By Abdelsalam ElTamawy

Matched Filtering and Signal Processing Using an Ultrasonic Sensor from Scratch

What we are After

- TOF measurement using ultrasonic transducers
- Digitally analysing it
- Use match filtering to determine the distance
- Complete digital to analog to digital processing pipeline

The humble HC-SR04

- Most common ultrasonic sensor
- Very cheap
- A great place to start from

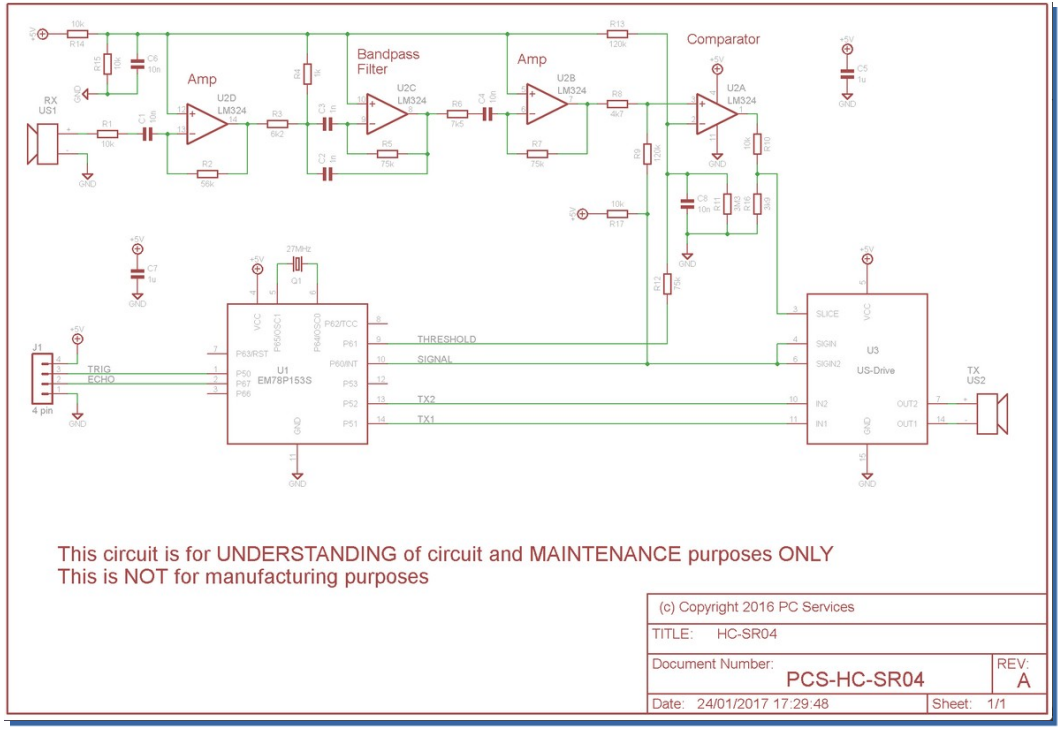
Initial attempts

- Easiest way to go about this
- Use what is already avialable and complete
- Reprogram embedded chip with new software
- Impossible to interface with embedded MCU
- Unpractical to solder onto SMD chip

Reverse Engineering

- Surprised it’s not opensource
- Needs reverse engineering
- Thankfully others have done done most of the work
- Various revisions in the wild
- Difficult to find exact version

Reference Schematic

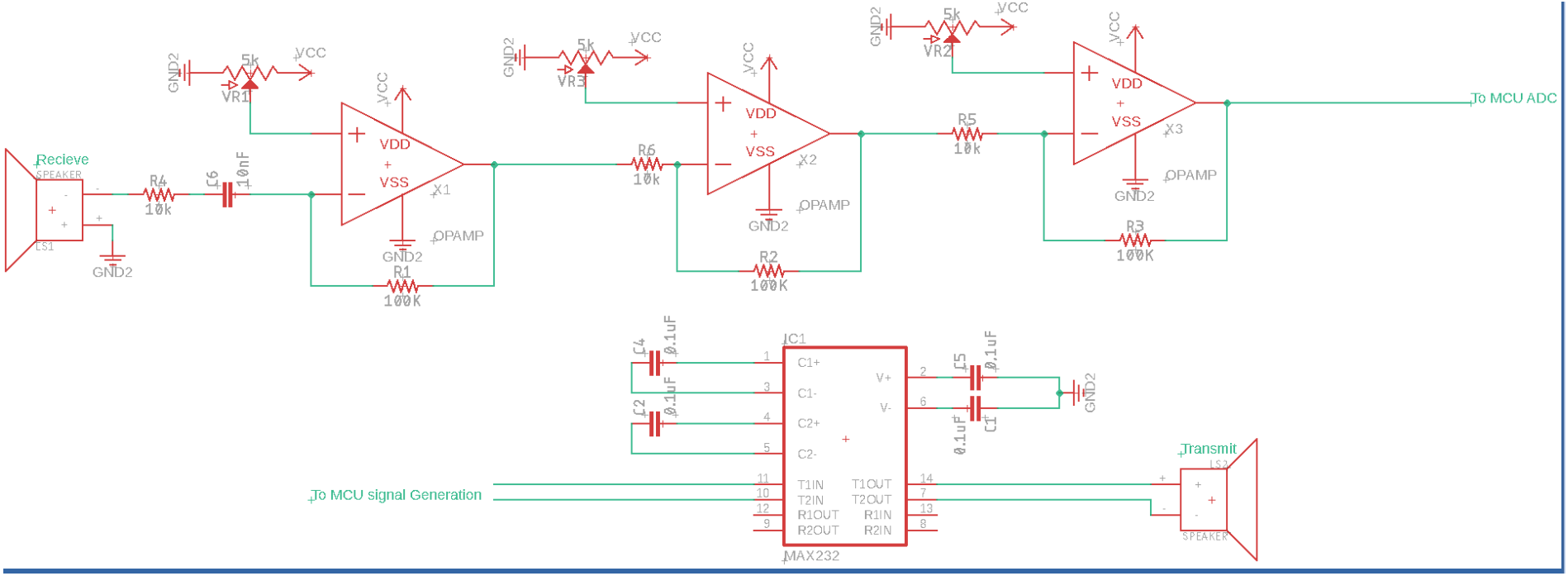


http://www.pcserviceselectronics.co.uk/arduino/Ultrasonic/electronics.php

Doing Things Differently

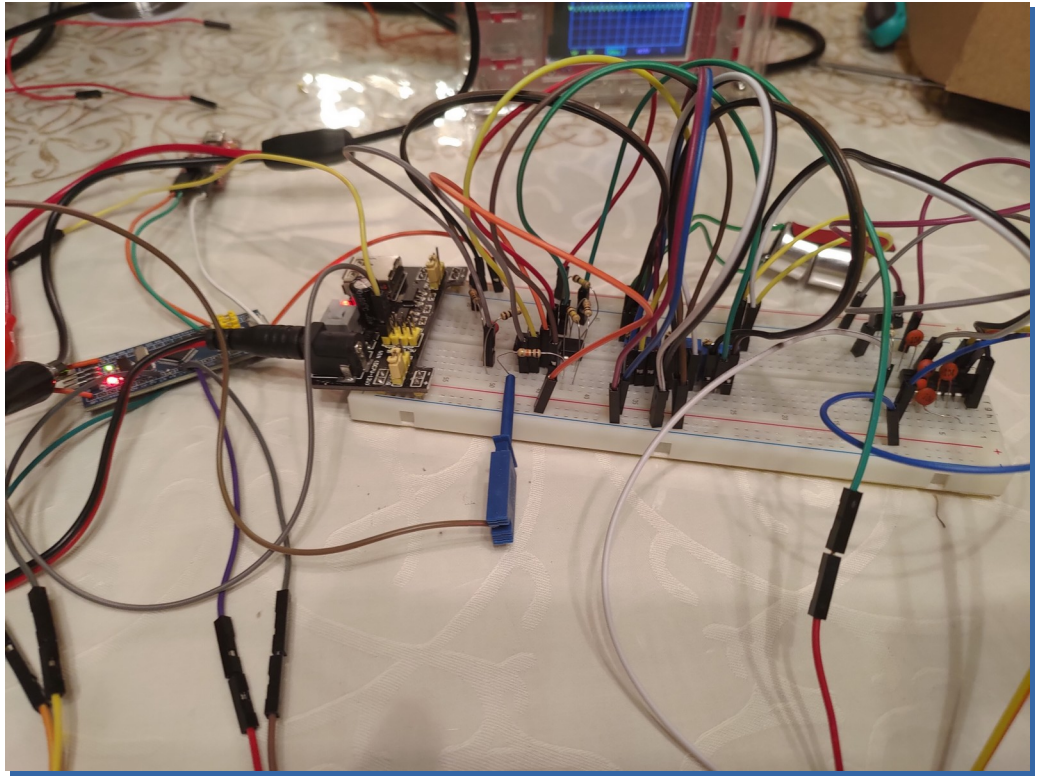
- Realize HC-SR04 does not use pattern matching
- Considerable design faults
- Can skip a few pulses
- Undefined behavior for out of range distances
- Clumsy interface timing

The New Circuit



The New Cricuit

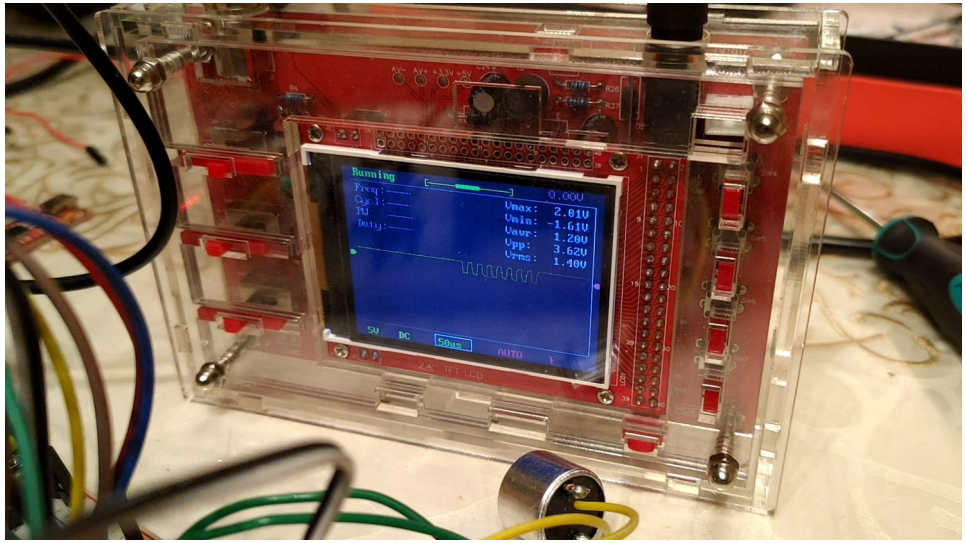
- Built as closely as possible to the HC-SR04



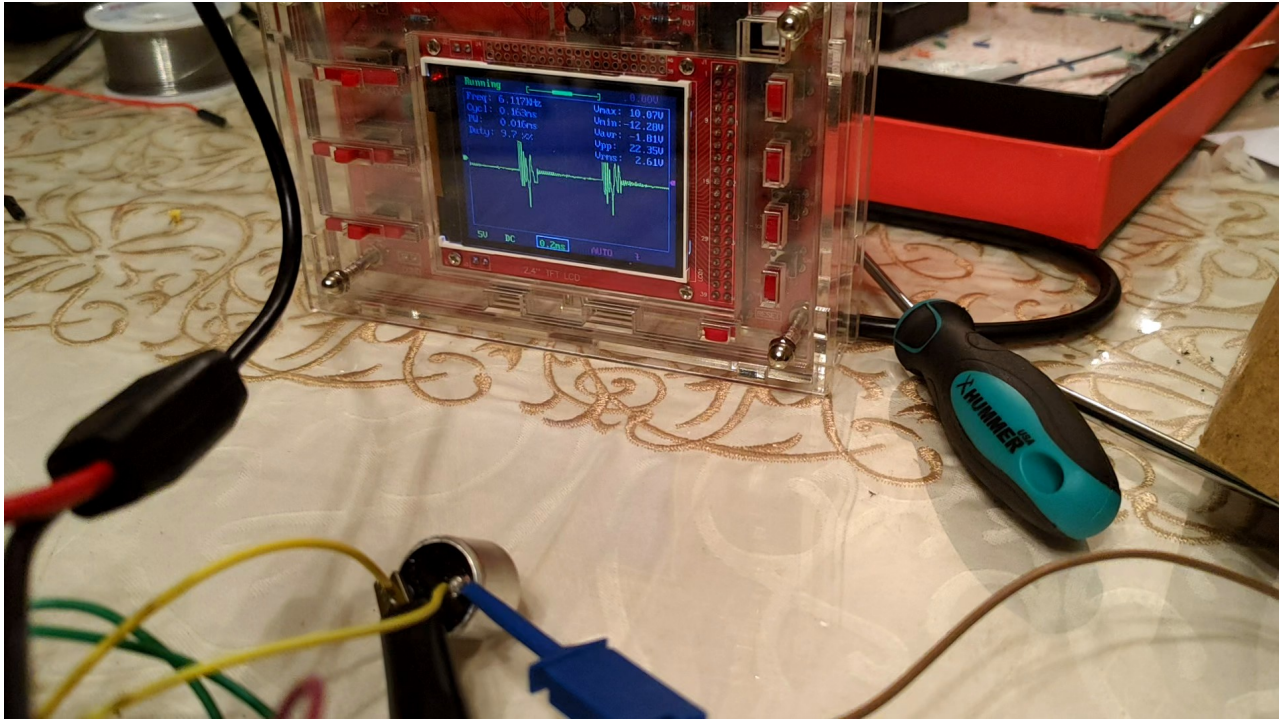
Digital to Analog Conversion

- Produce 8 40MHz pulses from MCU to match later
- Using linear driver MAX 232 IC to convert digital pulse to ultrasonic analog signal
- Almost identical to HC-SR04 signal boosting circuit
- Stick with tried and tested method

Digital to Analog Trigger



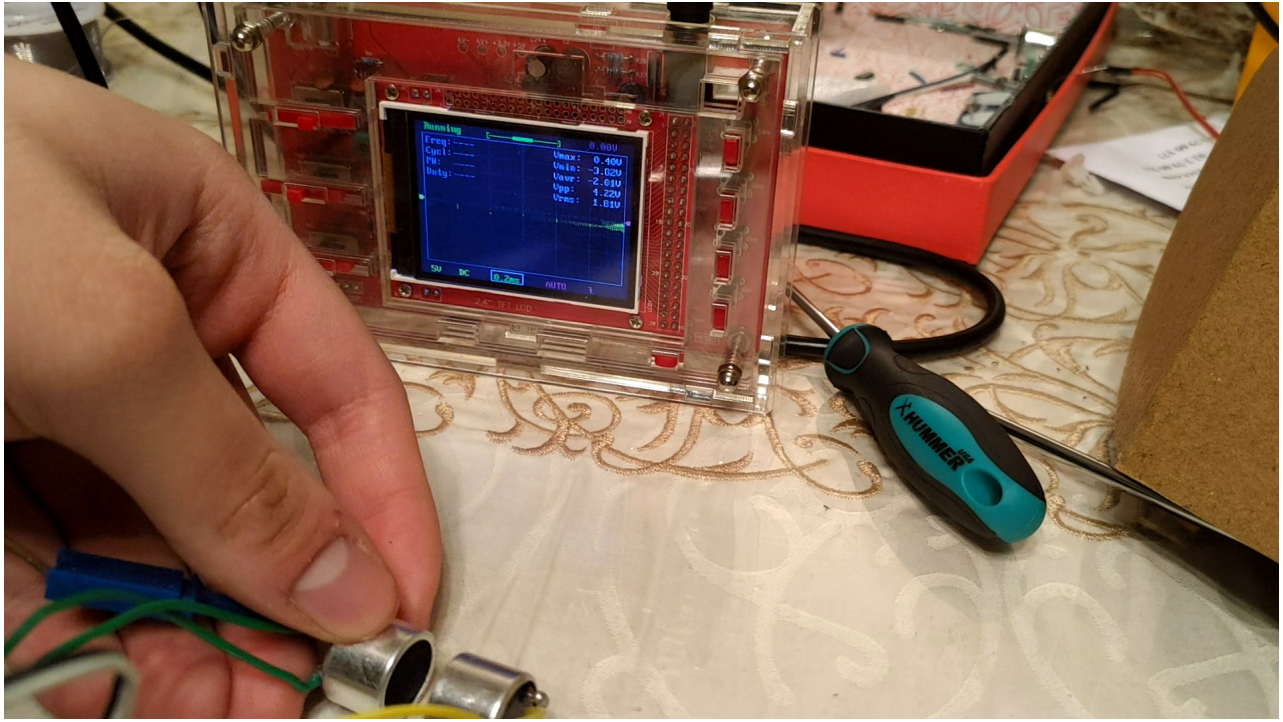
Conversion to Analog



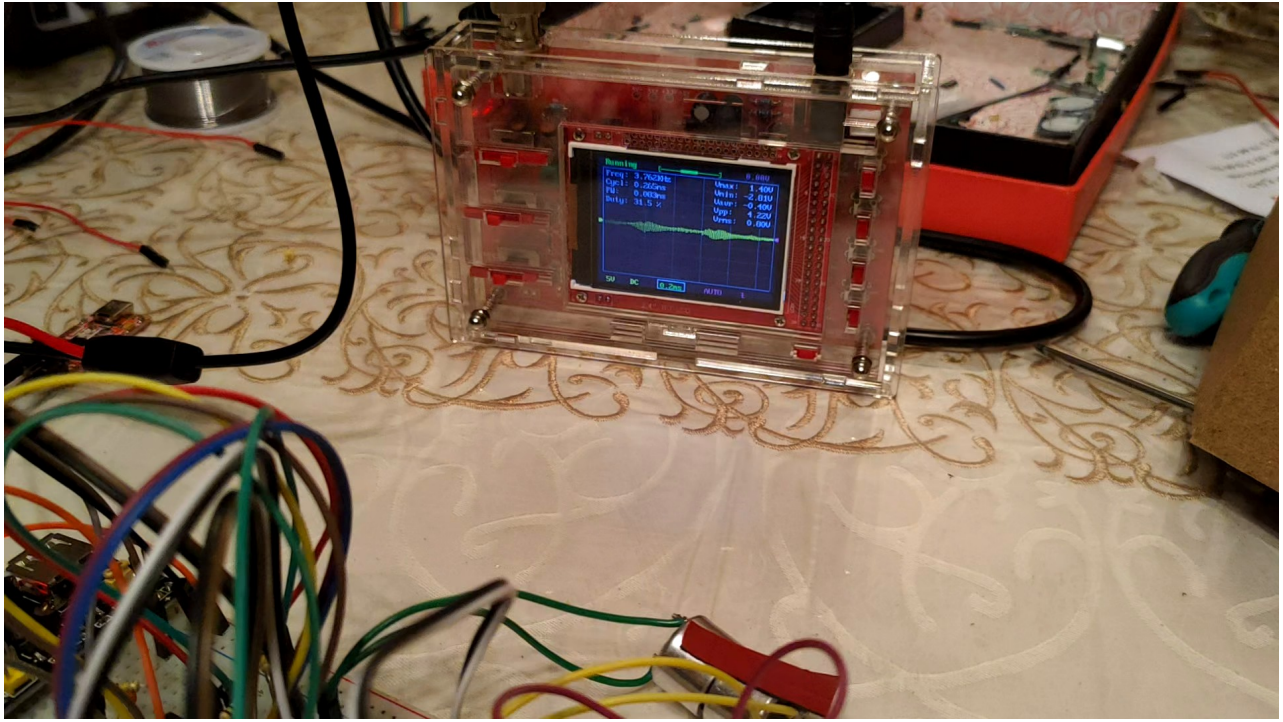
Receive and Filter

- Received signal is unclean and highly attenuated
- Use LM324 op-amps to amplify → filter → amplify signal
- Fine tune with potentiometers

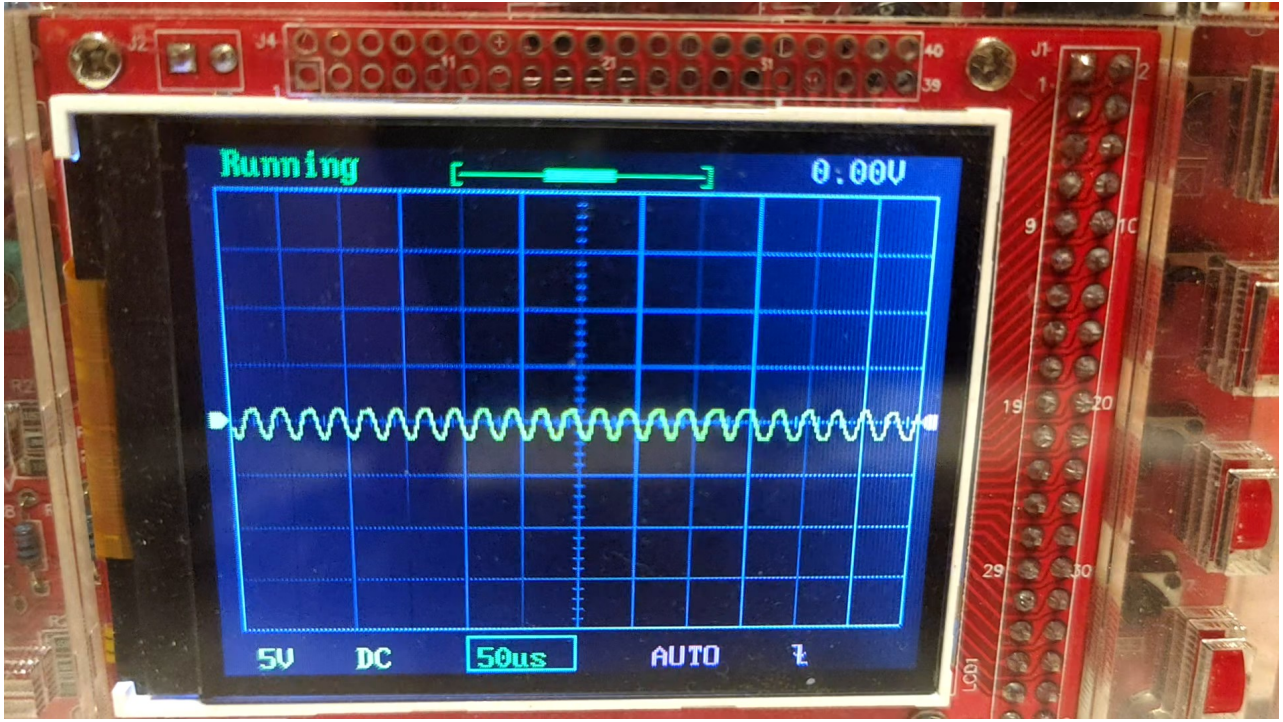
Transducer Recieve



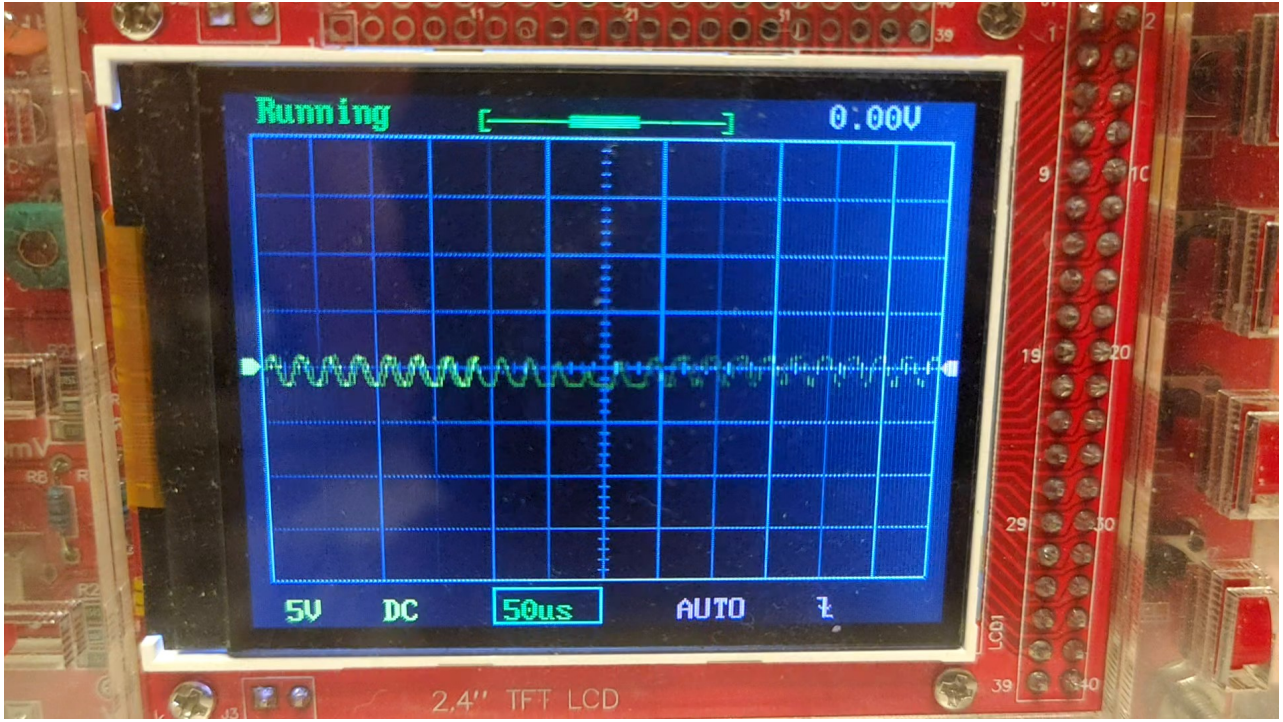
A Testing Signal



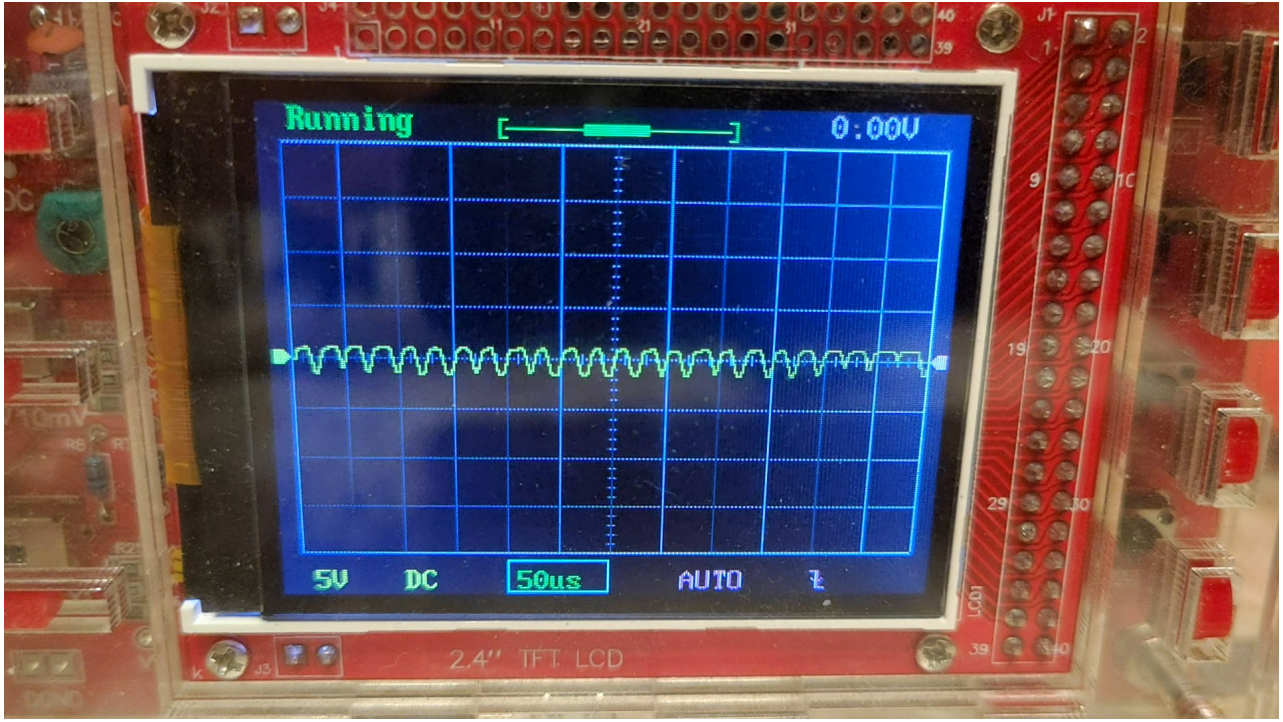
First Amplification



Bandpass Filtering

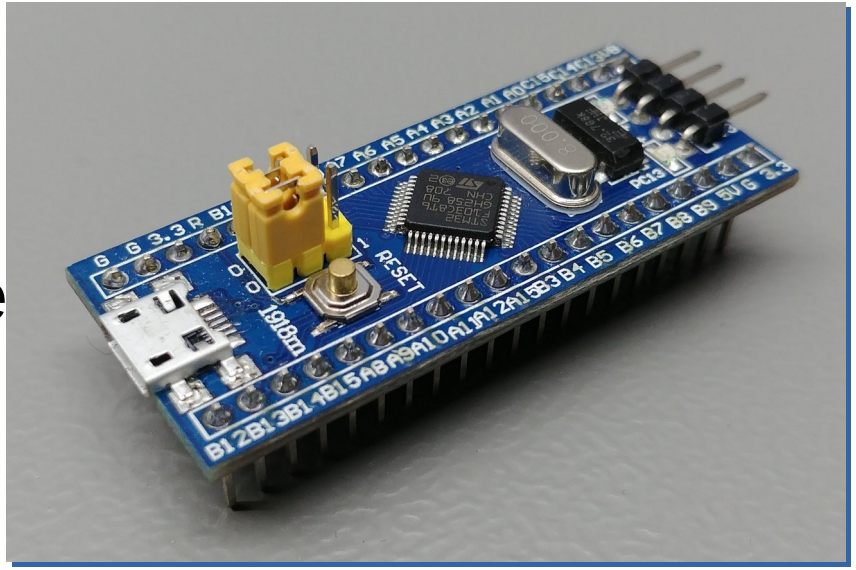


Final Amplification



The Micro Controler

- The STM32F103C8T6, “blue-pill” MCU
- Has built in ADC
- 72MHz clock
- 32-bit core
- Better choice than something like an arduino




```
RAM:   [======    ]  63.5% (used 12996 bytes from 20480 bytes)
Flash: [===       ]  28.8% (used 18864 bytes from 65536 bytes)
```

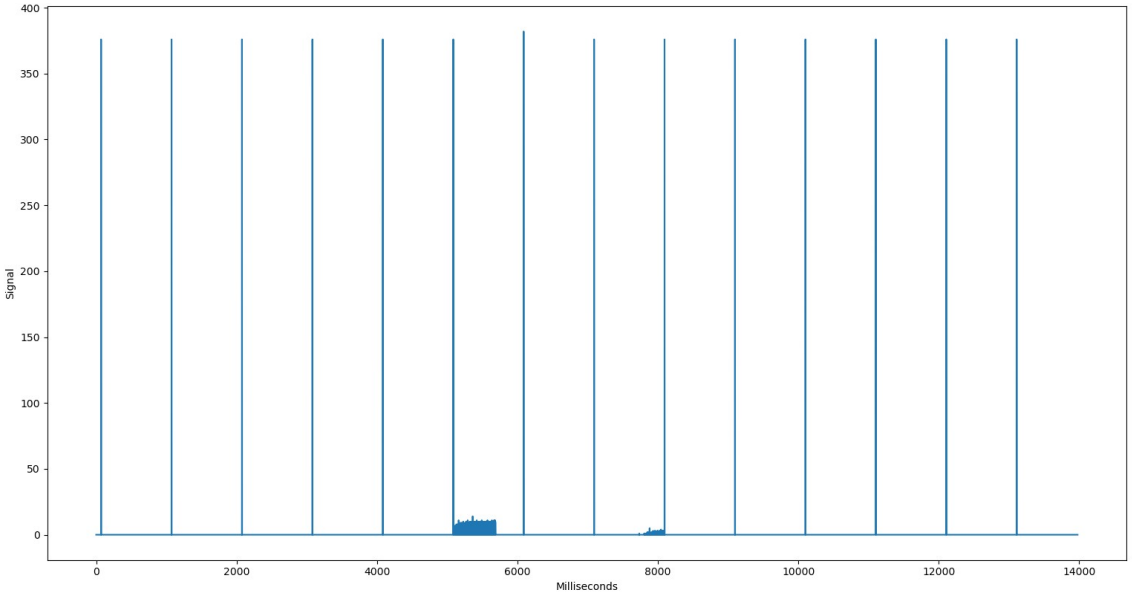
Analog to Digital

- Final filtered and amplified signal supplied to ADC
- 12-bit ADC
- 5MS/s max sampling rate
- Filtering ensures in range reference voltage

The Digital Signal

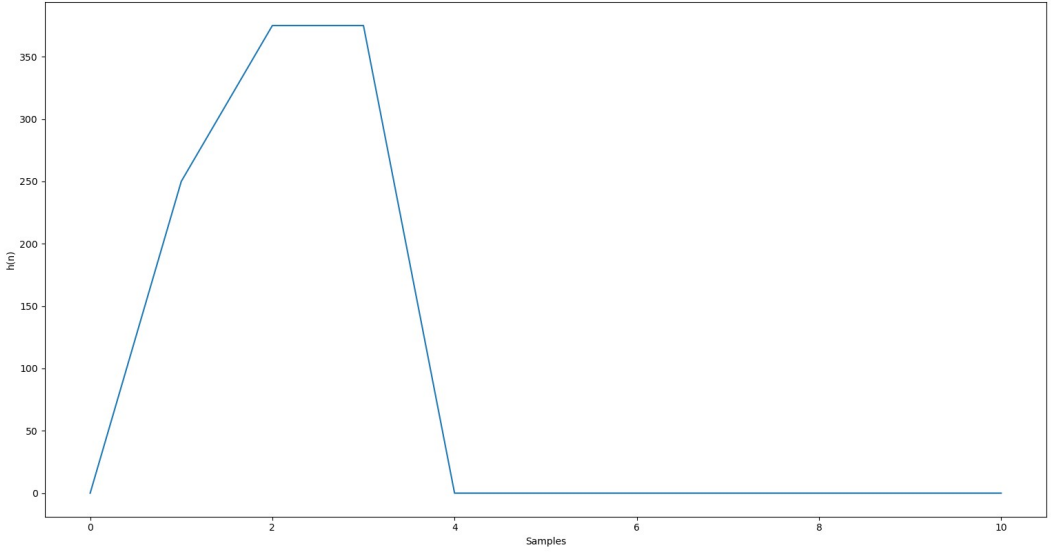
- Shannon's theorem → need 80KHz samping rate
- Keep in mind MCU limitations
- Consider goal of 2cm to 50cm
- Need to store about 1000 samples for this
- Expecting 8 pulses

The Digital Signal



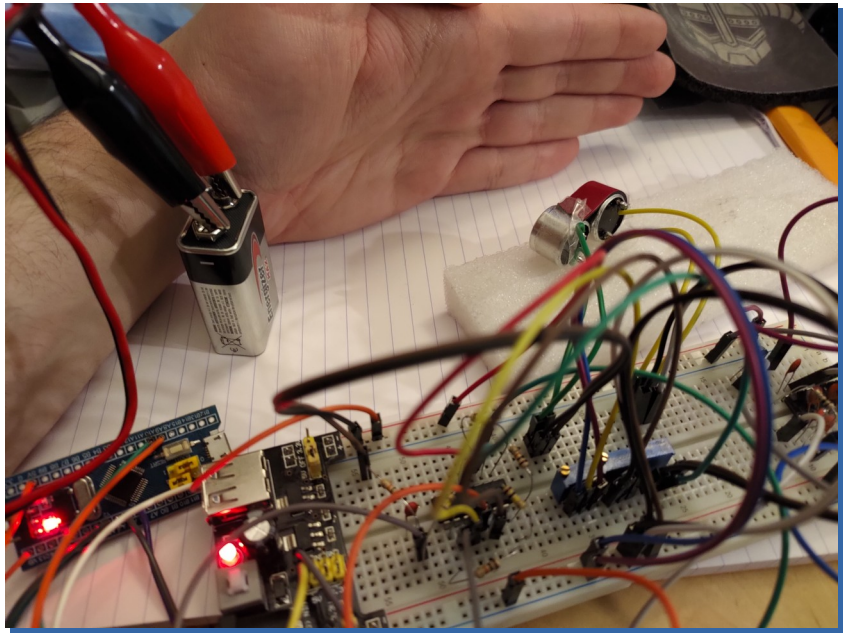
Match filtering

- Using prior information to construct match waveform
- Sample signal for 4ms then process it for ~0.4S



The Measurement

- Get time of flight by finding the peak of the correlation
- Divide by half and speed of sound to get distance



Serial Monitor:

```
74 mm
76 mm
76 mm
74 mm
74 mm
75 mm
74 mm
76 mm
75 mm
```

Possible Improvments and Limitations

- Using a perforated board
- Rewriting program in Native CMSIS or HAL for much faster and more accurate performance
- Further tuning of circuit resistances
- MCU has very limited RAM
- Using more singature waveform
- While HC-SR04 is ~1$, this design is about ~10$

This is DSP!

Thank You!

References

- http://www.pcserviceselectronics.co.uk/arduino/Ultrasonic/electronics.php
- https://www.analog.com/en/design-center/reference-designs/circuits-from-the-lab/cn0343.html#rd-description
- https://uglyduck.vajn.icu/ep/archive/2014/01/Making_a_better_HC_SR04_Echo_Locator.html