Work Project Report*

Michael Rooks†
Department of Physics and Geosciences
Angelo State University, San Angelo, USA

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In addition to day-to-day activities with the ALPHA collaboration, the following outlines the successful completion of my assigned project of building a better version of an existing piece of hardware that has come to be known as the "Serial Multiplexer".

I. DAY-TO-DAY ACTIVITIES

As outlined in my initial job description I was indeed afforded every opportunity to participate in all day-to-day activities by signing up for shift work. For the first couple of weeks I did some shift work were I gained exposure to a broad range of physics topics including: particle physics, atomic physics, non-neutral plasma physics, and particle trapping. In addition, I had some limited work with vacuum systems and cryogenic transfer. I also learned how to control the ALPHA apparatus with experimental control software programming, namely the hardware/software duo called the sequencer. The software portion resides in a program called LabView. The sequencer allows for manipulation and control of every step needed to create, confine, and perform spectroscopy on cold antihydrogen. During an antiproton shift I controlled the apparatus using the sequencer to make more than 100,000 antiatoms of antihydrogen. In the same sequence, 26 $\overline{\mathrm{H}}$'s were confined, microwave and laser spectroscopy performed and data analysis was taken. I am claiming the to be the first Texan to make and trap cold antihydrogen!

My arrival at CERN coincided with a very busy and somewhat frantic time at ALPHA. A major multi-million dollar addition is taking place requiring a lot of hands-on work. In addition there was a limited antiproton beam time window for experimentation. My first experience in this fast paced, hard-working, multicultural environment was to help build and align a newly placed beam-line connecting the positron accumulator to the ALPHA apparatus. During this time I learned how positron plasmas are confined, released, guided through the beam-line and detected by a microchannel plate, phosphor screen and ccd camera. This allows for the acquisition of the radial density and temperature of the positron plasma, a necessary step before attempting to combine positrons with anitprotons. During this time I worked with ALPHA team members (graduate students and post docs) troubleshooting equipment and attempting to get a good stream of positrons. I learned how meticulous record keeping and data logging is accomplished using the ALPHA data log and elog systems. After a few weeks of antiprotons and experimenting with antihydrogen the day-to-day operations shifted to preparing for and constructing the new ALPHAg apparatus. At this point I began my assigned project and helped intermittently with hands on work when I was available.

II. THE SERIAL MULTIPLEXER

I was assigned the task of improving upon an existing piece of equipment that has come to be called the serial multiplexer. While multiplexers are commercially available, the operating requirements for this type of multiplexer are unique, thus requiring it to be designed and built in house.

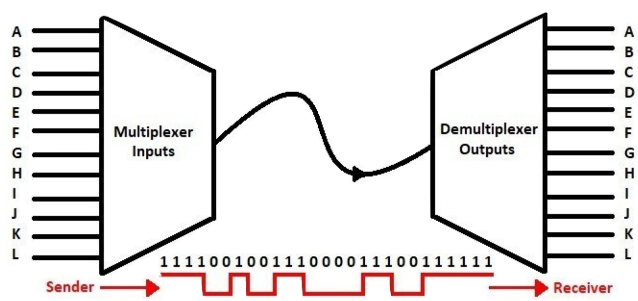

FIG. 1: Basic Operation of Multiplexer/Demultiplexer Pair

The serial multiplexer actually comes as a pair, one multiplexer and one demultiplexer. The basic operation is illustrated in figure 1. In our case we want to send a serial signal from the sender anytime there is a change of state (Logic 1 or 0) on one or more of the input pins regardless of whether the changes are synchronous or asynchronous. Likewise, we want the receiver to interpret the serial input and reproduce the output state regardless of synchronicity.

The serial multiplexer pair plays an important role in the operation of the ALPHA apparatus. The ALPHA apparatus is particularly sensitive to electromagnetic fields and the serial multiplexer acts as a kind of buffer between noisy equipment and the apparatus. It also reduces cable complexity.

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* Supervisor: Dr. Timothy Friesen

† CERN | EP/UAD | ALPHA

The previous version of the serial multiplexer pair had 8 input/outputs respectively. Those lines were quickly used up and more lines were needed. With the construction of the ALPHAg apparatus , even more lines are required. Thus, I set out to create the best serial multiplexer I could.

The Arduino Micro

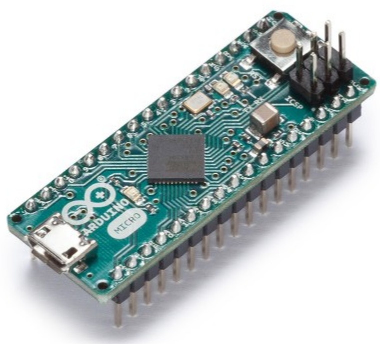

FIG. 2: Arduino Micro - ATmega32U4

At the heart of the serial multiplexer pair is the Arduino Micro. My first task was to learn everything about the Arduino Micro based on the ATmega32U4 microcontroller in order to maximize the number of input/outputs and minimize the transmission time from receiver inputs to sender outputs. The total number of usable digital i/o's was found to be 21. In order to use the i/o's the Arduino has to be programmed using the Arduino IDE based on c++. In order to maximize the response time the code had to be further written in such a way as to directly manipulate the port registers. Groups of i/o's are assigned to different ports and a code had to be written at the lowest level to assign the direction of the i/o and tell it to read or write respectively.

Figure 3 shows the setup for testing response times on each i/o pair. One Arduino was programmed as the sender and one as the receiver. After much testing it was found that 18 i/o's work best with an average response time of 35 μs.

Altium Designer

Knowing what the microcontroller is capable of I set out to design the circuit schematic and printed circuit board using the software Altium Designer. This part of the project proved to be the most difficult. Altium Designer is a very powerful, feature rich, not well documented, not so user friendly software for creating PCB design. During the first week of design I faced the the thought of incompletion. After spending many long days, nights and weeks working with the software I persevered

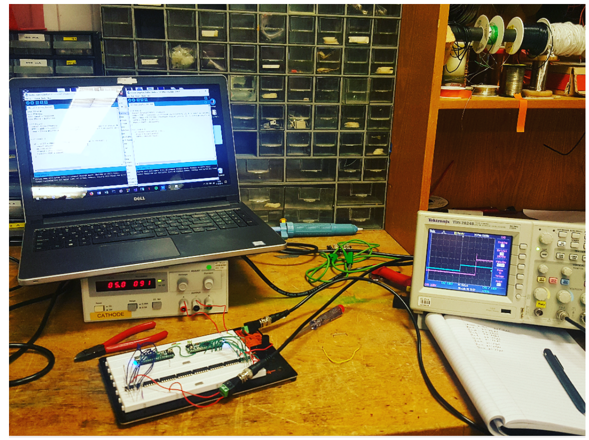

FIG. 3: Testing Arduinos with a function generator and oscilloscope

and became quite good at designing PCB's. There were no real challenges in board design as the board is meant to be placed in a rather large 3U 84HP Euro chassis.

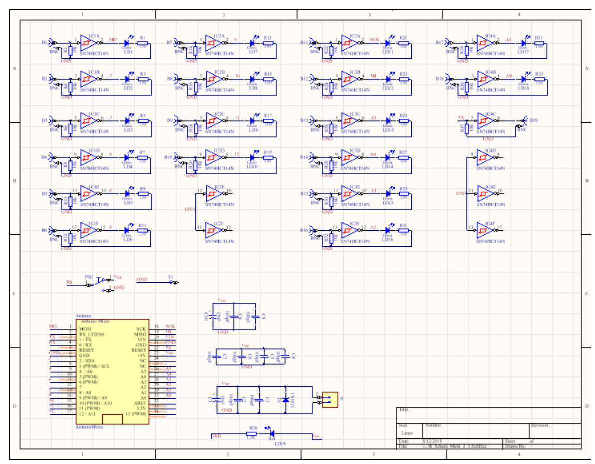

FIG. 4: Schematic of sender

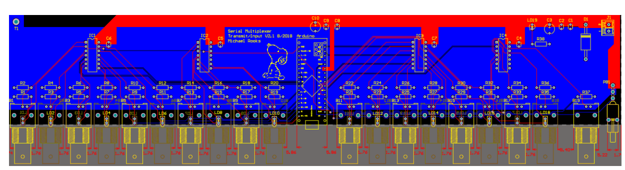

FIG. 5: Screenshot of PCB design for sender in Altium

Once I finalized the design it was just a matter of requesting a quote, creating a purchase requisition in EDH and having the boards printed and shipped.

Circuit Design and Technical Details

In order to avoid any chance of having a noisy signal some precautions were necessary. All digital inputs

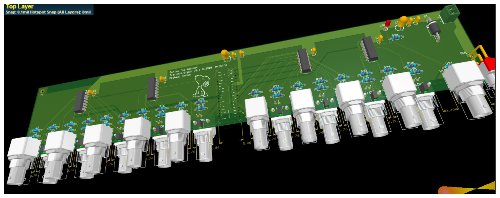

FIG. 6: Screenshot of 3D PCB design for sender in Altium

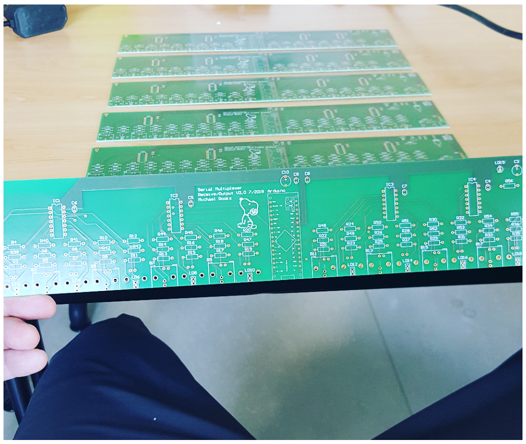

FIG. 7: Printed circuit boards

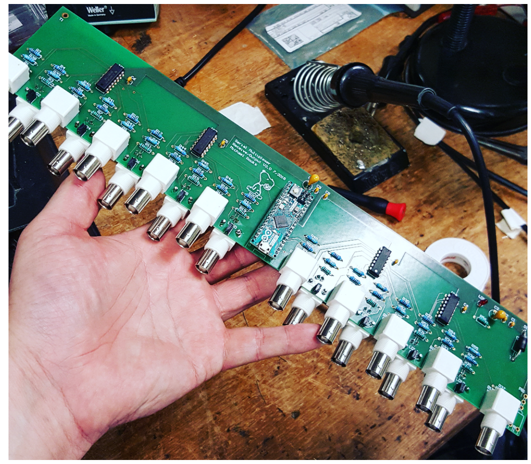

FIG. 8: Assembled circuit board

were routed into inverting Schmitt triggers (IC1-2) before reaching the Arduino. Similarly all Arduino outputs were routed to inverting Schmitt triggers (IC3-4) before reaching their respective BNC's. Also, inputs before the Schmitt trigger were tied to ground using pull-down resistors as well as all outputs from the Arduino before the Schmitt trigger. The use of pull-down resistors and Schmitt triggers insures nice clean square waves for logic pulses. RX and TX were also routed into Schmitt triggers. RX was pulled to ground with a resistor and TX was pulled to 5V with a resistor. All pull-up and pull-down resistors are 10kΩ. A 5V linear power supply was also used to reduce noise. These had to be modified simply by soldering jumpers to receive the correct A/C voltage here in Switzerland of 240V. 100pf capacitors were placed in parallel with all IC Vcc's including the Arduino. A Schottky diode was also employed for extra precaution.

Front and Rear Panels

In this design, the printed circuit board is mounted directly to the face plate using the BNC connectors on the board. Originally the idea was to make 2 or 3 sets of multiplexers as needed however with the new ALPHAg apparatus, room in the chassis racks has become an issue, therefore I designed the face plate to allow for 2 senders or 2 receivers per box. The plates were designed using the software Schaeffer AG Front Panel Designer.This software is also not very user friendly and unlike Altium does not not have enough features. The biggest challenge with this step was trying to calculate exactly where the holes needed to be. The software only allows for measurements with respect to the origin (bottom left corner). The panels are made from 3mm thick anodized aluminum so there's no room for error. I incorporated an extra 1mm diameter for each hole to allow for some error. A lot of time was spent researching data sheets on the BNC's, LED's, PCB's, Pushbuttons, and Arduino for exact measurements. At times it was necessary to use digital calipers. The rear panels were more simple only requiring one hole for the power plug and switch. Similar to the PCB boards, after designing was complete it was just a matter of requesting a quote, creating a purchase requisition in EDH and having the panels cut and shipped.

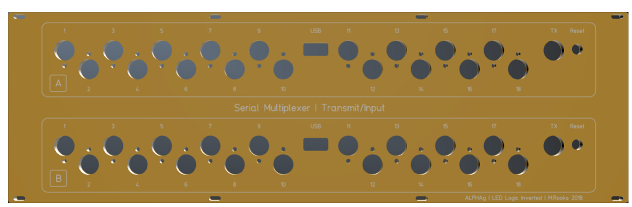

FIG. 9: Software generated front panel

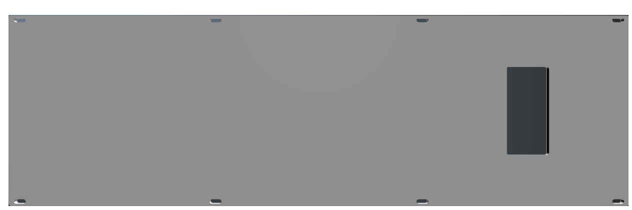

FIG. 10: Software generated rear panel

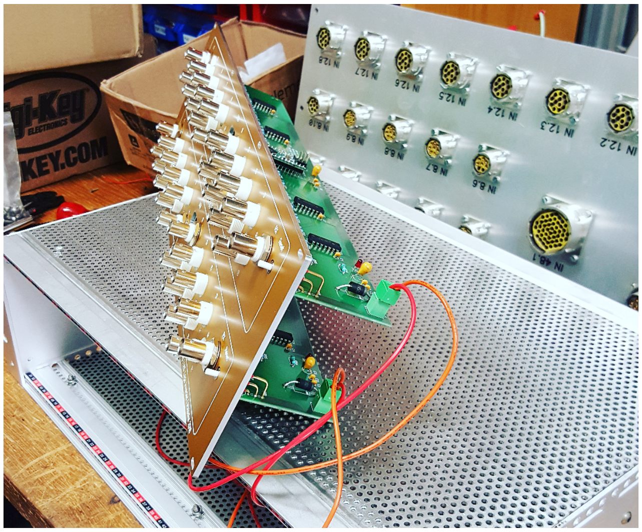

FIG. 11: Assembled front panel

FIG. 12: Pair of assembled serial multiplexers

III. CONCLUSION

All parts and circuit board components not requiring a quote were purchased through EDH at either the CERN store or materials request through Farnell or Radiospares. It should be noted that a routing error between components on the sender was found after the board was printed. The problem was resolved my modifying the board using jumper wires.

Before attacking this project I was told about two known problems with the previous version of multiplexers. The first problem is that the reset switch did not work correctly. The reset problem was resolved in both of the new boards. The second problem had to do with the receiver going into a bad state if the sender was to reset or power off and on again. With some research and testing it was found that when the Arduino microcontroller resets the TX pin momentarily switches to an input thus creating high impedance. The first low pulse is the startbit. With a pulldown resistor a startbit was being created as soon as the Arduino reset causing the receiver to take on a bad state. The problem was resolved by changing the pull-down resistor on the TX pin to a pull-up pin. This was also found after the boards were printed therefore, jumpers were used to modify the senders here as well.

I did correct the boards in Altium so that the next person to come along should not have any problems. A project folder was created at \\cern.ch\dfs\Experiments\ALPHA\Altium\Rooks\Serial Multiplexer Project\. In the project folder I've placed files for: both sender and receiver Arduino codes, front and rear panel designs, sender and receiver PCB's and schematics in Altium, a complete parts list with url links and part numbers for each part, and project notes.

When my supervisor first told me about this project I was very interested as it seemed both challenging and doable. I really enjoyed the challenge of learning to use the PCB designing software. I also enjoyed troubleshooting and solving the problems that came up. They're is great satisfaction in designing and building something that both looks pretty, works great and will play a roll in the next generation of anitmatter experiments at ALPHA. I'm glad that my supervisor gave me this project and I hope that future summer students will have similar opportunities.