



W.W. Hansen Experimental Physics Laboratory
STANFORD UNIVERSITY
STANFORD, CA 94305 – 4085

Gravity Probe B Relativity Mission

Integrated Test Facility (ITF) Drag-Free Gyroscope Simulator (DFGS) Detailed Description

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Approvals

NAME	SIGNATURE	DATE
Matthew LeMieux <i>Responsible Engineer</i>		
David Hipkins <i>GSS RE</i>		
William Bencze <i>Payload Electronics Manager</i>		
Kelly Burlingham <i>Software Quality Engineer</i>		

Tom Langenstein ITAR Assessment Performed, ITAR Control Req'd? _____ Yes _____ No

Revision History

REV	DATE	AUTHOR	COMMENTS
-	20 Feb 2003	SKS	Initial version
A	4 Mar 2003	MDL	Software version 1.1 Added documentation for the following software changes: <ul style="list-style-type: none">• Added support for MSS3.4.1, section 6• Added Timing Test support, section 5.3• Spin Up support, section 4.2.5• Micrometeorite support, section 4.2.5• Added applicable document section 2

TABLE OF CONTENTS

1 OVERVIEW	4
2 APPLICABLE DOCUMENTS	5
3 PHYSICAL LAYER	5
3.1 SIMULATION HARDWARE	5
3.2 CONNECTIONS TO OTHER ITF SYSTEMS	5
3.3 PC INTERFACE	5
4 SOFTWARE LAYER	7
4.1 DESIGN ENVIRONMENT	9
4.2 SIMULATOR SECTIONS	9
4.2.1 MIL-STD-1553 INTERFACE	10
4.2.2 THRUSTER COMMAND PROCESSING	10
4.2.3 ROTOR CHARGE SIMULATION (ONE PER GYROSCOPE)	12
4.2.4 GRAVITY GRADIENT MODEL (ONE PER GYROSCOPE)	13
4.2.5 GYROSCOPE DYNAMICS MODEL (ONE PER GYROSCOPE)	14
4.3 MISCELLANEOUS IO	15
4.4 CONTROLDESK USER INTERFACE	15
5 ALGORITHMS AND ANALYSIS	16
5.1 SPACECRAFT FRAME FORCE AND TORQUE TO ROTOR ACCELERATION	16
5.2 GRAVITY GRADIENT GENERATION	17
5.3 TIMING TEST	18
6 CONSTANT TABLES	19
7 PROGRAM VARIABLES	23

1 Overview

The ITF Drag-Free Gyroscope Simulator (DFGS) is a real-time software simulation of two Gravity Probe B gyroscope rotors inside their housings. It takes as inputs the current commanded electrode voltages by the gyroscope suspension system, the state of the UV charge control lamps, as well as the thruster firing commands generated by the attitude control routines in the main flight computer. The forces generated from these efforts are injected into a dynamic simulation of the gyroscope. The outputs of the simulation are the analog voltages for the gyro suspension system representing the position of the gyroscope rotor. Each input into the dynamics simulation can be enabled and disabled separately, allowing the user to disable feeds that aren't under test.

The DFGS consists of an expansion box connected to a standard Windows PC. The expansion box runs the real-time simulation at high speed, and is controlled and configured through a data link with the PC. The expansion box contains the main processor board, a MIL-STD-1553 interface card for receiving thruster commands, a digital IO card for receiving UV discretes and GSS configuration data, an analog-to-digital converter for receiving GSS control voltages, and a digital-to-analog converter for sending out sensed bridge voltages to the GSS. See Figure 1: DFGS System for the system block diagram.

09/11/02

ITF GSS Gyro Simulator Block Diagram

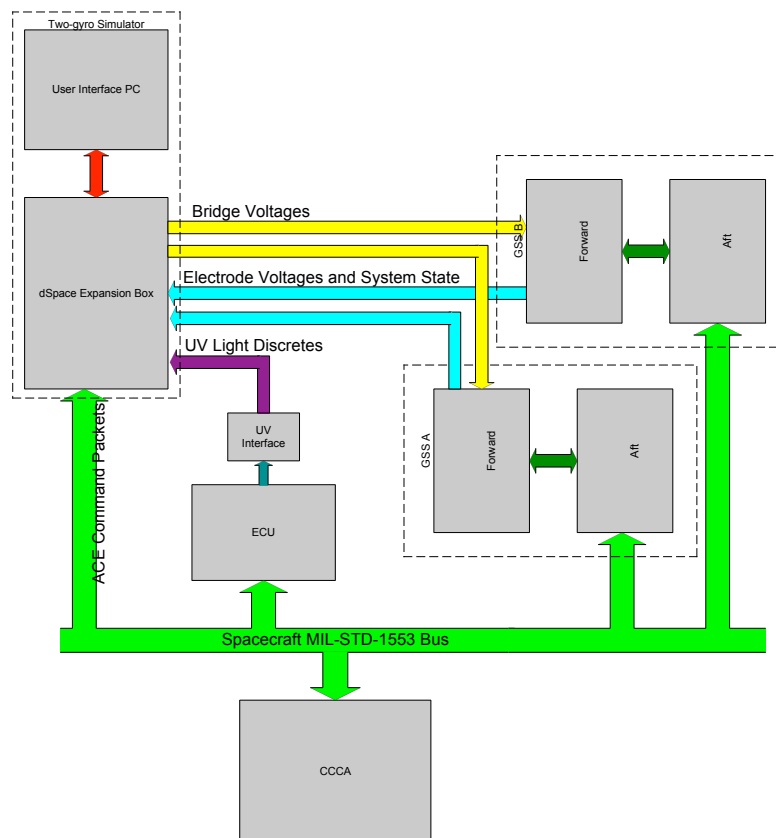


Figure 1: DFGS System

2 Applicable Documents

Document	Document No.	ALIAS
Integrated Test Facility Gyroscope Suspension System (GSS) Documentation	S0723	
Test Procedure for the Drag-Free Gyroscope Simulator Software, Rev. A	P0979	
Version Definition Document for the ITF Drag-Free Gyroscope Simulator, Rev. A	S0759	DFGS TP

3 Physical Layer

3.1 Simulation hardware

The DFGS runs in a real-time environment based on dSpace Inc. hardware, and is contained within an expansion box. The primary processor board, the ds1005, uses a 480 MHz PowerPC 750, sufficient to run the DFGS simulation at roughly a 2 kHz rate, far above both the 660 Hz maximum GSS update rate, and the 10 Hz thruster command update rate.

A ds2003 AD converter board is used to sample the six GSS commanded electrode voltages from both GSS units as well as important GSS system state data, and to feed them into the gyroscope dynamics simulation. On the output, a ds2103 DA converter board is used to send the two simulation-generated positions to the GSS units. A ds4001 Digital IO card reads in the UV discrete status (8 total, two per gyro), as well as optional configuration data from both GSS units.

Finally, a ds4401 interface card is used to connect to the spacecraft MIL-STD-1553 data bus. The DFGS uses remote terminal address 5, the same as the attitude control electronics (ACE) in the actual spacecraft. This allows the DFGS to masquerade as the ACE, receiving the thruster command packets. The DFGS also generates some dummy telemetry data (detailed in section III.B.1) that it transmits back to the flight computer upon request over the 1553 link.

3.2 Connections to other ITF systems

The DFGS has three connections to ITF GSS and UV electronics:

- (1) an analog input cable from each forward GSS unit connects to the AD converter in the expansion box, carrying the commanded electrode voltages, 6 per forward GSS;
- (2) an analog output cable from the DA converter in the expansion box carries the bridge position voltages to the forward GSS units, with three bridge voltages per unit; and
- (3) a digital IO cable from each GSS unit carries a portion of the forward mode register and arbiter status register, merges with the 8 digital UV lamp discretes from the UV interface, and connects to the digital IO card on the expansion box.

See Figure 2: DFGS Cabling Diagram for graphical details.

3.3 PC Interface

The expansion box simulation is configured and controlled from a Windows PC. A fiber-optic link runs from the PC to the expansion box, connecting to a link card. Configuration information (variables such as current gyro to simulate, initial positions/velocities, etc) can be sent from the PC to the expansion box. Also, the PC can log any data input into or generated by the

simulation. Examples include the current position of the gyroscope, and the acceleration generated by attitude control.

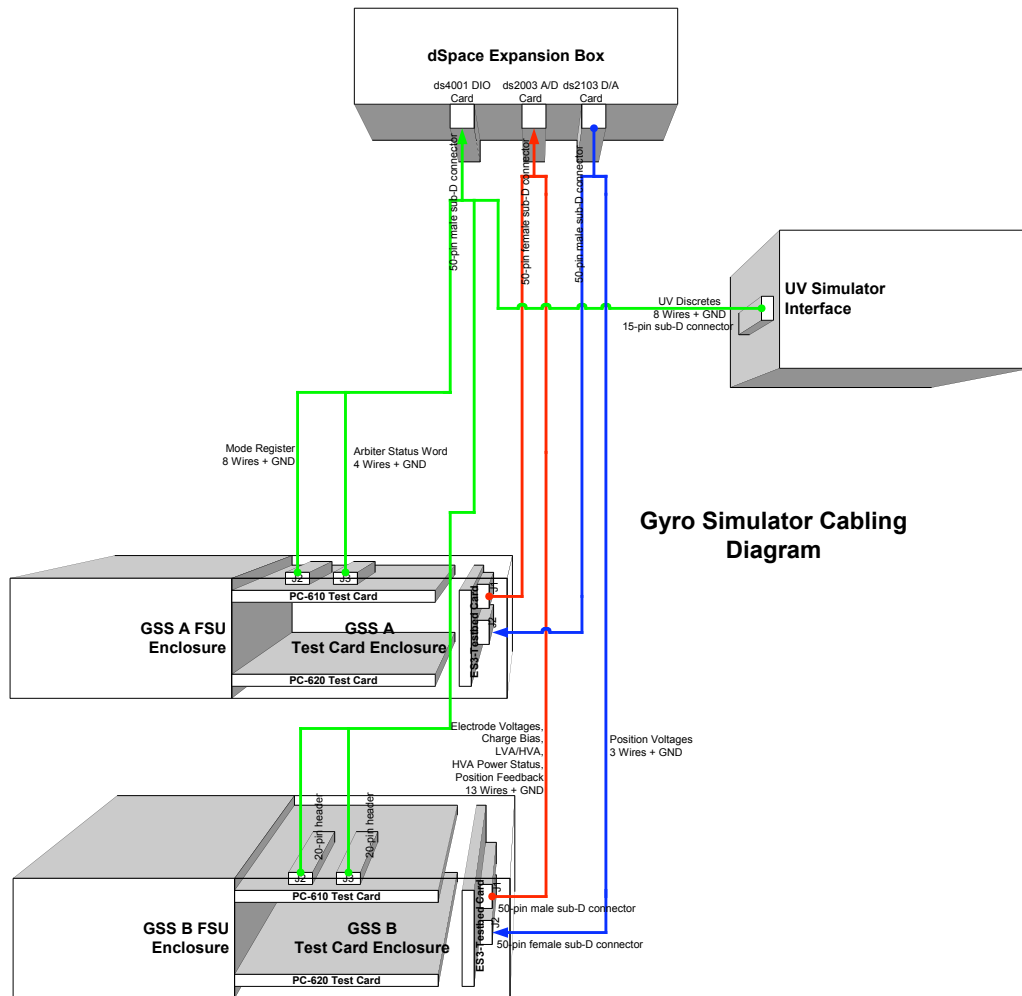


Figure 2: DFGS Cabling Diagram

4 Software layer

The DFGS is a real-time software simulation, running at a fixed rate. The system runs at 5 kHz. The primary loop samples inputs from the AD, Digital IO, and 1553 link cards, performs the necessary calculations, and then outputs results to the DA card, as well as communicating with the controlling PC as necessary. Figure 3: Hardware/Software Block Diagram of DFGS is a block diagram of the hardware and software of the DFGS.

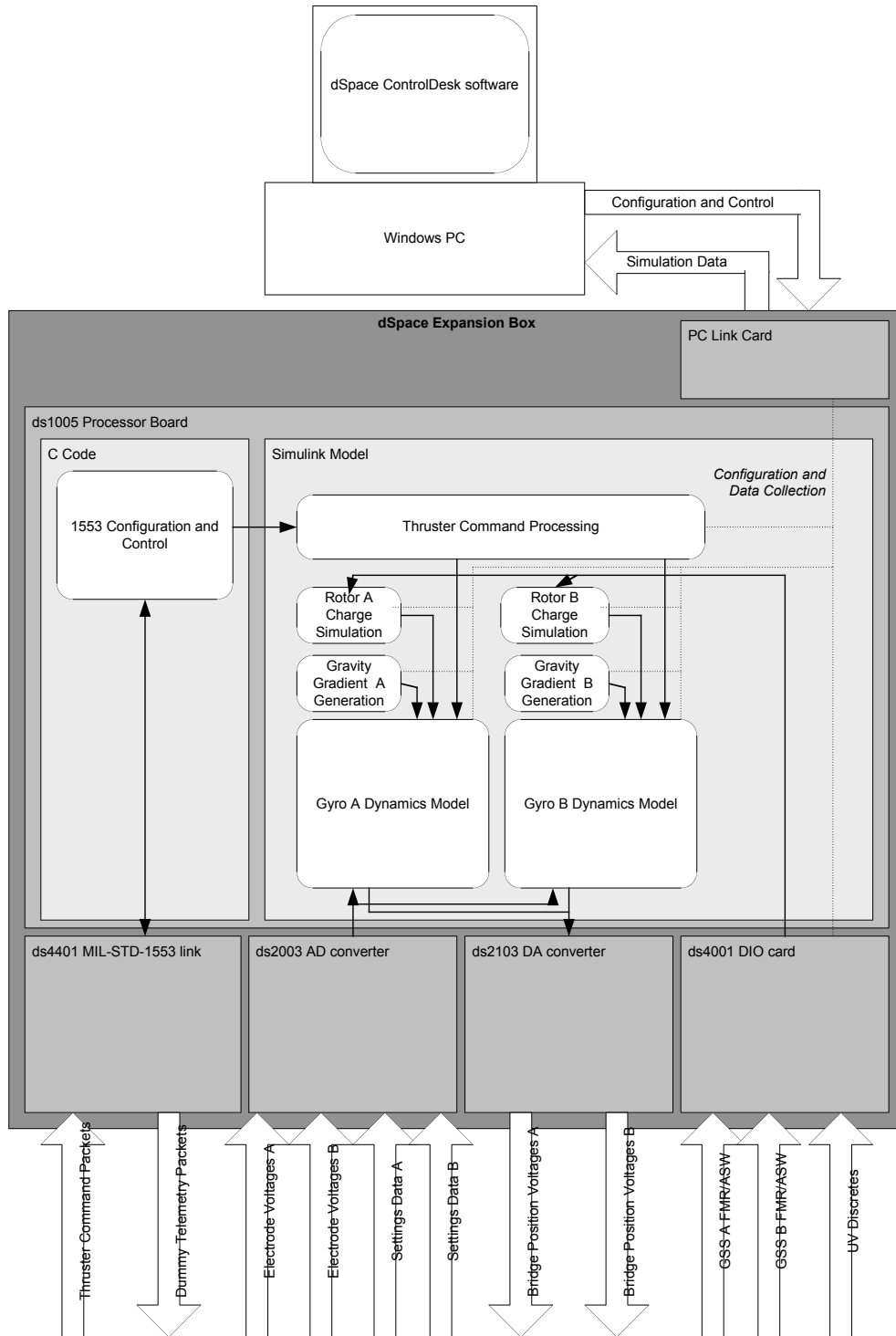


Figure 3: Hardware/Software Block Diagram of DFGS

4.1 Design environment

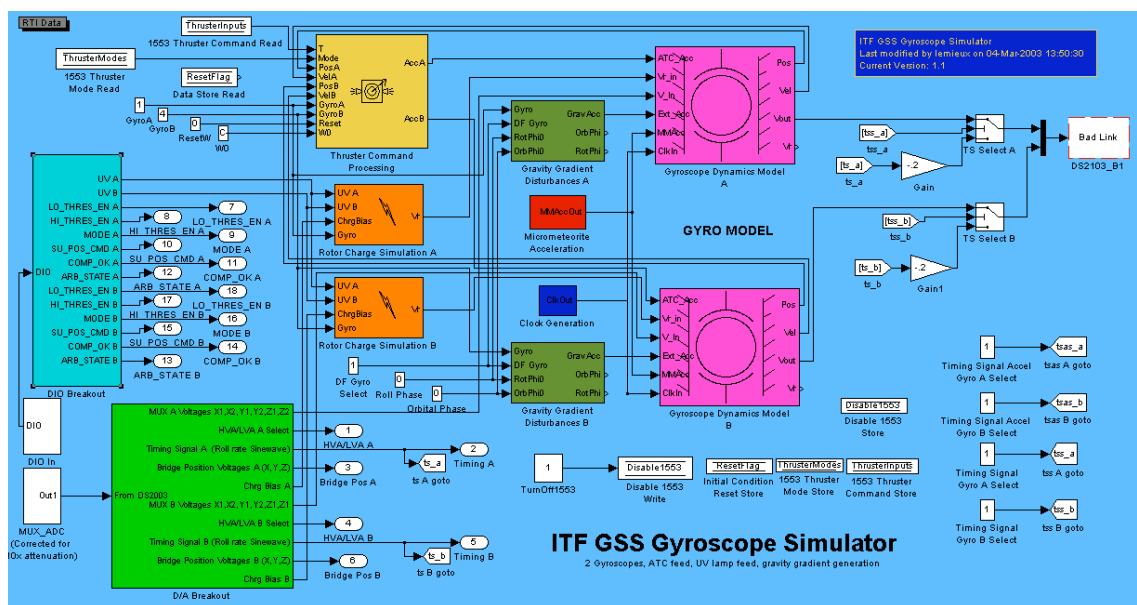
The DFGS is written mainly in Simulink block diagrams, as well as with some custom C code to interface with the 1553 link card. The Simulink model, along with the C code, is compiled by the dSpace software into a real-time model that is downloaded into the expansion box from the controlling PC. The execution rate of the real-time model is a compile-time option, within the limits of available processing power.

4.2 Simulator sections

The simulator has a roughly linear sequence of steps that it follows to convert thruster firing commands and electrode control voltages to position voltage outputs. The original gyro simulator consisted of a gyroscope dynamics model that accepted the commanded electrode voltages, and outputted the position voltages. DFGS adds a second gyroscope to this model, as well as thruster force injection, rotor charge simulation, and gravity gradient generation. The whole process can roughly be divided into five sections, described below.

Figure 4: Model Top Level is the top-level view of the simulator. The ThrusterInputs and ThrusterModes nodes on the left are interfaces to the C code.

Figure 4: Model Top Level



4.2.1 MIL-STD-1553 interface

Inputs:

ACE command packets on RT address 5 from CCCA

Outputs:

To CCCA:

Dummy telemetry data packets

To Thruster Command Processing:

1x16 vector of thruster command counts

1x16 vector of thruster control modes

The interface with the 1553 link card is a small set of C routines executed each simulation cycle by the primary real-time system. The interface configures the ds4401 link card upon simulation initialization, and then monitors the card each cycle. It checks for new command packets, which it parses upon reception. Only the entries for thruster commands (words 1-16 of the command packet) and the thruster mode word (word 29) are currently incorporated in the simulation. The command enable bits are currently not checked.

When the CCCA requests telemetry data packets, the interface generates a 32-byte packet containing all zeros, except for the 10 Hz rollover counter in word 1 of each packet. The 10 Hz counter is incremented by one after each round of telemetry packet reads. This should update the counter at the CCCA-expected 10 Hz rate.

4.2.2 Thruster Command Processing

Inputs:

1x16 vector of thruster command counts

1x16 vector of thruster control modes

2 1x3 vectors of gyro rotor positions

2 1x3 vectors of gyro rotor velocities

Gyro number selection for gyro A

Gyro number selection for gyro B

Reset signal for resetting angular velocity

1x3 vector of initial angular velocity for startup and reset

Outputs:

2 1x3 vectors of gyro rotor accelerations due to attitude control

Constants:

Array of thruster gains for each thruster in each mode

Array of thruster biases for each thruster in each mode

Thruster force to thruster pair force transform matrix

Thruster pair force to body frame force transform matrix

Thruster pair force to body frame torque transform matrix

Satellite mass

Satellite moment of inertia, body frame

Satellite inverse moment of inertia, body frame

Body-to-gyroscope frame transform matrices for each gyro

Gyroscope position vectors relative to center of gravity, electrode frame

The Thruster Command Processing system receives ATC-sent thruster commands, which it converts to apparent accelerations on the gyroscope rotors. It uses the current rotor positions and velocities, as well as which gyroscopes are currently being simulated, in the calculation. First, raw command counts are converted to Newtons using the following equations:

$$\text{Thruster_Force}(i) = \text{Gain}(i, \text{Thruster_Mode}(i)) * \text{Thruster_Command}(i) + \text{Bias}(i, \text{Thruster_Mode}(i))$$

Next, in two steps, the system converts the individual thruster forces into a single force and torque vector in the frame of the drag-free gyroscope electrodes. First, the 16 thruster forces are combined into 8 pair forces, since the thrusters operate as pairs with opposite thrust vectors. Then, two 8x3 transform matrices are used to calculate the force and torque vectors in the spacecraft body frame. The force vector is then divided by spacecraft mass to calculate the acceleration vector due to force.

$$\begin{aligned} \text{Pair_Forces}(i) &= \text{Thruster_Force}(2*i-1) - \text{Thruster_Force}(2*i) \quad (i=1..8) \\ \text{Force_Body_Frame} &= \text{ThrusterToBodyForce_Transform} * \text{Pair_Forces} \\ \text{Torque_Body_Frame} &= \text{ThrusterToBodyTorque_Transform} * \text{Pair_Forces} \\ \text{Linear_Acc_Body_Frame} &= \text{Force_Body_Frame} / \text{Spacecraft_Mass} \end{aligned}$$

The next step takes the torque vector as calculated above, and uses Euler's equations of motion to calculate the angular acceleration of the spacecraft in the body frame. It then integrates the angular acceleration to determine angular velocity.

$$\begin{aligned} \text{Angular_Acceleration_Body} &= (\text{Inverse_Moment_Of_Inertia}) * \\ &\quad (\text{Torque_Body_Frame} - \\ &\quad \quad \text{Angular_Velocity} \times (\text{Moment_of_Inertia} * \text{Angular_Velocity}) \\ &\quad) \\ \text{Angular_Velocity_Body} &= \text{Integral}(\text{Angular_Acceleration_Body}) + \text{Initial_Angular_Velocity} \end{aligned}$$

Because the electrode housing frame is a non-inertial, rotating frame, the pseudo-accelerations caused by the Coriolis and centripetal effects must be factored in. These effects are relative to the spacecraft center of mass, so a constant position vector from the center of the electrode frame to the cg of the spacecraft must be added to gyroscope position readouts. These calculations are gyroscope-specific, as they each have their own position and coordinate frame orientation. Therefore, the equations for the apparent linear acceleration of the gyroscope rotor in the spacecraft electrode frame become:

$$\begin{aligned} \text{Linear_Acc_Elec} &= \text{Electrode_Transform}(\text{Selected_Gyro}) * \text{Linear_Acc} \\ \text{Angular_Velocity_Elec} &= \text{Electrode_Transform}(\text{Selected_Gyro}) * \text{Angular_Velocity_Body} \\ \text{Angular_Acceleration_Elec} &= \text{Electrode_Transform}(\text{Selected_Gyro}) * \\ &\quad \text{Angular_Acceleration_Body} \\ \text{Rotor_Acceleration} &= - \text{Linear_Acc_Elec} - \\ &\quad \text{Angular_Acceleration_Elec} \times (\text{Rotor_Position} + \\ &\quad \quad \text{Housing_Position}(\text{Selected_Gyro})) - \\ &\quad 2 * \text{Angular_Velocity_Elec} \times \text{Rotor_Velocity} - \\ &\quad \text{Angular_Velocity_Elec} \times (\text{Angular_Velocity_Elec} \times \\ &\quad \quad (\text{Rotor_Position} + \\ &\quad \quad \quad \text{Housing_Position}(\text{Selected_Gyro}))) \end{aligned}$$

This calculation is performed for each gyroscope rotor, and the two resulting rotor acceleration vectors are then output. See Figure 5: Thruster Command Processing.

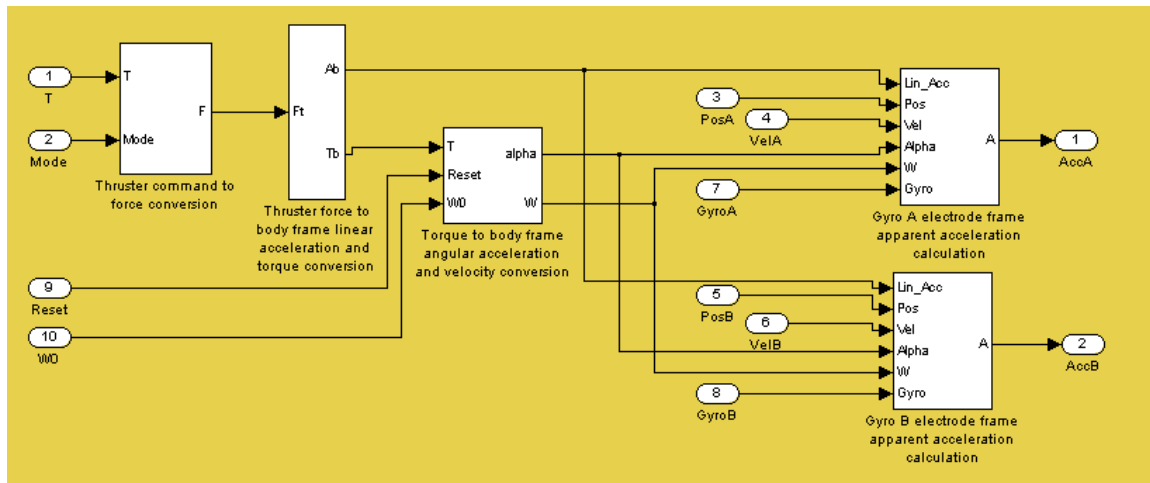


Figure 5: Thruster Command Processing

4.2.3 Rotor charge simulation (one per gyroscope)

Inputs:

Charge bias from forward GSS
UV light status

Outputs:

Rotor voltage

Constants:

Charge/Discharge rates for all charge bias settings

The rotor charge simulation contains a simple environmental charging model for the gyroscope rotor, including SAA passthrough. This simulation is uncorrelated with the outside world, so it does not match charging rate with actual orbital position as calculated by the VES. It takes in the charge bias setting from the GSS, which determines the voltage on the discharge electrodes. It also reads in whether the UV light channels to the gyro are lit or not, and uses these facts to calculate the instantaneous rotor charging rate. This value is then integrated to obtain the rotor voltage that is output to the dynamics simulation. See Figure 6: Rotor Charge Simulation A/B.

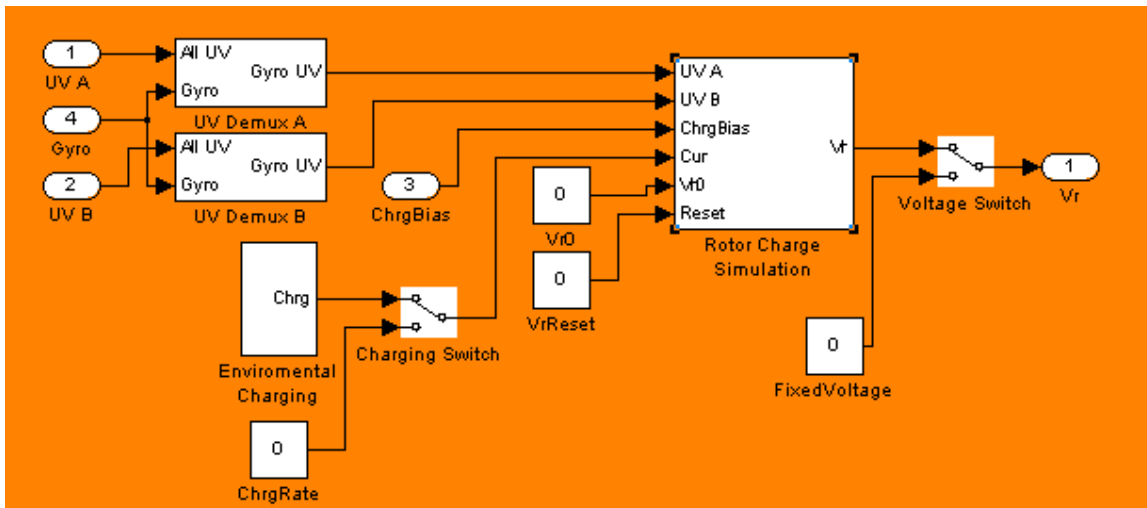


Figure 6: Rotor Charge Simulation A/B

4.2.5 Gyroscope dynamics model (one per gyroscope)

Inputs:

3-vector of attitude control rotor acceleration
Rotor voltage
3-vector of gravity gradient acceleration
6-vector of electrode voltages
3-vector micrometeorite impulse acceleration
1-vector clock input

Outputs:

To rest of model:
3-vector of rotor position
3-vector of rotor velocity
Corrected rotor voltage
To GSS forward unit:
3-vector of sensed bridge position voltages

Constants:

Initial position of rotor
Initial velocity of rotor
Locations of housing walls
Bridge capacitance values
Rotor mass

The gyroscope dynamics model incorporates the apparent gyroscope acceleration calculated above into a simulation of the gyroscope position. It also calculates the effects of the gyroscope suspension system commanded electrode voltages on the rotor, as well as the capacitance on the electrodes based on the position of the rotor. It also adds to it several external accelerations including: micrometeorite impact acceleration, spin up gas acceleration, and a constant applied acceleration. All accelerations are configured via the Control Desk interface by the operator. It outputs the position and velocity of the rotor, so that they can be fed back into earlier stages of calculation. Fundamentally, the simulation is a three-dimensional double-integrator with saturation limits at the wall positions, with a non-linear force calculation from the electrode voltages. It also includes a simulation of the GSS sensing bridge to calculate the sensed voltages. See Figure 8: Gyroscope Dynamics Model A/B.

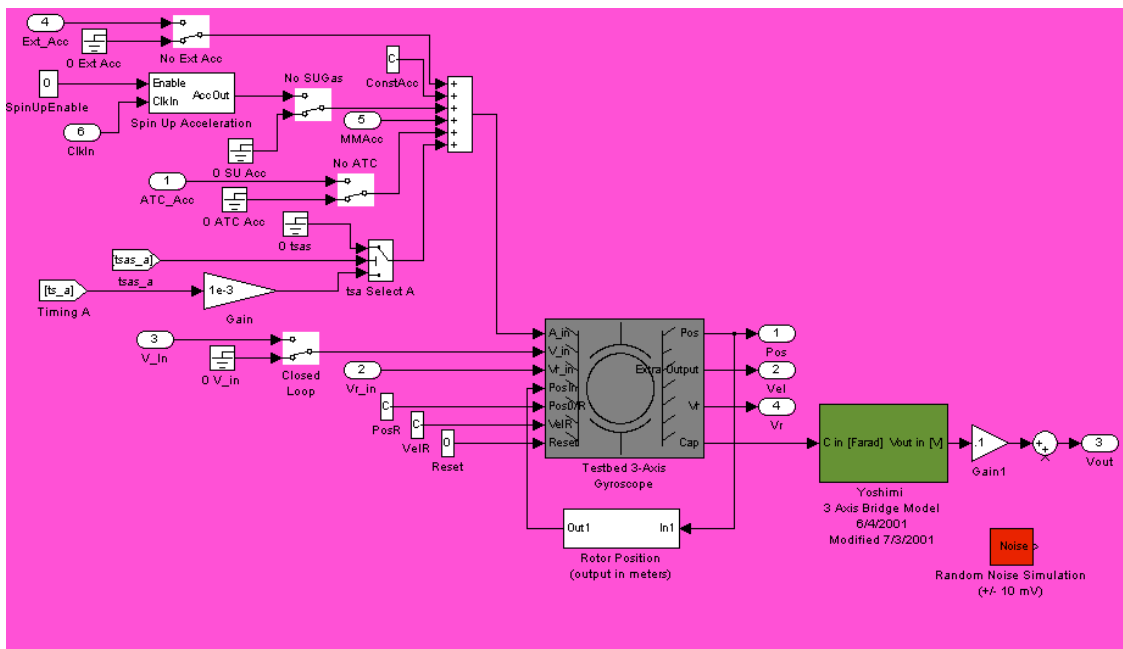


Figure 8: Gyroscope Dynamics Model A/B

4.3 Miscellaneous IO

The IO modules of the simulation are straightforward. As an example, see Figure 9: DIO Breakout.

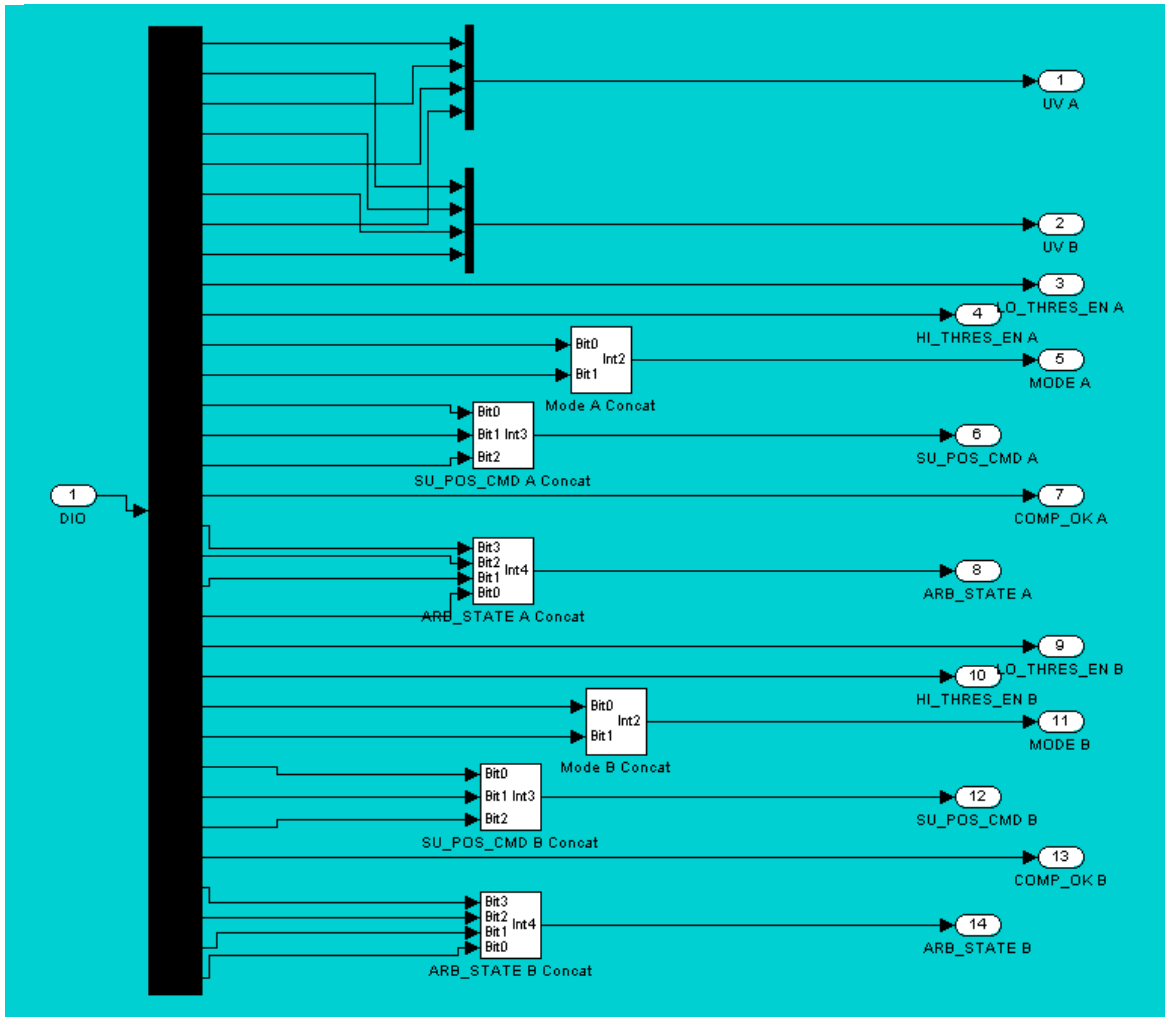


Figure 9: DIO Breakout

4.4 ControlDesk user interface

See the "ITF Drag-Free Gyroscope Simulator (DFGS) User Guide" document, S0720 for details of the user interface and configuration.

5 Algorithms and analysis

5.1 Spacecraft frame force and torque to rotor acceleration

In an inertial reference frame, a force applied to the satellite would create an apparent acceleration on the rotor, in the gyroscope electrode frame, which is simply the opposite of the acceleration that the spacecraft experiences as a result of the force. That is, the acceleration would simply be where F is the force applied to the spacecraft, and x is the position of the gyroscope rotor relative to the center of gravity of the spacecraft.

$$(1) \quad \ddot{x} = -\frac{F}{m_{GP-B}}$$

In addition, a torque applied to the spacecraft also generates an apparent acceleration on the gyroscope rotor, as the housing frame rotates around the rotor. A simple approach would be to treat this apparent acceleration as the opposite of the acceleration the rotor would experience as a result of the torque if it were attached to the housing. The torque acts about the center of mass of the spacecraft, which is a constant displacement away from the zero point of the electrode frame. Accounting for this offset, and adding this term to (1) results in

$$(2) \quad \ddot{x} = -\frac{F}{m_{GP-B}} - \ddot{\theta} \times (x + r)$$

where θ is the attitude of the spacecraft, and r is the position vector from the cg of the spacecraft to the center of the gyroscope electrode frame.

However, this term incorporates angular acceleration, not the torque vector. The angular acceleration can be calculated from the torque, using Euler's equations of motion for a rigid body, which states that

$$(3) \quad I \cdot \ddot{\theta} + \dot{\theta} \times (I \cdot \dot{\theta}) = T$$

where I is the moment of inertia tensor for the spacecraft (for this application, the deployed configuration is used), and T is the torque vector. Solving for angular acceleration, we obtain

$$(4) \quad \ddot{\theta} = I^{-1} \cdot [T - \dot{\theta} \times (I \cdot \dot{\theta})]$$

But this straightforward approach is not strictly correct. The electrode frame is a non-inertial, rotating frame, which requires the inclusion of other terms in the apparent acceleration. Specifically, two pseudoforces must be included: the Coriolis effect, and the centripetal effect. Each of these contributes an additional term to (2), resulting in

$$(5) \quad \ddot{x} = -\frac{F}{m_{GP-B}} - \ddot{\theta} \times (x + r) - 2\dot{\theta} \times \dot{x} - \dot{\theta} \times (\dot{\theta} \times (x + r))$$

where all the vectors are in the electrode frame.

Additionally, both (4) and (5) refer to the angular velocity of the spacecraft, which must be determined. This is done with an integration of the angular acceleration from time 0 to the current time, and with the inclusion of an initial angular velocity in the model.

$$(6) \quad \dot{\theta}(t) = \int_0^t \ddot{\theta}(t) dt + \dot{\theta}_{initial}$$

Equations (4), (5), and (6) combined allow for the calculation of the apparent gyroscope rotor acceleration from the applied force and torque vectors and the current position and velocity of the gyroscope rotor. They account for the non-inertial nature of the electrode measurement frame, and the three-dimensional nature of the applied torques.

5.2 Gravity gradient generation

A suspended gyroscope experiences a gravity gradient pseudoforce as the satellite follows the drag-free mass. This pseudoforce is proportional to the separation of the rotors, and assuming the rotor is aligned with the orbital plane, the resulting acceleration becomes:

$$(7) \quad F_{gg} = \frac{\mu}{m_{rotor} R^3} l \left\{ \begin{array}{l} \hat{x} \left[\frac{3}{2} \cos \phi_r \sin 2(\phi_o - \theta) \right] + \\ \hat{y} \left[-\frac{3}{2} \sin \phi_r \sin 2(\phi_o - \theta) \right] + \\ \hat{z} \left[\frac{1}{2} + \frac{3}{2} \cos 2(\phi_o - \theta) \right] \end{array} \right\}$$

Where Φ_o is the orbital phase, Φ_r is the roll phase, and Θ is the orientation of the spacecraft frame in relation to the local inertial frame.

5.3 Timing Test

The ITF Timing tests are a series of tests designed to measure GPB's time tagging system. A sketch of the ITF Timing Test Part B configuration is shown in Figure 11. Each payload box in the ITF is representative (engineering unit, flight like, or flight spare) of an actual box being flown during the mission. A sine wave output by the Roll Frequency Sine Wave generator, is injected into each payload box. The phase of the sine wave is known because a zero crossing pulse is input into the SRE PPS port (normally filled by the GPS PPS cable). The telemetry from each box also shows the sine wave, albeit phased delayed by the box's processing, as well as any space craft processing. The phase of the input sine wave is compared to the phase of the output sine wave, and the difference is the time delay. The basic setup for the test already exists;

approximately 30 minutes are required to unplug the GPS PPS cable from the Aft SRE and replace it with the Zero Crossing Pulse cable from the Roll Frequency Sine Wave Generator and Telescope Simulator. The gyro model used is discussed elsewhere in this document. A BNC cable from the Roll frequency Sine Wave Generator is plugged into the Jt1 plug on the forward GSU (shown on Test Card 3-ITF of the hardware documentation, S0723).

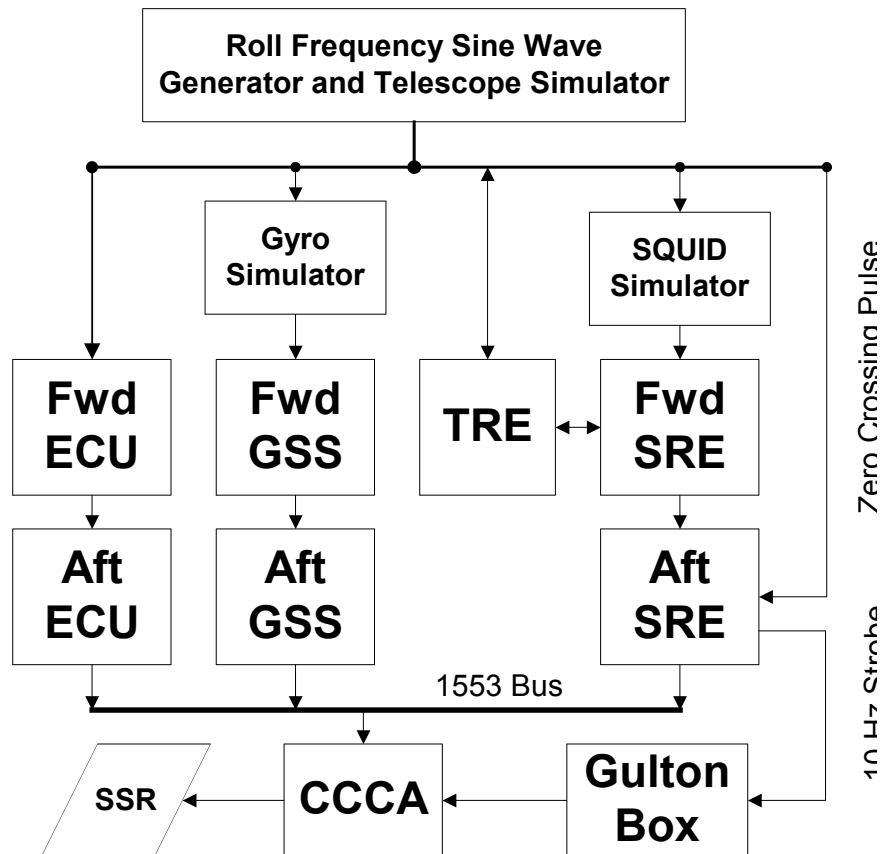


Figure 10

6 Constant Tables

The simulation depends on a large number of physical constants. The values used are summarized below. Note that many vectors used in the simulator are row vectors, requiring transform matrices to be transposed.

Thruster Command Gain, Open Loop =

0.49937495229926e-5, 0.32818857836230e-5,
0.36063607644118e-5, 0.41192172662735e-5,
0.40533710581568e-5, 0.38954651447159e-5,
0.36511279573848e-5, 0.40741346517242e-5,
0.46806192256532e-5, 0.38712399920224e-5,
0.35629258478825e-5, 0.37739587867414e-5,
0.49526684180526e-5, 0.45850175261606e-5,
0.39158238059532e-5, 0.34776495085792e-5

Thruster Command Bias, Open Loop=

0.00413978329141, 0.00352853037394,
0.00342814920534, 0.00250473625176,
0.00371463094928, 0.00360689524736,
0.00341002491873, 0.00335063940776,
0.00372125312135, 0.00314566725749,
0.00361483716894, 0.00371359529191,
0.00384754721515, 0.00409513805620,
0.00287223170520, 0.00322523603632

Thruster Command Gain, Closed Loop =

0.13415141236881e-4, 0.14627138728317e-4,
0.14579643513257e-4, 0.13028573467375e-4,
0.14648604201545e-4, 0.14243007286866e-4,
0.14231622714748e-4, 0.13824841282013e-4,
0.13077498259782e-4, 0.14417404849951e-4,
0.13866435894790e-4, 0.13986555182873e-4,
0.13878763516407e-4, 0.13880395538837e-4,
0.14048076789511e-4, 0.13848523260889e-4

Thruster Command Bias, Closed Loop =

-0.00051199808484, 0.00044875296170,
-0.00130100823545, -0.00005634549008,
-0.00053913224418, 0.00085341474090,
-0.00037984816593, -0.00048862818560,
-0.00046331116379, -0.00086186306563,
-0.00101391029548, -0.00070500145601,
-0.00143911396630, 0.00021342484667,
-0.00341075405664, 0.00038006513888

Thruster Command Gain, ATC Hack Mode, All Thrusters = 2.0e-6

Thruster Command Bias, ATC Hack Mode, All Thrusters = 0

Thruster Forces To Thruster Pairs Conversion=

[1 0 0 0 0 0 0 0;
-1 0 0 0 0 0 0 0;

```

0 1 0 0 0 0 0 0;
0 -1 0 0 0 0 0 0;
0 0 1 0 0 0 0 0;
0 0 -1 0 0 0 0 0;
0 0 0 1 0 0 0 0;
0 0 0 -1 0 0 0 0;
0 0 0 0 1 0 0 0;
0 0 0 0 -1 0 0 0;
0 0 0 0 0 1 0 0;
0 0 0 0 0 -1 0 0;
0 0 0 0 0 0 1 0;
0 0 0 0 0 0 -1 0;
0 0 0 0 0 0 0 1;
0 0 0 0 0 0 0 -1]

```

Thruster Pairs to Spacecraft Body Frame Force Transform=

```

[1 0 0;
1 0 0;
0 1 0;
0 1 0;
0 1 0;
0 1 0;
0 0 1;
0 0 1]

```

Thruster Pairs to Spacecraft Body Frame Torque Transform=

```
[0  2.51  0;
0  -1.9  0;
1.9  0  1.19;
-2.51 0  -1.19;
1.9  0  -1.19;
-2.51 0  1.19;
0  1.19  0;
0  -1.19  0] m
```

Spacecraft Body Frame to GSS1 Transform=

```
[-0.57735026918963 -0.40824829046386 0.70710678118655;
-0.57735026918963 -0.40824829046386 -0.70710678118655;
-0.57735026918963 0.81649658092773 0]'
```

Spacecraft Body Frame to GSS2 Transform=

```
[-0.57735026918963 0.40824829046386 -0.70710678118655;
-0.57735026918963 0.40824829046386 0.70710678118655;
-0.57735026918963 -0.81649658092773 0]'
```

Spacecraft Body Frame to GSS3 Transform=

```
[ 0.40824829046386 -0.57735026918963 0.70710678118655;
0.40824829046386 -0.57735026918963 -0.70710678118655;
-0.81649658092773 -0.57735026918963 0]'
```

Spacecraft Body Frame to GSS4 Transform=

```
[-0.40824829046386 -0.57735026918963 -0.70710678118655;
-0.40824829046386 -0.57735026918963 0.70710678118655;
0.81649658092773 -0.57735026918963 0]'
```

GP-B Moment of Inertia Tensor=

```
[5226 0 0;
0 5337 0;
0 0 3486] kg*m^2
```

GP-B Inverse Moment of Inertia Tensor=

```
1.0e-003 *
[0.19135093761959 0 0
0 0.18737118231216 0
0 0 0.28686173264487] 1/kg*m^2
```

GP-B Vehicle Mass:

3309.8 kg

CG to GSS1 Center of Housing= (electrode frame)

[-0.0984 0.0984 0] m

CG to GSS2 Center of Housing= (electrode frame)

[0.1567 -0.1567 0] m

CG to GSS3 Center of Housing= (electrode frame)

[-0.2150 0.2150 0] m

CG to GSS4 Center of Housing= (electrode frame)

[0.2734 -0.2734 0] m

Charge Bias to Charge Rate Mapping=
[0.00 1.8e-3/60/60 -18e-3/60/60] V/s

Orbit Period=
90*60 sec

Distance between gyros=
82.55e-3 m

Orbit radius=
6.3782e6+700e3 m

Gravitational Constant=
6.672e-11 Nm^2/kg^2

Mass of Earth=
5.983e24 kg

7 Program Variables

This section lists all the interesting variables in the gyroscope simulator, and their names as they appear on the ControlDesk variable browser. All these variables, unless otherwise noted, are under gyro_simulator_2/Model Root, and that part of the variable path is not listed.

Hardware inputs/outputs:

D/A inputs:

Bridge Position Voltages Loopback Gyro A:
D/A Breakout/Bridge Position Voltages A (X,Y,Z)
Timing Signal Gyro A (HV Power Status):
D/A Breakout/Timing Signal A (Roll rate Sinewave)
Unadjusted Gyro A Control Voltages:
D/A Breakout/MUX A Output Voltage MUX/Out1
HVA/LVA Relay Gyro A:
D/A Breakout/HVA/LVA A Select
Charge Bias Gyro A:
D/A Breakout/Chrg Bias A
Bridge Position Voltages Loopback Gyro B:
D/A Breakout/Bridge Position Voltages B (X,Y,Z)
Timing Signal Gyro B (HV Power Status):
D/A Breakout/Timing Signal B (Roll rate Sinewave)
Unadjusted Gyro B Control Voltages:
D/A Breakout/MUX B Output Voltage MUX/Out1
HVA/LVA Relay Gyro B:
D/A Breakout/HVA/LVA A Select
Charge Bias Gyro B:
D/A Breakout/Chrg Bias B

A/D Outputs:

Gyro A Bridge Position Voltages:
Gyroscope Dynamics Model A/Vout
Gyro B Bridge Position Voltages:
Gyroscope Dynamics Model B/Vout

Digital IO Inputs:

Light Valve A Status for Gyros 1-4:
DIO Breakout/UV A
Light Valve B Status for Gyros 1-4:
DIO Breakout/UV B
Gyro A Forward Mode Register: Low Threshold Enabled Bit:
DIO Breakout/LO_THRES_EN A
Gyro A Forward Mode Register: High Threshold Enabled Bit:
DIO Breakout/HI_THRES_EN A
Gyro A Forward Mode Register: Mode Bits:
DIO Breakout/MODE A
Gyro A Forward Mode Register: Spinup Position Command:
DIO Breakout/SU_POS_CMD A
Gyro A Forward Mode Register: Computer OK Bit:
DIO Breakout/COMP_OK A
Gyro A Arbiter Status Word: Arbiter Status:
DIO Breakout/ARB_STATE A
Gyro B Forward Mode Register: Low Threshold Enabled Bit:
DIO Breakout/LO_THRES_EN B
Gyro B Forward Mode Register: High Threshold Enabled Bit:
DIO Breakout/HI_THRES_EN B

Gyro B Forward Mode Register: Mode Bits:
DIO Breakout/MODE B
Gyro B Forward Mode Register: Spinup Position Command:
DIO Breakout/SU_POS_CMD B
Gyro B Forward Mode Register: Computer OK Bit:
DIO Breakout/COMP_OK B
Gyro B Arbiter Status Word: Arbiter Status:
DIO Breakout/ARB_STATE B

MIL-STD-1553 Inputs and Outputs:

Raw thruster commands:
1553 Thruster Command Read/Out1
Raw thruster modes:
1553 Thruster Mode Read/Out1
Reset flag (unused):
Data Store Read/Out1
1553 Link enable/disable (1-disable, 0-enable):
TurnOff1553/Out1

Top-level configuration variables

Gyro A simulation gyroscope
GyroA/Out1
Gyro B simulation gyroscope
GyroB/Out1
Initial spacecraft angular velocity (rad/s)
W0/Out1
Reset line for angular velocity (resets value on transition)
ResetW/Out1
Gravity Gradient drag-free gyro select
DF Gyro Select/Out1
Gravity gradient orbit model initial roll phase (rad)
Roll Phase/Out1
Gravity gradient orbit model initial orbit phase (rad)
Orbital Phase/Out1
Timing Signal Gyro A Select
Timing Signal Gyro A Select/Out1
Timing Signal Gyro B Select
Timing Signal Gyro B Select/Out1
Timing Signal Acceleration Gyro A Select
Timing Signal Accel Gyro A Select/Out1
Timing Signal Acceleration Gyro B Select
Timing Signal Accel Gyro B Select/Out1

ATC and thruster variables

Adjusted thruster mode vector:
Thruster Command Processing/Thruster command to force conversion/Sum/Out1
Currently used counts-to-force gain vector
*Thruster Command Processing/Thruster command to force conversion/Gain
Select/Out1*
Currently used counts-to-force bias vector
*Thruster Command Processing/Thruster command to force conversion/Bias
Select/Out1*
Thruster forces vector (N, all 16 thruster forces)
Thruster Command Processing/Thruster command to force conversion/F
Thruster pair forces vector (N, 8 thruster pair forces)
*Thruster Command Processing/Thruster force to body frame linear acceleration and
torque conversion/Thruster Pair Combine/out1*
Force on spacecraft CG (N, spacecraft frame)

Thruster Command Processing/Thruster force to body frame linear acceleration and torque conversion/Thruster-to-body frame force transform/out1
Torque on spacecraft CG (N*m, spacecraft frame)
Thruster Command Processing/Thruster force to body frame linear acceleration and torque conversion/Tb
Linear acceleration on spacecraft CG(m/s², spacecraft frame)
Thruster Command Processing/Thruster force to body frame linear acceleration and torque conversion/Ab
 $\omega \times (I * \omega)$ (ω =ang.velocity, I=moment of inertia)
*Thruster Command Processing/Torque to body frame angular acceleration and velocity conversion/w x (I*w)/Out1*
Spacecraft angular acceleration (rad/s²)
Thruster Command Processing/Torque to body frame angular acceleration and velocity conversion/alpha
Spacecraft angular velocity (rad/s)
Thruster Command Processing/Torque to body frame angular acceleration and velocity conversion/W
Gyro A currently selected body-to-electrode frame transform matrix:
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Multiport Switch/Out1
Gyro A electrode frame linear acceleration (m/s²)
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/linear acc to electrode frame/Out1
Gyro A electrode frame spacecraft angular acceleration (rad/s²)
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/alpha to electrode frame/Out1
Gyro A electrode frame spacecraft angular velocity (rad/s)
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/omega to electrode frame/Out1
Gyro A currently selected gyroscope position vector:
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Rotating Frame Compensation/Multiport Switch/Out1
Gyro A apparent centripetal acceleration (m/s²):
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Rotating Frame Compensation/Gain/Out1
Gyro A apparent coriolis force acceleration (m/s²):
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Rotating Frame Compensation/W x (W xR)/Out1
Gyro A linear acceleration due to angular acceleration (m/s²):
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Rotating Frame Compensation/Alpha X R/Out1
Gyro A rotating frame compensation net acceleration adjustment (m/s²):
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/Rotating Frame Compensation/Acc
Gyro A total apparent rotor acceleration due to ATC (m/s²):
Thruster Command Processing/Gyro A electrode frame apparent acceleration calculation/A
Gyro B currently selected body-to-electrode frame transform matrix:
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Multiport Switch/Out1
Gyro B electrode frame linear acceleration (m/s²)
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/linear acc to electrode frame/Out1
Gyro B electrode frame spacecraft angular acceleration (rad/s²)
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/alpha to electrode frame/Out1

Gyro B electrode frame spacecraft angular velocity (rad/s)
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/omega to electrode frame/Out1
 Gyro B currently selected gyroscope position vector:
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Rotating Frame Compensation/Multiport Switch/Out1
 Gyro B apparent centripetal acceleration (m/s^2):
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Rotating Frame Compensation/Gain/Out1
 Gyro B apparent coriolis force acceleration (m/s^2):
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Rotating Frame Compensation/W x (W x R)/Out1
 Gyro B linear acceleration due to angular acceleration (m/s^2):
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Rotating Frame Compensation/Alpha X R/Out1
 Gyro B rotating frame compensation net acceleration adjustment (m/s^2):
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/Rotating Frame Compensation/Acc
 Gyro B total apparent rotor acceleration due to ATC (m/s^2):
Thruster Command Processing/Gyro B electrode frame apparent acceleration calculation/A

Rotor charge simulation variables:

Gyro A UV Valve A Status:
Rotor Charge Simulation A/UV Demux A/Gyro UV
 Gyro A UV Valve B Status:
Rotor Charge Simulation A/UV Demux B/Gyro UV
 Gyro A Initial voltage for charging rotor model:
Rotor Charge Simulation A/Vr0/Out1
 Gyro A reset line for initial voltage for charging rotor model:
Rotor Charge Simulation A/VrReset/Out1
 Gyro A charge rate value for fixed charge rate model:
Rotor Charge Simulation A/ChrgRate/Out1
 Gyro A fixed rotor voltage for fixed voltage model:
Rotor Charge Simulation A/FixedVoltage/Out1
 Gyro A environmental model current charge rate output:
Rotor Charge Simulation A/Environmental Charging/Chrg
 Gyro A discharge rate for current charge bias setting:
Rotor Charge Simulation A/Rotor Charge Simulation/Multiport Switch/Out1
 Gyro A total discharge rate:
Rotor Charge Simulation A/Rotor Charge Simulation/Discharge On/Off/Out1
 Gyro A total charge rate:
Rotor Charge Simulation A/Charging Switch/Out1
 Gyro A combined charge/discharge rate:
Rotor Charge Simulation A/Rotor Charge Simulation/Sum/Out1
 Gyro A charging model rotor voltage:
Rotor Charge Simulation A/Rotor Charge Simulation/Vr
 Gyro A rotor voltage:
Rotor Charge Simulation A/Vr
 Gyro B UV Valve A Status:
Rotor Charge Simulation B/UV Demux A/Gyro UV
 Gyro B UV Valve B Status:
Rotor Charge Simulation B/UV Demux B/Gyro UV
 Gyro B Initial voltage for charging rotor model:
Rotor Charge Simulation B/Vr0/Out1
 Gyro B reset line for initial voltage for charging rotor model:
Rotor Charge Simulation B/VrReset/Out1

Gyro B charge rate value for fixed charge rate model:
Rotor Charge Simulation B/ChrgRate/Out1
Gyro B fixed rotor voltage for fixed voltage model:
Rotor Charge Simulation B/FixedVoltage/Out1
Gyro B environmental model current charge rate output:
Rotor Charge Simulation B/Environmental Charging/Chrg
Gyro B discharge rate for current charge bias setting:
Rotor Charge Simulation B/Rotor Charge Simulation/Multiport Switch/Out1
Gyro B total discharge rate:
Rotor Charge Simulation B/Rotor Charge Simulation/Discharge On/Off/Out1
Gyro B total charge rate:
Rotor Charge Simulation B/Charging Switch/Out1
Gyro B combined charge/discharge rate:
Rotor Charge Simulation B/Rotor Charge Simulation/Sum/Out1
Gyro B charging model rotor voltage:
Rotor Charge Simulation B/Rotor Charge Simulation/Vr
Gyro B rotor voltage:
Rotor Charge Simulation B/Vr

Gravity gradient simulation variables:

Gyro A body-to-electrode frame transform matrix:
Gravity Gradient Disturbances A/Multiport Switch/Out1
Gyro A normalized orbital gravity gradient vector:
Gravity Gradient Disturbances A/Gravity Gradient Acceleration Vector in Orbit Frame/f_gg_Orbit
Gyro A orbital phase:
Gravity Gradient Disturbances/OrbPhi
Gyro A actual orbital gravity gradient vector:
Gravity Gradient Disturbances A/CG_Gain/Out1
Gyro A separation from drag-free gyro. (measured in multiples of one gyro separation)
Gravity Gradient Disturbances A/Sum/Out1
Gyro A gravity gradient vector in spacecraft frame
Gravity Gradient Disturbances A/Orbit to Quartz Block Transformation/R_QB
Gyro A spacecraft roll phase
Gravity Gradient Disturbances A/RotPhi
Gyro A electrode frame gravity gradient acceleration
Gravity Gradient Disturbances A/GravAcc
Gyro B body-to-electrode frame transform matrix:
Gravity Gradient Disturbances B/Multiport Switch/Out1
Gyro B normalized orbital gravity gradient vector:
Gravity Gradient Disturbances B/Gravity Gradient Acceleration Vector in Orbit Frame/f_gg_Orbit
Gyro B orbital phase:
Gravity Gradient Disturbances/OrbPhi
Gyro B actual orbital gravity gradient vector:
Gravity Gradient Disturbances B/CG_Gain/Out1
Gyro B separation from drag-free gyro. (measured in multiples of one gyro separation)
Gravity Gradient Disturbances B/Sum/Out1
Gyro B gravity gradient vector in spacecraft frame
Gravity Gradient Disturbances B/Orbit to Quartz Block Transformation/R_QB
Gyro B spacecraft roll phase
Gravity Gradient Disturbances B/RotPhi
Gyro B electrode frame gravity gradient acceleration
Gravity Gradient Disturbances B/GravAcc

Gyroscope Dynamics Model Variables

Top level:

Gyro A combined acceleration (not including suspension forces):

Gyroscope Dynamics Model A/Sum3/Out1
Gyro A constant acceleration vector value:
Gyroscope Dynamics Model A/ConstAcc/Out1
Gyro A initial/reset position vector value:
Gyroscope Dynamics Model A/PosR/Out1
Gyro A reset velocity vector value:
Gyroscope Dynamics Model A/VelR/Out1
Gyro A reset line:
Gyroscope Dynamics Model A/Reset/Out1
Gyro A position (meters):
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Pos
Gyro A velocity (meters/sec):
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Extra Output
Gyro A adjusted rotor voltage (accounts for polarization from control voltages):
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Vr
Gyro A electrode capacitance values:
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Cap
Gyro A bridge model bridge position voltages, unscaled:
Gyroscope Dynamics Model A/Yoshimi 3 Axis Bridge Model 6/4/2001 Modified
7/3/2001/Vout in [V]
Gyro A bridge position voltages, scaled:
Gyroscope Dynamics Model A/Gain1/Out1
Gyro A bridge position voltages, with noise possibly added:
Gyroscope Dynamics Model A/Vout
Gyro A position in micrometers:
Gyroscope Dynamics Model A/Rotor Position (output in
meters)/X_Pos|Y_Pos|Z_Pos
Gyro A position noise (not currently added to position vector):
Gyroscope Dynamics Model A/Random Noise Simulation (+/- 10 mV)/Noise
Gyro A dynamics-model-visible commanded electrode voltages (0 if voltage feed is disabled):
Gyroscope Dynamics Model A/Closed Loop/Out1
Gyro A dynamics-model-visible attitude control acceleration (0 if ATC feed is disabled):
Gyroscope Dynamics Model A/No ATC/Out1
Gyro A dynamics-model-visible gravity gradient acceleration (0 if gravity gradient feed is disabled):
Gyroscope Dynamics Model A/No Ext Acc/Out1
Gyro B combined acceleration (not including suspension forces):
Gyroscope Dynamics Model B/Sum3/Out1
Gyro B constant acceleration vector value:
Gyroscope Dynamics Model B/ConstAcc/Out1
Gyro B initial/reset position vector value:
Gyroscope Dynamics Model B/PosR/Out1
Gyro B reset velocity vector value:
Gyroscope Dynamics Model B/VelR/Out1
Gyro B reset line:
Gyroscope Dynamics Model B/Reset/Out1
Gyro B position (meters):
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Pos
Gyro B velocity (meters/sec):
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Extra Output
Gyro B adjusted rotor voltage (accounts for polarization from control voltages):
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Vr
Gyro B electrode capacitance values:
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Cap
Gyro B bridge model bridge position voltages, unscaled:

*Gyroscope Dynamics Model B/Yoshimi 3 Axis Bridge Model 6/4/2001 Modified
7/3/2001/Vout in [V]*
Gyro B bridge position voltages, scaled:
Gyroscope Dynamics Model B/Gain1/Out1
Gyro B bridge position voltages, with noise possibly added:
Gyroscope Dynamics Model B/Vout
Gyro B position in micrometers:
*Gyroscope Dynamics Model B/Rotor Position (output in
meters)/X_Pos|Y_Pos|Z_Pos*
Gyro B position noise (not currently added to position vector):
Gyroscope Dynamics Model B/Random Noise Simulation (+/- 10 mV)/Noise
Gyro B dynamics-model-visible commanded electrode voltages (0 if voltage feed is
disabled):
Gyroscope Dynamics Model B/Closed Loop/Out1
Gyro B dynamics-model-visible attitude control acceleration (0 if ATC feed is disabled):
Gyroscope Dynamics Model B/No ATC/Out1
Gyro B dynamics-model-visible gravity gradient acceleration (0 if gravity gradient feed
is disabled):
Gyroscope Dynamics Model B/No Ext Acc/Out1

3-Axis Gyroscope Model:

Gyro A suspension system applied force:
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Fss Mux/Out1
Gyro A suspension system applied acceleration:
Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Gain3/Out1
Gyro A X-axis wall impact indicator:
*Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/X-Axis/Double Integrator
With Wall/Position/Saturation*
Gyro A Y-axis wall impact indicator:
*Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Y-Axis/Double Integrator
With Wall/Position/Saturation*
Gyro A Z-axis wall impact indicator:
*Gyroscope Dynamics Model A/Testbed 3-Axis Gyroscope/Z-Axis/Double Integrator
With Wall/Position/Saturation*
Gyro B suspension system applied force:
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Fss Mux/Out1
Gyro B suspension system applied acceleration:
Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Gain3/Out1
Gyro B X-axis wall impact indicator:
*Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/X-Axis/Double Integrator
With Wall/Position/Saturation*
Gyro B Y-axis wall impact indicator:
*Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Y-Axis/Double Integrator
With Wall/Position/Saturation*
Gyro B Z-axis wall impact indicator:
*Gyroscope Dynamics Model B/Testbed 3-Axis Gyroscope/Z-Axis/Double Integrator
With Wall/Position/Saturation*