Telescope Servo

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Telescope Servo Design Requirements

- **Control Position of 4 single axis telescopes**
  - **All 4 telescopes can be stepped simultaneously or independently**
- **Store Parameters for single step, flight computer will maintain table of scan parameters.**
- **Scan Range**
  - **Normal range of ±5 degrees**

    Minimum Step size 0.05 degrees

    Servo Position Accuracy ±0.01 degrees (±36 arc sec)
  - **Over scan of ±10 degrees for bearing lubrication**
- **Maintain position accuracy with static friction of 5 oz in**

Telescope Servo Design Requirements (Cont)

- **Elevation Knowledge**
  - **Telescope Bore Sight to Alignment cube**
    Total 1 σ error: 65 arc sec over ±5° scan range

    Electronics 25 arc sec

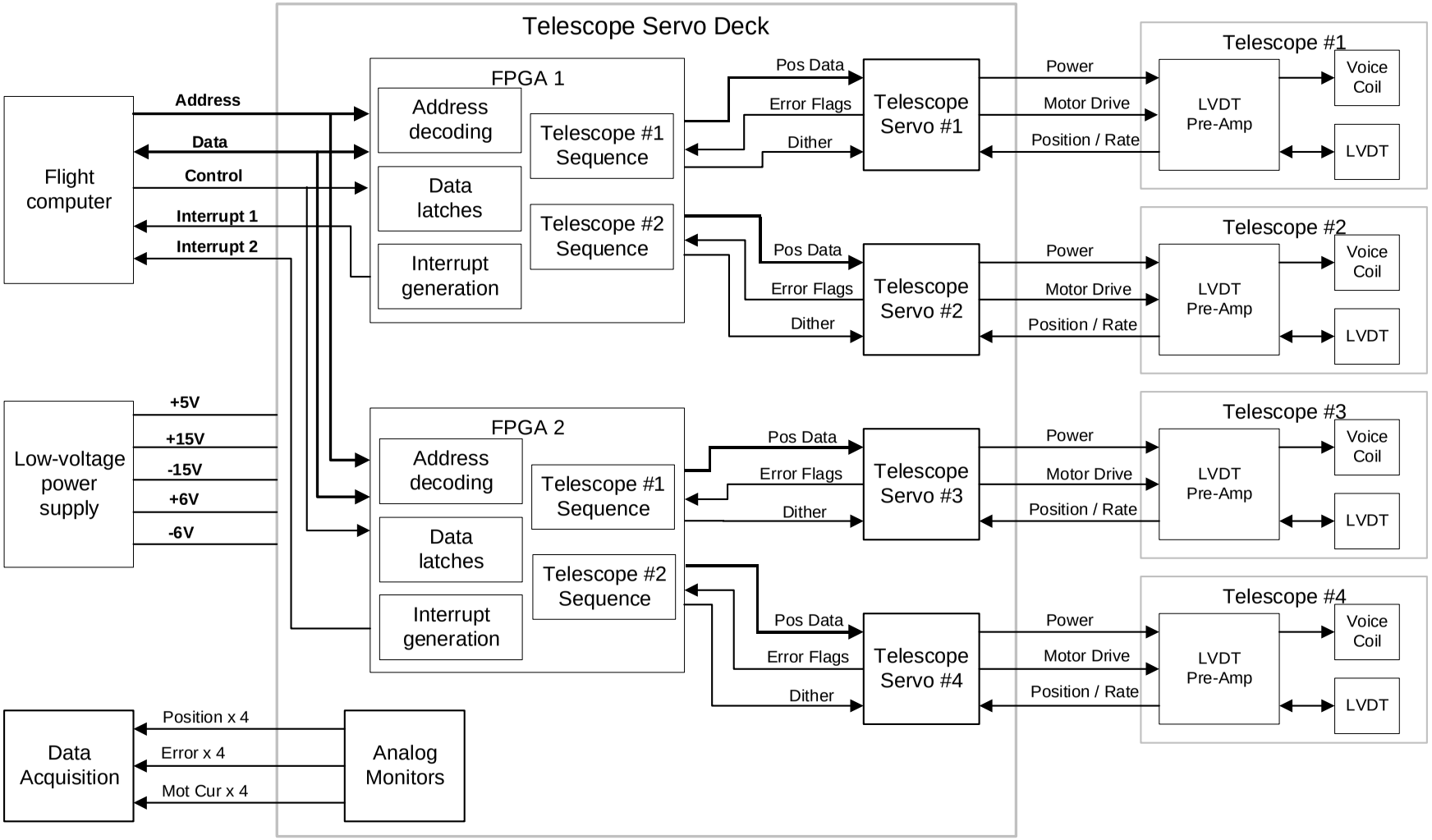
LVDT Pre-amp	**15 arc sec**
Servo	**8 arc sec**
Data Acq	**18 arc sec (1 LSB)**

    LVDT and Mechanical 60 arc sec
- **Limit voice coil power dissipation if telescope is driven into the stops**

Telescope Servo System Overview

- **Two Field-programmable gate arrays (FPGA) for flight computer interface, and telescope drive timing control.**
  - **Gate arrays are identical, each controls 2 telescopes**
- **Analog PID loop with Dither**
  - **Analog PID steps and holds telescope position**
  - **Dither uses lead lag error signals to overcome static friction**
- **LVDT for position feedback**
- **Rate feedback from LVDT for damping and velocity limit**
- **Latched position error signals to processor for position monitor**
- **Interrupt processor on step completion**

Telescope Servo System Block Diagram



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Telescope Servo Changes Since PDR

- **Eliminated Feedforward and Hold Drive Currents**
  - Difficult to calibrate Feedforward times and hold currents for all step sizes over temperature
  - Analog Servo can meet step time and position error requirements with reasonable gains
- **Dither uses error flags to determine pulse polarity**
  - Previous design used square wave drive to linearize static friction

    Settle times of 100 - 200 ms were necessary to reduce error

    Wastes Power - dither current doesn't drive telescope
  - Present design monitors position error flags and sets dither to drive position error towards zero

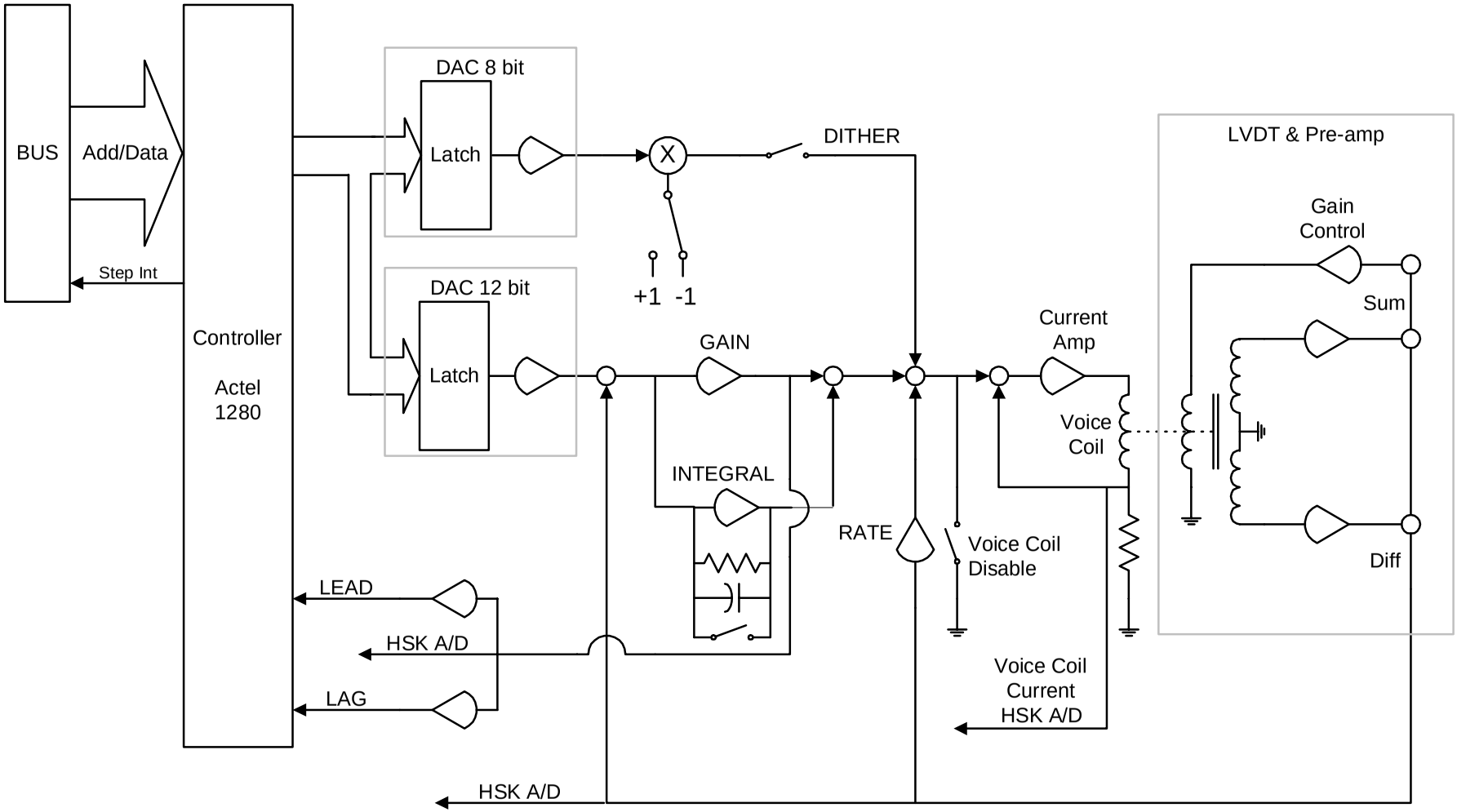
    Settle times of 25 - 30 ms

    Uses less power - Dither pulses are only produced if excessive position error exists. Pulses drive telescope to desired position

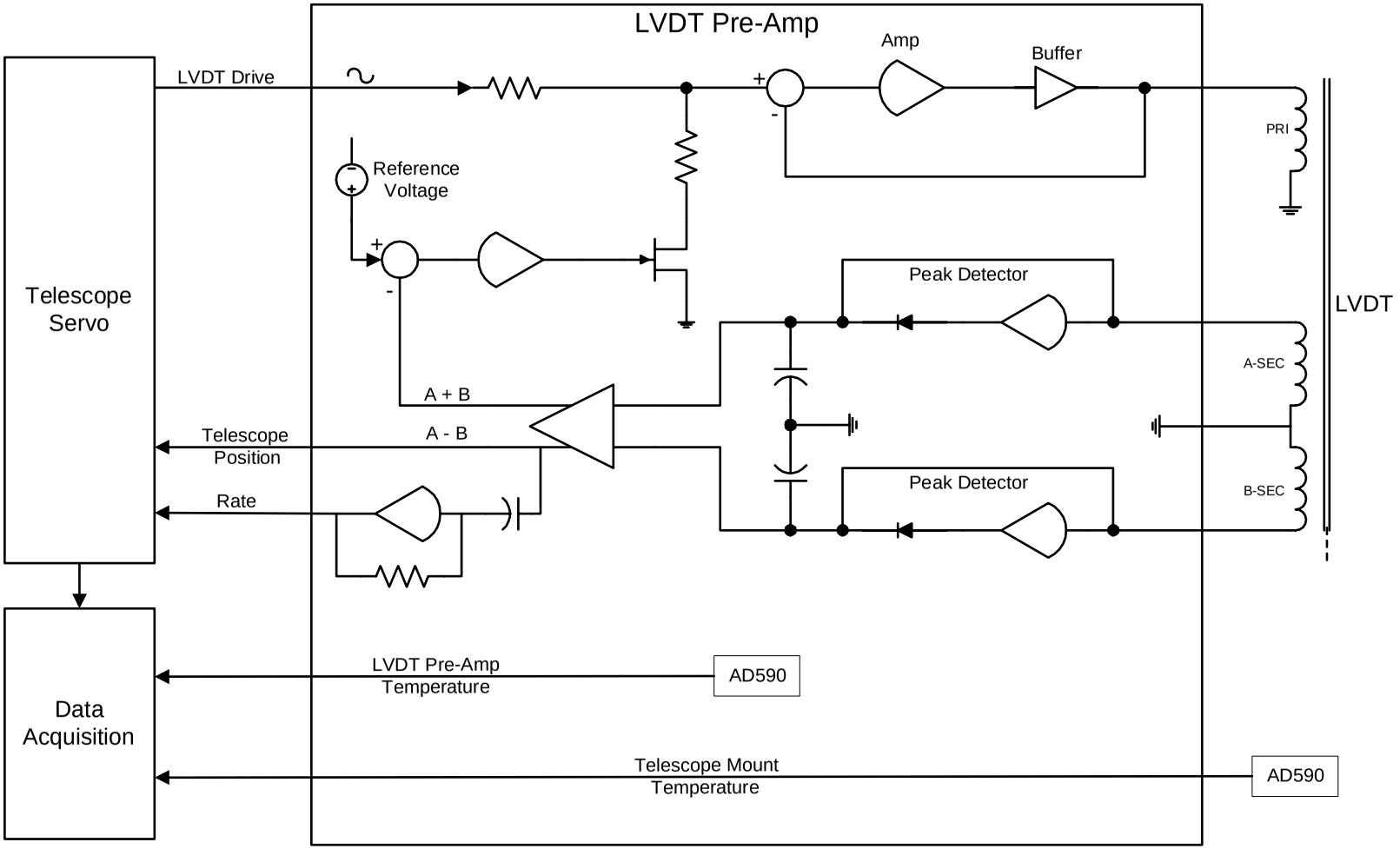
Telescope Servo Changes Since PDR (Cont)

- **Added over current detect to reduce power dissipated in the voice coil if telescopes are driven into the stops.**
  - **Maximum on duty cycle is 50% at max current**
  - **Reduces max voice coil power from 6 to 3 watts**
- **Flight Computer can independently disable the voice coil drive to each telescope.**
  - **Telescope drive / bearing failure can be disabled to reduce power consumption and let other telescopes operate normally**
  - **No additional hardware - uses same circuitry as voice coil over current detect.**

Telescope Servo
Analog Servo Loop



Telescope Servo
LVDT Pre-Amp Block Diagram



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Telescope Servo Modeling / Simulation

- **Telescope motion simulated using difference equations in Mathcad**
  - **Models effects of static friction**
  - **Simulates analog PID controller**
  - **Dither effects modeled**
  - **Models component limits**
    - **Motor Current**
    - **Op-amp saturation**
- **Model used to estimate power required to step telescope**
- **Simulation used to pick servo parameters**
  - **Good correlation between measured and simulated responses**

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Telescope Servo Design Specifications

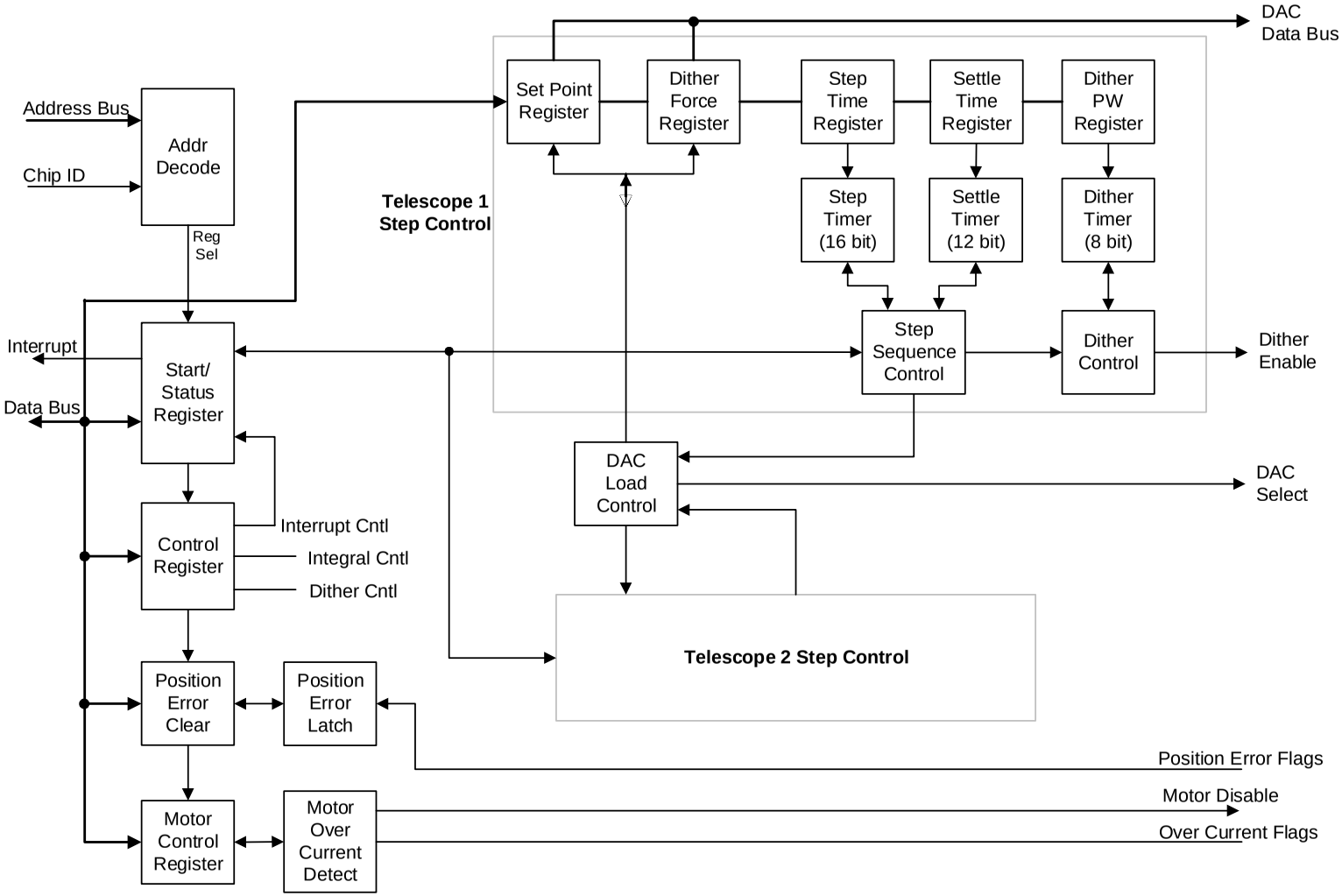
- **Telescope Step Parameters**
  - Position set point: 12 bit DAC, Range ±10.5°, Resolution 0.0051°
  - Step Time: 16 bit timer, Range 0 - 6.5535 sec, Resolution 0.1 ms
  - Settle Time: 12 bit timer, Range 0 - 409.5 ms, Resolution 0.1 ms
  - Dither Force: 8 bit DAC, Range 0 - 1.24 amps, Resolution 4.8 ma
  - Dither PW: 8 bit timer, Range .2 - 25.6 ms, Resolution 0.1 ms
- **Integral Amp Modes**
  - Integrator off all the time
  - Integrator on during Step and Settle times (normal mode)
  - Integrator on all the time
- **Dither Modes**
  - Off all of the time (set Dither PW to 0)
  - On during Settle time (normal mode)
  - On all of the time

Telescope Servo Design Specifications (Cont)

- **Servo Position Accuracy**
  - Lossy Integrator acts like a proportional gain at steady state
  - The max position error of servo loop is ±0.0085° for 5 oz in of friction
  - Dither error threshold set to ±0.005°
- **Rate feed back limits max velocity to 22°/sec**
  - The telescope moves at constant velocity for steps over 1°
- **Motor power limit has 6.5 sec on/off cycle**
- **LVDT Sensitivity is 0.48 V/deg**

Parameter	Telescope	LVDT	LVDT Pre-Amp
Scan Range	± 10.5 Deg	±0.525 in	±5.00V
Minimum Step Size	0.05 Deg	2.5 mil	23.9 mV
Position Accuracy	±0.01 Deg	±0.5 mil	±4.8 mV

Telescope Servo FPGA Block Diagram



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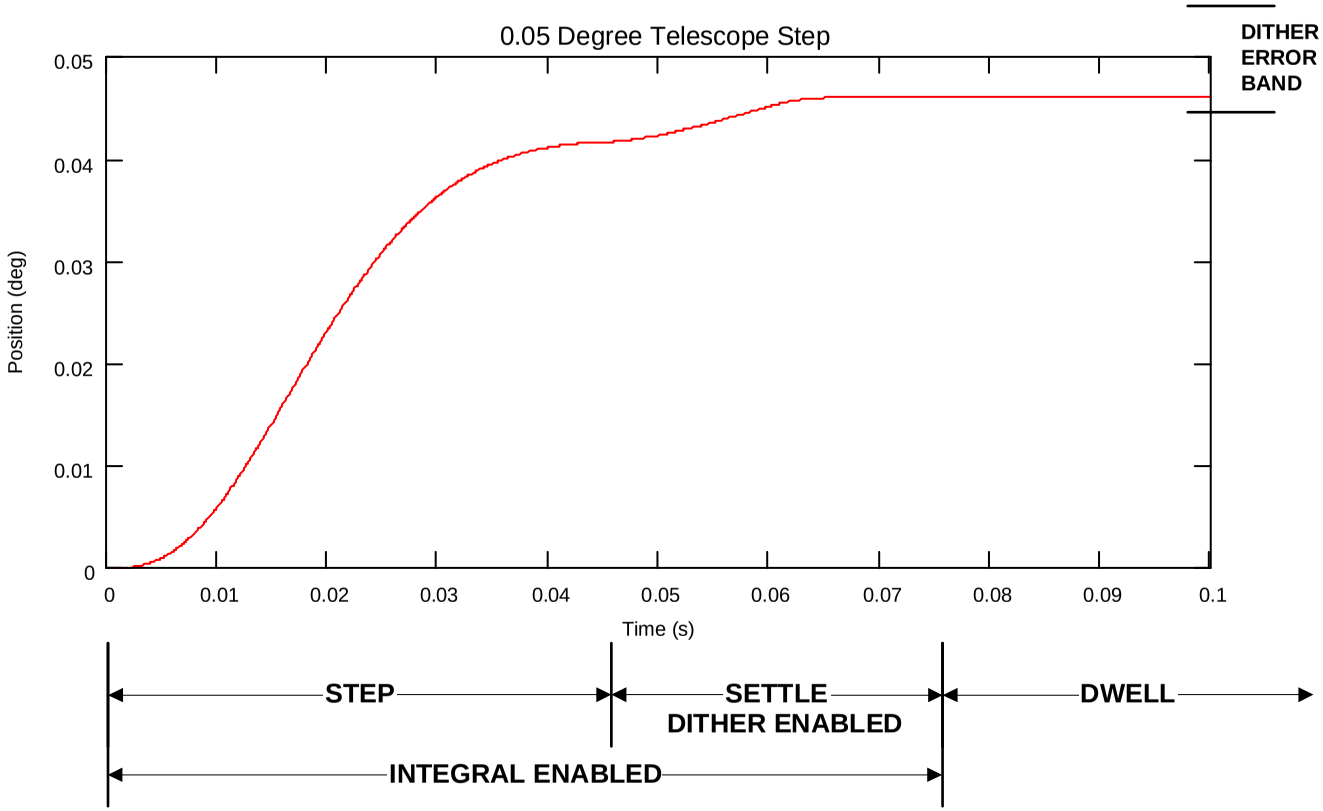
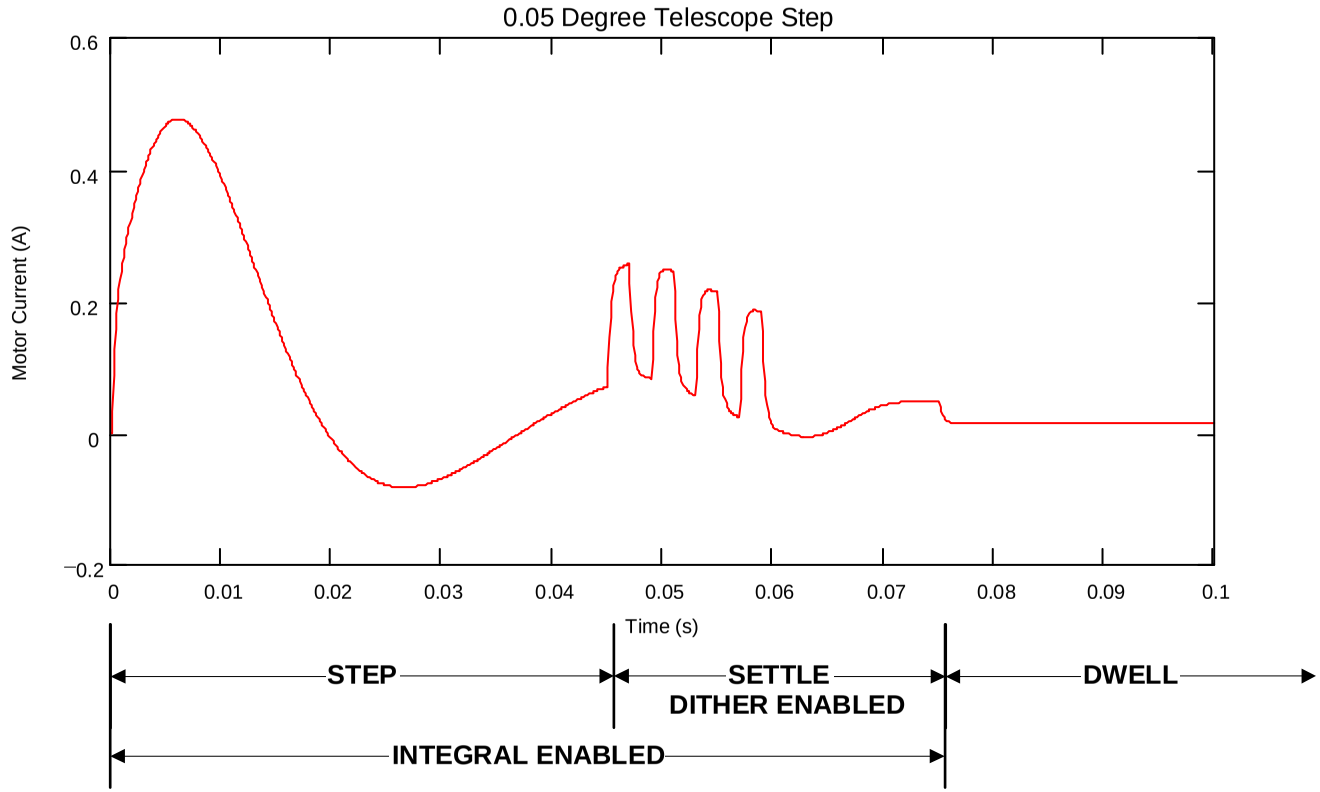
Telescope Servo Operating Sequence

- **Flight Computer Tasks**
  - Load step parameters for all telescopes to be moved
    - Telescope Position
    - Step Time
    - Settle Time
    - Dither Pulse Width
    - Dither Current
  - Check for any latched position errors from previous step
  - Issue command to start the telescope step
  - Clear latched position error register before step is completed
- **Servo Deck Tasks**
  - Moves telescope using analog servo during “Step Time”
  - Applies dither, if necessary, during “Settle Time”
  - Interrupt flight computer after “Settle Time” expires
  - Monitor and latch any position errors after “Settle Time”

Telescope Servo
Step Position Time Profile



Telescope Servo
Step Current Time Profile



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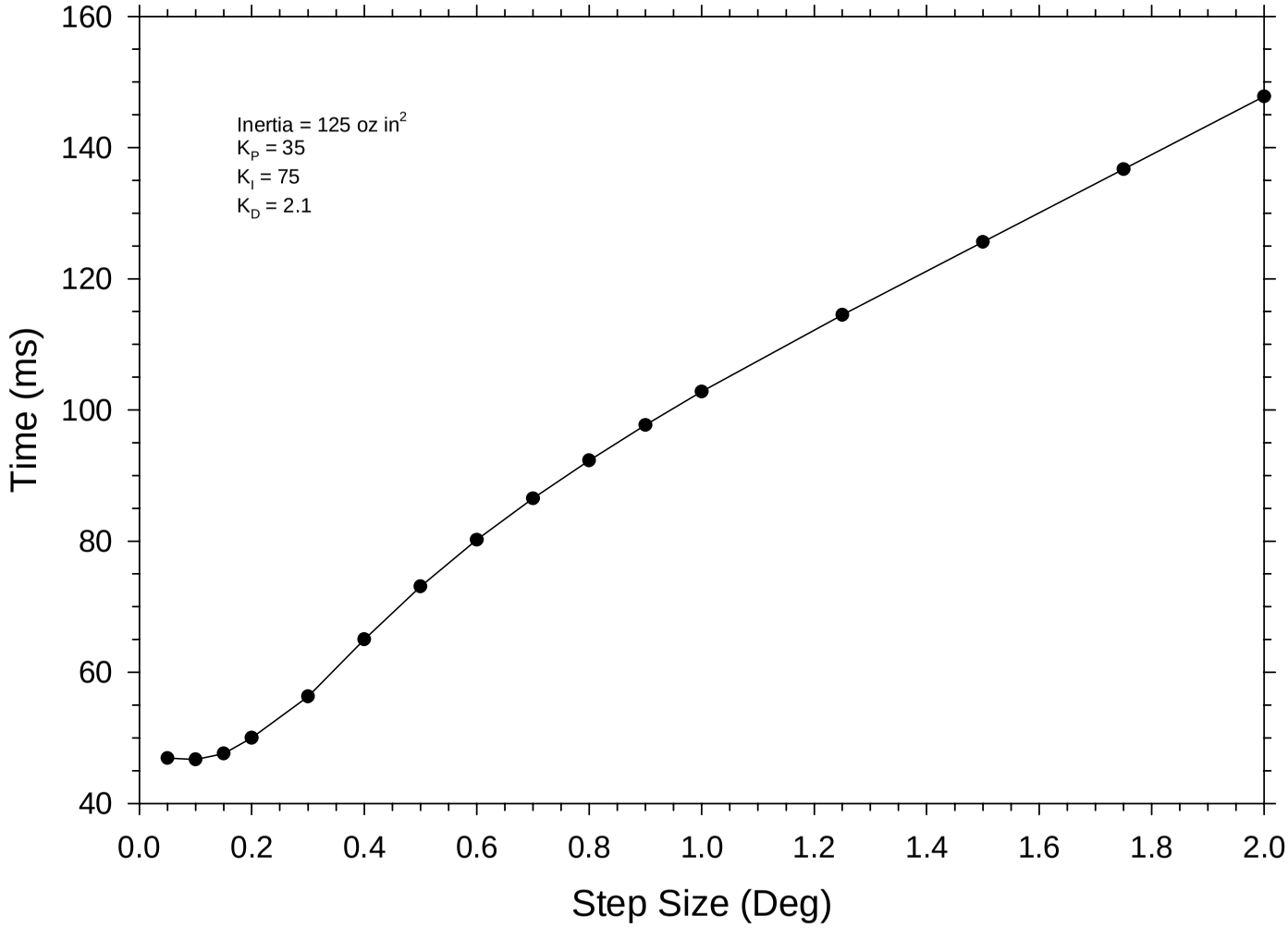
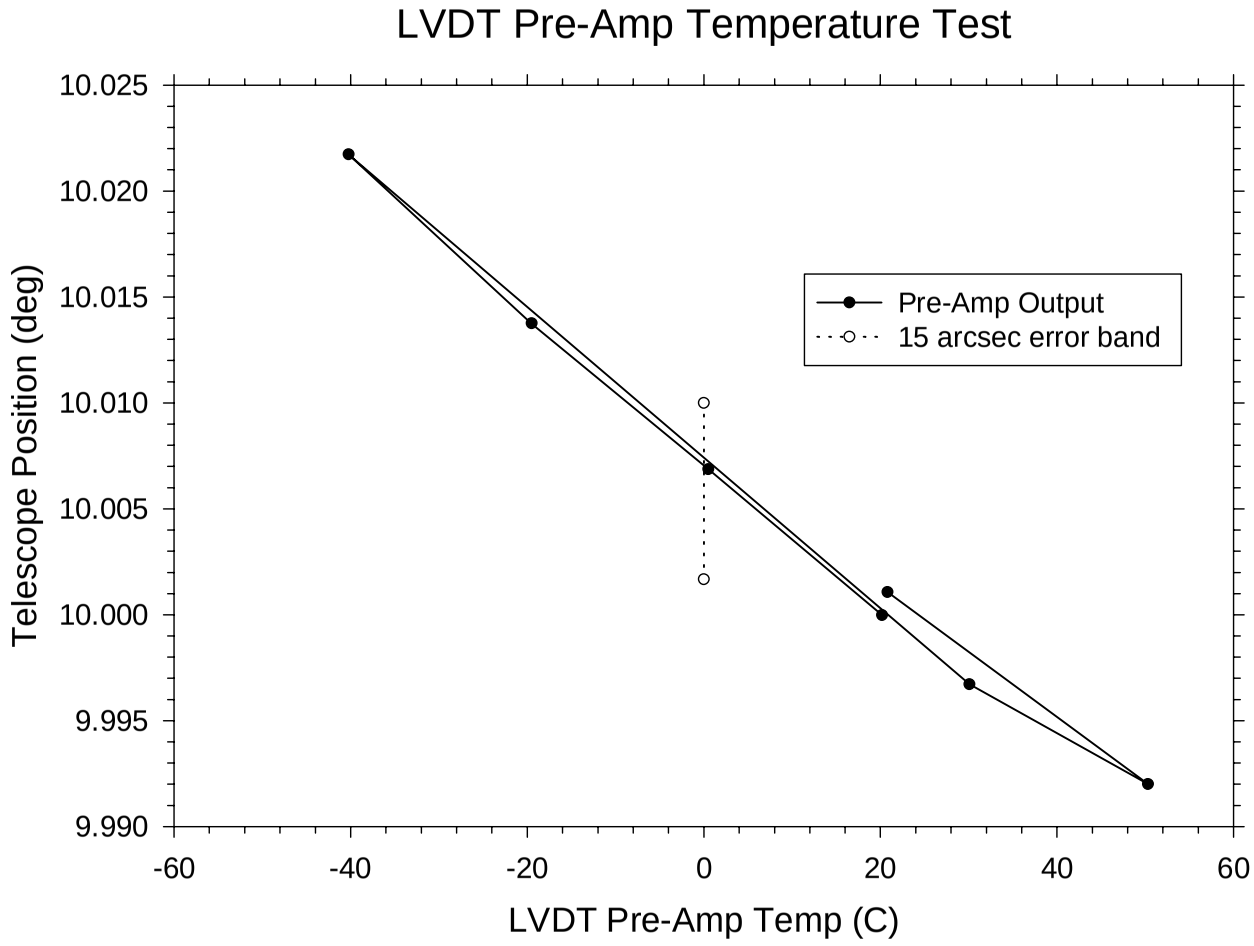
Telescope Servo Step Time

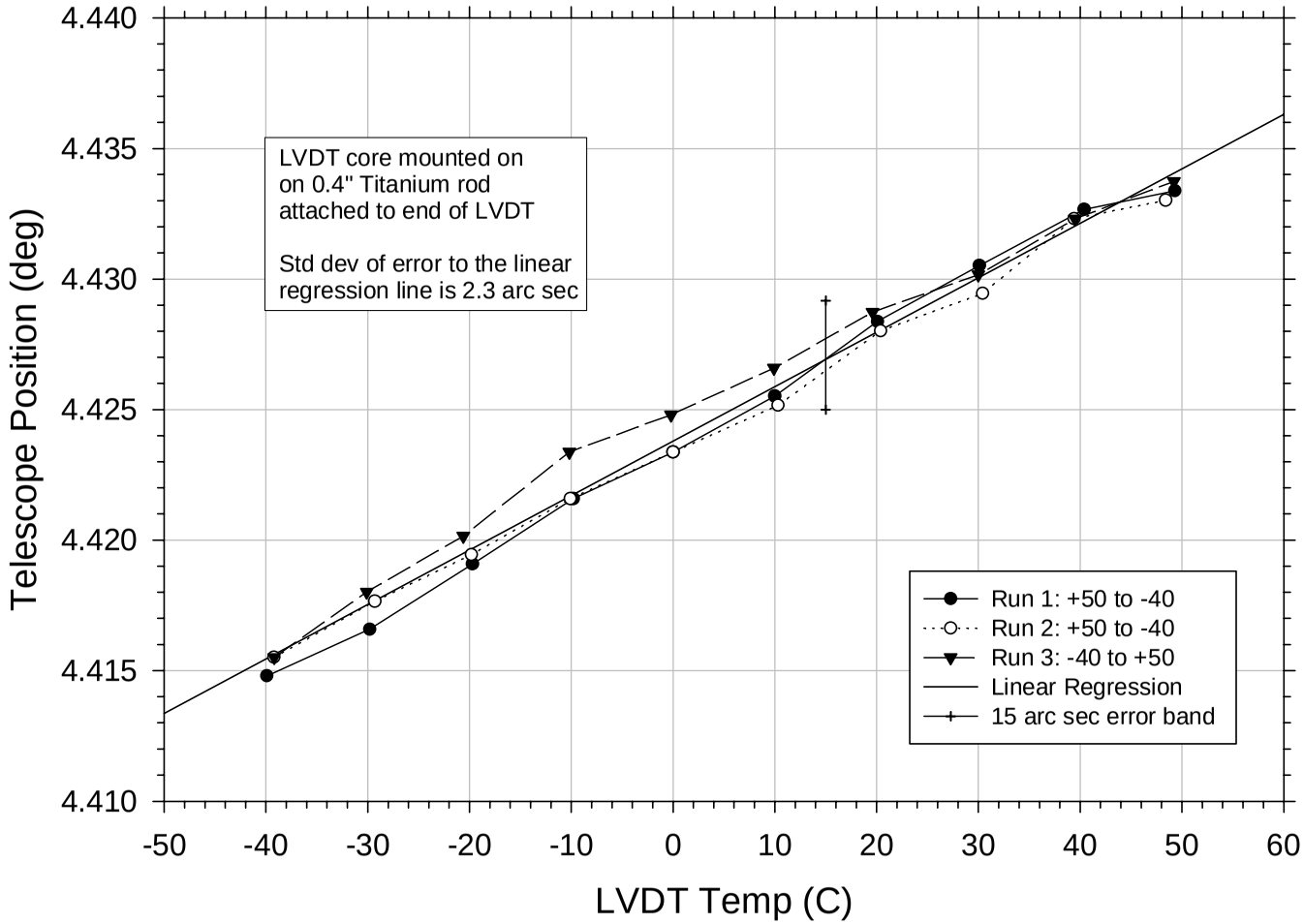


Telescope Servo
LVDT Pre-Amp Test Data



Telescope Servo LVDT Test Data

LVDT Temperature Test



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Telescope Servo Position Knowledge Calibration

- **Telescope Position vs LVDT readout requires calibration to achieve position knowledge requirement**
  - **Electronics Temperature Drift (LVDT Pre-amp, Data Acquisition and Telescope Servo Decks)**
    - **Calibrate Data Acquisition and Telescope Servo during deck level temperature tests**
    - **Characterize LVDT Pre-amp over temperature with telescope model**
  - **LVDT and mechanical non-linearities**
    - **Calibrate using Autocollimator and Theodolite**
  - **Telescope mechanical, LVDT, and Pre-Amp Temperature drift**
    - **Calibrate Telescope, LVDT and Pre-Amp using Theodolite to measure position with telescopes in temperature chamber**

Telescope Servo Calibration Method / Test Matrix

- **Measure angular position change of two reference mirrors over operational temperature range**
  - **On telescope barrel, 3 facets 5° apart (rotating mirror)**
  - **On telescope mount (fixed mirror)**

Test Condition	Position (deg)		
-20°C *	-5.0	0.0	5.0
-10°C *	-5.0	0.0	5.0
0°C *	-5.0	0.0	5.0
10°C *	-5.0	0.0	5.0
20°C *	-5.0	0.0	5.0
30°C *	-5.0	0.0	5.0
40°C *	-5.0	0.0	5.0
Room Temp **	-5.0 to 5.0 each degree		
Room Temp ***	-5.0 to 5.0 each 0.05 degree		
Room Temp ***	-10 to 5 and 5 to 10 each degree		

* Temperature chamber and autocollimating theodolite
** Autocollimating theodolite
*** Digital autocollimator

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Telescope Servo
Status / Implementation Plans

- **Prototype of analog servo and LVDT pre-amp assembled and tested**
- **Engr Model Servo and LVDT pre-amp assembled**

• **Engr Model testing complete**	**Late May**
• **Engr Model integration complete**	**Mid June**
• **Flight unit fab start**	**Late June**
• **Flight board test complete**	**Late July**
• **Integration with telescope start**	**Mid Sept.**