EVLA Memo 45: Antenna Positioning System Specifications

Bob Broilo

August 19^{th}, 2002

Contents

1 Introduction

This document describes the design specifications for the new antenna positioning systems for the Very Large Array 25m antennas. First, I give an overview of the existing system. Then, I include an analysis of the position loop computation scheme and transfer function. Then I provide detailed input and output requirements. Finally, I indicate which areas will be replaced with new electronics and the rough plans to do so.

The Very Large Array (VLA) antenna positioning systems consist of the azimuth (AZ) and elevation (EL) axis servos and the focus and rotation subreflector mount (FRM) stepper motors. The azimuth and elevation drives are controlled through the Antenna Control Unit (ACU). The subreflector is controlled with the Focus Rotation (F/R) Controller.

This document is not a complete specification. It could not be used alone to design an ACU and F/R Controller. It is intended to supplement Electrospace Systems Inc. documentation [1] and NRAO documents [7] as:

1. a summary of the required functionality
2. an analysis of the performance of the existing system and what needs to be addressed to meet EVLA [6] requirements
3. general guidelines for the implementation of the new system to assure it will be reliable, serviceable, reconfigurable, and meet the requirements.

1.1 ACU

The ACU has three major tasks:

1. It interprets the Monitor and Control (M&C) data stream to determine where to point the antenna and returns monitor data to the M&C system.
2. It does a digital compare of the desired position with an absolute position encoder[8]. It then converts the error to analog and uses an analog computer to implement a Proportional Integrative (PI) closed-loop servo.
3. It implements the logical safety interlocks, Emergency stops, power resets, automatic stowage, and other logical tasks.

In the existing ACU system, the position data is a 20-bit number for Elevation and a 21-bit number for Azimuth. See Table 1. The 21^{st} bit in Azimuth represents $360°$.

In each axis, the ACU subtracts the actual position from the desired position yielding the error value. The ACU ignores the higher bits in the error value and keeps the 12 least significant bits. The ACU feeds the 12-bit result to a Digital-to-Analog (D/A) converter creating a $\pm 5V$ error signal. The ACU

Table 1: Existing VLA Position Bits

bit	degrees	arcminutes	arcseconds	coarse resolver	fine resolver
20	180.0000			X	
19	90.0000			X	
18	45.0000			X	
17	22.5000			X	
16	11.2500			X	
15	5.6250			X	
14	2.8125			X	
13	1.4062			X	
12	0.7031	42.2		X	X
11	0.3516	21.1			X
10	0.1758	10.5			X
9	0.0879	5.3			X
8	0.0439	2.6			X
7	0.0220	1.3			X
6	0.0110	0.7	39.6		X
5	0.0055	0.3	19.8		X
4	0.0027	0.2	9.9		X
3	0.0014	0.1	4.9		X
2	0.0007	0.0	2.5		X
1	0.0003	0.0	1.2		X

then delivers the error signal to the A4 and A5 cards, which are sub-cards located in the ACU. These cards contain the analog computers for the Azimuth and Elevation loops, respectively.[1] The loop functionality is described in Section 2.

To prevent damage to the antenna in the event of a position encoder failure, calculation error, or manual operation error, the ACU has limit switch inputs and logic. The first limit activates a logic signal in the ACU that inhibits drive in the limited direction. The second limit disconnects electrical power to the drives and brakes. This engages the fail-safe brakes that lock the antenna in the current position. Any limit conditions are reported to the M&C system.

The ACU runs a 28V DC signal around the Emergency Stop (E-Stop) loop to detect an E-Stop condition. The E-Stop loop is a series connected set of Normally-Closed (NC) switches that interrupt the current flow when E-Stop is activated. These switches are positioned at major accessible locations around the antenna. When activated, they immediately disable the AZ and EL drives. The E-Stop loop is also interruptible through the Wye Comm system which allows operations to remotely E-Stop the antenna.

The ACU reports a number of digitized analog signals to the M&C system including motor currents, three-phase supply voltages, velocities, and others. It monitors the wind speed via two anemometers and stows the antenna when the winds exceed 50MPH. It reports numerous digital conditions to the M&C systems, including circuit breaker status, limits, over-temperatures, stow pin engaged, fire alarms, etc. The ACU can disconnect it's own AC power when

[1]They also perform some of the logic processing.

commanded to via the Wye Comm system.

The front panel of the ACU has various indicators of antenna position, desired position, digital status, selectable analog monitor data, etc. This panel also has the manual controls for the antenna so that the antenna can be positioned locally. Some of these controls are duplicated with a manual remote box to allow positioning from many locations on the antenna (for example, the Elevation platform).

The ACU is mostly discrete logic on a large wire wrap board, with a few separate plug-in cards for various functions. There is no way to change the ACU functionality without re-wiring, which is very difficult. Servicing the ACU is difficult as well, but the logic has been fairly reliable.

1.2 F/R Controller

The F/R Controller has very similar duties to the ACU:

1. It interprets the M&C data stream to determine where to put the subreflector and returns monitor data to the M&C system.

2. It sends the appropriate number of pulses to the stepper motors to move the subreflector to the desired position open-loop.

3. It implements the logical safety interlocks, Emergency stops, resets, power control, and other minor logical tasks.

The F/R Controller uses two 8-bit microprocessors to read the M&C data. The microprocessors generate the timed pulses to drive the apex stepper motors. The speed is ramped up to prevent stalling. The F/R is an open loop system and does not use position feedback directly. The microprocessors just send the required number of pulses to the translator drives to position the subreflector correctly. The translators switch the currents to the stepper motors windings in the correct order. The position is read using sychros and the data sent back to the M&C system to check correct motion.

Like the ACU, the F/R controller has limit switches, manual controls both on the front panel and remote, various indicators for status, and brake switching. A major difference from the ACU is optical isolation for the lines running all the way to the antenna apex to help reduce damage from lightning currents. Another difference is that it can control the power to various subsystems with Solid-State Relays (SSRs). Additionally, it has temperature sensors for the apex mount and rack temperature.

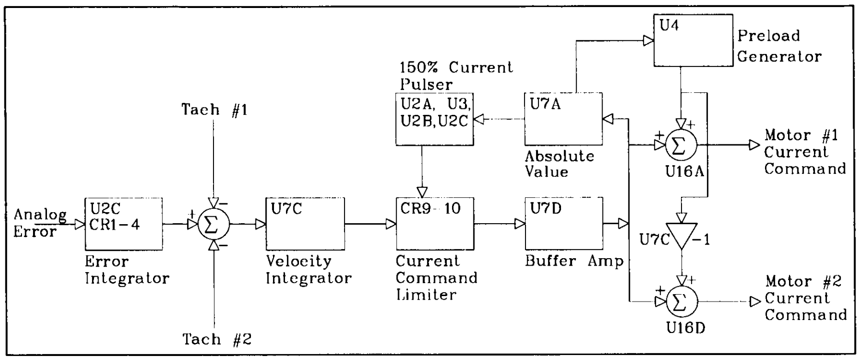

Figure 1: A4 and A5 Card Overview

2 ACU Loop Characterization

Two 5HP motors on each axis position the VLA antenna primary reflector. These motors are geared down and given a torque bias to take out the backlash [1].

The position loop is compensated on the A4 and A5 cards. These cards compute the desired motor current from the input error signal and motor speed feedback using analog circuits. The A4 and A5 cards are identical, but their behavior is slightly different depending on which slot they are put into. The slot determines which axis, AZ or EL. Each axis has different gains in the position loop compensation. Figure 1 shows an overview of the card in normal azimuth positioning operation. During fault conditions or manual positioning mode there are minor changes to the operation.

The cards implement a simple Proportional Integrator (PI) controller. The analog error signal is integrated to create a velocity command. The velocity command is compared to the sum of the tachometer feedbacks and then integrated to create the current command. A preload is added to one motor and subtracted from the other to create the torque bias.

The schematic for the A4 and A5 card as supplied by the original manufacturer [1] is poorly organized and has errors. It is very difficult to understand the functioning of the card from this drawing. To figure out what the card was doing, I reduced the drawing to functional elements and corrected the errors.[2] These functional elements are illustrated in Figure 1. I then generated the transfer functions for the loop compensation elements.

This exercise accomplishes two important goals. First, it forces complete understanding of the existing system as a foundation for designing an improved loop Second, it allows quick prototyping of the new loop hardware by programming in the existing compensation transfer function, which we know is stable.

The following subsections describe each functional element in Figure 1.

[2]This was the approach used by two Electrical Engineering students [4]. But, they made an unfortunate assumption that undermined their results, See Section 2.1.

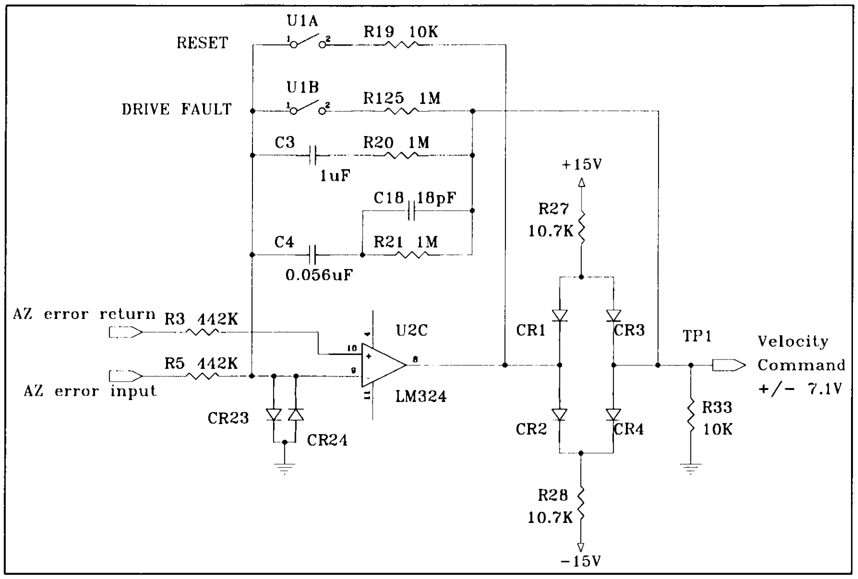

Figure 2: Error Integrator

2.1 Error Integrator

The schematic for the error integrator is shown in Figure 2. The components C3 with R20 and C4 with R21 control the response of the circuit at antenna mechanical frequencies, providing breakpoints at 0.16Hz and 2.8Hz, respectively. The capacitor C18 looks like it was added after prototyping. It adds another roll-off to the integrator response above about 50kHz, likely to prevent oscillations in the feedback loop. These oscillations may have been caused by parasitic inductance of R21, which is physically located far from U2.

The diodes CR24 and CR23 help the integrator behave well when driven to clipping. The bridge made of diodes CR1-4 with R27 and R28 limit the velocity command to ± 7.1V. FET switch U1a resets the integrator to prevent wind-up when the system is disabled. U1b changes the compensation when using just one motor. The resistor R33 is shown here connected to ground to simplify the drawing, but is actually connected to the virtual ground of the summing junction for the next integrator.[3] This simplification is used on other drawings in this report, and I hope it does not cause confusion.

The Laplace transfer function for this circuit is easily written as an inverting amplifier:

$$T(s) = -\frac{Z_2}{Z_1} \tag{1}$$

Where Z_1 is just R_3, and during normal operation:[4]

[3]The summing junction concept was overlooked in Tamara Barber and Shawn Sharp's analysis [4], and invalidated their conclusions. This subsequently skewed the assumptions made by Nathaniel Dale and Jack Landes [5].

[4]I intend "||" to mean "electrically in parallel with".

$$Z_2 = \left(\frac{1}{C_4 s} + \frac{1}{\frac{1}{R21} + C_{18} s}\right) || \left(R_{20} + \frac{1}{C_3 s}\right) \tag{2}$$

I started evaluating (1) by hand, but at some point realized how silly that was and let the math package Maple do the work. (2) becomes:

$$Z_2 = \frac{(1 + (C_{18}R_{21} + R_{21}C_4)s)(1 + R_{20}C_3 s)}{s(C_4 + C_3 + (C_4C_{18}R_{21} + R_{20}C_3C_4 + C_3C_{18}R_{21} + R_{21}C_3C_4)s + R_{20}R_{21}C_3} \tag{3}$$

Plugging in the component values into (3) and evaluating (1), the transfer function for the error integrator (in azimuth) is:

$$T_{\text{err}}(s) = -282\frac{(5.00 \times 10^5 + 2.80 \times 10^4 s)(s+1)}{s(7.00 \times 10^6 s + 6.6 \times 10^7 + 63.0s^2)} \tag{4}$$

And factoring to see the poles and zeroes:

$$T_{\text{err}}(s) = -1.26 \times 10^5 \frac{(s+17.9)(s+1)}{s(s+1.11 \times 10^5)(s+9.43)} \tag{5}$$

The only difference in elevation is that R3 and R5 are replaced with R4 and R6, which are 100K. Using (1), (4) becomes:

$$T_{\text{err}}(s) = -1250\frac{(5.00 \times 10^5 + 2.80 \times 10^4 s)(s+1)}{s(7.00 \times 10^6 s + 6.6 \times 10^7 + 63.0s^2)} \tag{6}$$

For the elevation axis.

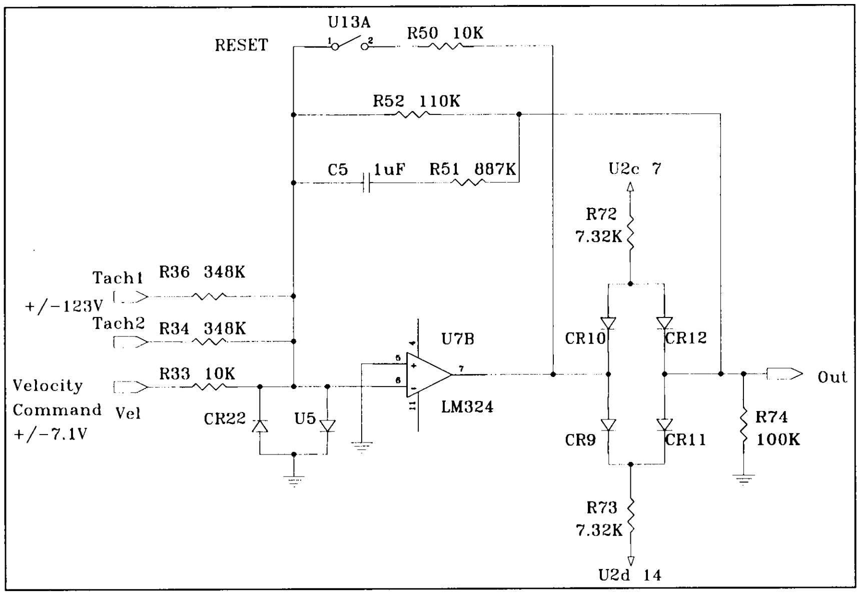

Figure 3: Velocity Integrator

2.2 Velocity Integrator

The Op-Amp U7b sums the velocity command with tachometer read backs and then integrates the result. The schematic for this subsystem is in Figure 3. Diode bridge CR9-12 are a limiter like CR1-4 in the error integrator, except that the clipping level can be varied to allow 100%/150%[5] current pulsing by the circuit in section 2.4. The integrator response kicks in around 0.18Hz, but R52 limits low-frequency gain. This means that the gain of the subsystem approaches 11 below 0.18Hz, and 9.8 above; not much integration here. U13a provides reset for the integrator windup.

We compute the transfer function similarly to that of the Error Integrator, except that it is the same for azimuth and elevation:

$$Z_2 = R_{52}|| \left(R_{51} + \frac{1}{C_5 s} \right) \tag{7}$$

Simplify to:

$$Z_2 = \frac{R_{52}(R_{51}C_5 s + 1)}{R_{51}C_5 s + R_{52}C_5 s + 1} \tag{8}$$

Plug in component values and then compute T_{vel}:

$$T_{\text{vel}}(s) = -11 \frac{0.887s + 1}{0.997s + 1} \tag{9}$$

[5]The actual voltages are 10.8V and 7.1V, which are approximately 162% and 106% of rated motor current, respectively.

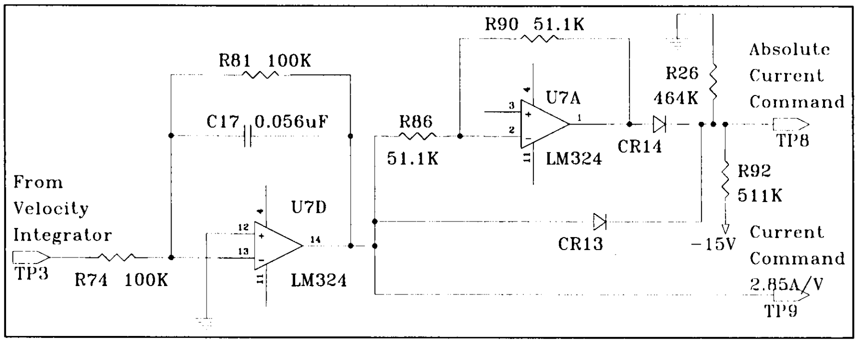

Figure 4: Buffer Amplifier and Absolute Value Circuit

No surprises here, general gain of 11 and close pole/zero pair on the real axis. So close, in fact, that they almost null each other. Again, not much integration going on in this circuit.

2.3 Buffer Amplifier and Absolute Value Circuit

Two circuits are illustrated in Figure 4: the buffer amplifier and the absolute value circuit. The buffer is a simple integrator with a gain limit of 1 and a 3dB frequency of 20Hz. The transfer function is:

$$T_{\text{buf}}(s) = \frac{R_{81} || \left(\frac{1}{C_{17}s}\right)}{R_{74}} = \frac{R_{81}}{(R_{81}C_{17}s + 1)R_{74}} = \frac{1}{1 + 0.0056s} \tag{10}$$

The output from the buffer circuit on TP9 is the current command. The motor current delivered by the drive amplifier is 2.85A/V. Some important values of this voltage are:

Current Command	Motor Current	Rated Current	
4.0V	11.5A	60%	Threshold to apply preload
4.3V	12.25A	65%	Threshold to remove preload
6.7V	19A	100%	
7.1V	20.2A	106%	limit of velocity integrator, normal
10.0V	28.5A	150%	
10.8V	30.78	162%	limit of velocity integrator, pulsed

The absolute value circuit just prepares the current command for use by the Current Pulser and Preload subsystems. You should note that it imposes one diode voltage drop to the current command from diodes CR13 and CR14. This is OK, because the circuits that use the output value all have thresholds of several volts.

For normal operation we can ignore this circuit in the transfer function.

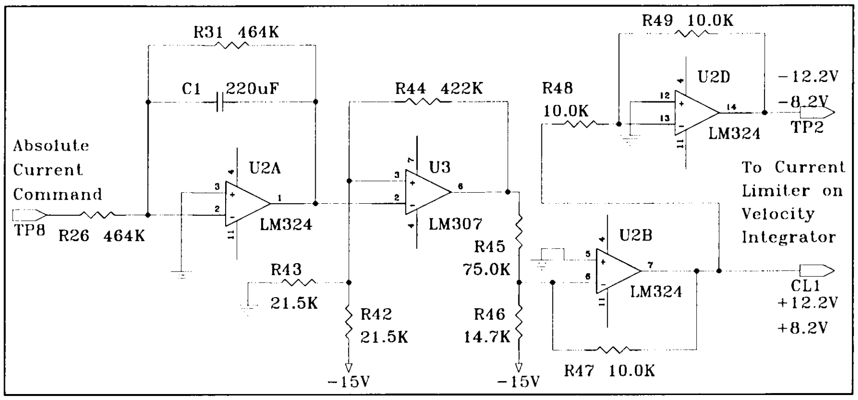

Figure 5: Current Pulser

2.4 Current Pulser

The current pulser allows the motors to run at up to 150% of rated motor current for short periods of time. When the time period expires, this circuit limits the motors to 100% maximum current for a while to cool off. This is a common method used in industrial drives to respond to occasional needs for higher torque. At the VLA, this extra motor current is occasionally needed during periods of high winds, ice on the gears, only one motor operational, etc.

Figure 5 shows the schematic for this subsystem. U2a integrates the absolute value of the current command with a time constant of $\tau = (R_{31}||R_{26})C_1 \approx 50\text{sec}$. The result is fed into a comparator with light hysteresis made from U3. The output from the comparator swings to +15V when the integrator output rises above -6.9V, and switches to -15V below -7.7V. U2c converts these voltages to +12.2V and +8.2V and buffers them, and U2d just inverts the result. The two voltages created by the current pulser are applied to the current limiter on the velocity integrator in section 2.2.

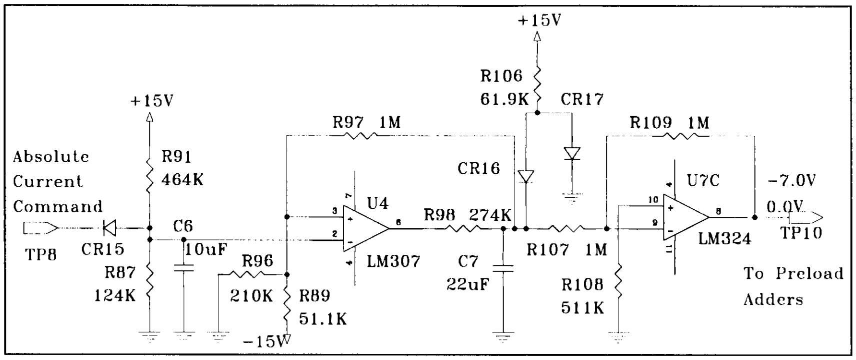

Figure 6: Preload Generator

2.5 Preload Generator

The preload generator, shown in Figure 6, creates the voltage offset to add and subtract from the current commands sent to the two drives. U4 switches if the current command increases above 4.3V[6] Capacitor C6 provides a short delay[7], and then capacitor C7 ramps the preload voltage down from 7.0V to 0V in 2.2 seconds, removing the preload. If the current command drops below 4.0V[8], C7 then ramps the preload back up from 0V to 7V in 10 seconds, reapplying the preload.

U7c is a simple inverter to apply the opposite preload to the other motor.

3 Inputs and Outputs

Complete input and output lists for both the ACU and F/R controller follow. There are a lot of signals, but most have simple functionality. For example, the motor temperature switch simply enables the drive fault flag for that motor. Many of the signals are for monitoring only.

3.1 ACU Inputs and Outputs

Most of the connections for the ACU are on the rear panel. All of the rear panel connectors are military style circular connectors. The new ACU will likely use mating circular connectors to allow a drop-in type replacement of the entire unit. These connectors are expensive but reliable. There are two front panel connections, a meter test point and a military circular connector for the remote box.

Most of the systems external to the ACU will not be upgraded at this time, including the drive cabinet, limit switches, fire alarm, etc. This avoids extensive re-wiring while upgrading the most critical part of the system.

The AC power for the ACU is 120V and comes in on a standard three-prong grounded cord which is permanently mounted to the rear panel.

[6] 3.1V+2 diode drops

[7] Somewhere around 3.75 seconds, but it's highly variable

[8] 2.8V+2 diode drops

Any new system should use a fused power filter with standard removable cable, similar to that on the new encoder system [8].

3.1.1 J1 Coarse Synchro

J1 is an MS3112E20-16P military circular connector. This is where the coarse synchro signals were input to run the rotational scales on the front of the ACU. This connection is no longer used, as the position information is now displayed on the new encoder system Data Receiver/Buffer (DRB).

3.1.2 J2 Interlocks, Limits

J2 is an MS3112E22-55P military circular connector. For the following pin listings I used some shorthand[9]. The "connection" column in the list is where the signal goes internal to the ACU.

Pin	Description	Connection	Type
A	first AZ CW lim sw	XA6 14	ID PU-1K
B	first AZ CW lim sw (NC)	J4 D	
C	sw GND	GND	
D	2nd AZ CW lim sw	XA6 J, E4	ID PU-1K
E	2nd AZ CW lim sw (NC)	J4 AA	
F	sw GND	GND	
G	first AZ CCW lim sw	XA6 11	ID PU-1K
H	first AZ CCW lim sw (NC)	J4 E	
J	sw GND	GND	
K	2nd AZ CCW lim sw	XA6 8, E3	ID PU-1K
L	2nd AZ CCW lim sw (NC)	J4 BB	
M	sw GND	GND	
N	first EL up lim sw	XA6 21	ID PU-1K
P	first EL up lim sw (NC)	J4 P	
R	sw GND	GND	
S	2nd EL up lim sw	XA6 27, E2	ID PU-1K
T	2nd AZ CW lim sw (NC)	J4 CC	
U	sw GND	GND	
V	first EL down lim sw	XA6 24	ID PU-1K
W	sw GND	GND	
X	first EL down lim sw (NC)	J4 HH	
Y	sw GND	GND	
Z	stow pin engaged sw	XA6 30	ID PU-1K
a	2nd EL down lim sw	XA6 /E, E1	ID PU-1K
b	2nd EL down lim sw (NC)	J4 DD	
c	sw GND	GND	
d	E stop	relay K1(XA6 33, E10)	(ID PU-1K)
e	+24V		
f	N/C		
g	GND		
h	drive fault reset	relay K2(TB1-4) (ID) (120V power)	

[9] I-input O-output PU-pull up PD-pull down D-digital A-analog sw-switch lim-limit CW-clockwise CCW-counterclockwise NC-normally closed N/C-no connection ?-unknown

i	N/C		
j	ped room fan	A11 BP2 14	ID TTL
k	GND	E11	GND
m	?		
n	?		
p	Ret	BP2 11	GND
q	Lead sw	BP2 10	ID PU-1K
r	N/C		
s	N/C		
t	N/C		
u	N/C		
v	Ret	BP2 13	GND
w	Lag sw	BP2 12	ID PU-1K
x	N/C		
y	N/C		
z	N/C		
AA	?		
BB	N/C		
CC	N/C		
DD	N/C		
EE	N/C		
FF	N/C		
GG	N/C		
HH	N/C		

3.1.3 J3 Tachometers, Temperatures

J3 is an MS3112E16-26PY military circular connector.

Pin	Description	Connection	Type
A	#1 AZ tach	XA4 S	IA
B	#1 AZ tach GND	GND	
C	#1 AZ motor overtemp	XA4 /B	ID PU-1K
D	#2 AZ tach	XA4 T	IA
E	#2 AZ tach GND	GND	
F	#2 AZ motor overtemp	XA4 /C	ID PU-1K
G	#1 EL tach	XA5 S	IA
H	#1 EL tach GND	GND	
J	#1 EL motor overtemp	XA5 /B	ID PU-1K
K	#2 EL tach	XA5 T	IA
L	#2 EL tach GND	GND	
M	#2 EL motor overtemp	XA5 /C	ID PU-1K
N	#1 AZ motor overtemp ret	GND	
P	#2 AZ motor overtemp ret	GND	
R	#1 EL motor overtemp ret	GND	
S	#2 EL motor overtemp ret	GND	
T	Smoke det	XA7 18, +5V	
U	Smoke det	J3 W, J3 N	
V	Smoke det trouble 16	A11 CP1-2	ID TTL
W	Smoke det trouble 15	J3 U, J3 N	

X	N/C
Y	N/C
Z	N/C
a	N/C
b	N/C
c	N/C

3.1.4 J4 Drive Cabinet

J4 is an MS3112E22-55P military circular connector. This is the con
the drive cabinet. The drive cabinet contains the current amplifiers.

Pin	Description	Connection	Type
A	#1 AZ disable	XA6 S	OD PD
B	#1 AZ current command +	XA4 V	OA
C	#1 AZ current command -	XA4 18	GND
D	first AZ CW lim sw (NC)	J2 B	
E	first AZ CCW lim sw (NC)	J2 H	
F	IM1A	XA4 34, XA7 C	IA
G	#2 AZ disable	XA6 T	OD PD
H	#2 AZ current command +	XA4 W	OA
J	#2 AZ current command -	XA4 19	GND
K	IM2A	XA4 33, XA7 F	IA
L	#1 EL disable	XA6 /A	OD PD
M	#1 EL current command +	XA5 V	OA
N	#1 AZ current command -	XA5 18	GND
P	first EL up lim sw (NC)	J2 N	
R	IM1E	XA5 34, XA7 K	IA
S	#2 EL disable	XA6 /B	
T	#2 EL current command +	XA5 W	OA
U	#2 AZ current command -	XA5 19	GND
V	IM2E	XA5 33, XA7 N	IA
W	#1 AZ blower CB	XA4 /F	ID PU-1K
X	#2 AZ blower CB	XA4 /H	ID PU-1K
Y	#1 AZ motor CB	XA4 /D	ID PU-1K
Z	#2 AZ motor CB	XA4 /J	ID PU-1K
a	Cabinet Common #2	E16	GND
b	#1 EL blower CB	XA5 /F	ID PU-1K
c	#2 EL blower CB	XA5 /H	ID PU-1K
d	#1 EL motor CB	XA5 /D	ID PU-1K
e	#2 EL motor CB	XA5 /J	ID PU-1K
f	CB Common	E15	GND
g	Brake relay +24V	E10	+24V
h	/AZ brake	XA6 R	OD PD
i	#1 AZ field monitor	XA4 /E	IA
j	#2 AZ field monitor	XA4 /E	IA
k	#1 EL field monitor	XA5 /E	IA
m	#2 EL field monitor	XA5 /E	IA
n	/EL brake	XA6 /C	OD PD
p	?		

q	Phase C	XA7 /M	IA
r	Phase B	XA7 /J	IA
s	Phase A	XA7 /E	IA
t	Cabinet Common #1	E15	GND
u	Cab temp SW	XA6 5	ID PU-1K
v	N/C		
w	N/C		
x	N/C		
y	N/C		
z	N/C		
AA	2nd AZ CW lim sw (NC)	J2 E	
BB	2nd AZ CCW lim sw (NC)	J2 L	
CC	2nd EL up lim sw (NC)	J2 T	
DD	2nd EL down lim sw (NC)	J2 DD	
EE	N/C		
FF	N/C		
GG	N/C		
HH	first EL down lim sw (NC)	J2 X	

3.1.5 J5 and J6 Azimuth and Elevation Position Data

These are the 20-bit parallel position data connections from the DRB. These connections should be abandoned and replaced with a serial connection, or the fiber data streams read directly with the new ACU.

3.1.6 J7 Data Set, Anemometers

J7 is an MS3112E12-10S military circular connector. This is the connection to the existing M&C system.

Pin	Description	Connection	Type
A	/XMIT	A11 BP2 6	OD DM8830 DLD
B	GND	E16	GND
C	Anemometer #1	A3 P1 14	IA
D	?		
E	DATA	A11 BP2 2	ID LED
F	/DATA	A11 BP2 1	ID LED
G	Anemometer #2	A3 P1 17	IA
H	XMIT	A11 BP2 5	OD DM8830 DLD
J	Anemometer #1	A3 P1 15	GND
K	Anemometer #2	A3 P1 17	GND

3.2 F/R Controller Inputs and Outputs

The F/R Controller has many modules interconnected with many cables. These are already described in the manual [7]. What I attempt to do here is list the connections that need to be acquired by a new system.

Ideally, the F/R Controller would have only one data connection to the apex of the antenna, through a two-way fiber link. The translator, position feedback, switches, brakes, and temperature sensors would be housed at the apex with a simple power feed and fiber pair. However, EVLA phase 2 may require a complete redesign of the F/R mount, so major modifications to the apex system should wait.

I am going to design a compromise. I will replace only the M7E and M11 modules with new electronics, but include the capability for simple fiber pair communication with the apex. This modified scheme keeps only the simplest components from the old system, and allows easy upgrades.

3.2.1 M7E P1

Many of these connections do not apply to an EVLA antenna.

Pin	Description	Connection	Type
A	+15V		
B	Logic GND		
C	+5V		
D	N/C		
E	-15V		
F-y	connections to M1, not needed for EVLA		
z	Foc brake SSR	A9 13	OD
AA-HH	antenna serial number, not needed for EVLA		

3.2.2 M7E P2

This is where the front panel controls, translators, and power controls connect.

Pin	Description	Connection	Type
A	Foc cmd LED	D22 29	OD
B	Foc brake LED	D22 30	OD
C	Foc up lim LED	B29 3	OD
D	Foc dn lim LED	B29 5	OD
E	Foc xlator power LED	A8 6	OD
F	Foc motor pulses LED	D22 31	OD
H	Foc drv up LED	B11 6	OD
J	Foc drv dn LED	B11 10	OD
K	Rot cmd LED	D22 29	OD
L	Rot brake LED	D22 30	OD
M	Rot pin in LED	D22 32	OD
N	Rot CW lim LED	B29 11	OD
P	Rot CCW lim LED	B29 13	OD
R	Rot xlater power LED	A8 10	OD
S	Rot motor pulses LED	?	
T	Rot drv CW LED	B21 6	OD
U	Rot drv CCW LED	B21 10	OD
V	P Band LED	D22 21	OD
W	L Band LED	D22 22	OD
X	C Band LED	D22 23	OD
Y	U Band LED	D22 24	OD
Z	K Band LED	D22 25	OD
a	X Band LED	D22 26	OD
b	Y Band LED	D22 27	OD
c	Z Band LED	D22 28	OD

d	Foc xlator drv up	A23 2	OD 15V
e	Foc xlator drv dn	A23 4	OD 15V
f	Foc xlator drv ret	GND	
h	Foc xlator SSR	A9 6	OD
j	Foc brake SSR	A9 3	OD
k	Rot xlator drv CW	A23 14	OD 15V
m	Rot xlator drv CCW	A23 12	OD 15V
n	Rot xlator drv ret	GND	
p	Foc xlator SSR	A9 10	OD
r	Ring ext SSR	B26 14	OD
s	Ring ret SSR	B26 6	OD
t	Foc xlator power mon	A1 2	IA
u	Rot xlator power mon	A1 6	IA
v	Foc ramp switch	PROM#2 32	ID
w	Foc drv up switch	PROM#2 33	ID
x	Foc drv dn switch	PROM#2 34	ID
y	Rot ramp switch	PROM#2 32	ID
z	Rot drv CW switch	PROM#2 33	ID
AA	Rot drv CCW switch	PROM#2 34	ID
BB	Band switch 1	PROM#2 37	ID
CC	Band switch 2	PROM#2 38	ID
DD	Band switch 3	PROM#2 39	ID
EE	Band switch active	PROM#2 36	ID
FF	Synchro Mon Hi	A20 12	IA
HH	Synchro Mon Lo	A20 8	GND

3.2.3 M11 P1

This is the major connection to the equipment at the apex.

Pin	Description	Connection	Type
A	+15V		
B	Logic GND	GND	
C	+5V		
D	N/C		
E	-15V		
F	Focus Synchro 1	AFOC S1	IA S/D conv
H	Rotation Synchro 1	AROT S1	IA S/D conv
J	Focus Synchro 2	AFOC S2	IA S/D conv
K	Rotation Synchro 2	AROT S2	IA S/D conv
L	Focus Synchro 3	AFOC S3	IA S/D conv
M	Rotation Synchro 3	AROT S3	IA S/D conv
N	Synchro Drive R1	AFOC, AROT RL	IA S/D conv
P	N/C		
R	Synchro Drive R2	AFOC, AROT RH	IA S/D conv
S	N/C		
T	Foc UP limit	C9 11	ID PU-1K
U	Rot CW limit	B9 5	ID PU-1K
V	Foc DN limit	C9 5	ID PU-1K
W	Rot CCW limit	B9 11	ID PU-1K

X	Ring IN SW	B9 18	ID PU-1K
Y	N/C		
Z	Ring OUT SW	B9 15	ID PU-1K
a	N/C		
b	P Band SW	B10 1	ID PU-1K
c	L Band SW	B10 3	ID PU-1K
d	C Band SW	B10 5	ID PU-1K
e	U Band SW	B10 13	ID PU-1K
f	K Band SW	B10 11	ID PU-1K
h	X Band SW	N/C	
j	Y Band SW	N/C	
k	Z Band SW	N/C	
m	SW GND	GND	
n	Foc Brake V	C2 5	IA VD
p	Rot Brake V	B2 5	IA VD
r	Foc Brake I	C2 7	IA VD
s	Rot Brake I	B2 7	IA VD
t	Foc Brake Common	GND	
u	Rot Brake Common	GND	
v	N/C		
w	F/R mount temp + AD590	E17B	IA
x	N/C		
y	F/R mount temp - AD590	-15V	OA
z	N/C		
AA	N/C		
BB	N/C		
CC	N/C		
DD	N/C		
EE	N/C		
FF	N/C		
HH	Analog GND	GND	

3.2.4 M11 P2

This connector will be abandoned because M7E and M11 will be integrated in the new F/R Controller.

4 Requirements and Goals for the New System

4.1 Science Requirements

These primary reflector tracking requirements are from the EVLA Project Book [6], and apply between 20° and 70° elevation.

	tracking RSS	drive rate
Required	2"	up to 1°/min
	8"	1°/min to 2.5°/min
Target	2"	up to 1°/min
	4"	1°/min to 2.5°/min

At high elevations, the azimuth velocity increases:

$$\omega_{\mathrm{AZ}} = \frac{\omega_{tracking}}{\cos\theta_{\mathrm{EL}}} \tag{11}$$

Using the worst-case conditions of 2.5°/min @ 70° elevation, (11) gives a maximum required azimuth velocity of 7.3°/min. The existing system has a maximum velocity of 40°/min, so there is plenty of speed. To make sure that the antenna is where it is supposed to be, the position encoder needs to be checked more often than 4"/2.5°/min $\approx$ 27ms. The sample period should be half that[10] or about 13ms[11]. Although there is doubt that the antenna can actually physically wander that quickly, the new encoders [8] output data every 0.6ms, easily meeting the sampling requirement. The encoders are accurate to better than 0.7".

The antenna settling times for a 30' motion need to be:

Required	< 5sec
Target	< 3sec

Experimentation on VLA antennas gave these results for a 31.6'[12] motion to settle to 6":

Azimuth	8 seconds
Elevation	4 seconds

The existing system does not meet the required performance, and is far from the target specification. Most of the settling time is spent oscillating after overshooting the desired position. Since the new system will initially use the existing loop transfer function, it will behave similarly. However, by adding some derivative to the PI loop, we may be able to improve the settling time without compromising the stability. This would be a temporary fix until the loop process is refined.[13]

4.2 Safety and Operational Requirements

The requirements are listed in decreasing order of importance. Compromises will be made to ensure the primary requirements are met most completely.

4.2.1 Safety: People and Antenna

The primary E-Stop is the collection of red mushroom-head type switches placed in accessible locations all over the antenna. This system needs to disable both azimuth and elevation axes, preferably also removing power from the SCR motor drives and setting the brakes. The most important function of this system to to provide an immediate stop of the antenna in the event of danger to personnel or property damage. A secondary use is to prevent injury or damage while maintenance is performed on the antenna. The E-Stop can be activated remotely by operations, but if locally set, cannot be cleared remotely.

[10] To meet the Nyquist criterion

[11] We can use the 13ms time period as a maximum latency in the loop software between position calculations.

[12] bits 10 and 11

[13] This would be a good project for a Masters Electrical Engineering/Robotics/Mechanical Engineering student

The F/R E-Stop should be a separate E-Stop from the primary. This E-Stop should disable the power to the F/R system to prevent injury or damage. It should not be enabled when the primary E-Stop is to allow F/R to be run while maintenance personnel are on the apex. It should set the primary E-Stop when activated. This is so that when someone on the apex hits the big red button, it disables the entire antenna. This E-Stop should be remotely enabled by operations like the primary E-Stop.

The entire system needs to recognize certain conditions and take appropriate action:

AZ or EL over-temperature Power down that motor's drive and field. If both motors, stow antenna and power down servo drive.

Translator over-temperature Power down translator.

AZ or EL over-current More than 31Amps, report fault condition.

Lube pump failure Report fault condition.

Circuit breaker open If one motor field or armature, power down that drive. If both motors, or other breaker, attempt to stow antenna and power down drive.

Encoder failure Try to reset DRB, if it still fails and EL still works, stow antenna.

F/R synchro failure use open-loop positioning.

AZ or EL Over-speed Faster than 1500RPM. Stow antenna and power down drive.

Axis in first limit Back axis out of limit until limit clears, reset DRB and try to re-point.

Axis in second limit Hardware drive power down.

High winds Above 50MPH, stow antenna and set brakes until wind drops.

Manual mode Disable commands from operations, do not auto-stow, do not back out of limit automatically.

Communication Loss For more than a minute or so, stow the antenna.

Apex too cold Turn on apex heat tape.

Apex stuck Limit attempts to position to avoid damage to translator.

4.2.2 Minimize RFI

The new system must take extraordinary measures to minimize produced RFI. The general plan for this is to start at the chip level, running clock speeds as slow as possible and filtering clock lines to reduce harmonics. Low voltage chips will be used if possible, at low power levels. Inter-chip signals should be slow and quiet[14] The next level of suppression is to design the printed circuit

[14] LVDS would work well.

board very carefully, using proper ground and RFI reduction techniques. Off-board lines must be properly routed and filtered. Finally, the metal box that houses the system needs to have the provision for RF gasketing and I/O connector filtering.

Due to the slow overall speed of the system's I/O, the primary source of RF radiation will be the MIB. We may be able to mount the MIB as a sub-card to the main board, with a small shield around it and lines filtered. If this controls the RFI acceptably then we could leave the overall housing of the system open. This improves the serviceability of the system drastically and eliminates the consequences of maintenance personnel not securing the lid to the housing.

The system will need to be RFI tested in a standard manner similarly to other EVLA modules.

4.2.3 Protection from Electro-static Discharge (ESD)

When the original ACU was built, TTL ruled the day. This technology dominated the design and production of the equipment. This makes the unit fairly robust in terms of immunity to damage or error by ESD.

The new ACU will be almost completely MOS technologies. While modern MOS chips are somewhat protected from ESD by diodes on inputs, there are still important design guidelines that will improve reliability.

All digital inputs must be terminated with pull-up or pull-down resistor of 10-100K. This prevents nasty latch-up, and also keeps operation predictable and power use down. This is especially important for lines leading to external connectors, because the lines may be disconnected at any time.

The system will be housed in a metal box with proper AC power safety grounding. This prevents ESD currents from traveling through the system circuits, and reduces the susceptibility of signal lines to nearby static discharges.

Another form of ESD that needs attention is lightning. The VLA antennas suffer direct lightning strikes. Most of the signals to the system will be from the elevation platform and pedestal room. These are well protected by the antenna structure and do not need further lightning protection.[15]

There are a few signals that will need to be carefully considered. The wires that connect the system to the F/R mount and E-Stop at the apex are obviously at risk from lightning. The anemometers are at the edge of the dish and are therefore very exposed. The existing F/R Controller uses opto-isolation between the M11 and M7E modules to help protect the microprocessors. However, the use of proper grounding techniques with adequate surge suppression should be enough to protect these lines.[16]

[15] The existing ACU does not suffer lightning-related failures and has no lightning protection.

[16] The ideal strategy would eliminate the signal cables and large stepper motor wires going to the apex and use a Fiber Cable. We would need to move the translators to the apex to accomplish this. Moving the translators would be very costly and beyond the requirements of EVLA as it is funded now. However, it would reduce RFI and eliminate many cable failures as well as protect the system from lightning. If the FRM is redesigned in a future upgrade, the interface should be simplified as discussed in Section 3.2.

4.2.4 Form Factor and Layout

The system will need some type of display and front panel switches so that people can do antenna maintenance in the field. The controls should at least provide local antenna positioning without the use of a laptop or tool. The existing system uses large switches to enable/disable functions, and large knobs to control azimuth and elevation motor speeds. A similar interface would work very well for the new system.

The system should be rack mountable in a standard 19" rack to minimize re-cabling. Excluding external equipment like motor drives, blowers, lube pumps, and heaters, it should run from 120VAC and use less than 15 Amps. It needs to have a remote reset input from operations, and a watchdog system that uses a pulse signal chained through every complex device that can execute a global reset. It needs to be able to sense and report the housing internal air temperature, motor temperatures, and drive cabinet temperature. The unit should function correctly in ambient air temperatures between 0 °C to 70 °C without the need for forced air cooling.

4.2.5 Bells and Whistles

The software nature of the new system should make it easy to add some useful features.

The controller should be programmed with the expected limit positions, and ignore commands to drive into those limits. This provides a nice "soft stop" ability to prevent running into the limits at full slew. It also gives the controller self-diagnosing information if it hits a limit unexpectedly. If desired, it could take action like resetting the encoders or flagging the event in a log.

The VLA will soon be converted to a digital tachometer system. The motor speed should read directly from the frequency of the digital signal, rather than adapting the new system to a frequency-to-voltage converter and then analog-to-digital. The anemometers can also be replaced with digital units. This eliminates running analog signals for long distances on the antenna, which will improve reliability.

Tachometer failures cause many reliability problems with the servo system. The new ACU should be able to recognize tachometer problems. For example, if the difference between the two tachometers on each axis is very large, then there is a problem with either tachometer or the motor/gearbox. Comparing the tachometers with the encoder reading should isolate the bad motor, and we can go to single-motor mode. If the tachometer is excessively noisy, we can flag it for maintenance.

The new system should be able to measure the motor temperature, and control the blower system. This will help keep the motors clean and dry, and save a lot of power. There will still need to be a motor over-temperature switch for redundancy and fail-safe operation.

The MIB will be aware of the time and date, so a local fault log can be kept to help with maintenance. This can help diagnose intermittent problems, and catch developing problems before any antenna downtime.

5 The Plan

Summarizing Section 3, we have the following minimum number of I/O lines:

	ACU	F/R	Total
Digital Inputs	30	21	51
Digital Outputs	7	39	46
Analog Inputs	17	16	33
Analog Outputs	4	15	19

Many functions have simple logic that are inefficient to write computer programs for and should not depend on a microprocessor to operate. This encourages the use of programmable logic. However, the display and floating-point calculation aspects of the operation are best done with a microprocessor.

The standard interface for all EVLA antennas will be the Module Interface Board (MIB) [3], which has a powerful microprocessor[17]. There will be a MIB for each subsystem to provide the Ethernet interface to the new M&C system. Some of the processing power of the MIB will be available for ACU and F/R work, so it will serve as a fine computational unit. The MIB will do the communication to and from the M&C system, calculate the servo loop compensation[18], drive the LCD display, enforce software limits, and do temperature setpoint calculations. The position data from the encoders is 25 bits, so a 32-bit data path for position data should be used.

The dozens of digital I/O lines can be handled with programmable logic. The programmable logic can communicate to the MIB with SPI, memory addressing, or other standard bus system. The logic gives us auto-stow, limits, and shutdowns even if the MIB ceases to function, or if we want some type of manual control system that disables the MIB control connection. The logic should drive some LEDs for basic status indication.

If the programmable logic is field reconfigurable or programmable, then the entire functionality of the ACU or F/R Controller can be easily changed in the future. We can design the board with an open-ended strategy so that new components, monitoring, and subsystems can be added without creating new circuit boards and extensive re-wiring.

If the drives for either Azimuth and Elevation or FRM are ever upgraded, the new system should provide an easy path to interface with them.

The fiber receivers in the DRB are serviced by tiny microprocessors[19] which could be replaced by state machines in the programmable logic. This would further reduce the complexity and chip count in the system. The final decision on this option would need an approximate gate count to implement the fiber receiver.

The analog I/O is all low bandwidth[20] and can be easily done with SPI bus A/D and D/A chips. These are readily available and cheap. It also makes it easy to add capability in the future by adding more chips.

[17] At this time the proposed microprocessor is a 96MHz TRICore with at least 1.5MB RAM on board running an RTOS [2]

[18] Probably a C or C++ subroutine called at a fixed rate. This makes it easy to upgrade the loop calculation in the future.

[19] "Picoprocessors": PIC16C55 chips.

[20] 100Hz sounds like a nice round number that is nice and slow but still gives a lot of room for future improvements

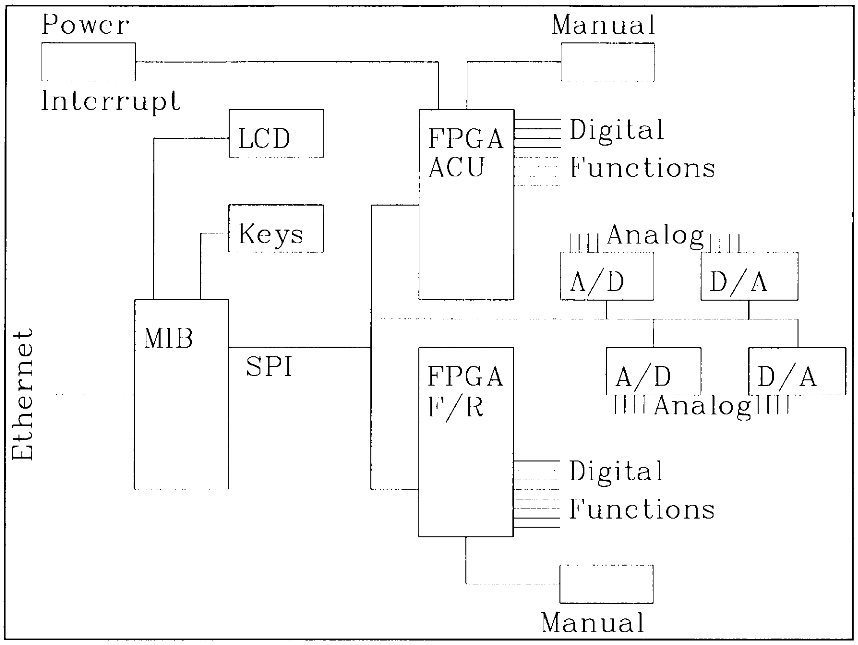

Figure 7: Concept for the new ACU and F/R system

Reset capability at the AC power supply level is desirable. There should be some SSRs[21] added with one-shot timers on them. This would allow the systems to do a cold-boot type reset triggered either by watchdog or Wyecom signals. This strategy will save down-time and after hours call-outs to do power resets.

Figure 7 is a concept view for the new system.

[21] Inspired by the F/R system[7]

6 Notes

This document was prepared with GNU Emacs 20.2.1, LaTeX 2_ε Version 3.14159 (Web2C 7.3.1), pdfLaTeX 2_ε Version 3.14159-13d (Web2C 7.3.1), and dvips 5.86 on Sun Solaris 2.5.1. I got relief from tedious algebra with Maple 7 (IBM INTEL LINUX) on Linux: kernel version 2.2.19. The figures and circuit modeling were done with OrCAD Capture 9.1, AutoCAD LT 98, and Electronics Workbench 5.12 on Windows NT 4.0 SP6.

Thanks to those who helped with ideas, advice, and inspiration: Dave Alderman, Walter Brisken, Barry Clark, Tom Frost, Clint Janes, Wayne Koski, and Lew Serna.

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