Development of an Inexpensive Scanning Tunneling Microscope

Niven Prasad, Thomas Uchimura, Justin Jee

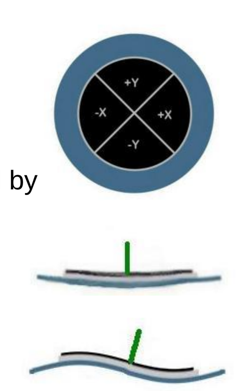
Introduction

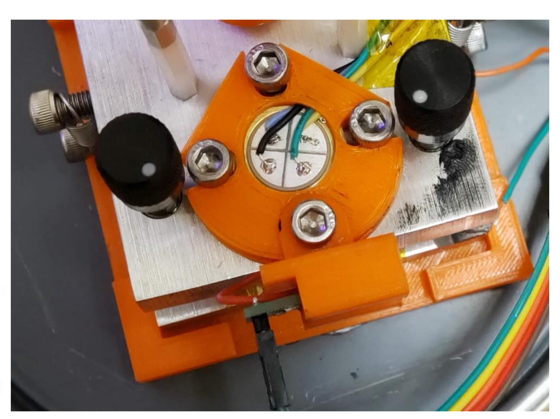
Scanning tunneling microscopy is a modern technique which creates images of atoms in a material surface, the invention of which won a 1986 Nobel Prize in Physics. The importance of a scanning tunneling microscope (STM) branches across many industries and fields of study, but a cost on the order of $100,000 makes it impractical for undergraduate lab courses. Development of an inexpensive STM gives chemistry, physics, materials engineering, and electrical engineering students at "Learn by Doing" schools hands-on experience with modern imaging techniques, inspiring them and further preparing them for a successful career. Cal Poly and many other colleges, could implement this open source device into lab sections of many courses across various majors, including solid state physics, quantum mechanics, physical chemistry, and electronics manufacturing.

Mechanical Design

Unimorph Disk Scanner

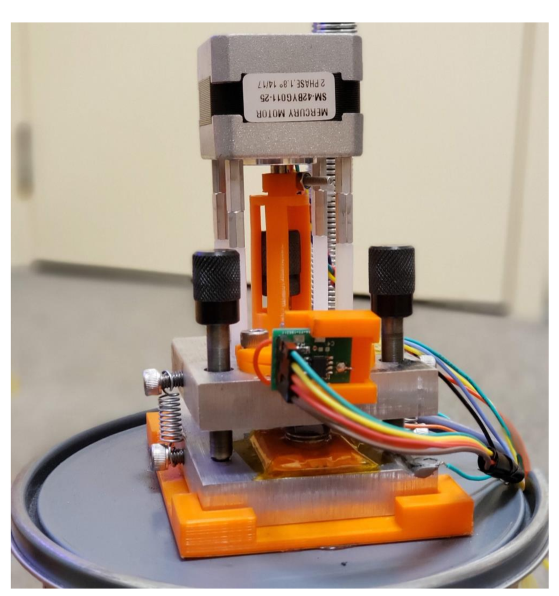
- Cut piezo buzzer electrode allows 3D scanning.
- $\pm$x and $\pm$y achieved by signal inversion
- z signal applied to brass disk





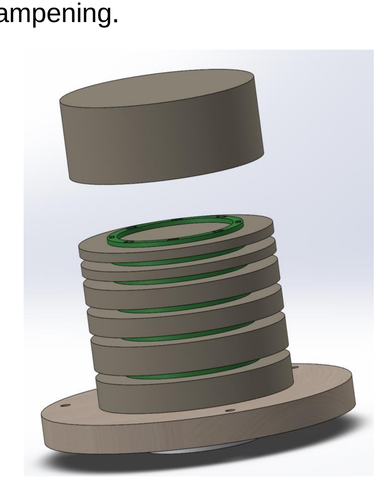
Coarse Approach

- Front two ¼-80 thumb screws offset from the scanner center by 1mm allows for 313µm/rev approach.
- Rear thumb screw offset from scanner center by 30mm in opposite direction. This allows for a 30x reduction in tip motion for 10µm/rev approach.
- Stepper motor with 200 step/rev allows for 52nm/step approach.
- No micro-stepping to avoid signal pickup on tunnel amplifier.



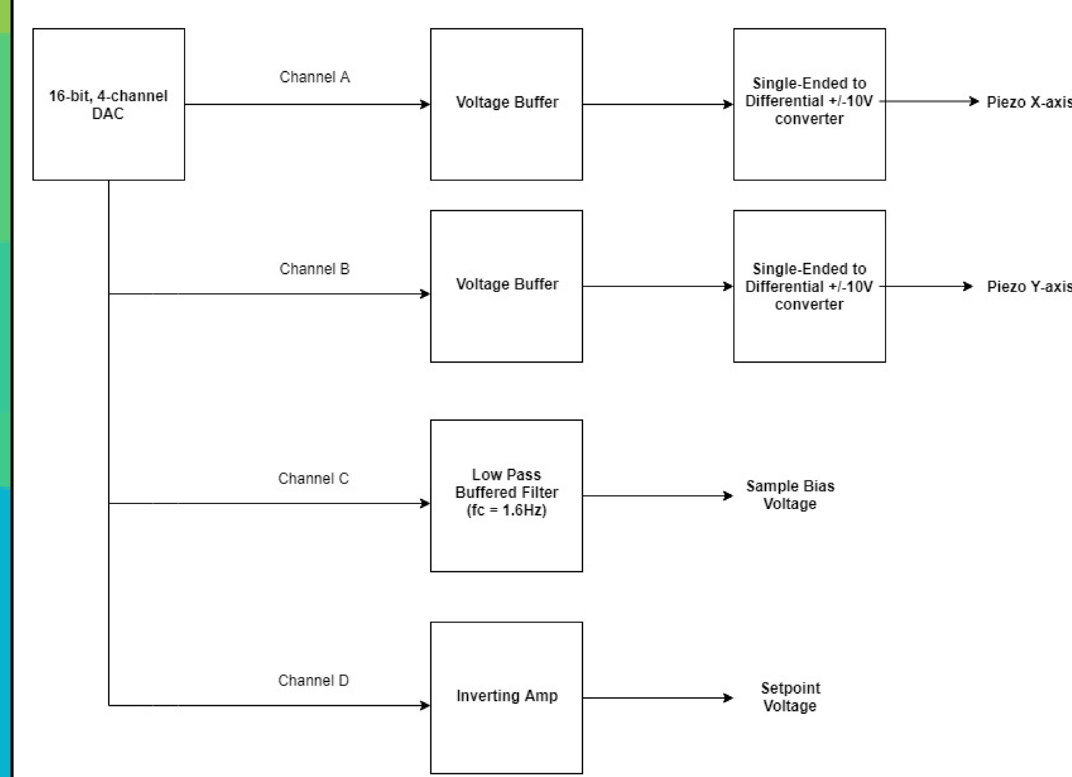
Vibration Isolation

- Stacked concrete blocks separated by pieces of viton rubber gasket achieves vibration dampening with f_0 = 100Hz.
- Viton gasket pieces glued to 3D printed holder for balance.
- A 3-spring pendulum creates a low frequency dampening system with $f_0 \approx$ 2Hz.
- A ½ inch thick 3 inch diameter aluminum cylinder is glued beneath the support plate. It interacts with neodymium magnets which provides magnetic dampening.



Signal Generation

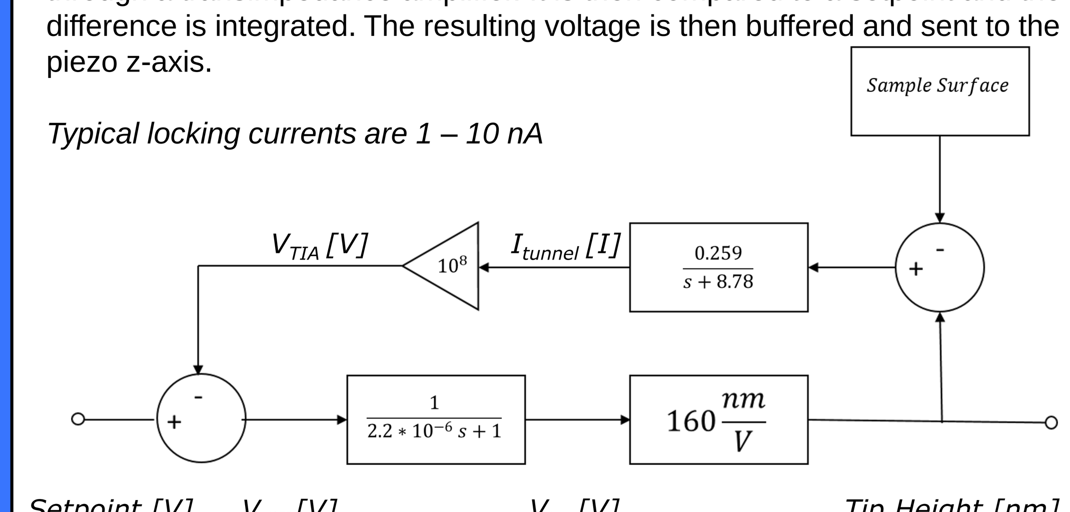
A 16-bit, 4 channel DAC was used to produce the necessary waveforms for scanning, set the bias voltage, and set the tunneling current setpoint. The DAC voltages for the X and Y axis of the scan head are transformed from 0 - 5V to +/- 10V, with a resolution of 305V/LSB. Assuming the piezo sensitivity to be ~60nm/V, this corresponds to an approximate scan range of 1200nm x 1200nm with a theoretical resolution XY resolution of 0.2 Angstroms. An Arduino Uno is used to control the DAC and ADC. It contains the algorithm to generate the scanning waveforms and read the ADC data. The data is serially sent to a host computer running MATLAB.

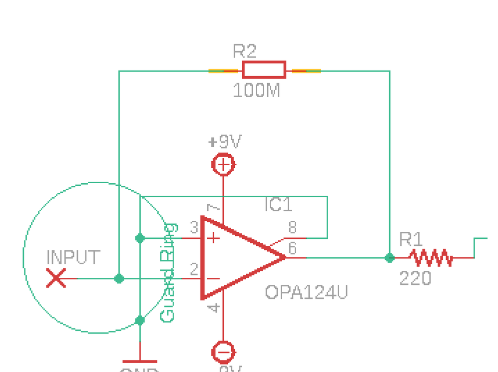


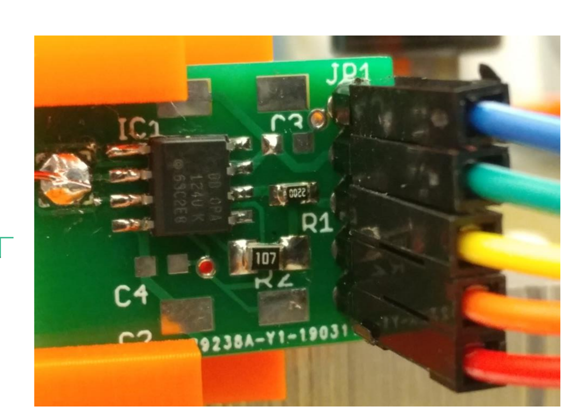
Tip Locking

Constant current STMs image by locking the tip at a specific tunnel current and recording the voltage across the z-axis of the scanner. The tunneling current has an exponential dependence on the tip height, increasing as the tip approaches the surface. This current is amplified and transformed to a voltage through a transimpedance amplifier. It is then compared to a setpoint and the difference is integrated. The resulting voltage is then buffered and sent to the piezo z-axis.

Typical locking currents are 1 – 10 nA



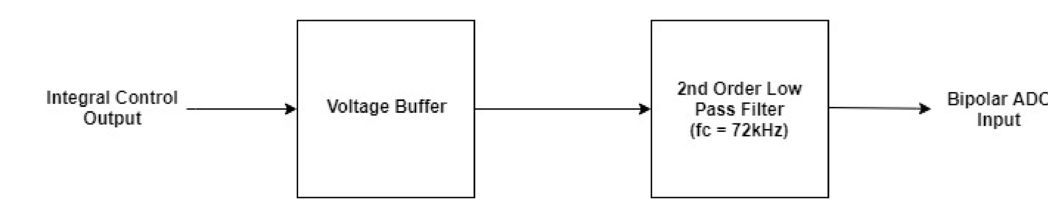


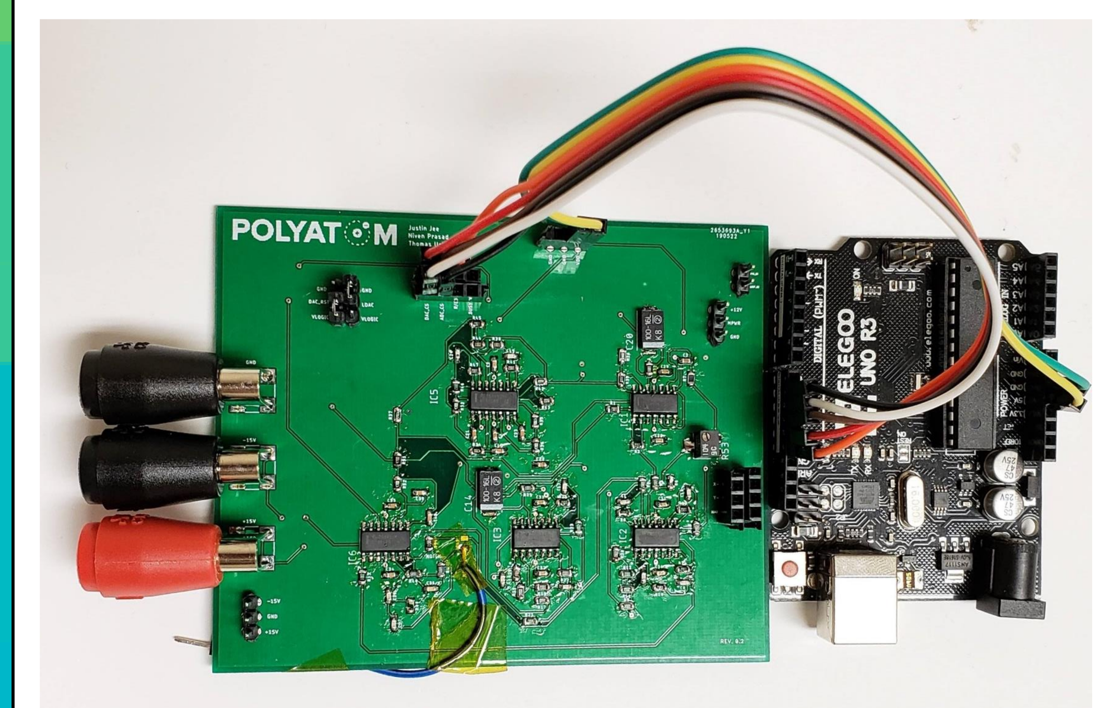


Transimpedance amplifier schematic (left) and mounted transimpedance circuit (right). The TIA is mounted on the microscope to keep tip wire lengths minimal. It also features a guard ring to prevent current leakage to the amplifier input.

Data Acquisition

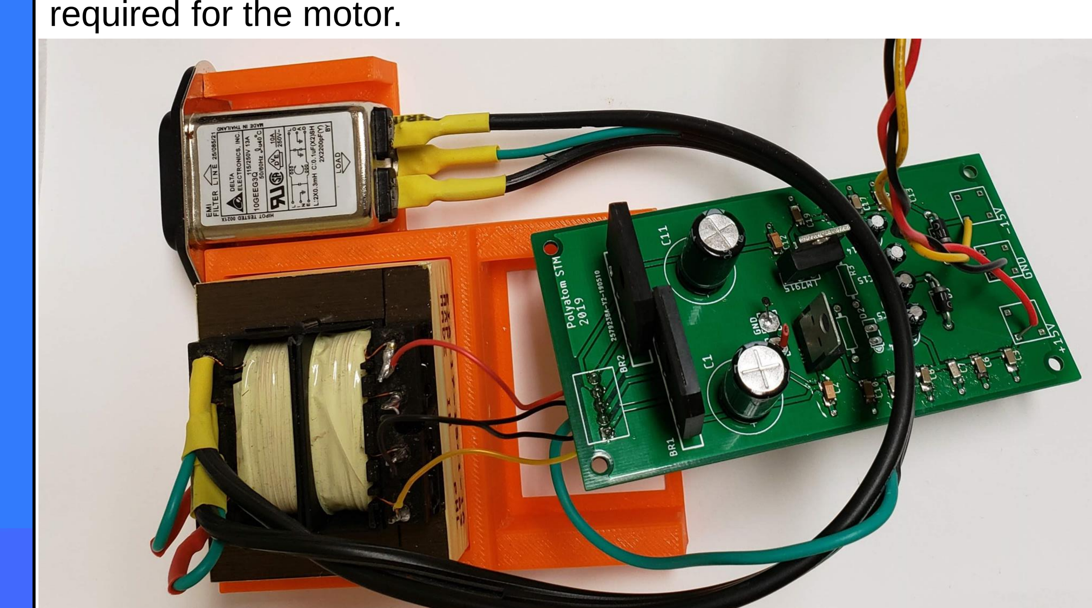
Two 16-bit ADC's were put on-board our PCB to investigate noise performance between the two. A differential ADC was used in conjunction with a single-ended to differential circuit and low pass filters, however, the noise performance on the PCB was poor and the cause was not found. The single-ended bipolar ADC produced superior noise performance and will be used in future designs.

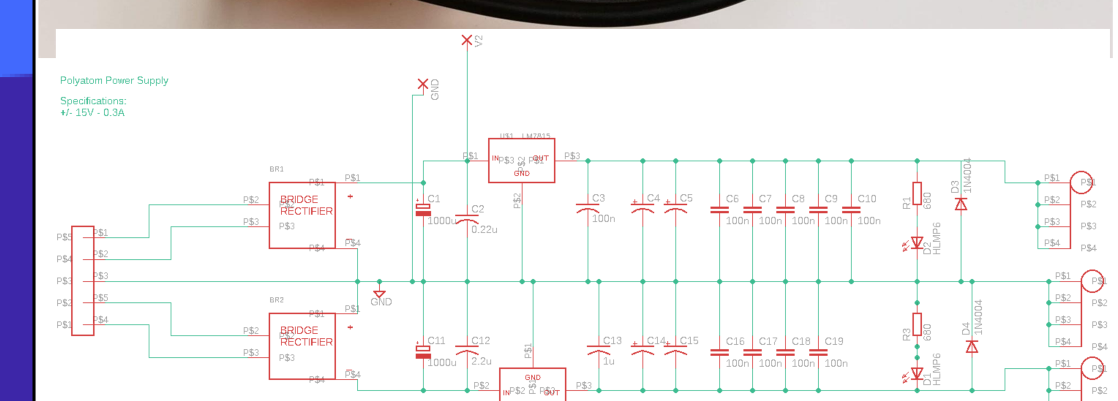




Power Supply

The low-cost STM requires rails of $\pm$15 V_{DC} for the transimpedance amplifier, piezo drivers, ADC, DAC, and control circuitry. Mains voltage is stepped down by a 10:1 transformer and rectified producing $\pm$18 V_{DC} which is then regulated to $\pm$15 V_{DC}. The STM draws 60 mA during normal operation excluding the stepper motor. A separate buck converter will supply the 12 V required for the motor.



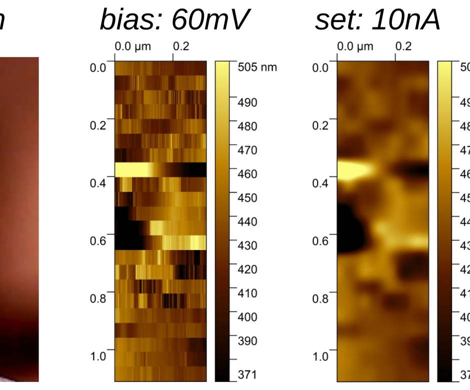


Images

Gold Plated Receptacle: 400nm x 1200nm

x-resolution: 0.5nm *y-resolution: 5nm* *bias: 60mV* *set: 10nA*

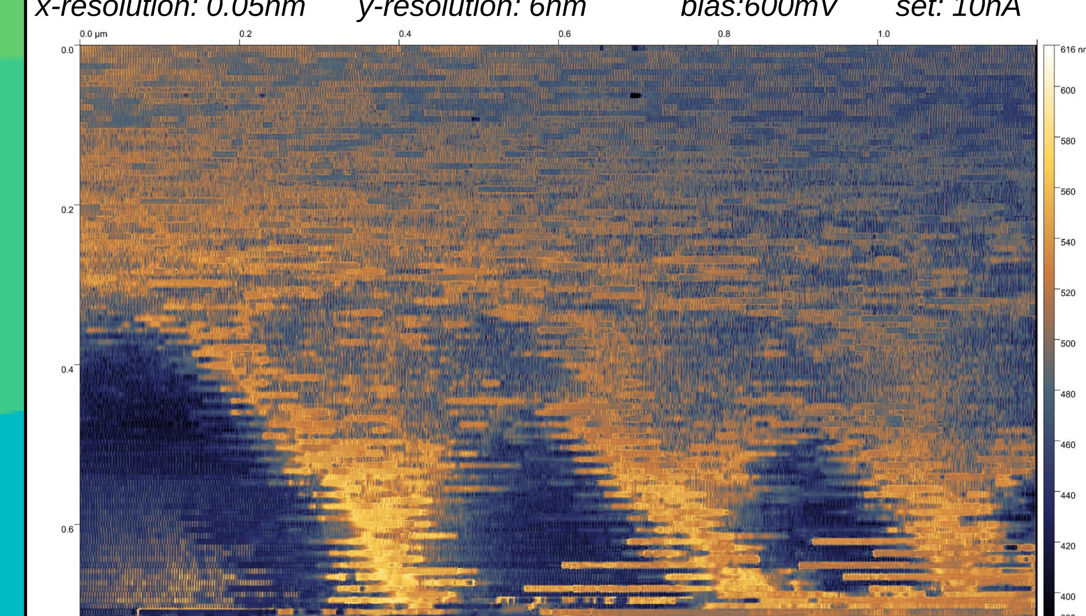
Locked tip and sample

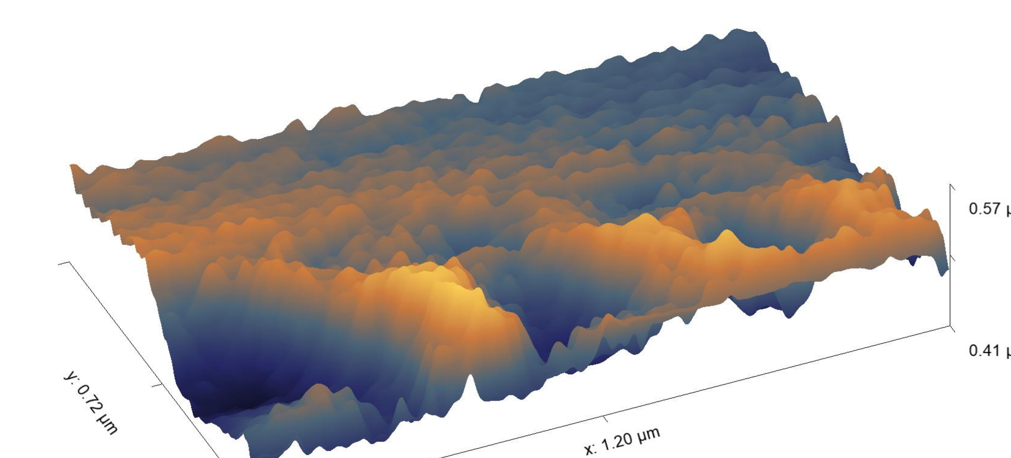


False color scan image raw data (left) and gaussian interpolation (right)

DVR+R Diffraction Grating: 1200nm x 600nm

x-resolution: 0.05nm *y-resolution: 6nm* *bias:600mV* *set: 10nA*





Next Steps

- Remove the solder mask on the TIA guard ring for proper operation.
- Add buck converter for stepper motor.
- Measure piezo movement with Michelson interferometer.
- Create a GUI for the STM in python.
- Create instruction and post them on Polyatom.com

Acknowledgments

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