

NRAO / GB Undergraduate
Senior Research and Design Projects

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1. Astronomy Research Projects

1.1. Analysis of Data from Mars Spacecraft Missions

Hanna Sizemore, NRAO/PSI

I use numerical models and laboratory experiments to understand the dynamics of water ice in the regoliths of terrestrial planets. My work is primarily focused on Mars, but I've dabbled in Antarctic problems, and I'm currently involved in the Dawn mission to dwarf planet Ceres. Both projects described below would involve numerical simulations (in C and Matlab) and interaction with one or more publically available data sets from Mars spacecraft missions. Other projects related to Mars and Ceres data products might later be available.

Project 1: Surface rock populations on Vastitas Borealis, Mars

A large amount of pure ice is buried under less than a meter of soil in the mid- to high latitudes of Mars. Currently, there is a lively debate going on in the Mars literature about how the ice was delivered to its current location. Was it (a) deposited from the vapor phase in regolith pore spaces then rearranged by frost heave, consistent with the cold dry climate we observe today, or (b) deposited as a snow pack and buried under a sublimation lag, implying that dramatic climate change has occurred on Mars in the past 0.5 to 4 million years? A key piece of evidence in this debate is the presence of abundant cobbles and boulders on the soil surface above the buried ice. Qualitatively, it seems that the rocks are too abundant for a meters-thick snow pack to have been deposited more recently than ~10 million years ago, but this remains untested.

The purpose of this project is to place the first quantitative constraints on the rate at which surface rocks can accumulate on Vastitas Borealis during the past 1-5 Ma. There are two processes that move rocks to the surface in the region and time frame of interest: (1) regelation of rocks through solid ice and (2) spallation of rocks from distant impacts. A student researcher could investigate one or both of these processes. Investigation of regelation would involve contribution to a simple numerical model currently in development, analysis of Mars Reconnaissance Orbiter (MRO) HiRISE images, and some interaction with Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) data. Investigation of impact spallation would involve development of an analytic model for production rates based on published scaling laws and crater size distributions, and analysis of HiRISE images.

Project 2: Frost heave processes in Martian Slope Streaks and Recurring Slope Lineae

Slope streaks and Recurring Slope Lineae (RSL) are ephemeral dark features seen in high-resolution images of the Martian surface. Melting of shallow ice and downslope migration of liquid water or brine may contribute to both types of features. If liquid water plays a role, periodic re-freezing should produce frost heave associated with these features. Indeed, topographic changes have been observed at the end stage of the development of some slope streaks. The purpose of this project is to quantify the magnitude of frost heave that could occur at the location of well-observed slopes streaks or RSL. A student researcher would help adapt an existing numerical model of Martian frost heave to operate in the geographic setting of a well-observed group of slope streaks or RSL, and compare model predictions to evidence for topographic change in HiRISE images.

1.2.The Green Bank North Celestial Cap Pulsar Survey

Ryan Lynch, NRAO

The physical conditions found in the cosmos are usually impossible to recreate on Earth. Luckily, nature provides us with exquisite natural laboratories in the form of pulsars. Pulsars are the remnants of massive stars that ended their life as supernovae. Pulsars have gravitational fields almost as strong as black holes, have the strongest magnetic fields known, emit radio, X-ray, and gamma-ray radiation, and spin up to several hundred times per second. Pulsars are also highly precise clocks, and that means they can be used to study extreme physics in superb detail.

The Green Bank Telescope is used for a rich variety of pulsar science. One of the biggest projects is the Green Bank North Celestial Cap (GBNCC) pulsar survey, which is looking for new pulsars. Students have the opportunity to make major contributions to the GBNCC survey by:

- Running survey observations with the GBT
- Looking for new pulsars in GBT data
- Helping to develop expand upon techniques for finding other exotic objects, such as Rotating Radio Transients (RRATs, a type of pulsar) and mysterious Fast Radio Bursts (FRBs, believed to be of unknown extragalactic origin)
- Developing new software tools to identify new pulsars
- Working with "big data" by improving the python-based pipeline and SQL database management
- "Timing" new pulsars, a process that uses their clock-like nature to measure physical properties

The GBNCC survey is also a great project for students interested in education and public outreach. Students will be supervised by Ryan Lynch in Green Bank and Profs. Maura McLaughlin and/or Duncan Lorimer at WVU.

1.3.GBT Observations of OH in the Interstellar Medium

Toney Minter, NRAO

The change in phase from atomic to molecular gas in the Interstellar Medium has been relatively poorly explored by observational astronomy. This has been primarily the result of the lack of diagnostic observational tool. Atomic gas distributions for the entire sky are known from 21cm spin-flip transition of atomic Hydrogen. Molecular gas observations, using observations of CO, have been mainly confined to the Galactic Plane. Recently the PLANCK mission has released a data set that indicates where molecular emission arises across the entire sky. The PLANCK "molecular" data are inferred from spectral energy distributions of the emission from the sky at many wavelengths. The GBT has provided the improved sensitivity that we can now study weak OH emission. OH should be the first molecule formed (before CO forms) and potentially allows for us to map the outer envelopes of molecular clouds to study the change in phase from atomic to molecular gas.

OH observations will be used to confirm that the PLANCK "molecular" data set does indeed indicate places out of the Galactic Plane where molecular gas is present. If significant OH is present, which early

observations suggest could be the case, then we can map the outer parts of molecular clouds where there should be significant interaction between the atomic and molecular phases.

1.4. Hydrogen in and around Galaxies

Jay Lockman, NRAO

The Green Bank Telescope is a superb instrument for studying neutral hydrogen in and around galaxies, and its sensitivity is unrivaled worldwide for some types of measurement.

The research that I and my collaborators are performing involves studying the hydrogen clouds that are found in the boundary layer between the Milky Way disk and its million-degree hot gaseous halo. It is not clear why there should be a population of hydrogen clouds above and below the Galactic plane, which share in the overall rotation of the Galaxy, but it is possible that they were launched by collective activity of supernovae and represent material blasted up only to return to some other location in the Galaxy. We have several ongoing projects to understand the distribution and properties of these clouds and their link to the star formation and long-term evolution of our galaxy. The key data come from the Green Bank Telescope and the Parkes (Australia) radio telescope surveys.

2. Electronics Projects

2.1.GBT Active Surface Upgrade Project

Jason Ray, Digital Engineer

Background

The Green Bank Telescope (GBT) is the world's largest fully steerable radio telescope. The structure stands 485 feet tall and weighs over 17 million pounds. This telescope is used to detect ultra-faint radio frequency signals from sources in outer space. Given the low level of these signals, it is very important to maintain the parabolic shape of the primary 100m reflector, particularly for high frequency observations. The GBT is so large that the shape of the primary reflector changes over elevation, mainly due to gravity. To correct this problem, the GBT has an active surface comprised of 2209 actuator assemblies, which can adjust the 2004 surface panels as needed to bring the surface back to the required parabolic shape.

The hardware components for this system were originally procured starting in early 1992, now making them over 20 years old, and at this point obsolete. Given the importance of the active surface for high frequency observing, the control system should be upgraded with modern hardware, software, and communications protocols.

Existing Hardware

The current system (Figure 4) is based on three MV167 VME computers that communicate with custom VME IIOP (Intelligent Input Output Processor) boards, which in turn communicate with the H-Drive modules and LVDT modules.

The H-Drive modules allow for bidirectional on/off control of 16 actuators each. The LVDT modules are analog input modules that can monitor 16 LVDT position sensors each. The Active Surface system contains 140 pairs of these modules, some of which are shown in Figure 1 below.



Figure 1 - Active Surface Control Modules

The actuator assembly consists of a small DC motor for movement up or down, and an LVDT for position sensing. Figure 2 below shows an actuator assembly in the lab, and Figure 3 shows actuators as they are installed at the edge of the GBT surface.

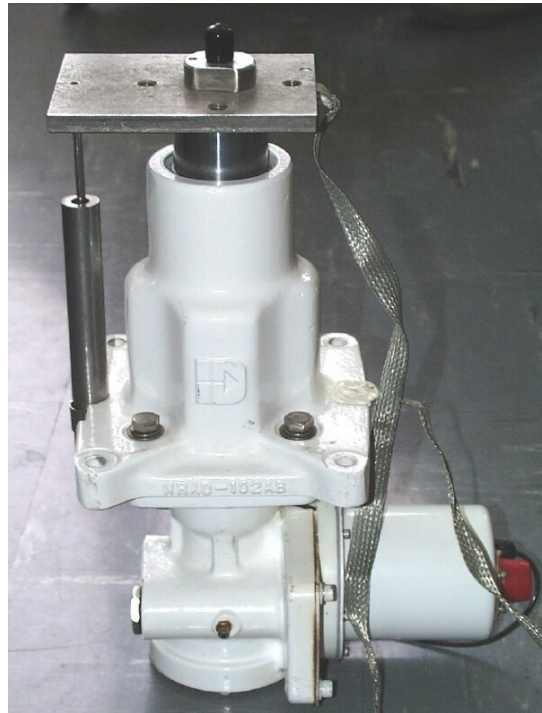


Figure 2 - Actuator Assembly



Figure 3 - GBT Surface Actuators

Upgrade Proposal

The scope of this project will be to design and develop an upgraded and modernized control system for the GBT Active Surface. Tasks will include:

- Picking up where the previous group left off
- Planning the project
- Gathering and defining the requirements
- Designing the hardware, software, and control system
- Participating in a design review
- Construct hardware
- Writing the software & firmware
- Testing and documentation of the finished device

See Figure 5 below for a block diagram and the proposed new system.

The VME computers and IO cards shall be replaced by a modern computer running Linux Redhat 64.

The proprietary IOP interface, for communicating between the computer and the control modules, shall be replaced by a standard, ethernet based interface (i.e., telnet).

The H-Drive and LVDT modules shall be replaced by microcontroller based modules that will provide control/monitor for 16 actuators each.

The current H-Drive modules only allow for simple “on/off” control of the motors. It is desirable for the new motor control module to have a higher quality control mechanism, such as pulse width modulation (PWM).

The new control system hardware, software, and communications protocols shall all have wide commercial acceptance in order to stave off obsolescence for as long as possible. The hardware components shall be highly reliable and readily available from standard parts suppliers.

The new control modules shall be designed with Radio Frequency Interference (RFI) mitigation in mind. This will include filtering the connections into and out of the modules in order to contain the RFI generated by the microcontroller and other electronics. Before deployment, these modules will have to pass RFI testing in the anechoic chamber at NRAO-GB.

While the basic design of the upgraded control system is very open, there are a few hard requirements for this project. First, the new hardware must make use of the current actuator cables. There are approximately 240 kilometers of actuator cable on the GBT, and replacing this cable with something different for the sake of the new control system is not an option.

Next, all of the actuator cables are terminated in the actuator room on terminal strips, (as shown in Figure 6) then through filter connectors to the control module bases. This comprises approximately 20,000 connections in the actuator room. The new control modules must have a similar form factor to make use of all of the existing wiring in the actuator room.

Work Experience

This project offers the opportunity to gain valuable, real-world work experience in the following areas:

- Project planning
- Electronics circuit design
- Printed circuit board design
- Control systems design
- Embedded firmware design
- Software design
- Mechanical packaging & RFI mitigation design
- Hardware construction, troubleshooting & testing

Deliverables

The deliverables from this project include:

- Project plan and schedule
- Hardware design of the control modules
- Software and firmware designs for the control modules
- Control system design
- Prototype system capable of controlling 16 actuators.
- Presentation of results including a demonstration of the system.
- Complete documentation of the system, including:
 - Drawings, schematics, PCB layout and fabrication files
 - Source code for all software and firmware

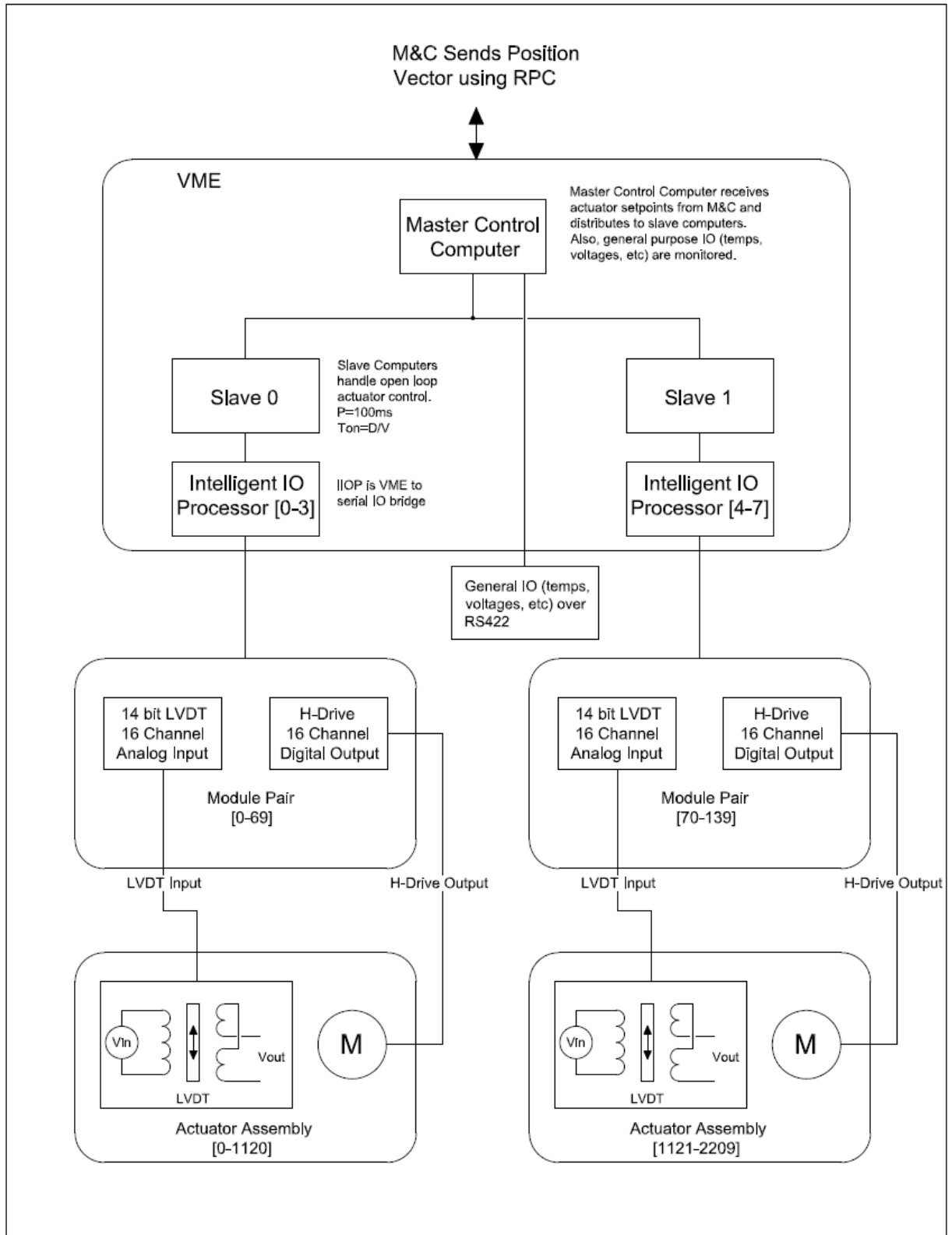


Figure 4 - Original System Block Diagram

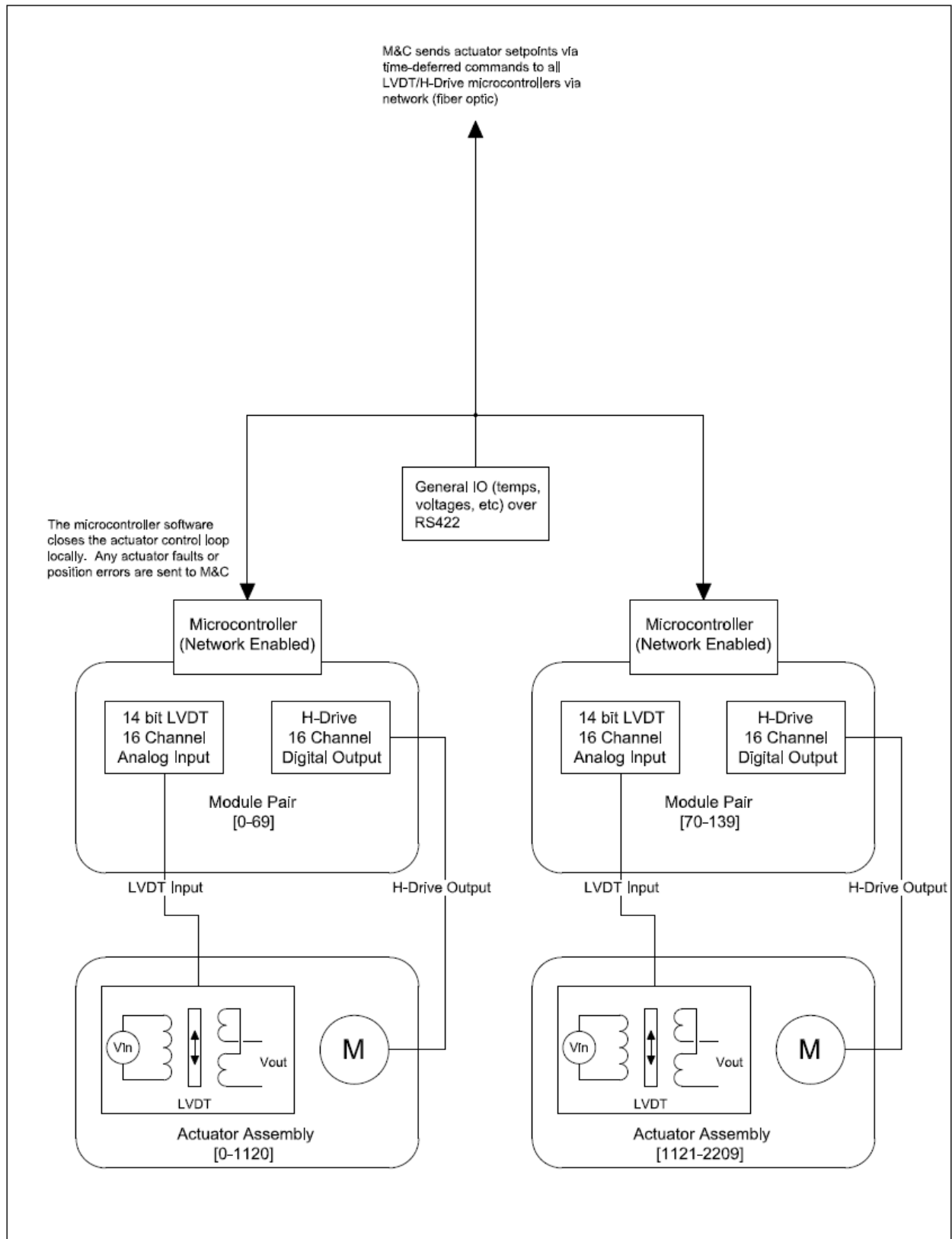


Figure 5 - Upgraded System Block Diagram

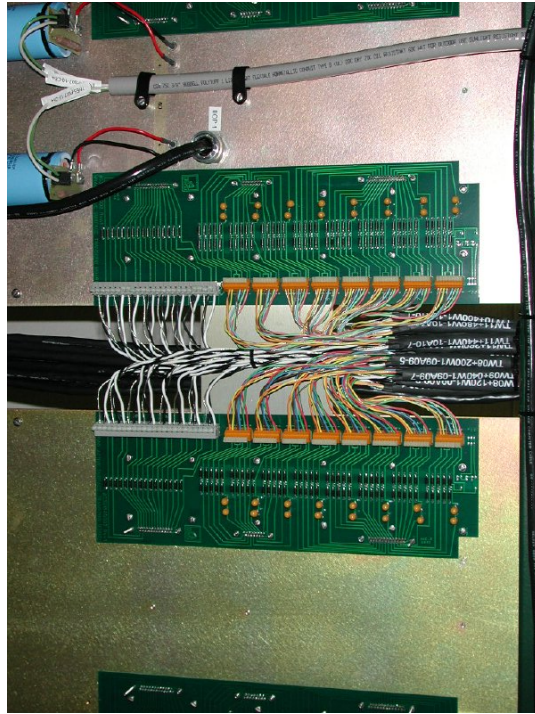


Figure 6 - Actuator Cable Termination



Figure 7 - Actuator Motor

2.2. Wideband Artificial Pulsar

Randy McCullough / Vereese Van Tonder, Digital Engineers

Background

Many radio astronomy observatories located world-wide utilize sophisticated digital backends in support of both pulsar search and pulsar timing projects. Here at NRAO/Green Bank, we currently operate GUPPI (the Green Bank Ultimate Pulsar Processing Instrument). In addition, we are about to embark upon the introduction of several pulsar modes into our latest digital backend -- VEGAS (the Versatile Green Bank Astronomical Spectrometer).

For early commissioning tests and continued support of these advanced backends, we are currently in need of a new Wideband Artificial Pulsar which will very closely approximate the natural characteristics of an actual pulsar. More specifically, we wish to faithfully reproduce both the pulsar period (typically in msec) and the pulsar pulse dispersion through the Interstellar Medium (as illustrated in Figure 1).

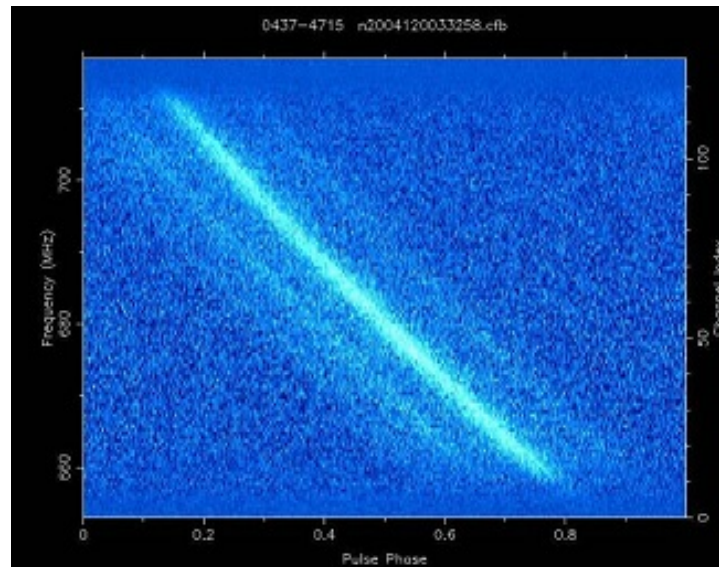


Figure 1 (Pulsar frequency versus pulse phase)

The creation of such a test instrument will facilitate autonomous qualification and quantification testing while removing reliance upon telescope and/or facility infrastructure availability.

We are currently operating a 1st generation Artificial Pulsar which has no provisions for representing pulse dispersion and is dependent upon the use of a standard laboratory signal generator for establishing the requisite pulse period (see Figure 2).



Figure 2 (Current Artificial Pulsar)

Project Description

It is currently envisioned that this design will be based upon a suitably chosen PIC uController made by Microchip and programmed in C (or other suitable uController); used in conjunction with a number of RF components such as wide band noise sources, digitally controlled band pass filters, summing amplifiers, attenuators, etc.

Candidate(s) are expected to fully define the target functionalities and performance parameters by conducting initial research through internet searches, consultations with pulsar astronomers, discussions with RF and digital engineers, etc.

Following this initial research, a draft Operator's Manual will be prepared which contains:

- A basic description of the Wideband Artificial Pulsar Instrument
- Target specifications
- Theory of operation with block diagram(s)
- Proposed schematics and/or wiring diagrams
- Basic outline of proposed software design
- Proposed packaging arrangement including operator controls, connectors, etc.
- List of operator-adjustable parameters along with their adjustment ranges, etc.
- Preliminary Bill of Materials

In addition to this draft Operator's Manual, the candidate(s) will also prepare a proposed project schedule, estimated manpower requirements, and estimated parts costs.

Following this, the candidate(s) will participate in a Preliminary Design Review; presenting the documents referred to above to a panel of reviewers comprised of pulsar astronomers, RF and digital

engineers, etc. The outcome of this PDR will be a set of revisions to be made to the draft Operator's Manual, a revised schedule, along with revised estimates of manpower requirements and parts costs.

At this point, the candidate(s) will begin work in conjunction with RF and digital engineers, lab technicians, and pulsar astronomers to carry out the design, development, construction, programming, testing, and documentation of the Wideband Artificial Pulsar Instrument.

Design, engineering, and testing tools which may be utilized throughout this project include:

- Autodesk Inventor (packaging and mechanical design)
- Eagle PCB (schematic capture and Printed Circuit Board Layout)
- Microwave Office (RF/Microwave design, modelling, etc.)
- Vector Network Analyzer
- Portable Spectrum Analyzer
- Portable Digital Oscilloscope
- Digital Multimeter
- etc.

The final step in completion of this project will be a technical seminar lasting between 15 and 30 minutes to be given before a general audience during which a summary of the project will be offered through the use of PowerPoint slides or similar presentation tool(s).

Project performance metrics will include: achievement of desired specifications, adherence to projected schedule(s), resource containment including manpower utilized and overall final parts costs, quality and user-friendliness of documentation, etc.

2.3.Data Acquisition Box (DT50 Replacement)

J.D. Nelson, Digital Engineer

Design a replacement for an obsolete microcontroller data acquisition system. This project includes:

- Planning the project
- Gathering and defining the requirements
- Designing the hardware and software
- Writing the software
- Testing and documentation of the finished device

Required Skills and Interests: An interest in microprocessor systems is required. Ability to program a microcontroller in C is required, A team approach is possible, with part of the team doing hardware, and part doing software.

2.4.Monitor and Control Interface Board

J. D. Nelson, Digital Engineer

Design a replacement for an obsolete microcontroller monitor and control system

- Planning the project
- Gathering and defining the requirements
- Designing the hardware and software
- Writing the software
- Testing and documentation of the finished device

Required Skills and Interests: An interest in microprocessor systems is required. Ability to program a microcontroller in C is required; a team approach is possible, with part of the team doing hardware, and part doing software.

2.5.A study on water-cooling of digital hardware and ADCs

John Ford, Digital Engineer

The Digital group is experimenting with using water-cooled devices to stabilize temperatures and get rid of excess heat. There has not been much work to date on the temperature stability of water cooling methods and practices.

The project work consists of:

- Planning the project
- Gathering and Defining the requirements
- Designing the experiments and collecting the data
- Data Analysis
- Writing a paper

Required Skills and Interests: An interest in analog systems and microprocessor systems is required. Ability to program small microcontrollers for acquiring data and using software for data analysis and presentation is required.

2.6.A controller design for water-cooling of digital hardware and ADCs

John Ford, Digital Engineer

The radio astronomy instrumentation needs precise temperature control of analog components to get good stability from the RF systems. One way to do this is to use a closed-loop control system for cooling sensitive parts. This project will be to design and build a control system for temperature stabilization of a digital signal processor's analog subsystem and FPGA chip. The project work consists of:

- Planning the project
- Gathering and Defining the requirements
- Designing the hardware and software
- Writing the software
- Testing and documentation of the finished device

Required Skills and Interests: An interest in analog systems and microprocessor systems is required. Ability to program small microcontrollers for controlling the temperature, acquiring data and using software for data analysis and presentation.

2.7.Battery Powered Broadband Noise Source

Carla Beaudet, Electronics Engineer

This project involves the design and construction of a compact broadband noise source for use in testing Radio Frequency Interference shielding

- Planning the project
- Gathering and defining the requirements
- Designing the hardware
- Testing and documentation of the finished device

Required Skills and Interests: An interest in communications, microwave technology, or radio astronomy systems is required.

2.8.Novel OMT Design

Michael Stennes, Microwave Engineer

The project would be to work on a novel OMT and waveguide probe that is easier/cheaper to produce. The electrical concept has been designed, built, and proven, but it would be nice to investigate other mechanical configurations and fab techniques. This is possibly a good project for mechanical engineering students, or one of any engineering discipline who has a talent, or a particular interest in mechanical concepts, properties of materials, and manufacturing methods.

Required Skills and Interests: An interest in communications, microwave technology, or radio astronomy systems is required. Knowledge of Computer Aided Design for mechanical systems is required.

2.9.Low Polarization Sensitive PIN photo-diode detector

Steve White, microwave engineer

Polarization sensitive photo-diodes limit the gain stability of analog over fiber links. Typically these diodes are fashioned with an angle polished fiber surface and an air gap before illumination of the PIN diode. This project involves investigating PIN diode construction and the attachment of fiber to the semiconductor. Optical modeling is required to establish return loss and coupling efficiency predictions. Also prototyping and measuring the diode characteristics are required to verify the modeling.

Required Skills and Interests: An interest in semiconductor technology, microwave technology, optical technology, electromagnetics or physics is required. Knowledge of Computer Aided Design for optical simulation and 3D modeling is required. .

3. Analysis/Software/Firmware

3.1.A test software system for automated receiver testing

Steve White, microwave engineer

This software system would step the LO and test the whole passband of a receiver with the lab spectrometer and a GPIB-controlled LO synthesizer. The project involves the following steps:

- Planning the project
- Gathering and defining the requirements
- Designing the software
- Writing the software
- Installation, testing and documentation of the finished system

Required Skills and Interests: This would be written in the Python programming language, and involves control of IEEE-488 based microwave instruments. An interest in communications, microwave technology, or software systems is required. A team approach is possible, with part of the team doing hardware, and part doing software.

3.2.A QPSK Demodulator

John Ford, digital engineer

Build a QPSK demodulator using a Xilinx FPGA and Xilinx ISE tools. The demodulator would accept analog data at a bandwidth of 140 MHz, and output QPSK demodulated symbols.

Required Skills and Interests: Matlab, Simulink, and VHDL programming languages are used. Strong knowledge of communications systems is required, and an interest in digital signal processing.

4. Monitor and Control Software Projects

4.1.Dynamic Scheduling System

Mark Whitehead, Software Engineer

The DSS scheduler interface was written in GWT and GXT. Better browser-based software technology has since been made available to web developers. For example, the GB PHT user interface was developed with extJS. Near term, we plan to replace GWT,GXT in DSS with extJS. This allows us to drop support for Eclipse/Java and consolidate GB SDD web application technology responsibilities. Requires a good grasp of full-life cycle software development, Javascript and effective code organization/modularization.

4.2.GBT Control System Session Monitor

Mark Whitehead, Software Engineer

As we begin to provide higher bandwidth displays (e.g. real time GFM, VEGAS data display) it becomes more important to be able to determine who is connected to the system and utilizing these displays. Currently it is not uncommon to find ten observers monitoring the GBT who have

no relation to the currently running observations. This is often the result of observers closing the client end of the VNC session, believing the remote desktop will be closed also. Long term, we plan to build a tool which monitors sessions and monitor 'feeds'. This tool will help in cleaning up unused connections and save time debugging connection-related problems. Requires a good grasp of full-life cycle software development, C++ and effective software design.

4.3.IF Manager

Mark Whitehead, Software Engineer

The IF Manager simulates frequency characteristics of signals along the entire GBT IF system path - from the receiver to the backend. Although the IF Manager can be very helpful in diagnosing problems with system configurations or changes to the system, the software is difficult to comprehend and expensive to debug, maintain and modify. Given other changes to the system, viz. data streaming, the development of the GB archive and the expanded, vital role of the configuration tool, it is time to re-visit the architecture and design of the IF manager and create a plan to improve it. Requires a good grasp of full-life cycle software development, the ability to maintain a "big picture"/systems engineering perspective and effective software design.

5. Web Projects

5.1.An Interactive Plotting Tool Embedded Within Plone

Richard Prestage, Scientist

NRAO uses the Plone content management system to support its web pages. An example web page is at:

<https://science.nrao.edu/facilities/vla/observing/RFI/Ka-Band>

We would like the ability to call up an application from within Plone, so that rather than the "plot" link simply displaying a static plot, it would provide the ability to pan and zoom the image. The first step of the project would be to confirm that such an application could coexist with the Plone content management system, and that this would be compatible with NRAO security policies. Then the student would implement the application, and update the Plone content appropriately. Requires a good grasp of web development programming.

6. Mechanical Projects

6.1.The effect of grain size and direction on cryogenic heat transfer

Dennis Egan, mechanical engineer

At cryogenic temperatures, especially in the newer generation of near 0°K cryogenic devices, the heat transfer rate of cooling straps and heat shields is extremely important. That annealing of copper improves its heat transfer rate is well known. What is not known is if the grain size and grain orientation have any effect on heat transfer rates.

6.2.Metal preparation methods for diffusion welding in vacuum and inert gas

Dennis Egan, mechanical engineer

6.3.Diffusion welding

Dennis Egan, mechanical engineer

Diffusion welding can bond similar and dissimilar metals using relatively low temperatures for low distortion and minimal material property changes. Exploration of preparation methods and welding environmental conditions could improve the feasibility of this process.

6.4.Bond condition evaluation of large area diffusion welded assemblies.

Dennis Egan, mechanical engineer

A way needs to be found to evaluate the mechanical and electrical bond in a diffusion welded assembly

6.5.Clean precise machining of UHMW and Teflon like plastics

Dennis Egan, mechanical engineer

Often a plastic lens is cut from a piece of stock. These lenses often include small close grooving or other precision features. Exploration of machining methods with more precise tolerances, less flash, and fewer pulled threads would improve the parts. One particular method of interest is supercooling the cutting tool with liquid Nitrogen but other methods are certainly of interest.

6.6.Metalizing precision plastic parts for use as feeds and signal processing components

Dennis Egan, mechanical engineer

This project could explore the feasibility and methods of fabrication of precision plastic components that then are metalized to form light, precise signal processing devices.

6.7.Numerical modeling of dynamic track loading that includes walking behavior.

Dennis Egan, Mechanical Engineer

There is no numerical model that includes the behavior of rail creep in the direction of travel. Without a model that includes this phenomenon significant rail stresses may be being overlooked. This project is applicable to all heavily loaded tracks. Besides us this includes railroads, stadium roofs, heavy cranes etc.