EVLA Memo 153 - ACU/Servo Upgrade Study

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1 Introduction

The Very Large Array (VLA) antenna system was designed in the early 1970's and construction of the array commenced in September of 1975. The effort culminated in formal inauguration of the VLA in 1980. Over the past years, the VLA has evolved into the Expanded Very Large Array (EVLA) which greatly extends the system's sensitivity and resolution. Although the EVLA has refurbished, improved or replaced most aspects of the original VLA system, such as the correlator, receivers, RF distribution and command/status communications, the servo control and drive systems remain original.

The EVLA would benefit greatly from an upgrade to the servo and drive systems for two major reasons. First, the current servo system hardware is at the end of life. System performance and downtime are already being adversely affected by steadily degrading components and increasing reliability issues, particularly in the Focus Rotation Mount (FRM) and AZ/EL Drive Amplifiers. It is becoming more difficult to find replacement parts and facilities to repair broken equipment and subsystems. Scientific use of the EVLA has already become dependent on the availability of used and stockpiled new original stock components from surplus houses, overseas suppliers and online auction sites. Additionally, some parts purchased from these sources have been found to be defective, substandard or even counterfeit or relabeled devices that did not work in the system. It is likely that servo component failures in the very near future will lead to extended down time due to non-availability of parts or repair services. Second, the application of current technology can enhance the EVLA's never ending quest for greater resolution and sensitivity. This enhancement would be due to the finer grained control and sensor technology available and the advancement of software techniques that allow for the implementation of sophisticated control schemes which can cancel many of the mechanical limitations of the mounts.

Various technologies have been developed in recent years to support the development and refurbishment of large radio telescopes. Specifically, the work done to commission and improve the performance of the Greenbank telescope and the work done to completely refurbish the Haystack Instrumentation Radar (HUSIR) is directly applicable to an effort to upgrade the EVLA servo and control systems. The Haystack Instrumentation Radar was developed in an open source environment that provides a low risk upgrade path which is completely supportable by the EVLA staff.

2 Scope

The purpose of this document is to provide a suggested path to upgrading the EVLA servo control system with an eye to the following key design criteria:

- Meet or preferably exceed current performance specifications.
- Modernize interfaces and actuators to enhance supportability and maintainability therefore effectively extending the life of the EVLA control system.
- Maximize time on target by enhancing servo settling time performance
- Open architecture (hardware and software) to allow for EVLA internal support and enhancement.

- Implement the upgrade path so that it is directly applicable to the Very Long Baseline Array (VLBA) as well.

In order to understand this path, the following information is provided:

- Current system specifications: The upgraded servo system must meet or (if possible exceed these criteria.
- Current system architecture: The current organization and design of the system is described so that it is possible to verify that all system components have been addressed in the study.
- Applicable upgrade approaches: Possible upgrade candidates for each subsystem are discussed and tradeoffs are presented where applicable.
- Cost and Schedule Estimates: A straw man schedule and budgetary costs are presented for planning purposes.

3 System Characteristics and Specifications

The characteristics and specifications of the current EVLA and VLBA antennas are captured here for easy reference. This data has been gleaned from various documents and reports which are referenced at the end of this report(1)(2)(3)(4) .

3.1 EVLA Servo System Characteristics

3.1.1 Elevation Axis

Elevation range of travel:	7^o to 125^o
Stow position:	92.8^o ($\pm 0.05^o$)
Maximum elevation velocity:	0.33 ^{o}/sec
Position Feedback:	20 Bit Inductosyn (MSB = 180^o) The Absolution position encoder Electronics Upgrade (3) increased the resolution of the Inductosyn data to 25 bits (MSB = 360^o), however the current ACU is still only capable of using bits 2 - 21
Accuracy under no wind conditions:	0.0008^o RMS
Elevation drive gear ratio:	20700:1
Elevation axis gear train spring rate (each):	3.9 x 10^9 ft-lbs/radian minimum
Elevation axis structure and gearbox inertia:	4.0 x 10^6 slug ft^2
Elevation axis deadweight unbalance:	55,000 ft-lbs in up direction at 5 degrees elevation
Elevation axis friction torque:	42,000 ft-lbs at antenna velocity of 0.002 ^{o}/sec

Elevation axis total loss at full speed:	47,000 ft-lbs at antenna velocity of 0.33 ^{o}/sec
Elevation axis wind torque constant:	149 ft-lbs/mph^2
Minimum elevation locked rotor frequency:	2.2 Hz

3.1.2 Azimuth Axis

Azimuth range of travel:	90^o to 630^o
Maximum azimuth velocity:	0.67 ^{o}/sec
Position Feedback:	21 Bit Inductosyn (MSB = 360^o) See note in elevation section
Accuracy under no wind conditions:	0.0008^o RMS
Azimuth drive gear ratio:	10350:1
Azimuth axis gear train spring rate (each):	4.4 x 10^8 ft-lbs/radian minimum
Azimuth axis structure and gearbox inertia:	2.3 x 10^6 slug ft^2
Azimuth axis friction torque:	41,000 ft-lbs at antenna velocity of 0.002 ^{o}/sec
Azimuth axis total loss at full speed:	43,000 ft-lbs at antenna velocity of 0.67 ^{o}/sec
Azimuth axis wind torque constant:	172 ft-lbs/mph^2
Minimum azimuth locked rotor frequency:	2.15 H

3.2 VLBA Servo System Specifications

The following specifications have been excerpted from reference (4). All outdoor equipment is designed to operate from -22°F to 104°F, 100% humidity, condensing. All indoor equipment is designed to operate from 56°F to 74°F, 95% humidity, non-condensing.

3.2.1 Azimuth Axis

Servo resolution:	22 bits binary, .31 arc seconds/lsb
Servo Accuracy:	Less than 3 lsb's or 1.24 arc seconds (0.0003°)
Maximum slew velocity:	1.5 °/second (3500 RPM)
Slew acceleration:	0.75 °/sec^2
Minimum smooth velocity:	0.004 °/sec (9.7 RPM)
Gear ratio:	14,133:1
Travel range:	± 270°
Motor Characteristics:	240 VDC armature, 150VDC field, 15HP @3500RPM Integral thermostat, blower, tachometer and brake
Torque:	25.9 ft-lbs @ full load; 37.5 ft-lbs @ 50% overload
Brake:	120 VAC, 75 ft-lbs with heater
Tachometer:	50 VDC/1000RPM
Position Feedback:	23 Bit inductosyn (MSB = 360°)

3.2.2 Elevation Axis

Servo resolution:	22 bits binary, .31 arc seconds/lsb
Servo Accuracy:	Less than 3 lsb's or 1.24 arc seconds (0.0003°)
Maximum slew velocity:	0.5 °/sec (2400 RPM)
Slew acceleration:	0.25 °/sec^2
Minimum smooth velocity:	0.004 °/sec (17.4 RPM)
Gear ratio:	25,044:1
Travel range:	0° – 125°
Motor Characteristics:	240 VDC armature, 150VDC field, 10HP @2500RPM

	Integral thermostat, blower, tachometer and brake
Torque:	24.2 ft-lbs @ full load; 36.2 ft-lbs @ 50% overload
Brake:	120 VAC, 75 ft-lbs with heater
Tachometer:	100 VDC/1000RPM
Position Feedback:	22 Bit inductosyn (MSB = 180^{o})

3.2.3 General Antenna Control Unit Characteristics

Computer Control:	21 position command per second for each of azimuth and elevation Command position A Command position B Stow
Local Control:	Command position A Command position B Stow Manual position Manual slew (velocity)
Auto Stow:	Dual motor drive and winds greater than 60 MPH Single motor drive and winds greater than 30 MPH Outdoor temperature less than -22^{o}F Inductosyn fault, Azimuth drive fault, Loss of computer link

4 Current System Architecture

A simplified block diagram of the current EVLA architecture is shown in Figure 1. It should be noted that this control system consists of an amalgamation of old and new technologies. The drive systems for the azimuth and elevation axis are the original motors and SCR systems controlled by the Electrospace Antenna Control Unit which is essentially unmodified. The position sensor (Inductosyn) interfaces to the ACU have been enhanced via the Absolute Position Encoder Electronics Upgrade ACU (3). Additionally, the monitor and control interfaces for the ACU utilize the new Module Interface Board (MIB) to provide connectivity to the standardized communications medium. The Focus/Rotation control system consists of synchos, S/D converters (obsolete) and translators (stepper motor controllers) which are no longer serviceable.

Table 4-1 through Table 4-5 show the essential connections to the ACU that must be replicated in any upgrade effort. It should be noted however that each signal line need not be replicated, only the functionality of the signals is required. Current technology allows for serial communications and daisy chain interfaces that can greatly reduce wiring connectivity and interconnection paths.

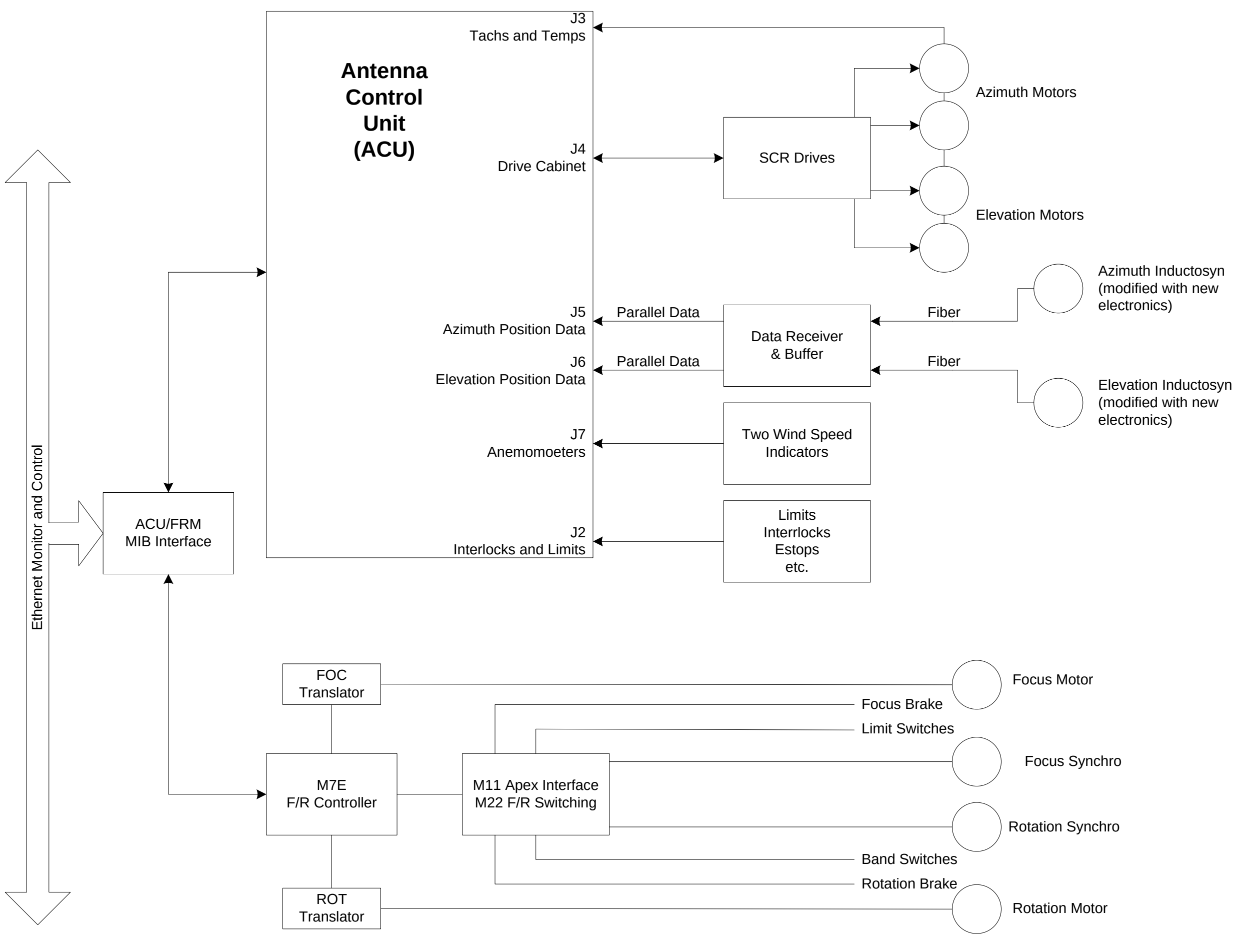

Figure 1 - Simplified Control System Block Diagram

Table 4-1 - J2, Limits and Interlocks (MS3112E22-55P)

Signal	Pin	Notes
Az CW Limit #1 (NC)	J2-A	Shorted to J2-C when not in limit condition
Az CW Limit #1 (NO)	J2-B	Shorted to J2-C when in limit condition
Az CW Limit Return	J2-C	
Az CW Limit #2 (NC)	J2-D	Shorted to J2-C when not in limit condition
Az CW Limit #2 (NO)	J2-E	Shorted to J2-C when in limit condition
Chassis Ground	J2-F	
Az CCW Limit #1 (NC)	J2-G	Shorted to J2-J when not in limit condition
Az CCW Limit #1 (NO)	J2-H	Shorted to J2-J when in limit condition
Az CCW Limit Return	J2-J	
Az CCW Limit #2 (NC)	J2-K	Shorted to J2-J when not in limit condition
Az CCW Limit #2 (NO)	J2-L	Shorted to J2-J when in limit condition
Chassis Ground	J2-M	
El UP Limit #1 (NC)	J2-N	Shorted to J2-R when not in limit condition
El UP Limit #1 (NO)	J2-P	Shorted to J2-R when in limit condition
El UP Limit Return	J2-R	
El UP Limit #2 (NC)	J2-S	Shorted to J2-R when not in limit condition
El UP Limit #2 (NO)	J2-T	Shorted to J2-R when in limit condition
Chassis Ground	J2-U	
El DN Limit #1 (NC)	J2-V	Shorted to J2-Y when not in limit condition
Stow Pin Engaged Return	J2-W	
El DN Limit #1 (NO)	J2-X	Shorted to J2-Y when in limit condition
El DN Limit Return	J2-Y	
Stow Pin Engaged	J2-Z	Shorted to J2-W when stow pin engaged
El DN Limit #2 (NC)	J2-a	Shorted to J2-Y when not in limit condition
El DN Limit #2 (NO)	J2-b	Shorted to J2-Y when in limit condition
Chassis Ground	J2-c	
E-Stop	J2-d	Shorted to J2-e when no E-Stop condition exists
E-Stop Return	J2-e	
Ground	J2-g	
Drive Fault Reset	J2-h	Shorted to J2-e to reset drives
Lead Switch Return	J2-p	
Lead Switch	J2-q	Shorted to J2-p when inactive (used to resolve cable wrap)
Lag Switch Return	J2-v	
Lag Switch	J2-w	Shorted to J2-v when inactive (used to resolve cable wrap)

Table 4-2 - J3, Motor Status (MS3112E16-26PY)

Signal	Pin	Notes
Az Tach 1	J3-A	Originally100V / 1000 RPM (115V at max speed = 1150 RPM) Now digital converted to analog via F/V converter
Az Tach 1 Return	J3-B	
Az Motor 1 Overtemp	J3-C	Contact closure with J3-N
Az Tach 2	J3-D	Originally100V / 1000 RPM (115V at max speed = 1150 RPM) Now digital converted to analog via F/V converter
Az Tach 2 Return	J3-E	
Az Motor 2 Overtemp	J3-F	Contact closure with J3-P
El Tach 1	J3-G	Originally100V / 1000 RPM (115V at max speed = 1150 RPM) Now digital converted to analog via F/V converter
El Tach 1 Return	J3-H	
El Motor 1 Overtemp	J3-J	Contact closure with J3-R
El Tach 2	J3-K	Originally100V / 1000 RPM (115V at max speed = 1150 RPM) Now digital converted to analog via F/V converter
El Tach 2 Return	J3-L	
El Motor 2 Overtemp	J3-M	Contact closure with J3-S
Az Motor 1 Overtemp Return	J3-N	Contact closure with J3-C
Az Motor 2 Overtemp Return	J3-P	Contact closure with J3-F
El Motor 1 Overtemp Return	J3-R	Contact closure with J3-J
El Motor 2 Overtemp Return	J3-S	Contact closure with J3-M
Smoke Detector	J3-T	No longer used
Smoke Detector	J3-U	No longer used
Smoke Detector Trouble 16	J3-V	No longer used
Smoke Detector Trouble 15	J3-W	No longer used

Table 4-3 - J4, Drive Cabinet (MS3112E22-55P)

Signal	Pin	Notes
Az Motor 1 Disable	J4-A	
Az Motor 1 Current Cmd +	J4-B	
Az Motor 1 Current Cmd -	J4-C	
Az CW Limit 1 (NC)	J4-D	
Az CCW Limit 1 (NC)	J4-E	
Az Motor 1 Current Monitor	J4-F	
Az Motor 2 Disable	J4-G	
Az Motor 2 Current Cmd +	J4-H	
Az Motor 2 Current Cmd -	J4-J	
Az Motor 2 Current Monitor	J4-K	
El Motor 1 Disable	J4-L	
El Motor 1 Current Cmd +	J4-M	
El Motor 1 Current Cmd -	J4-N	
El UP Limit 1 (NC)	J4-P	
El Motor 1 Current Monitor	J4-R	
El Motor 2 Disable	J4-S	
El Motor 2 Current Cmd +	J4-T	
El Motor 2 Current Cmd -	J4-U	
El Motor 2 Current Monitor	J4-V	
Az Blower 1 Circuit Breaker	J4-W	
Az Blower 2 Circuit Breaker	J4-X	
Az Motor 1 Circuit Breaker	J4-Y	
Az Motor 2 Circuit Breaker	J4-Z	
Cabinet 1 Common	J4-a	
El Blower 1 Circuit Breaker	J4-b	
El Blower 2 Circuit Breaker	J4-c	
El Motor 1 Circuit Breaker	J4-d	
El Motor 2 Circuit Breaker	J4-e	
Circuit Breaker Common	J4-f	
Brake Relay 24 Volts	J4-g	
/Az Brake	J4-h	Apply 24 Volt return to release both Az brakes
Az Field 1 Monitor	J4-i	
Az Field 2 Monitor	J4-j	
El Field 1 Monitor	J4-k	
El Field 2 Monitor	J4-m	
/El Brake	J4-n	Apply 24 Volt return to release both El brakes
?????	J4-p	
Phase C Monitor	J4-q	
Phase B Monitor	J4-r	
Phase A Monitor	J4-s	
Cabinet 2 Common	J4-t	
Cabinet Temperature Switch	J4-u	
Az CW Limit 2 (NC)	J4-AA	

Az CCW Limit 2 (NC)	J4-BB	
El UP Limit 2 (NC)	J4-CC	
El DN Limit 2 (NC)	J4-DD	
El DN Limit 1 (NC)	J4-HH	

Table 4-4 - J7, Data Set and Anemometers (MS3112E12-10S)

Signal	Pin	Notes
/XMIT	J7-A	MMIB
Ground	J7-B	
Anemometer 1	J7-C	Now a digital unit with F/V converter
?????	J7-D	
DATA	J7-E	MIB
/DATA	J7-F	MIB
Anemometer 2	J7-G	Now a digital unit with F/V converter
XMIT	J7-H	
Anemometer 1 Return	J7-J	
Anemometer 2 Return	J7-K	

Table 4-5 – M11 P1, Focus and Rotation Control Connections

Signal	Pin	Notes
+15 Volts	J1-A	MMIB
Ground	J1-B	
+ 5 Volts	J1-C	Now a digital unit with F/V converter
N/C	J1-D	
-15 Volts	J1-E	MIB
Focus Synchro Line 1	J1-F	MIB
Rotation Sychcro Line 1	J1-H	Now a digital unit with F/V converter
Focus Synchro Line 2	J1-J	
Rotation Synchro Line 2	J7-K	
Focus Synchro Line 3	J7-L	
Rotation Synchro Line 3	J7-M	
Synchro Reference 1 (400Hz)	J7-N	
N/C	J7-P	
Synchro Reference 2 (400 Hz)	J7-R	
N/C	J7-S	
Focus Up Limit	J7-T	
Rotation CW Limit	J7-U	
Focus Down Limit	J7-V	
Rotation CCW Limit	J7-W	
Ring In Switch	J7-X	
N/C	J7-Y	
Ring Out Switch	J7-Z	
	J7-a	

P Band Switch	J7-b	
L Band Switch	J7-c	
S Band Switch	J7-d	
C Band Switch	J7-e	
X Band Switch	J7-f	
Ku Band Switch	J7-h	
K Band Switch	J7-j	
Ka Band Switch	J7-k	
Switch return	J7-m	
Focus Brake V	J7-n	
Rotation Brake V	J7-p	
Focus Brake I	J7-r	
Rotation Brake I	J7-s	
Focus Brake Common	J7-t	
Rotation Brake Common	J7-u	
N/C	J7-v	
F/R Mount Temp +	J7-w	
N/C	J7-x	
F/R Mount temp -	J7-y	
Analog Ground	J7-HH	

5 Suggested Upgrade Approach

As with any complex design task, the approach to the upgrade of the EVLA provides a plethora of options. The upgrade approach suggested in this document recognizes this fact and provides a method to significantly improve the reliability, maintainability and functionality of the system via an incremental approach. This approach immediately addresses the most egregious maintainability issues while providing a logical path for the validation and implementation of further efforts.

Figure 2 shows a simple block diagram of a minimal upgrade. This approach replaces the current ACU with a contemporary processor and upgrades the Focus/Rotation subsystem with modern motors which are controlled via a simple serial interface. These motors also provide the I/O necessary for switch and brake control. The upgrade uses the current drives, inductosyns and other sensors. This approach is the minimum recommended because it provides an up to date flexible antenna controller supporting intelligent servo control algorithms and it replaces the Focus/Rotation subsystem which is causing more and more difficulties and is the most likely failure point. Figure 3 shows a complete upgrade. This path provides for the most modern control system available for the EVLA (and VLBA) antennas. Appendix 1 contains a very detailed diagram of the connections and interfaces required to support either path. The following paragraphs discuss the salient points of each of the possible upgrades to specific subsystems.

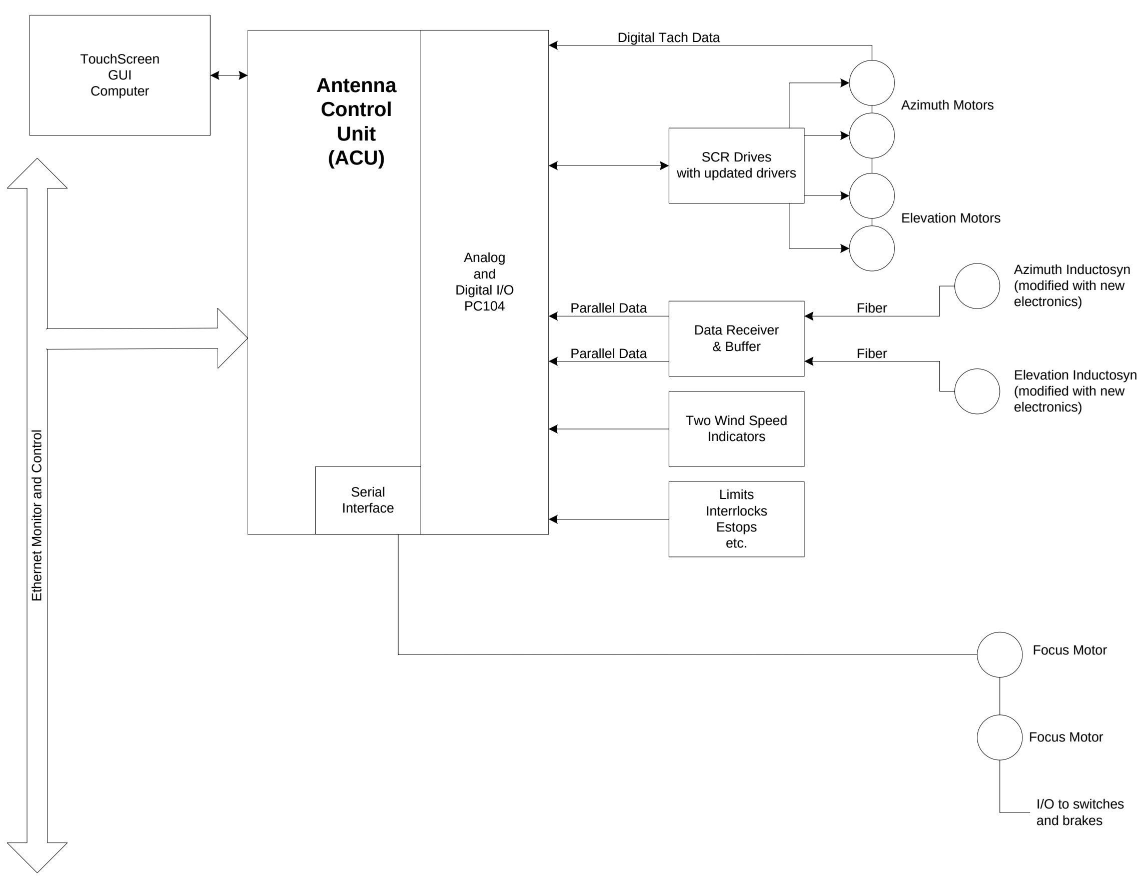

Figure 2 - Upgrade Reusing Current Drives and Sensors

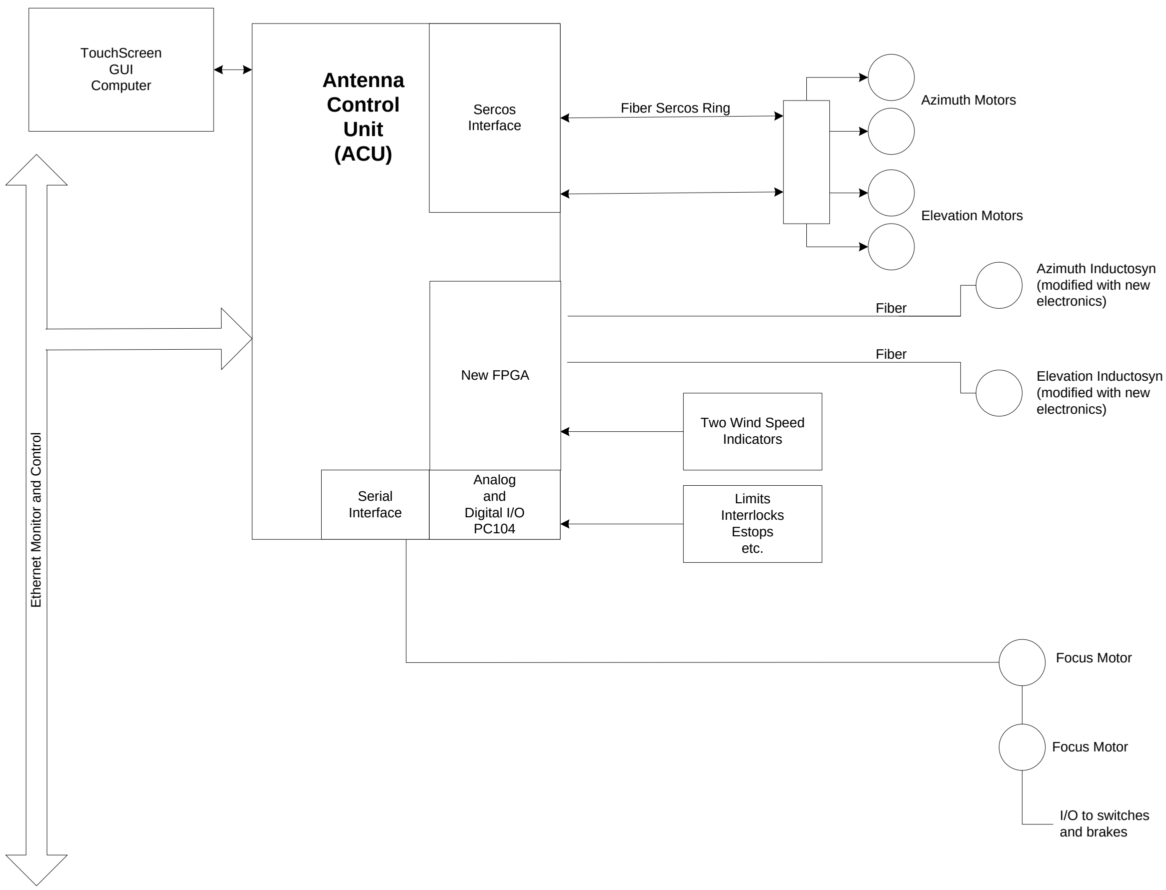

Figure 3 - Upgrade Maximizing Flexibility and Advantages of Up to Date Hardware

5.1 Basic ACU Architecture

The basis for any upgrade to the ACU portion of the EVLA control system must be a modern general purpose computer system which provides the bus structures necessary to support interfaces to the required equipment. This general purpose computer should run in a diskless environment and operate over a wide temperature range in order to provide the required reliability in the relatively harsh environment encountered in the base of each pedestal.

The EVLA has successfully used the PC104 bus architecture in other system upgrades. It is suggested that this same architecture be utilized for the ACU. Furthermore, the CPU card selected should support the PCI bus. These two bus structures, PC104 and PCI, will support all of the interfaces necessary for the program. The processor should be mounted on a motherboard that supports stacking of PC104 peripheral cards as well as two or three PCI cards. These motherboards are readily available and can be easily mounted in a chassis which can reside in the rack in the pedestal base. This processor is easily augmented with analog to digital converters, digital I/O and synchro to digital converters to provide the necessary connectivity to the pedestal and feed equipment. Figure 4 shows an example ACU processor card and supporting peripherals.

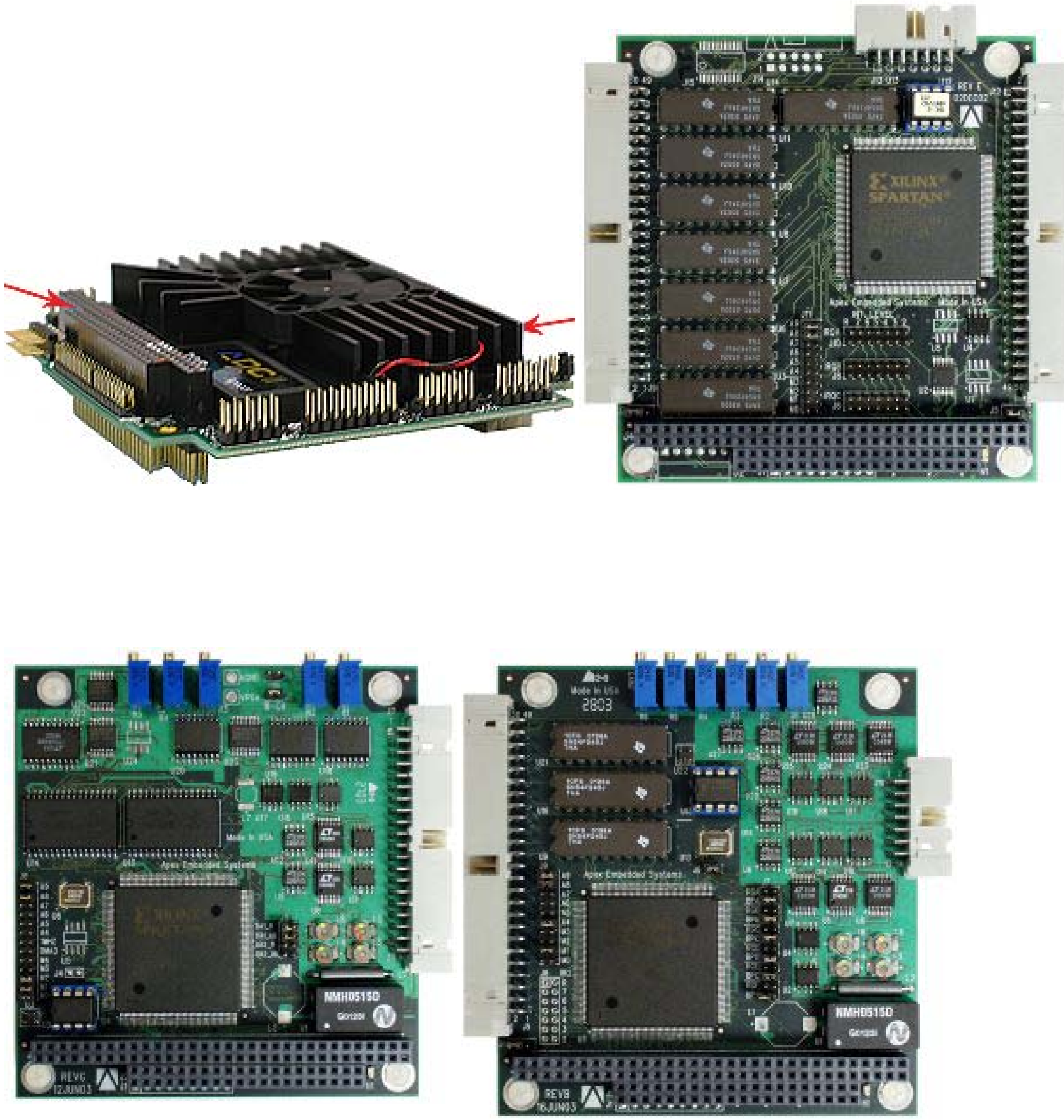

Figure 4 - PC-104 Processor and Peripherals

A second processor running a touch panel GUI would provide the environment necessary for local control and performance testing. The servo processor would run a real time operating system and provide the processing necessary for control. This processor would connect to the azimuth and elevation drives as well as the focus and rotation drives (see section 5.2 below). The second processor would run a standard operating system and provide a Graphical User Interface functions. A flat touch panel display connected to this processor provides interactive local control for testing and motion.

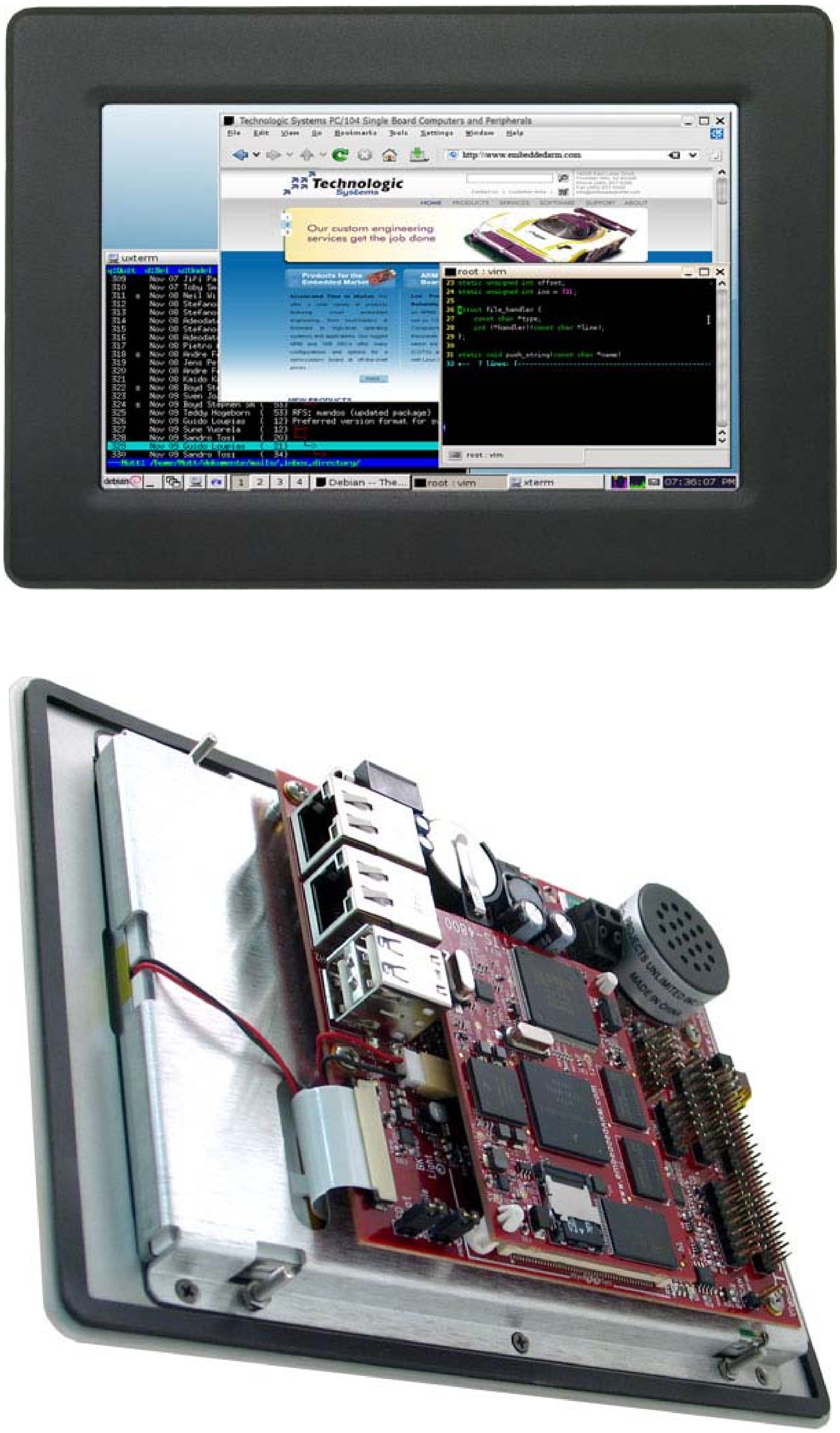

Figure 5 - Embedded Touch Panel Computer

The software that was developed for the Haystack Instrumentation Radar can be easily modified to run in this environment. This software has many features that are detailed in the *Haystack Antenna Control System Design Document* (5) which are directly applicable to and can greatly enhance the operation of the EVLA pedestals as follows

- Position and velocity loops closed every millisecond.
- Completely configurable compensators for both the position and velocity loops
- Fully configurable true torque bias, acceleration limits and torque limits greatly reduce stress and strain on the pedestal, back-structure and apex, thus reducing motion oscillations
- Allows for the implementation and evaluation of position preprocessors such as those proposed by Gawraonski (6) for the Deep Space Network antennas and Wells (7) for the Greenbank Telescope.
- Operates in the Real-Time Applications Interface augmentation of Linux to provide real time control
- Separate GUI and servo processors.
- Completely tested on a mount with extremely high performance requirements ($< 0.0005^{o}$)
- Completely open source to allow for EVLA personnel support and modification
- Position preprocessing which minimizes overshoot and transition time.

5.2 Monitor and Control Interface

In order to minimize the impact on the overall Monitor/Control system, the new ACU should emulate the current MIB interface. There is no need to use the MIB per se because the ACU itself has the processing power to provide the current antenna control system MIB functionality. This interface can be developed from the MIB simulator software that already exists which will eliminate cost and risk.

5.3 Focus/Rotation System Interface

The focus/rotation system is probably one of the weakest links currently in the system. The stepper motors and stepper motor drive are no longer maintainable. Figure 6 depicts a smart motor that contains a permanent magnet motor, drive amplifier, servo controller and optical encoder. Two of these motors can be used to replace the focus and rotation stepper motors and synchros. Connection to these smart motors is via RS-232 or RS-485. This can be effected over a single fiber pair because the motors can be daisy chained. The motors also have an Analog Input and Digital I/O capability which can be used to replace all of the original switching electronics and provide control of any required brakes. These two daisy chained motors on a single fiber pair can replace the entire F/R electronics suite.

Figure 6 - Example SmartMotor

5.4 Encoder, Tach and Anemometer Interfaces

The current interfaces may be used without modification; however the system connectivity can be greatly simplified by the use of a new FPGA that provides the conversion and interface to the digital tachometers and anemometers. Note, that if the SERCOS interface (Paragraph 5.5) is used, there is no longer any need for tachometers because velocity and torque information is passed over the Sercos ring. This FPGA should also support the interface to the encoders which would eliminate the need for the Data receiver and buffer device currently used to convert the fiber signal to a 22 bit parallel signal. This would allow the connection of the Inductosyn to be direct to the ACU via a fiber receiver. Additionally, it would pave the way to upgrading the Inductosyn with an absolute encoder. Use of absolute encoders can greatly enhance the positional resolution and accuracy while still only requiring a single pair of wires per encoder.

5.5 Azimuth and Elevation Drives

The current state of the art in drive systems greatly simplifies the accurate control of motors. The HUSIR system utilized Bosch-Rexroth drives via a SERCOS interface (Figure 7). These drives are proven to have exceptional low speed (i.e. less than sidereal rates) performance, retaining torque capability with no with no cogging or flat spots. The Sercos interface supports total axis synchrony and update rates of 2000 per second. Four motors, four drive amplifiers and two power supplies would replace the entire SCR drive cabinet, motors and tachometers for approximately $35,000 (quantity 1).

The suggested approach here is to leverage on the current SCR upgrade program and use analog interfaces to the current drive cabinets as an interim upgrade step. One antenna system would then be upgraded to SERCOS drives and motors for test and evaluation. Based on these tests (which are presumed to be successful) the remainder of the antennas would be upgraded.

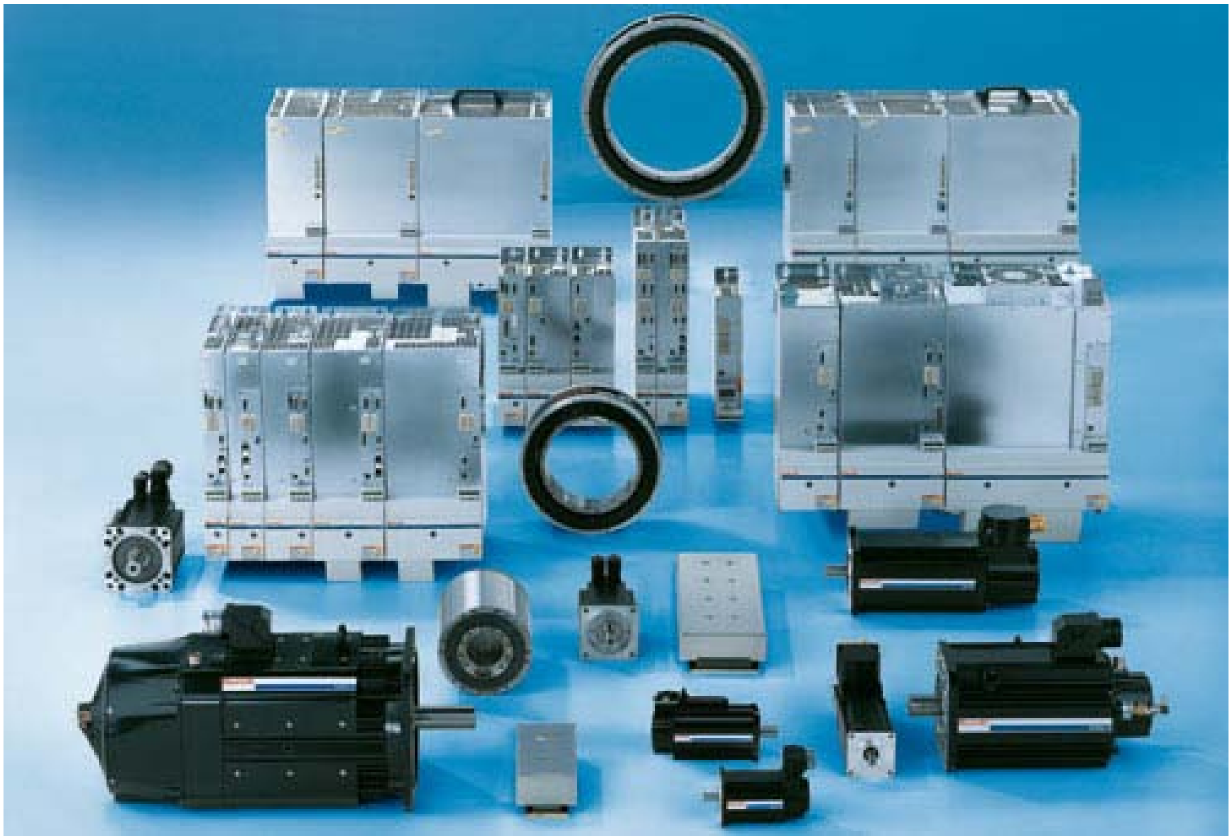

Figure 7 - SERCOS Drives and Motors

5.6 Radio Frequency Interference Mitigation

The use of modern high speed digital electronics, switching power supplies and inverter based drives results in a high risk of Radio Frequency Interference (RFI) to the telescope. RFI mitigation techniques similar to those used throughout the rest of the EVLA system will need to be implemented to ensure the continued integrity of the RFI environment at the VLA and VLBA sites.

The EVLA project adopted a layered philosophy toward RFI. Components are chosen based on their potential to contribute to RFI. Components considered high risk are measured in the VLA site RFI chamber and the results used to determine what further steps are required to minimize their impact. Circuit boards and other subassemblies are designed for minimum RF radiation and characterized in the RFI chamber. Those components are then packaged in RFI tight enclosures with filtered I/O to further minimize that radiation. Lastly, operational procedures are designed to minimize potential for RFI.

Some specific RFI considerations for the Antenna Control and Drive Systems include:

1) Mounting of all high speed digital electronics in shielded enclosures that also provide for the environmental requirements of the hardware inside.
2) Mounting of new inverter based drives in separate RFI shielded enclosure(s) either in the pedestal room or co-located with the drive motors. Connection cables from the drives to the motors will almost certainly require shielding.
3) Utilization of optical fiber for communications wherever possible. Fiber simply does not radiate RFI and provides complete isolation from ground noise and lightning events. Only critical signals such as final limits, E-stops and other safety interlocks need to be on copper. This technique has proven quite effective in the HUSIR antenna and throughout the EVLA system.
4) Special consideration is required for the Smart Motors proposed for use on the Focus Rotation Mount (FRM). These motors, containing integral digital electronics and an inverter based driver, are located at the antenna apex in front of the RF receivers. These will need extensive RFI testing and may need to be powered down whenever the FRM is not in motion. The only connections to these devices are a DC power cable and a communications cable or fiber.
5) Establish procedures (and possibly interlocks) to assure that any electronics only required for local control and maintenance be powered off during normal remote antenna operations. The LCD touch screen interface is of particular concern.

6 Cost and Schedule Estimates

Funding ($320K) has been requested to design, prototype and test a completely new system largely based on the hardware and software design used for the Haystack Instrumentation Radar (HUSIR). These funds will be used to develop and test a prototype system in a laboratory environment, then deploy it on a single EVLA antenna for integration and testing. This new system will include:

1) A new Antenna Control Unit (ACU) capable of
    a. Operating both the existing and new modern Azimuth and Elevation drive amplifiers and motors
    b. Operating the new Focus Rotation Mount (FRM) motors
    c. Interfacing to the new Ethernet based EVLA M&C system
    d. Interfacing to both the current and modern position encoders
    e. Utilizing new, more advanced algorithms for antenna movement, tracking and diagnostics
    f. Implementing all modern safety requirements
2) Completely new integrated smart motors for the Focus Rotation Mount
3) Shielded enclosures to protect the Science from RFI emissions common in modern electronics
4) Sufficient spare parts since it will be deployed on an operational antenna

The schedule for this effort is completely dependent on the allocation of FTE's to work on the project.

In varying levels, this project will require the efforts of:

1) Project / Systems Engineer
2) Design Engineers
3) Control Systems Software Engineer
4) M&C Software Engineering
5) Servo Technicians
6) RFI Engineer
7) Mechanical Engineer
8) Drafting
9) Machine Shop
10) Manager/Scheduler

7 References

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2. **Broilo, B.** *EVLA Memo 45: Antenna Positioning System Specifications.* August 2002.

3. —. *VLA Technical Report 76: Absolute Position Encoder Electronics Upgrade.* February 2000.

4. **Electrospace Systems, Inc. .** *VLBA Antennas 93C-15 Antenna Control Systems Servo System Drawings Volume 2.* February 1990.

5. **James V Eschbaugh, Michael T. Clark, Gregory W. Maglathlin.** *Haystack Antenna Control System Design Document.* Lexington Mass : Massachusetts Instititute of Technology Lincoln Laboratory, 2010.

6. **Gawronski, W.** *A Command Preprocessor for Antenna Motion without Overshoots.* s.l. : IPN Progress Report 42-150, 2002.

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8. **D. Weber, P. Harden, W. Koski.** *VLA Technical Report 56: Focus/Rotation Control System, Model E.* December 1984.

9. **P. Dooley, A.Sittler, N. Atencio, D. Weber, K. Tate.** *VLA Technical Report 71: The VLA WYE Monitor System Hardware.* August 1994.

10. **C. F. Helvey, E. C. Downey.** *Module Interface Board - MIB Service Port Interface Control Document Version 1.2.0 .* September 2004.

Appendix I

Detailed Block Diagrams

The following drawings are attached as separate PDF files in this portfolio:

Diagram 1: A block diagram of the new system reusing the existing azimuth and elevation DC motors and drive amplifiers from the current VLA system is shown.

Drawing 2: A block diagram of the new system using modern brushless motors and inverter based drives for azimuth and elevation is shown. The Bosch Rexroth IndraDriveM series drives and motors used in the HSUIR upgrade are being proposed for this application.

Both drawings show the new computer based Antenna Control Unit (ACU), the Animatics Smart Motors being proposed for the Focus Rotation Mount (FRM) and the associated interconnect required to support the EVLA and VLBA systems.

These are E-sized drawings generated in MS-Visio. Hard copies can be distributed on request.

VLA Expansion Project
Antenna Control System
Block Diagram using
VLA Motors & Drives

National Radio Astronomy Observatory
PO Box O, Socorro, New Mexico 87801
Drawn By: Jim Jackson, Systems Engineer

SIZE	FSCM NO	DWG NO	REV
E		E23010K0016	B
SCALE 1 : 1		Date: 26 May 2011	SHEET 1 OF 1

VLA Expansion Project
Antenna Control System
Block Diagram
New Motors & Drives

National Radio Astronomy Observatory
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SIZE	FSCM NO	DWG NO	REV
E		E23010K0016	B
SCALE 1 : 1		Date: 21 June 2011	SHEET 1 OF 1