REVISION BLOCK			
REV	DESCRIPTION	DATE	INCORP. BY

OVERVIEW

The goal of this document is to present the TCS1 control system in a clear and understandable way and to derive the transfer functions to be used in SIMULINK.
This document format combines notes, graphs, plots, graphics, etc. all on one page. It is not a traditional report style format.

The method used to present this material was to:
1) Present a hybrid block diagram of the entire system on one page. The block is not 100% mathematically or functionally correct. It is meant to present the system in an understandable way.
2) Explore each block or group of blocks, understand the function, and derive the transfer function for use in SIMULINK.

NOTE: Because of the way the blocks are implemented physically (e.g. inverting summer amplifier) the negative signs on some transfer functions may not show up in the SIMULINK model. For example, an inverting summing amplifier followed by an inverting amplifier with a gain of -1 can be simply shown as a simple summer. SO, keep in mind that if a negative sign is dropped, either the input has already been inverted into the block or its output will be inverted in the next block.

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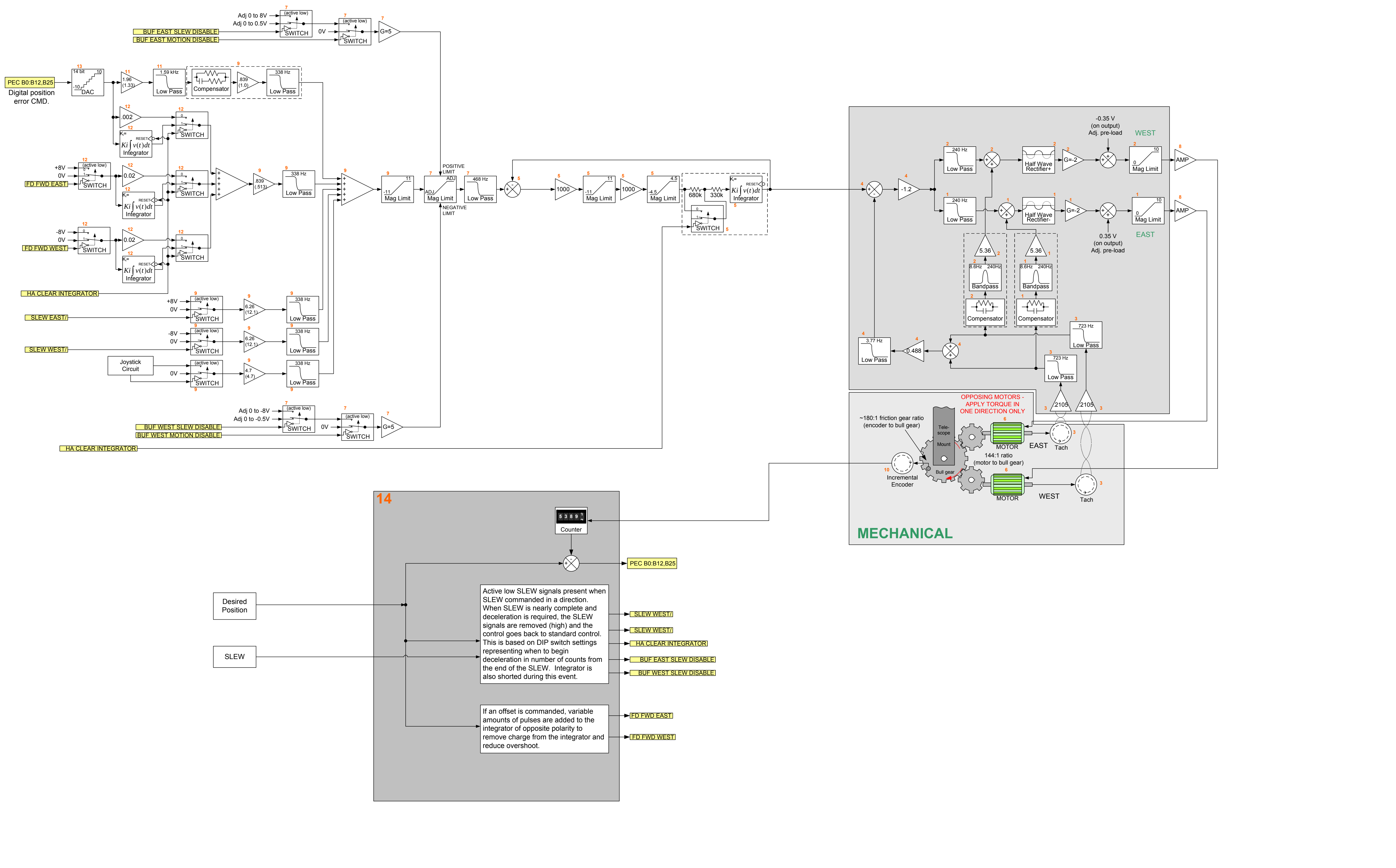
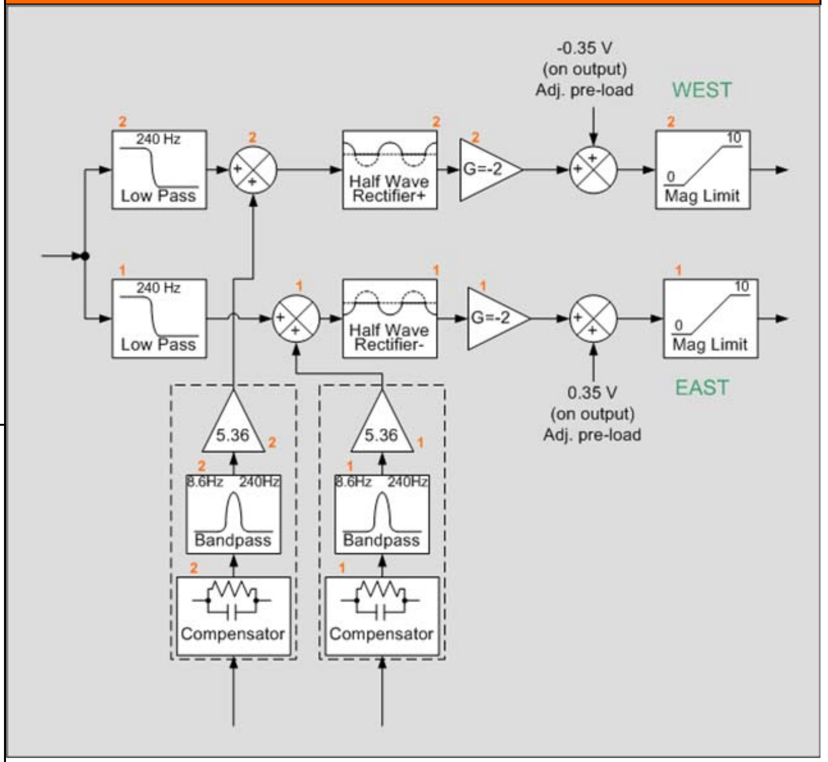


DWG #	REV	SIZE	SHEET
TCS1-CBD	-	D	2 of 25

BLOCK GROUP #1 & #2



Inverting Amp with low pass.
Gain =-300k/100k
=-3
f(-3dB) =1/(2πRC)
=1/(2π*300k*2200pF)
=240 Hz

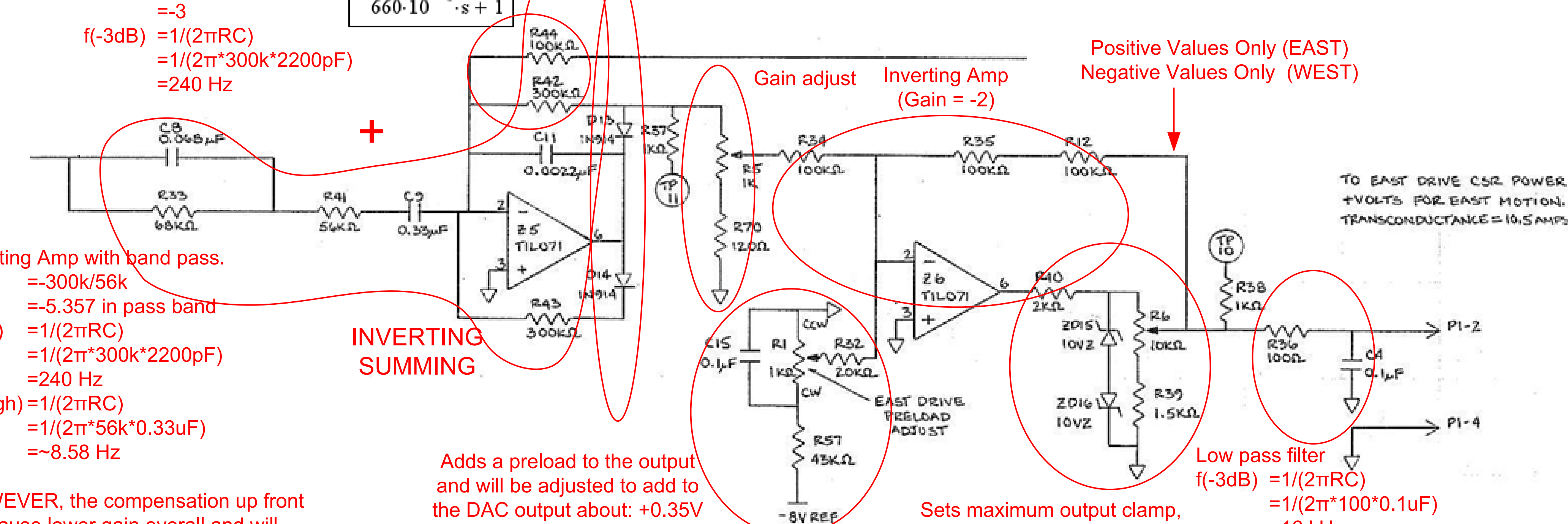
$$-\frac{3}{660\cdot10^{-6}\cdot s+1}$$

Half Wave Rectifier Output EAST=negative output (positive for WEST)

Gain adjust

Inverting Amp
(Gain = -2)

Positive Values Only (EAST)
Negative Values Only (WEST)



Inverting Amp with band pass.
Gain =-300k/56k
=-5.357 in pass band
f(low) =1/(2πRC)
=1/(2π*300k*2200pF)
=240 Hz
~f(high) =1/(2πRC)
=1/(2π*56k*0.33uF)
=~8.58 Hz

INVERTING SUMMING

Adds a preload to the output and will be adjusted to add to the DAC output about: +0.35V (East) or -0.35 (West).

Sets maximum output clamp, which must be less than the series Zeners, or ~10.7V.

Low pass filter
f(-3dB) =1/(2πRC)
=1/(2π*100*0.1uF)
=16 kHz

This is really high compared to 240 Hz upstream filter. This is for high frequency electronic noise induced or picked up.

HOWEVER, the compensation up front will cause lower gain overall and will cause additional lower gain at lower frequencies. Also, filter is not a "brick wall" filter. Pass band will have lower gain than calculated as the simulation illustrates..

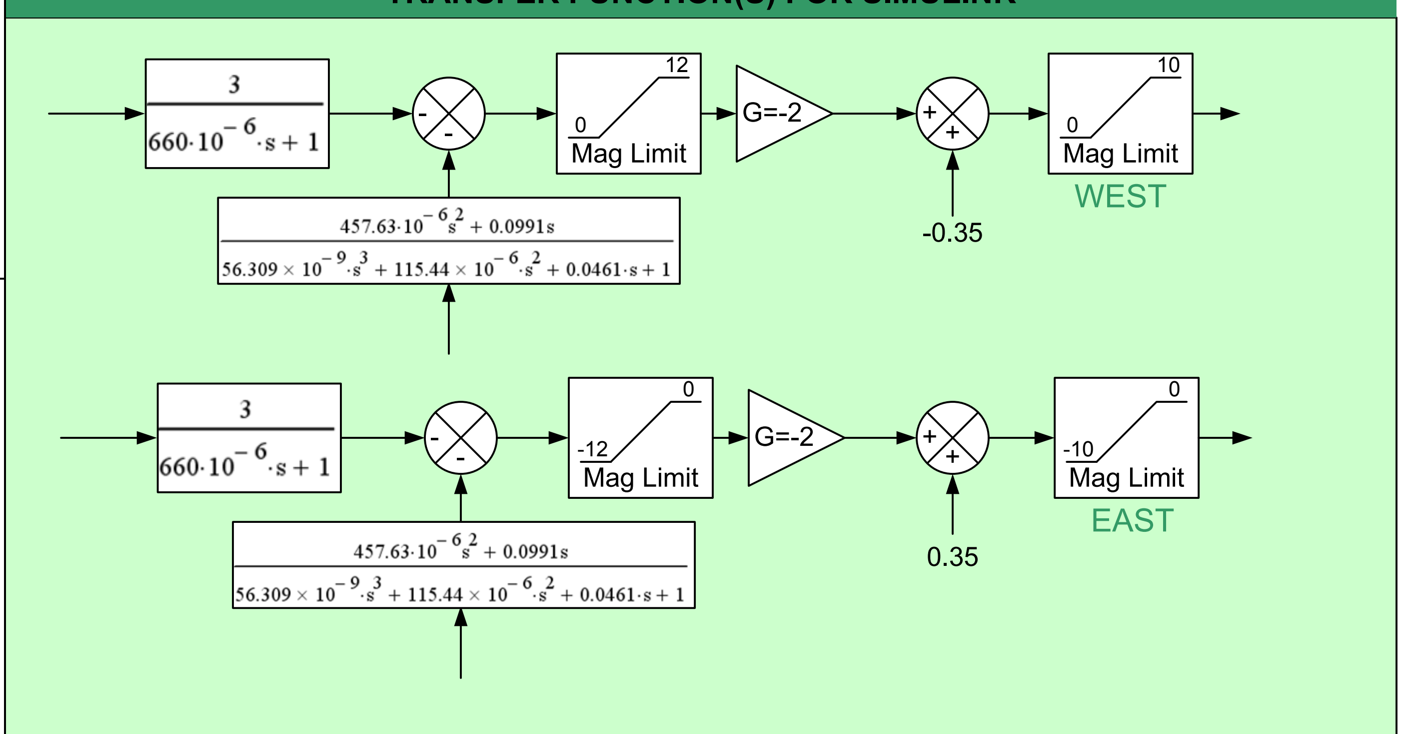
$$-\frac{457.63\cdot10^{-6}\cdot s^2+0.0991 s}{56.309\times10^{-9}\cdot s^3+115.44\times10^{-6}\cdot s^2+0.0461\cdot s+1}$$

ACTUAL GAIN
(input signal is 1V)

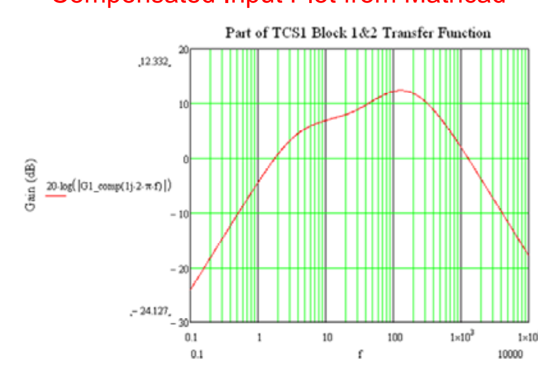
Measurement Cursors

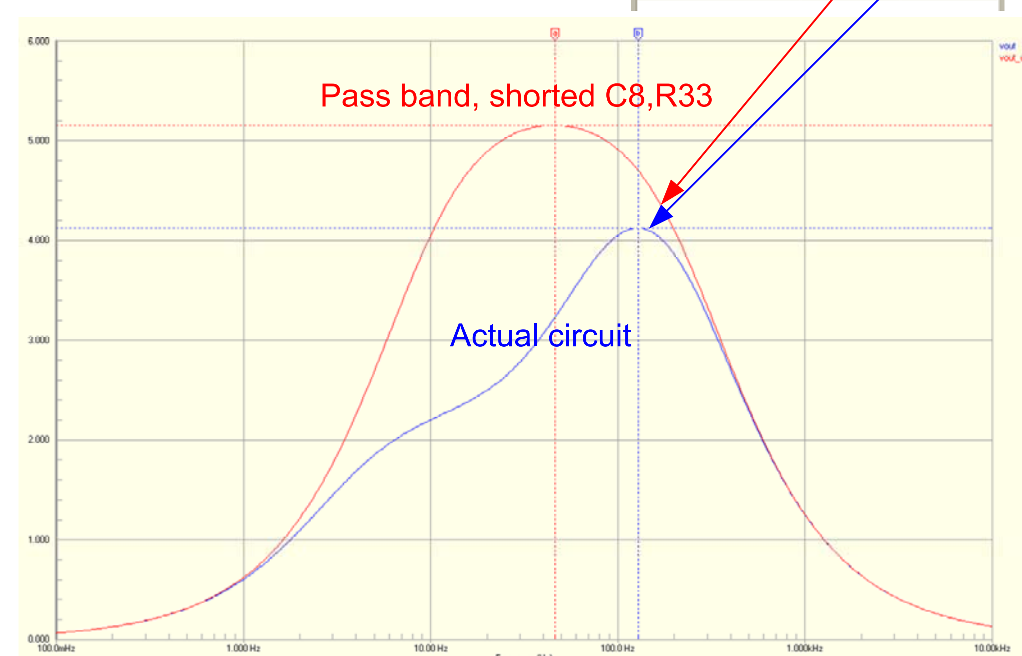
	Wave Name	X	Y
A	vout_uc	46.302	5.1543
B	vout	128.16	4.1240
	Measurement	X	Y
B - A		81.854	-1.0303

TRANSFER FUNCTION(S) FOR SIMULINK

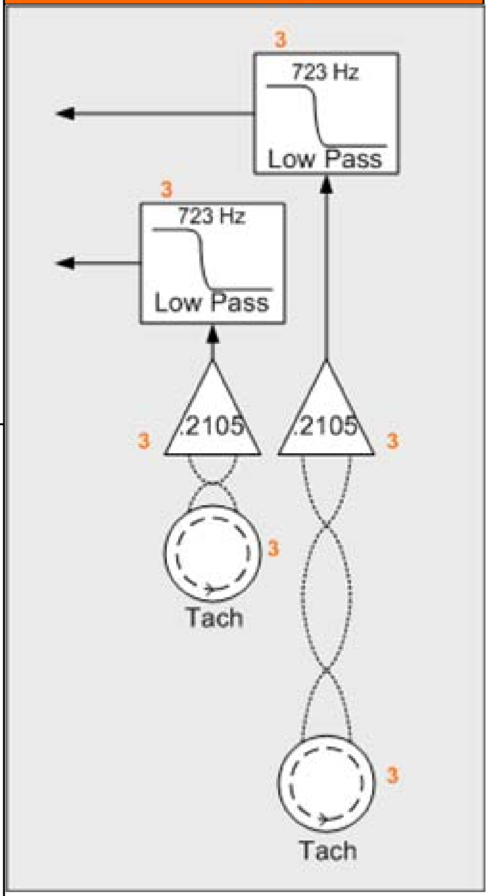


Compensated Input Plot from Mathcad





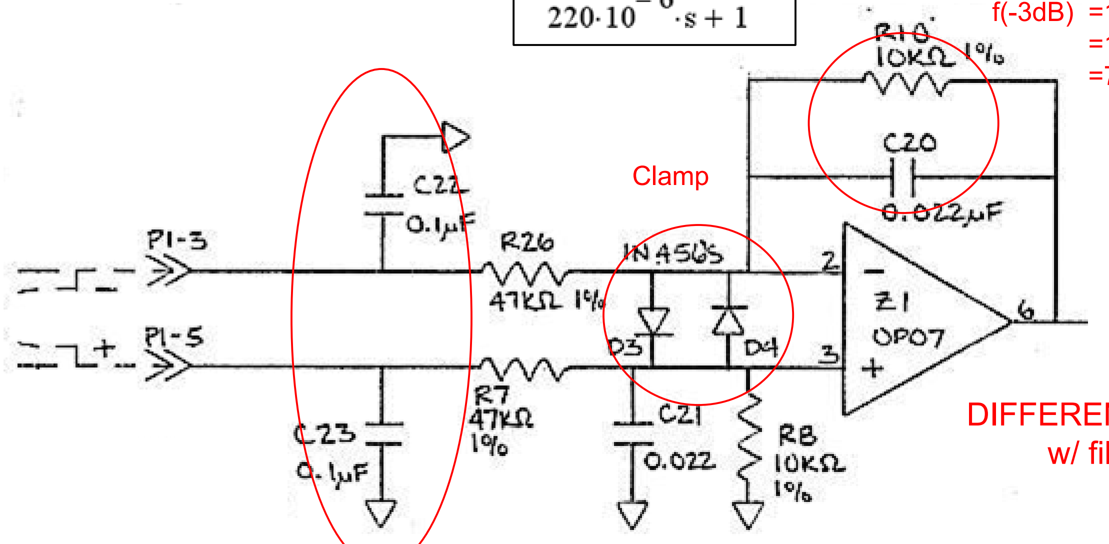
BLOCK GROUP #3



Identical amplifier input stage for EAST & WEST.

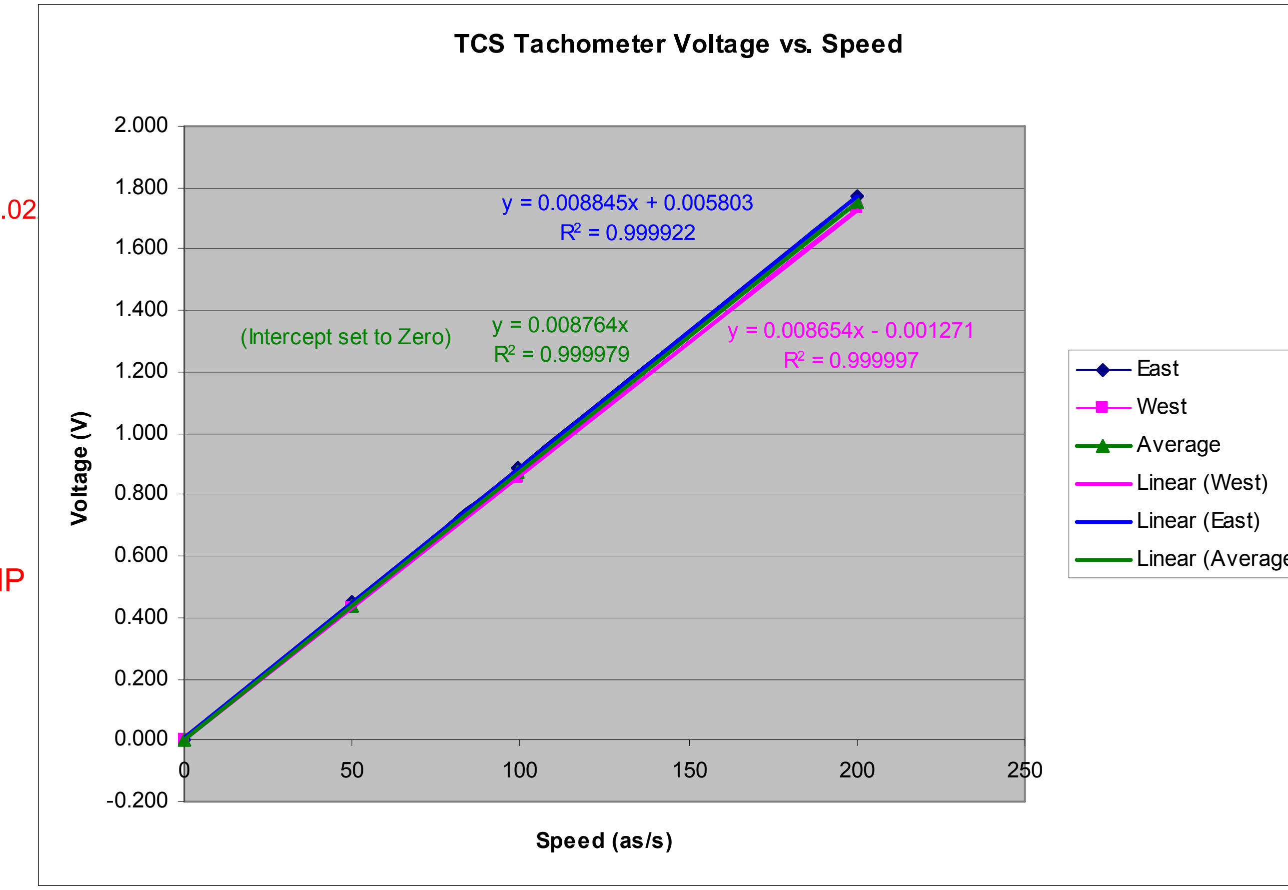
$$-\frac{0.213}{220\cdot 10^{-6}\cdot s+1}$$

Gain= Rf/Rs
10k/47k
0.213
f(-3dB) =1/(2πRC)
=1/(2π*10k*0.02
=723 Hz



DIFFERENTIAL AMP
w/ filtering

Very high frequency passive filtering
f(-3dB) =1/(2πRC)
Where R is the line + source impedance
which is low.



For the tachometer rad/s to volt conversion:

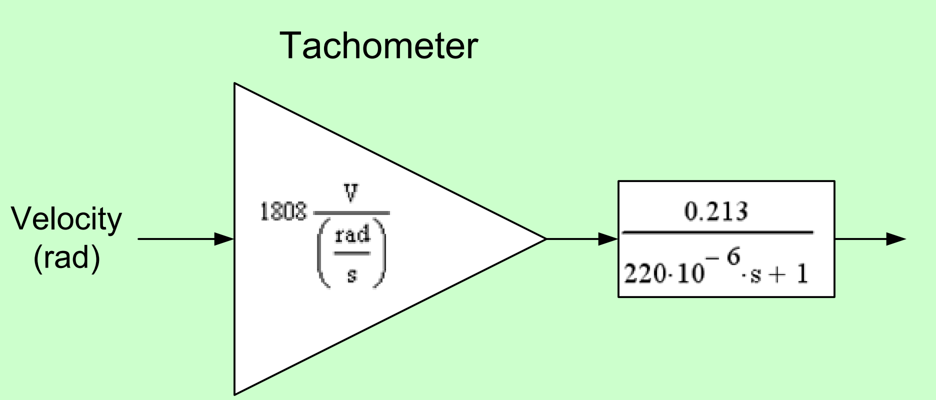
$$Tach=\frac{V}{arc\sec/s}\cdot\frac{arc\sec/s}{rad/s}$$

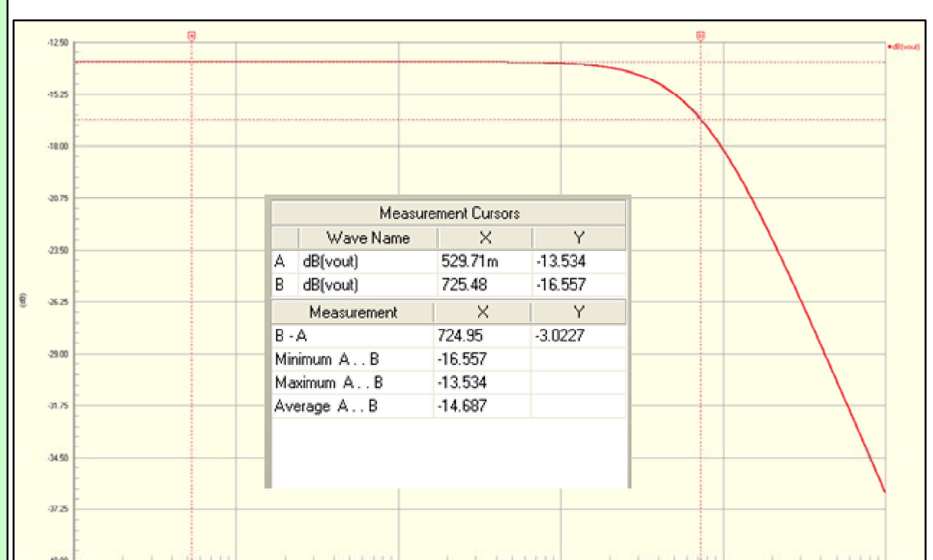
$$Tach=\frac{0.008764V}{arc\sec/s}\cdot\frac{206264.81arc\sec/s}{rad/s}$$

$$Tach=\frac{1807.704V}{rad/s}$$

NOTE:
This conversion is from TELESCOPE axis rotational velocity to volts. The mechanical model in SIMULINK provides axis velocity in rad/s at each motor geared output (after the 1:144 ratio).

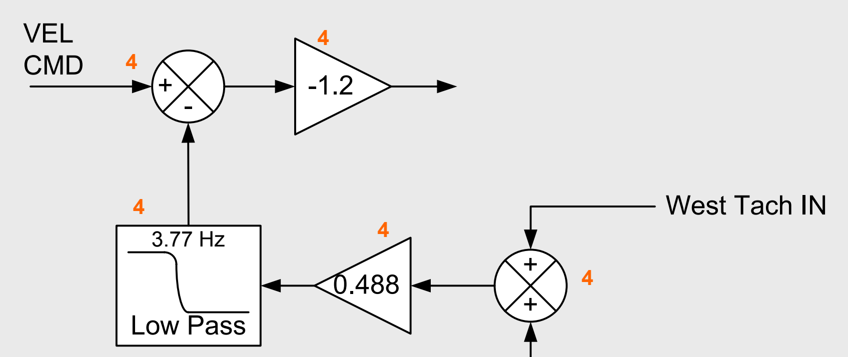
TRANSFER FUNCTION(S) FOR SIMULINK

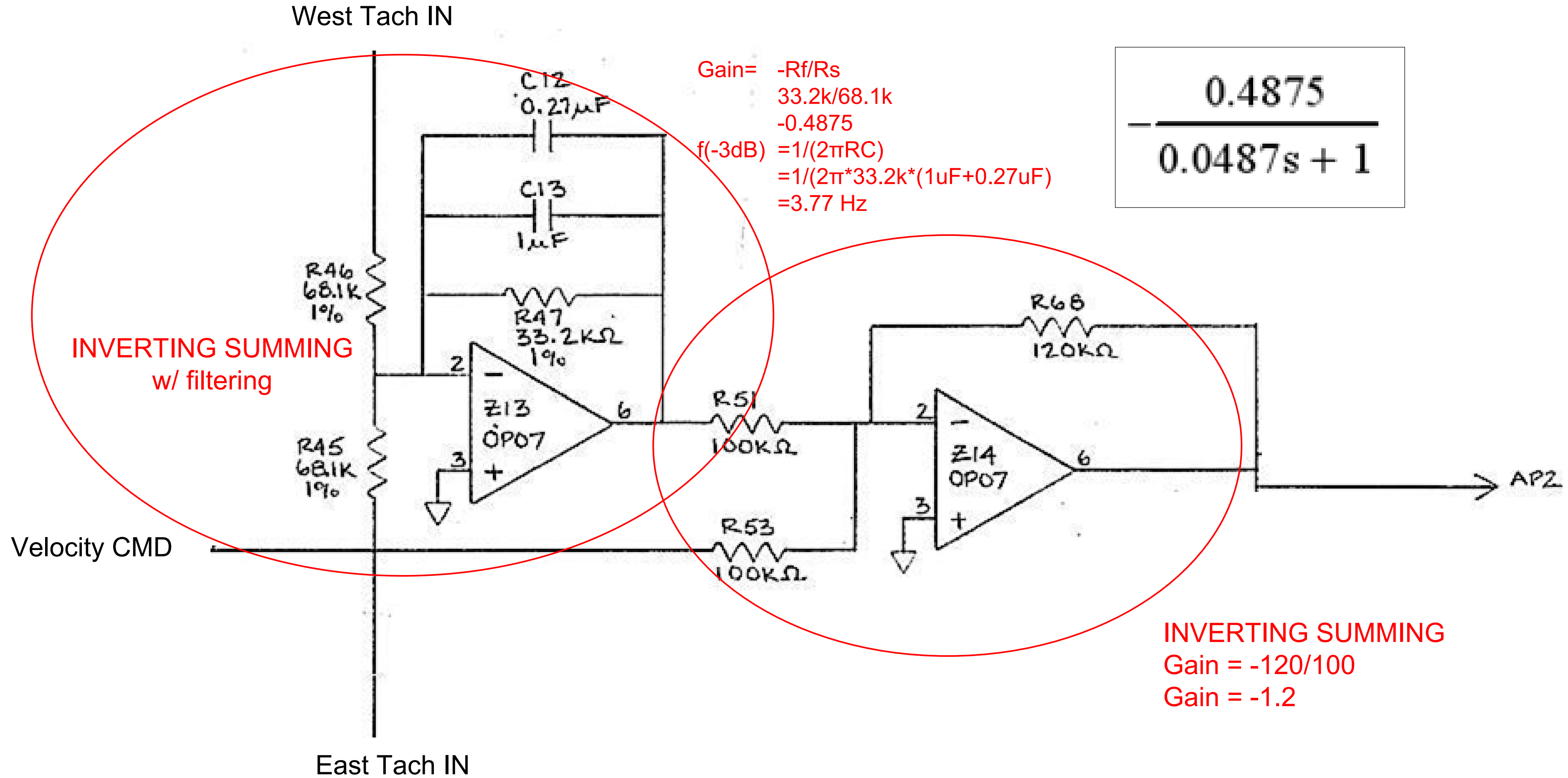




Measurement Cursors			
	Wave Name	X	Y
A	dB(vout)	529.71m	-13.534
B	dB(vout)	725.48	-16.557
	Measurement	X	Y
B - A		724.95	-3.0227
Minimum A .. B		-16.557	
Maximum A .. B		-13.534	
Average A .. B		-14.687	

BLOCK GROUP #4

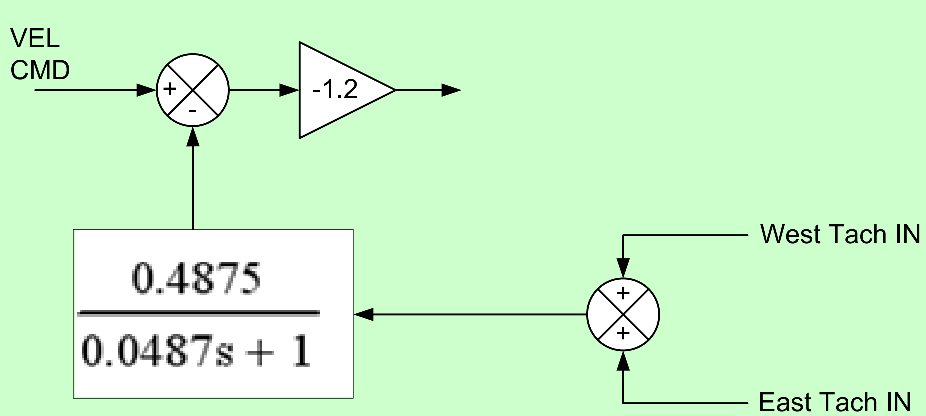




$$-\frac{0.4875}{0.0487s+1}$$

<u>By adding together ~½ of two individual signals, the output is approximately the average.</u>

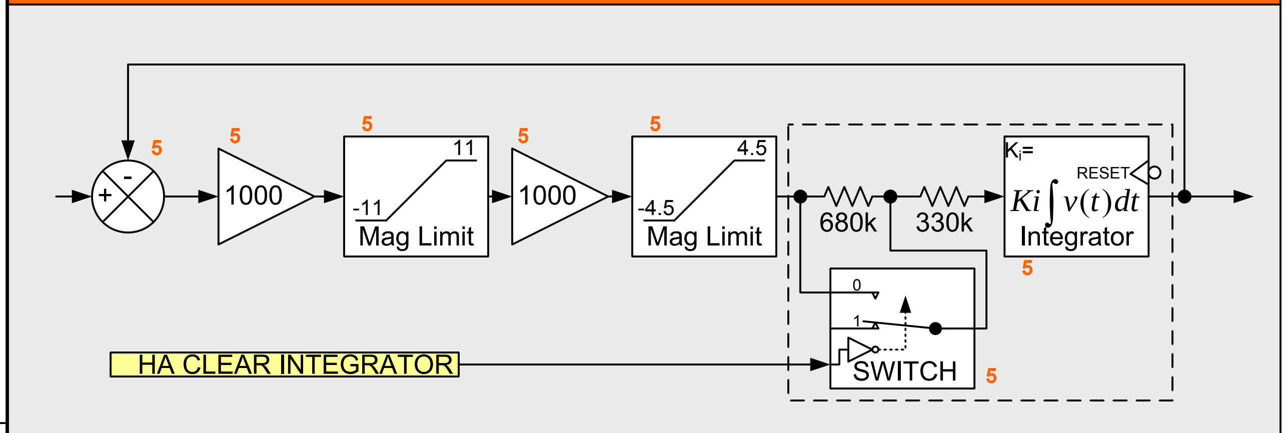
TRANSFER FUNCTION(S) FOR SIMULINK



NOTE: Be careful with the polarity signs here. The equation will be worked through to demonstrate the polarities.

$$Vout = 1.2\cdot(-VCMD - Vsum\_amp)$$
$$Vout = 1.2\cdot(-VCMD - (-0.4875\cdot(Etach + Wtach)))$$
$$Vout = 1.2\cdot(-VCMD + 0.4875(Etach + Wtach))$$
$$Vout = -1.2(VCMD - 0.4875(Etach + Wtach))$$

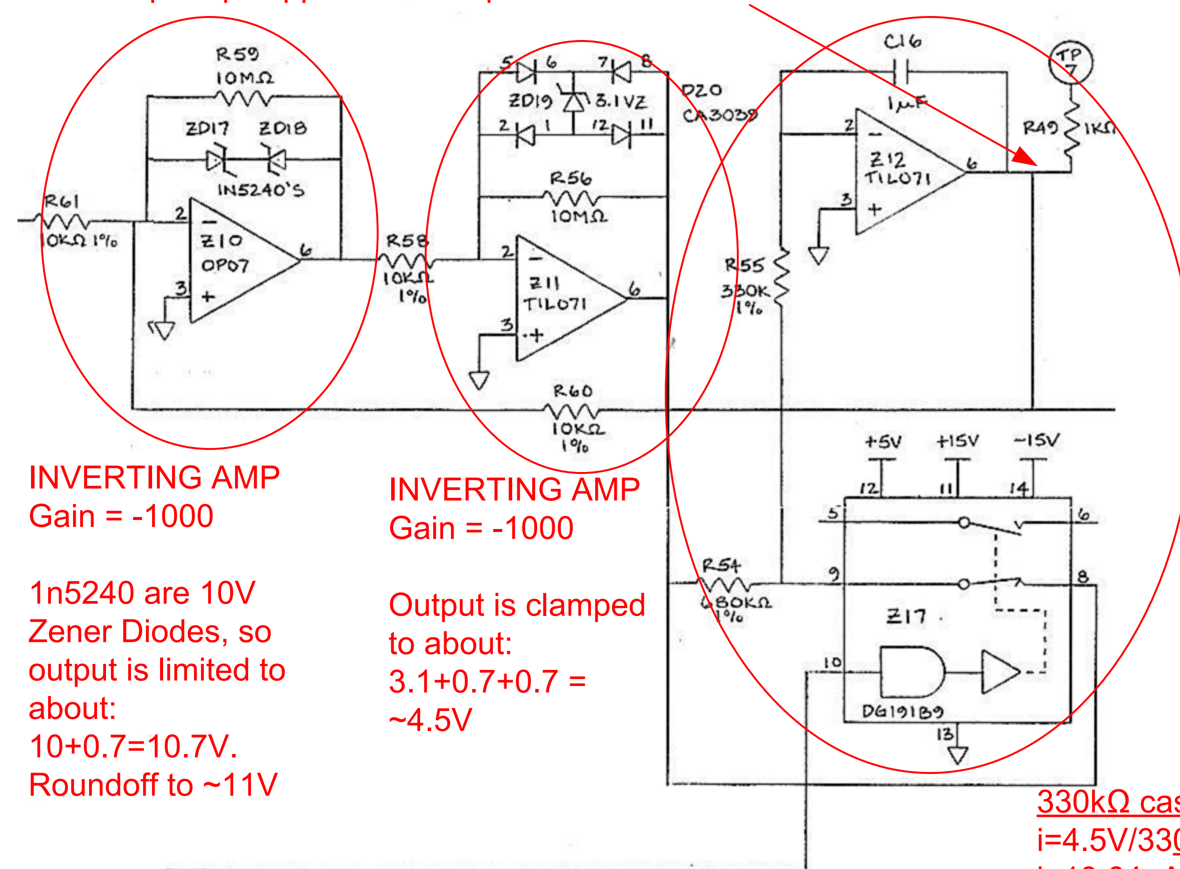
BLOCK GROUP #5



Notice the feedback and high gain of a million.
This can be represented as a slew limited amplifier with a gain of +1.

This circuit functions as an acceleration limiter.

Op-amp supplies limit output to about +/- 12V.



INVERTING AMP
Gain = -1000

1n5240 are 10V Zener Diodes, so output is limited to about:
10+0.7=10.7V.
Roundoff to ~11V

INVERTING AMP
Gain = -1000

Output is clamped to about:
3.1+0.7+0.7 = ~4.5V

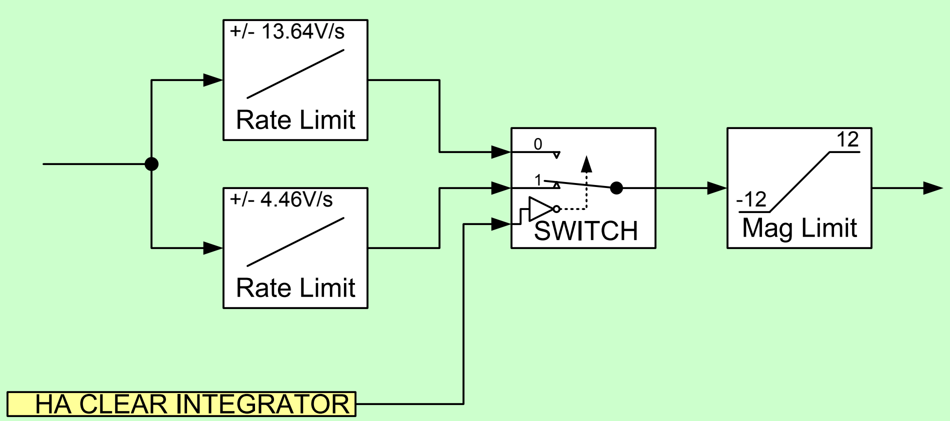
INTEGRATOR
Since the input to the integrator will always be either +/-4.5V due to the total gain of 1 million and the clamping diodes, the current going into the integrator will always be +/- a constant value (4.5V/resistor) and the result is a signal with a +/- constant slope. This slope is change in velocity, which is acceleration.
The integrator uses a capacitor.
Where the capacitor voltage change over time:
i=Cdv/dt
i/C=dv/dt

Therefore:

330kΩ case:
i=4.5V/330kΩ
i=13.64μA
dv/dt=13.64μA/1μF
dv/dt=13.64V/s

1010kΩ case:
i=4.5V/1010kΩ
i=4.46μA
dv/dt=4.46μA/1μF
dv/dt=4.46V/s

TRANSFER FUNCTION(S) FOR SIMULINK

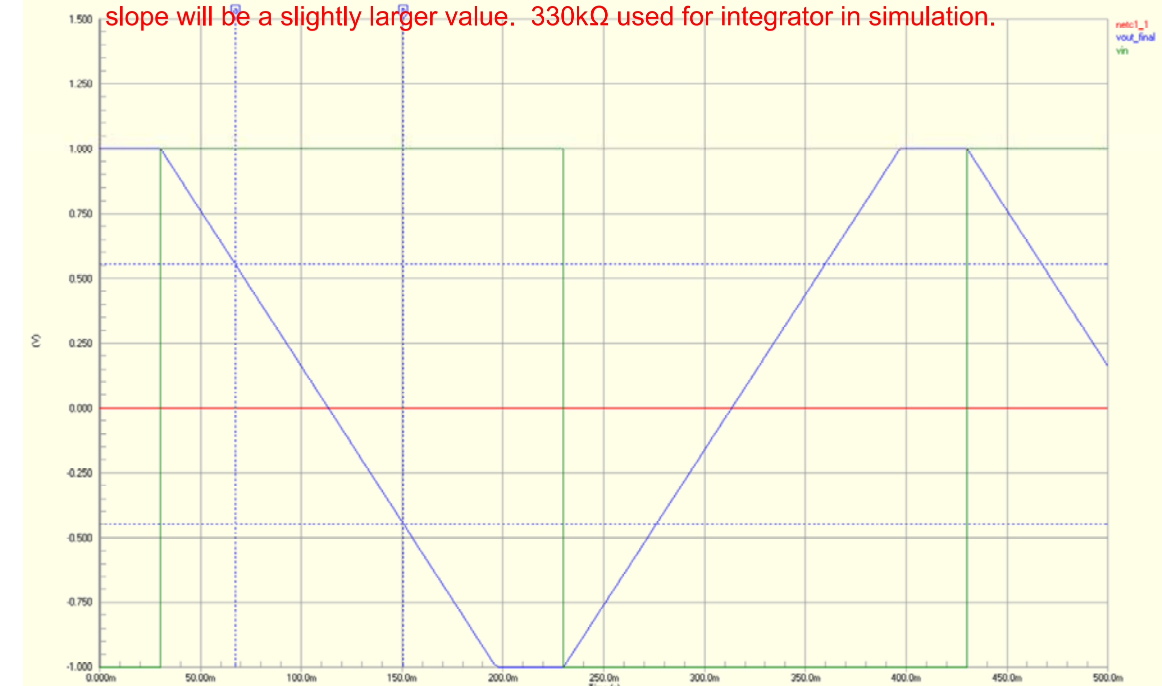


Results,

330kΩ simulation:
dv/dt=-1V/83.5ms
dv/dt=~12V/s

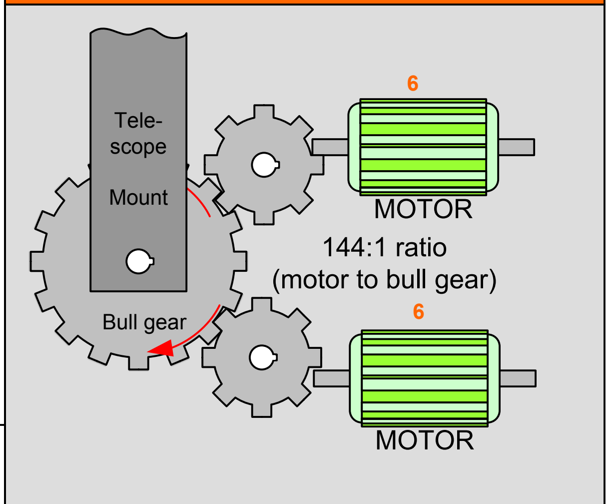
Measurement Cursors			
	Wave Name	X	Y
A	vout_final	67.135m	554.81m
B	vout_final	150.68m	-446.84m
	Measurement	X	Y
B - A		83.547m	-1.0017

NOTE: In this simulation the first stage was unclamped (it just saturated) and a 3.3V (1n746A) Zener was used. The result will be nearly identical with the exception that the slope will be a slightly larger value. 330kΩ used for integrator in simulation.



DWG # TCS1-CBD | REV - | SHEET 6 of 25

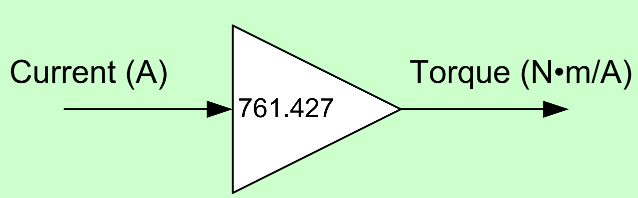
BLOCK GROUP #6



The motors are driven by a current amplifier. The output of the motor has a 144:1 gear ratio to the HA Axis. Since the motor is driven by a current drive amplifier, the equations for the torque involve the torque constant of the motor, current, and gear ratio. The back EMF produced by the motor is used as feedback for the amplifier in the amplifier model. The back EMF reduces the maximum current output of the amplifier. See the amplifier section for more details. See next page for motor datasheet and parameter values.

Imai measured 1Ω and 1.3Ω across the motors at the junction box with the amplifiers off but still connected on 11/2/07. This suggests "A" version of motor.

TRANSFER FUNCTION(S) FOR SIMULINK



ORIGINAL, Model 12016A

MOTOR TORQUE

$$Torque = IK_T \cdot Gear\_Ratio$$

$$Torque = I\left[3.90\frac{lb\cdot ft}{A}\right]\cdot(144)$$

$$Torque = I\left[561.6\frac{lb\cdot ft}{A}\right]$$

$$Torque = I\left[561.6\frac{lb\cdot ft}{A}\right]\cdot\left[\frac{1.355817952\ \mathrm{N\cdot m}}{lb\cdot ft}\right]$$

$$Torque = I\cdot\frac{761.427N\cdot m}{A}$$

MOTOR IMPEDANCE (@25C)

$$Z_{motor} = Z_{L\_winding} + R_{winding}$$

$$Z_{motor} = s(0.008)\Omega + 0.97\Omega$$

BACK EMF (used in amplifier section)

$$Back\_EMF = \theta_M \cdot K_b$$

$$Back\_EMF = \theta_M \cdot 5.30\frac{V}{rad/s}$$

SPARE, Model 12016A

$$Torque = IK_T \cdot Gear\_Ratio$$

$$Torque = I\left[12.8\frac{lb\cdot ft}{A}\right]\cdot(144)$$

$$Torque = I\left[1843.2\frac{lb\cdot ft}{A}\right]$$

$$Torque = I\left[1843.2\frac{lb\cdot ft}{A}\right]\cdot\left[\frac{1.355817952\ \mathrm{N\cdot m}}{lb\cdot ft}\right]$$

$$Torque = I\cdot\frac{2499.04N\cdot m}{A}$$

MOTOR IMPEDANCE (@25C)

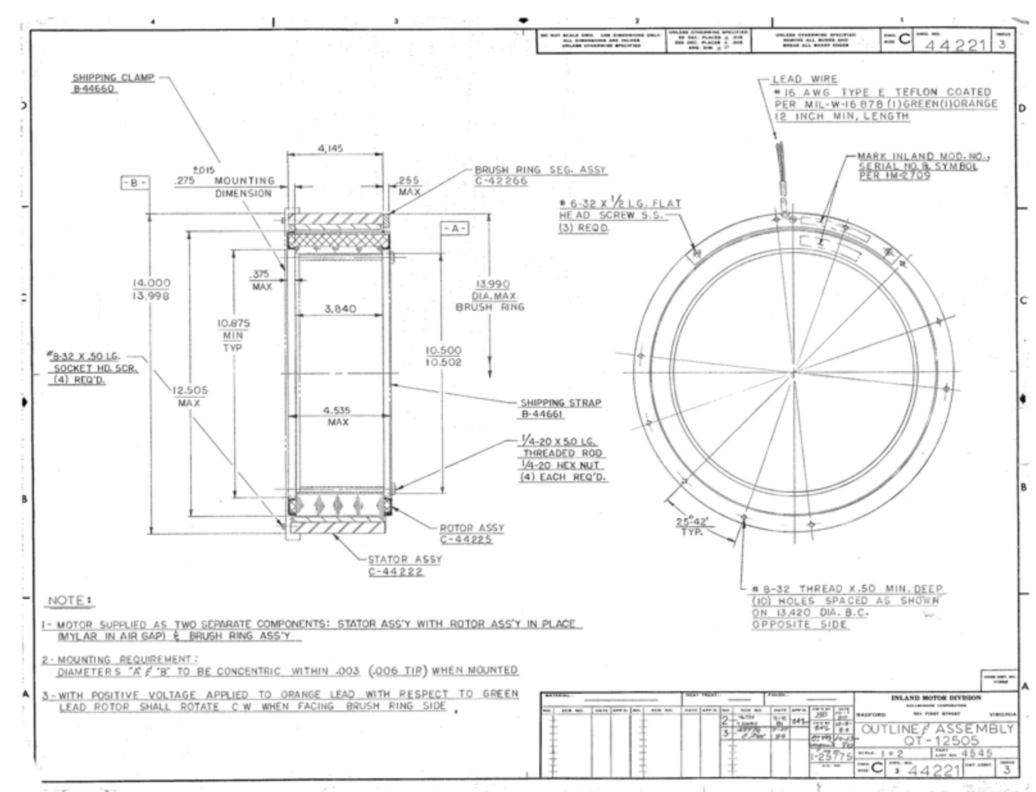
$$Z_{motor} = Z_{L\_winding} + R_{winding}$$

$$Z_{motor} = s(0.017)\Omega + 0.4.50\Omega$$

BACK EMF (used in amplifier section)

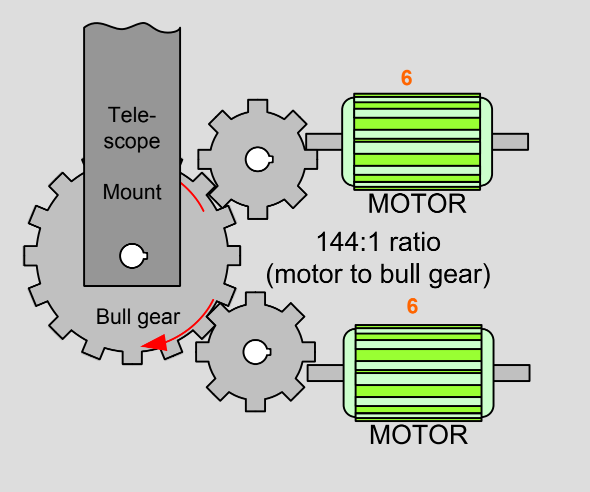
$$Back\_EMF = \theta_M \cdot K_b$$

$$Back\_EMF = \theta_M \cdot 17.4\frac{V}{rad/s}$$



DWG #	REV	SHEET
TCS1-CBD	-	7 of 25

BLOCK GROUP #6 CONTINUED



CURRENT MOTOR IN USE

INLAND MOTOR DIVISION — KOLLMORGEN CORPORATION

TORQUER CATALOG DATA SHEET

BY: R F DUGAN — DATE: 03/18/70
CHECKED BY: BPO — DATE: 03/19/70
MODEL T-12016
CD 5626
ISSUE 2

MOTOR SIZE CONSTANTS	UNITS	SYMBOL	VALUE
Peak Torque	lb-ft	Tp	200
Motor Constant	lb-ft/√W	Km	3.90
Electical Time Constant	ms	τE	8.50
Mechanical Time Constant	ms	τM	23.0
Power In Stalled At Pk Tq 25°C	watts	Pp	2600
Viscous Damping — Zero Z Source	lb-ft r/s	Fo	21.6
Viscous Damping — Inf.Z Source	lb-ft r/s	Fi	0.0900
Motor Friction Torque	lb-ft	Tf	1.000
Ripple Torque Ave. to Peak	percent	TR	2.00
Ripple Cycles Per Rev	cycles/rev	--	197
Ultimate Temp. Rise Per Watt	deg C	TPR	0.200
Max Permissible Winding Temperature	deg C	-	105
Rotor Moment of Inertia	lb-ft-s²	Jm	0.500
Max Power Rate	lb-ft/s²	P	80000
Max Theoretical Accel	rad/s²	αM	400
No Load Speed Theor @ Vp	rad/s	ωNL	9.30
Motor Weight	lb	-	194

Slots	99	A	5N(19X3)	WD	713
Bars	197	B	9N17	WD	1118
Poles	14	C		WD	
M.L. Rotor	3.50	D		WD	
M.L. Stator	7.31	E		WD	
Φ/Pole	0	F		WD	
MLT	1.18	G		WD	
Rad. Gap	0.0500	H		WD	
No. Brush	8.00				
Type Brush	CART	SAME AS T-12008 EXCEPT MOUNTING			
Brush Area	0	FLANGE/ROTOR HUB.			
Magnet Mat	AL5				
Rotor O.D.	12.0				
Rotor I.D.	99.0				
Stator O.D.	19.0				
Stator I.D.	12.1				
Overall Width	7.50				

NOTE
These data to be blanked out before going out to a customer or representative

WINDING CONSTANTS	UNITS	TOL	SYMBOL	A	B	C	D	E	F	G	H
DC Resistance(25°C)	ohms	±12%	Rm	0.970	3.10						
Volts @ Pk Torque (25°C)	volts	nom	Vp	50.0	87.5						
Amps at Peak Torque	amps	rated	Ip	51.5	28.2						
Torque Sensitivity	lb-ft/amp	±10%	Kt	3.90	7.10						
Back EMF	Vper rad/s	±10%	Kb	5.30	9.63						
Inductance	mH	±30%	LM	8.00	26.0						

Imai measured 1Ω and 1.3Ω across the motors at the junction box with the amplifiers off but still connected on 11/2/07. This implies model "A".

NO.	ECN NO.	DATE	APP'D

NO.	ECN NO.	DATE	APP'D

NO.	ECN NO.	DATE	APP'D

SPARE MOTOR

JUN 06 2001 17:07 FR KOLLMORGEN 540 731 4193 TO 18089744212 P.02/04
** TOTAL PAGE.04 **

INLAND MOTOR DIVISION — KOLLMORGEN CORPORATION

TORQUER CATALOG DATA SHEET

BY: C WYNN — DATE: 10/13/80
CHECKED BY: CRW — DATE: 10/14/80
MODEL QT-12505
CD 11441
ISSUE B

MOTOR SIZE CONSTANTS	UNITS	SYMBOL	VALUE
Peak Torque	lb-ft	Tp	200
Motor Constant	lb-ft/√W	Km	6.04
Electical Time Constant	ms	τE	3.78
Mechanical Time Constant	ms	τM	5.50
Power In Stalled At Pk Tq 25°C	watts	Pp	1095
Viscous Damping — Zero Z Source	lb-ft r/s	Fo	49.5
Viscous Damping — Inf.Z Source	lb-ft r/s	Fi	0.300
Motor Friction Torque	lb-ft	Tf	1.60
Ripple Torque Ave. to Peak	percent	TR	2.00
Ripple Cycles Per Rev	cycles/rev	--	139
Ultimate Temp. Rise Per Watt	deg C	TPR	0.100
Max Permissible Winding Temperature	deg C	-	155
Rotor Moment of Inertia	lb-ft-s²	Jm	0.270
Max Power Rate	lb-ft/s²	P	148000
Max Theoretical Accel	rad/s²	αM	740
No Load Speed Theor @ Vp	rad/s	ωNL	4.00
Motor Weight	lb	-	67.0

Slots	139	A	15N20	WD	2792
Bars	139	B	11N18.5	WD	4467
Poles	28	C		WD	
M.L. Rotor	3.84	D		WD	
M.L. Stator	4.15	E		WD	
Φ/Pole	0	F		WD	
MLT	0.927	G		WD	
Rad. Gap	0.0300	H		WD	
No. Brush	4.00				
Type Brush	SGR	SAME AS QT-12501 EXCEPT STACK AND			
Brush Area	0	RATING.			
Magnet Mat	18MGO	IP @ 131 CMILS/A			
Rotor O.D.	12.5				
Rotor I.D.	10.5				
Stator O.D.	14.0				
Stator I.D.	12.6				
Overall Width	4.48				

NOTE
These data to be blanked out before going out to a customer or representative

WINDING CONSTANTS	UNITS	TOL	SYMBOL	A	B	C	D	E	F	G	H
DC Resistance(25°C)	ohms	±12%	Rm	4.50	2.33						
Volts @ Pk Torque (25°C)	volts	nom	Vp	70.2	49.6						
Amps at Peak Torque	amps	rated	Ip	15.6	21.3						
Torque Sensitivity	lb-ft/amp	±10%	Kt	12.8	9.39						
Back EMF	Vper rad/s	±10%	Kb	17.4	12.7						
Inductance	mH	±30%	LM	17.0	9.10						

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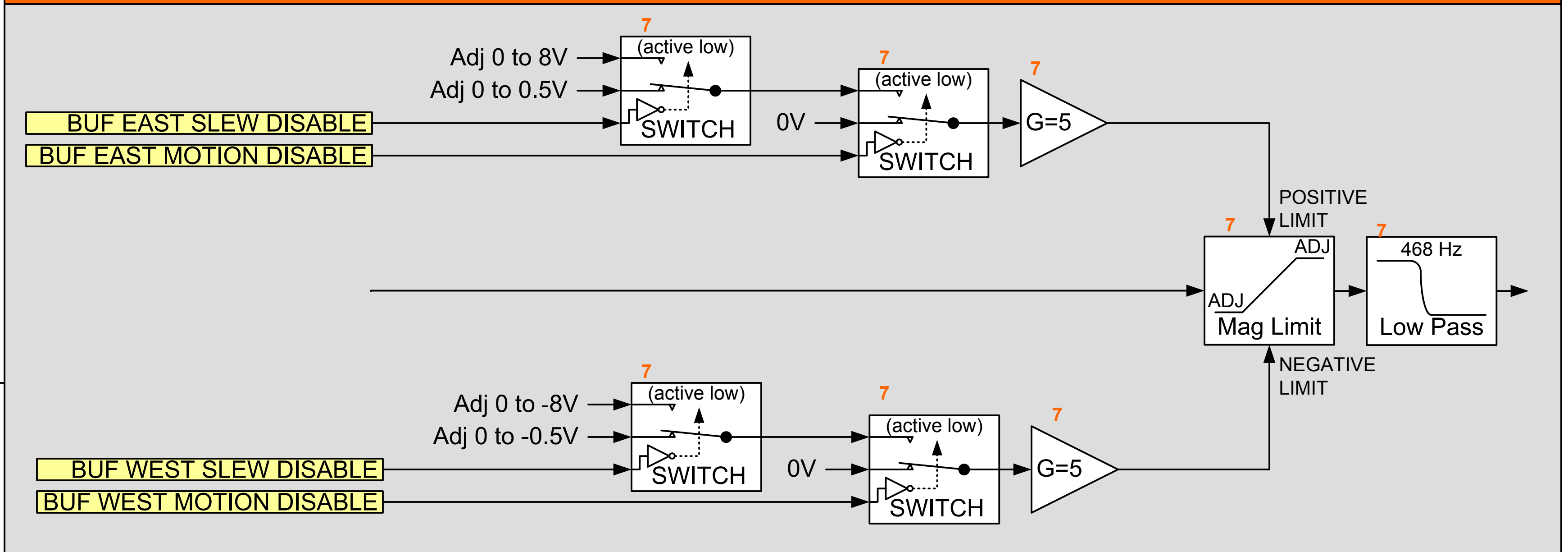
BLOCK GROUP #7



This is just a selectable magnitude limiter with a filter.
The "BUF MOTION DISABLE" can be ignored since it is a personnel safety feature, which isn't part of the servo analysis.
Also, it can be assumed that EAST and WEST slewing will have equal magnitude limiting.

INVERTING Summing AMP with half wave rectifier.
Only <u>positive</u> outputs allowed.

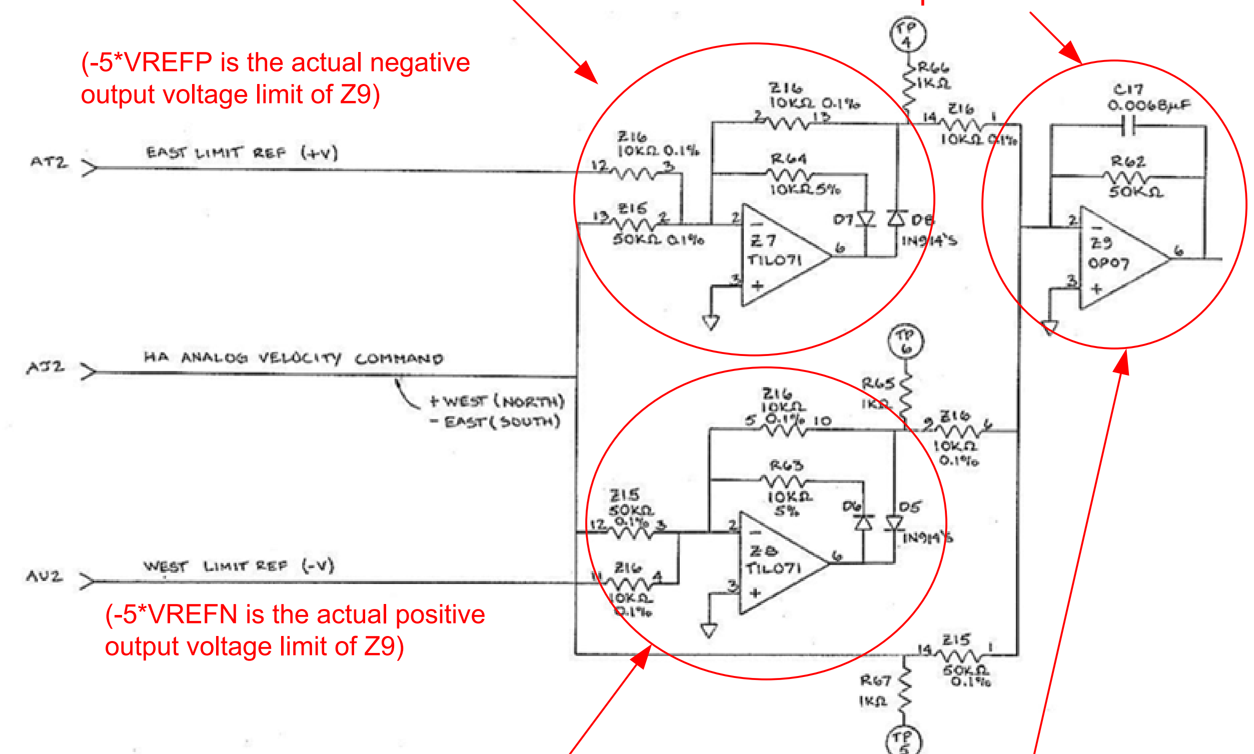
Op-amp equation when Vcmd is ≤ -5*Vrefp:
Vout=-Vrefp-0.2*Vcmd

Else, Vout=0.

INVERTING summing amp.
This stage subtracts the exact amount from the command that is required to clip it and keep it within 5*ref voltage .
The final result is the inverted value.

It also provides a filter.

(-5*VREFP is the actual negative output voltage limit of Z9)



(-5*VREFN is the actual positive output voltage limit of Z9)

INVERTING Summing AMP with half wave rectifier.
Only <u>negative</u> outputs allowed.

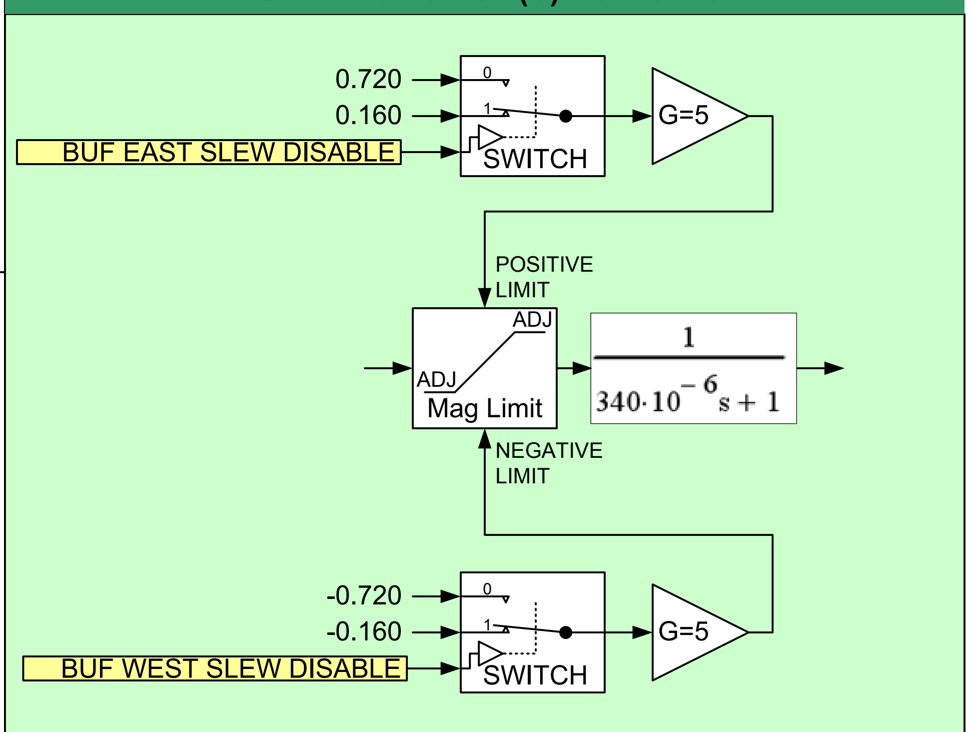
Op-amp equation when Vcmd is ≥ -5Vrefn:
Vout=-Vrefn-0.2*Vcmd

Else Vout=0.

$$-\frac{1}{340\cdot 10^{-6}s+1}$$

(Velocity CMD input only, excludes limit refs)

TRANSFER FUNCTION(S) FOR SIMULINK

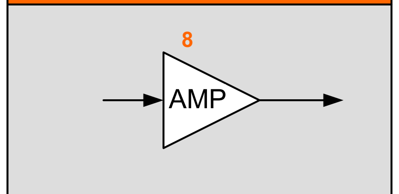


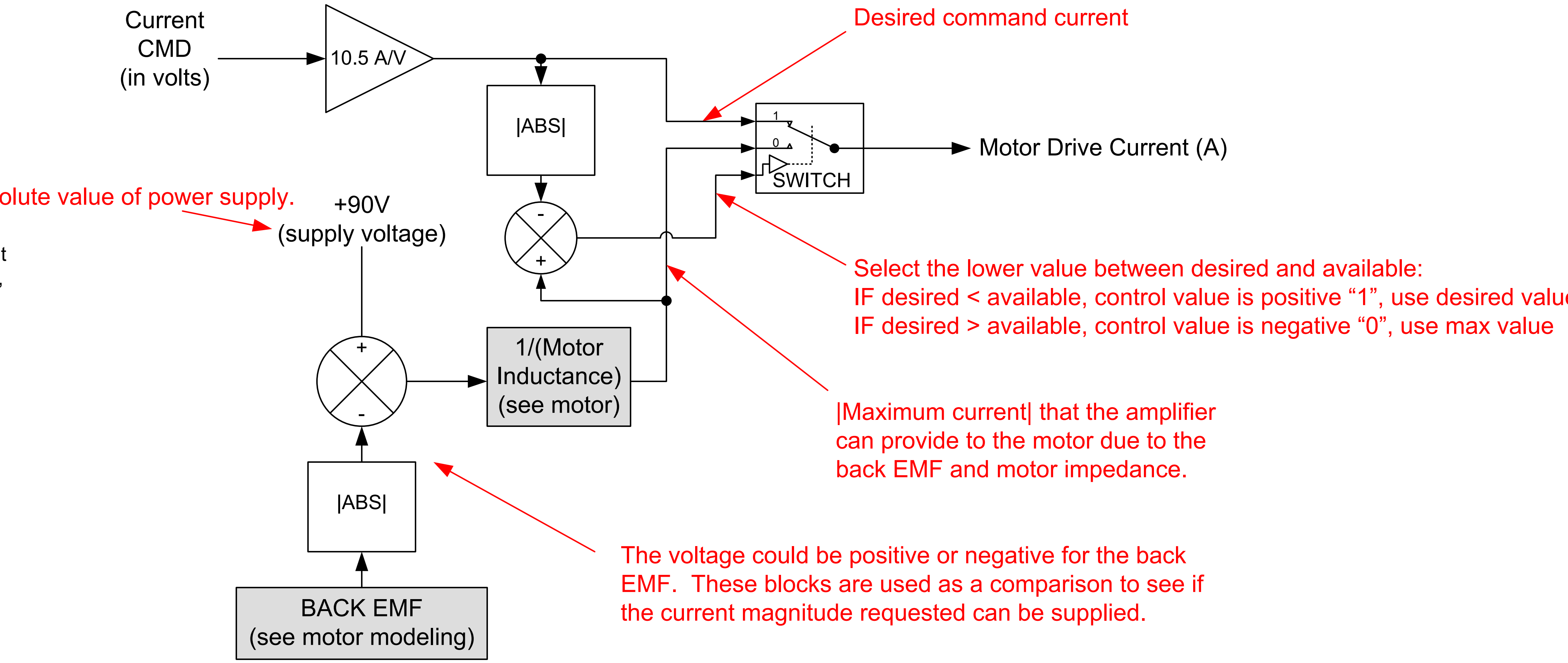
<u>Testing 11/7/07</u>

Z8A-9= 160 mV (EAST track)
Z8A-5= 717 mV (EAST slew)
Z7A-5= -720 mV (WEST track)
Z7A-9= -150 mV (WEST slew)

For model, use
+/- 160 mV for tracking/offset
+/- 720 mV for SLEW

BLOCK GROUP #8

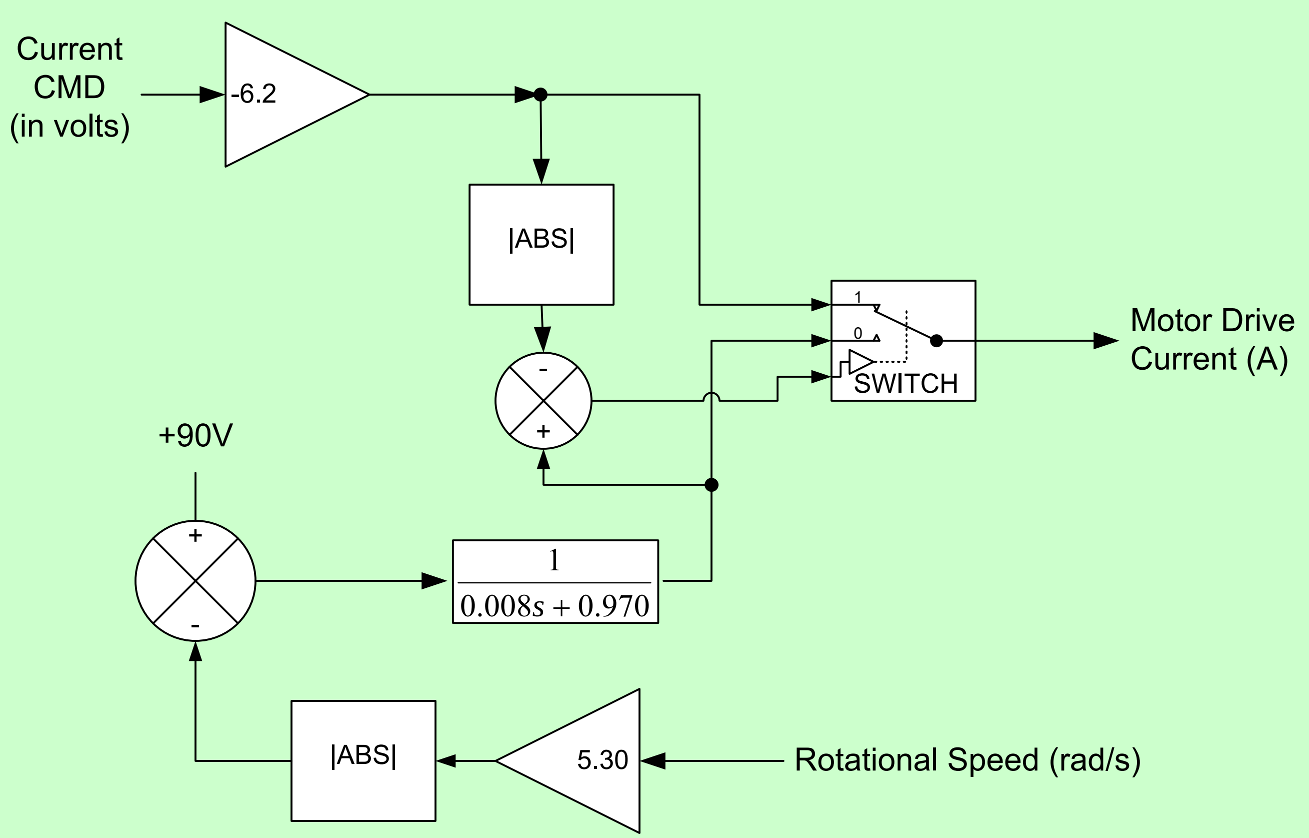




Each of the two motors is operated by a dedicated power amplifier (CSR Contraves, NC307). These amplifiers are classic switching amplifiers, in that they utilize an alternating polarity square wave with an adjustable duty cycle, to control the equivalent DC current. Their switching frequency is 20 kHz.

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. This is the nominal specified value. See test results below. However, the amplifier output current is limited by the impedance it is driving and its +90V supply used in the TCS. The motor impedance will change with frequency due to the inductance and the motor will also create a back EMF, which further reduces the available voltage to drive the motor. The CSR amp uses an H-Bridge driver. This means that it only uses a +90V supply but it can reverse the polarity on the motor, resulting in current flowing the opposite direction. In regards to modeling, it would appear as if the amplifier could supply +/- 90V to the motor.

TRANSFER FUNCTION(S) FOR SIMULINK



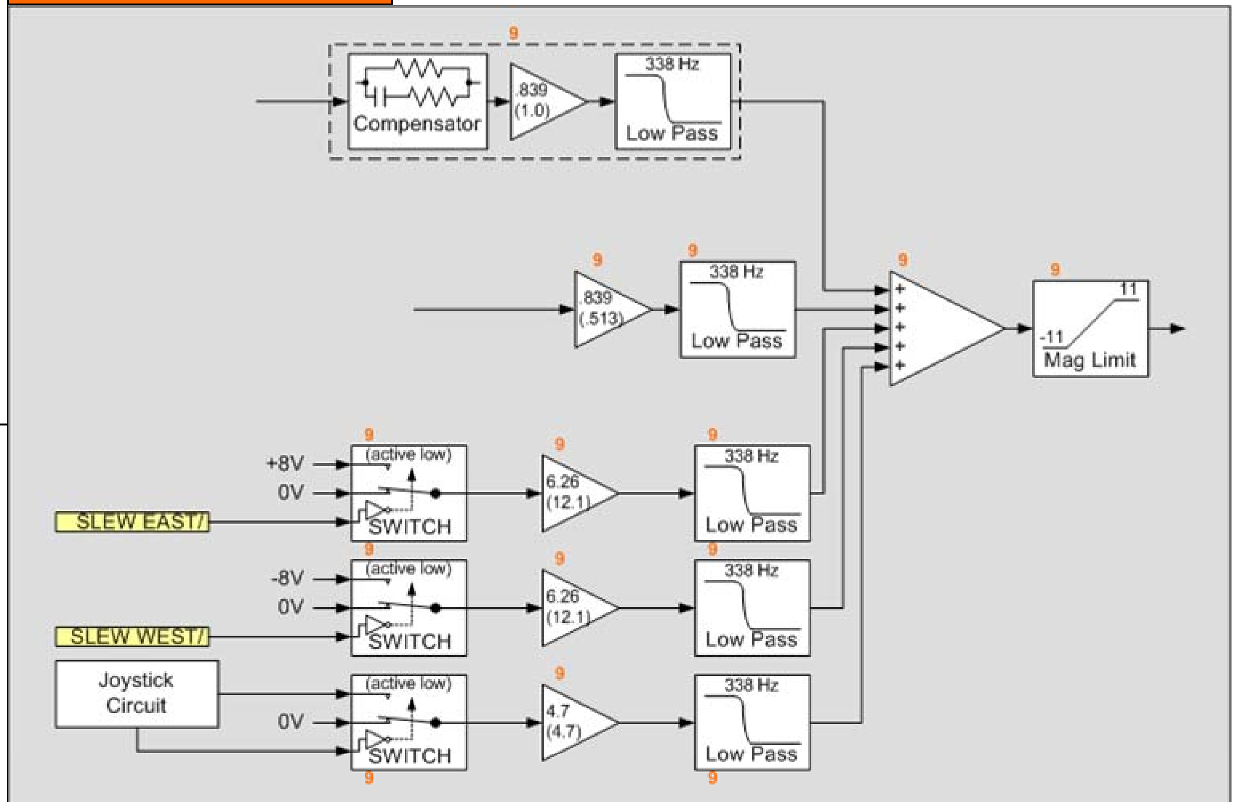
<u>Ideal amplifier model:</u>
This model is a very simplified model of a transconductance amplifier. It <u>does not</u> take into account any frequency response of any kind. However, for the purposes of the TCS model, it should be sufficient. The switching frequency of the amplifier is 20 kHz. The response of the amplifier is DC to 1000 Hz at rated current. The TCS control system is limited to the hundreds of hertz.

<u>Date Created:</u> 11/28/07
<u>Author:</u> E. Warmbier

<u>DESCRIPTION</u>
Measurments taken at NC307 amplifiers to compare the volts to amps command conversion and the amps to volts current monitor. FLUKE DVM put in series with actual armature wire originating at the NC307. "+" of multimeter was hooke up to "+" armature, so current flow is measured coming out of the amplifier.

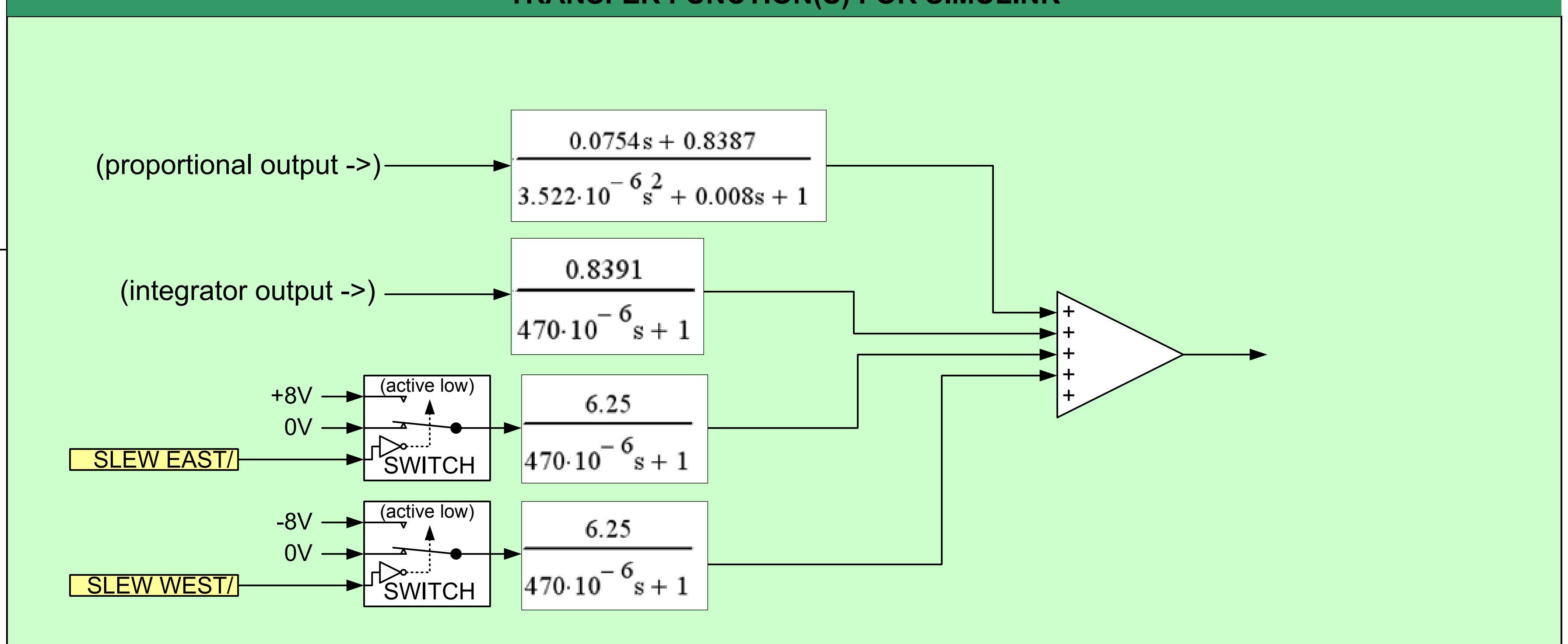
MOTOR & AXIS	FLUKE Current (A)	Term 6 CMD (V)	Term 8 Monitor (V)	Axis Tracking Speed (as/s)	CMD (A/V)	Monitor (A/V)
WEST	4.9	-0.79	0.42	10	-6.202532	11.66667
WEST	5.3	-0.86	0.45	6	-6.162791	11.77778
WEST	5	-0.82	0.42	30	-6.097561	11.90476
NORTH	2.74	-0.448	0.16	15	-6.116071	17.125
NORTH	2.7	-0.45	0.162	30	-6	16.66667
NORTH	3.14	-0.48	0.17	50	-6.541667	18.47059
				average	-6.18677	14.60191 WEST
				average		17.42075 NORTH

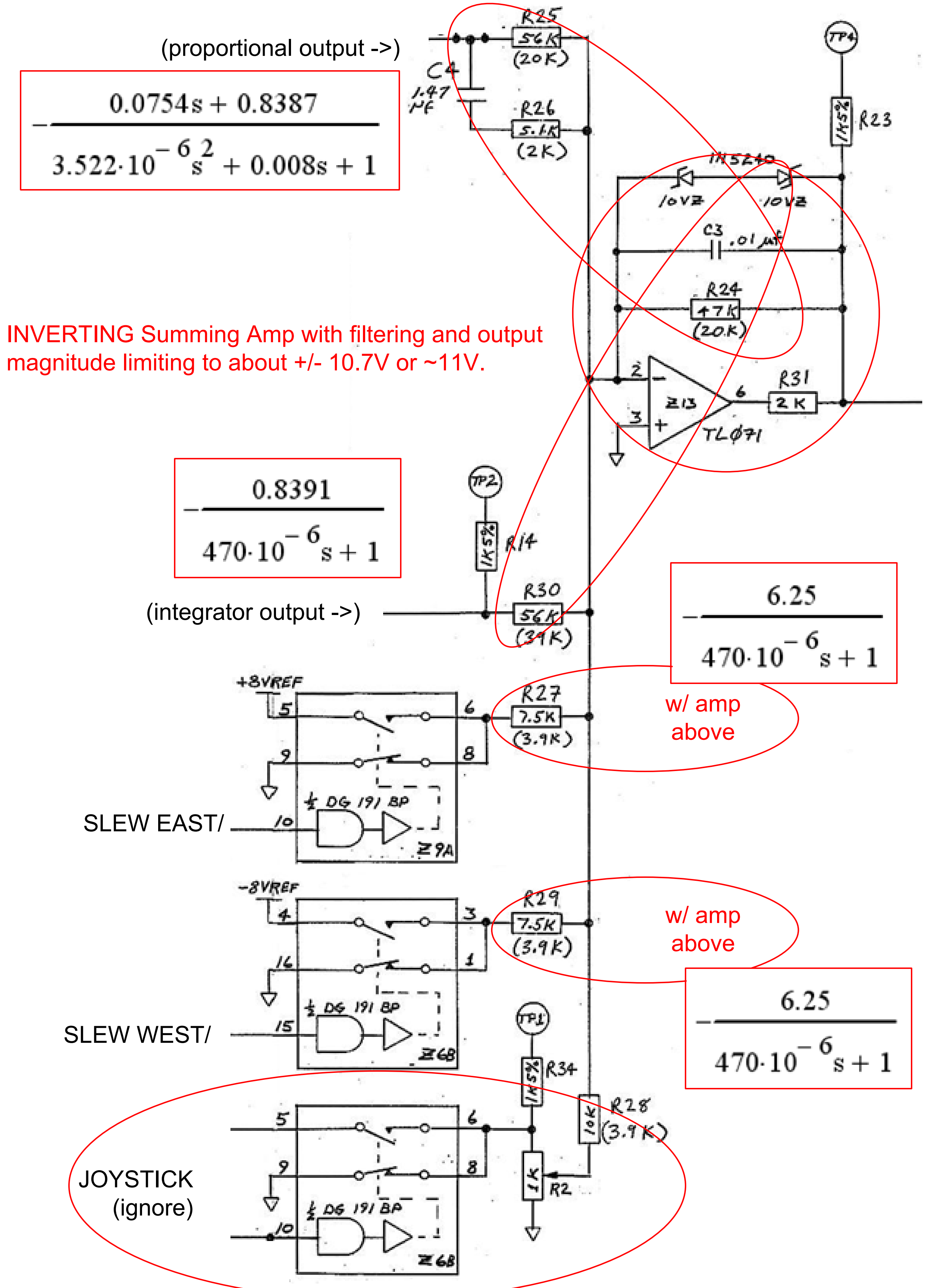
BLOCK GROUP #9



INVERTING Summing Amp with filtering and output magnitude limiting to about +/- 10.7V or roundoff to ~+/-11V. <u>However, the +/- 11V clamp may be ignored for the purposes of this model.</u> There is another limiter of lower magnitude that follows this stage. See block #7.

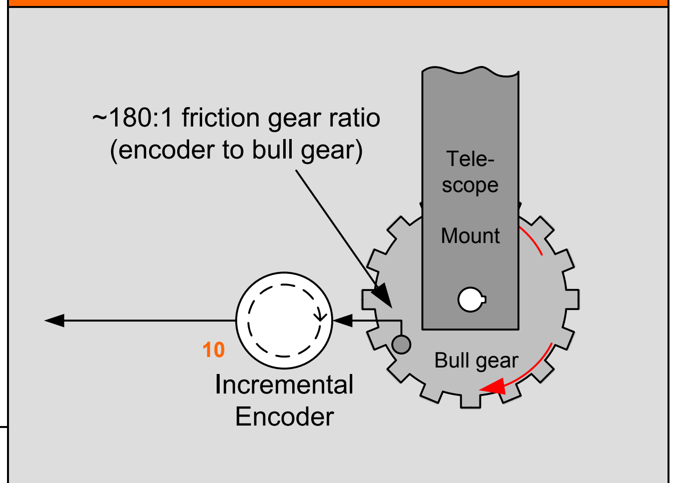
TRANSFER FUNCTION(S) FOR SIMULINK





Not using during servo modeling – ignore.

BLOCK GROUP #10



The encoder input is in terms of rotation position (radians) and output is in volts ultimately at the digital to analog converter.

Encoder — Friction Gear Ratio — A/D Scaling (see block #12) — 1 encoder pulse increments position counter by 1

$$Output\_Voltage = \left(\frac{3600 \cdot 40 pulses}{revolution} \cdot \frac{revolution}{(2\pi) radians} \cdot \frac{180 turns}{1 turns} \cdot \frac{20V}{2^{14} bits} \cdot \frac{bit}{pulse}\right) \cdot Radians$$

$$\frac{Output\_Voltage}{Radians} = \left(\frac{3600 \cdot 40 pulses}{revolution} \cdot \frac{revolution}{(2\pi) radians} \cdot \frac{180 turns}{1 turns} \cdot \frac{20V}{2^{14} bits} \cdot \frac{bit}{pulse}\right)$$

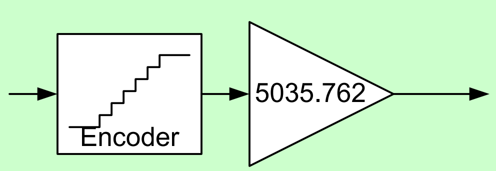
$$\frac{Output\_Voltage}{Radians} = 5035.762 \frac{V}{radians}$$

There is quantization of position due to the encoder. The encoder provides pulses, not a continuous output. The quantization is the number of radians that must be traveled before the next pulse. This is calculated as follows:

$$\frac{revolution}{3600 \cdot 40 pulses} \cdot \frac{(2\pi) radians}{revolution} \cdot \frac{1}{180} = 242.41 \cdot 10^{-9} \frac{radians}{pulse}$$

$$242.41 \cdot 10^{-9} \frac{radians}{pulse} \cdot 1 pulse = 242.41 \cdot 10^{-9} radians$$

TRANSFER FUNCTION(S) FOR SIMULINK



242.41E-9
quantization interval

RA Inc. Encoder

Dec Inc. Encoder

Teledyne Gurley Incrementel encoders, model 8626.

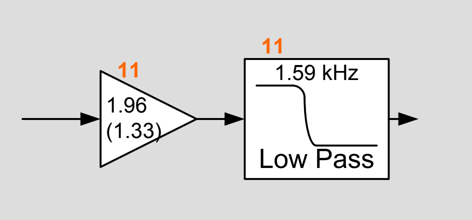
Both of the current incremental encoders have a 3600 line count and associated electronics capable of 40x interpolation for a total of 144 000 pulses/ revolution.

From BEI's website gloassary: http://www.motion-control-info.com/encoder_glossary.html

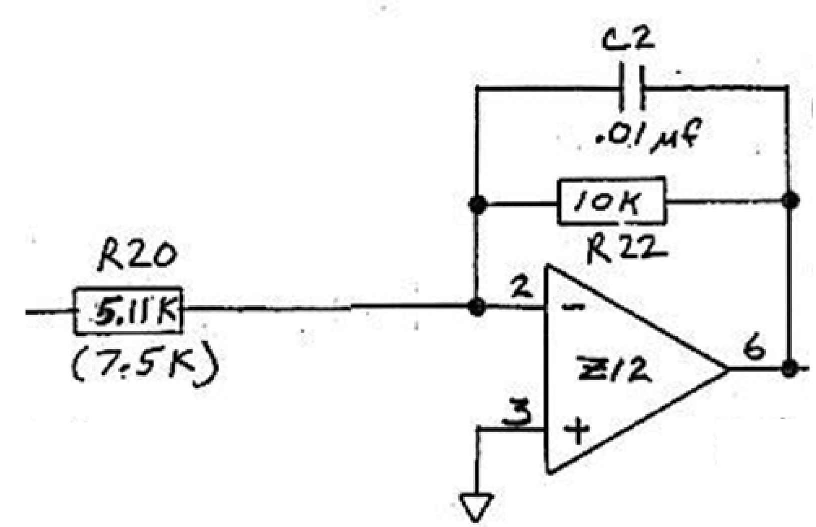
Interpolation
An electronic multiplication technique for increasing encoder resolution. Certain interpolation techniques can also increase the encoder bandwidth. See also, Edge Detection.

Line Count
This is often used to mean resolution. It refers to the number of lines that are contained in the code pattern of the code disk on an incremental encoder.

BLOCK GROUP #11



This is proportional gain of the PID with a low pass filter.



Inverting amplifier with filtering:

Gain= Rf/Rs
10k/5.11k
1.96

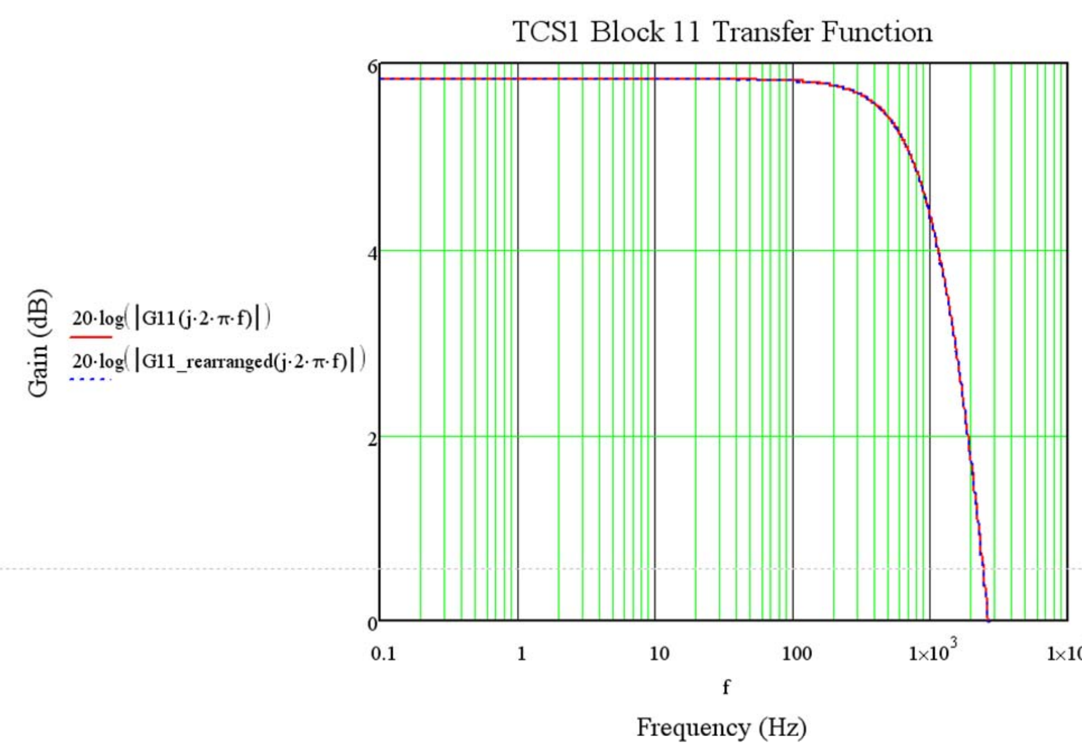
f(-3dB) =1/(2πRC)
=1/(2π*10k*0.01uF)
=1.59 kHz

HA AXIS

$$-\frac{1.96}{0.0001\cdot s + 1.0}$$

DEC AXIS:

$$-\frac{1.33}{0.0001\cdot s + 1.0}$$



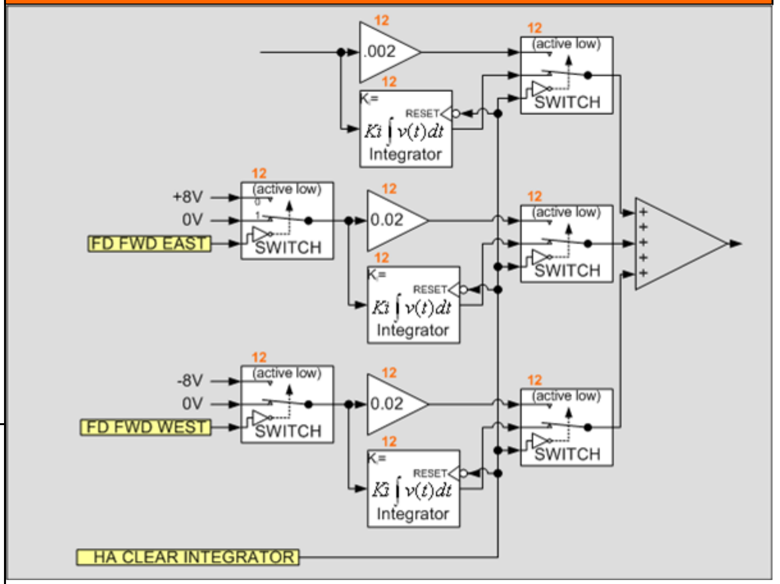
HA TRANSFER FUNCTION(S) FOR SIMULINK

$$\frac{1.96}{0.0001\cdot s + 1.0}$$

DEC TRANSFER FUNCTION(S) FOR SIMULINK

$$\frac{1.33}{0.0001\cdot s + 1.0}$$

BLOCK GROUP #12

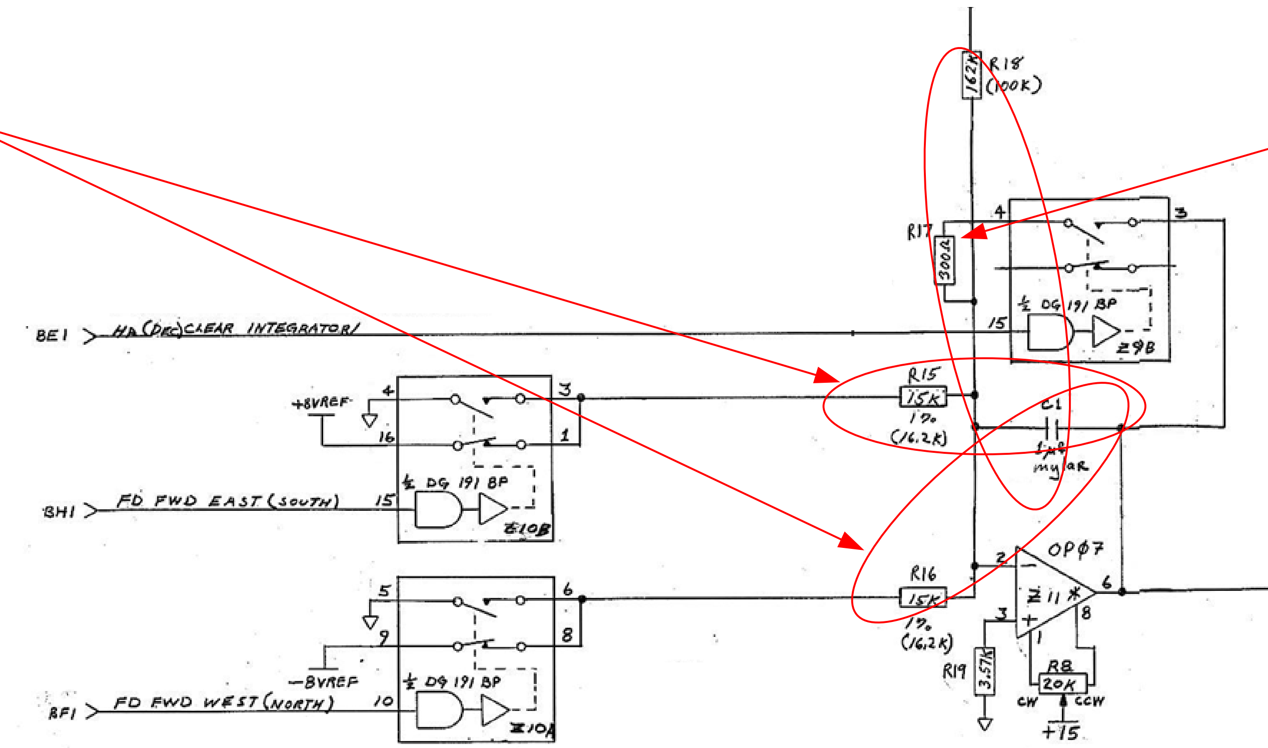


300Ω "Short"

$$-\frac{0.02}{300\cdot 10^{-6}s+1}$$

Normal

$$-\frac{1}{0.015s}$$



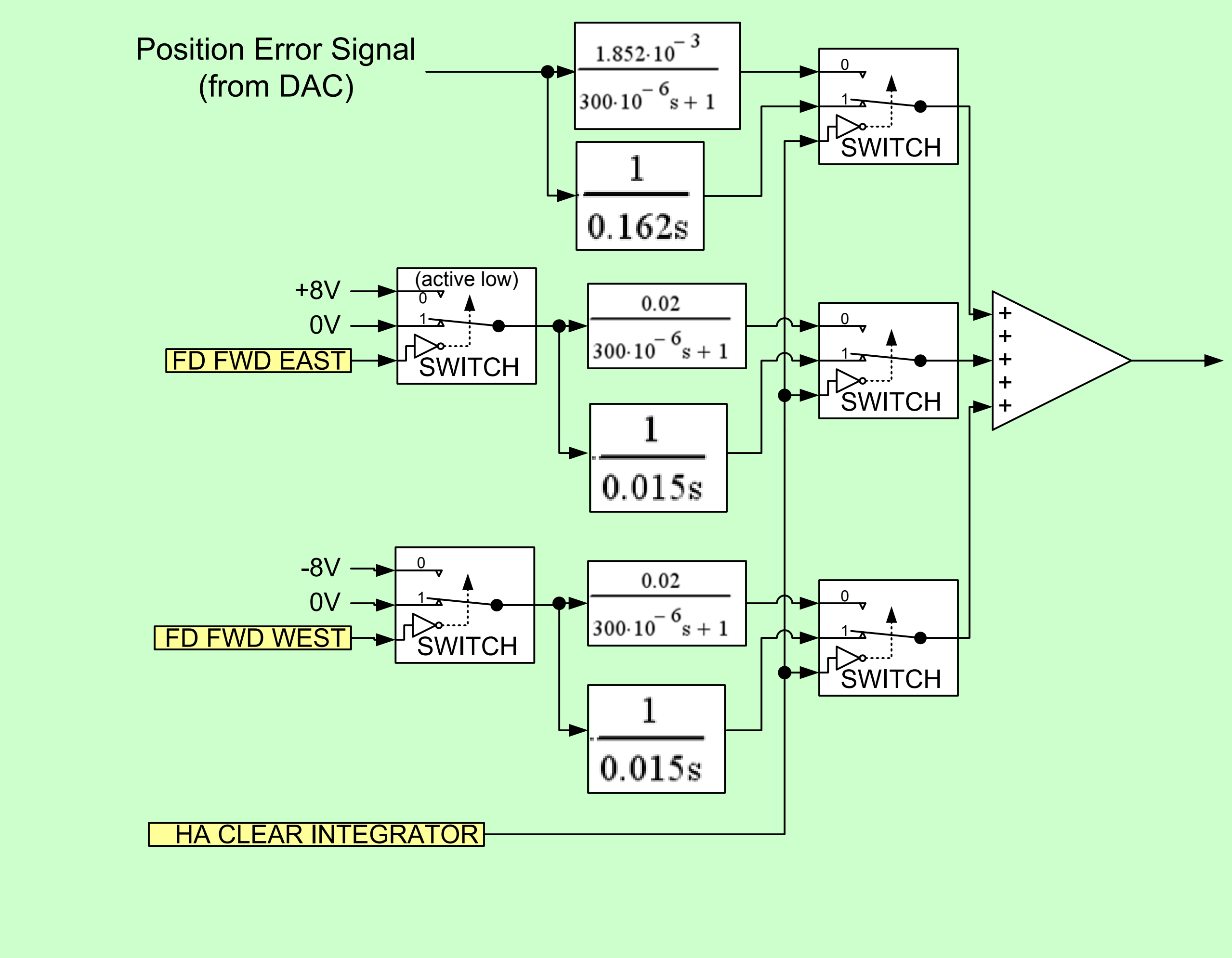
300Ω "Short"

$$-\frac{1.852\cdot 10^{-3}}{300\cdot 10^{-6}s+1}$$

Normal

$$-\frac{1}{0.162s}$$

TRANSFER FUNCTION(S) FOR SIMULINK



INVERTING Summing Integrator under normal operation.

Very low gain inverting summer with filter when R17 via switch is active (SLEW mode).
Essentially the integrator is shorted out since 300Ω is a low value and therefore the gains become very small.

Bottom line: "I" term for the PID controller is either active or it is shorted.

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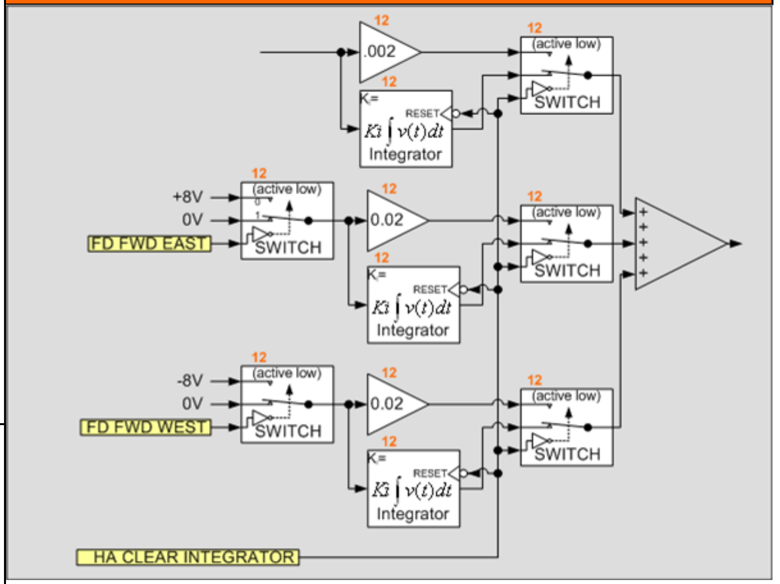
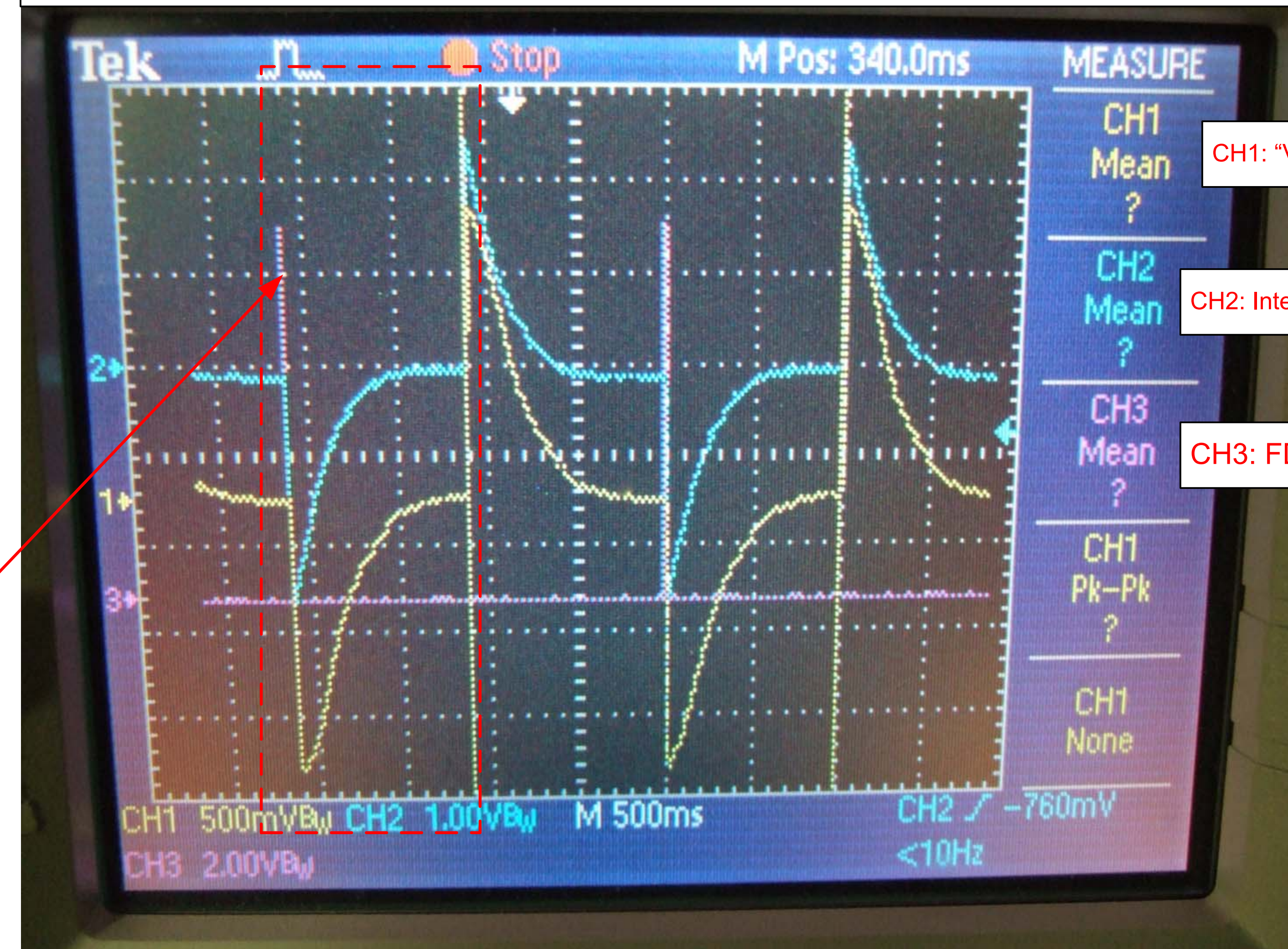
BLOCK GROUP #12 Continued



MANUAL (finger pushing button), REPETITIVE +/- 60 ARCSEC OFFSETS, 11/7/07



CH1: "VOUT" TP

CH2: Integrator Output TP2

CH3: FD FWD East

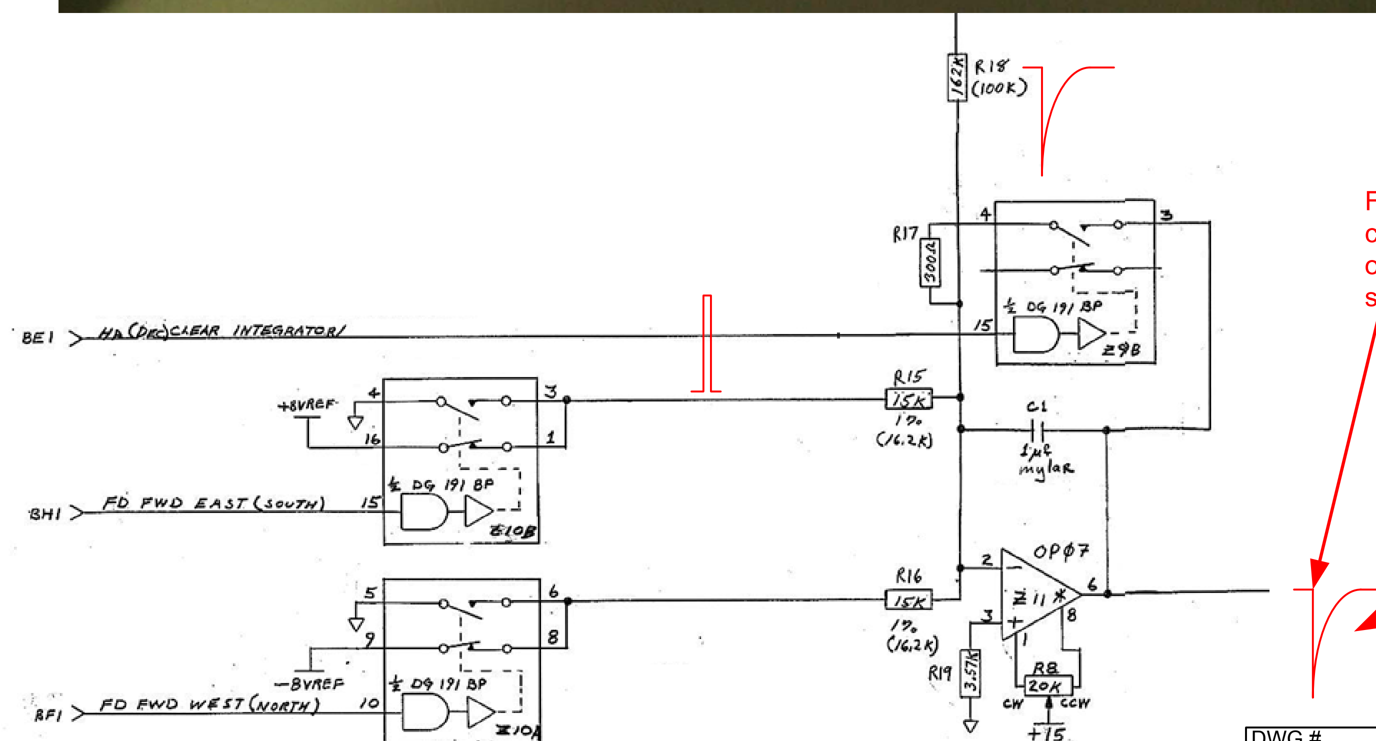
Below is a portion of the Ev Irwin memo about the offset operation and how the FD FWD is used.

From Ev Irwin Memo:

"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."

The scope plot seems to confirm the above statement. When the error reaches zero (CH1) the integrator output (CH2) is approximately the same as the value when the offset started. This is due to the charge injected by the FD FWD pulse (CH3). If this pulse did not exist, the integrator would have a positive value on its output due to integrating the error signal when the error reaches zero.

(Keep in mind that the op-amp is inverting.)

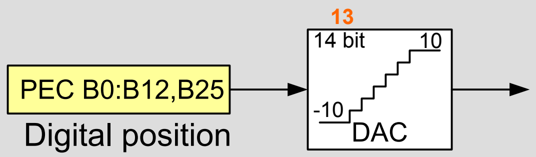


FD FWD pulse initially causes large jump in opposite polarity of error signal.

Error signal is then integrated which brings output back close to initial value.

Remember: inverting amplifier configuration.

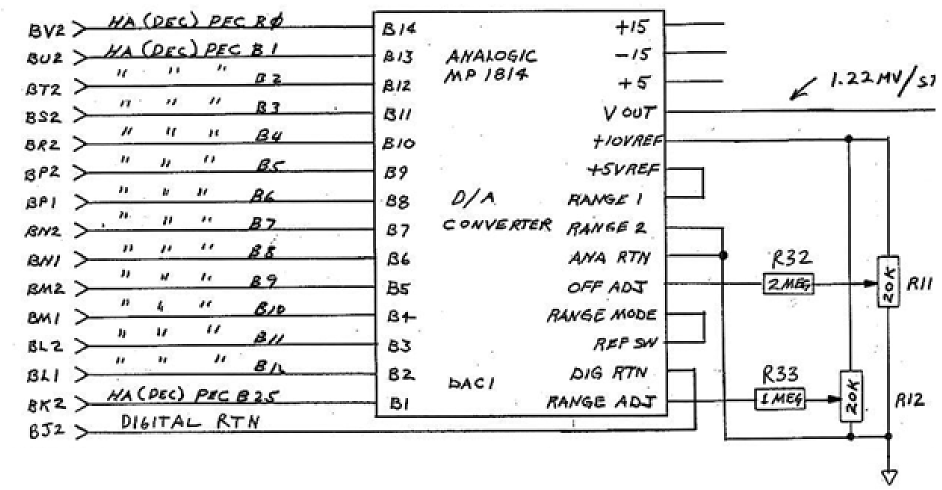
BLOCK GROUP #13



Digital position error CMD.

Digital to analog converter.
Voltage output.

The digital to analog converter gain was lumped into the encoder block. See block #10.



Note: no datasheet was located on the internet.
(It's an older obsolete DAC.)

It is known from operation and the above schematic that the DAC uses +/- 15V supplies, outputs +/-10V, and is 14 bits.

Given this information, the resolution can be calculated as:

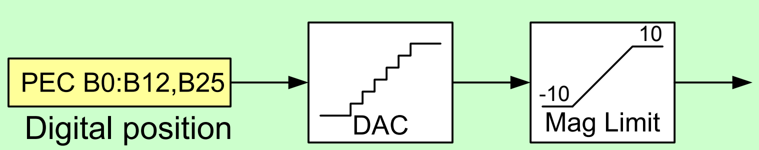
$$\frac{10-(-10)V}{2^{14}bits} = 1.22mV/bit$$

This value is used as the quantization interval for the quantization block in Simulink.

In addition, the DAC can only output +/- 10V. A limiter can be placed on the output.

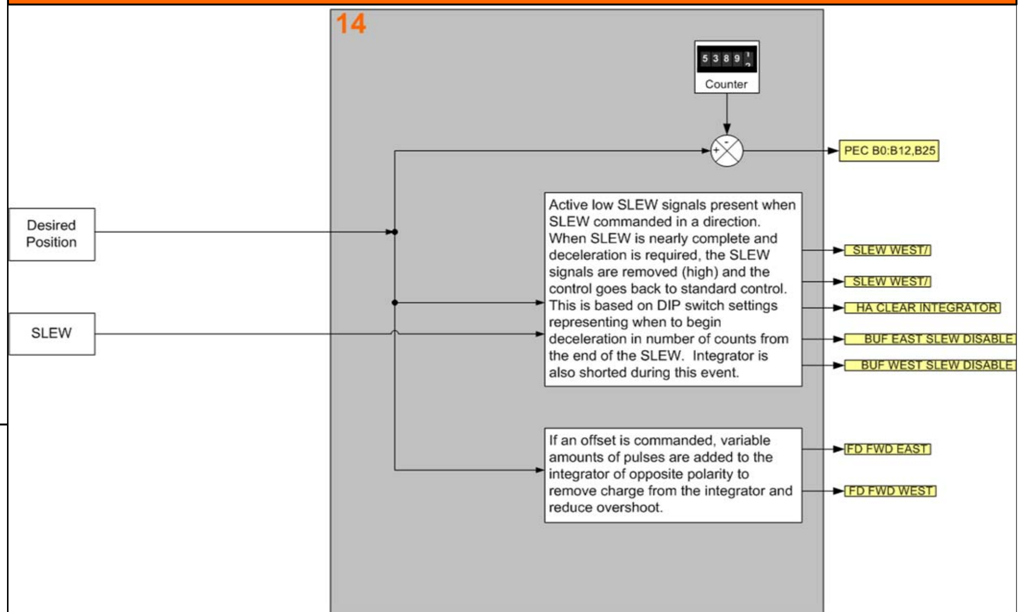
DEC TRANSFER FUNCTION(S) FOR SIMULINK

1.22E-3
quantization interval



Digital position error CMD.

BLOCK GROUP #13 CONTINUED



The SIMULINK modeling of this will be much simpler than the large amounts of digital circuitry that were required to create these signals.

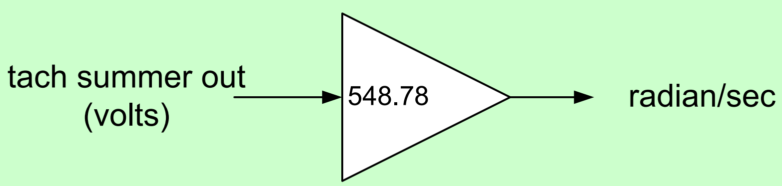
SEE BLOCK #12 for more information on the offset pulses. (“FD FWD EAST” and “FD FWD WEST”)

More work needs to done here. As of 11/27/07 two things are unknown:
1) Position error magnitude at which a slew ends
2) Offset pulse characteristics

The model currently uses values that work well in the simulation.

CONVERSIONS

CONVERSION FOR SIMULINK



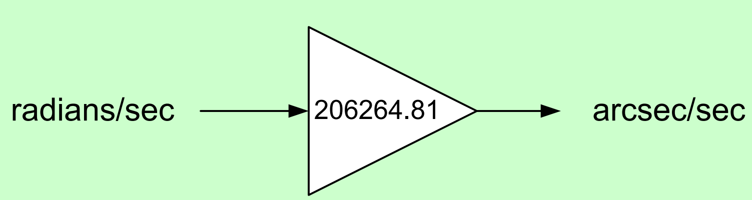
The tachometer summer circuit has a scaled, averaged, tachometer output in volts. In the SIMULINK simulation, it is convenient to display this in arcsec/sec. See conversion derivation for rad/s to arcsec/s used below. This is the feedback that the control system uses.

$$\frac{arc\sec}{\sec} = Output(V)\cdot\frac{1}{Tach\_conv}\cdot\frac{1}{Diff\_Amp}\cdot\frac{1}{summer\_gain}\cdot\frac{1}{Num\_tach\_input}\cdot\frac{arc\sec/s\_conversion}{rad/s}$$

$$\frac{radians}{\sec} = Output(V)\cdot\frac{1}{\frac{1808V}{rad/s}}\cdot\frac{1}{0.213}\cdot\frac{1}{0.488}\cdot\frac{1}{2}\cdot\frac{206264.81 arc\sec/s}{rad/s}$$

$$\frac{radians}{\sec} = Output(V)\cdot\frac{548.78 arc\sec/s}{V}$$

CONVERSION FOR SIMULINK



In Simulink, some of the outputs will be displayed on a scope. Radians/second are used in the model for radial velocity, but arcsec/sec is what the telescope control displays and uses. Converting it makes it easier to understand and compare to actual telescope data.

$$\frac{radians}{\sec} = \frac{radian}{\sec}\cdot\frac{180\deg}{\pi\cdot radian}\cdot\frac{60 arc\min}{\deg}\cdot\frac{60 arc\sec}{arc\min}$$

$$\frac{radians}{\sec} = 206264.81\frac{arc\sec}{\sec}$$

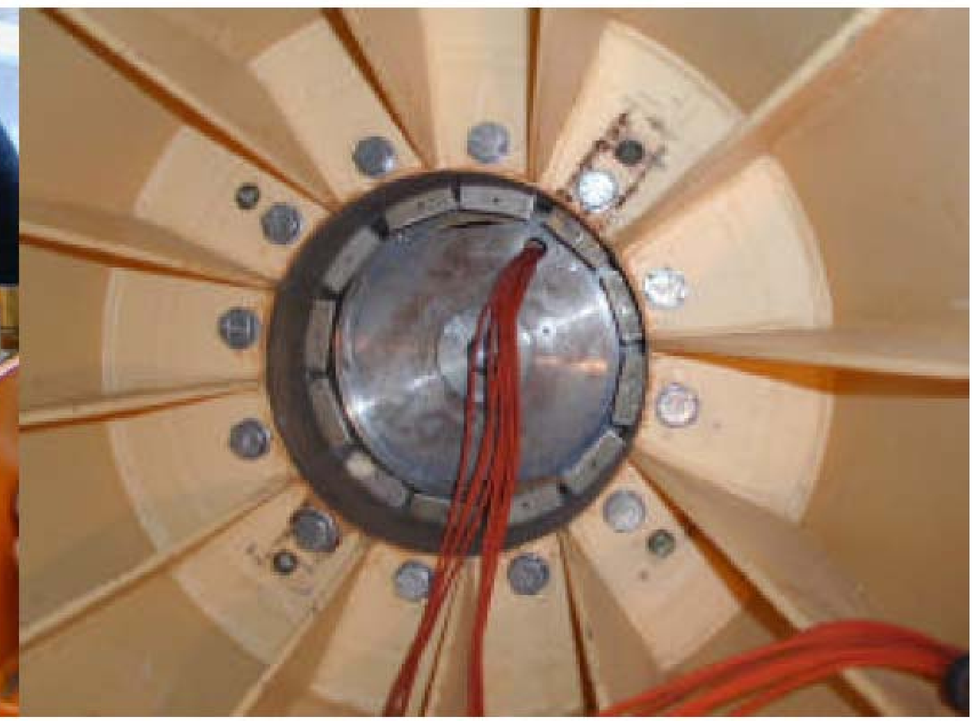
APPENDIX: ABSOLUTE POSITION ENCODERS

The current RA absolute position encoder (APE) is located in the North Pier. It is an inductosyn encoder with one half mounted on the yoke, and the other half mounted to the pier.

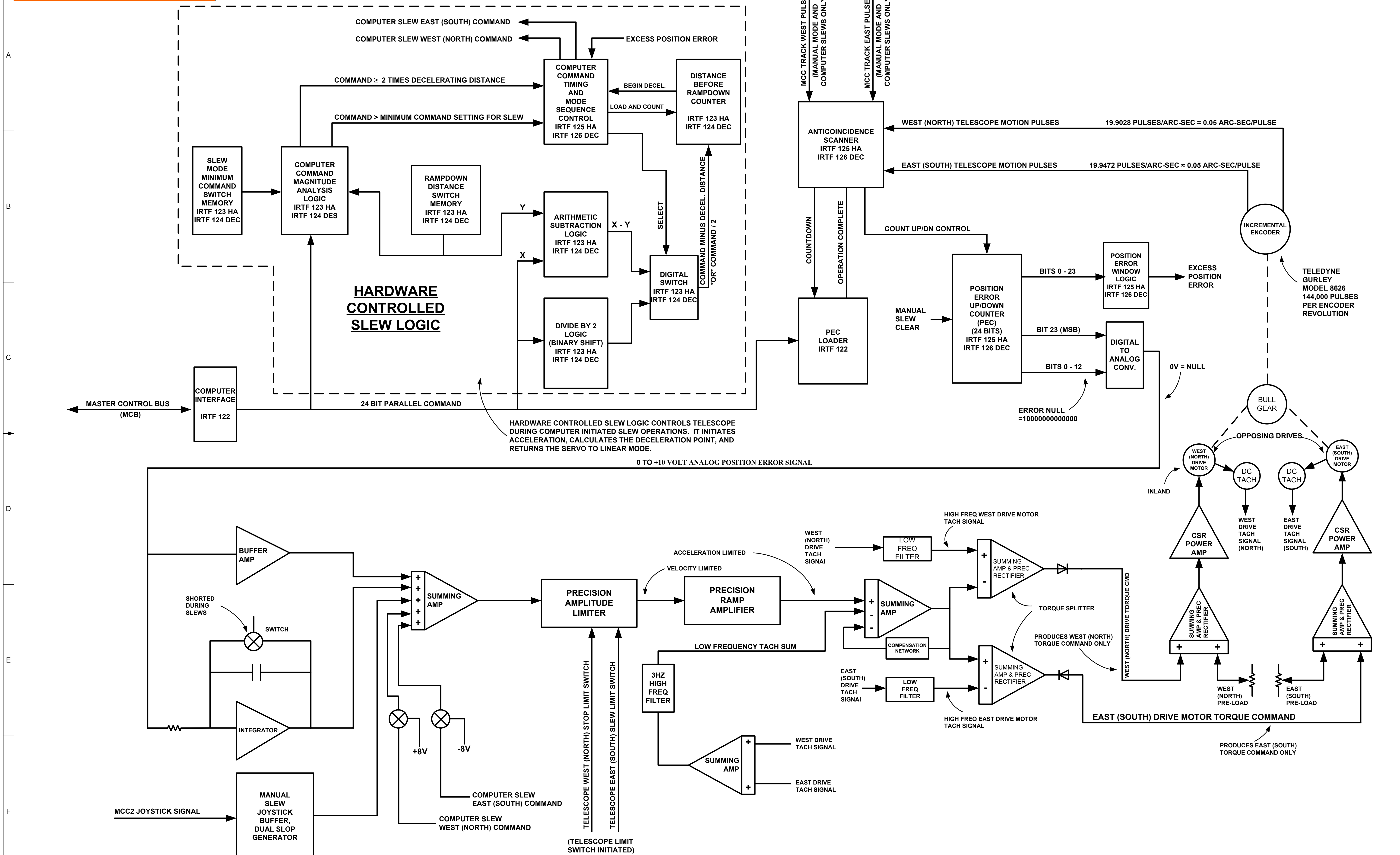
The DEC APE is located in the west arm of the yoke. It is also an induction type encoder (identical to the RA encoder) with one half mounted to the telescope central section, and the other half mounted on the yoke.

Both of the current APEs have a resolution of 0.1 arcsec.

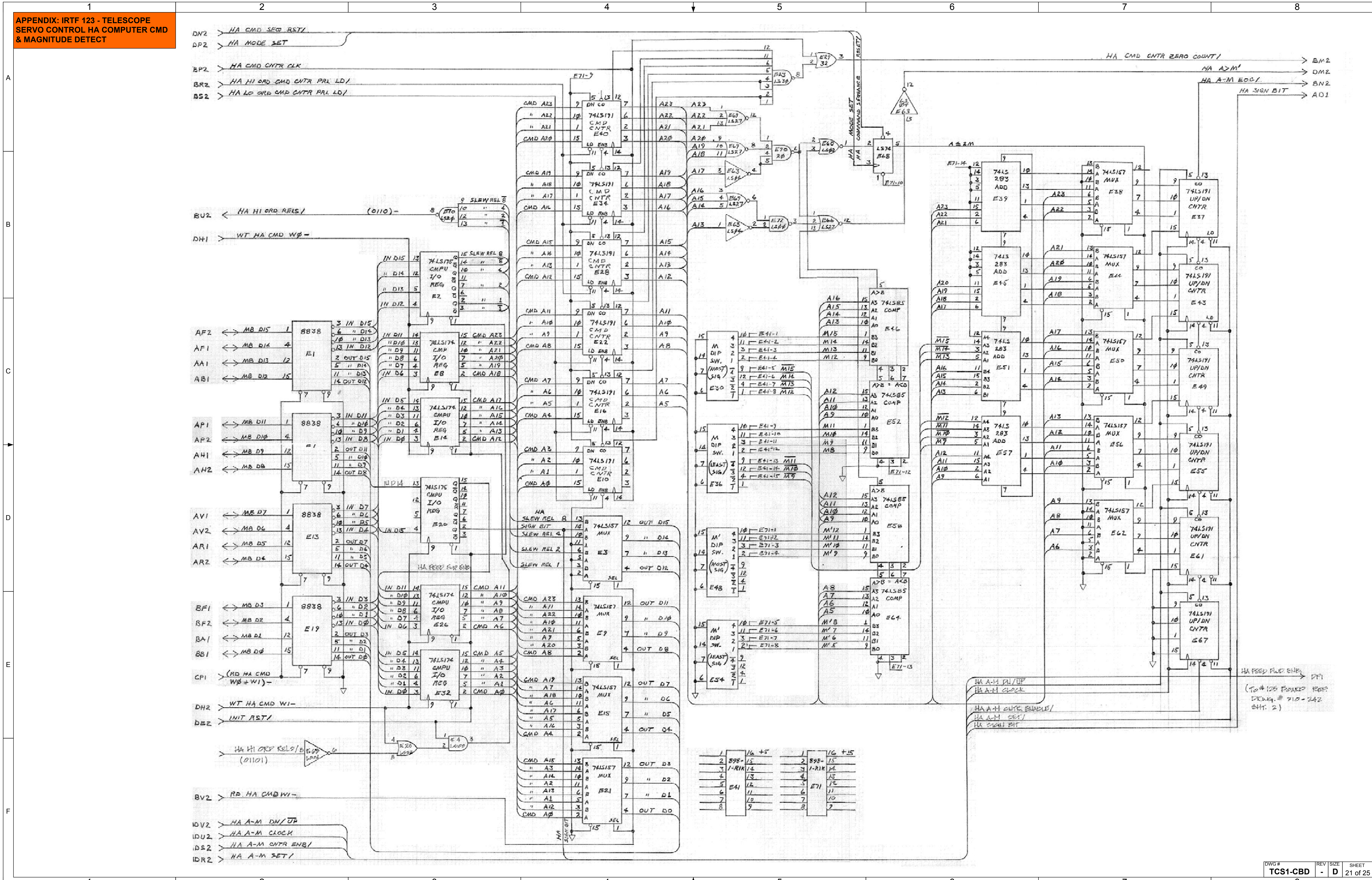

RA APE


DEC APE

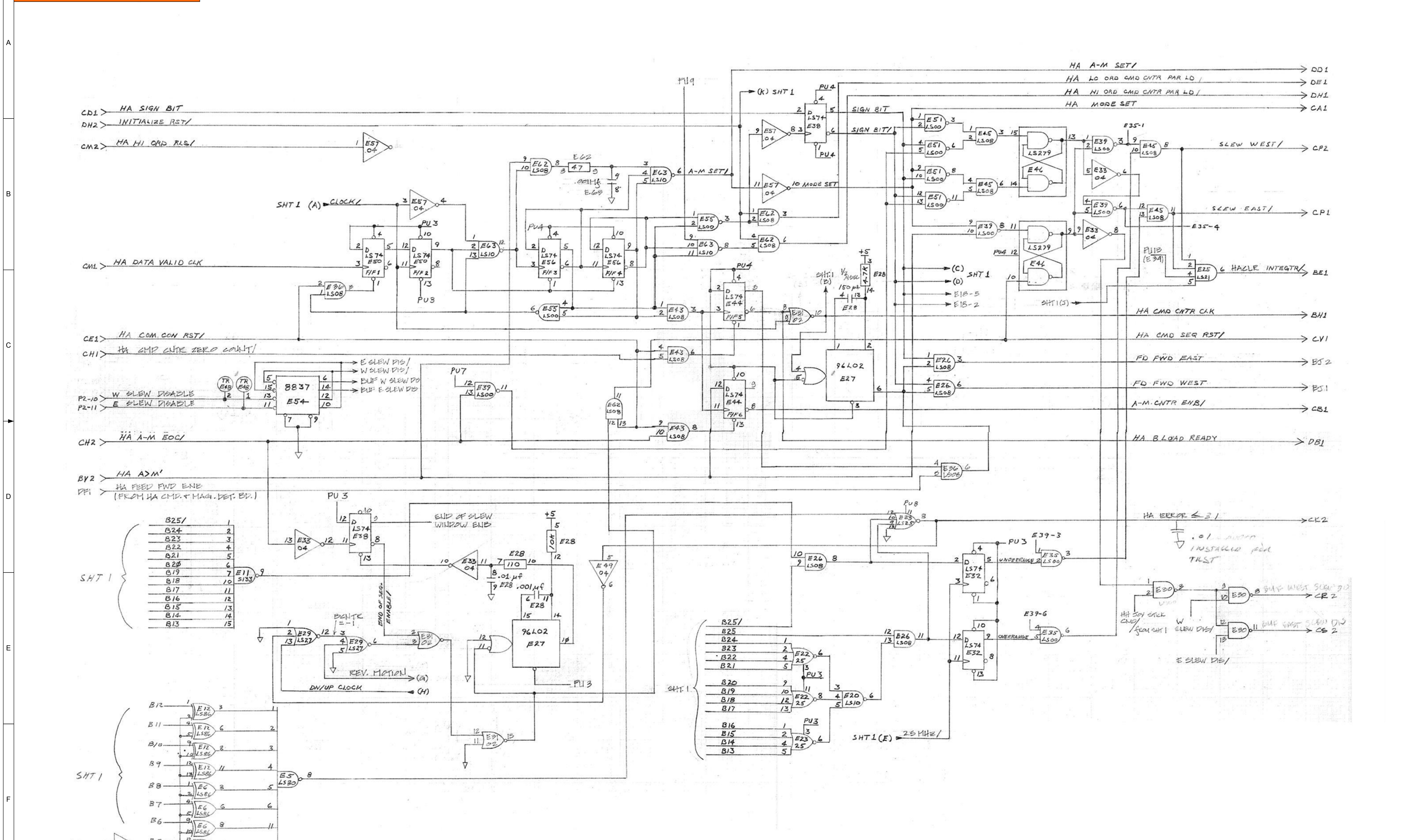
APPENDIX: TCS1 BLOCK DIAGRAM CIRCA 1980



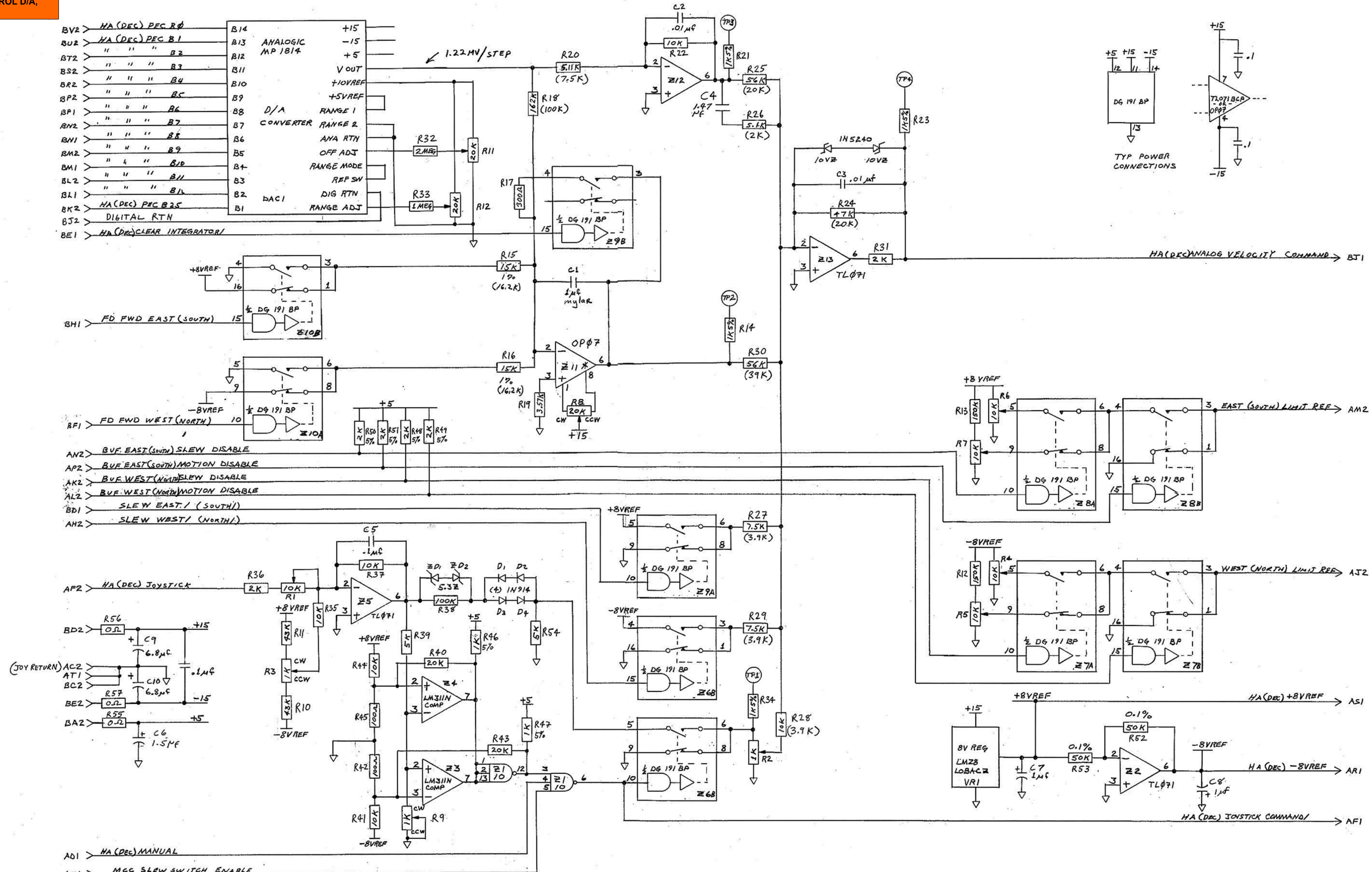
APPENDIX: IRTF 123 - TELESCOPE SERVO CONTROL HA COMPUTER CMD & MAGNITUDE DETECT



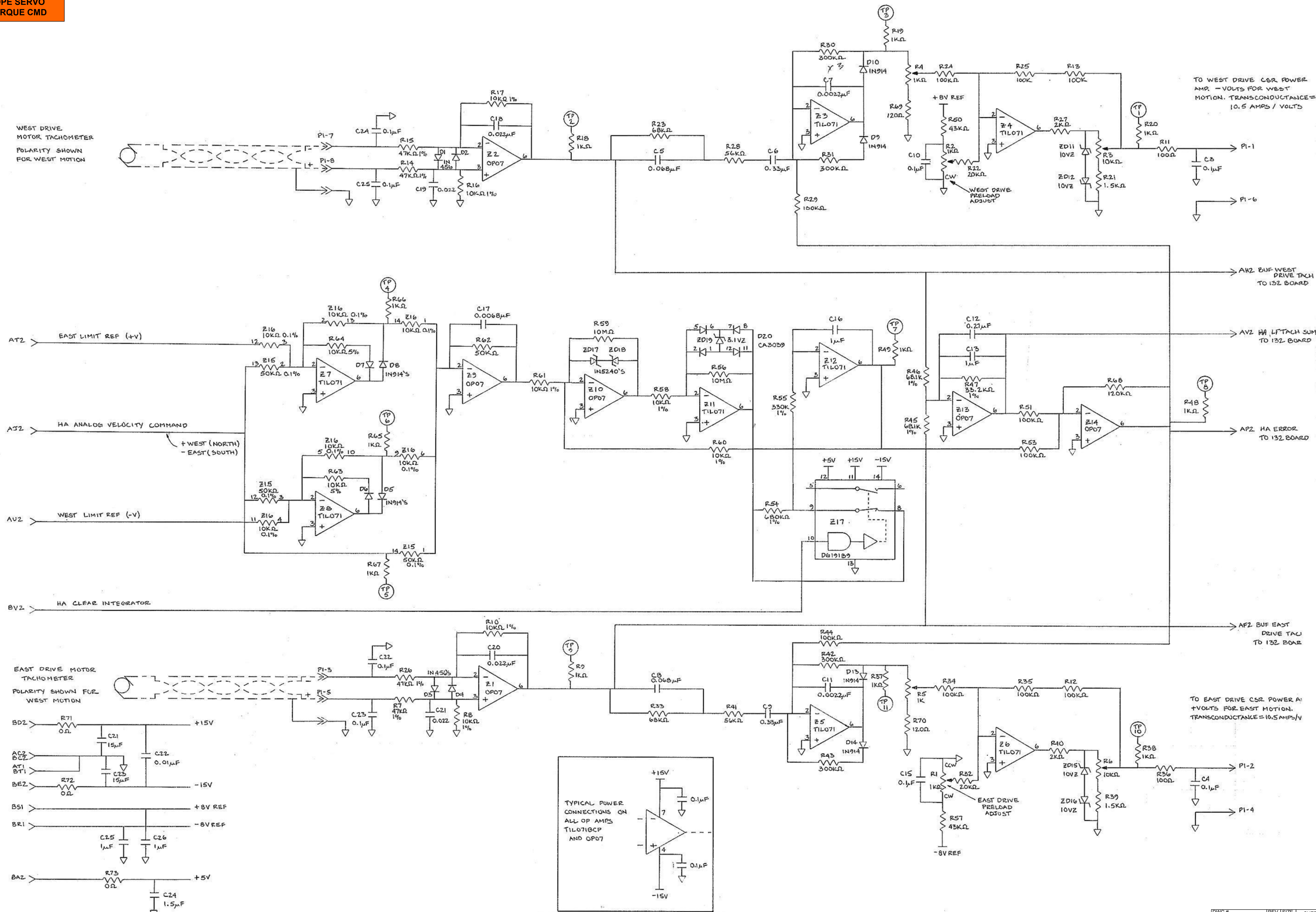
APPENDIX: IRTF 125 - TELESCOPE SERVO CONTROL HA SEQUENCE CONTROL BOARD

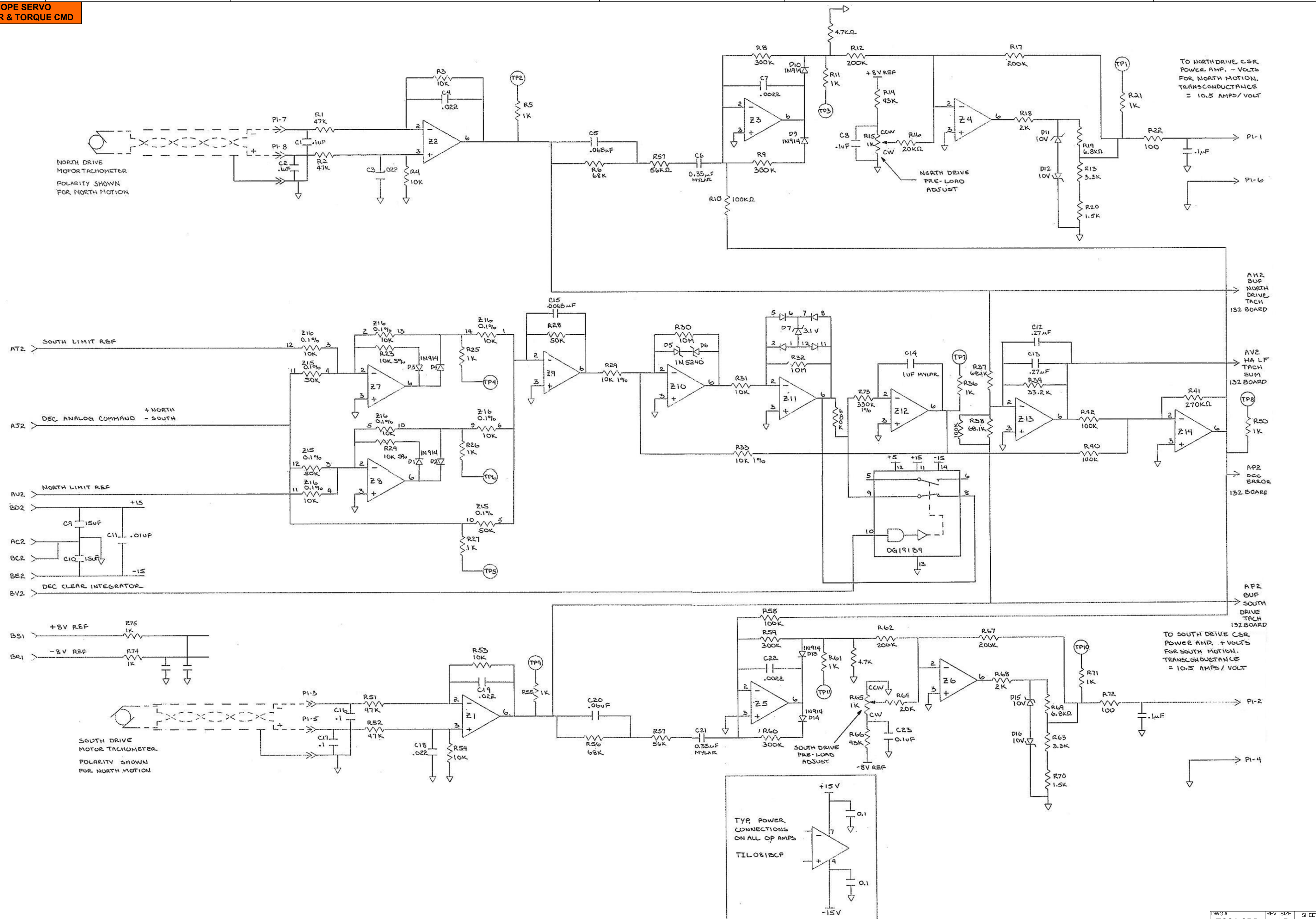


DWG # TCS1-CBD | REV - | SIZE D | SHEET 22 of 25



*NOTE: BRACKETED VALUES ( ) INDICATE THOSE COMPONENT VALUES ON THE DEC BOARD - IRTF 128 - WHICH ARE DIFFERENT FROM THE HA BOARD - IRTF 127; All OTHER COMPONENTS HAVE THE SAME VALUE ON BOTH BOARDS.


WEST DRIVE MOTOR TACHOMETER
POLARITY SHOWN FOR WEST MOTION
TO WEST DRIVE CSR POWER AMP. −VOLTS FOR WEST MOTION. TRANSCONDUCTANCE = 10.5 AMPS / VOLTS
WEST DRIVE PRELOAD ADJUST
AH2 BUF WEST DRIVE TACH TO 132 BOARD
AT2 EAST LIMIT REF (+V)
AJ2 HA ANALOG VELOCITY COMMAND
+WEST (NORTH)
−EAST (SOUTH)
AU2 WEST LIMIT REF (−V)
AV2 HA LT TACH SUM TO 132 BOARD
AP2 HA ERROR TO 132 BOARD
BV2 HA CLEAR INTEGRATOR
AF2 BUF EAST DRIVE TAC TO 132 BOAR
EAST DRIVE MOTOR TACHOMETER
POLARITY SHOWN FOR WEST MOTION
TO EAST DRIVE CSR POWER A +VOLTS FOR EAST MOTION. TRANSCONDUCTANCE = 10.5AMPS/V
EAST DRIVE PRELOAD ADJUST
TYPICAL POWER CONNECTIONS ON ALL OP AMPS TIL071BCP AND OP07
+15V
−15V
+8V REF
−8V REF
+5V
DG191BG
CA3059
P1-1
P1-2
P1-4
P1-6



DWG #	REV	SIZE	SHEET
TCS1-CBD	-	D	25 of 25