Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun
Energetic Particles

Preliminary Design Review

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EPI-Lo Software

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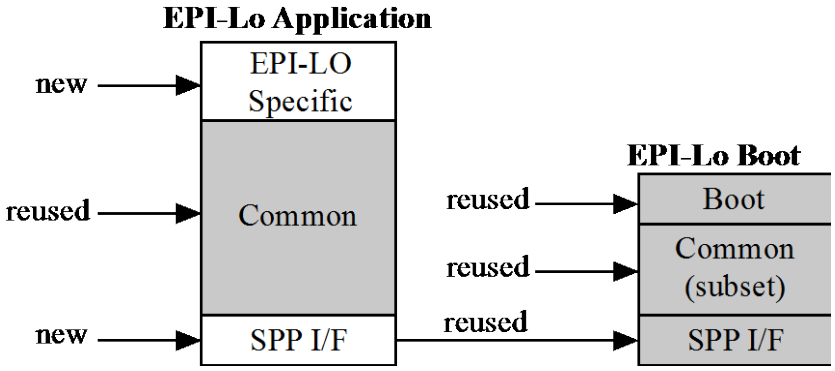
Overview

- EPI-Lo application software
  - EPI-Lo-specific software
  - Common software (reused)
  - SPP spacecraft interface software
- EPI-Lo boot software
  - Boot software (reused)
  - Common software (reused)
  - SPP spacecraft interface software (reused from application)



Common Software

- Packet telemetry
- Command handling
- Macros (stored command sequences)
- Memory management
- Monitoring and alarm generation
- Status reporting

Common S/W - Packet Telemetry

- Provides standard API to application
  - Delivers variable-length packets
  - Numeric ID identifies packet type/contents
  - Time tag of data collection time
- API also used within common code to deliver standard products:
  - Memory dump, memory checksum, etc.
  - Command echo
  - Alarm
  - Status/housekeeping

Common S/W - Commands

- Standard API for “clients” to register commands:
  - Numeric “opcode” and expected number of arguments
  - Pointer to code that implements command
- API also used within common code to register standard commands:
  - EPILO_CMD_NULL: do nothing; tests uplink and downlink paths
  - EPILO_STAT_CLR: reset counters
- Command process executes commands
  - Echoes opcode, up to ten argument bytes, and a result code
  - Also executes stored command sequences, macros …

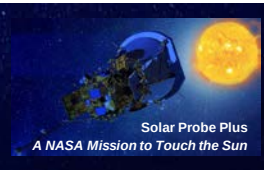
Common S/W - Macros

- Macros are stored sequences of commands
- 256 different macros can be defined
- 64 Kbyte of RAM is available for macro storage
- Macros can nest 16 deep; up to 64 macros can execute concurrently
- Real-time uplink commands take precedence over macro commands
- Commands from a macro are echoed; the echo includes a flag indicating that the command is from a macro

Common S/W - Macros (cont.)

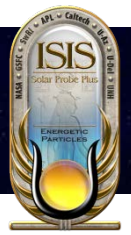
- Macros are “learned” by the instrument
  - EPILO_MAC_DEF starts a macro definition; any command uplinked with its “macro” arg set will be appended to the macro
  - EPILO_MAC_ENDDEF ends the definition
  - While a macro is being compiled, any real-time command, i.e., one without a set “macro” arg will be executed.
  - There is no need for macro compiler or macro memory management by ground software
- Other macro commands:
  - EPILO_MAC_DELAY and EPILO_MAC_PAUSE delay by a give number of seconds or until a given time, respectively
  - EPILO_MAC_NEST and EPILO_MAC_RUN nest a macro and starts a concurrently executing macro, respectively
  - EPILO_MAC_LOOP_BEGIN and EPILO_MAC_LOOP_END delimit a definite loop
  - EPILO_MAC_HALT kills a running macro

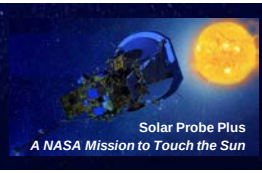
Common S/W - Memory Management



- Commands:
  - EPILO_MEM_LOAD: loads RAM
  - EPILO_MEM_COPY: copy memory; source and/or destination can be RAM or non-volatile MRAM
  - EPILO_MEM_READ: produce memory dump packets
  - EPILO_MEM_READ_ABRT: stop memory dump
  - EPILO_MEM_CHECK: produce a checksum packet summarizing given region
  - EPILO_MEM_RUN: jump to program at given address
- Note: these commands are the core of the boot software

Common S/W - Monitoring and Alarms





- Alarm packet is generated in response to a software problem or to a monitored value going out of limits
- Alarms from monitors can be transient or persistent
  - If a monitored value is out-of-limits just once, a transient alarm is reported
  - If a monitored value is consecutively out-of-limits twice, a persistent alarm is reported and the software may take corrective action
  - If a monitored value is consecutively out-of-limits more than twice, either corrective action is taken again, the shutdown macro is run, or nothing is done, depending on the thing being monitored
- Commands:
  - EPILO_MON_CNTRL enables or disables corrective action

Common S/W - Monitoring Algorithm

- High response (low response is similar):

```
high once:
      issue transient high alarm

high twice:
      issue persistent high alarm
      if enabled (via EPILO_MON_CNTRL command)
            execute high response macro for this alarm

high more than twice:
      case of monitor class
            current/voltage:
                  if enabled (via EPILO_MON_CNTRL command)
                        run shutdown macro
            temperature:
                  nop
            count rate:
                  if enabled (via EPILO_MON_CNTRL command)
                        re-execute high response macro
```

Common S/W - Status Reporting

- Status packet
  - Command and macro execution counters
  - Analogs: voltages, currents, and temperatures
  - Commanded instrument state
- Commands:
  - EPILO_STAT_INT: how often should status be reported

Common Software Reuse

- Common software reuse estimates for EPI-Lo
  - ~50% of application
  - >90% of boot
- Common software currently (or soon to be) in flight:
  - MESSENGER: EPPS, GRS, MAG, MASCS, MDIS, NS, and XRS
  - MRO: CRISM
  - New Horizons: LORRI and PEPSSI
  - Pucks: Juno/JEDI, RBSP/RBSPICE, MMS/EIS (2014)
  - BepiColombo/Strofio (2015)
- Automated regression test for common software (and for boot software)

SPP Spacecraft Interface Software

- Command and telemetry use 115200 baud UART protocol, 8 data bits plus odd parity
- Virtual 1PPS, i.e. falling edge of start bit of first byte in command ITF
- Redundant interface, side A vs. side B
  - Command arrival determines active side; telemetry sent only to that side
  - Dynamic side switching supported
- Interrupt driven: per-byte interrupt for command and telemetry, and side A and B 1PPS interrupts

SPP Host S/W – EPI-Lo to S/C

- Telemetry ITF
  - Variable length up to 8196 bytes (EPI-Lo limits to 2060 bytes)
  - Multiple telemetry ITFs can be sent but cannot straddle 1PPS (EPI-Lo sends one per second)
  - Frame header includes sync pattern, length, etc.; checksum at end of frame
  - Frame transmission synchronized to 1PPS
- CCSDS telemetry packets
  - Variable length, up to 4096 bytes (including headers)
  - Zero to many packets per frame
  - Packets can straddle frames
  - 64 APIDs available
  - Critical housekeeping packet:
    - Power off/power cycle request
    - 8 bytes of housekeeping

SPP Host S/W – S/C to EPI-Lo

- Command ITF
  - Variable length up to 512 bytes
  - S/C sends one command ITF per second
  - Frame header includes sync pattern, length, etc.; checksum at end of frame
  - Frame transmission synchronized to 1PPS
- CCSDS telecommand packets
  - Variable length, up to 362 (TBD) bytes (including headers)
  - One to many packets per frame
    - S/C time and status (telemetry) packet sent every second, always first
    - Zero or more command packets
  - Packets cannot straddle frames
  - Secondary header is optional (EPI-Lo does not use)
  - 64 APIDs available (EPI-Lo uses one)
- If command ITF is not received for a commandable number of seconds, EPI-Lo runs its safing macro TBD problem

SPP Host S/W – Time Keeping

- Time is set by spacecraft
  - 32-bit MET (seconds)
  - Time arrives every second (as part of time and status)
  - Virtual 1PPS from S/C generates interrupt; interrupt routine sets time, converted to milliseconds
- Time is updated by EPI-Lo
  - 1000 Hz interrupt routine updates time
  - Common software telemetry and command processes run at 1PPS, use coarse (1 s. resolution) time tags
  - Science can be tagged with TBD finer resolution

EPI-Lo Application Software

- Subsystems
  - MCP HV
  - SSD bias
  - Time-of-flight and angle/position measurement
  - Energy measurement
  - Event analysis
- Data Collection
  - Science products
  - Ancillary products
  - Integration control
- Miscellaneous
  - DACs and ADCs
  - Autonomous operation

EPI-Lo Application S/W – MCP HV

- MicroChannel Plates used in particle time-of-flight and angle/position measurements
- EPI-Lo software controls MCPs' High Voltage (HV) supplies
- There is a common supply (bulk) and four individual HVs (opto-isolator controlled)
- EPI-Lo software slowly ramps voltages to commanded levels
- At least two commands are required to turn on HV
- There are also commands to control current monitors implemented in hardware
- Commands:
  - EPILO_HV_COM_LEVEL: Set Common High Voltage Supply Level
  - EPILO_HV_COM_LIMIT: Set Common High Voltage Supply Limit
  - EPILO_HV_MCP_LEVEL: Set MCP High Voltage Supply Level
  - EPILO_HV_MCP_LIMIT: Set MCP High Voltage Supply Limit
  - EPILO_HV_MCP_STEP: Step MCP High Voltage Supply Level
  - EPILO_HV_CUR_ENB: Enable/Disable MCP HV Current Monitoring
  - EPILO_HV_CUR_LIMIT: Set MCP HV Current Monitoring Limit

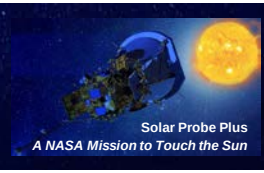
EPI-Lo Application S/W – SSD Bias

- Solid-State Detectors measure particle energy
- EPI-Lo software controls SSDs' Bias Voltage (BV) supply
- EPI-Lo software slowly ramps the supply voltage to commanded level
- At least two commands are required to turn on bias supply
- Commands:
  - EPILO_BV_LEVEL: Set SSD Bias Supply Level
  - EPILO_BV_LIMIT: Set SSD Bias Supply Limit
  - EPILO_BV_STEP: Step SSD Bias Supply Level

EPI-Lo Application S/W – Time-Of-Flight Subsystem

- Measures particle time-of-flight (TOF), angle (i.e. position) on the sensor, and pulse height
- EPI-Lo software controls discriminator thresholds
- Commands:
  - EPILO_TOF_CFD: Set TOF Constant Fraction Discriminator Threshold
  - EPILO_TOF_THRESH: Set TOF Pulse Height Discriminator Threshold

EPI-Lo Application S/W – Energy Subsystem



- Measures particle energy
- EPI-Lo software time-multiplexes hardware between electron and ion detectors
- EPI-Lo software controls thresholds, one set per detector
- Commands:
  - EPILO_EGY_THRESH: Set Energy Discriminator Threshold
  - EPILO_EGY_ANTI: Set Energy Anti-Coincidence Threshold

EPI-Lo Application S/W – Event Subsystem

- Analyzes data from TOF and energy subsystems to identify an “event”
- EPI-Lo software configures hardware to define a valid event
- Commands:
  - EPILO_EVT_MULTI: Enable/Disable Multiple Hit Reject
  - EPILO_EVT_WINDOW: Set Event Coincidence Window

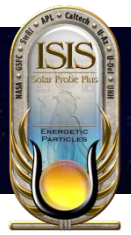
EPI-Lo Application S/W – Science Products

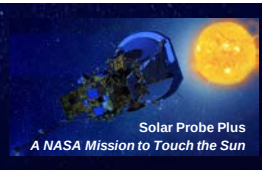
- Ions are collected with different energy resolution, angular (position) resolution, and cadence
  - Ions - Fast: 8 angles, 8 energies
  - Ions - Slow: 80 angles, 69 energies (29 H, 12 He, 14 Heavy group 1, and 14 Heavy group 2)
- Electrons are collected with different resolution and cadence
  - Electrons - Fast: 8 angles, 6 energies
  - Electrons - Slow - Regular: 8 angles, 32 energies
  - Electrons - Slow - Hi-Angle: 80 angles, 16 energies

EPI-Lo Application S/W – Ancillary Products

- Basic rates (i.e. singles) are collected
  - Hardware counters, e.g. SSD, Start1, Start2, Stop, Events queued, etc.,
    - 24-bit hardware counters accumulated in 32-bit software counters
    - Collected per-quadrant or octant
  - Software counters, e.g. Events processed
- Single events
  - Software reads events from hardware FIFO
  - A commandable number collected in raw event product

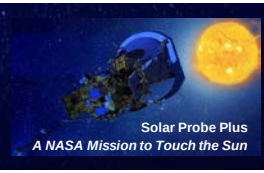
EPI-Lo Application S/W - Integration Control





- EPI-Lo software defines data products as fast or slow
- The time to integrate fast and slow data is commandable
- Each data product can be individually enabled or disabled
- Commands
  - EPILO_DAT_COLLECT - Set Data Collection Pattern
  - EPILO_DAT_ENB - Enable/Disable Data Products
  - EPILO_DAT_RAW - Control Amount of Raw Event Data
  - EPILO_DAT_TIME - Control Data Integration Time

EPI-Lo Application S/W – DACs and ADCs



- 1 Hz activity schedule
- Control QuadDACs over I2C bus
  - Set power supply levels, e.g. MCP HV
  - Set thresholds, e.g. MCP HV current
- Read ADCs over SPI bus
  - Read analogs (read three times and use median value)
  - Save in housekeeping
  - Monitor and report/respond to out-of-limit conditions

EPI-Lo Application S/W – Test Support

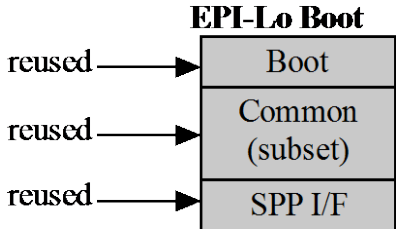
- EPI-Lo software provides commands to control an on-board pulser
- EPI-Lo software provides commands to select internal test points to bring out on the test port
- Commands:
  - EPILO_TST_PUL_CFG: Configure Pulser
  - EPILO_TST_PUL_ENB: Enable/Disable Pulser
  - EPILO_TST_POINT: Select Test Point Signals

EPI-Lo Application S/W – Autonomous Operations

- Time and status from spacecraft includes
  - Startup Mode: selects manual vs. autonomous operation
  - Solar Distance: current distance to the sun
- If autonomous operation is selected, EPI-Lo software will:
  - Automatically load macros from MRAM
    - Macros are stored command sequences
    - Macros can pause until a given MET or delay a given number of seconds
  - Run startup macro; this ramps up HVs, etc.
  - Monitor solar distance against a set of commandable thresholds
    - Different threshold crossings trigger different macros to run
    - Macros configure science collect, e.g. integration times, etc.
- If autonomous operation is not selected, EPI-Lo software will wait for commands

EPI-Lo Boot S/W

- Commands: memory load, copy, execute, dump, check
- Telemetry: status/housekeeping, memory dump, etc.
- High (>95%) code reuse
- Reuse:
  - SPP I/F from application
  - Common software (subset)
  - Boot software (boot programs from MRAM)
- New: wrapper, startup, etc.
  - If autonomous operation is selected, EPI-Lo software will automatically try to boot a series of programs from MRAM
  - If autonomous operation is not selected, EPI-Lo software will wait for commands



Software Development Environment

- Flight software and development tools are on Space Department's Unix system
  - /project/spp-instr
  - Backed up nightly
  - Tools are C-based and have been used on Sun OS, Linux, & Mac OS X
  - Only single developer can modify software
- Software versions
  - Numbered with integers, i.e. 1, 2, 3, etc.
  - Each version is in a subdirectory; name of subdirectory includes version number
  - Version number reported in telemetry
  - Each delivered version includes snapshot of libraries
  - Archived in Product Lifecycle Management (PLM) system
- Testing
  - Unit and integration testing done on Xilinx prototype board (no sensor); concocted events are in RAM
  - Further testing on EM with pulsers simulating events
  - Acceptance testing is done as part of of Instrument Test Procedure

Reference Documents

- 7434-9066, Solar Probe Plus (SPP) General Instrument (GI) ICD
- 16105-ISIS-IRD-01, “PRELIMINARY INSTRUMENT REQUIREMENTS DOCUMENT SOLAR PROBE PLUS PROJECT ISIS INSTRUMENT”
- 7464-9005, EPI-Lo Flight Software Specification
- 7464-9003, EPI-Lo Software Development Plan