Active Surface Upgrade Proposal

Background

The Active Surface system is an integral part of the GBT primary optics used for high frequency observing. The hardware components for the Active Surface were originally procured starting in early 1992 and component test and evaluation began shortly thereafter. Due to the long period between system build and GBT commissioning, some components of the Active Surface system were nearing obsolescence by the time the GBT started scientific observing. This proposal is to replace the current, obsolescent control system with a modern, reliable and maintainable one.

Scientific Justification

The "Phase I" specification for the GBT was for low-frequency operation: i.e., to deliver an antenna meeting a surface accuracy specification appropriate to $\lambda/16$ performance at 15 GHz (~1 mm rms with respect to the best-fit paraboloid at any elevation angle above 5°). Phase I operation is met simply by the homologous nature of the surface, without any active surface control. Phase II (to 43 Ghz) and Phase III (to 92 GHz) operation of the GBT requires use of the active surface. Thus any GBT observations made above 15 GHz requires full use of the active surface control system for acceptable telescope performance. Failure of one (or even up to a few hundred) individual actuators would result in only a small loss of observing efficiency. However, as described below, the Active Surface Control System is arranged in an upside down, tree like fashion. Thus any failure of the higher level parts of the system results in loss of successfully greater fractions of the active surface, until ultimately the whole system would become unavailable. The Active Surface Control System should therefore be thought of as akin to the antenna servo system; a single-point failure which requires high reliability and uptime, and a short mean time to repair.

Current Architecture

The hardware architecture for the active system is arranged in an upside down, tree like fashion, with the top nodes delegating responsibility in successively finer levels of granularity down to the actuators themselves.

A top down description of the hardware is as follows:

- **M & C system**: a Linux box located in the control room which computes actuator positions from a Zernike polynomial at the beginning and mid-point of each scan. These positions are sent as vector data over RPC to a Master control system

- **Master Control Computer**: is a MV167 VME single board computer running vxWorks real-time OS. It resides in a control room beneath the GBT dish itself. The primary responsibility of this node is to receive the position vector from M&C and divide and send the positions to the 2 Slave Control Computers, again, using RPC. Additionally, a monolithic state machine periodically
monitors the state of the actuators along with a variety of other ancillary devices. Messages are sent to the M&C system when any device goes in or out of a predefined error condition. Finally, this node can send periodic sample data to M&C upon request.

- **Slave Control Computers**: 2 MV167 VME single board computers running vxWorks OS. The Slave Control Computers reside in the same VME rack as the Master Control Computer, and periodically receive position data over RPC for roughly 1100 actuators. The Slave Control Computer’s ("the slaves") interface to the actuators is through VME Intelligent I/O Processor ("IIOP"). The primary responsibility of the slaves is open loop “on/off” position control of their actuators. The base control period for the slaves is roughly 100mSec. The control algorithm applied to all actuators is $T_{on} = \frac{P_{delta}}{V_{actuator}}$ where $T_{on}$ is total time the actuator H-Drive is enabled in either positive or negative direction, $P_{delta}$ is the difference between current and actual position and $V_{actuator}$ is the measured actuator velocity. Additionally, the slaves will periodically send actuator status data to the Master Control Computer for ultimate transport to M&C.

- **Intelligent I/O Processors**: 8 VME rack mounted I/O processors from Transition Technology. Each IIOP manages a field distributed I/O network (actuators, LVDTs) and essentially forms a “bridge” between the VME bus and a proprietary field bus. Each slave computer interfaces to 4 IIOP’s by way of VME memory mapping over which control data is written and monitor data is read. The IIOP in turn, interfaces to either 17 or 18 Actuator H-Bridge and LVDT Analog Input module pairs over an RS485 type network.

- **H – Bridge modules**: 140 Digital Output modules made by Transition Technology specifically for NRAO. Each H – Bridge module allows for bidirectional “on/off” control of 16 actuators. And H-Bridge module is paired with a LVDT module to form a comprehensive control/feedback package for each actuator.

- **LVDT modules**: 140 Analog Input modules made by Transition Technology specifically for NRAO. Each LVDT modules interface to the Linear Voltage Differential Transformer sensor and digitizes the feedback to a 14 bit signed integer.

- **Ancillary Devices**: a variety of I/O devices which are not directly involved in actuator control but provide critical support functions. Some examples are oscillators, voltage monitors, Estop, etc. These are connected to the Master Control Computer by way of legacy RS422 Monitor Control Bus (MCB) network.

The following diagram depicts a high level architectural view of the existing electronics:
Slave Computers handle open loop actuator control

\[ P = 100 \text{mSec} \]

\[ T_{on} = \frac{D}{V} \]

Master Control Computer receives actuator setpoints from M&C and distributes to slave computers. Also general purpose IO (temps, voltages, etc) are monitored.

M&C Sends Position Vector using RPC

Slave Computers handle open loop actuator control. IIOP is VME to serial IO bridge.

14 Bit LVDT 16 Channel Analog Input

Module Pair [0-69]

LVDT Output

H-Drive Output

Armature

Linear Variable Differential Transformer

Actuator Assembly [0-1120]

14 Bit LVDT 16 Channel Analog Input

Module Pair [70-139]

LDVT Output

H-Drive Output

Armature

Linear Variable Differential Transformer

Actuator Assembly [1121-2209]

General IO (temps, voltages, etc) over RS422

Current Challenges
A number of challenges exist with maintenance and reliability of the current architecture, thus, the motivation for this proposal. The individual components in the current system each have their own unique set of concerns. These are listed in (debatable) priority order.

- **Intelligent I/O Processor** – This I/O bus master was produced circa 1992 by Transition Technologies Inc. It provides a VME interface between NRAO’s control computers and TTI’s proprietary I/O devices (Actuator and LVDT modules).
  - **Availability**: No longer sold. We have one spare.
  - **Repairable**: Questionable or Unknown.
  - **Downtime**: Losing 1 IIOP results in loss of 1/8 of the surface.
  - **Risk**: High
  - **Remarks**: If there is any reason to engage in recreational worrying, it would be over the loss of these processors. Losing one of them results in a surface which is of limited use for observations using frequencies of 4 GHz on up. If nothing else, an upgrade plan must be developed which deals with end of life issues for these components.

- **LVDT / H-Bridge Module** – These modules were produced circa 1992 by Transition Technologies Inc. They provide the direct interface from the IIOPs to the Actuator assembly.
  - **Availability**: No longer sold. Fixed in house.
  - **Repairable**: Yes, most module components still available
  - **Downtime**: Losing 1 Module results in loss of a patch of 16 actuators
  - **Risk**: Medium
  - **Remarks**: These are proprietary modules and require the use of legacy software (16bit binaries) to configure them for telescope use. These modules also require the use of a PC containing proprietary PCI interface hardware for routine diagnostics and maintenance.

- **Master/Slave Control Computers** – These are legacy Motorola MV167 modules with either 8 or 16 MB of ram. They both use a well supported, though expensive and proprietary OS from WindRiver (vxWorks).
  - **Availability**: Available, used, refurbished and new from OEM suppliers.
  - **Repairable**: Yes
  - **Downtime**: If any of these boards fail to boot (rare), the Active Surface cannot be run.
  - **Risk**: Medium
Remarks: once ubiquitous, the MV167’s use is on the decline. NRAO is trying to wean themselves off of them. Supporting these means relying on 1 or 2 personnel who will retire in the next 10-15 years. Comments on software ... the Master and Slave applications run on separate processors, and though located within the same VME rack, they communicate through RPC. This is a high overhead means of inter-processor communication that relies on a notoriously indeterminate Ethernet driver. Slaves are in a rather fragile state. It has been observed that opening a Telnet session to them results in persistently missing the 100mSec control deadlines. Over the course of an observation, the Active Surface display will routinely show increasing numbers of actuators being disabled. A reboot clears this problem. An examination of message logs from 2/5/2011 through 5/8/2011 shows 64 Active Surface reboots, which seem roughly coincidental with the number of Active Surface enabled observations during this time. These reboots underscore the need to improve the reliability of the current software base.

Ancillary Devices - various field devices that support the Active Surface system connect to a Standard Interface Board (SIB). The SIB is a legacy, NRAO developed platform which allows various Analog and Digital devices to communicate to M&C over a Monitor Control Bus (MCB). The MCB is a RS422/485 type multi-drop network consisting of NRAO built interface electronics.

- Availability: Most of the Ancillary devices (except the Transnet supplies). Most of the chips on the MCB/SIB are obsolete.
- Repairable: Yes
- Downtime: Failure of some of these devices result in either Actuator Disables, or Active Surface downtime.
- Risk: Medium
- Remarks: These devices are periodically monitored for faults by way of a complex software state machine on the Master Control Computer. Some of these devices can generate disabling faults which results in software disable of actuators, or the entire Active Surface.

Proposed Upgrade

This section describes an upgrade path for the active surface hardware which will either mitigate or eliminate the concerns cited listed under “Current Challenges”. 
Replacement of the VME Master/Slave/IIOP modules

Today’s microprocessors combine flexibility, processing speed and low cost to create an attractive replacement for the monolithic processors in the existing system. Moreover, industry standard networking and serial protocols can replace the obsolete, unsupported proprietary I/O Bus topology present on the current system. This section describes an upgrade path for the current VME modules as follows:

- **Distribute Actuator Control Functionality to lowest practical level** – The H-Drive output and LVDT input path to the Actuators come from the dish into the Alidade room in groups of 16 I/O pairs which terminate at a LVDT/H-Drive module. It would be practical to consider this a point from where 16 actuators can be locally monitored and controlled. With the addition of a low cost, microcontroller, the control loops can be closed directly on the module, hence creating a “Control Module”. To initiate closed loop position control, the M&C system would need to send time-stamped position set-points down the Control-Module where the actuator positions are adjusted at the designated time.

- **Microcontroller Selection** – a microcontroller for the Control Module would need to be chosen which would be:
  - highly reliable (i.e. lower temperature operation, no moving parts such as fans, disk drives no reliance on external environmental controls)
  - low cost
  - support industry standard protocols on chip (e.g. SPI, Ethernet, etc)
  - An RFI quiet communications interface (optical fiber is desirable)

- The microcontroller could mount to the H-Drive/LVDT module via standard 50 pin Samtec connectors. Additionally, the microcontroller core should be based on a component with wide commercial acceptance in order to stave off obsolescence as long as possible. If a reasonable cost microcontroller platform can be purchased which meets these criteria, we would need to buy 140 units. Otherwise, building such a platform in house is conceivable given the large number of units required.

- **RFI Considerations** – The Control Module should be enclosed in a Faraday cage similar to the ones in use today (NOTE: RFI Engineering opinion needed here). Communications between M&C and the Control Module would be over Base F (Optical Fiber) which eliminates the need for expensive connectors and shielded cabling.

H-Drive/LVDT Module upgrade
The current H-Drive/LVDT module would need to be redesigned to utilize modern components, connectors for the microcontroller, and an external interface for existing field wiring. There is a high degree of confidence that this upgrade/redesign could be done in house utilizing staff of NRAO’s Electronics Division.

**MCB/Standard Interface Board Replacement**

A clean, comprehensive upgrade of the Active Surface hardware would require consideration of the SIB/MCB hardware currently in place. The SIB/MCB hardware is another legacy component in the M&C system which is deployed in various applications throughout the GBT, as well as the VLBA telescopes. Most of the chips in the SIB are obsolete. The SIB/MCB hardware could be replaced with the same Microcontroller platform selected for the Control Modules, piggy back mounted to a card containing A to D and D to A conversion capability.

The MCB/SIB replacement effort can occur in parallel with, but separately from the Active Surface upgrade, once the Microcontroller selection/build is complete. Additionally, there is strong interest from Socorro Electronics Division engineering members to have the SIB’s replaced in their telescopes (VLBA). Considerable thought has already been given this effort by their staff and synergies can be realized by coordinating our development goals with theirs.

**Upgrade Proposal – Summary**

This proposal is essentially an admonishment to eliminate the Active Surface control components in the existing VME chassis and replace them with a modern control system, distributed at the level of the H-Drive/LVDT modules. Additionally the low-level monitor and control functionality for the SIB connected devices would get delegated to a new SIB microcontroller. The current dependence on the H-Drive/LVDT module debug PC goes away, and is replaced by a simple Telnet interface.

Components eliminated by this upgrade would include:

- 3 MVME 167 Processor boards
- 1 Debug PC
- 8 Intelligent IO Processors
- 3 layers of hardware
- 12 major points of failure

Higher level logging of messages, faults and data would still occur on the M&C nodes as would the existing Active Surface Manager functionality.
Upgrade Path

- **Stage 1a (Control Module):** Includes selection of appropriate microcontroller platform, development of LVDT/H-Drive Module and associated control software. Deliverable should include demonstrating control of a single actuator using a Telnet interface. This interface would easily allow and engineer/technician to debug the Control Module from the bench, and would not require any other specialized hardware/software.

- **Stage 1b (SIB Replacement):** Design of SIB board replacement can occur in parallel with Stage 1a efforts, using same microcontroller. A common external communications interface based on Ethernet should be developed for both Stage1a/b efforts. Deliverable should include demonstration of monitor and control for selected Analog and Digital devices.

- **Stage 2 (Current VME Slave modification):** Modification of existing Master/Slave software to allow for the inclusion of new Control Modules. This would be done at the lowest level possible, most likely in the MVME 167 Slave hardware interface class(es). Testing would occur in the lab. Actuator motion can be achieved via existing Telnet accessible test utilities available on the vxWorks system.

- **Stage 3 (Deployment):** The upgrade to the actuator control system can be phased in. Either one LVDT/H-Drive or one IIOP’s worth of actuators can be converted at a time. The existing software interface to the hardware would be modified to talk to either the old control hardware or the new. The SIB replacement would be extensively bench tested and replaced during summer maintenance.

The following diagram illustrates the realization of the proposed architecture:
M&C sends Actuator Setpoints via time-deferred commands to all LVDT/H-Drive Microcontrollers via fiber optic.

The microcontroller s/w closes the actuator control loop locally. Any actuator faults or position errors are sent to M&C.

SoC Microcontroller (Network enabled)

General IO (temps, voltages, etc)

SoC Microcontroller (Network enabled)

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**Costs**

TBD

**Schedule**

TBD