PocketScope

ECE 445 DESIGN DOCUMENT SPRING 2026

Project # 14

Aaron Holl, Rohan Nagaraj, Caleb Peach

Professor: Craig Shultz

TA: Lukas Dumasius

1 Introduction

1.1 Problem

Currently there is no cheap and extremely portable oscilloscope that serves the needs of hobbyists and technicians. Oscilloscope functionality and signal generation is typically confined to laboratory instruments, which are prohibitively expensive to the average consumer since they are intended for university and commercial labs (1). The prices for lower-end oscilloscopes are in the $300-$700 range for standing oscilloscopes. For portable oscilloscopes, they range from $100 to $400 dollars, but the lower-end models leave much to be desired in build quality (2). Furthermore, the portable options are not sufficiently small to be stored comfortably in a pants or jacket pocket and spending $200 on an oscilloscope may be too expensive for most hobbyists, leaving many to settle for the much less expensive multimeter for their voltage measuring needs(3).

1.2 Solution

Our solution is a pocket-sized oscilloscope and signal generator designed to give engineers, technicians, and students a powerful diagnostic tool in a truly portable form factor. The device enables high-resolution voltage-versus-time and current-versus-time measurements, real-time FFT analysis, waveform visualization, and onboard data storage with export capability. In addition to measurement, it functions as a signal generator capable of producing configurable waveforms, allowing users to both stimulate and analyze circuits with a single device.

The system is battery-powered and built around an STM32G4 microcontroller, enabling real-time data acquisition and onboard digital signal processing without requiring a laptop. The analog front-end is designed to support both high-voltage measurements (up to approximately

±170 V with appropriate attenuation and protection circuitry) and high-precision measurements in the ±20 V range. By integrating protection, scalable input conditioning, ADC sampling, and embedded DSP into a compact enclosure, the device provides lab-grade functionality in a portable, self-contained platform.
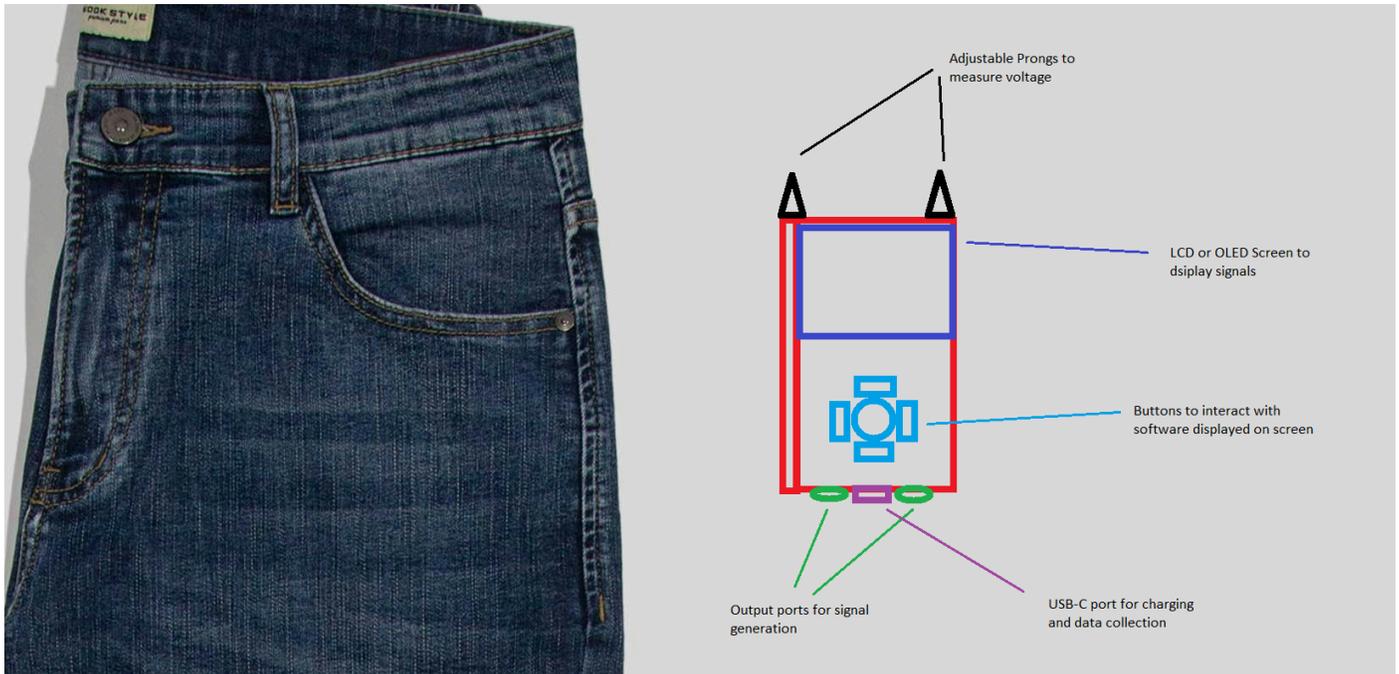
1.3 Visual Aid

Figure 1: Visual Aid

The PocketScope will fit within the size of jeans pocket and be a portable solution to oscilloscope functionality.

1.4 High Level Requirements

To consider our project successful, our design must fulfill the following:

1. Averaging the size of men's and women's jeans pockets, we come to an average height of 7.4'' and an average width of 6.45''. Therefore, for the PocketScope to comfortably fit in an average pair of straight jeans, it must be no longer than 7'' in its longest dimension, and no wider than 6''. The depth of the oscilloscope can vary within 1'' to 2'' to fit within a standard pocket. (4).

2. The device must accurately measure voltage signals in both a high-precision range of [-20 V, +20 V] and a protected high-voltage range of [-170 V, +170 V], using a 12-bit ADC (5). In the ±20 V range (40 V span), this corresponds to a resolution of

approximately 9.77 mV while in the ±170 V range (340 V span), this corresponds to approximately 83.0 mV.

3. The device must generate output signals within the [-20 V, +20 V] range and support at minimum three waveform types: sine, square, and sawtooth, with user-adjustable amplitude, frequency, phase, and duty cycle.

4. The device must perform onboard analytical processing, including real-time FFT-based spectral analysis and basic curve fitting, without requiring connection to an external computer.
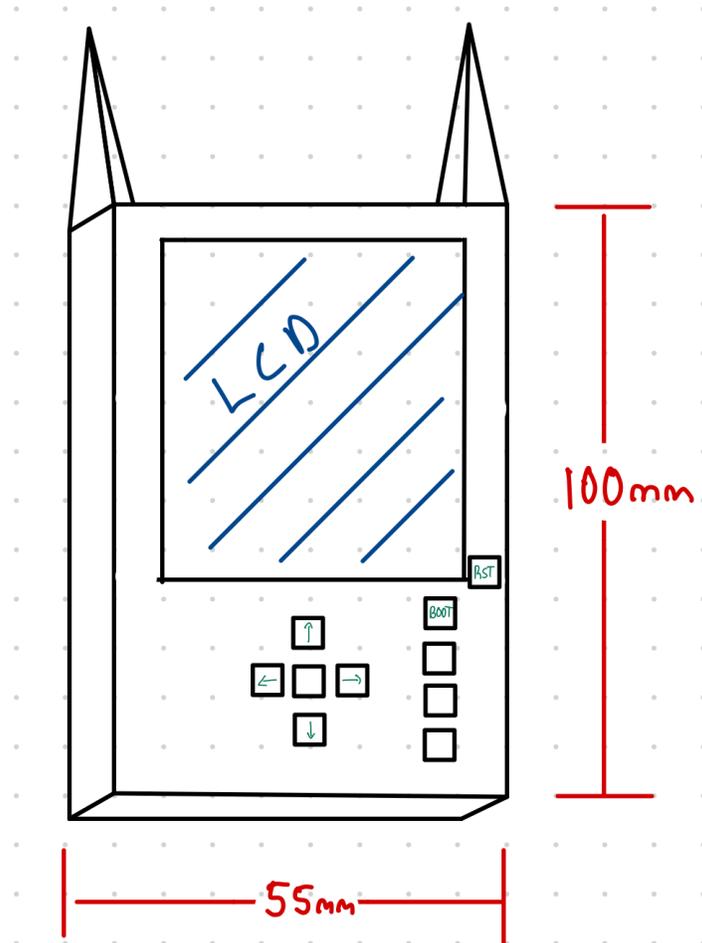
2 Design

2.1 Physical Design

Figure 2: Dimensions of PocketScope

The PocketScope is designed to be small enough to fit within a typical jeans pocket. Therefore the chassis for the device will be only slightly bigger than the PCB dimensions, at about 4" by 2.2". The LCD screen with dimensions of 2.3" by 1.4", will sit atop the PCB and take up the majority of the face of the device. The buttons that interact with the software and control BOOT/RST will take up the remaining space on the front face. The metal prongs will stick out from the chassis, connected to the voltage input terminals on the PCB.
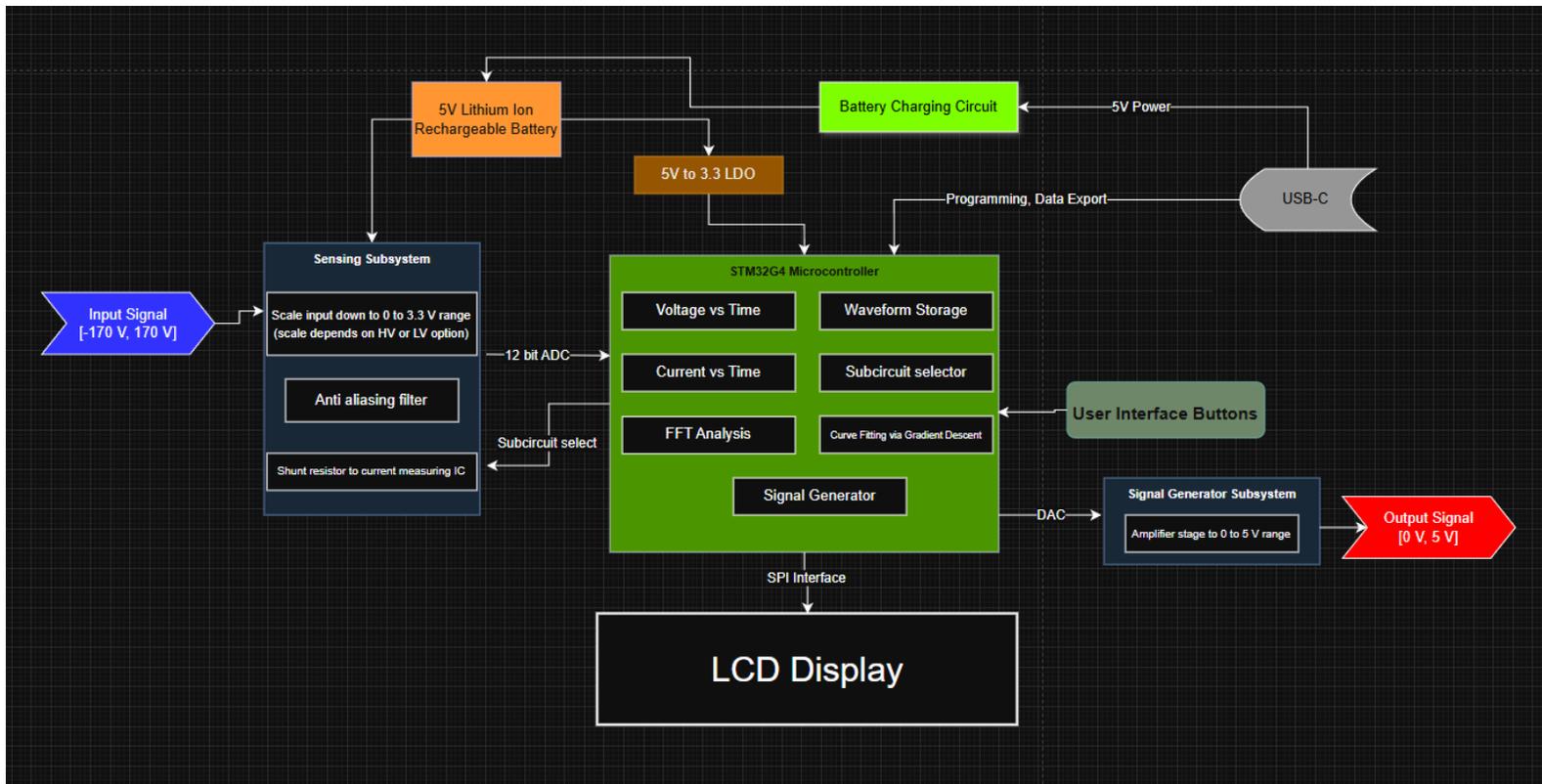
2.2 Block Diagram

Figure 3: Project Block Diagram

2.3 Functional Overview & Block Diagram Requirements

2.3.1 Sensing Subsystem

This system will take an input voltage from the conductive prongs on the device and scale down the signal to appropriate 0 to 3.3 V level for safe input into the microcontroller's ADC. Depending on if the signal is high or low voltage, the signal will be scaled differently but ultimately down to a 0 to 3.3 V level in order to maximize input voltage range and precision of the oscilloscope. The signal will first be scaled using a high impedance voltage divider followed by a summing op amp to get the signal above 0 V. The signal will then pass through an anti-aliasing filter to remove any unwanted noise above the 100 kHz bandwidth that the oscilloscope will be rated for. Then the filtered signal will be passed into the microcontroller's ADC pin for computation.

The filtered signal will also pass through a shunt resistor and into a current sensing IC, whose output will also be fed into an ADC pin in the microcontroller for current vs time measurements.

Requirements	Verification
Have a tolerance of < 1% on voltage measurements	- Use a waveform generator to generate 1V, 5V, 20V, and 120V on the input terminals of PocketScope - Run a debugger on the PocketScope and inspect what the voltage readings are. It should be less than 1% difference from what was selected on the waveform generator (or, if the waveform generator specifies a tolerance, it should be within 1% above this tolerance. Ideally, a waveform generator with a very low tolerance should be chosen)
Support up to 170V input	- Put the PocketScope into High Voltage mode by pressing the appropriate button. - Use a power supply to generate a signal starting at 20 V, and connect this to the terminals of the PocketScope. - View the waveform on the PocketScope display and slowly increase the voltage magnitude from 20 V to 170 V, watching for any errant readings.
Support up to .5 A input	- Put the PocketScope into Current Sensing mode by pressing the appropriate button. - Use a power supply to generate a signal starting at 100 mA and connect this to the terminals of the PocketScope. - View the waveform on the PocketScope display and slowly increase the current magnitude from 100 mA to 500 mA, watching for any errant readings.

2.3.2 User Interface Subsystem

The User Interface Subsystem serves as the primary bridge between the technician and the internal measurement hardware, enabling real-time visualization of high-speed signals. This system will take user inputs via buttons and display important information to the user. All of the user inputs will interface with

the compute unit via user interface buttons, and the outputs will be interfaced via serial peripheral interface (SPI) from the compute unit.

Requirements	Verification
Subsystem must draw less than 1.5 Watt of power	- The system can operate on a single 5 V supply. Thus connect a power supply to the PocketScope and monitor how much current is being drawn by the power supply under heavy computational conditions to verify it draws less than 1.5 W of power

2.3.3 Signal Generator Subsystem

This system allows the user to output the following waveforms at customizable frequencies, phase, duty cycle, and amplitude:
- Square Wave
- Triangle/Sawtooth Wave
- Sine Wave

These waveforms can be selected via the User Interface Subsystem and will be generated through the STM32G4's onboard DAC (5). That output will pass through a non-inverting op-amp configuration to scale the waveform to the battery's supply voltage of 5 V if the user desires. The output signal of the signal generator will be through the same contacts used to monitor analog signals through the oscilloscope function.

Requirements	Verification
Amplitude: 0 to 5 V range	- Utilizing a full-size lab oscilloscope, connect one of the channels to the output prongs of the Pocketscope. Set the display range to [0,5] volts. Turn on the signal generation function of the Pocketscope and watch the oscilloscope to ensure that the voltage magnitude varies appropriately as you adjust the output. The maximum output should fall within the [4.8,5.2] V range.
Frequency: 0 to 100 kHz	- Utilizing a full-size lab oscilloscope, connect one of the channels to the output prongs of

Requirements		Verification
		the Pocketscope. Turn on the signal generation function and watch the oscilloscope as you vary the frequency from the Pocketscope to watch the signal stretch and contract. The maximum output should fall in the [99, 101] kHz range.
Duty Cycle: 0 to 100%	-	Utilizing a full-size lab oscilloscope, connect one of the channels to the output prongs of the Pocketscope. Turn on the signal generation function and generate a square wave. Watch the oscilloscope as you vary the duty cycle from 0 to 100% and see that the percentage of high voltage output time increases compared to low output, ending with a simple high voltage output at 100%.
Phase: 0 to 360 degrees	-	Utilizing a full-size lab oscilloscope, connect one of the channels to the output prongs of the Pocketscope. Turn on the signal generation function and watch the oscilloscope as you vary the phase from the Pocketscope to watch the signal shift to the right. The signal should successfully return to its original location after the full 360 degrees.

2.3.4 Compute Subsystem

The compute subsystem acts as the brain of the PocketScope. This subsystem will handle interfacing with and processing the information from each of the other subsystems. This includes: keeping track of ADC readings (for voltage and current), calculating the FFT of a graph, performing ML (line matching) on the output graphs, handling the SPI communication for the LCD display, handling button inputs, and handling the DAC to generate an appropriate signal.

Because there were many independent tasks that needed to be managed, it was decided that using a real time operating system (RTOS) would be helpful, compared to having to manage running and timing tasks independently. Because we are using an STM32, it is natural to use freeRTOS for this, as there is a provided framework for freeRTOS usage. Each aforementioned task will be its own RTOS task.

Requirements	Verification
Perform a 512-point FFT transform in <100 ms (to keep up with frame rate)	- Connect a debugger to the STM running ADC drivers. - Call a get timer function before and after FFT calls, and use the debugger to read these values. - Ensure the timer value is <100ms apart.
Perform accurate line matching algorithms with less than 10% error on the measured outputs	- Set up a waveform generator with one of the signals to be predicted (noting the period, amplitude, etc of the output). - Plug the output terminals of the waveform generator into the input terminals of the PocketScope. - Inspect the output on the LCD display and verify that the predicted fit is within the expected tolerance

2.3.5 Battery Charging Subsystem

This system allows the user to plug a USB-C cable into their PocketScope to allow for the battery to recharge. The 5 V power from the USB-C will go into a battery IC and the output will charge the battery. This will allow the PocketScope to operate on the go.

Requirements	Verification
Must be able to charge the battery while in use	- Turn on the PocketScope and let the battery deplete to around 50% charge. - While looking at the on-screen battery life display, plug the usb-c charging cord into the PocketScope. - Use a lab oscilloscope to generate a signal, measure the signal with the PocketScope, and watch to see if the battery life increases or continues to deplete while in use.
Must add battery disconnection circuit to prevent fire hazard in the case of overdrawing power	- Intentionally draw battery power into an electronic load and verify the battery disconnects after it starts to draw over 1 W of power

Requirements	Verification
Must add overcharge protection to prevent fire hazard	- Verify the battery is not being charged when at full capacity by using a voltmeter to verify the charging circuit is at 0 V when plugged into USB-C power

2.4 Tolerance Analysis

Sensing Subsystem

The sensing subsystem presents a significant technical risk because measurement accuracy is directly dependent on the integrity of the signal delivered to the MCU's 12-bit ADC. The analog front-end must attenuate high-voltage inputs (up to ±170 V), condition lower-voltage precision inputs (±20 V), and suppress EMI, switching noise, and environmental pickup before digitization. Any excessive noise, improper filtering, or impedance mismatch could reduce effective number of bits, distort waveform shape, and degrade FFT accuracy and curve-fitting reliability.

To quantify this risk, consider that in the ±20 V measurement range the total span is 40 V. With a 12-bit ADC (4096 levels) (4), the resolution is 40 V / 4096 or around 9.77 mV per LSB. To prevent visible waveform distortion or FFT degradation, total system noise should remain below about ±0.5 LSB, or roughly ±4.9 mV. The ADC's own quantization noise has an RMS value of approximately LSB / $\sqrt{12}$ or 2.8 mV RMS, meaning the analog front-end (resistors, op-amps, layout, and filtering combined) should contribute less than about 4 mV RMS of additional noise to stay within budget.

For comparison, resistor thermal noise is relatively small: even a 1 MΩ equivalent resistance over a 100 kHz bandwidth produces on the order of tens of microvolts RMS, which is far below the millivolt-level noise budget. This shows that the dominant risks are EMI pickup, op-amp noise, and improper filtering. Therefore, the sensing subsystem will use properly selected divider impedances, buffering amplifiers, and low-pass filtering with a cutoff slightly above the intended signal bandwidth to suppress high-frequency interference while preserving waveform fidelity.

3 Cost and Schedule

3.1 Cost Analysis

Labor: Assuming an annual salary of 90,000 (typical for a UIUC graduate working in Illinois) [(6)](), we have an hourly rate of about $43.30 per partner. For 16 weeks in a semester, we can assume each partner dedicates about 4 hours/week to the project, giving 80 hours total. The cost per partner therefore is 43.3 x 2.5 x 64 =$ 6928. Multiplying by 3 to account for the three partners, we come to a **total labor cost of $20784.**

Parts:

Designator	Footprint	Quantity	Value	Supplier Links	Price
C10, C14	805	2	10uF		$0.00
C12, C13, C15, C16, C17, C18, C19, C20, C5, C6	805	10	1uF		$0.00
C7, C8	805	2	470pF		$0.00
D2	805	1	LED		$0.00
J1	Molex_KK-254_AE-6410-02A_1x02_P2.54mm_Vertical	1	Input Signal		$0.00
J3	USB_C_Receptacle_GCT_USB4105-xx-A_16P_TopMnt_Horizontal	1	USB_C_Receptacle_USB2.0_16P	https://www.digikey.com/en/products/detail/gct/USB4085-GF-A/9859662	$0.87
J5	Molex_Mega-Fit_76829-0108_2x04_P5.70mm_Vertical	1	LCD Display Connector		$0.00
Q1, Q2	SOT-23	2	AO3400A	https://www.digikey.com/en/products/detail/alpha-omega-semiconductor-inc/AO3400A/1855772	$0.92
R10, R11, R17,	805	10	10k		$0.00

R18, R19, R20, R21, R22, R23, R24					
R12	1206	1	1.1M		$0.00
R13	1206	1	10k		$0.00
R14, R9	805	2	330		$0.00
R15, R16	805	2	5.1k		$0.00
R3	1206	1	1M		$0.00
R4	1206	1	82k		$0.00
R5	805	1	1k		$0.00
R7	805	1	100k		$0.00
R8	805	1	51k		$0.00
SW1	SW_TH_Tactile_Omron_B3F-100x	1	BTN0	https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/B3F-1000/33150	$0.24
SW10	SW_TH_Tactile_Omron_B3F-100x	1	BTN7	https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/B3F-1000/33150	$0.24
SW2	SW_TH_Tactile_Omron_B3F-100x	1	BTN1	https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/B3F-1000/33150	$0.24
SW3	SW_TH_Tactile_Omron_B3F-100x	1	BTN2	https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/B3F-1000/33150	$0.24
SW4, SW7, SW8	SW_TH_Tactile_Omron_B3F-100x	3	BTN3	https://www.digikey.com/en/products/detail	$0.72

				il/omron-elect ronics-inc-em c-div/B3F-10 00/33150	
SW5	SW_TH_Tactile_Omron _B3F-100x	1	BTN4	https://www.d igikey.com/en /products/deta il/omron-elect ronics-inc-em c-div/B3F-10 00/33150	$0.24
SW6	SW_TH_Tactile_Omron _B3F-100x	1	BTN5	https://www.d igikey.com/en /products/deta il/omron-elect ronics-inc-em c-div/B3F-10 00/33150	$0.24
SW9	SW_TH_Tactile_Omron _B3F-100x	1	BTN6	https://www.d igikey.com/en /products/deta il/omron-elect ronics-inc-em c-div/B3F-10 00/33150	$0.24
U2	NXE1S0505MC_MUR	1	NXE1S05 05MC-R7	https://www.d igikey.com/en /products/deta il/murata-pow er-solutions-i nc/NXE1S05 05MC-R7/50 47358?s=N4I gTCBcDaIHI A0CiBGAyg BgKzYLIGE BaAJQHYAd ckAXQF8g	$3.05
U3, U5	SOIC-8_3.9x4.9mm_P1. 27mm	2	AD8606A RZ	https://www.d igikey.com/en /products/deta il/analog-devi ces-inc/AD86 06ARZ/75118	$10.36

				[5](#)	
U6	WSON-6-1EP_2x2mm_ P0.65mm_EP1x1.6mm_ ThermalVias	1	LP5912-3. 3DRV	[https://www.d igikey.com/en /products/deta il/texas-instru ments/LP591 2-3-3DRVR/6 005673?gclsr c=aw.ds&gad _source=1&g ad_campaigni d=179227959 60&gbraid=0 AAAAADrbL ljS1j_EWetB E2wjnBK-Oy wmt&gclid=C jwKCAiA-__ MBhAKEiw ASBmsBCA Q8rH1ksgVa mbrBirD9Jr3 d3SL3aP0oo8 QoxeL7hAT8 Niqj9AS9hoC X4cQAvD_B wE](#)	$1.18
U7	SOT-23-5	1	SN74LVC 1G14DB V	[https://www.d igikey.com/en /products/deta il/texas-instru ments/SN74L VC1G14DBV R/385724](#)	$0.12
U8	LQFP-48_7x7mm_P0.5 mm	1	STM32G4 73CETx	[https://www.d igikey.com/en /products/deta il/stmicroelect ronics/STM32 G473CET6/1 0326771](#)	$7.74
--	LCD Display	1	Adafruit Industries LLC 4311	[https://www.d igikey.com/en /products/deta](#)	$19.95

				il/adafruit-industries-llc/4311/10313914?gclsrc=aw.ds&gad_source=1&gad_campaignid=20228387720&gbraid=0AAAAADrbLlgGkNG8AON46xHZcF2CVRnZx&gclid=Cj0KCQiAtfXMBhDzARIsAJ0jp3CLPaq86xL0jHVQNO29bb3WZvOZM8WfpdJCUh8Rwz6MFv0nwkuL90YaAqYuEALw_wcB	
					$46.59

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Summing all of the materials, we come to a total of $46.59.

Total Cost: Labor + Materials: 20784 + 46.59 = **$20830.59**

3.2 Schedule

[Include a time-table showing when each step in the expected sequence of design and construction work will be completed (generally, by week), and how the tasks will be shared between the team members. (i.e. Select architecture, Design this, Design that, Buy parts, Assemble this, Assemble that, Prepare mock-up, Integrate prototype, Refine prototype, Test integrated system).]

	Aaron	Caleb	Rohan
March 2nd	Write/Test ML code	Get SW flashing working + write LCD drivers	Add current sensing IC to PCB design

March 9th	Write/Test ML code	Write ADC/DAC/Buttons/Display code/Solder	Solder/Hardware tests
March 16th	Spring Break	Spring Break	Spring Break
March 23rd	Begin CAD Design	Solder	Solder/PCB Redesign
March 30th	CAD prototype 1	Solder/Test Code/CAD prototype 1	Solder/PCB Redesign
April 6th	CAD prototype 2	Write FFT code	Solder/PCB Redesign
April 13th	Hardware integration	Test FFT code	Solder/Hardware integration
April 20th	Prep Demo	Prep Demo	Prep Demo
April 27th	Documentation Write Up	Documentation Write Up	Documentation Write Up

4 Ethics and Safety

The PocketScope is designed to increase the accessibility of diagnostic tools for hobbyists and students, fulfilling the ethical duty to assist the public in reaching a higher understanding of technology. To ensure safety, the device must mitigate the risks of electric shock from its 170V input range and thermal runaway from its lithium-ion battery. We will adhere to IEC 61010-1 for laboratory safety and IEC 62133 for battery compliance to prevent injury during field use. Additionally, in accordance with the IEEE Code of Ethics (1.1), we will prioritize public safety by clearly labeling the voltage limits of the non-isolated sensing prongs and ensuring our 12-bit accuracy claims are honest to prevent diagnostic errors by technicians.

5 References

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