EE 327
Project Proposal

Scanning Tunneling Microscope

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Project Outcome:

The goal of our EE327 STM project is to design and fabricate a functional low-cost scanning tunneling microscope.

The design incorporates a linear low-noise power supply, precision DACs/ADCs, and an ESP32/Teensy-based control system, all housed within custom-machined enclosures. The mechanical assembly relies on CNC and waterjet-cut parts, while the scanner uses a modified piezo buzzer element for 3-axis nanometric motion. Hopefully, this project will not only be a fun design challenge, but also may serve as an education tool. We hope to be able to image HOPG (Highly Oriented Pyrolytic Graphite) by the end of the quarter, which

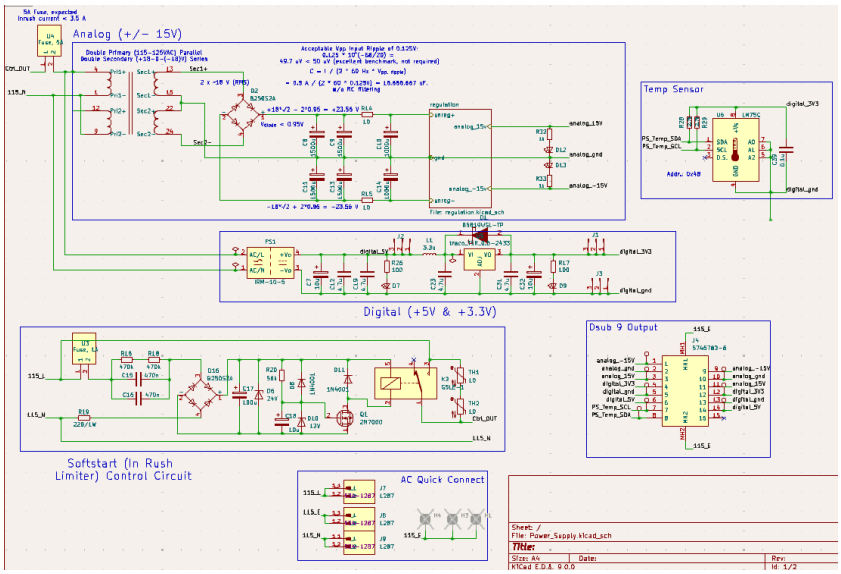
Gantt Chart

We group our design into two main components - electrical hardware and mechanical hardware. Of course, the software design is necessary as well, but we need to put some more thought behind how it works! We've detailed the various components of the project in the following pages.

This color code represents our progress on developing each component:
Completed
In Progress
Not started

Electrical:

- **+/- 15V, +5V, +3.3V, Low Noise Power Supply (PCB)**
  - Linear, includes softstart circuit (relay bypass + NTC thermistor)



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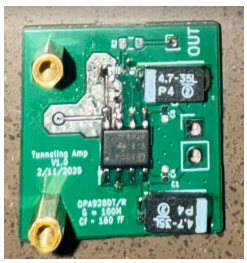
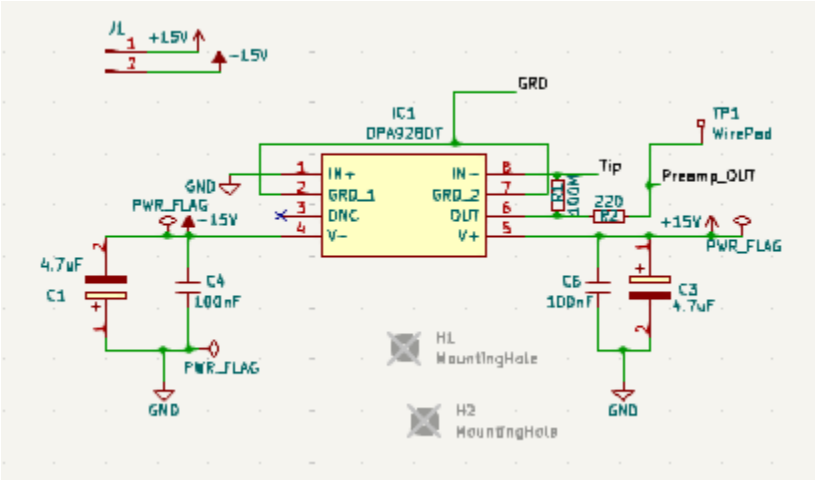
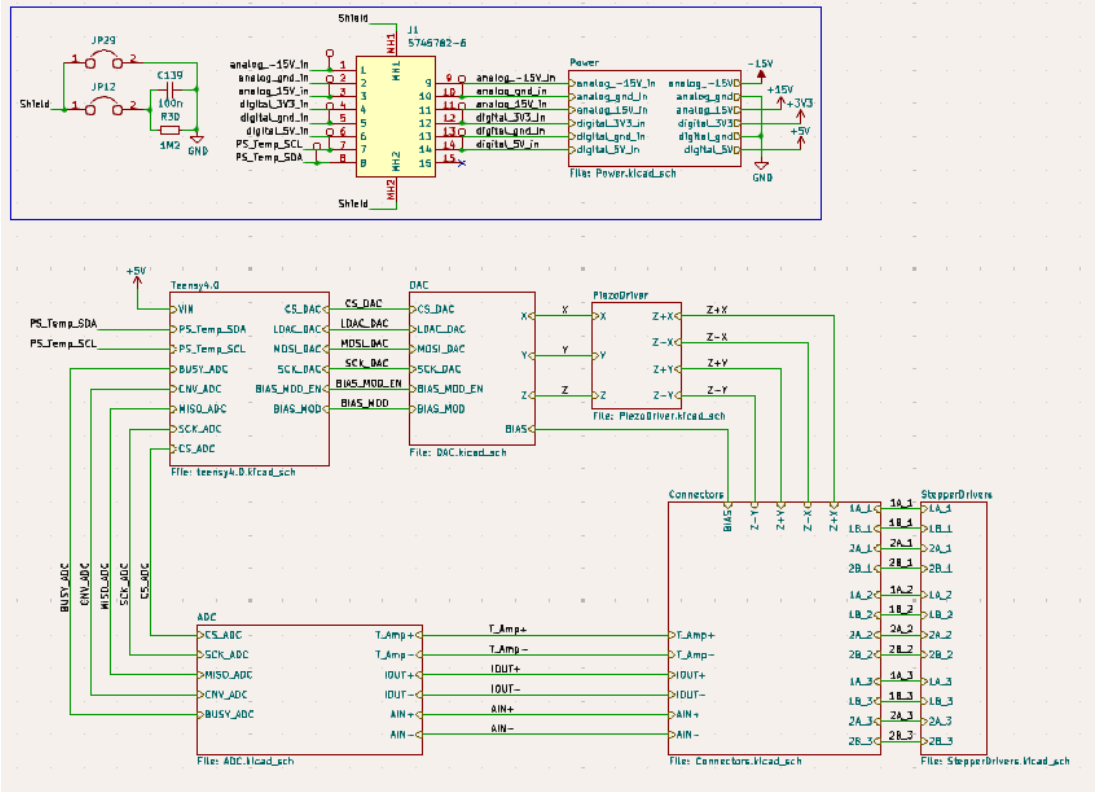
- **Tunneling Amplifier (PCB)**
    - Transimpedance amplifier designed for input currents ~1nA
    - 100MΩ feedback resistor
    - Low input bias current
    - Guard buffer to insulate input node from other conductors
    - Added functionality (if time allows), for tunneling spectroscopy
        - Sweep the bias voltage and measure current as a function of voltage





- **Mainboard (PCB)**
    - 16 bit ADC (LTC2326CMS-16), SPI Protocol
        - Converts voltage from tunneling amplifier to the digital domain
        - If time allows, will attempt scanning tunneling spectroscopy, need external function generator for AC chirp voltages
    - Teensy 4.0
        - Control MCU, chosen for high speed of main clock (600 MHz)
        - Implements z-feedback loop and outputs digital signals for piezo and bias current driving
        - Implements RTOS for precise timing / task prioritization of z-axis feedback loop, DAC updates (for piezo scanning / bias voltage), ADC sampling from tunneling amp, SPI communication with ADC/DAC, stepper motor coordination during course approach
    - DAC (piezo signal bias current output)
        - 16 bit, Quad Channel DAC (DAC8814IBDBT), SPI Protocol

    - Ref102 to generate precision 10V reference to prevent drifting
- Piezo Driver
    - Consists of 4 dual op amps, implementing addition/subtraction of signals to drive unimorph disk piezo scanner
- Stepper Drivers
    - Before z-axis of disk scanner extends towards sample, 3 steppers do coarse positioning until tunneling current is established
    - 3x A4988 Drivers (28-BYJ48 motors, 5V)



- **ESP 32 Breakout (Devkit C / Breadboard should be ok)**
    - Hosts web server / GUI to communicate with Teensy
        - Two way communication
        - Scan images, tunneling current line by line graphs
        - PID Control gains
        - Scan ranges / speed
        - Tunneling current setpoint
        - Z-voltage offset
        - Start / stop scan, auto-approach trigger, manual coarse adjustment slider
- **Base Interconnect (PCB)**
    - Dsub connectors
        - 4 Piezo driving signals (Z+X, Z-X, Z+Y, Z-Y)
        - Bias voltage
        - Stepper motor connections

    - 3x stepper motor output connectors
    - Flex cable piezo + bias outputs
- **Scan Head Interconnect (PCB), may be unnecessary…**
    - Flex cable inputs from base interconnect
    - Piezo + bias voltage outputs (40 AWG?)

Mechanical Design:

* All of the following will be designed in SOLIDWORKS

- **Sheet Metal Housings for Power Supply Board / Mainboard**
  - 1/16” ~ 1.6mm thick, aluminum/galvanized steel
  - Waterjet
- **Scan Head**
  - Requires low thermal expansion coefficient
    - Ideally Macor / brass, may need to use aluminum for budget
  - Sample + Bias
    - Isolated from grounded base with microscope glass
  - CNC
- **Coarse Approach Mechanism**
  - Fine Pitch Screws (¼-80)
    - Highly doubt these can be machined on lathes, will attempt
    - Cost a lot ~ $9 * 3 = $27, not including brass bushings or shipping
    - Need to mill a cutout to fit stepper shaft
  - 3x Stepper Motor (28-BYJ48) that fit into cutout of base
- **Unimorph Disk Scanner**
  - Piezo buzzer, ceramic cut into 4 quadrants
  - Applying Z+X, Z-X, Z+Y, Z-Y voltages to quadrants enables 3 axis motion
  - Standoff + Tip + buzzer should have high mechanical resonance
    - Calculate resonance by sweeping into system and measuring vibration with LDV
- **STM Tip Fabrication**
  - Method 1 (Less accurate, easier to perform)
    - Shearing 30 AWG tungsten wire (platinum iridium gives better results) with strippers
  - Method 2 (More accurate, complicated)
    - Electrochemical Etching, tips end up with a small layer of oxide which is a little difficult to remove
  - Regardless of chosen method, need to develop storage method
- **Vibration Isolation System**
  - 3 steel plates (still working out math for dimensions) with Viton ring separation
  - 1 aluminum baseplate
  - MDF support structure
  - Characterize using LDV (may not be necessary)

Bill of Materials *Will populate ASAP!!!

*Ongoing List! Note that passive components, like capacitors, resistors, and inductors are not listed! These are the main ICs, MCUs, etc., required!

Component	Purpose
Power Supply Board	
FLN 40/18 Transformer	Dual winding transformer, steps down 115 VAC to ~ +- 20 Volts
B250S2A	Full Bridge Rectifier (rectify AC voltage from transformer secondaries) Also used in soft start circuit
IRM-10-5	Mean Well AC-DC Converter (5V output)
TSR_0.5-2433	3.3V step-down non-isolated switching regulator to provide MCU voltage rail
TPS7A4700RGWR TPS7A3301RGWR	+15 Volt Regulation (Analog Circuitry) -15 Volt Regulation (Analog Circuitry)
LM75C	Temperature Sensor (I2C to Teensy to monitor power supply board temperature, will turn on PSU fan if too hot)
G5LE-1	24V Relay (Softstart bypass relay)
SL10-10002	NTC Thermistor (Softstart dissipation)
Tunneling Amplifier Board	
OPA928	Transimpedance Amplifier to convert tunneling current into measurable voltage
Mainboard	
Teensy 4.0	Main Control MCU
ESP32 DevkitC	Breakout to breadboard, will receive data from Teensy to stream to web server, will send data from web server (user input) to Teensy
Piezo Driver (2 TL072 Op Amps)	Simple addition / subtraction configuration to take in X, Y, Z, piezo signals from DAC and output Z+X, Z-X, Z+Y, Z-Y

REF102AU_2K5	10V reference voltage for DAC
DAC8814IBDBT	16 bit, 4 Channel DAC (outputs X, Y, Z, bias)
LT1469CS8-TRPBF + ADG419BR stages	Signal Conditioning, impedance matching, some filtering stages
LTC2326CMS-16-PBF	16 bit, ADC, takes in output of tunneling amplifier and matches with 2^16 entry look up table for digital reconstruction
A4988	Stepper Motor Driver
Base / Scan Head Interconnect Board	
Dsub Connectors	Connectors
Flex Cable Connectors	Connectors