Purpose:

Convert the analog voltage X-Y pen plotter output of the Tektronix 2232 oscilloscope to a series of HP-GL plotter graphics commands that are serailly output, via USB, to a PC file. The HPGL file can be processed by any print capturing application (like [PrintCapture](http://www.printcapture.com/)) and displayed as a plot image.

(HP-GL: [Hewlett-Packard Graphics Language](http://en.wikipedia.org/wiki/HPGL))

Subsystems:

1. [Arduino UNO](https://www.arduino.cc/en/Main/ArduinoBoardUno) for the ADC conversions, digital filtering, assembly of HPGL commands and serial output.
2. [Arduino Proto Shield](https://store.arduino.cc/usa/arduino/arduino-shields/proto-shield-rev3-uno-size) board for signal conditioning (voltage translation), voltage reference and power monitoring.

Design considerations:

1. Use Arduino UNO because it's the most common beginners model and can support an Arduino Proto Shield.
2. Power. The 5V voltage reference, and the summing amps, which output up to 5 volts, require at least 2 volts headroom. Therefore, cannot rely on the USB port as power source. Use 9V external walwart which gives plenty of headroom since this power supply, when plugged in, will also provide power to the Arduino board.
3. Scope outputs ±2.5 volts on X and Y. Arduino UNO analog pins accept only 0 to 5 volts. Need to translate ±2.5v to 0-5v. Use Unity gain summing amplifiers with a 2.5V voltage reference.
4. Need an indication that there is not sufficent power should an external power supply not be used. These ICs cannot operate on ~5V USB power. Add a bi-color red/green LED as a 'Go-No Go' indicator of sufficient power. A voltage divider network to divide 9V power down to 5V for Arduino analog input pin. Also, need schottky protection diode to proect Arduino pin for power supplies over 9 volts.
5. Summing amps must provide down to 0 volts (gnd). Too close to the rail for single-sided powered amps. Need bi-polar power, say ±9V. Use charge pump voltage converter to create **‑**9 volts for the summing amps. Plenty of headroom. Minimum parts count; 2 caps.
6. Current draw from two summing amps will drag down the negative voltage of the voltage converter. Calculation shows voltage dragged down to ~‑8.5 volts. Plenty of headroom left.
7. Precision 2.5V voltage reference must drive inputs of the two summing amps.
8. Use a precision 5V voltage reference for the Arduino AREF pin. Don't want to rely on Arduino voltage regulator as a reliable voltage reference.
9. A switch to start and stop the data stream. Some HP-GL initialization commands and finalization commands must be output.
10. Of course, power supply bypass caps for all ICs.
11. Measured maximum slew rate of scope plotter voltages is ~3v/sec. Adjust sampling rate accordingly so as not to have too many redundant plot points (current sampling rate is 615 points/sec).
12. Filtering applied dither: The analog X Y voltages of the Tektronix pen plotter output have copious added dither. That's fine for shaking loose the mecanical plotter arms and is filtered out by the mass inertia of the mechanical arms. BUT, the 10-bit ADC can pick up the dithered voltage at any instant in time. How to filter it out. A combination of analog and digital filtering.
    1. Analog: A 0.068µf (found by trial and error) capacitor to ground on the input couples with the 2KΩ output resistance of the analog output amplifier of the scope to produce an RC low pass filter. That attenuates a lot of the high frequency components of the dithered waveform but it can go only so far before image quality is degraded.
    2. Digital: A moving average filter of n=8. This gets rid of the two LSBs of the ADC value since they're considered noise bits anyway. With n=16 it softens the corners too much in the image.
13. Connect Tektronix shield ground to Arduino ground? Nah, signal ground is good enough, avoids ground loops.
14. Copper ground fill on circuit board.

References:

* Atmel ATmega328/P 8-bit AVR Microcontroller Datasheet.
* Arduino Programming Nootebook by Brian W. Evans.
* Arduino Uno Rev3 Schematic
* Tektronix 2232 Digital Storage Oscilloscope User Manual, 070-7066-01
* Tektronix 2232 Digital Storage Oscilloscope Service Manual, 070-7067-01
* The HP-GL/2 and HP RTL Reference Guide, A Handbook for Program Developers, 5961-3526