GeneSat-1

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The GeneSat-1 CubeSat technology demonstration nanosatellite mission is a cooperative effort between NASA and various universities partnered at the Center for Robotic Exploration and Space Technologies (CREST) located at NASA/ARC (NASA/Ames Research Center), Moffett Field, CA, and managed by RSL (Robotics Systems Laboratory) of SCU (Santa Clara University), including CalPoly, SSDL (Space Systems Development Laboratory) and NCSBT (National Center for Space Biological Technologies) of Stanford University. The overall objective is to study the effects of the microgravity environment on biological cultures (bacteria, genetic and biological probes to detect "gene expression") - hence, the label of **"GeneSat"** mission due to the biological payload. Specific mission requirements are: [1) 2) 3) 4) 5)]

1) To develop and test a flight-ready autonomous technology demonstration platform and to design advanced sensors to exploit cellular or microscopic organisms in a small form factor (miniaturized systems).

2) The spacecraft must be capable of accommodating multiple instrument technologies including fluorescent imaging of single proteins using GFP (Green Fluorescent Protein) techniques.

3) Support of specific investigations and assessments of technologies used in ground applications. The initial GeneSat-1 mission will focus on quantitatively detecting levels of GFP expressed in living cultures.

4) The goal of GeneSat-1 is to exploit and investigate the capabilities of Smallsats to accelerate the migration of key technologies to broader applications such as autonomous spacecraft operations, man-tended space vehicles, and novel ground-based research applications.

The GeneSat-1 payload must regulate the internal temperatures to ± 0.5ºC. In addition, some knowledge about the space environment must be sensed and downlinked by spacecraft. The sensor complement includes the measurement of the space radiation and the microgravity environments.

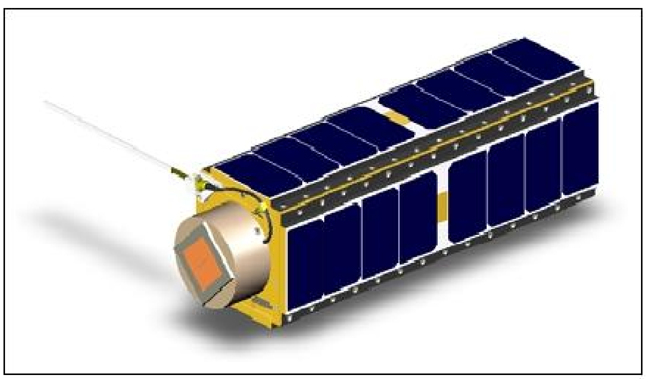

Figure 1: View of the GeneSat-1 nanosatellite (image credit: NASA/ARC)

Spacecraft:

The spacecraft conforms the a triple-cube architecture (of QuakeSat heritage), introducing the newly developed **"*.Sat bus"** of Stanford University, consisting of a bus module (1 CubeSat volume) and a payload module (2 CubeSat volumes) providing a robust, repeatable, low-cost technology validation platform for exploration research.. The entire satellite is about 100 mm x 100 mm x 340 mm in size with a mass of about 4.1 kg.

General satellite services are provided by a compact stand-alone bus module integrating the following subsystems: [6)]

• Attitude control elements (hysteresis rods, magnets, accelerometers, gyros)

• C&DH (Command and Data Handling)

• Solar cells for power generation (4-5 W on-orbit average)

• EPS (Electrical Power Subsystem)

• Secondary batteries

• Interface and payload subsystems

• Communications subsystem (radio and monopole antenna)

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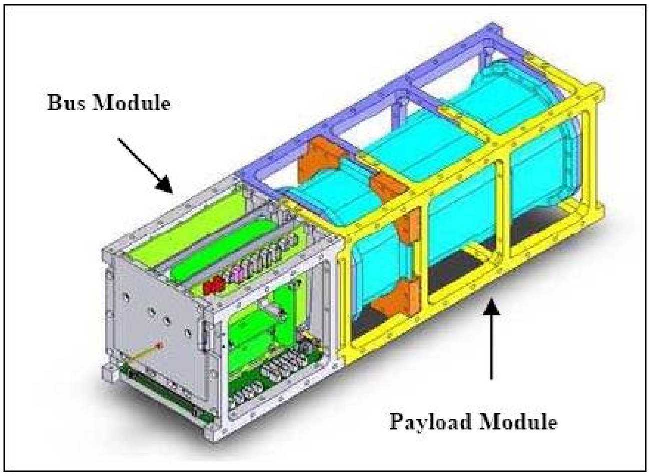

Figure 2: Illustration of the *.Sat bus in the GeneSat-1 configuration (image credit: Stanford University)

An effort has been made in the CubeSat bus design with the introduction of **"common hardware and software interface standards"** between the so-called general-service bus subsystems and the payload components. By defining the demarcation point between "bus" and "payload(s)", the ***.Sat bus** program permits the interface itself to become the focal point for independent development of the bus and the payload elements prior to integration.

Based upon the CubeSat specification, the *.Sat design implements a standardized set of mechanical, electrical, and software interfaces that allow the bus module, itself a single-sized CubeSat, to provide services such as attitude, power, C&DH, and communications, to one or more payload modules.

The primary structural frames of the S/C use 7075 Aluminum square tube-stock. The entire S/C frame is covered with full-length aluminum body panels which provide the functions of both needs, namely a thermal radiation surface for the payload, and a substrate for the solar arrays. The internal electronic subsystems of the bus module are fixed onto a backplane mounting board, providing a means for testing and servicing of individual components. All major interfaces into and out of the bus module (payload and umbilical) are located physically on this backplane board - in addition to the connections between the EPS, C&DH and communication subsystems. The mechanical interface between the bus module and the payload module utilizes a system of interlocking "feet".

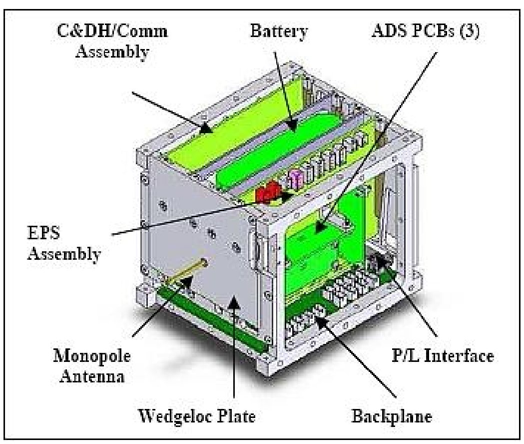

Figure 3: The internal elements of the *.Sat bus module (image credit: Stanford University)

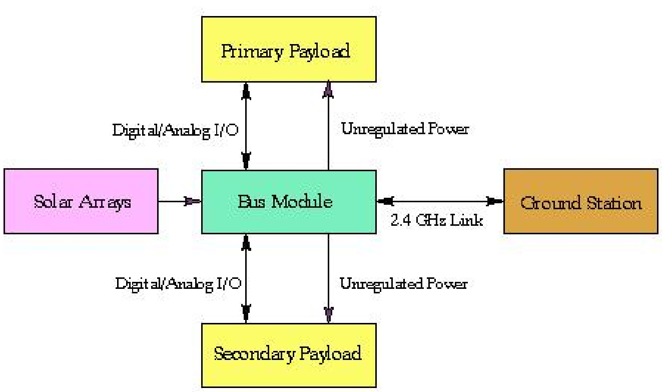

Figure 4: Key *.Sat data and power interfaces (image credit: Stanford University)

The internal *.Sat bus electronics components are mounted onto six custom PCBs (Printed Circuit Boards) with standard JST/JED-type board-to-board connectors. Two boards, the EPS and the C&DH (PIC18 microchips as OBC for all onboard monitoring and control), provide the bulk of service functions required. Other components, including the communications transceiver and the ADS (Attitude Determination Subsystem), are mounted within the core PCB configuration. ADS consists of 3 small boards which which are mounted orthogonally to each other and enabling the measurement of linear acceleration and spin rate in each of the S/C axes.

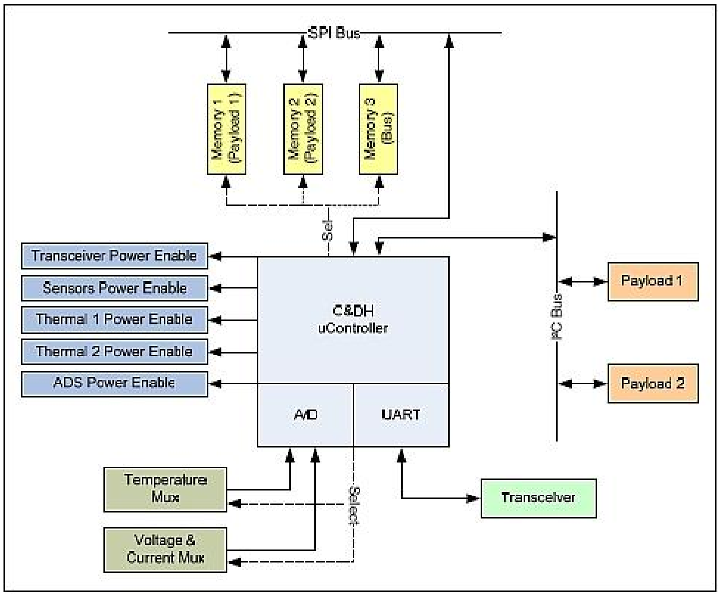

Figure 5: Block diagram of the C&DH subsystem (image credit: Stanford University)

Internal communications are implemented with the I^2C (Inter-Integrated Circuit) protocol standard, a two-wire bus with one line for the clock signal and the other line for serial data transmission. The standard clock rate is 100 kHz. The I^2C protocol supports a network of interconnected devices. The current *.Sat bus requires only the support for three devices (the bus and 2 payloads). The same I^2C bus connects the PIC18s I^2C module and the 2 payload connectors.

The EPS employs UTJ (Ultra Triple Junction) solar cells with an efficiency of 28.3%. A total cell area of 224 cm^2 is provided by 4 cell strings (or panels). Each panel provides a current of 0.92 A in orthogonal sun illumination corresponding to 8.2 W. Lithium-ion batteries are used for operations support in the ecliptic phase of the orbit. The composite battery pack is configured for an output voltage of 7.2 V and a capacity of 4.3 Ah.

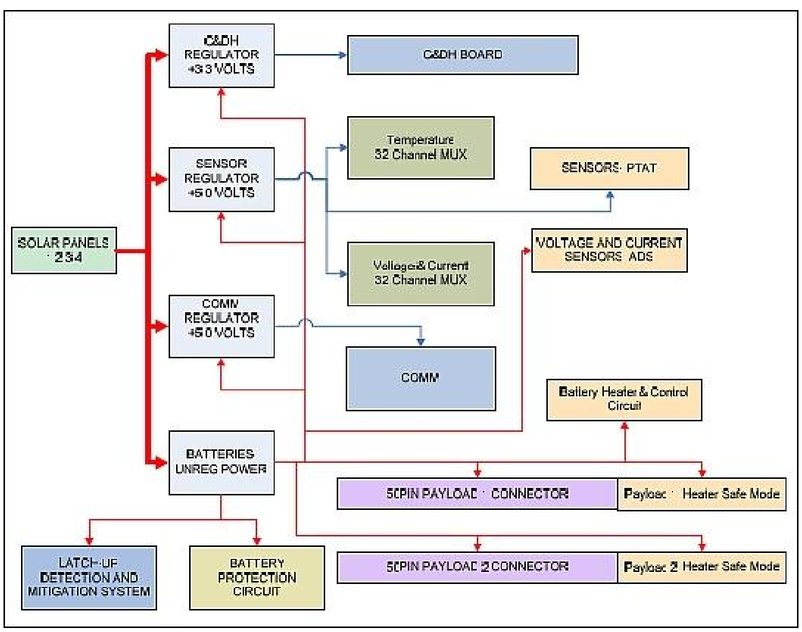

Figure 6: Block diagram of the EPS (image credit: Stanford University)

The ACS (Attitude Control Subsystem) is a simple passive system using the Earth's magnetic field in LEO. It consists of a set of permanent magnets and hysteresis rods placed on the inner faces of the S/C body panels. To estimate the overall micro-gravity level, the *.Sat bus employs a system of 3-axis rate-gyros and 3-axis accelerometers in conjunction with a crude sun sensor (based on the current input of the solar panels).

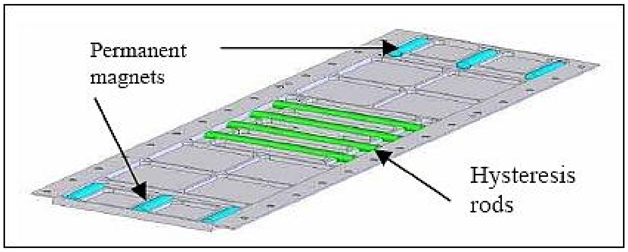

Figure 7: Magnet and hysteresis rod placement (image credit: Stanford University)

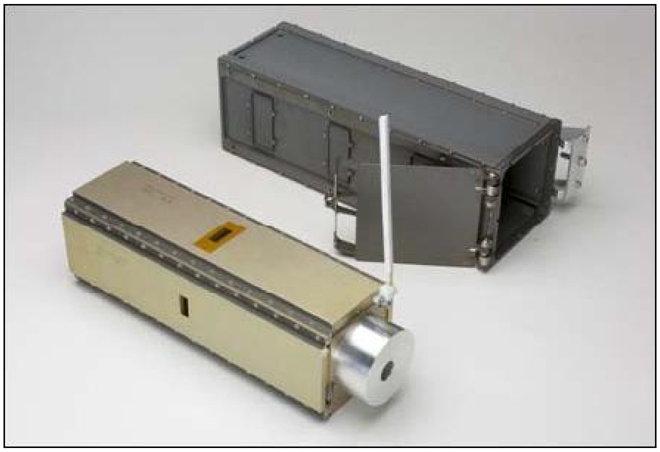

Figure 8: GeneSat-1 triple-cube nanosatellite (left) next to the P-POD (right) (image credit: NASA/ARC)

Launch: GeneSat-1 was launched on December 16, 2006 as a secondary payload on a Minotaur launch vehicle of OSC. The primary payload on this flight was TacSat-2 of AFRL. The launch site was NASA's Wallops Flight Facility, Wallops Island, VA, USA.

The CubeSat was deployed by a standard P-POD (Poly¿Picosatellite Orbital Deployer) system of CalPoly (the triple-cube configuration of GeneSat-1 utilizes the full three-cube capacity of a single P-POD). The total mass of GeneSat-1 (triple CubeSat + P-POD) was .

Total mass of GeneSat-1 (triple CubeSat + P-POD)	7.1 kg (4.1 kg + 3 kg)
Solar cells, battery	Triple-junction (Ga/As) solar cells, Li-ion
Satellite power (peak)	4-5 W
Passive attitude control	Permanent magnets, including hysteresis rods
Satellite volume	Triple cube configuration: 100 mm x 100 mm x 340 mm
OBC (On-Board Computer)	Microchip PIC processor
Science data downlink E/PO beacon/data downlink	~200 kB/day, ISM band (2.4 GHz) Amateur band (~437 MHz)
Bulk storage memory	Flash
Mission duration (spacecraft design life)	21 days (Experiment duration ~ 100 hours)

Table 1: Overview of GeneSat-1 parameters

Orbit: Circular orbit, altitude = 460 km, inclination = 40.5º.

RF communications: Command and telemetry data is broadcast between the spacecraft and a ground station in S-band (2.4 GHz) using a pair of COTS transceivers. The station relays the information to the MOC (Mission Operations Center) via an Internet link. The MOC is located at NASA/ARC. In addition, an amateur band beacon downlink (UHF band) is used to support an associated education/outreach program; several OSCAR-class amateur radio communication stations are available for use through the team's educational partners.

Mission status:

• The GeneSat-1 nanosatellite re-entered the Earth's atmosphere on the August 4, 2010. [7] [8]

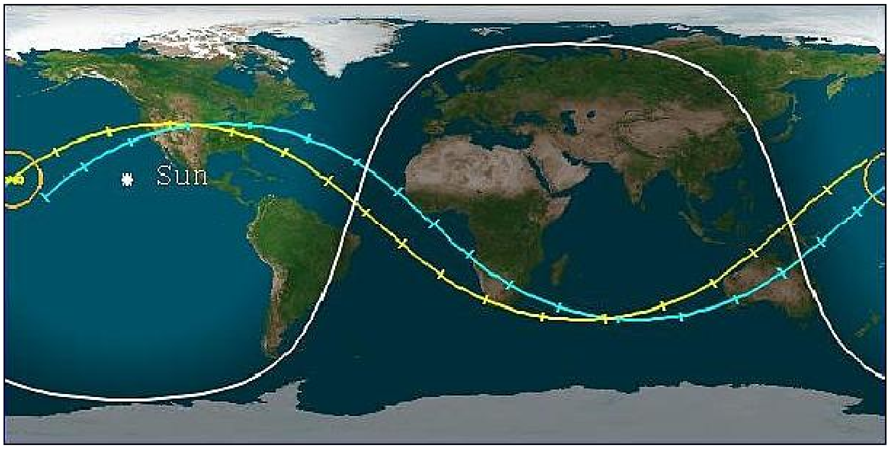

Figure 9: Ground track of the GeneSat-1 nanosatellite on August 4, 2010 at 5 minute intervals (image credit: The Aerospace Corporation)

• Launched on Dec. 16, 2006 and operating for more than three and a half years, the GeneSat-1 mission successfully met all of its mission objectives, providing an important contribution to the development of research-quality instrumentation for in situ biological research and processing. The mission established several spacecraft industry precedents (Ref. 5) :

- The mission's primary outcome was the validation of research-quality instrumentation for conducting in situ biological research in a spacecraft with a mass of < 5 kg.

- The satellite payload's complexity, miniaturization, and automation set a benchmark for spacecraft of this class.

- The mission also demonstrated the highly streamlined application of management practices, a unique government-industry-academia teaming arrangement, and a highly participatory education and outreach program.

GeneSat-1 is considered NASA's first modern, active nanosatellite, its development served as a pathfinder for managing high-risk missions with cost and schedule constraints that are extreme by NASA standards. In addition to providing these unique benefits, NASA's partnership with regional academic institutions allowed a critical flow of expertise relating to small satellite design and operation, and it provided significant education and workforce training experiences for the participating students and engineers (Ref. 5).

• GeneSat-1 is operating nominally in 2009 in its extended mission phase. Over two years after operation and a primary mission success declaration, the GeneSat-1 spacecraft has proven that the designs implemented for a short-lived study can last successfully for extended periods of time. This mission continues to play an important role in the development of research-quality in-situ spaceborne laboratories. Insights from its design as well as its prolonged operation have spawned a number of new flights carrying heritage components. This same heritage allowed for streamlined ground segment development to support new missions. [9) 10)]

• After approximately one month of on-orbit operations, all primary mission objectives had been met, and control of the mission was turned over to SCU (Santa Clara University) for student education and research experimentation. Since that time, additional trend analysis and experiments have been performed to further quantify the performance of the bus; such quantification is of particular interest for at least five heritage-based missions currently in development, three of which are set to launch in 2008 (PharmaSat, PreSat, NanoSail-D) and two slated for 2010.

• On Jan. 17, 2007, all operations for executing the primary mission criteria have been successfully performed, with results disseminated. [11) 12)]

• The GeneSat-1 biological experiment was initiated on Dec. 18, 2006. After 96 hours, the biological experiment was complete and all baseline data downloaded (Dec. 22, 2006).

Mission operations proceeded rapidly, with beacon reception established within the first orbit and successful 2.4 GHz command channel communications established on the second day of operations. Initial telemetry analysis showed a vehicle health state so positive that the primary biological experiment was initiated after about only two days in orbit. Over the course of the next four days, the experiment was autonomously executed. During this time, the mission operations team monitored the progress of the experiment and retrieved experimental data that was being stored on-board the spacecraft. By the conclusion of the 96-hour experiment, a complete baseline profile of science data had been retrieved and delivered to the science team for initial analysis.

Sensor complement:

The payload module features a pressurized sealed vessel, a cylinder containing the integrated fluidics, optical sensors, electrical/mechanical subsystems, internal heaters and controllers (Figure 10). The internal volume also provides humidified air to exchange with the microwells via a gas-permeable membrane. The LEDs (Light Emitting Diode) and detectors for the fluorescent optical assay are located outside the humidified headspace. The payload module represents a fully autonomous platform to perform genetic experiments on E.coli bacteria. The payload consists of a 12-well fluidics plate and uses 12 custom optical units for GFP and growth-rate measurement. [13) 14)]

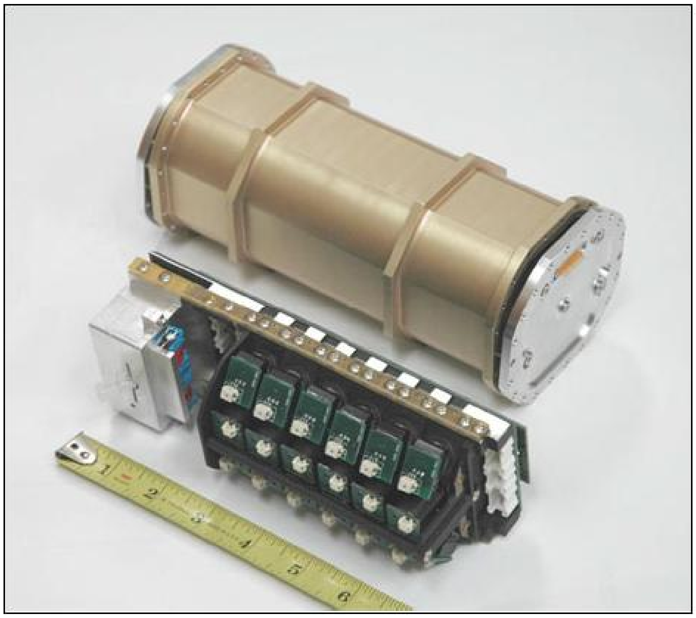

Figure 10: The pressurized payload volume and optical bench of GeneSat-1 (image credit: NASA/ARC)

Fluidics assembly. The integrated analytical fluidics assembly, designed by NASA/ARC, is a piece of mini-hardware (the size of a game card) which is outfitted with a pump, valves, microchannels, filters, membranes and wells - elements that maintain the biological viability of the select microorganism. The fluidics system includes ten 110 µL culture wells and two solid-state reference wells in microwell-plate format (Figure 11). The card is designed to ensure that all 10 wells fill evenly from the single inlet channel by restricting flow through any single well. The fluidics card was manufactured from multiple laser-cut acrylic layers using pressure-sensitive adhesive interlayers. The reservoir/pump unit is a 15 mL medical-grade polymer bag with a helical spring.

Inside the pressurized volume, off-the-shelf sensors for pressure, humidity, temperature at 6 locations, radiation dose, and a 3-axis accelerometer track environmental parameters throughout the mission. The internal payload environment is maintained at atmospheric pressure, 90% relative humidity, and an active phase temperature of 35± 0.5ºC. Once in orbit, samples of E.coli are dispensed into assay wells of the fluidics card. Sugar water is released to activate the experiment, with a suite of sensors monitoring the bacteria. The system warms the E.coli to growth temperature using customized metal/Kapton heater films under closed-loop control. Expressions of genetic signals are to be detected by the ultra-small optical system (Figure 12).

A dedicated blue-LED-excited fluorescent detection system (one per well) probes gene expression levels (gene expression is a process in which a gene is profiled by revealing information encoded within the gene into protein or RNA) by quantifying levels of light emitted by GFP which has been fused to a bacterial gene associated with metabolism. Concurrent light measurements are being made to normalize the fluorescence results to culture population as it grows.

Figure 11: Illustration of the microwell plate (image credit: NASA/ARC)

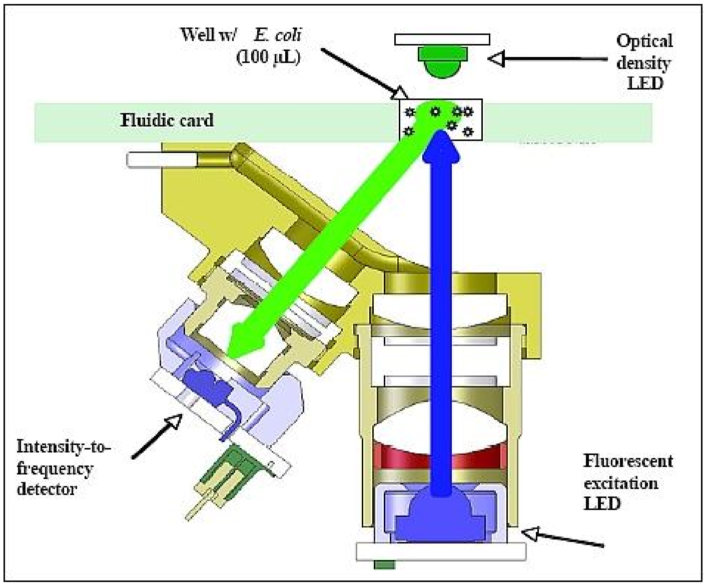

Figure 12: Schematic view of the integrated optical detector system (image credit: NASA/ARC)

GeneSat-1 ground segment:

GeneSat-1 uses a dedicated station of SRI International (Stanford University) with a 18 m parabolic antenna for its primary command and telemetry operations. Mounted to the antenna's tripod are the feeds for both the 2.4 GHz channel as well as the 437.1 MHz beacon receiver.

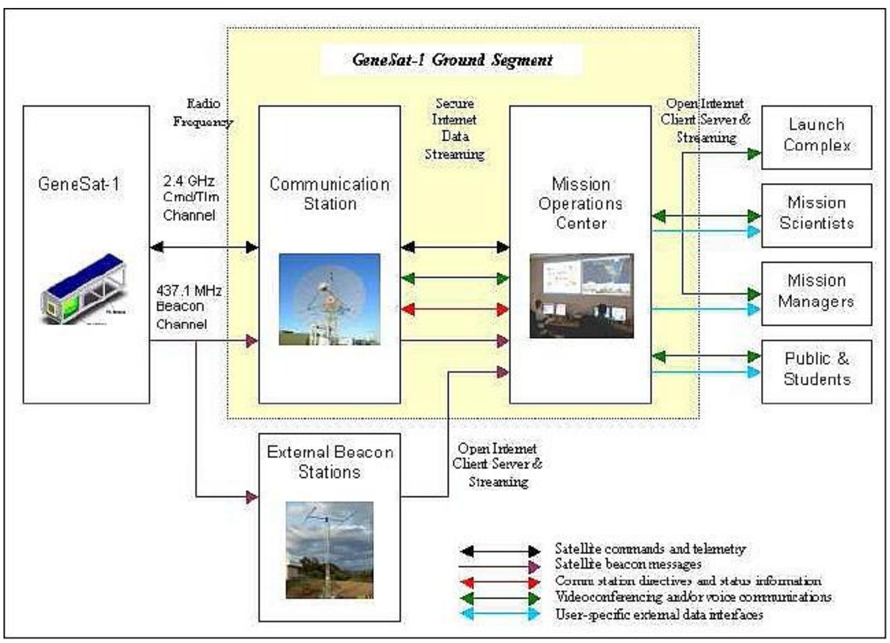

Figure 13: Overview of the GeneSat-1 system architecture (image credit: SCU, NASA/ARC)

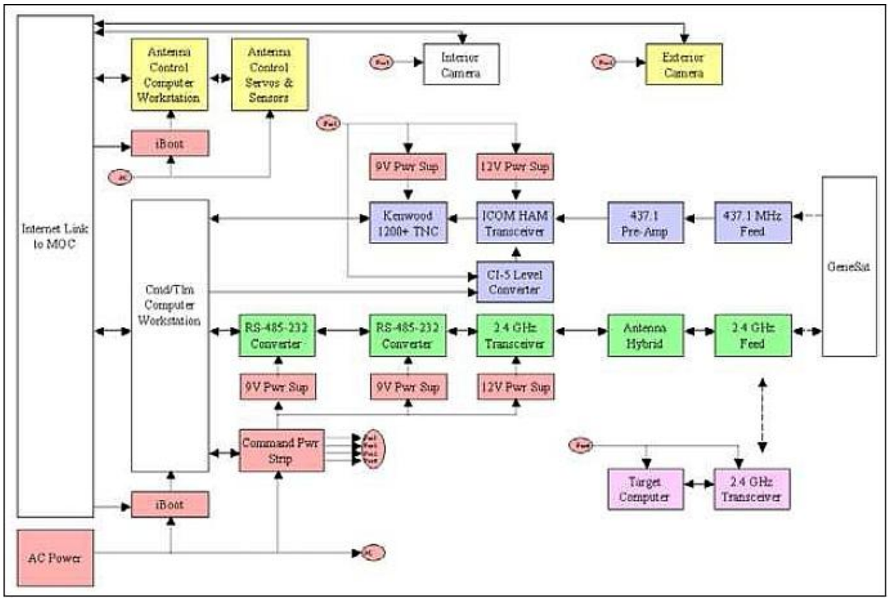

Figure 14: GeneSat-1 communication station block diagram (image credit: NASA/ARC)

Beacon receive stations: A significant portion of the GeneSat-1 mission's education/outreach program involved participation in the mission through direct reception of the spacecraft's beacon signal. Designed to be received by a standard OSCAR-class amateur radio station, this signal periodically broadcast satellite telemetry, allowing external participants to conduct performance analysis, follow the progress of the biology experiment, etc.

External operators were encouraged to submit their received telemetry to the GeneSat-1 team through a simple web site that returned a QSL card to operators. This telemetry, which was maintained separately from the primary GeneSat-1 databases, has been made available to a variety of external experimenters and educators.

Satellite command/telemetry data and communication station configuration/status data is relayed between the communication station and the Mission Operations Center (MOC) via encrypted communications through the public Internet (Figure 15).

Command and telemetry operations were performed through the use of satellite control software that allowed the operations team to remotely operate the GeneSat-1 vehicle. Although a Control Node can operate from any location with an Internet connection, programmatic security and configuration control requirements have led to the use of four Control Node locations: the Multi-Mission Operations Center (MMOC) at NASA/ARC, the SCU Robotic Control Center located in the NASA Research Park in Moffett Field, the GeneSat-1 operations development and training laboratory on the SCU campus, and within the SRI communication station.

The ground segment software architecture, shown in Figure 15, supports such operation from any networked location; however, for security and configuration control reasons, only pre-approved locations were used for such operations. These locations include the primary and secondary MOCs, the communication station location, and the satellite operations laboratory at SCU.

After routine tracking was established, the Ames MMOC served as the primary Control Node during the balance of GeneSat-1's primary operations phase. After approximately two months of on-orbit operations, all primary mission objectives had been met, and control of the mission was turned over to SCU for student education and research experimentation. Hence, the SCU MOC became the primary MOC once extended operations of GeneSat-1 started in Feb. 2007.

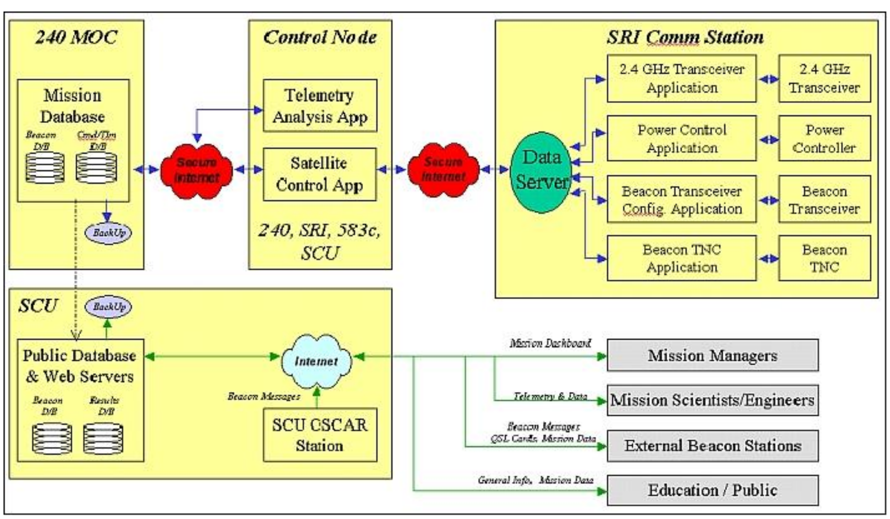

Figure 15: Layout of the Mission Control Center (image credit: NASA/ARC)

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The information compiled and edited in this article was provided by Herbert J. Kramer from his documentation of: "Observation of the Earth and Its Environment: Survey of Missions and Sensors" (Springer Verlag) as well as many other sources after the publication of the 4th edition in 2002. - Comments and corrections to this article are always welcome for further updates.