Systems Engineering Report

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Kepler ADCS general information			SER.ACS.015	Orig
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Introduction

This systems engineering report documents basic spacecraft and attitude control related information. Included in this report is information on:

1) Spacecraft mass properties
2) Reaction wheel orientations and capabilities
3) Reaction control thruster parameters
4) Star tracker parameters
5) Fine Guidance Sensor parameters
6) Sun reference attitude region available for science operations

1.0 General spacecraft parameters

Figure 1 below shows the spacecraft configuration and the spacecraft body frame coordinate system. The X-axis is aligned with the photometer boresight, the Y-axis is aligned with the solar array "normal" vector, and the Z-axis completes the right-handed orthogonal triad. Various attitude determination and control hardware components are highlighted.

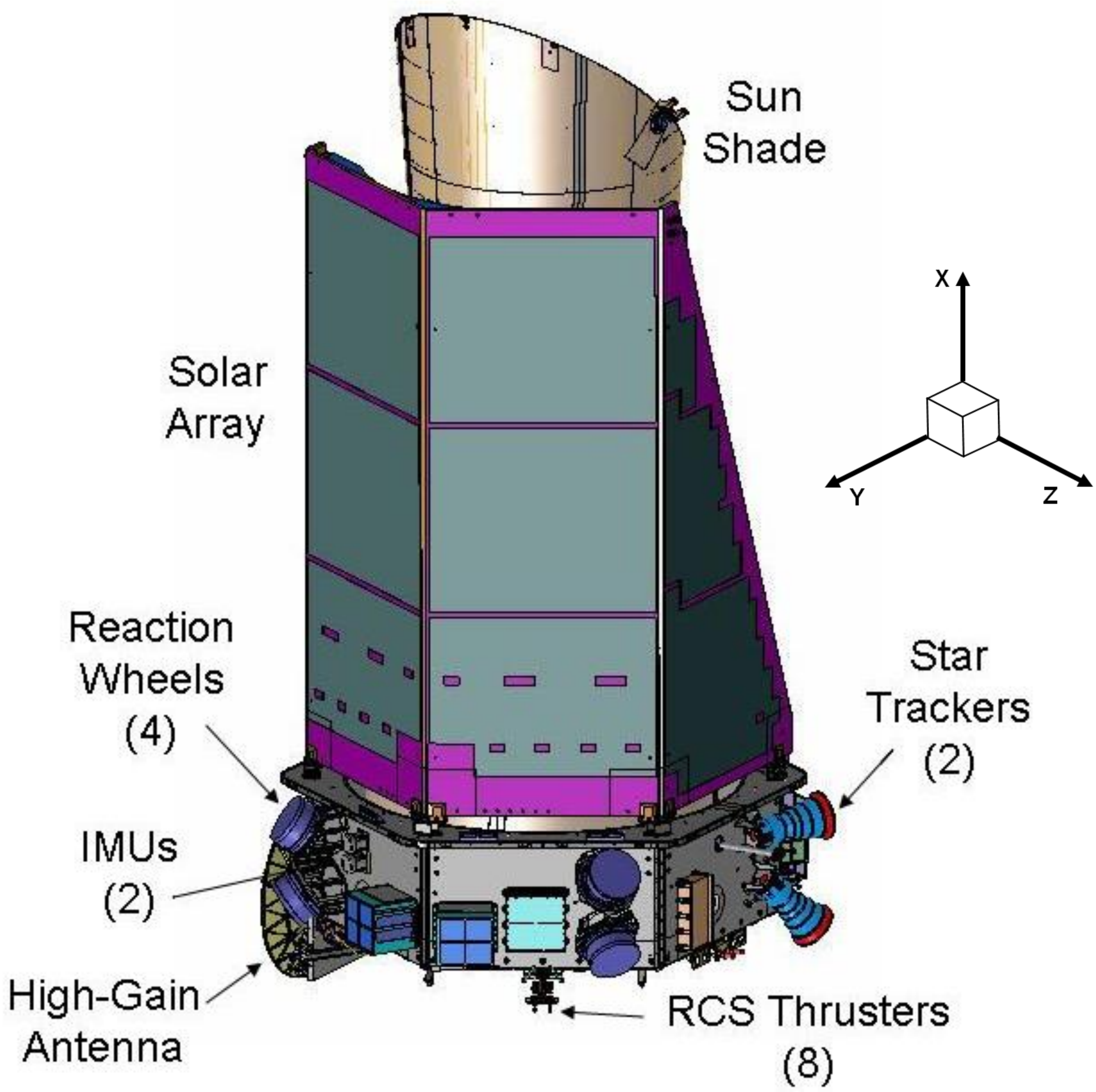

Figure 1
Kepler Spacecraft Attitude Components

Spacecraft mass properties are summarized in Table 1 below. These numbers are what appears in the parameters tables in the onboard flight software.

Table 1. Spacecraft mass properties.

Mass	1044.88 kg		
	X	Y	Z
CG (m)	1.20	0	0
Inertia (kg-m^2)	663.96	-1.34	1.33
		1699.4	19.42
			1769.7

2.0 Reaction wheel assembly

The Kepler spacecraft is equipped with four Goodrich TW-16B200 reaction wheels. Each wheel has an advertised momentum capacity of 16.6 Nms, which corresponds to a speed of 5100 RPM, and a reation torque capability of ±0.2 Nms. In practice, the full range of reaction torque (below 5100 RPM) is ±0.275 Nms, and the wheels can be spun faster than 5100 RPM (with a reduced reaction torque capability at this level).

Each wheel has an ultimate upper limit on its speed as determined by the overspeed circuit in the drive electronics. The overspeed limits are all set above 7000 RPM. Table 2 below shows the body frame reaction wheel spin axes.

Table 2. Reaction wheel spin axis unit vectors

	RW1	RW2	RW3	RW4
X	0.573526	-0.573526	0.573526	-0.573526
Y	0.484684	0.484684	0.484684	0.484684
Z	0.660328	0.660328	-0.660328	-0.660328

Reaction wheel orientations are only approximate. On orbit calibration of wheel spin axes were never conducted.

3.0 Reaction Control Thrusters

The Kepler spacecraft is equipped with 8 Aerojet MR-103G 1 Newton thrusters. The initial propellant was loaded to 11.4 kg. Current propellant load is close to 7 kg (tank pressure approximately 140 psi), which results in a thrust magnitude of 0.46 N. Figure 2 below shows the spacecraft bus (from the bottom deck) and the thruster locations.

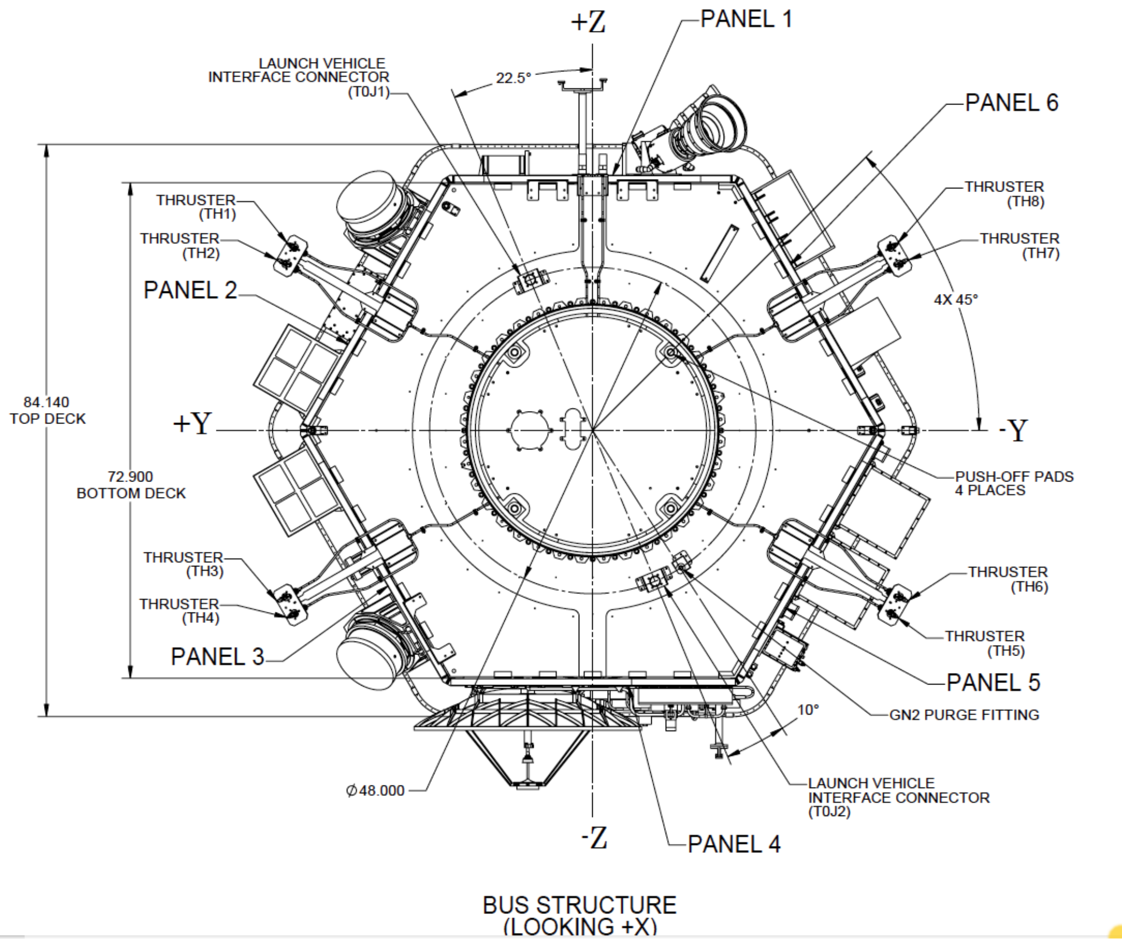

Figure 2. Thruster locations

Table 3 below shows the thruster locations and orientations. Thruster locations are the body frame locations. Thruster orientations represent the direction of the force on the vehicle, not the direction of the thruster plume. Center-of-mass information should be used to determine moment arm.

Table 3. Thruster parameters

Thruster orientations	X	Y	Z
RCS 1	0.5	0.75	0.433
RCS 2	-0.5	-0.8529	-0.1504
RCS 3	-0.5	-0.8529	0.1504
RCS 4	0.5	0.75	-0.433
RCS 5	0.5	-0.75	-0.433
RCS 6	-0.5	0.8529	0.1504
RCS 7	-0.5	0.8529	-0.1504
RCS 8	0.5	-0.75	0.433
Thruster locations			
RCS 1	0.0508	1.125	0.6899
RCS 2	0.0635	1.1801	0.637
RCS 3	0.0635	1.1801	-0.637
RCS 4	0.0508	1.125	-0.6899
RCS 5	0.0508	-1.125	-0.6899
RCS 6	0.0635	-1.1801	-0.637
RCS 7	0.0635	-1.1801	0.637
RCS 8	0.0508	-1.125	0.6899

Thruster locations and orientations are only approximate. On orbit calibration of thruster torque and force properties were never conducted.

4.0 Star tracker parameters

The Kepler spacecraft is equipped with two BATC CT-603 star trackers. These star trackers output a measurement quaternion, as well as the star centroids used to synthesize that measurement. Each tracker outputs a measurement at 5 Hz, has an 18° x 18° FOV, and tracks up to five stars between visual magnitudes of -1 and 5.3. Each tracker has contains a star catalog containing 2039 stars for attitude determination across most of the celestial sphere.

The tracker boresight vectors and body-to-tracker-measurement quaternions are shown below in Table 4.

Table 4. Tracker parameters

	Boresight vector: ST1	Qb2tr: ST1	Boresight vector: ST2	Qb2tr: ST2
X	0.105760	0.3874983321	0.1057607299	0.2049812991
Y	-0.87829591	-0.3416259713	-0.8782959142	-0.5400903415
Z	0.466273476	0.6389616897	0.4662734765	0.2876506229
		0.5699690318		0.7638993448

The CT-633 trackers can be commanded search locations to seek out specific stars in their catalog. This is referred to as the “Directed Search” command, and has been used with great success for transitions to and from the Fine Guidance Sensor. Ground processing tools exist to synthesize directed-search commands for the trackers at any sky attitude.

5.0 Fine Guidance Sensor parameters

The Fine Guidance Sensor (FGS) is composed of four narrow field-of-view CCDs co-located with the science CCDs in the corners of the Focal Plane Assembly Array (FPAA). Each FGS CCD sees an area of the sky of approximately 0.27° x 0.27°. Figure 3 below shows the layout of the FPAA and the locations of the Fine Guidance Sensor CCDs in each corner.

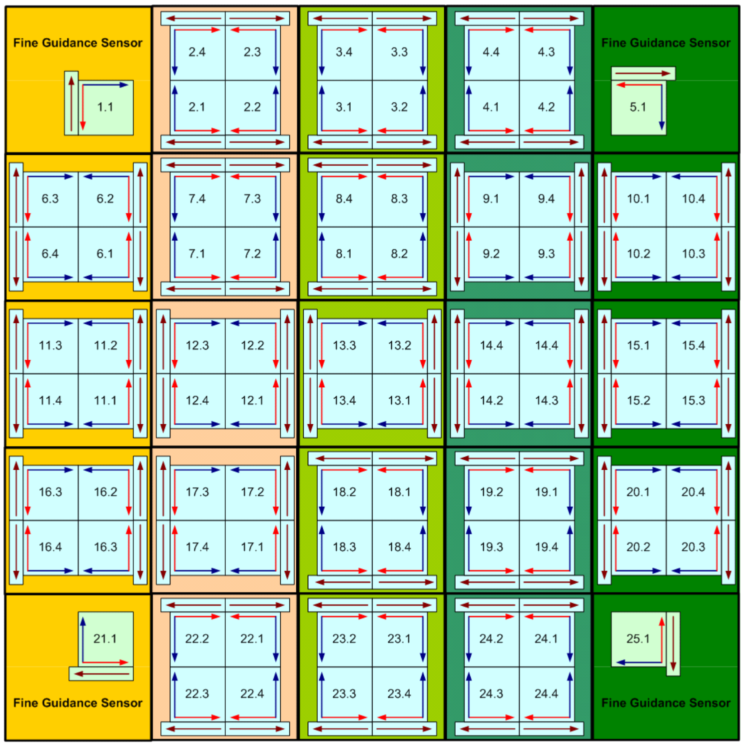

Figure 3. Kepler FPAA with FGS locations

Table 5 below shows the FGS CCD parameters. The final value in the table indicates the maximum number of pixels the FGS computer software component can process in a single frame before throughput becomes an issue.

Table 5. FGS Performance parameters

Parameter	Value
Image area	535 x 550 pixels
Pixel size	13 mm
Pixel IFOV	1.92 arc-sec
Update rate	9.634 Hz
Integration time	100 msec
Range of star magnitudes	8 – 14
Maximum # process pixels / frame	2560 / CCD

Local detector electronics readout all pixels from the FGS CCDs every 9.6 Hz frame, but only a small subset of those pixels are used for attitude determination. The CSC only receives pixels around pre-calculated guide star locations. Pixels for guide stars are determined before science operations and are loaded as table parameters. FGS CCD data was used in two modes:

1) Large aperture acquisition blocks to facilitate transition from the stars trackers (16 x 16 pixels)
2) Small aperture track track blocks with maximizes signal to noise ratio while capturing > 95% of starlight from each guide star (8 x 8 pixels).

During commissioning, several calibration activities were performed to determine the alignment between the star trackers and the Fine Guidance Sensor (to get the 3s absolute knowledge accuracy of the tracker below 16 arc-seconds). For future operations away from the nominal Kepler science attitude, either calibration activities will have to be performed again or larger pixel of interest blocks will have to be used. The theoretical upper limit for a track block is 49 x 49 pixels (94" x 94").

6.0 Sun reference areas available for science

There are two constraints on the vehicle attitude for science operations

1) The vehicle must remain power positive (available power > 650 W)
2) The Sun avoidance region must be observed

The Sun avoidance region is defined as a threshold angle between the Sun vector and the sun shade aperture normal vector ([0.788 -0.6157 0]). There are two limits for Sun avoidance: a Flight Software fault protection trigger of 96.7, and an Emergency Mode trigger of 94.5.

Figure 4 below shows the areas available with respect to the sun avoidance region and power availability contours. The solar array normal (body frame +Y-axis) is at azimuth = 0°, elevation = 0° on this plot. Keeping the sun anywhere within the blue and green regions and below the red line are available for science operations. Figure 4 only shows ½ of the available region (the XY plane forms the left boundary of the plot). The full region is symmetric about the X/Y plane.

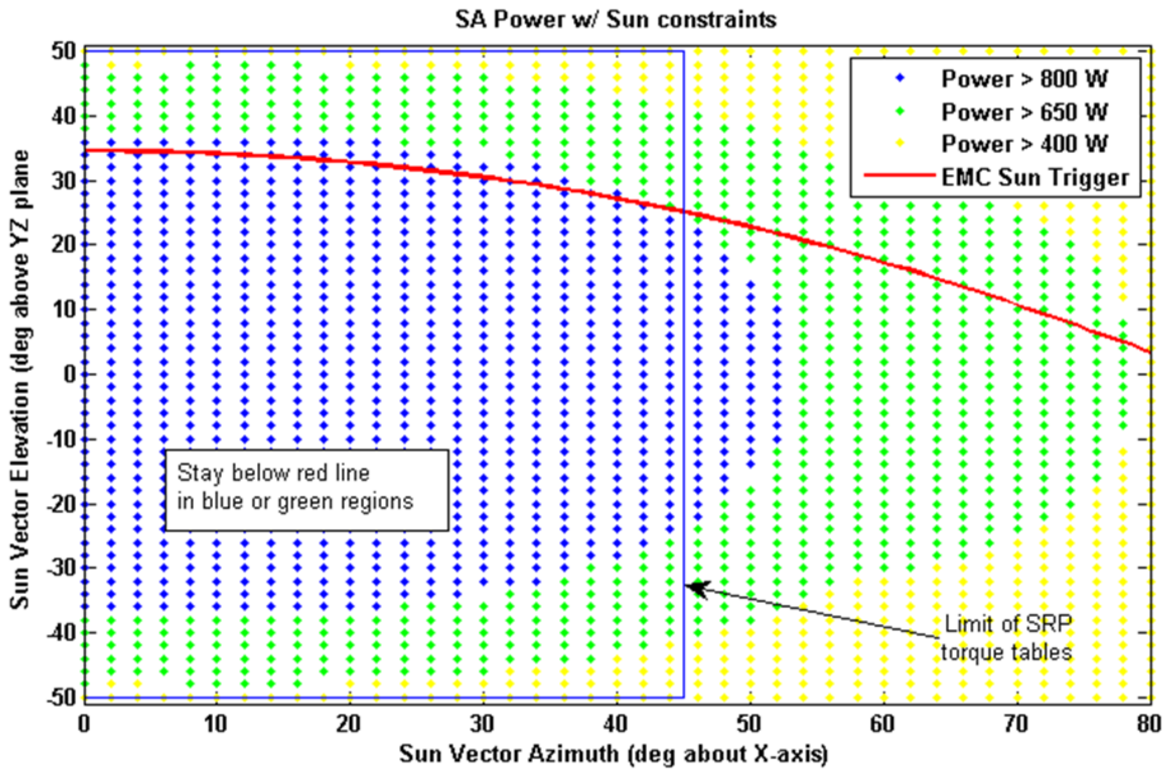

Figure 4. Sun reference area of science availability.

The blue box shows the region of Sun reference attitudes where the solar pressure torque has been pre-computed by a high fidelity Finite Element Model (see Kepler.SER.ACS.016).