

## THE HILAT SPACECRAFT

The HILAT (high latitude ionospheric research) satellite was built to provide measurements of both ionospheric parameters and their effects on radio frequency wave propagation. This article provides a description of the spacecraft and its early post-launch performance.

### INTRODUCTION

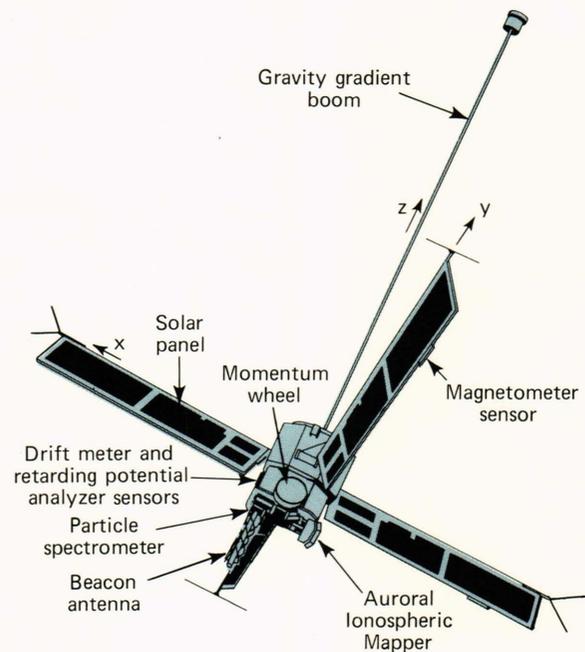
The HILAT satellite was successfully launched on June 27, 1983, into a near circular, 800-km-high orbit with an  $82^\circ$  inclination. The objective of this mission is to provide in situ and remote-sensing observations of the plasma density irregularities in the high-latitude ionosphere and of their effects on radio-frequency wave propagation.

Naturally occurring radio wave scintillation caused by structured plasmas in the ionosphere can hinder communications and surveillance systems. The Defense Nuclear Agency, which investigates these effects, has sponsored ionospheric research to measure and characterize such phenomena as signal fading and frequency coherence. This article describes the HILAT satellite, which was built for that agency to provide measurements of both ionospheric parameters and radio frequency propagation effects.

### SPACECRAFT DESCRIPTION

The HILAT satellite (Fig. 1), designated P83-1, is an operational-class, Navy Transit navigation satellite modified by APL to carry five instruments: a coherent beacon, a plasma monitor, a vector magnetometer, an electron spectrometer, and the Auroral Ionospheric Mapper. Details of the experiments are given in Table 1 of the article in this issue by Fremouw and Wittwer. To measure high-latitude plasma structure, HILAT carries a unique complement of experiments to perform in situ and remote-sensing observations of the ionosphere. These experiments include (a) radio beacons to measure scintillations caused by ionospheric irregularities; (b) in situ detectors to observe precipitating electron fluxes, plasma density, electric fields, and magnetic fields; and (c) an ultraviolet imaging system (1150 to 2000 angstroms) and nadir-viewing photometers (at 3914 and 6300 angstroms) to provide global views of the auroral regions.

Figure 2 is a block diagram of the HILAT satellite that includes the experiments, the portions of the Transit (Oscar 16) satellite that were provided to the program by the U.S. Navy as government furnished equipment and were retained in the HILAT configuration, and the APL modifications that were added to satisfy program requirements. Brief descriptions of



**Figure 1** — The orbital configuration of the HILAT satellite. Earth is always in the  $-z$  direction, and forward motion of the spacecraft is along the  $+x$  direction.

the HILAT subsystems follow. A full description can be found in Refs. 1 through 3.

#### The Command Subsystem

The command subsystem controls the operation of the spacecraft via an earth-to-spacecraft RF link. To satisfy the experiment requirements, the HILAT command system consists of the existing Transit auxiliary command system augmented by a second auxiliary command logic and power switching unit to increase the total number of commands from 8 to 16. Each command system is capable of eight switching operations via latching relays or the single pulse circuit sequencer contained within the power switch unit. The 16 HILAT commands are identified by circled command numbers on Fig. 2. During the operational phase of the program, commands are injected by the Navy Astronautics Group during passes of HILAT over its

**Table 1**—HILAT power subsystem characteristics.

Power available	45 W, average
Main DC/DC converter	$\pm 32.1$ , $+ 21.4$ , $\pm 10.7$ VDC ( $\pm 10\%$ )
Experiment DC/DC converters	$+ 28.0$ , $+ 5.0$ VDC ( $\pm 5\%$ )
Charge control system	Shunt regulator provides trickle charge or temperature-compensated voltage limit, $+ 10.7$ VDC (nominal)
Battery	Eight series-connected nickel-cadmium cells; rated capability of 12 ampere hours
Solar cell array type	Four panels, $167.6 \times 25.4$ cm substrates

network of stations headquartered at Pt. Mugu, Calif. These signals are received at the spacecraft by two dipole antennas mounted on opposing solar panels in the  $\pm y$  directions and are then applied to dual command receivers prior to detection and decoding in the auxiliary command logic units. On sensing its own address, the logic pulses its respective power switching unit to toggle the state of the designated magnetic latching relay. Information on the state of the command relays is sent via telltale bits in the housekeeping telemetry stream.

### The Power Subsystem

The HILAT power subsystem converts solar power to electrical power and stores a portion of it in nickel-cadmium battery cells for use during the eclipsed portions of the orbit. The subsystem supplies various regulated voltage levels to other subsystems of the spacecraft.

The power subsystem consists of a solar cell array, a rechargeable battery, battery charge control and overvoltage protection, and several converters and regulators to condition power for use by the experiments and spacecraft; details are given in Table 1. All of the solar arrays are configured to provide maximum available solar power to the main bus at all times. The integrated orbit average array power for HILAT will range from 43 to 50 watts, with a nominal average of 45 watts. For full sun orbits, the peak solar array current would be excessive for the Transit battery zener circuit. Hence a battery charge control system was provided that consisted of a shunt regulator to dissipate unwanted array power and prevent excessive battery overcharge or overvoltage. The spacecraft battery consists of eight nickel-cadmium cells wired in series. The battery has a rated capacity of 12 ampere-hours at 10.7 volts (nominal).

Experiment power conditioning is provided by newly designed  $+ 28$  volt and  $+ 5$  volt DC/DC converters.

The  $+ 28$  volt DC/DC converter incorporates a feature to protect the battery from excessive discharge. When low battery input voltage (8.8 volts) occurs, transistor switching in the converter ceases and the output voltage of the regulator is reduced to nominally 0 volt. This is termed the low-voltage sensing system and is shown conceptually in Fig. 2. After the batteries recharge, the sensing system can be reset by ground command. In the event of malfunction, the sensing system may be overridden by ground command.

It is important to the HILAT objectives that the experiments operate simultaneously. This mode of operation would require about 87 watts, a situation that the spacecraft solar array and battery could not sustain. Therefore, a spacecraft timer was designed to allow simultaneous operation of all experiments for one-quarter of an orbit (25.9 minutes). The orbital phase of the timer is adjustable by ground command to permit operation over any desired  $90^\circ$  sector of the earth. The period of the timer is adjustable from 98.24 to 103.97 minutes in 127 steps of 2.71 seconds duration to allow approximate synchronization with the true orbital period (101.95 minutes).

### The Doppler Subsystem

The Doppler subsystem provides a pair of ultrastable RF beacons necessary for Doppler velocity measurements. The Doppler subsystem (Fig. 2) consists of a dual 5 MHz oscillator, an oscillator switch, dual-buffer amplifiers, frequency multiplier, phase modulators, low- and high-frequency power amplifiers, transmitter filter, diplexer, and dual-frequency dipole antenna. One of the two oscillators is always powered, with selection determined by ground command. The oscillator is the source of Doppler beacon signals and provides the spacecraft timer with an ultrastable time reference. The 5 MHz oscillator frequency, offset by  $- 140$  parts per minute, is multiplied up to 50 MHz, separated into two isolated channels for phase-modulation, multiplied to 150 and 400 MHz, and amplified. A sharply tuned notch filter is used to eliminate undesirable sideband energy at the command receiver frequency. A diplexer for the 150 and 400 MHz signals and a dual-frequency dipole antenna were designed for HILAT. The dipole antenna is mounted at the end of the  $- x$  solar panel.

### The Attitude Control and Detection Subsystem

Three-axis attitude stabilization to a local vertical system is required for auroral imaging during the HILAT mission. Roll and pitch angles are held to less than  $\pm 5^\circ$  by gravity-gradient stabilization with an 85-foot-long Transit boom. Yaw stabilization is provided to  $\pm 10^\circ$  accuracy by a momentum wheel assembly with its spin axis transverse to the flight path. Other elements of the attitude stabilization system are two hysteresis rods (located in adjacent panels of the solar array) to provide motion damping, and a Z-coil to allow magnetic stabilization prior to gravity-gradient stabilization. When powered, the Z-coil provides a magnetic moment which is adequate to invert

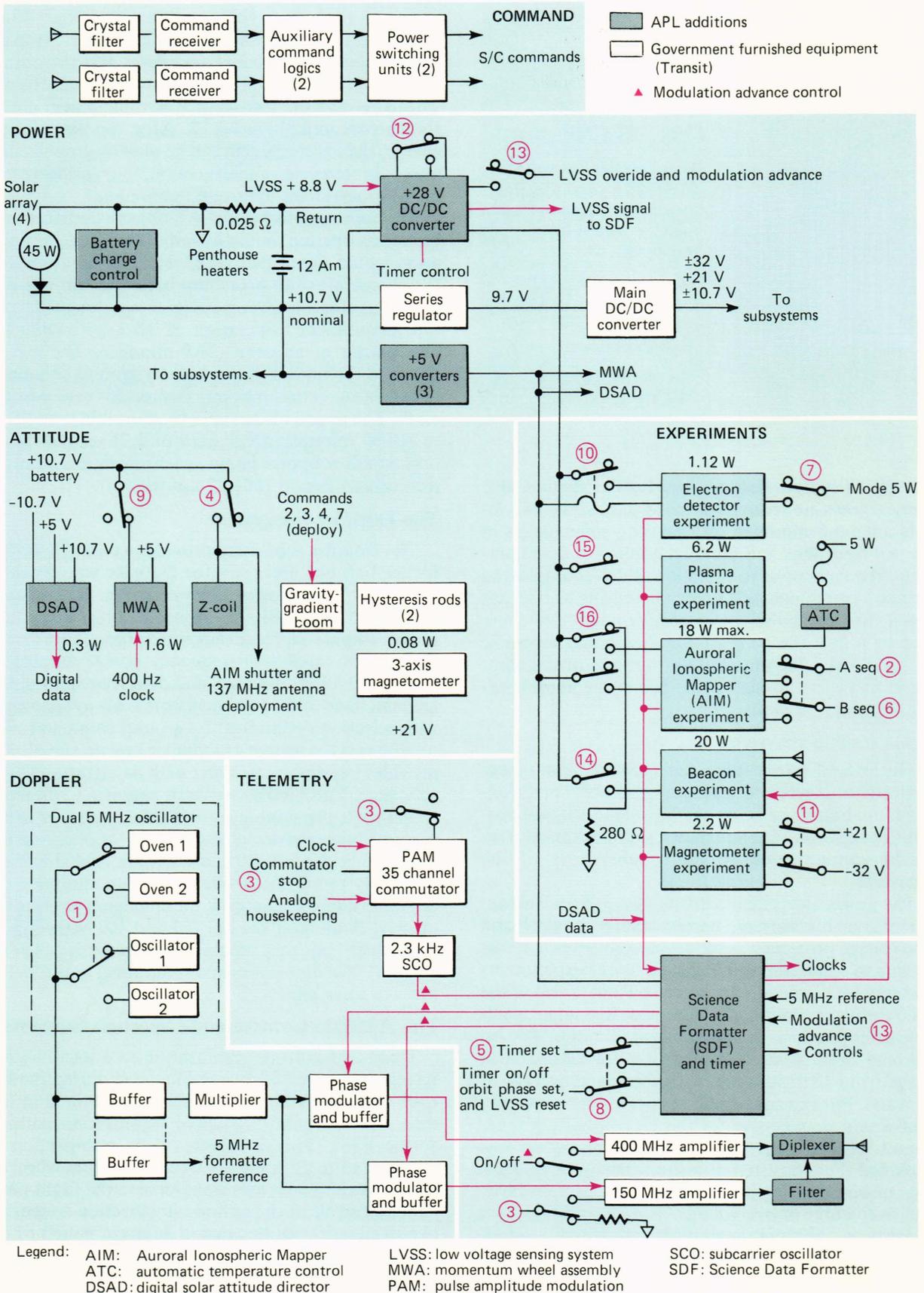


Figure 2 — Block diagram of the HILAT satellite.

the satellite even with the gravity-gradient boom deployed.

The spacecraft attitude is determined to an absolute accuracy of  $\pm 2^\circ$  by the use of three orthogonal axial magnetometers located on the  $-x$  and  $+y$  solar panels and on the spacecraft body, respectively, and a digital solar attitude detector system. The three magnetometers provide the data necessary to determine the attitude of the spacecraft with respect to the local earth's magnetic field vector. The attitude detector system allows determination of spacecraft attitude with respect to the incident solar illumination. It consists of three sensors with a field of view described by three  $128^\circ$  cones whose axes lie in a plane containing the sensors and the z-axis. The axes of the cones are separated by  $120^\circ$ . The accuracy of the attitude detector system is  $1^\circ$  in both elevation and azimuth. By combining both magnetic and solar attitude data, the spacecraft attitude can be determined in inertial space.

The peak HILAT libration angle (the angle between the gravity-gradient boom axis and the local vertical) for the two-month period during which APL controlled the satellite is shown in Fig. 3. A least squares fit shows that the libration angle was decaying exponentially with a time constant of 30 days and that the peak libration angle at the last observation time was about  $3^\circ$ . During this period, the spacecraft was primarily in full-sun orbits and not subjected to thermal transients that occur in partially eclipsed orbits.

#### The Telemetry Subsystem

The telemetry subsystem provides science data and spacecraft performance data from the spacecraft to the ground receiving stations. The Science Data Formatter (Fig. 2) designed for HILAT collects digital data from the five experiments and the digital solar attitude detector and assembles a composite science bit stream of approximately 4098 bits per second for return to the ground. It also provides time-tagging of the data and special timing pulses required by individual experiments. The data stream is output either to the beacon experiment for transmission at L band (at 1239 MHz) or to the Doppler subsystem for transmission (at 400 MHz). Selection of one or the other of these two transmission frequencies is determined by a modulation advance command from the ground. The modulation advance function steps are

Step	400 MHz	L-Band
1	Off	Science data (normal operation)
2	Science data	Unmodulated
3	Off	Unmodulated
4	Housekeeping data	Science data

Housekeeping data, consisting of spacecraft voltages, currents, temperatures, relay positions, etc., are processed for transmission using the Transit 35-channel analog commutator (Fig. 2). The pulse amplitude modulation wave train, which consists of 35

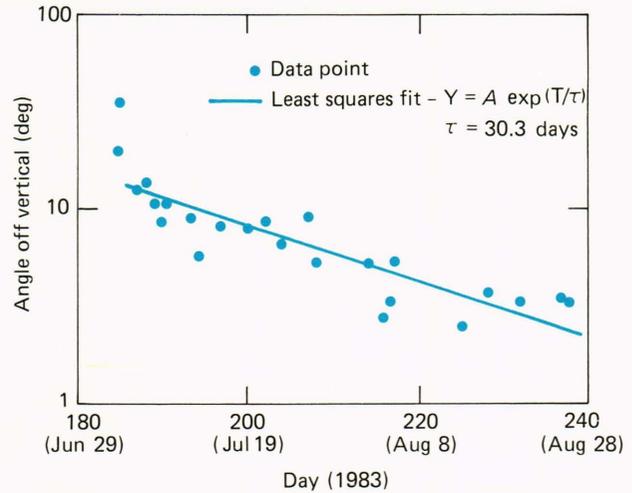


Figure 3 — Decay of the peak HILAT libration angle prior to operational status on August 26, 1983.

channel pulses in a serial form, is applied to the Transit 2.3 kHz subcarrier oscillator, which deviates either the 150 MHz transmitter (primary) or 400 MHz transmitter (backup). The primary/backup switching is unique to the HILAT satellite and is accomplished in the Science Data Formatter.

#### Thermal Design

The thermal design of HILAT provided operational temperatures from  $+54$  to  $-23^\circ\text{C}$  except for the Auroral Ionospheric Mapper experiment ( $+30$  to  $-10^\circ\text{C}$ ) and the satellite batteries ( $+30$  to  $0^\circ\text{C}$ ). An automatic temperature control unit was developed to allow active thermal control of the Auroral Ionospheric Mapper's scan motor (Fig. 2). All of the remaining thermal control is passive. The narrow battery temperature limits were the principal constraints for the HILAT passive thermal design. Performance in orbit indicates that the design goals were met.

#### TESTING

HILAT underwent an extensive test and environmental qualification program from January to May 1983. After integration of the spacecraft and the experiments, electromagnetic compatibility and vibration tests were performed at APL, and magnetics calibration and thermal vacuum testing were performed at the Goddard Space Flight Center. Figure 4 shows HILAT being prepared for the electromagnetic compatibility tests. The tests supported a readiness review on June 3, 1983, prior to shipment of the spacecraft to Vandenberg Air Force Base, Calif.

#### LAUNCH/ORBIT

On June 27, 1983, the HILAT satellite was launched successfully from Vandenberg Air Force Base at 1537:08.7 coordinated universal time on a NASA Scout rocket. The payload weight at launch was 250.22 pounds. The achieved orbit was 800 km (perigee) by 807 km (apogee) at an inclination of  $82^\circ$ . The HILAT



**Figure 4** — HILAT being prepared for electromagnetic compatibility tests at APL.

orbit was selected in light of its multiexperiment mission and represents a compromise between individual experiments. The altitude was high enough for imager global viewing and low enough for the various in situ measurements. The  $82^\circ$  inclination was chosen to give some passes near the geomagnetic meridian at the receiving locations.

The HILAT orbit results in a period of 101.95 minutes and a solar precession rate of approximately  $-7.5$  minutes per day. The orbit will precess 24 hours in approximately 6 months so that observations over all local time sections will be possible in roughly a calendar year. The orbital velocity is 7.436 km per second. An overhead pass will take approximately 15.7 minutes from horizon to horizon.

#### POST-LAUNCH EXPERIENCES

HILAT post-launch operations were conducted from the APL Satellite Tracking Facility. Details of the postlaunch operations plan are available in Ref. 4. A brief summary of the operations flow follows.

On July 1, 1983, after telemetry reception was established and the HILAT status was determined to be normal, the Z-coil was used to stabilize the spacecraft magnetically and the momentum wheel was energized. This induced a tumble rate about the pitch axis of 0.588 revolution per minute, which decayed to 0.057 revolution per minute in a day. With the spacecraft oriented with the beacon experiment antenna point-

ing earthward, the gravity-gradient boom was deployed on July 3. On July 4, the spacecraft timer was adjusted to provide science data when the satellite was over APL, and over the next five days the experiments were individually verified to be operating normally. After this verification, the full complement of experiments was turned on, allowing scientific data and housekeeping telemetry to be received daily.

Several data-taking “campaigns” were supported by HILAT. From July 11 to July 27, 1983, the 150 and 400 MHz transmitters were operated simultaneously to provide gravitational data to the Defense Mapping Agency to help upgrade the earth-gravity model. From July 22 to July 27, science measurements were made at Kiruna, Sweden, to provide auroral observations from a higher latitude than that at APL. The Auroral Ionospheric Mapper measurements provided the first daytime auroral images ever recorded. Unfortunately, there was a power supply failure on the auroral mapper experiment on July 23, and the ultraviolet detector stopped functioning. The visible photometers and the other experiments were not affected by this failure.

The HILAT timer was adjusted for normal operation over the north pole, and control of the spacecraft was transferred to the Navy Astronautics Group on August 26, 1983. Since that time, HILAT has been operational and functioning normally.

#### REFERENCES

- <sup>1</sup> *Payload Description of the HILAT Spacecraft P83-1* JHU/APL SDO/PAO-0348A (Feb 1983).
- <sup>2</sup> *DNA/Transit (HILAT) System Design and Interface Control Document*, JHU/APL SDO/PAO-0360 (Oct 1982).
- <sup>3</sup> *Technical Approach for the Transit/DNA Spacecraft*, JHU/APL SDO/PAO-0138 (Oct 1981).
- <sup>4</sup> *Post-Launch Operations Plan of the HILAT Spacecraft (P83-1)*, JHU/APL SDO/PAO-0582 (May 1983).

**ACKNOWLEDGMENTS**—The HILAT spacecraft is a Navy Navigation Transit satellite originally designed and fabricated and subsequently modified by The Johns Hopkins University Applied Physics Laboratory. The engineering success of HILAT is due to all the APL staff members who were part of the Transit and the HILAT teams. Special thanks go to S. D. Baran and L. H. Schwerdtfeger who were the payload and mechanical engineers, respectively. HILAT was funded by the Defense Nuclear Agency, and launch activities were supported by the Air Force Space Division. Launch vehicle support was provided by the NASA/Scout Program and the Vought Corporation. The beacon experiment was built by SRI, International; the plasma monitor and the electron spectrometer experiments were provided by the Air Force Geophysics Laboratory; the vector magnetometer experiment was built by APL; and the Auroral Ionospheric Mapper experiment was built by APL for the Air Force Geophysics Laboratory.