Development of a Wireless Remotely Operated Underwater Vehicle

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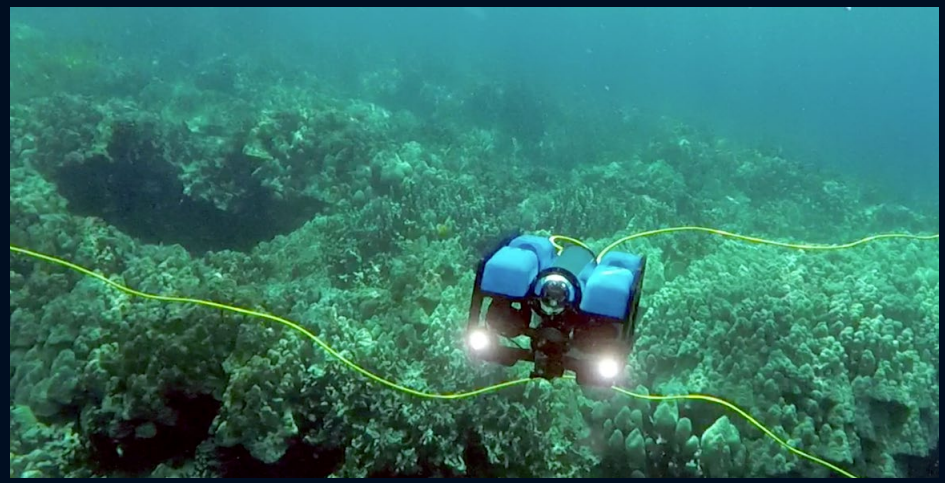
Background

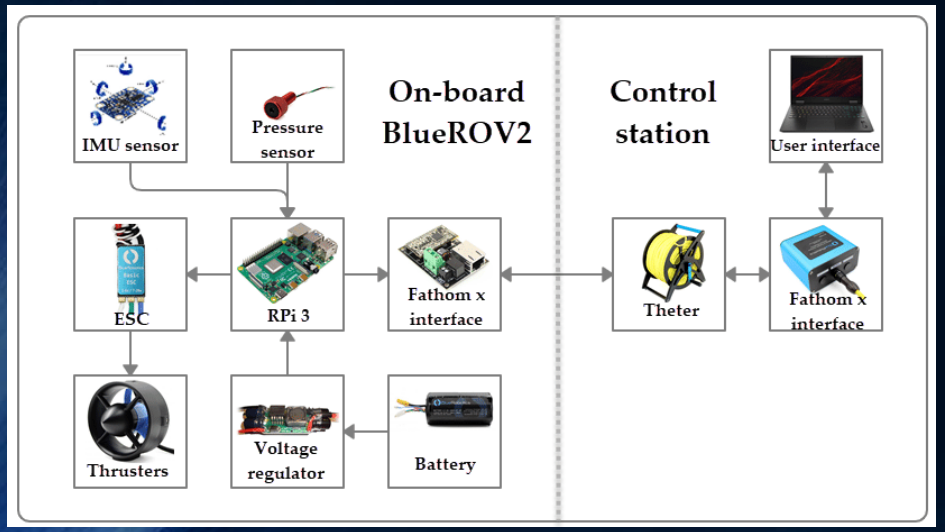


- **Project Goal:** Wireless remote control of a single or a swarm of underwater vehicles to effectively carryout subsea operations e.g., subsea mapping, search-and-rescue etc.

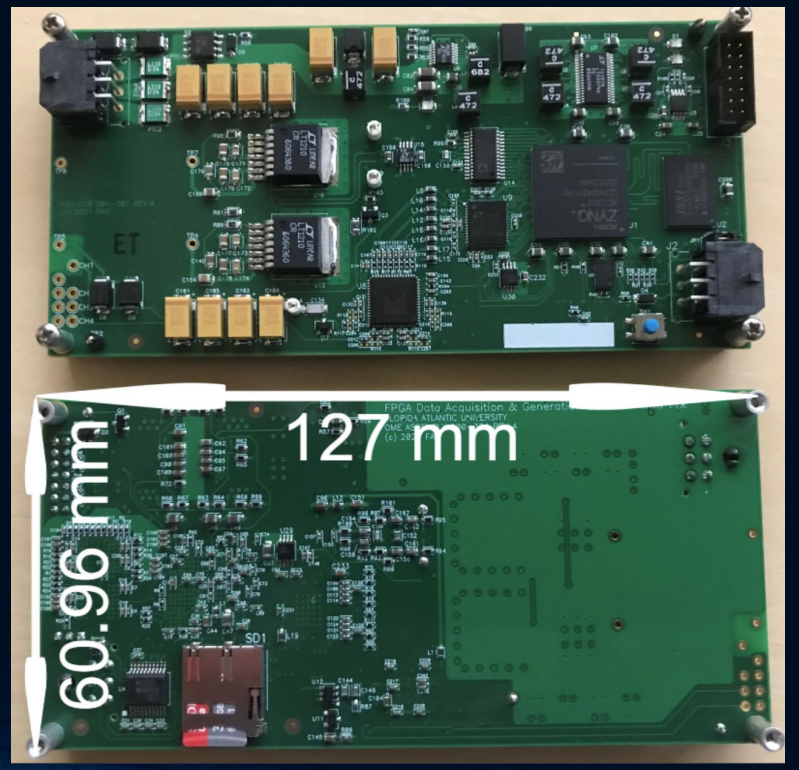
- Tether-based communications are limiting in distance and autonomous capabilities in remotely operated vehicles (ROVs)
- Autonomous underwater vehicles (AUVs) are expensive

In this Project

- Off-the-shelf ROVs: BlueROV2 built by Blue Robotics



- In-house built software-defined underwater acoustic modems

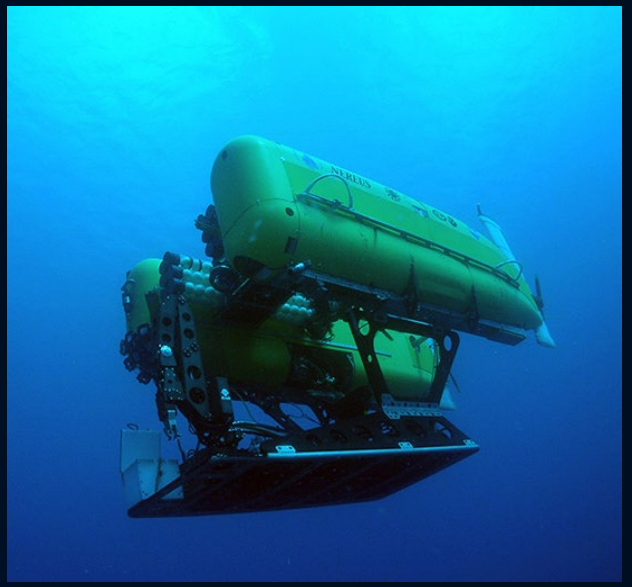


https://bluerobotics.com/store/rov/bluerov2/

https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9905700&tag=1

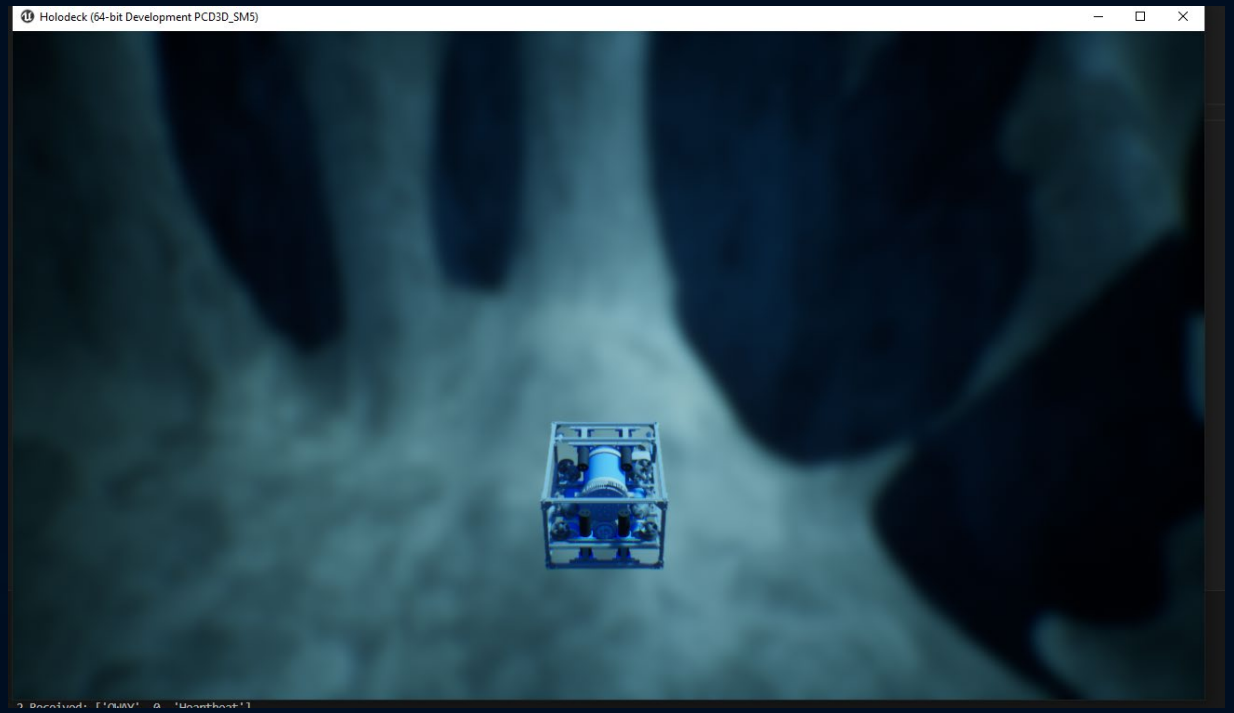
Related Work

- Underwater wireless communication methods
  - Acoustic sound waves (20 Hz – 20 kHz)
  - Radio frequencies (high attenuation)
  - Optics (highly directional)
- Hybrid Underwater Vehicles
- Nereus operated with SONAR or using a tether



Underwater Robotics Simulation

- HoloOcean: Realistic underwater robotics simulator with multi-agent missions
- Based on Holodeck: high-fidelity RL simulator built on Unreal Engine 4
- Objective: Extract information required for simulating the underwater acoustic communication channel between the ROV and the surface-station



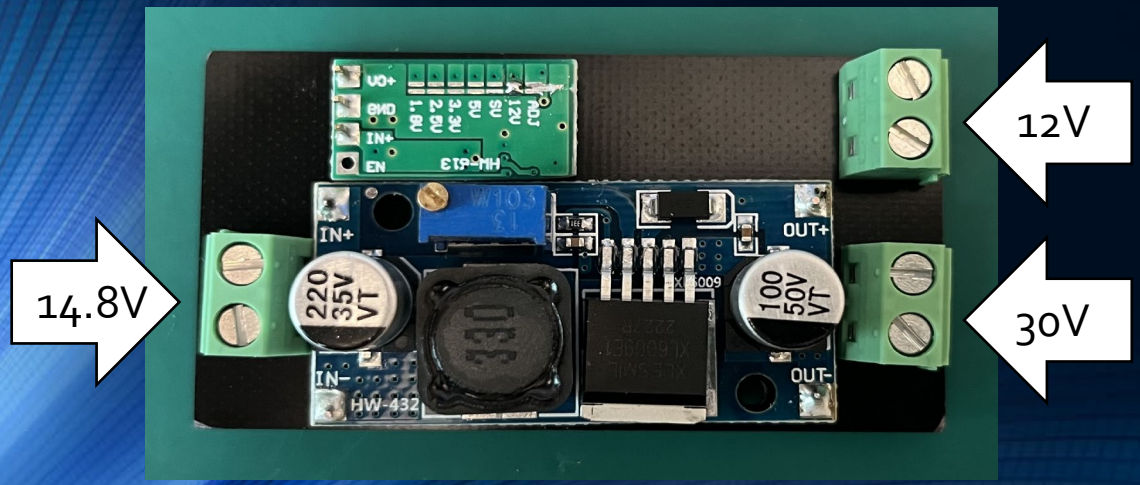
Underwater Modem Power

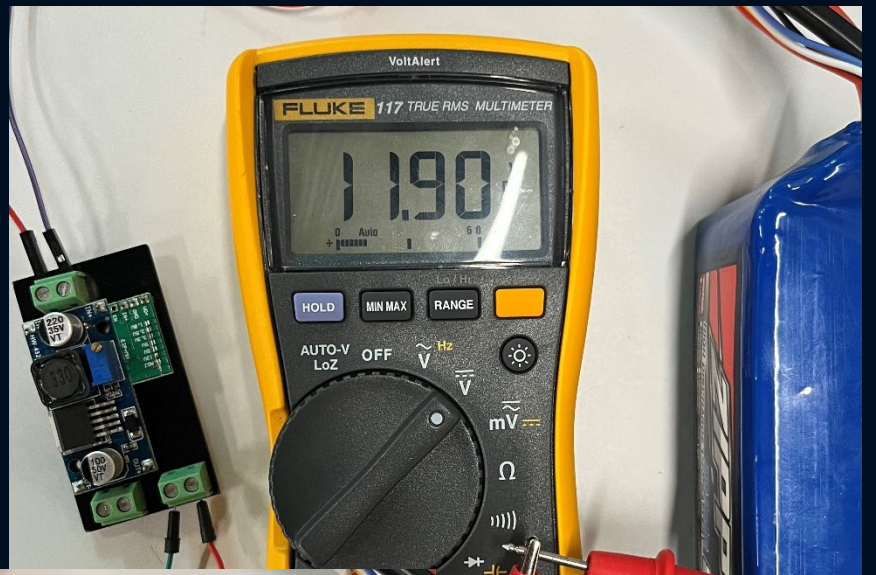
Input:

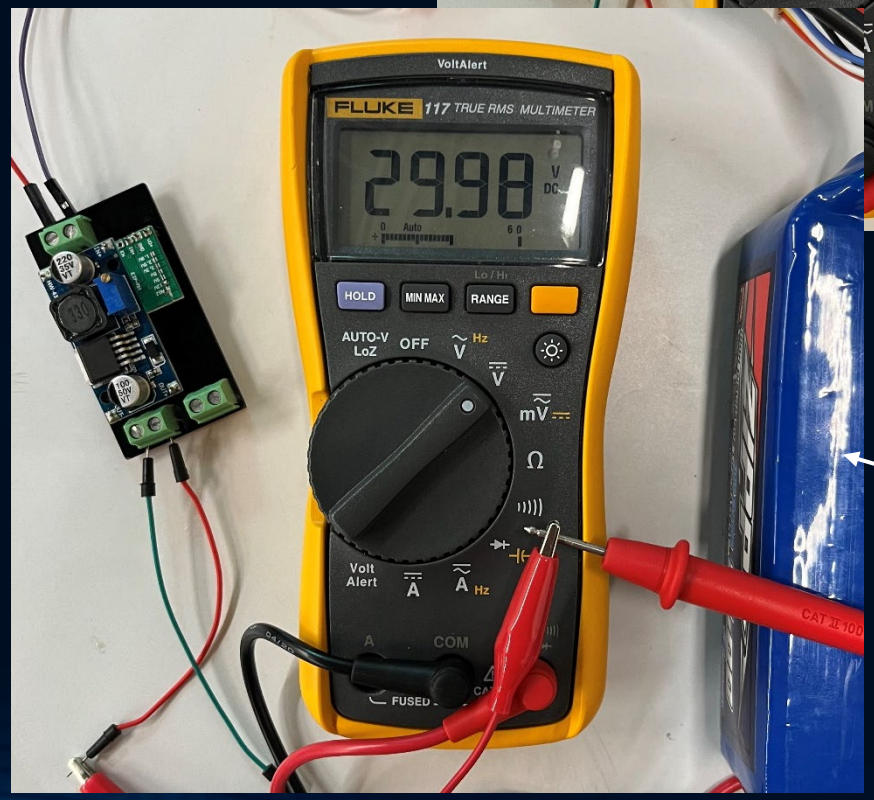
- 14.8V Blue Robotics battery

Outputs:

- 30V – Modem Analog Components
- 12V – Modem Digital Logic







Blue Robotics Battery

Underwater Modem: Signal Modulation

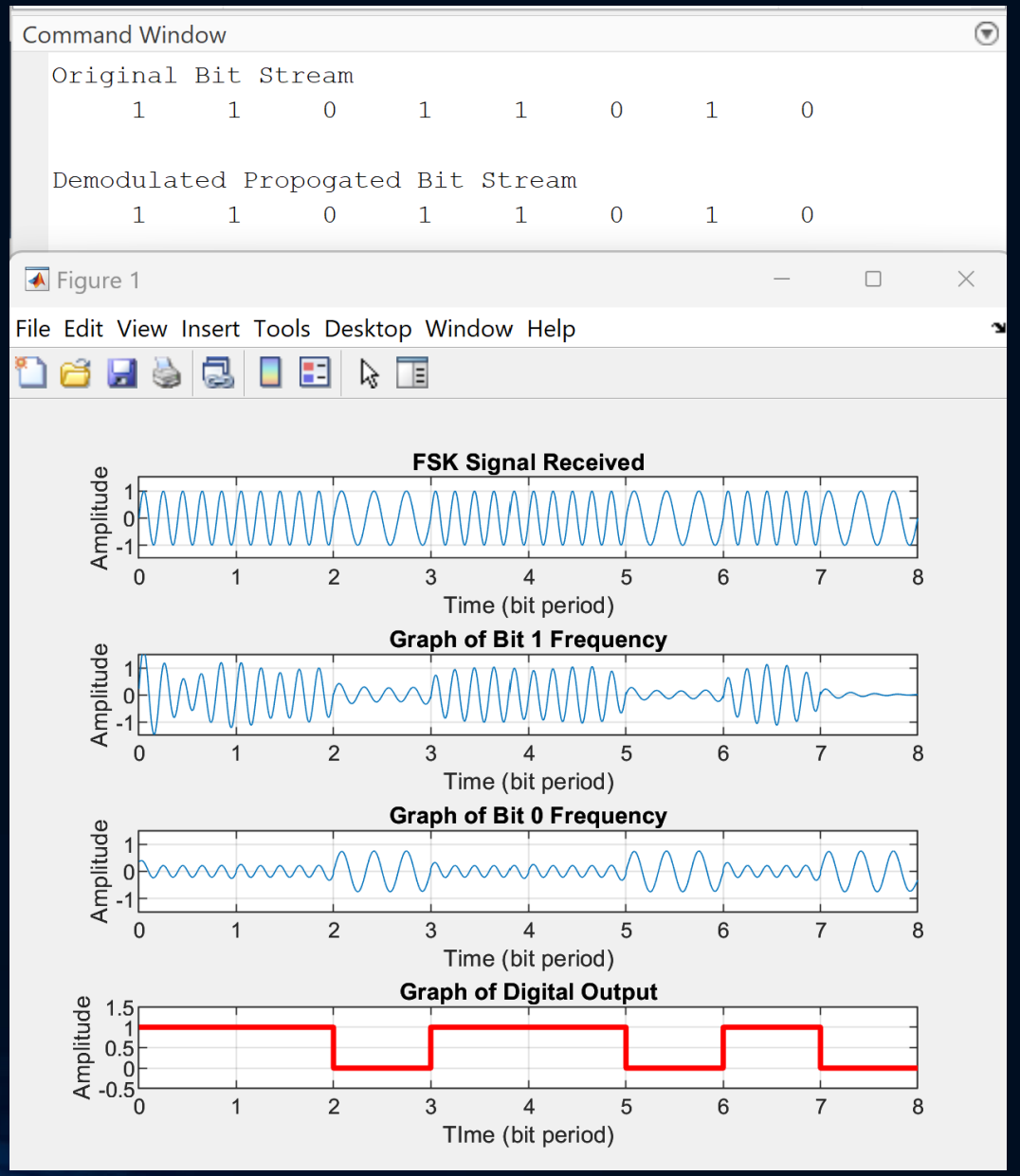
Binary Frequency Shift Keying (BFSK) simulation

- Bit 1 = 148 kHz
- Bit 0 = 152 kHz
- Lowpass/Highpass filter to separate the two frequencies

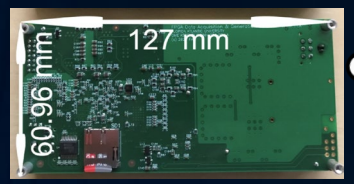
$$\text{For t} = 1 \text{ bit}, \begin{cases} \int \text{Lowpass filter} > \int \text{Highpass filter}, & \text{Output Bit} = 0 \\ \text{Else}, & \text{Output Bit} = 1 \end{cases}$$

Experimental evaluation of BFSK with the FAU modem

Link Distance (m)	Data rate (bps)	Freq.-Hops j	T_g (ms)	$f_j = f_c + j\Delta f$ (Hz)	Δf (Hz)	BW = $\Delta f + 1/T$ (Hz)	BER
2 (Tank)	66.7	0	14	150k	2k	4k	0.0049
2 (Tank)	66.7	0	14	100k	2k	4k	10^{-4}
2 (Tank)	500	16	1	100k	2k	64k	0
2 (Tank)	1000	32	0.5	100k	1k	64k	0
2 (Tank)	2000	32	0	100k	1k	64k	0.1037
5 (Pool)	58.9	0	16	100k	2k	4k	0.00178
5 (Pool)	500	16	1	100k	2k	64k	0.001185
5 (Pool)	500	32	1	100k	1k	64k	0.0047
5 (Pool)	1000	8	0.5	88k	5k	75k	0
5 (Pool)	2000	8	0	88k	5k	75k	0.086
8 (Pool)	25	0	39	100k	2k	4k	0.0082
8 (Pool)	500	16	1	100k	2k	64k	0.0065
8 (Pool)	1000	8	0.5	88k	5k	75k	0.052
10 (Pool)	23.8	0	41	100k	2k	4k	0.006
10 (Pool)	500	16	1	100k	2k	64k	0.042
10 (Pool)	1000	8	0.5	100k	5k	75k	0.35
50 (Harbor)	100	16	9	100k	2k	64k	0.014

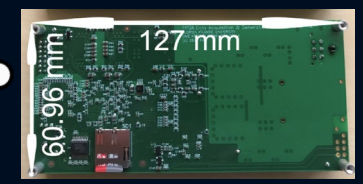


ROV-Topside Computer Wireless Communication and Control Protocol



Topside Computer

1. Heartbeat Message 1 Hz
2. Request to Control
3. Acknowledgement
4. Control Messages
5. System Status Messages 10 kHz

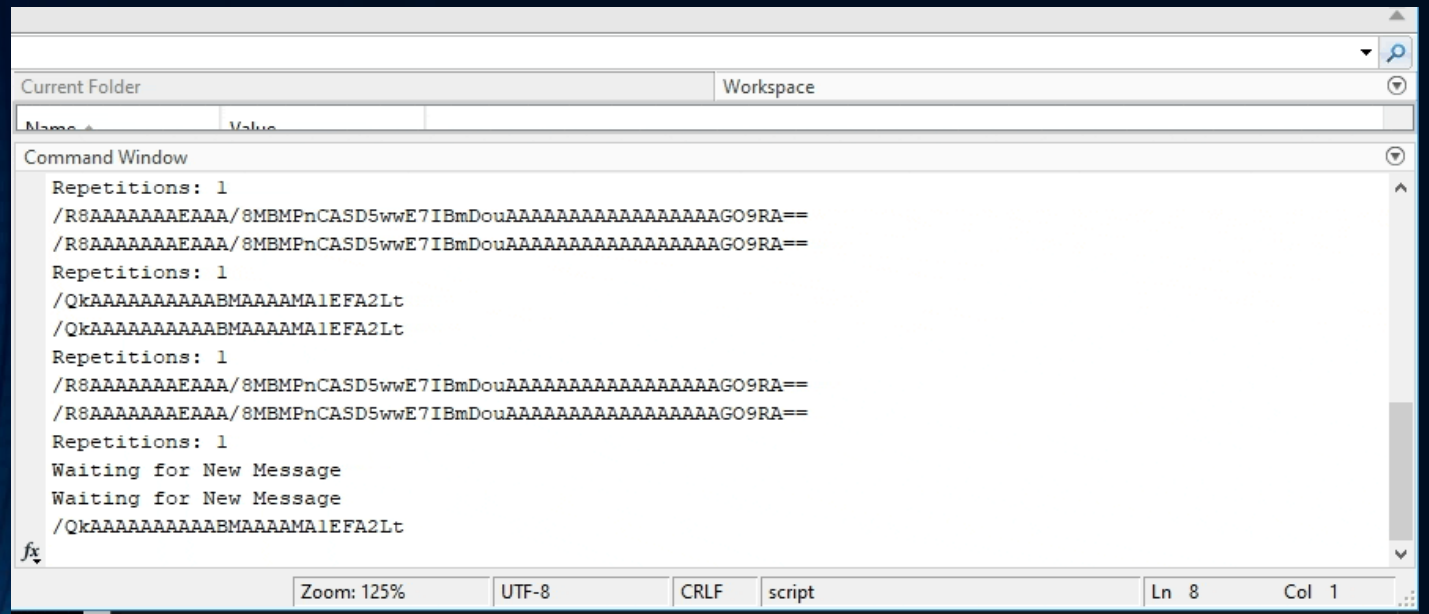


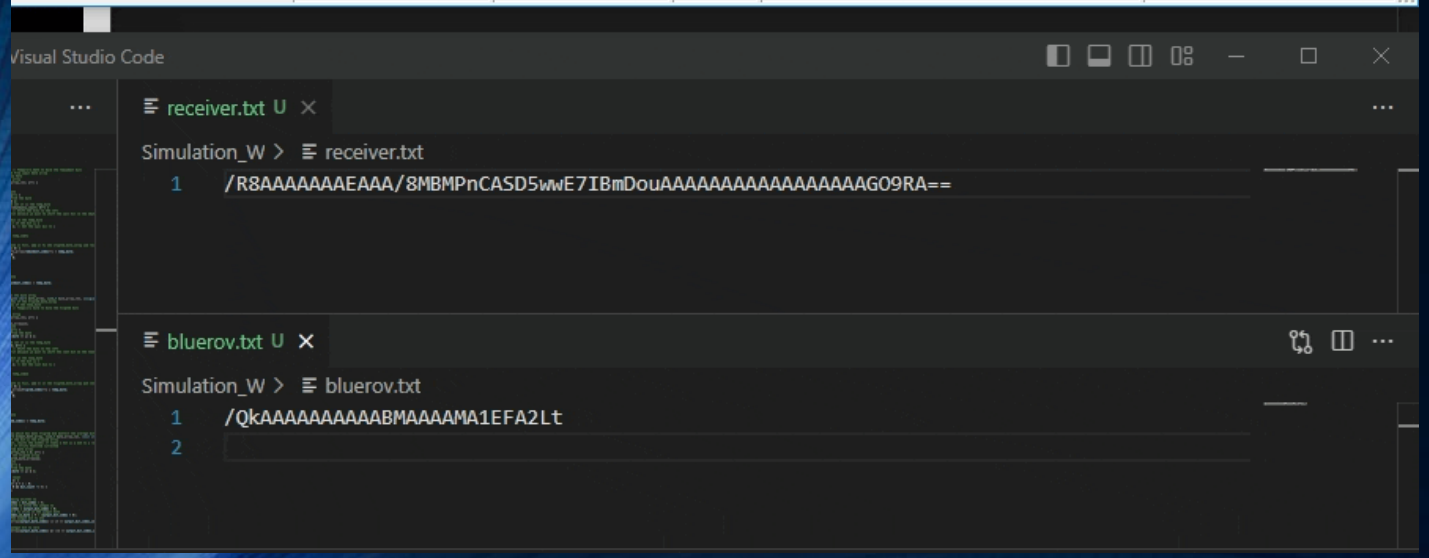
ROV

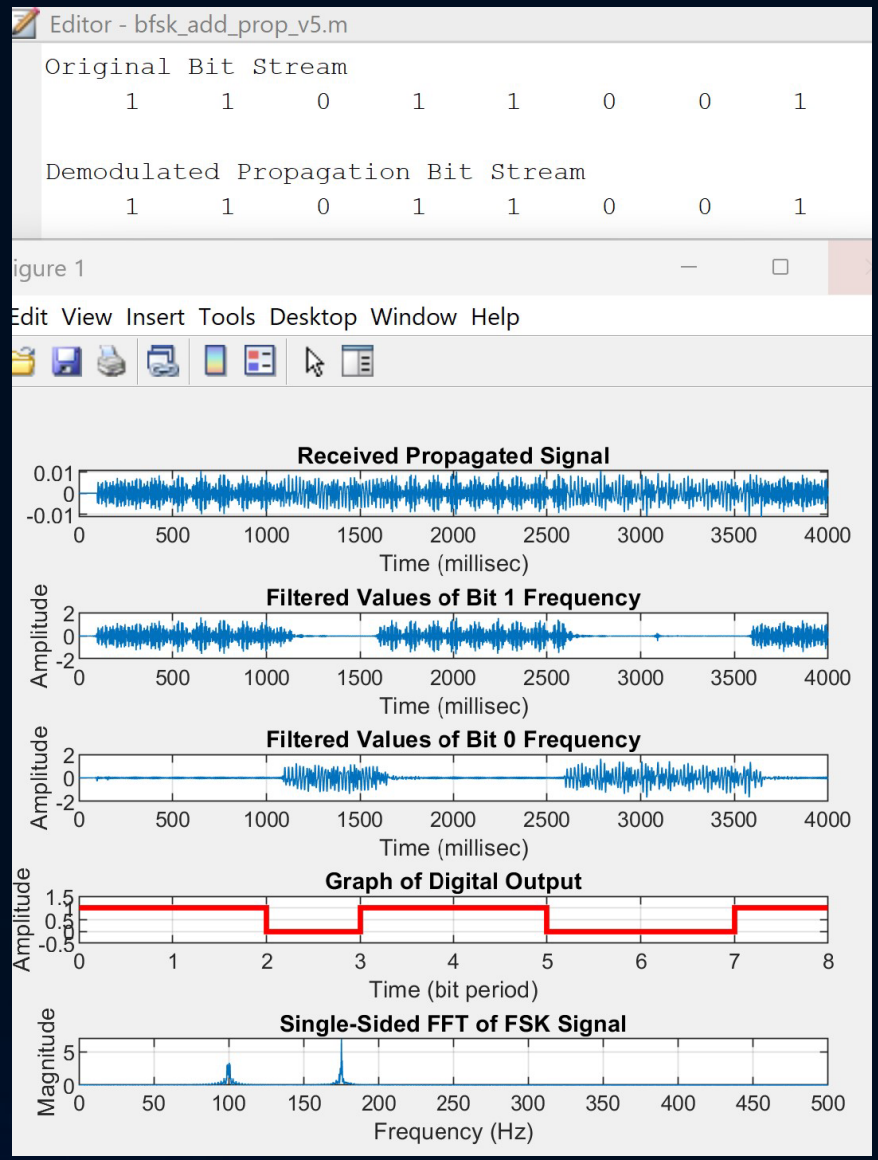
https://bluerobotics.com/store/rov/bluerov2/

https://www.google.com/search?rlz=1C1CHBF_enUS862US862&sxsrf=AB5stBhg6ocvH7L_IZTERLrv87LwKnunaQ:1690490162279&q=QGroundControl&tbm=isch&source=lnms&sa=X&ved=2ahUKEwi5q_nM3q-AAxXJl2oFHW1yCyMQ0pQJegQITBAB&biw=1536&bih=707&dpr=2.5#imgrc=FydDaorqOtolfM

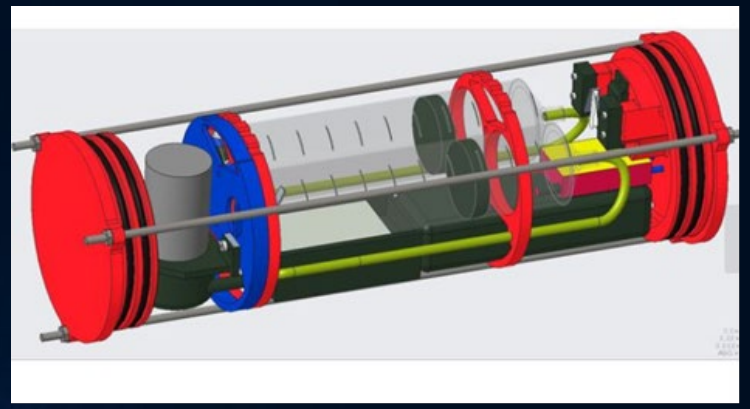
ROV-Top side Computer Wireless Communication Simulation







Towards the Deployment of a Swarm of ROVs



- Smaller – 60% Lighter
  - BlueROV -25lbs
  - NewROV – 10 lbs
- More efficient – 83% Less Power
  - BlueROV - 6 thrusters
  - NewROV – 1 thruster
- Lower Cost – 90% Cheaper
  - BlueROV - 4000 USD
  - NewROV – 400 USD

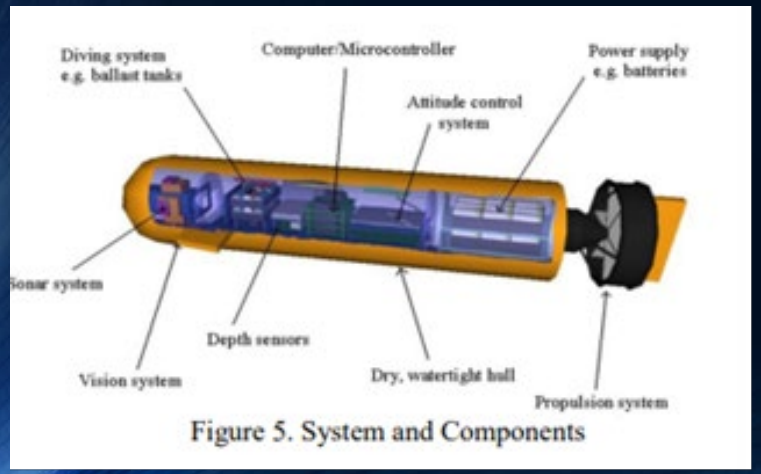
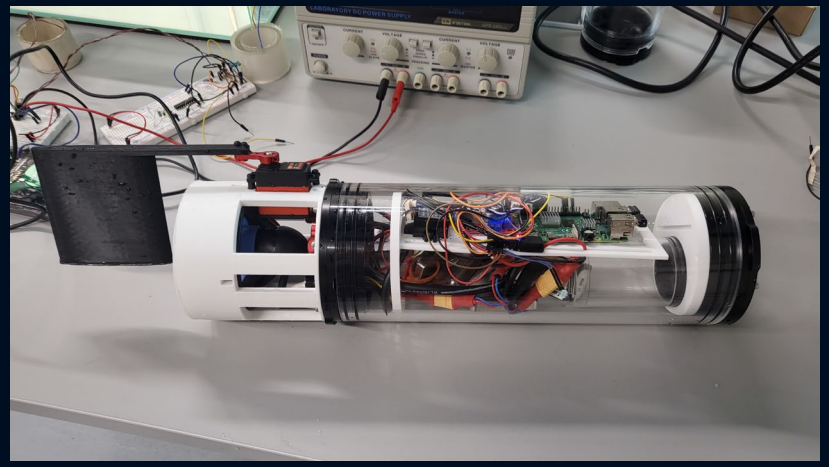
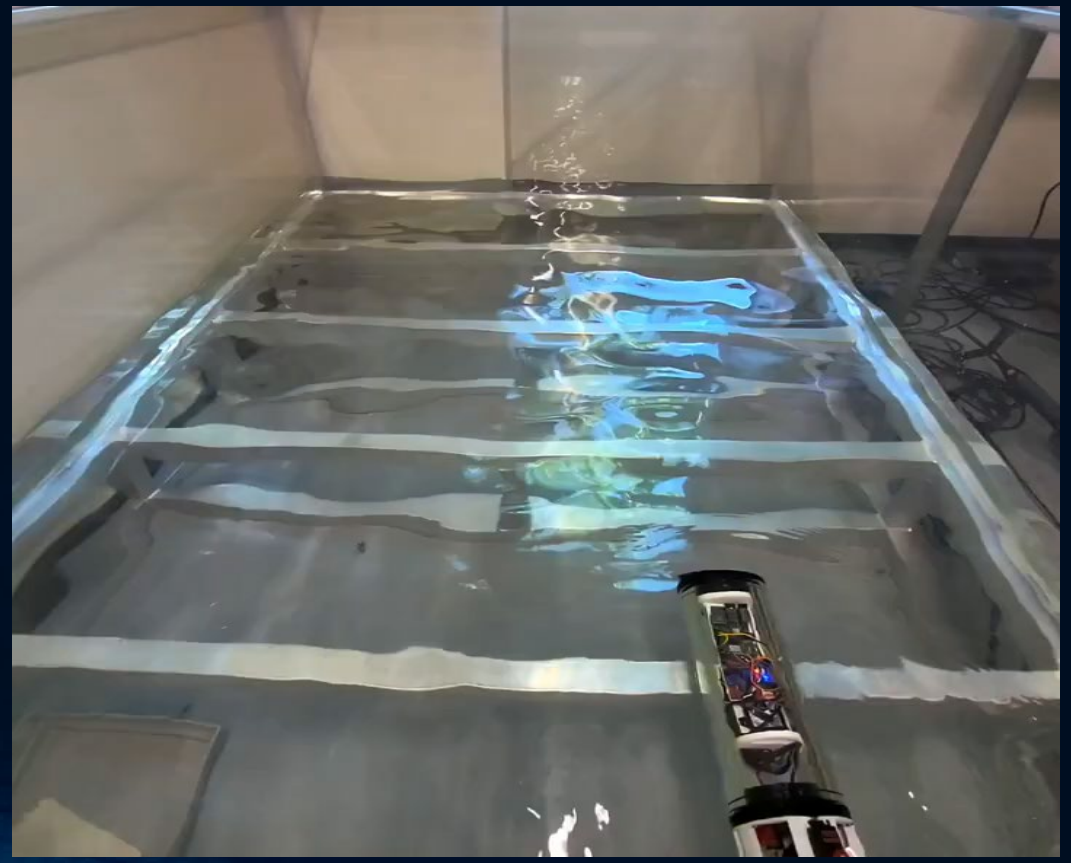


Figure 5. System and Components

New ROV

- Raspberry Pi 4 – onboard computer
- Servo – rudder control for left and right movement
- Thruster & ESC: forward and backward movement
- Ballast Tank: buoyancy control for up and down movement
- Battery- power source
- Acrylic Tube- Outer shell
- 3D Prints- Custom mounting





Conclusions

- Designed, built and tested a power management module to integrate the FAU underwater acoustic modem on-board the BlueROV2
- Simulated a simple non-coherent signal modulation based on Frequency Shift Keying in ideal and underwater channels to test ROV-Topside Computer wireless communication
- Interfaced the BFSK simulations with MAVLink message protocol for bidirectional communication between the ROV and Topside computer
- Extracted environmental information from an underwater robotics simulator (HoloOcean) to increase the fidelity of our underwater comms simulations
- Designed, built and tested a small, low-cost, lightweight ROV to evaluate the feasibility of deploying a fleets of ROVs in the future

Future Goals

- Interface HoloOcean with MATLAB and the MAVLink message protocol to simulate end-to-end underwater robotic communications
- Move from simulation to real-world testing:
  - Test bi-directional communication using the FAU underwater acoustic modems
  - Test ROV-to-ROV and ROV-to-Topside communication
- Test alternative swarm messaging protocols e.g., using Robotic Operating System (ROS)
- Test high-speed resilient underwater acoustic communications based on OFDM and CDMA