# Niobium Metal Underwater Circuit Connector

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Abstract

Unmanned underwater vehicles suffer from a relatively short battery life. Our solution to this problem is to create an underwater circuit connector that is durable and efficient. When implemented the onboard batteries of the UUV can be charged without the vehicle resurfacing. We also designed a way to implement data transfer in our connector so that information can be collected while the UUV charges. Our connector uses niobium metal rods due to its special property of self passivating by creating an oxide layer when exposed to high voltages. Our results showed that this oxide insulation is increasingly effective when it was exposed to larger voltages.

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## Introduction and Background

-Niobium History

The primary component of our underwater circuit connector is niobium metal due to its unique properties. Niobium, atomic number 41, is a transition metal. It has a high heat resistance with a melting point of 2477°C and a boiling point of 4774°C. At cryogenic temperatures niobium acts as a superconductor and so it allows the passage of electric current without resistance. This metal is also resistant to corrosion due to an oxide layer that build around it.

-Northrop Grumman

Northrop Grumman is a leading global security company and the sponsors of our underwater circuit connector project.  They primarily deal with providing innovative systems, products, and solutions to various fields such as autonomous systems, cyber security, and logistics to the government as well as commercial customers. Northrop Grumman is made up of four business sectors: Aerospace Systems, Electronic Systems, Information Systems and Technical Services. Our project to design an underwater circuit connector falls into the Electronic Systems sector.

-Problems with UUVs

Our current project focus on the problems with how current unmanned underwater vehicles have a limited operating time and have to constantly resurface.

## Problem Statement

Unmanned Underwater Vehicles (UUVs) are increasingly being used in commercial, military, and research science sectors. Current UUVs have onboard batteries for power and therefore have mission lives limited by the capacity of those batteries. Having a system available for docking and charging of these batteries would greatly improve data collection and allow UUV to stay submerged for longer periods of time.

## Current Status of Art

Present technology for dealing with this problem include conductive wet mate underwater connectors and subsea transformers each with their own set of problems. Wet mate connectors rely on a complex method of wiping and sealing mechanisms to prevent water leakage. These techniques are unreliable when it comes to the protection of its components.  Another problem with wet mate connectors is their current inductive coupling technology for power circulation. The current coupling solution has substantial efficiency loss, are very complex, and they of a large size and weight.  Subsea transformers face a similar issue when it comes to size and weight. Due to the fact that they are very large maintenance becomes rather difficult to preform.  These transformers also use very high voltages and currents which greatly exceed what is necessary for the scope of this project.

Design Requirements

- Functional two contact wet mate connector
- Contacts must be self insulating
- Carry DC power at up to 48V @25A with very low resistance
- Capable of sending a 2.4Ghz 802.11 signal across the connector
- Capable of functioning in fresh and salt water
- Capable of withstanding water pressure at up to 600m
- Capable of functioning at varying temperature ranging from –2°C to 50°C
- Capable of surviving underwater for a minimum of 25 years

Solution Approaches and Top Design

The first part of our design solution was determining how to design the housing that would be used to hold the niobium contacts. We had two primary designs for the housing of our connector(figure 1). Each design was evaluated based on certain criteria. This set of criteria included protection from water leaks, durability(when connected and when disconnected), and pressure resistance at 600m. The design we chose initially(left image in figure1) ran into problem due to the special properties of the niobium metal which make traditional soldering and welding techniques ineffective. Due to this condition and lack of resources our second design was used instead(right image in figure 1).

The second part of our design solution was designing a suitable method to realize data transfer in our connector. We decided to use a bias tee design in order to implement this. Figure 3 shows the connection of the UUV and power supply being made. This design uses two communication modules to control data transfer as well as handling the initial docking confirmation. One module is stored within the UUV itself while the other is stored with the power supply. Currently we plan to use Xbee communication Modules for our communication. Figure 4 shows the connector while it is disconnected. However even while disconnected there is a continuous RF signal being sent by communication module A in order to test for a connection. Once connected module B will receive the signal and send a reply. Once this connection has been confirmed module B will send another signal to the relay switch in the power supply so that power can begin to flow. Once the UUV has been fully charge and whatever data that has been captured has been successful transferred module A lets module B know that it can switch off the relay.

Projects Final Goal

- Functional two contact connector using niobium contacts
- Carries DC current rated at 48V @25A
- Connector properly functions in fresh and salt water at depths of up to 600m
- Capable of sending a 2.4Ghz signal with minimal to no interference
- Connector has a lifespan of at least 25 years

Project's Spring 2016 Target Goal

- Two contact connector using niobium contacts
- Construction of CAD housing for the connector
- Capable of sending DC current across the connector
- Connector works inside and outside of fresh and salt water

Implementation, Testing, and Evaluation

Testing occurred in both fresh and salt water, but the focus being put on salt water. A solution was created to mimic seawater by adding 35 grams of sea-salt for every liter of water. This was the constant that was used for all water testing in our evaluation of niobium.

The niobium needed to be pretreated to create the oxide layer for insulation. The layer is created by passing electric current in an anodizing bath, causing oxygen to separate from the liquid. The oxygen combines with the niobium to form a layer of niobium oxide ($NbO_2$). The higher the voltage during treatment, the thicker the oxide layer that is formed. The first treatment of niobium in testing was at 20V DC, and successfully created a thin oxide layer that caused a purple tint to appear on the metal(figure 2). Fully assembling the connector and proper sealing of the copper connectors we were able to get an average of 10% of the current across the connection. A 90% leakage is not efficient, nor environmentally friendly enough for our application. Niobium treated at 20V DC is 10% more efficient than copper in similar scenarios, but needed to be treated at a high voltage to get a thicker, better insulating oxide layer. The second treatment of niobium was at 48V DC, and created a thicker oxide layer of a goldish color. Reassembling the connector and properly sealing the copper side of the connections we were able to get an average of 16% of the current across the connection when testing at 20V DC. A 84% leakage is still not efficient as our goal is to bring this as close to zero as possible, but this improvement solidifies the theory that we can keep increasing the voltage to obtain an oxide layer thick enough for our application.

These two data points can be interpolated to find an approximation of the voltage treatment needed for perfect insulation across the conductor at 20V DC. If we assume this is a linear regression and that the leakage current doesn't plateau, a 330V DC supply would be needed to create the oxide layer necessary to prevent leakage.

## Conclusions

Our goal is to find a way to either replenish or extend the battery life of UUVs while they are underwater. Through the use of an underwater circuit connector we will be able to safely charge the onboard batteries and thus extend the mission lives of these UUVs. Niobium is the main component for this project. The metal is self passivating allowing it to be used without any complex mechanisms for wiping and sealing of the contacts which is what current wet mate connectors have to implement. The niobium is pretreated by sending an electric current through the metal in an anodizing bath. Higher voltages resulted in a greater the oxide layer and thus more insulation. Therefore we need to expose the niobium to higher voltages before we can use it as contacts for our connector. Progress on this connector, especially working with the niobium, was slowed down due to difficulties obtaining the proper supplies as well as finding feasible methods of welding the metal.

## Recommendation for Future Works

The approach of a low voltage RF is imperative to keeping the niobium contact points from created an oxide layer that is too thick to scratch itself away from head on contact. The low voltage will allow the RF signal to confirm proper attachment, signaling the high voltage relays to activate(figure 3).

Follow the above procedure in treating the niobium at different voltages to collect more data on the voltage leakage levels to get a better approximation of the relationship between treatment voltage and current leakage.

References


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Appendix

Figure 1.

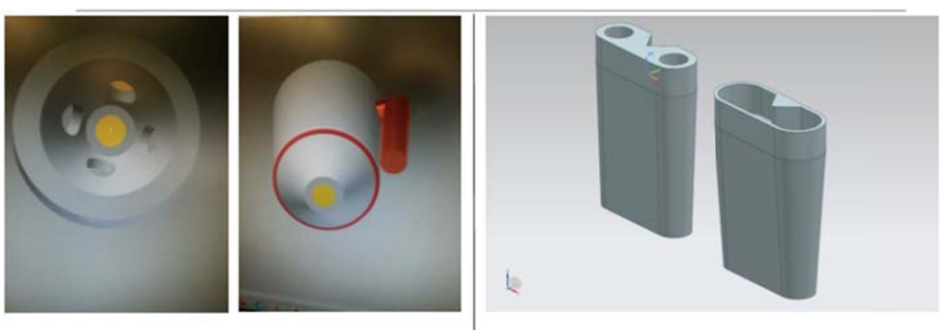

Figure 2.

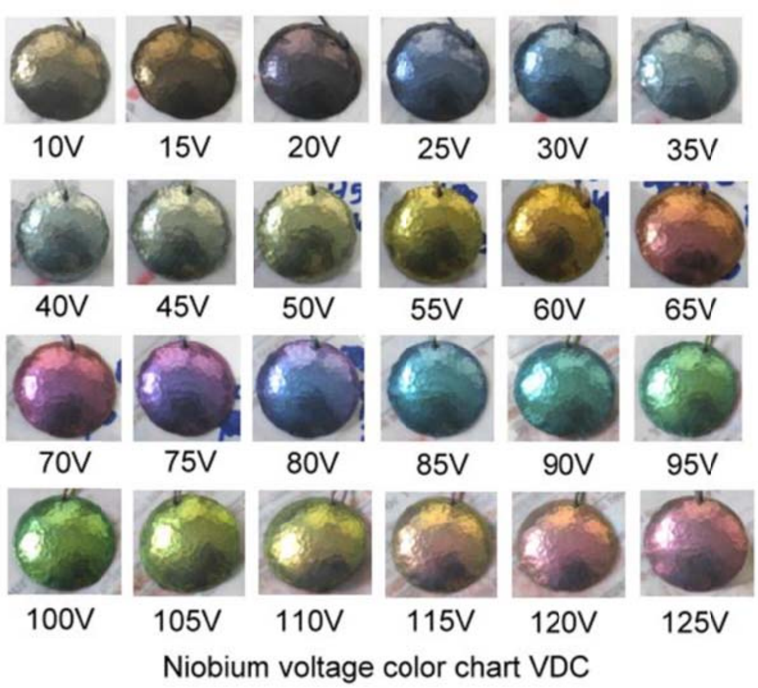

Figure 3.

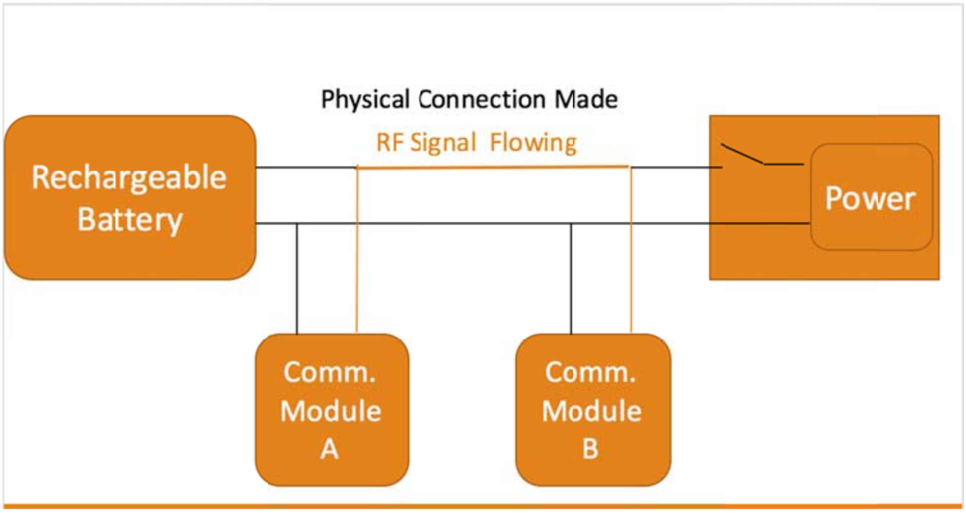


Figure 4.