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Gravity Probe B Relativity Mission

# S0884 Rev -

# Verification of Gyroscope Readout Bias Requirements
# T003 3.6.2, 3.5.2.1, 3.5.2.2, and 3.5.2.3

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# 1. Introduction

The purpose of this document is to verify the following paragraphs in the Gravity Probe B System Design and Performance Requirements (T003):

## 3.5 Signal Processing – Low Frequency SQUID Readout Signal

### 3.5.1 Description

The low frequency SQUID readout signals consist of the signal at the roll frequency (and modulation of the phase and amplitude of that signal at orbital period, at the annual period, and linearly with time), at the spacecraft dither frequency (section 19.5), and at the calibration signal frequency (section 3.5.3).

### 3.5.2 Bias Variation

The bias variation in the sampled SQUID readout signal due to the SQUID, the top hat filters, the SQUID electronics, and the A/D converter meets the following requirements:

### 3.5.2.1 Linear Variation

The amplitude of any linear variation in the body-fixed bias signal at roll frequency (linear variation in the inertially fixed bias) and the body fixed calibration signal shall be less than 0.1 marcsec for data taken over the course of one year during the time the guide star is valid.

### 3.5.2.2 Annual Variation

The amplitude of any variation at annual rate in the body-fixed bias at roll frequency (annual variation in the inertially fixed bias) and the body-fixed calibration signal shall be less than 0.4 marcsec for data taken over the course of one year during the time the guide star is valid.

### 3.5.2.3 Orbital Variation

The amplitude of any variation at orbital rate in the body-fixed bias signal at roll frequency (orbital variation in the inertially fixed bias), the body-fixed calibration frequencies, or the body-fixed dither frequency shall be less than 0.1 marcsec for data taken over the course of one year during the time the guide star is valid when these components are simultaneously estimated with the components at roll frequency, calibration frequency, and dither frequency.

## 3.6 Signal Processing – High Frequency Readout Signal

### 3.6.1 Description

The high frequency SQUID signals consist of signals in the high frequency readout chain up to the fifth harmonic of the gyroscope spin speed. These signals include the roll frequency component of the high frequency readout signal, the high frequency calibration signal, and the signals at all of the first five harmonics of the gyroscope spin speed.

### 3.6.2 Bias Variation of High Frequency Readout Signal

The variation in the bias of the SQUID output due to the SQUID, the top hat filters, the SQUID electronics, and the A/D converter at the first five harmonics of the gyroscope spin frequency shall be determined to 2 milliarcsec.

## 2. Verification of Requirements

The physical source of bias variation in the gyroscope readout signal have been analyzedin "Bias Variations in the Gravity Probe B Gyroscope Readout System" [1]. Theses contributions to the variations in the bias at the satellite roll frequency and their expected magnitude are listed in the table below. As discussed in this report, many of these expected values are worst case estimates. Non-linearity effects, which may cause both bias and scale factor variations are covered separately. It is interesting to note that all of these effects depend on temperature variations at the satellite roll frequency. The numbers in Table 1 are based on the nominal 3 minute roll period. To the extent that the satellite roll period may be increased, the amplitude of these roll frequency signals would be expected to decrease.

Table 1 Summary of Sources of Roll Frequency Bias Variation

| Source | Supported Gyroscope | Drag Free Gyroscope |
|---|---|---|
| London Moment and Roll Frequency Miscentering | 0.0011 mas | 0.014 mas |
| Trapped Flux and Roll Frequency Miscentering | 0.0001 mas | 0.001 mas |
| SQUID Temperature Sensitivity | 0.0035 mas | 0.0035 mas |
| SQUID Readout Electronics Temperature Sensitivity | 0.021 mas (Range 2) | 0.021 mas (Range 2) |
| Root-Square-Sum | 0.021 mas | 0.025 mas |

The report also discusses bias variations at the roll frequency modulated by twice orbital frequency. These bias variations may have a small effect on the overall accuracy of the experiment, but they are not directly relevant to these requirements. They will be discussed in the verification of Requirement 2, Detection and Calibration, of the Twelve Fundamental Requirements (T002). The report also discusses bias variations at incommensurate frequencies. Since these frequencies are not expected to coincide with the calibration signal frequency or the satellite dither frequency, they are also not discussed here.

### *2.1 Low Frequency Bias Variations – T003 Requirements 3.5.2*

There is no direct requirement on a constant roll frequency bias variation of the gyroscope readout system. It is only to the extent that the amplitude or phase of this bias variations changes that there will be an effect the overall accuracy of the experiment. The amplitude and phase of these thermal effects will change as the orientation of the sun with respect to the satellite's roll axis and the plane of the orbit changes during the year. It will also vary at the orbital period as the satellite moves into and out of the earth's shadow and the amount of solar radiation reflected from the earth changes. There may also be a long term linear drift of the roll frequency amplitude if there is a degradation of the reflectivity of the FOSAR.

In view of these variations, a conservative approach to verifying these requirements is to assume that the temporal variation at the orbital and annual frequencies and the linear drift of the roll frequency amplitude is equal to 100% of the expected peak-to-peak amplitude. Taking the root-square-sum of the effects listed in Table 1, the peak-to-peak amplitude is 0.042 mas (milli-arc-seconds) for the supported gyroscopes and 0.050 mas for the drag-free gyroscope. This represents a margin greater than 50% for T003 requirements 3.5.2.1, 3.5.2.2, and 3.5.2.3.

### 2.2 High Frequency Bias Variations – T003 Requirement 3.6.2

Although SQUID noise is not a systematic bias error source, SQUID noise does limit our ability to determine the signal amplitudes SQUID noise was verified in PLSE-12 requirement 3.7.1.7.2.1 to be 10 micro flux quanta per root Hz. This corresponds to a noise of 40 marcsec/Hz$^{0.5}$. The integration time to reach 2 marcsec/Hz$^{0.5}$ is 400 seconds. No integration time is specifically called out in the requirement, however, the intent of the requirement is that we be able to observe and track variation in the bias on a time frame which is short compared to the mission duration. The 400 second integration time satisfies this need.

Other than for the noise and linearity of the SQUID electronics and A/D converter, there are no other known errors sources for this requirement which result from the SQUID electronics or A/D converter. The effects of noise in the electronics has already been accounted for in the total noise as measured in PLSE-12 requirement 3.7.1.7.2.1. The effects of linearity in the A/D converter will be covered in the verification of T003 requirement 3.2.1.2.

A possible but unlikely contribution to the bias variation is a spurious spin speed magnetic signal from adjacent gyroscopes. Such signals could corrupt the spin speed of the gyroscope being readout by its associated readout system. After analysis, it has been determined that this is not a credible error source. In order for this error source to make a significant contribution, the spin speed of the adjacent gyroscope would have to be almost identical to the spin speed of the primary gyroscope. The spin speed of the gyroscope is measured over the course of the mission for an integration time of order $5 \times 10^7$ seconds. This allows a spin speed determination of order 10 microHz. In fact, by tracking the phase of the trapped flux signal, the capability to measure spin speed is several orders of magnitude better than quoted here. For spin speeds that are separated by more than 10 micro Hz, there will be no impact on the error. The likelihood of violating such an overlap is 10 microHz divided by the range of expected spin frequencies. This gives a probability of requirement violation of less than 0.001%. Furthermore, if such an overlap does occur, we have the capability of adjusting the spin speed (with gas) so as to avoid this overlap.

According to paragraph 3.6.1 of T003, this requirement on the high frequency signals not only includes the spin speed signals but also the roll frequency signals as measured by the high frequency signal processing path. There are no additional sources of error in this high frequency signal processing path that are not included in the low frequency signal processing path. The accuracy to which the high frequency signals are determined may conservatively be given as the same value used for the low frequency signals. This value of 0.05 mas is significantly better than the required value of 2 mas. Therefore, this requirement, T003 3.6.2, is verified.

## References:

1. Keiser, G.M., J. Lockhart, and B. Muhlfelder, *Bias Variations in the Gravity Probe B Readout System*, GP-B, Hansen Laboratories, Stanford University, S0352, Rev. -, May 16, 2003