Update on Dependable Multiprocessor (DM) CubeSat Technology

presented at the

2011 Summer CubeSat Workshop/ Small Satellite Conference

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Outline

- Brief overview of DM technology
- Recap of 2010 Summer CubeSat Workshop presentation
- Update on DM CubeSat technology development since 2010 Summer CubeSat Workshop
  - DM CubeSat Testbed
  - SMDC TechSat
- Elicit interest in possible joint DM-CubeSat and/or DM small satellite experiment
- Summary and Conclusion

Recap of 2010 Summer CubeSat Workshop Presentation

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- Introduced DM technology to the Small Satellite/CubeSat community
- Provided overview of the current DM CubeSat effort
- Elicited interest in possible joint DM-CubeSat and/or DM small satellite experiment
    - radiation issues
    - thermal issues
    - structural issues
    - benefits of increased on board processing

Dependable Multiprocessor – What is it?

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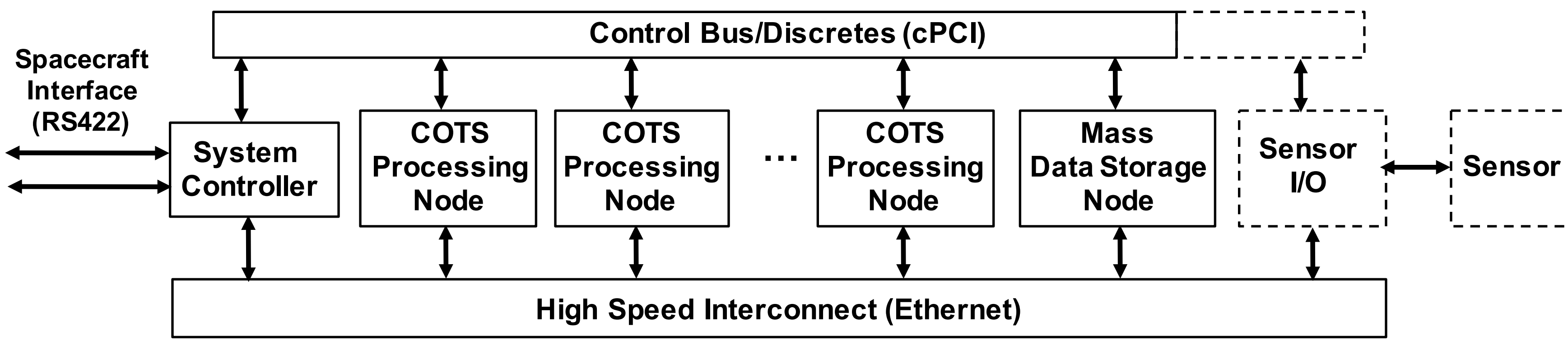
- cluster of COTS high performance processors
- operated under the control of a reliable system controller and technology- and platform-independent fault tolerant middleware
- flexible
  - user-configurable fault tolerance includes hybrid replication [temporal and spatial self-checking and TMR (Triple Modular Redundancy) for critical functions and ABFT (Algorithm-Based Fault Tolerance)]
- scalable
- easy to use

DM ST8 Flight Experiment System



The platform and technology-independent DM Middleware (DMM) is DM technology; DM technology is not the underlying hardware

Update on DM CubeSat Technology Development

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- DM CubeSat accepted as a 2010 Army SERB (Space Experiments Review Board) experiment
- DM CubeSat experiment merged with SMDC High-Power CubeSat experiment called SMDC TechSat for presentation at the 2010 DoD SERB
- SMDC TechSat project proceeding
  - successful PDR in May 2011
  - Flat-Sat Demo scheduled for September 2011
  - CDR scheduled for April 2012
  - experiment flight-ready October 2012
- DM CubeSat Testbed developed at Honeywell

SMDC TechSat Flight Experiment Configuration

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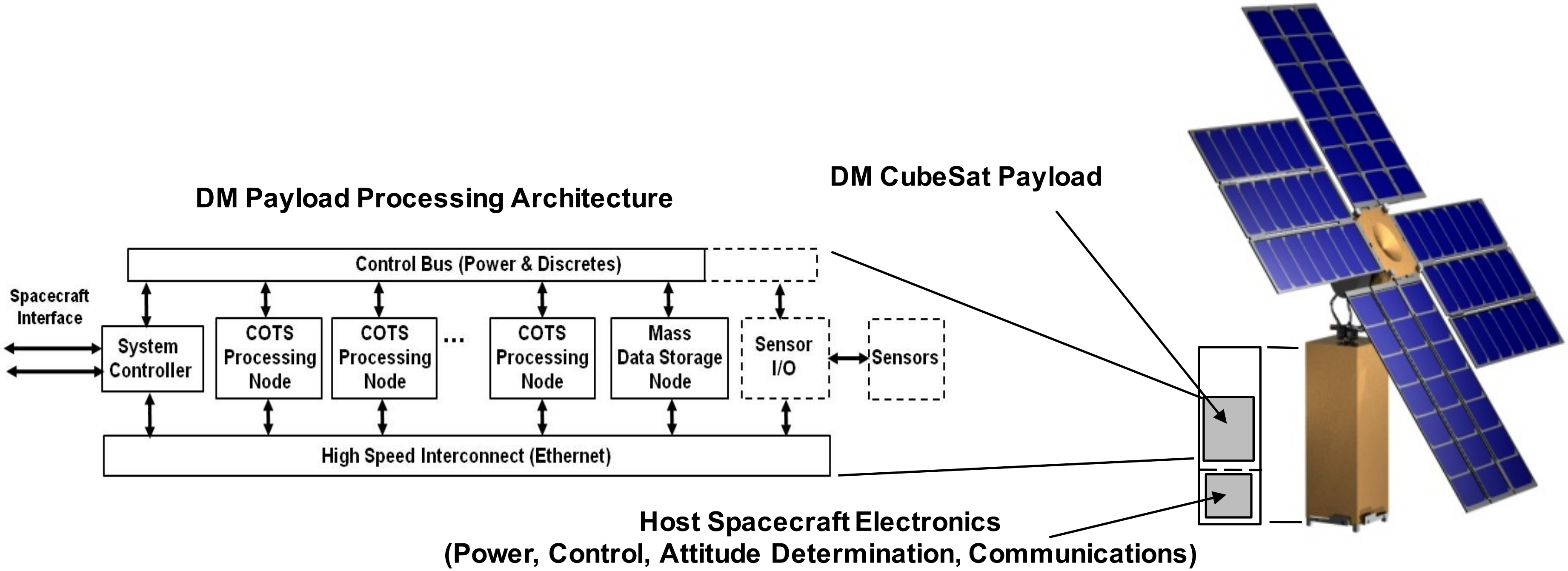

Launch Size:	**10 cm x 10 cm x 34 cm**
Deployed Size:	**78 cm x 78 cm x 44 cm**
Mass:	**6 kg**
Power:	**~ 65 Watts (Peak) (85 Watts goal)**
	~ 40 Watts (On-Orbit Average)

Example: Gumstix™ Computer on Module (COM) - A Small, Light-Weight, Low-Power Processing Solution *

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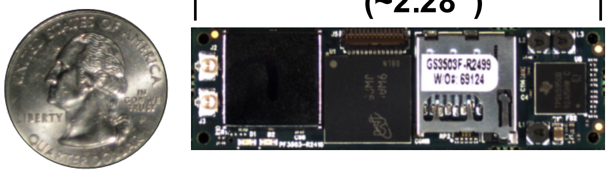
Gumstix Processor Module:

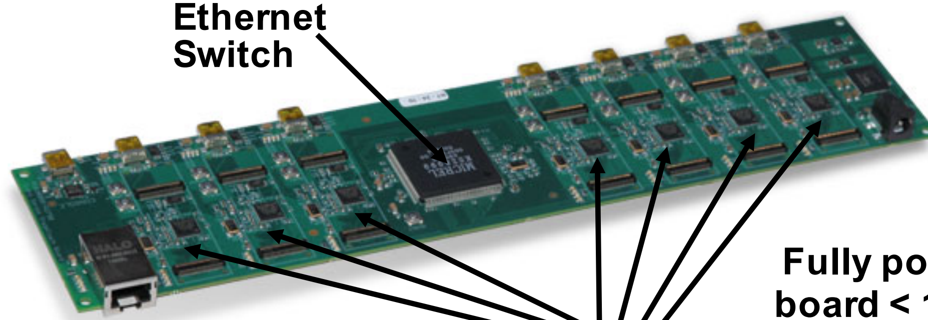
58 mm (~2.28")



17 mm (~0.67")

~1600 DMIPS
OMAP 3503 Application Processor with ARM Cortex -AP8 CPU
256 MBytes RAM
256 MBytes Flash
5.6 grams
~ 2 Watts

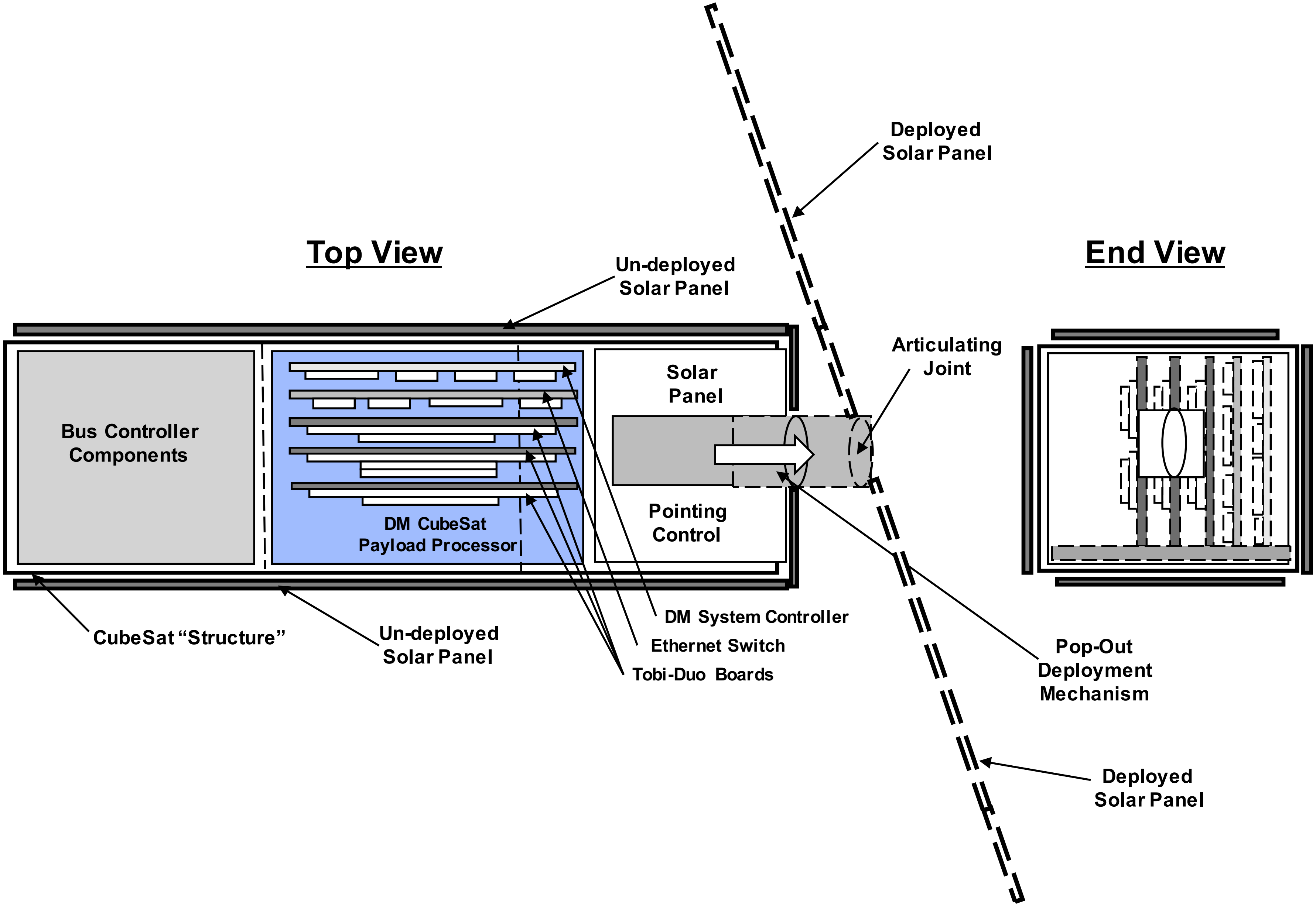
Gumstix Cluster: Seven (7) Gumstix Modules on "Stage Coach" Expansion Board



Fully populated board < 18 Watts

- Gumstix™ COM Modules
  - -- Gumstix™ Overo Earth (Basic Processor, Memory & I/O)
  - -- Gumstix™ Overo Water (Processor, DSP, Memory & I/O)
  - -- Gumstix™ Overo Fire (Processor, DSP, Memory, I/O, & BlueTooth/WiFi)

Possible SMDC CubeSat Configuration



DM CubeSat Testbed Development To Date

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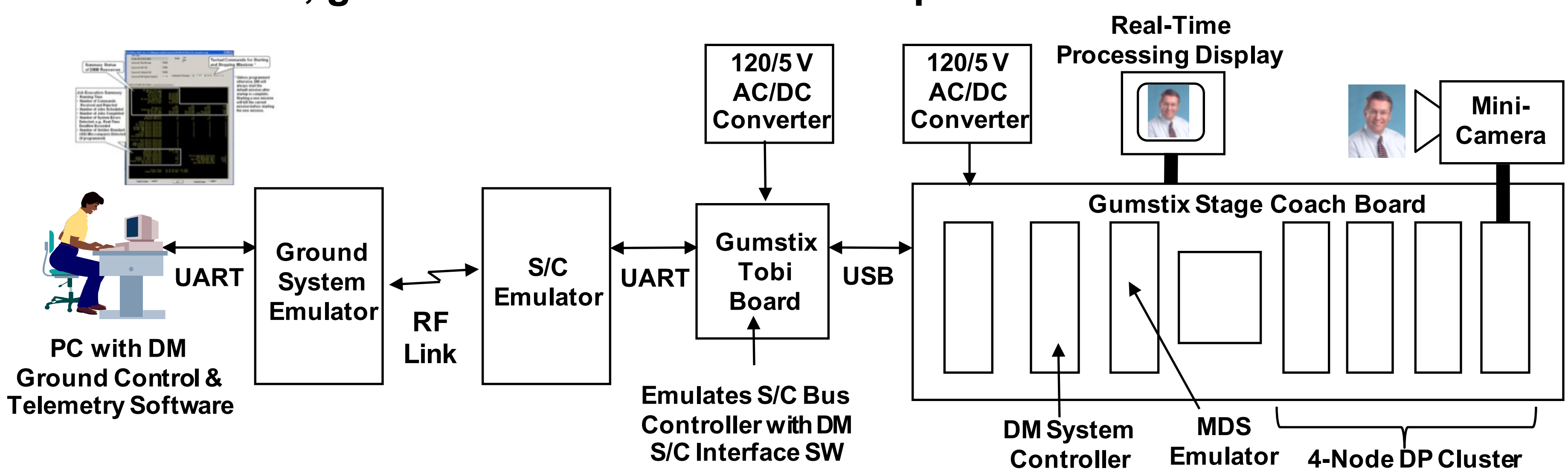
- Built DM CubeSat Testbed
- Completed initial end-to-end, DM, space-ground , flight experiment command and telemetry system over RF link using Pumpkin Sat space and ground communication modules
  - leveraged $14M NASA-funded NMP ST8 DM technology development
    - -- Dependable Multiprocessor Middleware (DMM)
    - -- ground control and telemetry software
    - -- multiple applications (HSI, SAR, LU Decomposition, et al.)
  - integrated Gumstix camera with DM payload processor
  - implemented JPEG data compression algorithms
- Demonstrated DM CubeSat Testbed system operation including fault recovery and real-time, ground-commanded data compression



DM CubeSat Testbed Photo (1 of 2)

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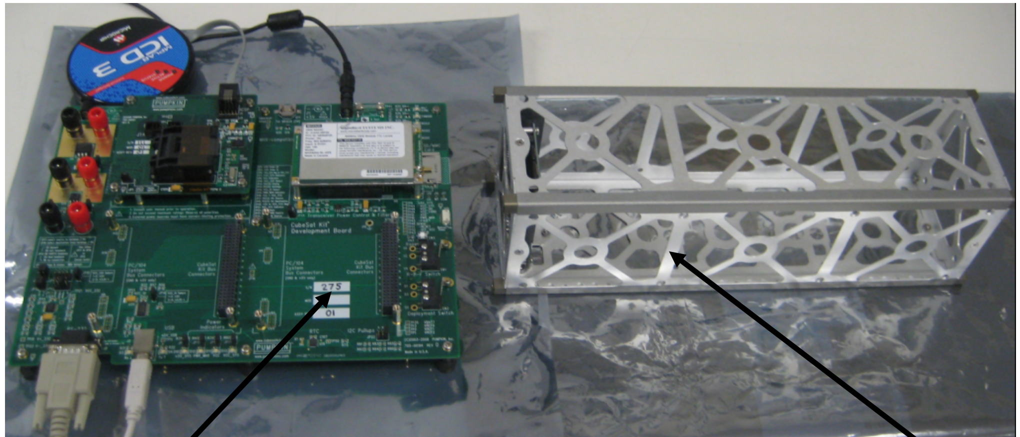
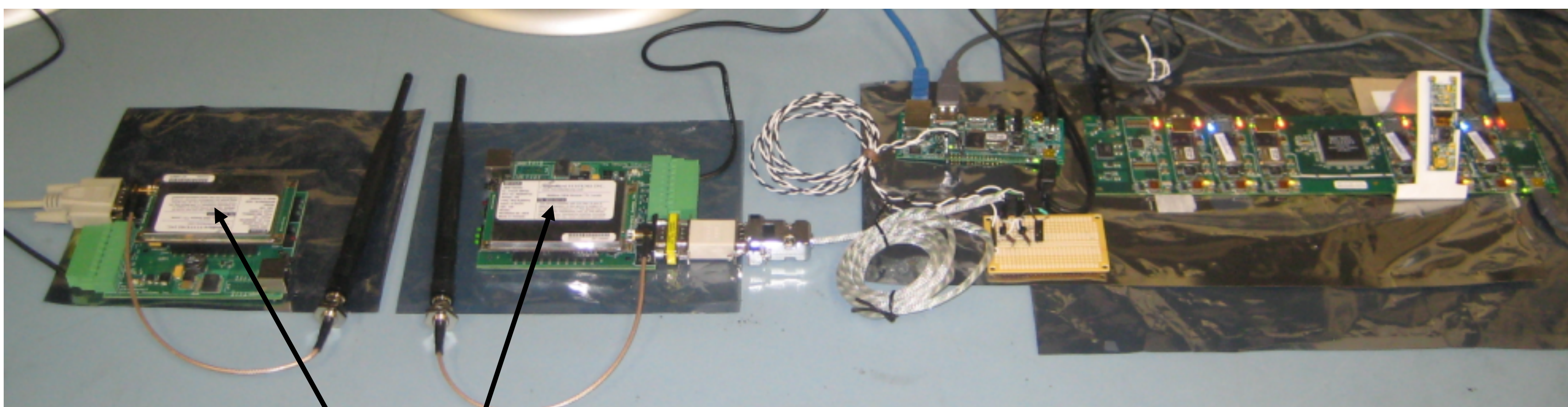


Pumpkin CubeSat Kit Development Board

Pumpkin Sat 3U Skeleton



Pumpkin Comm. Modules

DM Payload Processor

DM CubeSat Testbed Photo (2 of 2)

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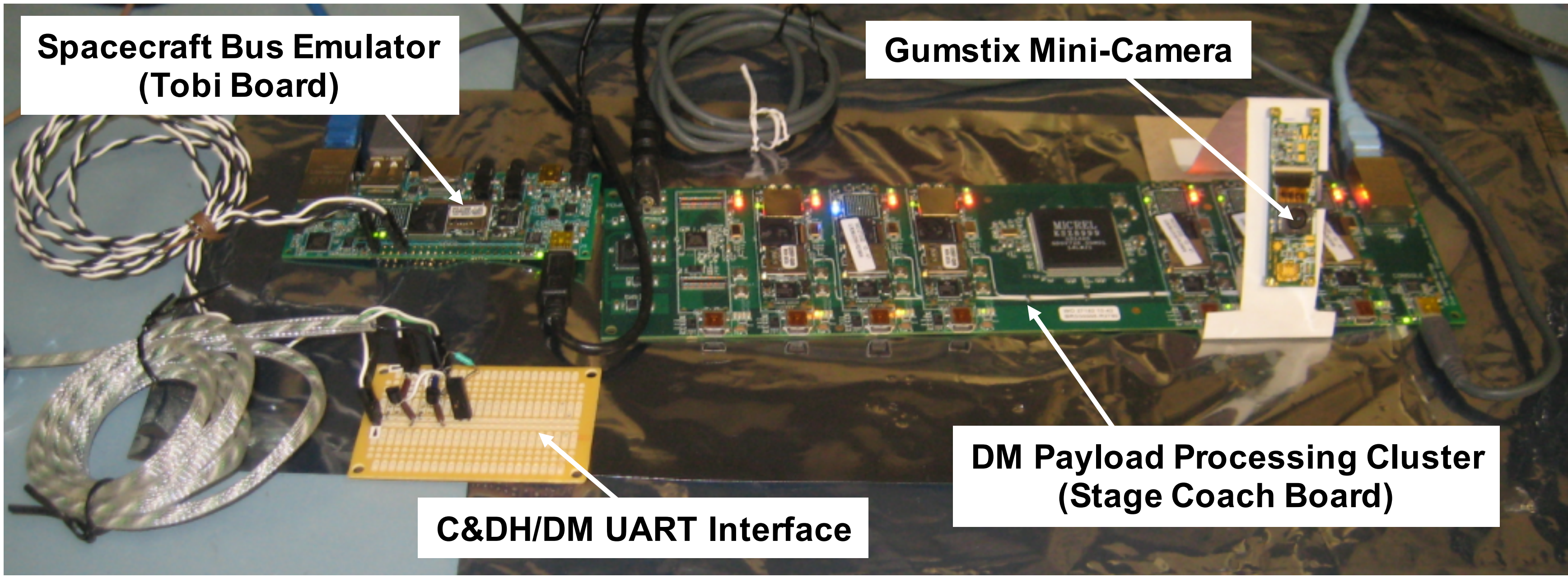

Example: DM Ground-Commanded Programmable Data Compression – JPEG 2000 Algorithm

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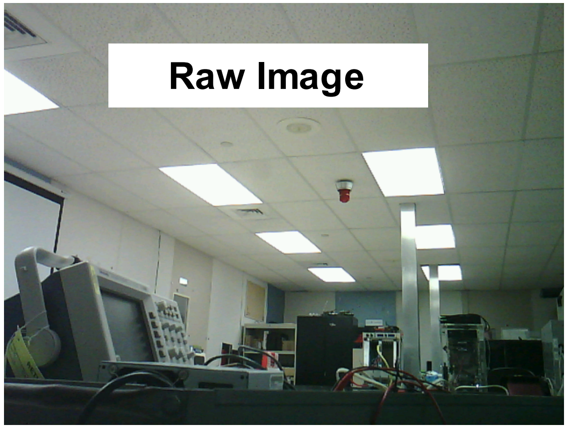
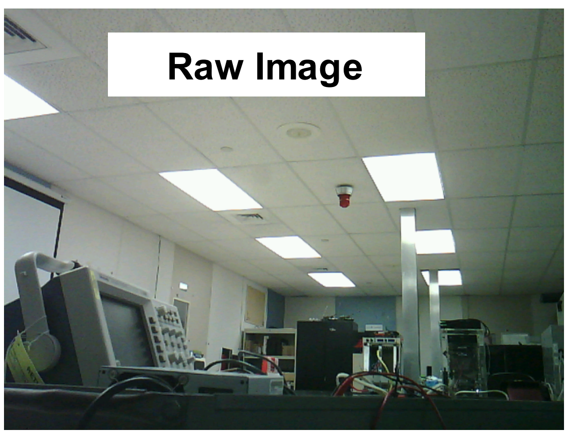


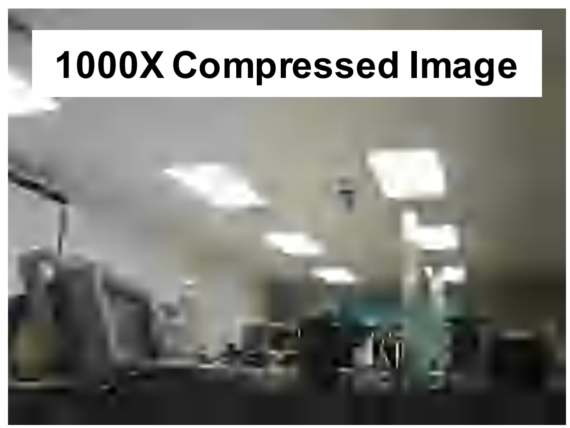
Raw Image Size: 921654 Bytes
Frame Time: 15 seconds

Compressed Image Size: 435734 Bytes
Execution Time: 2.449 seconds

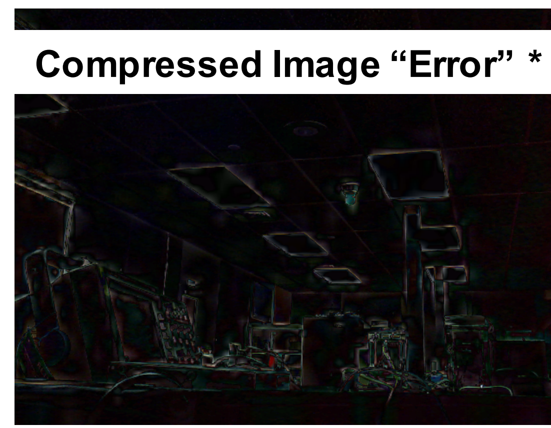
Average R error = 0.0 ^
Average G error = 0.0 ^
Average B error = 0.0 ^



Raw Image Size: 921654 Bytes
Frame Time: 15 seconds



Compressed Image Size: 922 Bytes
Execution Time: 3.041 seconds



Average R error = 11.183 ^
Average G error = 8.626 ^
Average B error = 9.947 ^

* ABS [Raw Image Pixel (x,y) – Compressed Image Pixel (x,y)]
^ Average difference in pixel value over the entire image (8-bit pixel data; range 0 - 255)

DM Payload - Command & Telemetry

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- DM ground system console provides the top-level control of the DM system
- DM ground system console provides status of DM components via the State-of-Health (SOH) Data display ^
- DM ground system console provides display of DM events via the Experiment Telemetry Data display ^
- DM ground system logs SOH status and DM events activity ^

^ The DM ST8 system was designed to be a flight experiment, instrumented to characterize the radiation environment and the DM response to radiation induce errors;
We are using this software to lower cost and risk for the SMDC TechSat

DM Payload - SOH Display – Key Areas of Interest

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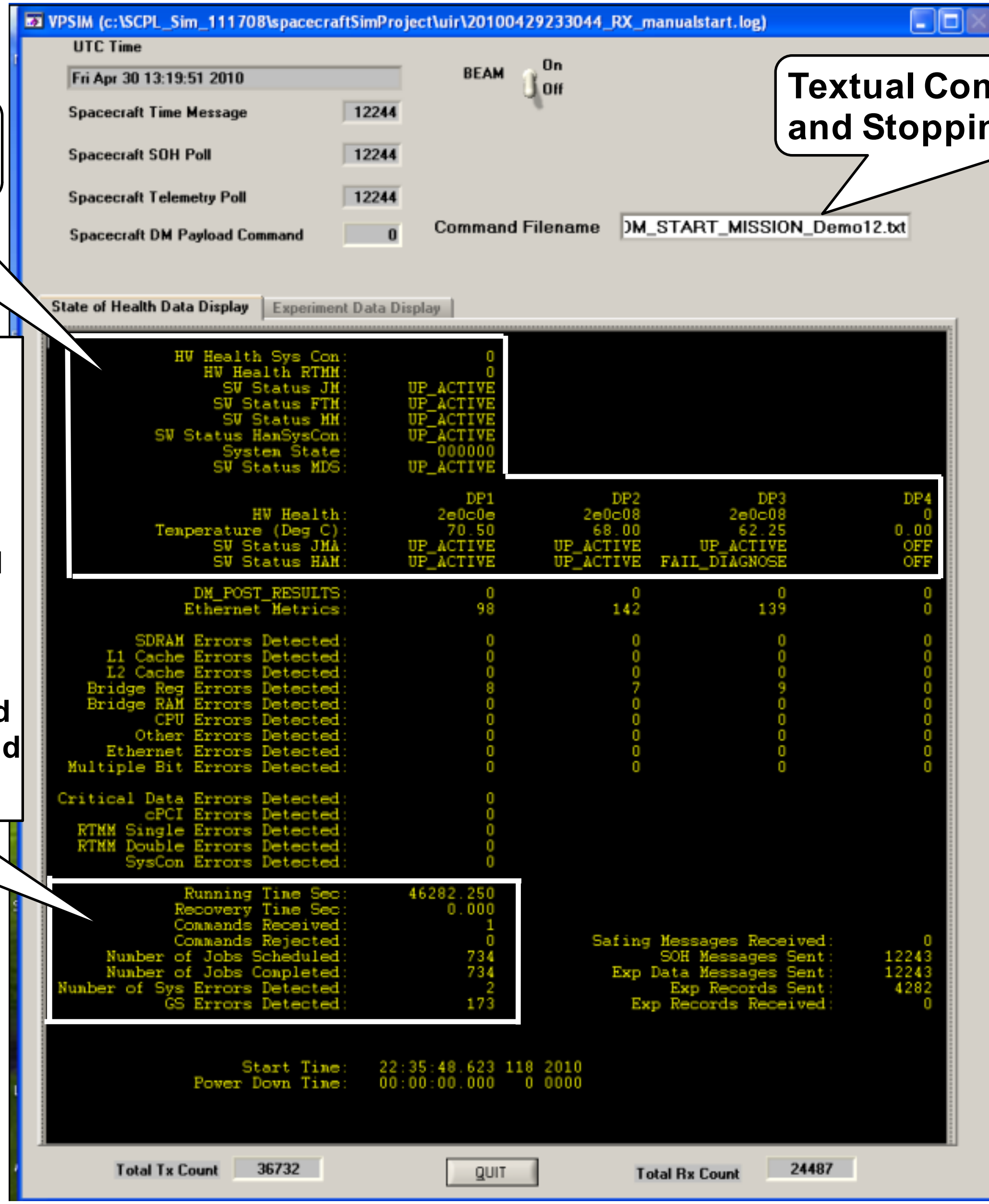
Summary Status of DMM Resources

Job Execution Summary
- Running Time
- Number of Commands Received and Rejected
- Number of Jobs Scheduled
- Number of Jobs Completed
- Number of System Errors Detected, e.g., Real-Time Deadline Exceeded
- Number of Golden Standard (GS) Mis-compares Detected (if programmed)



Textual Commands for Starting and Stopping Missions *

* Unless programmed otherwise, DM will always start the default mission after startup is complete; Starting a new mission will kill the current mission before starting the new mission.

DM Payload - SOH Data Display

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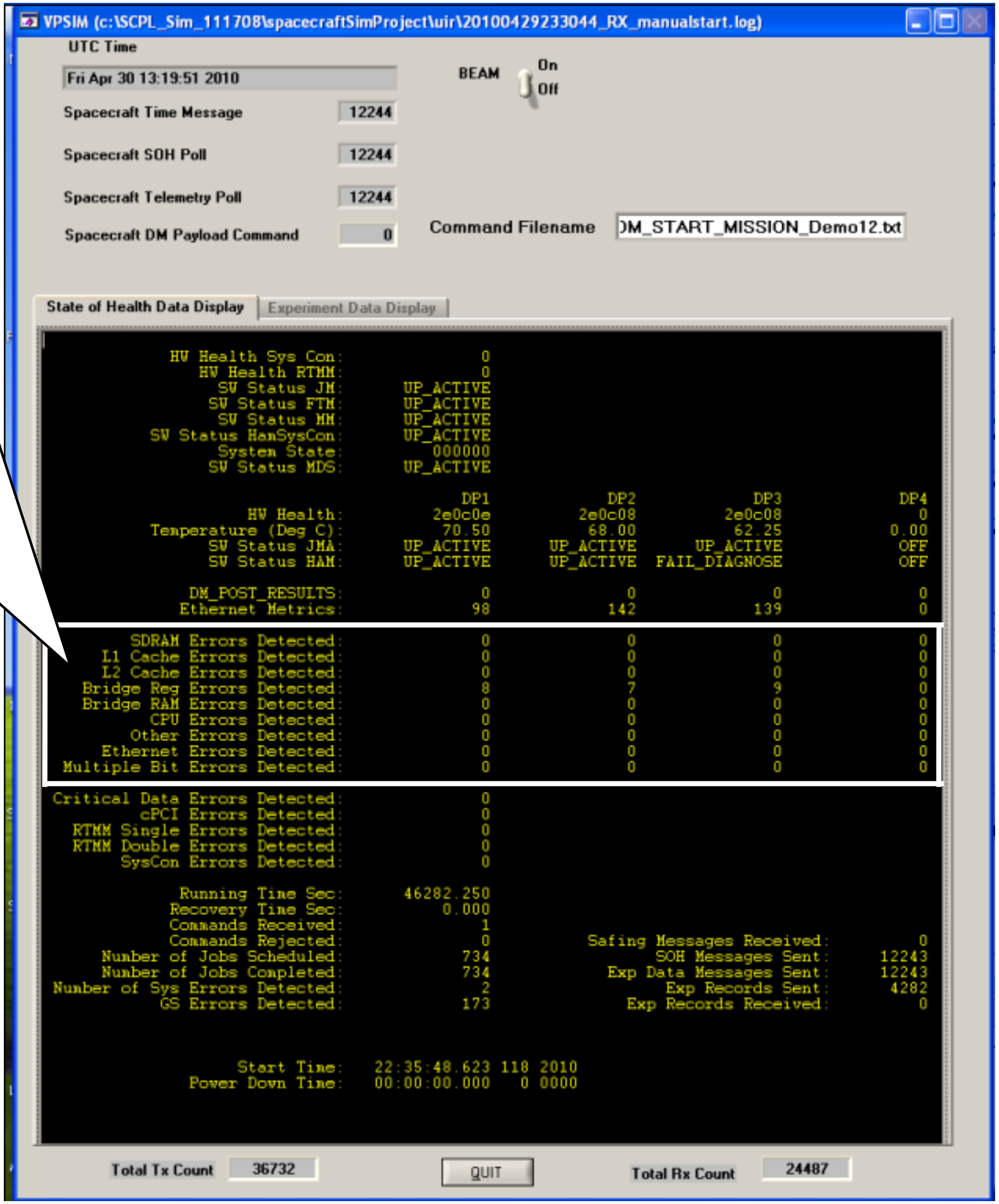
If you see these numbers increase and you are not in a radiation test facility running beam tests or you are not doing Software-Implemented Fault Injection (SWIFI) experiments, head for shelter because it means that you are being bombarded with radiation. (DM is a poor man's omni-directional radiation detector.) *



* A few bridge "errors" are detected during power-up self-test; this is normal; after power-up testing is complete, these numbers should not change

DM Payload - Experiment Data Telemetry Display

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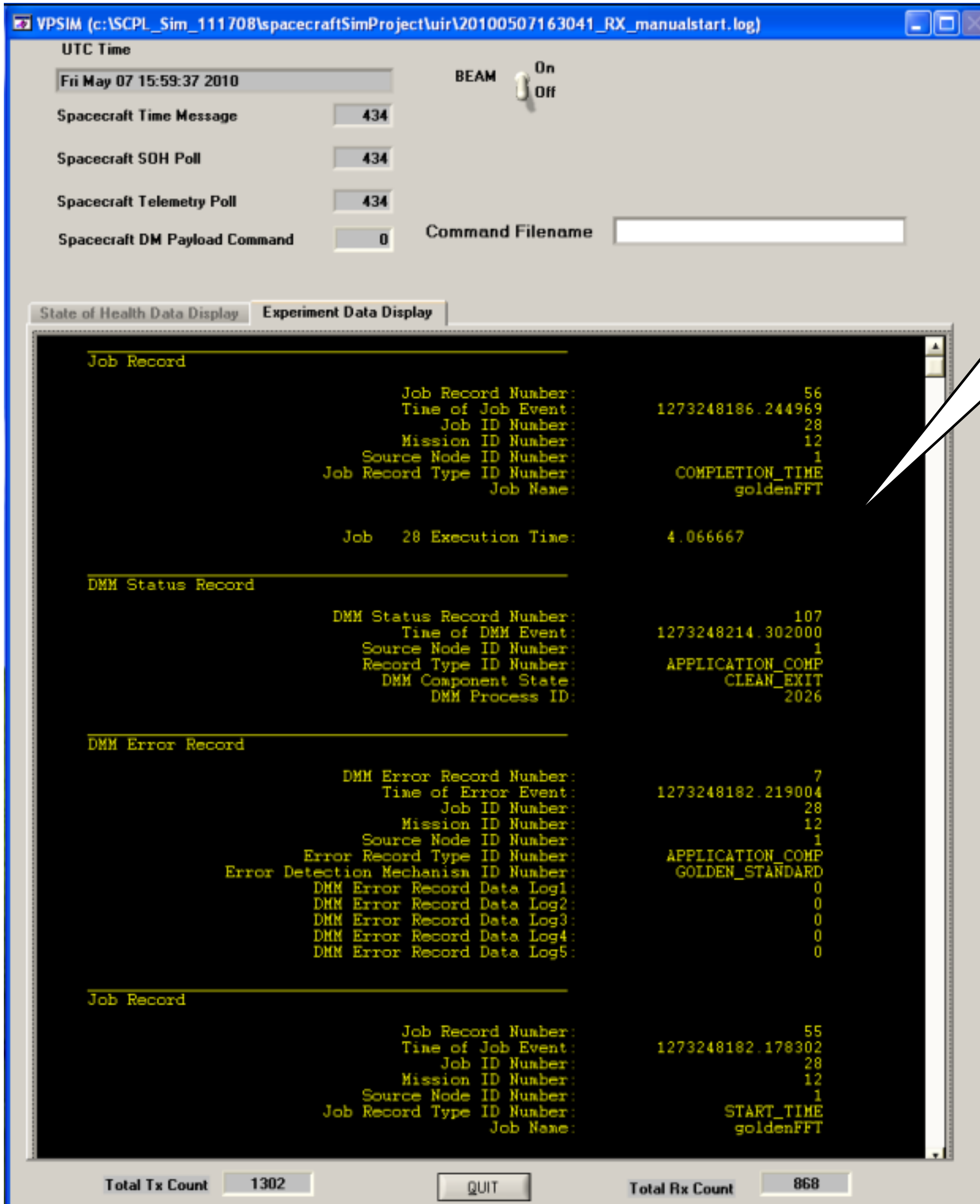

Scrolling Experiment Data Telemetry Display *

* Displays the most recent testbed events
- application activity
- DMM component activity
  - -- Job Record
  - -- DMM Error Record
  - -- DMM Status Record
- oldest event at the bottom of the screen
- most recent event at the top of the screen
- all of the telemetry data records are logged and can be saved for further analysis

DM Payload - Experiment Data Telemetry Log

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The Experiment Data Telemetry log is created and updated automatically whenever the VPSIM is operating. QUIT VPSIM will close the file. The log file is time-stamped with the time VPSIM started for this run.

DMM Error Record

DMM Error Record Number:	2
Time of Error Event:	1272490230.114953
Job ID Number:	8
Mission ID Number:	12
Source Node ID Number:	1
Error Record Type ID Number:	APPLICATION_COMP
Error Detection Mechanism ID Number:	GOLDEN_STANDARD
DMM Error Record Data Log1:	0
DMM Error Record Data Log2:	0
DMM Error Record Data Log3:	0
DMM Error Record Data Log4:	0
DMM Error Record Data Log5:	0

DMM Status Record

DMM Status Record Number:	34
Time of DMM Event:	1272491175.974000
Source Node ID Number:	1
Record Type ID Number:	APPLICATION_COMP
DMM Component State:	CLEAN_EXIT
DMM Process ID:	22813

Job Record

Job Record Number:	16
Time of Job Event:	1272490234.242974
Job ID Number:	8
Mission ID Number:	12
Source Node ID Number:	1
Job Record Type ID Number:	COMPLETION_TIME
Job Name:	goldenFFT
Job 8 Execution Time:	4.116667

DMM Status Record

DMM Status Record Number:	35
Time of DMM Event:	1272490951.307000
Source Node ID Number:	1
Record Type ID Number:	APPLICATION_COMP
DMM Component State:	UP_ACTIVE
DMM Process ID:	23149

DMM Status Record

DMM Status Record Number:	36
Time of DMM Event:	1272491417.974000
Source Node ID Number:	2
Record Type ID Number:	APPLICATION_COMP
DMM Component State:	UP_ACTIVE
DMM Process ID:	21693

DMM Status Record

DMM Status Record Number:	37
Time of DMM Event:	1272490552.307000
Source Node ID Number:	3
Record Type ID Number:	APPLICATION_COMP
DMM Component State:	UP_ACTIVE
DMM Process ID:	20267

Job Record

Job Record Number:	17
Time of Job Event:	1272490426.276307
Job ID Number:	9
Mission ID Number:	12
Source Node ID Number:	7
Job Record Type ID Number:	START_TIME
Job Name:	HSIPARCPABFTI_MPI

Job ID numbers are used to correlate related Experiment Data Telemetry records

In the Job Record , the decimal Source Node ID Number is the binary representation of the number of nodes assigned to the application, e.g., decimal 7 is 0111; Nodes 1, 2, and 3 are assigned to this job

DM-Based Gumstix Supercomputer in Space (?)

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- Sandia National Laboratory's 196 TI OMAP 3530 Gumstix™ Overo Tide Mini Supercomputer running Linux
  - http://www.linuxfordevices.com/c/a/News/Sandia-StrongBox-and-Gumstix-Stagecoach/?kc=rss
  - developed for botnet research as part of SNL's Mega Tux project
- History of trying to put COTS supercomputing in space
  - DARPA's pioneering Space Touchstone effort to fly Intel Paragon Supercomputer in space
  - part of the genesis of DM technology
- Application of DM technology to a Gumstix-based supercomputer
  - DM technology is as scalable as the high performance interconnect and the skill of the developer of the parallel application
  - FTM sub-modules to avoid bottlenecking a single FTM node, but this has been done before on the AOSP (Advanced Onboard Signal Processor) project
    - -- no single node monitored the entire AOSP network
    - -- multiple "FTM" nodes monitored different groups of nodes, checked on each other, and could re-constitute a group and a new monitoring node if a monitoring node went down, etc.
  - need for a distributed MDS function (?)
  - need for distributed check-pointing (?)
  - other …….

Summary & Conclusion

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- **DM technology benefits**
  - DMM is technology-, platform-, and application-independent
    - -- the Gumstix™ ARM is just the most recent successful porting target
  - allows space applications to use state-of-the-art COTS processors
    - -- onboard processing no longer need to be 2-3 generations behind state-of-the-art terrestrial processors
  - applicable to a wide-range of missions
  - allows more onboard processing within a given size, weight, power, and cost constraints
  - supports more science/more autonomy
  - offers faster onboard processing, faster frame processing
  - reduces downlink bandwidth requirements
  - provides processed data/information directly to the user
- **Combination of small, light-weight, low-power, high performance COTS processing with high-power CubeSat technology has been indentified as the next key CubeSat development**
- **DM and DM CubeSat technology is moving closer to flight**
- **NASA, the DM project, and Honeywell are interested in exploring collaborative CubeSat, Small Satellite, UAV, UAS, and HAA flight opportunities**

Acknowledgements

Honeywell

- The Dependable Multiprocessor* effort was funded under NASA NMP ST8 contract NMO-710209
- The DM CubeSat effort to date has been carried out on Honeywell internal investment

For more information contact:

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* The Dependable Multiprocessor (DM) project was originally known as the Environmentally-Adaptive Fault-Tolerant Computer (EAFTC) project

Recent References

Honeywell

[1] Samson, Jr., John R., “Implementation of a Dependable Multiprocessor CubeSat,” Proceedings of the 2011 IEEE Aerospace Conference, Big Sky, MT, March 8, 2011.

[2] Samson, Jr., John R., “Dependable Multiprocessor (DM) CubeSat Implementation,” 2010 Summer CubeSat Workshop, August 8, 2010.

[3] Samson, Jr., John R., Grobelny, Eric M., Clark, M., Driesse-Bunn, S., Van Portfliet, S., “NMP ST8 Dependable Multiprocessor: Technology and Technology Validation Overview,” Proceedings of the 48th AIAA Aerospace Sciences Meeting Conference, Orlando, FL, January 4-8, 2010.

[4] Grobelny, Eric M., Samson, J., Clark, M., Driesse-Bunn, S., Van Portfliet, S., “NMP ST8 Dependable Multiprocessor: Technology Validation Approach and Results,” Proceedings of the 48th AIAA Aerospace Sciences Meeting Conference, Orlando, FL, January 4-8, 2010.

[5] Samson, Jr., John R., Grobelny, Eric M., Driesse-Bunn, S., Clark, M., Van Portfliet, S., “Post-TRL6 Dependable Multiprocessor Technology Developments,” Proceedings of the 2010 IEEE Aerospace Conference, Big Sky, MT, March 7-12, 2010.

[6] Samson, Jr., John R., and Grobelny, E., “NMP ST8 Dependable Multiprocessor: TRL6 Validation – Preliminary Results,” Proceedings of the 2009 IEEE Aerospace Conference, Big Sky, MT, March 8-13, 2009.

Back-up Charts

Non-Intrusive DM Flight Experiment

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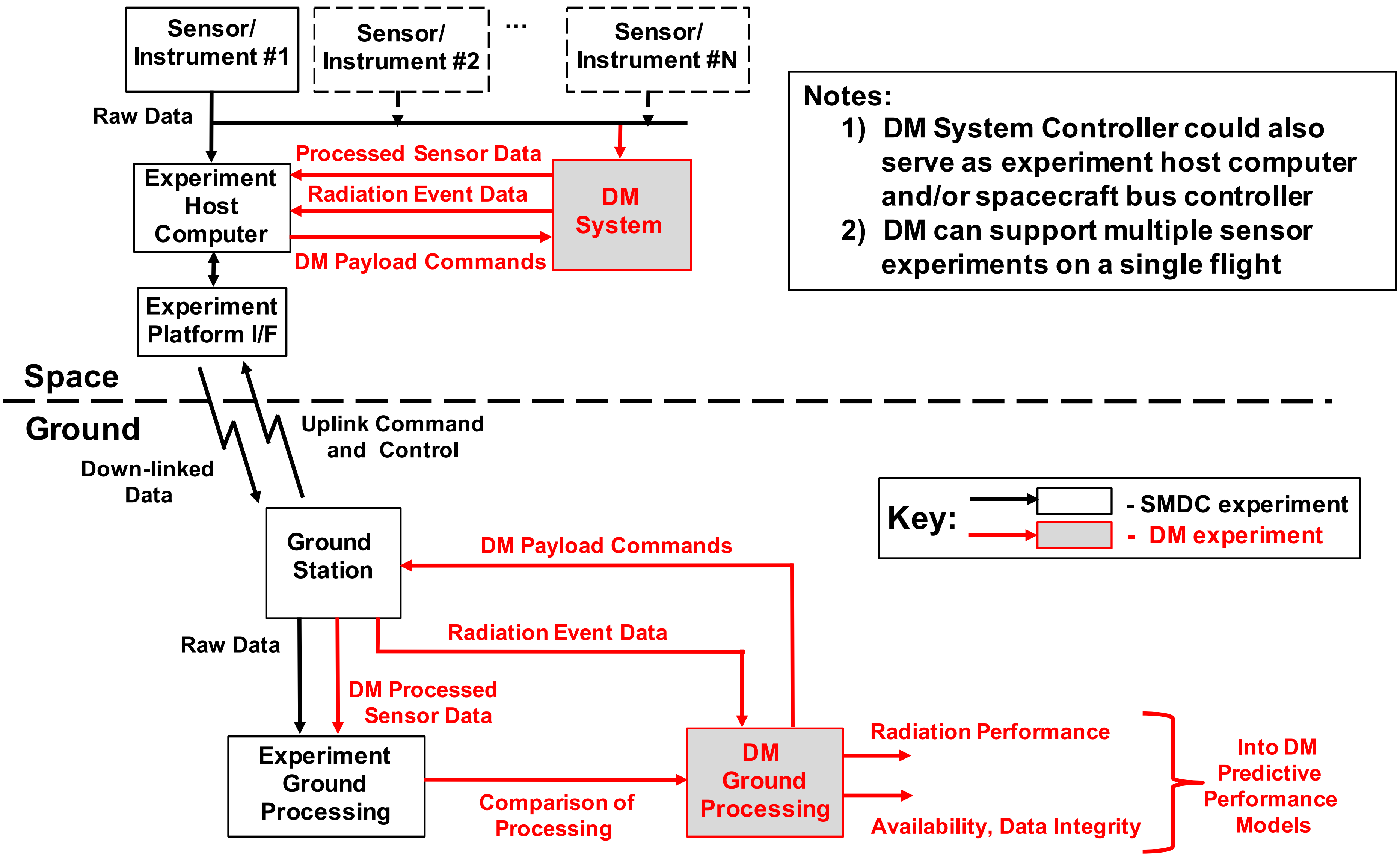

Notes:
1) DM System Controller could also serve as experiment host computer and/or spacecraft bus controller
2) DM can support multiple sensor experiments on a single flight

Baseline SMDC TechSat DM Flight Configuration

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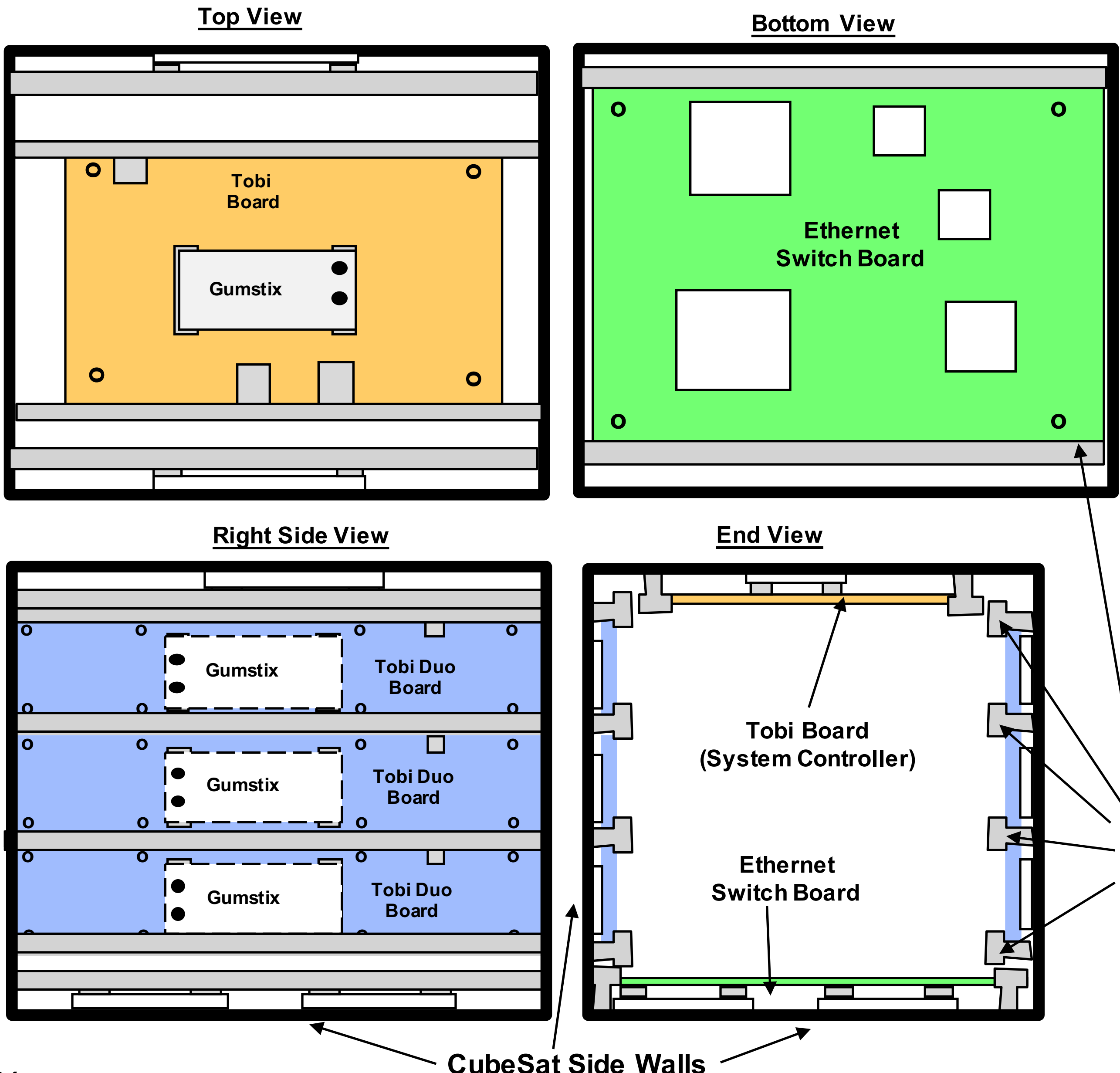

Notes:

1) The flight system will have the DM circuit boards mounted directly to the side walls of the CubeSat

2) The high profile RJ-45 connectors on the COTS boards will be replaced with other space qualified connectors or with directly hard-wired connections

4) The mechanical mounting will require board "stiffeners" and thermal paths for power dissipation & possibly for warm-up heating

5) This configuration offers spatial advantages, thermal advantages, and radiation environment sensing advantages as the "poor man's radiation sensors," i.e., semi-conductor memory elements cover the major surfaces of the CubeSat

6) The physical implementation needs to provide a portal for the main SMDC TechSat experiment camera to be able to observe the articulating solar panels; the camera needs to be placed near the middle of the CubeSat