Dither Gyro Scale Factor Calibration – GOES-16 Flight Experience

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Abstract

This poster is a sequel to a paper presented at the 34th Annual AAS Guidance and Control Conference in 2011, which first introduced dither-based calibration of gyro scale factors. The dither approach uses very small excitations, avoiding the need to take instruments offline during gyro scale factor calibration.

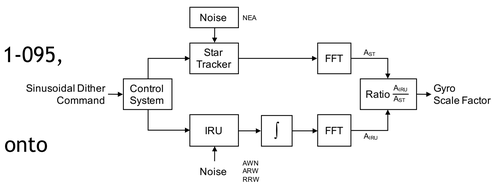
In 2017, the dither calibration technique was successfully used to estimate gyro scale factors on the GOES-16 satellite. On-orbit dither calibration results were compared to more traditional methods using large angle spacecraft slews about each gyro axis, requiring interruption of science. The results demonstrate that the dither technique can estimate gyro scale factors to better than 2000 ppm during normal science observations.

Background

Motivation

- Gyro scale factor (SF) will drift after launch
  - Initial 15-yr stability estimate: 5%, 50000 ppm
- Scale factor error corrupts compensation of dynamic motion, which is needed to operate through thruster maneuvers
  - On-board instrument pointing (control)
  - Ground-processed image geolocation (knowledge)
- On-orbit scale factor calibration required
- Standard calibration methods require large angle slews, interrupting instrument operations, reducing science availability for ~1 hour
- Maximize science data availability
  - Meet science requirements during thruster maneuvers
  - Minimize downtime for calibrations

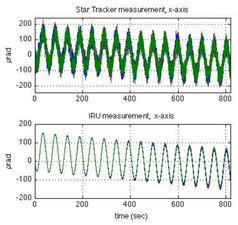
Notional Approach



- First presented in AAS 11-095, "GOES-R Gyro Scale Factor Calibration"
- Impart subsonic "tone" onto spacecraft attitude
- Tone is compliant with attitude, rate, torque allocations
- Detect imparted tone in gyro and star tracker data
- Compute ratio of amplitudes of detected tones
- Gyro / Star Tracker ratio is gyro scale factor estimate
- Repeat and average

Expectations

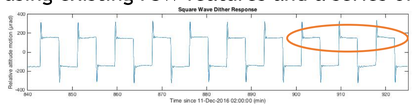
- Simulated results in AAS 11-095
  - Calibration accuracy: 2150 ppm, 1σ
- On-Orbit calibration accuracy for GOES-R
  - Success Criterion <10000ppm, 3σ
  - Goal <5000ppm



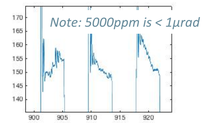
Implementation

Square Wave Excitation

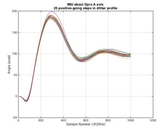
- GOES-16 flight software (FSW) has no requirement to support dither
- Lockheed Martin devised a method to generate a square-wave dither profile using existing FSW features and a series of attitude step commands



- Performed during GOES-16 post launch test (PLT)
- Plateaus corrupted by transients from GN&C heaters
  - Square wave response not repeatable
  - Degraded calibration accuracy



Quasi-Sinusoidal Excitation



- Attitude Control System (ACS) response to dither step commands exhibits large but very repeatable overshoot
- Increased frequency of step commands to match half-period of overshoot to yield quasi-sinusoidal response

Flight Results

Calibration Accuracy

- Variations of dither calibration with square and quasi-sinusoidal profile tested on-orbit, consistently beating 5000 ppm accuracy goal

Date	Waveform	Amplitude (μrad)	Period (sec)	Duration (hr)	Dither Axis	Worst Case SF Error (ppm)
12/11/2016	square	200	500	14.5	each gyro (4)	2117
12/16-17/2016	square	200	500	14.5	each gyro (4)	571
5/1/2017	quasi-sine	450	24	1	s/c yaw axis	885
5/1/2017	quasi-sine	450	24	1	s/c yaw axis	941
5/3/2017	quasi-sine	450	24	1	s/c yaw axis	765
5/5/2017	quasi-sine	450	24	1	s/c yaw axis	850
6/13/2017	quasi-sine	200	24	4	each gyro (4)	1174
6/15/2017	quasi-sine	350	24	1	s/c yaw axis	893
9/29/2017	quasi-sine	350	24	1	s/c yaw axis	1075
11/14/2017	quasi-sine	190	24	4	s/c yaw axis	577

Error shown is relative to scale factor calibration using 19° slews

← Baseline

Requirements Compliance For Baseline Dither

- Key Attitude Control Requirements

	Earth Pointing		Sun Pointing	
Requirement	**Specification**	**Performance**	**Specification**	**Performance**
Attitude control	< ±360 μrad	±190 μrad	< ±90 arc-sec	±10 arc-sec
Attitude rate error	< ±100 μrad/sec	±60 μrad/sec		
Attitude stability, 60 sec	< 500 μrad, p-p	380 μrad	< 6 arc-sec, radial	12 arc-sec*
Wheel torque, per wheel	< ±0.35 Nms	±0.12 Nms		

**sun-pointing stability exceedance likely due to step commands*

GOES-16 Operations and Beyond

Dither Calibration

- Dither gyro scale factor calibration baselined for GOES-16 operations
- Profile parameters:

Waveform	Amplitude	Period	Duration	Dither Axis
Quasi-Sine	190 μrad	24 sec	4 hr	Yaw

- Calibrations to be centered on midnight, near each equinox
  - Geostationary Lightning Mapper (GLM) false events sensitivity reduced
  - Sun vector nearest to yaw axis, reduced sun-pointing coupling
- Trend dither calibration data to determine if re-calibration using 3.5° slews is warranted (~10x more accurate)

Next Steps

- GOES-S (soon to be GOES-17) GN&C FSW includes onboard sinusoidal dither generator
  - Harmonically purer excitation
  - More benign disturbances than current step commands
  - Less spacecraft commanding

Conclusion

- Dither calibration of gyro scale factors previously shown feasible in AAS 11-095 using high-fidelity simulation
- Dither method successfully demonstrated in flight on GOES-16 in 2016-17
  - Achieved <1200 ppm, 3σ accuracy
  - All instruments perform normal operations during calibration

- Dither calibration baselined for operations on GOES-R Series
- Onboard dither excitation incorporated into GOES-S, T, and U
- Dither Calibration is Patent Pending

Acknowledgements

Preparation and execution of on-orbit calibrations and flight data analysis performed under NASA Goddard Space Flight Center contracts NNG15CR65C and NNG09HR00C.

Grateful acknowledgement is given to the GOES-R Flight Project, GOES-R Mission Operations Support Team (MOST), Lockheed Martin (Denver), NOAA Office of Satellite and Product Operations (OSPO)/GOES Engineering.