# VLA Technical Report No 57 <br> AN OVERVIEW OF THE NEW VLA FOCUS/ROTATION CONTROL SYSTEM <br> D. WEBER, P. HARDEN, W. KOSKI JANUARY 1985 

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### 1.0 INTRODUCTION

This manual is a description of the new VLA Focus/Rotation Control system; it provides a brief functional description of the system, electronics and control programs for those who are interested in the principles of operation. Also included are: an $F / R$ Mount description, drive dynamics considerations, control and data formats, a description of the Telescope Operator F/R Overlay format and a fault diagnosis procedure.

This manual is an abstraction of FOCUS AND ROTATION CONTROL SYSTEM, MODEL E, VLA Technical Report No 56. Readers who are interested in a more detailed description of the system are referred to this manual.

### 1.1 PERFORMANCE SUMMARY

The following table summarizes the performance of the new F/R System.

| Parameter |
| :---: |
| Command execution time |
| Max drive rate |
| Readout resolution, (14 bit conversion) |
| Command repeatability |
| Physical stability |


| Focus |
| :--- |
| $\mathbf{6 4 ~ s e c / 1 2 ~ i n c h e s ~}$ |
| $0.197 \mathrm{in} / \mathrm{sec}$ |
| $0.000732 \mathrm{in} / \mathrm{bit}$ |
| 0.00036 in, RMS |
| $>0.001 \mathrm{in}$ |

Rotation
$15 \mathrm{sec} / 180 \mathrm{deg}$
$16.7 \mathrm{deg} / \mathrm{sec}$
$1.318 \mathrm{arc}-\mathrm{min} / \mathrm{bit}$
$\underline{2} \mathrm{arc-min}, \quad$ RMS
$-4 \mathrm{arc}-\mathrm{min}^{-}$

### 1.2 BACKGROUND

Specifications for the new system resulted from the need for better system performance and experience with the earlier mechanism and electronics. The $F / R$ Mount has undergone extensive mechanical redesign and the new control system design has been generalized so that changes in the F/R Mount can easily be accomodated by software changes in the controller programs. The new control system provides more powerful control, extensive local fault analysis, higher position resolution, more reliable position readout devices, faster mechanism response time and easier maintainance.

The stability of the Subreflector Rotation position is a very critical parameter in that small Subreflector angular position errors cause large antenna pointing errors. Focus position instability impacts the visibility data phase. Section 6.0 describes the effects of Subreflector position errors on pointing and phase. Much of the mechanical and electrical redesign effort has been directed at reducing the Rotation position uncertainty. The unreliability of the position readout potentiometers has also been a persistant problem which has cost many dollars for replacement parts and many man-hours for maintainance and repair time.

The essence of the mechanical redisign is to reduce the brake-Rotation ring gear lost motion by relocating the Rotation brake to the traveling platform and coupling the brake to the ring gear with one gear pass. This reduces the Rotation gear slack to about four arc-minutes. The Rotation position readout sensor has been relocated so as to be closely coupled (one gear pass) to the Subreflector mounting drum. This change eliminates about 1.5 degrees (out of 3200 degrees) of lost motion in the Rotation ring gear-readout potentiometer gear train.

To improve reliability, the Focus and Rotation position readout sensors were changed from potentiometers to synchros and high resolution (14 bits) Synchro to Digital Converters. In a given environment, synchros are an order of magnitude more reliable than multi-turn, precision potentiometers. The higher resolution readout has provided a great improvement in the capability of the controller to precisely set and monitor the Rotation position. The use of synchros and an integrating S/D Converter has made the position readout circuitry virtually invulnerable to noise perturbations on the long cable runs from the Apex to the Pedestal Room. An F/R Mount incorporating these features and a new F/R Controller were installed on Antenna 12 for trial.

After the Antenna 12 prototype system operated for a year without failure or noticeable performance degradation, it was decided to retrofit the new designs into all antennas during the periodic antenna refurbishment schedule. The new $F / R$ Controller and redesigned $F / R$ Mount have also been installed in Antennas 20 and 13 during their refurbishment.

Antennas 20 and 13 also have a 327 MHz dipole/ring feed system installed in front of the subreflector; this has added several mechanical components to the $F / R$ Mount and Apex structure. When the 327 MHz receiver is in use, the feed ring is extended to enclose the 327 MHz dipoles. When the other receiving bands are used, the ring is retracted back toward a quadrapod spar. Although the ring is not part of the F/R System, the F/R System controls the ring motion because of the proximity of the ring actuator to the Apex junction box and the flexibility of the F/R control electronics.

Beside the changes described above, a number of mechanical improvements have been incorporated in the F/R mount mechanical design. Notable examples are:

Renovation of the aluminum Rotation bearing surfaces by steel inserts.

The use of better weather-proof flexible boots over the lead screws and spline shaft.

The use of heaters on the gear box and traveling platform to warm the gear train lubricant in cold weather. This reduces cold weather lubricant stiffening which can cause drive sticking due to the marginal drive motor torques.


FIG. 1 - F/R SYSTEM - FUNCTIONAL BLOCK DIAGRAM


## PEDESTAL ROOM F/R COMPONENTS



FIG. 2 - PEDESTAL ROOM F/R COMPONENTS


APEX JUNCTION BOX


PEDESTAL ROOM JUNCTION BOX
FIG. 3 APEX \& PEDESTAL RM. JUNCTION BOX LAYOUTS

### 1.3 F/R CONTROL SYSTEM DESCRIPTION

See Figure 1, F/R Control System Block Diagram and Figures 2 \& 3 which show the location of the $F / R$ Control System Components.

The $F / R$ Controller closes the position loops and activates all driving elements of the F/R Mount, senses positions and discretes, analyzes conditions in the mount and Pedestal Room to detect faults and reports on these states to Central Control via Data Set 3.

In CMP (Central Computer control) mode, the F/R Controller receives a position command from the Data Set which activates an inter upt in either the Focus or Rotation portion of the controller. The controller tests the Multiplex address and command argument (some Focus arguments are not accepted because of mechanical constraints), and it calculates motor ramping parameters, steering direction and activates the associated brake and stepper motor translator. If brake voltage and current and translator power are above test thresholds and there are no system faults, the controller begins to emit drive pulses to the Stepper Motor Translators so as to null the error. The pulse rate is ramped from 100 Hz to 1000 Hz ( 500 Hz in Focus) in 50 Hz steps. Drive continues at 1000 Hz until a calculated ramp down position is reached at which time the stepping rate is ramped down to 100 Hz for convergence to the commanded set point. When the set point is reached the controller turns off the Stepper Translator AC and activates the brake.

During ramp-up, main drive, ramp down and convergence, position changes are compared with what they should be to test for drive sticking or dragging. If this happens, the stepping rate is reduced to 100 Hz and the drive is ramped back up to 250 Hz (the peak torque speed of these motors) and the controller attempts to complete the command. In the event that the drive sticks again, the controller aborts the command. When drive sticking occurs, a "Drive Fault" bit is set in the controller status data readout and this bit flags this message on the Operator's Data Checker program and the Operator's F/R Overlay.

In the LOCAL mode (selected by the F/R Controller front panel switch), the $F / R$ system is controlled by actuation of the manual control switches on the $F / R$ Power Supply. These switches are: Focus Drive Up/Down; Rotation Drive CW/CCW; and the Focus and Rotation Ramp/ 100 Hz switches. LED displays on the Power Supply panel indicate actuation of the brakes, translators etc. In the LOCAL mode the computer commands are ignored and command inputs come from the switches mentioned above. The portion of the control program which implements LOCAL control is similar to the portion which implements CMP (central computer) control and calls the same drivers to perform basic functions such as turning on the brakes, ramping up/down, providing monitor data to the Data Set, etc.

The controller is not directly connected to any circuitry in the Apex; all position and discrete readouts from the Apex are sensed by an Apex Interface unit which transfers this data to the controller via an optically isolated serial link. The Apex Interface front panel displays the Focus and Rotation position in 14 bit octal code and the state of various discretes and activity sensors on an LED display. Logic in the Apex Interface tests for malfunctions; in the event that any of these occur an inhibit (YOWP!) is sent to the $F / R$ Controller to disable all drive outputs. When limit conditions are sensed by the Apex Interface, drive inhibits are sent to the F/R Controller to inhibit further drive into the limit (but not out of the limit). The Apex Interface is
isolated from the controller as a lightning protection measure; it is the sacrificial element in the event of strikes on the Apex structure, thus restricting damage to this unit which has a minimum of parts.

The 327 MHz Feed Ring position is controlled by the new F/R Controller. The Ring position may be manually controlled.

A NAP mode has been incorporated to enable the controller to ignore position commands until reset by a RESET command. This permits reduced performance operation in the event of a drive failure.

A Switching Module contains the brake controllers (DC power supplies) and solid state relays to switch the AC for the brake controllers, translators and 327 MHz feed ring actuator. A 400 Hz synchro exciter in the Switching Module provides the 400 Hz required by the synchros and the S/D Converters.

A $20 T$ BOX capability has been incorporated into the system to permit manual control of the Subreflector position by a $20 T$ BOX which may be plugged into either the $F / R$ control bin or the Apex Junction Box. Discrete and position readouts on the $20 T$ BOX display the F/R Mount state.


FIG. 4- APEX F/R COMPONENTS

## DETAIL "A" F/R "TROMBONE"



FIG.5-APEX ASSEMBLY EXPLODED ISOMETRIC VIEW


FIG.6-F/R MOUNT - LOCATIONS OF MAJOR COMPONENTS

### 1.4 F/R MOUNT DESCRIPTION

The $F / R$ Mount is almost inaccessible; most of the mechanism parts are enclosed by the gearbox or hidden by the barrel and support structure. This section was written to provide a brief description of the mechanism for those who would like to know how it operates but are reluctant to climb up to the apex for a direct examination.

The $F / R$ Mount is a two axis mechanism consisting of three rings, four guide shafts, four lead screws, two gear trains, two drive motors, two fail-safe brakes and two position readout synchros. Figure 4 depicts the F/R Mount and Subreflector as they appear from the inside of the dish. Figure 5 depicts an exploded isometric view of the F/R Mount and the associated components. Figure 6 depicts the locations of the motors, brakes and Focus position readout synchro.

The top ring is a gear box for the two drive trains; the motors are mounted on the top of the gear box. The Focus motor and gears rotate lead screws which move the Traveling (middle ring) platform up and down the Guide Shafts to produce the Focus motion. The Focus brake is mounted on the top of the gear box and is coupled to the Focus gear train inside the box.

The Rotation motor and gear train drives a sliding spline gear which rotates a large ring gear mounted on the Traveling platform to produce the Rotation motion. The Rotation brake is mounted on the traveling platform and is coupled to the Rotation ring gear through a single gear pass.

A flange on the center of the "42" diameter barrel is bolted to the Rotation ring gear. The Subreflector is bolted to the bottom of the barrel and counter-weights are bolted to the top of the barrel. The bottom ring is a supporting member for the guide rods and lead screws.

Elastomer spring couplings between the drive motors and gear trains buffer the motors so that they are not subjected to large instantaneous inertial loads such as at initial drive motion. The spring deflection is proportional to the loads imposed upon the motor by the drive.

The brakes are fail-safe; that is they are always engaged until energized.
The Rotation gear train reduction ratio is $108: 1$, that is, each 1.8 degree motor step rotates the Subreflector by $1.8 / 108$ or 0.01666 degrees so that 21,600 motor steps are required to rotate the Subreflector 360 degrees. The Focus gear train reduction ratio to the lead screws is 2.54:1. The lead screw pitch is .200 so that five rotations of the lead screws are required to move the traveling platform one inch. The total Focus travel is 12 inches (ignoring that lost by limit switch inhibit action) so that the total number of motor steps required to traverse this Focus range is: $1.8 * 200 * 5 * 2.54 * 12=30480$ motor steps.

Focus and Rotation positions are read out as 14 bit values (16384 counts range). The motor-step/readout-resolution ratios are: 21600/16384 $=1.318$ steps/bit (also $1.318 \mathrm{arc}-\mathrm{min} / \mathrm{bit}$ ) in Rotation motion and 30480/16384 $=1.860$ steps/bit (also $0.0003937 \mathrm{in} / \mathrm{step}$ and $0.000732 \mathrm{in} / \mathrm{bit}$ ) in Focus motion.

Rotation position is read out by a synchro mounted on a tripod above the
barrel. The synchro shaft is coupled to the center of the drum through a sliding "Trombone" which takes out the Focus motion of the barrel; see Figure 5 for details on this mechanism. A tubular shaft attached to the top of the Trombone drives the Rotation position synchro through a flexible coupling and pick-off gear (1:1 ratio) which drives an anti-backlash gear on the synchro shaft.

Focus position is read out by a 10:1 anti-backlash reduction gear box and synchro coupled to the Focus gear train. The gear box is used because the synchro and gear box mimic the 10 -turn helipot used with the older system.

Focus upper/lower limit switches sense the extremes of Focus motion and cause the F/R Controller to inhibit further drive into the limit. There are no Rotation limit switches as the Rotation drive is capable of continuous rotation; in executing a Rotation command, the F/R Controller rotates the Subreflector through the smallest angle to move to a new position. This permits faster band changes.

The 327 MHz feed dipoles travel up and down with the Subreflector Focus motion but do not rotate with the Subreflector Rotation motion. This nonrotation is accomplished by mounting the dipoles on a square shaft which is prevented from rotating by a square-holed collar attached to the top of the Rotation synchro gear box. The dipoles are caused to move with the Subreflector in Focus motion by a thrust bearing in the Subreflector which is attached to the square shaft. The square shaft passes through the Trombone, the Rotation synchro drive shaft and slides through the square-holed collar in Focus motion. Coaxial cables carry the RF signals from the feed and are routed through the square shaft. Since this square shaft penetrates the Rotation readout box, a seal ring under the square-holed collar prevents water entry. Details of this mechanism are depicted in Figure 4.

### 1.5 DRIVE DYNAMICS

The purpose of all this mechanical and electronic hardware is to position the Subreflector; the control system design must deal with the dynamics of the drives which involve large work, inertial and frictional loads. Thus section describes aspects of these dynamics which determined the characteristics of the control programs.

The drive motors are stepper motors which are high torque, low shaft speed devices which are frequently used to implement drive systems with minimal or no gear trains. The motors are caused to rotate by time-sequencing the four motor winding currents with high power transistor switches; the switches sink these currents to ground in accordance to a sequence of states which determine the direction of rotation. Each state change is called a "step" which causes the shaft to rotate by a discrete angular increment ( 1.8 degrees in these motors). The motors are driven by a Translator which contains the transistor switches, associated logic and power supplies. The Translator switches state changes are caused by applying a drive pulse to either of two inputs which cause the motor to rotate in the cw or ccw direction by one angular increment fór each drive pulse.

An important characteristic of these motors is torque breakage which occurs when the imposed load exceeds the motor torque producing capabilities. These motors have torque/speed curves which fall off with increasing speed; this
is the maximum load which the motor can drive if it is started at zero or low speed and gently ramped up in stepping rate. Figure 7 shows the HS1500 (Ant 1 20) \& FD309 (Ant 21 - 28) Torque/Speed curves. These curves are based upon bench torque tests and Superior Electric data. A second curve (not shown) is the torque load at which the motor will start from a dead stop; this second curve is much lower and goes to zero very quickly. When torque breakage occurs, the motor stops; the only way to get it to drive again is to either reduce the load or reduce the stepping speed to a rate where the motor can resume stepping. Torque breakage does not gradually increase with the load; it is a thresholdlike effect in which a slight increase in load at the critical torque causes the motor to stop.

This torque breakage phenomena has happened to the VLA F/R System many times due to unusually heavy loads (such as cold weather viscous friction drag or ice loading) with the result that the drive is "stuck". Torque breakage can damage the translators; a stuck drive motor does not generate a back EMF so the driver boards must sink a great deal more current during the switching transient.

A second important property of these motors is motor resonance: at the motor resonant frequency, the torque delivered by the motor is greatly reduced and the rotor vibrates (in shaft angle) at each step. In the antenna 1-20 motors the resonance occurs at about 550 Hz and the available motor torque is reduced to about 450 oz-in, - about one-third of the available torque at 500 \& 600 Hz . The Ant 21-28 motors and translators are a newer design with no pronounced resonances.

A third important property of these motors is the large holding torque which they exhibit when stopped with a steady state current in the windings.

The task of the controller is to get the drives into motion and to gently ramp the motors up to the maximum speed so as to quickly get to the commanded set point. Near the set point the drives are to be quickly ramped down and driven to the set point at low speed; attempting to stop at the set point at high speed results in an overshoot of several tens of steps. Because of the large work and cold weather vicous friction loads, the drive acceleration profiles have been made very gentle so that the inertial loads are never more than about $10 \%$ of the available motor torque.

Ideallly one would like to start the drives at a very low initial rate, say a few Hz , and proceed up from there. However; drive motion has been constrained to start at 100 Hz ; operating the drive trains at rates lower than 100 Hz causes excessive gear train rattle which reduces the life of the gears.

The new controller drive speed ramp-up is a sequence of 50 Hz step increases in stepping rate, starting at 100 Hz and going up to a maximum of 1000 Hz in Rotation and 500 Hz in Focus. The ramp-down is a sequence of 50 Hz steps to the convergence speed of 100 Hz .

When the stepping speed is changed, the motor rotor moment of inertia absorbs a portion of the motor torque; that is during accelerataion, not all of the torque shown on the curves above is available at the motor shaft. After the motor acceleration torque requirements are met, the remaining torque is available for the drive work, viscous and coulomb friction loads. This is one of the reasons why the ramp-up profile has been made so gentle.

The elastomer spring coupling between the motor and drive plays a vital role; without it the motors would be unable to drive the heavy work and inertial loads. Stepper motor manufacturers recommend that motors which are rigidly coupled to inertial loads have a load inertia less than three times the motor inertia; this ratio is $4: 1$ in the Rotation drive. The spring buffers the motor; it is deflected in proportion to the drive load and tends to average the motor velocity impulses so that the motor never sees any incremental load greater than the wind-up resulting from a motor step.

For a step change in stepping rate the transient wind-up torque is approximatly given by: $\operatorname{Ttr}=T w u^{*} \exp (-K * t i m e / I d)$, where $T w u$ is the spring wind-up, Id is the drive moment of inertia, and $K$ is viscous and coulomb friction. For the ramp-up sequence of the controller, the worst case transient torque occurs at the initial step to 100 Hz and is about 175 oz -in. The 50 Hz step transient torque is half this value. The transient decay time depends upon (mostly) viscous friction which varies with temperature. The step duration is much longer than the decay time.

At the peak motor torque ( 1500 oz -in @ 250 Hz , Ant $1-20$ ) the coupling could wind up to as many as 14 motor steps before motor torque breakage. Thus the Focus and Rotation motors could be ahead of the drive as much as 19 arc min in Rotation and 0.006 inches in Focus. At the completion of a command, the brake is engaged and the translator power is turned off; this allows the spring wind-up to release by back-driving the motor. The magnitude of this wind-up is the sum of all the drive loads at the time that the motion is stopped. Another effect of wind-up is that at the start of command execution, the initial motion is less than would be realized with a rigid coupling.

Viscous friction is proportional to velocity; the higher the drive rate the greater the viscous friction. Viscous friction is also an inverse logarithmic function of temperature: $\mathrm{Kv}=\mathrm{Kl}+\mathrm{k} 2 / \mathrm{lnT}$. This temperature dependence causes great changes in the F/R Mount viscous friction load. With a hydrocarbon grease, over the +100 to -20 deg $F$ temperature range, Kr can be expected to change by a factor of about 650. An unobtrusive Kv load at summer temperatures becomes a huge load at freezing temperatures; at about +30 deg F , it's a toss-up as to whether the Focus drives will stick. This temperature sensitivity is the reason that the renovated $F / R$ Mounts have heaters to warm the Focus and Rotation drive gear lubricant. A temperature sensor on the bottom of the gear box monitors the temperature which is typically about 10 deg $C$ above ambient when the heaters are in operation.

Coulomb (rubbing) friction depends upon the force pressing the surfaces together, the roughness of the surfaces and a friction factor dependent upon properties of the two materials. The Coulomb friction of these drives has not been measured under operating conditions.

Although the equations of motion of the Focus and Rotation drives are very similar, the load parameters are quite different: Rotation has a small work load (about 100 oz-in of subreflector unbalance at the motor shaft) whereas Focus has a huge (drive up) work load (about 600 lb ) consisting of the heavy moving platform, the drum, subreflector and 327 MHz feed hardware. Viscous friction is more of a problem in Focus because the Focus ring gear (where most of the viscous friction occurs) is only a gear ratio of 1:2.54 down from the motor in comparison to the Rotation ring gear which is down 1:8 from the motor.

The ring gears and race clearances are of similar size so the viscous frictions (at the gears) are similar. Winter experience shows that the Focus drive is much more vulnerable to cold weather sticking than Rotation. Both drives have roughly comparable inertial loads. In summary, the Focus is in general much more heavily loaded than Rotation; for this reason the maximum drive speed for Focus has been restricted to 500 Hz to avoid the bad torque dip at 550 Hz .

The new controller utilizes a motion analysis algorithm which detects torque breakage and causes the drive rates to be reduced to 100 Hz and then ramped back up to 250 Hz , the peak torque for these motors. If the torque breaks again, the drive is shut down. This motion analysis is a very powerful feature as the Rotation drive can be ramped to 1000 Hz (versus 400 Hz in the old controller) for fast response to band changes and the relialability of the system under adverse conditions is greatly improved because the motion analysis fallback drive insures that the controller will re-attempt drive at the speed which produces the maximum motor torque. The failure rate of the Translators should decrease since the driver transistors do not have to attempt to drive stuck mechanisms.

The torque requirements of the $F / R$ Mount have never been fully characterized, either by mathematical modeling or by actual measurements. Viscous and coulomb frictional loads are unknown.


HTR 1500/1008/HS1500 TORQUE vs. SPEED CHARACTERISTICS


TM600/M172-FD306 TORQUE vs. SPEED CHARACTERISTICS
FIG. 7 - TORQUE/SPEED CURVES

### 2.0 F/R CONTROL SYSTEM ELECTRONICS

The electronics components described below make up the F/R Control System, Model E. The M - series modules are VLA designs and the stepper translators and motors are high torque, high speed, special order units manufactured by Superior Electric.

### 2.1 M7 MODEL E, F/R CONTROLLER DESCRIPTION

This section describes the $F / R$ Controller digital logic and the control programs. The control programs are the control logic of the system; the digital logic of the controller is the vehicle which is manipulated by the programs to implement the control functions.

The F/R Controller has been implemented with two microprocessors (one for each axis) consisting of an 8085A microprocessor, an 8156A RAM-I/0 port-Timer, two 8755A EPROM-I/O ports, address decode logic and a 2716 EPROM for program expansion. Both processors have identical architectures and are almost independent except for the power reset logic and the 5 MHz processor clock. Address decode logic provide address enables for the RAM, EPROMS and seriai Input/Output Registers. These decodes are also used as strobes to reset interrupt request flip-flops, single step drive motors and initiate data input from the Apex Interface.

The Timer logic in the RAM can be driven by 10 KHz , 1 KHz or 100 Hz clocks. The EPROM I/O ports operate as output/input ports to output control discretes and input response and manual control discretes.

The Data Set interface logic is a set of serial I/O registers and latches to store the command/data arguments, Mux address and Command/Data flags. The reader is referred to the Data Set Manual for details on the serial operations of loading a command from or unloading data to a Data Set. In operation, a command is serially loaded into a 24 bit shift register, the processor is interrupted by the command strobe and enters an interrupt routine to read the SMA address, command/data flags, and command argument by a series of byte reads via the address/data bus The command strobes and clocks are qualified by the SMA - 3 ("8") bit so that addresses $320-327$ (octal) activate the Focus processor and the addresses 330-337 activate the Rotation processor.

Monitor Data readout is address qualified and output in a similar manner; the Data Set STRI pulse interrupts the addressed processor which enters the an interrupt routine to read the SMA bits and command/data flags to identify the specific data being requested. The processor outputs the requested data by a sequence of three byte writes via the address/data bus to the data output registers. The Data Set then emits clock pulses to serially read the Monitor Data. Mux addresses 220-227 activate the Focus processor and mux addresses 230 - 237 activate the Rotation processor.

An 8 channel analog multiplexer selects power supply, translator power, bin temperature and the synchro excitation current for $A / D$ conversion by the Data Set.

F/R Mount data is serially input from the Apex Interface when the controller outputs a data request strobe pulse to the Apex Interface which activates the readout logic to cause a serial train of 6 bytes of data to be
loaded into Apex Data Registers. The processor then reads the Apex Interface data by a sequence of byte read operations via the address/data bus. The data and clocks are isolated from the Apex Interface by optical isolators for lightning glitch protection.

Clock logic provides processor and system clocks and a 5 MHz clock for the Data Set. Processor Reset logic causes the 8085 reset lines to be activated to re-initialize the processors. Processor Reset is activated as a result of: a SYSTEM RESET command, (Mux 337, octal); SOFT RESET commands (Mux 321, 331, octal); actuation of the COMPUTER/LOCAL switch; a power reset circuit or processor halt resets generated by sensing the S0 \& S1 8085 processor states.

A YOWP! input from the Apex Interface and connector interlock signals develop a drive disable term to inhibit drive when something bad is sensed by the Apex Interface or a cable is disconnected.

The M7 module temperature is read out as Bin Temperature; the scaling is $100 \mathrm{mv} / \mathrm{deg} \mathrm{C}$.

Control discretes drive interface logic which provides drive pulses to the Translators and turns on solid state relays to apply AC power to Translators, brakes and the Ring actuator. The drive disable term (mentioned above) inhibits all outputs in the event that the Apex Interface sends over a YOWP! signal.

The stepper motor clock rate is generated by two decade counters. Control discretes from the EPROMs determine the counter radix. The minimum stepping rate is 100 Hz and maximum is 1000 Hz with many intermediate rates selectable via program control. A divide by 4 counter driven by the stepper clock causes an interrupt to signal the program to analyze drive motion.

One-shot activity sensors on the Translator drive pulse outputs provide a monitor output of the presence and polarity of translator drive and provide a visual indication on the M8 display panel.

Limit switch inputs provide direct inhibits to the UP/DOWN and CW/CCW Translator drive outputs.

Translator power is sensed by an EPROM I/O port bit.
A brief description of the program operation is found in Section 1.3; the interested reader is referred to the manual cited above for a detailed description. The following comments convey some of the salient features of these programs.

The Focus, Rotation and Ring control programs are straightforward, well commented and easy to follow but also require an understanding of the control task, F/R Mount mechanism, control system hardware and Data Set interactions.

The Focus and Rotation control programs are very similar and differ in only a few (but important) respects such as the fact that the program moves the Subreflector in either CW or CCW direction (whichever is the shortest distance) to null the error; the Focus drive cannot do so. Other differences are: Focus command limit tests, Ring commands (handled by the Rotation controller) and the maximum drive speeds.

There are two ways that the F/R Mount can be driven: COMPUTER mode (ie the central control computers via the Data Set) and LOCAL via the switches on the M8 panel. The LOCAL code and the COMPUTER mode code invoke the same subroutines and device drivers because many of the functions to be performed are common to both modes.

There are 4 commands that are recognized and executed by the $F / R$ Controller: POSITION, RESET, NAP and RING. The RESET command terminates the execution of POSITION, NAP and RING commands. The NAP command inhibits execution of POSITION and RING commands. The asynchronous execution of these commands is interrupted by the higher priority 39.2 HZ monitor data requests from the Data Set.

### 2.2 M11 APEX INTERFACE

The Apex Interface contains the logic and conversion equipment to sense conditions in the Apex and serially transmit this data to the F/R Controller upon request. Except for the common time base, analog multiplexer-A/D logic and display logic, the logic is partitioned into two independant, asynchronous sections associated with the Focus and Rotation processors in the $F / R$ Controller.

The Apex Interface is powered by a dedicated power supply in the M8 to isolate all Apex signal lines. The links between it and the $F / R$ Controller are isolated by optical isolators to protect the balance of the system from disagreeable phenomena associated with lightning.

The analog and conversion circuitry consists of an 8 channel multiplexer, a sample/hold unit, an A/D converter, a precision +10 volt reference and two Synchro to Digital converters. The reference voltage and A/D gain and zero may be adjusted by removing a front panel adjustment panel cover.

The F/R Mount temperature is sensed by an AD590 temperature sensor mounted in a metal box bolted to the underside of the F/R Mount gearbox. The temperature readout verifies the operation of the heaters and is scaled to produce $100 \mathrm{mv} / \mathrm{deg} \mathrm{C}$.

Figure 8 (below) depicts the location of these analog data adjustments and the display messages.


Figure 8, Apex Interface display and analog adjustments
The numeric displays show positions as 4 digit octal values derived from the $S / D$ converter 14 bit straight binary code output; the value may range between 0000 (full DOWN/CCW) and 3777 (full UP/CW). The associated values seen on the Data Tap octal display will be: 2000 and 1777 respectively since the msb is inverted to make the monitor data a 2's complement value.

The discretes display indicate the following when illuminated:
UL \& LL - Focus Upper or Lower limit switch actuated
CW \& CCW - Rotation CW or CCW limit switch actuated
RR \& RE - Ring Retract or Ring Extend switch actuated
M1,M2,M3 - Apex Interface analog mux address bits
FA - Focus Data readout to controller active
RA - Rotation Data readout to controller active
AA - A/D Converter active
P,L,C,U,K,X,Y,Z - Band Pin Switch Actuated (not presently used)

### 2.3 M8 F/R POWER SUPPLY

The M8 F/R Power Supply contains the system logic and Apex Interface power supplies. This unit also serves as a control/display panel for processordriven display LEDs to indicate important discrete states such as Command Active, Translator power on, Brake V*I ok, Up drive line pulsing, etc. Switches enable manual slew control of the Focus and Rotation axes at either a 100 Hz stepping rate or by ramping up to high speeds to travel long distances. Band select switches and associated LEDs enable future manual control of an Index Locking Pin if the need should arise. Figure 9 depicts the M8 control panel switch functions and discrete indications.

Monitor States \& Controls:
UL/LL - Focus limits
CWL/CCWL - Rotation limits
UP/DOWN - Focus drive dir
CW/CCW - Rot drive dir
BRK - Brake volts*amps ok
TRANS - Trans power on
CMD - Command active
MOT - not used
EXT - Ring extended
RET - Ring retracted
P,L,U,C,K Pin select
switches \& LEDs, not used
DRIVE UP/DWN - slew
Focus when depressed
RAMP/100 Hz - ramp speed
or drive © 100 Hz
DRIVE CW/CCW - slew
Rot when depressed
EXT/RET - initiates
ring program


Figure 9, M8 Controls \& Displays

### 2.4 M22 F/R SWITCHING MODULE

The switching module contains solid state relays to power the Translators, brakes and Ring actuator, Brake controllers to power the F/R Mount brakes and a 400 Hz Synchro Exciter to power the position readout synchros. The relays are optically isolated and are driven by the F/R Controller logic. A manual switch and test points on the panel enable manual brake actuation and set point adjustment.

The Synchro Exciter is a 400 Hz power oscillator contained on a removeable PC board. A current transformer on the board generates a voltage proportional
to the synchro load current which is read as monitor data. Circuitry in M7 scales the voltage at 1 volt/synchro load thus enabling a confirmation that currents are present in both synchro rotors.

### 2.5 STEPPER MOTOR TRANSLATORS

Two types of Superior Electric stepper motor translators are used in the F/R System: 1) HTR 1008, used with the HS 1500 motor on antennas 1 - 20; 2) TM 600, used with the M112-FD309 motors used on Antennas 21-28. These two types of motors and translators are not interchangeable. The Antenna 1 - 20 Translator/Motors produce lower torque than the later units and exhibit a pronounced resonance at 550 Hz ; they are also more vulnerable to damage under drive sticking conditions which can cause driver board failure. The later units are not invulnerable but are less subject to damage under sticking conditions.

Although it would be possible (with some signal conditioning circuitry) to uniquely identify Translator failures (other than blown fuses), it has not been implemented. Any case of hard drive sticking (indicated by a DRIVE fault) in mild weather is probablay a Translator driver board failure or blown Translator fuse. A blown fuse (a frequent failure due to heavy loads or power glitches) is identified by the absence of Translator power at the start of command execution. A bad driver board is identified at the antenna by oscilloscope observation of the motor drive waveforms.

### 3.0 SYSTEM TROUBLE-SHOOTING

An important system design consideration is the ablity to monitor the conditions in the electronics and the $F / R$ Mount to identify malfunctions and diagnose faults. A great deal of diagnostic information is brought back in the Monitor data. This section describes some trouble-shooting guidelines for the system based upon remote observations via the monitor data and direct easurements at the antenna; Section 4.0 describes the Operator $F / R$ Overlay.
A) CHECK COMMUNICATIONS WITH CONTROLLER

This is a vital requirement.
a. Is analog data present? -- look at mux $0-7$, power supply voltages, etc, also see MW1.
b. Is analog data within limits? -- check for bad power supplies.
c. Is digital data present? --- examine DS \#3, 220 - 227, Foc; 230 - 237, Rot. If missing or bad, send a RESET to restart the processor; does the data reappear? If not the controller is bad or is not hearing the Data Set.
d. Is the digital data reasonable? --- evaluate as shown in $\mathbf{D}$.
B) CHECK FAULT \& MODE FLAGS

Are there fault or mode flags coming back from the controller?
These are major descriptors of the conditions seen by the F/R Controller.
OPERATOR -- the opertor has sent an out of range Foc command.
CONTROLLER -- the controller has sensed an illegal condition during program execution.

DRIVE -- the mechanism is not driving properly, probably a bad translator, cold sticking, mechanical drag or jam.

TRANSLATOR -- translator did not turn on of of within 1 sec .
BRAKE -- brake voltage*current bad or did turn on or off within 1 sec .
UPPER/LOWER LIMIT -- limit switch activated, should never happen under Computer control, result of some malfunction.

TIMEOUT -- commanded position has not been attained within allotted time.

APEX INTERFACE DEAD -- Apex Interface has not responded to a data request from F/R Controller.

CABLE INTERLOCK -- a bin I/O cable is loose or disconnected.
SYSTEM -- a system malfunction has been sensed by controller.

RING EXTENDING (or RETRACTING) and TIMEOUT -- The 327 MHz ring is not moving.

APEX ANALOG FAULT -- one of the Apex Interface signals is out of range.
YOWP! -- Some serious fault has been sensed by Apex Interface, all brake, translator \& Ring drive is inhibited.

LOCAL mode -- the controller will not accept commands in LOCAL mode, go set the M7 switch to CMP mode.

APEX INTERFACE DEAD -- the Apex Interface is not responding to data requests from the F/R Controller.

CMD ACTIVE -- a position command is being executed.
NAP ACTIVE -- position and ring commands are being ignored, send a RESET command to clear NAP mode.
C) CHECK COMMAND-F/R RESPONSE

The analysis of the controller response to a command is a very important aspect of system trouble shooting. The digital monitor data should be examined in these tests as the command and response discretes provide detailed information about what is happening in the system.
a. Send a position command, does ECHO = CMD ?
-- yes: command input logic is working, the controller responded to a CMD from the Data Set,interpreted it properly \& initialized the control program.
-- no: command not being heard, may be bad F/R Controller, Data Set, Ant Buffer, IF/LO problem.
b. Does a position command cause any drive movement ?
-- yes: but slow \& with a DRIVE, TRANS or BRAKE fault; check the digital data for conditions. The drive appears to be sticking, check the translator.
-- no: \& with DRIVE, TRANS or BRAKE faults, indicates a drive problem, bad translator or stuck drive; check the digital data for conditions. Check the translator. Wire a substitute motor into the pedastal room junction box. Will the motor run in the LOCAL mode? Climb up to F/R Mount \& disengage motor from the mount; will it run in the LOCAL mode?
c. Will controller accept a NAP command? Test by sending a POSITION command after a NAP command.
-- no: F/R Controller is not working properly, NAP command is a very simple command to execute.
d. Will the controller accept a soft RESET command? (mux 321 \& 331). RESET causes Apex data to be all zeros until
updated.
-- no: F/R Controller is not working properly, a soft RESET is the simplest command to execute.
e. Will the controller respond to a hardware RESET command, MUX 337?
-- no: F/R Controller is really busted.
D) CHECK MONITOR DATA VALUES AND STATES

All discrete control states, all sensible response states and analog monitor data from the F/R Controller and Apex Interface are available for fault analysis. Section 5.0 details the data formats. In general any command will activate several of these control and response discretes; if there is a problem these states should be examined on a Data Tap. If a Position command is to be executed, the translator power, brake, steer up/down ( $\mathrm{cw} / \mathrm{ccw}$ ) and clock enable control discretes should be l's. The clock rate control discretes should sequence through a lot of states if the drive is to be ramped up in speed. The response discretes should show brake V*I, translator power on and drive up/down (cw/ccw) pulsing.

The following analog/digital data values should be examined:
a. Is synchro: - 2 V ? -- yes: synchro excitor in M22 is ok

- 1 V? -- yes: one synchro rotor lead open

0 V? -- yes: synchro excitor in M22 bad or fuse blown
b. Is the position readback stable?
-- yes: synchro \& S/D converter probably working, drive a little, does the position change?
-- no: S/D converter bad, no synchro excitation or a synchro wiring problem.
c. Is mount temp - 10 deg above ambient when ambient is <45 F?
-- yes: heaters \& temp probe ok.
-- no: mount heaters may not be working, is drive sticking?
d. Is bin temp > 30 deg $C$ ?
-- yes: damage can result, go check the fans.
e. Are power supply voltages within tolerance?
-- no: go fix the problem.

### 4.0 TELESCOPE OPERATOR F/R OVERLAY DESCRIPTION

A replica of the new $F / R$ Overlay is shown below; all fault flags are shown.

| NEW FOCUS/ROTATION ANT (20) |  |  |  |
| :---: | :---: | :---: | :---: |
| SYSTEM | focus | ROTATION | APEX INTERFACE |
| LOCAL |  |  | MOUNT TEMP 16.900 |
| TIMED OUT | NAP | NAP | -15 V -15.000 |
| SYSTEM FAULT |  |  | +15V 15.000 |
| I/O CABLES | UP TRANSL | CW TRANSL | +5V 5.000 |
| YOWP! | DRIVE PULSES | DRIVE PULSES | +10V 10.000 |
| RING | LOWER LIMIT |  | FOC VEL 0.000 |
| EXTENDED |  |  | ROT VEL 0.000 |
|  | BRAKE | BRAKE | GROUND 0.000 |
|  | DRIVE | DRIVE | ANALOGS NOT OKINACTIVE |
|  | TRANSLATOR | TRANSLATOR |  |
|  | CONTROLLER | CONTROLLER |  |
|  |  |  | F/R CONTROLLER |
| POSITION | 7469 | -3471 | +5V 5.000 |
| COMMAND | 7469 | -3471 | +15V 15.000 |
| CMD ECHO | 7469 | -3471 | -15V -15.000 |
| ERROR | 0 | 0 | FOC TRAN 2.600 |
|  |  |  | ROT TRAN 2.600 |
|  |  |  | SYNCHRO 2.000 |
|  |  |  | BIN TEMP 24.00 |
|  |  |  | GROUND 0.000 |

$F=F O C U S, R=R O T A T I O N,(N=N A P)$, (RING CMDS) $E=E X T E N D, W=R E T R A C T$
S=STOP ESC-M=MASTER CLEAR
F/R FAULT MESSAGES
LOCAL - Although not a malfunction, the CMP/LOCAL switch was left in LOCAL. CMP should normally be displayed here.

TIMED OUT - The commanded position has not been attained within the allotted time.

SYSTEM FAULT - The F/R Controller has detected a serious system fault.

I/O CABLES - Some bin I/O cable has been disconnected or is loose.

YOWP! - A serious problem has been sensed by the Apex Interface.
RING EXTENDING/RETRACTING - The 327 MHz ring has received a command and is moving the Ring in the indicated direction. A TIME OUT fault indicates that the ring has not attained the commanded state within the allotted time.

BRAKE - The brake V*I has not reached the commanded state
within 1 second.
TRANSLATOR - The translator has not reached the commanded state within l second.

CONTROLLER - CONTROLLER indicates that the controller has sensed a malfunction in its operation.

ANALOGS NOT OK - Indicates that an Apex Analog fault has been reported by the F/R Controller.

INACTIVE - Indicates that the Apex Interface is not responding to data requests from the F/R Controller. This is a major malfunction

## F/R DISCRETES DISPLAY

UP TRANSLATOR - The Focus translator is being driven with UP pulses. Down is the complementary case.

CW TRANSLATOR - The Rotation translator is being driven with CW pulses. CCW is the complementary case.

LOWER LIMIT - The Focus drive has driven to a limit switch, this should never happen under central computer control, something is really wrong. UPPER LIMIT is the complementary case.

RING EXTENDED - The 327 MHz Ring has been extended into position and has actuated the position sensing switch. RING RETRACTED is the complementary case. When the Ring is traveling between the two positions neither switch should be actuated. There is no other readout of Ring position.

NAP - NAP indicates that the processor is ignoring position and ring commands. A RESET command clears this mode.

## COMMAND/POSITION DATA

POSITION - POSITION is a decimal value which ranges between +8191 to - 8192. Typical (Ant 20) Rotation command arguments are: $P$-6158; L -2033; C -7054; K +7925; $U$ +7020; X -4460 (decimal values).

COMMAND - COMMAND is the decimal value of the position command set point.

COMMAND ECHO - COMMAND ECHO is the command argument heard by the $F / R$ Controller and is returned as monitor data to verify command reception.

COMMAND ERROR - The controller calculates the difference between
the commanded position and the present position; this is read out as monitor data.

## APEX INTERFACE ANALOG DATA

MOUNT TEMPERATURE is the temperature sensed on the middle of the bottom of the gear-box and serves to verify that the gear-box and platform heaters are working in cold weather. The heater controller switches on when the ambient temperature is below about 45 deg $F$. The temperature readout is in degrees $C$ and should be about 10 deg C above ambient when the ambient is below 45 F . When the $\mathrm{F} / \mathrm{R}$ Mount temperature drops below 0 deg, the controller signals an Apex Analog fault.

APEX INTERFACE POWER SUPPLIES indicate the voltages which operate this interface. The $+/-15$ volts should be within $+/-.3$ volts and the +5 volt tolerance is $+/-.15$ volts. The +10 volt tolerance is $+/-0.040$ volts. This data has a granularity of .020 volts/bit. Ground is a measure of A/D zero drift and should be less than $+/-0.040$ volts. Foc and Rot velocities are a measure of drive velocity and are scaled 13 volts/in/sec for Focus and 5.2 volts/deg/sec for Rotation.

F/R CONTROLLER ANALOG DATA
F/R POWER SUPPLIES indicate the voltages which operate the $F / R$ Controller and associated logic. The $+/-15$ volts should be within $+/-.1$ volt and the +5 should be within $+/-.2$ volts. The translator power should be $+2.6+/-.5$ volts. These translator voltages are present only during command execution. The Synchro voltage should read $+2+1-.5$ volts. Ground is a measure of the Data Set A/D zero drift and should be less than +/ . 010 volts. Bin temperature reads out directly in deg $C$ and should be less than 30 deg.

### 5.0 CONTROL/DATA FORMATS

Mux refers to the multiplex address in octal format. RAM loc denotes the byte symbolic address in RAM memory.

COMMAND FORMATS:

| Mux addr | 320/Foc | 330/Rot | 336/Ring |
| :---: | :---: | :---: | :---: |
| Ram loc Data | rampas <br> null | rampas <br> null | none <br> null |
| b23 80H | 0 | 0 | 0 |
| b22 40 H | 0 | 0 | 0 |
| b21 20H | 0 | 0 | 0 |
| b20 10H | 0 | 0 | 0 |
| b19 08H | 0 | 0 | 0 |
| b18 04H | 0 | 0 | 0 |
| bl7 02H | 0 | 0 | 0 |
| b16 01H | 0 | 0 | 0 |
| Ram loc | rampbs | rampbs | none |
| Data | Foc arg | Rot arg | null |
| b15 80H | 0 | 0 | 0 |
| b14 40H | 0 | 0 | 0 |
| b13 20 H | 2**13,msb | 2**13,msb | 0 |
| bl2 10 H | 2**12 | 2**12 | 0 |
| b11 08H | 2**11 | 2**11 | 0 |
| blo 04H | 2**10 | 2**10 | 0 |
| b9 02H | 2**9 | 2**9 | 0 |
| b8 01H | 2**8 | 2**8 | 0 |
| Ram loc | rampes | rampcs | none |
| Data | Foc arg | Rot arg | Ring arg |
| b7 80 H | 2**7 | 2**7 | 0 |
| b6 40 H | 2**6 | 2**6 | 0 |
| b5 20H | 2**5 | 2**5 | 0 |
| b4 10 H | 2**4 | 2**4 | 0 |
| b3 08H | 2**3 | 2**3 | 0 |
| b2 04 H | 2**2 | 2**2 | 0 |
| bl 02 H | 2**1 | 2**1 | 0 |
| b0 01H | 2**0 | 2**0 | ext/ret, l=ext |

A SYSTEM RESET command (Mux 337)causes abortion of active commands and reinitiallizes the two processors. A software RESET command (Mux 321 \& 331) resets the addressed processor. The control argument is not used in RESET commands.

NAP commands (Mux 322/Foc \& 332/Rot) cause all subsequent position commands to be ignored until cancelled by a RESET command. The command argument is not used.

DIGITAL MONITOR DATA
Digital monitor data formats are a composite of values and associated discrete or fault data. A 1 in a fault bit denotes a fault state.

Focus Digital Monitor Data:

| Mux addr | 220/Foc | 221/Foc | 222/Foc |
| :---: | :---: | :---: | :---: |
| Ram loc | posd+2 | erro+2 | echo +2 |
| Data | faults | modes | null |
| b23 80H | operator | 0 | 0 |
| b22 40 H | controller | cmd active | 0 |
| b21 20 H | drive | nap active | 0 |
| b20 10H | translator | timeout | 0 |
| b19 08H | synchro, $=0$ | Apex Int dead | 0 |
| b18 04H | brake | cable int'lk * | 0 |
| b17 02H | upper lim | system * | 0 |
| b16 01H | lower lim | cmp/loc, $0=$ Cmp |  |
| Ram loc | posd+1 | errot 1 | echo +1 |
| Data | Foc pos | Foc pos error | Foc cmd echo |
| b15 80H | 0 | 0 | Cmd bit echoed |
| b14 40H | 0 | 0 | Cmd bit echoed |
| bl3 20H | 2**13, msb | 2**13, msb | 2**13, msb |
| bl2 10H | 2**12 | 2**12 | 2**12 |
| bll 08H | 2**11 | 2**11 | 2**11 |
| b10 04H | 2**10 | 2**10 | 2**10 |
| b9 02H | 2**9 | 2**9 | 2**9 |
| b8 01H | 2**8 | 2**8 | 2**8 |
| Ram loc | posd | erro | echo |
| Data | Foc pos | Foc pos error | Cmd echo |
| b7 80 H | 2**7 | 2**7 | 2**7 |
| b6 40H | 2**6 | 2**6 | 2**6 |
| b5 20H | 2**5 | 2**5 | 2**5 |
| b4 10H | 2**4 | 2**4 | 2**4 |
| b3 08 H | 2**3 | 2**3 | 2**3 |
| b2 04 H | 2**2 | 2**2 | 2**2 |
| bl 02 H | 2**1 | 2**1 | 2**1 |
| b0 01H | 2**0 | 2**0 | 2**0 |

* $1=$ no fault, low true

| Mux | 223/Foc | 224/Foc | 225/Foc |
| :---: | :---: | :---: | :---: |
| Ram loc | dscr +2 | adcr +2 | anad+2 |
| Data | clock control | Apex Foc Discr | Apex Anlg Faults |
| b23 80H | 2**7,msb | 0 | gnd |
| b22 40 H | 2**6 | 0 | 0 |
| b21 20 H | 2**5 | 0 | foc vel |
| b20 10H | 2**4 | 0 | +10 volts |
| b19 08H | 2**3 | 0 | +5 volts |
| b18 04H | 2**2 | Foc brk V*I | +15 volts |
| b17 02H | 2**1 | Foc upper 1 im | -15 volts |
| b16 01H | 2**0 | Foc lower 1 im | mount temp |
| Ram loc | dscr +1 | adcr +1 | anad+1 |
| Data | cmd sense | Foc vel | Apex analog data |
| b15 80H | Foc trans pwr | 0 | 0 |
| bl4 40 H | Foc brake pwr | 0 | Mux addr 4 |
| bl3 20 H | 0 | 0 | Mux addr 2 |
| bl 210 H | 0 | 0 | Mux addr 1 |
| bll 08 H | Foc drv up | 2**11,msb | 2** 11 ,msb |
| bl0 04H | Foc drv down | 2**10 | 2**10 |
| b9 02H | 0 | 2**9 | 2**9 |
| b8 01H | Foc clock en | 2**8 | 2**8 |
| Ram loc | dscr | ader | anad |
| Data | activity sense | Foc vel | Apex analog data |
| b7 80H | motor pulsing, $=0$ | 2**7 | 2**7 |
| b6 40H | down pulsing | 2**6 | 2**6 |
| b5 20H | up pulsing | 2**5 | 2**5 |
| b4 10H | trans pwr mon | 2**4,1sb | 2**4 |
| b3 08H | 0 | 0 | 2**3 |
| b2 04H | cable intl'k* | 0 | 2**2,1sb |
| bl 02 H | Yowp!* | 0 | 0 |
| b0 01H | cmp/loc, $0=1 \mathrm{loc}$ | 0 | 0 |



| Mux | 233/Rot | 234/Rot | 235/Rot |
| :---: | :---: | :---: | :---: |
| Ram 10c | dscr +2 | adcr +2 | anad+2 |
| Data | clock control | discretes | apex an faults |
| b23 80H | 2**7, msb | sum pins, $=0$ | gnd |
| $\text { b22 } 40 \mathrm{H}$ | $2 * * 6$ | pc4, $=0$ | rot vel |
| b21 20H | 2**5 | pc2 " | 0 |
| b20 10H | 2**4 | pcl " | +10 volts |
| b19 08H | 2**3 | 0 | +5 volts |
| b18 04H | 2**2 | brake V*I | +15 volts |
| b17 02H | 2**1 | Rot cw 1 im , $=0$ | -15 volts |
| bl6 01H | 2**0 | Rot ccw lim, $=0$ | mount temp |
| Ram 10c | dscr +1 | adcr +1 | anad+1 |
| Data | cmd sense | rot vel | apex analogs |
| b15 80H | Rot trns pwr | 0 | 0 |
| b14 40H | Rot brk pwr | 0 | ana mux 4 |
| b13 20H | Ring ret pwr | 0 | ana mux 2 |
| bl 2 10H | Ring ext pwr | 0 | ana mux 1 |
| b11 08H | Rot drv CW | 2**12,msb | 2**12, msb |
| b10 04H | Rot drv ccw | 2**11 | 2**11 |
| b9 02H | 0 | 2**10 | 2**10 |
| b8 01H | Rot clk en | 2**9 | 2**9 |
| Ram loc | dscr | ader | anad |
| Data | activity sense | rot vel | apex analogs |
| b7 80 H | mot pulsing | 2**8 | 2**8 |
| b6 40H | ccw pulsing | 2**7 | 2**7 |
| b5 20H | Cw pulsing | 2**6 | 2**6 |
| b4 10H | trans pwr mon | 2**5,1sb | 2**5 |
| b3 08H | 0 | 0 | 2**4 |
| b2 04H | cable intl'k* | 0 | 2**3 |
| b1 02H | Yowp!* | 0 | 2**2,1sb |
| b0 01H | cmp/loc, $0=10 \mathrm{C}$ | 0 | 0 |

ANALOG MONITOR DATA:

| Mux | Parameter | Nominal Value \& Tolerance |
| :---: | :---: | :---: |
| OH | 5 logic pwr | +5 volts, +/- . 2 volts. |
| 1H | analog gnd | 0 volts $+/-10 \mathrm{mv}$. |
| 2 H | +15 volts/2 | +7.5 volts +/- 100 mv . |
| 3H | -15 volts/2 | -7.5 volts +/-100 mv. |
| 4H | Foc Trans pwr | +2.5 volts +/- . 5 volts |
| 5H | Rot Trans pwr | +2.5 volts +/- . 5 volts |
| 6H | Bin Temp | . 1 volt/deg C |
| 7H | Synchro current | +2.5 volts +/-1 volt |

SPECIAL PURPOSE MONITOR DATA
Fault monitor data is a selection of the data listed above which has been formatted to combine all fault data into one single word for convenience in examining fault bits. The $F / R$ Mount temperature data has been put into a dedicated monitor word for convenience in driving a strip chart recorder.

Focus and Rotation Special Purpose Monitor Data

| Mux addr | 226/Foc | 236/Rot | 227/Foc |
| :---: | :---: | :---: | :---: |
| Ram loc | faul+2 | faul+2 | temp+2 |
| Data | faults | faults | F/R Mount Temp |
| b23 80H | lab test | lab test | 0 |
| b22 40H | lab test | lab test | 0 |
| b21 20 H | lab test | lab test | 0 |
| b20 10H | timeout | timeout | 0 |
| b19 08H | Apex Int dead | Apex Int dead | 0 |
| b18 04H | cable Int'ik | cable Int'lk | 0 |
| bl7 02H | system | system | 0 |
| bl6 01H | Motion Analysis | Motion Analsis | 0 |
| Ram loc | faul +1 | faul ${ }^{\text {l }}$ | temp+1 |
| Data | Apex Analog | Apex Analog | F/R Mount Temp |
| b15 80H | gnd | gnd | 0 |
| bl4 40 H | 0 | 0 | 0 |
| bl3 20 H | Foc vel | Rot vel | 0 |
| bl2 10H | +10 volts | +10 volts | 0 |
| bll 08H | +5 volts | +5 volts | 2**11,msb |
| b10 04H | +15 volts | +15 volts | 2**10 |
| b9 02H | -15 volts | -15 volts | 2**9 |
| b8 01H | mount temp | mount temp | 2**8 |
| Ram loc | faul | faul | temp |
| Data | faults | faults | F/R Mount Temp |
| b7 80 H | operator | operator | 2**7 |
| b6 40H | controller | controller | 2**6 |
| b5 20H | drive | drive | 2**5 |
| b4 10 H | translator | translator | 2**4 |
| b3 08H | synchro, $=0$ | synchro, $=0$ | 2**3 |
| b2 04H | brake | brake | 2**2,1sb |
| b1 02 H | upper 1 im | 0 | 0 |
| b0 01H | lower lim | 0 | 0 |

### 6.0 SUBREFLECTOR POSITION SPECIFICATIONS

The following specifications were abstracted from a note by Peter Napier, 20/2/81 and are the design criteria for the F/R Controller and F/R Mount. These specifications are adequate for 22 GHz normal operation, or very high dynamic range observations at 1.5 and 5 GHz . The specifications result in some loss of performance if the VLA is used at 44 GHz .

## Definitions:

```
\(\Delta 0=\) pointing error on sky
\(\Delta X=\) movement of subreflector transverse to main
reflector axis
\(\Delta 0=\) tilt of subreflector orthogonal to main reflector axis
\(\Delta \theta=\) rotation of subreflector around main reflector axis
    \(F=\) focal length of main reflector
\(M=\) cassegrain magnification
\(R=\) feed circle radius
```



Subreflector Transverse Movement Sensitivity:

$$
\Delta 0=\Delta X / F \quad \text { for } \Delta 0=5 \text { arc }-\sec , \Delta X=0.009 \mathrm{in} .
$$

Subreflector Tilt Sensitivity:

$$
\begin{aligned}
\Delta 0=2 \star \Delta 0 / M \quad \text { for } \Delta 0 & =5 \mathrm{arc}-\mathrm{sec}, \\
\Delta 0 & =20 \text { arc-sec. } .
\end{aligned}
$$

Subreflector Rotation Sensitivity:

$$
\begin{aligned}
\Delta 0=\Delta \theta^{*} R / M^{*} F \quad \text { for } \Delta 0 & =5 \mathrm{arc}-\mathrm{sec}, \\
\Delta \theta & =6.8 \mathrm{arc}-\mathrm{min}
\end{aligned}
$$

Focus Position Sensitivity:

A 0.20 wavelength position error causes a $5 \%$ gain loss. At a wavelength of $1.2 \mathrm{~cm}, \Delta Z=0.09 \mathrm{in}, 2.25 \mathrm{~mm}$.

Barry Clark says $\Delta Z$ should be less than $0.01 \mathrm{in}, 0.25 \mathrm{~mm}$.
These last two parameters are associated with the two drive motions.

