The on-board Attitude Determination System for MAXI

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ABSTRACT

ADS（Attitude Determination System）is the on-board attitude determination system using a Star sensor (VSC) and Gyroscope (RLG).

The purpose of ADS is rapidly providing accurate attitude determination results to world investigators through the MAXI alert ground system. It is required that the accuracy of the occurrence of X-ray events must be less than 0.1 degree in direction in any situation of data downlink and VSC data acquisition.

KEY WORDS: MAXI, ADS, RLG, VSC

1. Introduction

It is commonly understanding that in the design phase of an Attitude Determination System, using sensor data quality is an important factor.

Taking this in consideration, the MAXI-ADS are designed to have the following functions

For the purpose of improving the VSC data noise characteristics, three logics are used to reject noise, generated by several causes, in VSC data. Especially the disturbance on orbit environment which interferes with VSC must be concerned.

RLG has a characteristic of the large readout noise. And the attitude disturbance around 8Hz will be expected due to ergometers used by astronauts. So RLG output data above 20Hz will be cut-off by a low-pass filter.

And the ADS algorithm is modified based on the on-board attitude determination systems, which is mainly used in Astronomy Missions of JAXA/ISAS.

In this paper, ADS function, operational condition, attitude determination algorithm and the test results will be introduced.

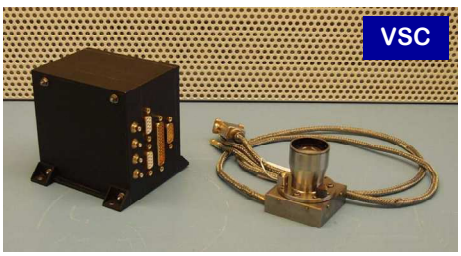
2. Introduction of MAXI ADS

The MAXI ADS is the embedded function in the MAXI on-board Application Software in the MAXI-DP master CPU, to avoid using ISS-JEM data interface directly.

MAXI ADS consists of one Star sensor and one Ring Leaser Gyro only. This is much simpler in comparison with common attitude determination sensor systems. Fig1 shows the outline view of VSC and RLG.

The ADS is the embedded function in MAXI on-board Application Software in the MAXI-DP master CPU which is the main CPU of MAXI-DP. Fig2 shows ADS System Configuration.

Fig3 shows VSC and RLG coordinate system definitions with regard to the MAXI coordinate system.



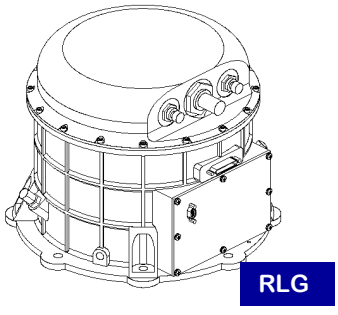


Fig1 MAXI ADS using sensors

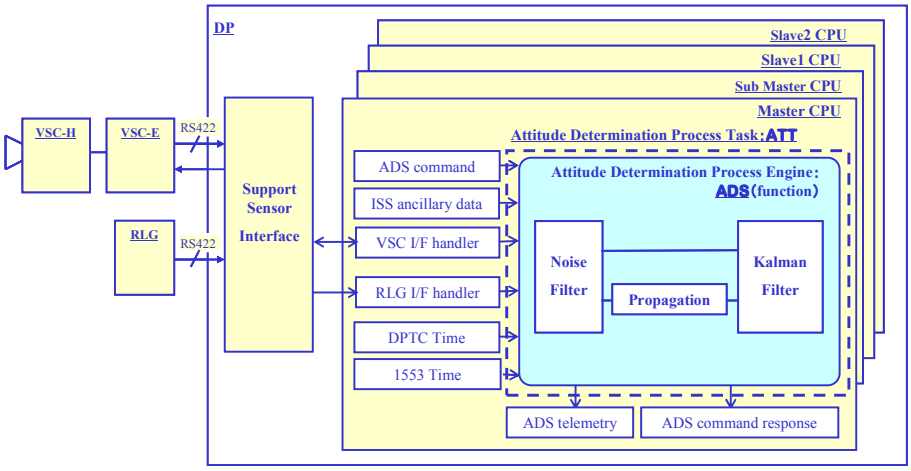
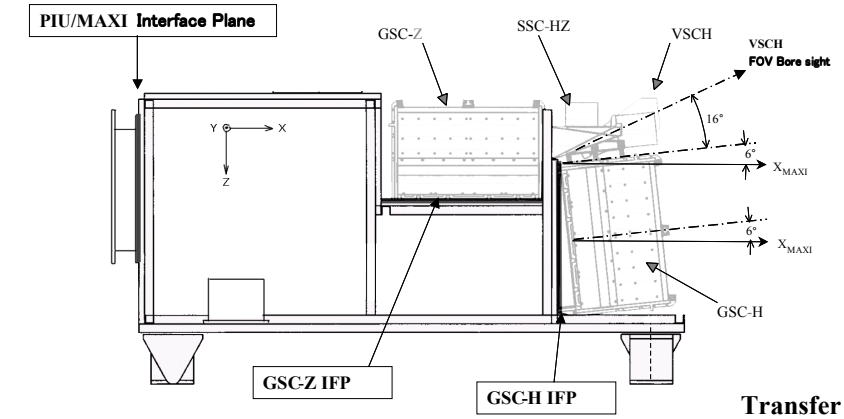
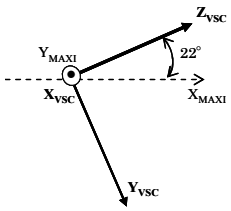


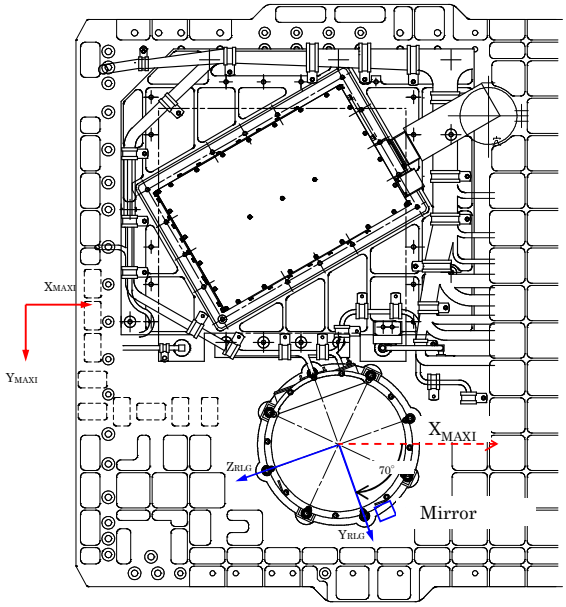
Fig2 ADS System Configuration

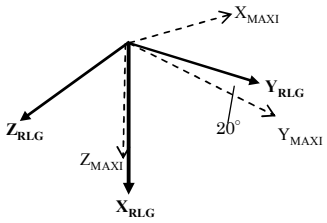




Transfer Matrix : $\Sigma_{MAXI} \rightarrow \Sigma_{VSC}$

$$\begin{bmatrix} \cos(90°)\cos(90°+22°) & \sin(90°) & -\cos(90°)\sin(90°+22°) \\ -\sin(90°)\cos(90°+22°) & \cos(90°) & \sin(90°)\sin(90°+22°) \\ \sin(90°+22°) & 0 & \cos(90°+22°) \end{bmatrix}$$





Transfer Matrix : $\Sigma_{MAXI} \rightarrow \Sigma_{RLG}$

$$\begin{bmatrix} \cos(-90°) & 0 & -\sin(-90°) \\ \sin(-90°)\sin(-20°) & \cos(-20°) & \cos(-90°)\sin(-20°) \\ \sin(-90°)\cos(-20°) & -\sin(-20°) & \cos(-90°)\cos(-20°) \end{bmatrix}$$

RLG Onboard Location (MAXI coordinate System)

Fig3 VSC and RLG Coordinate system definition

3. MAXI ADS Function

The MAXI ADS functions are as follows:

- ADS rejects undesired VSC anomaly data caused by SAA, Sun and Day side of Earth Interference etc.
- ADS cuts high frequency RLG Readout noise off with Low Pass Filter.
- ADS propagates with filtered RLG data and updates the correction data with filtered VSC data.
- Kalman filter is used for estimating the residual attitude error.

4. MAXI ADS Operational Condition

4.1 VSC data operational Condition

VSC anomaly data on orbit environment must be rejected by ADS. The detailed explanations are described in the following.

- **VSC anomaly data rejection Logic**

  There are three logics for the VSC anomaly data rejection as follows.

  - **VSC Quality flag**

    Using the VSC telemetry item which VSC has decided the Quality result.

  - **On-board Autonomous calculation**

    Using the result of the Sun and the Day side of the Earth avoidance calculated by ADS with ISS ancillary data.

  - **External Command**

    Using ADS command operated from the ground station. Mainly this is prepared for SAA.

- **Definitions of Operational Condition**

  Fig4 shows VSC the concept of anomaly data rejection of ADS on orbit environment.

  External Commands are effective anytime

  Alternative Selection VSC Quality flag or On-board Autonomous calculation can be selected

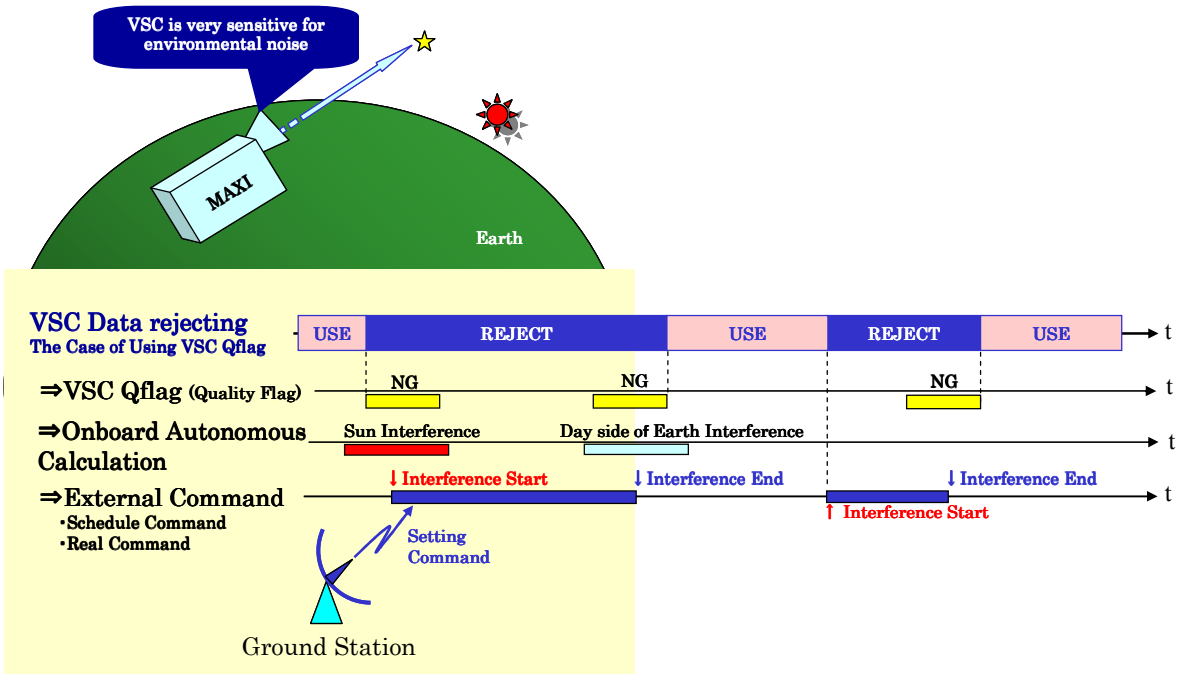


Fig4 VSC anomaly data rejection of ADS on orbit environment concept

4.2 RLG data filtering (Noise Filter)

RLG outputs 200Hz angular data with noise, generated by several causes. ADS gets about 200 data set every 1s. To improve the RLG data, noise characteristics on every RLG data is filtered because RLG data has a characteristic of large readout noise.

Also the attitude disturbance is monitored. Especially around 8Hz will be expected due to ergometers used by astronauts. And at least 90% of the amplitude must be kept after being filtered.

●Filter Design

The Error data above 20Hz between the RLG data and the values estimated by calculation angular rate for 50 ms, will be cut-off by the elliptic low-pass filter as follows. Fig5 shows the amplitude-frequency response.

- Design Method : IIR (Ellipse)
- Sample Frequency : 200Hz
- Cut-off Frequency : 20Hz
- Stopband Frequency : 25Hz
- Passband Attenuation : 0.4dB
- Stopband Attenuation : 30dB
- Filter Order : 5

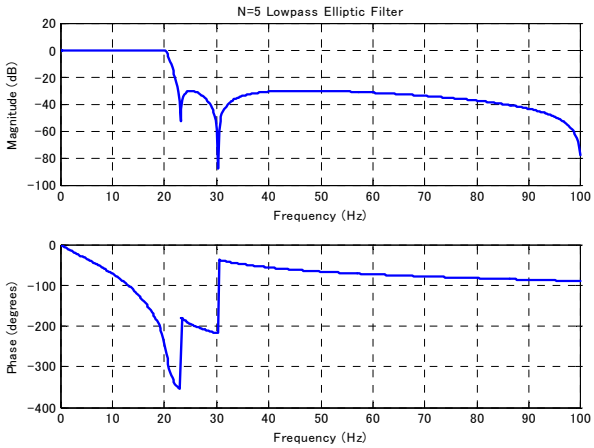


Fig5 Filter frequency response

4.3 ADS Timing Chart

Fig6 shows the ADS Timing Chart.

ADS determines the one previous cycle attitude with allowance for the 5 second VSC telemetry latency.

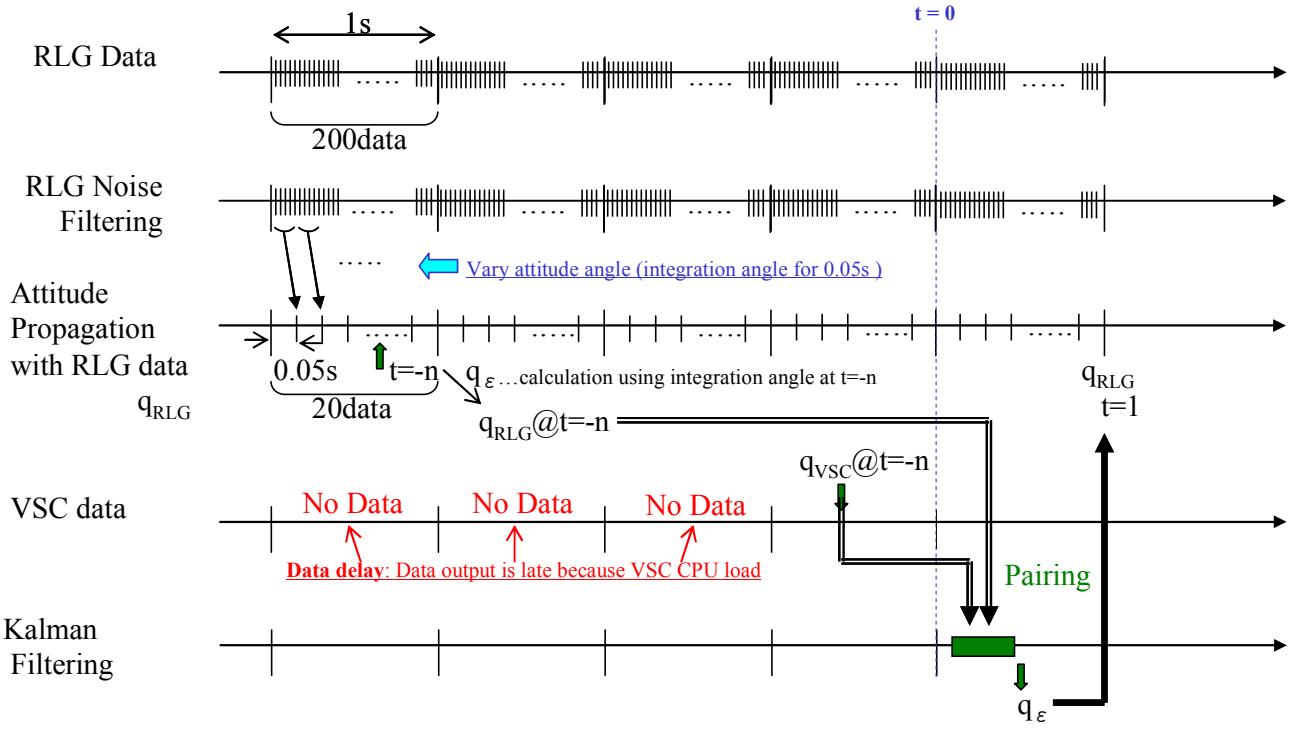


Fig6 ADS Timing Chart

5. MAXI ADS attitude determination algorithm

Fig7 shows the configuration of the Kalman Filter process.

,where $\mathbf{q}(t)$ is the actual attitude, $\bar{\mathbf{q}}_t$ is the estimated attitude and $\mathbf{K}_t$ is the Kalman Gain.

The algorithm of estimation uses for NOT actual attitude BUT propagated attitude error.

$\hat{\mathbf{q}}'_{\mathrm{v},t}$ $\hat{\mathbf{b}}'_t$ are propagated attitude error and bias error.

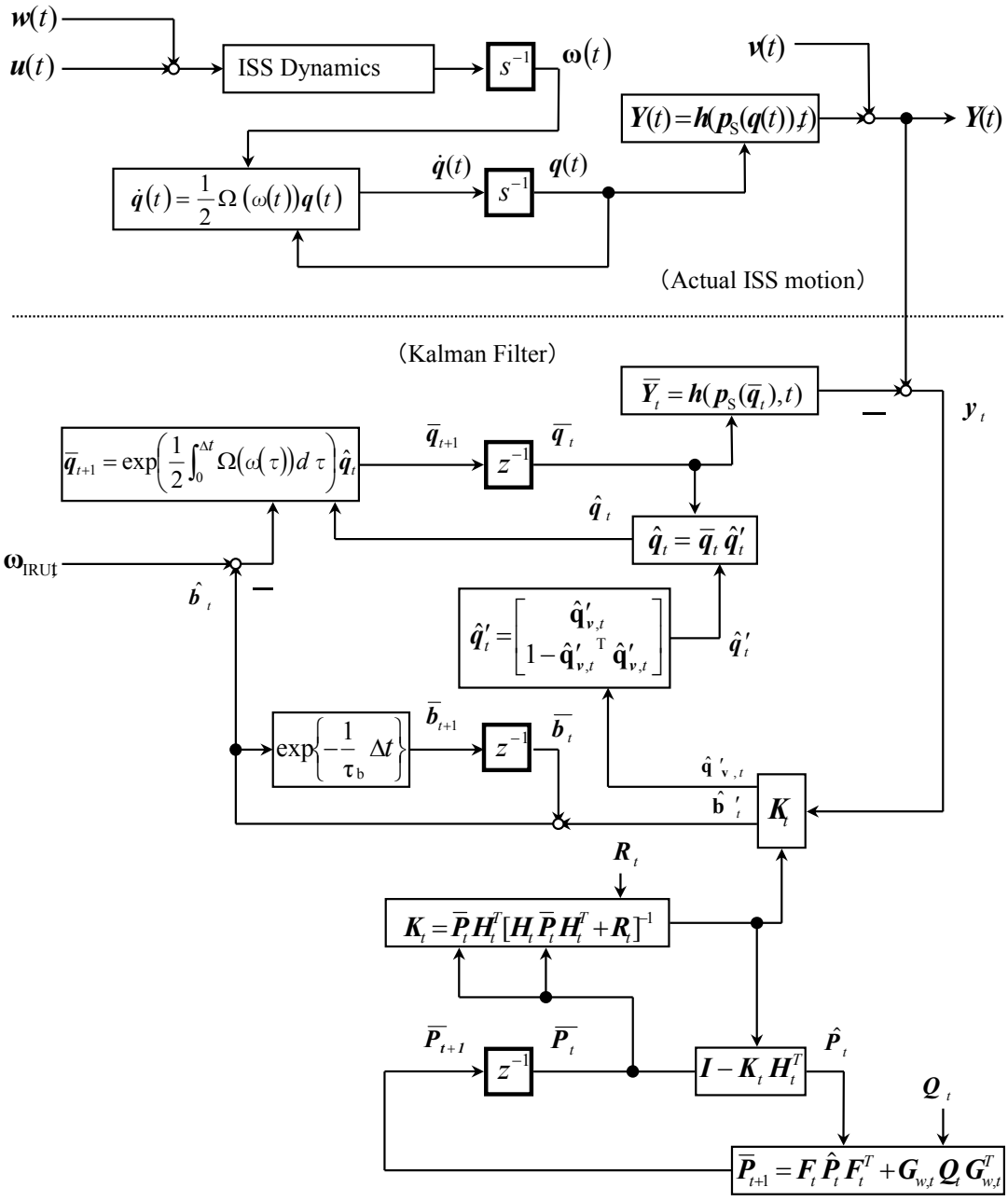


Fig7 The Kalman Filter process configuration

6. MAXI ADS the test results

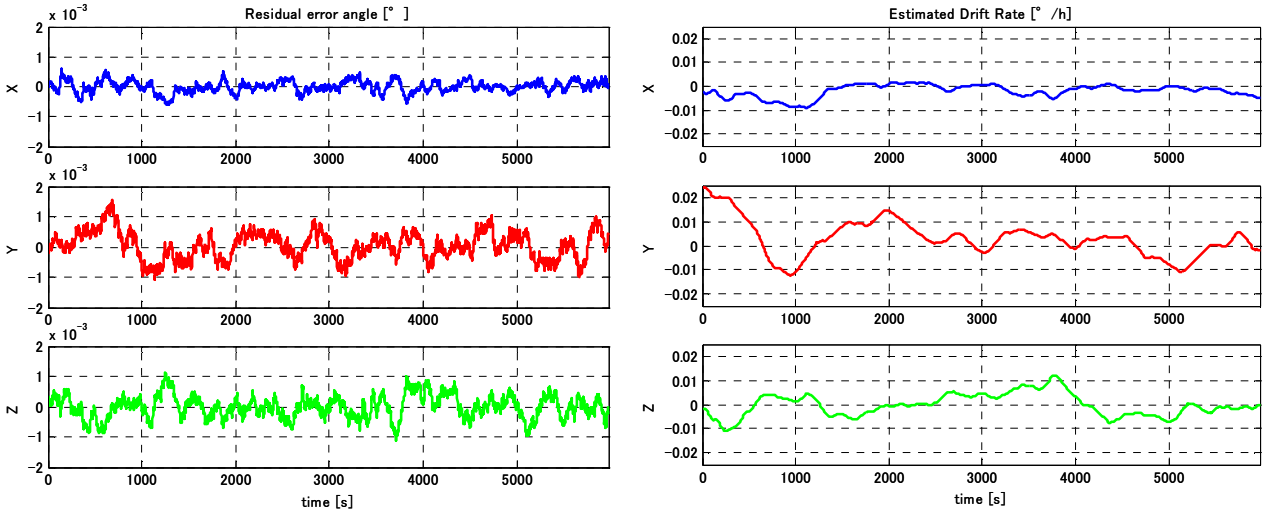
An example of the ADS Kalman Filter Logic Evaluation result is shown in Fig8. This is based on a simulation during one ISS orbit with updated data of VSC.

The result shows that the ADS Kalman Filter logic realizes the accuracy within 0.002°of MAXI attitude on every axis. As the acceptable margin of error for the ADS Kalman Filter Logic is less than 0.016°at the design phase, this result satisfies the request.

7. Conclusion

MAXI ADS can realize rapidly providing accurate attitude determination results to world investigators through the MAXI alert ground system. And the attitude accuracy can be less than 0.1 degree in direction in any situation of data downlink and VSC data acquisition.

It is planned to calibrate RLG alignment and pulse weight after starting the MAXI operation.



ADS Kalman Filter Logic Evaluation example

Fig8 ADS Kalman Filter Logic Evaluation result

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