Notes on the STS-2 Block Diagram

Revised 22 April, 2008

Pendulum geometry:
The first block, between the ground acceleration and the mass motion, represents the geometry between the hinge-to-mass radius and the radius to the center of the sensor plates. It also takes into account the excess rotational moment of inertia of a distributed pendulum structure over a simple pendulum.

Given: d_1 = radius to the center of mass
d_2 = radius to the displacement sensor axis
d_3 = radius of inertia (radius of gyration)

$\ddot{X}_{sensor} / \ddot{X}_{ground} = d_2 d_1 / d_3^2 \cong 1.15$

Pendulum mechanical response:
Note 1) $= 1/(s^2 + 2\omega_0 h_0 s + \omega_0^2)$
where $\omega_0 = 2\pi/4$ sec, giving $T_0 = 4$ sec natural period (not 6)
with damping factor, $h_0 \cong 0.4$ Called 'ζ_0' in my spreadsheet.
I am surprised to see it this large.

Capacitive displacement transducer:
$A_0 = 275{,}000$ V/m Called 'r' in my spreadsheet. (See note 2)

Filters:
Note 2) $K = (1/s + 0.066)/(1/(475s)+0.066)$
Has gain of 475 at DC. Begins falling from ~0.0105Hz at 20 dB/decade, leveling out at 5Hz with gain = 1. This is called the 'inverse filter' Note that this effectively raises the DC value of A_0 to 130,625,000 V/m In the spreadsheet this was called 'My displacement amp gain boost' A similar element was added in my STM-8 loop redesign to obtain adequate loop gain at the low-mid frequencies and is needed in the STS-2 for the same reason.

B3 '3rd order Bessel filter – 1600 Hz'
where $B3 = 1/((1+7.52E\text{-}5s)(1+9.94E\text{-}5s+4.72E\text{-}9s^2))$
This is intended to filter the large 40kHz second, and higher harmonics of the demodulated displacement transducer output. The normalization frequency in the Bessel formula is 911.5Hz. That gives a filter which is 3dB down at 1600 Hz. Such a filter attenuates a 40kHz signal by a factor of over 5600 (75dB).

Feedback Branches:
Note 3) Integrator branch = ω_{INT}/s where $\omega_{INT} = 1/\ 77.1$ sec
Note that this implies infinite integrator response at zero frequency. In the real world the integrator DC response is limited by the finite gain of the integrator amplifier and the leakage time constant of the integrating capacitor, etc., but it still could be extremely large. ω_{INT} is not a corner frequency but is better thought of as a scale factor, defining the frequency where the integrator response = 1.
The integrator scaling resistor R_3 = 697K In my spreadsheet this is called R_I.

Proportional Branch: $R_I = 1.73M$ Note that this is probably a typo and should more properly be labeled R_P.

Derivative branch: $C = 6.8\ \mu f$. Called C_d in my spreadsheet.

Moving coil transducer: $\sigma = 31.5$ N/A Called G_n in my spreadsheet. Needs network analyzed. Impedance = 560 ohms at high frequencies, 240 ohms at DC. This is much lower than the proportional and integral branch impedances, so their currents will sum quite accurately. The impedance of C, however becomes low, (= 560 ohms at 36Hz) and needs to be factored into the overall transducer response. The coil inductance L = 0.51H. Not clear whether this is defined with the boom clamped or free to move.

Differential Output Stage:

Note 4) Has a low-pass filter $1/(s/\omega_{dd} + 1)$ where $\omega_{dd} = 2\pi \times 40\ sec^{-1}$, which gives a pole at 40Hz. This stage is implemented in a way which has a gain factor of 2 from DC to 40Hz (but is not shown). Since this is outside of the feedback loop, its response simply multiplies the over-all instrument response.

Pendulum Geometry:

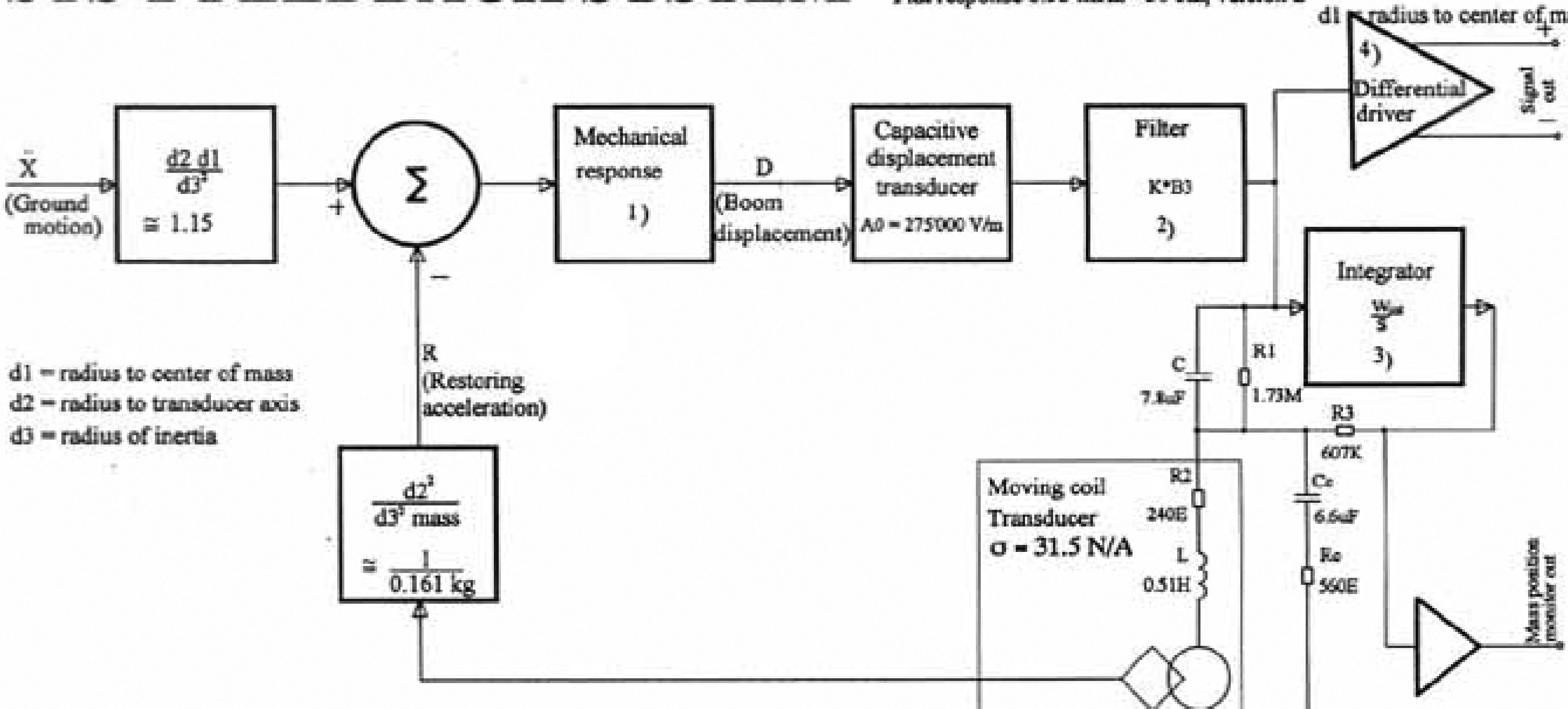
The effective feedback force is multiplied by d_2^2/d_3^2 where d_2 and d_3 are as defined above. Apparently the transducer coil is coaxial with the sensor plates, i.e. it also acts at a distance of d_2 from the pivot. Given $d_2^2/d_3^2 = 1/.161$ then $d_2/d_3 \cong 2.5$ We can also see from above that since $d_2/d_3 \times d_1/d_3 \cong 1.15$ then $d_1/d_3 \cong 0.46$

Instrument Response:

On the 'STS-2 Velocity response' graph, we see that the response has a substantial peak near 60Hz. The size of the peak indicates that the loop phase margin is quite small, approximately 19 degrees, which is confirmed by comments on page 14 of the manual. If one of my engineers had given me a design showing such a peak, I would have sent him back to try again. The issue is that rather small changes in the value of certain components can cause the loop to start oscillating at 60Hz. A safer design would sacrifice a little response at the high end in order to ensure feedback stability, and in the process the peak would disappear.

STS-2 FEEDBACK SYSTEM

Flat response 8.33 mHz - 50 Hz, version 2



1) $\frac{1}{s^2 + 2 w_0 h_0 s + w_0^2}$, $w_0 \cong \frac{6.28}{4\,\mathrm{sec}}$, $h_0 \cong 0.4$

2) $K = \frac{(1/s + 0.066)}{(1/(475s) + 0.066)}$ (Inverse filter)

$B3 = \frac{1}{(1+7.52e\text{-}5s)(1+9.94e\text{-}5s+4.72e\text{-}9s^2)}$ (Bessel 3rd order 1600 Hz)

3) $w_{int} = \frac{1}{77.1\,\mathrm{sec}}$

4) With low-pass filter: $\frac{1}{s/w_{dd} + 1}$, $w_{dd} = 6.28 \cdot 40\,/\mathrm{sec}$

29-1-98, SZBLOCK4.SCH