# Status Update 02/16-03/01 Underwater Communication: Scuba Chat

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# Goal

To create an underwater transmitter and receiver using an ultrasonic modem

# Underwater Communication Summary

# Motivation

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- Underwater communication is useful for many:
  - Researchers
  - Underwater welders and other industrial workers
  - Scuba divers and underwater cave explorers
- Currently most underwater communication devices are specialized and developed for high budget projects (e.g. miliary)
- We could not find any affordable underwater communication devices on the market

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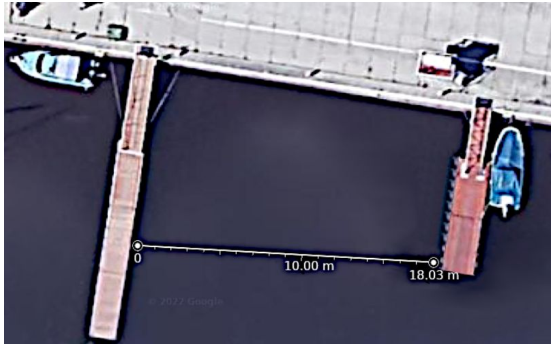
# Existing work

- A 2022 paper (Low-Cost Underwater Communication System: A Pilot Study by Boguslaw Szlachetko, 2022) introduced a prototype for a low cost ultrasonic communicator
  - Used only a microcontroller and commercially available piezoelectric transducer
  - 40 kHz carrier frequency
  - QPSK modulation, 4 kbps
  - Noncoherent demodulation because they did not have PLL block
  - Single transmitter, single receiver




applied sciences

MDPI

*Article*

**Low-Cost Underwater Communication System: A Pilot Study**

**Boguslaw Szlachetko**

Faculty of Electronics, Photonics and Microsystems, Wroclaw University of Science and Technology, Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland; boguslaw.szlachetko@pwr.edu.pl

**Featured Application: The basic field of application of the presented communication modem is underwater robotics. The ultrasound modem would be potentially used to send simple commands and feedback from the robot as well as supporting the robot positioning task.**

**Abstract:** The aim of the paper is to present a simplified implementation of quadrature phase shift keying (QPSK) based underwater communication system. The presented solution addresses the problem of developing inexpensive, compact ultrasound modems able to be mounted on underwater robots. Simplifications introduced into the modulation and demodulation of QPSK signals do not disturb any parameter of the data link. The paper indicates that it is possible to realize modulation and demodulation on a simple microcontroller. Many hints are given on how to use hardware blocks embedded in a microcontroller, such as ADC, DMA, timers, etc. Experiments performed with the prototype modems allow to reach 4 kbps data rate on a distance of about 18 m.

**Keywords:** underwater communication; phase modulation; BPSK; QPSK; ultrasound transducer

# Project Goals

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- We would like to build on the concepts put forward in the Szlachetko paper by using the FPGA and ARM cores on our PYNQ boards instead of only the microcontroller
  - Directly use sin and cos waves instead of approximating with square waves
  - Coherent demodulation using a PLL block
  - Two way communication
  - Front end display with alert LEDs and LCD showing written messages
  - Stretch goal: underwater earpiece using text to speech to read messages aloud in case of murky water conditions
- Long term, if this project was turned into a commercial product the FPGA could be replaced with a custom ASIC

# Applicable Concepts from WES Program

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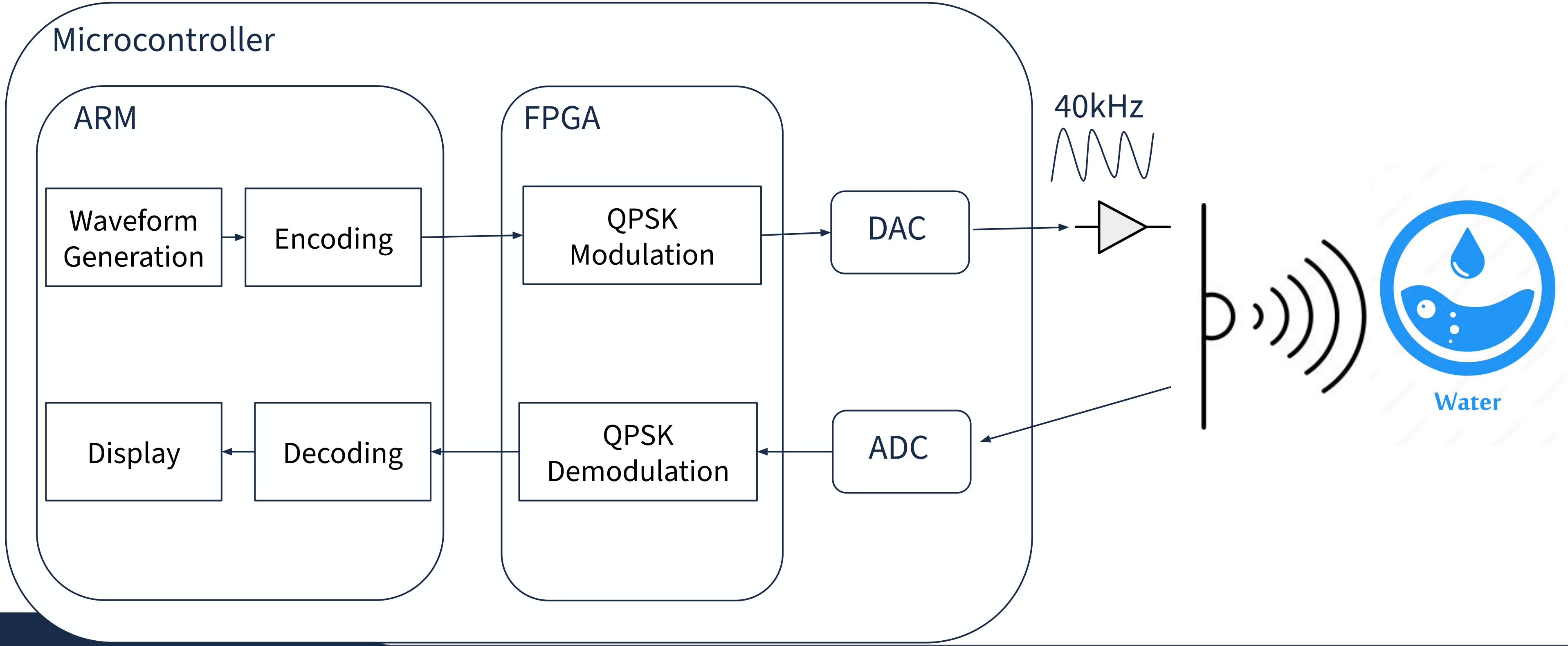
- Digital Signal Processing techniques regarding QPSK signals (Modulation, Demodulation, Encoding, Decoding, Error Correction, PLL, etc) from WES267, WES268A/B
- FPGA development with HLS (CORDIC, DMA, ADC, DAC, etc) from WES237C
- Interfacing with Sensor/Actuators from WES237A
- Utilize TCP/UDP Communication protocols from WES237A*

# System Overview

# Block Diagram



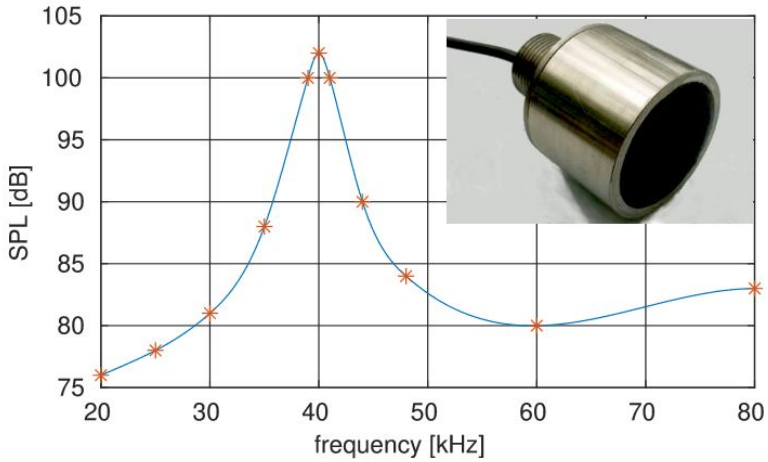
# Potential Hardware Components

- Hurricane Off-the-shell ultrasonic transducer: TD0040 ($85)
- Class-A Amplifier (for better signal integrity) vs. Class-D Amplifier
- PYNQ board or  an FPGA SoC Microcontroller
- Portable Battery
- Waterproof casing (will work with makerspace to 3D print)
- LCD Screen/Display/LEDs

# Theoretical

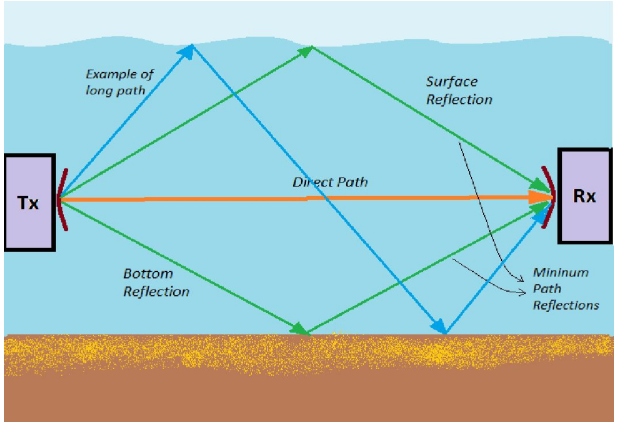
# Modulation

- We intend to use QPSK modulation at a 40 kHz carrier frequency
- We may first test with BPSK as proof of concept
- We won’t be able to use OFDM because the bandwidth available with a commercially available ultrasonic transducer is quite small
- We will apply a RRC filter on both the transmit and receive sides



# Underwater Channel

- Underwater acoustic environments are susceptible to significant multipath propagation effects.
- Open sea environments have refraction effects from different layers of ocean water at different temperatures and pressures
- Constrained environments such as caves, reefs, and swimming pools (our most likely test environment) have very high amplitude delay paths, often higher amplitude than the direct path.
- Our receiver needs to be optimized to handle these multipath effects

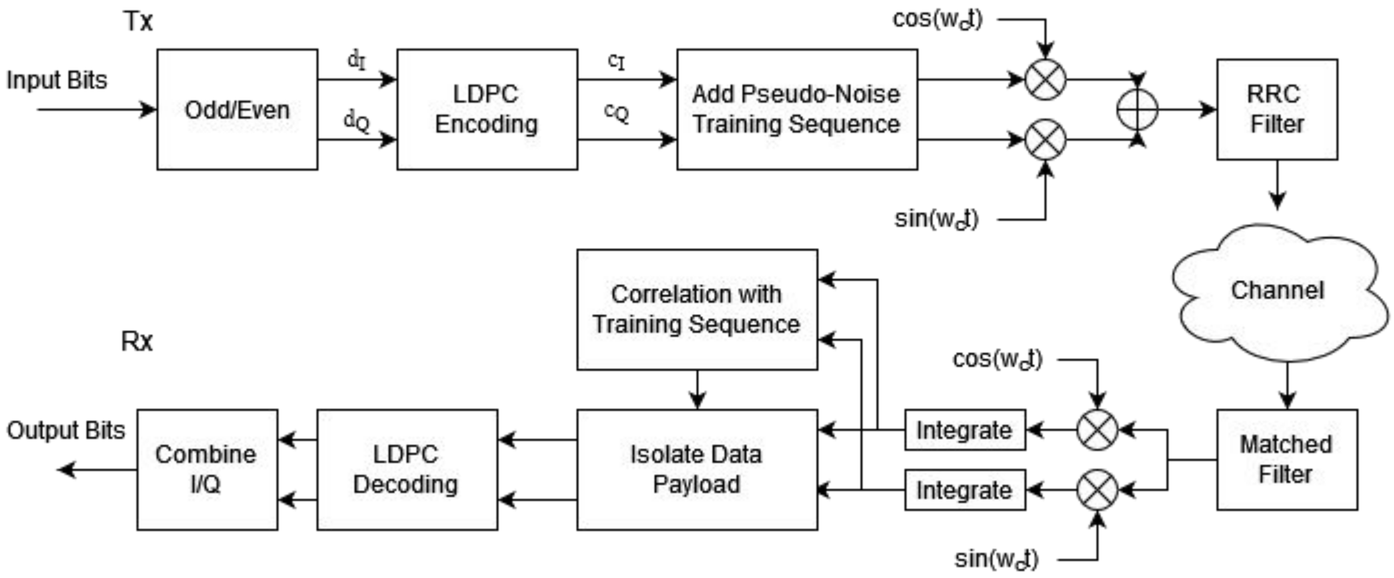


# Proposed Packet Structure

| T | G | Payload |
|---|---|---|
| 64 bits | 32 bits | ~1150 bits |

- We will use a PN training sequence to synchronize our packets and estimate the channel
- A gap period will decrease multipath interference between the training sequence and the payload
- A payload of 1150 bits should be enough to carry 800 data bits (after FEC) for a 100 character written message, or can send a distress alert with plenty of redundancy
- Assuming we are able to successfully use this packet structure with QPSK at 40 kHz carrier frequency, we would be able to send each message in half of a second.

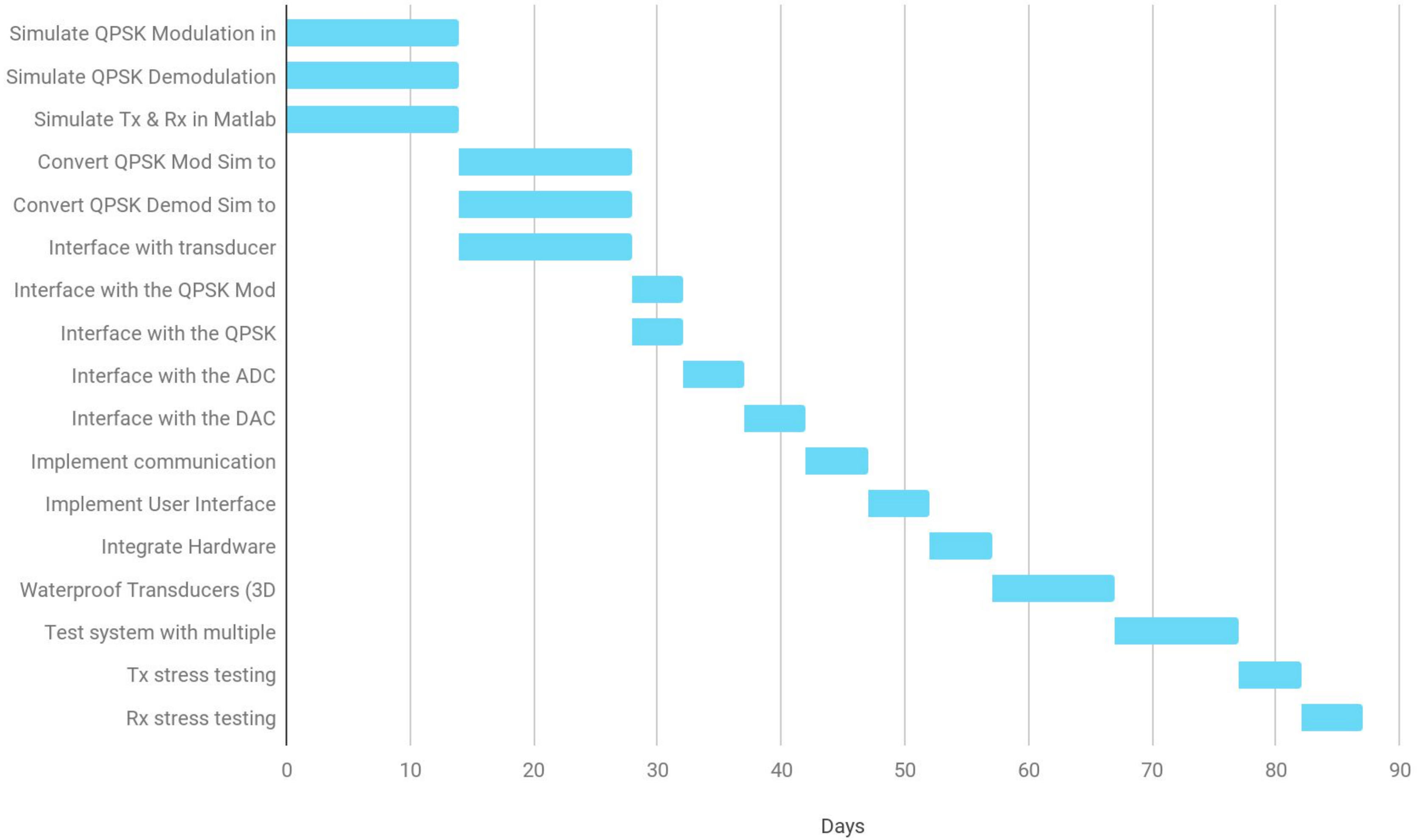
# Simplest Theoretical Design




Next step: add channel estimation + carrier phase estimation

# Milestones

| TASK NAME | START DATE | DAY | END DATE | DURATION* (WORK DAYS) | DAYS COMPLETE* | DAYS REMAINING* | TEAM MEMBER |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| Simulate QPSK Modulation in Matlab | 2/20 | 0 | 3/5 | 14 | 0 | 14 | Sophie |
| Simulate QPSK Demodulation in Matlab | 2/20 | 0 | 3/5 | 14 | 0 | 14 | Sophie |
| Simulate Tx & Rx in Matlab | 2/20 | 0 | 3/5 | 14 | 0 | 14 | Sophie |
| Convert QPSK Mod Sim to HLS | 3/5 | 14 | 3/19 | 14 | 0 | 14 | Lilian |
| Convert QPSK Demod Sim to HLS | 3/5 | 14 | 3/19 | 14 | 0 | 14 | Lilian |
| Interface with transducer | 3/5 | 14 | 3/19 | 14 | 0 | 14 | Sienna & Akshaya |
| Interface with the QPSK Mod IP Core through DMA to PYNQ | 3/19 | 28 | 3/23 | 4 | 0 | 4 | Team |
| Interface with the QPSK Demod IP Core through DMA to PYNQ | 3/19 | 28 | 3/23 | 4 | 0 | 4 | Team |
| Interface with the ADC | 3/23 | 32 | 3/28 | 5 | 0 | 5 | Sienna & Akshaya |
| Interface with the DAC | 3/28 | 37 | 4/2 | 5 | 0 | 5 | Sienna & Akshaya |
| Implement communication protocols between Tx and Rx | 4/2 | 42 | 4/7 | 5 | 0 | 5 | Sienna & Lilian |
| Implement User Interface | 4/7 | 47 | 4/12 | 5 | 0 | 5 | Sienna |
| Integrate Hardware | 4/12 | 52 | 4/17 | 5 | 0 | 5 | Team |
| Waterproof Transducers (3D Print enclosure) | 4/17 | 57 | 4/27 | 10 | 0 | 10 | Team |
| Test system with multiple scenarios | 4/27 | 67 | 5/7 | 10 | 0 | 10 | Team |
| Tx stress testing | 5/7 | 77 | 5/12 | 5 | 0 | 5 | Team |
| Rx stress testing | 5/12 | 82 | 5/17 | 5 | 0 | 5 | Team |

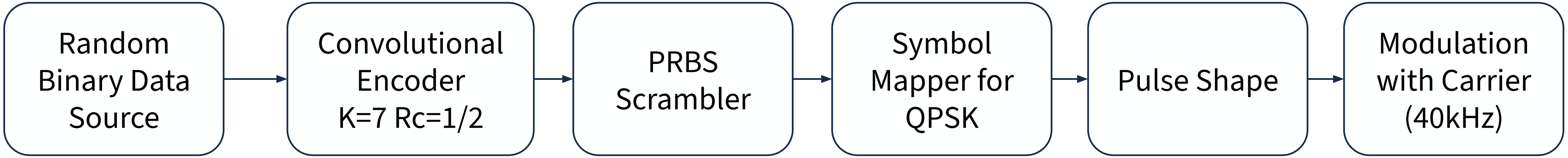

Simulate QPSK Modulation in
Simulate QPSK Demodulation
Simulate Tx & Rx in Matlab
Convert QPSK Mod Sim to
Convert QPSK Demod Sim to
Interface with transducer
Interface with the QPSK Mod
Interface with the QPSK
Interface with the ADC
Interface with the DAC
Implement communication
Implement User Interface
Integrate Hardware
Waterproof Transducers (3D
Test system with multiple
Tx stress testing
Rx stress testing
0
10
20
30
40
50
60
70
80
90
Days

# Progress

Creating Matlab Simulation of Transmitter and Receiver to convert to FPGA code

# Transmitter

# Block Diagram



# Results

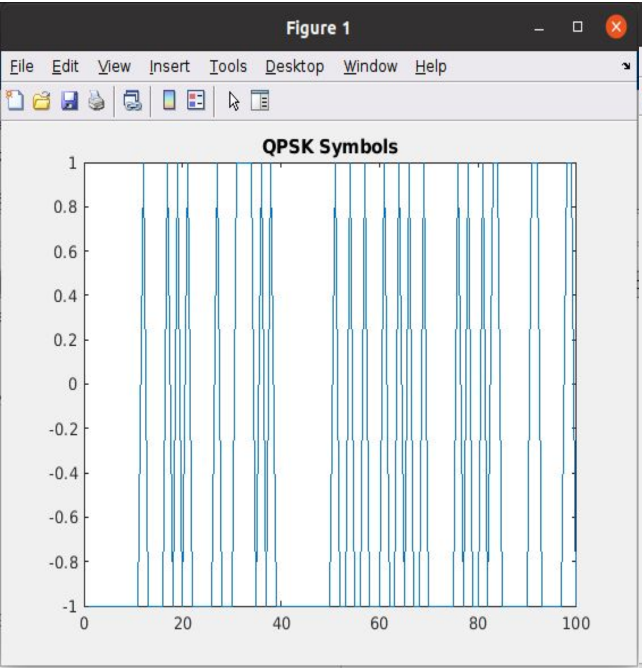


Figure 1
File Edit View Insert Tools Desktop Window Help
QPSK Symbols
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0 20 40 60 80 100

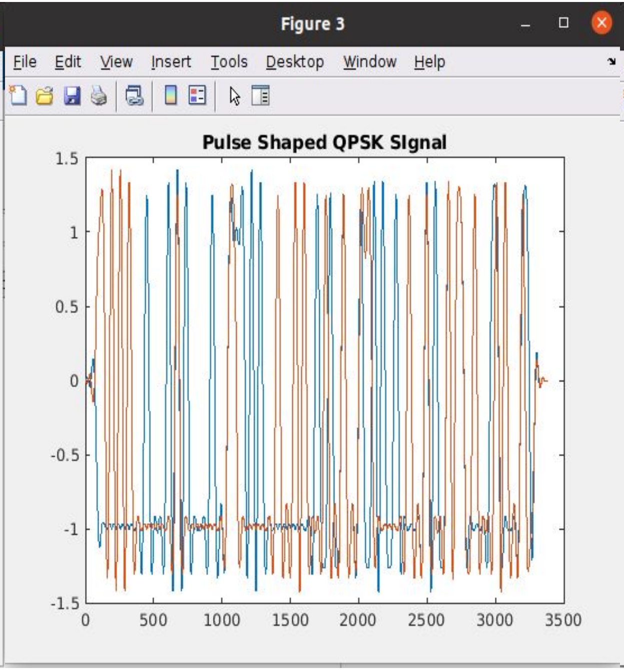


Figure 3
File Edit View Insert Tools Desktop Window Help
Pulse Shaped QPSK Signal
1.5
1
0.5
0
-0.5
-1
-1.5
0 500 1000 1500 2000 2500 3000 3500

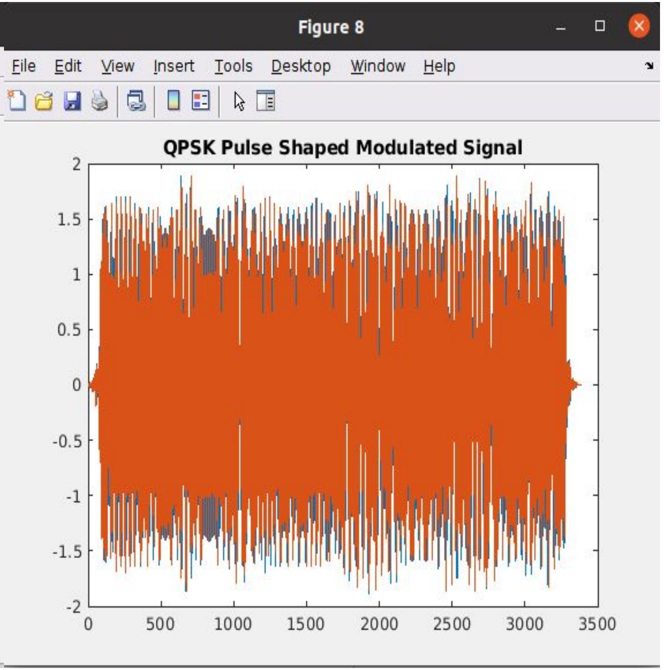
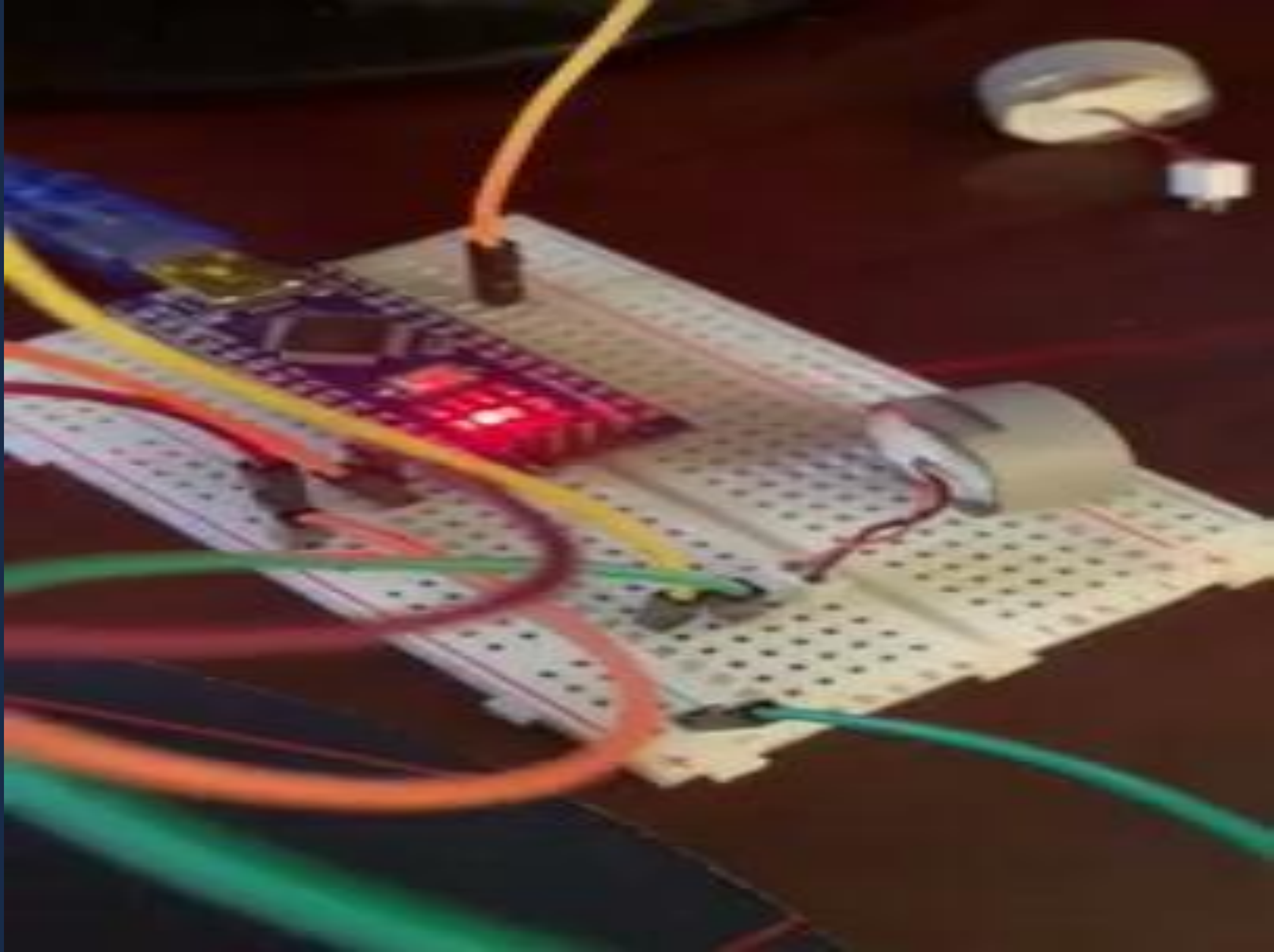
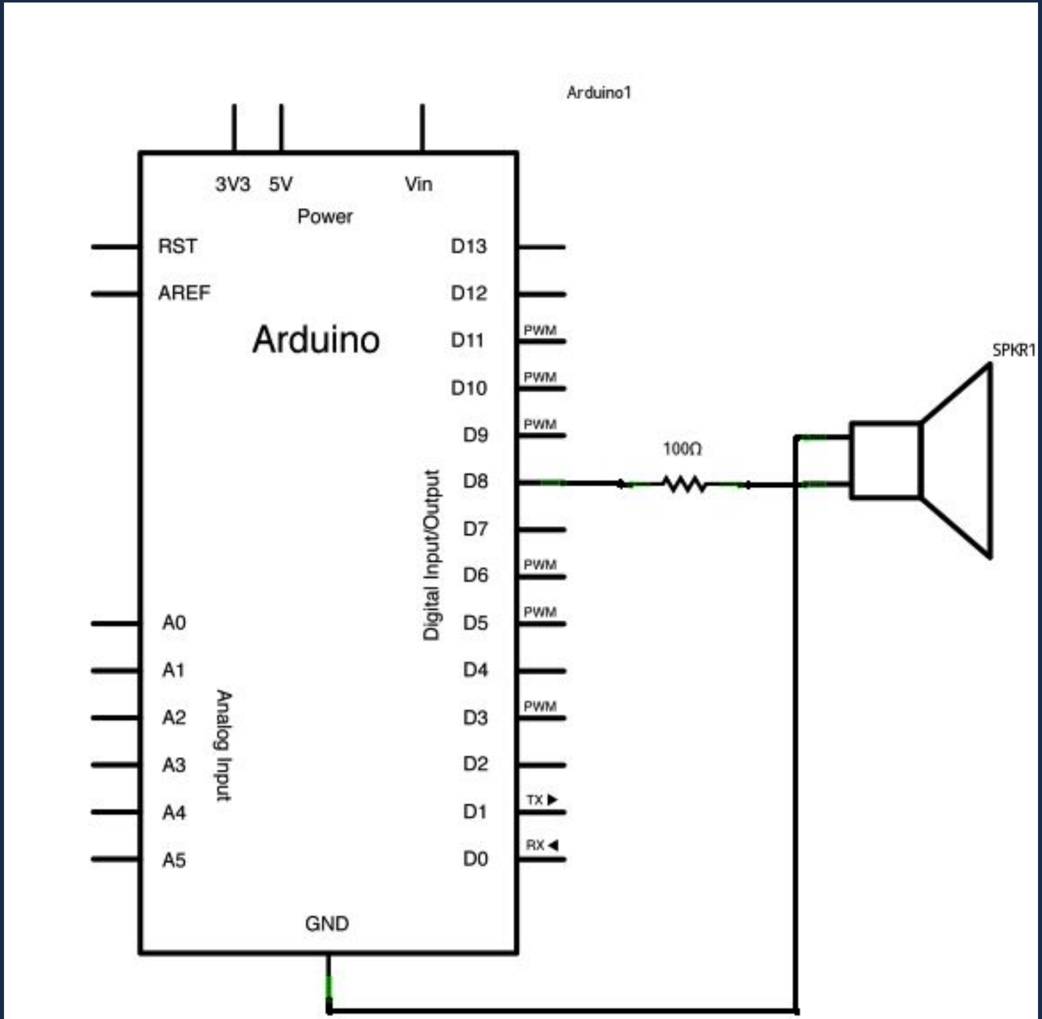


Figure 8
File Edit View Insert Tools Desktop Window Help
QPSK Pulse Shaped Modulated Signal
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0 500 1000 1500 2000 2500 3000 3500

# Tx Music



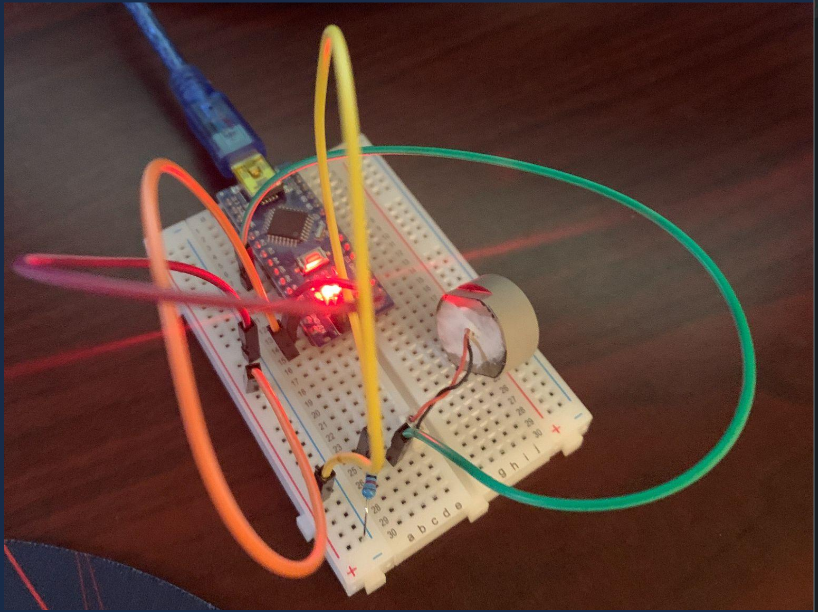
# Tx Schematic

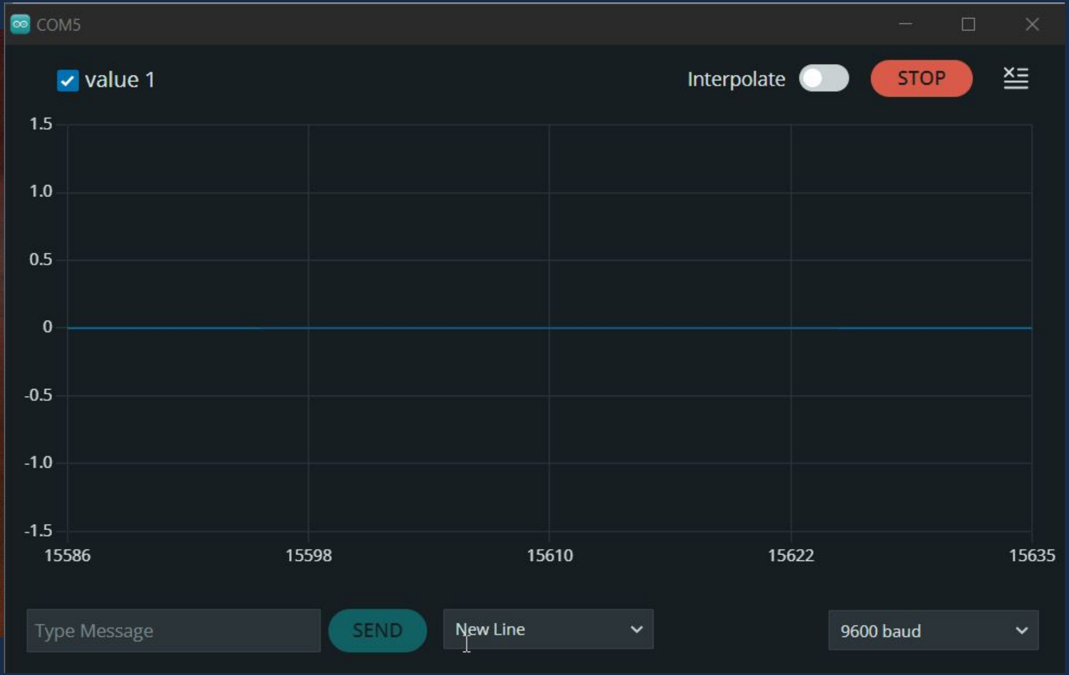


# Channel

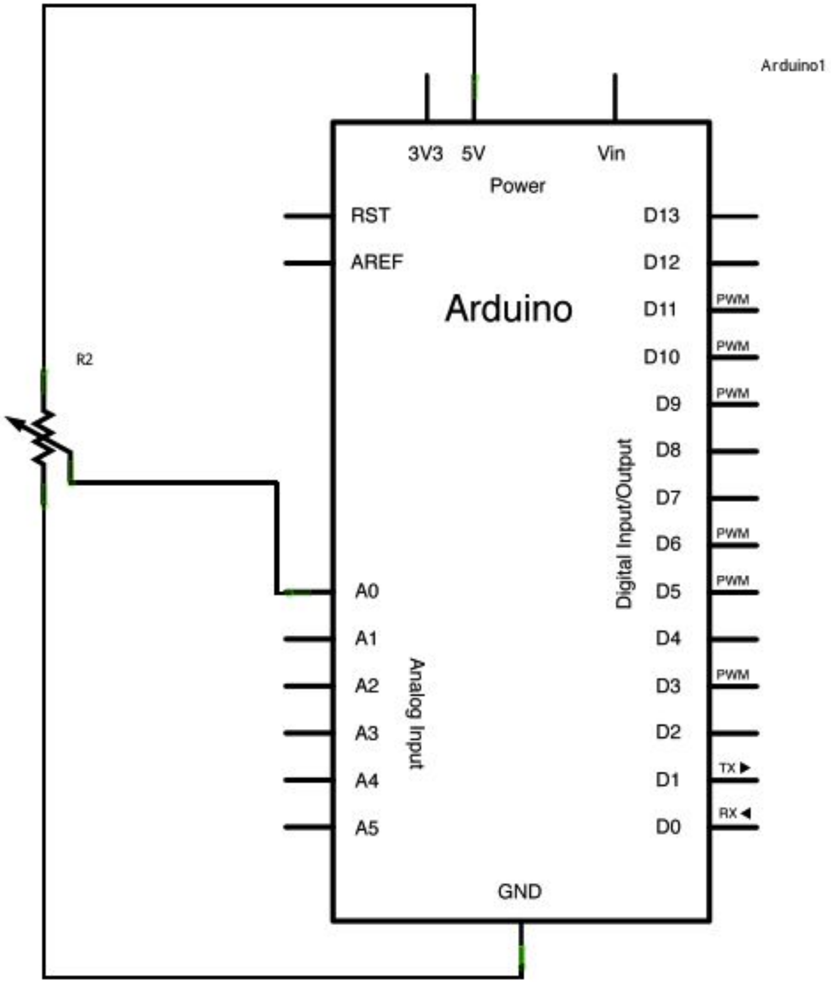
# Receiver

# Rx Serial Input?





# Rx Schematic



# Questions & Concerns

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- Interfacing with the ultrasonic transducer
- Handling contention between two way transmit and receive