Document title:

ESAT DATASHEET

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ESAT is an educational nanosatellite that aims at becoming the perfect tool for hands-on training in space engineering at all levels. The potential users range from elementary schools, where STEM skills development is pursued, to university engineering courses and all the way up to engineering companies. For all of them, this realistic satellite simulator offers a wide variety of education activities.

Figure 1: ESAT.

1. Main features

- User expandable.
- Open source and open environment.
  - Arduino based.
- CubeSat standard.
  - 10 x 10 x 10 cm.
  - Less than 1 kg weigh.
- Multiple subsystems.
  - Electrical power.
  - Command and data handling.
  - Attitude determination and control.
  - Thermal payload.
  - Structure.
- Battery powered.
- USB and Wi-Fi connections.
- Graphical ground segment.
- Ground support equipment.
  - Turning table.
  - Sun simulator.
  - Magnetic field simulator.
  - Protoboard.
- Various connection topologies.
  - Multiple client & server.
  - Multiple-client & single-server.

2. Subsystems

2.1. Electrical Power Subsystem (EPS)

The EPS handles the electrical power of the whole ESAT, managing the batteries, the solar cells with their power regulators and converters, the power buses, the arming jumpers and the external charging. Consist on two boards, the main electrical power subsystem board (EPS) and the battery module (BM), plus two side solar panels.

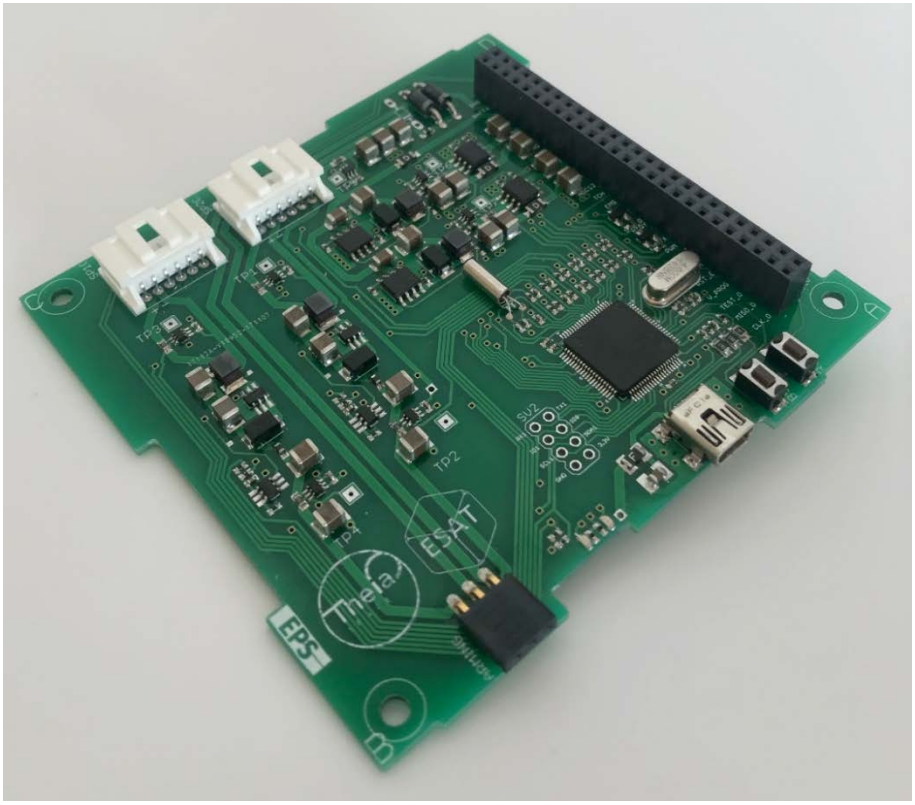

Figure 2: ESAT EPS board.

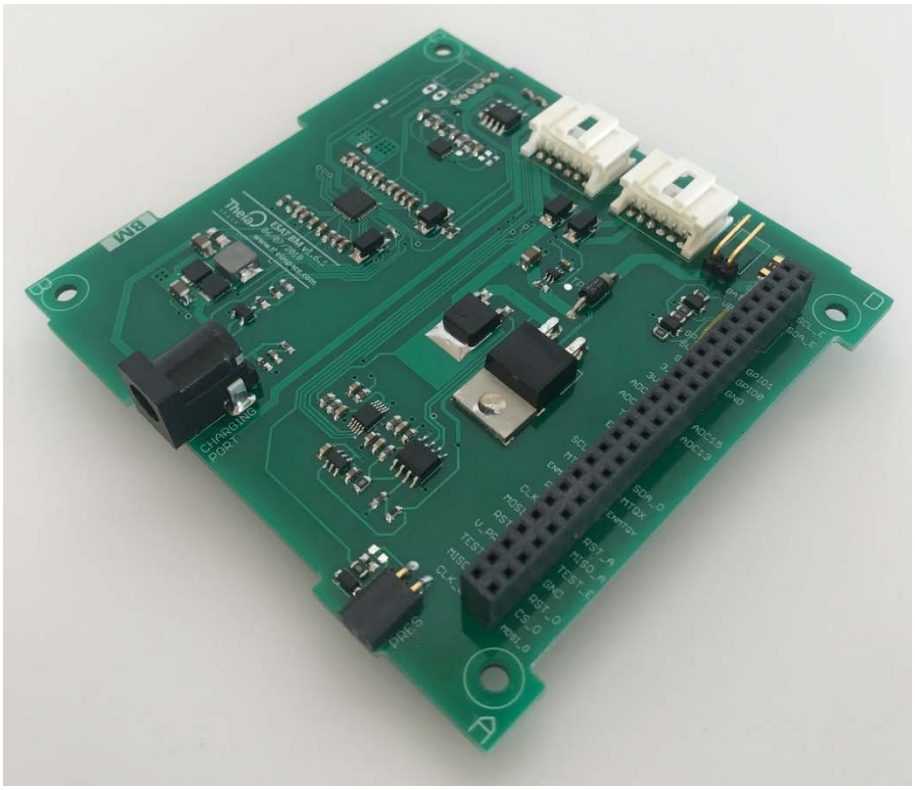

Figure 3: ESAT BM board (batteries are placed below).

Figure 4: ESAT solar panel.

- Features:
  - 2 x MPPT-capable solar panel switched-mode power DC/DC converters with solar panel input current, voltage and output current monitoring (EPS board).
  - Direct Energy Transfer (DET) solar panel regulator with input voltage, output current and shunt voltage monitoring (BM board).
  - 2 x side solar panels with up to 1 W power and temperature sensor.
  - 2 x Li-Po 1400 mAh battery cells with built-in temperature sensor (BM board).
  - Temperature-compensated standalone battery manager with external charging port and safety apply-before-flight enable jumper (BM board).
  - Additional apply-before-flight jumper (EPS board).
  - 3.3 V standalone switched power regulator (EPS board).
  - 5 V standalone switched power regulator (EPS board).
  - Switchable 3.3 V bus.
  - Switchable 5 V bus.
  - Raw battery voltage bus.
  - Programmable microcontroller with full-speed USB port partial-powering capable (EPS board).
  - PC52 rectangular double-row system bus connector (EPS and BM boards).
  - Mounting holes (EPS and BM boards).
  - 10 cm x 10 cm size (EPS and BM boards).

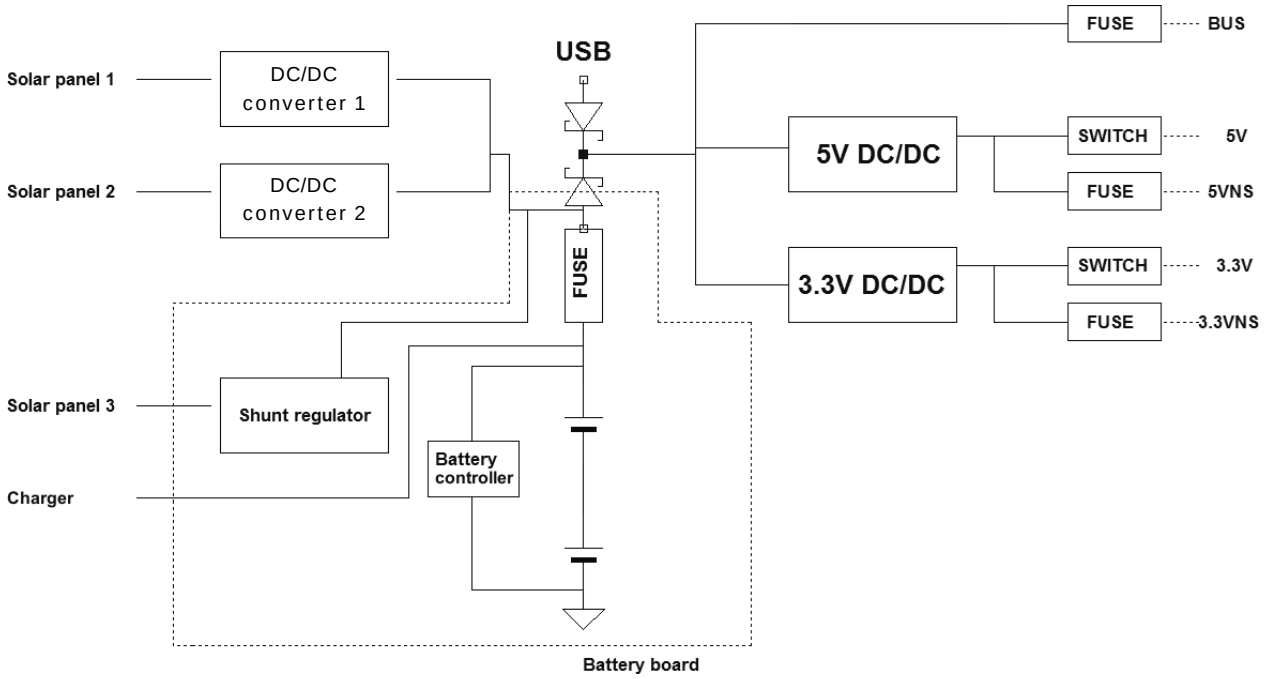

Figure 5: ESAT power system; solar panel 3 represents panels 1+2 connected in series.

2.1.1. MPPT-capable solar panel switched-mode power DC/DC converters

- Two independent modules working in parallel.
- Software controlled switching technology.
- Boost topology. Transfer function: $V_{out} = V_{in} \cdot \frac{1}{(1-D)}$
- Different working modes:
  - MPPT.
  - Sweep.
  - Fixed duty cycle.
  - (Custom).
- On-board currents testing points.
- Available telemetries:
  - Input (solar panel) current.
  - Output current.
  - Input (solar panel) voltage.

2.1.2. Direct energy transfer (DET) solar panels regulator

- Demonstrative linear shunt regulator.
- Output can be isolated from the rest of the device.
- Ratings:
  - Shunt activation voltage: 8.2 -8.5 V.
  - Maximum current: 2000 mA

2.1.3. Solar panels

- 2 x 100 mm x 80 mm side solar panels.
- Up to 1 W power.
- Thermocouple temperature monitored.
- Ratings:
  - Nominal voltage: 5.5 V.
  - Open circuit voltage: 7.9 V.
  - Nominal current: 180 mA.
  - Short circuit current: 190 mA.
  - Maximum temperature: 80 ºC.

2.1.4. Battery cells

- 2 x 1400 mAh Li-Po cells.
- Can be unplugged.
- Ratings:
  - Cell nominal capacity @ 0.2 C discharge: 1400 mAh.
  - Cell voltage: 3.7 V.
  - Fully charged cell voltage: 4.2 V
  - Maximum allowed discharge cell voltage: 3.0 V
  - Maximum charge current: 1400 mA (1.0 C).
  - Maximum discharge current: -2800 mA (2.0 C).
  - Total stored energy: up to 10 Wh.
  - Charging temperature range: from 0 ºC to 45 ºC.
  - Discharging temperature range: form -20 ºC to 60 ºC.
  - Storing temperature: -20 ºC to 45 ºC.
  - Life cycles: > 300.

2.1.5. Battery charger

- AC/DC wall power supply.
- Input ratings:
  - Input voltage: 100-240 V AC.
  - Frequency: 50-60 Hz.
  - Plug: IEC 60083 C type (CEE7/16 - Europlug).
    Note: for IEC 60083 A type (NEMA 1-15P - USA) and IEC 60083 D type (BS 1363 - UK) plug types regions, an adaptor can be delivered under request.
- Output ratings:
  - Voltage: 12 V DC.
  - Current: ≥ 500 mA.
  - Plug: NES/J 21 5.5 x 2.1 mm type.
  - Polarity: positive centre.

2.1.6. Battery controller

- Monitors the battery charge and discharge processes.
- Standalone.
- Cell discharge balancing feature.
- Apply-before-flight safety jumper.
- Four stage charge:
  - Pre-charge.
  - Constant current (CC).
  - Constant voltage (CV).
  - Termination.
- Safety protections with hysteresis control and temperature compensation:
  - Charging over temperature: 55 ºC.
  - Discharging over temperature: 60 ºC.
  - Cell undervoltage: 3.2 V.
  - Cell charging undervoltage: 2.8 V.
  - Cell overvoltage: 4.3 V.
  - Nominal charging current: 600 mA.
  - Maximum discharging current: -1100 mA.
  - Charging overcurrent trip point: 900 mA.
  - Discharging overcurrent trip point: -1400 mA.
- Available telemetries:
- Battery current, cell voltages and temperature telemetries.

2.1.7. 3.3 V buses

- Standalone switching regulator.
- Can be powered via USB.
- Unswitchable bus.
  - Fuse protected.
- Switchable bus with overcurrent protection.
- Ratings:
  - Voltage range: 3.3 V – 3.6 V.
  - Unswitchable bus max current: 250 mA.
  - Switchable bus max current: 600 mA.
- Voltage and current telemetries.

2.1.8. 5 V buses

- Standalone switching regulator.
- Unswitchable bus.
  - Fuse protected.

- Switchable bus with overcurrent protection.
- Ratings:
  - Voltage range: 4.6 V – 5.3 V.
  - Unswitchable bus max current: 250 mA.
  - Switchable bus max current: 1000 mA.
- Voltage and current telemetries.

2.1.9. Raw battery voltage bus

- Fuse protected.
- Ratings:
  - Voltage range: ~battery voltage.
  - Max current: 250 mA.
- Voltage and current telemetries.

2.2. On Board Computer (OBC)

The OBC manages the data handling across the ESAT, as well as communications, time keeping and telemetry storage.

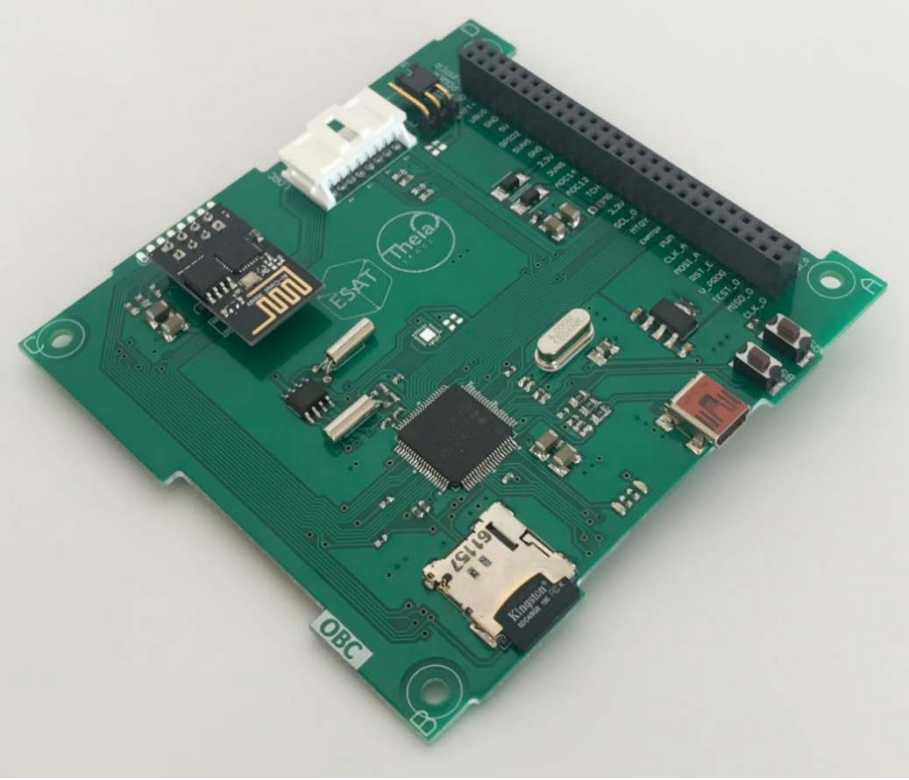

Figure 6: ESAT OBC board.

- Features:
  - Wireless communication based on ESP8266 ESP-01 Wifi module.
  - SD-card for telemetry storing.
  - Real time clock with backup battery.
  - Power domain selection jumper.
  - General purpose input and output lines.
  - Programmable microcontroller with full-speed USB port for debugging and powering the board.
  - PC52 rectangular double-row system bus connector.
  - Mounting holes.
  - 10 cm x 10 cm size.

2.2.1. Computing and data handling

- Routes data across all the subsystems.
- Delivers system telemetry via Wifi and OBC USB port.

2.2.2. Wifi communication

- Connects to the Ground Segment server to deliver the telemetry and receive the telecommands.
- Based on Expressif ESP8266EX chip.
- Supports ESP-01 board.
  - Low profile connector.
  - 1 MB flash size.
- User programmable. External programmer included.
- 802.11 b/g/n Wifi version
  - WPA2-PSK encryption.
- Supported network configuration modes:
  - Auto (DHCP).
  - Static IP.
- TCP connection:
  - DNS service support.
- Debugging telemetries:
  - Hostname.
  - Wireless SSID.
  - MAC address.
  - Host IP address.
  - Subnet IP mask.
  - Default gateway IP address.
  - Primary DNS server IP address.
  - Secondary DNS server IP address.
  - Network connection mode (DHCP / Static IP).

- Server address.
- Server port.
- Connection status flag.
- WLAN connection status flag.
- Wireless channel.
- RSSI.

2.2.3. SD-card telemetry storage

- Stores all subsystems telemetry.
- Can be downlinked filtered by time gap.
- Micro SD cards up to 8 GB have been tested and are supported.

2.2.4. Real time clock

- Keeps the ESAT time during power off.
- Cell button battery backup power.

2.2.5. Health and status

- Monitors the OBC microprocessor.
- Telemetries:
  - CPU load.
  - Current RAM usage.
  - Maximum RAM usage.
  - CPU voltage.
  - CPU temperature.
  - System uptime.

2.3. Attitude Determination and Control Subsystem (ADCS)

The ADCS detects the current orientation (azimuth) of the ESAT and rotates the satellite to follow certain angle regarding the reference system.

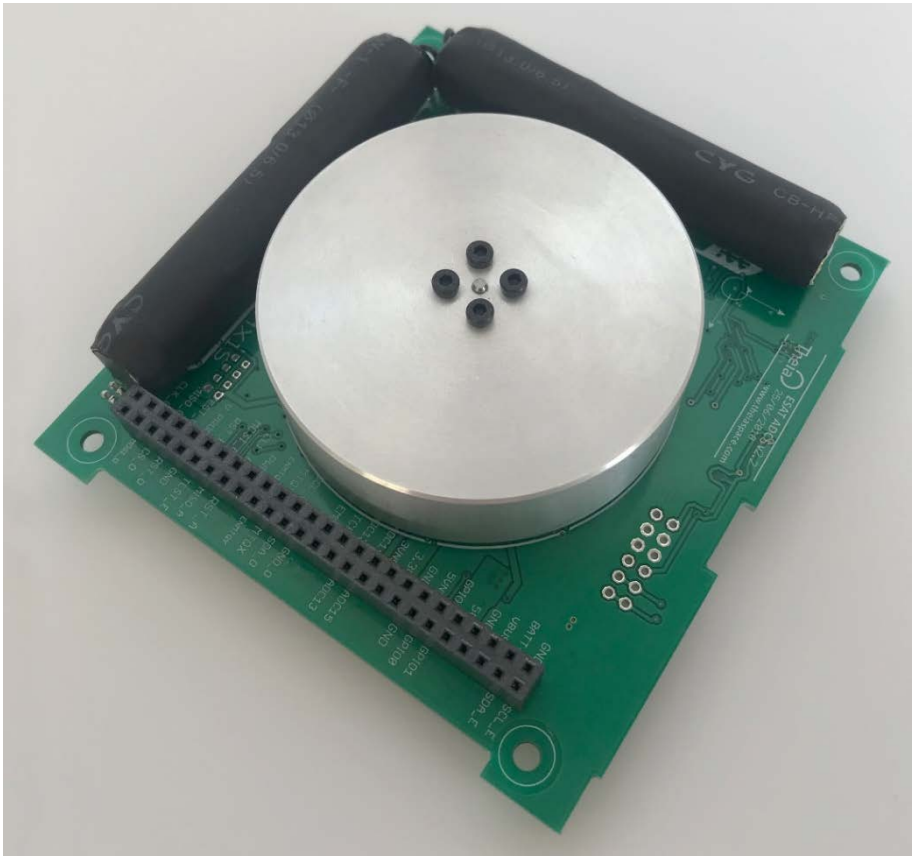

Figure 7: ESAT ADCS board.

- Features:
  - One axis (Z) attitude determination and control.
  - Magnetic attitude determination.
  - Solar attitude determination.
  - Momentum wheel attitude control.
  - Magnetorquers attitude control.
  - Multiple control algorithms.
  - 6 axis inertial measurement unit (IMU) with accelerometer and gyroscope plus 3 axis magnetometer.
  - Aluminium reaction wheel with dedicated electronic speed controller and tachometer.
  - Two magnetorquers along X and Y axes with polarity LED indicators.
  - 4 coarse sun sensor on side panels and solar panels.
  - 32 bit ARM programmable microcontroller with floating point unit and full-speed USB port.
  - PC52 rectangular double-row system bus connector.
  - Mounting holes.
  - 10 cm x 10 cm size.
  - 22.5 mm height.

2.3.1. Attitude determination

- Magnetic attitude is based on magnetometer readings.
- Solar attitude is computed based on coarse sun sensor readings.
- Rotational speed is computed based on the gyroscope measurements.

2.3.2. Attitude control

- Rotates the ESAT to follow a certain attitude.
- Settable PID attitude control algorithm with dead band.
- Multiple run modes:
  - Follow magnetic angle.
  - Follow solar angle.
  - Detumble.
  - Maximum torque (continuous rotation with magnetorquers, clockwise and counter-clockwise).
- Actuation can be switched between magnetorquers and reaction wheel.
- Rotational speed used by control algorithm can be obtained either from gyroscope measurements or from magnetic angle derivative.
- Ratings:
  - Magnetic angle accuracy: ±10 degrees.
  - Solar angle accuracy: ±10 degrees.
  - Gyroscope rotational speed accuracy: 1 degree / s.

2.3.3. Reaction wheel

- Changes the satellite azimuth quickly once assembled on the rotatory table.
- Brushless motor with a digital electronic speed controller and a user settable PID control loop.
- Duty cycle and angular speed control.
- Can rotate clockwise and counter-clockwise.
- Ratings:
  - Wheel absolute speed range: -8000 rpm to 8000 rpm.
  - Wheel nominal operation speed range: -7200 rpm to 7200 rpm.
  - Wheel weight: 50 g
  - Wheel height (alone): 16.5 mm
  - Wheel height (assembled, with mounting screws): 20.3 mm
  - Wheel diameter: 60 mm
  - Wheel inertia moment: 330 g cm^2.

- Wheel current consumption (4500 rpm): 550 mA.
- Wheel peak power consumption: 1100 mA.

2.3.4. Magnetorquers

- Two solenoids placed along X and Y axis.
- Polarity LED indicators.
- Demagnetizing algorithm.
- Ratings:
  - Length (each): 70 mm
  - Diameter (each): 13.5 mm
  - Weight (each): 42g
  - Current consumption @ 5 V (each): 160 mA
  - Magnetic momentum (each): 0.5 A m^2.

2.4. Thermal payload (TPL)

The ESAT thermal payload subsystem heats and cools a sample.

Figure 8: ESAT Thermal Payload.

- Features:
  - Closed loop temperature control.
  - Multiple settable LED visual indicators.
  - Can be powered from either 5 V bus or battery raw voltage bus (jumper selectable).
  - Compatible with 1.x.y ADCS board versions stacks.
  - Half PC52 rectangular double-row system bus connector.
  - Easy assembly.
  - Reduced size (4.8 cm x 3.6 cm).
- Ratings:
  - Resistor current consumption (5 V bus powered): 105 mA.
  - Resistor current consumption (raw battery bus powered, 8.2 V): 180 mA.
  - Idle current (3.3 V switchable bus): < 5 mA.

2.5. Structure (STR)

A machined aluminium structure plus four stainless steel threaded rods holds all the boards and the solar panels. The remaining sides are closed by transparent machined methacrylate panels, allowing a full, clear view of the inner components while the ESAT is running.

Figure 9: ESAT Structure.

- Features:
  - Machined aluminium top and bottom frames.
  - Anodized aluminium corner rails.
  - 2 mm transparent machined methacrylate for sides, top and bottom panels.
  - M2 hex socket bolts.
  - All bolts, nuts and threaded rods are made of non-ferromagnetic stainless steel.
  - Steel inserts in all threaded holes.
- Ratings:
  - Height: 105 mm.
  - Width: 105 mm.
  - Depth: 105 mm.
  - Weight (without bolts): 160 g

3. Ground support equipment (GSE)

The ground support equipment lets the user simulate certain orbit conditions and obtain a full ESAT usage experience.

3.1. Rotatory table

The rotatory table allows the ESAT to turn around Z axis freely.

- Two parts:
  - Turntable.
  - Fixed stand.
- Hand-tailored turntable hanging sharp tip:
  - Low friction.
  - Free rotation.
- Possibility to rotate using either the magnetorquers or the momentum wheel.
- PLA 3D printed balancing hoops.
- Delivered with 5 g fine balancing counterweights.
- Ratings:
  - Turntable height: 22 cm
  - Turntable greatest diameter: 27.5 cm
  - Stand height: 28 cm
  - Stand base side length: 15 cm
  - Assembled maximum height (without ESAT): 31 cm
  - Turntable weight (without counterweights): 470 g

3.2. Magnetic simulator

The magnetic simulator overrides the Earth magnetic field around the ESAT, producing a stronger and controlled magnetic field to enhance magnetic attitude determination and magnetorquers actuation.

- Two neodymium powerful permanent magnets enclosed in PLA cases.
- Magnets are raised to be placed at the same height than the ADCS board.
- Ratings:
  - Magnetic field intensity: 700 μT.
  - Magnets assembly nominal distance: 30 cm.
  - Magnets recommended height from stand: 30 cm

3.3. Sun simulator

The sun simulator consists on a powerful LED lamp that can be uses to illuminate the ESAT at any desired position.

- Hand-held.
- Mains powered.
- Fan cooled.

- Usages:
  - Simulate and follow any solar attitude.
  - Simulate the battery charging process using the solar panels.
- Ratings:
  - LED nominal power: 100 W.
  - LED nominal luminous flux: 9000 lm.
  - Mains input power: 120 W.
  - Input voltage: 100-150 V AC or 200-240 V AC.
  - Input frequency: 50-60 Hz.

    Note: Indicate the required mains voltage on purchase request. Otherwise sun simulator may not work properly and even being damaged.
  - Connection type: IEC 60320 C14 male type + IEC 60320 C13 to IEC 60083 E + F type (CEE7/7 - *Schuko*) power cord.

    Note: for IEC 60083 B type (NEMA 5-15P - USA) and IEC 60083 D type (BS 1363 - UK) plug types regions, a specific IEC 60320 C13 power cord can be delivered under request.

    Note: 100-150 V AC sun simulator version must be grounded.
  - Weight (without power cord): 1.5 kg.

3.4. Protoboard

The prototyping board allows the user to design and test any experimental circuit and test it in conjunction with the rest of the satellite.

- 85 mm x 55 mm protoboard.
- Connectors for the solar panels and the coarse sun sensors.
- Additional 3.3 V and 5 V regulators powered using the ESAT charger.
- 3.3 V and 5 V buses power present LEDs.
- Can be used standalone and stacked with the ESAT.
- Prototyping cables and components included.
- PC52 rectangular double-row system bus connector.
- Mounting holes.
- 10 cm x 10 cm size.
- Ratings:
  - Maximum 3.3 V independent regulator current output: 800 mA
  - Maximum 5 V independent regulator current output: 950 mA
  - External power input: 12 V DC.
  - Power input connector type: NES/J 21 6.0 x 1.95 mm type, positive centre.

3.5. GSE tools

Ground support equipment is delivered disassembled along with the tools required for its final assembling:

- Assembling hex keys.
- Magnetic compass.
- Spirit level.
- Balancing counterweights.
- PC52 system bus connector spacer.
- Spares.

4. ESAT integration

4.1. ESAT standalone

Features:

- Height: 110 mm.
- Width: 106 mm.
- Depth: 106 mm.
- Weight: 715 g.
- Current consumption:
  - Idle: 150 mA @ 3.3 V + 20 mA @ 5 V.
  - Wheel at 4500 rpm: 150 mA @ 3.3 V + 550 mA @ 5 V.
  - Magnetorquers enabled: 150 mA @ 3.3 V + 350 mA @ 5 V.
- Maximum current consumption (wheel start): 150 mA @ 3.3 V + 1100 mA @ 5 V.

4.2. ESAT + GSE assembly (rotatory table + magnetic simulator)

Features:

- Height (total): 41 cm.
- Width (total): 35 cm.
- Depth (total): 27.5 cm.
- ESAT + turntable weight (without counterweights): 1185 g.
- ESAT + turntable inertia momentum (may vary depending on the number of counterweights used): 0.0006-0.0007 g cm^2.

5. Data handling and data formatting

Telecommands and telemetry are exchanged using CCSDS packets (https://public.ccsds.org/Pubs/133x0b1c2.pdf) fitted into KISS frames (http://www.ax25.net/kiss.aspx).

5.1. CCSD packets

CCSDS space packets are built according CCSDS packets standard. Their structure is described in the next figures.

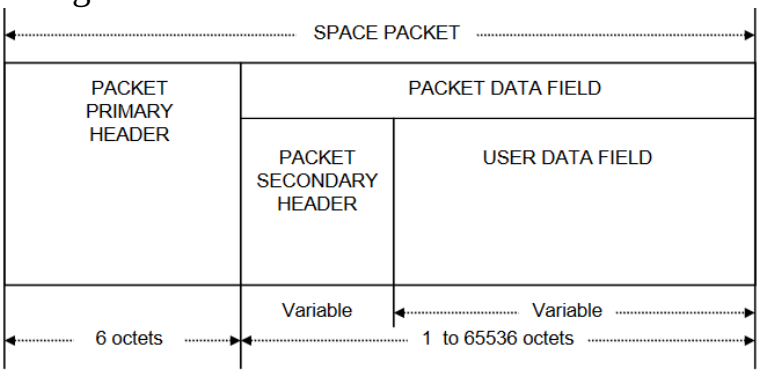

Figure 10: CCSDS packet structure.

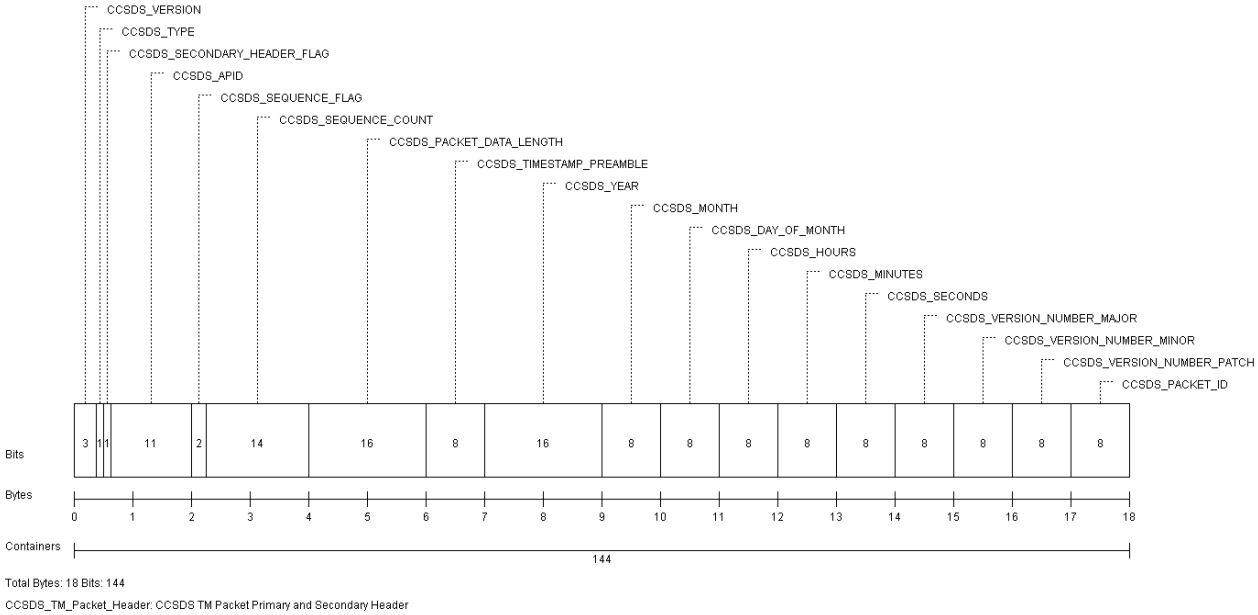

Figure 11: ESAT CCSDS packet primary and secondary header.

The application process identifiers (APID) used for the ESAT subsystems are the followings:

- 0: OBC
- 1: EPS

- 2: ADCS
- 3: WIFI
- 4: Thermal Payload

5.2. KISS frames

KISS communication protocol encapsulates all CCSDS packets exchanged between the ESAT and the ground segment. Their structure is summarised in the following table:

Begin	Command	DATA	End	0xC0 escaping	0xDB escaping
0xC0	0x00	L bytes	0xC0	0xDB 0xDC	0xDB 0xDD

The maximum overhead added by the KISS frame encapsulation for a packet length of L bytes is 2L + 3.

6. Firmware

ESAT uses free/open-source software for its on-board firmware. It is written in C++ using Arduino environment (https://www.arduino.cc/). This allows customization and integration with Arduino examples and third-party sketches.

7. Ground segment (GS)

Ground segment is based on Ball Aerospace COSMOS (https://cosmosrb.com/). Written in Ruby using free/open-source software, this interface offers plenty of features and customizations:

- XTCE command and telemetry standard support.
- Custom telemetry and telecommands displays for each subsystem.
- Auto data logging.
- Replay module.
- Script runner.
- Telemetry plotting.
- Data extraction.
- USB and TCP/IP communications.
- Multiple-client & server or multiple-client & single-server configurations.

7.1. GS launcher

Starts the GS utilities.

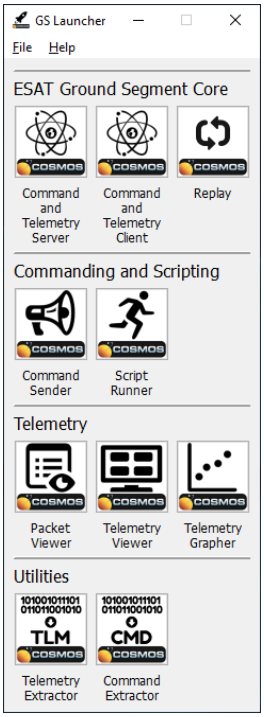

Figure 12: Ground segment launcher.

7.2. Command and telemetry server

Starts and handles the communications with the ESAT, either TC/IP or via COM port (USB). It also lets you check the amount of packets received from each type and the errors.

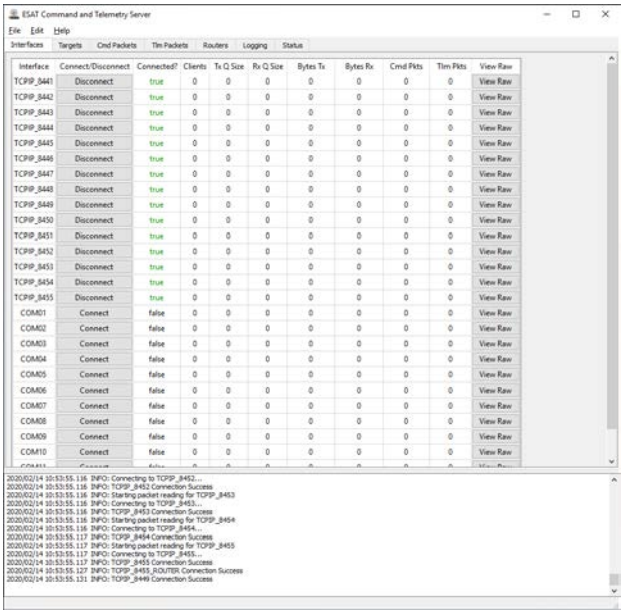

Figure 13: Command and telemetry server.

7.3. Command and telemetry client

Similar to Command and telemetry server but handles the connection to the server instead.

7.4. Replay

Loads telemetry from a log file instead of the ESAT real time one. Log file must be browsed before.

7.5. Command sender

Lets you send a telecommand without using the commanding displays. Certain commands are only available through the command sender.

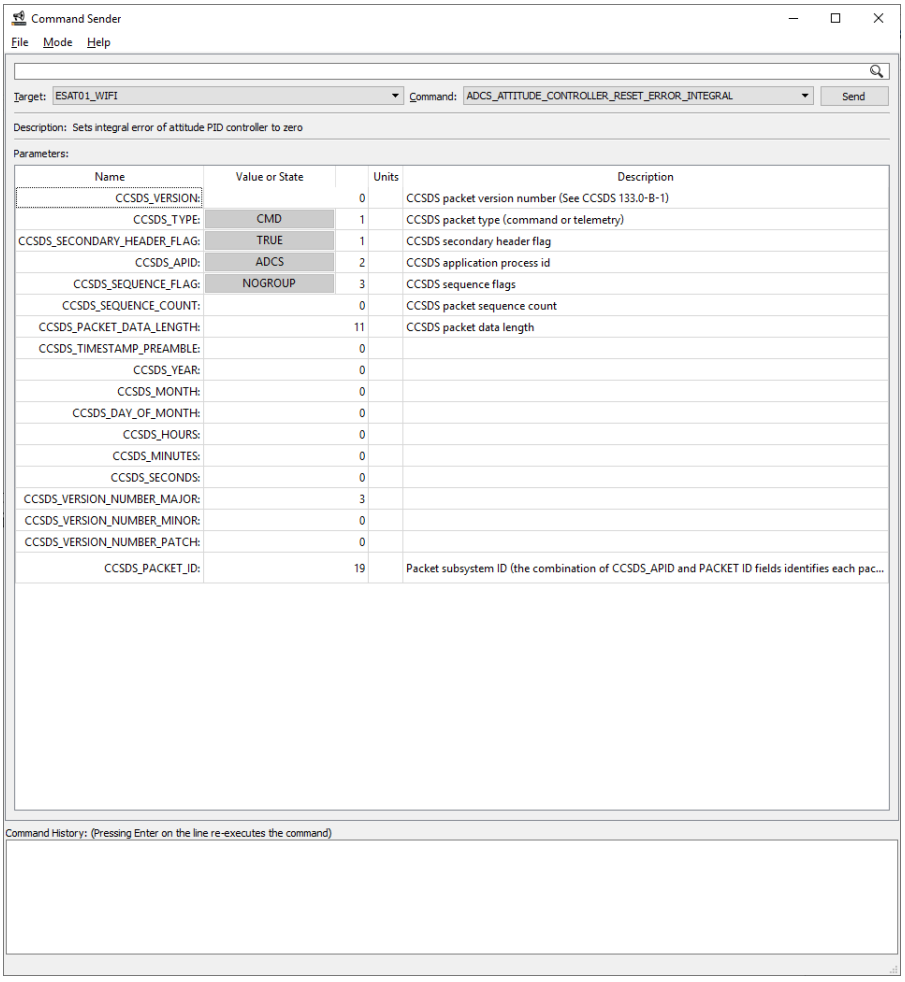

Figure 14: Command sender.

7.6. Script runner

Script runner can be used to program and execute Ruby-based scripts to perform automatic tasks. A COSMOS scripting guide is available here: https://cosmosrb.com/docs/scripting/.

7.7. Packet viewer

Packet viewer lets you check each telemetry packet contents in detail.

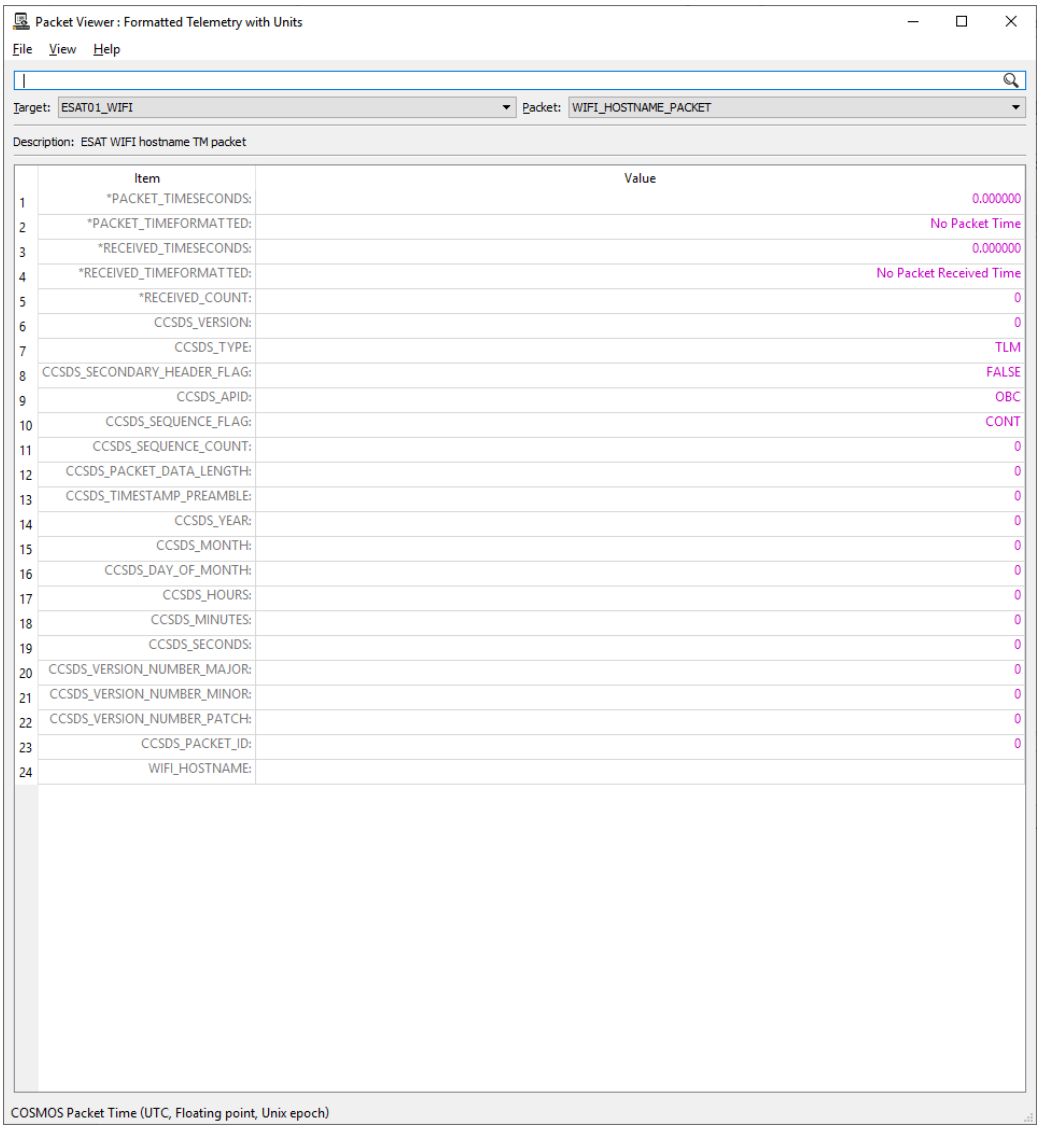

Figure 15: packet viewer.

7.8. Telemetry viewer

Launcher for all telemetry and telecommands displays, either connected via Wifi or USB COM port:

- Display for the ADCS telemetry.
- Display for the ADCS commands.
- Display for the EPS telemetry and commands.
- Display for the OBC telemetry and commands.
- Display for the Thermal Payload telemetry and commands.
- Display for the Wifi telemetry and commands.

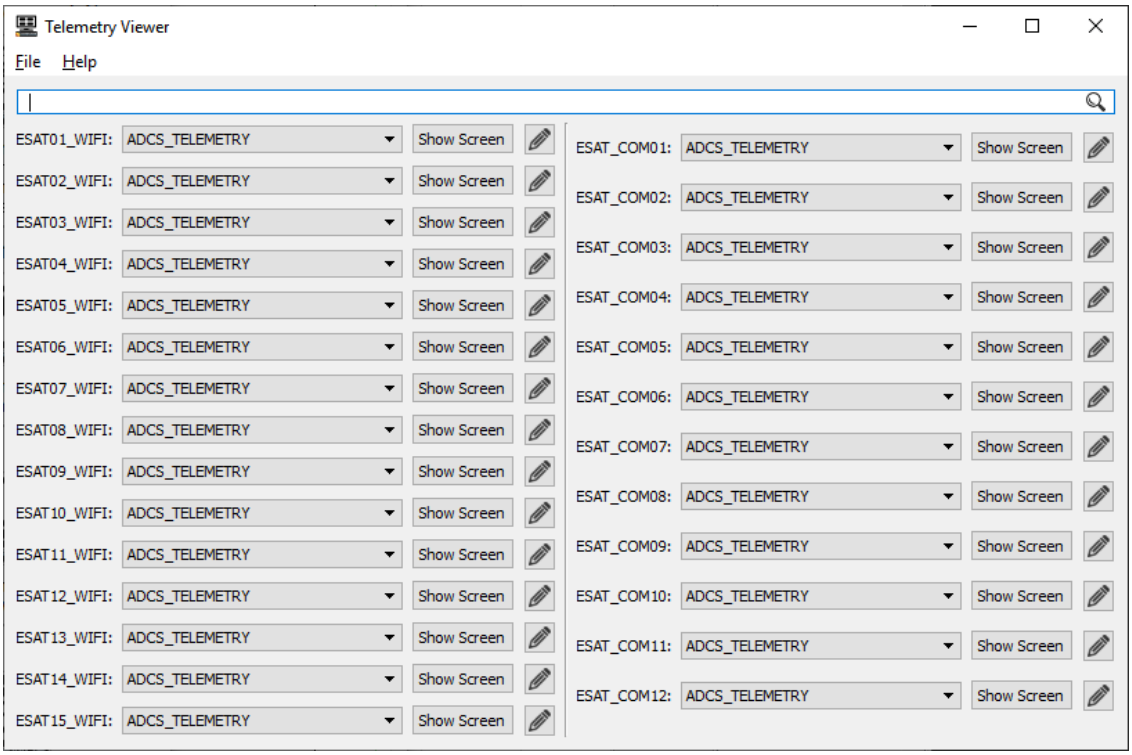

Figure 16: Telemetry viewer (launcher).

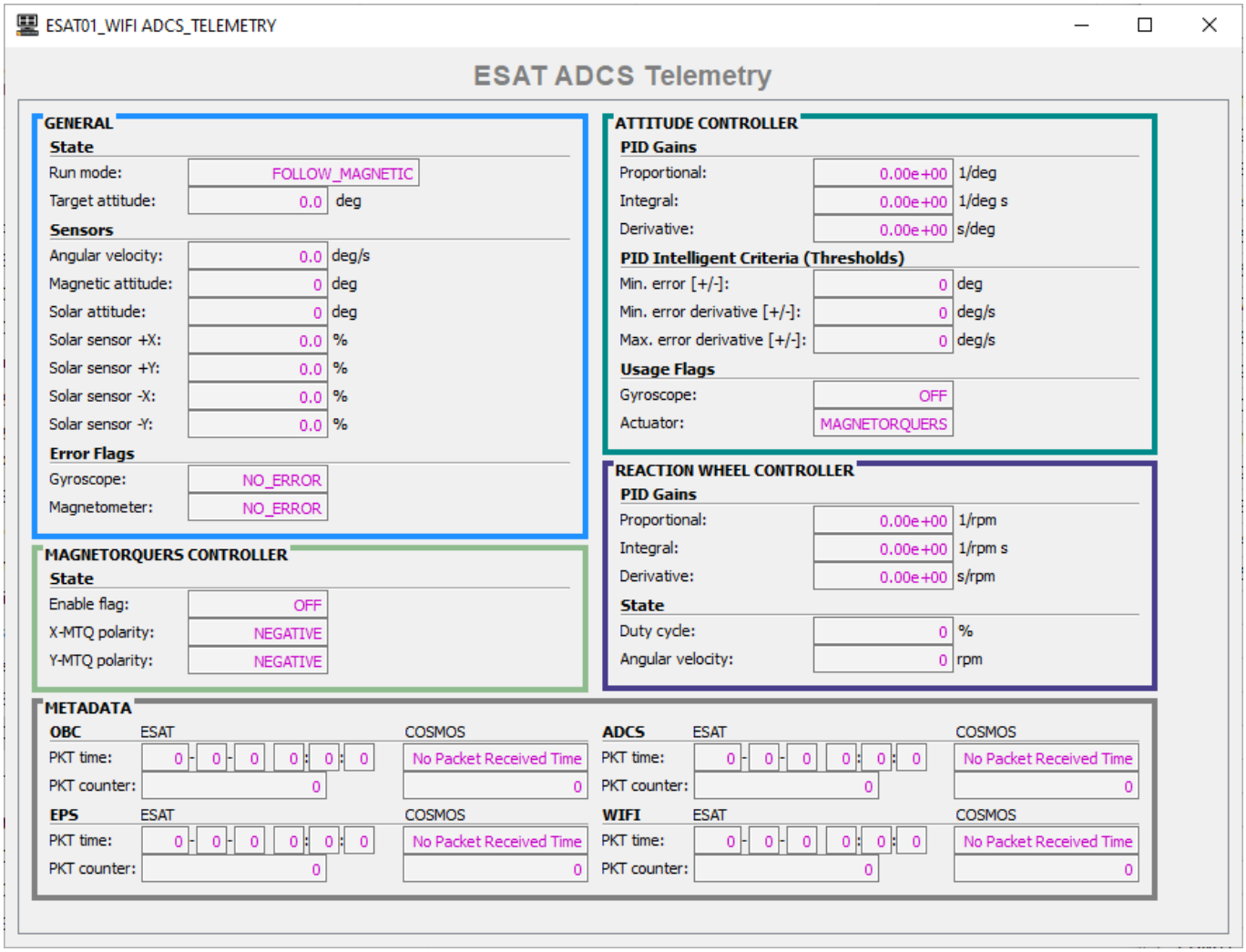

Figure 17: Display for the ADCS telemetry.

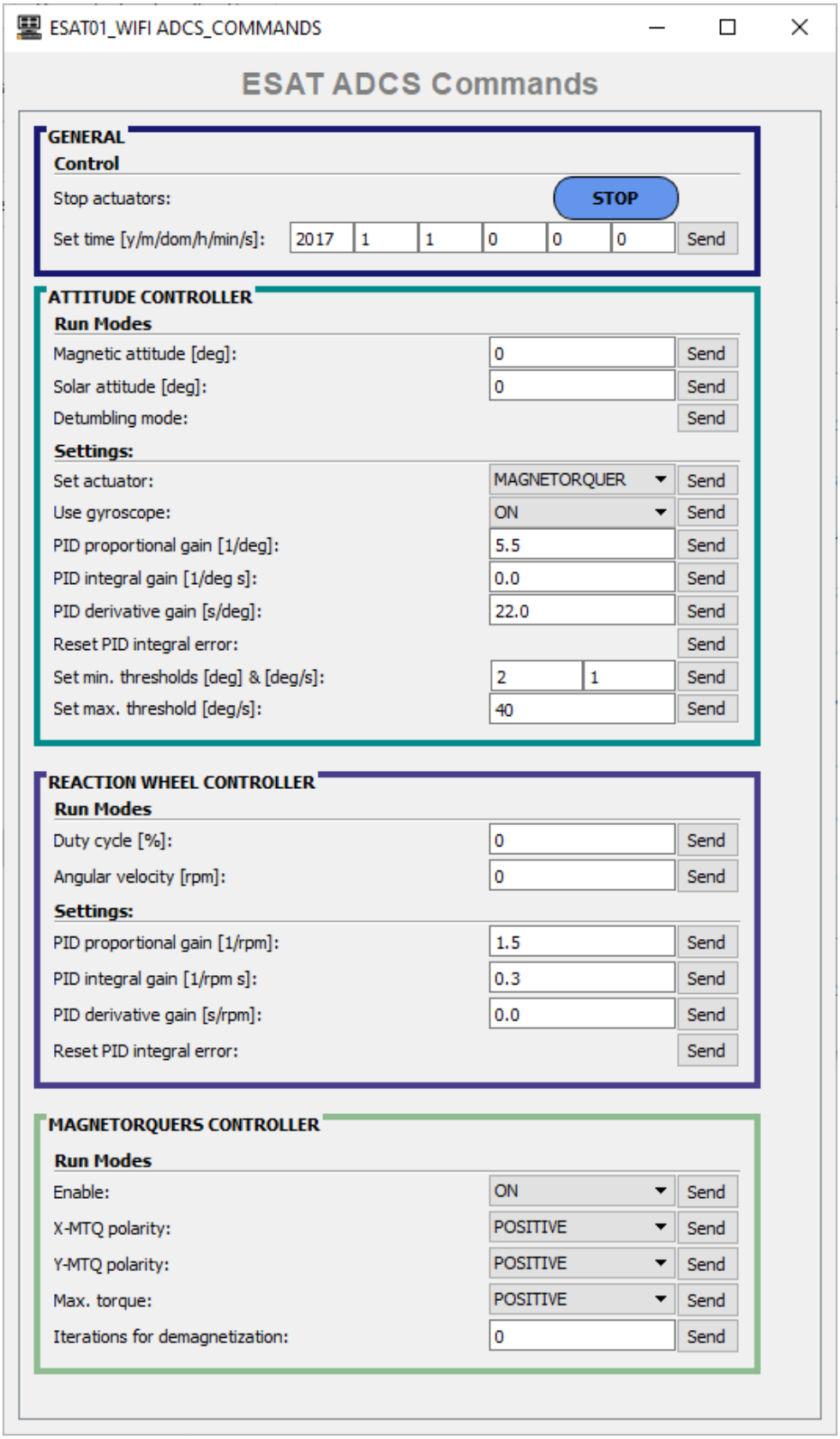

Figure 18: Display for the ADCS commands.

7.9. Telemetry grapher

Telemetry values plotter. Allows multiple plots and tabs, pause, stop and resume plotting, zoom and time reference changes.

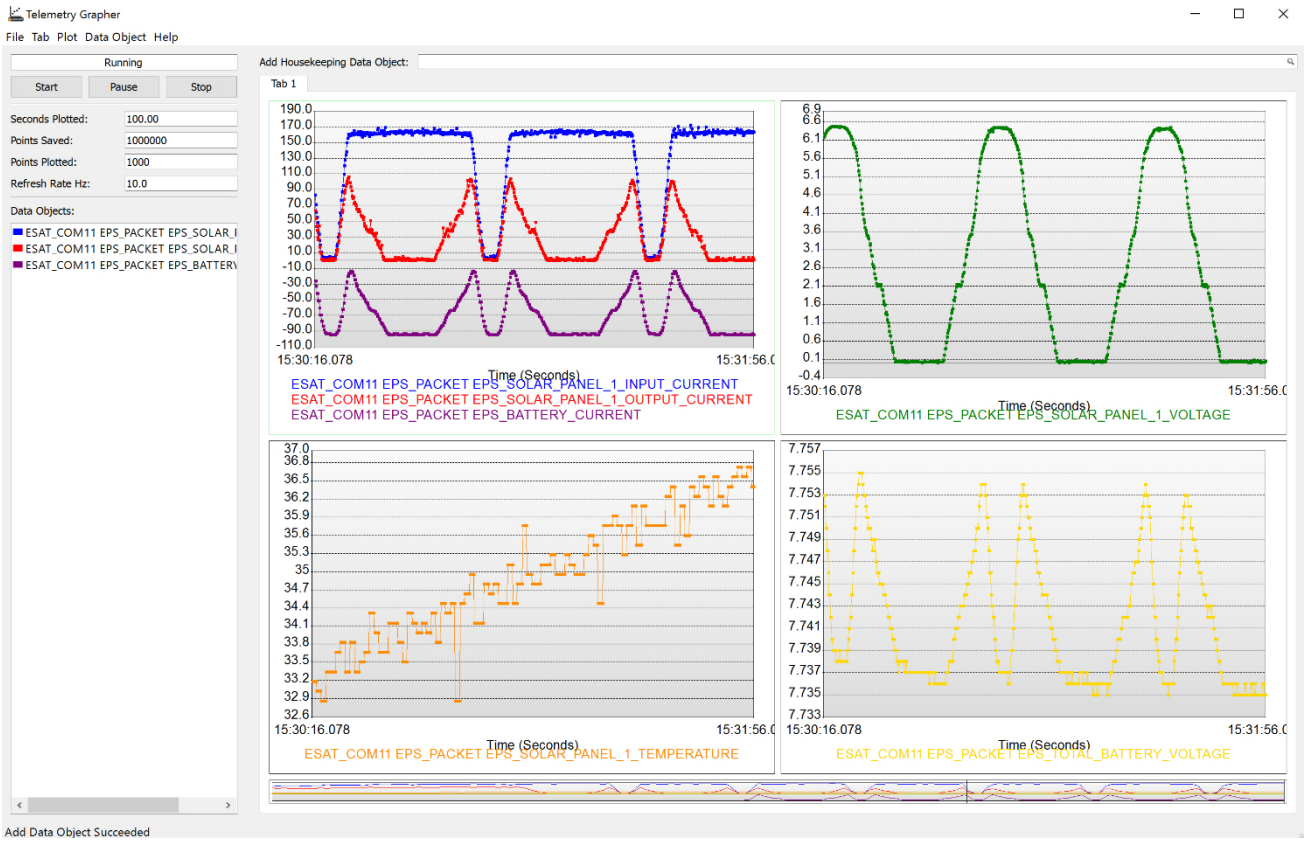

Figure 19: Telemetry grapher.

7.10. Telemetry extractor

Converts telemetry data from a stored log file to standard file format.

7.11. Command extractor

Converts telecommands sent log information to a standard file format.

DISCLAIMER

Hardware and software specifications included in this document are prone to change without prior notice due to product updates and improvements. Final delivered product characteristics may drift from the exact values detailed in this document.