CINEMA CubeSat Flight Software
Handling High Data Rates

David McGrogan
Space Sciences Laboratory
University of California, Berkeley

CubeSat Developer’s Workshop April 21, 2010
CINEMA has been brought to you by:

Principal Investigator
Robert Lin, SSL

System Engineer
David Curtis, SSL

STEIN Scientist
Davin Larson, UCB

MAGIC Scientist
Tim Horbury, ICL

Other contributors:
David Glaser, SSL
Dorothy Gordon, SSL
Peter Harvey, SSL
John Sample, SSL
CINEMA
(CubeSat for Ions, Neutrals, Electrons and MAgnetic fields)

• Monitor space weather
• Demonstrate self-orientation, miniaturized sensors, CubeSat possibilities
• Main sensors: STEIN particle detector, magnetometers
STEIN Particle Detector

STEIN: SupraThermal Electron, Ion, Neutral

Four detector “pixels”, \( \leq 30K \) counts/sec each

Range: few to 100 KeV

Resolution: \( ~1 \text{ KeV FWHM} \)
Magnetometers

Magnetoresistive magnetometers minimize size

3 axes, inboard and boom-deployed

Resolution: 2-10 nT in science mode, 25 nT in ACS mode

Fluxgate mag.
MR mag. (1-axis)
MR mag. assembly (3-axis)
Attitude Control System (ACS)

Axis found via magnetometers, solar panels, sun sensor
Spin speed and axis controlled using torque coils (red)
Solid State Storage

Standard SD card
Shock and vibration tested
Resistant to temperature extremes (-25°C - 85°C)
Holds well over a week’s worth of data (average)
System Modes

- **Safe** – Minimal Power Configuration, all optional systems off; boots/resets to Safe
- **ACS** – Only SD card, torque coils, and low speed MAG active; used to control attitude
- **Science** – SD card, STEIN, and MAG active, radio transmit allowed, torque coils disabled
- **Engineering** – Everything enabled
Mission Plan

• Early operations
  – Safe Mode until contact with ground station
  – Deploy magnetometer boom
  – Self-diagnostics, calibration
  – Reorient spin plane to ecliptic, spin up

• Normal operations
  – STEIN, mag. collecting data at full speed
  – Ground contact at least once/day
Maximum Data Rates

- STEIN: 120K particles/sec peak, 16 bits/particle
- All data stored on SD card; must handle peaks
- RF downlink: 1 Mbps constant
- 10 MIPS processor limit (power consumption)
Dealing with Demands

• Using max-size blocks & interleaving reading/writing requires almost $\frac{1}{2}$ of processor (peak)
• Doesn’t include SD card busy time fluctuations
• Ability of RTOS to regularly schedule this task plus many others unknown, also overhead
• More deterministic solution desired
Task Division

• Background tasks
  • Run at specific times
  • Must finish within a fixed time limit
  • Command handling, ADC sampling, data transmission…

• Foreground tasks
  • Run asynchronously, round-robin in remaining time
  • No hard limit on execution time
  • ACS calculations, SRAM scan, memory peek/poke…
Background Task Scheduling

- Each task must run with a given frequency
- Fixed schedule ensures this
- Tasks must finish in allotted time

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>HSK</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>16</td>
<td>TM</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>24</td>
<td>CMD</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>PWR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>48</td>
<td>SSR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>56</td>
<td>MAG</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
</tbody>
</table>
Direct Memory Access (DMA)

- Sequential data moved between peripheral and RAM automatically
- No processor time required
- 2 KB of DMA RAM in dsPIC33
Serial and DMA

- Commands arrive quickly
- DMA replaces built-in serial buffer with RAM
- Operates independent of current task
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller (Master) <-> SD card (Slave)

Data

Clock

76543210

Clock
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller
Master

SD card
Slave

Data

Clock

65432107

Clock
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller (Master) → SD card (Slave)

Data

Clock

54321076

Clock
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller (Master) <-> SD card (Slave)
Data
Clock

Clock
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller (Master) <-> SD card (Slave)

Data

Clock

32107654 <-> 32107654

Clock
Serial Peripheral Interface (SPI)

Inter-device shift register

Micro-controller (Master)  <->  SD card (Slave)

Clock

Data

76543210  <->  76543210

Clock
SPI and DMA

- SPI slaves need an input to produce output
- Entire transfer can be automated
SPI and DMA

- SPI slaves need an input to produce output
- Entire transfer can be automated
• SPI slaves need an input to produce output
• Entire transfer can be automated
More DMA Channels

- 8 DMA channels available
- Only one channel per cycle moves data
Fudging the rules with DMA

- Combination of DMA with Background Task Table lets background task actions continue after task returns
- Transmit task could set up DMA and return
Fudging the rules with DMA

- No conflict concerns due to fixed schedule
- Next task is known, can be programmed to avoid conflict
- STE follows TX

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>HSK</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>16</td>
<td>TM</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>24</td>
<td>CMD</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>40</td>
<td>PWR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>48</td>
<td>SSR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
<tr>
<td>56</td>
<td>MAG</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
</tr>
</tbody>
</table>
The Average Case

- Particle flux peaks should be rare
- Downlink capacity is $\sim 8$ Kbps average
- STEIN output thus limited, may be attenuated
- Other sensor inputs $< 1$ Kbps

Ability to handle 2 megabit data flows will be infrequently used, but will prevent data loss
Flight Software Modules
Contacts

Visit us at:
http://ssl.berkeley.edu

For more information:
David McGrogan – dpmcgrog(at)eecs.berkeley.edu

Science questions:
John Sample – jsample(at)ssl.berkeley.edu
Solar Panel
Patch Antennas
Deploy Switch
Deploy Springs
S-Band Transmitter
Bus Avionics
MAGIC Magnetometer
Stowed Stacer Boom
Sun Sensors
STEIN Attenuator
STEIN Detector and Electronics Cover
STEIN Collimator
Stacer Boom Release
Patch Antennas
Solar Panel
Deploy Switch
Deploy Springs
S-Band Transmitter
Bus Avionics
MAGIC Magnetometer
Stowed Stacer Boom
Sun Sensors
STEIN Attenuator
STEIN Detector and Electronics Cover
STEIN Collimator
Stacer Boom Release
Even Better Multitasking

- DMA makes simultaneous data streams easier
- Communication routines can be simplified or do other work (e.g. CRC)
Maximum Data Rates

- **STEIN**: 120K particles/sec peak, 16 bits/particle
- All data stored on SD card; must handle peaks
- RF downlink: 1 Mbps constant
- 10 MIPS processor limit (power consumption)
Data Flow Requirements

- 10 MIPS limit due to power demand
- Must send or get 1 byte every 31.25 cycles
- Includes handshaking, SD card busy time, pointer updates, all other tasks

Diagram:

STEIN → 1.28 Mbps → Micro-controller → >1.28 Mbps → SD card
Background Task Scheduling

- 512 bytes takes 0.8 ms to move with SPI
- Run background tasks at 1024 Hz
- Tasks must finish in allotted time

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>HSK</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>TM</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>CMD</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>PWR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>SSR</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>MAG</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td>STE</td>
<td>TX</td>
<td>STE</td>
<td></td>
</tr>
</tbody>
</table>
DMA and SPI
Stuff I need to know

- What’s the real peak sample rate of STEIN? 80K flat or 30K/detector * 4 detectors? (it’s the 120000)
- Switch slides 7,8
- Acronym explanation is good
- FIFO, SPI
- STEIN diagram?
- Block diag
- What have others done?
- 7min current; slow down
- SD card
- CINEMA specs/capabilities
- Why: detect solar particles, test ACS ability, show that students can do things, etc. Look at proposal, Glaser’s presentation last year
- Credit people