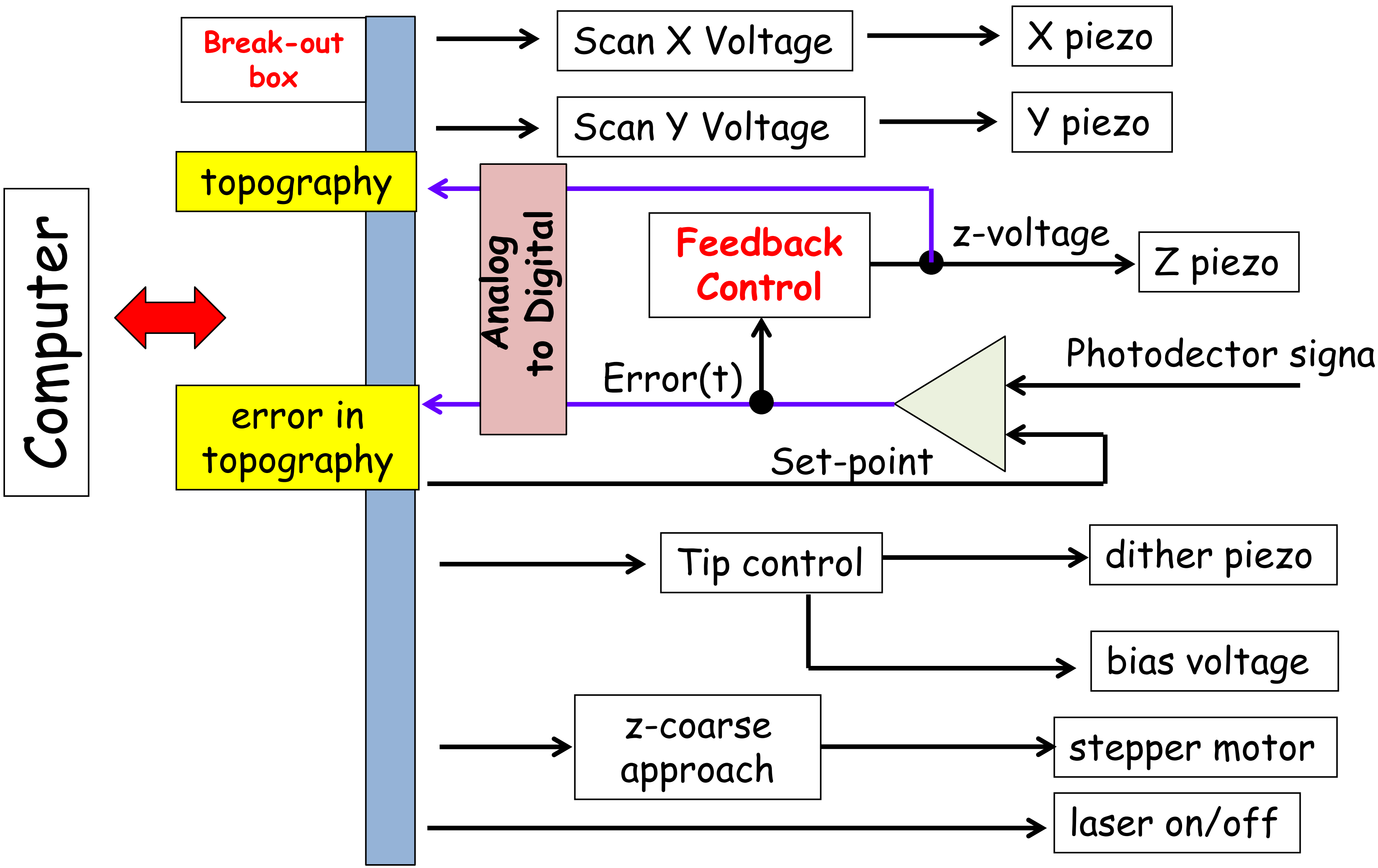
Important System (Electronic) Signals

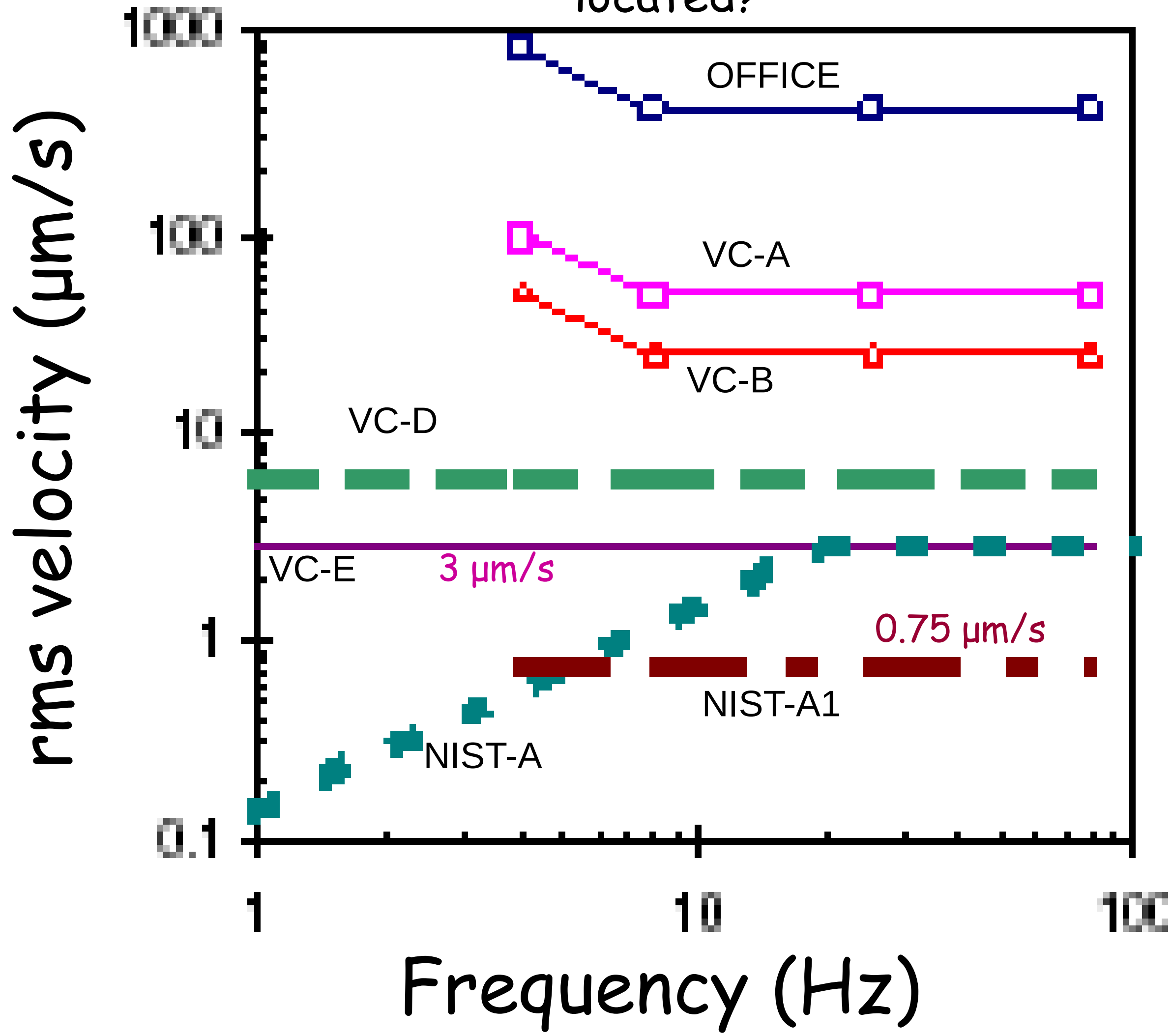


Set a long-term goal: view the AFM as a system that must be integrated into a proper environment. Perform measurements that better characterize the overall performance of your AFM as a SYSTEM

see: J. Weaver, M. Voorhis, and R. Reifenberger, Journal IEST **52**, 1-12 (2009).

Environmental Characterization: Floor Vibrations

Using a vibrometer to measure the spectrum of the building /floor vibrations. What is the vibrational quality of the room where your AFM is located?



NIST = National Institute of Standards and Technology (USA)

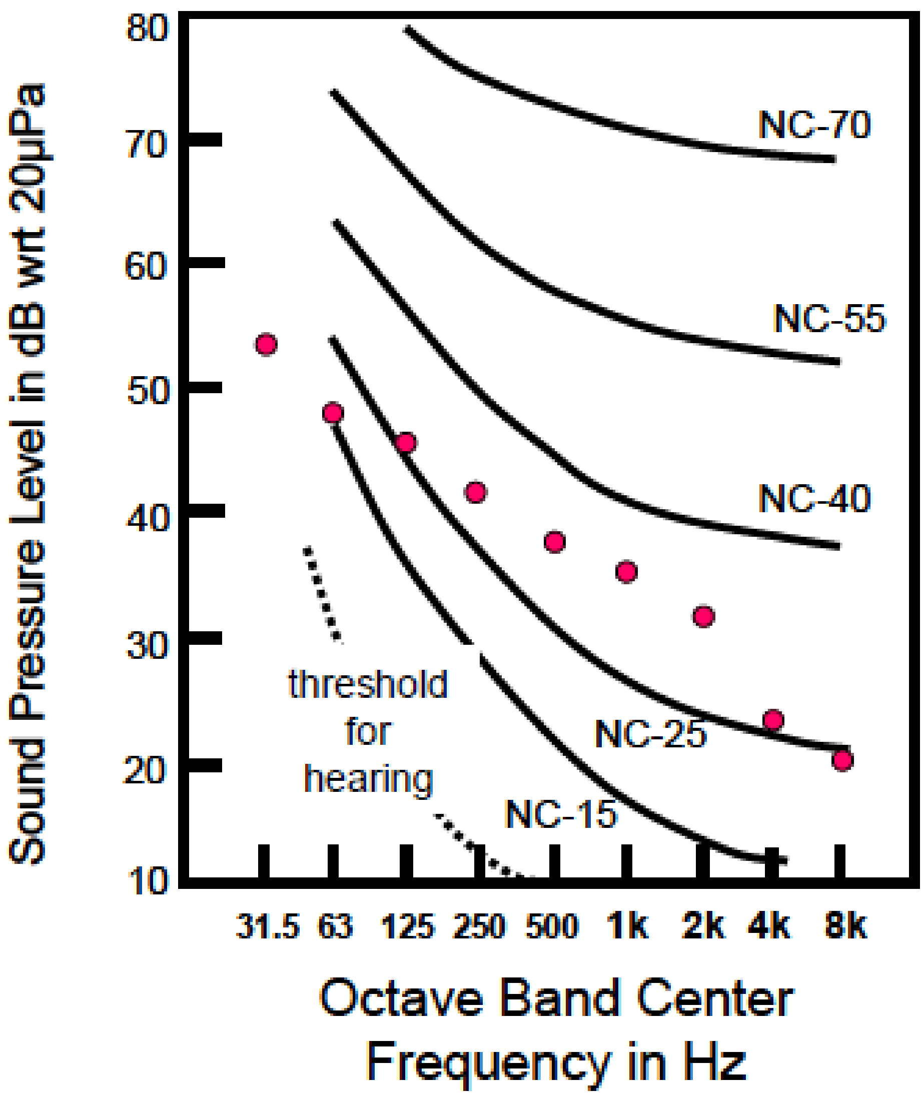
Vibration Standards
(1 - 100 Hz)

Category	Criterion	Definition
Human Sensitivity	ISO Office	400 to 800 μm/s (16,000 to 32,000 μin/s)
General Laboratory	VC-A	50 μm/s (2,000 μin/s); relaxed below 8 Hz
	VC-B	25 μm/s (1,000 μin/s); relaxed below 8 Hz
Highly Sensitive	VC-D	6 μm/s (250 μin/s)
	VC-E	3 μm/s (125 μin/s)
Ultra Sensitive	NIST - A	0.025 μm (1 μin) **displacement** for 1 Hz < f < 20 Hz; 3 μm/s (125 μin/s) VC-E **velocity** for 20 Hz < f < 100 Hz
	NIST – A1	6 μm (250 μ in) **displacement** for f < 5 Hz; 0.75 μm/s (30 μin/s) **velocity** for 5 Hz < f < 100 Hz

Thanks to Hal Amick (Colin Gordon & Assoc. ; Ahmad Soueid (HDR);
Matt Sears and Tom Gerbo (Sears-Gerbo Architects)

Environmental Characterization: Acoustic Noise

Using a sound meter, measure the spectrum of acoustic vibrations. What is the ambient acoustic noise level in the room where your AFM is located?



Airborne acoustic noise is usually defined to lie in the range from ~20 Hz to 20 kHz.

Environmental Characterization: Thermal Stability

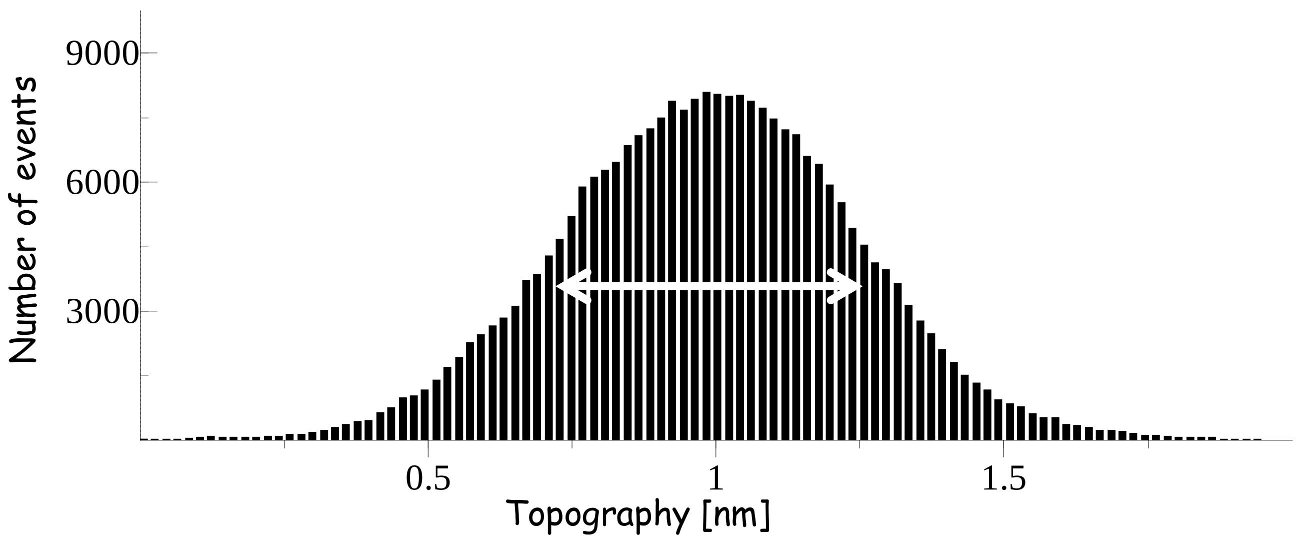
Using a temperature/relative humidity data logger, measure the variations in temperature and humidity over a 12 hour time span. What is the temperature stability of the room that your AFM is located?

Characterizing the z-Noise in Your AFM System

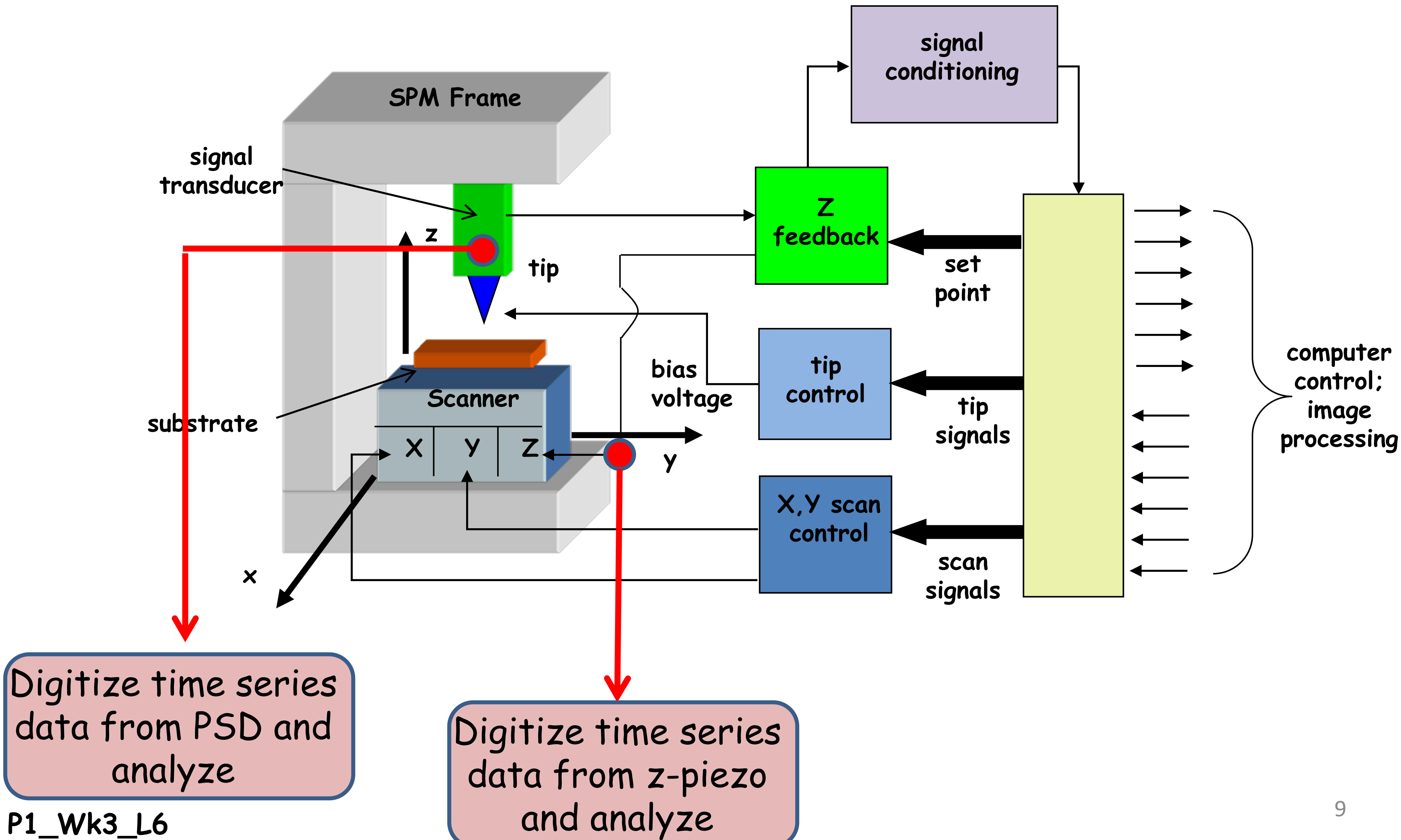
Place the tip in contact at a fixed set point on a hard, flat sample like freshly cleaved HOPG. Perform a "zero-size", contact mode scan, so that the sample does **not** move in x or y direction.

Acquire a 256 x 256 "image" at a reasonable scan rate (~ 1 Hz).

Make a histogram of the height distribution of the image as shown below. Ideally, the histogram should resemble a very sharp spike. The full width at half maximum of the histogram tells you about the inherent z-stability of your AFM (includes vibration and acoustic noise).



Develop the ability to obtain time-series data at various points in your AFM system



Characterizing the Photodetector Sensor Noise in Your AFM System

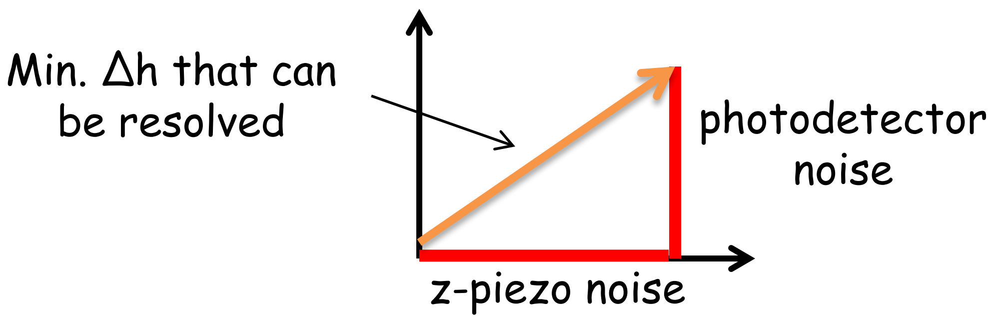
With the **tip out of contact** with the sample, align the laser on the photodiode. Digitize the output from the 4-quadrant photodetector to collect a time-series data record over a time period of a few seconds. You should have many thousands of data points. Alternatively, you can acquire a "zero-size" image as described before.

- ❑ Perform an FFT of the time series signal; look for well-localized noise peaks in different spectral regions. This data provides information about the specific frequencies that limit the performance of your instrument.

- ❑ Remove any slow thermal drift from your "zero-size" image using a plane subtraction. Make a histogram of the distribution of the pixels in your image. The width of the distribution tells you about the z-noise in your photodetector.

Estimate the height resolution of your AFM?

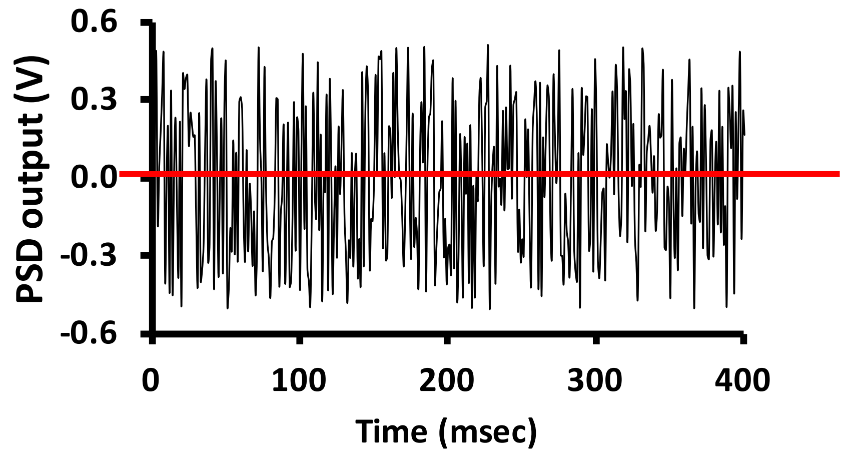
Assuming the z-piezo noise and the photodector noise add in quadrature, estimate what is the minimum change in signal from the PSD that your AFM can detect? Convert this voltage into a distance in nanometers.



Your answer will depend on the noise floor of your electronics, the frequency of the desired signal, the time interval over which you make the measurement, and the location of your AFM.

Characterizing the Thermal Noise in Your AFM System

Carefully calibrate the sensitivity and spring constant of a particular cantilever. Now, move the tip above the sample and digitize the PSD output for a few seconds to collect a time-series data. Do **not** readjust or realign the laser spot after calibrating k. Subtract off any dc offset voltage, so the average value of the signal is zero.



Calculate the rms value of the noise (in Volts). Using the calibrated sensitivity and known spring constant, convert V_{rms} (in Volts) into q_{rms} (in meters). Does

$$q_{rms}\left(\text{measured}\right) = \sqrt{\frac{k_B T}{k}}\left(\text{theory}\right)$$

$T = $ temperature of lab (in K)

$k = $ calib. spring constant

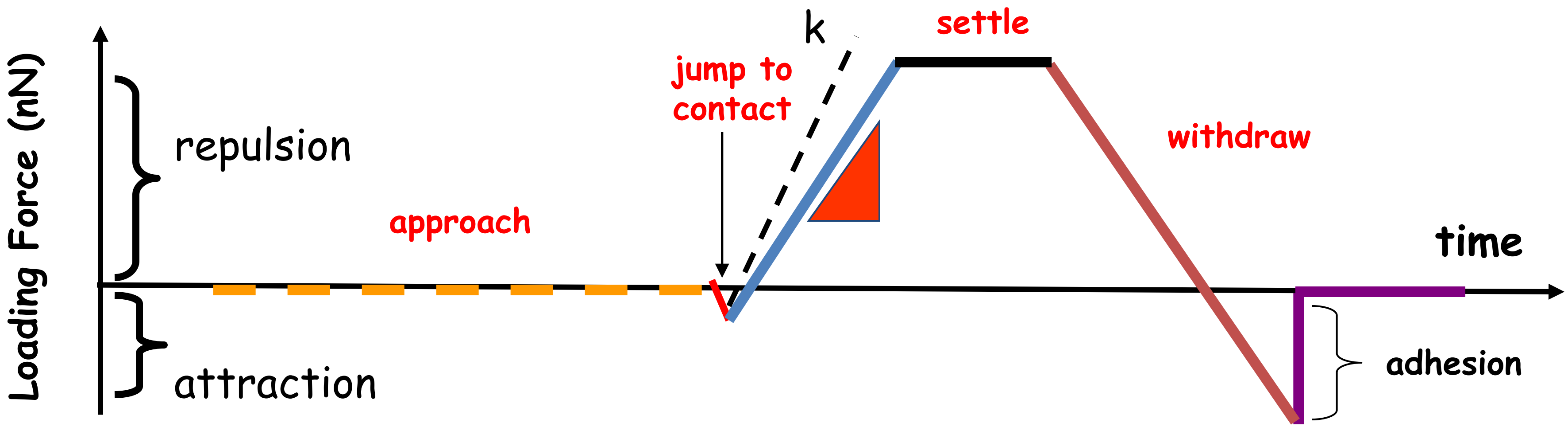
$k_B = 1.38 \times 10^{-23}\ \text{J} / \text{K}$

Discussed in Part II

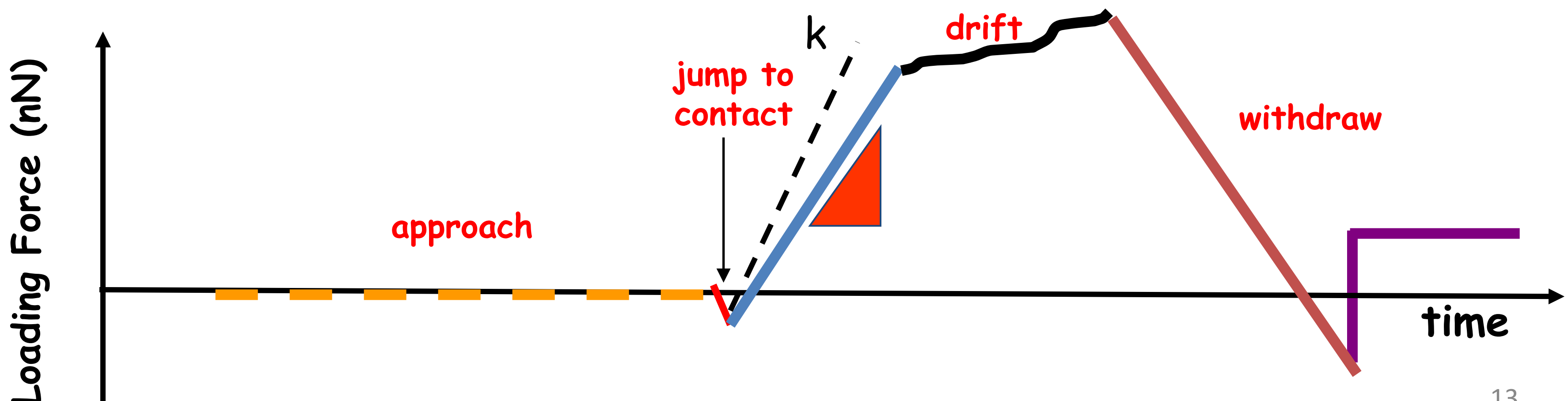
Thermal Stability

Measure PSD output vs. time during a period of constant load. What is the measured drift rate in nm/second?

A. Force vs. Time (Ideal)



B. Force vs. Time (Observed)



Laser System

The distribution of light intensity across the beam of a laser operating in the TEM_{oo} mode is given by

$$I(r) = \frac{4P_o}{\pi D^2} e^{-\left(\frac{2r}{D}\right)^2}$$

where P_o is the incident power and D is a parameter that represents the beam diameter. The beam diameter can depend on the power as well as the distance along the beam from the laser.

Make an effort to determine the laser spot size of your AFM when it strikes the cantilever. At the very minimum, check the specifications provided by the manufacturer.

Next Up: Cantilever Mechanics