

# Vibration Isolation for Scanning Tunneling Microscopy

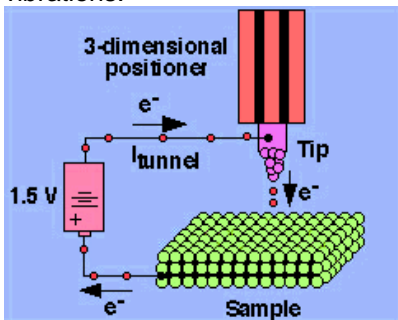
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## ABSTRACT

Scanning Tunneling Microscopy measures tunneling current from conducting surfaces. Through analysis, it is possible to make a three dimensional picture accurate on an atomic scale of a surface and probe microscopic phenomenon. The procedure is dependent on the distance between the surface of the microscope tip and the sample surface. High tolerances on a scale less than an angstrom are required and outside vibrations can be fatal to the results of the experiment. A vibration sensor helps determine the location and magnitude, and can also be a tool in evaluating the effectiveness of current vibration reducing equipment. For my project, I constructed a vibration sensor to detect vibrations in the lab. The detector successfully detected vibrations during several test on two STM systems.

## I. INTRODUCTION

Scanning tunneling microscopy (STM) has only been around for 15 years but has revealed some amazing facts about the world we live in. Invented in the early 1980's by Bert Binnig and Heinrich Rohrer, the technique has been used to probe everything from atomic surface configurations to semiconductor junctions. The principle behind STM is relatively simple. A voltage is applied to a very sharp metal tip. The tip is very close to the sample material but never touches it. Electrons then 'tunnel' across the gap between the tip and the sample. By measuring the tunneling current, it is possible to determine the shape of the surface and electrical properties of the sample. Since the tunneling current decreases exponentially, the distance between the tip and the sample is critical. A shift of an angstrom can drastically change the results. Because of this, great care is taken to isolate the STM from any outside vibrations.



An artist's representation of an STM[1].

Because the isolation system is such a crucial part of the STM apparatus, measurements must be taken to determine if it is working properly or not. A device to detect vibrations would be a useful tool. In the April 1996 [2] issue of Scientific American, a circuit to detect earthquakes was proposed. With some slight modifications, the same circuit can be used to detect vibrations that may affect the STM.

## II. THEORY OF OPERATION

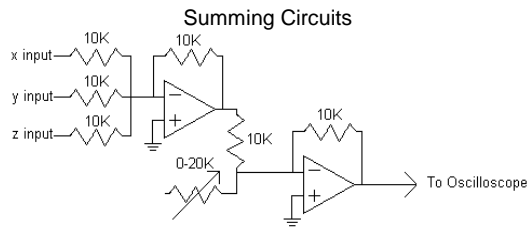
### a. AXL05 Accelerometer Chip

The ability for the circuit to detect vibrations rests mainly with the accelerometer chips. Inside the chip are three plates making a series of two capacitors. The two outside plates are fixed. The third plate is anchored on either side by springs. The setup can be compared to a mass on a spring. The displacement of the mass when it oscillates is proportional to the acceleration of the mass, or

$$F = ma = -kx$$

As the center plate moves, the distance between the plates varies. This change in voltage is then processed and outputted to the rest of the circuit.

## b. AD741 Operation Amplifiers and



Each accelerometer is sensitive to vibrations in only one direction. To get a measure of the vibrations in 3-space we then have to add the three outputs. This is done by hooking the outputs up in parallel to the negative input of an inverting operational amplifier circuit, thereby summing the outputs of the three accelerometers. This allows for the simultaneous measurement of vibrations in all axes.

The output from the first summing circuit was then hooked up in parallel with a potentiometer to the negative output of the second Op-amp. This created a second summing circuit. Inserting the potentiometer made it possible to adjust the offset level of the output and make viewing easier, as discussed in section III b.

## c. ADP3367 +5V Chip

The +5V chip is powered by a standard 9V battery. It takes in 9V and outputs 5V. Because the accelerometers and potentiometers draw very little current, it is possible to power them both with a single +5V chip.

## III. CONSTRUCTION

### a. Construction Details

There were three main types of devices on which the circuit depended: AD741 Op Amp, ADP3367 +5V chip, and the AXL05 Accelerometer chip. All these parts are static sensitive and a ground strap was worn at all times during construction to avoid damaging the components. Six 10ohm resistors were also required in the circuit. Resistors with a 5% tolerance were chosen. All connections to the front panel were made with coaxial cable to reduce the presence of electrical noise in the signal.

The accelerometer chips resided in 10 pin sockets that were soldered to

approximately 2cm square surface mount circuit boards. All connections were made by hand using high tolerance resistors and capacitors with a standard soldering iron.

Since wire wrap was the main method for making connections, a small dilemma arose when the time came to make connections from the front panel and accelerometer chips to the rest of the circuit. All the connections to the front panel were done with coaxial cable to reduce noise. Since coax wire cannot itself be wire wrapped, an alternative method was used. A standard socket with the plastic cover taken off was inserted in the vector board. The front panel wires were then put into the socket, secured with a bead of solder, and the connections were then made from the socket pins.

The circuit itself was contained in a metal box approximately 6" in length. The board was screwed onto rubber stoppers to help dampen any resonance effects in the support board. The accelerometer circuits were mounted to nylon posts, also as a damping aid. The whole box sat on rubber feet as a further measure. Despite these efforts, a problem was noticed with the device when testing began. It was determined that acoustical noises caused the cover for the circuit to resonate. Wood was added to the outside of the box to lessen the effect of this noise. The result was that lower frequencies (less than 1kHz) were dampened out but higher frequencies were not. Because the frequencies of interest are on the lower end, however, the problem was deemed solved.

### b. Circuit Design Modifications

The circuit followed the basic design from Scientific America but the following changes:

1. Insertion of POWER ON/OFF switch. After the circuit was built, it was noticed that the device would run continuously unless a switch was added. A triple pole switch was inserted into the front panel. The positive and negative ends of the batteries hooked in parallel were each hooked to one pole of the switch. The positive end of the third battery was connected to the third pole. Because the negative end of the battery was grounded, there was no need to hook it up to the switch.

2. Insertion of ON/OFF switches for accelerometer chips. By the addition of an ON/OFF switch on the 5V line going to each individual accelerometer chip, it is possible to isolate the direction of detection of motion. In this way it is possible to look at vibrations in the X, Y, or Z axis (or any combination of the three). Double pole switches were used to leave room for further expansion.

3. Addition of potentiometer connected to second Op-amp. Since each accelerometer puts out 2.5V for zero acceleration, it is difficult to keep the output viewable on the oscilloscope. By adding the potentiometer, we were able to zero the value of the output on the oscilloscope regardless of how many directions of motion were being observed.

4. The capacitor on the accelerometer circuit board, referred to in the literature as C5, was changed from .006 $\mu$ F to .022 $\mu$ F. For a reason that has yet to be determined, the circuit works much better with the .022 $\mu$ F capacitor.

The circuit itself was built on a vector board using standard 14 and 18 pin sockets. The connections were made using either the wire wrap technique or soldering. All ground connections except for those of the switches were made to the BNC ground. Because there was a clear coating on the box that the circuit resides in, the inside surface had to be sanded so that the ground wires for the switches could make a good connection to the box. Standard 9V battery holders from Newark catalogue were mounted on the inside wall of the box.

#### IV. CALIBRATION

Since the values of capacitors were slightly different than those recommended in the literature, it was necessary to determine the output displayed on the oscilloscope in relation to the vibration that the accelerometer chips detected.

Recall that the general equation for a sinusoidal vibration can be written as

$$x = A \sin \omega t$$

where  $A$  is the amplitude,  $\omega$  is frequency,  $t$  is time, and  $x$  is position. The accelerometer chips cannot directly measure any of these values; they measure only the acceleration

that the chip is experiencing. The acceleration  $a$  can be found by the equation

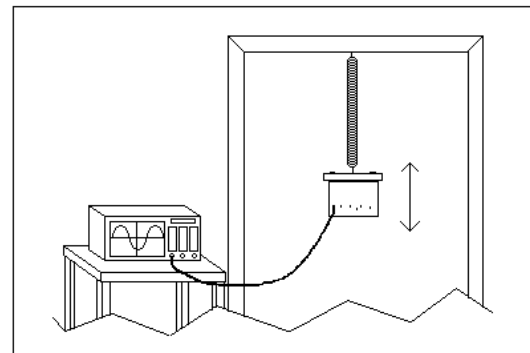
$$\frac{d^2x}{dt^2} = -\omega^2 A \sin \omega t$$

so

$$a = -\omega^2 A \sin \omega t$$

By measuring the frequency and amplitude of vibration, we can determine the maximum acceleration where  $\sin \omega t = 1$ .

A spring approximately 30cm in length with diameter around 1cm was hung from the center of an unoccupied doorway. The detector was then suspended upside down from the spring (for the convenience of the experimenters). A long BNC cable was then connected from the box to an oscilloscope. The wire was placed so that it would not impede the motion of the box or spring.



Drawing of calibration setup

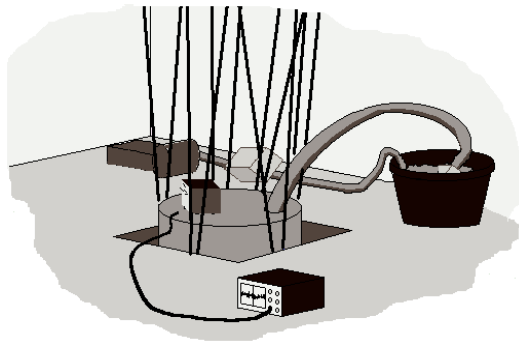
The main power and z-axis switches were then turned on. A meter stick was placed beside the box and spring to measure the amplitude of oscillation. The box was sent into oscillatory motion and the results of detection were displayed on the oscilloscope.

It was determined that for every 1g of acceleration (9.8m/s), 400mV were outputted to the oscilloscope per accelerometer. This agreed perfectly with the value expected based on the AXL05's specifications. Further measurement showed that the other two axes were equally sensitive. The x-axis and y-axis accelerometers performed similarly to the z-axis in all tests.

v. TESTING

a. Ilari's STM

b.



The first system tested was an STM dewar that will be used for capacitance testing. The system is suspended via bungee cords in a concrete reinforced pit in the dirt to reduce the effect of vibrations on the experiment. Our goal was to see if any vibrations from the mechanical pump or from the floor could be detected on the dewar. The sources of vibration we used were the mechanical pump that is hooked up to the Dewar (a good source of consistent high frequency vibration) and a rubber mallet pounded on the floor (to mimic stomping feet of closing doors in the lab). First, we put the detector on the floor to determine how much vibration could be detected as a means of comparison. No signal could be detected from the pump and a 40mV signal was detected from the hammer. We then detected vibrations with the dewar on the floor and detector sitting directly on the dewar. Vibrations with the hammer could not be detected but vibrations from the pump could. After steps were taken to dampen vibrations from the pump, the measured signal was reduced to less than 2mV. The next test was to suspend the dewar. The signal from the pump was not detectable from the hammer test yielded different results. When the hammer was hit on the floor near the side of the dewar farthest from the cables, no signal could be detected. When the hammer was hit near the cables however, a 10-20mV signal was detected. Due to the nature of the experiment, it was determined unnecessary to isolate the cables at this time.

Our test brought us to several conclusions. First, the system is better isolated from vibrations when suspended

from the ceiling. Second, the steps taken to dampen the vibrations emitted by the mechanical pump were successful. Third, it may be necessary to suspend the cables from the ground, as they may be carriers of vibrations during the experiment.

b. Serg's STM

Serg's setup is different in the fact that the system is isolated from the floor with a system of isolation stages and is not floating as in Ilari's system. In this case, the dewar is lifted from the floor by air shocks. The shocks sit on a system of five plates and o-rings that also help dampen vibrations. Mass can then be added to reduce the resonant frequency of the system.

We did several tests varying the amount of pressure in the air springs and the amount of mass added to the system. The first test was a measure of how the resonant frequency of the system changed by changing the pressure in the springs. The analysis showed that at lower pressure, the system exhibited a lower resonant frequency. One hypothesis for this is that as air is added to the springs, they become stiffer and transfer more of the energy of vibration to the system.

The second test was a measure of frequency dependence with changing mass. The goal was to add mass and keep the air pressure in the air springs constant. As we added mass to the system, however, the air springs became unstable and began to collapse. This made it necessary to increase the air pressure. The problem with this is that the mass of the system is increasing which should lower the resonant frequency; however, the air pressure is increasing which increases the resonant frequency. As the data showed, the two effects cancel each other out and the resonant frequency of the system doesn't change. We were not able to determine if the increased mass of the system helped dampen vibrations introduced outside the system.

Serg's system, although the smaller of the two, experiences more complicated vibration problems because of the air springs. Although it may be possible to fully understand the effects being experienced by the system, time constraints demanded that the testing be halted for the time being. A

new approach will be taken to testing. After the microscope is up and running, test will be done to see which methods decrease vibrations the most.

## VI. CONCLUSION

In this project, a vibration detector was successfully constructed and used for testing. With it, we were able to explore the resonant frequencies of various STM systems. In Ilari's system we were able to determine that our method of isolating the pump from the system was successful. We also discovered that there is coupling between the cables and microscope that may cause problems in the future. Serg's system was harder to draw conclusions about. Data was taken that may prove useful in future test, however. The vibration detector has proven a useful preparatory tool for STM experiments.

## REFERENCES

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