11. Attitude Control

The GOES-NOP attitude control subsystem (ACS) provides attitude information and maintains the required spacecraft attitude for all mission phases from launch through end of life. The subsystem consists of redundant microprocessor-based control electronics, sun sensors, earth sensors, star trackers, gyros, reaction wheel assemblies (RWAs), a solar array drive (SAD), and an X-ray positioner (XRP) mechanism. A block diagram of the ACS is shown in Figure 11-1.

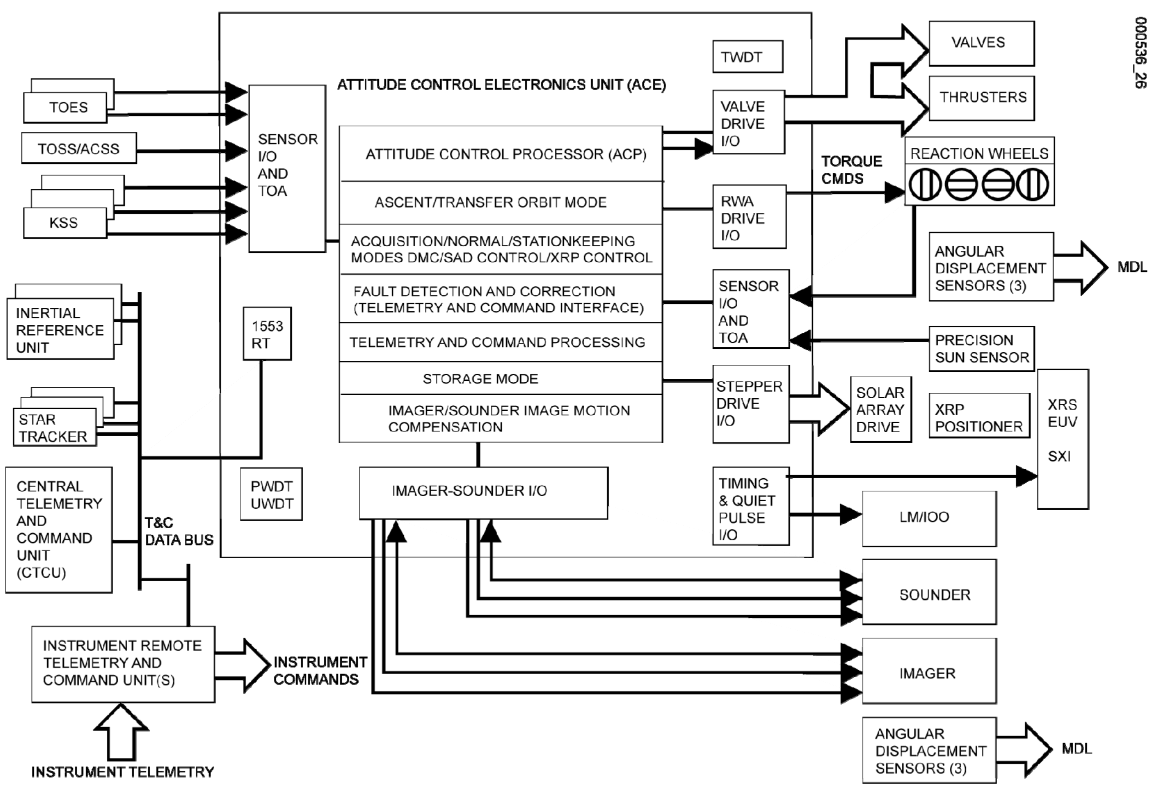

Figure 11-1. GOES-NOP Attitude Control Subsystem

Normal on-orbit attitude control operations are based on a zero momentum concept that provides precise pointing for the Imager and Sounder, communications service equipment, and scientific instruments. Bus control is accomplished by applying torque to an RWA pyramid. The SAD and XRP articulate the suite of scientific instruments mounted on the instrument mounting platform (IMP). Twelve 9.25-N bipropellant thrusters provide attitude control during orbit maneuvers. The ACS during transfer orbit is mostly passive with control applied only during reorientations, spin speed changes, or liquid apogee motor (LAM) burns.

Attitude Control Electronics

The attitude control electronics (ACE) contains electronic circuitry and software to control spacecraft attitude, support battery charge management, maintain bus thermal control, perform fault detection and correction, and interface to the GFE Instruments. The ACE includes a microprocessor that performs attitude data processing and control algorithm calculations to close the loop between the sensors and the actuators. The ACE receives all commands to the subsystem as derived from the central telemetry and command unit, processes them, and coordinates related hardware functions. Most telemetry signals from the ACS are formatted in the ACE.

The various ACE control modes, illustrated in Figure 11-2. Each box in the figure corresponds to an ACE control mode, with the active sensors, actuators, and control algorithms indicated. The transitions between the modes are indicated either by a solid arrow for autonomous transitions or by a dashed arrow for ground-commanded transitons. The GOES-NOP mission timeline proceeds generally from the bottom of the figure to the top, which also reflects the use of increasingly sophisticated control algorithms to achieve the high levels of performance required by the GOES-NOP mission objectives. In the case of a fault requiring entry into safehold, the ACE will autonomously transition downward into a mode that employs simpler control algorithms consistent with spacecraft health and safety, as is described further below.

The interface electronics portion of the ACE provides appropriate time-of-arrival and analog-to-digital conversion, thruster control, positioner motor control, RWA speed regulation, time tagging, and instrument compensation signals. Analog sensors interfaced directly to the ACE include an infrared Transfer Orbit Earth Sensor [TOES] and several slit sun sensors used for transfer orbit, acquisition, and IMP control (transfer orbit sun sensor [TOSS], acquisition sun sensor [ACSS], and precision sun sensor [PSS]). The hemispherical keyhole sun sensors (KSSs) used to protect the Imager and Sounder and aid sun acquisition interface directly to the ACE. A hemispherical inertial reference unit (HIRU) and star trackers (STs) interface with the ACE via the 1553 serial bus on which the ACE is a remote terminal. These sensors provide attitude and rate data for processing by the ACE. Data from these units are also formatted and telemetered to the ground for mission operational checks of attitude determination performance.

Reaction Wheels

Four wheels provide three-axis torque and momentum storage capability. The wheels are each capable of storing 75 N·m·s of momentum and of providing 0.2 N-m of reactive control torque. Nominal on-orbit operation uses all four wheels in order to provide pointing control.

Solar Array and IMP Positioning

The SAD and XRP mechanisms position the solar array and IMP, respectively. The SAD structurally supports the yoke and solar array while articulating the rotation of the array about the spacecraft pitch axis, thus maintaining commanded sun pointing of the array and IMP. The SAD transfers power, control, and telemetry signals across slip rings at the rotary interface. The XRP structurally supports the instrument mounting platform (IMP) and rotates the IMP about an axis that is nominally perpendicular to both the array normal and the spacecraft pitch axis, thereby maintaining commanded sun pointing of the IMP.

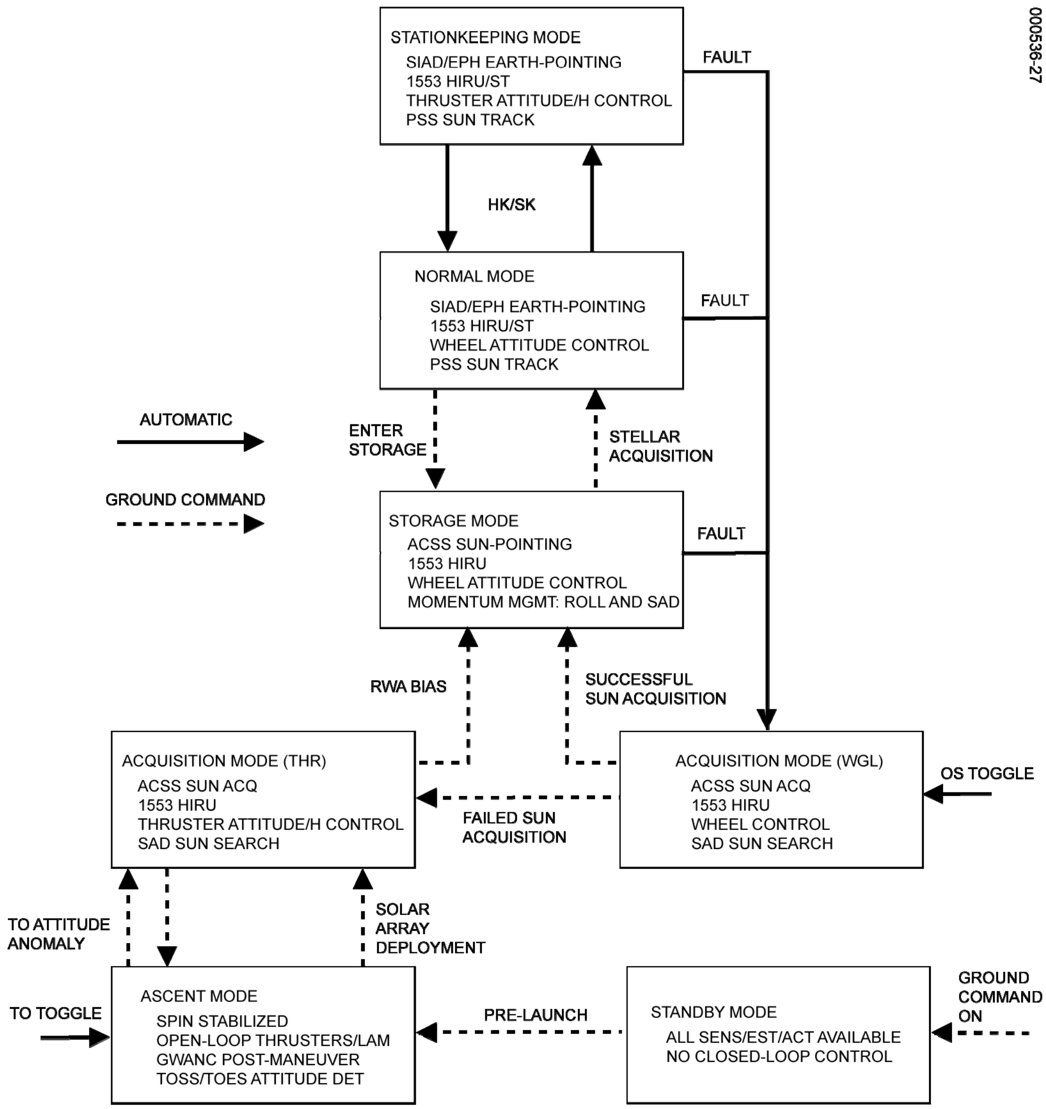

Figure 11-2. GOES Attitude Control Electronics Operational Modes

Image and Dynamic Motion Compensation Support

The ACE provides compensation signals to the Imager and Sounder. These signals are made up of dynamic motion compensation (DMC) and image motion compensation (IMC). DMC provides a compensation signal to the Imager and Sounder servos based on processed attitude information from the HIRU and STs. DMC is able to compensate for disturbances that exceed the dynamic range of the bus attitude controller, allowing for highly accurate Imager and Sounder pointing that would not be possible using the bus controller alone. The IMC signal is generated from ground uploaded coefficients that represent orbit and instrument attitude profiles observed by the ground. The DMC and IMC signals support the image navigation and registration (INR) function.

Space Environment Monitor Support

The ACS supports the space environment monitor (SEM) payload. The ACE monitors the magnetometers for saturation, and cycles them to restore nominal performance in the event that saturation is observed. The SAD and XRP steer the IMP located on the solar array yoke to steer the sun-pointed XRS/EUV and SXI. To maintain sun pointing throughout the seasons, the IMP contains a yoke-mounted PSS that provides the ACE with sun pointing measurements necessary to derive closed-loop stepping profiles for the SAD and XRP. The SAD and XRP in turn move the IMP in east-west (azimuth) and north-south (elevation) directions to track the sun, pausing every minute to provide a stable imaging environment for the Solar X-ray Imager (SXI). Upon ground command, the ACE can command the SAD or XRP to slew the IMP to any azimuth or declination position ±14° away from the sun to facilitate instrument calibrations and/or background measurements. The ACE relays XRS-B or EUV-A data to the SXI, for use by its flare detection algorithms.

Safehold: Sun Acquisition Mode

Sun Acquisition Mode (AQM) is the ACE-control mode that puts the spacecraft into a safe-hold configuration (i.e. a power/thermal-safe attitude). AQM may be either manually commanded or autonomously commanded by the on-board fault protection logic. While AQM is designed to place the spacecraft in a safe state without the use of thrusters, it may also be ground-commanded to use thrusters, as during the solar array deployment acquisition sequence. The spacecraft can safely remain in AQM for at least 2 days without operator intervention, at which time the spacecraft should be transitioned into Storage Mode, as described below.

Except for the initial sun acquisition, AQM is invoked when the spacecraft loses stellar inertial attitude control or detects a situation that might endanger the spacecraft or spacecraft components. AQM is capable of controlling the spacecraft to attain and hold a sun-pointing attitude, and furthermore guarantees the safety of the primary imaging payload for a broad set of initial attitudes and rates. The fault protection design ensures that no anomaly, including an operator error in combination with a single latent failure, can cause the spacecraft to acquire a combination of attitude and rate that is unsafe for the payload. Using the output of the KSSs and ACSS in conjunction with control provided by the reaction wheels, AQM orients the spacecraft pitch axis perpendicular to the sun and places the sun midway between the spacecraft roll and minus yaw axes (see Figure 2-3). During the process of sun acquisition, but after the spacecraft is brought to a safe sun attitude with respect to instrument coolers, the solar array is slewed to face the sun while the spacecraft is simultaneously brought to a final safe sun attitude. In steady-state operation, the AQM rotates the spacecraft about the sun line in order to provide thermal, power, and attitude safety, as well as maximum telemetry and command access. Unlike STM, however, AQM does not control spacecraft momentum through periodic adjustments to the spacecraft sun-line rotation rate and solar array offset from sun normal.

Storage Mode

Storage Mode (STM) ensures spacecraft health and safety for long periods of time by providing autonomous momentum management in addition to sufficient solar array power and a safe/stable thermal environment. The spacecraft configuration in STM is equivalent to AQM. Placing the spacecraft in STM following an anomaly will provide extended periods of time for a technical response. STM is normally used for vehicle storage, autonomously controlling spacecraft momentum through periodic adjustments to the spacecraft sun-line rotation rate, and solar array offset from sun normal.

Stellar Inertial Attitude Determination (SIAD)

The attitude determination module in the ACP combines the measurements from the star trackers and HIRU to produce a precise on-board estimate of spacecraft attitude necessary to support the stringent INR requirements. The module uses HIRU rates corrected by computed error residuals. The module processes both HIRU data, and star position data to produce an optimal estimate of the spacecraft attitude.

The stars in the tracker FOV are identified by matching position and magnitude with stars in the on-board catalog. The star catalog is optimized to provide adequate brightness and spatial separation to ensure sufficient stars are available during operations. Updates to the star catalog may be uploaded to the ACE as required.