

1. Overall TCS Telescope Servo Control Electronics

The following is an overall description of the HA axis Servo Control Electronics HA SCE. With the exception of a few component values to accommodate the differences in mass and structural resonance's (compensation network parameters) the DEC axis is identical to the HA axis.

Each telescope axis bull gear is driven by two opposing torque motors. Strictly speaking, each motor is capable of driving the telescope axis (hereafter referred to simply as telescope) in either direction. However, to eliminate motor gear bull gear backlash (anti-backlash), each motor is driven by electronics designed to drive the motor in one direction only; hence the term, "opposing" motors"

Each of the two motors is operated by a dedicated power amplifier (CSR Inc.). These amplifiers are classic switching amplifiers, in that they utilize an alternating polarity square wave with an adjustable duty cycle, to control the equivalent DC current. Their switching frequency is of 20KHz. Internally, these amplifiers sense and filter the instantaneous output current to produce a voltage which is a direct analog of the motor current. This motor current sensing voltage is made available to users as a motor current monitor voltage. In the IRTF TCS, it is used for that purpose and display on the MCC. In addition to providing it for use as an external current monitor, it is also internally compared with an externally generated input command voltage. The difference is then internally used to control a variable duty cycle excitation waveform generator thereby controlling the motor current. Functionally, the amplifier becomes a transconductance amplifier - with a transfer function of 10.5 amps of equivalent output current per volt of input command voltage.

In addition to providing a simple voltage to current conversion capability, the CSR amplifiers are also capable of being used as stand-alone velocity servo controllers. This is because they are equipped with an additional summing amplifier which, when used to difference the input command voltage with an externally generated DC tachometer signal, a velocity control servo amplifier is formed. Note - While this option was not used in the telescope motion control system, it was used in the IRTF's Dome Control System. In that system, one CSR amplifier was configured as a velocity control servo - driving its own dome rotation motor - and the other two other CSR amplifiers were configured as simple transconductance amplifiers - each driving their own motor. In addition driving its motor, the first CSR amplifier (master) delivered its velocity error signal to the transconductance input of the other two CSR amplifiers (slaves).

Each telescope power amplifier is driven by circuitry located on a Tach Summer & Torque CMD Board.

The purpose of this board is to:

- 1) Provide a fixed minimum current or torque command to each power amplifier to prevent backlash.
- 2) Receive a DC tachometer signal from each of the two opposing motor tachometers, scale it, filter it for noise above 723 Hz, and AC couple it (above 3.89 Hz) into a dedicated summing amplifier (one for each motor circuit. It was discovered early on in the development of the TCS, that there existed a significant amount of torsion between a given motor and the bull gear twisting of motor shaft). The simplest method of reducing the affect of this torsion was to create two separate servo loops, one for each motor/tachometer combination in the frequency range where this torsion affect dominates. To accomplish this, at frequencies above 3.89 Hz, each servo loop (axis pusher) used only the tachometer associated with that pusher (motor). In other words, each motor "sees" its own tachometer above 3.89 Hz. Having accomplished this, the two tachs could be safely DC summed to produce a combined tach signal for velocity feedback, provided the individual higher frequency torsional effects were adequately filtered out (velocity error pole at 3.7 Hz).
- 3) Produce a velocity error signal by differencing the summed two tach signals with an analog velocity command signal. This signal is derived on the same board after amplitude and slope limiting.
- 4) Limit the velocity command signal to preset values (including zero for stop commands) corresponding to maximum allowable velocity for tracking and slewing and select these limits under the control of telescope limit switches (slew and stop).
- 5) Limit and control telescope acceleration.
- 6) Precision rectify the processed and limited velocity command signal passed on to the power amplifiers, so that each amplifier is driven by a unipolar signal only. By doing so, its supported motor will be

torqued in one direction only (push – not pull). In other words, both motors push at an anti-backlash level, while only one motor instantaneously pushes harder than the other to produce motion.

The Tach Summer & Torque CMD Board receives telescope velocity command signals from circuitry located on a D/A, Joystick, and Integrator Board. This velocity command signal is a bipolar signal representing a command to move the telescope at a velocity speed of TBD arc-sec per seconds. It can originate in one of several sources. In manual mode, it is ultimately generated by the MCC Joystick. In a computer initiated telescope full slew operations, it is a fixed 10.0 volts (polarity determines the desired direction of motion (west versus east). This 10 volts is clamped (limited by clamping) to lower fixed values on the Tach Summer & Torque CMD Board and what the level is set to is controlled by the status of the telescope limit switches.

The purpose of the D/A, Joystick, and Integrator Board is to:

- 1) Generate an analog position error signal. This error signal is a bipolar analog voltage with a sensitivity of 1.22 mv for each telescope incremental encoder step the telescope's position has deviated from the desired position servo loop null (relative position). To accomplish this, a 26 bit digital up/down counter (Position Error Counter or PEC) – located on a Sequence Control Board – is counted up by commands from the computer and down by telescope position changes signaled by incremental encoder. The least significant 13 bits of the PEC is connected to a digital to analog converter (D/A) which is located on the D/A, Joystick, and Integrator Board. The most significant bit of the PEC is connected to most significant bit of the same D/A.
- 2) The DC position error signal from the D/A is split into two paths, one is simply amplified and HF filtered (Feed-forward path) and the other is connected to an active integrator. The integrator is configured with a slope constant of 6.17 volts per volt and uses an analog reset switch to discharge the integrator and reduce its gain to zero.
- 3) The Feed-forward signal is amplified with a DC gain of 0.84, a pole at 1.6KHz, a zero at 1.93 Hz with a roll-up gain of 9.2. The integrator output is summed with the Feed-forward signal with a DC gain of 0.86. The combined Feed-forward and Integrator signals are then frequency limited using a single pole at 338 Hz.
- 4) In addition to using the PEC D/A signal as an input, during offset or beam switching operations, the Integrator receives pulses of fixed amplitude but varying numbers. These pulses inject charge into the integrator of opposite polarity as is the direction of desired position change. The purpose of these pulses is to reduce overshoot and improve settling time. The number of pulses – and therefore total injected charge is one-for-one equal to the commanded number of steps required for relative position change. In other words, when the telescope is commanded to step 400 steps to the east, there is a delay while the telescope moves to the east. During that time, the integrator integrates the error so that when the telescope finally reaches the desired new position, there is excess charge in the integrator. To remove this charge, there would have to be an overshoot with a negative error. The feed-forwarding pulses inject negative charge into the integrator thereby shortening or eliminating the need for overshoot. NOTE – At first, one might wonder why not simply short out the integrator, as is done during slew operations? Unfortunately, during tracking, the integrator contains the amount of charge necessary to produce an output voltage equal to the value required to track the telescope. To short the integrator, would remove that charge, forcing the telescope to briefly stop and thereby worsening the settling time – not improving it.
- 5) Receive an analog joystick signal from the MCC, scale it, check to see if it exceeds a minimum value (exceeds deadband) before adding it into the velocity command signal.
- 6) Generate precision velocity limit signals for use by the Tach Summer & Torque CMD Board. These limits are ultimately used as clamp levels and include: East and West Slew Velocity Limits and stop limits.

SORRY EVERYBODY, BUT I HAVE RUN OUT OF TIME. HOWEVER, I WILL SLOPPELY TELL YOU (FOR NOW) THAT ON THE Tach Summer & Torque CMD Board:

- 1) Z4 and Z6 are simple summing amps which add in the adjustable anti-backlash pre-loads. They also limit the maximum voltage which may be sent to the CSRs. Zeners ZD11,12,15, and 16 accomplish this. Note that they are inside the Z4 and Z6 feedback loops.
- 2) Z3 and Z5 are precision rectifiers. Z3 produces only positive voltages and Z5 produces only negative.
- 3) Z2 and Z1 differentially receive their respective DC tachometers, scale them down (5:1), filter them for hash (723Hz) and AC couple them to Z3 and Z5 respectively. SORRY AGAIN! HAVE TO QUIT – NOTE HOWEVER THE POLE_ZERO COMBINATION ON THE INPUTS OF Z3 and Z5. WILL HAVE MORE TO SAY ON THIS WHEN I RETURN.
- 4) Z13 sums the two tach signals and rolls them off at 3.7 Hz
- 5) Z9,Z10,Z11,and Z12 can be thought of as being equivalent to a single operational amplifier with a well defined slew limit. Z9,Z10,Z11,and Z12 form an amplifier with a DC Gain of -1 . Should a saturating input voltage be applied to this circuit, a smooth, well defined ramp of either 1.0 or 1.5 volts per second is produced and is selected by analog switch Z17. The slow one is for slewing, while the faster one is for offset stepping or beam switching. Z10 forms an inverting amplifier with a gain of 1,000 and is clamped to the zener values of ZD17 and ZD18. The output is fed to a precision limiter, also with a gain of 1,000. This clamp value is 3.1 volts. The precision output (3.1 max) is then connected to an integrator Z12. If input signals into R61 are small (as is during tracking) the circuit behaves like a simple amplifier with a closed loop gain of -1 . Should the input not be small, as is during large steps or slewing, the velocity command will be a fixed and well defined slope (acceleration).
- 6) Z7,Z8 and Z9 form a precision clamp circuit. East and West Limit Reference voltages brought in from the D/A, Joystick, and Integrator Board via pins AT2 and AV2 respectively. They limit the output of Z9 to them. Hence, when a telescope West Slew Limit Switch is encountered, the West Limit Reference Voltage is lowered on the D/A, Joystick, and Integrator Board and the output of Z9 is limited to that value ...NEEDS VERIFICATION ... AGAIN NO TIME.. If a West Stop Limit Switch is encountered, the Z9 drops to zero.

THAT'S IT!!! HAVE TO GO ---BY BY

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