Pinless Subsea Connector

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Abstract

Autonomous underwater vehicles (AUVs) are used for surveying and data acquisition of underwater environments. These vehicles can reach up to thousands of kilograms and exist up to 6000m below sea level. As a result, the cost to physically deploy and withdraw these devices is large. Subsea docking stations are used to charge and collect data from AUVs. The current standard in the field for facilitating connections between the docking station and AUV are wet mate connectors. This technology involves a pluggable electrical connector that can make/unbreak connections underwater. However, wet mated connectors have limited mating cycles which introduce the need for routine replacement and maintenance.

We are proposing the design of a pin-less connector with zero physical electrical connections or latches in order to increase the life-time of the connection and reduce cost. The pin-less connector also provides high tolerance in terms of rotational misalignment. In other words, the AUV can connect in any orientation to the docking station. This increases the speed of connections and reduces mechanical deterioration of the connectors.

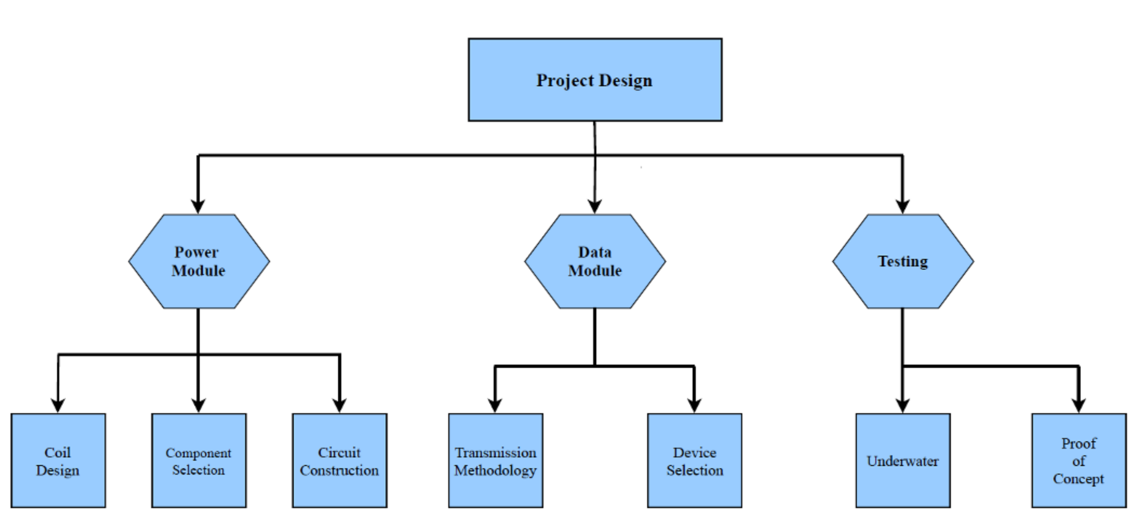
AUVs can store terabytes of data and anywhere from 0.6kWh - 45 kWh of energy; for this reason a high power and high data rate solution are proposed in order to decrease the downtime of AUVs.

OBJECTIVES

The main objectives for this project were to create a connector which did not require a physical, electrical interface in order to mate. In order to sustain the needs of an AUV, this connector must deliver high power and high data rate. The engineering specifications as negotiated with the client are summarized in the table below.

Requirement	Engineering Spec	Importance
Pin-less interface	0 – 10 mm distance	Critical
Pressure Tolerance	< 5” diameter	Moderate
Compatible with existing technologies	1 transmitter/receiver pair per plug/socket connector	Moderate
Power Efficiency	80% ideal efficiency	Critical
	Seawater gap 0-10 mm	Critical
	> 100 W input power	Critical
Data Performance	> 10 Mbps	Critical
	BER < 10e-9	Moderate
Scalable to higher performance	Design plans for scaling to 350W and 1 kW	Moderate
	Design plans for scaling to 100 Mbps and 1 Gbps	Moderate
Low Budget	$2000	Critical
Input and Output voltage	Input Voltage :48 V_{DC} Output Voltage: 36-48 V_{DC}	Moderate

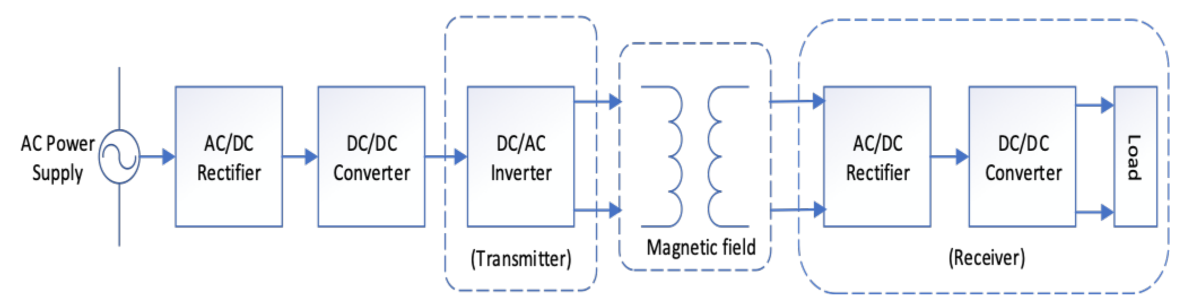
The project was split into three parts as shown in the work breakdown structure below. The largest focus for this project was the power module and formulating a suitable coil design. Subsequently, the focus was shifted towards the data module in which the primary goal was module viability and existing solution investigation. Finally, the testing and integration of both modules was conducted in order to deliver a proof-of-concept.



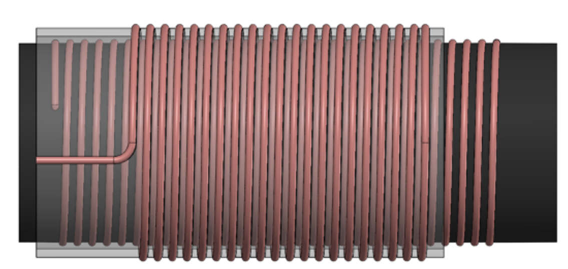
MATERIALS & METHODS

Our proposed and implemented solution was split into two distinct modules: wireless power transfer and wireless data transmission. In this way we individually tackled our goals of 100W with the 'Power Module' and 10+ Mbps with the 'Data Module'.

The power module system architecture is shown below. In general, the scope of this module covered (1) the design of a DC:AC switching circuit, (2) coil design for wireless transmission, and (3) signal rectification and DC:DC conversion to suitable load voltage.

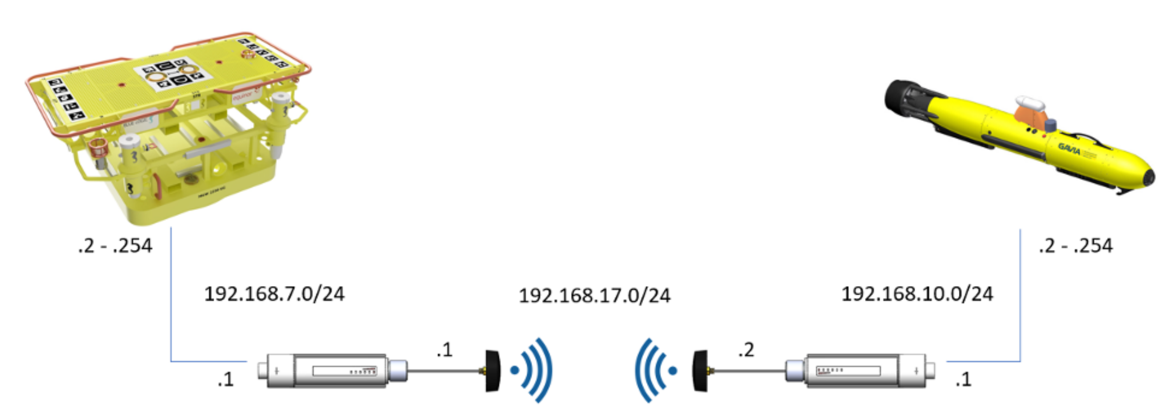


The transmitter side electronics consist of the DC:AC inverter composed of three parts: (1) 555-timer circuit for PWM generation, (2) gate-driver circuitry, and (3) an H-bridge. Together this created a switching circuit which alternated the polarity seen by the primary-side coil, of the input DC voltage. We chose to energize our coils using a square wave input because the efficiency losses associated with filtering to a pure sine were greater than those associated with a square wave driving signal. The receiver side electronics consist of a simple diode-bridge rectifier and a DC:DC converter to step the voltage to the required input voltage of the custom application.



The coil design was optimized for coupling efficiency for our specific application. Typically, the recommended coil topology for underwater wireless power transfer is flat spiral coils. Given that our connector size is not constrained in the axial direction, a helical topology was chosen instead. By placing one helical coil in each connector, we achieved an axial coil distance since the coils nest together as shown in the image above. Through simulations we found this to be the ideal topology. Similarly, the coil pitch, driving frequency, and turn ratio, was fine-tuned through simulation. The values chosen were C/A of 2.2, frequency of 100 kHz and turns ratio of 30:20.

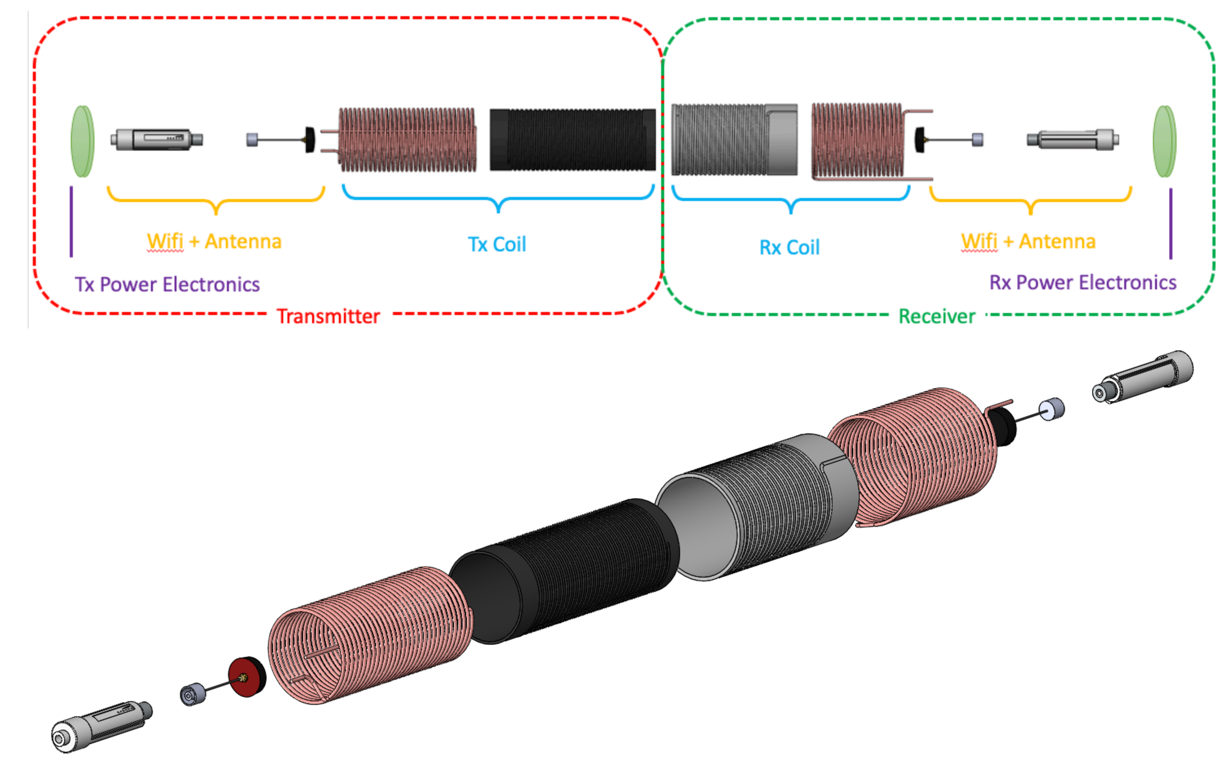
Wi-Fi was chosen as the communication mode due to resilience against attenuation through short distances of sea water. The high frequency of operation of Wi-Fi mitigates against interference with the power module.



The diagram above shows the network connectivity of the (left) docking station to the (right) AUV through the Wi-Fi module and antenna. The selection of this Wi-FI module was informed by our investigation of existing solutions and desire to achieve a form-factor that agreed with our coil dimensions. The Ubiquiti Bullet AC Wi-Fi module was chosen because of its high bit-rate and slender profile. The omni-directional Wi-Fi antenna shown is the lowest profile, commercially available antenna suitable for this application. The Wi-Fi module integrated with power module can be seen in the following images.

MATERIALS & METHODS cont.

Seen below is the exploded view of both modules and how they will physically fit together. The Wi-Fi components are mirrored on each side whereas the power module has differing coil topologies and electronics for each side.



RESULTS

The efficiency of the proposed connector design is summarized in the table below. Notably, at 20V, we came extremely close to the 80% target efficiency. Unfortunately, due to restricted access to resources in the final weeks of our project, we were unable to test at 48V input voltage nor were we able to test at suitable magnitudes for input power.

Input Voltage [V]	Input Current [A]	Input Power [W]	Output Voltage [V]	Output Current [A]	Output Power [W]	Efficiency
20	0.12	2.6	12.35	0.167	2.062	79.3%
24	0.2	4.8	15.79	0.236	3.729	77.69%
28	0.31	8.68	18.52	0.354	6.564	75.6%

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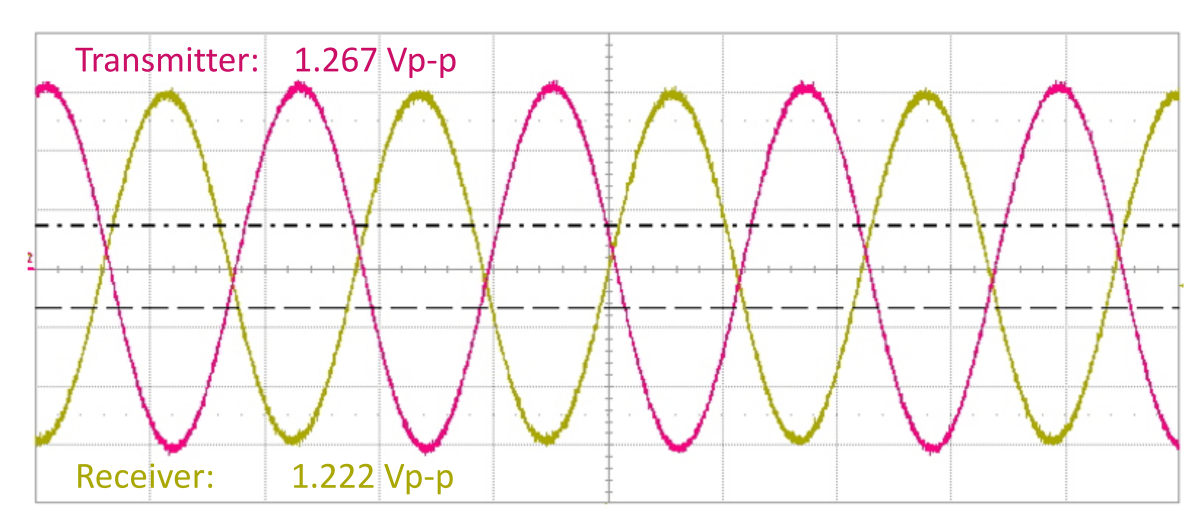

The waveform above shows the input and output waveforms and their associated peak-to-peak voltages. Similarly, coil inductances were measured using an LCR meter. The comparison between simulated inductances and coupling factor with measured values is summarized in the table below.

	Simulated	Measured	Error (%)
Primary Inductance (uH)	48.5	37.9	21.86
Secondary Induction (uH)	35.01	30.9	11.74
Coupling Factor	0.84	0.87	3.57

CONCLUSIONS

The proposed solution involved high power inductive coupling through a novel coil design and high bit-rate data transmission designed using commercially available components. The coil design was first simulated and then prototype testing was completed underwater. The coupling factor was measured to be 0.87; this reflects a successful design of coil parameters and agrees with simulated values. Having high coupling implies the ability to scale the coil parameters to meet higher power requirements for different AUV supply demands. In addition, the tests were carried out to validate the overall efficiency of the power circuits involved. The overall efficiency of the power module was measured to be 75%. This result matches the engineering requirements of the client of 80% efficiency under ideal conditions. The electric components in each of the circuit topologies can be upgraded to sustain high current and thus provide higher power transfer in the kW scale. Since our design is based on blocks that are partially independent, the DC-DC converter at the output could be varied depending on the need of the AUV's input voltage. This feature adds compatibility and feasibility to our design which allows for the integration of the connector into many applications. Furthermore, the data transfer resulted in a peak transmission rate of 120 Mbps and steady state throughput of 10 Mbps. The test was carried underwater and thus proves that data transmission is functional at a distance that is even larger than the specified limit of 1 cm gap. Overall, the critical requirements and engineering specs of the subsea pin-less connector were achieved, and the main objectives were met. At the same time, our goal of maintaining a low-cost attribute compared to existing products was achieved with total budget value of $769.86. With that low cost, a margin of $1000 is left for future development towards the components and materials used. More work needs to be done in order to scale the electronics to kW specification. Additionally, a full mechanical packaging solution must be designed in order to protect the electronics from high pressure and environmental exposure.

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